ENCYCLOPEDIA OF GLOBAL WARMING

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Volume 1

Abrupt climate change-Energy Policy Act of 1992

Editor

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Publisher's Note

The *Encyclopedia of Global Warming* (3 volumes) provides comprehensive coverage of the questions of global warming and climate change, including scientific descriptions and explanations of all factors, from carbon dioxide to sunspots, that might contribute to climate change. The set includes 540 essays, all of which were written specifically for it.

• Scope of Coverage

The *Encylcopedia of Global Warming* is designed to provide students at the high school and undergraduate levels with a convenient source of information on the fundamental science and sociopolitical issues, including the debates and controversies, surrounding climate change. The study of climate change involves not only scientists but also politicians, policy makers, businesses, government and nongovernment agencies, and the general public. A student attempting to understand both the environmental science and social issues and controversies will encounter not just scientific terms and concepts but political organizations, geographic areas, social concepts, persons, countries, organizations, and laws as well. This encyclopedia comprises entries from all those areas, including topics on both sides of the debate and entries from scholars who believe in human-driven global climate change as well as those who are less convinced. Our objective is to provide factual and objective information—not advocacy.

The essays in the set fall into one or more of the following broad categories: animals (16 essays); Arctic and Antarctic (7); astronomy (10); chemistry and geochemistry (41); climatic events and epochs (18); conferences and meetings (6); cryology and glaciology (19); diseases and health effects (7); economics, industries, and products (44); energy (29); environmentalism, conservation, and ecosystems (51); ethics, human rights, and social justice (8); fossil fuels (9); geology and geography (25); laws, treaties, and protocols (37); meteorology and atmospheric sciences (98); nations and peoples (39); oceanography (33); organizations and agencies (70); physics and geophysics (10); plants and vegetation (30); pollution and waste (24); popular culture and society (22); science and technology (23); transportation (4); and water resources (14).

• Essay Length and Format

Essays in the encyclopedia range in length from 400 to 2,000 words. They appear in one of six major formats:

- *Term* essays begin by defining a term and then explain its significance for climate change.
- *Overview* essays provide broad overviews of a scientific, policy, or social phenomenon or debate. They include a list of key concepts related to the topic, followed by background, several topical sections, and a concluding section explaining the climatological context of the topic.
- *Organization* essays provide the date of establishment of the organization, the URL of its official Web site, and discussions of its mission and significance for climate change.
- *Biographical* essays provide the profession, birth date, birthplace, death date, and death place of their subjects, followed by descriptions of their life and climate work.
- *Top-Twenty Emitter* essays provide information on each of the twenty nations with the highest annual emissions of greenhouse gases. These essays begin with a list of key facts, including the population, area, gross domestic product, and annual greenhouse gas emissions of the country, as well as its Kyoto Protocol status. They then provide discussions of the historical and political context of the nation's climatic impact, continue with the nation's relevant contributions to global warming and to international action, and conclude with a summary and foresight of the nation's future commitments and likely actions.
- *Law and Treaty* essays provide the date of passage or ratification of their subjects, as well as lists of all participating nations. They continue with discussions of background, summary of provisions, and significance for climate change.

Each essay longer than 400 words concludes with an annotated bibliography of suggestions for further reading, and all essays include an author byline and a list of cross-references to other related essays in the set.

• Special Features

Several features distinguish this series as a whole from other biographical reference works. The front matter includes the following aids:

- *Abbreviations and Acronyms:* Each volume includes a list explaining the abbreviations and acronyms used in essays throughout the set.
- *Common Units of Measure:* Measurements in the body of the set are in metric units only. Each volume's front matter includes a table converting metric/SI units into imperial units for the user's convenience.
- *List of Tables, Maps, and Sidebars:* The set includes more than 150 textual sidebars, tables, graphs, charts, maps, and other elements that illustrate or expand upon the essays with key supplementary information. A list of all such elements appears in the front matter of each volume.
- *Complete Table of Contents:* This list of the contents of the entire set appears in all three volumes.
- *Categorized List of Contents:* Each volume also includes a complete list of contents by category, to aid the reader in finding all essays relevant to a particular broad topic.

The back matter to Volume 3 includes several appendixes and indexes:

- *Biographical Dictionary of Key Figures in Global Warming:* A compendium of the people most influential in shaping discoveries, debates, and actions involving climate change.
- *Popular Culture About Global Warming:* A list of major books, films, television programs, and other mass media portraying global warming for a popular audience.
- *Time Line:* A chronology of all major events relating to human understanding of and response to climate change.
- *Glossary:* A complete glossary of technical and other specialized terms used throughout the set.
- *General Bibliography:* A comprehensive list of works on climate change for students seeking more information on the subject.
- *Web Sites:* A list of Web resources, including the official Web sites of key organizations, as well as online databases and other sources of information.
- *Subject Index:* A comprehensive index to all concepts, terms, events, persons, places, phenomena, and other topics of discussion.

• Acknowledgments

Salem Press would like to extend its appreciation to all involved in the development and production of this work. The essays have been written and signed by scholars of history, the sciences, and other disciplines related to the essays' topics.

Special thanks go to Professor Steven I. Dutch, of the Geosciences Program, University of Wisconsin—Green Bay, who developed the contents list and coverage notes for this set. A geologist, Professor Dutch is familiar with the methods, findings, and uncertainty of paleoclimatology. Because he is uninvolved in policy debates over climate change, and at the same time is familiar enough with the science to evaluate claims about climate, he was able to take on the task of assisting Salem Press in compiling a reference encyclopedia that addresses a broad variety of climate-change issues. Moreover, his research focus on the use and abuse of scientific evidence in public controversies has sensitized him not only to the controversies in this field but also to the need to create a contents list that addresses a broad variety of topics and issues. Hence, readers will find not only atmospheric science concepts but also topics like conspiracy theories, junk science, and pseudoscience covered in these pages, along with basic political approaches to climate policy (in essays such as "Conservatism," "Liberalism," and "Libertarianism"), as well as the inclusion of organizations active on both sides of the debate.

Without all the expertise of both Professor Dutch and the many contributing writers, a project of this nature would not be possible. A full list of the contributors' names and affiliations appears in the front matter of this volume.

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Abbreviations and Acronyms

AMO: Atlantic multidecadal oscillation
AQI: Air Quality Index
C^{14}: carbon 14
CCS: carbon capture and storage
CDM: clean development mechanism
CER: certified emissions reduction
CFCs: chlorofluorocarbons
CH_4: methane
CITES: Convention on International Trade in Endangered Species
CMP: Conference of the Parties to the United Nations Framework Convention on Climate Change, functioning as the meeting of the Parties to the Kyoto Protocol
CO: carbon monoxide
CO_2: carbon dioxide
CO_2e: carbon dioxide equivalent
COP: Conference of the Parties [to a treaty, such as the Framework Convention on Climate Change or the Convention on Biological Diversity]
COP/MOP: Conference of the Parties to the United Nations Framework Convention on Climate Change, functioning as the meeting of the Parties to the Kyoto Protocol
COP-1: First Conference of the Parties
CSD: Commission on Sustainable Development
DNA: deoxyribonucleic acid
EEZ: exclusive economic zone
ENSO: El Niño-Southern Oscillation
EPA: Environmental Protection Agency
ERU: emission reduction unit
FAO: Food and Agriculture Organization
GCM: general circulation model
GDP: gross domestic product
GHG: greenhouse gas
GWP: global warming potential
H_2: hydrogen (molecular)
HCFCs: hydroclorofluorocarbons
HFCs: hydrofluorocarbons
IAEA: International Atomic Energy Agency
IGY: International Geophysical Year
IMF: International Monetary Fund
INQUA: International Union for Quaternary Research
IPCC: Intergovernmental Panel on Climate Change
ITCZ: Inter-Tropical Convergence Zone
IUCN: International Union for Conservation of Nature
LOICZ: Land-Ocean Interactions in the Coastal Zone
MOC: meridional overturning circulation
MOP: meeting of the Parties [to a treaty, such as the Kyoto Protocol]
MOP-1: first meeting of the Parties
N_2O: nitrous oxide
NAAQS: National Ambient Air Quality Standards
NAM: Northern annular mode
NAO: North Atlantic Oscillation
NASA: National Aeronautics and Space Administration
NATO: North Atlantic Treaty Organization
NGO: nongovernmental organization
NOAA: National Oceanic and Atmospheric Administration
NO_x: nitrogen oxides
NRC: National Research Council
O^{16}: oxygen 16
O^{18}: oxygen 18
O_2: oxygen (molecular)
O_3: ozone
OECD: Organization for Economic Cooperation and Development
OPEC: Organization of Petroleum Exporting Countries
PFCs: perfluorocarbons
QELRCs: quantified emission limitation and reduction commitments
RuBisCO: Ribulose-1,5-bisphosphate carboxylase/oxygenase
SAM: Southern annular mode
SCOPE: Scientific Committee on Problems of the Environment
SF_6: sulfur hexafluoride
SO_2: sulfur dioxide

SSTs: sea surface temperatures
SUV: sports utility vehicle
THC: Thermohaline circulation
UNCED: United Nations Conference on Environment and Development
UNDP: United Nations Development Programme
UNEP: United Nations Economic Programme
UNESCO: United Nations Educational, Scientific, and Cultural Organization
UNFCCC: United Nations Framework Convention on Climate Change
UV: ultraviolet
VOCs: volatile organic compounds
WHO: World Health Organization
WMO: World Meteorological Organization

Common Units of Measure

Common prefixes for metric units—which may apply in more cases than shown below—include *giga-* (1 billion times the unit), *mega-* (one million times), *kilo-* (1,000 times), *hecto-* (100 times), *deka-* (10 times), *deci-* (0.1 times, or one tenth), *centi-* (0.01, or one hundredth), *milli-* (0.001, or one thousandth), and *micro-* (0.0001, or one millionth).

Unit	***Quantity***	***Symbol***	***Equivalents***
Acre	Area	ac	43,560 square feet 4,840 square yards 0.405 hectare
Ampere	Electric current	A *or* amp	1.00016502722949 international ampere 0.1 biot *or* abampere
Angstrom	Length	Å	0.1 nanometer 0.0000001 millimeter 0.000000004 inch
Astronomical unit	Length	AU	92,955,807 miles 149,597,871 kilometers (mean Earth-Sun distance)
Barn	Area	b	10^{-28} meters squared (approx. cross-sectional area of 1 uranium nucleus)
Barrel (dry, for most produce)	Volume/capacity	bbl	7,056 cubic inches; 105 dry quarts; 3.281 bushels, struck measure
Barrel (liquid)	Volume/capacity	bbl	31 to 42 gallons
British thermal unit	Energy	Btu	1055.05585262 joule
Bushel (U.S., heaped)	Volume/capacity	bsh *or* bu	2,747.715 cubic inches 1.278 bushels, struck measure
Bushel (U.S., struck measure)	Volume/capacity	bsh *or* bu	2,150.42 cubic inches 35.238 liters
Candela	Luminous intensity	cd	1.09 hefner candle
Celsius	Temperature	C	1° centigrade
Centigram	Mass/weight	cg	0.15 grain
Centimeter	Length	cm	0.3937 inch
Centimeter, cubic	Volume/capacity	cm^3	0.061 cubic inch
Centimeter, square	Area	cm^2	0.155 square inch

Unit	*Quantity*	*Symbol*	*Equivalents*
Coulomb	Electric charge	C	1 ampere second
Cup	Volume/capacity	C	250 milliliters 8 fluid ounces 0.5 liquid pint
Deciliter	Volume/capacity	dl	0.21 pint
Decimeter	Length	dm	3.937 inches
Decimeter, cubic	Volume/capacity	dm^3	61.024 cubic inches
Decimeter, square	Area	dm^2	15.5 square inches
Dekaliter	Volume/capacity	dal	2.642 gallons 1.135 pecks
Dekameter	Length	dam	32.808 feet
Dram	Mass/weight	dr *or* dr avdp	0.0625 ounce 27.344 grains 1.772 grams
Electron volt	Energy	eV	$1.5185847232839 \times 10^{-22}$ Btus $1.6021917 \times 10^{-19}$ joules
Fermi	Length	fm	1 femtometer 1.0×10^{-15} meters
Foot	Length	ft *or* ′	12 inches 0.3048 meter 30.48 centimeters
Foot, cubic	Volume/capacity	ft^3	0.028 cubic meter 0.0370 cubic yard 1,728 cubic inches
Foot, square	Area	ft^2	929.030 square centimeters
Gallon (British Imperial)	Volume/capacity	gal	277.42 cubic inches 1.201 U.S. gallons 4.546 liters 160 British fluid ounces
Gallon (U.S.)	Volume/capacity	gal	231 cubic inches 3.785 liters 0.833 British gallon 128 U.S. fluid ounces
Giga-electron volt	Energy	GeV	$1.6021917 \times 10^{-10}$ joule
Gigahertz	Frequency	GHz	—
Gill	Volume/capacity	gi	7.219 cubic inches 4 fluid ounces 0.118 liter

Unit	*Quantity*	*Symbol*	*Equivalents*
Grain	Mass/weight	gr	0.037 dram 0.002083 ounce 0.0648 gram
Gram	Mass/weight	g	15.432 grains 0.035 avoirdupois ounce
Hectare	Area	ha	2.471 acres
Hectoliter	Volume/capacity	hl	26.418 gallons 2.838 bushels
Hertz	Frequency	Hz	$1.08782775707767 \times 10^{-10}$ cesium atom frequency
Hour	Time	h	60 minutes 3,600 seconds
Inch	Length	in *or* ″	2.54 centimeters
Inch, cubic	Volume/capacity	in^3	0.554 fluid ounce 4.433 fluid drams 16.387 cubic centimeters
Inch, square	Area	in^2	6.4516 square centimeters
Joule	Energy	J	$6.2414503832469 \times 10^{18}$ electron volt
Joule per kelvin	Heat capacity	J/K	$7.24311216248908 \times 10^{22}$ Boltzmann constant
Joule per second	Power	J/s	1 watt
Kelvin	Temperature	K	–272.15 Celsius
Kilo-electron volt	Energy	keV	$1.5185847232839 \times 10^{-19}$ joule
Kilogram	Mass/weight	kg	2.205 pounds
Kilogram per cubic meter	Mass/weight density	kg/m^3	$5.78036672001339 \times 10^{-4}$ ounces per cubic inch
Kilohertz	Frequency	kHz	—
Kiloliter	Volume/capacity	kl	—
Kilometer	Length	km	0.621 mile
Kilometer, square	Area	km^2	0.386 square mile 247.105 acres
Light-year (distance traveled by light in one Earth year)	Length/distance	lt-yr	5,878,499,814,275.88 miles 9.46×10^{12} kilometers

Unit	*Quantity*	*Symbol*	*Equivalents*
Liter	Volume/capacity	L	1.057 liquid quarts 0.908 dry quart 61.024 cubic inches
Mega-electron volt	Energy	MeV	—
Megahertz	Frequency	MHz	—
Meter	Length	m	39.37 inches
Meter, cubic	Volume/capacity	m^3	1.308 cubic yards
Meter per second	Velocity	m/s	2.24 miles per hour 3.60 kilometers per hour
Meter per second per second	Acceleration	m/s^2	12,960.00 kilometers per hour per hour 8,052.97 miles per hour per hour
Meter, square	Area	m^2	1.196 square yards 10.764 square feet
Metric. *See* unit name			
Microgram	Mass/weight	mcg *or* µg	0.000001 gram
Microliter	Volume/capacity	µl	0.00027 fluid ounce
Micrometer	Length	µm	0.001 millimeter 0.00003937 inch
Mile (nautical international)	Length	mi	1.852 kilometers 1.151 statute miles 0.999 U.S. nautical miles
Mile (statute or land)	Length	mi	5,280 feet 1.609 kilometers
Mile, square	Area	mi^2	258.999 hectares
Milligram	Mass/weight	mg	0.015 grain
Milliliter	Volume/capacity	ml	0.271 fluid dram 16.231 minims 0.061 cubic inch
Millimeter	Length	mm	0.03937 inch
Millimeter, square	Area	mm^2	0.002 square inch
Minute	Time	m	60 seconds
Mole	Amount of substance	mol	6.02×10^{23} atoms or molecules of a given substance

Unit	*Quantity*	*Symbol*	*Equivalents*
Nanometer	Length	nm	1,000,000 fermis 10 angstroms 0.001 micrometer 0.00000003937 inch
Newton	Force	N	x 0.224808943099711 pound force 0.101971621297793 kilogram force 100,000 dynes
Newton meter	Torque	N·m	0.7375621 foot-pound
Ounce (avoirdupois)	Mass/weight	oz	28.350 grams 437.5 grains 0.911 troy or apothecaries' ounce
Ounce (troy)	Mass/weight	oz	31.103 grams 480 grains 1.097 avoirdupois ounces
Ounce (U.S., fluid or liquid)	Mass/weight	oz	1.805 cubic inch 29.574 milliliters 1.041 British fluid ounces
Parsec	Length	pc	30,856,775,876,793 kilometers 19,173,511,615,163 miles
Peck	Volume/capacity	pk	8.810 liters
Pint (dry)	Volume/capacity	pt	33.600 cubic inches 0.551 liter
Pint (liquid)	Volume/capacity	pt	28.875 cubic inches 0.473 liter
Pound (avoirdupois)	Mass/weight	lb	7,000 grains 1.215 troy or apothecaries' pounds 453.59237 grams
Pound (troy)	Mass/weight	lb	5,760 grains 0.823 avoirdupois pound 373.242 grams
Quart (British)	Volume/capacity	qt	69.354 cubic inches 1.032 U.S. dry quarts 1.201 U.S. liquid quarts
Quart (U.S., dry)	Volume/capacity	qt	67.201 cubic inches 1.101 liters 0.969 British quart
Quart (U.S., liquid)	Volume/capacity	qt	57.75 cubic inches 0.946 liter 0.833 British quart
Rod	Length	rd	5.029 meters 5.50 yards

Unit	*Quantity*	*Symbol*	*Equivalents*
Rod, square	Area	rd^2	25.293 square meters 30.25 square yards 0.00625 acre
Second	Time	s *or* sec	$1/60$ minute $1/3600$ hour
Tablespoon	Volume/capacity	T *or* tb	3 teaspoons 4 fluid drams
Teaspoon	Volume/capacity	t *or* tsp	0.33 tablespoon 1.33 fluid drams
Ton (gross or long)	Mass/weight	t	2,240 pounds 1.12 net tons 1.016 metric tons
Ton (metric)	Mass/weight	t	1,000 kilograms 2,204.62 pounds 0.984 gross ton 1.102 net tons
Ton (net or short)	Mass/weight	t	2,000 pounds 0.893 gross ton 0.907 metric ton
Volt	Electric potential	V	1 joule per coulomb
Watt	Power	W	1 joule per second 0.001 kilowatt $2.84345136093995 \times 10^{-4}$ ton of refrigeration
Yard	Length	yd	0.9144 meter
Yard, cubic	Volume/capacity	yd^3	0.765 cubic meter
Yard, square	Area	yd^2	0.836 square meter

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ENCYCLOPEDIA OF
GLOBAL WARMING

Editor's Introduction

The debate over whether global warming is occurring has lessened over the past decade, and the focus of the debate has shifted. More and more participants on both sides agree that climate data show a warming trend. The debate now revolves around how long-term and significant that trend is, whether it is due mainly to human (anthropogenic) causes, and what course of action society should take to deal with climate change. Any reference work on global warming and climate change will inevitably, therefore, be controversial. If it is dominated too much by believers in climate change, legitimate climate change skeptics might dismiss it as simply another expression of the "party line." If it incorporates too many skeptical viewpoints, climate change activists will see it as taking a weak stance or possibly even being a covert attempt to advance the skeptics' cause.

Salem Press's *Encyclopedia of Global Warming* strives to incorporate the views of academically qualified scientists, historians, economists, and political scientists, presenting objective information without bias or a polemic tone. Some of the contributors are scientists who accept the anthropogenic basis for recent climate change; some are more reserved in their judgment, cognizant of the complexity of climate change and the limitations of computer models used in predicting climate; and some doubt the role of human action in climate change. Salem Press made a conscious effort to seek out and incorporate the views of academically qualified skeptics, because they would be able to articulate the positions of skeptics most accurately and fairly.

A reader unfamiliar with the climate change debate should understand not only the science itself but also the social and political landscape surrounding the debate. Someone reading about climate change in the newspapers or online will inevitably encounter terms such as "liberal," "conservative," "conspiracy," and so on. For that reason, the encyclopedia includes not just articles on scientific terms and concepts but also overviews of organizations active on both sides of the controversy and essays on basic political terms—such as "liberalism," "libertarianism," and "conservatism"—as they pertain to the debate over climate change. Also, some people on both sides in the climate change debate have accused the other side of promoting poor or even false science and of having political or financial motivations. To provide some help in dealing with such claims, articles are included on topics such as conspiracy theories and junk science and pseudoscience.

Quantitative climate data are available only for the last century or so. To determine earlier climatic conditions, scientists must rely on proxy measures of climate. For example, diaries and news accounts of bodies of water freezing over that normally do not freeze, unusual frosts, rainfall, or drought can furnish clues about climate variation but cannot be directly converted into present numerical values. All the methods used to derive temperatures from pre-instrument times are subject to error and subjective interpretation. In the absence of written records, climatologists must rely on physical indicators such as tree rings, pollen, marine microfossils, and oxygen isotope ratios. Measurements of such proxies can be calibrated against written and instrumental records but nevertheless introduce still another level of uncertainty into the results. Further back in geologic time, there are climatic indicators such as coal beds, evaporites, and glacial deposits, and there are geochemical indicators of temperature and atmospheric oxygen and carbon dioxide concentration. These records require their own methods of interpretation. It is neither scientifically nor socially irresponsible to ask how reliable the climate record is or how one can separate anthropogenic from natural climate change. Indeed, even a cursory browse through climatological journals will turn up many papers that ask precisely those questions. Intellectually honest activists and skeptics alike agree that the surest way to make their case is to make the science as rigorous and reliable as possible.

The late U.S. senator Ed Muskie of Maine once famously lamented that there were not "more one-armed scientists," because scientists were always saying "On the other hand. . . ." One of the things that most separates scientists from nonscientists is that scientists can tolerate ambiguity. Nonscientists find ambiguity in science extremely frustrating. Unfortunately, many people are willing to fill that void with promises of certainty, or to point to ambiguity as proof that science has no answers, or to consider some other interpretation as preferable to the scientific view.

Ambiguity in science might be likened to the strike zone in baseball. To a skilled pitcher or hitter, the strike zone is a big target. Its boundaries are a bit fuzzy. Different umpires might call balls and strikes a bit differently. To someone sitting in the stands, the strike zone is a speck. Nobody familiar with baseball would try to claim that a wild pitch into the stands was a strike merely because the strike zone has fuzzy edges. Despite the ambiguities in science, it is able to categorize some theories as definitely right or definitely wrong. There is a very limited zone of strikes—correct ideas—and a vast realm of wild pitches—incorrect ideas. Regardless of whether or not anthropogenic climate change is occurring, pointing to some local anomaly such as an unusually early frost or a lake where ice breaks up unusually late is simply wrong. It is fallacious reasoning, because it tries to draw a general conclusion about a complex subject from an isolated piece of data. Pointing to unresolved questions as evidence that science in general is unreliable, or using unresolved questions to justify belief in some alternative theory, is also simply wrong.

However, at some point practical decisions have to be made about matters on which existing scientific evidence remains ambiguous. When a food additive or environmental chemical poses an unknown level of risk, someone must decide whether the risk seems low enough to be tolerable or high enough to warrant controlling the substance and incurring the costs of doing so. Someone must decide whether a given penalty deters crime, even if the social science data are unclear. Someone must decide whether an emerging flu strain warrants a response, even before there are many cases. Someone must decide whether the threat posed by anthropogenic climate change warrants a certain level of response. Although there are many uncertainties about global warming, there is an overall consensus among scientists that it is occurring. The real debate is about prudence. What is the prudent response? Should society accept change as inevitable, make limited attempts to reduce carbon dioxide emissions to maximize effect while minimizing economic costs, or assume the worst and mount a strenuous global campaign to reduce carbon emissions, even at huge cost?

The average citizen has a role to play in the decision-making process, principally in the voting booth. Even with the best information on climate change, voters have to weigh a candidate's stance on climate against his or her stance on other important issues. Nevertheless, it is important that voters be as accurately informed about climate change as possible and also that they be skilled at detecting misleading arguments. The intent of this encyclopedia is to help its readers do that.

Steven I. Dutch
University of Wisconsin-Green Bay

Abrupt climate change

• **Category:** Meteorology and atmospheric sciences

Abrupt climate change entails drastic warming or cooling, regionally or globally, that takes place within a few years or decades and that persists for at least a few decades. Such a transformation would have a lasting effect on human institutions and infrastructure.

• Key concepts

albedo: the fraction of radiation reflected by a surface

feedback: a process in which any change accelerates further changes of the same type (positive feedback) or counteracts itself (negative feedback)

greenhouse gases (GHGs): atmospheric gases, such as carbon dioxide, water vapor, and methane, that trap heat radiation from Earth's surface by absorbing it and reemitting it

proxy: remnant physical evidence from which past climatic conditions can be inferred

thermohaline cycle: the "great conveyor belt" of ocean currents powered by density gradients created by heat and relative salt content

tipping point: the point at which the transition from one state in a system to another becomes inevitable

• Background

In 1840, Louis Agassiz published his theory that the Earth had passed through an ice age. As a result of Agassiz's work, the corollary idea that the globe's climate could change dramatically for extended periods entered scientific thinking. Scientists assumed, however, that such change occurred very slowly and smoothly over many millennia. When, in 1922, meteorologist C. E. P. Brooks first proposed that climate can change swiftly, he was largely ignored. During the early 1990's, however, a steady accumulation of data from four main sources strongly supported Brooks's hypothesis. These data suggested that in past epochs the atmosphere went from warm to cool or from cool to warm within decades, perhaps even within a few years.

• Proxy Evidence for Abrupt Change

The theory of abrupt change rests on proxy data from ice cores taken from the ice sheets covering Greenland and Antarctica, as well as from tree rings, sediments in oceans and lakes, and coral. In each of these proxies, layers of material are laid down annually and vary in thickness in accordance with annual atmospheric conditions. In tree rings, for instance, wet years foster greater growth in trees, which is reflected in wider rings than those produced during dry years. In addition to such evidence, gases in bubbles trapped in ice reveal the relative abundance of elements at the time they were trapped, which in turn provides clues to atmospheric temperatures at that time.

Taken together, proxy evidence demonstrates not only sudden climate change in past epochs but also frequent change. The most recent of four ice ages lasted from 120,000 to 14,500 years ago. Even during that frigid period, there were twenty-five periods of abrupt warming, called Dansgaard-Oeschger events, and six extended plunges in temperature, called Heinrich events; in all of them, change took place within decades.

The most studied example of abrupt change is the period known as the Younger Dryas, which began about 12,800 years ago. As the Northern Hemisphere was warming from the ice age, it suddenly relapsed into ice-age temperatures and stayed cold until 11,500 years ago, when temperatures over Greenland rose by 10° Celsius within a decade.

• Mechanisms for Abrupt Change

The United States National Research Council defines abrupt climate change as occurring when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause.

Mechanisms for such change are poorly understood. It appears that some physical process forces an aspect of the climate system to pass a tipping point—for instance, in the albedo, average cloud cover, or salinity of ocean water. After the tipping point, positive feedback in the system accelerates the warming or cooling trend.

In the case of the Younger Dryas, scientists know that the water of the North Atlantic suddenly be-

An iceberg calved from Greenland's Jacobshavn glacier. Abrupt climate change could drastically increase the melting of this and other glaciers. (Konrad Steffen/MCT/Landov)

came less salty, which slowed or altered the course of the thermohaline cycle. The warm waters of the Gulf Stream no longer flowed north of Iceland and back down along the European coast, causing the continent to relapse to ice-age temperatures. The freshening probably resulted from a sudden outflow of water from a freshwater inland sea, Lake Agassiz, in north-central North America. The physical event that led to this forcing is a point of controversy. Scientists have proposed the breaking of an ice dam after gradual warming or possibly a meteor impact. Forcings for other abrupt changes in past climates include alterations in the salinity of the tropical Atlantic Ocean, evaporation and cloud cover in the South Pacific Ocean, melting of methane clathrates (frozen methane in the ocean beds), and the periodic warming of the South Pacific known as the El Niño-Southern Oscillation (ENSO).

• **Anthropogenic Global Warming**

Scientists worry that increasing levels of greenhouse gases (GHGs) in the atmosphere, much of them released by the burning of fossil fuels, have trapped radiant energy from the Sun in the atmosphere and increased average global temperatures in both the atmosphere and the oceans. This greenhouse effect could lead to abrupt climate change in several ways.

The vast ice sheets in the Arctic and Antarctica have the highest regional albedo on Earth, but they are shrinking rapidly, especially in the Arctic. There, the ice rests primarily on water, which is darker than ice and absorbs more heat. As the ice disappears, there is more exposed ocean surface to absorb solar energy, and the warmed water in turn helps melt the ice faster, creating a positive feedback loop. This melted ice will not affect ocean levels or salinity, but if ice sheets melt off the land of

Antarctica or Greenland, ocean levels could rise by dozens of meters within a century, lowering ocean salinity enough to stall the thermohaline cycle, which could cool Europe rapidly and drastically even while the rest of the world warmed. Should ocean water heat up too much, clathrates could melt and send billions of metric tons of methane into the atmosphere, accelerating global warming further. The augmented thermal energy in the atmosphere is likely to redistribute wind and rainfall patterns, plunging some regions into drought while making others wetter; catastrophic storms, such as hurricanes and tornados, could become more frequent and severe.

• Context

Some scientists argue than the Earth is entering a new geological age, the Anthropocene, because humanity itself now takes part in shaping Earth's overall surface conditions, climate in particular. Particulate pollution (especially soot), waste heat, release of GHGs, water consumption, and alteration of soil and plant cover affect not only the land, water bodies, and atmosphere but also modern civilization. If human effects on the environment trigger abrupt climate change, the onset of icy conditions in the Northern Hemisphere, droughts, superstorms, or rising sea level—all of which are possible according to computer models of climate change—would require radical, swift, and comprehensive measures to adapt or relocate much of Earth's human population. Not only would that be an expensive undertaking, but it would also mark a shift in the course of human history as profound as the Industrial Revolution.

Roger Smith

• Further Reading

Cox, John D. *Climate Crash: Abrupt Climate Change and What It Means for Our Future*. Washington, D.C.: Joseph Henry Press, 2005. A history of climate change, its effects on human culture, and its scientific study; provides exceptionally clear explanations of fundamental concepts.

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming*. Rev. ed. London: Penguin, 2007. A well-explained review of environmental science, the evidence for global warming, and what people can do about it; written by a scientist who was once a skeptic.

Lynas, Mark. *Six Degrees: Our Future on a Hotter Planet*. Washington, D.C.: National Geographic, 2008. Based entirely upon scientific research and computer models; describes the specific rapid climate changes that are possible for each degree Celsius's rise in average world temperature.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change*. Boston: Beacon Press, 2007. An earnest, dramatic, and thorough survey of climate change studies and the possible results of abrupt climate change by a noted environmental journalist.

See also: Agassiz, Louis; Albedo feedback; Antarctica: threats and responses; Arctic; Climate change; Climate reconstruction; Thermohaline circulation; Younger Dryas.

Adiabatic processes

• Category: Meteorology and atmospheric sciences

• Definition

Adiabatic processes are those in which no heat transfer takes place. In an atmospheric adiabatic process, a parcel of air undergoes changes in its internal temperature but does not lose or gain heat to its ambient (surrounding) environment. According to Boyle's law, air, like any gas, experiences changes in pressure proportionate to changes in volume: When a parcel of air expands to fill more space, it decreases in pressure. When it contracts to fill less space, the air parcel increases in pressure.

As air rises, it expands, and as it descends, it is compressed. This is due to ambient pressures around the parcel of air: A given parcel of air that is near the Earth's surface has a great deal of air above it, weighing it down and increasing its total pressure. By contrast, a parcel of air that is higher up in the atmosphere has less air above it and thus less pressure upon it. As air parcels circulate in the atmosphere, they expand or contract until they reach a state of pressure equilibrium with other air parcels around them. At the same time, their internal temperatures decrease as they expand and increase as they contract. These adiabatic changes in temperature can be observed and mathematically averaged into what are known as “lapse rates.”

There are three lapse rates to be considered. First, the environmental lapse rate is the most common baseline rate of change of the overall atmosphere as one ascends into it. This rate is 4° Celsius per 1,000 meters of altitude. Thus, for every 1,000 meters one ascends off the ground, one observes a drop in temperature, on the average, of 4° Celsius. (The atmosphere can also be in a state of inversion, in which temperatures increase rather than decrease as one ascends.)

The next lapse rate is the dry adiabatic lapse rate, which applies to air parcels that are not saturated with moisture. This rate is 10° Celsius per 1,000 meters. As an air parcel rises and cools, its temperature may approach its dew point, meaning that it may become saturated with moisture, causing water vapor to condense into liquid water. In the process of condensation, heat is released, and cooling begins to take place at a slower pace (because of the injection of heat into the ambient environment). This slower rate of cooling, known as the wet adiabatic lapse rate, is about 5° Celsius per 1,000 meters.

• Significance for Climate Change

The lifting condensation level (LCL) of a station’s location to some degree can be looked at on a climatological basis. The LCL is the point to which a parcel of air ascends while it cools adiabatically at the dry adiabatic rate. The altitude of the LCL can be calculated by taking the known values of the parcel’s air temperature and dew point temperatures in Celsius at the base of its rise, subtracting these values, and then dividing them by 8. That value is multiplied by 1,000 to arrive at the LCL in meters. If conditions are right, condensation will begin to take place and clouds will form at the LCL, and precipitation may be initiated. From that point on, if the parcel were to continue its rise past the LCL, it would expand and cool at the wet adiabatic rate.

Seasonal shifts occur in the average altitude of the LCL. Summertime LCLs are generally higher than wintertime LCLs. Similarly, changes in the climate could impact the average elevations of the LCL. Theoretically, if conditions were to warm as well as dry, some studies suggest the LCL would increase in altitude. The result of this would be to make cloud bases higher, with the possibility of shifting precipitation zones.

It has been suggested that deforestation could also play a role in modifying the altitude of the LCL. In the Monteverde region of Costa Rica, lowland moisture plays an important part in the positioning of the cloud base as winds blow moist air up the coastal range. Deforestation in the region may have lowered humidity, pushing the cloud base to higher altitudes. Consequently, various biological zones have shifted upward in altitude, forcing a shift in flora and fauna.

In contrast, if moister conditions prevail, soils may increase in moisture levels, which can lead to conditions conducive to an increase in evapotranspiration by plants. According to some studies, this increase in humidity would have the effect of lowering the LCL in regional areas. In any case, the adiabatic process does not change, only the positioning of the LCL.

M. Marian Mustoe

• Further Reading

Aguado, Edward, and James E. Burt. *Understanding Weather and Climate*. 4th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Survey of the elements of meteorology. Adiabatic processes and the establishment of the lifting condensation level are discussed.

Ahrens, C. Donald. *Meteorology Today*. 9th ed. Pacific Grove, Calif.: Thomson/Brooks/Cole, 2009. Provides explanations of adiabatics and temperature inversions.

Blanchard, D. C. *From Raindrops to Volcanoes: Adventures in Sea Surface Meteorology*. Mineola, N.Y.: Dover, 1995. Explains how precipitation forms and provides examples of how to measure precipitation.

See also: Atmospheric dynamics; Climate feedback; Clouds and cloud feedback; Dew point; Humidity; Rainfall patterns.

Advancement of Sound Science Center

- **Category:** Organizations and agencies
- **Date:** Established 1993

- **Mission**

The Advancement of Sound Science Center (TASSC), previously the Advancement of Sound Science Coalition, was a lobbying group run by the public relations firm APCO and founded by the tobacco industry. Originally established to provide scientific arguments against the dangers of secondhand smoke, TASSC expanded its mission to also advance the idea that warnings about other environmental dangers, including global warming and chemical exposure, were based on what the group labeled "junk science." TASSC's chief spokesman was libertarian Steven Milloy, junk science commentator for Fox News and creator of the Web site junkscience.com. Other advisers to TASSC included former New Mexico governor Garrey Carruthers and global warming skeptics S. Fred Singer, Michael Fumento, and Patrick J. Michaels. TASSC received financial support from Amoco, Exxon, Dow Chemical, Occidental Petroleum, Philip Morris, and other corporations.

- **Significance for Climate Change**

It is difficult to separate the activities of Steven Milloy from those of TASSC. TASSC was operated out of Milloy's home, and there was no other paid staff. Initially, TASSC was listed as the sponsor of the Web site junkscience.com, but after the Web site's corporate ties were exposed, the site ran under the sponsorship of Citizens for the Integrity of Science, another group run by Milloy using the same mailing address and phone number that TASSC had used.

TASSC played a role in raising early questions about the scientific consensus about the causes of global warming. In 1997, for example, the group invited citizens to read about global warming on its Web site and then to send emails to President Bill Clinton about proposed reductions in greenhouse gas (GHG) emissions. Articles available on the Web site were unanimously dismissive of the seriousness of global warming. One, titled "Kangaroo Court: The Working Group on Public Health and Fossil Fuel Combustion," argued that "A kangaroo court of junk scientists predicts that 8 million people will die during 2000 to 2020 from particulate matter air pollution associated with fossil fuel, unless the world limits GHG emissions to levels advocated by European nations."

In 2004, Milloy was among the public critics of the Arctic Climate Impact Assessment. In 2008, his Web site offered "The Ultimate Global Warming Challenge," a half-million-dollar prize to the first person to prove, "in a scientific manner, that humans are causing harmful global warming."

Cynthia A. Bily

See also: Cato Institute; Competitive Enterprise Institute; Fraser Institute; Libertarianism; Pseudoscience and junk science; Skeptics.

Aerosols

- **Category:** Chemistry and geochemistry

Aerosols are among the least well understood influences on global climate, but anthropogenic aerosols, especially sulfate aerosols released by fossil fuel combustion, seem to exert a cooling influence on the climate. This cooling effect, however, appears insufficient to counteract the warming caused by GHGs.

- **Key concepts**

cloud condensation nuclei: atmospheric particles such as dust that can form the centers of water droplets, increasing cloud cover

Dust Veil Index: a numerical index that quantifies the impact of a volcanic eruption's release of dust and aerosols

global dimming: the effect produced when clouds reflect the Sun's rays back to space

stratosphere: part of the atmosphere just above the troposphere that can hold large amounts of aerosols produced by volcanic eruptions for many months *troposphere:* location in the lower atmosphere where the majority of aerosols form a thin haze before being washed out of the air by rain

• Background

Effects of aerosol pollutants such as volcanic dust have been debated for a long time. A 1783 eruption of a volcanic fissure in Iceland seemed related to an unusually cool summer in France that year. In 1883, the volcanic dust from the explosion of Krakatoa in the East Indies dimmed the sunlight for months, as had the 1815 eruption of Tambora. Some scientists perceived a pattern of temporary cooling from such events. Others asked if pollutants should be expected to warm, rather than cool, the atmosphere.

Aerosols are minute airborne solid or liquid particles suspended in the atmosphere, typically measuring between 0.01 and 10 microns. They may be of either natural or anthropogenic origin. Natural aerosol sources include salt particles from sea spray; clay particles from the weathering of rocks; volcanically produced sulfur dioxide, which oxidizes to form sulfuric acid molecules; and desert dust. Anthropogenic (human-produced) aerosol sources include industrial pollutants such as sulfates, created by burning oil and coal; smoke from large-scale burning of biomass, such as occurs in slash-and-burn clearing of tropical forests; and pollution from naval vessels' smokestacks.

Normally, most aerosols rise to form a thin haze in the troposphere; rain washes these out within about a week's time. Some aerosols, however, are found in the higher stratosphere, where it does not rain. They can remain in this atmospheric layer for months. Aerosols may influence climate in several ways: directly, through scattering and absorbing radiation, and indirectly, by acting as cloud condensation nuclei or by modifying the optical properties and lifetimes of clouds.

On windy days, bubbles created by breaking waves toss salt into the air when they burst, forming aerosols. Salt aerosols scatter sunlight, lessening the amount of energy that reaches Earth's surface and cooling the climate. The interaction of sea salt with clouds also causes cooling. The resulting whitening of the Earth further reduces the amount of sunlight that can reach the ground. Oceans cover over 70 percent of Earth's surface, and sea salt is a major source of aerosols in areas far distant from land.

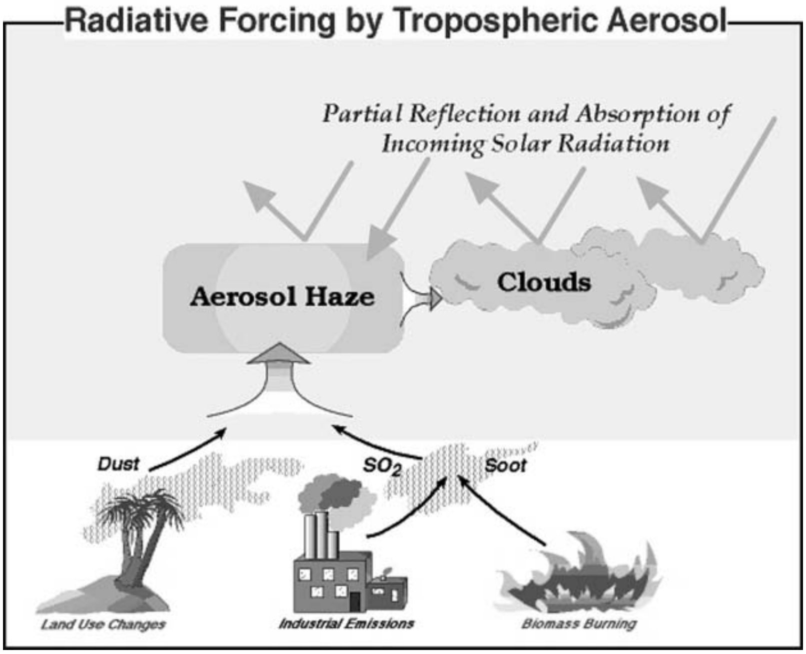
Wind also helps form aerosols over land. Particles carried by the wind push and bounce over one another, abrading the surfaces of rock and other landforms. These particles wear rocks down progressively over time, converting their surfaces into dust and other particles. When these particles are incorporated into the air, they too form aerosols.

Following major volcanic eruptions, sulfur dioxide gas vented during the eruptions is converted into sulfuric acid droplets. These droplets form an aerosol layer in the stratosphere. Winds in the stratosphere scatter the aerosols over the entire globe, and they may remain in the atmosphere for about two years. Since they reflect sunlight, these aerosols reduce the amount of energy that reaches the troposphere and the Earth's surface, resulting in cooling.

Another significant natural aerosol is desert dust. "Veils" of dust stream off deserts in Asia and Africa, and they have also been observed on the American continent. These particles fall out of the atmosphere after a short flight, but intense dust storms often blow them to altitudes of 4,500 meters or higher. Since the dust is made up of minerals, the particles both absorb and scatter sunlight. Absorption warms the layer of the atmosphere where they are located, possibly inhibiting the formation of storm clouds and contributing to desertification.

• Early Speculation About Aerosols

Long before there was much interest in aerosols as a factor in climate change or any equipment capable of adequately analyzing aerosol data, a few individuals speculated about a possible aerosol-climate connection. The first man credited with reporting his ideas was Mourgue de Mondtredon, a French naturalist who in 1783 documented the eight-month-long Laki eruption in southern Iceland. The eruption caused the grass to die: Three-quarters of the region's livestock and one-quarter of its people starved to death. For months, a haze hovered over western Europe. When Benjamin Franklin was visiting in France in 1783, he experienced an unseasonably cold summer and speculated that the Laki volcanic "fog" had noticeably dimmed the sunlight.



Aerosols can both reflect and absorb solar radiation, making their role in the greenhouse effect particularly complex. (NOAA)

A century later, in 1883, the eruption of the Indonesian volcano Krakatoa (Krakatau) sent up a veil of volcanic dust that reduced sunlight globally for months. Scientists were unable to determine what effect the eruption might have had on the average global temperature, but scientists thereafter acknowledged volcanoes as a possible natural influence on Earth's climate.

A few scientists who examined temperatures after major volcanic eruptions between 1880 and 1910 perceived a pattern of temporary cooling. Only later would older records reveal that the 1815 eruption of Tambora in Indonesia had affected the climate more severely than had the Krakatoa eruption. Speculation led some to ask if volcanic eruptions had precipitated ice ages or had cooled the Earth to the extent that dinosaurs became extinct.

• Early Twentieth Century Aerosol Research

Throughout the first half of the twentieth century, it was known that volcanic aerosols could affect climate. As a result, some scientists suspected that other kinds of dust particles could have similar climatic effects. Physics theory seemed to support the notion that these particles should scatter radiation from the Sun back into space, thereby cooling the Earth. These ideas remained largely speculative, though some researchers began to focus on the possibility that human activity might be a major source of atmospheric particles.

In the 1950's, nuclear bomb tests provided improved data on aerosol behavior in the stratosphere. It was determined that stratospheric dust would remain for some years, but would stay in one hemisphere. Research in the early 1960's indicated that large volcanic eruptions lowered average annual temperatures. Some researchers, however, deemed those results enigmatic, since temperatures had fallen during a period of few eruptions. Meteorologists acknowledged that other small, airborne particles could influence climate, but throughout the first half of the century, speculation fell short of conclusion.

Gradually, scientists shifted their focus to anthropogenic atmospheric particles. Measurements by ships between 1913 and 1929 noted that sea air showed an extended decrease in conductivity, apparently caused by stack smoke and gases from ships and possibly from industry on land. Even in 1953, however, scientists were uncertain about the significance of the pollution.

During the 1950's, some scientists asked whether aerosols might affect climate by helping form clouds. Since cloud condensation nuclei are essential for providing a surface for water droplets to condense around, the notion of seeding clouds with silver iodide smoke to make rain was widespread. By this time, aerosol science was just coming into its own as an independent field of study, having been given impetus by the concern that disease-carrying aerosols and poisonous gas could be lethal. Public concern over urban smog also fueled studies by aerosol experts. By and large, however, scientists avoided the study of cloud formation. Field testing often produced contradictory results and was extremely expensive, and many researchers believed that aerosols' effects on clouds were too complex to comprehend.

• Aerosol Research in the Later Twentieth Century

By the early 1960's, the scientific community was beginning to pay more attention to the possibility that humans influenced clouds. One noted astrophysicist had long had an interest in aerosols after seeing the effects of the Dust Bowl in the 1930's. He noticed changes in the skies over Boulder, Colorado, and pointed out jet airplane contrails, predicting correctly that they would spread, thin, and become indistinguishable from cirrus clouds. The apparent ability of aircraft to create cirrus clouds revealed the possibility that they might be causing climate changes along major air routes. Others questioned the possibility of anthropogenic activity as the source of pollution settling on polar ice caps. At the time, the theory did not receive much credence.

Around 1970, the British meteorologist Hubert Horace Lamb's Dust Veil Index established a connection between dust and lower temperatures. While scientific studies at this time did not yet find strong evidence for an increase in global turbidity, they did document regional hazes that spread in a radius of up to one thousand kilometers or more from industrial centers. The scientific debate shifted from the existence of anthropogenic dust to the effects of that dust. It remained a subject of controversy whether and under what circumstances dust would cool or heat the climate, especially after a spacecraft on Mars in 1971 found that a large dust storm had caused substantial warming of the Martian atmosphere.

Deadly droughts in Africa and South Asia in 1973 caused public concern about climate change, but it was not confirmed that sulfate pollution had contributed to the Sahel drought until the end of the century. Scientific publications in the mid- to late 1970's discussed warming or cooling effects without reaching accord, although a majority felt that greenhouse warming would dominate. At this time, only a few researchers noted that aerosol pollution might cancel out some greenhouse warming and thus temporarily mask its effects. Others denied that industrial pollution could mitigate the enhanced greenhouse effect caused by carbon dioxide (CO_2) emissions.

The 1980's brought the realization that additional factors contributed to climate and climate change. For example, climate scientists generally treated aerosols as a globally uniform background, largely of natural origin, when in fact different aerosol properties obtained in different regions based on relative humidity. Many questions remained.

By 1990, it was acknowledged that from one-fourth to one-half of all tropospheric aerosol particles were anthropogenic. These included industrial soot and sulfates, smoke from forest clearing fires, and dust from overgrazed or semiarid land turned to agriculture. Impressive advances in laboratory instrumentation made possible much more sophisticated satellite observations, greatly increasing the resolution of climate models. The key paper establishing the net effect of aerosols on Earth's heat balance was published in the early 1990's; it concluded that radiation scattering due to anthropogenic sulfate emissions was counterbalancing CO_2-related greenhouse warming in the Northern Hemisphere.

It became apparent that earlier climate projections might be erroneous, because they had not factored in sulfate aerosol increases. Climatologists redoubled their efforts to produce accurate models and projections of Earth's climate. In 1995, for the first time, new results that took into account aerosol influence yielded a consistent and plausible picture of twentieth century climate. According to this picture, industrial pollution had temporarily depressed Northern Hemisphere temperatures around the mid-century. A 2008 study found that black carbon aerosols had exerted a much greater warming effect than had been earlier estimated, because the combined effects of black carbon with sulfate aerosols had not been taken into account. It seemed clear that reducing sooty emissions would both delay global warming and benefit public health.

• Context

A number of aerosol specialists have questioned whether they have underestimated the cooling effect of aerosols. If they had, they would have underestimated those aerosols' restraint of greenhouse warming, significantly underestimating the extent of global warming in the absence of anthropogenic aerosol pollution. Much uncertainty remains, and each new study introduces new complexities. It seems clear that reducing sooty emissions would both delay global warming and benefit public health, yet nagging questions remain: Since aerosol and clouds, unlike gases, are not distributed evenly throughout the atmosphere, uniform samples cannot be obtained. Further, the properties of clouds and aerosols are incompletely understood, and scientists are only beginning to understand some of the interactions that take place between aerosols, clouds, and climate. Thus, these interactions have not yet been incorporated into their models.

Victoria Price

• Further Reading

Levin, Z., and William R. Cotton, eds. *Aerosol Pollution Impact on Precipitation: A Scientific Review.* New York: Springer, 2009. Discusses the principles of cloud and precipitation formation, the sources and nature of atmospheric aerosols and their distribution, techniques for measuring aerosols, effects of pollution and biomass aerosols on clouds and precipitation, and parallels and contrasts between deliberate cloud seeding and aerosol pollution effects.

Massel, Stanislaw R. *Ocean Waves Breaking and Marine Aerosol Fluxes.* Sapot, Poland: Institute of Oceanology of the Polish Academy of Sciences, 2007. Addresses the basic processes and mechanics of steep and breaking waves, experimental insights into wave-breaking mechanisms, wave-breaking criteria, and various aspects of marine aerosols and marine aerosol fluxes, especially in the Baltic Sea.

Spury, Kvetoslav R., ed. *Aerosol Chemical Processes in the Environment.* New York: Lewis, 2000. Five sections treat general aspects of aerosols, laboratory studies of aerosols, the synthetic chemistry of aerosols, aerosol deposits on buildings, and aerosols in the atmosphere.

See also: Atmospheric chemistry; Atmospheric dynamics; Carbonaceous aerosols; Chemical industry; Clouds and cloud feedback; Ozone; Stratosphere; Sulfate aerosols.

Agassiz, Louis

Swiss naturalist, paleontologist, geologist, and glaciologist

Born: May 28, 1807; Môtier-en-Vuly, Switzerland
Died: December 14, 1873; Cambridge, Massachusetts

Agassiz was the originator of the concept of the "Great Ice Age," an idea of fundamental importance to understanding the phenomenon of cyclical change in Earth's climate.

• Life

Louis Agassiz was born and raised in French Switzerland, descended on his father's side from six generations of Protestant clergy. Breaking from the family tradition of a career in the ministry, he studied the sciences, receiving a doctorate in philosophy from the University of Erlangen, Bavaria, in 1829 and a doctorate in medicine from the University of Munich, Bavaria, in 1830. Journeying to Paris, he came to know and be admired by two of the leading scientists of the time, Georges Cuvier and Alexander von Humboldt. The latter obtained an appointment for Agassiz in 1832 as instructor in the natural sciences at the newly founded Academy of Neuchâtel (now the University of Neuchâtel) in Switzerland.

Visiting the United States in 1846, Agassiz turned the focus of his research to North America. The following year, Harvard University appointed him professor of zoology and geology. During his tenure at Harvard, Agassiz became the father of science education in the United States, forming a vanguard generation of professional scientists. He was widely and popularly renowned as a lecturer and writer, and he realized one of his focal ambitions with the founding in 1857 of the Museum of Comparative Zoology at Harvard. In opposition to

Charles Darwin, he disputed the theory of evolution, believing species were complete as they had been created in a divine plan. He married Cecile Braun (sister of the noted botanist, Alexander Braun) in 1833; the couple had three children together. Widowed in 1848, Agassiz married Elizabeth Cabot Cary two years later. Elizabeth later became the first president of Radcliffe College.

- **Climate Work**

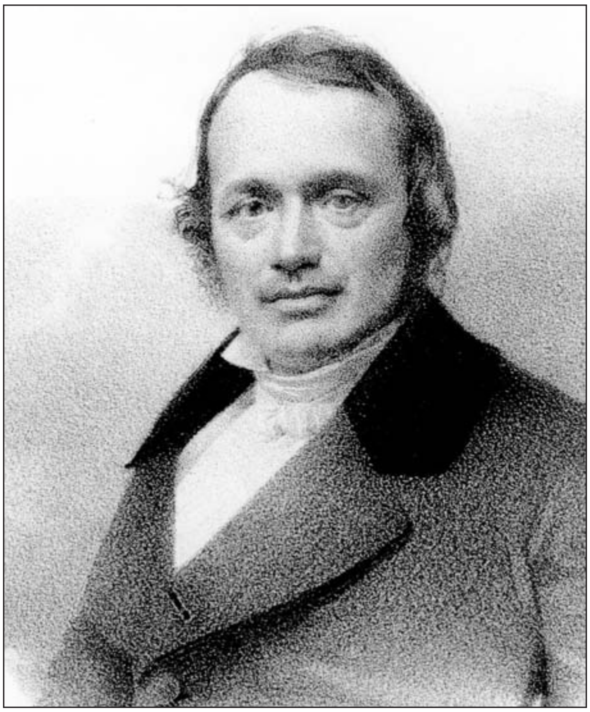
To understand the phenomenon of global warming, one must realize that the Earth is capable of long-term, extreme changes of temperature and climate. The first scientific understanding of such change did not emerge until the nineteenth century. Agassiz was among a small group of natural scientists who first postulated that there had been some period in the Earth's history when the environment had been so cold that it sustained a vast sheet of ice over much of the planet.

Agassiz arrived at this perception through an indirect but steady course of research in various fields. As a university student, he had received a singular assignment. The renowned naturalist, Carl Martius, who had recently returned from an expedition in Brazil, gave Agassiz responsibility for classifying a large collection of fish fossils gathered during the trip. Agassiz completed this project and published his findings, as well as another work on fossil fish. He then advanced a new method for zoological classification. In 1836, he received the Wollaston Medal from the Geological Society of London.

From his field research in Switzerland, Agassiz became interested in glaciers and their influence on molding ancient terrains. His observations led him to be among the first to maintain that at one time, amid a series of catastrophes, vast sheets of ice had covered much of the Earth. He thus proposed that there had been an "ice age." In coming to this conclusion, Agassiz was extending and refining emerging speculations about glaciers and rock formation expressed by several contemporary naturalists.

In the United States, Agassiz continued his formidable research and publishing projects, writing a comparative study of the physical characteristics of Lake Superior, followed by his monumental *Contributions to the Natural History of the United States of America* (1857-1862, four volumes). He also wrote a textbook that would be highly influential in the formation of generations of American scientists, *Principles of Zoology, Part 1: Comparative Physiology* (1848). His teaching method emphasized students' direct engagement with objects of scientific observation. The French Academy of Sciences awarded him the Cuvier Prize in 1852. A culminating achievement of his career was an expedition to Brazil and the Amazon about which he wrote, with his second wife, in *A Journey in Brazil* (1868). Erroneously, he maintained that Brazil had once been covered by ice, basing his conclusion on glaciation in other portions of the Americas, including the Andes and Rocky Mountains and the drainage basin of the Missouri, Mississippi, and Ohio rivers. Agassiz was the intimate of a brilliant generation of naturalists. He brought the knowledge and methodology of that group to the United States, forming the foundation of modern American science and science education and crucially shaping the development of environmental awareness.

Edward A. Riedinger



Louis Agassiz. (Library of Congress)

• **Further Reading**

Agassiz, Elizabeth Cary. *Louis Agassiz: His Life and Correspondence in Two Volumes.* 2 vols. 1885. Reprint. Bristol, Avon, England: Thoemmess Press, 2003. Biography and collection of letters published by Agassiz's second wife. The combination of primary and secondary materials is extremely useful for understanding Agassiz's personal and professional life.

Bolles, Edmund Blair. *The Ice Finders: How a Poet, a Professor, and a Politician Discovered the Ice Age.* Washington, D.C.: Counterpoint, 1999. Interweaves the concurrent findings regarding an ice age by Professor Agassiz; Charles Lyell, an Arctic explorer with a poetic imagination; and Elisha Kent Kane, a Scottish geologist who organized a scientific political constituency.

Huxley, Robert. *The Great Naturalists.* London: Thames & Hudson, 2007. Traces the development of natural history as reflected in the lives, observations, and discoveries of some of the world's leading naturalists, including Aristotle, Alexander von Humboldt, and Charles Darwin. Places Agassiz among his fellow naturalists.

See also: Glacial Lake Agassiz; Glaciations; Glaciers; Ground ice; Ice shelves.

Agenda 21

• **Category:** Conferences and meetings
• **Date:** Adopted June 14, 1992; reaffirmed September 4, 2002

Agenda 21 is a comprehensive plan of action to address global carbon emissions. It mandates cooperation at the global, national, and local levels to reduce the emissions of industrialized nations and to slow the rate of increase of emissions in developing nations.

• **Background**

From June 3 to June 14, 1992, the United Nations hosted the Conference on Environment and Development, informally known as the Earth Summit, in Rio de Janeiro, Brazil. Representatives of 172 nations participated, along with representatives of twenty-four hundred nongovernmental organizations (NGOs). The goal of the conference was to find new ways for nations to conserve natural resources and drastically reduce pollution while still developing economically. To achieve these goals, the world would need to study and improve industrial production (paying particular attention to the handling of toxics), find alternative energy sources to reduce reliance on carbon-emitting fossil fuels, encourage mass transit, and protect increasingly scarce sources of freshwater.

Five documents were produced at the 1992 Earth Summit: the Rio Declaration on Environment and Development, the Convention on Biological Diversity, an agreement on forest principles, the U.N. Framework Convention on Climate Change, and Agenda 21. Drafting of Agenda 21 had begun in 1989, and during the subsequent two years of negotiations several specific reduction targets and funding plans were deleted. The final draft was presented at the summit.

The 1992 Agenda 21 plan called for a five-year review of progress, which was conducted at a special session of the United Nations General Assembly in 1997. In 2002, at the World Summit on Sustainable Development held in Johannesburg, South Africa, participants affirmed their commitment fully to implement Agenda 21.

• **Summary of Provisions**

The nine-hundred-page Agenda 21 document is divided into forty chapters in four major sections. Section 1, "Social and Economic Dimensions," covers programs to reduce poverty and help guide developing nations in building their economies sustainably. Section 2, "Conservation and Management of Resources for Development," addresses atmospheric protection, deforestation, desertification, conservation of biological diversity, and other issues. Section 3, "Strengthening the Role of Major Groups," describes programs undertaken by international NGOs, by women and children, by workers and unions, and by business and industry. The fourth section, "Means of Implementation," addresses financial resources, transfer of technology, science, and international cooperation.

A Defining Moment in History

The opening paragraph of the Preamble to Agenda 21 presents an unusually stark statement of the challenges facing humanity at the beginning of the twenty-first century and the need for international cooperation to meet those challenges.

Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being. However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can—in a global partnership for sustainable development.

While some 98 percent of the nations on Earth signed on to Agenda 21, it is not a legally binding document but simply a plan for future action. The 1992 plan included programs in developing nations that were expected to cost billions of dollars annually, and industrialized nations agreed to contribute approximately $125 billion per year toward those costs. The plan also created a new body of the United Nations Economic and Social Council (ECOSOC), the Commission on Sustainable Development, to oversee and coordinate activities that further the goals of Agenda 21.

• Significance for Climate Change

Most observers believe that the goals of Agenda 21 have not been achieved, nor has adequate progress been made. One serious problem has been funding. At the 1992 Earth Summit, nations made nonbinding agreements to contribute funding for specific projects, including phasing out the use of chlorofluorocarbons (CFCs) and supporting the sustainable development efforts of underdeveloped nations. However, few countries have contributed the amounts agreed to, in part because economic recessions in industrialized nations, including the United States, have led these nations to shift their spending commitments to protect their own short-term domestic stability. There has also been resistance to Agenda 21 from those who believe that it undermines state sovereignty. Although the program was intended in part to draw together an international community of concerned citizens, few people, at least in the United States, are aware that Agenda 21 exists.

Agenda 21 has been successful, however, in inspiring national, regional, and local actions. These smaller programs, known as "Local Agenda 21" or "LA-21" programs, have been adopted in Cambridge and Manchester in the United Kingdom; Seattle, Washington; Chicago, Illinois; Whyalla, Australia; and cities in Finland, the Netherlands, Spain, and South Africa. Other national and state governments have created legal requirements or advisory bodies to address relevant parts of Agenda 21.

Cynthia A. Bily

• Further Reading

Dodds, Felix, ed. *The Way Forward: Beyond Agenda 21.* London: Earthscan, 1997. Collection of essays by experts in several disciplines, examining the successes and the remaining challenges Agenda 21 poses internationally, nationally, and at the grassroots level.

Picolotti, Romina, and Jorge Daniel Taillant. *Linking Human Rights and the Environment.* Tucson: University of Arizona Press, 2003. Considers environmental degradation as a human rights issue affecting mostly poor and vulnerable people and looks to Agenda 21 and other environmental policies and treaties as potential remedies for ongoing abuses.

Robinson, Nicholas A. *Strategies Toward Sustainable Development: Implementing Agenda 21.* Dobbs Ferry, N.Y.: Oxford University Press, 2005. Covers all of the action plans generated by Agenda 21; annotations and commentary.

Sitarz, Dan. *Agenda 21: The Earth Summit Strategy to Save Our Planet.* Boulder, Colo.: EarthPress, 1993. Sitarz, an environmental attorney, reworks the language of the nine-hundred-page Agenda 21 agreement to make it readable by the general public.

World Bank. *Advancing Sustainable Development: The World Bank and Agenda 21.* Washington, D.C.: Author, 1997. The official World Bank analysis of the successes and shortfalls of Agenda 21 in its first five years.

See also: Annex B of the Kyoto Protocol; Convention on Biological Diversity; Earth Summits; International agreements and cooperation; Kyoto Protocol; United Nations Climate Change Conference; United Nations Conference on Environment and Development; United Nations Framework Convention on Climate Change.

Agriculture and agricultural land

• **Categories:** Economics, industries, and products; plants and vegetation

Modern, large-scale agriculture has led to increased GHG emissions, primarily resulting from high energy inputs, land clearing, soil degradation, and overgrazing by livestock. The massive conversion of forests into farms has reduced the land's capacity to function as a carbon sink. As a result, more GHGs are emitted into the atmosphere, contributing to global warming and climate change.

• Key concepts

carbon cycle: processes through which carbon atoms circulate among Earth's atmosphere, terrestrial biosphere, oceans, and sediments—including fossil fuels

climate change: a statistically significant variation in either the mean state of the climate or its variability

energy-intensive agriculture: a method of farming that involves working on a large scale, utilizing significant resources, energy, and mechanization; often also referred to as industrialized agriculture

greenhouse effect: phenomenon in which certain gases in a planet's atmosphere trap heat that would otherwise escape into outer space, thereby increasing the planet's surface temperature

• Background

There is now a consensus that the mean temperature of the Earth will increase by an average of 2.0° to 5.8° Celsius in the twenty-first century. Some environmental models, taking into account likely changes in vegetation cover, predict an even higher rise of 8° Celsius during the century. The resulting elevated temperatures (even at the lower end of the estimates) will have significant effects on Earth's biosphere, including human life. Many factors are associated with this predicted temperature rise, but agriculture is among the major contributors.

• Direct Impacts of Agriculture on Climate Change

Agricultural activity is a significant source of greenhouse gases (GHGs). GHG levels are affected by land clearing, high energy inputs, soil degradation, and intensive animal husbandry. Based on current estimates, agriculture contributes to 25 percent of the world's carbon dioxide (CO_2) emissions, 60 percent of methane gas emissions, and 80 percent of nitrous oxide emissions. Agriculture's high energy input results primarily from manufacturing chemical fertilizers, herbicides, and pesticides; operating farm machinery; irrigating farmland using pumps and other machines; and transporting products over long distances. Collectively, these activities account for more than 90 percent of the total energy expenditure in agriculture.

The burning of fossil fuels releases CO_2 into the atmosphere. The CO_2 concentration in the atmosphere has increased from 277 parts per million to 382 parts per million since the beginning of the Industrial Revolution in the mid-eighteenth century. Industrialized agriculture is believed to have contributed to 25 percent of that increase.

Overuse of fertilizers, in addition to energy inputs in fertilizer manufacturing, contributes significantly to climate change. More than half of all synthetic fertilizers applied to the soil either end up in local waterways or emit to the atmosphere. A portion of the excess nitrogen fertilizers in the soil is converted into nitrous oxide, which is 296 times more potent than CO_2 in trapping heat and which has a long atmospheric lifetime of 114 years. Each year, nitrous oxide emissions alone account for the equivalent of 1.9 billion metric tons of CO_2 emissions.

The second greatest GHG emission by agriculture is methane, released in small amounts by rice paddies and in much larger amounts by livestock. As the demand for meat increases, more livestock are raised and are fed higher-protein diets. Both the number of livestock and their protein-rich diets increase the amount of methane they emit. Methane gas is fourteen times more potent than CO_2 in trapping heat. Its concentration has almost tripled since the Industrial Revolution, from 600 parts per billion to 1,728 parts per billion.

- **Indirect Impacts of Agriculture on Climate Change**

Agriculture also contributes indirectly to climate change. Clearing trees and other natural stands to make land suitable for agricultural uses removes important carbon sinks, so less carbon is returned to the terrestrial biosphere and more CO_2 finds its way into the atmosphere, where it contributes to climate change.

The effect of land clearing on climate change is evident from the consequences of the destruction of tropical rain forests. For instance, large areas in Brazil have been cleared to facilitate soybean production. This clearing disrupts the local water cycle, which in turn alters Brazil's climate. In rain forests, water circulates as a result of evaporation, which greatly increases humidity. Natural tree stands act to buffer extremes of heat, cold, and drought. When the trees are removed, the buffer disappears. Moreover, the amount of water vapor in the air decreases, causing shifts in rainfall patterns, moisture levels, air temperature, and weather patterns generally.

The conversion of forests into agricultural lands has significantly altered Earth's vegetation cover. Such changes in the land surface affect Earth's albedo—that is, the proportion of incident radiation reflected by the planet's surface. Changes in the albedo in turn can affect the surface energy budget, which affects local, regional, and global climates. Changes in vegetation also produce changes in the global atmospheric concentration of CO_2. Agricultural landscape ranks among the lowest in carbon sequestration. Thus, as more land is devoted to agricultural uses, more of Earth's carbon is converted to CO_2 and emitted to the atmosphere, contributing to global warming.

- **Effects of Climate Change on Agriculture**

Potential climate changes associated with elevated GHGs and an altered surface energy budget include an increased incidence of heat waves, severe storms, and floods, as well as elevated sea levels. Some 30 percent of the agricultural lands worldwide could be affected by these changes. Global warming alone is projected to have considerable effects on agriculture. A warming of 2° Celsius or more could reduce global food supplies and aggravate world hunger. The impact on crop yields will vary considerably across different agricultural regions. Warm regions, such as tropics and subtropics, will be threatened by climate change, while cooler regions, mainly in temperate or higher latitudes, may benefit from warming.

Global climate change may have significant effects upon livestock systems as well. First, the productivity and quality of rangelands may be adversely affected. This in turn will affect the quality and productivity of livestock. Second, higher grain prices resulting from the disruption of crop production will lead to higher costs for livestock products. Third, increased severity and frequency of storms may intensify soil erosion and decrease the productivity of rangelands. Fourth, global warming could result in changes in the distribution and severity of livestock diseases and parasites, which may threaten the health of animals, especially those in intensively managed livestock systems.

- **Possible Solutions**

Unlike any other industrial GHG emitters, agriculture has the potential to change from being one of the largest GHG sources to being a net carbon sink, reversing its role in climate change. Several practical measures can be taken to mitigate the climate change caused by intensive agriculture. These include the reduced and more efficient use of chemical fertilizers, protection of soil, improvement of paddy rice production, and reduction of demand for meat.

A Chinese farmer works drought-afflicted fields in Shanxi province. Drought is among the greatest threats to world agriculture. (Reuters/Landov)

Precision farming can reduce the need for chemical fertilizers. In precision farming, fertilizers and other agrochemicals are applied based on crops' needs, in precise amounts and on a carefully managed schedule. The reduced application of these chemicals not only cuts GHG emissions but also alleviates other environmental problems such as water pollution and eutrophication of waterways.

As a result of intensive farming, agricultural soils have some of the lowest carbon contents of all land types. If these soils can be modified to absorb more of Earth's carbon, the result will be a net reduction in atmospheric carbon. Low soil carbon content can be reversed through a number of measures, including planting cover crops, fallowing, and engaging in conservation tillage. These practices will increase the amount of organic matter (and thus the carbon content) in the soil. They will also reduce soil erosion and surface runoff, thereby reducing the need for chemical fertilizers. Collectively, these measures can turn agricultural soils into carbon sinks, changing the nature of their impact on climate change.

To reduce methane emissions from rice production, better cultivation techniques will need to be adapted. For example, rather than continuously flooding rice paddies, farmers could supply water to the paddies only when it is needed during the growing season and keep the paddies dry during the nongrowing season. Such measures could reduce methane emission from rice fields significantly.

Livestock raising is the second largest source of GHGs in agriculture. The most efficient way to cut methane emission due to livestock is simply to reduce the number of farm animals. As an ever-increasing demand for meat and dairy products drives increasing animal husbandry, one effective approach to cut methane emission is to reduce the demand for meat, especially in developed countries where consumers have tremendous buying power. Reduced meat and dairy consumption would go a long way toward curbing methane emissions.

• Context

Agriculture and climate change are interlocked processes, in that each exerts effects on the other in a complex fashion. Climate changes, especially shifts in precipitation and temperature, are widely believed to have significant effects on agriculture, because these two factors determine the carrying capacity of any ecosystem. At the same time, modern agriculture is a major contributing factor to global warming, as altered land cover and the emission of CO_2, methane gas, and nitrous oxide from intensive farming increase the GHG content of the atmosphere. However, it remains possible to transform industrialized agriculture, using techniques that could render it more sustainable and mitigate its effects upon global and local climates.

Ming Y. Zheng

• Further Reading

Bazzaz, Fakhri, and Wim Sombroek, eds. *Global Climate Change and Agricultural Production: Direct and Indirect Effects of Changing Hydrological, Pedological, and Plant Physiological Processes.* New York: Wiley, 1996. Assesses the effects of global climate change on the agricultural production of crops and livestock. Covers issues such as the CO_2 fertilization effect, the adverse effects of elevated levels of ultraviolet-B (UVB) radiation and ozone on plant growth and productivity, and the environmental effects of livestock.

Marland, Gregg, et al. "The Climatic Impacts of Land Surface Change and Carbon Management, and the Implications for Climate-Change Mitigation Policy." *Climate Policy* 3 (2003): 149-157. Reviews evidence on how changes in land use and altered vegetation cover affect surface energy budget in addition to GHG emission, which in turn affects local, regional, and global climate.

Palo, Matti, and Heidi Vanhanen, eds. *World Forests from Deforestation to Transition?* Boston: Kluwer Academic, 2000. Addresses global and subnational issues concerning the world's forests, societies, and environment from an independent and nonpolitical point of view. Emphasizes the importance of developing a scientific understanding of the interconnectedness between forests, human activity, and the environment, and of the consequences of environmental change for societies' development and growth.

Paustian, Keith, et al. *Agriculture's Role in Greenhouse Gas Mitigation.* Arlington, Va.: Pew Center on Global Climate Change, 2006. Well-researched and clearly written paper. Offers reasonable measures and reachable goals for mitigating GHG emission by agriculture.

See also: Aerosols; Air travel; Albedo feedback; Amazon deforestation; Animal husbandry practices; Anthropogenic climate change; Carbon cycle; Carbon dioxide; Carbon dioxide equivalent; Carbon dioxide fertilization; Civilization and the environment; Climate change; Composting; Deforestation.

Agroforestry

• **Categories:** Plants and vegetation; economics, industries, and products

• Definition

Agroforestry encompasses a broad range of land-use practices involving the integration of trees with annual crops. Though as old as agriculture itself, agroforestry has only recently attracted scientific attention. Many agroforestry practices have the potential to contribute to climate change mitigation, adaptation, or both.

A land-use system is defined as agroforestry if it includes at least one perennial species (generally a tree) and one crop species that interact on the same land. Usually, the role of the trees is to provide the crop with nutrients, shade, improved soil quality, physical support, or protection from wind, water, or pests. The goal is to achieve a net benefit as compared to growing the species in monocultures. The complementarity can be economic (for example, income diversification) as well as biophysical. Agroforestry systems may also provide fuelwood, timber, fruit, and other products. However, when trees are grown solely for these purposes and are not intended to improve cropland, the practice is usually not considered agroforestry.

- **Significance for Climate Change**

Agroforestry trees can contribute to climate mitigation by sequestering carbon in their biomass, in the soil, and in wood products. Although agroforestry systems usually store less carbon per unit area than do forests, they have the advantage of allowing the land to remain in use for the production of food or other crops. Additionally, a large total land area is suitable for agroforestry practices, implying a potential for large-scale carbon sequestration—similar in magnitude to that of reforestation, according to a 2000 estimate by the Intergovernmental Panel on Climate Change (IPCC). However, the distributed and diverse nature of agroforestry poses challenges for carbon accounting. Carbon sequestration alone is unlikely to drive the adoption of agroforestry, but it can provide a coincentive.

Agroforestry can also play a role in climate adaptation. Trees can moderate local microclimate, protecting crops by lowering temperatures and reducing soil evaporation. They can ameliorate drought by improving soil water-holding capacity. They can reduce damage from extreme climate events, such as floods and wind storms. Able to access deep supplies of water and nutrients, mature trees are generally less susceptible to climatic fluctuations than are annual crops and can provide alternative sources of food and income under adverse climates.

Achieving these benefits requires a careful choice of species and of management practices, since biophysical interactions in an agroforestry system can be complex. Agroforestry projects often must also consider socioeconomic issues such as land tenure, gender roles, and risk aversion. The potential of agroforestry for climate mitigation and adaptation is likely significant, but still largely unexplored.

Amber C. Kerr

See also: Agriculture and agricultural land; Carbon cycle; Carbon 4 plants; Carbon 3 plants; Deforestation; Forestry and forest management; Forests; Sequestration; Tree-planting programs.

Air conditioning and air-cooling technology

- **Categories:** Economics, industries, and products; science and technology

Air conditioning and air cooling account for roughly half of residential energy use and some 15 percent of industrial energy use. Some refrigerant chemicals have GWPs more than one thousand times that of CO_2. Changes in air conditioning and cooling technologies can reduce global warming significantly.

- **Key concepts**

coefficient of performance: a standard measurement of energy efficiency

energy efficiency rating: ratio of heat energy produced or removed to power expended

global warming potential: the climatic impact of a given mass of greenhouse gas, measured as a function of the impact of the same mass of carbon dioxide

total equivalent warming impact: a measurement, in mass of CO_2 equivalent, of the global warming potential of an entire system

- **Background**

Air conditioning systems use energy to remove heat from a given location, transferring it to the exterior in the form of exhaust. Some of the energy is invariably wasted as heat, and this additional heat must also be exhausted. Thus, air conditioning results in net heat release to the environment. The warming effect is aggravated, moreover, because higher forms of energy such as electricity are used to power air conditioners. Generating and transmitting this electricty entails further production of waste heat, as well as greenhouse gas (GHG) emission. Demand for air conditioning peaks along with other demand for electricity during summer days. Auxiliary generators used to meet peak demand are less efficient and often burn fossil fuels.

In 1998, for example, the total equivalent warming impact (TEWI) of European air conditioning was 156 million metric tons of carbon dioxide (CO_2) equivalent. Of that TEWI, 25.6 million metric tons were attributable to direct hydrofluorocarbon emissions and around 130 million metric tons were attributable to indirect emissions. In the same year, the TEWI of 303 million automotive air conditioning systems worldwide represented 0.14 percent of total anthropogenic TEWI.

• Approaches and Choices

There are two basic approaches to cooling the air in an enclosure: refrigeration and evaporation. In the refrigeration cycle, a fluid is compressed so that its temperature rises and is circulated through pipes over which air or water is forced, thus removing heat. The compressed, cooled refrigerant is then expanded through a nozzle, so that its temperature drops sharply before it absorbs heat in an exchanger from the air in the enclosure. The refrigerant with the heat absorbed is then compressed and its heat removed in the exhaust heat exchanger. This process need not include phase change. When a substance evaporates, it absorbs a great deal of heat from the environment, called the latent heat. In large industrial systems, the hot coil heat is removed using flowing water, some of which evaporates into the air flowing through a cooling tower.

• Choice of Refrigerants

Refrigerants enable the exchange of a large amount of heat with the least expenditure of work. Desirable properties for these substances include low boiling point, high latent heat of vaporization,

On Dyess Air Force Base, in Abilene, Texas, a chilled glycol slurry is used to cool buildings in an effort to decrease the base's environmental footprint. (Ralph Lauer/MCT/Landov) high specific heat, and high critical temperature. Ammonia (R-717) is used in industrial systems. Sulfur dioxide, being toxic, has been abandoned in favor of Freon, a fluorocarbon. Early chlorofluorocarbon (CFC) refrigerants such as R-12 for cars and R-22 for homes were phased out in the early 1990's, because they deplete the ozone in the upper atmosphere. A popular replacement, tetrafluorohydrocarbon R-134, has a global warming potential (GWP) of 1,410 (that is, it contributes 1,410 times as much to the greenhouse effect as does an equivalent mass of CO_2). All gases with a GWP above 150 are slated to be banned in Europe by 2011.

Some modern refrigerants are R-290a (a mixture of isobutane and propane), R-600a (isobutene), and R-744 (CO_2). European automobile manufacturers have announced a switch to CO_2-based systems, but others argue that improving existing R-134a-based systems will prove more effective if the complete system effects are included.

• Alternative Cooling Systems

Ancient Roman mansions were cooled by water flowing through channels in the walls. In areas with significant day-night temperature differences and low humidity (such as deserts), large, modern, industrial systems use ice blocks that freeze overnight as evaporative air coolers. Ground source heat pumps (GSHPs) use the constant temperature 1-2 meters below the ground as a "free" reservoir and heat exchanger to increase efficiency. Subsurface temperature can remain tens of degrees below or above surface air temperature in summer or winter, respectively.

Using solar heat directly to power air conditioning is an ideal solution, because the demand for air conditioning generally corresponds with the presence or availability of solar heat. Approaches for solar air conditioning include using photovoltaic panels to generate the necessary electricity and using evaporation cycles. These cycles require the incoming air to be dry, as in deserts, and are less effective in humid areas.

• Context

Because of the triple pressures of ozone depletion, global warming due to energy use, and global warming due to GHG emissions, air conditioning is poised for a revolution in the first quarter of the twenty-first century. Researchers are developing heat pumps and solar power solutions for residential and industrial air conditioning, as well as CO_2 closed-system cycles for automobiles. Such technologies would reduce energy demand and global warming effects. With improving efficiency and affordability of solar conversion, air conditioning is likely to shift substantially to solar energy, enabling a major reduction of peak power demands and the attendant fossil combustion.

Narayanan M. Komerath

• Further Reading

Bellstedt, Michael, Frank Elefsen, and Stefan S. Jensen. "Application of CO_2 (R744) Refrigerant in Industrial Cold Storage Refrigeration Plant." *EcoLibrium: The Official Journal of AIRAH*, June, 2002, 25-30. Contains data on the global warming potential of various refrigerants. Describes a large facility where CO_2 is used as the secondary-stage refrigerant with a glycol and water mixture as the primary coolant fluid.

Bhatti, M. S. *Global Warming Impact of Automotive Air Conditioning Systems*. Warrendale, Pa.: Society of Automotive Engineers, 1998. Argues the relative merits of R-134 systems versus CO_2 systems.

Chadderon, David. *Air Conditioning: A Practical Introduction*. 2d ed. London: Taylor and Francis, 1997. Systematic introduction to the theory, concepts, and practical applications of air conditioning. Gives system examples and deals with how to design air conditioning systems. Each chapter has learning objectives laid out.

Fischer, S. K. *Comparison of Global Warming Impacts of Automobile Air-Conditioning Concepts*. Washington, D.C.: Office of Scientific and Technical Information, 1995. Compares the global warming potential of vapor-compression air conditioners used in automobiles with four alternatives. Argues that designs using CO_2 and water can reduce the total equivalent warming impact by up to 18 percent.

United Nations. *1998 Report of the Refrigeration, Air Conditioning, and Heat Pumps Technical Options Committee*. New York: United Nations Environment Programme, 1998. Formal U.N. assessment for the Montreal Protocol, the predecessor

of the Kyoto Protocol. Gives data on consumption of CFCs and HCFCs and all applications of air conditioning and air cooling, including cold storage and food processing.

See also: Chemical industry; Chlorofluorocarbons and related compounds; Energy efficiency; Hydrofluorocarbons; Industrial greenhouse emissions; Solar energy.

Air pollution and pollutants: anthropogenic

- **Category:** Pollution and waste

Although gaseous air pollutants can pose serious health hazards, only a few gases, such as carbon dioxide, warm the atmosphere. Particulate matter suspended in the air may have the opposite effect, blocking solar radiation and cooling the atmosphere.

• Key concepts

aerosols: minute particles or droplets of liquid suspended in Earth's atmosphere
anthropogenic: deriving from human sources or activities
chlorofluorocarbons (CFCs): chemical compounds with a carbon backbone and one or more chlorine and fluorine atoms
greenhouse effect: global warming caused by gases such as carbon dioxide that trap infrared radiation from Earth's surface, raising atmospheric temperatures
ozone: a highly reactive molecule consisting of three oxygen atoms
parts per million: number of molecules of a chemical found in one million molecules of the atmosphere

• Background

Air pollution has been a problem since humans began burning carbon-based fuels while living in large cities. The first known air-pollution ordinance was passed in London, England, in 1273 in an attempt to alleviate the soot-blackened skies caused by excessive combustion of wood in the heavily populated city. From the mid-eighteenth through the mid-twentieth centuries, the increasingly heavy use of coal for heat, electricity, and transportation resulted in filthy cities and an escalating crisis of respiratory diseases. It was not until the latter half of the twentieth century that governments began attacking the problem by enacting legislation to control noxious emissions at their source.

Before discussing anthropogenic air pollution, one must first define "clean air." Earth's atmosphere is approximately 78 percent nitrogen (N_2), 21 percent oxygen (O_2), and 1 percent argon. These concentrations may be reduced slightly by water vapor, which can make up between 1 percent and 3 percent of the atmosphere. In addition, there are many trace elements present in the atmosphere in concentrations so small that they are measured in parts per million. Among the trace elements near Earth's surface are 0.52 part per million of oxides of nitrogen and 0.02 part per million of ozone, both of which occur both naturally and anthropogenically. This combination of N_2, O_2, argon, water, ozone, and oxides of nitrogen constitutes clean air. Any change in these concentrations or introduction of other compounds into the atmosphere constitutes air pollution, which occurs in one of two forms: gases and particulate matter.

• Gaseous Air Pollutants

The primary gaseous pollutants are oxides of carbon, oxides of sulfur, oxides of nitrogen, and ozone. Carbon oxides occur whenever a carbon-containing fuel is burned; in general, a carbon fuel unites with oxygen to yield carbon dioxide (CO_2) and water vapor. If the combustion is incomplete as a result of insufficient oxygen, carbon monoxide will also be produced. Although CO_2 is a relatively benign compound, the vast amount of fossil fuels (coal, oil, and natural gas) burned since the Industrial Revolution began have raised its atmospheric concentration from about 280 parts per million to about 380 parts per million. CO_2 molecules, while transparent to visible light coming from the Sun, reflect infrared radiation emitted by the Earth when the visible light is absorbed and radiated as heat, thus raising Earth's temperature in proportion to the amount of CO_2 in the atmosphere. As CO_2 concentrations increase, this greenhouse effect will increase Earth's temperature, causing droughts, more severe storms of greater intensity, the shifting of climate zones, and rising sea levels.

Carbon monoxide (CO) is a toxic compound that can cause death by suffocation even when present in relatively small amounts. CO is two hundred times more reactive with hemoglobin than is oxygen; thus CO replaces oxygen in the bloodstream, depriving cells of their necessary oxygen. Deprived of sufficient blood oxygen, an organism will die in about ten minutes.

Since almost all coal contains sulfur, burning coal causes sulfur to react with oxygen to create sulfur dioxide (SO_2), which reacts with water vapor in the atmosphere to produce H_2SO_4, sulfuric acid. This pollutant reaches Earth's surface as a component of rain (acid rain), and it pollutes rivers, lakes, and other bodies of water.

Nitrogen oxides are synthesized whenever air is rapidly heated under pressure and then cooled quickly, as occurs in automobile cylinders and thermoelectric power plants. The two main compounds of this pollution are nitric oxide (NO) and nitrogen dioxide (NO_2); both are toxic, but NO_2 is worse (in equivalent concentrations, it is more harmful than CO). Nitrogen dioxide affects the respiratory system and can lead to emphysema, while nitric oxide often combines with oxygen to form nitric acid (NO_3), another component of acid rain.

NO_2 can also combine with oxygen to form NO and ozone (O_3), a very reactive and dangerous form of oxygen. Combustion-caused ozone is undesirable near Earth's surface, but the compound occurs naturally in the upper atmosphere (about 19 kilometers above the surface) when energetic ultraviolet (UV) light from the Sun interacts with oxygen. Although the ozone composing it constitutes less than 1 part per million of Earth's atmosphere, the ozone layer plays an extremely important role. It prevents most of the Sun's UV light from reach-

A junkyard fire pumps pollutants into the atmosphere. (©iStockphoto.com/Dimitrije Tanaskovic) ing Earth's surface, a highly desirable effect since it is UV radiation that causes sunburn and skin cancer.

• Chlorofluorocarbons

When first synthesized in the 1930's, chlorofluorocarbon (CFC) was hailed as an ideal refrigerant (Freon), because it was nontoxic, noncorrosive, nonflammable, and inexpensive to produce. Later, pressurized CFCs were used as the propellant in aerosol cans and as the working fluid for air conditioners. In 1974, the chemists Mario Molina and F. Sherwood Rowland proposed that the huge quantities of CFCs released into the atmosphere from aerosol sprays (500,000 metric tons in 1974 alone) and discarded refrigerant units were slowly migrating to the stratosphere. There, the CFCs were decomposed by the highly energetic UV radiation from the Sun, releasing large quantities of ozone-destroying chlorine.

Any decrease of the ozone layer could increase the incidence of skin cancer, damage crops, and decimate the base of the marine food chain. The reduction of ozone was most pronounced over Antarctica, where an "ozone hole," first detected in the early 1970's, was increasing in size annually. Pressured by environmentalists and consumer boycotts, the U.S. government imposed a 1978 ban on aerosol cans and refrigeration units utilizing CFC propellant, forcing the chemical industry to support the ban and to develop alternatives; several other nations soon followed suit. By 1987, the depletion of the ozone layer became so problematic that most CFC-using nations met in Montreal, Canada, to produce an international treaty calling for immediate reductions in all CFC use, with a complete phase-out by 2000. This Montreal Protocol, by 2001, had limited the damage to the ozone layer to about 10 percent of what it would have been had the agreement not been ratified.

• Smog

The word "smog" is a melding of "smoke" and "fog." When a local atmosphere becomes stagnant—for example, during a temperature inversion—pollution levels in the smog can become severe enough to call these smogs "killer fogs." At least three times during the twentieth century, these killer fogs have caused a statistically significant increase in the death rate, particularly among the old and those with respiratory problems. The first documented killer fog occurred in 1948 at Donora, Pennsylvania, when a four-day temperature inversion stagnated a fog that became progressively more contaminated with the smoky effluents of local steel mills. The second documented case occurred in 1952 in London, England, when fog, trapped by another four-day temperature inversion, mixed with the smoke pouring from thousands of chimneys where coal was being burned. Many elderly people and people with respiratory ailments succumbed to these deadly events. Finally, during Thanksgiving, 1966, New York City experienced an increased death rate due to a choking smog.

A second, completely different type of smog is photochemical smog, a noxious soup of reactive chemicals created when sunlight catalyzes reactions of hydrocarbons and nitrogen oxides. This catalysis first occurred in Los Angeles in the late 1940's, when automotive traffic increased drastically, emitting thousands of metric tons of exhaust daily. As mentioned above, car engines, in addition to emitting carbon oxides, emit nitrogen oxides, ozone, and some residual unburned hydrocarbons from the fuel. When light acts on these chemicals, it produces photochemical reactions that create aldehydes (compounds, such as formaldehyde, that are well known for their obnoxious odors) and other dangerous compounds that can induce respiratory ailments, irritate eyes, damage leafy plants, reduce visibility, and crack rubber. Although photochemical smog was first observed in Los Angeles because of the abundant sunlight and heavy automotive traffic, it has since become prevalent in many other large cities.

• Particulates

Particulate matter consists of soot, fly ash, or any other small particles or aerosols suspended in the air that can be breathed into the lungs or ingested with food. It is generated by combustion, dry grinding processes, spraying, and wind erosion. Particulate concentrations in the body can, over time, lead to cancer of the stomach, bladder, esophagus, or prostate.

The human respiratory system has evolved a

Sample Air Pollutants Regulated by the U.S. Environmental Protection Agency

- Acetaldehyde
- Acrylic acid
- Antimony compounds
- Arsenic compounds (inorganic, including arsine)
- Asbestos
- Benzene
- Beryllium compounds
- Cadmium compounds
- Calcium cyanamide
- Carbon disulfide
- Carbon tetrachloride
- Chlorine
- Chloroform
- Chloroprene
- Chromium compounds
- Cobalt compounds
- Coke oven emissions
- Cyanide compounds
- Ethylene glycol
- Fine mineral fibers
- Formaldehyde
- Glycol ethers
- Hydrochloric acid
- Hydrogen fluoride (Hydrofluoric acid)
- Lead compounds
- Manganese compounds
- Mercury compounds
- Methanol
- Nickel compounds
- Parathion
- Phosphorus
- Radionuclides (including radon)
- Selenium compounds
- Styrene

Source: Environmental Protection Agency Technology Transfer Network.

mechanism to filter out and prevent certain sizes of particulates from reaching the lungs. The first line of defense is the nose and nasal passageway, whose mucus membranes and hairs will catch and remove particles larger than 10 microns (one one-hundredth of a millimeter). After passing through the nasal passages, air travels through the trachea, which branches into the right and left bronchi. Each bronchus is divided and subdivided about twenty times, terminating in the small bronchioles located inside the lungs. These end in 300 million tiny air sacs called alveoli, where oxygen is passed to the bloodstream and CO_2 removed for exhalation.

Particles ranging in size from 2 to 10 microns usually settle on the walls of the trachea, bronchi, and bronchioles, before reaching the alveoli. They are eventually expelled by ciliary action, a cough, or a sneeze. Particles smaller than 0.3 micron are likely to remain suspended in inhaled air and then removed from the lungs with exhaled air, similarly failing to enter the bloodstream. Humans thus have evolved a protective mechanism that shields them from particles of all sizes smaller than 0.3 micron and larger than 2 microns. No defense mechanism evolved for this intermediate size range, because during the long course of human evolution there were very few particles of this size in the environment. In recent centuries, however, many particles in this range—including coal dust, cigarette smoke, and pesticide dusts—have been added to the environment. Since no natural defense exists to eliminate these hazards from the human body, they coat the alveoli, causing such illnesses as black lung, lung cancer, and emphysema.

• Context

The issue of whether or not global warming is caused by humans is still being debated, but strong measures were taken in the latter half of the twentieth century to control the noxious gases and particulate emissions known as air pollutants. When it was discovered that the ozone layer was being depleted by CFCs, the Montreal Protocol was ratified by most industrial nations. Both of these historic precedents indicate that strong, effective action and international cooperation is possible when a perceived threat to humanity and the environment is grave enough. Since the preponderance of scientific evidence seems to suggest that global warming is due to humanity's excessive use of fossil fuels, perhaps it would be prudent to err on the side of caution and begin to curtail the disproportionate dependence on nonrenewable resources.

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Further Reading

Elsom, Derek. *Smog Alert: Managing Urban Air Quality*. Covelo, Calif.: Island Press, 1996. Emphasizes the causes of, dangers of, and preventive measures for photochemical smog.

Krupa, S. V. *Air Pollution, People, and Plants: An Introduction*. St. Paul, Minn.: American Phytopathological Society, 1997. Inclusive coverage of air pollution's causes and effects.

Roan, S. *Ozone Crisis: The Fifteen-Year Evolution of a Sudden Global Emergency*. New York: John Wiley, 1989. Traces the science and history of the ozone hole leading up to the Montreal Protocol.

Seinfeld, J., and S. N. Pandis. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. Hoboken, N.J.: Wiley, 2006. Comprehensive coverage of all aspects of air pollution, from chemical reactions and thermodynamics of the atmosphere to global cycles and statistical models.

Vallero, Daniel. *Fundamentals of Air Pollution*. 4th ed. Burlington, Mass.: Academic Press, 2008. Huge, sophisticated tome (more than eleven hundred pages) covering every aspect of air pollution. Not for the technologically timid.

Wilson, Richard, and John Spengler. *Particles in Our Air: Concentrations and Health Effects*. Covelo, Calif.: Island Press, 1996. Provides a practical overview of aerosols and their health effects.

See also: Air pollution and pollutants: natural; Air pollution history; Air quality standards and measurement; Carbon dioxide; Carbon monoxide; Chlorofluorocarbons and related compounds; Coal; Fossil fuel emissions; Greenhouse effect; Ozone.

Air pollution and pollutants: natural

Category: Pollution and waste

Nature generates pollutants in sufficient volumes to impact Earth's climate. Particulates and sulfur compounds released in volcanic eruptions can lower mean global temperatures for a few years. However, natural air pollutants are generally less persistent in the atmosphere and have a more transient impact on climate than do human-generated ones.

Key concepts

aerosol: a suspension of solid particles or droplets of liquid in a gas

anthropogenic: generated by humans or human activities

greenhouse effect: global warming caused when atmospheric gases such as water vapor, carbon dioxide, and methane absorb and retain solar energy; Earth's natural greenhouse effect keeps the planet warm enough to support life, and this term is often used to refer to an enhanced, climate-altering greenhouse effect resulting from greenhouse gases contributed by human activity

greenhouse gases (GHGs): a gas in the atmosphere that absorbs infrared radiation, thereby raising temperatures at the planet's surface

ozone: a highly reactive form of oxygen whose molecules are made up of three oxygen atoms (O_3)

stratosphere: the part of Earth's atmosphere that extends from the top of the troposphere to an altitude of 50 kilometers above the planet's surface

troposphere: the densest part of Earth's atmosphere, extending from the planet's surface to altitudes of 8 to 14.5 kilometers; most of Earth's weather is confined to this layer

Background

The term "air pollution" evokes images of belching industrial smokestacks, rush-hour freeways, and smog-shrouded city skylines: human-caused (anthropogenic) air pollution. Natural processes, however, generate a number of gaseous compounds and particulates that would be regarded as pollutants if human activity had produced them. Among these are oxides of carbon, nitrogen, and sulfur; hydrocarbons; ozone; volatile organic compounds (VOCs); and ash, soot, and other particulates. Nature emits many of these in quantities great enough to affect air quality and global climate.

Common Natural Air Pollutants

Carbon dioxide (CO_2) occurs naturally in Earth's atmosphere. Only in the late twentieth and early twenty-first centuries did it come to be regarded as a pollutant, when anthropogenic (human-generated) CO_2 was suspected to have a role in global climate change. Along with water vapor, CO_2 is one of the atmosphere's chief absorbers of infrared radiation and is considered a greenhouse gas (GHG)—that is, a gas that keeps solar energy from reradiating into space. The presence of greenhouse gases in Earth's atmosphere allowed the planet to develop a climate conducive to life. However, in the later decades of the twentieth century concerns began to arise that a buildup of greenhouse gases from fossil-fuel use and other human activity could significantly and irreversibly raise temperatures around the globe.

Ozone (O_3) is a highly reactive form of oxygen well known for its role in protecting Earth's surface from damaging ultraviolet (UV) radiation. In the troposphere (lower portion of the atmosphere), however, O_3 acts as a GHG, contributing to increased surface temperatures. At ground level, O_3 is the main component of smog. Sources of O_3 in the troposphere include O_3 that migrated down from the overlying stratosphere and O_3 produced photochemically from nitrogen oxides (NO_x). Higher up, within the stratosphere, is where O_3 performs its UV-absorbing function. Stratospheric O_3 also absorbs visible solar radiation that would otherwise warm the Earth's surface. A decrease in stratospheric O_3 or an increase in tropospheric O_3 results in a rise in surface temperatures.

The hydrocarbon compound methane, CH_4, is classed as a hazardous substance, primarily due to its combustibility. This GHG occurs in the atmosphere at lower concentrations than CO_2, but according to the Intergovernmental Panel on Climate Change (IPCC) its global warming potential over a one-hundred-year period is twenty-five times higher than that of CO_2. Because of CH_4's strong global warming potential, combined with its comparatively short lifetime in the atmosphere (roughly twelve years), curbing CH_4 emissions has the potential to mitigate global warming over the next few decades.

Nitrous oxide, N_2O, by contrast, has an atmospheric lifetime of about 120 years and a 100-year global warming potential 298 times that of CO_2. Other nitrogen oxide compounds (NO_x), while unlikely to contribute directly to climate change, react with volatile organic compounds (VOCs) in the presence of heat and sunlight to form tropospheric O_3. Atmospheric NO_x, which can travel long distances from its source, also causes acid precipitation and is a major component of smog.

Sulfur dioxide, SO_2, another cause of smog and acid precipitation, absorbs infrared radiation. However, its chief climate-altering ability is not as a GHG but as a stratospheric aerosol. Clouds of SO_2 aerosol absorb the Sun's energy and cause a resulting drop in tropospheric temperatures.

VOCs, also found in smog, are carbon-containing compounds that readily become gas or vapor. While they do not directly influence climate, they are important O_3 precursors, especially at the ground level. By enhancing tropospheric O_3 concentrations, they promote global warming.

Carbon monoxide, CO, is a toxic air pollutant. A weak absorber of infrared radiation, it has little direct impact on global climate. However, it contributes to climate change through chemical reactions that boost concentrations of CH_4 and O_3 in the troposphere. CO ultimately oxidizes to CO_2.

Particulate matter includes tiny solid and liquid particles such as dust, salt, smoke, soot, ash, and droplets of sulfates and nitrates. Injected into the atmosphere by anthropogenic or natural processes, these form aerosols, suspensions of particles in air. The length of time these particulates remain in the atmosphere is related to the altitude at which they were introduced and their particle size. Aerosols influence climate directly by reflecting and absorbing atmospheric solar and infrared radiation. While some aerosols cause surface-temperature increases and others cause decreases, the overall effect of aerosols is to lower temperatures. Aerosols influence climate indirectly by serving as condensation nuclei for cloud formation or altering optical properties and lifetimes of clouds.

Major Natural Air Pollutants

- Dust
- Mold spores
- Pollen
- Radon
- Volcanic ash

Smoke billows from Mount Nyiragongo. (©iStockphoto.com/Guenter Guni)

- **Volcanic Activity**

Volcanic eruptions, the chief source of natural air pollutants, have a demonstrated and complex impact on climate. Gaseous and particulate emissions cause O_3 depletion as well as global atmospheric warming and cooling.

Volcanic eruptions damage O_3 by injecting SO_2 into the stratosphere, where the gas is converted to a sulfate aerosol. The aerosol particles interact with chlorine and bromine in anthropogenic chlorofluorocarbons (once widely used as aerosol can propellants and refrigerants) to produce compounds that break down O_3 molecules. While volcanoes also produce the O_3-degrading compound hydrochloric acid (HCl), it remains largely confined to the troposphere, where it can be washed out by rains.

Volcanism is a significant source of CO_2. According to the United States Geological Survey, subaerial and submarine volcanoes emit an annual total of 130 to 230 million metric tons of CO_2. By comparison, the Carbon Dioxide Information Analysis Center estimates the total global CO_2 emissions from fossil fuel burning in 2007 to have been 8.47 billion metric tons.

Despite their GHG emissions, volcanic eruptions produce a net cooling effect on surface temperatures. This is due in part to dust and ash that remain suspended in the atmosphere after an eruption. These particulates lower mean global temperatures by blocking sunlight, thereby reducing the amount of solar radiation that can reach the planet's surface. The dominant cooling effect, however, results from SO_2 blasted into the stratosphere. The gas combines with water vapor to form droplets of sulfuric acid. This aerosol can remain suspended in the atmosphere, where the droplets absorb solar radiation and cause a decrease in tropospheric temperatures. Global cooling associated with volcanic activity diminishes after a few years as the particles settle out of the atmosphere.

Major volcanic activity in past centuries—notably the 1783 Laki eruption in Iceland, the 1815 eruption of Mount Tambora in Indonesia, and the

1883 eruption of Tambora's neighbor Krakatoa (Krakatau)—have been followed by several months of abnormally cold weather around the globe. More recently, the eruptions of Mount Pinatubo in the Philippines and Mount Hudson in Chile, both during 1991, caused a decrease in mean world temperatures of approximately 1° Celsius over the next two years.

- **Wildfires**

As wildfires burn, they release carbon stored in vegetation to the atmosphere in the form of CO_2, CO, and CH_4. Researchers Christine Wiedinmyer and Jason Neff estimate that average annual CO_2 emissions from wildfires during the years 2002 through 2006 were 213 (±50 standard deviation) million metric tons for the contiguous United States and 80 (±89 standard deviation) million metric tons for Alaska. This contribution of greenhouse gases—the equivalent of 4 to 6 percent of North America's anthropogenic emissions during that period—has the potential to exacerbate global warming, which can in turn create a hotter, drier environment conducive to larger, more devastating wildfires.

Wildfire combustion products include the GHGs CO_2, CH_4, and N_2O, as well as CO, nitric oxide, and VOCs, all of which promote global warming by enhancing tropospheric O_3. Methyl bromide produced during wildfires can also contribute to global warming by destroying stratospheric O_3.

Wildfires generate large volumes of particulates in the form of smoke, ash, and soot. Clouds of fire-related particulates both absorb and block sunlight, so that their tropospheric effects are both warming and cooling. Particle color influences whether energy is absorbed (dark particles) to produce warming or reflected (light particles) to cause cooling. If soot settles out of the atmosphere onto snow or ice, its dark particles reduce the reflectivity of the frozen surface while enhancing sunlight absorption. Heating, and accelerated melting of the snow or ice, result.

- **Other Sources**

Oceans and oceanic processes generate a number of natural air pollutants. According to the United Nations Environment Programme (UNEP), oceans produce about 90 billion metric tons of CO_2 annually, emissions that are offset by the estimated 92 billion metric tons that oceans absorb. Oceanic phytoplankton releases dimethyl sulfide, which forms SO_2 as an oxidation product. Oceans also contribute CO, CH_4, N_2O, and NO_x to the atmosphere. Ocean spray sends sea-salt particles aloft, where they decompose in the presence of sunlight to release chlorine molecules that can interact with anthropogenic air pollutants to produce tropospheric O_3.

On land, according to UNEP, vegetation emits 540 billion metric tons of CO_2 but takes in 610 billion metric tons. Another GHG, CH_4, is emitted from a host of terrestrial sources: digestive processes in wild animals and termites; decomposition of wild animal wastes; lakes and wetlands; tundra; and natural oil and gas seeps. Warmer global temperatures could lead to an increase in CH_4 emissions from regions where there is now permafrost.

Other naturally occurring air pollutants include CO from vegetation and the oxidation of naturally occurring hydrocarbons; N_2O and NO_x produced during bacterial denitrification of soil; NO_x created within thunderstorms by lightning; hydrogen sulfide (H_2S) generated during decay underground or under water; SO_2 produced through the oxidation of H_2S; VOCs emitted from coniferous and eucalyptus forests and other vegetation; ammonia released from wild animal wastes; radon gas produced as radium in rock and soil undergoes radioactive decay; and particulate matter in the form of ultrafine soil, dust, pollen, and spores.

- **Context**

Understanding how naturally occurring substances and processes influence climate is a vital part of comprehending the roles that human activity and anthropogenic materials play. The boundaries between the natural and the anthropogenic are often indistinct. Naturally occurring gases and particulates interact with human-made ones to produce O_3 in the troposphere or damage it in the stratosphere. Deforested areas are left vulnerable to wind erosion that carries soil particulates into the atmosphere. Lightning causes massive wildfires, but so do arsonists and human carelessness.

What is clear is that natural pollutants are not the major concern. Although anthropogenic CO_2 is dwarfed by the natural carbon cycle and there have been episodes where natural emissions have been huge and have had long-lasting effects (such as the possible massive volcanic sulfur emission at the end of the Permian epoch and the possible methane release in the Eocene), human effects can be more important because (1) humans can change the atmosphere on a very rapid time scale compared to natural effects, and (2) humans introduce substances that have a potent effect on the atmosphere and are not normally found in nature, such as chlorofluorocarbons (CFCs). Hence, anthropogenic substances can surpass naturally occurring ones in their current and long-term impacts on the balance between incoming solar radiation and outgoing infrared radiation within Earth's atmosphere.

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• **Further Reading**

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. The "Summary for Policymakers," "Technical Summary," and "Frequently Asked Questions" sections are informative condensations of this nearly thousand-page volume. Table TS.2 of the "Technical Summary" lists GHGs' global warming potentials.

Knipping, E. M., and D. Dabdub. "Impact of Chlorine Emissions from Sea-Salt Aerosol on Coastal Urban Ozone." *Environmental Science and Technology* 37, no. 2 (2003): 275-284. A highly technical paper on sea salt's role in coastal ozone production. Figures, tables, equations, references.

Robock, Alan. "Volcanic Eruptions and Climate." *Reviews of Geophysics* 38, no. 2 (May, 2000): 191-219. This technical paper on the effects of volcanic eruptions on climate is a challenging but not impenetrable read for the nonscientist. Figures, tables, plates, glossary, references.

Wiedinmyer, Christine, and Jason C. Neff. "Estimates of CO_2 from Fires in the United States: Implications for Carbon Management." *Carbon Balance and Management* 2, no. 10 (November 1, 2007). A technical look at the variability of CO_2 emissions from fires across the United States and how they compare to anthropogenic emissions. Figures, tables, references.

Wuebbles, Donald J., and Jae Edmonds. *Primer on Greenhouse Gases.* Chelsea, Mich.: Lewis, 1991. A technical but accessible introduction to climate and climate change. An extensive table (in chapter 6) identifies natural sources of GHGs, where applicable, and summarizes their climate effects.

See also: Aerosols; Air pollution and pollutants: anthropogenic; Air pollution history; Air quality standards and measurement; Atmosphere; Atmospheric boundary layer; Atmospheric chemistry; Atmospheric dynamics; Atmospheric structure and evolution; Carbon dioxide; Carbon dioxide equivalent; Carbon 4 plants; Carbon monoxide; Carbon 3 plants; Carbonaceous aerosols; Chlorofluorocarbons and related compounds; Clouds and cloud feedback; Dust storms; Enhanced greenhouse effect; Fire; Global dimming; Greenhouse effect; Greenhouse gases; Methane; Mount Pinatubo; Nitrous oxide; Ozone; Sulfate aerosols; Volatile organic compounds; Volcanoes.

Air pollution history

• **Category:** Pollution and waste

Air pollution resulting from human action dates primarily from the Industrial Revolution. Humans, however, have had some impact on the environment for at least five thousand years. As industrialized agriculture and manufacturing have increased, humans have added increasing amounts of pollutants to the atmosphere.

• **Key concepts**

air pollution: degradation of air quality through human or natural means

anthropogenic: derived from human actions or sources

forest clearing: destruction of forests in order to create land suitable for human habitation or use

greenhouse gases (GHGs): anthropogenic and natural gases that trap heat within the atmosphere, increasing Earth's surface temperature

health hazard: pollution that produces potential harm to human health

industrialization: development and dissemination of mechanical, mass-producuction technologies

• Background

The history of anthropogenic air pollution is generally traced from the Industrial Revolution of the eighteenth and nineteenth centuries. As by-products of manufacturing processes and through burning the coal and oil necessary to power them, industries added substantial amounts of heavy metals, acidic compounds (such as sulfur dioxide), and carbon dioxide (CO_2) to the atmosphere. The first significant effect on the air occurred, however, when humans cleared land for agriculture. This effect increased over time, as more land was cleared and small-scale industry developed. Thus, before the Industrial Revolution began, human activity was already generating air pollution.

• The Development of Agriculture

At least five thousand years ago, humans began to clear forests for agriculture. Burning of the cleared wood, livestock emissions, and human waste produced methane gas, which is a greenhouse gas (GHG). The gradual increase in Earth's human population contributed to an increasing amount of methane being added to the atmosphere. As more complex agriculture developed, forest clearance increased, leading to a gradual increase in the amount of CO_2 in the atmosphere. The impact of land clearing varied, but the activity continued to add methane and CO_2 to the atmosphere. By the thirteenth century, much of England, for example, had been deforested. Agriculture created pollutants that were not direct health hazards but that added to the levels of GHGs in the atmosphere.

• Ancient Societies

The increase of human population that started several thousand years ago was initially quite slow. As ancient societies became more complex, it became necessary to create larger numbers of tools, to mine and refine the materials used for production, and to develop more complex energy sources. Each of these processes contributed to air pollution, although it is very difficult to quantify their contributions precisely. Aside from smoke and odors, most people were unaware of air pollution.

Smelting metals and creating tools added small amounts of heavy metals and sulfur and nitrogen oxides to the atmosphere. At times, these pollutants were carried by wind currents for considerable distances. For example, it appears that traces of the pollutants derived from Roman metal smelting may be found in Greenland's ice cap. Smelting also required energy; this energy was produced by burning wood. Thus, early proto-industrial concerns added to air pollution, both through cutting down trees and through burning their wood. Ancient Romans and early medieval Europeans were unaware of this pollution except for the occasional downdrafts of smoke from a nearby smelter or the increase of smoke from heating in towns.

• The Middle Ages

By the fourteenth century, an awareness of some negative effects of air pollution began to develop. Some of the awareness focused on unpleasant and noxious odors that resulted from butchering and from human waste in cities such as London. There was also concern over the increasing amount of smoke in the air in urban areas such as London or Paris. The smoke at the time was primarily wood smoke, although some coal was also being used to heat homes and provide power. Official concern tended to focus on the dirt that resulted from burning fossil fuels and the noxious odors that came from burning coal in particular. More harmful pollutants, such as sulfur and nitrogen oxides, were ignored, because people were unaware of their existence. They were equally unaware of the GHGs that were a by-product of burning fossil fuels.

As forests were consumed in the late Middle Ages in Western Europe, producers of goods turned increasingly to coal as an energy source. Burning coal led to an increase in various air pollutants in the atmosphere, although the amounts were still quite small throughout the sixteenth and seventeenth centuries. Increased population led to increased demand for goods, as well as for home heating, food, and building construction. All of these demands contributed to a further clearing of land for agriculture and lumber production, although now the lands cleared were often in North and South America and Asia, rather than in Europe.

• Industrialization

The Industrial Revolution of the eighteenth and nineteenth centuries led to a dramatic increase in atmospheric pollutants. The growth of industrial society was accompanied by an increase in population, which further drove increased industrial and agricultural production. The magnitude of industrialization dating from the early nineteenth century led to a drastic increase in the use of fossil fuels, first coal and then oil. Burning these fossil fuels added CO_2 to the atmosphere, as well as pollutants such as sulfur and nitrogen oxides. Burning fossil fuels and metal fabrication also led to the addition of heavy metals to the atmosphere. Later, other pollutants, such as chlorofluorocarbons, were generated as by-products of industrial society.

• Context

Human activity has affected Earth's atmosphere for thousands of years, and the atmospheric concentration of anthropogenic substances has increased with humanity's population and technological sophistication. The increase in anthropogenic influences on the atmosphere has led to an increased awareness and understanding of air quality and pollution. Such an understanding has led in turn to changing definitions of those terms: Until the late twentieth century, only foreign substances with direct toxic or pathogenic effects were considered pollutants. For example, CO_2—which occurs naturally in the atmosphere and is not directly toxic—was not categorized as a pollutant. The discovery of

Smoke from an iron and steel plant billows into the sky. (Jianan Yu/Reuters/Landov) the greenhouse effect, and of the role of CO_2 and other gases in that effect, has led many scientists and governments to reconsider their earlier definitions, and many now classify all GHGs as air pollutants. This discovery has also led historians to reconsider the history of air pollution itself and to see in a new light the role that early agriculture played in shaping atmospheric chemistry. By considering the evolution of human technology over several millennia in relation to the global atmosphere and climate, scientists can gain a fuller understanding of the extent to which anthropogenic inputs to the atmosphere may have contributed to changes in the climate.

John M. Theilmann

• **Further Reading**

Goudie, Andrew. *The Human Impact on the Natural Environment: Past, Present, and Future.* 6th ed. Malden, Mass.: Blackwell, 2006. Provides concise analysis of the nature of air pollution as affected by human action.

Ruddiman, William F. *Plows, Plagues, and Petroleum.* Princeton, N.J.: Princeton University Press, 2005. Ruddiman, a leading climate researcher, argues that human pollution has had a long-term, increasing, and negative impact on the climate.

Somerville, Richard C. J. *The Forgiving Air.* Berkeley: University of California Press, 1996. Good overview of the interaction of technology and environmental change in the atmosphere.

Theilmann, J. M. "The Regulation of Public Health in Late Medieval England." In *The Age of Richard II*, edited by James L. Gillespie. New York: St. Martin's Press, 1997. Good analysis of various forms of pollution, including air pollution, that uses late medieval England as a case study.

Williams, Michael. *Deforesting the Earth.* Chicago: University of Chicago Press, 2003. Comprehensive account of the various effects, including air pollution, of the human deforestation of the Earth.

See also: Agriculture and agricultural land; Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air quality standards and measurement; Asthma; Carbon dioxide; Clean Air Acts, U.S.; Coal; Emissions standards; Fossil fuels; Industrial emission controls; Industrial greenhouse emissions; Industrial Revolution; Ozone; Population growth.

Air quality standards and measurement

• **Categories:** Pollution and waste; laws, treaties, and protocols

Warmer temperatures and air pollution are interrelated: Rising temperatures result in increases in ozone production and energy utilization. Increased energy demands result in more power plant utilization, which leads to greater emissions.

• **Key concepts**

Air Quality Index (AQI): a numerical index for reporting air pollution levels to the public

Clean Air Acts: a set of federal laws that form the basis for the United States' air pollution control effort

criteria air pollutant: air pollutants for which acceptable levels of exposure can be determined and ambient air quality standards have been set

National Ambient Air Quality Standards (NAAQS): standards established by the EPA that limit acceptable outdoor air pollution levels throughout the United States

particulate matter: any nongaseous material in the atmosphere

• **Background**

Climate change affects atmospheric composition and dynamics. In addition to changing global weather patterns, climate change may have a negative impact on air quality. In particular, formation of ozone and particulate matter are influenced by weather conditions such as temperature and precipitation. Air pollution concentrations are also influenced by management strategies that control emissions. The need to reduce anthropogenic influences on the climate, through mitigation of greenhouse gas (GHG) emissions, and to adapt to future climate change is a significant environmental problem. Adapting to global climate change is necessary to protect air quality.

- **Climate Change and Air Quality**

Air quality is affected by human activities such as driving automobiles or other vehicles, burning coal or other fossil fuels, and manufacturing chemicals. In most countries, transportation is one of the major contributors to air pollution, and it generates many pollutants. Transportation causes wear and tear on cars and on roads, which produces road dust. Heating and cooling residential and commercial buildings requires a great deal of energy, most of which is supplied by burning fossil fuels, constituting another major source of air pollutants and GHGs. Residential heating, particularly from burning wood, also contributes particulate matter and many toxic compounds to the atmosphere.

There are a number of connections and synergistic effects between climate change and air quality. Climate change, including changes to temperature, precipitation, cloud cover, and relative humidity, may affect the atmospheric concentrations of many important chemical species and change the rate at which ozone and particulate matter are formed in the atmosphere, with warmer temperatures increasing ozone and particulate-matter formation. High temperatures also cause the evaporation of toxic substances such as mercury, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), from sediments.

Warmer temperatures lengthen pollen and mold seasons and encourage spore production. Climate change may increase the frequency of stagnant air masses, which may cause pollutant buildup in certain regions. Changes in temperature can affect methane emissions. Widespread climate changes may also alter human activity patterns such as agriculture, biomass burning, and energy consumption, including the demand for heating or cooling. This, in turn, would affect the emissions of pollutant gases and particles resulting from these activities. Changes in land use and in fire and drought patterns may affect smoke and mineral dust aerosols in the atmosphere.

- **Air Quality Monitoring Techniques**

Air quality is measured through direct monitoring or through emissions inventories. Air quality monitoring is the main method for determining concentrations of particular pollutants in the atmosphere at specific points in time. Air quality monitoring is used to determine the Air Quality Index (AQI), a composite indicator of outdoor air quality that is communicated to the public through the media and generally includes recommendations for protection against pollutant-associated health effects.

Emissions inventories estimate the amount of pollutants emitted into the atmosphere from major mobile, stationary, and natural sources over a specific period of time—for example, a day or a year—and form the basis for efforts such as trend analysis, air quality monitoring, regulatory impact assessments, and human exposure modeling. The Environmental Protection Agency (EPA) maintains the National Emission Inventory database, which contains information about sources that emit criteria air pollutants and hazardous air pollutants.

In many countries, air quality monitoring networks provide measurements of pollutant species. Many air quality monitoring programs include both global and regional networks that measure background atmospheric composition at selected remote sites. Other programs include regulatory monitoring networks that analyze day-to-day variations in air quality at numerous sites, primarily in urban areas. Most air quality monitoring sites are focused on heavily populated areas and are designed to determine whether a specific area is in compliance with air quality standards. Urban and regional air quality monitoring networks rely on ground-based sites that sample within the boundary layer.

Remote-sensing or satellite instruments provide global-scale observations of specific pollutants in the atmosphere. A variety of instruments attached to balloons or aircraft are used for atmospheric measurements over a wide range of altitudes. Particulate matter measurements can be conducted in real time, but routine aerosol mass measurements generally rely on particle accumulation over extended sampling times followed by laboratory analyses. Urban areas in the United States are monitored through the EPA's air quality programs, but large data gaps exist in a number of rural areas, and

National Ambient Air Quality Standards for Criteria Pollutants

Pollutant	*Averaging Time*	*Pollutant Level*	*Effects on Health*
Carbon monoxide: colorless, odorless, tasteless gas; it is primarily the result of incomplete combustion; in urban areas the major sources are motor vehicle emissions and wood burning.	1-hour 8-hour	35 ppm 9 ppm	The body is deprived of oxygen; central nervous system affected; decreased exercise capacity; headaches; individuals suffering from angina, other cardiovascular disease; those with pulmonary disease, anemic persons, pregnant women and their unborn children are especially susceptible.
Ozone: highly reactive gas, the main component of smog.	1-hour 8-hour	0.120 ppm 0.080 ppm	Impaired mechanical function of the lungs; may induce respiratory symptoms in individuals with asthma, emphysema, or reduced lung function; decreased athletic performance; headache; potentially reduced immune system capacity; irritant to mucous membranes of eyes and throat.
Particulate matter < 10 microns (PM10): tiny particles of solid or semisolid material found in the atmosphere.	24-hour Annual arithmetic mean	150 $\mu g/m^3$ 50 $\mu g/m^3$	Reduced lung function; aggravation of respiratory ailments; long-term risk of increased cancer rates or development of respiratory problems.
Particulate matter < 2.5 microns (PM2.5): fine particles of solid or semisolid material found in the atmosphere.	24-hour Annual arithmetic mean	65 $\mu g/m^3$ 15 $\mu g/m^3$	Same as PM10 above.
Lead: attached to inhalable particulate matter; primary source is motor vehicles that burn unleaded gasoline and re-entrainment of contaminated soil.	Calendar quarter	1.5 $\mu g/m^3$	Impaired production of hemoglobin; intestinal cramps; peripheral nerve paralysis; anemia; severe fatigue.
Sulfur dioxide: colorless gas with a pungent odor.	3-hour 24-hour Annual arithmetic mean	0.5 ppm 0.14 ppm 0.03 ppm	Aggravation of respiratory tract and impairment of pulmonary functions; increased risk of asthma attacks.
Nitrogen dioxide: gas contributing to photochemical smog production and emitted from combustion sources.	Annual arithmetic mean	0.053 ppm	Increased respiratory problems; mild symptomatic effects in asthmatics; increased susceptibility to respiratory infections.

Notes: ppm equals parts per million and $\mu g/m^3$ equals micrograms per cubic meter.
Source: United States Environmental Protection Agency (EPA); URL http://www.epa.gov.

insufficient data are available for large regions of the Earth.

• Air Quality Management Methods

Contemporary air quality management plans focus on controlling state and local emissions, although the EPA has also initiated regional air quality management strategies. In general, there are two types of air quality standards. The first type, the National Ambient Air Quality Standards (NAAQS's), are set by the EPA and include target levels for specific pollutants that apply to outdoor air throughout the country. The EPA has set NAAQS's for six principal pollutants, called "criteria pollutants." They are carbon monoxide, lead, nitrogen dioxide, particulate matter (PM_{10} and $PM_{2.5}$), ozone, and sulfur dioxide. The second class of standards constitutes the Air Quality Index (AQI), which uses a scale to communicate the relative risk of outdoor activity to the public.

The Clean Air Acts (1963-1990) require the EPA to set NAAQS's for pollutants from a variety of sources considered harmful to public health and the environment and have significantly strengthened air pollution regulation. The Clean Air Acts set target levels for air pollutants and provide reporting and enforcement mechanisms. Two types of national air quality standards were established through these acts: Primary standards set limits to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protecting against decreased visibility and damage to animals, crops, vegetation, and buildings.

The Clean Air Rules, established in 2004, are a suite of rules focused on improving U.S. air quality. Three of the rules, the Clean Air Interstate Rule (CAIR), the Clean Air Mercury Rule, and the Clean Air Nonroad Diesel Rule, address the transportation of pollution across state borders. CAIR is a management strategy that covers twenty-eight eastern states and the District of Columbia and focuses on the problem of power plant pollution drifting from one state to another. This rule uses a cap-and-trade system to reduce sulfur dioxide and nitrogen oxides.

The Clean Air Mercury Rule (CAMR) represents the first federally mandated requirement that coal-fired electric utilities reduce their emissions of mercury. Coal-fired power plants are the largest remaining domestic source of anthropogenic mercury emissions, and with the CAMR, the United States is the first nation in the world to control emissions from this major source of mercury pollution. Together, the CAMR and the CAIR create a multipollutant strategy to reduce U.S. emissions. The effects of these laws have been very positive, with substantial reductions in emissions of carbon monoxide, nitrogen oxide, sulfur dioxide, particulate matter, and lead. The Clean Air Nonroad Diesel Rule changes the way diesel engines function to remove emissions and the way diesel fuel is refined to remove sulfur. These rules provide national tools to achieve significant improvement in air quality.

• Global Air Quality Management

Air pollution emissions can affect air quality beyond national borders. Westerly winds transport ozone from the eastern United States into Canada and the North Atlantic. Air masses reaching the United States carry pollution originating from many other parts of the world, including Asian industrial pollutants and African dust aerosols. Saharan dust has affected atmospheric particulate-matter concentrations in several inland areas of the American southeast. Long-range transport of gases and of aerosols from burning biomass has also been detected.

Many areas of the world are moving toward mitigating the GHG emissions that contribute to global climate change. As urbanization and industrialization have increased, urban air quality has become a significant public health concern throughout many regions, particularly in developing countries. Particulate air pollution is a chronic problem in much of Asia as a result of coal combustion in factories and power plants and the use of coal and wood for cooking and heating homes.

Automobiles continue to be an increasingly important contributor to air pollution in much of the world, with more than 600 million vehicles in use, a number that is growing exponentially. Motor vehicles are the predominant source of air pollution in many Latin American cities, where automobile use has been restricted in order to manage severe air pollution occurrences. In the United States, air quality has shown steady improvement, partly because of air quality regulatory programs and new, cleaner technologies that have improved both motor vehicles and stationary pollution sources.

The Kyoto Protocol includes provisions that limit GHG emissions from industrialized countries throughout the world. Carbon dioxide (CO_2) is the predominant GHG emitted by most countries, and controlling CO_2 emissions is an essential component of air quality monitoring strategies. Non-CO_2 GHG emissions also have considerable global warming potentials and are important targets for emission reductions. Although ozone and particulate matter also contribute to global warming, control of these species is not currently included in the Kyoto Protocol. Ozone and particulate matter could be effective targets for emission control efforts, however, since many countries already have regulations focused on controlling these species and since reducing ozone and particulate-matter emissions can improve local air quality, health, and agricultural productivity.

- **Context**

Climate change will alter the extent and nature of air pollution and the general composition of the atmosphere and will be influenced by both natural and anthropogenic factors. While climate change may exacerbate the frequency of smog episodes and related health effects, air pollution is already a serious health concern around the world. Changes in air pollution emissions occurring over the next several decades could affect global health, as emissions may reach areas far beyond their local sources. Efforts under way and contemplated to address climate change may have the related benefit of reducing air pollution in general. However, climate change may also reduce the effectiveness of existing programs: Many of the national control programs currently in place may prove be less effective than was originally expected. As climate change progresses, more stringent air quality standards and management will likely be necessary. Multipollutant approaches that protect human health and climate will require a global perspective to meet air quality objectives.

C. J. Walsh

- **Further Reading**

Alley, E. Roberts, Lem B. Stevens, and William L. Cleland. *Air Quality Control Handbook*. New York: McGraw-Hill, 1998. Provides comprehensive coverage of the provisions and implications of the 1990 Clean Air Act Amendments and examines the origins and effects of air pollution and the history of air quality control management.

Godish, Thad. *Air Quality*. 4th ed. Boca Raton, Fla.: CRC Press, 2003. For students, this text provides a comprehensive overview of air quality issues, including descriptions of atmospheric chemistry, effects of pollution on public health and the environment, and regulatory practices used to achieve air quality goals.

Griffin, Roger D. *Principles of Air Quality Management*. Boca Raton, Fla.: CRC Press, 1994. Includes a chapter on air quality standards and monitoring and a chapter on global concerns about air quality.

Harrop, Owen. *Air Quality Assessment and Management*. London: Taylor & Francis, 2002. Describes available techniques for air quality assessment, with details on the concepts and methodologies involved and principles of air quality management.

National Research Council. Committee on Air Quality Management in the United States. *Air Quality Management in the United States*. Washington, D.C.: National Academies Press, 2004. Provides an overview of current air quality management in the United States, with recommendations for mitigation efforts and regulations.

See also: Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Catalytic converters; Clean Air Acts, U.S.; Emissions standards; Industrial emission controls; Motor vehicles.

Air travel

- **Categories:** Economics, industries, and products; transportation

Because they are released so high in the atmosphere, emissions from airplanes have greater relative effects upon air *quality than do emissions from ground vehicles. The extent of those emissions' effects upon Earth's climate is a much studied and hotly debated issue.*

• Key concepts

aircraft emissions: gases and particulate matter expelled from aircraft engines

greenhouse effect: an atmospheric warming phenomenon by which certain gases act like glass in a greenhouse, allowing the transmission of ultraviolet solar radiation but trapping infrared terrestrial radiation

greenhouse gases (GHGs): gases that tend to hold heat within the atmosphere and contribute to the greenhouse effect

ozone: a greenhouse gas that absorbs ultraviolet radiation

radiative forcing: a change in the balance between incoming and outgoing radiation that increases or decreases overall energy balance

stratosphere: the atmospheric region just above the tropopause that extends up to about 50 kilometers

troposphere: the lowest layer of the atmosphere, in which storms and almost all clouds occur, extending from the ground up to between 8 and 15 kilometers in height

• Background

Powered flight was introduced in 1903, when Wilbur Wright and Orville Wright conducted the first short flight at Kill Devil Hills, North Carolina. The first thirty-five years of powered flight had minimal impacts upon Earth's climate. The advent of widespread aerial cargo and passenger service in the late 1930's and early 1940's arguably marks the first significant influence upon Earth's climate by aircraft. However, beginning in the 1960's, air travel's impact became much more pronounced, as jet aircraft were introduced. The effects of air travel were increased in 1978, when the United States deregulated the airline industry, resulting in a significant increase in the annual number of jet aircraft flights.

• Air Travel Growth Rate

Since 1960, air travel has grown by approximately 9 percent per year. A mode of transportation once regarded as available only to the wealthy quickly became the preferred, affordable method of long-distance travel. With this rapid growth has come a proportionate increase in the impact that air travel has on Earth's environment and climate. It is expected that air travel will continue to grow at an annual rate between 6 and 11 percent during the twenty-first century. This significant anticipated growth suggests that substantial progress must be made in limiting the negative effects that air travel has on the environment.

• Impact of Air Travel on Earth's Climate

Aircraft engines emit gases and particulates into the upper troposphere and lower stratosphere. These gases modify atmospheric composition, resulting in either increases or decreases in radiative forcing. Water vapor and carbon dioxide (CO_2) emissions result in positive radiative forcing. In addition, sulfur and soot emitted by aircraft engines combine with water to form condensation trails, commonly called contrails, resulting in further positive radiative forcing. Both processes warm the climate.

• Impact of Air Travel on Earth's Ozone Layer

Ozone, a greenhouse gas, absorbs ultraviolet radiation. The majority of this absorption occurs in the stratosphere. A wide variety of human interactions with the environment deplete ozone in the atmosphere. Subsonic aircraft engines emit nitrogen oxides in the troposphere and lower stratosphere that increase ozone, reducing the amount of ultraviolet radiation reaching Earth's surface. Supersonic aircraft, flying higher in the stratosphere, have an opposite effect, depleting ozone at those higher altitudes.

Best estimates are that net air-travel-related radiative forcing comprises approximately 3.5 percent of total human atmospheric radiative forcing. Currently, most air travel is conducted by subsonic aircraft operating in the upper troposphere and lower stratosphere. However, significant research and development is under way to introduce supersonic and hypersonic aircraft into the air transportation fleet. If this occurs, much of the ozone-depletion offset generated by subsonic aircraft will be negated by ozone-depleting supersonic aircraft operating primarily in the stratosphere.

An experimental Boeing 747-300 aircraft equipped with a biofuel engine prepares to take off from Tokyo's Haneda airport. (Issei Kato/Reuters/Landov)

With the retirement of the Concorde supersonic transport, there were no operational civil supersonic transport aircraft. However, beginning around 2015, a new civil supersonic aircraft fleet is expected to develop and grow at a brisk rate, resulting in more than one thousand civil supersonic aircraft in service by 2040. If this occurs, air-travel-related radiative forcing will increase by almost 40 percent over 2008 levels.

Interestingly, a disproportionate amount of positive radiative forcing occurs in the delicate upper portion of the Northern Hemisphere as a result of the high volume of jet aircraft traffic in that region. Increases in atmospheric temperatures in the polar region have a potentially significant effect on rising ocean levels resulting from polar-cap and glacial-ice melting.

• Reducing Air Travel Impacts

A number of options exist to reduce air travel's impact upon the environment. Rises in petroleum-based fuel prices reduce the impact of air travel on the environment by making air travel less cost effective and reducing the demand for flights. In addition, airlines are striving to work worldwide with air traffic control organizations to reduce ground holds and increase flight efficiency through more direct routings and highly planned, efficient descents from altitude.

Technological advances in jet-engine design and efficiency also offer great promise for reducing environmental impacts. State-of-the-art turbine engines, utilized on most new transport aircraft, are much more efficient than older versions. Finally, a basic solution to reduce air travel's impact upon the environment is to reduce the need to travel at all. Modern computing technologies, including high-quality video conferencing, make possible complex online meetings. These meetings can be held with participants located throughout the world, reducing the need for business travel.

• Context

Air travel is growing at a brisk rate; it has an impact upon global warming, but there are mitigation measures available. It remains unclear, however, to what extent governments, aircraft manufacturers, and airline companies will institute such mitigation measures. Research and development of greener aircraft technologies is an expensive and time-consuming venture. As with all ventures, governments and companies must attempt to strike a compromise between the environmental impacts of aviation and economic factors related to technological innovation. The long-term availability of aircraft fuel and the will of airlines and aircraft manufacturers to adopt green technologies remain unclear.

Alan S. Frazier

• Further Reading

Dokken, David J., et al. *Special Report on Aviation and the Global Atmosphere*. Geneva, Switzerland: World Meteorological Organization, Intergovernmental Panel on International Climate Change, 1999. Comprehensive report on the impacts of air travel on Earth's climate.

General Accounting Office, U.S. *Aviation and the Environment: Aviation's Effects on the Global Atmosphere Are Potentially Significant and Expected to Grow*. Washington, D.C.: Author, 2000. A report commissioned by a member of the House of Representatives presenting a summary of air travel's effects upon climate change.

See also: Carbon footprint; Emission scenario; Emissions standards; Fossil fuel emissions; Ozone; Transportation.

Albedo feedback

• Category: Physics and geophysics

• Definition

Albedo (Latin for "whiteness") is a measure of the amount of incident radiation, such as sunlight, that a surface reflects. Arctic ice, for example, has a high albedo, meaning that most of the light hitting it is reflected back into space, so little of the solar energy striking ice is absorbed into the Earth's surface in the form of heat. When the ice melts into liquid water, however, surfaces darken and absorb more light, warming the planetary surface. As the ocean surface warms, more of the remaining ice melts, further increasing the amount of solar heat being absorbed. This cycle in which lower albedo creates conditions that cause a further decrease in albedo is an example of a positive feedback loop.

Albedo, measured as the fraction of solar radiation reflected by a surface or object, is often expressed as a percentage. Snow-covered surfaces have a high albedo, the surface albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo. The Earth's planetary albedo varies mainly through varying cloudiness, snow, ice, leaf area, and land cover. The warming of the Arctic influences weather in the United States. Outbreaks of Arctic cold have become weaker as ice coverage erodes.

Earth's albedo usually changes in the cryosphere (ice-covered regions), which has an albedo much greater (at around 80 percent) than the average planetary albedo (around 30 percent). In a warming climate, the cryosphere shrinks, reducing the Earth's overall albedo, as more solar radiation is absorbed to warm the Earth still further. Cloud cover patterns also could change, resulting in further albedo feedback. Changes in albedo have an important role in changing temperatures in any given location and, thus, the speed with which ice or permafrost melts.

• Significance for Climate Change

The rate of Arctic warming around the beginning of the twenty-first century has been eight times the average rate during the twentieth century. Changes in albedo are among the factors contributing to this increase. The number and extent of boreal forest fires have also grown, increasing the amount of soot in the atmosphere and decreasing Earth's albedo. As high latitudes warm and the coverage of sea ice declines, thawing Arctic soils also may release significant amounts of carbon dioxide (CO_2) and methane now trapped in permafrost.

Arctic warming has shortened the region's snow-covered season by roughly 2.5 days per decade, increasing the amount of time during which sunlight is absorbed. Gradual darkening of Arctic surfaces thus produces significant changes in the total amount of solar energy that the area absorbs. Scientists have estimated this increase in surface energy absorption at 3 watts per square meter per decade. This means that, in areas such as the Arctic where albedo has changed markedly, the effect of this change on climate has been roughly equal to the effect of doubling atmospheric CO_2 levels. Moreover, the continuation of contemporary trends in shrub and tree expansion would amplify atmospheric heating by two to seven times.

Changes in albedo over a broad area, such as the Arctic, can produce a significant effect, allowing Earth to be "whipsawed" between climate states. This feedback has been called the "albedo flip" by James E. Hansen, director of the Goddard Institute for Space Studies (GISS) of the National Aeronautics and Space Administration (NASA). The flip provides a powerful trigger mechanism that can accelerate rapid melting of ice. According to Hansen, greenhouse gas (GHG) emissions place the Earth perilously close to dramatic climate change that could run out of control, with great dangers for humans and other creatures. Changes in albedo have been greatest in Earth's polar regions, especially in the Arctic, where snow and ice are being replaced during summer (a season of long sunlight) by darker ocean or bare ground.

Changes in albedo also play a role in increasing Arctic emissions of methane, tropospheric ozone (O_3), and nitrous oxide (N_2O). All of these are GHGs. Tropospheric ozone is the third most influential anthropogenic GHG, after CO_2 and methane.

Black carbon (soot) also has a high global warming potential and deserves greater attention, according to Hansen. Soot's albedo causes massive absorption of sunlight and heat and compounds warming, especially in the Arctic. Increases in soot due in part to combustion of GHGs can play a role

Sun strikes the water of a Norwegian Arctic fjord in April, 2007. The fjord water, normally frozen in April, may be part of a warming-induced albedo feedback loop. (Francois Lenoir/Reuters/Landov) in accelerating climate change to tipping points, at which feedbacks take control and propel increasing levels of GHGs past a point where human control ("mitigation") is possible.

Bruce E. Johansen

• **Further Reading**

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Popularization of Alley's scientific work on climate change in the Arctic.

Appenzeller, Tim. "The Big Thaw." *National Geographic,* June, 2007, 56-71. Surveys ice melt in the Arctic, Antarctic, and mountain glaciers. Explains albedo feedback, describing why the process has been accelerating.

Chapin, F. S., III, et al. "Role of Land-Surface Changes in Arctic Summer Warming." *Science* 310 (October 28, 2005): 657-660. A scientific treatment of global warming and albedo's effects.

Foley, Jonathan A. "Tipping Points in the Tundra." *Science* 310 (October 28, 2005): 627-628. Explains the role of Earth's albedo in provoking climate to a tipping point in the Arctic.

See also: Arctic; Climate feedback; Clouds and cloud feedback; Greenhouse effect; Greenhouse gases; Greenland ice cap; Ground ice; Permafrost; Sea ice; Sea surface temperatures.

Alkalinity

• **Category:** Chemistry and geochemistry

• **Definition**

Alkalinity is a measurement of the capacity of a solution to neutralize acid by taking up hydrogen atoms. On the pH scale, which rates the alkalinity or acidity of a given substance, alkalines, or bases, are denoted by numbers greater than 7, whereas acids are denoted by numbers less than 7. Some substances that contribute to a solution's alkalinity are dissolved ammonia, borate, hydroxide, nitrate, phosphate, silicate, and sulfide. The alkalinity of a substance can help protect the pH balance of the substance, as naturally basic substances can effectively neutralize or recover from the addition of acids.

• **Significance for Climate Change**

Rainwater is normally a weak carbonic acid solution. In the atmosphere, the water molecules in rain mix with carbon dioxide (CO_2) molecules, which, because of their weak bonds, can then form hydrogen and bicarbonate ions. Acid precipitation results when pollutants, such as sulfur dioxide or nitrogen oxides, remove low-pH acids from the atmosphere in the form of rain, snow, sleet, or hail. If water or soil where this acidic precipitation falls lacks natural alkalinity, as is the case with soils based on granite or other hard rocks with low carbonate content, the water or soil will be unable to neutralize the acid and the pH balance of the water or soil may be affected, altering the dynamics of the ecosystem.

The alkalinity of a body of water or soil can act as a buffer that can prevent drastic changes in the pH balance and, thus, can more easily recover from the addition of any type of acid. Thus, mildly basic bodies of water protect aquatic life and are less vulnerable to acid rain. The carbon in carbonate rocks, such as limestone, acts as a hydrogen absorber. Often, to increase the alkalinity of a body of water and thus to protect against fluctuations in the pH balance leading to algal bloom, calcium carbonate (also called limestone) is added.

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• **Further Reading**

Brimblecombe, P., et al., eds. *Acid Rain: Deposition to Recovery.* New York: Springer, 2007. Compilation of conference proceedings discussing acid rain and its effects on nutrient cycling.

Jenkins, J. C., K. Roy, C. Driscoll, and C. Buerkett. *Acid Rain in the Adirondacks: An Environmental History.* Ithaca, N.Y.: Cornell University Press, 2007. Discusses scientific investigation into the effects of acid rain on a particular ecosystem. Graphs, diagrams, maps.

Schindler, D. W. "Effects of Acid Rain on Freshwater Ecosystems." *Science* 239, no. 4836 (January 8, 1988): 149-157. Discusses the processes contributing to acid increase in bodies of water.

See also: Ocean acidification; pH.

Alleroed oscillation

• **Categories:** Climatic events and epochs; cryology and glaciology

• **Definition**

The Alleroed oscillation was a temperature fluctuation that occurred near the end of the last glaciation period, about thirteen thousand years ago. For several centuries following the oscillation, Europe, the British Isles, and the northern Atlantic warmed to present-day levels. Other areas remained untouched. The Alleroed oscillation is but one of several climate swings affecting the North Atlantic region over a period from 17,700 years ago to 11,500 years ago. These oscillations, revealed in European terrestrial sediments, are known as the Oldest Dryas, Boelling, Older Dryas, Alleroed, and Younger Dryas oscillations. Some oscillations provided warming conditions to circumscribed areas, as during the Alleroed oscillation, while others—such as the Younger Dryas oscillation, the last major cold event—were probably global in scope.

• **Significance for Climate Change**

The climate of the North Atlantic region underwent a series of abrupt cold/warm oscillations when the ice sheets of the Northern Hemisphere retreated. During the Alleroed oscillation, the warm temperatures allowed for a mix of flora and fauna that would look familiar today: Deer, horses, bear, and beaver found a congenial environment in Europe's evergreen and deciduous forests.

Questions arise about the feedback effects of such warming swings. For example, a phenomenon called the thermohaline circulation, or the great ocean conveyor, involves large ocean currents that flow like rivers around the globe, affecting local climates in the process. These currents depend on the ocean's salinity and temperature, so the Alleroed oscillation probably altered their course or strength. However, modeling for the effect of climate warming on the thermohaline circulation is difficult, and definitive conclusions are therefore elusive.

A more likely climate impact from the Alleroed oscillation would have resulted from warmer Arctic temperatures stimulating plant growth. Plant cover darkens the landscape and causes more sunlight to be absorbed, rather than reflected back into the atmosphere. Thus, as plant growth spreads, a feedback effect promotes higher temperatures, which encourages further plant growth over an increasing terrestrial range.

Some climate simulations further support the idea that temperature swings in the North Atlantic Ocean may have wide-ranging climatic effects. These simulations indicate that North Atlantic Ocean cooling causes North Pacific Ocean cooling, which in turn results in a drier climate in western North America.

Finally, current observable increases in global temperature are threatening glacier systems in the Antarctic. This may lead to sea-level increases worldwide, with serious consequences as the sea encroaches on vulnerable landmasses. Whether this occurred during the Alleroed oscillation is subject to speculation, but research indicates that it probably did.

Richard S. Spira

See also: Abrupt climate change; Climate change; Climate feedback; Climate zones; Ground ice; Thermohaline circulation; Younger Dryas.

Alliance of Small Island States

• **Categories:** Organizations and agencies; nations and peoples

• **Date:** Established 1991

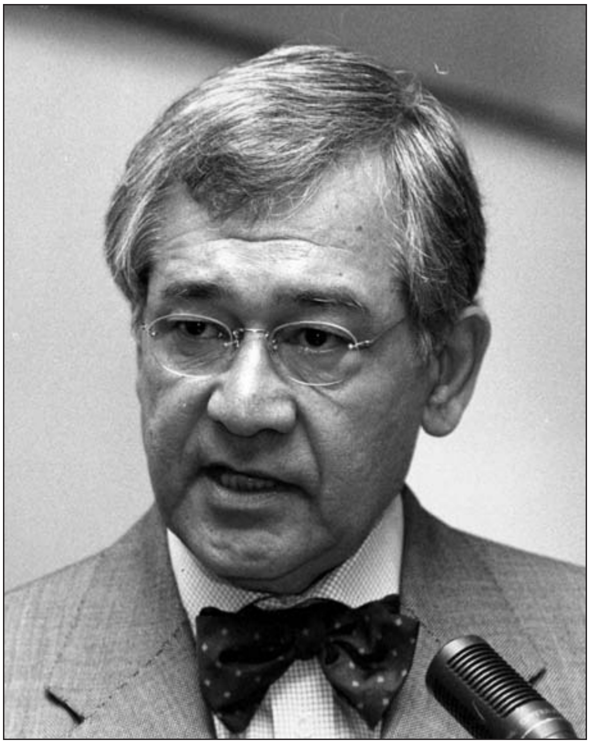
- **Web address:** http://www.sidsnet.org/aosis/index.html

- **Mission**

A coalition of small island and low-lying coastal nations, the Alliance of Small Island States (AOSIS) speaks collectively about environmental concerns and about issues affecting economic growth. AOSIS includes Antigua and Barbuda, the Bahamas, Barbados, Belize, Cape Verde, Comoros, the Cook Islands, Cuba, Cyprus, Dominica, the Dominican Republic, the Federated States of Micronesia, Fiji, Grenada, Guinea-Bissau, Guyana, Haiti, Jamaica, Kiribati, the Marshall Islands, Mauritius, Nauru, Niue, Palau, Papua New Guinea, Samoa, São Tomé and Principe, the Seychelles, Singapore, the Solomon Islands, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Tonga, Trinidad and Tobago, Tuvalu, and Vanuatu. American Samoa, Guam, the Netherlands Antilles, and the U.S. Virgin Islands are officially recognized as AOSIS observers. The alliance's member states, thirty-seven of which are also members of the United Nations, represent about 5 percent of the world's population.

Because of their small size and their proximity to water, AOSIS nations face several risks in common as global warming progresses. The warming of seawater causes sea levels to rise, increasing the dangers of flooding and of salt water flowing into freshwater supplies. Warmer water also increases the frequency and the intensity of tropical storms and disrupts corals and fish that are important to these nations' economies. In addition to climate change, island and coastal nations are threatened by spilling and dumping from the large freighters operated by larger industrialized nations.

AOSIS has no formal charter or budget and works through collaboration and consensus within the structures of the United Nations. It works to present a unified voice to amplify the influence of its small member states and to educate and persuade larger nations. In 1999, AOSIS hosted the Workshop on the Clean Development Mechanism of the Kyoto Protocol, with fifty participants including guests from the Philippines, Mauritania, the United States, the United Kingdom, Australia, Norway, New Zealand, and Switzerland. A second workshop in 2000 produced a joint statement of cooperation between AOSIS and Italy and was followed by a third workshop in 2001—sponsored by the governments of New Zealand, Norway, and Switzerland—and the 2005 Conference of the Parties to the Climate Change Convention (COP-11).



Samoan ambassador Tuiloma Neroni Slade, the president of the Alliance of Small Island States, speaks at the alliance's meeting on climate change in Nicosia, Cyprus in January, 2001. (AP/Wide World Photos)

AOSIS participates in international negotiations on climate change, particularly through the United Nations Framework Convention on Climate Change (UNFCCC). In 2007, AOSIS submitted a proposal for long-term cooperative action to address climate change, underscoring several basic principles: Nations must take care that activities within their control do not harm other nations; precautionary measures must be taken to protect future generations; the most vulnerable parties to the UNFCCC must be protected; and those who create the most environmental damage must assume the greatest amount of responsibility for reversing it. The goal of the

AOSIS proposal was to keep long-term global temperature increases below 2° Celsius.

- **Significance for Climate Change**

AOSIS presented an active and influential voice in the drafting of the UNFCCC at the Earth Summit in Rio de Janeiro, Brazil, in 1992. At the First Conference of the Parties to the UNFCCC (COP-1), held in Berlin in 1995, AOSIS submitted a draft protocol calling for a 20 percent reduction, based on 1990 levels, of greenhouse gas emissions by 2005. Although the specifics of the so-called AOSIS Protocol were not adopted, the language and the vision of the protocol informed subsequent negotiations leading to the Berlin Mandate and the Kyoto Protocol.

With its dozens of members, AOSIS made up one of the largest unified coalitions at COP-1 and succeeded in persuading larger nations that its cause was just. International climate negotiations now recognize the principle that small nations should be represented based on the amount of risk they face, rather than based solely on population or economic power. Although AOSIS continues to participate actively in international education and negotiation, it remains the group of nations most seriously threatened by global warming. While the member nations have benefited internally from projects leading to enhanced energy technologies, the group's repeated calls for industrialized nations to reduce their own emissions in order to slow sea-level rise have largely gone unheeded.

Cynthia A. Bily

- **Further Reading**

Acharya, Anjali. "Small Islands: Awash in a Sea of Troubles." *World Watch* 8, no. 6 (November/December, 1995): 24-33. Describes the ecological challenges faced by small island nations and argues that the formation of AOSIS is a good first step for these nations to take control of their own interests.

Bowness, Nicholas, and Alina Zyszkowski. *Small Islands, Big Issues: Sustainable Development of Islands.* Washington, D.C.: Counterpart International, 1997. This report covers the action plan for the "Sustainable Development of Small Island States," drafted in Barbados in 1994, and profiles the AOSIS member states.

"Not Enough Money to Keep Small Islands Afloat." *Africa News Wire*, December 14, 2007. A news story reporting the AOSIS response to the new Adaptation Fund, meant to help vulnerable nations cope with global warming, negotiated at the United Nations climate conference in Bali in 2007.

Roberts, J. Timmons, and Bradley C. Parks. *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy*. Cambridge, Mass.: MIT Press, 2006. Analyzes why underdeveloped southern nations, including small island states, are reluctant to cooperate with wealthier, more polluting northern countries to solve the global climate crisis.

Wilford, Michael. "Law: Sea-Level Rise and Insurance." *Environment* 35, no. 4 (May, 1993): 2-5. Explains how the AOSIS, concerned about rising sea levels, has formed an international insurance pool to share the risks of drastic climate change.

See also: Islands; Kyoto Protocol; Sea-level change; Sea surface temperatures; United Nations Framework Convention on Climate Change.

Amazon deforestation

- **Category:** Plants and vegetation

The Amazon rain forest, sometimes called "the lungs of the world," plays a key role in global climate, and it supports a diverse population of species, many of which exist nowhere else on Earth. Loss of Amazonian forest lands through both human clearing and drought has significant effects upon climate regulation and Earth's biodiversity.

- **Key concepts**

carbon sink: an entity that absorbs and stores carbon, thereby removing CO_2 from the atmosphere

rain forest: a tropical area dominated by evergreen trees whose leaves form a continuous canopy and that receives at least 254 centimeters of rain per year *savanna:* grassland with scattered trees, characteristic of tropical areas with seasonal rainfall on the order of 50 centimeters per year

• Background

The Amazon rain forest occupies more than 10,000,000 square kilometers of land in South America, the bulk of which is located in Brazil (60 percent) and Peru (13 percent). Nearly untouched as late as 1970, the region underwent rapid development in the last quarter of the twentieth century. Annual rates of clearing in Brazil peaked at 29,059 square kilometers in 1995 and 27,429 square kilometers in 2004. Between 1970 and 2006, the total area of rain forest in Brazil shrank from 41,000,000 square kilometers to 34,400,254 square kilometers, a decrease of 16 percent, leading to predictions of total annihilation of the Amazon within a century. As a result of international pressure and domestic conservation efforts, the annual clearing rate declined to 13,100 square kilometers in 2006, but it rose again in 2008 as increased world demand for soybeans and ethanol encouraged expansion of Brazilian agriculture.

A forest of this magnitude affects world climate in numerous ways. On a regional level, dense vegetation supports higher temperatures, higher rainfall, less runoff, and lower daily and seasonal temperature fluctuations. In the long term, high global temperatures favor forests. On a geologic time scale, the warmest periods have coincided with the greatest extent of rain forest, whereas much of the area later occupied by the Amazon rain forest was savanna during the height of the last Pleistocene glaciation.

Plants extract carbon dioxide (CO_2) from the atmosphere via photosynthesis. An expanding forest acts as a carbon sink, removing CO_2 from the air and sequestering carbon in its woody parts. A mature forest is in equilibrium, emitting as much carbon through animal consumption and decomposition as it fixes through photosynthesis. Clearing or burning forests releases CO_2 into the atmosphere; however, if tree trunks are converted to lumber and the land is subsequently used to grow crops, the net carbon release may be relatively small.

Workers in Rondonia, Brazil, burn a portion of the Amazon rain forest to clear land for agriculture. (Getty Images)

• Contribution of Global Warming to Amazon Deforestation

Global climate change can affect a forest profoundly. Although warm temperatures in general favor forests, shifts in patterns of prevailing winds brought about by small changes in oceanic temperatures may bring drought to regions accustomed to high rainfall and flooding to formerly arid regions. Although such perturbations are common in the geologic record and the Earth's biota has repeatedly shown a rapid response, the rate of recovery is slow on a human time scale.

Increasing atmospheric CO_2 may actually stimulate forest growth in the tropics. High CO_2 levels favor rapid growth of trees, which tend to crowd out understory species, leaving fewer niches for animal species, particularly insects dependent on specific food plants. In the short term, such highly productive forests may be commercially desirable for lumber production, but ecological diversity and sustainability suffer.

Cycles of the El Niño-Southern Oscillation (ENSO) cause large natural fluctuations in rainfall in the Amazon basin. During the unusually severe drought of 2005-2006, some scientists predicted that tree species would die off and natural fires would destroy significant areas of forest, creating a climate feedback loop that would turn much of the Amazon into savanna. The forest appears to be unexpectedly resilient, however. During a drought year, deep-rooted trees remain green, and they even grow faster than normal, owing to the absence of cloud cover.

Some efforts to address environmental problems elsewhere in the world contribute to Amazon deforestation. Strenuous conservation efforts in the developed world, unaccompanied by reduction in wood-product consumption, increase logging pressure in places like Brazil. The United States' drive to produce and deploy corn-based ethanol opened the way for rapid growth in Brazil's soybean production. Brazil is also a leading producer and exporter of ethanol derived from sugarcane. These crops are rarely planted directly on cleared jungle land, but cattle ranchers displaced by soybeans and sugarcane migrate to the Amazon.

Finally, decreasing levels of sulfur dioxide resulting from more stringent pollution controls in Europe and North America have been implicated in Brazil's devastating 2005 drought. This effect, the subject of a May, 2008, article in *Nature*, was the first firm scientific evidence of the importance of sulfur dioxide emissions in canceling the greenhouse effect of CO_2.

• Contribution of Deforestation to Global Warming

The effects of Amazonian deforestation on world species diversity eclipse its large-scale climatic effects, as loss of the forest may lead to the extinction of thousands of species. Nonetheless, even if only CO_2 emissions are considered, the deforestation's climatic effect is not negligible. CO_2 from slash burning following logging may account for as much as half of Brazil's carbon contribution to the atmosphere, estimated at 90 million tons in 2004. Although Brazil ranks sixteenth in terms of its contribution to world CO_2 pollution, it accounts for only a little over 2 percent of the world total and has a very low per capita level of fossil fuel consumption because Brazilians rely on hydroelectric power and ethanol.

Some of the released carbon is recaptured when land is used for crops or pastureland. However, indiscriminate logging combined with a drier and more uncertain climate due to global warming may ultimately convert large areas of the Amazon to semiarid grassland of minimal value as a carbon sink. This scenario, which appeared to many to be imminent during the 2005-2006 drought, is now thought to be avoidable through feasible management schemes, some of which are already being implemented.

• Context

It is tempting to view environmental threats en masse and to assume that a policy that ameliorates one ecological disaster will have a correspondingly benign effect on others. The interactions between global warming and the deforestation of the Amazon rain forest demonstrate that this is not always the case. The forest has shown itself to be more resilient to drought than scientists anticipated. The principal, immediate, global-warming-related threat to the Amazon rain forest appears to be the rapid expansion of Brazilian agriculture in response to rising world demand for biofuels. Models for controlling this expansion so as to encourage efficient land use and sustainability favor large agricultural businesses over individual farmers and pay inadequate attention to preserving biodiversity.

No discussion of a global-warming issue is complete without mention of population issues. The populations of Brazil and other countries bordering on the Amazon are growing at a very rapid rate. Despite the overall low level of energy consumption in the area, this population growth increases human impact on the environment exponentially. The Amazon ecosystem is apparently robust enough to withstand present levels of global CO_2 emissions, but unless exponential trends are reversed, the grim scenario of degradation to savanna looms in the future.

Martha A. Sherwood

• Further Reading

Alverson, Keith D., Raymond S. Bradley, and Thomas Pedersen, eds. *Paleoclimate, Global Change, and the Future*. Berlin, Germany: Springer Verlag, 2003. Collection of scholarly papers comparing past climate changes with present anthropogenic trends.

Cox, Peter M., et al. "Increasing Risk of Amazonian Drought Due to Decreasing Aerosol Pollution." *Nature* 453 (May 8, 2008): 212-215. Groundbreaking letter announcing the finding that aerosol pollution is capable of counteracting the greenhouse effect.

Gash, John H. C. *Amazonian Deforestation and Climate*. New York: John Wiley, 1996. Based on a 1994 symposium; reports on a series of intensive studies of pasture and forest upon which predictions of future climatic trends are based.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry et al. New York: Cambridge University Press, 2007. Chapter 13, "Latin America," contains a wealth of statistical information on climate change in the Amazon.

London, Mark. *The Last Forest: The Amazon in the Age of Globalization*. New York: Random House, 2007. Documents continuing destruction and local climatic change in the Amazon; optimistic about Brazil's efforts to encourage more sustainable growth.

See also: Agriculture and agricultural land; Brazil; Carbon cycle; Carbon dioxide; Ethanol; Extinctions and mass extinctions; Forestry and forest management; Forests.

American Association for the Advancement of Science

- **Category:** Organizations and agencies
- **Date:** Established 1848
- **Web address:** http://www.aaas.org

• Mission

The American Association for the Advancement of Science (AAAS) was founded in Philadelphia in 1848. With nearly 150,000 members, it is the largest and among the most influential general science organizations in the world. From its inception, the association has admitted both professional and amateur scientists as members. It is organized by subdivisions for all areas of the physical sciences and some social sciences.

The AAAS's multidisciplinary character has fostered one of the most important dynamics of the association, its interdisciplinary and cross-disciplinary characteristics, creating a synergy of knowledge. A further dynamic of the AAAS is its regular engagement and communication with the lay public through publishing and media outlets that divulge the latest scientific findings. Among its most distinguished publications has been *Science* magazine, noted for its tradition of popular diffusion of advanced, cutting-edge scientific research.

• Significance for Climate Change

The leadership of the AAAS has often been at the forefront of worldwide scientific discoveries. One of its earliest presidents, Louis Agassiz, was among a group of geologists in the mid-nineteenth century who first discovered that the Earth, over long geological ages, experienced periods of cooling and warming. Investigating the causes of these alterations has engaged many of the association's members. Of paramount importance has become identifying the human role in global warming—the extent to which increased carbon emissions due to human exploitation of coal, gas, and petroleum prompts atmospheric changes that have intensified solar heat and thereby altered fundamental biological processes. This project poses challenges along the entire spectrum of the sciences and demands concerted interaction.

Investigating global warming and its anthropogenic factors has involved not only the research of AAAS members but also communication of their findings through the popular media. *Science* has included numerous articles on global warming, and the association has prepared guidebooks and curricular guidelines regarding it. Moreover, presentations and debates at the association's annual conferences have concentrated on the multifaceted scientific aspects of global warming. This debate culminated in 2007, when the AAAS board of directors issued a statement declaring that the events of global warming comprise "early warning signs of even more devastating damage to come, some of which will be irreversible."

Edward A. Riedinger

See also: American Astronomical Society; American Geophysical Union; American Institute of Physics; American Meteorological Society; Scientific credentials; Scientific proof.

American Association of Petroleum Geologists

- **Categories:** Organizations and agencies; fossil fuels
- **Date:** Established 1917
- **Web address:** http://www.aapg.org

- **Mission**

The American Association of Petroleum Geologists (AAPG) is an international professional organization that supports research in the science of geology and in technologies used to locate underground reservoirs of oil, manage them, and extract their contents. Its approximately thirty thousand members from 116 countries include geologists, geophysicists, oil company executives, university professors, consultants, and students. Of the members, slightly more than half work to find oil reservoirs or develop existing reservoirs. Full membership requires a degree in geological sciences and three years' experience, but there are associate memberships for those lacking practical work experience and student memberships for those pursuing degrees in geology or a related field.

Geographically, the AAPG is divided into six regional sections within the United States and six international regions. It comprises four divisions with distinct missions. The Division of Environmental Geosciences seeks to keep members up to date on the relation of the petroleum industry to environmental problems through education, support of research on the effects of oil exploration, and the sharing of research with governmental agencies. The Division of Professional Affairs sets ethical standards, provides certifications, and helps in career planning in order to promote professionalism

American Association of Petroleum Geologists Policy Statement

The following policy statement expresses the AAPG's official attitude toward climate change.

Although the AAPG membership is divided on the degree of influence that anthropogenic CO_2 has on recent and potential global temperature increases, the AAPG believes that expansion of scientific climate research into the basic controls on climate is important. This research should be undertaken by appropriate federal agencies involved in climate research and their associated grant and contract programs.

among its members. The Division of Energy Minerals fosters research and disseminates information on energy minerals, unconventional hydrocarbons (such as gas hydrates and oil sands), geothermal energy, oil shale, tar sands, gas hydrates, energy economics, and remote sensing. The Division of Student Programs offers publications, lectures, and grants-in-aid for undergraduate and graduate students.

• **Significance for Climate Change**

Adopted in 2007, the AAPG policy statement posted on the association's Web site expresses doubt about the accuracy of climate simulation models produced on computers and calls for further basic research. Moreover, the AAPG argues that although reducing emissions from fossil fuel use is a worthy goal, the environmental gains must be weighed against the potential economic costs. Accordingly, it advocates using carbon sequestration technologies and energy conservation.

Roger Smith

See also: Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Geological Society of America; Oil industry.

American Astronomical Society

• **Category:** Organizations and agencies
• **Date:** Established 1899
• **Web address:** http://www.aas.org

• **Mission**

The American Astronomical Society (AAS) fosters research into climate change both on Earth and on other planets, as well as research into the role of the Sun in global warming. The AAS is the largest professional organization in North America for scientists who conduct research in astronomy and related sciences. Among its approximately sixty-five hundred members are astronomers, mathematicians, geologists, and engineers. Its mission is to promote the advancement of knowledge by awarding grants and prizes for research, publishing journals, arranging conferences, fostering debate and discussion on its Web site, posting news items, and issuing public policy statements on educational and political issues related to astronomy and planetary science.

The Council of the AAS governs the organization and considers recommendations from its thirty-eight committees to support research, award prizes, and set policy. The society comprises the Division for Planetary Science, Division on Dynamical Astronomy, High Energy Astrophysics Division, Historical Astronomy Division, and Solar Physics Division. It sponsors *The Astronomical Journal*, *The Astrophysical Journal*, *Bulletin of the AAS*, and *Icarus*, as well as departmental newsletters.

• **Significance for Climate Change**

Among AAS members are planetary scientists studying climate change on Earth and other planets in the solar system, and AAS publications present their findings. Of particular pertinence are investigations into how variations in the Sun's energy output affect planetary warming on Earth and other bodies, such as Venus and Saturn's moon Triton.

On June 2, 2004, the AAS Web site posted its endorsement of "Human Impacts on Climate," the policy statement of a sister organization, the American Geophysical Union (AGU). Acknowledging the closer involvement of the AGU in scientific subdisciplines directly addressing terrestrial climate change, the AAS endorsement notes that

> . . . the human impacts on the climate system include increasing concentrations of greenhouse gases in the atmosphere, which is significantly contributing to the warming of the global climate. The climate system is complex, however, making it difficult to predict detailed outcomes of human-induced change: there is as yet no definitive theory for translating greenhouse gas emissions into forecasts of regional weather, hydrology, or response of the biosphere.

Accordingly, the AAS calls for further peer-reviewed research. It especially cites the need for improved observations and computer modeling in order to provide governments with a solid basis for making decisions about how best to mitigate the harmful effects of climate change and to help communities adapt to such change.

Roger Smith

See also: American Geophysical Union; Planetary atmospheres and evolution; Sun.

American Chemical Society

- **Category:** Organizations and agencies
- **Date:** Established 1876
- **Web address:** http://www.acs.org

- **Mission**

The American Chemical Society (ACS) is the world's largest scientific society, with more than 160,000 members worldwide. Its members are professional chemists and engineers. It is a nonprofit organization, headquartered in Washington, D.C., with 33 technical divisions and 189 local sections. It publishes the weekly *Chemical and Engineering News*, the *Journal of the American Chemical Society*, and a number of other scientific journals. The ACS's *Strategic Plan: 2008 and Beyond* provides its mission statement: "to advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people." The society promotes interest in chemistry, as well as scientific research and education, and maintains a practical focus on solving problems and meeting challenges through chemistry. In addition to providing services for its members, the ACS sponsors scientific meetings and provides resources for educators.

- **Significance for Climate Change**

The ACS officially endorses the position that climate change is anthropogenic and attributable in part to increases in greenhouse gases (GHGs) and aerosol particles in Earth's atmosphere. It asserts that urgent action is required to respond to these conditions. Recommendations in the ACS position statement on global climate change include increased funding for research to better predict climate changes and their impact; GHG emission reductions; and increased investments in technologies that conserve energy and use nonfossil fuel.

The ACS has formed the Green Chemistry Institute to promote the concept and techniques of green, or environmentally friendly, chemistry. According to the Green Chemistry Institute,

> Green chemistry differs from previous approaches to many environmental issues. Rather than using regulatory restrictions, it unleashes the creativity and innovation of our scientists and engineers in designing and discovering the next generation of chemicals and materials so that they provide increased performance and increased value while meeting all goals to protect and enhance human health and the environment.

The institute hosts annual green chemistry and engineering conferences. As part of its chemistry education activities, ACS plans annual activities in celebration of Earth Day and has created a series of podcasts presenting the problems facing humanity in the twenty-first century and the potential role of chemistry in solving those problems.

Susan J. Karcher

See also: Chemical industry.

American Enterprise Institute

- **Category:** Organizations and agencies
- **Date:** Established 1943
- **Web address:** http://www.aei.org

- **Mission**

In the ongoing public debate over climate policy, regulatory proposals by governmental agencies and nongovernmental organizations (NGOs) are often challenged by policy analysts who value free markets, small government, economic growth, and individual rights. The American Enterprise Institute (AEI) is a public policy think tank associated with the latter values. A subset of AEI scholars regularly evaluate, criticize, and promote climate-related policies through in-house publication of books and policy articles, as well as external publications and appearances in mainstream media. The organization also holds conferences and roundtable discussions at which policy experts discuss diverse elements of climate-policy-related science. These conferences are advertised to decision makers, corporate leaders, AEI supporters, and subscribers, as well as national media outlets in Washington, D.C. Transcripts of AEI conferences are also posted to the organization's Web site, sometimes accompanied by streaming video excerpts.

Most broadly, AEI, like most think tanks, attempts to influence public opinion and government decision makers in order to favor the development of government policies that the institute supports. AEI's mission includes protecting and supporting democratic capitalism, limited government, private enterprise, individual liberty and responsibility. It also advocates for vigilant and effective defense and foreign policies, political accountability, and open debate. The institute's motto is "Competition of ideas is fundamental to a free society." AEI describes its target audience as "government officials and legislators, teachers and students, business executives, professionals, journalists, and all citizens interested in a serious understanding of government policy, the economy, and important social and political developments."

- **Significance for Climate Change**

The analysis of AEI researchers is widely cited in the mainstream media, where it influences opinion among the institute's core audience, the broader public, and policy makers seeking to attract the AEI customer base. While AEI does not adopt an institutional point of view on any given policy issue, AEI's analysts have expressed a diverse spectrum of opinion regarding the relationship of greenhouse gases (GHGs) to climate change and an equally broad spectrum regarding what ought to be done about the threat of anthropogenic climate change. Some AEI analysts have sought to disclaim a human influence on climate and resisted GHG mitigation efforts, while others have accepted an anthropogenic influence on climate, and still others have suggested policy options including emission trading, carbon taxation, expanded adaptation efforts, and geoengineering.

Kenneth P. Green

See also: Nongovernmental organizations; United States; U.S. energy policy.

American Geophysical Union

- **Category:** Organizations and agencies
- **Date:** Established 1919
- **Web address:** http://www.agu.org

- **Mission**

The American Geophysical Union (AGU) is a professional organization whose members conduct research in a wide variety of disciplines devoted to understanding Earth's composition, dynamics, and environment in space. The AGU has a membership of more than fifty thousand researchers, teachers, and students who study the Earth, its atmosphere and oceans, space, and other planets. It is divided into eleven sections, each for a scientific discipline: Atmospheric Sciences; Biogeosciences; Geodesy; Geomagnetism and Paleomagnetism; Hydrology; Ocean Sciences; Planetary Sciences; Seismology; Space Physics and Aeronomy; Tectonophysics; and Volcanology, Geochemistry, and Petrology. An elected council composed of six general officers and the president and president-elect of each section governs the AGU, authorizing programs, controlling finances, and approving policies.

The AGU's mission is to promote the scientific study of Earth and its surrounding space and to pass on discoveries to the public through research projects, professional meetings, the journal *Eos*, books (often available through its Web site), a weekly newsletter, and educational programs for nonscientists. Moreover, the AGU fosters cooperation among scientific organizations supporting geophysics and related fields. Three principles

> **"Human Impacts on Climate Change"**
>
> *The AGU's important evaluation of anthropogenic climate change reads, in part, as follows:*
>
> Warming greater than 2° Celsius above nineteenth century levels is projected to be disruptive, reducing global agricultural productivity, causing widespread loss of biodiversity, and—if sustained over centuries—melting much of the Greenland ice sheet with ensuing rise in sea level of several meters. If this 2° Celsius warming is to be avoided, then our net annual emissions of CO2 must be reduced by more than 50 percent within this century.

guide its mission: adherence to the scientific method, the free exchange of ideas, and accountability to the public.

- **Significance for Climate Change**

The AGU's policy statement, "Human Impacts on Climate Change," revised and reaffirmed in late 2007, unambiguously declares that Earth's climate is out of balance because of unnatural global warming caused by anthropogenic greenhouse gases and aerosols. Moreover, it warns of civilization-altering consequences that require concerted, dramatic action. The AGU emphasizes the uncertainty of the projections upon which its judgments are based. However, it also stresses that all projections, regardless of specifics, indicate that climate change will have serious consequences for life in the twenty-first century. The uncertainty, according to the union, rests only in the precise nature of those consequences.

The AGU statement goes on to emphasize that, unlike ozone depletion, climate change is the result of fundamental aspects of modern human society, so it cannot be mitigated easily. At base, climate change results from human energy use, which lies at the heart of virtually all aspects of modern civilization. To mitigate anthropogenic influences upon global warming, then, the AGU asserts that government, scientists, industry, and consumers will all need to cooperate in finding and adopting solutions.

Roger Smith

See also: American Astronomical Society; American Chemical Society; American Institute of Physics; Anthropogenic climate change; Climate change; Human behavior change.

American Institute of Physics

- **Category:** Organizations and agencies
- **Date:** Established 1931
- **Web address:** http://www.aip.org

- **Mission**

The membership of the American Institute of Physics (AIP) investigates basic properties of matter and energy, including those that underlie processes causing climate change. A nonprofit corporation, the AIP promotes research in physics and application of the knowledge acquired in the interests of human welfare. It provides professional services to its ten member societies: the Acoustical Society of America, the American Association of Physicists in Medicine, the American Association of Physics Teachers; the American Astronomical Society, the American Crystallographic Association, the American Geophysical Union, the American Physical Society, AVS (Science and Technology of Materials, Interfaces, and Processing; originally the American Vacuum Society), the Optical Society of America, and the Society of Rheology. A forty-two-member governing board, headed by an executive director, oversees the institute's services and financing. Among the membership are more than 125,000 scientists, engineers, and students.

The AIP helps its member societies and individual members by publishing more than twenty-five journals of scientific and engineering societies, magazines, and conference proceedings. It reports on employment and educational trends, encourages interaction between science and industry, and compiles scientific archives. The institute also mentors undergraduate physics programs and advocates for science policy to the public and the U.S. Congress.

- **Significance for Climate Change**

In 2004, the governing board of the AIP endorsed “Human Impacts on Climate Change,” the policy statement issued by its member society, the American Geophysical Union, in 2003. Additionally, its Web site offers “A Hyperlinked History of Climate Change Science.” In the introduction, Spencer R. Weart, director of the Center for History of Physics, concludes that twenty-first century computer modeling combined with data collected from many sources support the conclusion that climate change is likely to result from human emissions:

> Depending on what steps people took to restrict emissions, by the end of the century we could expect the planet’s average temperature to rise anywhere between about 1.4° and 6° Celsius.

The AIP saw some hope, however, in the fact that the media had begun to trust scientists who predicted further climate change based on the apparent validity of their past predictions.

Roger Smith

See also: American Chemical Society; American Geophysical Union; Anthropogenic climate change; Human behavior change.

American Meteorological Society

- **Category:** Organizations and agencies
- **Date:** Established 1919
- **Web address:** http://www.ametsoc.org

- **Mission**

The eleven thousand members of the American Meteorological Society (AMS) are scientists, students, and lay enthusiasts involved in the atmospheric, oceanic, and hydrologic sciences. The AMS supports them by producing and sharing information on these fields and through educational programs. Its elective council ensures that the society’s strategic goals are pursued through the activities of its six major divisions: the Commission of the Weather and Climate Enterprise, the Commission on Professional Affairs, the Education and Human Resources Commission, the Publications Commission, the Scientific and Technological Commission, and the Planning Commission.

The AMS publishes nine journals, hosts twelve annual conferences, and provides a Web site for news, policy statements, and professional development. It offers certifications for broadcast and consulting meteorologists, a career center, scholarships and grants for students, and awards for service and research in the pursuit of seven goals: advancing knowledge through publications and meetings, accelerating development of the application of the knowledge, promoting science-based decision making, educating the public, attracting new talent into its ranks, developing cooperation, and supporting national and international programs of benefit to society.

- **Significance for Climate Change**

The extensive policy review on climate change, “An Information Statement of the American Meteorological Society,” adopted in 2007, concludes that Earth is undergoing global warming to which human activity is a significant contributing factor. This warming, the statement continues, will continue beyond the next century and will affect animal life and ecosystems, as well as human civilization. The statement emphasizes that government policy must adopt the twin goals of reducing climate change and confronting the reality that some climate change will continue no matter what humans do, so plans will need to be made to enable society to adapt to that change: “Prudence dictates extreme care in managing our relationship with the only planet known to be capable of sustaining human life.”

Roger Smith

See also: Anthropogenic climate change; Climate models and modeling; Human behavior change.

American Physical Society

- **Category:** Organizations and agencies
- **Date:** Established 1899
- **Web address:** http://www.aps.org

• Mission

The world's second largest organization of physicists, the American Physical Society (APS) takes a firm stand relating to the belief that global warming is occurring and that human activities play a significant role in changing the atmosphere in ways that affect climate change. The APS was initially organized, in 1899, to advance and diffuse the knowledge of physics, and in its early years the main activity of the society was to hold scientific meetings. In 1913, the APS turned to publishing scientific journals as a major activity. Later, the group became active in public and governmental affairs, as well as in the affairs of the international physics community. The society also provides a number of educational programs and functions as a lobbying and advocacy agency, making official statements made on issues of critical importance to the nation.

Typical of advocacy statements adopted by the APS Council is a strong statement in 2007 that made clear the position of the APS on global warming and climate change:

> Emissions of greenhouse gases from human activities are changing the atmosphere in ways that affect the Earth's climate. . . . The evidence is incontrovertible: Global warming is occurring. If no mitigating actions are taken, significant disruptions in the Earth's physical and ecological systems, social systems, security and human health are likely to occur. We must reduce emissions of greenhouse gases beginning now.

The APS urged scientists to redouble their efforts to understand the relationship between human activity and climate change and to develop new technologies to mitigate anthropogenic warming.

• Significance for Climate Change

The APS engages in significant public advocacy. It prepares personalized letters and e-mails for citizens to send to legislators, provides contact information for various science coalitions, and holds grassroots meetings to educate the public as to government activities and procedures. APS presentations provide an overview of lobbying efforts and governmental actions. In addition to published statements and lobbying efforts made by individuals in the APS, over forty-six thousand members of the society work to educate the public about the gravity of the global warming phenomenon in the hope of changing behaviors that contribute to emission of greenhouse gases.

Victoria Price

See also: American Geophysical Union; American Institute of Physics.

Amphibians

- **Category:** Animals

• Definition

Amphibian species are distributed worldwide and include frogs, toads, salamanders, and newts. They are cold-blooded animals, or ectotherms, and their physiology is affected by their external environment. Amphibian populations face an extinction crisis, as they have experienced dramatic population decreases worldwide since the 1980's. An estimated one-third of amphibian species are currently in decline, with many amphibian species now either threatened or extinct.

In the late 1980's, scientists began to report mass mortalities of amphibians at an alarming rate, with causes not well understood. Although amphibian extinctions have occurred globally, declines have been particularly significant in the western United States, Central and South America, and Australia. Among the amphibian species that experienced dramatic population declines are the golden toad, *Bufo periglenes,* of Costa Rica and many harlequin frog species (*Atelopus*) that were once common in South America. These frog species are listed as critically endangered. These species lived in pristine areas, so their extinctions raised particular con-

A tiny Corroboree frog sits on a zookeeper's thumb. The Corroboree is among Australia's most endangered amphibians. (Mick Tsikas/Reuters/Landov)

cern, because they could not be linked to human activities.

A number of potential explanations for amphibian declines have been proposed, with many of the causes also affecting other organisms. The causes of amphibian declines are likely to be complex; many probably act synergistically. Some causes may include destruction of both terrestrial and aquatic habitats, introduced species, overexploitation, pollution, and pesticides. Many amphibian declines, however, have occurred in pristine habitats where such effects are unlikely. Therefore, although habitat loss is known to have affected amphibians for decades, recent research has focused on the effects of environmental contaminants, increased ultraviolet radiation, emerging diseases, and climate change.

Since the health of amphibian populations is thought to be an indicator of overall environmental health, reports of global amphibian declines have led to considerable public concern. The causes of amphibian declines might also threaten other species of animals and plants. One reason amphibians are thought to be indicator species for environmental health is their sensitivity to the environment. Amphibians' skin is extraordinarily thin, which makes them very sensitive to even small changes in temperature, humidity, and air or water quality. Their skin is also very permeable, which makes them very sensitive to toxins in both land and water environments.

• Significance for Climate Change

Climate change has probably contributed to the observed decline of many amphibian species worldwide. Although there is no simple answer to what is causing amphibian declines, many factors related to global warming are believed to play a role. Global warming is thought to initiate amphibian declines by triggering epidemics such as fungal diseases. Ozone layer depletion as a result of increased pollution leads to greater ultraviolet (UV) radiation exposure, which damages the delicate skin of amphibians, as well as their eyes, eggs, and immune systems.

Amphibian reproduction is affected by climate change: Changes in breeding behavior have been linked to increased temperatures due to global warming. UV radiation may also reduce hatching success and the rate of survival to metamorphosis. Global warming increases the metabolic rate of toads during hibernation and thus affects their body condition. Environmental temperature has a dramatic effect on amphibians' immune systems, so climate change may affect their defenses against invading pathogens. Tropical amphibian species, especially those in higher altitudes, are particularly susceptible to adverse effects related to global warming.

Although other pathogens play a role, chytrid fungi are believed to be responsible for many amphibian declines. About two-thirds of the 110 known harlequin frog species in Central and South America disappeared in the 1980's and 1990's; the cause was thought to be an infectious disease triggered by changes in environmental temperatures. These abundant frog deaths led to the discovery of a pathogenic fungus, *Batrachochytrium dendrobatidis*, which belongs to a family known as chytrids. By moderating temperature extremes that used to keep the growth of this fungus in check, global warming has arguably created ideal conditions to support its growth and reproduction. However, although many scientists support a connection between outbreaks of chytrid fungus, amphibian population declines, and global warming, this link is now controversial, with some questioning the role of temperature changes in fungal outbreaks.

The disease caused by chytrid fungi, chytridiomycosis, is fatal for otherwise healthy animals. Frogs with chytridiomycosis generally exhibit skin lesions that affect respiration across the skin, resulting in mortality. Since its discovery, the fungus has been linked to many amphibian extinctions. Amphibian declines due to chytrid fungus are most common at higher elevations in the tropics, and chytrid fungus is believed to be the cause of decline in three-quarters of frog species in Costa Rica and Panama and in species in the United States as well.

C. J. Walsh

• Further Reading

Cherry, Lynne, and Gary Braasch. *How We Know What We Know About Our Changing Climate: Scientists and Kids Explore Global Warming*. Nevada City, Nev.: Dawn, 2008. Written for teenagers and young adults; includes a chapter about the effects of changing climate on tropical rain forests.

Hofricher, Robert. *Amphibians: The World of Frogs, Toads, Salamanders, and Newts*. Toronto: Key Porter Books, 2000. Introductory textbook on the biology of amphibians, including many photographs. The last sections of the book discuss the effects of environmental degradation on amphibians.

Lannoo, Michael, ed. *Amphibian Declines: The Conservation Status of United States Species*. Berkeley: University of California Press, 2005. Includes a comprehensive description of amphibian status, including the life history of every known amphibian species in the United States. Also includes a chapter on the effects of global climate change on amphibian populations.

Linder, Greg, Sherry K. Krest, and D. W. Sparling. *Amphibian Decline: An Integrated Analysis of Multiple Stressor Effects*. Pensacola, Fla.: Society of Environmental Toxicology and Chemistry, 2003. Experts in the field address the role of various stressors, including global warming, in amphibian population declines.

Pounds, J. A., et al. "Widespread Amphibian Extinctions from Epidemic Disease Driven by Global Warming." *Nature* 439 (2006): 161-167. A much-cited scientific article that describes a link between chytrid fungus, global warming, and amphibian declines in Costa Rica.

See also: Endangered and threatened species; Extinctions and mass extinctions; Lichens.

Animal husbandry practices

• Categories: Animals; economics, industries, and products

• Definition

Humans raise livestock to meet individual and community nutritional and commercial demands for animal products. Livestock farmers range from individuals, who may raise a few animals to supply their families with protein sources or earn income in local markets, to commercial agriculturists who invest in industrial methods to manage numerous livestock simultaneously. Animal husbandry practices reflect diverse human cultures and types of livestock, from nomads in developing countries who tend herds of indigenous livestock that migrate to water and forage resources to farmers in developed countries who often rely on technology to mass-produce genetically standardized animals at centralized locations.

- **Significance for Climate Change**

Climate issues associated with animals worldwide caused the Food and Agriculture Organization (FAO) of the United Nations to assess livestock's environmental impact. In the early twenty-first century, several billion livestock, including bovines, goats, sheep, swine, and poultry, inhabited the Earth, and 30 percent of the planet's land was used for grazing and to grow livestock feed crops. An estimated 1.3 billion people participated in animal husbandry-related work. Annual meat production totaled 229 million metric tons and milk production was 580 million metric tons in 2001, with experts projecting that those amounts would double in fifty years to meet increasing food demands.

By spring, 2008, U.N. representatives determined that livestock produced 18 percent of the greenhouse gases (GHGs) associated with global warming, noting that those emissions exceeded the amounts produced collectively by land and air transportation vehicles. Media referred to the "carbon hoofprint" when discussing livestock's contribution to global warming. Animal husbandry was found to be responsible for 82 million metric tons of carbon dioxide (CO_2) emissions annually. In addition, each individual beef cow emitted approximately 80 kilograms of methane yearly and each dairy cow emitted 150 kilograms. The European Union (EU) suggested that farmers cull their herds to limit emissions. By 2008, New Zealand became the world's first nation to consider taxing farmers whose livestock emitted more GHGs than legislated allowances. The Pastoral Greenhouse Gas Research Consortium investigated scientific ways to manage livestock emissions.

Animal husbandry practices include clearing land for grazing livestock and planting grain crops to sustain them. Deforestation to establish ranches results in greater amounts of CO_2 reaching the atmosphere. Approximately 70 percent of Amazon rain forests have been cleared to maintain livestock, which often harm fields by stripping them of vegetation, causing exposed soil to become eroded or compacted. Subterranean storage of precipitation is disrupted, sometimes initiating desertification. Clearing land for livestock occasionally involves draining wetlands.

The loss of trees and vegetation due to farmers transforming forests into fields reduces albedo (the proportion of incident radiation reflected by Earth's surface): Bared ground absorbs rather than reflects sunlight and heat, intensifying global warming. Although Earth's Arctic ice is distant from most animal husbandry procedures (except for reindeer farming in northern latitudes), the conversion of ice to seawater due to decreasing albedo affects livestock globally. In some areas, extreme heat associated with lower albedo frequently dries up water resources used for animal husbandry. Elsewhere, rising water levels due to increased ice melting displaces livestock.

Excess CO_2 detrimentally affects indigenous plant growth, particularly that of native forages stifled by GHGs. Woody shrubs exotic to prairies thrive when exposed to CO_2. Weeds, some toxic to livestock, spread and often deprive soil of moisture. Climate change can motivate livestock to seek new food and water sources, and these migrating livestock transport seeds from plants and parasites to new locations when they travel, carrying them in fur, hooves, and intestinal tracts, further altering ecosystems.

Veterinary professionals report cases of livestock diseases previously unknown in specific geographical areas, attributing their spread to changed climates. In 2006, bluetongue, an insect-transmitted viral disease usually confined to southern France, was detected in several thousand northern European livestock, necessitating quarantines. Warm temperatures enable insect populations, including tsetse flies and mosquitoes, to extend into locations where usually cooler climates would have inhibited them. When frosts are infrequent, lungworm larvae survive in grasses, causing respiratory disease in livestock.

An FAO report has estimated that one livestock breed becomes extinct each month during the early twenty-first century. Industrial animal husbandry practices limit production to selected western breeds, which replace many native livestock in developing countries. By 2002, only one-fourth of sows in Vietnam were indigenous breeds. The FAO promoted preserving genetic material from indigenous livestock breeds that possessed such resilient traits as heat tolerance and drought hardiness, which might be crucial to future animal husbandry as global warming alters climatic conditions.

In November, 2006, a U.N. climate conference at Nairobi, Kenya, discussed how global warming threatened nomadic livestock herders in Africa. Early twenty-first century droughts caused an estimated 500,000 nomads to cease raising livestock, as deserts began overtaking fields, disrupting the normal four seasons that herders need to raise livestock. Violence resulted, as herders battled for water and pasture resources limited by climate changes.

Elizabeth D. Schafer

• **Further Reading**

Morgan, Jack A., et al. "Carbon Dioxide Enrichment Alters Plant Community Structure and Accelerates Shrub Growth in the Shortgrass Steppe." *Proceedings of the National Academy of Sciences* 104, no. 37 (September 11, 2007): 14,724-14,729. Experimental results indicate GHGs cause displacement of indigenous livestock forage.

Seo, Sungno Niggol, and Robert Mendelsohn. "Climate Change Impacts on Animal Husbandry in Africa: A Ricardian Analysis." World Bank Policy Research Working Paper 4261. Washington, D.C.: World Bank, 2007. Economic study examining the influences of temperature, precipitation, and animals' heat tolerance upon farmers' decisions.

Steinfeld, Henning, et al. *Livestock's Long Shadow: Environmental Issues and Options*. Rome: Food and Agriculture Organization of the United Nations, 2006. Comprehensive report discussing animal husbandry and global warming; suggests ways to limit damage and restore resources. Extensive bibliography.

Watson, Paul. "New Zealand Aims for Greener Pastures: Officials Ruminate on How to Curb Methane from the Nation's Livestock, a Culprit in Global Warming." *Los Angeles Times*, June 8, 2008, p. A-6. Describes governmental efforts to reduce animal husbandry emissions, farmers' reactions, and possible scientific solutions.

See also: Agriculture and agricultural land; Amazon deforestation; Carbon dioxide; Carbon footprint; Deforestation; Greenhouse gases; Methane.

Annex B of the Kyoto Protocol

• **Category:** Laws, treaties, and protocols
• **Date:** Adopted December 11, 1997; entered into force February 16, 2005; amended November, 2006

The Kyoto Protocol's second annex allowed countries to collaborate on emissions-reducing projects and to trade and purchase emissions credits. This system gave wealthier nations incentives to reduce emissions and encouraged them to work with developing nations to reduce theirs.

• **Participating nations:** *1997:* Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States; *2006:* Belarus

• **Background**

The Kyoto Protocol to the Framework Convention on Climate Change, whose goal is to reduce the emissions of greenhouse gases (GHGs) that lead to global warming, was adopted in December, 1997, after nearly thirty months of international negotiations. The text of the protocol included twenty-eight articles; Annex A, listing the six GHGs covered by the treaty and sources of gas emissions; and Annex B, listing countries participating in the emissions credit trading agreement.

Several of the specific requirements of Annex B were crafted by and adopted under pressure from the United States. The emissions credit trading system closely follows the system adopted in the United States under the 1970 Clean Air Act Extension, and emissions from American military marine and aviation operations are not subject to regulation. The United States, however, has not ratified the Kyoto Protocol.

• Summary of Provisions

The Kyoto Protocol regulated the emissions of six specific GHGs. Parties to Annex B agreed to reduce their emissions of these gases between 2008 and 2012. Countries agreed to different reduction amounts, based on factors including the types and quantities of energy they produced and their relative levels of pollution. European Union countries, for example, were required to reduce their emissions to 8 percent less than 1990 levels, and the United States had a reduction target of 7 percent below those levels. Iceland agreed to increase its emissions by no more than 10 percent over 1990 levels. While each country had a different target, the target for the Annex B nations as a whole was 5 percent below 1990 emission levels.

Annex B created a system under which countries that could not immediately meet their emissions goals could purchase permits or credits from other Annex B nations that did not need them. For example, if a country exceeded its target methane emissions, it could purchase methane emission permits from a country that had exceeded its reduction goal; the total amount of methane emitted globally would remain the same. Further, a country could earn credits by financing or otherwise supporting a project in another country. Through another provision called the clean development mechanism, an Annex B party could earn credits by helping develop clean energy projects in developing nations not party to Annex B. These provisions created flexibility, as each country could determine whether it was more cost effective to meet its targets through reducing emissions or through purchasing credits.

Countries participating in Annex B must monitor and report their GHG emissions or be banned from project-based credit trading. If it is learned after the fact that a country has failed to comply with these terms, that country will be stripped of any earned credits.

• Significance for Climate Change

Scientists and economists began to question the potential effectiveness of Annex B immediately after its adoption. They wondered, for example, whether the United States would ever be able to meet its target without tremendous economic cost and whether there would be enough credits available for purchase to make the emissions credit trading system work. In fact, the United States did not ratify the Kyoto Protocol and is not participating in international emissions credit trading, thereby reducing any effectiveness the agreement might have had. No country has passed national legislation that requires it to comply with the terms of Annex B.

Scientists including Tom M. L. Wigley, a senior scientist with the National Center for Atmospheric Research, and Gyeong Lyeob Cho of the Korea Energy Economic Institute have generated computer models to predict how effective the provisions of Annex B will be in reducing global warming. Exam-

Annex B Nations

The following table lists the parties to Annex B of the Kyoto Protocol and the emissions target of each. The emissions target refers to the maximum annual average of greenhouse gas (GHG) emissions each nation has committed to producing during the period between 2008 and 2012.

Parties	*Annex B Commitment*[a]
European Union, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland	–8
United States[b]	–7
Canada, Hungary, Japan, Poland	–6
Croatia	–5
New Zealand, Russian Federation, Ukraine	0
Norway	+1
Australia	+8
Iceland	+10

a. Percentage by which 2008-2012 average emissions must be below, or may be above, the Party's 1990 baseline emissions.

b. The United States has not ratified the Kyoto Protocol.

ining scenarios under which the Annex B countries continue to reduce their emissions after 2012, when Annex B expires, they have concluded that small increases in reductions after 2012 will have minimal impact on overall warming. Much greater reductions than those called for under Annex B will be necessary to affect climate change, according to these models.

Cynthia A. Bily

• Further Reading

Douma, Wybe, and L. Massai. *The Kyoto Protocol and Beyond: Legal and Policy Challenges of Climate Change*. West Nyack, N.Y.: Cambridge University Press, 2007. Collects presentations from two international conferences; looks at the "flexible mechanisms" provisions of the Kyoto Protocol and how these provisions should be implemented and adapted after 2012.

McKibbin, Warwick J., and Peter J. Wilcoxen. *Climate Change Policy After Kyoto: A Blueprint for a Realistic Approach*. Washington, D.C.: Brookings Institution, 2002. The authors, both economists, argue that the international negotiated approach of the Kyoto Protocol is unrealistic and will not reduce carbon emissions.

Wigley, Tom M. L. "The Climate Change Commitment." *Science* 307 (2005): 1766-1769. Argues that anthropogenic global warming is a reality and that stopping further warming will require reductions of GHGs well beyond the levels required under existing agreements.

See also: Clean Air Acts, U.S.; Emissions standards; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. energy policy.

Antarctic Treaty

• Categories: Laws, treaties, and protocols; Arctic and Antarctic

• Date: Opened for signature December 1, 1959; entered into force June 23, 1961

The Antarctic Treaty depoliticized Antarctica and created free access for research scientists, protecting the continent and leading to research that improved understanding of climate change.

• Participating nations: *1959:* Argentina, Australia, Belgium, Chile, the French Republic, Japan, New Zealand, Norway, the Union of South Africa, Soviet Union (now Russia), United Kingdom, United States; *2000:* Brazil, Bulgaria, China, Ecuador, Finland, Germany, India, Italy, Netherlands, Peru, Poland, South Korea, Spain, Sweden, Ukraine, Uruguay; *Observing nations:* Austria, Belarus, Canada, Colombia, Cuba, Czech Republic, Denmark, Estonia, Greece, Guatemala, Hungary, North Korea, Papua New Guinea, Romania, Slovak Republic, Switzerland, Turkey, Venezuela

• Background

Antarctica, the land and ice that surround the South Pole, is the only continent with no indigenous human population. Exceeding 12 million square kilometers, it is nearly 1.5 times larger than the continental United States. An ice layer averaging more than 1.6 kilometers in thickness covers approximately 95 percent of the continent's land area. Although few terrestrial species are found on the continent, the surrounding waters are rich in marine life, supporting large populations of marine mammals, birds, fish, and smaller creatures, some found nowhere else on Earth. Antarctica and its surrounding waters play a key but not yet fully understood role in the planet's weather and climate cycles.

In the early twentieth century, seven nations asserted territorial claims on Antarctica; these claims persisted unresolved for decades. International scientific cooperation among twelve countries during the 1957-1958 International Geophysical Year (IGY) led to the establishment of sixty research stations on the continent. As the IGY drew to a close, the scientific community argued that Antarctica should remain open for continuing scientific investigation, unfettered by territorial rivalries. This led to the negotiation of the Antarctic Treaty, which entered into force in 1961.

- **Summary of Provisions**

The signatory nations have agreed that "it is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord." Initially, twelve nations signed and became consultative parties; sixteen additional nations were later granted consultative party status, and eighteen more acceded to the treaty as participant-observers only.

The treaty provides that the continent of Antarctica will include all land and ice shelves south of 60° 00′ south. It prohibits military activity on the continent and promotes scientific cooperation among the parties. Antarctica is to be open to scientific investigation and cooperation, as well as free exchange of information and personnel. Signatory nations agreed to freeze existing territorial claims and make no new ones. Nuclear explosions and disposal of radioactive wastes are prohibited. Treaty-state observers are to have free access, including aerial observation, to any area and may inspect all stations, installations, and equipment. Members are to discourage activities by any country in Antarctica that are contrary to the treaty, and disputes will be settled peacefully among the parties or by the Inter-

The Antarctic Treaty

Articles I to III and V of the Antarctic Treaty lay out the major goals and objectives of the agreement and the positive obligations of its signatories.

Article I

1. Antarctica shall be used for peaceful purposes only. There shall be prohibited, inter alia, any measure of a military nature, such as the establishment of military bases and fortifications, the carrying out of military manoeuvres, as well as the testing of any type of weapon.

2. The present Treaty shall not prevent the use of military personnel or equipment for scientific research or for any other peaceful purpose.

Article II

Freedom of scientific investigation in Antarctica and cooperation toward that end, as applied during the International Geophysical Year, shall continue, subject to the provisions of the present Treaty.

Article III

1. In order to promote international cooperation in scientific investigation in Antarctica, as provided for in Article II of the present Treaty, the Contracting Parties agree that, to the greatest extent feasible and practicable:

a. information regarding plans for scientific programs in Antarctica shall be exchanged to permit maximum economy of and efficiency of operations;

b. scientific personnel shall be exchanged in Antarctica between expeditions and stations;

c. scientific observations and results from Antarctica shall be exchanged and made freely available.

2. In implementing this Article, every encouragement shall be given to the establishment of cooperative working relations with those Specialized Agencies of the United Nations and other technical organizations having a scientific or technical interest in Antarctica. . . .

Article V

1. Any nuclear explosions in Antarctica and the disposal there of radioactive waste material shall be prohibited.

2. In the event of the conclusion of international agreements concerning the use of nuclear energy, including nuclear explosions and the disposal of radioactive waste material, to which all of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX are parties, the rules established under such agreements shall apply in Antarctica.

national Court of Justice. Finally, provisions were made to amend the treaty, leading to subsequent agreements and treaties.

- **Significance for Climate Change**

The impact of this agreement on issues of global warming and climate change has been twofold: First, Article 7 of the treaty made possible free access to the continent by climatologists, atmospheric scientists, biologists, geologists, oceanographers, and other researchers from around the world, and their investigations have revealed much about the impact of rising global temperatures on Antarctic ice shelves, sea-level change, endangered or threatened species, and other changes relating to climate.

Second, consultative meetings, held every two years until 1993 and annually thereafer, have resulted in additional agreements addressing environmental issues, such as species loss and tourism, as well as economic issues. For example, the 1982 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which addresses fishery management, used ecosystem criteria, rather than political boundaries, to define the applicable territory. The Antarctic Treaty Consultative Meeting (ATCM) is now held annually. During each ATCM, there is also a meeting of the Committee of Environmental Protection (CEP). The Scientific Committee on Antarctic Research (SCAR) is an observer at ATCMs and CEPs and provides independent scientific advice as requested in a variety of fields, particularly on environmental and conservation matters.

In 1991, the historic Antarctic Environmental Protocol was adopted. It banned mineral and oil exploration for a minimum of fifty years. Annexes to the protocol contain legally binding provisions regarding environmental assessments, protection of indigenous plants and animals, waste disposal, marine pollution, and designation of protected areas. The protocol entered into force in January, 1998, after ratification by all consultative parties.

Phillip Greenberg, updated by Christina J. Moose

- **Further Reading**

Bastmeijer, Kees. *The Antarctic Environmental Protocol and Its Domestic Legal Implementation.* New York: Kluwer Law International, 2003. Collection of essays providing an overview of the Antarctic Treaty System, including implementation and enforcement. Illustrated, bibliographic references, index.

Joyner, Christopher C. *Governing the Frozen Commons: The Antarctic Regime and Environmental Protection.* Columbia: University of South Carolina Press, 1998. Addresses governance structures, regime dynamics, resource conservation and management, environmental protection and preservation, and science and tourism. Illustrations, maps, references, index.

Stokke, Olav Schram, and Davor Vidas, eds. *Governing the Antarctic: The Effectiveness and Legitimacy of the Antarctic Treaty System.* New York: Cambridge University Press, 1997. Essays contributed by political scientists and international lawyers consider the Antarctic Treaty System's impact on the environment, tourism, fisheries, and mineral activities.

Triggs, Gillian, and Anna Riddell, eds. *Antarctica: Legal and Environmental Challenges for the Future.* London: British Institute of International and Comparative Law, 2007. Papers presented at a conference organized by the British Institute of International and Comparative Law and the Foreign and Commonwealth Office in June, 2006. Bibliographical references.

Watts, Arthur. *International Law and the Antarctic Treaty System.* New York: Cambridge University Press, 1993. Surveys the legal framework for Antarctic activities by examining the 1959 treaty and subsequent additions.

See also: Antarctica: threats and responses; Ice shelves; International agreements and cooperation; International waters; Ocean life; Penguins.

Antarctica: threats and responses

- **Category:** Arctic and Antarctic

Antarctica contains 90 percent of the world's ice and 75 percent of its freshwater. If a rise in the planet's temperature were to cause this store of ice to melt completely, it *would result in the world's sea levels rising by approximately 60 meters.*

• Key concepts

Antarctic peninsula: a peninsula stretching northward toward South America that contains about 10 percent of the ice of Antarctica

East Antarctic ice sheet: ice sheet located east of the Transantarctic Mountains that stores over 60 percent of the world's total freshwater

glacier: a mass of ice that flows downhill, usually within the confines of a former stream valley

ice sheet: a mass of ice covering a large area of land

ice shelf: a platform of freshwater ice floating over the ocean

mass balance: the difference between the accumulation of snow and the ablation of ice on a given glacial formation

sea ice: frozen ocean water

West Antarctic ice sheet: the smallest ice sheet in Antarctica, located west of the Transantarctic Mountains

• Background

Antarctica, located around the South Pole, is the world's fifth largest continent, with a surface area of 12.4 million square kilometers. Approximately 5,500 kilometers wide at its broadest point, it is surrounded by the southern portions of the Atlantic, Pacific, and Indian Oceans. This immense landmass is covered with an ice sheet larger than the continent itself. At its maximum winter extent, during the month of July, the ice sheet measures about 14 million square kilometers and contains 30 million cubic kilometers of ice.

• The Antarctic Ice Sheet: Unevenly Divided

More than 98 percent of Antarctica is covered with ice of an average thickness of about 2,100 meters. Most of the 2 percent of the continent not covered by ice is in the Antarctic Peninsula. The Antarctic ice sheet reaches a thickness of almost 5,000 meters at its highest point. From a geologic standpoint, Antarctica is made up of two structural provinces: East Antarctica and West Antarctica. East Antarctica is a stable shield separated from the much younger Mesozoic and Cenozoic belt of West Antarctica. The contact zone between these two provinces is the Transantarctic Mountains and the depression separating the Ross Sea and the Weddell Sea.

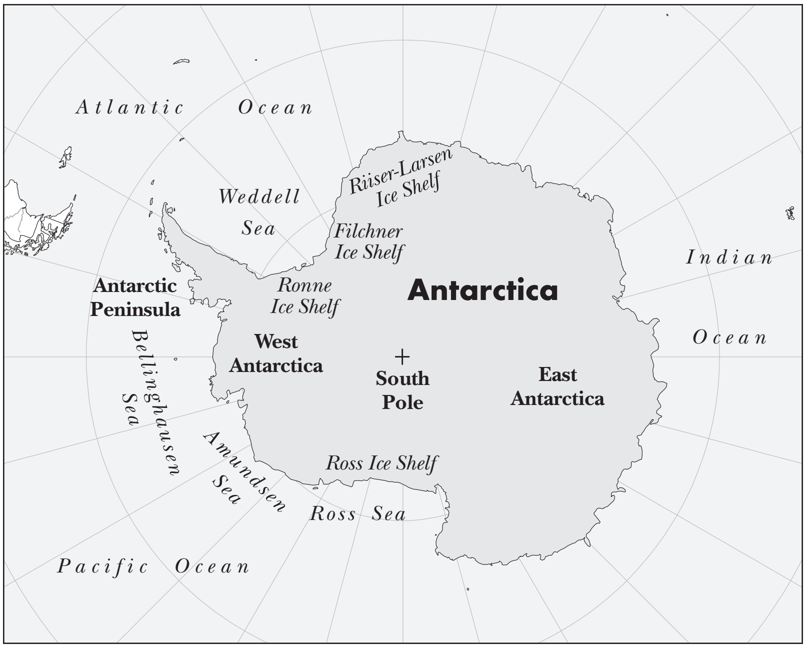
The Transantarctic Mountains divide the ice-covered continent into two ice sheets, the largest masses of ice known on Earth. The East Antarctic ice sheet, which is mostly situated in the Eastern Hemisphere, comprises 90 percent of the Antarctic ice. It is surrounded by the southern Atlantic Ocean, the Indian Ocean, and the Ross Sea. The South Pole is located in the East Antarctic ice sheet. The East Antarctic continental landmass on which it rests is close to sea level. Besides its ice sheets, Antarctica has many ice streams, glaciers, and ice shelves. While the East Antarctic ice sheet is dome-shaped, the West Antarctic ice sheet is more elongated along the mountains in the center of the peninsula.

As its name implies, the West Antarctic ice sheet is located in the Western Hemisphere. The northernmost part of the West Antarctic ice sheet protrudes in a peninsula that ends beyond the Antarctic Circle, south of South America. The backbone of the peninsula is composed of high mountains, an extension of the Andes Mountain Range, reaching about 2,800 meters. The northernmost latitude of the peninsula is 63°13′ south. The largest part of the West Antarctic ice sheet along the Amundsen Sea flows into the Ross Ice Shelf, a platform of floating ice on which the American research station McMurdo is located.

The peninsula glaciers drain into the Weddell and Bellingshausen seas and the Ronne and Filchner ice shelves. Unlike the East Antarctic ice sheet, this ice sheet sits on a continental platform that in some places is 2,500 meters below sea level. It is therefore more influenced by changes in ocean temperatures than is the East Antarctic ice sheet. The West Antarctic ice sheet experiences warmer temperatures than the East Antarctic ice sheet, both because it extends at lower latitude and because it has a lower average elevation.

• Measuring Temperature Change in Antarctica

Because of its high latitude and high elevation, Antarctica is the coldest continent on Earth. The ice that covers Antarctica results from the transforma-



tion of snow into ice. The amount of precipitation that Antarctica experiences is not uniform over the entire continent; the coasts, with lower elevation and higher temperatures, record about six times more annual snow accumulation than does the much higher and colder interior, which receives less than 3 centimeters of water-equivalent precipitation annually. The lowest temperature ever recorded on Earth (−89.6° Celsius) occurred at Vostok, a Russian research station, where only 166 millimeters of precipitation is received on average per year.

As Antarctic snow layers are progressively transformed into ice, they preserve evidence of the temperature at the time the snow fell in the form of isotope ratios within the ice. As a result, ice cores may be drilled from the Antarctic ice and examined to obtain a chronology of Antarctic temperatures. Antarctic weather stations, moreover, have been recording temperature and measuring precipitation for about 150 years, albeit not in a continuous manner. During and after the International Geophysical Year (1957-1958), weather stations were systematically installed at the forty-eight bases created in Antarctica by twelve countries. One of the most challenging tasks that these stations have faced has been the physical maintenance of the devices measuring such a harsh environment. Anemometers, which measure wind speed, are particularly vulnerable to the ferocious katabatic winds that sweep the continent, sublimating (reducing through evaporation) the surface ice as well as damaging the devices that measure them.

• Effects of Global Warming in Antarctica

Antarctica plays an important role in assessing climatic changes. Its ice reveals the variation of temperature of the continent over 800,000 years. It is also the perfect laboratory for studying the effects of human activities on Earth's atmosphere. Considered hostile to humans and unexplored until the beginning of the twentieth century, Antarctica came into the spotlight when the ozone hole over it was discovered and when the world's longest ice core was retrieved at Vostok. The ozone hole threatens the planet by allowing short-wavelength ultraviolet radiation to penetrate the lower atmosphere.

Scientists are concerned over the potentially calamitous effect of the melting of Antarctic ice. In 2006, for example, Eric Rignot, a French glaciologist working at the University of California, computed that Antarctica had lost 178 billion metric tons of ice, mostly from the Antarctic Peninsula. This would result in a rise in sea level of about 0.5 millimeter. Though the amount is relatively small, the trend it indicated was troubling; the loss had increased from the 102 billion metric tons recorded in 1996. From 1996 to 2006, some glaciers in the west began moving more rapidly toward the sea and thus produced more icebergs, as their terminuses have collapsed into the sea.

• Measuring Ice Losses

To understand and compute the mass balance of the ice in Antarctica, one must determine whether the continent loses or gains mass. Antarctica gains

An iceberg is calved from the Antarctic ice sheet. (Reuters/Landov)

mass when snow falls. The entire continent, which is about 1.5 times the size of the United States, contains only about one hundred weather stations, so it is not easy to estimate with a great degree of certainty how much snow accumulates on it. The error margin is likely to be high. Melting is rare in Antarctica, because the temperature tends to remain below the freezing point year-round. In 2008, Rignot estimated that 99 percent of the ice lost in Antarctica forms icebergs. However, the total picture of ice loss is not completely uniform; while Antarctica is losing ice at a greater rate and the area covered by sea ice in the Arctic has steadily decreased, sea ice in Antarctica has slightly increased, particularly along the East Antarctic ice sheet's coast.

- **Context**

The Intergovernmental Panel on Climate Change, which was awarded the 2007 Nobel Peace Prize for its intensive research on the projected effects of climate change, has stated that the mass balance of the Antarctic ice sheet that could contribute to sea level was 0.21 ±0.35 millimeter per year. From the computation above, there is a possibility that the Antarctic ice sheet could be responsible for a decrease of sea level by 0.14 millimeter per year.

Scientists agree that the northern part of the West Antarctic ice sheet has been melting, but there have been conflicting assessments of the behavior of the East Antarctic ice sheet. Measurements taken by the weather stations in the interior of the East Antarctic ice sheet show a slight decrease in temperature and an increase in precipitation. Other temperature assessments have been performed using satellite information based on the amount of infrared light reflected by the snow covering the continent. These show a slight increase in temperature in the coastal margins of the continent and an increase in temperature on the West Antarctic ice sheet. In the January 22, 2009, issue of *Nature*, Eric Steig, a geochemist and glaciologist at the University of Washington, reported that his study of surface temperatures collected from 1957 until 2007, combined with satellite information, indicates that, even though some portions of the continent have been cooling for a long time, Antarctica as a whole has warmed by 0.5° Celsius.

Knowledge of the processes by which the great ice masses of Antarctica grow and shrink is not yet perfect. Improving that knowledge will be of increasing importance, and understanding the climatological mechanisms at work on the continent will be crucial in assessing the impact of human activity on the health and stability of the Earth.

Denyse Lemaire and David Kasserman

• **Further Reading**

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Provides ice-core research information and contextualizes the work of geoscientists in relation to the cryosphere. Concise and clear, with superb artwork and photographs.

Copeland, Sebastian. *The Global Warning.* San Rafael, Calif.: Earth Aware Editions, 2007. This abundantly illustrated book about Antarctica tends to focus on the potential calamitous effects of global climate change using clear and simple language.

McGonigal, David. *Antarctica: Secrets of the Southern Continent.* Richmond Hill, Ont.: Firefly Books, 2008. Describes the discoveries of the International Polar Year, 2007-2008, in various fields, including geology, geography, and climatology. Discusses potential effects of global warming.

Trewby, Mary. *Antarctica: An Encyclopedia from Abbott Ice Shelf to Zooplankton.* Toronto: Firefly Books, 2002. General encyclopedia of Antarctica that explains all major features of the continent.

Turney, Chris. *Ice, Mud, and Blood: Lessons from Climates Past.* New York: Macmillan, 2008. Examines various discoveries derived from ice cores and how these discoveries led to a better understanding of paleoclimates.

See also: Antarctic Treaty; Arctic; Cryosphere; Glaciers; Greenland ice cap; Ice cores; Ice shelves; Mass balance; Sea ice.

Anthropogenic climate change

• **Categories:** Economics, industries, and products; environmentalism, conservation, and ecosystems; energy

Since the Industrial Revolution, two types of human activity have contributed significantly to changes in Earth's climate: modifications of the planet's surface and the invention and deployment of new energy technologies.

• **Key concepts**

aerosols: tiny particles suspended in Earth's atmosphere

albedo: the fraction of incident light reflected from a body such as Earth

anthropogenic: deriving from human sources or activities

fossil fuels: energy sources such as coal, oil, and natural gas that were formed by the chemical alteration of plant and animal matter under geologic pressure over long periods of time

global dimming: a reduction in the amount of sunlight reaching the surface of the Earth

greenhouse gases (GHGs): atmospheric gases that trap heat within a planetary system rather than allowing it to escape into space

urban heat island: a spot on Earth's surface that is significantly warmer than the surrounding area as a result of human alterations to the landscape

• **Background**

Large-scale human impact on the Earth extends back many centuries. However, at the beginning of the Industrial Revolution, in the mid-eighteenth century, the pace of human effects on the natural environment increased. The invention of power sources such as the steam engine, the internal combustion engine, and systems for delivering electric power sped anthropogenic environmental alterations in three ways. First, these technologies made it easier to modify the landscape; second, they created a vast demand for energy to fuel them; and finally, emissions from steam and internal combustion engines altered the composition of the atmosphere.

• Human Capacity to Affect Climate Change

By far the largest source of energy available to Earth is the Sun. Solar energy is the ultimate source of most other energy on the Earth's surface, including wind, hydroelectric, and biomass energy. After solar energy, the most important energy source in the Earth is geothermal energy, generated mostly by the decay of radioactive elements within the Earth. Tidal energy is also generated from interactions between the Earth, Moon, and Sun. The amount of solar energy available on Earth is about twenty-seven hundred times the amount of energy provided by geothermal heat and twenty-nine thousand times the amount of tidal energy.

Humans can affect climate by modifying the Earth's ability to absorb or reflect heat from the Sun and by modifying the atmosphere's ability to retain heat. Compared to those effects, the direct production of heat by human activities is insignificant. The annual supply of solar energy is more than eight thousand times the total amount of human energy use. In other words, human energy use in one year is equal to roughly one hour of global sunlight. By comparison, the total energy in the world's nuclear arsenals is about one-ten thousandth of the annual input from the Sun, or less than an hour's worth of sunlight. A large-scale nuclear war would inject smoke and dust into the atmosphere that would have a far greater effect on climate than would the heat given off by the nuclear explosions themselves. During the 1991 Persian Gulf War, the smoke emitted from burning oil wells in Kuwait had a strong cooling effect on areas under the smoke layer, but the heat from the oil fires had negligible effects on local or regional weather.

• How Human Changes to Earth's Surface Affect Climate

When humans modify the landscape, or surface, of Earth, they trigger climate change in a number of ways. First, by replacing forest with cleared land for use as farmland or pasture, or simply by felling timber for wood or fuel, they increase the albedo of Earth's surface: More sunlight is reflected back into space and less is absorbed and retained by the Earth. Old forests, especially conifer forests, are generally dark, whereas younger growth or cleared land is much lighter. Generally, making the surface lighter reflects more solar energy back into space and contributes to climatic cooling, and making the surface darker contributes to warming.

Many human changes to the landscape affect local climate. One of the most familiar examples is the urban-heat-island effect. Cities impede the flow of air, trapping heat, and they also contain large areas of materials such as asphalt and concrete that absorb heat. As a result, cities tend to be significantly warmer than nearby countryside. Other effects associated with urban heat islands include increased rainfall and stalling of intense rainstorms.

Among the most extreme climatic effects associated with human changes to Earth's surface are those due to the drying of the Aral Sea in central Asia. Since 1960, diversion of water for agriculture has reduced the area of the Aral Sea (actually a vast lake) by more than 80 percent. The original size of the Aral Sea was about 68,000 square kilometers, making it the fourth largest lake in the world—large enough to have significant moderating effects on the regional climate. These effects have almost entirely disappeared with the drying of the lake, and the climate has become more continental, with hotter summers, colder winters, and much less rainfall. Similarly, increased drought has been linked to the vast Three Gorges Dam hydroelectric project in China, which, according to Wang Hongqi, a

Global Anthropogenic GHG Emissions, 2004

Gas	*Percent of Global Emissions*
Carbon dioxide (burning fossil fuels)	57
Carbon dioxide (deforestation and biomass decay)	17
Methane	14
Nitrous oxide	8
Carbon dioxide (other sources)	3
F-gases	1
Total	100

Data from Intergovernmental Panel on Climate Change.

Beijing-based atmospheric physicist, "has artificially altered the natural terrain, elongated the vent channel, and disturbed water vapor circulation, resulting in an imbalance of temperature" and leading to drought.

- **Indirect Human Modifications of the Atmosphere**

Human changes to the landscape also affect the atmosphere. Human activities may create dust and smoke, for example, which can reflect sunlight back into space or block sunlight from reaching Earth's surface. Such activities thus increase Earth's albedo and cool the planet, but they can also prevent radiation from being reflected back into space from the surface and thus trap heat, warming the planet. For example, studies of condensation trails, or contrails, of aircraft have shown that they reflect sunlight back to space but also prevent heat from the surface from escaping, so that their overall effect is to warm the Earth. Tiny particles, or aerosols, can also serve as nuclei for the condensation of water droplets and affect fog, cloud cover, or precipitation.

The degree to which human dust and smoke alter visibility is remarkable. In preindustrial times, it was normal in most places for visibility to exceed 100 kilometers. The Great Smoky Mountains were so named precisely because the persistent haze in the valleys, due to natural emissions by the forests, was unusual. Persistent haze unrelated to local weather was so unusual in preindustrial times that it was recorded by chroniclers and has been used by geologists to pinpoint the dates of large volcanic eruptions in remote areas of the world. Visibility in heavily populated contemporary industrial regions is often only a few kilometers, and even remote national parks in the western United States are threatened with diminished visibility. Some studies have suggested that global dimming, the reduction of sunlight reaching the surface of the Earth by dust, haze, and smoke, may have masked the effects of global warming.

Human changes to the landscape often release greenhouse gases (GHGs). These changes generally result in the destruction of biomass, either by burning or by decay, thereby adding carbon dioxide (CO_2), one of the six major GHGs, to the atmosphere. Drainage of wetlands for agriculture can also result in the decomposition of organic material and also adds CO_2 to the atmosphere.

Human activities release other GHGs, particularly methane. Modification of the land can release methane trapped in the soil. Agriculture increases the amount of methane in the atmosphere in several ways. Livestock produce large amounts of methane in their digestive tracts, so increased numbers of cattle lead to increased methane emissions. Clearing of forest lands for agriculture reduces the ability of soils to absorb and oxidize methane. Certain types of agriculture, notably rice production, create oxygen-poor conditions for the decay of organic materials and thus emit methane. Finally, burial of waste rather than incineration results in methane emission.

According to a controversial theory by William Ruddiman, if it were not for human activities, the Earth would already have passed the peak of the present interglacial period and would be on the way to the start of the next glacial advance. Ruddiman argues that, while clearing forests for agriculture increased the CO_2 content of the atmosphere, increased methane production—especially that due to rice cultivation—is the more important climatic change agent.

- **Direct Human Changes to the Atmosphere**

Beginning with the Industrial Revolution, human activities began modifying the composition of the atmosphere directly on a large scale. The burning of fuels—first wood and then fossil fuels—released increasing amounts of smoke and gases directly into the atmosphere. Among the most important emissions were CO_2, nitrogen oxides, sulfur dioxide, and ozone-depleting chemicals.

CO_2 is the most important anthropogenic GHG contributing to the enhanced greenhouse effect. The latter effect supplements Earth's already significant natural greenhouse effect, in the context of which water vapor is the single most important GHG in Earth's atmosphere.

Nitrogen oxides are the result of high-temperature combustion during which atmospheric nitrogen and oxygen combine. Ordinary fires are not hot enough to cause reactions between nitrogen and oxygen, but at temperatures above 1,600° Celsius the two gases can react. Lightning is a natural source of nitrogen oxides, but human activities also create large amounts, especially in internal combustion engines. Nitrogen oxides react with hydrocarbons to cause smog as well as ozone in the lower atmosphere. Ozone high in the atmosphere protects Earth's surface from ultraviolet light, but at ground level ozone is a pollutant that contributes to respiratory problems. Finally, nitrogen oxides combine with water vapor to form nitric acid and contribute to acid precipitation.

Sulfur dioxide is emitted naturally by volcanoes but also is produced by smelting of sulfide ores or burning fossil fuels that contain sulfur. Sulfur dioxide is a GHG, but its most important environmental effect is that it combines with water vapor to create sulfuric acid. Tiny droplets or aerosols of sulfuric acid can aggravate respiratory problems, contribute to atmospheric haze, and make rain and snow more acidic, contributing to acid precipitation.

Ozone-depleting chemicals include a large number of synthetic chemicals, mostly organic chemicals containing chlorine or bromine. Both of these elements are highly effective at destroying ozone, and ozone-depleting chemicals are extremely stable, enabling them to survive long enough to reach high altitudes. International controls on ozone-depleting chemicals, such as the Montreal Protocol and the Kyoto Protocol, have slowed the depletion of stratospheric ozone, but the existing chemicals in the atmosphere will continue to have an effect for a long time. Although ozone-depleting chemicals also act as GHGs, in most respects global warming and ozone depletion are separate problems.

• Context

Although the amount of CO_2 and other GHGs in the atmosphere has increased and strong evidence exists that the global climate has become warmer in the recent past, the actual web of cause and effect relating to climate change is extremely complex, and many unanswered questions remain. The consequences of making a wrong decision about climate change could be serious. If human activities are responsible for climate change, then failure to act could lead to catastrophic environmental, social, and economic changes. If human activities contribute only insignificantly to climate change, then attempting to halt climate change through government policies could have catastrophic economic effects without ameliorating climate change. The enormous stakes and the sheer complexity of climate are the reasons that the debate about global warming is so fierce.

Steven I. Dutch

• Further Reading

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It.* New York: Hill and Wang, 2008. Broecker, one of the world's most experienced climate researchers, summarizes the evidence for climate change. Among his observations: "If you're living with an angry beast, you shouldn't poke it." Illustrations, references, index.

Fagan, Brian. *The Great Warming: Climate Change and the Rise and Fall of Civilizations.* New York: Bloomsbury, 2008. Writing from an anthropologist's perspective, Fagan examines the impact of the Medieval Warm Period on regional climates and their civilizations. Though weakened by deriving its temperature graphs from the disputed hockey stick graph, this study is useful for its descriptions of the potential impact of climate change—including intense and abrupt global warming—on human civilizations. Illustrations, maps.

Leroux, Marcel. *Global Warming, Myth or Reality? The Erring Ways of Climatology.* New York: Springer, 2005. French climatologist Leroux questions global warming and anthropogenic contributions by noting the limitations of climate models' abilities to predict the impact of the greenhouse effect and postulating alternate causes of climate change, suggesting that there may be some benefits to climate change. Figures, bibliography, index.

Ruddiman, William F. *Plows, Plagues, and Petroleum: How Humans Took Control of Climate.* Princeton, N.J.: Princeton University Press, 2005. Summarizes human impacts on climate and presents the case that agriculture delayed the onset of the next glaciation. Illustrations, figures, tables, maps, bibliography, index.

Sagan, Carl, Owen B. Toon, and James B. Pollack.

"Anthropogenic Albedo Changes and the Earth's Climate." *Science* 206, no. 4425 (December 21, 1979): 1363-1368. Sagan is best known as an astronomer, popularizer of science, and spokesperson for the nuclear winter hypothesis, but this article is a pioneering study of how human activities can affect global climate.

See also: Aerosols; Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Climate and the climate system; Climate change; Deforestation; Enhanced greenhouse effect; Greenhouse effect; Greenhouse gases.

Anthropogeomorphology

• **Categories:** Economics, industries, and products; environmentalism, conservation, and ecosystems

Anthropogeomorphology, the alteration of the Earth's surface by human activity, has profound effects on the environment, including land, air, and water, and has the potential to alter local climates as well.

• Key concepts

additive processes: processes that enhance surface topography

alluviation: soil erosion that results in the filling of watercourses or harbors

dew point: the temperature at which water vapor condenses into liquid water

orographic precipitation: precipitation caused by changes in topography that drive air higher, where it cools and condenses

polders: Dutch land areas reclaimed from sea or marsh

subtractive processes: processes that reduce surface topography

• Background

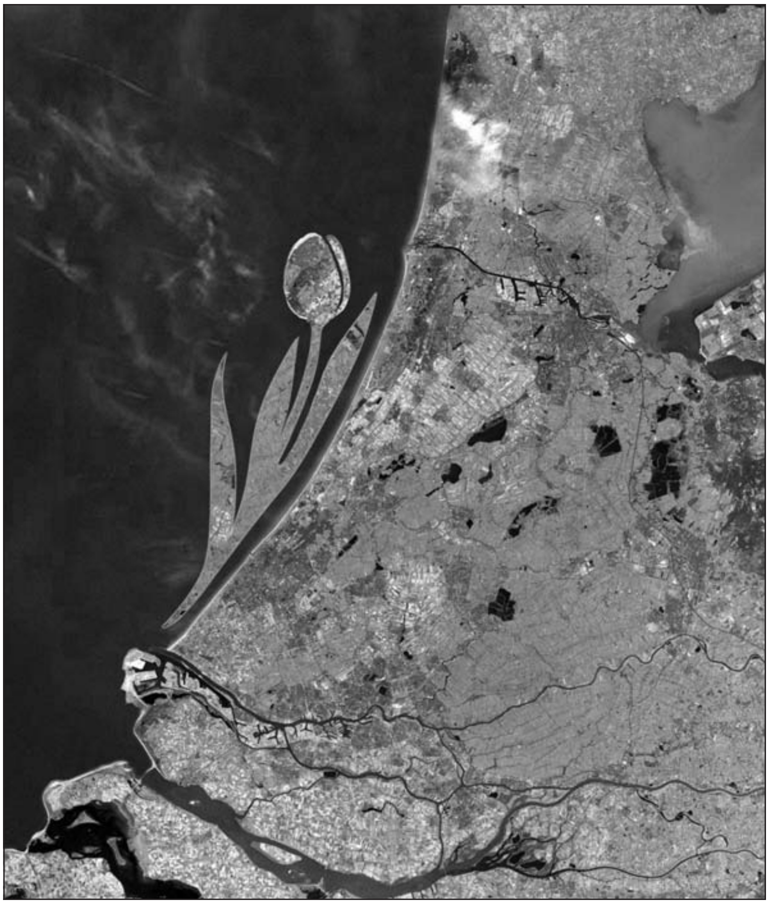
Human civilizations alter natural landscapes, both land and water. They partially remove or scrape away natural landforms (subtractive processes), and they build up new topographic features (additive processes). Humans have long reshaped existing bodies of water, created new bodies of water, redirected water in canals or aqueducts, changed the paths of existing rivers, scraped away surfaces, and reclaimed land from seas or marshes behind dikes and seawalls. There is some evidence that these modifications of the landscape affect local climates.

Anthropogenic changes in the landscape easily surpass the scope of natural erosional processes globally. Overconsumption of water resources in such places as the Jordan Valley in the Levant causes bodies of water such as the Sea of Galilee and the Dead Sea to shrink. It also increases desertification by changing the watershed and reducing evaporation with increased land temperature. Replanting trees in arid zones can mitigate surface temperatures and increase orographic precipitation at lower elevations, where evaporation is reduced with dew point and condensation is reached more easily. This has occurred, for example, in Israel's Judaean Hills, where rainfall increased dramatically over thirty documented years after reforestation.

• Anthropogeomorphology and Climate Change

One anthropogenic subtractive process has been documented for millennia. Plato noted that severe soil erosion in fourth century B.C.E. Greece was causing much lost topsoil. Ancient observers were sometimes able to determine causes of topsoil loss, such as aggressive deforestation to clear farmland or destruction of native plant roots by animal grazing. Sheep and goat herds were particularly destructive, because they consumed root systems as well as surface plants, effectively killing the plant cover.

Once there were no longer roots to hold the soil, erosion often removed devastating volumes of surface soil. As soil cover moved downward, the resulting alluviation filled river bottoms, lakes, and harbors, which were eventually silted up, changing surface landscapes. Coastlines also changed when alluviated river deltas encroached into bodies of water, as, for example, the Rhone River encroached into the Mediterranean Sea. Erosion is normally a subtle, gradual process, but it can be accelerated by extreme deforestation through human agency. Erosion was exacerbated in the late Roman Empire and afterward in North Africa, where Atlas Mountain deforestation by humans resulted in alluviated coastal watersheds and silted up harbors. This erosion combined with rising land temperatures when rainfall ceased, partly as a result of deforestation, to render the climate much less hospitable. Ultimately, once great North African cities such as Sabratha and Leptis Magna were abandoned as a result of these climate changes.



Artist's rendering of a proposed artificial island off the coast of the Netherlands. Tulip Island would increase the nation's living space and also protect the coastline from rising seas. (Reuters/Landov)

• Alteration of Seacoasts

Another example of ancient anthropogenic land change along seacoasts occurred at Tyre (now in Lebanon), beginning in 332 B.C.E., when Alexander the Great built a stone causeway out to the then-island city in a siege. Over millennia, the causeway trapped enough marine-transported sandy alluvium that the land bridge—originally around 7 meters across—widened into today's peninsula, which is so much broader that a casual observer would not guess that there was once an open water channel of almost 400 meters between the mainland and island. Prevailing currents from the north built up far more seaborne sandy alluvium on the curved northern side of the peninsula, whereas the southern side of the artificial peninsula remains more contiguous to the original causeway. The volume of sand and eventual structures added over time now approximate about 200 hectares and millions of metric tons of alluvium. This land extension has changed local water and air circulation patterns along and over the coast of Lebanon.

• Dams and Reservoirs

Humans have also created many artificial, interior bodies of water, such as reservoirs and artificial lakes. Water storage in artificial lakes fills millions of hectares of land surface on every continent, with concomitant climatic impacts ranging from temperature changes to increased evaporation. Additional anthropogenic aquatic change includes the construction of major canals, such as the Suez Canal linking the Mediterranean and Red Seas and the Panama Canal linking the Pacific Ocean and the Caribbean Sea. Construction of such canals includes the creation or exploitation of connecting lakes and locks to accommodate sea-level differences.

One dramatic human engineering project, China's Three Gorges Dam, is already threatening to offset potential hydroelectric economic gains. Water has seeped into steep lands along the dam's perimeter, causing more than 35 kilometers of banks to cave in, resulting in more than 20 million cubic meters of rockslide since 2003. In addition, there is mounting evidence than regional rainfall has been decreased, leading to drought and loss of biodiversity, while fault activity has increased where the dammed lake sits across two major, active fault lines.

• Land Reclamation

Conversely, the Zuider Zee's extensive dikes in the Netherlands reclaimed from the North Sea millions of hectares of land slightly below or just at sea level. The reclaimed land was used extensively for farming. The major dike (Afsluitdijk) created new land polders that gradually reduced the former early twentieth century Zuider Zee by about 38 percent.

A similar phenomenon exists around urban New Orleans, where former swamps and Mississippi River delta wetlands were drained, and dense human settlements were generally protected by extensive levees. Hurricane Katrina's surge in summer, 2005, however, emphasized the fragility of such land reclamation and urbanization. Levee failure caused devastating flooding of 80 percent of New Orleans at great local, regional, and national cost.

Channeling former coastal rivers into stone or concrete storm drains is a major surface change, mostly aimed at reducing flooding. Precedents for such projects can be found in pre-Columbian Inca Peru, along the Urubamba River in the Yucay Valley. Around 1400, Inca engineers not only took out natural oxbows and straightened the river but also created farmland from the natural floodplain, where there had been no prior extensive agriculture, thus humidifying the air in the Yucay Valley.

• Anthropogeomorphology and the Mining Industry

Perhaps the most extensive modern anthropogeomorphologic surface change in North America has been produced by the Canadian oil sands industry, which engages in open pit mining of the Athabaska River Valley in Alberta. Boreal forest and earth are scraped away to depths of about 30 meters in many places over a 390-square-kilometer area. This mining is creating vast, toxic, mine-tailing sludge lakes and growing pollutant containment problems. Naphthenic acid and polycyclic aromatic hydrocarbons, which are not easily degradable for centuries, leak from the mines into water tables, as well as the Athabaska River.

The oil sands industry extracts enormous quantities of bitumen-laced sands, heats them, and cleans them using hot water and other agents. This process has resulted in a huge spike in aerosol CO_2 emissions over northern Canada, at a much higher rate than the emission rate of conventional oil production. Oil produced in Alberta's oil sands is mostly consumed by the United States; this single source supplies 10 percent of total U.S. foreign oil.

It takes 3.6 metric tons of earth to produce one barrel of oil, and 750,000 barrels of synthetic crude oil are produced per diem in Alberta. This nonstop daily process mixes 907,000 metric tons of crushed oil sands with 181,000 metric tons of water to be heated to boiling temperatures for steam. It requires considerable energy, generated from natural gas, and yields a vast landscape of stored toxic waste. Environmental scientists are beginning to link accelerated Arctic ice-cover loss with the northern Canadian oil sand industry. The industry may raise local temperatures through deforestation, as well as adding steam to the air.

• Context

Anthropogeomorphology as a by-product of human activity is a growing concern, as evidenced by a burgeoning global environmental response. Quantitative analyses of climatic changes resulting from anthropogeomorphology have yet to be produced, but growing attention to the subject will render such analyses of great scientific and political interest. Once the phenomenon is better understood, it may be possible not only to prevent further projects from creating negative climatic effects but also to launch projects to mitigate local and global climate trends.

Patrick Norman Hunt

• Further Reading

Atlas of Israel: Cartography, Physical and Human Geography. New York: Macmillan, 1985. Documents and maps all geophysical data available in Israel for over forty years of quantitative measurements from meteorology, oceanography, demography, and other disciplines.

Hvistendahl, Mara. "China's Three Gorges Dam: An Environmental Catastrophe?" *Scientific American*, March 25, 2008. Assessment of China's initial failure to consider the dam's ecological impacts and recent acknowledgment of its possible consequences for the environment.

Kunzig, Robert. "Scraping Bottom: The Canadian Oil Boom." *National Geographic*, March, 2009. Fair but controversial report on the Canadian oil industry's bringing about both an economic boom and environmental degradation.

LaFreniere, Gilbert. *The Decline of Nature: Environmental History and the Western Worldview*. Bethesda, Md.: Academica Press, 2008. Examines human policies that have affected nature through history, detailing both philosophical attitudes underlying those policies and their possible catastrophic results.

Nikiforuk, Andrew. *Tar Sands: Dirty Oil and the Future of a Continent*. Berkeley, Calif.: Greystone Books, 2008. Examines potential long-term environmental effects of Canada's oil sands industry in light of possible climatic changes and the ethics of fossil fuel consumption.

See also: Climate engineering; Flood barriers, movable; Land use and reclamation; Levees.

Aral Sea desiccation

- **Category:** Water resources

Water availability has fluctuated in the Aral Sea as a result of natural and anthropogenic forces. Anthropogenic effects in the second half of the twentieth century brought about an environmental disaster, as the sea shrank drastically, with deadly effects on agriculture, vegetation, and human and animal populations in the region.

• Key concepts

anthropogenic: caused or produced by humans

hazardous: poisonous, corrosive, flammable, explosive, radioactive, or otherwise dangerous to human health

herbicides: substances or preparations for killing plants, such as weeds

pesticides: chemical preparations that kill pests, including unwanted animals, fungi, and plants

Pleistocene epoch: first half of Quaternary period, beginning about two million years ago and ending about ten thousand years ago

Pliocene epoch: Tertiary period, beginning about ten million years ago and ending about two million years ago, known for its cool climate, mountain building, and increased mammal populations

• Background

The dramatic drying of Central Asia's Aral Sea is sometimes called one of the greatest ecological disasters of the twentieth century. Over the past ten thousand years, the area and volume of this internal lake have greatly fluctuated as a result of both natural and anthropogenic forces. Anthropogenic forces in particular greatly reduced the sea at the end of the twentieth century, from 67,500 square kilometers in 1960 to 17,382 square kilometers in 2006.

The Aral Sea is located in an area of cold temperatures and deserts: the Karakumy is to the south, the Kyzylkum Desert is to the southeast. The sea's 1.8-million-square-kilometer drainage basin encompasses six central Asian countries: Iran, Turkmenistan, Kazakhstan, Afghanistan, Tajikistan, and Uzbekistan (including the Karakalpak Autonomous Republic). Kazakhstan and Uzbekistan are physically adjacent to the Aral Sea. Although nine streams flow within the drainage basin, the Syr Dar'ya and the Amu Dar'ya are the major rivers. *Dar'ya* translates from the Turkic languages of central Asia as "river."

In 1918, the Soviet Union decided to develop the area around the Aral Sea to grow cotton. The decision was economic: Cotton, "white gold," provided revenue for the government. Herbicides, pesticides, and fertilizers were heavily used to bolster crop production, and the Amu and Syr Dar'ya were diverted for irrigation.

The Soviet irrigation programs were inefficient, with open waterways and irrigation basins subject to evaporation. Open-air channels were dug through sandy deserts with the thirteen-hundred-kilometer Karakam Canal diverting between 20 and 30 percent of the Amu Dar'ya's flow west to Turkmenistan.

Between 1987 and 1989, the Aral Sea divided into the small Aral Sea in the north, fed by the Syr Dar'ya, and the large Aral Sea in the south, supplied by the Amu Dar'ya. Using the years 1960 to January, 2006, as a baseline, the water level of the little Aral fell by 13 meters, the large Aral by 23 meters.

• Displaced Fishing Industry

Historically, the Aral Sea fishing industry employed several thousand workers and provided, according to commercial fishing reports, one-sixth of the Soviet fish supply. The lowered lake level reduced the industry and increased the distance between the lake and fishing ports. Decreased water flow to the river deltas and wetlands diminished fish spawning and feeding, so that of the thirty-two fish species formerly existing in the lake, only six survived. Those remaining survived by inhabiting small water areas of river deltas—areas that play a large role in regenerating lake fish supplies. Commercial fisheries did not exist after the mid-1980's.

When lake water is reduced by evaporation and freshwater input is negligible, salts within the water are concentrated and approach the salinity of a typical ocean, 35 grams of salt per liter. Since the Aral Sea was becoming more saline in the 1970's, a saltwater fish, the Black Sea flounder (*Platichthys flesus lulscus*) was introduced into the sea. The intent was to enable the lake's fishing industry to survive, but by 2003 the flounder no longer existed in the Aral Sea, whose salinity had reached greater than 70 grams per liter.

• Hazardous Lakebed Deposits

As the Aral Sea shrinks, calcium sulfate, calcium carbonate, sodium chloride, sodium sulfate, and magnesium chloride are deposited on the exposed seafloor. In addition to these salts, pesticide residues of organochlorines, dicholorodiphenyl-tricholoethanes

Ruined ships lie on sand that was once the bed of the Aral Sea. (Shamil Zhumatov/Reuters/Landov)

(DDT), hexachloro-cyclohexane compounds (HCH, Lindane), and toxaphene remain. Other toxic materials present are the result of biological weapons testing and failed industrial sites.

The region immediately surrounding the Aral Sea—Uzbekistan, Kazakhstan, and parts of Turkmenistan—are affected by hazardous dust and salt storms. Most major storms occur in a one-hundred-kilometer margin along the north-northeastern coastal zone. Some 60 percent of these storms trend southwesterly, for 500 kilometers, depositing salts, agrochemical dusts, and aerosols on the delta of the Amu Dar'ya. This southern river delta region is densely populated, so toxic storms affect human and animal health and economic stability. Another 25 percent of the storms trend west, moving over and beyond the Ust-Urt plateau, an area of livestock pastures.

Toxic dust storms harm the human food supply and physical health of domestic and wild animals. The human risk associated with airborne salt and dust is high, and greater than average incidences of respiratory illnesses, eye problems, throat and esophageal cancer, skin lesions and rashes, and liver and kidney damage are reported in the Aral Sea region.

• Aral Sea Geology

The Aral Basin has experienced geologic cycles of diversion and desiccation. During the Pliocene epoch, the ocean withdrew from Eastern Europe and Turkestan, leaving remnant basins such as the Aral, Caspian, and Black seas. Late Pliocene continental crust movements created a more permanent depression in the area of the Aral Sea, which was filled with water, some of which came from the ancestral Syr Dar'ya.

The effects of the Pleistocene epoch are recorded by terrestrial sedimentary deposits. Eolian processes operated in the Aral depression during the early and middle Pleistocene. During the late Pleistocene, fluvial processes filled the depression by inflows from the ancestral Amu Dar'ya; then, the basin was filled for a second time with waters from the Syr Dar'ya.

Both rivers affect lake level changes, but when the 2,525-kilometer course of the Amu Dar'ya migrates away from the basin, lake level drops. Diversions of the Amu Dar'ya are natural, resulting from filling fluvial channels during heavy rains or floods. Some river diversions are the result of human actions, such as improper or failing irrigation systems or intentional destruction of river dams and levees during political upheaval or war.

• Aral Sea Restoration

The Aral Sea cannot be reestablished to its pre-1960 status, because to do so would mean curtailing irrigation, which uses 92 percent of all Aral water withdrawals. Curtailment of irrigation would mean crop failure and economic and social collapse in the Aral Basin. After the fall of the Soviet Union in 1991, Kyrgyzstan, Uzbekistan, Turkmenistan, Kazakhstan, and Tajikistan joined together to address the Aral Sea crisis. Two major agencies were formed by these new regional states. with the International Fund for the Aral Sea (IFAS) taking the lead role in 1997. Also, the United Nations, the European Union, and many other international aid agencies operated to improve the region.

In order to regulate flow in the little Aral, Kazakhstan and the World Bank constructed an eighty-five-million-dollar, thirteen-kilometer earthen ditch connected to a concrete dam with gates and spillways. Completed in November, 2005, this system brought early success: The water level increased to 42 meters from 40 meters, and, by summer of 2006, the lake area increased by 18 percent. Salinity decreased by one-half to almost 10 grams per liter in 2006, but future levels will vary, by area, from 3 to 14 grams per liter. Decreased salinity increases fish population, aiding the fishing industry and the Kazakhstan economy. A former fish-processing plant has reopened in Aralsk, Kazakhstan, to process lake carp, Aral bream, Aral roach, Pike perch, and flounder—the top five species caught in autumn, 2007.

• Context

The Aral Sea Basin has become synonymous with irreversible environmental disaster. The entire region demonstrates the potential for humans to act as geomorphic change agents. The area's inhabitants diverted rivers for irrigation; replaced desert vegetation with such crops as melons, cotton, and rice; and altered natural water chemistry to salinities greater than that of ocean water. Anthropogenic environmental degradation has also affected human health in the Aral Basin.

Populations around the sea are in a state of upheaval, dislocation, and poverty as a result of the collapse of the fishing industry and a lack of government support from the former Soviet Union since the early 1990's. Essential medications and adequate hospital facilities are not available when economic conditions are stagnant. Health problems begin in the youngest populations: High infant mortality, low birth weight, growth retardation, and delayed puberty are present in the basin.

Poor quality and insufficient quantities of drinking water in the basin have increased typhoid, hepatitis A, and diarrhea in all age groups. High levels of mineralized water within the basin may contribute to kidney and liver diseases. Also increasing are acute respiratory diseases—killing almost one-half of all children. Dust storms sourced from former seabeds deliver salt and toxic chemical sediments to humans and areas of human habitation.

Possibly the greatest health risk is from pesticides, which contaminate the water and food supplies and infiltrate during dust storms. Pesticides may be applied to crops, especially cotton, several times during a growing season. Lindane (HCH) has also been used biannually to rid sheep's skin and fleece of vermin.

It is difficult to determine the relative importance of each human health issue, especially when population groups may suffer multiple medical problems and live in impoverished conditions. What is clear is that residents of the Aral Sea are experiencing a pronounced health crisis, not unlike the environmental one that surrounds them.

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- **Further Reading**

Micklin, P. "The Aral Sea Disaster." *Annual Review of Earth and Planetary Science* 35 (2007): 47-72. Excellent collection of data on the water balance, salinities, and hydrology of the Aral Basin; human and ecological consequences of the disaster; improvement efforts by global aid agencies; and engineering mitigation.

_______. "Desiccation of the Aral Sea: A Water Management Disaster in the Soviet Union." *Science* 241, no. 4844 (September 2, 1988): 1170-1176. Micklin's early work on causes of sea recession and resulting environmental problems; details local water quality improvements and future schemes for preservation of the Aral.

Micklin, P., and N. V. Aladin. "Reclaiming the Aral Sea." *Scientific American* 298, no. 4 (April, 2008): 64-71. Outlines the collapse of the Aral Sea due to wasteful irrigation of the desert; the geography of residual lakes; the 2005 dam construction and future of the Amu Dar'ya; and application of lessons learned from the Aral disaster to other regions with similar risks.

Nihoul, J. C. J., P. O. Zavialov, and P. Micklin, eds. *Dying and Dead Seas: Climatic Versus Anthropic Causes*. Dordrecht, the Netherlands: Kluwer Academic, 2004. Synthesis of sixteen lectures given at the May, 2003, North Atlantic Treaty Organization Advanced Research Workshop in Belgium on dead or dying internal seas and lakes; assesses the past and present roles of natural and anthropogenic causes.

Whish-Wilson, P. "The Aral Sea Environmental Health Crises." *Journal of Rural and Remote Environmental Health* 1, no. 2 (2002): 29-34. Provides general background on the disaster; in-depth health status assessment of the region; list of causes and outcomes of pollution and its effects on humans and the environment; and details of the health community's response.

See also: Diseases; Drought; Fishing industry, fisheries, and fish farming; Floods and flooding.

Arctic

- **Category:** Arctic and Antarctic

Global warming is being felt most intensely in the Arctic, whose ice and snow have been melting away. Arctic Ocean ice cover shrank more dramatically between 2000 and 2007 than at any time since detailed records have been kept.

• Key concepts

albedo: proportion of incident radiation reflected by Earth's surface

drunken forest: forest that leans at an odd angle as a result of melting permafrost

feedback loops: climatic influences that compound or retard each other, accelerating or decelerating the rate of global warming

permafrost thawing: defrosting of previously permanently frozen ground, usually in or near the Arctic

tipping point: the point at which feedback loops take control and propel climate change

• Background

According to the Arctic Climate Impact Assessment Scientific Report, produced by 250 scientists under the auspices of the Arctic Council, Arctic sea ice was half as thick in 2003 as it had been thirty years earlier. The melting of ice in the Arctic accelerated through 2007, advancing the projected date of an ice-free summer to perhaps 2020. During September, 2007, the Arctic ice cap shrank to its smallest extent since records have been kept, 4.12 million square kilometers, versus the previous record low of 5.28 square kilometers in 2005. The shrinkage from 2005 to 2007 represents a loss of more than 20 percent of the Arctic's ice cover, or an area the size of Texas and California combined.

• Retreat of Arctic Ocean Ice

Scientists were shaken by the sudden retreat of the Arctic ice during the summer of 2007, which was much greater than their models had projected. Some said that a tipping point had been reached and that the Arctic could experience ice-free summers within a decade or two. At the annual American Geophysical Union meeting in San Francisco during December, 2007, scientists reported that temperatures in waters near Alaska and Russia were as much as 5° Celsius above average.

Scientists at the University of Washington said the Sun's heat made the greatest contribution to the record melting of the Arctic ice cap at the end of summer, 2007. Sunlight added twice as much heat to the water as was typical before 2000. Relatively warm water entering the Arctic Ocean from the Atlantic and the Pacific Oceans was also a factor, according to Michael Steele, an oceanographer at the University of Washington. Energy from the warmer water delayed the expansion of ice in the winter as it warmed the air.

In addition to the retreating extent of sea ice in the Arctic, a greater proportion of the ice that does remain in the region is thin and freshly formed, unlike older, thicker ice that is more likely to survive future summer melting. The proportion of older, "durable" ice dropped drastically between 1987 and 2007, according to studies by Ignatius G. Rigor of the University of Washington. In addition to a decrease in the extent of Arctic Ocean ice, by 2007 large areas of the ice that remained were only about one meter thick—half what they had been in 2001, according to measurements taken by an international team of scientists aboard the research ship *Polarstern.*

• Walrus Deaths

With ice receding hundreds of kilometers offshore during the late summer of 2007, walruses gathered by the thousands on the shores of Alaska and Siberia. According to Joel Garlich-Miller, a walrus expert with the U.S. Fish and Wildlife Service, walruses began to gather onshore late in July, a month earlier than usual. A month later, their numbers had reached record levels from Barrow to Cape Lisburne, about 480 kilometers southwest, on the Chukchi Sea. Walruses dive from the ice to feed on clams, snails, and other bottom-dwelling creatures. As a result of increased melting, however, the Arctic ice has receded too far from shore to allow walruses to engage in their usual feeding patterns.

A walrus can dive 180 meters, but water under receding ice shelves is now more than a thousand meters deep by late summer. The walruses have been forced to swim much farther to find food, using energy that could cause increased calf mortality. In addition, more calves are being orphaned. Russian research observers have reported many more walruses than usual on shore, tens of thousands in some areas along the Siberian coast. These creatures would have stayed on the sea ice in earlier times.

Walruses are prone to stampedes when they gather in large groups. The appearance of a polar bear or a human hunter, or even noise from a low-flying small airplane, can send thousands of pan-

By the end of 2005, scientific projections for the Arctic were becoming more severe. A climate modeling study published in the *Journal of Climate* indicated that if humanity does not address global warming in the near future, irreversible damage may take place. The paper's lead author, Govindasamy Bala of the U.S. Energy Department's Lawrence Livermore National Laboratory, predicted that it might take twenty or thirty years before the scope of anthropogenic changes becomes evident, but that after that the damage would be obvious.

The *Journal of Climate* study projected that the global concentration of atmospheric carbon dioxide (CO_2) would be double that of preindustrial levels in 2070, triple in 2120, and quadruple in 2160—predicting slightly less than present-day rates of increase. It was the first study to assume consumption of all known reserves of fossil fuels. This model anticipates that the Arctic will see the planet's most intense relative warming, with average annual temperatures in many parts of Arctic Russia and northern North America rising by more than 14° Celsius by about 2100.

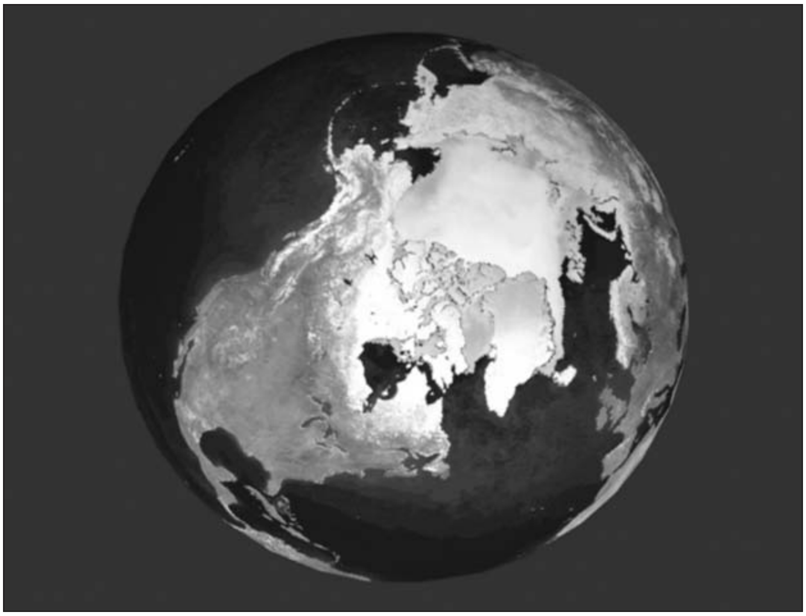
icked walruses rushing to the water, stampeding one another into bloody pulp. Thousands of Pacific walruses were killed on the Russian side of the Bering Strait during the late summer of 2007, when more than forty thousand hauled out on land at Point Shmidt as ice retreated northward.

• Forecasts

In the past, low-ice years often were followed by recovery the next year, when cold winters or cool summers kept ice from melting further. That kind of balancing cycle stopped after 2002. The year 2004 was the third in a row with extreme ice losses, indicating acceleration of the melting trend. Arctic ice has been declining by about 8 percent per decade as part of this trend.

• Acceleration of Ice-Cap Melting

Julienne Stroeve and her colleagues compared more than a dozen models of Arctic ice-melt and found that nearly all of them underestimated the actual speed of ice-melt, in many cases by large amounts. These findings have two important implications, according to a summary of Stroeve's study in *Science*. First, the effect of increasing greenhouse gases may have been greater than has been believed. Second, future loss of Arctic Ocean ice may be more rapid and extensive than predicted. Within a decade, projections of the first ice-free



A global view of Arctic sea ice in 2000. (NASA-JPL)

summer in the Arctic have moved from the end of the twenty-first century to roughly the year 2020. Even projections made by the Intergovernmental Panel on Climate Change (IPCC) in its 2007 assessments (forecasting an iceless Arctic in summer between 2050 and 2100) were out of date weeks after they were made public, according to reports by scientists at the National Center for Atmospheric Research and the University of Colorado's National Snow and Ice Data Center. The study, "Arctic Sea Ice Decline: Faster than Forecast?" was published during early May, 2007, in the online edition of *Geophysical Research Letters.*

Beginning in the mid-1990's, scientists observed pulses of relatively warm water from the North Atlantic entering the Arctic Ocean, further speeding ice-melt. Mark Serreze, senior research scientist at the National Snow and Ice Data Center, said that such warm-water pulses represented yet another potential kick to the system that could accelerate rapid sea-ice decline and send the Arctic into a new state. As Arctic ice retreats, ocean water transports more heat to the Arctic, and the open water absorbs more sunlight, further accelerating the rate of warming and leading to the loss of more ice.

The entire Arctic system is thus beset by accelerating feedback loops that intensify climate change. For example, permafrost has been melting, injecting additional CO_2 and methane into the atmosphere. In Alaska, trees that have become destabilized in melting permafrost lean at angles, creating so-called drunken forests.

The speed of ice breakup can sometimes be astonishing. For example, the thirty-meter-thick Ayles shelf of floating ice, a shelf roughly sixty-five square kilometers in area, had extended into the Arctic Ocean from the north coast of Ellesmere Island in the Canadian Arctic for roughly three thousand years. The Ayles shelf was detached during the summer of 2005 by wind and waves in warming water. The break-up was observed by Laurie Weir of the Canadian Ice Service in satellite images of Ellesmere Island during August, 2005. The images showed a broad crack opening and the ice shelf flowing out to sea with a speed that could be observed hour by hour.

In 1906, Arctic explorer Robert Edwin Peary surveyed 26,160 square kilometers of ice shelves. Nine-tenths of these have broken up over the last century, according to Luke Copland, director of the Laboratory for Cryospheric Research at the University of Ottawa.

• Context

The extent of Arctic Ocean ice has been declining year-round for more than three decades, according to an analysis of satellite data compiled during 2006 by the U.S. National Ice Center. Data sets of the Thirty-Year Arctic Sea Ice Climatology show shrinkage in the Arctic Ocean summer ice cover of more than 8 percent per decade, according to Pablo Clemente-Colón, the ice center's chief scientist. While the extent of winter sea ice has also been decreasing, summer shrinkage has become more pronounced.

A tipping point toward an ice-free Arctic in summer probably already has been passed, according to James E. Hansen, director of the National Aeronautics and Space Administration's Goddard Institute for Space Studies. The complete loss may occur rapidly, on the time scale of a decade, once ice loss has reached such a degree that the albedo feedback becomes a dominant process, according to Hansen. The albedo feedback refers to the fact that loss of some sea ice increases the amount of solar energy absorbed by the Arctic because the liquid ocean is darker than the ice, absorbing more of the Sun's heat and thus increasing ice melt. Hansen and his team could not determine the exact level of added CO_2 necessary to cause complete ice loss, but they declared that once such a state were reached, it would be difficult to return to a climate with summer sea ice, because of the long lifetime of atmospheric CO_2.

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• **Further Reading**

Alley, Richard B. *The Two-Mile Time Machine Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Popular version of Alley's scientific work on climate change in the Arctic.

Amstrup, S. C., et al. "Recent Observations of Intraspecific Predation and Cannibalism Among Polar Bears in the Southern Beaufort Sea." *Polar Biology* 29, no. 11 (October, 2006): 997-1002. Details conditions under which some polar bears, unable to reach ice masses from which they used to hunt ringed seals, have been eating their own young.

Appenzeller, Tim. "The Big Thaw." *National Geographic*, June, 2007, pp. 56-71. Survey of ice melt in the Arctic, the Antarctic, and mountain glaciers, with explanations describing why the process has been speeding up.

Arctic Climate Impact Assessment Scientific Report. New York: Cambridge University Press, 2006. Detailed scientific reports of Native American peoples' experiences and scientific trends regarding global warming in the Arctic, where temperatures have been rising more quickly than anywhere else on Earth.

Schiermeier, Quirin. "On Thin Ice: The Arctic Is the Bellwether of Climate Change." *Nature* 441 (May 10, 2007): 146-147. Examines the Arctic's crucial role in global climate.

Serreze, Mark C., and Roger G. Barry. *The Arctic Climate System.* New York: Cambridge University Press, 2006. A glaciologist looks at the decline of ice in the Arctic, along with other issues related to climate change.

See also: Albedo feedback; Antarctica: threats and responses; Arctic peoples; Arctic seafloor claims; Ground ice; Ice cores; Ice shelves.

Arctic peoples

• **Categories:** Arctic and Antarctic; nations and peoples

The lives of approximately 150,000 Inuit and Eskimo who ring the Arctic Ocean in Greenland, Canada's Arctic, Alaska, and Russia have been substantially changed by some of the most rapid warming on Earth.

• **Key concepts**

Inuit: indigenous people of the Canadian Arctic

Inuit Circumpolar Conference: group representing the interests of 150,000 Inuit aand Eskimo in international forums

pack ice: a solid mass of sea ice formed when smaller masses and fragments are forced together under pressure

• **Background**

Around the Arctic, in Inuit villages connected by the oral history of traveling hunters as well as by e-mail, weather watchers report striking evidence that global warming is an unmistakable reality. Rapid changes have been evident at all seasons. During the summer of 2004, for example, several yellow-jacket wasps (*Vespula intermedia*) were sighted in Arctic Bay, a community of seven hundred people located on the northern tip of Baffin Island, at more than 73° north latitude. Inuktitut, the Inuit language, has no word for the insect.

• Inuit Hunters' Experiences

The Arctic's rapid thaw has made hunting, never a safe or an easy way of life, even more difficult and dangerous. Arctic weather has changed significantly since roughly the middle 1990's. Several hunters have fallen through unusually thin ice and sustained severe injuries or died. Changing weather is only one factor. Inuit hunters' dogs have an ability to detect thin ice, which they may refuse to cross. Snowmobiles, which have replaced dogs for many Inuits, have no such sense. While pack ice was visible from the Alaskan north coast year-round until a few years ago, it has now retreated well over the horizon, forcing hunters to journey more than 160 kilometers offshore to find bearded seals and walruses.

Pitseolak Alainga, an Iqaluit-based hunter, has said that climate change compels caution: One must never hunt alone. Before venturing onto ice in fall or spring, Alainga cautions, hunters should test its stability with a harpoon. Alainga knows the value of safety on the water. His father and five other men died during late October, 1994, after an unexpected ice storm swamped their hunting boat. The younger Alainga and one other companion barely escaped death in the same storm. Alainga believes that more hunters are suffering injuries not only because of climate change but also because basic survival skills are not being passed from generation to generation as they were in years past, when most Inuit lived off the land.

A young Nenets girl stands next to a sled. The Nenets are indigenous peoples of the Russian Arctic. (Vasily Fedosenko/Reuters/Landov)

Inuit daily life has changed in many other ways because of the rapidly warming climate. Many Inuit once used ice cellars to store meat in frozen ground. The climate has warmed so much that the cellars are no longer safe, even as far north as Barrow, Alaska. Meat that once could be safely stored in permafrost has been spoiling. With increasing inability to hunt, Inuit are being forced to buy imported food at prices several times those paid for the same goods at lower latitudes. Diabetes and other problems associated with imported food have been increasing. Drinking water obtained by melting ice has become dirtier. A warmer climate increases risks for insect-vector diseases, even West Nile virus.

• Shishmaref, Alaska

Six hundred Alaskan Native people in the village of Shishmaref, on the far western shore of Alaska about 160 kilometers north of Nome, have been watching their village erode into the sea. The permafrost that once reinforced Shishmaref's waterfront is thawing. Shishmaref residents decided during July, 2002, to move their entire village inland, a project that the U.S.

Army Corps of Engineers estimated would cost more than $100 million. By 2001, seawater was lapping near the town's airport runway, its only long-distance connection to the outside world. By that time, three houses had been washed into the sea. Several more were threatened. The town's drinking water supply also had been inundated by the sea. By fall, 2004, Shismaref's beaches had retreated still farther during vicious storms. The same storms flooded businesses along the waterfront in Nome and damaged power lines, fuel tanks, and roads in at least a half dozen other coastal villages.

• Artificial Hockey Ice and Air Conditioning

By the winter of 2002-2003, warming Arctic temperatures were forcing hockey players in Canada's far north to seek rinks with artificial ice. Canada's *Financial Post* reported that global warming had cut in half the hockey season, which ran from September until May in the 1970's. Instead, the season—dependent in some areas upon natural ice—had come to begin around Christmas and end in March. The northern climate has changed so swiftly that by the summer of 2006, the Inuit were installing air-conditioning in some buildings near the Arctic Circle. Traditional Inuit homes are built with southern exposure to soak up every available hint of the sun's warmth. Windows are usually small, and they rarely open easily. Some Inuit were developing severe heat rashes during the summer.

• Context

The Inuit are very conscious of their pivotal role in a natural world undergoing climate change, as they seek to avoid destruction of an environment that has sustained them for many thousands of years. The Inuit Circumpolar Conference has petitioned the Inter-American Commission on Human Rights regarding violations of fundamental human rights among Arctic peoples. The petition defends the rights of Inuits as a people within evolving international human rights law. It seeks a declaration from the commission that emissions of greenhouse gases (GHGs) from the United States—the source of more than 25 percent of the world's greenhouse GHGs during the last century—is violating Inuit human rights as outlined in the 1948 American Declaration on the Rights and Duties of Man.

The petition asserts that the Inuits' rights to culture, life, health, physical integrity and security, property, and subsistence have been imperiled by global warming: With accelerating loss of ice and snow, hunting, travel, and other subsistence activities have become more dangerous and in some cases impossible. The petition does not seek monetary damages. Instead, it requests cessation of U.S. actions that violate Inuit rights to live in a cold environment—not a small task, since such action would involve major restructuring of the U.S. economic base to sharply curtail emissions of GHGs. The petition anticipates the types of actions that will have to take place on a worldwide scale, including alterations to the rapidly expanding economies of China and India, to preserve the Inuit way of life, as well as a sustainable worldwide biosphere.

Bruce E. Johansen

• Further Reading

Johansen, Bruce E. "Arctic Heat Wave." *The Progressive*, October, 2001, 18-20. On-the-scene reporting from Baffin Island describing the effects of accelerating warming on Inuit hunters.

Lynas, Mark. *High Tide: The Truth About Our Climate Crisis.* New York: Picador/St. Martin's, 2004. Elegantly written travelogue describing effects of climate change around the world, with detailed emphasis on the Arctic's people.

Watt-Cloutier, Sheila, and the Inuit Circumpolar Conference. *Petition to the Inter-American Commission on Human Rights Seeking Relief from Violations Resulting from Global Warming Caused by Acts and Omissions of the United States.* Iqualuit, Nunavut: Author, 2005. This legal brief contains copious detail describing how global warming is changing the lives of Inuit people at a very personal level, with many case studies.

Wohlforth, Charles. *The Whale and the Supercomputer: On the Northern Front of Climate Change.* New York: North Point Press, 2004. Detailed compendium of global warming's intensifying effects on Arctic peoples, focusing on Northern Canada.

See also: Antarctica: threats and responses; Arctic; Diseases; Human behavior change; Maldives; Polar climate.

Arctic seafloor claims

- **Category:** Arctic and Antarctic

Global warming has led to significant declines in Arctic Ocean ice coverage, allowing unprecedented access to seafloor resources. Estimates place approximately one-quarter of the world's fossil fuel reserves beneath the Arctic seafloor, making seafloor competition a likely source of future geopolitical conflict.

• Key concepts

albedo: the proportion of incident light reflected from a surface

continental shelf: a submerged extension of a continental coastline, where the ocean is relatively shallow and the seafloor is built from terrestrial sediments

Gakkel Ridge: an Arctic Ocean spreading zone that continues the Mid-Atlantic Ridge

Lomonosov Ridge: An 1,800-kilometer submerged ridge crossing the geographic North Pole from Russia to Greenland

methyl hydrates: icelike substances formed under pressure beneath permafrost and Arctic Ocean sediments that trap gases such as methane within an ice lattice

placer deposits: accumulations of minerals washed onto the continental shelf from river runoff

United Nations Convention on the Law of the Sea: an international treaty that grants an exclusive economic zone to all countries bordering significant bodies of water

• Background

During the late twentieth and early twenty-first centuries, Arctic Ocean ice was in steady retreat. Ice thickness declined by 40 percent, and ice shrinkage freed over 2.6 million square kilometers of water along the ocean's coastlines. Record rates of ice shrinkage in 2007 and 2008 opened the Northwest Passage to navigation for the first time in recorded history.

Loss of polar ice creates open water that absorbs light rather than reflecting it, reducing the Arctic albedo, delaying yearly ice formation, promoting early spring melt, and thinning the permanent ice shelf. While costly to the Arctic ecosystem, ice loss has allowed unprecedented access to researchers, shippers, and resource explorers from the five countries bordering Arctic waters: the United States, Russia, Canada, Norway, and Danish Greenland.

• Arctic Resources

Research conducted in the Arctic indicates the potential existence of 90 billion barrels of oil and 4.5 trillion cubic kilometers of natural gas buried beneath the seafloor. Most fuel deposits lie close to shore, where they are readily extractable using existing technologies. Placer deposits of diamonds and gold also lie close offshore. Farther from the coast can be found large deposits of oil shale, methyl hydrates, and coal-bed methane.

Current technologies do not allow extraction of these deposits, and some, such as methyl hydrate, remain unproven as a fuel resource. However, increasing global fuel demands will make even these deposits attractive to future exploitation. Moreover, the discovery of undersea volcanoes and hydrothermal vents in the deep Arctic in 2001 added precipitated deposits of gold, silver, and copper to the list of recoverable resources. The lure of seafloor wealth has stimulated intense competition among those countries wishing to establish Arctic seafloor claims.

• Claiming the Seafloor

Territorial jurisdiction within Arctic waters has long been disputed. The United Nations Convention on the Law of the Sea (UNCLOS)—which was concluded in 1982 and entered into force in 1994—was designed specifically to address such disputed seafloor claims. Under UNCLOS, every country bordering an ocean or an inland sea is granted sovereign rights over natural resources within an exclusive economic zone (EEZ) extending outward from its coastline for 370 kilometers.

Most known Arctic resources lie within these EEZs, but the Arctic is a relatively shallow ocean, and resource deposits near the North Pole and the Gakkel Ridge, both considered international territory, have triggered competing claims under Article 76 of UNCLOS. Article 76 allows the extension of a country's EEZ to up to 650 kilometers offshore. To claim this additional territory, the claimant must prove that the continental shelf lying beyond its established 370-kilometer zone is an extension of its already-claimed shelf zone. The new territory also must not include any area more than 185 kilometers beyond the point where the water's depth reaches 2,500 meters. Article 76 could allow almost 90 percent of the Arctic seafloor to become part of the EEZs of the five bordering nations.

- **The Lomonosov Ridge**

The Lomonosov Ridge, lying between Siberia and Greenland, parallels the Gakkel Ridge, passes through the geographic North Pole, and represents the primary legal battlefield for Article 76 claims. The Lomonosov Ridge has a complicated and unique geological history. Core sampling indicates that it split off of the Eurasian margin of the continental shelf along northern Scandinavia and Russia some 50 million years ago. Coring also indicates that the Arctic was at one time a swampy inland sea, bolstering the likelihood that the ridge and the ocean basin it created are rich in buried fossil fuel reserves. The promise of such riches led the Russia Federation in August, 2007, to claim a portion of the Lomonosov Ridge, the Alpha-Mendeleyev ridge system, as well as part of the Amerasian basin: The Russian submersible *Mir-1* planted a flag 4 kilometers beneath the ice of the geographic North Pole, thereby symbolically claiming more than 1.2 million square kilometers of seafloor.

Under Article 76, such a claim is valid only if Russia can prove that the Lomonosov Ridge is currently a geological extension of its continental shelf. Though core samples indicate that the ridge originated from the Eurasian margin, faulting patterns near Siberia suggest that it has since become detached from the Siberian shelf. Russia's first

A Russian deep-sea submarine is lowered into the Arctic Ocean, where it will conduct a mission designed to bolster Russia's claims to the mineral resources of the sea floor. (AP/Wide World Photos) claim to the Lomonosov Ridge was rejected by UNCLOS in 2002 based on limited geological evidence.

Canada and Denmark maintain that Russia will be unable to prove that the Lomonosov Ridge is an extension of its shelf. They have filed counterclaims of their own. The stakes are huge: Successful claimants stand greatly to increase their fuel reserves and to generate billions of dollars in revenue. So far, the United States, a nonsignatory to UNCLOS, has stayed out of the debate, but with the potential gains so high it is unlikely that it will remain on the sidelines.

• Context

At one time, research in the Arctic Ocean was nearly impossible. Its 14-million-square-kilometer surface was covered by heavy pack ice almost year-round, making access—even with icebreakers—dangerous and of scant utility. Global warming has changed this situation dramatically. Ice thinning and ice-free periods in the Arctic have made both access and research easier, even though they come at the expense of the ocean and its inhabitants. Given the rate of ice melt and the lure of valuable natural resources, competition over seafloor claims is expected to be fierce.

Decisions made under Article 76 will be binding. Thus, once these decisions are made, the consequent redrawing of undersea maps will have profound effects on regional nationalism and access to resource wealth. Successful claimants will determine access, set the environmental rules governing exploration and exploitation, and control royalties and pricing. However, drilling, pipeline transport, and shipping will all remain dangerous even in an ice-free environment. Moreover, full exploitation of the fuel and mineral resources found in the Arctic seafloor could contribute to global warming, enhancing a warming feedback cycle that may further facilitate research and mining, but only at the expense of global sustainability.

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• Further Reading

Cressey, Daniel. "The Next Land Rush." *Nature* 451 (January 3, 2008): 12-15. Science-news feature discussing surveying efforts to determine the international legitimacy of Arctic seafloor claims. References.

Funk, McKenzie. "Arctic Land Grab." *National Geographic*, May, 2009, pp. 104-121. Excellent story describing international claims to Arctic seafloor resources and the relationship of contemporary and future claims to global warming. Multiple maps depict land claims, drilling operations, and ice loss since 1980.

Krajick, Kevin. "Race to Plumb the Frigid Depths." *Science* 315 (March 16, 2007): 1525-1528. Science-news feature discussing Russia's claim to Arctic seafloor resources.

Moore, T. C., et al. "Sedimentation and Subsidence History of the Lomonosov Ridge." *Proceedings of the Integrated Ocean Drilling Program* 302 (2006): 1-6. One of many papers published online by the IODP on the geology of the Arctic Ocean. Describes the geologic history encoded in core samples from the Lomonosov Ridge.

See also: Antarctic Treaty; Arctic; Arctic peoples.

Arrhenius, Gustaf

Swedish oceanographer and geochemist

Born: September 5, 1922; Stockholm, Sweden

Arrhenius determined that ocean sedimentation can be used to reconstruct paleoclimates. This reconstruction provides a basis for projecting future climates.

• Life

Gustaf Arrhenius—the son of Dr. Olof Vilhelm Arrhenius, a chemist, and the grandson of the Nobel laureate Svante August Arrhenius—was born into a family history of scientists, Arrhenius naturally chose science as his career field. Even in his teens, his fascination with oceanography was evident, when, for a science project, he made a study of the physical and chemical properties of the fjord where he lived. After college, he was offered a position as geochemist on two deep-sea expeditions.

Arrhenius's first expedition was in 1946 on the ship *Skagerak*; the crew tested a new piston corer invented by Borje Kullenberg, as well as new seismic and optical techniques in the Mediterranean and eastern Atlantic. The expedition was a success. The second expedition was an eighteen-month (1947-1948) trip around the world. This trip supplied the cores from the east equatorial Pacific region that Arrhenius studied for his Ph.D. While on the expedition, Arrhenius flew back to England to marry Eugenie de Hevesy, the daughter of George de Hevesy, who worked with radioisotopes. The Arrheniuses would have three children, Susanne, Thomas, and Peter, and settle in La Jolla, California.

During the time that Arrhenius was working on the cores, Roger Revelle invited him to join the Scripps Institution of Oceanography in San Diego, California, as a visiting research oceanographer in time for the Capricorn expedition to the Marshall Islands. After the expedition, Arrhenius studied cores collected by the expedition for the western Pacific region. He remained at Scripps thereafter. Arrhenius received a Ph.D. in 1953 from Stockholm University and became an associate professor of biogeochemistry at Scripps in 1956. During these years, he studied crystal structures of natural and synthetic materials, superconductivity, space chemistry, prebiotic chemistry, and the earliest sedimentary records of Earth, Mars, and the moon. Arrhenius has published over 150 articles and books.

• Climate Work

Arrhenius analyzed the deep-sea cores from the east equatorial Pacific region for carbonate, humus carbon, nitrogen, and phosphorus in his father's laboratory. The cores were 19 meters long and represented the last one million years. Using his data and data from other analyses—such as the analysis of Radiolaria (amoebid protozoa with intricate mineral skeletons), diatoms (unicellular algae containing silica), foraminifera (amoeba-like animals that grow shells), and coccoliths (calcite plates from phytoplankton, a single-celled type of algae)—Arrhenius was able to determine a cyclic nature of the sedimentation.

Sediment is an indication of the condition of the ocean above. The nature of the ocean is an indication of the atmosphere above the ocean. Arrhenius was able to determine the dates of the different sections of the cores from carbon 14 studies and learned that the ice ages had a cyclic nature during the period of time, the Pleistocene era, covered by those deep-sea cores. In later years, that study was expanded to 380 million years and to sediments from all around the world.

By determining Earth's climatological history, scientists are better able to project the planet's climatological future. Arrhenius's grandfather, Svante, had predicted that if a large amount of carbon dioxide were released into the atmosphere, it would cause changes in the climate. Arrhenius's work helps set a baseline for scientists seeking to determine whether modern climate change is anthropogenic or natural.

C. Alton Hassell

• Further Reading

Arrhenius, Gustaf. "Carbon Dioxide Warming of the Early Earth." *Ambio* 26, no. 1 (February, 1997): 12-16. Arrhenius returns to the subject matter of his early work, the climate of ancient times, commenting on it from the point of view of later endeavors.

_______. "Oral History of Gustaf Olof Svante Arrhenius." Interview by Laura Harkewicz. San Diego, Calif.: Scripps Institution of Oceanography Archives, 2006. Arrhenius discusses his career and his association with the Scripps Institution of Oceanography.

"G. Arrhenius' Analyses of Ocean-Floor Sediment Cores Taken on the Swedish Deep-Sea Expedition." *Bulletin of the Geological Society of America* 63 (May, 1962): 515-517. Short note describing Arrhenius's Ph.D. research. Bibliography.

Sears, Mary. *Oceanography: Invited Lectures Presented at the International Oceanographic Congress Held in New York, 31 August-12 September 1959*. Washington, D.C.: International Oceanographic Congress, 1959. Includes a summary of the concept that the climate leaves a record in the sedimentation on the ocean floor in the chapter titled "Geological Record on the Ocean Floor." Illustrations, charts, maps.

Wang, Y., G. Arrhenius, and Y. Zhang. "Drought in the Yellow River: An Environmental Threat to the Coastal Zone." *Journal of Coastal Research* 34

(2002): 503-515. Summarizes climatological effects contributing to Yellow River drought and its consequences for the environment. Bibliography.

See also: Arrhenius, Svante August; Ice cores; Paleoclimates and paleoclimate change; Sea sediments.

Arrhenius, Svante August

Swedish physical chemist

Born: February 19, 1859; Castle of Vik, near Uppsala, Sweden
Died: October 2, 1927; Stockholm, Sweden

Sometimes called the "father of climate change," Arrhenius was the first to quantify the relationship between enhanced or diminished atmospheric CO_2 concentrations and the elevation or depression of Earth's surface temperature, which later inspired others to develop more sophisticated mathematical models of global warming.

• Life

A surveyor's son and a child prodigy who was reading and calculating by age three, Svante August Arrhenius was a brilliant student throughout his education in Uppsala, Sweden, at the elementary, high school, and university levels. After receiving his bachelor's degree from Uppsala University, Arrhenius traveled in 1881 to Stockholm, where, at the Physical Institute of the Swedish Academy of Sciences, he began his lifelong interest in the conductivities of such electrolytes as sodium chloride. Besides an experimental section dealing with electrolytic conductivities, his doctoral dissertation contained a theoretical portion in which he proposed the revolutionary idea that, in very dilute solutions, electrolytes are present as charged atoms or groups of atoms (called ions). Incredulous over this radical theory, his examiners passed him but "without any praise," the lowest category.

After receiving his doctorate in 1884, Arrhenius studied and conducted research with some influential European scientists who were establishing the new field of physical chemistry, and he developed equations describing how rates of chemical reactions increased with temperature. His academic career comprised increasingly prestigious positions at Uppsala University (1884-1891), Stockholm University (1891-1905), and the Nobel Institute for Physical Chemistry (1905-1927). In 1903, he became the first Swede to win the Nobel Prize, which conferred official approval on his electrolytic theory of dissociation. Although his most important contributions were in physical chemistry, he also developed interesting ideas in immunochemistry, regarding the equilibrium between toxins and antitoxins, and geology, regarding the cause of ice ages. In exobiology, his theory of panspermia posited that cosmic microorganisms originated life on Earth. After the end of an early two-year marriage, which produced a son, he married Maria Johansson, with whom he had two daughters and a son. He died in Stockholm in 1927 but was buried in Uppsala, the city of his youth and early accomplishments.

• Climate Work

In his famous 1896 paper on climate change, Arrhenius acknowledged the influence of such precursors as Joseph Fourier and John Tyndall. In 1825, Fourier had grasped that Earth's atmosphere acts "like the glass of a hot-house," letting through high-energy (ultraviolet) radiation but retaining low-energy (infrared) radiation. In 1859, Tyndall, using spectrophotometry, discovered that certain gases, such as water vapor and carbon dioxide (CO_2), had the power to absorb ultraviolet rays. Arrhenius became interested in this phenomenon because of his curiosity about the cause of the ice ages. Earth's ice sheets had expanded when the global temperature was low and retreated when it was high, and Arrhenius speculated that changes in atmospheric CO_2 concentrations might explain these variations.

In 1895, Arrhenius presented a paper to the Stockholm Physical Society titled "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground." He was not a climatologist, but he had the ability to take the data collected by others and forge a mathematical model of how even small amounts of "carbonic acid" (CO_2) could affect global temperatures. For example, he calculated that a modest decline in atmospheric CO_2 would be sufficient to lower global temperatures by 4° to 5° Celsius, sufficient to cause the spread of ice sheets between the 40th and 50th northern parallels. On the other hand, particularly in his later writings, he understood that doubling concentrations of atmospheric CO_2 would lead surface temperatures to rise by about 5° Celsius.

In Arrhenius's view, atmospheric CO_2 was due to "volcanic exhalations," organic decay, the burning of coal, and the decomposition of carbonates. He also understood that greater human populations with increased energy use would result in higher levels of atmospheric CO_2, with concomitant global warming. He did not see such warming as detrimental, however, for he believed that warmer climates would lead to better harvests and fewer famines.

Svante August Arrhenius. (©The Nobel Foundation)

Some scientists found Arrhenius's calculations implausible, because they were based on a highly oversimplified model of the Earth's extremely complex atmosphere. Geologists rejected his theory as an explanation for the ice ages, since he was unable to find a satisfactory mechanism for the removal of so much CO_2 from the atmosphere (later analyses of many ice cores falsified Arrhenius's theory). Other scientists were unconcerned about anthropogenic increases in atmospheric CO_2, because they felt that oceans and plants would mitigate any CO_2 buildup.

It was not until after World War II, when advanced technologies resulted in improved atmospheric data and larger and faster computers supported more rigorous mathematical models, that climatologists were better able to understand past, present, and future concentrations of atmospheric CO_2 and other greenhouse gases. To many of these scientists, Arrhenius became an admired predecessor, especially when, during the 1970's and 1980's, CO_2 was recognized as the key molecule in climate change. Like his theory of ionic dissociation, which was initially ridiculed then widely accepted, Arrhenius's theory of the influence of CO_2 on global temperatures passed through a long period of rejection before it achieved the scientific consensus that has now become the basis of significant political actions.

Robert J. Paradowski

- **Further Reading**

Arrhenius, Svante. "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground." *Philosophical Magazine and Journal of Science*. 5th ser. 41 (April, 1896): 237-275. An English translation, also available online, of the paper presented to the Stockholm Physical Society that some see as pivotal in later developments of the study of climate change.

Christianson, Gale E. *Greenhouse: The Two-Hundred-Year Story of Global Warming*. Washington, D.C.: Walker, 1999. Presents an illuminating survey of the history of global warming, including Arrhenius's contributions.

Crawford, Elisabeth. *Arrhenius: From Ionic Theory to the Greenhouse Effect*. Canton, Mass.: Science History, 1996. This biography also contains a historical analysis of Arrhenius's scientific work along with a critical discussion of several misinterpretations of his role in the story of climate change.

Fleming, James Rodger. "Global Environmental Change and the History of Science." In *The Modern Physical and Mathematical Sciences*. Vol. 5 in *The Cambridge History of Science*, edited by Mary Jo Nye. New York: Cambridge University Press, 2003. This updated recapitulation of the author's *Historical Perspectives on Climate Change* (1998) analyzes Arrhenius's precursors, his own contributions, and his successors. Many notes to primary and secondary sources.

See also: Carbon dioxide; Greenhouse effect; Greenhouse gases.

Asia-Pacific Partnership

- **Category:** Laws, treaties, and protocols
- **Date:** Announced July 28, 2005; launched January 12, 2006

The Asia-Pacific Partnership is a pact designed to increase the development and dispersal of new technologies in order to reduce the emission of GHGs.

- **Participating nations:** Australia, Canada, China, India, Japan, South Korea, United States

- **Background**

When the Kyoto Protocol to the United Nations Framework Convention on Climate Change was adopted on December 11, 1997, several industrialized nations had reservations about its fairness and potential effectiveness. The United States, the only developed nation that did not ratify the Kyoto Protocol, believed that complying with the treaty would put undue strain on the U.S. economy. President George W. Bush objected in 2001 to provisions that called for the United States to reduce its carbon emissions while exempting China and India, which with the United States were among the world's largest emitters of greenhouse gases (GHGs). India and China, on the other hand, objected to the idea that they should deny technological advancement to their large and poor populations. Bush promised to develop an alternative plan that would address GHG emissions more effectively than the Kyoto Protocol while at the same time eradicating poverty and protecting human health, American jobs, and American investments.

The Asia-Pacific Partnership on Clean Development and Climate (APP) was announced on July 28, 2005, after months of closed-door negotiations. At the APP's first ministerial meeting in Sydney, Australia, in January, 2006, ministers created a formal charter to provide a structure for the partnership, as well as a work plan. According to the White House, the goals of the APP grew out of the work of earlier initiatives, including the Carbon Sequestration Leadership Forum, the International Partnership for a Hydrogen Economy, and Methane to Markets. With Canada, which joined the APP in 2007, member countries are responsible for about one-half of the world's GHG emissions and contain about one-half of the world's population. Australia, China, India, and the United States are the world's four largest coal-consuming nations.

- **Summary of Provisions**

The formal documents do not include timetables, targets, or dedicated funding; these aspects of the partnership are voluntary and are set individually by each country. The stated goals of the APP are to develop new clean technologies, increase the use of existing clean technologies, address growing energy needs, reduce GHG emissions, protect economic development, enhance international collaboration, and find ways to make use of the private sector.

Eight public-private task forces were established at the Sydney meeting to focus on aluminum, buildings and appliances, cement, cleaner fossil energy, coal mining, power generation and transmission, renewable energy and distributed generation, and steel. In its discussions of the work plan, the Bush administration emphasized the potential of clean coal, coal gasification, and nuclear power, as well as the increased opportunity for investment that would drive private industry innovation.

The APP's work plan describes several specific tasks. Partners will identify possible storage sites for carbon sequestration, develop appropriate power solutions for rural areas, find cleaner ways to manufacture cement and steel, and improve the energy efficiency of buildings. Other projects include creating renewable energy hubs in rural areas of India and China, granting scholarships for studying photovoltaics and solar energy engineering, and developing small wind turbines for remote areas.

• Significance for Climate Change

Observers are divided about the possible impact of the Asia-Pacific Partnership. Supporters argue that the flexibility inherent in the partnership will lead to greater compliance and success, while complementing the work of the Kyoto Protocol. Governments and businesses have welcomed the APP as an alternative to the Kyoto Protocol, which some have seen as too restrictive and not cost-effective. Opponents, including many environmental groups, contend that since the partnership's targets are voluntary and since each nation is responsible for monitoring its own compliance, little will be achieved. They believe that the APP was created to supplant, not to complement, the Kyoto Protocol. Some opponents, however, have acknowledged that the formation of APP was a sign of progress. Nonetheless,

From left: Japanese minister of the environment Yuriko Koike, U.S. secretary of energy Samuel Bodman, Australian minister for foreign affairs Alexander Downer, and South Korean minister of commerce Lee Hee-beom participate in the inaugural meeting of the Asia-Pacific Patnership. (David Gray/Reuters/Landov) in the first two years after the formation of the Asia-Pacific Partnership, none of the member countries succeeded in lowering its GHG emissions.

Cynthia A. Bily

• **Further Reading**

Eichengreen, Barry, Yung Chul Park, and Charles Wyplosz, eds. *China, Asia, and the New World Economy*. New York: Oxford University Press, 2008. Collection of ten essays, including two about Asia's increasing demands for energy and its role in global climate change.

Flannery, Tim. "The Ominous New Pact." *The New York Review of Books* 53, no. 3 (February 23, 2006): 24. Examines the political influence of the Asia-Pacific Partnership and the implications of its reluctance to reduce the consumption of coal.

Gerrard, Michael B., ed. *Global Climate Change and U.S. Law*. Chicago: American Bar Association, 2007. Comprehensive reference book covering legal issues involved in climate change, as well as the Asia-Pacific Partnership and other international frameworks in which the United States participates.

Klare, Michael T. *Rising Powers, Shrinking Planet: The New Geopolitics of Energy*. New York: Metropolitan Books, 2008. Argues that it is increasingly important that the United States cooperate with "petro-superpowers," including Russia, China, and India, in developing alternative energy and working against global climate change.

See also: Byrd-Hagel Resolution; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. energy policy.

Asthma

• **Category:** Diseases and health effects

• **Definition**

Asthma is an inflammatory disease brought on by an allergen or other environmental trigger. This trigger starts a complex interaction among immune system inflammatory cells (mast cells and eosinophils), their mediators (cytokines), the cells lining the airways (the airway epithelium), the smooth muscle that controls the diameter of the airways, and the nervous system. The inflammatory process results in airway hyper-reactivity or bronchial constriction, airway swelling (edema), and an overproduction of mucus, which may form an airway-blocking mucus plug.

Clinically, asthma is characterized by periodic airway obstruction resulting from constriction of lung airways or bronchioles. The increased effort required to overcome this obstruction results in the symptoms of breathlessness, wheezing, coughing, and chest tightness. In severe cases, airway constriction limits the amount of oxygen transported to the bloodstream, leading to hypoxia, which may be life threatening. Importantly, this increase in airway resistance can be reversed with inhalation of medication or a bronchiole dilator that relaxes the airway's smooth muscle and rapidly reduces the symptoms. Airway constriction may occur in response to numerous environmental factors, such as allergens (molds, dust, or pollen), but it may also be induced by cold air, exercise, or occupational exposure. Avoiding allergens can be an effective way of controlling asthma in some patients.

• **Significance for Climate Change**

Around 34.1 million Americans have been diagnosed with asthma by a health care professional. Risk factors for developing asthma include a family history of allergic disease, elevated levels of the allergen-specific immunoglobulin E (IgE), viral respiratory illnesses, exposure to allergen triggers, obesity, and lower income levels. Some studies have shown that exposure to allergens from dust mites during a baby's first year may later lead to development of asthma, while others may develop asthma symptoms following a respiratory-tract viral infection. Increased enviromental temperatures can lead to increased allergens in the environment. Global warming may promote growth of molds and fungi that may increase lung inflammation and trigger asthma attacks. Moreover, higher temperatures and higher carbon dioxide levels, along with an earlier spring, stimulate plant growth, causing more pollens to be released into the air. Increased temperatures are also predicted to increase humidity in urban areas, and each 10 percent increase in indoor humidity has been shown to increase the incidence of asthma symptoms by 2.7 percent. With an epidemic of childhood asthma observed in Western countries, the need for new treatments focusing on reducing the inflammatory disease process, along with the recognition of environmental triggers, will result in better disease control for asthma patients in the future.

Robert C. Tyler

See also: Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Air quality standards and measurement; Diseases; Mold spores.

Atlantic heat conveyor

- **Categories:** Oceanography; meteorology and atmospheric sciences

• Definition

The Atlantic heat conveyor transfers heat from the equator northward to the polar region of the Atlantic Ocean, through the meridional overturning circulation (MOC). Because the Earth is a sphere, incoming solar radiation heats the surface of the Earth unevenly, with the equator receiving a greater amount of heat per surface area than the polar regions. This uneven heating creates temperature gradients that drive atmospheric currents (wind) and surface currents in the ocean.

In the Atlantic Ocean, the Gulf Stream is the surface current that transports heat from the equator to the polar region. The Gulf Stream is a western boundary current that originates in the Gulf of Mexico and travels north along the east coast of the United States and Newfoundland. Near 50° north, the Gulf Stream splits into two branches: the North Atlantic drift (or North Atlantic current) and the Azores current. The North Atlantic drift (NAD) flows northeastward toward northern Europe, while the Azores current flows east toward the Azores and then south as the Canary current. The Gulf Stream is a large, fast-moving current, transporting between 30 million and 150 million cubic meters of water per second. This flow of water transports approximately 1.4 petawatts (1.4×10^{15} watts) of heat per year. As the Gulf Stream moves north and mixes with cooler surface water from the poles, it releases this heat.

The Atlantic heat conveyor may be responsible for maintaining a milder climate in northern Europe, as compared to Newfoundland, which is located at the same latitude. However, this idea has been challenged by scientists, who hypothesize that atmospheric heat transport is more important in maintaining a mild climate in northern Europe than is oceanic heat transfer.

• Significance for Climate Change

The Atlantic heat conveyor delivers a large amount of heat to the Arctic region from the equator, making it an important component of the global climate system and of any changes in that system. One consequence of global warming is the melting of glaciers in the Arctic, which would lead to a large flux of freshwater into the surface waters of the Greenland Sea. This cap of freshwater could serve as a barrier to the northward flow of the Gulf Stream, thereby blocking the Atlantic MOC and the heat conveyor. Thus, according to this conceptual model, projected global warming would actually lead to a localized cooling of the Northern Hemisphere, particularly Europe.

In 2005, scientists from the National Oceanography Center presented data to suggest that the Atlantic MOC had slowed during the late twentieth century. These data were subsequently challenged by other scientists, who presented different data sets that showed no MOC slowdown. Despite the controversy regarding whether such slowdown has occurred, computer models consistently indicate that a shutdown of the Atlantic heat conveyor could lead to a lesser warming or even cooling in the Northern Hemisphere as a result of global warming. Geologic evidence suggests that the Younger Dryas, a time of global cooling that lasted from 12,800 to 11,500 years before present, may have been caused by MOC collapse in the Atlantic because of a large influx of freshwater to the North Atlantic from the emptying of glacial Lake Agassiz.

The hypothesis of the Atlantic heat conveyor has been criticized by scientists from the Lamont-Doherty Earth Observatory, who believe that the atmospheric transport of heat and the slow response time of the ocean are the main reasons for Europe's mild climate. Additionally, they point to long waves in the atmosphere, created as air masses flow around the Rocky Mountains, as a third potential cause of a mild European climate. According to this hypothesis, global warming will not stop the Atlantic heat conveyor, nor will it lead to a cooling of Europe. This view, however, is not widely held among climate scientists or policy makers. In its Fourth Assessment Report, released in 2007, the Intergovernmental Panel on Climate Change (IPCC) found that there was insufficient evidence to determine if there were trends—either weakening or increasing—in the magnitude of the Atlantic heat conveyor.

Anna M. Cruse

- **Further Reading**

Alley, Richard B. "Abrupt Climate Change." *Scientific American* 291, no. 5 (November, 2004): 62-69. Article written by one of the pioneers of ice-core records; explains the science behind abrupt climate change and thermohaline circulation.

Schellnhuber, Hans, et al., eds. *Avoiding Dangerous Climate Change*. New York: Cambridge University Press, 2006. Collection of papers presented by leading climatologists at the Avoiding Dangerous Climate Change conference, hosted by the British government in 2005. In particular, chapters 5 and 6 discuss THC in the Atlantic Ocean. Figures, tables, references.

Seager, Richard. "The Source of Europe's Mild Climate." *American Scientist* 94, no. 4 (July/August, 2006): 334-341. Dissenting hypothesis on the role of the Atlantic heat conveyor in maintaining a mild climate in Europe, written by a leading climate scientist.

Vellinga, Michael, and Richard A. Wood. "Global Climatic Impacts of a Collapse of the Atlantic Thermohaline Circulation." *Climatic Change* 54, no. 3 (August, 2002): 251-267. Presents data from a computer model to determine the rate of climate response if thermohaline circulation in the Atlantic were to collapse. Among the variables investigated are air temperature, rainfall patterns, the location of the Inter-Tropical Convergence Zone, and variations in oceanic primary productivity.

See also: Europe and the European Union; Gulf Stream; Intergovernmental Panel on Climate Change; Meridional overturning circulation; Ocean dynamics; Younger Dryas.

Atlantic multidecadal oscillation

- **Categories:** Oceanography; meteorology and atmospheric sciences

- **Definition**

The Atlantic multidecadal oscillation (AMO) is a global-scale mode of multidecadal climate variability (that is, it is an example of a cyclical or semi-cyclical pattern of climate change that repeats on a timescale on the order of several decades). The AMO is based on sea surface temperatures in the North Atlantic Ocean between the equator and 70° north latitude. Generally, the AMO is computed as a detrended ten-year running mean of these sea surface temperatures and represents variability across the entire North Atlantic basin.

The AMO exhibits a long-term, quasi-cyclic variation at timescales of fifty to seventy years. Modeling studies reveal that multidecadal variability in the North Atlantic Ocean is dominated by this single mode of sea surface temperature variability. The range in AMO values between warm and cold extremes is only about 0.6° Celsius; however, because the North Atlantic Ocean is so large, even small differences in sea surface temperatures represent extremely large exchanges in energy between the ocean and atmosphere.

The predominant hypothesis is that the AMO is primarily driven by the thermohaline circulation. This hypothesis is supported by both instrumental and climate-model studies. The thermohaline circulation is the large-scale ocean circulation that moves water among all of the world's oceans and is driven by density differences in ocean water caused by heat and freshwater fluxes. When the thermohaline is fast, warm water is moved from tropical areas into the North Atlantic Ocean and the AMO enters a warm phase. When the thermohaline is slow, warm water is not readily moved into the North Atlantic Ocean and the AMO enters a cool phase. During the twentieth century, the AMO was in a warm phase from 1926 through 1963, and it was in cool phases from 1905 through 1925 and 1964 through 1994. In 1995, it entered another warm phase.

Research has suggested that the North Atlantic Ocean may provide information that explains significant amounts of multidecadal climate variability. For example, when the AMO is in a warm phase, the likelihood of drought in North America increases, and when the AMO is in a cool phase, the likelihood of drought in North America decreases. Analysis of major U.S. droughts during the last century indicates that North Atlantic Ocean surface temperatures were warm during the 1930's and 1950's droughts, as well as during the dry period that began in the late 1990's. In contrast, both the early (1905-1920) and late (1965-1995) twentieth century pluvials in the western United States were associated with cool North Atlantic Ocean surface temperatures. The AMO also has been linked to the occurrence of hurricanes in the North Atlantic Ocean. During warm phases of the AMO, hurricanes are more frequent, whereas when the AMO is in a cool phase hurricane frequency decreases.

• Significance for Climate Change

Because the AMO is an important mode of multidecadal climate variability, there are a number of important implications of the AMO for the study of climate variability and change. Understanding what portion of climate variability is due to multidecadal variability, such as that driven by the AMO, allows the discrimination of anthropogenic changes in climate from natural variability. Knowledge of multidecadal climate variability, such as that indicated by the AMO, also has implications for defining and potentially estimating risks in agriculture, water resources, public health, and nature. Variability of the AMO also has an effect on global temperature, and the beginning of a new warm phase of the AMO in 1995 may have contributed to the strong warming of global temperatures in the years immediately following.

Some scientists suggest that if the AMO shifts into a cool phase, the cooling of North Atlantic Ocean surface temperatures may reduce the amount of global warming and may result in a leveling of global temperatures for about a decade. In addition, research has indicated that North Atlantic Ocean surface temperatures may have predictability on the order of a decade or longer, which has important implications for climate forecasting.

The actual physical mechanisms that explain the associations between the North Atlantic Ocean and global climate are still unknown, but several possible mechanisms have been recognized. North Atlantic Ocean surface temperatures may affect Northern Hemisphere atmospheric circulation, such that the frequency of zonal versus meridional atmospheric flow is modulated. Decadal-to-multidecadal variability of North Atlantic Ocean surface temperatures may be aliasing for low-frequency or lagged variations of the tropical oceans. North Atlantic Ocean surface temperatures may be influencing the location and strength of subtropical high pressures. Finally, the North Atlantic Ocean may be modulating the strength and variability of tropical Pacific Ocean surface temperatures.

Gregory J. McCabe

• Further Reading

Enfield, D. B., A. M. Mestas-Nuñez, and P. J. Trimble. "The Atlantic Multidecadal Oscillation and Its Relation to Rainfall and River Flows in the Continental U.S." *Geophysical Research Letters* 28 (2001): 277-280. Provides an explanation of the effects of the AMO on precipitation and streamflow in North America.

Knight, Jeff R., Chris K. Folland, and Adam A. Scaife. "Climate Impacts of the Atlantic Multidecadal Oscillation." *Geophysical Research Letters* 33, no. 17 (September, 2006). Describes some of the climate effects of variations in the AMO.

McCabe, G. J., M. A. Palecki, and J. L. Betancourt. "Pacific and Atlantic Ocean Influences on Multidecadal Drought Frequency in the United

States." *Proceedings of the National Academy of Sciences* 101 (2004): 4136-4141. Identifies a link between the AMO and drought occurrence in the western United States.

Sutton, R. T., and D. L. R. Hodson. "Climate Response to Basin-Scale Warming and Cooling of the North Atlantic Ocean." *Journal of Climate* 20 (2007): 891-907. Discusses the use of a climate model to assess the effects of basin-wide warming and cooling of the North Atlantic Ocean.

Zhang, Rong, Thomas L. Delworth, and Isaac M. Held. "Can the Atlantic Ocean Drive the Observed Multidecadal Variability in Northern Hemisphere Mean Temperature?" *Geophysical Research Letters* 34, no. 2 (January, 2007). Discusses a link between the AMO and Northern Hemisphere temperature variability.

See also: Atlantic heat conveyor; Ekman transport and pumping; El Niño-Southern Oscillation; La Niña; Meridional overturning circulation; Sea surface temperatures; Thermohaline circulation.

Atmosphere

• **Category:** Meteorology and atmospheric sciences

Earth's climate system has five components: the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. Among these components, the atmosphere is the most sensitive to changes in Earth's climate. Thus, current data suggesting global warming are mostly atmospheric, observed as an increase of near-surface air temperature over the last hundred years.

• Key concepts

condensation: the transformation of a substance from its gaseous to its liquid state, accompanied by a release of heat

convection: motion in a fluid that results in the transport and mixing of the fluid's physical properties, such as heat

coupled atmosphere-ocean models: computer simulations of alterations in and interactions between Earth's atmosphere and oceans

El Niño and La Niña: periodic warming and cooling of the eastern tropical Pacific Ocean that affects global weather patterns

greenhouse gases (GHGs): atmospheric trace gases that allow sunlight to reach Earth's surface but prevent heat from escaping into space

latent heat: the heat released or absorbed by a change of state, such as condensation

• Background

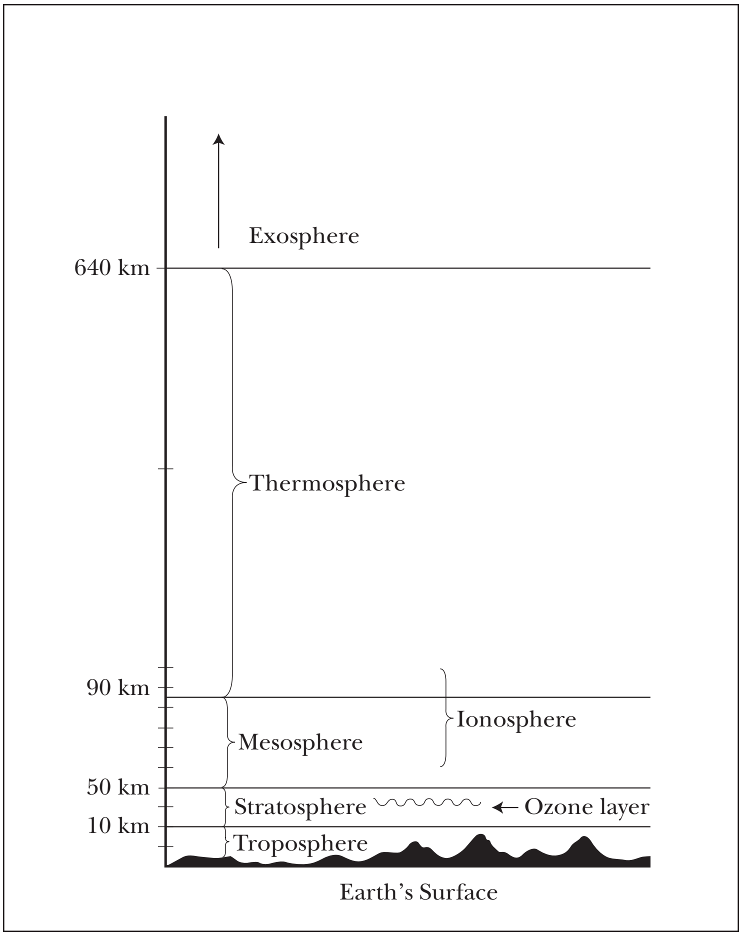
The atmosphere is a layer of gas surrounding the Earth. It is a mixture of several components, mostly gas-phased molecules. The total weight of Earth's atmosphere is about 5.08 quadrillion metric tons. Its existence makes possible life on Earth, and changes in its composition may destroy life on Earth.

The atmosphere's various physical properties affect many aspects of human existence. Its optical properties make the sky blue and create rainbows and auroras. It carries sound waves, making aural communication possible. It also propagates heat, and seasonal changes in atmospheric thermal properties result in cooler and warmer temperatures at different times of year. More generally, the weather is a function of the atmosphere: Wind, precipitation, humidity, and storm systems are all atmospheric phenomena.

• Atmospheric Structure

Because of the Earth's gravity, most atmospheric molecules are distributed very close to the Earth's surface. That is why the atmosphere is relatively thin. More than 90 percent of Earth's atmosphere lies within 32 kilometers of the planet's surface, and the lower atmosphere begins to shade into the upper atmosphere and outer space at an altitude of about 80 kilometers. This distance is only a fraction of the Earth's radius, which is about 6,400 kilometers.

The atmosphere's density and pressure decrease steadily with altitude. Altitudinal variations in temperature, on the other hand, are more complex. The temperature decreases with altitude from the surface to about 10-16 kilometers high. From that height to about 20 kilometers, the temperature remains relatively constant. From 20 to 45 kilometers,



Above the homosphere, collisions among atoms and molecules are infrequent, and the air is unable to keep itself well mixed. This layer is therefore called the heterosphere. Furthermore, above the stratosphere, large concentrations of ions and free electrons exist, in a layer known as the ionosphere.

- **The Energy Budget and the Greenhouse Effect**

The Sun is the ultimate energy source for the Earth. Solar energy reaches the Earth via solar radiation. During daytime, the Earth is warmed by the Sun, while during nighttime the Earth cools. The sunlight that the Earth receives is a form of electromagnetic radiation with a relatively short wavelength, called "shortwave radiation." When the Earth cools during night, the heat it releases into space is another form of electromagnetic radiation with a relatively long wavelength—"longwave radiation," or infrared radiation (IR).

If Earth did not have an atmosphere, it would simply receive shortwave solar radiation during the day and give out longwave radiation at night. When an equilibrium was reached (meaning that the amount of energy received was equal to the amount of energy given out), the Earth would be balanced at an equilibrium temperature. This temperature would be much lower than is the actual temperature on Earth: Some scientists have estimated it at about –18° Celsius. Earth's surface temperature is thus much warmer than it would be without an atmosphere.

This difference in temperature is a result of the greenhouse effect. Shortwave solar radiation can mostly penetrate Earth's atmosphere and reach the its surface. Infrared radiation, by contrast, is intercepted by the atmosphere, and some of this longwave radiation is reflected back to Earth's surface, increasing the equilibrium temperature of the planet. The strength of the greenhouse effect

the temperature increases with height, and at altitudes of 45-50 kilometers it again remains constant. Above 50 kilometers, the temperature again begins to decrease with altitude, continuing until reaching a height of about 80 kilometers. From that height to about 90 kilometers, temperature is constant. From 90 kilometers to the end of Earth's atmosphere, temperature increases with altitude. Based on these altitudinal temperature variations, scientists divide the atmosphere into sections: the troposphere, tropopause, stratosphere, stratopause, mesosphere, mesopause, and thermosphere.

The atmosphere can also be classified according to its composition. In the lower atmosphere (below 80 kilometers), weather convection and turbulence mixing keep the composition of air fairly uniform. This area is therefore known as the homosphere.

and the warmth of Earth's equilibrium temperature are dependent on the specific composition and properties of the atmosphere. Changes in atmospheric chemistry can significantly alter Earth's energy balance and equilibrium temperature.

• Atmospheric Composition, Chemistry, and GHGs

The atmosphere is composed of nitrogen (about 78 percent by volume), oxygen (21 percent), and various trace gases (totaling about 1 percent). If all trace gases were removed, these percentages for nitrogen and oxygen would remain fairly constant up to an altitude of about 80 kilometers. At the planet's surface, there is an approximate balance between the destruction (output) and production (input) of these gases.

The two most plentiful components of the atmosphere, nitrogen and oxygen, are of significance to life on Earth. Humans and animals cannot live without oxygen. By contrast, the trace noble gases, such as argon, neon, and helium, are not very active chemically. Water vapor is distributed inconsistently in the lower atmosphere; its concentration varies greatly from place to place and from time to time, and it can constitute from 0 to 4 percent of local air. This variable concentration is one reason that water vapor is so important in influencing Earth's weather and climate.

Water vapor provides the main physical substance of storms and precipitation, and its condensation into liquid water generates the large amount of energy (latent heat) necessary to initiate powerful and violent storms. Water vapor is also a greenhouse gas (GHG): It strongly absorbs longwave radiation and reemits this radiation back to the Earth, causing global warming. Clouds, which are generated from water vapor, also play an extremely important role in climate and climate change.

Another very important GHG is carbon dioxide (CO_2). Observations indicate that the concentration of CO_2 in the atmosphere has been rising steadily for more than a century. The increase of CO_2 concentration indicates that CO_2 is entering the atmosphere at a greater rate than its rate of removal. This rise is largely attributable to the burning of fossil fuels, such as coal and oil. Deforestation also contributes to the increase in atmospheric CO_2 concentration. Estimates project that by sometime in the second half of the twenty-first century, CO_2 levels will be twice as high as they were early in the twentieth century. Other GHGs include methane, nitrous oxide, and chlorofluorocarbons.

Ozone (O_3) is another important gas for Earth's weather and climate. At Earth's surface, O_3 is a major air pollutant, and it is closely monitored for its effects on air quality. However, at upper levels (about 25 kilometers high), O_3 forms a shield for Earth's inhabitants from harmful ultraviolet solar radiation. For this reason, the loss of O_3 high in the atmosphere as a consequence of human activity has become a serious global-scale issue. One of the examples of O_3 depletion is the O_3 hole found over Antarctica. Finally, aerosols, including particulate matter, are also important constituents of the atmosphere, affecting weather formation, air quality, and climate change.

• Weather and Climate

Atmospheric conditions can generally be classified as either weather or climate. Weather is a particular atmospheric state at a given time and place. Climate is an average of weather conditions at a given location over a period of time.

Weather includes many atmospheric phenomena of different scales, including middle latitude cyclones (extratropical cyclones), hurricanes (tropical cyclones), heavy rains and floods, mesoscale convective systems, thunderstorms, and tornadoes. Climate includes atmospheric conditions that are millennial, centennial, decadal, interannual, or seasonal. For example, global warming can occur on a centennial or longer timescale, an El Niño or La Niña episode will generally occur on an interannual timescale, and seasonal changes occur on relatively short timescales of months, weeks, or days.

• Global Warming and Climate Change

Earth's climate has changed constantly over its history. The planet has experienced many cold periods, as well as several warm periods. For example, about ten thousand years ago, the Earth cooled during a period known as the Younger Dryas, when the average global temperature was about 3° Celsius colder than it is today. However, about six thousand years ago, the Earth reached the middle of an interglacial period, known as the Mid-Holocene Maximum. The temperature then was 1° Celsius higher than today's norm. Some of the natural mechanisms causing this climatological variabilty include: drift of plate tectonics, volcanic activities, ocean circulations, variations in Earth's orbit, and solar variability.

The rapid warming that has occurred in the past hundred years seems to coincide with the socioeconomic development and industrialization of humankind. During the past century, human life and societies began to depend heavily on burning fossil fuels. As a result, increasing amounts of CO_2 have been added to the atmosphere. Global temperatures and CO_2 levels evince a consistent upward trend during the same period. Therefore, many scientists believe that human activity may have contributed to global warming.

Various coupled atmosphere-ocean models have projected that Earth will experience an average temperature increase over the course of the twenty-first century of between 1.4° and 5.8° Celsius. Some possible consequences of this global warming include higher maximum and minimum temperatures, more hot days and heat waves, fewer cold days and frost days, more intense precipitation events, more summer drying and drought, increased tropical cyclone intensity, increased Asian summer monsoon precipitation variability, intensified droughts and floods associated with El Niño events, and increased intensity of midlatitude storms. Global warming will also exert some profound effects on many other social and environmental issues. For example, the distribution of water resources and farming may be changed by future warmer climates. Warming-induced sea-level rise can have significant effects on many countries' coasts. Arctic sea-ice melting can also have geopolitical and economic consequences.

• Context

The atmosphere is central to almost all aspects of human existence, constituting not only the source of vital oxygen but also the medium of movement, sound, and weather. It is also the most variable component of Earth's climate system. Because that system is so complex and interconnected, changes in the atmosphere will inevitably result in changes to the rest of the system, some of which are extremely difficult to predict. At the same time, feedback from other components of Earth's environment may exert a significant influence on the atmosphere, including producing positive and negative feedback loops that help alter or maintain Earth's climate.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere.* 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Widely used introductory textbook on atmospheric science; covers a wide range of topics on weather and climate.

Climate Change Science Program, U.S. *Our Changing Planet.* Washington, D.C.: Author, 2006. Report by a committee established in 2002 to empower the U.S. national and global community with the science-based knowledge to manage risks and capitalize on opportunities created by changes in the climate and related environmental systems.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Comprehensive overview of global climate change published by a network of the world's leading climate change scientists under the auspices of the World Meteorological Organization and the United Nations Environment Programme.

_______. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon, et al. New York: Cambridge University Press, 2007. Companion volume to *The Synthesis Report* that provides more detail on various aspects of climate change and global warming.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere.* 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Introductory textbook that covers a wide range of atmospheric sciences.

See also: Atmospheric boundary layer; Atmospheric chemistry; Atmospheric dynamics; Atmospheric structure and evolution; Climate and the climate system; Climate change; Ekman transport and pumping; El Niño-Southern Oscillation; Greenhouse effect; Greenhouse gases; Hadley circulation; Inter-Tropical Convergence Zone; Mesosphere; Ocean-atmosphere coupling; Oxygen, atmospheric; Stratosphere; Thermosphere; Troposphere.

Atmospheric boundary layer

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Also known as the planetary boundary layer (PBL), the atmospheric boundary layer (ABL) is the lowest 10-20 percent of the troposphere, the lowest layer of the atmosphere. Its contact with a planetary surface directly influences its behavior. The ABL contains a disproportionately large amount of the mass and the kinetic energy of the atmosphere. It is the most dynamically active of the layers of Earth. The phrase "boundary layer" originates in the study of boundary layers in fluid flows: The boundary layer is the layer of fluid that is most influenced by friction with the Earth's surface. A defining characteristic of the ABL is turbulence caused by thermal convection, due to thermal buoyancy, and wind shear, due to frictional forces. The atmospheric boundary layer has three layers: the surface layer, the core, and the entrainment layer, also called the capping inversion layer.

• **Significance for Climate Change**

The atmospheric boundary layer is important for ensuring that Earth's atmospheric composition remains relatively homogeneous throughout, despite external heat and energy inputs. Consequently, it is important for ensuring that life can be sustained on Earth. ABL considerations are particularly important in the area of the urban environment. The development of large cities has changed the ABL in those areas, resulting in surface heating, and artificial boundary layers have developed that trap pollutants. Calculations of the boundary layer can help architects develop urban environments in such a way as to minimize impact on the boundary layer. ABL research can help improve weather forecasts, especially long-term forecasts and forecasts of longtime climate models. Without a properly constituted boundary layer, Earth would lose the unique conditions that make it hospitable to human existence.

The ABL is important meteorologically in the area of assessing convective instability. The entrainment zone (at the top of the ABL) acts as a lid on rising air parcels attributable to temperature inversion. If that entrainment layer is broken, capped air parcels can rise freely, resulting in vigorous convection that produces severe thunderstorms. When sunlight enters the atmosphere, a part of it—known as the albedo—is immediately reflected back to space; the remainder penetrates the atmosphere, and the Earth's surface absorbs it. This energy is then reemitted by the Earth back into the atmosphere in the form of longwave radiation. Carbon dioxide and water molecules absorb this energy, then emit much of it back toward Earth again. This delicate exchange of energy between the Earth's surface and the atmosphere is what keeps the average global temperature from changing drastically from year to year. When this exchange is disrupted, climate problems result.

Victoria Price

See also: Albedo feedback; Atmosphere; Atmospheric dynamics; Atmospheric structure and evolution; Planetary atmospheres and evolution; Stratosphere; Thermosphere; Thunderstorms; Troposphere; Weather forecasting.

Atmospheric chemistry

• **Categories:** Chemistry and geochemistry; meteorology and atmospheric sciences

The Earth's global temperature, as well as the amount of solar radiation reaching its surface, can be significantly influenced by changes in the concentrations of chemicals naturally present in the atmosphere, such as natural GHGs, and by anthropogenic chemicals, such as CFCs.

• Key concepts

anthropogenic: caused by humans

chlorofluorocarbons (CFCs): compounds of chlorine, fluorine, and carbon, popularly known by the trade name Freon

greenhouse effect: result of atmospheric trace gases that allow high-energy sunlight to reach the terrestrial surface but absorb low-energy heat that is radiated back

greenhouse gases (GHGs): tropospheric gases such as carbon dioxide, methane, and water vapor that cause the greenhouse effect

ozone layer: a stratospheric region containing relatively high concentrations of triatomic oxygen (ozone) that prevents much ultraviolet solar radiation from reaching Earth's surface

primary air pollutants: harmful substances that are emitted directly into the atmosphere

secondary air pollutants: harmful substances that result from the reaction of primary air pollutants with principal atmospheric components

stratosphere: an atmospheric region extending from about 17 to 48 kilometers above the Earth's surface

troposphere: an atmospheric region extending from the Earth's surface to about 17 kilometers high over equatorial regions and to about 8 kilometers high over polar regions

• Background

The significance of the Earth's atmosphere is vastly disproportionate to its size. Although its thickness relative to Earth's sphere is comparable to an apple's skin, it is essential for life. It was not until the eighteenth century that scientists began to understand the role of atmospheric gases such as oxygen and carbon dioxide (CO_2) in plant and animal life, and it was not until the end of the nineteenth century that scientists grasped the details of how soil microorganisms utilized atmospheric nitrogen to create compounds necessary for the health of plants and animals. Throughout the twentieth century, climatologists, atmospheric chemists, and others gathered information about how such anthropogenic gases as CO_2, methane, and nitrous oxide were increasing Earth's greenhouse effect and elevating the planet's average global temperature. This enhanced greenhouse effect fosters climate changes that are potentially so devastating that some scholars have called climate change the most important issue of the twenty-first century.

• Chemical Composition of the Earth's Atmosphere

Approximately three-quarters of the Earth's air mass is located in the troposphere, and dry air in this region is 78.1 percent nitrogen, 20.9 percent oxygen, and 0.93 percent argon by volume. The troposphere also contains trace amounts of many other gases, such as methane, various nitrogen oxides, ammonia, sulfur dioxide, and ozone, and these come from both natural and anthropogenic sources. Human activities have not changed the concentrations of the major gases in the atmosphere—nitrogen and oxygen—but scientific evidence accumulated over the past century indicates that human beings, particularly in advanced industrialized societies, are dramatically affecting the concentrations of certain trace gases. Examples of these include CO_2, methane, nitrous oxide, carbon monoxide, chlorofluorocarbons (CFCs), and sulfur dioxide. Some of these atmospheric trace gases, such as CFCs, result from certain industries and their products, such as refrigerants and aerosols. Others, such as CO_2 and sulfur dioxide, are produced by burning fossil fuels. Agricultural practices are also significant sources of such gases as methane and nitrous oxide.

Although the Earth's stratosphere contains much less matter than the troposphere, it contains similar proportions of such gases as nitrogen and oxygen. It differs markedly from the troposphere, however, in its concentrations of water vapor and ozone. Stratospheric water-vapor concentrations are only about one-thousandth of tropospheric conentrations, but ozone concentrations are much higher in the stratosphere. Ozone is localized in a layer ranging from about 15 to 35 kilometers above Earth's surface. This ozone layer, whose molecules are created when oxygen interacts with high-energy solar radiation, prevents about 95 percent of the Sun's ultraviolet radiation from reaching Earth's surface, where it could damage living organisms. The ozone layer also prevents tropospheric oxygen from being converted to ozone, which, in the lower atmosphere, is a dangerous air pollutant.

• Chemical Reactions in the Troposphere

Besides being home to such major gases as nitrogen and oxygen, the troposphere contains hundreds of other distinctive molecules, leading to myriad chemical reactions, some of which have an influence on climate change. Because oxygen is such a reactive species, many of these reactions are oxidations, and some scientists see these reactions as constituting a low-temperature combustion system. Fueling this combustion are chemicals released from both natural and artificial sources. For example, methane enters the troposphere in large amounts from swamp and bog emissions, termites, and ruminant animals. Human activities contribute a large number of organic compounds, and CO_2 and water are the end results of their oxidation. CO_2 and water vapor are powerful greenhouse gases (GHGs).

Atmospheric chemists have also been attempting to work out in detail the influence of chemical radicals on tropospheric gases. Such charged groups of atoms as the hydroxyl radical (composed of hydrogen and oxygen) play an important role in the daytime chemistry of the troposphere, and the nitrate radical (composed of nitrogen and oxygen) is the dominant nighttime oxidant. Fossil-fuel combustion is a significant contributor to tropospheric pollution. Particulates such as soot were a factor in some "killer smogs," and scientists have recently discovered that particulates contribute to global dimming, a lessening of sunlight's ability to penetrate particle-filled hazes and reach the Earth's surface. Sulfur dioxide, which is produced by the combustion of certain kinds of coal and oil, can be a primary air pollutant, since it is toxic to living organisms as well as damaging to buildings. It can also be a secondary air pollutant, because it reacts with water vapor to create sulfuric acid, which is an acid-rain component, causing harm to various lifeforms, including trees and fish.

• Chemical Reactions in the Stratosphere

Just as in the lower atmosphere, chemical reactions in the upper atmosphere exhibit great variety, and some of these reactions have an important influence on climate change. Over the past decades, the chemical species that has received the most attention has been ozone. Scientists paid heightened attention to the chemical reactions in the ozone layer when, in the late 1980's, a hole was discovered in this layer above the Antarctic. During the 1970's scientists had found a threat to the ozone layer when they worked out the reactions between chlorine-containing radicals and ozone. These reactions changed ozone molecules into diatomic oxygen molecules, thus weakening the ability of the ozone layer to protect Earth's surface from high-energy solar radiation.

A primary source of these catalytic, chlorine-containing species turned out to be CFCs. General Motors had introduced CFCs in 1930, and they proved to be successful in such products as refrigerator and air-conditioning coolants, as well as aerosol propellants. Because of the widespread and accelerating use of CFCs, the tropospheric concentrations of these chemicals increased from the 1930's to the 1970's, when Mexican chemist Mario Molina and American chemist F. Sherwood Rowland showed that CFCs, although seemingly inert in the troposphere, became very reactive in the stratosphere. There, ultraviolet radiation split the CFCs into highly reactive radicals that, in a series of reactions, promoted the debilitation of the protective ozone shield.

The exhaust from aircraft and spacecraft also helped deplete stratospheric ozone. Despite attempts, such as the Montreal Protocol (1987), to reduce concentrations of CFCs and other ozone-depleting chemicals in the atmosphere, the Antarctic ozone hole continued to grow in the 1990's and early twenty-first century. This meant that countries near Antarctica began experiencing higher levels of ultraviolet solar radiation.

• Atmospheric Chemistry and Global Climate Change

Humans tend to be most aware of weather—that is, a local area's short-term temperature and precipitation variations. Scientists such as atmospheric chemists tend to concentrate on climate, or a large region's long-term variations in temperature, precipitation, and cloud cover. Because of discoveries revealing the extreme complexity of chemical reactions in the atmosphere, atmospheric chemistry has become a profoundly interdisciplinary field, depending on new facts and ideas found by physicists, meteorologists, climatologists, oceanographers, geologists, ecologists, and other scientists.

Paleoclimatologists have studied changes in Earth's atmosphere over hundreds of millions of years, while other environmental and atmospheric chemists have focused on such pivotal modern problems as global warming. These studies have led to research aimed at understanding the causes of global warming and the development of theories to explain existing data. Particularly useful has been computerized modeling of Earth's atmosphere, through which experiments can be performed to help scientists understand likely future effects of climate change. These theoretical predictions have placed pressure on various governments to make important changes in policy, such as taxing fossil-fuel use to motivate reductions in GHG emissions.

Atmospheric chemists have come to realize that the goal of their research on global climate change is to understand the relevant chemical species in the atmosphere, their reactions, and the role of anthropogenic chemicals, especially GHGs, in bringing about global warming. Many atmospheric chemists believe that the greenhouse effect is a certainty, and they are also highly confident that human activities generating GHGs are a significant element in the recent rise in average global temperatures. Less certain are predictions about the future.

Computer models developed to synthesize and test theories about the complex chemical interactions in the troposphere and stratosphere necessarily involve assumptions and simplifications. For example, the numbers of chemical compounds and their reactions have to be reduced to formulate even a crude working model of the Earth's atmosphere. Despite these problems, many environmental chemists, building on what they are most sure of, have played an important part in several countries in determining governmental policies as they relate to global climate change.

• Context

Atmospheric chemists' discoveries have had a major influence on how environmentalists and other scientists understand the gravity, interrelatedness, and complexity of atmospheric problems. Many atmospheric chemists educate their students and the public about issues relating to global climate change, while others have been carefully monitoring the changes in the Earth's atmosphere. They have also participated in international discussions and agreements about controlling GHG emissions, developing substitutes for CFCs, and passing local and international laws that would lessen the likeli-

Global Sulfur Emissions by Source and Latitude

Atmospheric chemical inputs can vary greatly by region, as illustrated by the table below listing the vastly different sources of atmospheric sulfur in different parts of the globe.

Latitude	*Anthropogenic* %	*Marine* %	*Terrestrial* %	*Volcanic* %	*Biomass Burning* %
90° south	0	0	0	0	0
75° south	0	80	0	19	1
58° south	2	97	0	0	1
45° south	22	72	0	9	1
28° south	67	28	0	1	4
15° south	21	47	1	22	10
0°	21	39	1	33	7
15° north	40	30	1	19	1
28° north	85	6	0	8	1
45° north	88	4	0	7	1
58° north	86	3	0	10	1
75° north	30	40	0	23	7
90° north	0	0	0	0	0

Source: Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration.

hood of some catastrophic scenarios predicted by various computer models. Just as the many components and reactions in the atmosphere make a full understanding of these complexities very difficult, so, too, environmental chemists find themselves in an even more complex milieu in which they have to integrate their understanding with those of other scientists, industrialists, and government officials in both developed and developing countries. Therefore, though global climate change is, at root, a physical and chemical issue, to solve the problem of global climate change will require an integrated, multidisciplinary, and international approach that, though daunting, appears to be increasingly necessary.

Robert J. Paradowski

- **Further Reading**

Birks, John W., Jack G. Calvert, and Robert E. Sievers, eds. *The Chemistry of the Atmosphere: Its Impact on Global Change—Perspectives and Recommendations.* Washington, D.C.: American Chemical Society, 1993. Intended to be "many things to many different people," including scientists, politicians, and the public, this book grew out of an international conference on atmospheric chemistry. Contains lists of concrete proposals to ameliorate harmful atmospheric changes. Appendixes and index.

Jacob, Daniel J. *Introduction to Atmospheric Chemistry.* Princeton, N.J.: Princeton University Press, 2007. Undergraduate textbook written by a Harvard professor; provides an overview of the new and rapidly growing field of atmospheric chemistry. Illustrations and index.

Makhijani, Arjun, and Kevin R. Gurney. *Mending the Ozone Hole: Science, Technology, and Policy.* Cambridge, Mass.: MIT Press, 1996. Called "the most comprehensive overview of the ozone-depletion problem," this book, accessible to both scientists and general readers, analyzes the problem as well as various solutions. Helpful summaries of chapters, appendixes, notes, twenty-five pages of references, and an index.

Seinfeld, John H., and Spyros N. Pandis. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change.* New York: John Wiley & Sons, 1998. This massive volume is intended "to provide a rigorous, comprehensive treatment of the chemistry of the atmosphere." Assumes a reader has had introductory courses in chemistry, physics, and calculus, including differential equations. Many figures and tables, appendixes, and index.

Wayne, Richard P. *Chemistry of Atmospheres.* 3d ed. New York: Oxford University Press, 2000. Undergraduate textbook that analyzes the principles of atmospheric chemistry, including both traditional and contemporary developments and both terrestrial and other planetary atmospheres. Illustrated with many graphs and figures; with an extensive bibliography and index.

See also: Atmosphere; Atmospheric dynamics; Atmospheric structure and evolution; Climate models and modeling; Climate prediction and projection; Greenhouse gases; Oxygen, atmospheric; Ozone; Stratosphere; Troposphere.

Atmospheric dynamics

- **Category:** Meteorology and atmospheric sciences

Scientists speculate that, while global warming may not increase the number of storms occurring on Earth, it may increase their average severity.

- **Key concepts**

air parcel: a theoretical house-sized volume of air that remains intact as it moves from place to place

Coriolis effect: in the Northern Hemisphere, the westward deflection of southward-moving air and the eastward deflection of northward-moving air—caused by Earth's rotation

stratosphere: the atmospheric region just above the tropopause and extending up about 50 kilometers

tropopause: the transition region between the troposphere and the stratosphere

troposphere: the lowest layer of the atmosphere—

in which storms and almost all clouds occur—extending from the ground up to between 8 and 15 kilometers high

• Background

In the eigthteenth century, Edmond Halley, for whom Halley's comet is named, charted the monsoons and the trade winds, making the first known meteorological map. In an effort to understand the trade winds, Halley correctly surmised that the Sun-warmed air over the equator would rise high into the atmosphere and then flow toward the poles. He further supposed that the air would cool off and sink at the poles, and then return to the equator as a surface wind, but he could not explain why the trade winds came from the northeast, or even the east, instead of from the north.

• The Role of the Coriolis Effect

Earth is about 40,000 kilometers around at the equator, and it rotates once in twenty-four hours, so at the equator the land, sea, and air are rushing eastward at nearly 1,700 kilometers per hour. At 45° north latitude, by contrast, Earth is only about 28,000 kilometers in circumference, so a point located at that latitude travels eastward at about 1,200 kilometers per hour.

Consider a parcel of air at rest with respect to the land at the equator. Suppose that it is filled with red smoke so that its location is easily seen. Now let the parcel move northward; because of its eastward momentum, it will also be moving eastward with respect to the land north of the equator. This eastward deflection of northward-moving air parcels is called the Coriolis effect and is named for Gaspard-Gustave de Coriolis, who studied it in 1835. Also as a result of the Coriolis effect, if an air parcel at rest with respect to the land at some point north of the equator begins moving southward toward the equator, it will be deflected westward, because its eastward momentum will be less than that of the ground below it.

Fifty years after Halley's surmises, George Hadley explained the direction of the trade winds by referring to the Coriolis effect. Hadley believed that air parcels heated at the equator rose high and then migrated north to the pole. Cooled during the journey, the parcel would sink to the surface and head back south. Because of the Coriolis effect, the southward moving air would be deflected westward. This would explain the trade winds north of the equator, and this proposed air circulation route was called a Hadley cell.

The American meteorologist William Ferrel pointed out that atmospheric dynamics could not actually be that simple, since the prevailing winds at midlatitudes are westerlies, not easterlies such as the trade winds. Ferrel suggested that the Hadley cell extended only to about 30° latitude north of the equator, where the cooled air sank and returned to the equator. The Ferrel cell lies between about 30° north latitude and 60° north latitude. Air rises at 60°, flows southward, cools and descends at 30°, and flows northward and from the west near the ground—hence the westerlies. The Polar cell extends from 60° to the pole, with air rising at 60° and sinking at the pole. The cells of the Southern Hemisphere mirror those of the Northern Hemisphere.

• Jet Streams

Where the Ferrel cell meets the Polar cell, the temperatures and pressures of the air masses are generally different. These differences give rise to winds blowing north from the Ferrel cell toward the Polar cell, but this wind is soon deflected eastward by the Coriolis effect. Hemmed in between the Polar and Ferrel cells, the wind becomes the polar jet stream—a river of air 160 to 500 kilometers wide, 1 kilometer deep, and generally 1,500 to 5,000 kilometers long. Several discontinuous segments of the jet stream together might come close to circumnavigating the Earth. These segments wax and wane over time and sometimes disappear completely.

The polar jet stream forms at the tropopause, 7 to 12 kilometers above sea level. (The tropopause is the transition region between the troposphere below and the stratosphere above.) The speed of the jet stream averages 80 kilometers per hour in the summer and 160 kilometers per hour in the winter, but it can reach speeds of up to 500 kilometers per hour. While it generally flows eastward, sometimes it also meanders hundreds of kilometers south and then back north.

A second jet stream, the subtropical jet stream, occurs between the Hadley and the Ferrel cells, but since the tropopause is higher there, this jet stream is between 10 and 16 kilometers above ground level. This jet stream tends to form during the winter, when temperature contrasts between air masses are the greatest. Other low-level jet stream segments may form near the equator. The jet streams of the Southern Hemisphere mirror those of the Northern Hemisphere. Studies show that jet streams help carry carbon dioxide (CO_2) from where it is produced to other parts of the world.

There are practical reasons for studying jet streams. Jet streams influence the paths of storms lower in the atmosphere, so meteorologists must take them into account in their forecasts. Pilots flying from Tokyo to Los Angeles can cut their flight times by one-third if they can use the jet stream for a tailwind. One percent of the energy of the world's jet streams could satisfy all of humanity's current energy needs. Someday, it may be possible to use balloons to lift windmills into the jet streams, but they would need to be tethered to the ground to keep them from being blown along with the jet stream.

• Oscillations

India was stricken by a severe famine and drought in 1877 because the monsoons failed. In response, Gilbert Walker headed a team at the Indian Meteorological Department using statistical analysis on weather data from the land and sea looking for a link to the monsoons. They eventually found a link between the timing and severity of the monsoons and the air pressure over the Indian Ocean and over the southern Pacific Ocean. The team found that high pressure over the Pacific meant low pressure over the Indian Ocean, and vice versa. Walker named this alternating of pressures the Southern Oscillation and linked it with the monsoon. It has since been linked to other weather phenomena.

Normally, there is a large region of high pressure in the Pacific just off the coast of South America. The trade winds near the surface blow westward from this high-pressure region to a low-pressure region over Indonesia. The winds pick up moisture as they cross the Pacific and deliver it in the monsoons over Indonesia, India, and so forth. Energy from the condensation of moisture heats the air and causes it to rise higher; then, the air flows back eastward to the South American coast, cools, and sinks to complete the Walker cycle.

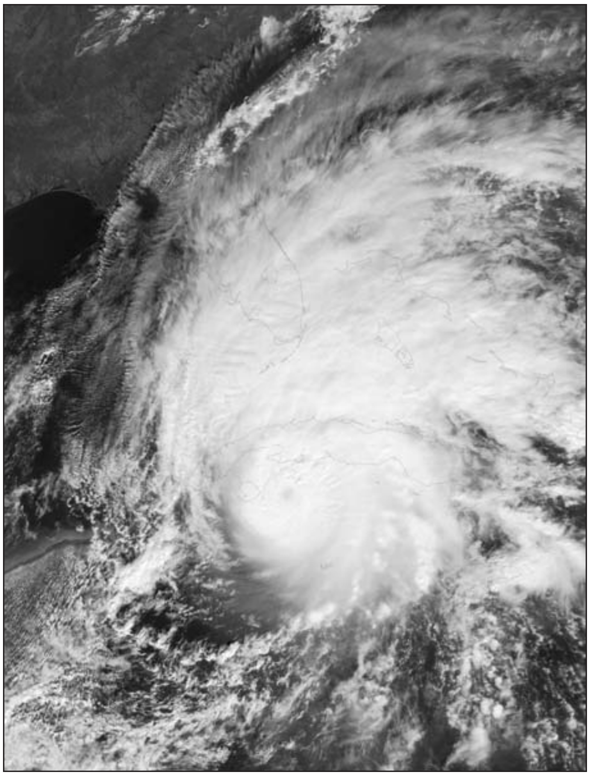
Just after Christmas, a warm current flows south by the coasts of Ecuador and Peru. In some years, that current is stronger and warmer, and then it brings beneficial rains to the South American coast—a Christmas gift. The event is called El Niño (little boy) with reference to the Christ Child. It is also called the El Niño-Southern Oscillation, or ENSO. The trade winds weaken, and warm water surges eastward to the South American coast. Air rises as it is heated by the warm coastal waters, and air comes from the west to replace the air that rose. As a result, the trade winds are reversed and blow eastward. The winds that carried moisture from the Indian Ocean toward the equator are weakened, so the monsoons are weakened. Low pressure develops over the Indian Ocean and pulls the subtropical jet stream south. The displaced jet stream brings more rain to East Africa and drought to Brazil. Central Asia, the northwestern United States, and Canada experience heat waves, while Central Europe experiences flooding.

After a few years, the El Niño event weakens and things return to normal—except that two-thirds of the time nature overshoots "normal," and La Niña (little girl) appears. The west-blowing trade winds return but are much stronger than normal. Cool water rises from the deep and forms a cool region off the west coast of South America. Colder-than-normal air blows over the Pacific Northwest and over the northern Great Plains, but the rest of the United States enjoys a milder winter. The Indian monsoons strengthen, and the subtropical jet stream returns to its normal position. Eventually, things quiet down and return to normal.

Since El Niño begins when warm water collects off the western coast of South America, global warming will probably increase the frequency and intensity of El Niño. The accompanying heat waves, flooding rains, and droughts will likely be more severe.

• Fronts and High-Pressure Air Masses

A weather front is the boundary between two air masses of different densities. They normally differ in temperature and humidity. Cold air is denser than warm air, so the air of an advancing cold front



Hurricane Michelle, in November, 2001. (NASA)

wedges beneath and lifts warm air. This upward motion produces low pressure along the front, and as the air lifts and cools, moisture condenses and forms a line of clouds or showers along the front. Light rain may begin 100 kilometers from the front, with heavy rain beginning 50 kilometers from the front.

Cold fronts generally come from the north and head south, while warm fronts generally come from the south and head north. The leading edge of an advancing warm front takes an inverted wedge shape, such that the high cirrus clouds that mark the approach of the front may be hundreds of kilometers ahead of the front's ground-level location. The cloud base continually lowers as the front approaches, and with enough moisture present rain may extend 300 kilometers in front of the ground-level front. Fronts are the principal cause of nonrotating storms.

Sinking air forms a high-pressure area at the surface. This air is usually dry, having delivered its moisture elsewhere, rendering the sky clear. If there were any warm, moist air, it would be prevented from rising by the descending air of the high-pressure area, so it could not form clouds and rain. Many of the world's deserts form where the circulating air of the Hadley cell descends. Any high-pressure area that remains in place for a long time can cause drought. Winds blowing outward from the high-pressure area will be turned by the Coriolis effect in a direction established by a simple rule: If—in the Northern Hemisphere—one stands so that the low-pressure area is on one's left, the wind will be at one's back. In the Southern Hemisphere, the wind would be at one's front.

• Hurricanes and Low-Pressure Air Masses

Rising air forms a low-pressure area near Earth's surface. Higher-pressure air from outside the area will flow toward the low-pressure area (like water running downhill), but it will be turned by the Coriolis effect and slowly spiral inward. This air will eventually be caught up in the rising air currents, will cool off as it rises, will be heated as its moisture condenses, and will then rise higher and contribute to the updraft. At this point, the low-pressure area has become a storm. If its rotation speed is over 120 kilometers per hour, the storm has become a hurricane. Global warming calculations predict that if CO_2 levels increase, the number of hurricanes occurring annually will not increase, but the average intensity of these storms will increase.

• Context

More than a century ago, Sir Gilbert Walker began the process of describing the world's weather in one comprehensive model. The weather in each part of the world is tied in some fashion to the weather elsewhere—through jet streams, circulation cells, or movement of air masses. As Earth's global climate undergoes changes, the interrelationship of the planet's weather systems becomes more important than ever, since the climate change will affect not only individual weather patterns and events but also the way in which those individual events affect one another and Earth's weather generally.

Charles W. Rogers

• **Further Reading**

Lutgens, Frederick K., Edward J. Tarbuck, and Dennis Tasa. *The Atmosphere: An Introduction to Meteorology.* 10th ed. Boston: Prentice Hall, 2006. Textbook covering atmospheric structure, air masses, circulation, storms, oscillations, the changing climate, and more.

Lynch, John. *The Weather.* Buffalo, N.Y.: Firefly Books, 2002. An outstanding book for beginners, lavishly illustrated and well written. Goes one layer deeper than typical introductory books, but it is not difficult to understand. Includes a short chapter on global warming.

Walker, Gabrielle. *An Ocean of Air: Why the Wind Blows and Other Mysteries of the Atmosphere.* New York: Harvest Books, 2007. Well written and easily read. Elucidates how the atmosphere behaves and how people learn about it.

See also: Climate change; Climate feedback; Coriolis effect; Hadley circulation; Jet stream; Polar climate; Stratosphere; Troposphere; Weather vs. climate.

Atmospheric structure and evolution

• **Category:** Meteorology and atmospheric sciences

Earth's atmosphere is a blanket that keeps the planet a beneficial 35° Celsius warmer than it would be otherwise. Human activities, however, are adding GHGs to the atmosphere that may raise the temperature enough to alter the climate.

• **Key concepts**

albedo: percentage of incident light Earth reflects back into space

greenhouse gases (GHGs): gases that allow sunlight to pass through to the ground but trap, at least partially, the infrared radiation that would otherwise escape into space

ice age: a period during which sea ice and glaciers cover a significant fraction of Earth's surface

late heavy bombardment: a period about 3.9 to 4.0 billion years ago, when Earth was pummeled by debris from space at one thousand times the normal rate, heating the atmosphere and melting the crust

Milanković cycles: recurring time periods during which the shape of the Earth's orbit, the tilt of its axis, and the occurrence of its farthest distance from the Sun all change

• **Background**

The atmosphere is an ocean of gases held to the Earth and compressed by gravity. If greenhouse gases (GHGs) were newly introduced into the atmosphere, less energy would leave the Earth than strike it, so the planet would warm until those two rates balanced. (Infrared radiation from a warmer Earth has a shorter wavelength and is therefore more likely to escape into space.) GHGs keep Venus 500° Celsius, Earth 35° Celsius, and Mars 7° Celsius warmer than each planet would be without its atmosphere. Without the greenhouse effect, much of Earth would be permanently covered with snow and ice.

• **Earth's First Atmosphere**

If Earth's atmosphere had formed along with Earth itself, its composition would be expected to reflect the relative abundance of solar elements extant at the time and present in gases heavy enough to be retained by Earth's gravity. Hydrogen and helium are the two most abundant gases, but Earth's gravity is not strong enough to hold them, so they gradually escape into space. Oxygen is the next most abundant gas, but it is so chemically active that, without plant life to replenish it, it would soon disappear from Earth's atmosphere. Neon is next in abundance, is chemically inert, and is heavy enough to be retained by Earth's gravity. The fact that it is not the most abundant gas in Earth's atmosphere provides evidence that Earth's primordial atmosphere escaped into space, probably during a flare-up of the young Sun or during the late, heavy bombardment following the Earth's formation.

Scientists believe that the current atmosphere consists of gases released as rocks and minerals inside the Earth were heated by the energy from radioactive decay. These gases were subsequently emit-

Solar Abundances of the Elements

Element	*Solar Nebula Abundance per Hydrogen Atom*
Hydrogen	1
Helium	0.16
Oxygen	0.00089
Neon	0.0005
Carbon	0.0004
Nitrogen	0.00011
Silicon	0.000032
Magnesium	0.000025
Sulfur	0.000022
Argon	0.0000076

ted by volcanoes. Water vapor is the most abundant volcanic gas. It condensed to form the oceans. The next most abundant volcanic gases are carbon dioxide (CO_2), nitrogen, and argon. CO_2 is removed from the atmosphere when it dissolves in the oceans, where most of it eventually combines with calcium oxide ions, precipitates out, and forms carbonate rocks (limestone). Sulfur dioxide and sulfur trioxide are chemically active and do not stay in the atmosphere very long. Thus, if the Earth's atmosphere came from volcanoes, it should be dominated by nitrogen, followed by CO_2 and then argon. The atmospheric CO_2 would soon be depleted as it dissolved in the oceans. The atmospheres of Venus and Mars are richer in CO_2 than is Earth's atmosphere, because those planets have no oceans to remove their CO_2.

In the absence of oxygen, iron dissolves in water, but when oxygen is dissolved in the same water, iron oxide precipitates out and sinks to the bottom. Ore deposits of this iron compound first appeared about 2.6 billion years ago and peaked about 1.8 billion years ago. This probably reflects the increasing abundance of plants that released oxygen into the atmosphere and the increasing atmospheric concentraton of oxygen that resulted. Earth's atmospheric oxygen concentration reached a maximum of 30 percent 300 million years ago and a minimum of about 12 percent 200 million years ago. It now stands at about 21 percent.

- **The Faint Early Sun Paradox**

Stars such as the Sun roughly double in brightness over their lifetimes as normal stars. The Sun is already 30 percent brighter than it was when it first became a normal star, 4.56 billion years ago. Based on contemporary values of Earth's albedo and its atmosphere, Earth should not have had liquid water before about 2 billion years ago. There is, however, abundant geological evidence that liquid water has existed on Earth for at least 3.8 billion years. Mars exhibits a similar paradox, since it seems to have had abundant surface water 3.8 billion years ago.

If the Sun had been born 7 percent more massive, the Earth would have been warm enough for liquid water. Because at normal rates the Sun can have lost only 0.05 percent of its mass since it was born, however, this is probably not the case. A sufficiently large amount of CO_2 in the atmosphere could have made the early Earth warm enough for water, but geological evidence for that much atmospheric CO_2 is lacking. However, Philip von Paris and his colleagues at the Aerospace Centre in Berlin have developed a plausible computer model that allows the early Earth to have developed liquid water with only 10 percent of the CO_2 previously thought necessary, an amount not ruled out by geological evidence.

Composition of Air and of Volcanic Gases

	Percent by Volume	
Gas	*Air*	*Volcanic* Gas*
N_2 (nitrogen)	77	5.45
O_2 (oxygen)	21	
H_2O (water vapor)	0.1 to 2.8	70.8
Ar (argon)	0.93	0.18
CO_2 (carbon dioxide)	0.033	14.07
Ne (neon)	0.0018	
CH_4 (methane)	0.00015	
NH_3 (ammonia)	0.000001	
SO_2 (sulfur dioxide)		6.4
SO_3 (sulfur trioxide)		1.92
CO (carbon monoxide)		0.4
H (hydrogen)		0.33

*Kilanea volcano, Hawaii.

• Structure of the Atmosphere

The atmosphere has settled into a series of layers, one on top of the other, like the layers of an onion. The lowest layer of the atmosphere is called the troposphere. It extends from the ground up to about 15 kilometers over the equator and slants down to just 8 kilometers in height over the poles. The word "troposphere" is based on the Greek word *tropos*, which means "turning" or "mixing." Storms are a result of the mixing that takes place in this layer, so storms and almost all clouds are confined to the troposphere. In the troposphere, temperature decreases by about 8° Celsius with each 1 kilometer of altitude. Tourists are often surprised to find that the South Rim of the Grand Canyon, in Arizona, is 12° Celsius cooler than the inner gorge, 1.5 kilometers below.

The atmospheric layer above the troposphere is the stratosphere (from the Latin *stratum*, meaning "horizontal layer"). It extends from the troposphere up to an altitude of about 50 kilometers. Commercial airliners usually cruise in the lower stratosphere, where the reduced air density produces less drag and where they are above clouds and storms. The ozone layer, which protects Earth life from most of the Sun's ultraviolet radiation, is located in the stratosphere, mostly between 20 and 40 kilometers high.

Above the stratosphere lies the mesosphere (from the Greek *mesos*, meaning "middle"). The mesosphere extends from about 50 kilometers up to 80 or 90 kilometers in altitude. Incandescent trails may be observed in the mesosphere. These trails result when meteoroids the size of sand grains or pebbles strike Earth from space: They are heated by the friction of their swift passage through the mesosphere until they disintegrate.

The thermosphere (from the Greek *thermos*, meaning "heat") begins about 90 kilometers above the ground and extends upward to about 600 kilometers high. Gas molecules of the thermosphere absorb solar energy and convert it into kinetic energy (energy of motion). The speed of a molecule is a measure of its temperature, and speeds corresponding to temperatures of up to 15,000° Celsius are expected in thermosphere gas molecules. While that may seem hot, an unprotected person in the thermosphere would soon freeze, because such gas molecules are few and far between, making the average temperature of this layer extremely cold. Auroras form in the lower thermosphere when high-energy particles slam into air atoms.

The International Space Station (ISS) orbits in the thermosphere, about 340 kilometers above Earth's surface. The atmosphere there is thin enough that drag on the ISS is small, but not zero. The advantage to this location is that, although it must periodically be reboosted by a supply ship while in use, when the ISS is finally abandoned it will slowly and naturally deorbit itself.

Beginning in the lower thermosphere, air atoms are far enough apart that when ultraviolet light from the Sun drives electrons away from their parent atoms, they do not recombine for some time. The clouds of free electrons (or ions) that thus form can reflect radio waves. This region is the ionosphere. Depending upon the intensity of incident sunlight, the ionosphere can extend throughout the thermosphere and up into the exosphere. The exosphere begins 500 to 600 kilometers high and extends up to about 10,000 kilometers, where it shades into interplanetary space.

• Earth's Greenhouse Gases

Clouds and water vapor together are responsible for roughly 80 percent of Earth's greenhouse warming. People can affect the amount of water vapor in the atmosphere locally by deforestation, for example, but the global amount is determined by Earth's vast oceans. The global amount of atmospheric water vapor remains quite constant over time, so most atmospheric scientists conclude that it cannot be responsible for recent warming. Water vapor also plays a major role in feedback; for example, if Earth warms, more water will evaporate from the oceans, becoming vapor. More water vapor will produce more clouds, and more clouds blanketing Earth will keep it warmer, but more clouds will also reflect more sunlight back into space, keeping Earth cooler. Experts indicate that the warming effect will be greater than the cooling effect, but it is nevertheless apparent that global warming is quite a complex phenomenon.

CO_2 accounts for most of the rest of Earth's greenhouse effect. The amount of atmospheric CO_2 is increasing by about 0.4 percent per year, with per-

Glacial and Interglacial Periods

Years Before Present (thousands)	*Temperature Deviation**	*Description*
0.2 to 0.4	-1	Little Ice Age (Northern Europe)
0.8 to 1.2	+1	climatic optimum
20 to 500	+2 and -6	4 cold periods and 4 warm periods
Years Before Present (millions)		
3 to 10	+1 to +2	warm period
10 to 25	+3	Antarctica thawing
25 to 35	+1	Antarctica glaciation
35 to 80	up to +6	Eocene optimum
260 to 360	-2 to -5	Karoo glaciation
420 to 450	+2 to -5	Andean-Saharan glaciation
635 to 800	-5	Cryogenian glaciation
2,400 to 2,100	-5	Huronian glaciation

*Rough global averages; deviation is from 17° Celsius, expressed in ° Celsius.

haps the majority of that increase coming from transportation, power generation, and other human activities. It also comes from volcanoes and burning vegetation. CO_2 is removed from the atmosphere by plants and by being dissolved in the ocean. In the ocean, it may combine with calcium to make limestone. It is also removed from the ocean by sea creatures that use limestone to make their shells.

Methane is present in the atmosphere in only trace amounts, but, molecule for molecule, it is about twenty times more effective than CO_2 as a GHG. Atmospheric methane has increased by 11 percent since 1974. Significant amounts of it are released by coal and oil production, cattle and sheep, swamps and rice paddies, and jungle termites.

• Ice Ages

Life on Earth has survived many cooling and warming cycles in the past, but scientists do not fully understand the causes of climate change. Different factors dominate changes at different times. For example, increased atmospheric CO_2 from volcanoes may warm Earth enough to end an ice age, but in other cases atmospheric CO_2 might not increase until centuries after the climate warms. A few of the other factors to consider are Milanković cycles, solar intensity, albedo, and the ability of the oceans to absorb CO_2 and to lock it in limestone.

• Context

At one other time, humanity stood on the verge of having the power to change the climate. When world stockpiles of nuclear weapons were at their highest levels, some people wondered if an all-out nuclear war would result in nuclear winter—months or years of freezing temperatures and little sunlight—followed by ten thousand years of nuclear spring—temperatures several degrees above normal and dangerous levels of ultraviolet light reaching the ground. Although it is doubtful that there were ever enough warheads to cause nuclear winter, stockpiles have been reduced. Humans are again on the verge of being able to change the climates of Earth, and enough is not known to predict all of the results of changing the climate or of taking actions designed to avoid changing it.

Charles W. Rogers

• Further Reading

Archer, David. *Global Warming: Understanding the Forecast.* Malden, Mass.: Blackwell, 2007. Slightly technical but written for nonscientists. Explains various issues relating to global warming, including the interaction of greenhouse gases with other gases, with rocks, and with the ocean.

Barry, Roger G. *Atmosphere, Weather, and Climate.* 8th ed. New York: Routledge, 2003. Comprehensive, nontechnical introduction to these subjects. Treats the composition and structure of the atmosphere, circulation, and storms.

Walker, Gabrielle. *An Ocean of Air: Why the Wind Blows and Other Mysteries of the Atmosphere.* New York: Harvest Books, 2007. Explains how the atmosphere behaves.

See also: Atmosphere; Atmospheric chemistry; Atmospheric dynamics; Carbon dioxide; Earth history; Earth structure and development; Greenhouse effect; Greenhouse gases; Mesosphere; Ocean-

atmosphere coupling; Ocean dynamics; Planetary atmospheres and evolution; Stratosphere; Thermosphere; Troposphere.

Australia

- **Category:** Nations and peoples
- **Key facts**

Population: 21,262,641 (July, 2009, estimate)
Area: 7,692,208 square kilometers
Gross domestic product (GDP): $800.5 billion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 408 in 1990; 491 in 2000; 534 in 2004
Kyoto Protocol status: Ratified 2007

- **Historical and Political Context**

Australia is a federal parliamentary state. The British monarch, Queen Elizabeth II, is the chief of state, although constitutional links with Britain were ended in 1968. Prime Minister Kevin Rudd became the head of state in 2007. Australia achieved federation status in 1901. Despite the nature of its geography, bound by water in all directions, Australia has eschewed isolationism and fought alongside the British in World Wars I and II and with the United States in the Korean and Vietnam Wars. During the 1960's, the country sought to deal more fairly with its indigenous population of aborigines. In 2001, Australia joined the United States in its response to the September 11 terrorist attacks.

- **Impact of Australian Policies on Climate Change**

When Prime Minister Kevin Rudd was elected, ending the eleven-year ministry of John Howard, he made ratifying the Kyoto Protocol a priority of his ministry. Shortly after his election, Rudd was invited to the United Nations Climate Change Conference in Bali. Australia's pledge to ratify the Kyoto Protocol signaled a policy shift from that of the previous government; Australia had previously signed the protocol but had not ratified it.

Industrialized, Annex I parties to the Kyoto Protocol such as Australia are committed to cut their greenhouse gas (GHG) emissions by an average of 5 percent from their 1990 levels between 2008 and 2012. A heavier burden is placed on industrialized countries than on developing nations, because the

former are better able to pay the cost of emission cuts than are the latter.

In 2008, Australia participated in negotiations on reducing deforestation at the fourteenth Conference of the Parties (COP-14) in Poznan, Poland. (COP is the highest body of the U.N. Framework Convention on Climate Change and consists of environment ministers who meet once a year to discuss the convention's developments.) Australia, Canada, New Zealand, and the United States opposed provisions designed to protect the rights of indigenous peoples. As a result, major changes to the draft agreement on deforestation were required prior to the 2009 conference (COP-15) in Copenhagen, Denmark. The goal of the required changes was to preserve the rights of indigenous and local peoples and communities, promote biodiversity, and address the causes of deforestation in a manner acceptable to the objecting parties.

• Australia as a GHG Emitter

As of 2008, Australia was ranked as the world's sixteenth-highest GHG emitter. To reduce such emissions, the Kyoto Protocol established carbon quotas for member countries, which may develop new carbon sinks, such as reservoirs of foliage or forests, in order to offset their carbon emissions. These sinks are known as "Kyoto lands." The use of carbon sinks to mitigate the global warming effects of emissions may be useful to countries with large areas of forest or other vegetation that are otherwise struggling to comply with the protocol. Specific legally binding quotas for reduction of GHG emissions have been established for the developed, Annex I nations, including Australia. Developing, non-Annex I countries, such as Brazil annd Indonesia, are not compelled to restrict their GHG emissions. In such countries, emissions may come in large part from the cultivation of lands and the destruction of forests. However, for developed nations such as Australia, land use would have little effect in meeting Kyoto quotas, since most Australian land has already been cultivated.

While the Organization of Petroleum Exporting Countries (OPEC) Gulf States have the highest GHG emissions, data from 2000 show that—of the top twenty emitters—those with highest per capita emissions were the Annex I countries. Australia, the United States, and Canada ranked fifth, seventh, and ninth, respectively. Their per capita emissions (7.0, 6.6, and 6.1 metric tons per person) were approximately double the emissions of the highest-ranked developing country in the top twenty (South Korea, at 3.0 metric tons), and they were six times those of China (1.1 metric tons). Australia's high per capita emissions are due in part to the nation's large area and low population density (about 2.7 persons per square kilometer in 2006), as well as its dependence on energy-intensive fossil fuel to transport people and goods over large distances, its use of coal to generate power, and the energy it needs to expend on resource extraction generally.

• Summary and Foresight

Before 2007, the Howard government argued that ratifying the Kyoto Protocol would jeopardize Australian jobs and industry. It opposed Australia's commitment to the treaty, on the grounds that some major polluters, including developing, non-Annex I countries such as China and India, would not be compelled to cut their GHG emissions. Critics argued that by not ratifying the protocol, Australia would tarnish its image as an environmentally progressive nation. Australia has been a leader in opposing whaling and in advocating for conservation of Antarctica and the South Pacific Ocean.

The Rudd government, despite ratifying the Kyoto Protocol, was criticized as it entered the climate change debate at COP-14, because it did not set specific targets for cutting GHG emissions by 2020. Developing nations such as India questioned why they should commit to such targets if industrialized countries did not. Earlier, the Intergovernmental Panel on Climate Change (IPCC) had declared that global GHG emissions must peak by 2015 and then begin to decline if catastrophic environmental consequences are to be avoided. The European Union has already committed to reducing GHG emissions by 20 percent by 2020.

COP-14 was supposed to provide continuity between the negotiations begun at COP-13 in Bali (2007) and a finalized agreement to be reached at COP-15, where the successor treaty to the Kyoto Protocol would be completed. COP-14 was unsuccessful; developed (Annex I) nations such as the United States, Canada, and Australia did not submit promised proposals on GHG emission reductions, finance, and technology. At COP-13, Australia had been welcomed with enthusiasm because of its environmental expertise in the region, but its refusal to set 2020 emission targets undercut its reputation, because setting such targets is perceived to be a criterion for global leadership. Without making such committments, it is difficult for developed nations to convince developing nations that they are serious about fighting climate change. One way of trying to close the gap between the developed, Annex I nations and the developing, non-Annex I countries may be to focus on per capita emissions or GHG emission intensity (emissions measured per economic unit) in order to provide individual nations with more equitable shares of energy use. For Australia, as well as the United States and Canada, this may involve more constraints, but for the developing countries there may be greater opportunities for economic growth.

Cynthia F. Racer

• **Further Reading**

Lohmann, Larry, ed. *Carbon Trading: A Critical Conversation on Climate Change, Privatization, and Power.* Uppsala, Sweden: Dag Hammarskjöld Foundation, 2006. Tackles the controversial aspects of carbon trading.

Lowe, I. *Living in the Hothouse: How Global Warming Affects Australia.* Melbourne: Scribe, 2005. Details Australia's global warming challenges.

Macintyre, S. *A Concise History of Australia.* New York: Cambridge University Press, 2000. Complete history of Australia, from 1600 to 1999.

See also: Annex B of the Kyoto Protocol; Kyoto lands; Kyoto mechanisms; Kyoto Protocol; United Nations Framework Convention on Climate Change.

Automobile technology

• **Categories:** Transportation; economics, industries, and products; science and technology

Efforts to refine or replace automotive internal combustion engines are immensely important for preventing further damage to the atmosphere. Advances in construction materials, increased use of electronic sensors, and strategies for reducing size and weight are also important.

• **Key concepts**

electric cars: automobiles that run completely on electricity, without the need to burn fuels

flexible (flex) fuel: a technology that allows vehicles to burn more than one type of fuel in the same engine

hybrid vehicles: automobiles that run on more than one power source, such as electric batteries and fuel-burning engines

hydrogen engines: engines that run on hydrogen, based either on fuel cells that oxidize the hydrogen or on hydrogen combustion

internal combustion engines: engines that burn fuel in a chamber to generate force

• **Background**

Although cars with steam engines were common in the early twentieth century and a few electric cars were produced, the internal combustion engine became the dominant means of powering automobiles after ignition systems were refined. Large vehicles such as the Cadillac became iconic symbols of prosperity, but as early as the late 1950's, American consumers and manufacturers became interested in the advantages of smaller cars, leading to the success of the American Motors Corporation's Rambler and Ford's Mustang.

In the second half of the twentieth century, efforts to limit the negative consequences of internal combustion engines focused on controlling the amount of toxins in their emissions. After the oil crisis of 1973, Japanese and European automakers aggressively marketed small cars that required less fuel than larger automobiles. In the United States, the use of unleaded gasoline and catalytic converters was mandated in the last decades of the twentieth century in order to reduce air pollution.

Larger cars returned to popularity after oil prices stabilized, but tightening emissions standards, increasing concern about the environment, and further price fluctuations eventually led to even smaller cars being produced. Swiss watch manufacturer

Swatch originated the idea of the extremely compact "smart car." In India, the Tata Motor Company's Nano, introduced in 2009, economized by reducing both its size and the number of parts. It used only three nuts on the wheels and one windshield wiper, and it was glued together rather than welded.

• Flexible-Fuel and Alternative-Fuel Engines

The design of flexible-fuel engines has given more choices to consumers. In Brazil, in response to the government's ethanol requirements, the introduction of the Volkswagen Gol, GM's Chevrolet Celta, and others has helped transform that nation's consumption patterns. The number of flexible-fuel vehicles in Brazil, where ethanol is made from sugarcane, rose to 7 million by 2009. In the United States, where agricultural land is more scarce and ethanol is made from corn, many engines are not capable of running on mixtures with high ethanol content, and colder weather could lead to ignition problems. Modern flexible-fuel engines have electronic sensors to detect fuel content and are able to change valve timing, cylinder pressure, fuel injection, and other functions automatically.

The search for new engine technologies has also been a focus for entrepreneurs, such as Johnathan Goodwin, whose company H-Line Conversions specializes in converting the engines of large vehicles such as Hummers and vintage Cadillacs so they can run on biodiesel fuel. His expensive vehicles have been popular with celebrities. Manufacturers have also experimented with the use of hydrogen in internal combustion engines and in fuel cells, but because existing methods of processing hydrogen

Compact smart cars are designed to minimize environmental footprint while maximizing efficiency. (Getty Images) consume so much energy, it is generally thought to be an impractical automobile fuel.

• Beyond the Combustion Engine

Although the technology is older than combustion engines and was initially more popular, electric cars were sidelined by gasoline-powered vehicles from the 1920's through the twentieth century. Electric cars were cleaner, quieter, and simpler, but they were also more expensive and slower. Their batteries required recharging, which limited the distances they could travel. In the 1990's, electric cars were revived in response to environmental demands. Between 1997 and 1999, the major automakers introduced several all-electric cars in California. These included GM's EV1 and S-10 electric pickup, Honda's EV Plus, a Ford Ranger pickup, and Toyota's RAV4 EV. However, these models were all discontinued. It was difficult to reverse the petroleum trend and restructure the interdependent automobile and fuel industries. The lack of a supportive infrastructure (such as sufficient recharging stations equivalent to gas stations) also remained a problem.

To circumvent these problems, the hybrid vehicle was developed. Such vehicles could supplement the electric power they drew from batteries with a gasoline-burning engine for long distances, thus achieving greater fuel economy and power with the combined technologies than either could deliver alone. The first hybrid electric automobile in the U.S. mass market was Honda's two-door Insight, introduced in 1999. In 2000, Toyota debuted the Toyota Prius, the first hybrid four-door sedan, and the Honda Civic Hybrid followed in 2002. All major automobile manufacturers have developed hybrid vehicles. Amid the high gas prices of 2008, hybrids were in demand, especially the industry-leading Toyota Prius. However, by April, 2009, lower gas prices and a worldwide sales slump escalated competition. Honda's new, lower-priced Insight challenged the Prius. Other new models included the Mercury Milan and Ford Fusion hybrid sedans.

Because all-electric and hybrid vehicles can be charged by solar and wind sources, as well as by plugging into power grids, they are valued for their potential to combat global warming. The most popular all-electric car at the beginning of the twenty-first century was the REVA, a three-door car produced in India. Additional manufacturers such as Tesla Motors have entered the market, and sales are increasing worldwide. Electric and hybrid cars are also taking advantage of new advances in chassis construction, introducing lighter but strong materials as an alternative to steel.

• Context

The rapid changes in the automobile industry and the diversity of automotive technologies at the beginning of the twenty-first century herald a period of intense competition and experimentation, in contrast to the massive standardization characteristic of the late twentieth century. The move away from fossil fuels and toward smaller vehicles contributes significantly to efforts in fighting anthropogenic global climate change.

Alice Myers

• Further Reading

Bethscheider-Kieser, Ulrich. *Green Designed Future Cars: Bio Fuel, Hybrid, Electrical, Hydrogen, Fuel Economy in All Sizes and Shapes*. Los Angeles: Fusion, 2008. This beautiful pictorial book features futuristic, eco-friendly automobiles.

Blume, David, and Michael Winks. *Alcohol Can Be a Gas! Fueling an Ethanol Revolution for the Twenty-first Century*. Santa Cruz, Calif.: International Institute for Ecological Agriculture, 2007. Over twenty-five years in the making, this is the definitive book on alcohol fuel. Illustrations, index, bibliography, glossary.

Carson, Lain, and Vijay Vaitheeswaran. *Zoom: The Global Race to Fuel the Car of the Future*. New York: Twelve, 2007. Award-winning journalists analyze the auto industry and alternative fuels and call for a grassroots rebellion demanding clean energy. Index and bibliography.

Clemens, Kevin. *The Crooked Mile: Through Peak Oil, Biofuels, Hybrid Cars, and Global Climate Change to Reach a Brighter Future*. Lake Elmo, Minn.: Demontreville Press, 2009. Presents an optimistic overview of trends. Illustrations, bibliography, index.

Fuhs, Allen. *Hybrid Vehicles and the Future of Personal Transportation*. Boca Raton, Fla.: CRC Press, 2009. This comprehensive guide to hybrid vehicles includes their history, environmental impact, and implications for energy efficiency. Illustrations, bibliography, index.

Hasegawa, Yozo, and Tony Kimm. *Clean Car Wars: How Honda and Toyota Are Winning the Battle of the Eco-friendly Autos*. Singapore: John Wiley & Sons, 2008. Explains how the leading Japanese automakers are using clean-car technology to expand global market share.

Sperling, Daniel, and Deborah Gordon. *Two Billion Cars: Driving Toward Sustainability*. New York: Oxford University Press, 2009. This scholarly study includes statistics on emissions and alternative technologies. Illustrated. Bibliography and index.

See also: Biofuels; Catalytic converters; Fossil fuels; Fuels, alternative; Hybrid automobiles; Motor vehicles; Transportation.

Average weather

• **Category:** Meteorology and atmospheric sciences

• Definition

The term "average," from a statistical point of view, denotes the arithmetic mean of a set of numbers taken from a sample or a representative population. That is, the average rainfall for the month of January for a specific place is the average of the actual January rainfalls for a period of time. In most cases, this use of "average" in weather and climate studies and applications makes sense, but in some cases it can give an erroneous impression of the average weather.

For example, to determine the average January rainfall for the city of Tauranga, New Zealand, one must first decide which January rainfalls to average. In Tauranga, rainfalls have been measured from several sites for the periods 1898-1903, 1905-1907, and 1910-2009. For a correct analysis, data for all the observation sites must first be carefully adjusted so that they apply to the current recording site. When this is done, the average for all of these January months is 88 millimeters. This average includes a rainfall of 268 millimeters in January, 1989 (the wettest January recorded), and a rainfall of only 1 millimeter in January, 1928 (the driest January recorded). The average in this case is therefore of some use and reveals something about the January rainfalls over a period of one hundred years in Tauranga, but it is not an exhaustive description, especially if one seeks to determine whether Tauranga is getting wetter or drier.

For other weather elements, such as temperature, sunshine, cloudiness, and wind, the situation is similar: The average for a particular period, such as a month, season, year, decade, or set of years, is simply the average of the values found in a series of observations.

• Significance for Climate Change

As noted, in most cases, this use of the average in weather and climate studies and applications makes sense, but in some cases it can give an erroneous and sometimes distorted view of the average weather. For example, in the case of temperatures, a problem has arisen in climate change discussions, because the average temperature is traditionally determined by climatologists by taking the average of the highest (maximum) and the lowest (minimum) temperatures for a particular day. While this practice produces useful information, especially when comparing the average temperatures of, say, Chicago with those of Bangkok, a difficulty arises when the daytime and nighttime temperatures are important. For example, in a continental climate, such as that of Moscow, the difference between the daytime and nighttime temperature is significant, whereas in a tropical climate, such as that of Singapore, the day-to-night temperature difference is relatively small.

Average weather is generally reflected by measurements of average rainfall, average day- and nighttime temperatures, average sunshine, and so on. However, when one considers changes in climate—small changes in the average weather over time—it becomes necessary to take particular note of the period involved and the specific weather element being measured. For example, climate change may cause a particular place to be wetter in the winter and drier in the summer. To measure such a change, one would need to assess the changes in the summer rainfall and the winter rainfall over a period of time of at least thirty years and ideally one hundred years. Such an analysis might show that during the first fifty of the last one hundred years, winter rainfalls were lower than those of the following fifty years, whereas summer rainfalls were higher. One must therefore treat all climate data with a degree of caution and be careful always to compare apples with apples.

For example, if one considers again the city of Tauranga, New Zealand, as a typical example, temperature observations have been taken there since 1913. Various observation sites have been used, and data from all sites have been adjusted to reflect what the temperature would have been if all observations had been taken from the same site. With these adjustments, the highest average monthly temperatures for each month in Tauranga have occurred in January, 1935; February, 1928; March, 1916; April, 1938; May, 1916; June, 2002; July, 1916; August, 1915; September, 1915; October, 1915; November, 1954; and December, 1940. The highest annual average daily maximum temperature was 20.4° Celsius, recorded in 1916, followed by 20.2° Celsius in 1928, 20.1° Celsius in 1914, and 20.0° Celsius in 1998. These observations show that, despite the indications of global warming in some parts of the world, not all areas are the same, and memories can be deceiving.

W. J. Maunder

See also: Extreme weather events; Meteorology; Rainfall patterns; Seasonal changes; Weather forecasting; Weather vs. climate.

Axelrod, Daniel

American paleoecologist

Born: July 16, 1910; New York, New York
Died: June 2, 1998; Davis, California

Axelrod showed how past climate change had caused the plants of an area to change. Extrapolating from his observations and methods, scientists may be able to predict the effects upon vegetation of future changes in climate.

• Life

Daniel Axelrod was the oldest of five children born to parents who immigrated to the United States from Russia. The family soon moved to Guam, then to Waikiki, Hawaii, and, when Daniel was a teenager, to Berkeley and finally to Oakland, California. Axelrod, a Boy Scout, spent a lot of time out in the open country looking at plants and animals. He claimed that during that time he became a naturalist. With a B.A. in botany from the University of California at Berkeley, he went to work for the California Forest Service to earn money to go to graduate school. Axelrod received an M.A. in 1936 and a Ph.D. in 1938, both in paleobotany from the University of California at Berkeley. His Ph.D. work was under Ralph Chaney, who required him to minor in geology and to study climatology, evolution, and genetics before he started his graduate work.

After graduate school, Axelrod worked at the U.S. National Museum and the Carnegie Institution in Washington, D.C., as a postdoctoral research fellow. During World War II, Axelrod served in the Army Air Forces as a photo analyst. His knowledge of vegetation in the Pacific allowed him to distinguish enemy sites and movements, as well as conditions that U.S. troops were likely to encounter. His work earned him the rank of major and a Bronze Star. After the war, Axelrod (or, as he liked to be called, Ax) joined the geology faculty of the University of California, Los Angeles (UCLA). From 1962 through 1967, he held a joint appointment in botany and geology. In 1967, he moved to the University of California at Davis to help start a new geology department. Retirement from Davis in 1976 provided Axelrod with more time to conduct research. He was preparing breakfast before going to work in 1998 when he experienced a fatal heart attack. He was survived by his widow, Marilyn Gaylor Axelrod, and a stepdaughter.

• Climate Work

Educated in both botany and geology, Axelrod was well trained to analyze botanical fossils and correlate changing flora with the geological indicators of climate change. From fossils of seeds, leaves, stems, and flowers, he was able to build a model of the vegetation and climate of a time period. His specialty was the western area of North America during the Tertiary period (65 million to 1.8 million years ago). In his long career, he produced more than 140 publications and collected more than eight thousand fossil specimens. While at the U.S. National Museum, he learned how to preserve, store, and catalog specimens. He was known for his carefully preserved fossils.

One of Axelrod's insights was into the distribution of angiosperms, plants whose seeds are inside a fruit, such as a tomato or cucumber. By looking at angiosperm fossils, Axelrod determined that they originated in tropical areas and, over millions of years, migrated toward both poles. Axelrod also introduced the concept of altitude as a factor that controlled which plants grew in which area. His deduction that the Rocky Mountains are young on a geological time scale came from the fact that the same type of plants grow on both sides of the mountains. There has not been enough time for the plants to evolve into different types. He published papers that show where the continents were connected based on the places where similar plants existed.

Axelrod's most important contribution to global warming studies is to be found in the many papers in which he demonstrated how climate controls the movement of vegetation. Madrean plants that were in the Mohave area 18-20 million years ago were in the San Francisco area by 7-8 million years ago. The plants had moved northward as the desert grew. Axelrod showed that forests were more diverse in the past than they are now. As climate has changed in a certain area, only trees that are adapted to the new climate survive, and today there are forests composed predominantly of one tree species. Axelrod even predicted the effects of a change to a drier climate over a half million years and a million years. His methods were straightforward enough to enable others to follow in his footsteps, predicting changes in vegetation that may result from changes in climate.

C. Alton Hassell

• Further Reading

Axelrod, Daniel I. *History of the Coniferous Forests: California and Nevada*. Berkeley: University of California Press, 1976. Provides insight into the evolution of western forests in response to changes in western climate.

_______. *A Miocene (10-12 Ma) Evergreen Laurel-Oak Forest from Carmel Valley, California*. Berkeley: University of California Press, 2000. Typical of the work of Axelrod, this book presents the connection between the botany and the geology of the Carmel Valley. Illustrations, maps, bibliography.

Barbour, M. G. "Dan Axelrod: Paleoecologist for the Ages." *Fremontia* 27, no. 1 (1999): 29-30. Among the various obituaries and tributes to Daniel Axelrod, this is the one most commonly cited by the people who knew him.

Erwin, Diane M., and Howard E. Schorn. "Daniel I. Axelrod, 1910-1998: In His Own Words." *Bibliography of American Paleobotany*. St. Louis, Mo.: Paleobotanical Section, Botanical Society of America, 1998. The bulk of this article is drawn from a 1994 taped interview with Axelrod. It includes a list of the scientist's publications.

Marriott, Gerard, and Ian Parker. *Biophotonics*. Part B. San Diego, Calif.: Academic Press, 2003. Although Axelrod thought modern paleobotanists spent too much time with instrumentation and not enough time outside, he made use of methods such as total internal reflection fluorescence microscopy, as described in this book. Illustrations, bibliography, index.

See also: Atmospheric structure and evolution; Earth history; Ecosystems; Geological Society of America.

Bangladesh

- **Category:** Nations and peoples
- **Key facts**

Population: 156,050,883 (July, 2009, estimate)
Area: 144,000 square kilometers
Gross domestic product (GDP): $206.7 billion (purchasing power parity, 2007 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 33.7 in 2004
Kyoto Protocol status: Ratified October, 2001

- **Historical and Political Context**

Among the world's nations, Bangladesh has one of the largest populations at risk from coastal flooding due to sea-level rise and storm surges. It is located in South Asia and borders India, Myanmar, and the Bay of Bengal. The country became part of the new nation of Pakistan in 1947, after India and Pakistan became independent from England. It was known then as East Pakistan. In 1971, it became independent with the help of India after a brief civil war and changed its name to Bangladesh.

Bangladesh is about the size of Wisconsin, with a population of about 154 millon, which makes it one of the most densely populated countries in the world. Its government is a parliamentary democracy, and Islam is the state religion. The 1972 constitution has undergone fourteen amendments and creates three branches of governments, the executive, legislative, and judicial branches. The prime minister is the head of government (executive) and elected by the majority party in parliament. The unicameral parliament is known as Jatia Sangsad and is made up of 345 members, including 45 seats reserved for women. The highest judicial body is the supreme court, which is independent of the executive branch.

The nation has experienced political instability since its inception. It had fourteen governments between 1972 and 2008. The first two national leaders were assassinated, beginning with President Sheikh Mujibur in 1975. The country's limited resources can be blamed in part on this political violence. Being residents of a developing nation, a majority of Bangladesh's people depend on agriculture. However, flooding has continued to decrease the available farmland in the country. The government has been unable to address basic issues, such as protection of life and property.

In many poor countries, when governments fail to provide for the people, those people turn to religious extremism for an answer. There is a growing Islamic extremist movement in Bangladesh that threatens domestic stability. For example, in 2002, the government arrested seven Arab nationals on charges of providing arms and training to militant Islamic groups in Dhaka who were funded by Al-Haramain, a Saudi-based agency. As a result of this growing Islamic extremism, India decided to fence off Bangladesh in order to keep out Muslim terrorists.

At a cost of over $1 billion, India is building a 4,000-kilometer border fence that will run through five Indian states. The fence is designed to prevent infiltration by Islamic terrorists, smuggling, and illegal immigration from Bangladesh. On January 22, 2007, Bangladesh postponed an election and declared a state of national emergency as a result of continued political instability. Fakhruddin Ahmed, with the help of the military, established a caretaker government aimed at cracking down on corruption and preparing for free elections in late 2008.

On December 29, 2008, a general election was held, and the Awami League Party led by Sheikh Hasina Oajed won the election by defeating the Bangladesh National Party. As a result, the military-controlled caretaker government handed power to Sheikh Hasina as prime minister on January 5, 2009. The eldest daughter of Sheikh Mujibur Rahman, the founding father of Bangladesh, Hasina had already served as prime minister from 1996 to 2001.

- **Impact of Bangladeshi Policies on Climate Change**

Flood control measures in Bangladesh were limited mainly to building embankments (artificial levees), polders, and drainage canals. The Bangladesh Water Development Board has constructed about seventeen hundred flood-control structures along with several thousand kilometers of embankments and drainage canals. Most of these projects have created a false sense of security for the residents, even though many of the projects have experienced breaching and erosion since they were constructed. During the 1999 floods, the Gumtl embankment at Etbarpur was breached, creating substantial damage to properties and the environment. The government also adopted a World Bank-sponsored flood action plan after the 1988 flood. The plan calls for the construction of hundreds of kilometers of tall embankments along the major rivers of the country's delta, as well as huge drains and several compartments on the floodplains.

By 1992, the government began to shift its policy from a narrow focus on flood control to flood and water management. It produced several five-year plans with guidelines for development. One of the plans entailed involving all concerned government agencies, as well as local people, in implementing

A Bangladeshi man washes clothing in the polluted Buriganga River in Dhaka. (Andrew Biraj/Reuters/Landov) future embankments and other flood-control and drainage programs.

After the 1998 floods, the government worked with several nongovernmental organizations (NGOs) and donor nations to set up both short-term and long-term projects aimed at controlling or managing floods. These projects included government distribution of free seeds to farmers to reduce food shortages, as well as construction of large flood-protection shelters raised above the ground to protect both people and animals. The government also constructed flood-proof storage sheds to hold grains and other food supplies, dams upstream of the capital city of Dhaka, and a major embankment around the city itself. Emergency flood warning systems were improved and contingency plans formulated for the deployment of rescue and relief services. Villages—particularly remote villages that are difficult to reach during flooding—were stocked with emergency medical stores. The government also implemented reforestation programs and animal grazing controls in an attempt to increase absorption and reduction of water runoff. These projects were bold and very costly for Bangladesh alone, but the government hoped that the United Nations, donor countries, and NGOs would come to its aid.

• Bangladesh as a GHG Emitter

According to a United Nations development report, Bangladesh in 2004 accounted for 0.1 percent of global emissions, an average of 0.3 metric ton of carbon dioxide (CO_2) per person. As a result, it is not bound by a specific target for greenhouse gas (GHG) emission reductions. The emission levels of Bangladesh and other developing countries are so low that they are not bound by the Kyoto treaty. The treaty commits only the industrialized countries that ratified it to reduce the amount of six GHGs by 5.2 percent of the 1990 levels during the five-year period from 2008 to 2012.

• Summary and Foresight

Bangladesh is situated in the delta of three major rivers, the Ganges, Brahmaputra, and Meghna, which eventually empty into the Bay of Bengal. These rivers have large volumes of water with large drainage basins that increase the flood risk. Moreover, Bangladesh is a very low-lying country: Almost 70 percent of its land area is less than 1 meter above sea level, and 80 percent of it is located in a floodplain. Thus, the country's location, climate, and geography make it susceptible to the effects of climate change and also extremely hard to protect from those effects. The courses of its rivers are constantly shifting, making it difficult to build up riverbanks to protect farmland. Bangladesh has responded to climate change with huge projects and programs, but it will need cooperation from its neighbors, especially India.

Femi Ferreira

• Further Reading

Cash, Benjamin A., Xavier Rodó, and James L. Kinter III. *Non-ENSO Variability and the Regional Climate of Bangladesh: Implications for Cholera Risk.* Calverton, Md.: Center for Ocean-Land-Atmosphere Studies, 2008. Brief, detailed examination of Bangladesh's climate and climate variability with a focus on epidemiology and climatic effects on disease.

Huq, Saleemul, et al. *Mainstreaming Adaptation to Climate Change in Least Developed Countries (LDCs).* London: International Institute for Environment and Development, 2003. Bangladesh and Mali are the two nations discussed as case studies in this treatise on proper responses to global warming in developing nations.

Orford, Margie. *Climate Change and the Kyoto Protocol's Clean Development Mechanism: Brazil, Bangladesh, Indonesia, South Africa.* London: ITDG, 2004. Detailed monograph examining the Kyoto Protocol-related obligations and activities of Bangladesh and three other nations.

Zedillo, Ernesto, ed. *The Future of Globalization: Explorations in Light of Recent Turbulence.* New York: Routledge, 2008. Collection of essays on global economic development, including one on Bangladesh's place in the world economy and two on the environmental implications of global development.

See also: Flood barriers, movable; Floods and flooding; India; Nongovernmental organizations; Water resources, global.

Barrier islands

- **Category:** Geology and geography

- **Definition**

Barrier islands are narrow strips of land that are oriented parallel to the mainland and that lie on average a few kilometers offshore. Barrier islands are largely composed of sand-sized grains of sediment plus some finer sedimentary material and organic debris. They are separated from the mainland by an intervening body of water called a lagoon or bay. Barrier islands therefore have two shorelines, one facing the open ocean and the other facing the mainland. The side facing the open ocean is typically a much more energetic shoreline, experiencing higher waves and storm surges. The ocean-facing side is typically much straighter than the mainland-facing side, which is a low-energy coastal area.

Barrier islands may have several origins, but the most common is thought to be related to the post-ice age rise in sea level that commenced about eighteen thousand years ago. This sea-level rise inundated the world's coastal areas, and many barrier islands probably formed from coastal sand ridges and dune fields that were surrounded by the rising sea. Once the barrier islands were established, sand that was eroded from land and washed along the shore by wave currents helped build and maintain the islands.

Barrier islands are nourished—that is, restocked with sand—by a process called longshore drift. Longshore drift is the movement of sand down the seaward coast of a barrier island, resulting from the effects of wind waves that approach the seaward coastline of the island at a slight angle. These wind waves wash up on the barrier island coast (beach face) at an angle, and their return flow is directly back to the sea but slightly displaced in the wave's direction. As a result, the waves move sand and other material down the beach.

- **Significance for Climate Change**

Barrier islands are significantly affected by climate change. As global sea levels rise, barrier islands are at risk of being inundated or eroded away, as has been seen in many areas of the world. The loss of barrier islands or a diminution in their width and continuity is a direct effect of sea-level change in many places. Increased storm activity, a result of climate change in general and of changes in sea surface temperatures in particular, affects barrier islands because they are at the front line when a sea storm comes ashore. Storm wave energy is spent on barrier islands, and the result can be dissection of the barrier islands or their complete destruction.

Barrier islands are integral parts of typically fragile coastal ecosystems, which are home to many plant and animal species. If climate change causes the loss of barrier-island habitats for coastal species, these organisms will need to adapt or perish.

Barrier islands require a continual sand supply to persist. This supply can be interrupted in many ways, including through climate change. Climatic changes that affect local runoff, for example, might reduce the flow of rivers that bring sand to the coastline and nourish the barrier islands there. There are other ways to lose sand supply, including human intervention.

The potential loss of barrier islands represents the possibility that areas of mainland currently sheltered by barrier islands will become primary coastlines. This would result in many changes in coastal geomorphology and ecosystems, as the protected mainland would become the focus of wave energy, altering the shape, population, and dynamics of shorelines.

Barrier islands on some coastlines of the world contain some of the most expensive real estate developments. These developments, some of which lie upon narrow sand islands less than 3 meters above sea level, are at imminent risk of loss as climatic conditions change. Such loss could entail huge economic losses for many countries and states, which depend upon tax revenues from entities built upon the islands.

In the past, barrier islands developed along the world's coastlines in much the same way that they had developed since the end of the last ice age. Studying ancient barrier islands, which are now part of the sedimentary rock record of the Earth, and comparing them to modern barrier islands helps scientists understand ancient climates and the history of climate change and its effects. There are lessons to be learned from the sedimentary record of barrier islands—particularly that conditions are always changing, especially at the oceanic coastline.

Barrier islands are analogous to living things in that they use energy to survive, they grow larger and smaller, they experience and recover from injuries, and they have a life cycle that ends in death. Climate change can bring on the death of a barrier island or present challenges to the continued survival of that island.

David T. King, Jr.

• Further Reading

Morton, Robert A. *Historical Changes in the Mississippi-Alabama Barrier Islands and the Roles of Extreme Storms, Sea Level, and Human Activities.* Reston, Va.: U.S. Geological Survey, 2007. Extensive study of natural and anthropogenic effects upon the Mississippi-Alabama barrier islands; invaluable resource for understanding the diversity of influences impinging upon these islands.

Pilkey, Orrin H., and Mary Edna Fraser. *A Celebration of the World's Barrier Islands.* New York: Columbia University Press, 2003. Very well illustrated popular-science book, coauthored by one of the world's foremost experts on barrier islands, Pilkey. Discusses the natural history of barrier islands and their modern peril.

Pilkey, Orrin H., Deborah Pilkey, and Craig A. Webb. *The North Carolina Shore and Its Barrier Islands.* Durham, N.C.: Duke University Press, 2000. Scientific and ecological guide to one of the classic barrier island coastlines of the world, North Carolina and its Outer Banks. Provides an outstanding introduction to barrier-island studies and issues in a changing global environment.

See also: Alliance of Small Island States; Coastal impacts of global climate change; Coastline changes; Islands; Ocean dynamics.

Basel Convention

• **Categories:** Laws, treaties, and protocols; pollution and waste
• **Date:** Opened for signature March 22, 1989; entered into force May 5, 1992

The Basel Convention is an international agreement to promote the environmentally sound management of hazardous waste and to reduce irresponsible disposal in less developed countries.

• **Participating nations:** *1989:* Jordan; *1990:* Hungary, Norway, Saudi Arabia, Switzerland; *1991:* Argentina, China, El Salvador, Finland, France, Mexico, Nigeria, Panama, Romania, Sweden, Uruguay; *1992:* Australia, Bahamas, Bahrain, Brazil, Canada, Chile, Cyprus, Estonia, India, Latvia, Liechtenstein, Maldives, Mauritius, Monaco, Poland, Senegal, Sri Lanka, Syrian Arab Republic, United Arab Emirates; *1993:* Antigua and Barbuda, Austria, Bangladesh, Belgium, Czech Republic, Ecuador, Egypt, Indonesia, Iran, Japan, Kuwait, Malaysia, Netherlands, Peru, Philippines, Saint Lucia, Seychelles, Slovakia, Slovenia, Tanzania; *1994:* Comoros, Côte d'Ivoire, Croatia, Cuba, Democratic Republic of Congo, Denmark, European Community, Greece, Ireland, Israel, Italy, Lebanon, Luxembourg, Malawi, New Zealand, Pakistan, Portugal, Republic of Korea, Saint Kitts and Nevis, South Africa, Spain, Trinidad and Tobago, Turkey, United Kingdom, Zambia; *1995:* Barbados, Costa Rica, Germany, Guatemala, Guinea, Honduras, Iceland, Micronesia, Morocco, Namibia, Oman, Papua New Guinea, Paraguay, Qatar, Russian Federation, Tunisia, Vietnam; *1996:* Bolivia, Bulgaria, Colombia, Kyrgyzstan, Mauritania, Nepal, Saint Vincent and the Grenadines, Singapore, Turkmenistan, Uzbekistan, Yemen; *1997:* Belize, Benin, Burundi, Gambia, Mongolia, Mozambique, Nicaragua, Thailand, former Yugoslav Republic of Macedonia; *1998:* Algeria, Botswana, Dominica, Republic of Moldova, Niger, Venezuela; *1999:* Albania, Andorra, Armenia, Belarus, Burkina Faso, Cape Verde, Georgia, Lithuania, Madagascar, Uganda, Ukraine; *2000:* Dominican Republic, Ethiopia, Kenya, Kiribati, Lesotho, Mali, Malta, Serbia; *2001:* Azerbaijan, Bosnia and Herzegovina, Cambodia, Cameroon, Guyana, Libyan Arab Jamahiriya, Nauru; *2002:* Bhutan, Brunei Darussalam, Djibouti, Samoa; *2003:* Equatorial Guinea, Ghana, Jamaica, Kazakhstan, Marshall Islands; *2004:* Chad, Cook Islands, Liberia, Rwanda, Togo; *2005:* Eritrea, Guinea-Bissau, Swaziland; *2006:* Central African Republic, Montenegro, Sudan; *2007:* Congo (Republic of the); *2008:* Democratic People's Republic of Korea, Gabon

• Background

The Basel Convention is a treaty designed to promote environmentally sound management of hazardous waste while controlling and ultimately reducing the transboundary movement of hazardous waste for disposal to countries with less stringent regulations or enforcement. The convention requires countries to engage in more responsible management of hazardous waste, with a preference toward preventing pollution and minimizing the amount of waste produced. It promotes the domestic management of waste, rather than its disposal in other nations. In addition to protecting ecosystems from hazardous materials, the convention has a potential positive effect on Earth's climate: If less waste is produced and fewer raw materials and less energy are consumed, fewer greenhouse gases (GHGs) will be emitted into the atmosphere.

In the early and mid-1980's, the environmentally irresponsible management of hazardous waste drew international attention and outrage. Throughout the 1980's, industrialized nations began strengthening domestic hazardous-waste laws and regulations to foster more responsible hazardous-waste management to protect public health and the environment. An important component of this phase was the incorporation of the concept of waste minimization into the waste-management hierarchy. Waste minimization, the reduction in the quantity or toxicity of the hazardous waste generated, is the most desirable option under the waste-management hierarchy; it is followed by recycling, then treatment, and finally, the least preferable, responsible disposal. This model sought to eliminate or reduce significantly the disposal of untreated hazardous waste. However, the cost to treat and manage hazardous waste increased, resulting in escalated irresponsible dumping of untreated hazardous waste in less developed countries.

• Summary of Provisions

In response to this situation, the international community under the auspices of the United Nations Environment Programme drafted the Basel Convention in 1987. The convention was opened for signature in 1989 and went into force in 1992. It stipulates that if waste from one country is to be managed in another country, its transportation and management are to be conducted under conditions that do not endanger human health or the environment. The convention also prohibits the irresponsible disposal of hazardous waste in less developed countries. By 2008, 170 parties had ratified the convention. However, not all the major industrial countries are parties. For example, the United States became a signatory to the convention in 1990 but has never ratified it. The two other nonparty signatories to the convention are Afghanistan and Haiti.

Although the Basel Convention generally prohibits the shipment of hazardous waste between parties and nonparties, Article 11 of the convention allows the transboundary shipment of hazardous waste

Preamble to the Basel Convention

The Basel Convention's Preamble, excerpted below, sets out the context and international legal framework within which the convention was conceived.

The Parties to this Convention. . .

Affirming that States are responsible for the fulfilment of their international obligations concerning the protection of human health and protection and preservation of the environment, and are liable in accordance with international law,

Recognizing that in the case of a material breach of the provisions of this Convention or any protocol thereto the relevant international law of treaties shall apply,

Aware of the need to continue the development and implementation of environmentally sound low-waste technologies, recycling options, good house-keeping and management systems with a view to reducing to a minimum the generation of hazardous wastes and other wastes,

Aware also of the growing international concern about the need for stringent control of transboundary movement of hazardous wastes and other wastes, and of the need as far as possible to reduce such movement to a minimum,

Concerned about the problem of illegal transboundary traffic in hazardous wastes and other wastes,

Taking into account also the limited capabilities of the developing countries to manage hazardous wastes and other wastes . . .

Convinced also that the transboundary movement of hazardous wastes and other wastes should be permitted only when the transport and the ultimate disposal of such wastes is environmentally sound, and

Determined to protect, by strict control, human health and the environment against the adverse effects which may result from the generation and management of hazardous wastes and other wastes,

HAVE AGREED AS FOLLOWS. . . .

from parties to nonparties, provided such shipments are subject to separate agreements that are no less stringent that the requirements of the convention. For example, the United States, a nonparty country, has bilateral agreements for hazardous-waste management with Mexico and Canada, both party countries. In addition, the United States has a multilateral agreement addressing transboundary shipments of hazardous waste with the thirty member-countries of the Organization for Economic Cooperation and Development (OECD).

The Basel Convention controls the transboundary movements of hazardous and other wastes (those wastes listed in Annex I of the convention) under a "prior informed consent" procedure. Any shipment made without prior consent is deemed illegal. Under Article 11, shipments to and from nonparties are illegal unless there is a special agreement in place that does not undermine the Basel Convention.

For shipments between party countries, the Basel Convention requires the state of export to notify the state of intended disposal, as well as any states through which the shipment is intended to pass (transit states). This notification must contain detailed information describing the proposed shipment of hazardous waste. The shipment may commence only upon receipt of the written consent of the state of import, upon confirmation of the existence of a contract with a disposer specifying that the hazardous waste will be managed in an environmentally sound manner, and upon confirmation that the states of transit have consented to allow the waste to move across their territories. If the shipment is authorized, it must be accompanied at all times by a movement document that provides detailed information about the shipment and that must be signed by each person who takes charge of the waste. Finally, the disposer must confirm receipt of the waste and completion of disposal in accordance with the original notification documents.

The Basel Convention also requires parties to ensure that hazardous waste is managed and disposed of in an environmentally sound manner. In accordance with the convention, environmentally sound procedures include minimization of quantities moved across borders, treatment and disposal of wastes as close as possible to their place of generation, and prevention and minimization of waste generation in the first place. In addition, parties to the convention are expected to adopt controls applicable to the movement and manipulation of hazardous waste from its generation through its storage, transport, treatment, reuse, recycling, recovery, and final disposal.

In 1995, an amendment to the convention was offered as Decision III/1, known as the Basel Ban. If ratified, the ban would prohibit all hazardous-waste exports from the most industrialized countries of the OECD and the European Union to all non-OECD and non-European Union member countries. However, the Basel Ban amendment has not yet entered into force, as only about one-half the number of required countries has ratified it.

• Significance for Climate Change

One of the underlying goals of the Basel Convention is to recast waste as a resource, rather than as an undesirable residue. This recasting promotes the reuse and reclamation of valuable and finite resources, a principle of sustainable development. When waste is reduced, reused, or recycled, there is less demand for virgin, raw materials in the manufacturing and processing stages. This significantly reduces energy consumption throughout the life cycle. As a result of less waste and energy being consumed, the emission of GHGs is correspondingly reduced. However, some criticism remains that without ratification of the Basel Ban, the "effluent of the affluent" will continue, countering principles of sustainability. By forcing all countries to better manage their waste rather than allowing for controlled exports, the Basel Ban likely would generate a greater focus on waste minimization, resulting in further reductions in GHG emissions.

Travis Wagner

• Further Reading

Clapp, Jennifer. *Toxic Exports: The Transfer of Hazardous Wastes from Rich to Poor Countries.* Ithaca, N.Y.: Cornell University Press, 2001. Detailed discussion of the evolution of the Basel Convention, its weaknesses, and the challenges related to the international trade of hazardous waste.

Lipman, Zada. "A Dirty Dilemma." *Harvard International Review* 23, no. 4 (Winter, 2002): 67-72. Discusses some of the economic challenges and issues of sovereignty relating to countries that rely on exporting hazardous waste, as well as others dependent on its importation.

"The New Frontier." *Environmental Policy and Law* 37, no. 1 (2007): 22-24. Summarizes the most significant challenges facing the Basel Convention parties, including electronic waste and ship breaking.

United Nations Environment Programme. *The Basel Convention: A Global Solution for Controlling Hazardous Wastes.* New York: Author, 1997. Comprehensive overview and description of the Basel Convention.

See also: International agreements and cooperation; Sustainable development; United Nations Environment Programme.

Baseline emissions

• **Category:** Pollution and waste

• Definition

Baseline emissions are the greenhouse gas emissions that would take place in the absence of emission mitigation policies or projects. Sometimes referred to as the emissions in the "business-as-usual" scenario, baseline emissions are often compared with the actual emissions brought about by a project or policy in order to determine how effective the project or policy was at reducing emissions. This information is often used to award carbon offset credits to the project's sponsor.

- **Significance for Climate Change**

Determining baseline emissions is an important part of emissions-offsetting schemes, in which nations, corporations, or other entities receive tradable credits in return for reducing their emissions. Most notably, the "project-based mechanisms" under the United Nations Framework Convention on Climate Change (UNFCCC)—joint implementation (JI) and the clean development mechanism (CDM)—award carbon credits by subtracting the actual emissions of a project from the baseline emissions. The resulting quantity is the reduction in emissions generated by the project when compared to the business-as-usual scenario. Carbon credits may then be purchased by entities that expect to exceed their minimum negotiated emission levels. They may also be used by the recipient to offset high emission levels elsewhere in the country.

Baseline emissions cannot be measured. They are counterfactual, involving what would have happened had a project not taken place, and thus require expert judgment to be ascertained. In the CDM, the executive board, with the help of a methodologies panel, approves methodologies for determining baseline emissions for various types of projects.

Baseline emissions are directly tied to the profitability of specific emission-reduction projects and to the environmental integrity of emissions-offsetting mechanisms. If the baseline emissions of a given project are low, fewer credits will be awarded for the project sponsor to sell or use to offset emissions elsewhere. The project becomes less profitable, and fewer investors are drawn to invest in emission-reduction projects. If the baseline is high, more credits may be awarded to the project, allowing the project sponsor, or whoever buys the credits, to emit more elsewhere. The project becomes more profitable, but awarding more credits than were "actually" reduced threatens the environmental integrity of the mechanism. Because of the stakes involved, the entity awarding carbon credits generally implements procedures to help prevent "gaming" the baseline—that is, manipulating the baseline to change the number of credits awarded in order to benefit certain parties.

The cost, effort, and uncertainty associated with setting the baseline for emission reduction projects is sometimes so great that it makes projects unprofitable or unattractive. In response to this, some have suggested standardizing baselines to streamline the process. Another suggestion has been to move from project-based offsetting to "sectoral" offsetting, in which baseline emissions for an entire sector would be calculated and compared to actual emissions in order to award credits to mitigation strategies on a scale larger than individual projects.

Douglas Bushey

See also: Certified emissions reduction; Clean development mechanism; Emissions standards; Fossil fuel emissions; Industrial emission controls; Industrial greenhouse emissions; United Nations Framework Convention on Climate Change.

Bayesian method

- **Category:** Science and technology

- **Definition**

In statistics, there are two very different approaches to making inferences about unknown parameters: the frequentist, or non-Bayesian, and the Bayesian. One of the key differences between these two approaches is the notion of probability employed. The frequentist approach defines probability as the relative frequency of an event occurring in repeated trials; probability under this definition is also termed "objective probability." The Bayesian approach regards probability as a measure of the uncertainty inherent in a researcher's rational belief about the values of parameters or unknown quantities of concern. Another important difference is related to the specification of unknown parameters. The frequentist approach considers parameters as unknown but nonrandom values. By contrast, the Bayesian method regards parameters as random variables and uses probability distribution to specify possible values of those parameters.

In application, the Bayesian method is basically a way of learning from data. A Bayesian application refers to a three-step process employed to update a researcher's rational belief about unknown parameters or about the validity of a proposition, given the data observed. The first step concerns the formulation of a prior distribution for an unknown parameter in a statistical model of concern. The prior distribution reflects knowledge or results from past studies. Next, data or observations are collected to incorporate information about the parameter that generates those data. In the final step, the prior distributions are updated with the new data to create a new distribution. This method follows from a theorem formulated by and named after the Reverend Thomas Bayes, a British mathematician (1702-1761).

Applications of the Bayesian method and its implications for rational decisions are especially useful in studies for which the researcher has just a few data points available or for which uncertainty over some parameters needs to be resolved in the light of new data or observations. The method has become very popular over the past few decades in part because of the drastic growth of computer power, which renders much more feasible the calculations necessary to resolve simulations. There are various applications of the Bayesian method in such sciences as biostatistics, health outcomes, and global climate, to name just a few.

• Significance for Climate Change

Climate is the long-term average of weather events occurring in a region. The weather on a day in January in Chicago may be mild or sunny, but the winter climate in the city is on average cold, snowy, and rainy. Climate change reflects a change in long-term trends of the aggregate of these weather events. For example, annual precipitation can increase or decrease, and the climate can become warmer or colder. On a global scale, global warming refers to an increasing trend of Earth's temperature, which in turn causes changes in rainfall patterns, a rise in sea level, and a wide range of impacts on ecological systems and human life. The prediction of these changes and their impacts is difficult, because many uncertainties are associated with various relations and parameters present in the climate system. However, there has been significant study of these uncertainties under different methodologies.

As an approach to analyze uncertainty that allows incorporating expert knowledge and empirical observations into the analysis of updated data, the Bayesian method provides a powerful tool to study climate change. Recent studies have employed the Bayesian method to construct statistical models characterizing climate change. In those models, typical climate variables include, but are not limited to, surface air temperatures, precipitation, sea level, and ocean heat contents, on either a global or a regional scale. These models are built to serve many purposes, such as attribution, estimation, detection, and prediction of climate change.

In order to illustrate how the Bayesian approach can be applied to climate change, take the case of sea-level rise as an example. A recent study in this area tries to develop a Bayesian model for using evidence to update probability distributions for a climate model's parameters, which reflect the unknown states of nature, including sea-level rise. Once developed, the model and its updated probability distributions can be used to make projections of sea-level rise.

The steps to build such a model are as follows: First, define a prior probability distribution over the parameters of a model of sea-level rise as formulated based on expert knowledge or past studies. Second, draw a certain number of samples of those parameters at random from the prior distribution, then feed these samples into the model to calculate projected sea levels. Third, observe the actual sea levels and use the data to update the model's projections using the Bayes theorem. The updated projections are then translated into a new probability distribution. In the next cycle, with new data on sea levels obtained, the second and third steps are repeated, and the probability distribution is updated once more. Thus, each new observation of sea levels is incorporated into the model, providing better data and refining the probability distributions to increase the predictive accuracy of the system. The model parameters are partially resolved over time.

Although the Bayesian method provides an attractive approach for analyzing climate change, it is subject to some criticism. First, the idea of subjective judgments of prior probabilities, which influence the inferences drawn from models, is not accepted by many scientists. Critics of the Bayesian method argue that subjectivity prevents observers from viewing data objectively, so inferences should be based on observed data alone. Another problem is that people do not actually think like Bayesians. There is ample empirical evidence that people fail to update their prior beliefs using Bayes' law and that they act differently from the assumptions of Bayesian analysis would predict. It should be noted that there are alternative approaches to the Bayesian method to analyze uncertainty involving climate change, such as fuzzy set theory.

To N. Nguyen

• **Further Reading**

Bolstad, William M. *Introduction to Bayesian Statistics.* Hoboken, N.J.: John Wiley & Sons, 2007. Introduces the Bayesian approach to statistics. Covers the topics usually found in an introductory statistics book but from a Bayesian perspective.

Gelman, Andrew, et al. *Bayesian Data Analysis.* New York: Chapman & Hall, 2004. Includes an introduction to Bayesian inferences starting from basic principles, a text for graduate students to learn current approaches to Bayesian modeling and computation, and a handbook of the Bayesian method for researchers in the sciences.

Hobbs, Benjamin F. "Bayesian Methods for Analyzing Climate Change and Water Resource Uncertainties." *Journal of Environmental Management* 49, no. 1 (January, 1997): 53-72. Outlines the advantages of the Bayesian method when applied in analysis of uncertainty involving climate change, with an emphasis on the risks that changes pose to water resources systems.

See also: Climate prediction and projection; Meteorology; Weather forecasting.

Benefits of climate policy

• **Category:** Laws, treaties, and protocols

Climate policy decisions are particularly difficult to make because the accuracy of climate projections is difficult to evaluate. Even if the changes themselves were predictable, the consequences of those changes are not. Thus, the relative benefits and dangers of a particular course of action are difficult to determine.

• **Key concepts**

climate impact: the effects of climate and climate change on the socioeconomic well-being of an area

climate impact statement: empirical case study designed to help predict future impacts of climate on society

market benefits: positive effects of a given climate policy on production and trade, including prevention or mitigation of damages

nonmarket benefits: positive effects of a given climate policy on health, social and psychological welfare, and other attributes that are not primarily economic

• **Background**

In the 1980's, such books as W. J. Maunder's *The Uncertainty Business: Risks and Opportunities in Weather and Climate* (1986) emphasized the risks and opportunities presented by Earth's natural climate, subject to contingent human influences. Since then, mainly as a result of the works of the Intergovernmental Panel on Climate Change (IPCC), emphasis has moved markedly to considerations of the human impact on the climate system. However, irrespective of this change in emphasis, weather and climate have always given rise to risks and opportunities, and communities and individuals who can adapt to these challenges will always be in a position to lessen the costs of climate variations and climate changes. They will also be in a better position to increase the benefits and profits arising from climate variations and climate changes.

In Maunder's follow-up project, *The Human Impact of Climate Uncertainty: Weather Information, Economic Planning and Business Management* (1989), most of the emphasis was on variations in the natural climate. While these remain important, during the following twenty years a greater emphasis was placed on anthropogenic effects on the climate system. Nevertheless, good economic planning should take into account the best possible advice from climate experts on likely climatic changes during the relevant planning horizons, regardless of the causes of those changes.

• The Reliability of Climate Forecasts

To understand how a society might best respond to a change in its regional—as well as the global—climate, it is highly desirable to know how societies have been affected by, and how they have coped with, past climatic events, such as droughts, warm periods, cold periods, and wet periods. The climate of the future might not be exactly parallel to the climate of the past, particularly if anthropogenic factors become significantly more influential. Barring unforeseeable shocks to social and economic systems, however, socioeconomic institutions are likely to act in ways similar to their actions in the past. With better climate forecasts, societies can act in a much more informed manner to eradicate their weaknesses and capitalize on their strengths. Socioeconomic organizations would then be better prepared for future climate change, even if the nature of that change remains uncertain.

U.S. secretary of energy Stephen Chu, left, and U.S. secretary of commerce Gary Locke shake hands in Beijing, China, after announcing a joint project by the two nations to conduct energy-efficiency research. Climate policy, based in science, has profound effects upon trade and commerce. (Jason Lee/Reuters/Landov)

• The Formulation of Climate Policy

If organizations and individuals are going to take a positive attitude in dealing with climate change, again considering climate change from all causes, it is important that they understand the uncertainties of any climate forecast. The forecasts made by the various reports from the IPCC must be taken into account, but these forecasts have been subject to changes since the first IPCC report was published in the early 1990's, and they will continue to be modified as new information comes to light. Furthermore, while the majority of climate scientists generally agree with the forecasts made by IPCC scientists, there is a sizable group of climate scientists who have considerable concerns about the lack of emphasis being placed on the natural causes of climate change.

In particular, some scientists believe that the IPCC minimizes the role of variations in solar output, volcanic eruptions, the oceans, and other factors beyond human control. From a policy point of view, therefore, it is important for decision makers to take note not only of the average and extreme values forecast by the various IPCC reports but also of the possibility that some of these forecasts may prove to be wrong, particularly as the natural causes of climate change become better understood. Caution, therefore, should be a key concern, and decision makers concerned with climate change should be aware of the uncertainties involved in understanding and predicting that change.

• Context

Society would benefit considerably from correct policy decisions based on accurate climate forecasts. The world of climate forecasting and the world of decision making, however, are both far from perfect. The state of contemporary climate forecasting in particular is difficult to assess, because new computer models are making predictions about events decades in the future, and the accuracy of those predictions and their underlying methodology will not be known until decades have passed. Even accurate scientific predictions must be interpreted through the lens of policy and politics, adding a significant further complication.

For example, the 2007 IPCC report, states

> continued greenhouse gas emissions at or above current rates would cause further warming, and induce many changes in the global climate system during the twenty-first century that would "very likely" be larger than those observed during the 20th century.

Similarly, the 2007 IPCC report gives a best estimate, and a likely range of best estimates, for a global average temperature range for the last decade of the twenty-first century compared with the last two decades of the twentieth century.

Depending on the climatic greenhouse gas (GHG) scenario used, the best estimates of temperature increase range from 0.6° Celsius to 4.0° Celsius, and the likely range within these scenarios extends from 0.3° Celsius to 6.4° Celsius. Given these ranges, policy makers must determine which is the most appropriate forecast to use and how such a forecast will be used in planning activities in the future. Relevant activities vary widely, from constructing dams, to building roads to ski resorts, to planting new vineyards, and even to wholesale relocation of island inhabitants to avoid the consequences of sea-level rise.

The 2007 IPCC report projects many regional impacts of climate change during the next one hundred years. Under a range of climate scenarios, Africa's arid and semiarid land is projected to increase by 5-8 percent by 2080. In Europe, climate change is expected to magnify the regional differences in the distribution of natural resources and assets. Negative impacts will include the increased risk of inland flash floods, more frequent coastal flooding, and increased erosion due to storminess and sea-level rise. North American cities that currently experience heat waves are expected to be further challenged by an increased number, intensity, and duration of heat waves, with potential for adverse health impacts. Whether such forecasts are correct and whether society adapts itself to such forecasts remains to be seen.

W. J. Maunder

• Further Reading

Emanuel, K. "Increasing Destructiveness of Tropical Cyclones over the Past Thirty Years." *Nature* 436 (2005): 686-688. Written by a key research scientist in the field of tropical storms, particularly their destructiveness, frequency, and intensity.

Maunder, W. J. *The Uncertainty Business: Risks and Opportunities in Weather and Climate.* London: Methuen, 1986. Considers the atmosphere as a unique resource that may be tapped, modified, despoiled, or ignored. The "risks and opportunities" concept is particularly significant in any consideration of global warming.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years.* Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008. Describes a fifteen-hundred-year climate cycle that, according to the authors, offers the only explanation for modern global warming supported by physical science.

See also: Ecological impact of global climate change; Economics of global climate change; U.S. energy policy.

Bennett, Hugh Hammond

American soil conservationist

Born: April 15, 1881; near Wadesboro, Anson County, North Carolina

Died: July 7, 1960; Burlington, North Carolina

Bennett recognized that climate influences soil erosion, and he incorporated assessments of temperature, precipitation, and other climatic factors into soil-conservation techniques.

• Life

During childhood, Hugh Hammond Bennett observed soil damages on his family's 486-hectare North Carolina farm. He studied chemistry and geology at the University of North Carolina, earning a B.S. in 1903. Employed by the Bureau of Soils in the U.S. Department of Agriculture (USDA), Bennett traveled throughout the United States, documenting topsoil losses detrimental to agriculture and noting scientific causes of erosion. A pioneer soil conservationist, he stressed that soil resources were finite. In 1933, he became director of the Soil Erosion Service, a federal agency offering farmers conservation assistance. In 1935, Bennett encouraged U.S. legislators to establish the Soil Conservation Service in the USDA and was selected as its chief, promoting scientific conservation methods while holding that position and after his 1951 retirement.

• Climate Work

Bennett emphasized evaluating climate factors while planning soil conservation strategies to control erosion. He noted how climate affects crops in his book *The Soils and Agriculture of the Southern States* (1921), and he prepared reports discussing climate and conservation for scholarly journals. Bennett urged agriculturists to comprehend climate issues associated with lands they farmed in order to avoid such disasters as dust storms like those which had devastated the western United States in the 1930's. In public lectures and magazine articles, he promoted planting cover crops to collect precipitation, using contour tillage to stop runoff, and leaving stubble mulch in harvested fields to protect soil from wind.

Bennett devoted chapters to climate and its role in soil erosion in several books. In *Soil Conservation* (1939), he described how temperature, wind speed, humidity, and the amount and duration of precipitation affect soils. Bennett noticed that varying climates influence the speed and form of erosion, remarking that warmer temperatures accelerate chemical activity such as leaching in soil. He also stated that climates could be altered from moist to arid after winds blew topsoil away, exposing clays that could not absorb sufficient precipitation. Bennett reiterated this information in both editions of his classic text, *Elements of Soil Conservation* (1947 and 1955).

Bennett's climate insights helped soil conservation achieve recognition as a scientific field and inspired soil conservationists internationally, as they modeled their work on his techniques. Bennett's concepts retain value as global warming intensifies climate changes that impact twenty-first century landscapes.

Elizabeth D. Schafer

See also: Agriculture and agricultural land; Conservation and preservation; Soil erosion.

Berlin Mandate

- **Category:** Laws, treaties, and protocols
- **Date:** Negotiated March 28-April 7, 1995

The Berlin Mandate established the series of international meetings that led to the Kyoto Protocol.

• Participating nations: Albania, Algeria, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, The Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Belize, Benin, Bolivia, Botswana, Brazil, Burkina Faso, Cameroon, Canada, Chad, Chile, China, Comoros, Cook Islands, Costa Rica, Côte d'Ivoire, Cuba, Czech Republic, Democratic People's Republic of Korea, Denmark, Dominica, Ecuador, Egypt, Estonia, Ethiopia, Fiji, Finland, France, The Gambia, Georgia, Germany, Greece, Grenada, Guinea, Guyana, Hungary, Iceland, Italy, Jamaica, Japan, Jordan, Kenya, Kuwait, Lao People's Democratic Republic, Lebanon, Liechtenstein, Luxembourg, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia, Monaco, Mongolia, Myanmar, Nauru, Nepal, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Republic of Korea, Romania, Russian Federation, Saint Kitts and Nevis, Saint Lucia, Samoa, Saudi Arabia, Senegal, Seychelles, Slovak Republic, Solomon Islands, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Thailand, Trinidad and Tobago, Tunisia, Tuvalu, Uganda, United Kingdom, United States of America, Uruguay, Uzbekistan, Vanuatu, Venezuela, Vietnam, Zambia, Zimbabwe

• Background

When the United Nations Conference on Environment and Development, also known as the Earth Summit, was held in Rio de Janeiro in 1992, the result was the international treaty known as the

United Nations Framework Convention on Climate Change (UNFCCC). The purpose of this treaty, which went into effect in 1994, was to prevent "dangerous anthropogenic interference with Earth's climate system." Instead of specific limits on emissions for individual nations, the treaty simply called for future protocols that would set these limits, but the intention was that industrialized nations, known as Annex I countries, would reduce their emissions to 1990 levels by the year 2000. In 1995, the first annual Conference of the Parties (COP-1) was held in Berlin, Germany, to analyze progress and make plans for the future. It was generally agreed that industrialized nations would not be able to honor their emission reduction commitments by 2000. The Berlin Mandate, an agreement reached at that meeting, was an attempt to establish goals that could reasonably be met.

- **Summary of Provisions**

Realizing that the 2000 targets would not be met, the framers of the Berlin Mandate gave the parties the ability to begin making plans and commitments "for the period beyond 2000." Following the understanding reached in the UNFCCC, industrialized nations would continue to bear most of the responsibility for emissions reductions, because they generated most of the emitted greenhouse gases (GHGs) and because they were most able to make reductions. However, it was agreed that

> the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions.

The Berlin Mandate called for a two-year analytical and assessment phase to be conducted by the Intergovernmental Panel on Climate Change (IPCC) and suggested that this research phase might lead to new targets

Berlin Mandate

The Berlin Mandate is an agreement to create a process to strengthen provisions of the United Nations Framework Convention on Climate Change. Article 2 of the mandate, reproduced below, establishes the objectives and protocols governing that process.

The process will, inter alia:

(a) Aim, as the priority in the process of strengthening the commitments in Article 4.2(a) and (b) of the Convention, for developed country/other Parties included in Annex I, both

- to elaborate policies and measures, as well as
- to set quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010 and 2020, for their anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, taking into account the differences in starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort, and also the process of analysis and assessment referred to in section III, paragraph 4, below;

(b) Not introduce any new commitments for Parties not included in Annex I, but reaffirm existing commitments in Article 4.1 and continue to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4.3, 4.5 and 4.7;

(c) Take into account any result from the review referred to in Article 4.2(f), if available, and any notification referred to in Article 4.2(g);

(d) Consider, as provided in Article 4.2(e), the coordination among Annex I Parties, as appropriate, of relevant economic and administrative instruments, taking into account Article 3.5;

(e) Provide for the exchange of experience on national activities in areas of interest, particularly those identified in the review and synthesis of available national communications; and

(f) Provide for a review mechanism.

for the years 2005, 2010, and 2020. The second Conference of the Parties (COP-2) was to present a progress report including "an analysis and assessment, to identify possible policies and measures for Annex I Parties which could contribute to limiting and reducing emissions by sources and protecting and enhancing sinks and reservoirs of greenhouse gases." The study, with recommendations for further binding agreements, would be completed in time to be presented by the Ad Hoc Group on the Berlin Mandate (AGBM) at COP-3.

• Significance for Climate Change

The AGBM met eight times between COP-1 and COP-3. At Kyoto, Japan, where COP-3 was held, it proposed what became known as the Kyoto Protocol. Based on the findings of the IPCC, the protocol created binding targets for Annex I countries. The United States, the largest emitter at the time, was to reduce its GHG emissions to about 7 percent below 1990 levels; European Union nations would reduce by 8 percent, and Japan by 6 percent. Although they had agreed in theory to the provisions of the Berlin Mandate, many industrialized nations protested that refusing to hold developing nations, or non-Annex I nations, to binding reduction targets was both unfair and unwise. These developing nations were undergoing rapid population growth and industrial development, and it was recognized that by 2010 they would be the largest emitters of GHGs. Citing this disparity and its own need for continued economic growth, the United States did not ratify the treaty, although by 2008, 183 other countries had ratified it.

Cynthia A. Bily

• Further Reading

Chasek, Pamela S., David Leonard Downie, and Janet Welsh Brown. *Global Environmental Politics*. 4th ed. Boulder, Colo.: Westview, 2006. Introductory textbook in environment-related international relations; begins with the emergence of global environmental politics and considers climate change, among other issues.

Montgomery, W. David. *Toward an Economically Rational Response to the Berlin Mandate*. Boston: Charles River Associates, 1995. Written immediately after the Berlin Mandate was approved, this brief book proposes economic considerations and tools important for drafting a U.S. response.

Niskanen, William L. *Reflections of a Political Economist: Selected Articles on Government Policies and Political Processes*. Washington, D.C.: Cato Institute, 2008. This collection by an advocate of free markets and limited government includes the essay "Too Much, Too Soon: Is a Global Warming Treaty a Rush to Judgment?"

Paterson, Matthew. *Global Warming and Global Politics*. New York: Routledge, 1996. A history of the early years of global warming as a political issue and of the negotiations leading to international agreements including the Berlin Mandate.

See also: Greenhouse gases; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; United States.

Biodiversity

• **Categories:** Animals; plants and vegetation

Global warming is an emerging threat to biodiversity around the world. As temperatures rise, the geographic location of climatic envelopes will shift significantly, forcing species to migrate. Those that are not able to keep up with their respective climatic envelopes may become extinct.

• Key concepts

biodiversity: the total variation within and among all species of life in a given area, ecosystem, or context

climatic envelope: the range of temperatures, precipitation, and other climatic parameters to which a species has adapted

coral bleaching: whitening of coral that occurs when the coral expels a single-celled, symbiotic alga as a result of stress caused by environmental factors such as warm temperature and pollution

living planet index (LPI): a number representing the population sizes of vertebrate species representative of terrestrial, freshwater, and marine ecosystems around the world; a higher LPI is indicative of higher biodiversity

• Background

Biological diversity allows myriad species to work together to maintain the environment without costly human intervention. Thus, biodiversity is an irreplaceable natural resource crucial to human well-being. Habitat destruction, pollution, invasive species, overexploitation, and global climate change have led to an accelerated decline in biodiversity in recent decades. As a result, the current rate of species extinctions is estimated at one hundred to one thousand times greater than the natural rate. If the biodiversity decline is not slowed, Earth will be much less inhabitable for future generations.

• Past and Current Extinctions

There is no doubt that climate plays a central role in fluctuations of biodiversity. At least four out of five recognized mass extinction events on Earth are attributable to climate changes. The Triassic event (around 200 million years ago) was triggered by atmospheric carbon dioxide (CO_2) levels increasing to one hundred times the current level. The Permian-Triassic extinction (about 251 million years ago), the greatest mass extinction on record, resulted from global temperature rises to between 10° and 30° Celsius higher than today's average temperature. That single event is believed to have wiped out 95 percent of the life in Earth's oceans and nearly 75 percent of terrestrial species.

Climate change has also led to the emergence of new species. In fact, some experts believe that rapid climate changes in Africa might have created suitable conditions for the emergence of modern humans. In particular, rapid changes in water sources are believed to have forced primitive hominids rapidly to change and adapt. Under this theory, *Homo sapiens* evolved from its progenitor species as a result of these changes. In general, however, the birth of new species following a mass extinction usually takes millions of years. Recovery from severe losses of biodiversity does not occur on a human timescale.

Many experts believe that Earth is currently in the midst of a sixth mass extinction event. Although there are many debates raging over the extent of the current biodiversity loss, very few scientists dispute the fact that species extinction is occurring as a result of climate change and human activities. Comprehensive studies conclude that 15 to 37 percent of Earth's species will become extinct by 2050 as a result of projected climate changes. Such massive extinctions will wreak havoc on ecosystems around the world.

• Impact of Climate Change on Biodiversity

Climate changes can affect species in a number of ways. These include the expansion, contraction, and shift of habitats; changes in temperature, precipitation, and other environmental conditions; increased frequency of diseases; emergence of invasive species; and disrupted ecological relationships. With a rising temperature, extreme and severe weather events will become more frequent, including extreme high temperatures, extreme severe storms, large floods, a decrease in snow cover and ice caps, rising sea levels, and alteration to the distribution of infectious diseases and invasive species.

As temperatures rise, habitats for many plants and animals will be altered, eliminating the homes and niches to which they have adapted. It is estimated that up to 60 percent of northern latitude habitats could be affected by global warming. In response to global warming, plants and animals will migrate to more suitable climes. Specific effects have already been observed. The tree line near Olympic National Park has moved up in altitude by more than 30 meters since the 1980's. The red fox is spreading northward in Australia in response to the warming climate. Many fish species along the Pacific coast are shifting their habitats northward in search of cooler waters.

• Biodiversity Loss Due to Human Activities

Before the rapid explosion of human populations, many species may have responded to climate change by migrating northward or southward to the cooler regions. Contemporary human activities such as urbanization, road construction, agriculture, and tourism have fragmented, converted, and destroyed many habitats and potential migration routes and thus make it much more difficult for species to migrate. As a result, many species struggle to cope with climate change as they decline in population, often facing outright extinction.

The replacement of low-intensity farming systems with industrial agro-ecosystems has led to a significant decline in biodiversity. For example, the deforestation of tropical rain forests represents an alarming threat to biodiversity. In some regions, forest cover remains high, but intensive management has turned natural forests into stands of very few or single tree species, leading to the loss of many animal species as well. The disappearance of wetlands worldwide has been dramatic over the last century, ranging from 60 percent in China to 90 percent in Bulgaria. The living planet index declined by 37 percent between 1970 and 2000.

- **Context**

The loss of biodiversity is both real and accelerating, as Earth continues to warm. Approximately 25 percent of conifers, 52 percent of cycads, 12 percent of bird species, 23 percent of mammals, and 32 percent of amphibians are threatened with extinction. The irreversible loss of biodiversity poses serious threats to the well-being of present and future generations. The societal response to this threat has been slow, stemming from a lack of awareness of the vital role biodiversity plays. The key to the solution is education.

There is often a perception of conflict between the need to preserve biodiversity and the goal of economic development. Policy makers and businesses will need to work together to encourage and reward economic development that is friendly to biodiversity. Biodiversity is more complex than many other environmental concerns because it involves several levels of biological organization, including genes, individuals, species, populations, and ecosystems. It cannot easily be measured by a single indicator such as temperature or rainfall. Nevertheless, countries can work together to build consensus and achievable goals aiming at slowing down the biodiversity decline or even restoring habitats for the recovery of threatened species.

Ming Y. Zheng

A May, 2008, meeting of the United Nations Conference on Biological Diversity. From left: General Assembly president Srgjan Kerim, European Union Commission president Jose Barroso, German chancellor Angela Merkel, German environment minister Sigmar Gabriel, and Canadian prime minister Stephen Harper. (Ina Fassbender/Reuters/Landov)

• Further Reading

Braasch, Gary. *Earth Under Fire: How Global Warming Is Changing the World.* Afterword by Bill McKibben. Berkeley: University of California Press, 2007. Very important topic clearly presented and supported by photographs and firsthand data the author collected during his travels around the world. The author's research is meticulous, his reasoning is sound, and his conclusion is clear.

Emanuel, Kerry. *What We Know About Climate Change.* Cambridge, Mass.: MIT Press, 2007. Useful reference summarizing what is and is not known about global warming. Arguments are well substantiated.

Fotherqill, Alastair, et al. *Planet Earth: As You've Never Seen It Before.* Berkeley: University of California Press, 2006. As a companion to a television series on Discovery Channel and the British Broadcasting Corporation, this remarkable book depicts natural wonders and represents an eloquent rallying call to significantly strengthen efforts to preserve these wonders. Illustrated with spectacular color photographs.

Lovejoy, Thomas E., and Hannah Lee, eds. *Climate Change and Biodiversity.* New Haven, Conn.: Yale University Press, 2005. Series of essays, well edited and presented in a cohesive flow. A must read for all who love nature and wildlife and want to know the impacts of climate change upon them.

See also: Amazon deforestation; Amphibians; Dolphins and porpoises; Forests; Mangroves.

Bioethics

• **Category:** Ethics, human rights, and social justice

Climate change raises difficult moral issues because the need to allocate limited funds and resources requires some classes, peoples, and generations to be prioritized over others. Bioethics seeks to create rational frameworks to facilitate the resolution of these issues.

• Key concepts

ethics: the application of moral philosophy to real-world decision making

intergenerational equity: relative equality of treatment between present and future generations, including the obligation of present generations to preserve limited resources for the future

prioritization: using a rational principle to determine the order of precedence among individuals or groups when allocating limited resources

• Background

Bioethics is a discipline that seeks to determine the most ethical course of action when faced with a decision involving medical care, medical or biological research, or life and living processes generally. As such, it is implicated in many decisions dealing with the human response to climate change, because those decisions require balancing the interests of people in different locations, of different classes, and of different generations.

Sensitivity to temperature, and to change in temperature, is a central fact of almost all physical objects and processes, living or not. Extremes of cold and of heat disrupt physiological processes and thereby undermine ecological stability. Heat waves in summer in large population centers, for example, frequently result in illness and death. Such health threats create practical problems of predicting and planning for them, as well as training for and executing appropriate responses. They also raise many of the issues familiar in discussions of medical ethics.

• Prioritization and Prediction

A central question in preparing responses to possible threats related to global warming is that of prioritization. Finite resources must be allocated equitably or according to some other compelling moral principle. It may be necessary to sacrifice a group or individual to advance the well-being of others or to abrogate property rights to serve the general welfare. Moreover, because predicting the future is never a certainty, principles must be established to measure or evaluate the uncertainty of predictions and the acceptable level of risk. Often, a balance must be struck between the two: If an event seems unlikely and its consequences would be minor, preparing for it is less important than preparing for either a near certainty with minor consequences or an unlikely event with severe consequences.

A particularly thorny issue involves intergenerational equity, the comparative claims of present and future generations. The moral philosopher John Rawls spoke of the "just savings" a society is required to put aside for the future. Choices made today will often affect those who live decades or centuries from now. Insofar as these effects can be anticipated, the needs, preferences, and well-being of future generations must be taken into account. It is difficult, however, to weigh those interests against those of the present generations, not least because only one party is able to participate in making decisions. This means not only that the decision makers will be biased in favor of themselves but also that it is impossible to determine with certainty what the preferences of unborn future generations will be. Indeed, as utilitarian theorist Derek Parfit emphasizes, it is possible that the choices made by present generations will determine which individuals are and are not born to be members of future generations.

In order to make ethical decisions regarding the proper response to global warming, it is necessary to establish a framework for evaluating future harms and benefits. Some economists invoke a social "discount rate" to resolve this problem. This method entails calculating the current cost of preventing future harm and comparing it to the cost of that harm in the future.

• Competing Present Interests

Even restricting attention to the present, serious questions arise regarding the most ethical distribution among and within nations of the burdens of climate calamity and the costs of avoiding it. The Kyoto Protocol, for example, treats developing and industrialized nations differently and establishes more stringent standards for the latter. To hold every nation to the same standard (say, so much greenhouse gas emission per capita) would advantage those nations already well developed industrially, which would thereby benefit from their past pollution, and disadvantage developing nations that need to produce significant pollution in the present if they are to progress economically.

On the other hand, using different standards may disadvantage industrialized nations that are competing with developing nations in a global market. More stringent rules regulating labor and environmental impact, for example, can make production in developed nations more expensive than production of the same products in developing nations. However, the lax standards that make production cheaper in developing nations may impose indirect costs not only on companies but also on all members of society. As journalist Alexandra Harney remarks,

> pollution from Asia is believed to be affecting weather up and down the west coast of North America. . . . The sacrifices China makes to stay competitive in manufacturing affect the rest of the world.

• Context

Bioethics is a branch of applied ethics, a relatively recent subdiscipline of the ancient discipline of ethics. Bioethics seeks to ascertain consistent principles to guide decisions regarding such literal life-and-death issues as euthanasia, medical ethics, and proper responses to global warming. Because climate change is such a large-scale phenomenon, both spatially and temporally, the unique challenges it poses to bioethics involve the need to reconcile the disparate interests of all nations and their inhabitants, as well as present and future generations. The scale of the problems posed by climate change requires both individuals and governments to think globally while acting locally.

Edward Johnson

• Further Reading

DeVries, Raymond, and Janardan Subedi, eds. *Bioethics and Society: Constructing the Ethical Enterprise.* Upper Saddle River, N.J.: Prentice Hall, 1998. Sociologists discuss the emergence of the field of bioethics and its supplantation of law, literature, and religion among medical decision makers and their overseers.

Friedman, Thomas L. *Hot, Flat, and Crowded: Why We Need a Green Revolution, and How It Can Renew America.* New York: Farrar, Straus and Giroux, 2008. A well-known journalist and social commentator offers practical arguments about the proper responses to overpopulation, global warming, and other environmental problems.

Garvey, James. *The Ethics of Climate Change: Right and Wrong in a Warming World*. New York: Continuum, 2008. Broad philosophical survey of the ethical issues raised by global warming.

Harney, Alexandra. *The China Price: The True Cost of Chinese Competitive Advantage*. New York: Penguin, 2008. Account of the environmental and other sacrifices China has made to achieve its economic preeminence.

Lomborg, Bjørn. *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. New York: Knopf, 2007. Lomborg approaches questions of how best to weigh the costs of future harms in the spirit of an economist.

Parfit, Derek. *Reasons and Persons*. New York: Oxford University Press, 1984. Subtle discussion of the intellectual complexities of moral thought from a staunchly utilitarian perspective, including analysis of the social "discount rate" as a problem in dealing with the claims of future persons.

Posner, Richard. *Catastrophe: Risk and Response*. New York: Oxford University Press, 2004. A prolific federal judge and public intellectual analyzes flaws in familiar approaches to catastrophic risk—cases in which the natural tendency is to underestimate impact because of low probability.

Rawls, John. *A Theory of Justice*. Cambridge, Mass.: Harvard University Press, 1971. Analysis from a leading nonutilitarian theorist, with implications for how justice is understood across generations.

Reich, W. T. "The Word 'Bioethics': Its Birth and the Legacies of Those Who 'Shaped It.'" *Kennedy Institute of Ethics Journal* 4 (1994): 319-335. Discusses the 1971 origin of the word and the field, and the consequences of their beginnings for later thinkers.

Singer, Peter. *One World: The Ethics of Globalization*. 2d ed. New Haven, Conn.: Yale University Press, 2004. One of the world's most influential experts on applied ethics applies his utilitarian perspective to international problems, including environmental pollution and global warming.

See also: Benefits of climate policy; Conservation and preservation; Intergenerational equity; Journalism and journalistic ethics; Polluter pays principle; Poverty; Precautionary approach.

Biofuels

• **Category:** Energy

• **Definition**

Biofuels are renewable fuels generated from organisms or by organisms. Biofuels are considered by many as a future substitute for fossil fuels. For millions of years, living organisms played a crucial role in the formation of fossil fuels such as oil, natural gas, and coal. As fossil fuels are being depleted, humankind is looking for alternative energy sources. Once again, living organisms can be used to generate such fuels, including ethanol, biodiesel, butanol, biohydrogen, and biogas (mostly methane). One of the applications for biofuels is to use them as gasoline and diesel substitutes. At present, two biofuels are used in vehicles globally: ethanol and biodiesel. Biogas is mainly used to generate electricity. These biofuels are made from plant biomass, including corn, soybean, sugarcane, rapeseed, and other plant material. Solar energy is converted and stored in plant cells in the form of carbohydrates or lipids, and this energy can be transferred into biofuel energy.

Ethanol (C_2H_5OH), or grain alcohol, the most common biofuel, is produced by yeast fermentation of sugars derived from sugarcane, corn starch, and grain. In the United States, most of ethanol is produced from corn starch. Biodiesel, another commonly used biofuel, is made mainly by transesterification of plant oils, such as soybean, canola, or rapeseed oil. Its chemical structure is that of the fatty acids alkyl esters. Biodiesel may also be produced from waste cooking oils, restaurant greases, soap stocks, animal fats, and even algae.

Biogas, which is 50-75 percent methane, is a product of anaerobic fermentation of biomass. In many countries, millions of small farmers maintain

Biofuel Energy Balances

The following table lists several crops that have been considered as viable biofuel sources and several types of ethanol, as well as each substance's energy input/output ratio (that is, the amount of energy released by burning biomass or ethanol, for each equivalent unit of energy expended to create the substance).

Biomass/Biofuel	*Energy Output per Unit Input*
Switchgrass	14.52
Wheat	12.88
Oilseed rape (with straw)	9.21
Cellulosic ethanol	1.98
Corn ethanol	~1.13-1.34

Data from the British Institute of Science in Society.

a simple digester at home to generate energy. There are more than five million household digesters in China, used by people mainly for cooking and lighting, and over a million biogas plants of various capacities in India.

Other types of biofuels are on the road to commercialization. Among them, the most promising is butanol. Butanol (C_4H_9OH) is an alcohol fuel, but, compared with ethanol, it has higher energy content (roughly 80 percent of gasoline energy content). It does not pick up water as ethanol does, nor is it as corrosive as ethanol, and it is more suitable for distribution through existing pipelines for gasoline. Butanol is produced as a result of fermentation by the bacterium *Clostridium acetobutylicum*. Substrates for fermentation utilized for butanol production—starch, molasses, cheese whey, and lignocellulosic materials—are the same as for ethanol.

• Significance for Climate Change

Use of fossil fuels releases carbon dioxide (CO_2), which contributes to global warming. Biofuel utilization can produce considerably less CO_2 compared to fossil fuel utilization. In general, burning biofuels releases only that CO_2 that was captured by plants during photosynthesis. They can be considered "CO_2 neutral," in that the CO_2 released by burning can be reassimilated by plants. However, significant amounts of CO_2 are also generated during biofuel production. Estimated CO_2 emission during production of biofuels greatly depends on the method of their manufacture.

Production of biofuels from crops such as corn under the current fossil-fuel-based agricultural system would significantly increase greenhouse emissions. Emissions result from growing feedstock, applying fertilizers, transporting the feedstock to factories, processing the feedstock into biofuels, and transporting biofuels to their point of use. Manufacturing biofuels from corn starch and plant vegetable oil requires burning considerable amounts of natural gas, diesel, or coal to provide energy.

In contrast, net emissions of CO_2 during biofuel production from lignocellulose can be nearly zero. Lignocellulose is a combination of lignin, cellulose, and hemicellulose that strengthens plant cell walls. Cellulose and hemicellulose are made from sugars that can be converted into biofuels. Electricity from burning the lignin could provide enough energy to replace coal or natural gas during the production of biofuels from lignocellulose. Burning lignin does not add any CO_2 to the atmosphere, because the plants that are used to make the biofuels absorb CO_2 during their growth. Most important, lignocellulose may be obtained from nonedible plants, such as switchgrass and poplar, or nonedible parts of plants, such as corn stalks and wood chips.

Lignocellulose is also a very attractive biofuel feedstock because of its abundant supplies. On a global scale, plants produce about 90 billion metric tons of cellulose per year, making it the most abundant organic material on Earth. In addition, cultivation of nonedible plants for biofuel production requires fewer nutrients, fertilizers, and herbicides and less cultivated land and, thus, fewer energy resources. However, current methods to process cellulosic parts of plants into simple sugars in order to ferment them into ethanol are costly. Major research and development efforts are under way to lower the cost of converting lignocellulose to biofuel.

There is also considerable interest in algae-based biofuels, especially biodiesel. Research conducted by the U.S. Department of Energy Aquatic Species Program from the 1970's to the 1990's demonstrated that many species of algae produce sufficient quantities of oil to become economical feedstock for biodiesel production. Oil productivity of many algae greatly exceeds oil productivity of the best-producing oil crops. Algal oil content can exceed 80 percent of cell dry weight, with oil levels commonly at about 20 to 50 percent of cell dry weight. In addition, cropland and potable water are not required to cultivate algae, because they can grow in wastewater. Although development of biodiesel from algae is a very promising approach, this technology is not yet ready for immediate commercial implementation and needs further research.

Sergei Arlenovich Markov

• Further Reading

Chisti, Yusuf. "Biodiesel from Microalgae." *Biotechnology Advances* 25 (2007): 294-306. Review of the current state of technology for generating biodiesel from microalgae.

Glazer, Alexander N., and Hiroshi Nikaido. *Microbial Biotechnology: Fundamentals of Applied Microbiology*. New York: Cambridge University Press, 2007. Analysis of the pros, cons, and pitfalls of generating and burning ethanol for fuel.

Wald, Matthew L. "Is Ethanol for the Long Haul?" *Scientific American*, January, 2007, 42-49. Excellent discussion about the future of ethanol fuel.

See also: Biotechnology; Clean energy; Energy efficiency; Energy from waste; Energy resources; Ethanol; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Pollen analysis.

Biotechnology

• Category: Science and technology

Although the application of traditional biotechnology can be linked to a number of detrimental effects on the environment, modern biotechnological methods appear poised to reduce the levels of GHGs being released into the atmosphere.

• Key concepts

biodiesel: plant-derived oil that can be used to power diesel engines

biofuels: renewable resources that originate from living organisms and that can be burned for no net gain in CO_2 emissions

biomass: plant and other organic materials that can be used as fuel

ethanol: ethyl alcohol, a product of fermentation that can be used as a biofuel

modern biotechnology: advanced biological methods, such as genetic manipulation and cloning, that alter organisms so they are better suited to achieve human goals

recombinant DNA technology: methods whereby DNA from one organism can be recombined with that of another; the basis of modern biotechnology

traditional biotechnology: selective breeding of living organisms

white biotechnology: environmental biotechnology, the application of biotechnological principles affect the environment to positively

• Background

Biotechnology, broadly defined as the use of living organisms to achieve human goals, has been practiced for thousands of years, beginning with the domestication of animals and plants. Common usage of the word, however, typically refers to the use of more modern biological methods to achieve many of the same purposes. The term "modern biotechnology" is sometimes used to differentiate contemporary techniques from "traditional biotechnology." Biotechnology is not a scientific discipline in itself but is intrinsically interdisciplinary in nature, involving mostly agricultural techniques at first but more recently combining principles from such fields as microbiology, cell and molecular biology, and engineering.

• Traditional Biotechnology

Biotechnology likely had its origins between 10,000 and 9,000 B.C.E. with the domestication of dogs in Mesopotamia and Canaan. The first crops, consisting of emmer wheat and barley, are thought to have been grown in this same area within the following millennium. At this time, human impact on the environment was minimal, but as more land was subsequently cleared for the growing of crops and the raising of livestock, the potential to affect the environment increased, albeit slowly. These changes accelerated following the Industrial Revolution, as technologies to modify Earth's landscape were developed. By the late twentieth century, deforestation had become a major contributor to atmospheric carbon dioxide (CO_2) levels, while livestock could be linked to the release of methane, another greenhouse gas (GHG), into the atmosphere.

• Modern Biotechnology

Around this time, biotechnology underwent a revolution, as scientific breakthroughs made it possible directly to change the genetic makeup of virtually any organism. Prior to this, desired changes in organisms had been achieved primarily by selective breeding, a slow and inexact process. Beginning in the 1970's, techniques were developed that allowed scientists to cut deoxyribonucleic acid (DNA) at specific sequences (using purified enzymes called restriction enzymes) and to "glue" these liberated fragments of DNA into a vector that allowed for their propagation in host organisms, thereby cloning a particular gene or DNA segment. This entire process, sometimes called recombinant DNA technology, greatly altered both the speed and the scope of the genetic changes that could be achieved in targeted organisms.

It was not long before recombinant techniques had led to such outcomes as the production of human insulin in the bacterium *Escherichia coli* (in 1982), the production of ethanol from sugar in the same microbe (in 1991), and the development of a tomato that instead of ripening on the vine, could be picked while green and artificially ripened following shipping (in 1992). These particular examples represent the first applications of modern techniques in three different categories of biotechnology: medicine ("red biotechnology"), environmental science ("white biotechnology"), and agriculture ("green biotechnology"). The first category quickly became dominant over the other two in terms of money invested in the science, accounting for nearly 90 percent of venture capital in the twenty-five years following its introduction. The other two categories split the remaining investments nearly equally during the same time period.

• White Biotechnology

Sometimes called "environmental biotechnology," white biotechnology has been utilized to clean up contaminated environments via bioremediation, prevent the discharge of pollutants from currently existing industries, and generate resources in the form of renewable chemicals and biofuels. While bioremediation comprises a large portion of white biotechnology, it is the latter two goals that are expected to have the greatest effects on alleviating global warming.

Recognizing that the burning of fossil fuels is not likely to disappear overnight, scientists have been focusing on the use of living organisms to remove a portion of the CO_2 found in fossil fuel emissions. One candidate for this removal is phytoplankton, microscopic aquatic algae. Phytoplankton are known to make up a large portion of the carbon fixation cycle, which converts CO_2 (or dissolved carbon) to sugars during photosynthesis, thereby removing it from the surrounding environment. In nature, phytoplankton eventually die and sink to the bottom of the ocean, removing the carbon from circulation, if only temporarily on a geological timescale.

The burning of fossil fuels has the undesirable consequence of releasing into the environment carbon that has been sequestered in this way for millions of years, adding to the "new" carbon that is released from the burning of biomass. Experiments have been performed in which effluents from power plants were passed through columns filled with algae to reduce their CO_2 emissions. One problem that remained, however, was how to dispose of the algae, since simply allowing them to decompose would return the sequestered carbon back to the atmosphere. One possible solution that was explored involved burning dried algal pellets as fuel. Although still resulting in the release of CO_2, this burning allowed more energy to be obtained for a given amount of emission.

The burning of biomass for fuel is preferable to the burning of fossil fuels in terms of its effects upon global warming, since this process can be thought of as "CO_2 neutral," in that it simply returns to the atmosphere CO_2 that was recently sequestered by the organism in question. Biomass made up the majority of fuel prior to the Industrial

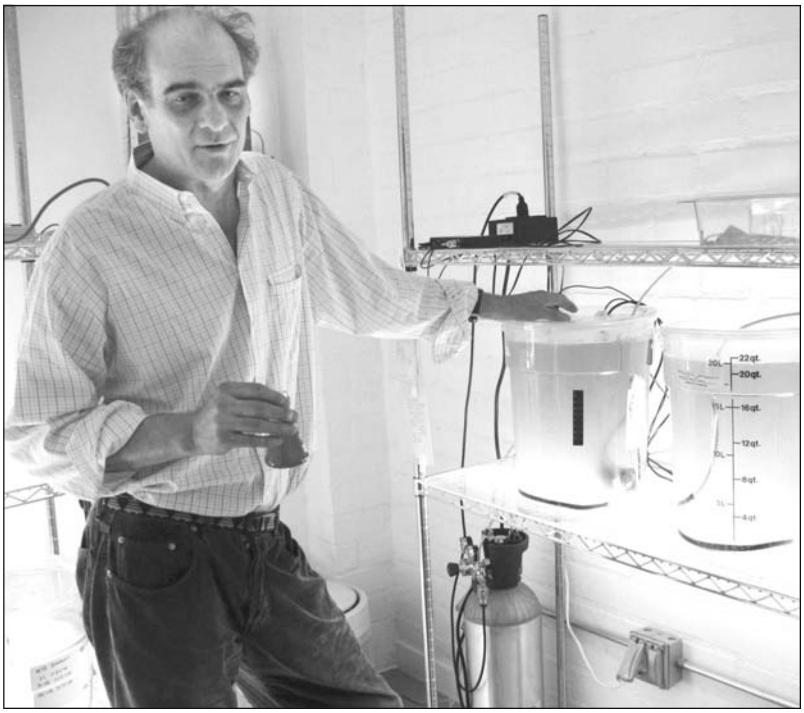
Revolution, and it is still relied on by about 50 percent of the world's population to meet its daily fuel needs. The widespread use of wood for fuel, however, although technically CO_2 neutral, is less desirable than the use of other forms of biofuel, since it contributes to deforestation and utilizes a resource that takes a considerable amount of time to replenish, compared to agricultural products. Another drawback of solid biofuel such as wood or plant waste is that it does not represent a practical replacement for petroleum-based products in automobiles, a major contributor of CO_2 emissions, after power stations and industrial processes. Biomass is therefore typically converted into various alcohols, oils, or gases in order to be used in such applications as the powering of automobiles. Conversion to these forms eases its transportation and storage.

• Biofuels

The fermentation of crops to obtain ethyl alcohol, or ethanol, was first performed in Egypt around 4000 B.C.E., although it was not known at the time that the process was being carried out by microscopic yeast. The purpose of such fermentation, however, was the brewing of alcoholic beverages, not the production of fuel. It was not until the energy crunch of the 1970's that ethanol began being mass-produced for fuel from either corn or sugarcane, the former conversion being practiced primarily in the United States, with the latter being most prevalent in Brazil. Brazil subsequently emerged as one of the few success stories regarding biofuels, as a result of the somewhat unique situation of having its sugarcane-growing centers in close proximity to its main population centers. This served to reduce shipping costs, while processing costs were contained by using the residual cane waste, or bagasse, as fuel for the processing plants.

In the United States, where the price of ethanol is more closely linked with the price of oil by the increased costs of processing corn and shipping ethanol to major population centers, debate continues on whether its production as a fuel is economically viable. It has been argued that any fuel that directly competes with food crops will result in increased food prices and ultimately lead to the expansion of farming, so that CO_2 emissions could actually experience a net increase as a result of U.S. corn ethanol production. At current production efficiencies, it has been estimated that, even if all of the corn grown in America were converted to ethanol, it would be able to replace only about 20 percent of domestic gasoline consumption. In order to solve some of these drawbacks, focus has shifted to the use of genetically modified organisms to efficiently convert the cellulose found in corn stover, the waste equivalent of bagasse, into ethanol for fuel.

One alternative to the production of ethanol as fuel is the use of plant oils in diesel engines. The use of these oils actually dates from the origination,



Nicholas Eckelberry, cofounder of OriginOil, displays containers of algae that his company is attempting to turn into an efficient biofuel. (Reuters/Landov) in 1894, of the engine itself, which was designed by its German inventor, Rudolf Diesel, to burn a variety of fuels, including coal dust and peanut oil, in addition to petroleum products. The use of plant oils, or biodiesel, has seen its greatest adoption in Europe, often in conjunction with public transportation fleets, but is increasingly used in the United States as well. Rapeseed oil is typically used in the former case, while soybean oil is a more likely fuel in the latter. Unfortunately, biodiesel has shared many of the same problems that ethanol production from biomass has, including relatively high costs of production, as well as competition with the use of the same crops for food. One possible solution has been the genetic modification of algae so they accumulate excess oil, which can then be purified. Such algae could potentially be grown in aquatic environments that would not compete with the land normally used for food crops.

One biofuel that perhaps holds the most promise is hydrogen gas, H_2. While this gas can be easily adapted for use in automobiles or to generate electricity, it differs from the other fuels discussed in that the combustion of H_2 produces no CO_2 whatsoever, only water. One technical hurdle that must be overcome is that H_2 is normally released at a very low efficiency by the algae and bacteria that are known to produce it. These organisms typically undergo a process called photolysis, where an H_2O molecule is split using energy derived from sunlight. The enzyme responsible for creating the H_2 gas, however, is inhibited by the presence of the oxygen that is created during photolysis. Genetic engineering may be the key to improving the efficiency of H_2 production, so its use as a biofuel may soon be realized.

• Context

Throughout the years, humans have used the living things around them to meet their basic needs, as well as to achieve various other purposes, slowly changing these organisms through selective breeding in order to cause them to be better suited for their desired application. Achieving human purposes has not always had a positive effect on the environment, with the domestication of both plants and animals being responsible for steadily releasing large amounts of CO_2 and methane into the atmosphere. It has only been fairly recently that humans have acquired the motivation and the technology to begin to address some of these detrimental changes. The ability to change organisms rapidly via recombinant DNA technology may hold the promise of engineering organisms to clean up the environment and to reduce the emissions of greenhouse gases. Although still in its early stages, compared to biotechnology aimed at alleviating medical problems, environmental biotechnology is emerging as one possible solution to the threat of global warming.

James S. Godde

• Further Reading

Evans, Gareth M., and Judith C. Furlong. *Environmental Biotechnology: Theory and Application.* Hoboken, N.J.: John Wiley & Sons, 2003. Explains carbon cycles in phytoplankton, as well as detailing the organism's potential use in reducing the CO_2 emissions of power plants. Describes Rudolf Diesel's use of plant oil in his engine.

Kircher, Manfred. "White Biotechnology: Ready to Partner and Invest In." *Biotechnology Journal* 1 (2006): 787-794. Gives the history of different "colors" of biotechnology, along with the relative levels of venture capital invested in them.

Scragg, Alan. *Environmental Biotechnology.* New York: Oxford University Press, 2005. Defines biotechnology, including white biotechnology, giving a historical perspective. Explains the concept of CO_2 neutrality. Contains extensive discussion of various biofuels.

Tollefson, Jeff. "Not Your Father's Biofuels." *Nature* 452 (February, 2008): 880-883. Describes a patent for ethanol-producing *E. coli.* Details the competition between crops for food and crops for fuel, the cost of shipping ethanol in the United States, and the use of cellulose for ethanol production.

See also: Biofuels; Clean energy; Energy efficiency; Energy from waste; Energy resources; Ethanol; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Pollen analysis.

Bowen's ratio

- **Category:** Meteorology and atmospheric sciences

- **Definition**

The main process for transporting the daytime energy surplus at Earth's surface to the atmosphere is convection, which is heat transfer by turbulent air motion. There are two types of convective flows (fluxes), the sensible and latent heat fluxes. If the movement of energy from the surface can be sensed as a rise or fall in temperature, then it is referred to as the sensible heat flux (D). If the flow of energy involves moisture, as in evaporation or transpiration from plants, there will be no change in temperature. In this case, the energy is held dormant in the evaporated moisture for release should the water vapor revert to its liquid state via condensation. This is called the latent heat flux (E). Climate is characterized by the apportionment of energy at the Earth's surface between D and E, the ratio of which is known as Bowen's ratio (β), so that $\beta = D/E$. Negative β values indicate that one and only one of the two fluxes is negative. D is negative when the air is heating the surface. E is negative when condensation (dew) occurs.

- **Significance for Climate Change**

Bowen's ratio is a climate index. If β is greater than 1, D is greater than E. Since such values indicate that most of the heat being moved into the atmosphere is in sensible form, they also indicate that the climate is warmer than it is when β is less than 1. When β is less than 1, E is greater than D and most of the energy transfer does not contribute directly to warming the air. This transfer may increase atmospheric humidity, however, making the climate cool and humid. The size of Bowen's ratio is determined chiefly by the availability of water for evaporation. If water is available, the latent heat flux will dominate.

A rise in the concentration of greenhouse gases in the atmosphere means there is more available energy at the Earth's surface. This additional energy can be used either to heat the atmosphere by way of the sensible heat flux (increased warming) or to evaporate water via the latent heat flux. Since 71 percent of the Earth's surface is water, most of the additional energy would contribute to an enhanced latent heat flux. The resulting warming of the atmosphere would be less in this case than if all the additional available energy was accounted for by the sensible heat flux alone.

C R de Freitas

See also: Atmospheric dynamics; Dew point; Evapotranspiration; Greenhouse effect; Humidity; Latent heat flux.

Brazil

- **Category:** Nations and peoples
- **Key facts**

Population: 191,908,598 (May, 2008)
Area: 8,456,510 square kilometers
Gross domestic product (GDP): $1.838 trillion (purchasing power parity, 2007 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 550 in 2004
Kyoto Protocol status: Ratified, 2002

- **Historical and Political Context**

Settled by Portugal in 1500, Brazil developed as a colony (1500-1822), then as an independent empire (1822-1889), and finally as a republic (1889-present). Of continental proportions, Brazil extends east across South America from the Andes Mountains and south from the equator to well below the Tropic of Capricorn. Slave labor, supporting mineral and agricultural plantation exports, forged the socioeconomic axis of the country for nearly four centuries (slavery was abolished in 1888). Several million Africans were forcibly transported to Brazil, one-third of all people shipped in the transatlantic slave trade. Brazil has the second-largest population of African descent in the world after Nigeria. The population is largely multiracial, and there is a vibrant Afro-Brazilian culture.

The abolition of slavery brought a wave of immigrants to Brazil from southern Europe. A nucleus of salaried labor emerged, producing a core of consumer demand that stimulated the country's industrial, capital, and urban development during the twentieth century. At the beginning of the twenty-first century, Brazil rose as the major economy of the region. However, its historical roots of inequality had produced a society with extreme divisions of wealth and poverty.

Subject to political instability and sporadic authoritarian regimes, Brazil achieved a democratic equilibrium around the turn of the twenty-first century. It is a nation rich in a vast array of mineral resources, including vast petroleum reserves, is endowed with abundant labor and land, and is widely favored by foreign investment capital. Brazil, together with Russia, India, and China (the so-called BRIC countries), stands out as among the most energetically and fervently developing nations in the world. With long-suppressed mass consumer demand, economic development requires extensive energy resources.

• Impact of Brazilian Policies on Climate Change

Although Brazil ranks among the leading emitters of greenhouse gases (GHGs) in the world, in no way does it contribute on the scale of the United States or China. However, Brazilian emissions are significant because of their unique mix. Brazil is the largest industrial economy in South America and is home to major automobile, steel, cement, electronics, communications, and aviation manufacturers. It has vast mineral-extraction operations, and its abundant reserves of iron ore are shipped to all parts of the world. Moreover, it is a major cattle producer: The national herd approaches nearly 200 million head and grows at about 2 percent per year. Furthermore, Brazil is the home of the largest tropical rain forest in the world, the Amazon, with vast stretches being burned or cut down for logging or for agricultural or pasture land.

Long an underdeveloped country, Brazil has resolutely and energetically engaged in development. Its populist, labor government has worked to bring the benefits of economic growth to all classes of society, with annual GDP growth averaging 4 percent in the early twenty-first century. Such development intensified GHG emissions through expanded manufacturing, construction, and transportation; enlarged farming and pasture areas; and deforestation.

In some ways, Brazil has been able to limit its GHG emissions. Its extensive hydroelectric resources allow it to economize on fossil fuels. With Paraguay, Brazil has built and operates the largest hydroelectric facility in the world, the Itaipú Dam. Brazil has also been a pioneer in the development of sugarcane ethanol. Virtually all vehicles manufactured in Brazil must use gasohol, a mix of fossil and vegetable fuel. However, as a result of Brazil's sophisticated development of offshore oil drilling, the country holds the promise of becoming a petroleum exporter. Satellite monitoring of the rain forest only moderately and unevenly has checked voracious deforestation.

• Brazil as a GHG Emitter

Although Brazil is a signatory to the Kyoto Protocol, as a developing country it is not among the Annex I nations. Thus, it is not required to provide regular, standardized accountings of its GHG emissions to the United Nations. The Brazilian Institute for Tropical Agriculture calculates Brazil's total GHG inventory as more than one-half billion metric tons. This amount places Brazil among the top

ten emitters in the world. However, such emissions account for less than 2 percent of the world total, ranking Brazil with countries such as the United Kingdom, South Korea, and Mexico.

The U.N. Statistics Division reports that one-third of Brazil's GHG emissions are carbon dioxide (CO_2) resulting from fossil fuel burning and deforestation. During the initial years of the twenty-first century, more than 20,000 square kilometers of rain forest (about the size of New York State) were being destroyed annually, contributing 200 million metric tons of CO_2. The nation's extraordinarily large livestock herd also produces significant methane emissions, and the fertilizers employed in ever-expanding agricultural areas emit nitrous oxide.

• Summary and Foresight

Brazil is a unique country of tropical and subtropical abundance and diversity. Its forests and mineral resources offer the promise of development, both for itself and for numerous other regions. The global growth of commodities markets has resulted in a singular phase of Brazilian prosperity. This growth came after years of political and economic instability. In 2002, a union leader who headed the Workers' Party, Luis Inácio da Silva, won the presidency, bringing an unprecedented populist yet market-friendly party to power. Da Silva helped drive a political will to exploit Brazil's natural resources for the benefit of all classes.

The energy requirements for such development, however, result in GHG emissions that contribute to environmental degradation. Brazil is acutely aware of the dilemma it faces and the responsibility it has for maintaining the integrity of its tropical environment, especially the Amazon. With its ethanol programs and satellite vigilance of the rain forest, it has made some guarded progress in controlling its GHG emissions. The Kyoto Protocol was prefigured by the United Nations Conference on Environment and Development, convened in Rio de Janeiro in 1992, which issued the Rio Declaration on the Environment and Development.

Edward A. Riedinger

• Further Reading

Andersen, Lykke E. *The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon.* New York: Cambridge University Press, 2002. Provides comparative econometric models of deforestation in the Amazon River basin and economic growth as a means for formulating economic policy.

Barbosa, Luiz C. *The Brazilian Amazon Rainforest: Global Ecopolitics, Development, and Democracy.* Lanham, Md.: University Press of America, 2000. Examines the political issues in Brazil related to Amazon deforestation in order to formulate viable environmental policy for sustainable development.

Hudson, Rex A., ed. *Brazil: A Country Study.* 5th ed. Washington, D.C.: Federal Research Division, Library of Congress, 1998. The section on Brazil's economy includes data on resources, production, and other factors affecting the nation's contribution to global climate change.

Wood, Charles R., and Roberto Porro, eds. *Deforestation and Land Use in the Amazon.* Gainesville: University Press of Florida, 2002. Collection of articles reviewing historical phases of Amazon deforestation and contemporary patterns of economic and geographic use.

See also: Amazon deforestation; Deforestation; Forests; Kyoto Protocol; United Nations Conference on Environment and Development; United Nations Framework Convention on Climate Change.

Brundtland Commission and Report

• Category: Organizations and agencies
• Date: Commission established 1983; report published as *Our Common Future* in 1987
• Web address: http://www.un.org/documents/ga/res/38/a38r161.htm

• Mission

The secretary-general of the United Nations, heeding growing concerns about the global environment, convened the World Commission on Environment and Development in 1983. The commission took its name from its head, Gro Harlem Brundtland, a former prime minister of Norway. Representatives of the commission traveled the globe, gathering statements of mounting environmental concerns and possible solutions. It quickly became clear that environmental problems do not respect national boundaries and that only a collective, global effort could effect change. The commission's mandate arose from the "accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development."

The Brundtland Commission, in its report to the U.N. General Assembly, recommended the creation of a long-term environmental strategy to achieve sustainable development. Begun in 1983, the body produced a mission statement that anticipated a continuing effort to the year "2000 and beyond." The final report looked forward to change brought through cooperation among all countries, regardless of their socioeconomic condition or fundamental resources. The commission hoped to accomplish its goals by integrating environmental, economic, and social objectives to form a comprehensive strategy.

The Brundtland Commission, which published its report *Our Common Future* in 1987, recommended the creation of a universal declaration on environmental protection and sustainable development in the form of a new charter. The commission recognized the need for broad participation in environmental programs and solutions, so it required that at least half its members come from developing countries and that the voices of governmental and nongovernmental organizations, industry, scientists, and others with environmental concerns be heard and consulted. In an effort to embrace and consider a broad range of views, the commission stressed that there must be a continuing dialogue among not only the scientific community and environmentalists but also all sections of public opinion, particularly youth, as well as those concerned with the fragile balance between development and the environment.

The commission's message to the General Assembly was not an inflexible mandate but addressed varying environmental concerns for societies rich and poor, developed and undeveloped, resource abundant and resource scarce, industrial and rural. It expressed the hope for an inclusive and worldwide cooperative effort. Finally, the commission asked for "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The findings of the World Commission on Environment and Development, as presented in *Our Common Future*, served as a framework for later environmental discussion. This was clearly in evidence during the 1992 U.N. Conference on Environment and Development in Rio de Janeiro, where the concept of "sustainable development" was firmly set in place as a "worthy universal goal."

Brundtland Report

The Brundtland Report provides the following summary statement of the status of the relationship between nature and humanity near the end of the twentieth century.

Over the course of this century, the relationship between the human world and the planet that sustains it has undergone a profound change. When the century began, neither human numbers nor technology had the power radically to alter planetary systems. As the century closes, not only do vastly increased human numbers and their activities have that power, but major, unintended changes are occurring in the atmosphere, in soils, in water, among plants and animals, and in the relationships among all of these. The rate of change is outstripping the ability of scientific disciplines and our current capabilities to assess and advise.

• Significance for Climate Change

The Brundtland Report raised awareness of the accelerating human impact on the environment and declared that solutions depended upon cooperative global effort. The paperback version of the report, published late in 1987, warned readers that "Most of today's decision makers will be dead before the planet suffers the full consequences of acid rain, global warming, ozone depletion, widespread desertification, and species loss." In response to that prophetic statement, in 2005, a U.N. Millennium Project report confirmed that sixteen out of twenty-five ecosystems were being critically degraded and demonstrated the negative impact of unsustainable development paths. Further, as if echoing the twenty-two-year-old concerns of the Brundtland Commission, the Intergovernmental Panel on Climate Change demonstrated the negative effects of unsustainable development paths. When *Our Common Future* was published, the fight against global warming was a distant consideration, and only four pages were devoted to the subject. It is noteworthy, however, that the report's central tenet is basic to the challenges of climate change: the need for global cooperation to achieve solutions to global environmental problems.

Richard S. Spira

• **Further Reading**

Bruno, Kenny, and Joshua Karliner. *Earthsummit.biz: The Corporate Takeover of Sustainable Development.* Oakland, Calif.: Food First Books, 2002. From Rio to Johannesburg, the book details corporate accountability to environmental interests and the need to achieve sustainable practices in the twenty-first century.

Park, Jacob. "*Our Common Future* Twenty Years Later: Rethinking the Assumptions of the World Commission on Environment and Development." Paper presented at the International Studies Association Forty-eighth Annual Convention. Chicago: International Studies Association, 2007. Comments on the practical applications of the Brundtland Report for business and on industrial environmental practices that have gained growing acceptance in the United States.

World Commission on Environment and Development. *Our Common Future.* New York: Oxford University Press, 1987. The Brundtland Report, detailing the need for global cooperation to address mounting environmental concerns in the late twentieth century.

See also: Agenda 21; Antarctic Treaty; Earth Summits; International agreements and cooperation; Kyoto Protocol; Stockholm Declaration; United Nations Climate Change Conference; United Nations Conference on Environment and Development; United Nations Conference on the Human Environment; United Nations Division for Sustainable Development; United Nations Environment Programme; United Nations Framework Convention on Climate Change.

Budongo Forest Project

• **Categories:** Organizations and agencies; environmentalism, conservation, and ecosystems
• **Date:** Established 1990
• **Web address:** http://www.budongo.org

• **Mission**

The Budongo Forest Project was founded in 1990 by chimpanzee specialist Vernon Reynolds in the Budongo Forest of Uganda, East Africa. Its mission is to blend "research and conservation to ensure sustainable management and utilisation of the Budongo Forest Reserve as a model for tropical rain forest management." Originally created to preserve the forest with the aim of protecting the native chimpanzees that inhabit it, the project has increased the scope of its research to include other species. The Budongo Forest, at more than 352 square kilometers, is home to over 300 bird species, 850 plant species, and 400 types of butterflies and moths. The project has built accommodations for staff and for visiting researchers and students from around the world, and dozens of articles based on research at Budongo have been published in scientific journals.

In 2007, the project was recognized by the Ugandan government as an official nongovernmental organization and was renamed the Budongo Conservation Field Station. The station receives much of its funding from the Royal Zoological Society of Scotland, the Oakland Zoo in California, and the United States Agency for International Development (USAID). The Edinburgh Zoo in Scotland operates a large primate enclosure named the Budongo Trail.

The Budongo Forest was used by loggers for six decades, and the governmental forestry service had maintained records and maps going back almost a century. These records have proven to be invaluable to scientists studying how tropical forests grow and how they respond to being harvested. With this information and with new research, the project hopes to protect against deforestation from hunting, logging, gathering, clearing for farming, and other human interference, including global warming. For example, one conservation effort encourages local inhabitants to grow the medicinal plant *Ocimum kilimandscharicum*, used for aromatherapy, in sustainable community farms, rather than gathering the plant in the wild. Other projects encourage beekeeping and other ways of earning a living without cutting down trees. While logging and gathering of seeds and other nontimber products is legal in the Budongo Forest, the project explores sustainable ways to manage these harvests.

• Significance for Climate Change

While the connection between tropical rain forests and global warming has never been an emphasis of the Budongo Forest Project, the world's attention to global warming has presented the project with a larger audience and potentially with a larger base of support. Tropical rain forests, in addition to providing habitat for a rich variety of plant and animal species, protect the Earth from some of the effects of global warming by acting as carbon sinks, absorbing carbon from the atmosphere. It has been estimated that the Budongo Forest sequesters more than 726,000 metric tons of carbon dioxide each year. As tropical forests shrink, their capacity to absorb carbon also decreases, increasing the threat of global warming.

Researchers at Budongo have initiated projects to help local people grow and make a living from sustainable tree crops. These projects are described in scientific articles whose titles include "Effectiveness of Forest Management Techniques in Budongo," "The Ecology of Long-Term Change in Logged and Non-logged Tropical Moist Forest," and "Understanding of National and Local Laws Among Villagers with Special Reference to Hunting." Unfortunately, these projects have had difficulty obtaining funding; although Uganda is a signatory to international conservation treaties, it has not given funding priority to efforts to preserve biodiversity, and the field station itself has only a small budget. In 2007, Uganda and its neighbors proposed that the carbon sequestered by natural forests should be included in the global carbon credit system created by the Kyoto Protocol, thus generating funds for conservation in forested nations. The resolution did not pass.

The Budongo Forest Project was initially founded to protect Uganda's native chimpanzees. (©iStockphoto/Liz Leyden)

The success of conservation work at Budongo has led to another major effort in Uganda: In October, 2008, the National Forestry Authority and the poverty relief organization World Vision launched a national campaign to plant thirteen million trees by 2011. Community groups living at the edges of forest reserves planned to make formal agreements with the Forest Authority, which would provide incentives for conservation and nonconsumption projects, including tree planting, ecotourism, and the establishment of woodlots.

Cynthia A. Bily

• **Further Reading**

Howard, P. C. *Nature Conservation in Uganda's Tropical Forest Reserves*. Gland, Switzerland: International Union for Conservation of Nature, 1991. Reports on the status of Uganda's tropical high forest reserves, describing native species and human disturbance and making recommendations for conservation and sustainable development.

Malhi, Yadvinder, and Oliver Phillips. *Tropical Forests and Global Atmospheric Change*. New York: Oxford University Press, 2005. Scientific analysis by two prominent researchers, demonstrating the effects of global warming on tropical forests and their implications for the future of carbon storage and exchange as the forests decline.

Reynolds, Vernon. *The Chimpanzees of the Budongo Forest: Ecology, Behaviour, and Conservation*. New York: Oxford University Press, 2005. Written by the founder of the Budongo project, this technical but accessible volume combines natural history of chimpanzees with the author's reflections on the importance of conservation.

Weber, William, et al., eds. *African Rain Forest Ecology and Conservation: An Interdisciplinary Perspective*. New Haven, Conn.: Yale University Press, 2001. Written by conservation scientists, this collection describes the ecology and human uses of African rain forests and argues that the forests must be conserved.

See also: Deforestation; Forestry and forest management; Forests; Intergovernmental Panel on Forests.

Building decay

• **Category:** Economics, industries, and products

• **Definition**

Human-made structures have evolved architecturally for the environmental conditions in which they have traditionally been constructed. They are fixed in their locations and constructed from materials that age at different rates and with different consequences. As a result, most human structures are ill suited to almost any significant environmental change. Their long-term viability will likely be hampered by any change in climate or biological environment. Any change to the global climatic regime thus presents significant dangers to the integrity of most human structures.

• **Significance for Climate Change**

If climate change continues to become more pronounced, rising temperatures and climate patterns will shift toward polar regions. As these shifts occur, ecosystems will also migrate, subjecting structures to new conditions. One likely and dramatic result of increased global warming is a rise in sea level. Even small changes in sea level would have spectacular localized effects, and, because a disproportionate share of the world's population lives within 50 kilometers of a sea shoreline, a large number of human structures would be at risk of inundation, in which case the residents would become environmental refugees.

Changes in sea level would have dramatic effects on storm patterns, stressing many structures not designed to sustain severe weather conditions. Changes in rainfall patterns generally result in changes in runoff: Many foundations and gutter systems would prove inadequate for significantly increased runoff and would suffer from turbulent flow patterns. Extreme fluctuations in temperature, wind, and rainfall coinciding with global warming would result in changes to humidity, subjecting building materials to wetter conditions than they were originally designed to repel. Expected results would include accelerated material disintegration, mold infestation, corrosion, and rot, which would degrade and weaken structures and their foundations.

Low soil moisture conditions preceding severe rainfall events increases the impact and magnitude of flooding. In areas expected to undergo decreased soil moisture, floods will cause increasing amounts of damage. Between floods, the same low soil moisture could lead to increased ground movement, causing building foundations to degrade. Moreover, changing climate patterns often cause species migration. If this trend continues, buildings in areas previously unaffected by certain pests will

This middle-school classroom in Lianyuan, China, collapsed as a result of termite damage in May, 2007. Increased global warming may increase the population and range of these pests. (Reuters/Landov)

need protection from an influx of destructive, invasive species.

Sea-level rise could cause changes to groundwater regimes, resulting in saltwater infiltration, subsidence, and drainage alterations, all potentially affecting the structural integrity of buildings. If shifts in global climatic conditions continue, buildings could be subjected to drastic changes in freeze-thaw cycles, oscillating between evaporation and condensation and between wet and dry conditions. Changes in a range of conditions, including temperature, humidity, light, wind turbulence, and vibration, would all create stresses on buildings that they were not constructed to withstand.

As the effects of global climate change broaden, three basic agents of structural deterioration will be prominent: biological agents, physical agents, and chemical agents. These agents may contribute to decomposing a structure independently or by co-association. Increased humidity, higher temperatures, and sufficient water availability may allow for both the spread of and longer seasonal life cycles among invasive plants, insects, animals, algae, fungi, lichens, bacteria, and boring worms. If so, biodegradation of buildings would increase significantly. Higher populations of climbing plants, termites, ants, molds, roosting birds, and tunneling animals would negatively affect the mechanical and physical integrity of many structures.

Physical decay includes discoloration of building materials from radiation damage due to increased sunlight, such as may result from changes in cloud cover and from ozone layer loss. Organic building materials, such as wood, straw, reeds, leafs, and grasses, suffer greater thermal decomposition when temperatures increase. Differential thermal expansion results in increased mechanical failures in porous building materials such as wood, stone, glass, and concrete. Mechanical stress due to increased sway and vibration from altered wind patterns also increases structural wear. Hygrometric stress due to changes in humidity can result in swelling and warping of organic and composite building materials.

Changes to weather patterns could subject many buildings to increased nonchemical erosion from windblown materials, such as dust and sand, and increase weathering due to water flow across their surfaces. Changes to global climate could result in changes to regional atmospheric chemistry, resulting in modifications to normal building-decay rates. Invasive windblown materials can increase static electrical charges, attracting dust, humidity, and soot to structural surfaces and enhancing chemical deterioration cycles.

As shifts in the climatic regime take place, chemical decay will likely increase in certain areas, as water and salts are introduced into porous structures, causing crystallization stress that may lead to mechanical failure. Stone and masonry buildings are particularly vulnerable to such stress. Organic materials may experience photodegradation by a combination of light, chemicals, and humidity, inducing destructive chemical changes. Humidity, chemicals, and temperature may also hydrate and make brittle structural materials such as glass, plastic, bronze, and copper.

Chemical dissolution and transformational stresses are also likely to increase in certain regions as global climate changes. Acidic precipitation—rain, snow, and fog carrying reactive solids, chemical pollutants, catalytic particles, trace gases, and corrosive compounds—is especially damaging to construction materials, including ferrous metals, granite, limestone, sandstone, marble, gypsum, dolomite, glass, and wood. Tarnished metals, rust, discoloration, exfoliation, acid etching, loss of surface details, decomposition, and enhanced weathering are all well-documented symptoms of atmosphere-induced chemical structural decay. Human behaviors release large quantities of reactive chemicals into the atmosphere as air pollution, resulting in increased acid deposition and enhanced structural decay. The chemicals responsible for these deteriorative effects are often the same chemicals implicated as anthropogenic causes of global warming and climatic change.

Randall L. Milstein

- **Further Reading**

Brimblecombe, P., ed. *The Effects of Air Pollution on the Built Environment*. London: Imperial College Press, 2004. Discusses ways in which structural materials are likely to be damaged by air pollutants.

Prykryl, R., and B. J. Smith, eds. *Building Stone Decay: From Diagnosis to Conservation*. London: Geological Society, 2007. Outlines the causes of structural decay and the environmental factors controlling them.

Samuels, R., and D. K. Prasad, eds. *Global Warming and the Built Environment*. London: E&FN Spon, 1994. A discussion of the interaction between built and natural environments relating to global climate change.

Smith, B. J., and P. A. Warke. *Stone Decay: Its Causes and Controls*. Shaftesbury, Dorset, England: Donhead, 2004. A descriptive volume on the environmental and biological causes of stone and masonry deterioration; discusses remediation measures.

See also: Air pollution and pollutants: anthropogenic; Flood barriers, movable; Floods and flooding; Levees; Rainfall patterns.

Byrd-Hagel Resolution

- **Category:** Laws, treaties, and protocols
- **Date:** Passed July 25, 1997

The Byrd-Hagel Resolution declared the "sense of the Senate" that the United States should not agree to limit its greenhouse gas emissions unless developing nations, including China and India, were also required to limit theirs.

- **Background**

When the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in

May, 1992, it identified major industrialized countries, including the United States, as Annex I parties, and other countries as underdeveloped parties. This division became a long-standing source of controversy, as the United States and other industrialized nations came to resent the fact that they were subject to regulations under the treaty to which the developing nations were not subject.

In 1995, at the First Conference of the Parties (COP-1) in Berlin, the Berlin Mandate was adopted. It called for the creation of a new protocol that would require strict commitments on the part of Annex I parties to limit greenhouse gas (GHG) emissions but would exempt developing countries from new commitments. This provision increased the dissatisfaction on the part of the United States, particularly in the light of the fact that China, India, and Brazil—all heavy polluters—were among the developing nations that would not face strict regulation.

Through the 1990's and well into the first decade of the twenty-first century, the United States was the world's largest emitter of carbon dioxide (CO_2) because of its heavy use of fossil fuels. However, the GHG emissions of the developing country parties was rapidly increasing, and by some estimates they were expected to surpass those of the industrialized nations by 2015.

On July 25, 1997, Senate Resolution 98 was introduced before the 105th Congress. Its cosponsors were Democrat Robert Byrd of West Virginia and Republican Chuck Hagel of Nebraska. What became known as the Byrd-Hagel Resolution provided a chance for the Senate to express its opinion about ongoing international climate negotiations. Agreeing to the resolution by a vote of 95 to 0, the senators declared that the United States should not agree to any binding restrictions on its own GHG emissions if the developing country parties were excluded from such restrictions. Inconsistent restrictions, they asserted, would cause serious harm to the U.S. economy, because companies in developing nations would have an unfair advantage over their U.S. competitors in trade and in wages.

- **Summary of Provisions**

The resolution declared that it was the "sense of the Senate" that the United States should not sign any protocol of the UNFCCC mandating new commitments on the part of Annex I parties without plac-

The Byrd-Hagel Resolution

The Byrd-Hagel Resolution was a "sense of the Senate" resolution, expressing the majority opinion of the body without having the full weight of law. However, because the resolution passed on a 95-0 vote, it sent a clear message to President Bill Clinton that the Senate would not ratify the Kyoto Protocol unless it was significantly altered.

Resolved, That it is the sense of the Senate that—

(1) the United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change of 1992, at negotiations in Kyoto in December 1997, or thereafter, which would—

(A) mandate new commitments to limit or reduce greenhouse gas emissions for the Annex I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period, or

(B) would result in serious harm to the economy of the United States; and

(2) any such protocol or other agreement which would require the advice and consent of the Senate to ratification should be accompanied by a detailed explanation of any legislation or regulatory actions that may be required to implement the protocol or other agreement and should also be accompanied by an analysis of the detailed financial costs and other impacts on the economy of the United States which would be incurred by the implementation of the protocol or other agreement.

ing limits on the emissions of developing country parties—nor should it sign any protocol that would harm the U.S. economy. In addition, the resolution reiterated the constitutional requirement that any treaty be submitted to the Senate for ratification and called for detailed explanations, including information about financial cost, to support any future climate change agreement.

• Significance for Climate Change

The vote on the Byrd-Hagel Resolution occurred when the Kyoto Protocol was nearly written but not yet finalized. The fact that the resolution was put forward by bipartisan cosponsors and that it passed unanimously seemed to indicate a strong consensus within the Senate. However, Byrd stated later that he had intended the resolution only to provide broad guidelines for negotiators and that he thought the Kyoto Protocol was a sensible compromise document. Hagel, on the other hand, opposed the Kyoto Protocol and continued to work against any agreement that went against the specifics of the resolution.

On December 11, 1997, less than five months after the passage of the Byrd-Hagel Resolution, the Kyoto Protocol was adopted at the Third Conference of the Parties (COP-3). The United States signed the treaty in 1998 but did not ratify it. During the Bill Clinton administration, which ended in 2001, the White House did not send the Kyoto Protocol to the Senate for ratification. The George W. Bush administration stated formally that it would not support the treaty, citing the Byrd-Hagel Resolution as evidence that the U.S. economy would be unfairly harmed by any agreement that did not include restrictions on developing nations, particularly China. By the end of the Bush administration, the United States had neither ratified nor officially withdrawn from the treaty. The language and the arguments of the Byrd-Hagel Resolution continued to inform negotiations and resolutions through Bush's two terms as president.

Cynthia A. Bily

• Further Reading

Lisowski, Michael. "Playing the Two-Level Game: U.S. President Bush's Decision to Repudiate the Kyoto Protocol." *Environmental Politics* 11, no. 14 (Winter, 2002): 101-119. Describes how President George W. Bush invoked the Byrd-Hagel Resolution as part of his rationale for rejecting the Kyoto Protocol.

Rabe, Barry George. *Statehouse and Greenhouse: The Emerging Politics of American Climate Change Policy*. Washington, D.C.: Brookings Institution Press, 2004. Examines the shortcomings of federal regulations regarding climate change and the emergence of sensible state-level policies.

Schneider, Stephen Henry, Armin Rosencranz, and John O. Niles. *Climate Change Policy: A Survey*. Washington, D.C.: Island Press, 2002. Textbook surveying in accessible language the scientific, economic, and policy contexts of the global warming debate.

Victor, David G. *Climate Change: Debating America's Policy Options*. New York: Brookings Institution Press, 2004. Analysis of three approaches to climate change policy, with an appendix containing transcripts of the Senate debate over the Byrd-Hagel Resolution.

See also: Berlin Mandate; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. energy policy; U.S. legislation.

California

- **Category:** Nations and peoples

California has the largest population, most vehicles, most diverse economy, and most productive agricultural sector of any U.S. state. It produces about 1.4 percent of the world's GHGs and 6.2 percent of total U.S. GHGs.

• Key concepts

geothermal energy: energy generated from heat stored in the Earth

greenhouse gases (GHGs): atmospheric trace gases that absorb and emit infrared radiant energy and warm the atmosphere and the Earth's surface

ozone: a molecule of three oxygen atoms that can form in the lower atmosphere by photochemical reaction of sunlight with hydrocarbons and nitrogen oxides

runoff: precipitated water that flows into rivers, lakes, streams, oceans, and other water bodies

snowpack: accumulated snow in mountainous areas that melts during warmer months

• Background

California's climate, population, economy, and agriculture share a complex relationship with global warming. The state has a highly productive and diverse industrial complex, ranging from manufacturing and oil production to biotechnology and telecommunications. Population and industry are concentrated in the state's southern and coastal regions, where the water supply is limited. An expansive agricultural sector supports a food production capacity important for California, the United States, and the world, but it depends on irrigation water and a workforce of more than 1 million. California has led the United States in food and agricultural production for over fifty years and leads the nation in exporting agricultural products. Irrigated crops account for a majority of the $34 billion market value contribution agriculture makes toward California's total economic output of $1.8 trillion.

• Population and the Water Supply

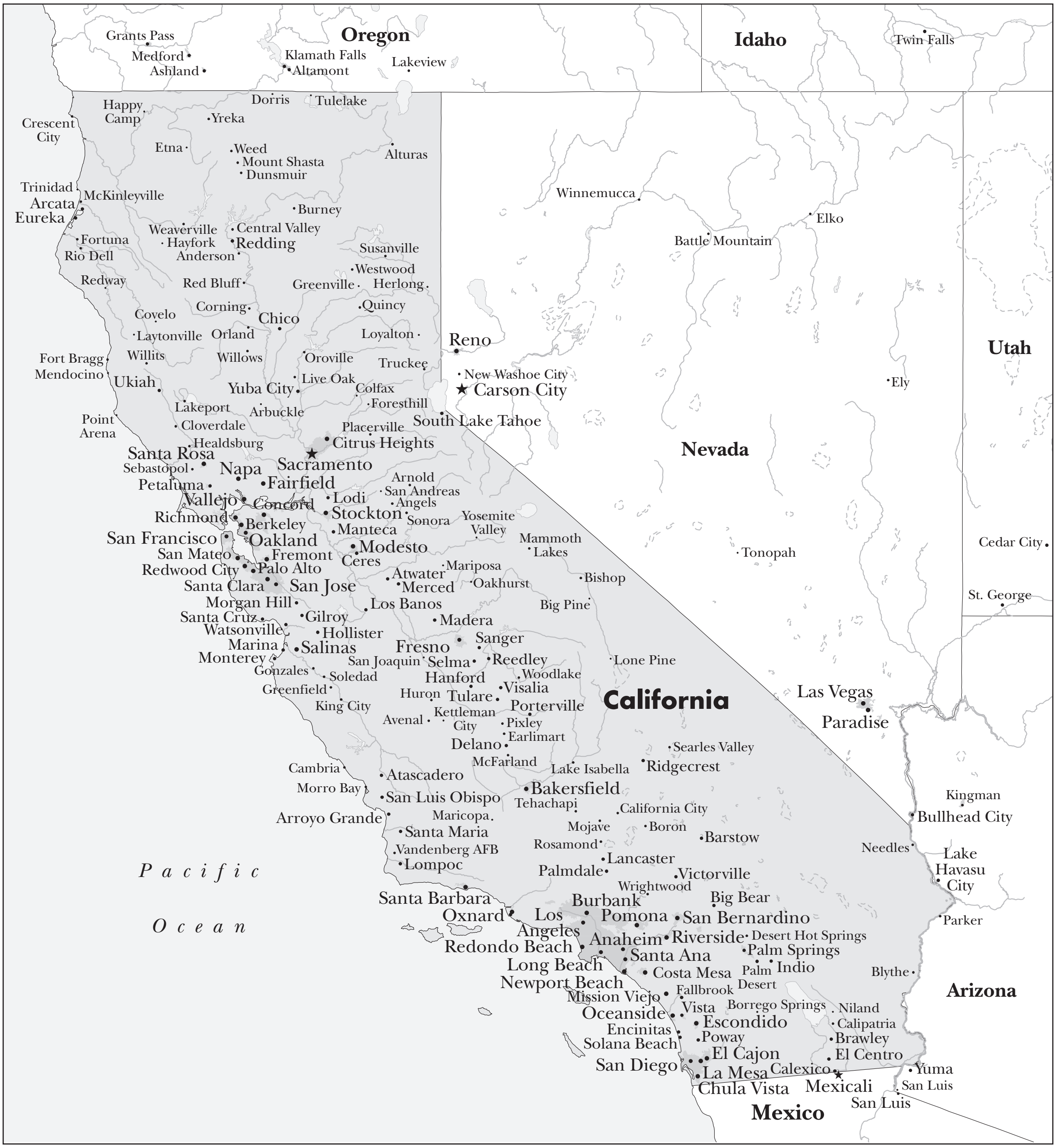
California's 37 million people represent 12 percent of the nation's population, and the state's population is expected to approach 50 million by 2025. Nearly 60 percent of the populace is concentrated in Southern California, and 90 percent resides in metropolitan areas. Population growth is expected to be greater in inland counties, but coastal counties containing the major metropolitan areas will continue to account for over 60 percent of the population. Population growth has critical implications for almost every area of public policy, but issues particularly relevant for California are social services, education, transportation, the environment, the water supply, and loss of agricultural land.

Contrasting seasonal precipitation and temperature patterns, the influence of topography, and proximity to the coast create a variety of climates within California. However, the population favors the water-limited regions of southern and coastal California, while the mountains of northern and central California produce an abundant but variable water supply. The time and space mismatch between the water supply and the water needed by the population and agriculture is overcome by a statewide water storage and conveyance system. California's water system is a collection of constructed facilities and natural features blended by a mixture of overlapping agencies and jurisdictions from all levels of government.

• Vulnerability to Climate Change

California's climate is expected to warm by as much as 1.1° Celsius over thirty years, with greater summer than winter warming likely. Precipitation changes are uncertain, but the seasonal precipitation pattern is expected to continue. The warmer climate will produce a reduced winter snowpack; an earlier start of spring snowmelt; an increase in winter runoff as a fraction of total runoff; an increase in winter flooding frequency; decreases in total runoff; increased stress on drinking water and irrigation water supplies; increased droughts, floods, and wildfires; decreased agricultural productivity; and increased threats to human health. California's 2050 global warming impacts could approach total annual costs and revenue losses of $15 billion.

The impact of warmer temperatures on the win-



ter snowpack has major consequences. Snow accounts for up to 50 percent of California's stored water, but this figure may be reduced to 12 to 42 percent in a warmer climate. More precipitation occurring as rain rather than snow increases immediate runoff and heightens chances for more severe and frequent floods. Protecting against floods requires lower reservoir levels that reduce the water supply capacity of reservoirs, reduce available irrigation water, and reduce the ability of reservoirs to offset drought. Furthermore, summer hydropower generation is reduced when reservoir levels are lowered.

Most crops and forests will benefit from increased atmospheric carbon dioxide (CO_2) concentrations, but warmer temperatures may aggravate ozone pollution, which makes plants more susceptible to diseases and pests. Higher and more extreme temperatures increase the likelihood of air pollution episodes, which are a public health threat, and over 90 percent of California's current population lives in areas that violate the state's air quality standards for ozone or particulate matter. Warmer temperatures will increase the wildfire risk to homes and forests by 11 to 55 percent and will contribute to air quality problems.

• Reducing Climate Change Contributions

California is the world's twelfth-largest emitter of greenhouse gases (GHGs), producing 500 million metric tons, or 13.5 metric tons per capita. However, the state has reduced per capita GHG emissions by 10 percent. Transportation is California's largest source of GHG emissions, but the state has a long history of adopting rigorous vehicle GHG emission standards beyond federal Environmental Protection Agency requirements. Beginning in 2009, all new vehicles sold in California have an environmental performance sticker, rating the car on smog emissions and the amount of GHG emissions per mile, including emissions related to the production and distribution of the fuel.

The California Global Warming Solutions Act of 2006 is the United States' first comprehensive regulatory and market-mechanisms program. The legislation, along with related initiatives that include penalties for noncompliance, are designed to achieve quantifiable, cost-effective GHG emissions equal to 1990 levels by 2020. By 2050, GHG emissions are to be reduced to 80 percent of their 1990 levels. A 2008 Governor's Executive Order requires California utilities to derive 33 percent of their energy from renewable sources by 2020.

Electric power generation accounts for 28 percent of California's GHG emissions, and natural gas accounts for 56 percent of annual power generation. However, California has aggressively pursued renewable energy, which currently accounts for 14 percent of California's annual energy use. Geothermal is California's largest renewable source of electric power. Small hydroelectric, wind, and biomass contribute about equal shares, and solar provides about 0.2 percent. Nearly half of the nationwide venture capital investment in clean technology is in California.

• Context

California's role in global warming extends well beyond its position as an individual state. If California was a nation, it would have the thirty-third-largest population and the seventh-largest economy in the world. It is a world leader in developing energy-efficient technology, in implementing new technology, and in efforts to shift energy production to renewable resources. California's gross domestic product (GDP) is 11.5 percent of the U.S. GDP.

Projected temperature increases for California are smaller than estimated global temperature increases, but even small temperature increases are significant for California's population, agriculture, and economy, because they alter the character of a water supply that is already approaching its limits. The challenge of providing a reliable water supply is magnified by global warming and the uncertainty of its effects on California's climate.

Marlyn L. Shelton

• Further Reading

Godish, Thad. *Air Quality*. 4th ed. Boca Raton, Fla.: Lewis, 2004. Comprehensive overview of air-quality fundamentals and issues, including global warming, public health, and regulatory programs. Illustrations, figures, tables, bibliography, index.

National Assessment Synthesis Team. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. New York: Cambridge University Press, 2000. This report by leading scientists combines national-scale analysis with an examination of potential climate change impacts at the regional scale and for five selected sectors. Illustrations, figures, maps.

Vanrheenen, Nathan T., et al. "Potential Implications of PCM Climate Change Scenarios for Sacramento-San Joaquin River Basin Hydrology and Water Resources." *Climatic Change* 62, nos. 1-3 (2004): 257-281. Impacts on California water

resources are explored using several climate change and water management assumptions.

See also: Florida; Louisiana coast; New Orleans; United States.

Canada

- **Category:** Nations and peoples
- **Key facts**

Population: 33,487,208 (July, 2008, estimate)
Area: 9,984,670 square kilometers
Gross domestic product (GDP): $1.307 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 600 in 1990; 650 in 1995; 758 in 2004
Kyoto Protocol status: Ratified, 2002

• Historical and Political Context

Canada was first explored by English and French explorers at the end of the fifteenth and beginning of the sixteenth century. Both England and France laid claim to Canada; England by John Cabot's landing at Newfoundland in 1497 and France by Jacques Cartier's discovery of the Saint Lawrence River. A long period of conflict between the two countries over ownership of Canada ensued. With the Treaty of Paris signed in 1763, France recognized Canada as belonging to England and relinquished all of its claims. Canada has continued to maintain a close relationship to England (today referred to as the United Kingdom). However, through a series of British parliamentary acts Canada has been granted legislative independence from the United Kingdom. This process began in 1867 with the British North American Act and continued into the twentieth century with the Statute of Westminster (1931) and the Canada Act (1982).

Canada has also enjoyed a long association with the United States, Britain's other former North American colony. Economically the two countries have had a long mutual dependency as each is the other's major trading partner. During their long trade relationship, Canada and the United States have often disagreed, imposed tariffs, and at times been almost isolationist in their attitudes. However, with the implementation of the North American Free Trade Agreement in 1994, their relationship has in general become one of free trade. Canada's economy has evolved from rural to industrialized, yet primary material, timber, oil, and gas, continue to play a very important role in the country's economic sector.

Domestically, Canada is a country of a varied geographic makeup and of a widely divergent population. Multiculturalism and diversity dominate Canada's social and cultural life. Both English and French are recognized as official languages. While British and French cultural heritage and traditions are certainly a major part of Canada's culture, those of aboriginal tribes and Irish, Scot, and other immigrant groups as well as American influences are very visible in Canadian society. Canada is an active participant in the global community as a member of many international organizations including the United Nations, the G-8, the North Atlantic Treaty Organization (NATO), and Francophonie.

• Impact of Canadian Policies on Climate Change

Canada is a vast country which possesses very large reserves of natural resources, both renewable and nonrenewable. Hydropower, a clean renewable source of energy, has been an important source of energy for Canada, especially for electricity. However, from 1990 to 2004, the demand for electricity in Canada increased some 23 percent and Canada increased its use of fossil fuels to meet this demand. Canada is in the process of developing the oil sands in the Athabasca Basin in the province of Alberta. The oil in the oil sands is bitumen, a thick viscous oil which requires considerable processing to be usable. The oil cannot be extracted by drilling but requires either open pit extraction or strip mining. The extraction of this oil emits in excess of 33 million metric tons of greenhouse gases (GHGs), accounting for approximately 5 percent of Canada's emissions. If Canada follows its present program in regard to the oil sands, the emissions from the oil sands production would reach 12 percent by 2020. The oil producers and the Canadian government

are involved in a heated battle with environmentalist groups over the extraction and use of this oil.

In addition, Canadians have changed their preferences in choice of motor vehicles. Sport utility vehicles (SUVs) and small pickup trucks now outnumber passenger automobiles on the roads of Canada. This has resulted in an increase in fuel consumption. Consequently, the majority of the increase in GHG emissions during the period has come from the energy sector, which is responsible for 81 percent of the GHGs emitted.

• Canada as a GHG Emitter

According to Environment Canada's report, Canada had GHG emissions totaling 600 million metric tons of carbon dioxide equivalent in 1990. The Kyoto Protocol, which Canada ratified in December of 2002, calls for Canada to reduce these base year (1990) emissions by 6 percent. The GHG emissions target established for Canada by the 2008-2012 period is 568 million metric tons. From 1990 to 2004, Canada's GHG emissions rose some 27 percent. Although the greenhouse emissions per unit of GDP fell by 2004 by 14 percent, the Canadian economy experienced considerable expansion that resulted in a net increase in the total emissions. In addition, the ratio of GHG emissions to the population rose by 10 percent. Canada was responsible for approximately 2.3 percent of the GHG emissions in the world. This amount of emissions ranked Canada seventh in the world in GHG emissions. The 2004 emissions of 758 million metric tons were 35 percent above the Kyoto Protocol target.

• Summary and Foresight

Canada's greenhouse emissions were 35 percent above the Kyoto Protocol target in 2004; by 2006 Canada had reduced its emissions to 21 percent above the Kyoto Protocol. In January of 2006, a conservative government which opposed Canada's participation in the Kyoto Protocol was in place. In April, the government announced that Canada could not possibly meet its Kyoto Protocol target for the 2008-2012 period. The government further stated that it was seeking an alternative to participation in the Kyoto Protocol and proposed the possibility of joining the Asian-Pacific Partnership on Clean Development and Climate. The federal government also proposed legislation setting mandatory emission limits for industry. Subsequently, a bill was introduced to force the government to take the necessary steps for Canada to achieve its Kyoto Protocol target. The bill passed but has been ignored by the government.

Shawncey Webb

• Further Reading

Charnovitz, Steve, and Gary Clyde Hufbauer. *Global Warming and the World Trading System.* Washington, D.C.: Peterson Institute for International Economics, 2009. Discusses reductions in GHGs and their relation to trade and to trade organizations, especially the World Trade Organization.

Details methods of reduction of GHGs without hurting domestic and global carbon-intensive industries. Appendix on using biofuel to save energy and reduce GHG emissions.

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Change: A Guide to the Debate.* New York: Cambridge University Press, 2006. Excellent introduction to climate change from a scientific viewpoint, as well as a clear review of global politics and their effects on decision making. Written for the general reader. Well illustrated with graphs and tables. Excellent suggestions for further reading.

Lee, Hyun Young. "Sand Storm." *Wall Street Journal*, March 9, 2009, pp. R8-R9. Good article from an economics and world trade viewpoint. Also discusses how U.S. cap-and-trade policy could affect Canadian oil sands development and vice versa.

Marsden, William. *Stupid to the Last Drop: How Alberta Is Bringing Environmental Armageddon to Canada (And Doesn't Seem to Care).* Reprint. Toronto: Vintage Canada, 2008. Argues that development of the oil sands would destroy natural resources and habitat. Discusses the roles of various levels of government.

Shogren, Jason F. *The Benefits and Costs of the Kyoto Protocol.* Washington, D.C.: AEI Press, 1999. Excellent for understanding the Kyoto Protocol and the framework it creates for Canadian climate policy.

See also: Canadian Meteorological and Oceanographic Society; Kyoto Protocol; United Nations Framework Convention on Climate Change; United States.

Canadian Meteorological and Oceanographic Society

- **Categories:** Organizations and agencies; meteorology and atmospheric sciences
- **Date:** Established 1967
- **Web address:** http://www.cmos.ca

• Mission

The Canadian Meteorological and Oceanographic Society (CMOS) is Canada's national umbrella organization promoting research in weather and weather extremes, global warming, ozone depletion, and surface air quality. Among approximately eleven hundred members of CMOS are meteorologists, climatologists, oceanographers, limnologists, hydrologists, and cryospheric scientists. Governing the society are its national executive and council, the latter comprising the heads of fourteen centers located throughout Canada. The council appoints an executive director and members to serve on various committees, among them the Scientific, University, and Professional Education Committee; the School and Public Education Committee; the Prizes and Awards Committee; the Consultant Accreditation Committee; and the Media Weathercaster Endorsement Committee. CMOS is headquartered in Ottawa.

In addition to promoting professional and public education, CMOS accredits media weather forecasters and helps specialists study the meteorological aspects of hydrology, agriculture, and forestry. It publishes a scientific journal, *Atmosphere-Ocean*, as well as a bimonthly bulletin and *Annual Review.* It presents annual awards to scientists, graduate students, postdoctoral fellows, and volunteers and provides scholarships. Is also sponsors precollege teachers' participation in Project Atmosphere, run jointly with the American Meteorological Association and the U.S. National Oceanic and Atmospheric Administration.

• Significance for Climate Change

In March, 2007, CMOS issued its Comprehensive Position Statement on Climate Change. Noting that Canada's climate was changing rapidly, affecting its ecosystems and wildlife, the statement insisted that there was strong evidence (95 percent confidence) that atmospheric and oceanic warming in the previous fifty years were mostly the result of fossil-fuel burning and clearing of forest vegetation. Global warming, in fact, disproportionately impacts Canada and the Arctic. Accordingly, the CMOS issued a call to action.

Given the increasing significant load of greenhouse gases (GHGs) in the atmosphere, future warming seems inevitable. Because upcoming changes will occur rapidly, appropriate adaptation policies and programs must be designed to help increase humans' adaptive capacities. Climate-change protection is needed now. The global reduction of GHG emissions cannot be achieved by any single country, but each country must contribute its share toward accomplishing the global goal. The atmosphere, ocean, and biosphere together constitute a highly complex system. Climatologists' ability to make comprehensive climate projections is hindered by the lack of accurate characterization of important processes and feedbacks within this system. Further process studies, assessments of paleoclimate evidence, modeling, and observations are needed to understand and to improve predictions of climate change at the global and especially regional levels. Research is essential to humans' ability to mitigate and adapt to climate change.

Roger Smith

See also: Canada; Meteorology; Ocean-atmosphere coupling; Ocean dynamics; Weather forecasting; Weather vs. climate.

Canaries in the coal mine

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Originally, canaries were used in coal mines, because small quantities of methane gas and carbon monoxide are deadly to them. Thus, a canary in a coal mine would die long before these substances became lethal to the miners carrying it. The term has come to be used to describe any such sensitive indicator of an emergent threat or problem. Several species and events act as "canaries" in the "coal mine" represented by global warming. These include the ecosystems and species most vulnerable to increases in extreme weather patterns (those most threatened by extreme heat, drought, flooding, hurricanes, and so on); ice sheets and other frozen formations in danger of melting; endangered animal species such as polar bears, amphibians, and butterflies; and plants vulnerable to increased or invasive exotic insect populations.

• **Significance for Climate Change**

Nineteen of the twenty hottest years since 1850 occurred after 1980, and the Earth was warmer in 2005 than at any time in the past two thousand years. Periods of extreme heat place strain on people, animals, and plants and can be responsible for hundreds of human deaths in a given area. A record European heat wave in 2003 is blamed for the loss of over fifty thousand human lives. In such heat waves, the most common causes of death are pollution or preexisting medical conditions that are aggravated by the heat. Because those with such conditions are more sensitive to heat waves than are healthy people, they may be considered to function as canaries in the coal mine.

Warm air holds more water than does cold air. Thus, with warmer temperatures, more moisture is removed from the ground, and droughts occur. The droughts, such as those in Africa, kill millions of people through starvation and increased vulnerability to disease. Warmer temperatures also mean that rains or snows fall harder in a shorter period of time, increasing the risks of flooding. Monsoons—patterns of heavy rainfall that particularly affect Asia—strengthen and weaken in relation to the Earth's temperature. Major flooding is responsible for loss of human lives and property, as well as the destruction of crops. The most vulnerable to this destruction are the poorest members of society, those with the fewest resources.

Tropical storms (also known as hurricanes, cyclones, or typhoons) are becoming stronger and more frequent. Oceans store a vast amount of heat in their depths, and warm ocean waters give rise to tropical storms and provide the fuel they need to grow. Because of the many factors involved with the storms, there is no clear evidence that they may occur more frequently as a result of global warming. The strength of the storms in the Atlantic Ocean, however, does appear to be affected somewhat by global warming. Three of the six 2005 North American hurricanes were the most powerful Atlantic storms ever observed. The year marked the first

Amphibians such as this gold frog are particularly sensitive to their environment, causing them to function as canaries in the coal mine of climate change. (Alberto Lowe/Reuters/Landov)

time four Category 5 hurricanes occurred in a single year since records began being kept in 1851.

The rate of change and level of warming are far above average for the Arctic region. The warm temperatures cause melting of the ice sheets near the shore, so life for subsistence whalers and seal hunters becomes more difficult. In addition, less ice near the shore means that violent storms are not kept offshore and crash into the coastal towns, eroding the coastline.

Polar bears are greatly affected by the decreasing ice sheet and warmer Arctic temperatures. The bears hunt for seals on sea ice in the springtime. When the ice is gone, the bears fast on land. With ice-free spells lengthening, cub birth weights are dropping, females are becoming thinner, and desperate bears are appearing in human settlements seeking food. The World Wildlife Foundation estimates that polar bears may not be fat enough to reproduce by 2012 if the lower weight trend continues. If polar bears cannot adapt to a land-based life, they may become extinct in the wild.

As glaciers in the Arctic and Antarctic melt, sea levels rise and the oceans become warmer and more acidic. As the sea level increases, millions of people living close to the ocean and in drought- or flood-prone areas will be greatly affected, as lower-lying areas are more prone to flooding and storm surges. Venice is already sinking in the rising waters and is threatened by storm surges. Minor flooding requires residents and visitors regularly to wade through ankle-deep water in the streets.

Amphibians and reptiles, because of their need for a particular range of air temperature and their slow mobility, cannot adapt to climate changes quickly. Frogs are among the most threatened species worldwide, and climate change is responsible for several cases of depletion or extinction. Climate change helps fungi attack amphibians more effectively, while drought allows light to penetrate shallow water sources and weaken the developing embryos of some toad species. In 1987, after an unusually warm, dry spring, twenty of fifty frog species vanished completely in Costa Rica.

Butterflies, which have been carefully studied for centuries, indicate climate change as well. Drought and flood can cause a population to crash. Slowly rising temperatures, as well as other pressures that restrict their range, threaten the populations. As temperatures rise and climate zones move, some species have expanded their habitat northward.

Insects are extremely adaptable to change, but their presence may not be beneficial. Insects may eat crops, and warming northern forests are being devastated as beetles that thrive in warmer climates migrate into them. As temperatures warm, parasitic diseases are more likely to spread and become more severe. Mosquitoes carrying malaria are expanding their territory, infecting more than four times as many people in 2005 as in 1990. Dengue fever, caused by four potentially fatal, mosquito-borne viruses, is also on the increase. Cases of the West Nile virus are showing up further north each year.

The frogs, butterflies, and trees suffering from climate change are canaries in the coal mine. They act as signals of the dangers to stronger and more resilient species that may develop if global warming continues. By the same token, those segments of human society most vulnerable to climate change now will not remain the only segments vulnerable in the future. These canaries demonstrate dangers that will only increase if the Earth's temperature continues to rise.

Virginia L. Salmon

• Further Reading

DiMento, Joseph F. C., and Pamela Doughman, eds. *Climate Change: What It Means for Us, Our Children, and Our Grandchildren.* Cambridge, Mass.: MIT Press, 2007. Explains various aspects of climate change, including different public and scientific responses. Illustrated, with glossary and index.

Henson, Robert. *The Rough Guide to Climate Change: The Symptoms, the Science, the Solutions.* New York: Penguin Putnam, 2006. Presents well-balanced, organized, and easy-to-follow information on climate change. Includes illustrations, charts, side articles, and bibliography.

Lomborg, Bjørn. *Cool It: The Skeptical Environmentalist's Guide to Global Warming.* New York: Alfred A. Knopf, 2007. Looks at global warming from the perspective of both environmental and human concerns. Includes notes, index, and extensive bibliography.

See also: Amphibians; Antarctica: threats and responses; Arctic; Arctic peoples; Coastal impacts of global climate change; Extreme weather events; Health impacts of global warming; Islands; Penguins; Polar bears; Poverty.

Carbon cycle

• Categories: Chemistry and geochemistry; plants and vegetation

The natural geochemical carbon cycle maintained an equilibrium of atmospheric and dissolved CO_2 for thousands of years. This equilibrium, however, has been disrupted by the anthropogenic emission of CO_2, which has increased CO_2 concentrations in the atmosphere and is associated with climate change.

• Key concepts

carbon fixation: conversion of CO_2 into organic molecules through such processes as photosynthesis or calcification

detritus: the residue left behind by decay or disintegration

limnetic zone: the upper layers of open ocean through which light penetrates and which thus supports photosynthesis by planktonic organisms

pH: a measure of the acidity of a solution, which is related to the activity of dissolved hydrogen ions in that solution

photosynthesis: the physiological process in plants that converts light energy into chemical energy

respiration: the physiological process that breaks down organic carbon-containing molecules to obtain energy and that releases CO_2 as a by-product

sedimentation: settling of suspended particulate material, for instance in response to gravity, to form a bottom layer

• Background

The biological carbon cycle primarily depends on two physiological processes of living things: photosynthesis and respiration. Photosynthesis converts light energy to chemical energy, which then is used to incorporate carbon dioxide (CO_2) into organic compounds, a process called carbon fixation. The organic compounds can be used by organisms as a source of energy through the process of respiration, which breaks chemical bonds to release energy for use. This breakdown of organic molecules provides energy to living cells and releases CO_2 back to the environment as a by-product. All living organisms respire, but plants do so at a much slower rate than they normally photosynthesize. As a result, overall global net photosynthesis is approximately equal to net respiration, and CO_2 levels are in balance.

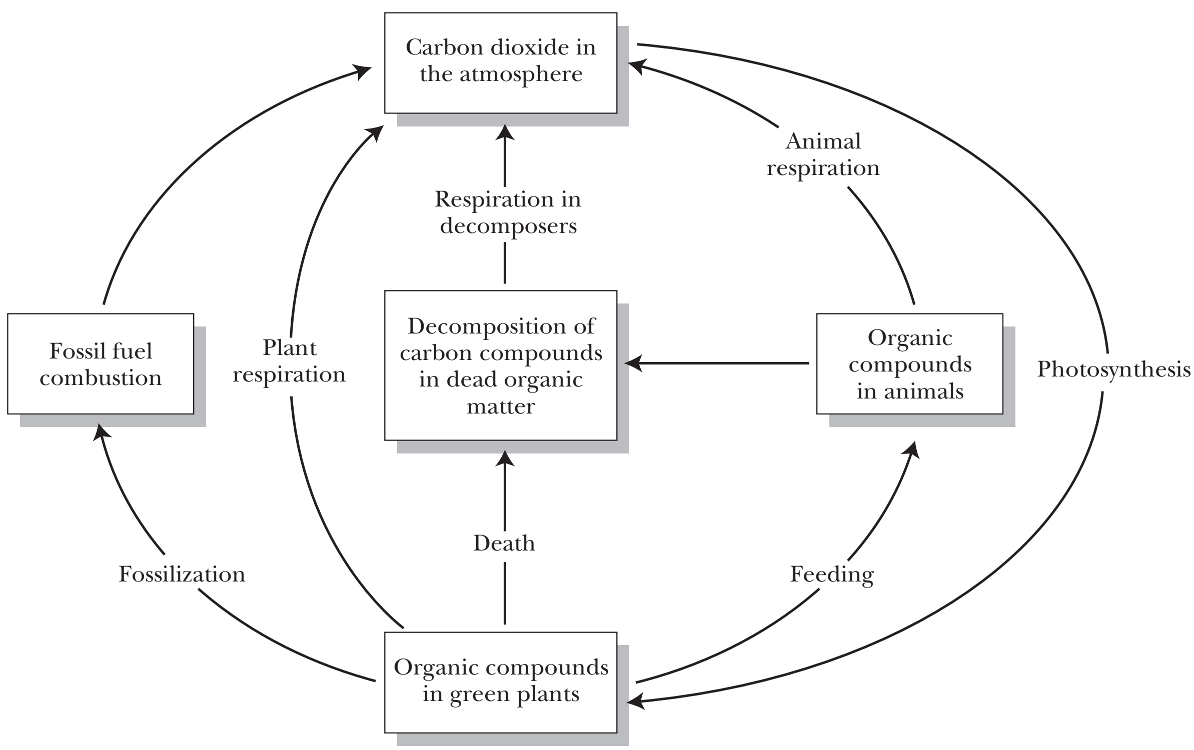
- **Terrestrial Ecosystems**

In terrestrial ecosystems, the atmosphere is a major reservoir of carbon, holding about 750 billion metric tons (gigatons) of carbon in the form of CO_2. Nearly as much, about 610 gigatons of carbon, forms the biomass of living plants. Each year, plants convert about 120 gigatons of carbon from CO_2 into new organic tissue, with nearly that amount returned to the atmosphere through respiration of plants and animals, as well as through decomposition of dead organisms. A small amount of excess fixed carbon is added to the soil as humus. Over the millennia, this accumulation of organic material has formed soils that provide a reservoir of about 1,500 gigatons of carbon.

The depth and richness of soil are directly related to the photosynthetic productivity of the plants supported in a particular environment. The vegetation of Earth's temperate areas has produced deep, rich soils during the past ten to twenty thousand years that in turn promote high plant productivity in these regions. (Thus, although plants are predicted to migrate poleward in response to increasing temperatures associated with climate change during the twenty-first century, they will be moving into areas of poorer soils that will decrease plant productivity, even though other environmental factors may be positive.) Over a longer period of time during the past 3 to 3.5 million years, organic remains that did not decompose were converted into geological deposits of coal and oil. About 4 trillion metric tons of carbon are sequestered in these fossil fuels.

Scientists calculate that, at the start of the Industrial Revolution in the mid-eighteenth century, the atmospheric reservoir contained about 580 gigatons of carbon. This means that atmospheric CO_2 has increased by about 30 percent during the past

The Carbon Cycle



three hundred years, largely as a result of CO_2 being released to the atmosphere by burning fossil fuels. Fossil fuel consumption during the early twenty-first century adds about 5.5 gigatons of carbon to the atmosphere every year. In addition, changes in land use, particularly deforestation, contribute another 1.6 gigatons of carbon per year. While added CO_2 stimulates photosynthesis, particularly by carbon 3 plants, this activity fixes less than 1.9 gigatons of carbon per year. About 2 gigatons of carbon per year diffuse into the oceans, particularly in colder waters, but the majority remains in the atmosphere, increasing CO_2 concentrations and promoting global warming.

• Marine Ecosystems

A direct connection between the terrestrial and marine ecosystems exists in the equilibrium between atmospheric CO_2 and dissolved CO_2 in the oceans. This equilibrium shifts slightly toward the oceans as CO_2 reacts with water (H_2O) to form carbonate (CO_3^{-2}) or bicarbonate (HCO_3^-) ions along with hydrogen ions (H^+), which lowers pH, increasing the acidity of the oceans. Oceans absorb about 2 gigatons of carbon per year in this way.

The limnetic zone of the oceans supports a biotic carbon cycle similar to that of terrestrial ecosystems. About 1 trillion metric tons of carbon is dissolved in the near-surface waters that serve as a reservoir for marine organisms, which account for about 3 gigatons of carbon. These organisms convert CO_2 to calcium carbonate, a building block of shells and other portions of marine life. The dissolved organic compounds produced by marine organisms account for nearly 700 gigatons of carbon.

• Sedimentary Rock and Fossil Fuels

When marine organisms die, their remains form a detritus of organic materials that slowly sinks to the seafloor. A huge amount of carbon, about 38.1 trillion metric tons, is accounted for by this deep ocean detritus, which eventually forms bottom sediments.

Marine sediments are molded by the pressure of the ocean as well as by volcanic heat, eventually forming sedimentary rocks. By far the largest amount of carbon on Earth is found in the lithosphere, in carbon-containing sediments and sedimentary rocks such as chalk, limestone, and dolomite. Scientists estimate that these calcium-carbonate-rich deposits—formed by corals, shell-producing animals, coralline algae, and marine plankton millions of years ago—contain up to 100 quadrillion metric tons of carbon.

Similarly, coal and oil are the carbon remains of ancient organisms stored in the Earth. As is true of sedimentary rock, these remains are transformed over millions of years by the heat and pressure of the Earth, which compresses them into a new form. Contemporary burning of fossil fuels returns about 5.5 gigatons of carbon to the atmosphere each year.

• Context

Initially, it seemed that rising CO_2 levels in Earth's atmosphere would be partially compensated for by increased rates of plant photosynthesis and also by increased uptake of CO_2 by the oceans. The increased photosynthesis promoted by higher CO_2 levels, however, is countered by a decrease resulting from higher temperatures. Moreover, the rising acidity of the oceans resulting from higher levels of dissolved CO_2 counters the photosynthetic benefits of higher CO_2 levels. The global carbon cycle is thus much more complex than was imagined even a decade ago.

Marshall D. Sundberg

• Further Reading

Fagan, Brian. *Floods, Famines, and Emperors: El Niño and the Fate of Civilizations.* New York: Basic Books, 1999. Good introduction to climatology, integrating atmospheric and oceanographic interactions and the relationship between major climatological events and human history.

Field, Christopher B., and Michael R. Raupach, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Washington, D.C.: Island Press, 2004. This introduction to the carbon cycle covers relevant biological, geochemical, and societal interactions.

Odum, Eugene. *Ecological Vignettes: Ecological Approaches to Dealing with Human Predicaments.* Amsterdam, the Netherlands: Harwood Academic, 1998. Examines human impacts on the environment and urges the adoption of an economic approach to ecology.

Wigley, T. M. L., and David Steven Schimel, eds. *The Carbon Cycle*. New York: Cambridge University Press, 2000. The multiauthored chapters of this comprehensive volume summarize results of the Intergovernmental Panel on Climate Change and address both the scientific and the political aspects of this complex relationship.

See also: Carbon dioxide; Carbon dioxide fertilization; Carbon 4 plants; Carbon isotopes; Carbon monoxide; Carbon 3 plants; Carbonaceous aerosols; Photosynthesis; Plankton; Sequestration.

Carbon dioxide

• **Category:** Chemistry and geochemistry

Carbon dioxide is the greenhouse gas that contributes the most to global warming. A naturally occurring gas, it is also a by-product of burning fossil fuels, which has become the most important determinant of its rate of increase in Earth's atmosphere.

• Key concepts

anthropogenic: created by human action
fossil fuel: fuels formed by pressure on plant or animal material over time, including oil, gas, and coal
greenhouse gases (GHGs): gases that trap heat within Earth's atmosphere, increasing global temperatures

• Background

Carbon is one of the building blocks of life on Earth; all plants and animals are composed largely of carbon. Carbon dioxide (CO_2) emission is a normal part of the respiration cycle. CO_2 is also emitted from the burning of plant or animal material. The burning of fossil fuels for energy causes CO_2 to be emitted into the atmosphere, and forest clearing also results in a net increase in atmospheric CO_2. Once in the atmosphere, CO_2 acts as a greenhouse gas (GHG), trapping heat in the atmosphere and contributing to global warming. Presently, CO_2 is the most common GHG in the atmosphere, and its atmospheric concentration is growing rapidly. The proper regulation of human activities that exacerbate this situation is therefore the focus of a good deal of attention.

• Fossil Fuels

Burning fossil fuels is the major contributor to the anthropogenic contribution of CO_2 in the atmosphere. Approximately 57 percent of GHGs are constituted by CO_2 generated by burning fossil fuels. Another 17 percent comes from the decay of biomass and deforestation. The Intergovernmental Panel on Climate Change (IPCC) has indicated with a high degree of confidence that human activities since 1750 have contributed to the addition of these and other GHGs to the atmosphere. When the scientist Charles Keeling began measuring the accumulation of CO_2 in the atmosphere from an observatory atop Mauna Loa, Hawaii, in 1958, his measurements indicated that the concentration of CO_2 in the atmosphere was 315 parts per million. By 2005, the measured concentration of CO_2 was 379 parts per million, which exceeded the natural range of atmospheric CO_2 levels over the last 650,000 years. The CO_2 content of the atmosphere, derived from ice-core data, has varied over time by 10 parts per million around a mean value of 280 parts per million.

Industrialization was initially fueled by coal in the eighteenth and nineteenth centuries. Coal continued to be a major source of energy for much of the twentieth century, but oil and natural gas also began to be used for energy in increasing amounts. Gasoline, derived from oil, fueled the growth of automobile culture in many parts of the world in the twentieth century. One thing that all of these energy sources have in common is that they are fossil fuels. Combustion of fossil fuels produces CO_2, along with smaller quantities of other GHGs. Much of industrial civilization in the early twenty-first century is powered by fossil fuels.

Some cleaner fuels that do not generate CO_2 are becoming available, and more efficient energy sources and automobiles are being built that generate less CO_2. However, CO_2 will continue to be a by-product of industrial society for years to come. Controlling the impact of CO_2 on global climate will require different approaches to energy generation and consumption, as well as new technologies such as carbon sequestration that remove carbon from the atmosphere.

U.S. Anthropogenic GHG Emissions, 2006

Greenhouse Gas	*Amount (kilograms of CO_2 equivalent)*	*Percent of Total GWP*
Energy-related carbon dioxide	5,825.5	82.3
Other carbon dioxide	108.8	1.5
Methane	605.1	8.6
Nitrous oxide	378.6	5.4
All other Kyoto gases*	157.6	2.2

Data from U.S. Energy Information Administration.

*Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

• Land Use

Human use of the land has led to the accumulation of CO_2 (and methane, another GHG) in the atmosphere for a period extending back several thousand years. The growth of population in the last two hundred years has magnified this impact. Clearing forested land for agriculture has generally led to the burning of much of the cleared vegetation. As noted above, combustion of carbon-based entities produces CO_2 as a by-product. The decay of biomass, often generated by agriculture, also produces CO_2. As societies have increased their use of metals over time, metal smelting—first using wood for its energy source, then coal—has also contributed CO_2 to the atmosphere.

Some of the CO_2 that has been anthropogenically generated has been fixed in the oceans and wetlands as peat, rather than in the atmosphere. As wetlands are drained for other uses, however, this carbon sink is diminished, so that more carbon enters the atmosphere. Population pressure and the demands for agricultural products drive land clearing and wetland degradation in many parts of the world. Land clearing continues to increase dramatically in some parts of the world, such as the Amazon basin in Brazil.

• Who Produces CO_2?

The industrial nations of the world have been the major producers of CO_2 over time. As each nation has industrialized, it has begun burning fossil fuels extensively, as well as clearing land for agriculture. Industrial countries continue to generate most of the world's CO_2, either directly through energy generation and automobile use or indirectly by their demand for agricultural products from other areas, which leads to further land clearing in those areas. Nations that are rapidly industrializing, such as China and India, are doing so largely through the use of fossil fuels. Although the United States is currently the largest consumer of fossil fuels, China is poised to move into second place and will probably surpass the United States by 2030 as a producer of GHGs. Even less-industrialized nations make extensive use of fossil fuels.

Dealing with CO_2 emissions in the future will require concerted efforts by industrial countries. Less industrialized nations cannot be expected to forgo the economic progress generated by industrialization, but they too will have to manage their carbon footprints over time.

• Context

CO_2 is the major driver of what is called the greenhouse effect. Some estimates of the amount of CO_2 that will be in the atmosphere by 2100 are as high as 1,000 parts per million if emissions grow unchecked. Such a concentration could produce a global temperature increase of 5° Celsius or more, a change not seen for several million years. Even if the growth of CO_2 in the atmosphere is brought somewhat under control, its concentration could still reach 440 parts per million, which could produce a temperature increase of as much as 3° Celsius. Controlling the rate of carbon emissions into the atmosphere without harming people's economic well-being will be a challenge. Failure to control the growth of carbon emissions will lead to what several authorities consider to be a much different and undesirable life for much of the planet. The production of CO_2, which has been the hallmark of economic progress, may lead to economic decay if it is not checked.

John M. Theilmann

- **Further Reading**

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It.* New York: Hill and Wang, 2008. Examination of the role of CO_2 in climate change and what can be done. Broecker is a leading climate scientist.

Houghton, John. *Global Warming: The Complete Briefing*. 4th ed. New York: Cambridge University Press, 2009. Excellent, comprehensive discussion of global warming and the role of CO_2 that includes extensive references. Houghton is the former chairman of the Scientific Assessment Working Group of the IPCC.

Ruddiman, William F. *Plows, Plagues, and Petroleum.* Princeton, N.J.: Princeton University Press, 2005. Especially good at demonstrating the long-term impact that agriculture has had on climate.

Smil, Vaclav. *Cycles of Life.* New York: Scientific American, 1997. Good description of the carbon cycle and how it relates to human life.

Volk, James. *CO_2 Rising*. Cambridge, Mass.: MIT Press, 2008. Excellent analysis of the carbon cycle, as well as energy use and CO_2 emissions.

See also: Carbon cycle; Carbon dioxide equivalent; Carbon dioxide fertilization; Carbon equivalent; Carbon footprint; Carbon 4 plants; Carbon isotopes; Carbon monoxide; Carbon taxes; Carbon 3 plants; Emissions standards; Greenhouse effect; Greenhouse gases.

Carbon dioxide equivalent

- **Category:** Pollution and waste

- **Definition**

Various greenhouse gases (GHGs) such as methane, nitrous oxide, chlorofluorocarbons, and carbon dioxide (CO_2) have different potential effects on global warming. In order to compare GHGs based on their global warming potential (GWP), CO_2 is commonly chosen as a reference gas. The carbon dioxide equivalent (CO_2e) for a given amount of GHG is defined as the amount of CO_2 that would have the same GWP measured over a specified time period, usually one hundred years. More formally, the CO_2e for emissions of a given gas is calculated by multiplying the amount of the gas emitted by its associated GWP.

For example, the GWP for methane over a one-hundred-year time horizon is 21. Thus, the CO_2e of one metric ton of methane is equal to 21 metric tons. In other words, one metric ton of methane released into the atmosphere would have the same effect on global warming over one hundred years as would 21 metric tons of CO_2.

- **Significance for Climate Change**

The CO_2e metric provides a universal standard measure by which to evaluate and compare the global warming effects of emissions of various GHGs, as well as to calculate the total effects of the GHGs present in Earth's atmosphere. Those uses of CO_2e have important implications for decisions about climate-change mitigation. On one hand, CO_2e measurements of GHG emissions make it easy to compare the various impacts of different plans to prevent such emissions. The fact that the CO_2e of methane is 21 times that of CO_2 helps determine whether to focus on methane or CO_2 reduction in a given context.

On the other hand, the calculation of total effect of GHGs expressed in CO_2e concentration can provide a way to compare existing concentrations of GHGs in the atmosphere with theoretical critical threshold levels. Recent studies have confirmed that one such threshold is represented by a global temperature rise of 2° Celsius during the twenty-first century. In order to prevent surpassing this threshold, the total concentration of all GHGs must be less than 450 parts per million in CO_2e. However, GHG concentration is already beyond that level.

In addition to facilitating global climate study, the CO_2e metric as a reference for evaluating GHGs also plays an important role in emissions trading. Various national and international regulatory structures allow polluters that reduce their emissions below a certain level to trade emissions credits (the right to pollute) to other entities whose emissions are still above the maximum permitted level. The existence of a universal standard of emission measurement, CO_2e, allows these credit systems to function much more effectively and efficiently.

To N. Nguyen

See also: Baseline emissions; Carbon dioxide; Carbon equivalent; Carbon footprint; Certified emissions reduction; Emissions standards; Fossil fuel emissions; Greenhouse gases; Industrial emission controls; Industrial greenhouse emissions.

Carbon dioxide fertilization

• **Categories:** Chemistry and geochemistry; plants and vegetation

• **Definition**

In the context of climate change, carbon dioxide (CO_2) fertilization is the stimulation of biospheric carbon uptake by rising atmospheric CO_2 concentrations. That is, as the CO_2 level increases, plants absorb more carbon and sequester it in biomass, removing it from the atmosphere and increasing their own size and productivity. This fertilization is realized by photosynthetic enzymes. It involves multi-scale processes, from the level of individual leaves and plants all the way up to regional and global ecosystems, and it is regulated by many other factors.

CO_2 and water (H_2O) are the two basic substrates of photosynthesis, which is driven by solar energy and regulated by an enzyme, Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO). When all other factors are constant, photosynthesis increases as CO_2 concentration increases. Thus, photosynthesis is sensitive to CO_2 concentration.

The photosynthetic sensitivity to CO_2 concentration is universal to all carbon 3 plants, because all carbon 3 plants share the same enzyme, RuBisCO, to catalyze photosynthesis. The sensitivity is also virtually independent of light and nutrient levels, but it declines with CO_2 concentration. This sensitivity can be measured as the percentage increase in carbon fixation caused by a 1 part per million increase in CO_2 concentration. In other words, a CO_2 sensitivity of 0.2 percent means that if CO_2 concentration increases by 1 part per million, plants will fix 0.2 percent more carbon than they did at the previous concentration.

When atmospheric CO_2 concentration increases from 280 parts per million (the preindustrial level) to 440 parts per million (a level projected to be reached in the 2030's), photosynthetic CO_2 sensitivity declines from 0.183-0.352 percent to 0.077-0.183 percent. Assume that atmospheric CO_2 concentration increases by 2 parts per million per year and that global photosynthetic carbon fixation is 120 billion metric tons per year and is accomplished entirely by carbon 3 plants. Under such conditions, Earth's land ecosystems will fix roughly an additional 600 million metric tons of carbon per year as a result of photosynthetic sensitivity. Carbon 4 plants, however, are less sensitive to CO_2 concentration than are carbon 3 plants.

When plants grow under different CO_2 concentration, they adjust their leaf structures and biochemical properties, resulting in photosynthetic acclimation. Photosynthetic acclimation is regulated by sugar signals at the biochemical level and is usually related to nutrient supply. Acclimation may increase or decrease photosynthetic sensitivity. Many studies indicate that photosynthetic acclimation greatly varies with species and environmental conditions. However, on average across all studies conducted in natural ecosystems, photosynthetic acclimation is not very substantial.

Photosynthetically fixed carbon is stored in plant biomass and soil organic matter (SOM). Carbon storage may last for years, decades, or centuries in plant wood pools and for up to thousands of years in soil pools, but it is very ephemeral in leaf and fine root pools. Carbon storage in wood pools is regulated by plant allocation and species. Carbon storage in soil pools is regulated by nutrient availability. Many CO_2 experiments in natural ecosystems indicate that rising atmospheric CO_2 concentration results in carbon storage in plant and soil pools. However, the CO_2 fertilization may not occur under conditions in which some other growth factor is severely limiting, such as low temperature or low nutrient availability.

• Significance for Climate Change

CO_2 fertilization is a major mechanism of terrestrial carbon sequestration and a negative feedback mechanism protecting ecosystems from climate change. CO_2 is a major greenhouse gas (GHG). Buildup of CO_2 in the atmosphere results in climate warming. Since terrestrial ecosystems absorb approximately 120 billion metric tons of carbon from the atmosphere every year, a small stimulation of photosynthetic carbon uptake by CO_2 fertilization can substantially influence global carbon balance and reduce the likelihood or degree of climate change. Several global analyses indicate that nearly 30 percent of the CO_2 emitted by human activities is absorbed by land ecosystems. CO_2 fertilization is one of the major mechanisms responsible for land carbon sequestration.

Because photosynthetic enzymes are sensitive to CO_2 concentration, the CO_2 fertilization factor should gradually decline as atmospheric CO_2 concentration increases. However, as the world continues to consume fossil fuels, the yearly increase in atmospheric CO_2 concentration becomes larger over time. CO_2 fertilization will remain a major mechanism in the regulation of atmospheric CO_2 concentration.

Most experimental and modeling studies demonstrate that nitrogen deposition acts synergistically with atmospheric CO_2 concentration to stimulate carbon sequestration in land ecosystems. Nitrogen deposition is expected to increase by another two- to threefold in the future. This increase is likely to enhance the effects of CO_2 fertilization on plant growth and carbon sequestration. CO_2 fertilization effects are also regulated by other global change factors, such as climate warming and altered precipitation regimes.

In addition to regulation of CO_2 concentration in the atmosphere, stimulation of food production by CO_2 fertilization helps mitigate climate change impacts on developing countries. Although CO_2 fertilization's effects on food production are relatively small in comparison to those of nitrogen fertilization and genetic breeding, food production still can increase by 10-20 percent when atmospheric CO_2 concentration increases by 200-300 parts per million.

CO_2 fertilization-based increases in plant growth and carbon sequestration are fundamentally driven by rising atmospheric CO_2 concentrations. If those concentrations level off as a result of effective climate-mitigation activities, the effects of fertilization will also level off. If atmospheric CO_2 concentration declines, as hypothesized in some scenarios of the Intergovernmental Panel on Climate Change, CO_2 fertilization will also decrease, and land ecosystems will likely release some CO_2 from plants and soils into the atmosphere. Thus, any analysis of climate dynamics and climate change mitigation must take into account CO_2 fertilization effects, whether positive or negative.

Overall, CO_2 fertilization stimulates carbon storage in plants and soil, reduces buildup of GHGs in the atmosphere, and determines the airborne fraction of anthropogenic carbon emissions.

Yiqi Luo

• Further Reading

Curtis, P. S., and X. Z. Wang. "A Meta-analysis of Elevated CO_2 Effects on Woody Plant Mass, Form, and Physiology." *Oecologia* 113 (1998): 299-313. Summarizes more than five hundred reports of the effects of elevated CO_2 on key plant physiological processes. Determines that both total biomass and net CO_2 assimilation increase significantly when CO_2 is elevated.

Luo, Y., D. Hui, and D. Zhang. "Elevated Carbon Dioxide Stimulates Net Accumulations of Carbon and Nitrogen in Terrestrial Ecosystems: A Meta-Analysis." *Ecology* 87 (2006): 53-63. Synthesizes over one hundred studies of CO_2 effects on plant and soil carbon sequestration as regulated by nitrogen availability. On average, elevated CO_2 significantly increased plant growth, soil carbon storage, and accrual of nitrogen capital in ecosystems, potentially supporting long-term carbon sequestration.

Luo, Y., and H. A. Mooney. "Stimulation of Global Photosynthetic Carbon Influx by an Increase in Atmospheric Carbon Dioxide Concentration." In *Carbon Dioxide and Terrestrial Ecosystems*, edited by G. W. Koch and H. A. Mooney. San Diego, Calif.: Academic Press, 1996. Systematically analyzes CO_2 fertilization according to the CO_2 sensitivity of RuBisCO, which is an invariant function independent of species and major envi-

ronmental factors. Photosynthetic sensitivity becomes a scalable parameter to estimate global plant carbon uptake as stimulated by rising atmospheric CO_2 concentration.

See also: Carbon dioxide; Carbon 4 plants; Carbon 3 plants; Forests; Photosynthesis; Reservoirs, pools, and stocks; Sequestration; Sinks.

Carbon equivalent

• **Categories:** Pollution and waste; meteorology and atmospheric sciences

• **Definition**

The carbon equivalent (CE), similar to carbon dioxide equivalent (CO_2e), is a metric measure used to quantify how much global warming a given quantity of gas can cause (global warming potential, or GWP), using the functionally equivalent concentration of carbon, converted to the amount of carbon dioxide (CO_2) that would have the same GWP as the reference. In contrast to the CE, the CO_2e uses the functionally equivalent CO_2 concentration as the reference (the amount of CO_2 that would have the same GWP). CE is usually given for a specified timescale, effectively expressing the time-integrated radiative forcing. This also differentiates CE from CO_2e, which describes the instantaneous radiative forcing.

• **Significance for Climate Change**

The CE of a gas or a mixture of gases is a metric measure that can be used to compare the GWP of greenhouse gases (GHGs) for the purposes of analysis, computer modeling, and reporting—as was done, for example, in such international treaties as the Kyoto Protocol and the Montreal Protocol. The CE of a gas is calculated by multiplying the mass (in metric tons) by the GWP of the gas and is expressed for a specified timescale. CE values can be converted to CO_2e units simply by multiplying the CO_2 by $^3/_{11}$ (the ratio of the molecular weight of carbon to that of CO_2). Time is an important factor when comparing CE or GWP values, as they are functions of the time periods over which these values are calculated.

The United Nations climate change panel, known as the Intergovernmental Panel on Climate Change (IPCC), an intergovernmental organization charged with evaluating the risk of climate change caused by human activity, expresses CE in billions of metric tons of CO_2e. In industry, CE units are often expressed in millions of metric tons of CO_2e; for vehicles, units are in grams of CO_2e per kilometer. For example, the GWP for methane gas over one hundred years is 25; the equivalent value for nitrous oxide is 298. This means that the emission of 1 million metric tons of methane or nitrous oxide has the equivalent ability to contribute to global warming as 25 million or 298 million metric tons of CO_2, respectively. Over the same timespan, the hydrofluorocarbons fluoroform (HFC-23) and 1,1,1,2-Tetrafluoroethane (HFC-134a)—shown to have large negative effects on the environment—have GWPs of 14,800 and 1,430, respectively.

Rena Christina Tabata

See also: Carbon dioxide; Carbon dioxide equivalent; Global warming potential; Greenhouse gases; Hydrofluorocarbons; Kyoto Protocol; Methane; Montreal Protocol; Nitrous oxide.

Carbon footprint

• **Category:** Pollution and waste

Measuring one's carbon footprint is a useful tool for evaluating the effect upon the climate of one's GHG emissions and for ascertaining the results of specific changes in laws, regulations, or behavior.

• **Key concepts**

carbon dioxide equivalent (CO_2e): measurement of the environmental effect of a given amount of greenhouse gas that specifies the amount of CO_2 that would have the same effect

carbon-neutral activity: an activity that has no net effect on the concentration of greenhouse gases in the atmosphere

emission credits: purchasable shares in an emission-reducing project that are used to measure attempts by an entity to offset its GHG emissions
greenhouse gases (GHGs): atmospheric trace gases that trap heat, preventing it from escaping into space
offsetting: the practice of supporting GHG-reducing efforts elsewhere in order to mitigate the effects of one's own emissions

• Background

The carbon footprint of an entity or an activity is its total annual contribution to the greenhouse effect. It is measured in units of mass of carbon dioxide (CO_2) per year, but it includes the entity's output of all greenhouse gases (GHGs) into the atmosphere. The effects of other GHGs are measured in terms of the equivalent amount of CO_2 necessary to produce the same effect, the gases' carbon dioxide equivalent (CO_2e).

The U.S. emission of CO_2 into the atmosphere increased at an average rate of 1.1 percent per year during the 1990's, but at an average of 3.1 percent per year in the early twenty-first century. This rate of increase is attributable to a higher intensity of energy use per unit of domestic product. The carbon footprint of a person is expressed as the CO_2e, in kilograms, of GHG emissions caused by that individual's lifestyle.

One portion of a person's carbon footprint is constituted directly by the CO_2 emitted by such activities as home heating, cooking, and driving an automobile. Other portions are less direct, as they comprise the CO_2 emissions of manufacturers whose products the person purchases or benefits from, vehicles used to ship those products, power plants whose electricity the person uses, and so forth. Carbon footprint measurements are being developed to educate individuals, organizations, and nations as to how to reduce the global warming effect of their activities. A given carbon footprint is a subset of the overall ecological footprint of the totality of human activities.

• Carbon Footprint by Individual Activity

When measuring the carbon footprint of an individual, one generally excludes breathing and other bodily functions and focuses on a person's discretionary lifestyle, although people will disagree as to what is and is not discretionary. The primary factors that contribute to an individual's carbon footprint are the amount of travel performed, the energy consumed in heating and cooling homes, and the amount of trash generated. Several "calculators" have been developed that take into account various factors.

As an example, 1 liter of gasoline contains 637 grams of carbon. Burning that gasoline in air generates 2,334 grams of CO_2. Thus, a car running 19,200 kilometers per year at an average of 10.5 kilometers per liter of gasoline emits about 4.26 metric tons of CO_2 per year. The carbon footprint of an average American family of four might include the emission of 12.7 metric tons of CO_2 from home energy use, 11.6 metric tons from driving two cars, 10.7 metric tons from food (including its growth or husbandry, processing, packaging, transportation, and preparation), and 3.2 metric tons from air travel, for a total of 38.2 metric tons of CO_2 emissions per year.

The carbon footprint of food is a complex and controversial issue. It depends strongly on where one lives (because of the cost and energy used by transportation and storage) and the type of food product. Some food products go through numerous processing steps that consume large amounts of energy. On average, one unit of energy gained from food consumed in the United States requires as many as seven to ten units of energy to produce. Some of this inefficiency is due to the macroeco-

Global Annual Carbon Emissions by Sector, 2000

Economic Sector	*Percent of Total CO_2 Emissions*
Power stations	29.5
Industrial processes	20.6
Transportation fuels	19.2
Residential, commercial, and other sources	12.9
Land use and biomass burning	9.1
Fossil fuel retrieval, processing, and distribution	8.4

Data from the Netherlands Environmental Assessment Agency.

Average Carbon Footprints Around the World

Nation	*Average Carbon Footprint per Capita, 2004 (metric tons)*
Kuwait	38.00
United States	20.40
Australia	16.30
Russia	10.50
Germany	9.79
United Kingdom	9.79
Japan	9.84
Italy	7.69
China	3.84
India	1.21

Data from U.S. Department of Energy.

nomics of agriculture in a nation like the United States. For example, it was estimated in the late 1990's that over 90 percent of all fresh vegetables consumed in the United States came from the San Joaquin Valley of California, implying large transportation costs. Breakfast cereal requires thirty-two times as much energy to produce as does an equivalent amount of blended flour.

The energy cost of packaging food is also very large. The aluminum container of a prepackaged frozen dinner, which has no nutritive value, requires 3 times as much energy to produce as does 1 kilogram of blended flour. Producing a 36-centiliter aluminum soda can requires 3.4 times as much energy. All of this energy comes with attendant costs in CO_2 emissions. Thus, several lifestyle choices made for convenience lead to the creation of much larger carbon footprints than are necessary.

People who live in some metropolitan areas may appear to have smaller carbon footprints if they use public transportation or enjoy shorter commutes rather than driving themselves long distances to work. The per capita carbon footprints of residents of many U.S. cities can be compared to one another, taking into account only the contributions from transportation and residential energy use. Among the cities with the smallest footprints is Honolulu, Hawaii, at 1.356 metric tons per year. Los Angeles; New York; Portland, Oregon; Seattle, and San Francisco all have per capita carbon footprints between 1.4 and 1.6 metric tons. At the other extreme, smaller but spread-out, semirural towns in the Snow Belt have footprints of around 3.4 metric tons.

The average per capita carbon footprint for the one hundred largest U.S. metropolitan areas is 2.235 metric tons. However, this calculation is based primarily on personal transportation and heating costs. It does not include the significant costs of transporting food and other supplies to these cities. For some people, a large carbon footprint is calculated simply because they have to take long airplane trips occasionally. Although the fuel mileage of modern airliners per person is considerably better than that of most cars, airline travel can easily exceed twice the automobile miles driven per year, and emissions of airplanes are more damaging than are those of automobiles, because they are released so much higher up in the atmosphere.

Food, air transportation, and the energy involved in making personal technology products contribute vastly to individuals' carbon footprints. When these are included, the average per capita footprint of a U.S. resident is 20 metric tons, compared to a worldwide average of 4.4 metric tons. Much of the difference lies in the energy intensity of the products that are used in developed nations, as is demonstrated by the previous discussion of food. Industrialized nations have built very efficient systems for minimizing the monetary cost of consumer goods, but these systems operate at a high cost in energy use. They are able to obtain and employ energy at low prices through efficient power plants and transmission grids. However, the cost in CO_2 emissions of this heavy energy use shows up as a large national carbon footprint. Because of these features of the U.S. economy, even the least privileged and the most conservation-minded Americans appear to have carbon footprints that are double that global average. Thus, measures to reduce U.S. carbon footprints must be accompanied by national policy decisions and major systemic changes in order to be successful.

• Carbon Footprints of Businesses and Organizations

Businesses and organizations have large carbon footprints, because they use fleets of vehicles and large buildings that have to be lit and climate-controlled every day. The emissions due to transportation and incidental energy use accrue in addition to direct emissions from manufacturing. On the other hand, larger organizations can implement dramatic reductions in their carbon footprints through means that are not yet available to individual homes. Examples include the installation of large areas of rooftop solar photovoltaic panels by companies such as Google and WalMart.

Facilities located in areas with predictable weather, such as California, are able to produce much of the electricity they require with solar technology that does not generate emissions. Producing the solar panels themselves requires a significant amount of energy and emissions, but once installed they operate with zero emissions for a long time. Likewise, many large organizations have switched to vehicles that are operated on natural gas (mostly methane) instead of gasoline or diesel fuel. Since methane released into the atmosphere has a global warming potential more than twenty times that of CO_2, burning methane achieves a net reduction in equivalent CO_2 emission. Large buildings are also able to use combined solar heating, power generation, and even air conditioning using appropriate building surface systems.

Many organizations are working to become carbon neutral. Such entities buy credits from low-emission projects such as wind farms and apply the credits toward their own emissions. It is often impossible to reduce actual emissions to zero, or in some cases at all. For example, air travel cannot be avoided completely. In such cases, trading emission credits to achieve carbon neutrality is a viable solution, as it supports the development of green technologies in the future.

• Measures to Reduce Carbon Footprints

Individuals' carbon footprints may be reduced by recycling plastics, glass, paper, and magazines; using more fuel efficient cars; reducing the number of miles driven per year per person by either car pooling, using public transportation, or simply reducing travel; changing to fluorescent lightbulbs; and turning thermostats up during summer and down during winter. National carbon footprints can be reduced through appropriate policies. The signatories to the Kyoto Protocol have adopted a complex system of certified emissions reduction credits (or carbon credits) that can be traded on the open market, allowing a large marketplace to develop for emission reduction schemes. In the United States, federal tax credits have offset the higher initial costs of installing modern, low-emission water heaters, home heaters, air conditioners, and energy-saving windows in homes, as well as the costs of hybrid and fuel-cell automobiles. Some nations are phasing out the use of incandescent lightbulbs, forcing their replacement with more efficient, longer-lasting compact fluorescent bulbs. Policies that encourage telecommuting at work also contribute strongly to emission reductions.

Rapid increases in the cost of fossil fuels have induced dramatic changes in the economics of energy use. For instance, as mass-produced food prices increase, locally grown food from smaller farms becomes competitive. When consumers purchase more local foods, the emissions from food shipments decrease.

Policies that improve transportation options for people and help them live closer to population centers have been shown to reduce carbon footprints. In the United States, individuals are moving farther away from cities in order to enjoy better living environments, and when jobs change, people may choose to remain in the same homes rather than move closer to their new workplace. This results in long-distance commuting. Moreover, more houses are built to meet the increasing demand for rural accommodation, and these houses require heating using mainly natural gas. Thus, the individual's desire for better living can have a negative effect on the environment with increased emission of CO_2. Other activities, such as the frivolous use of fire extinguishers, can have huge carbon footprints, because fire suppressants such as halon 1310 can have CO_2e's thousands of times greater than that of CO_2.

• Context

The carbon footprint has become an increasingly important concept as decisions at the personal, community, industry, state, and national levels are guided by the need to reduce GHG emissions. Changes in energy policy that reward utilities for the efficiency of their overall operation, rather than just for delivering ever-larger amounts of power, can greatly help reduce carbon footprints. Finally, shifting to increased use of "clean coal" power plant technology and to nuclear power can substantially reduce carbon footprints by rendering the power generation underlying much industrial human activity carbon neutral.

Padma Komerath

• Further Reading

Brown, M. A., F. Southworth, and A. Sarzynski. *Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel.* Washington, D.C.: Author, 2005. Short note showing examples of how to calculate the CO_2 emissions from motor fuels.

________. *Shrinking the Carbon Footprint of Metropolitan America.* Washington, D.C.: Brookings Institution, 2008. This report gives data on the carbon footprints in U.S. metropolitan areas, with breakdowns by type of activity. It discusses policy issues in reducing carbon footprints and argues for improved coordination between different federal agencies.

Environmental Protection Agency. U.S. Office of Transportation and Air Quality. *Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003.* Washington, D.C.: Author, 2006. This sixty-eight-page report documents the emissions from different modes of transportation, including road, air, rail, and water travel. Appendix B gives data on different components of transportation.

See also: Anthropogenic climate change; Carbon dioxide; Carbon dioxide equivalent; Carbon equivalent; Carbon taxes; Energy efficiency; Greenhouse effect; Greenhouse Gas Protocol; Greenhouse gases; Human behavior change; Transportation.

Carbon 4 plants

• Category: Plants and vegetation

• Definition

During photosynthesis, plants absorb carbon dioxide (CO_2) from the atmosphere and convert, or fix, it into a variety of organic molecules that can be used to provide energy to cells or to provide the raw materials to build more cells and tissues. Carbon 4 fixation evolved over the past 30 million years, but it spread widely in tropical grasslands and savannas only about 5 million years ago as a result of its ability to concentrate CO_2 in photosynthetic plant tissues in a cooling climate without undergoing photorespiration. Carbon 4 plants have come to account for about 30 percent of worldwide photosynthesis, and they include important crops such as maize, sugarcane, millet, and sorghum. The carbon 4 pathway is particularly important in hot, dry climates, because this pathway is much more efficient than the carbon 3 pathway at fixing low levels of CO_2 without competition from oxygen.

Carbon 4 plants often have a tight bundle sheath of carbon 3 cells around the vascular bundles of leaves. This physically separates the cells where "normal" carbon 3 photosynthesis occurs from the leaf mesophyll cells where atmospheric CO_2 is fixed. In carbon 4 mesophyll cells, the enzyme Phosphoenolpyruvate carboxylase (PEP carboxylase) binds CO_2 to a three-carbon PEP molecule to form a four-carbon organic acid, malic acid. The malate diffuses from the mesophyll cells where it is produced into the bundle sheath cells where CO_2 is released to be used in the carbon 3 pathway.

• Significance for Climate Change

Carbon 4 evolved and spread rapidly in response to low levels of atmospheric CO_2 during past geological periods, because PEP carboxylase is much more efficient than is ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) in binding CO_2, and it is not affected by oxygen levels. With rising CO_2 levels, it might seem that the advantage of carbon 4 over carbon 3 photosynthesis would decrease. However, hot, dry conditions strongly favor the carbon 4 pathway. Atmospheric gases must diffuse through microscopic openings in the surface of leaves and green stems called stomata. Warming causes plants to lose water vapor through their stomata, which leads to wilting and even death. Plants respond to water loss by closing their stomata, thus reducing gas exchange with the atmosphere. If the stomata remain closed for very long, CO_2 soon becomes depleted inside the plant tissues, and this favors carbon 4. Hot temperatures and dry conditions have a much greater influence on photosynthesis than do ambient CO_2 levels. As a result, with continued global warming, plants with carbon 4 metabolism will be increasingly important in agriculture and carbon 4 plants will become even more widespread in the environment.

Marshall D. Sundberg

See also: Carbon cycle; Carbon dioxide; Carbon 3 plants; Photosynthesis.

Carbon isotopes

- **Category:** Chemistry and geochemistry

- **Definition**

An atom consists of a small nucleus surrounded by a cloud of electrons. The nucleus is made of protons and neutrons, collectively called nucleons. All atoms of a specific chemical element have the same atomic number (number of protons or electrons) but differing numbers of neutrons. The total number of protons and neutrons in an atom is called its nucleon number. Forms of chemically identical atoms with differing nucleon numbers are called isotopes.

Carbon atoms have an atomic number of 6, but they may have a nucleon number of 12, 13, or 14. Carbon 12 (C^{12}) and carbon 13 (C^{13}) are stable isotopes; carbon 14 (C^{14}) is radioactive, decaying with a half-life of 5,730 years. Earth's supply of C^{14} is continuously replenished by cosmic-ray bombardment of individual nitrogen atoms, which can replace a proton of nitrogen 14 with a neutron, reducing its atomic number by one and changing the chemical identity of the atom from nitrogen to carbon. This process takes place only in the atmosphere, so any carbon that has been isolated from the atmosphere for more than sixty thousand years will be effectively free of C^{14}.

- **Significance for Climate Change**

Carbon dioxide (CO_2) is a greenhouse gas (GHG), contributing to global warming by slowing the escape into space of infrared radiation from the surface of the Earth. A change in the amount of CO_2 in the atmosphere is the net result of a disequilibrium between the processes that add atmospheric CO_2 (such as respiration and combustion) and the processes that subtract atmospheric CO_2 (such as photosynthesis and oceanic absorption). Estimates of the amount of carbon entering the atmosphere are substantially greater than the estimates of the amount removed. The difference is greater than the observed increase in atmospheric CO_2, however, implying that there is an unidentified carbon reservoir absorbing the remainder.

Carbon isotope ratios help constrain the type and location of processes collecting carbon. All atoms of carbon are chemically identical, but isotopes differ in mass and therefore in physical properties. In particular, atoms of C^{12} move faster at a given temperature than do atoms of C^{13} and more readily participate in chemical reactions. The ratio of the isotopes within a given sample of carbon is an important indicator of the chemical and physical history of that sample. Photosynthesis preferentially takes up C^{12}, so biomass is C^{13}-deficient compared to atmospheric CO_2. Respiration, combustion, and oceanic absorption of CO_2, however, show little discrimination among carbon isotopes.

Fossil fuels are of biological origin and are therefore deficient in C^{13}; because of their age, they are also completely free of C^{14}. Thus, the combustion of coal and oil emits a disproportionate amount of C^{12} into the atmosphere, thereby increasing the percentage of that isotope and reducing the percentage of C^{13} and C^{14} in the atmosphere. Analysis of the relative proportions of carbon isotopes can therefore provide a valuable clue as to the contribution of fossil fuels to the increase of total atmospheric CO_2.

Billy R. Smith, Jr.

See also: Carbon cycle; Carbon dioxide; Coal; Fossil fuels; Greenhouse gases; Ocean-atmosphere coupling; Photosynthesis.

Carbon monoxide

- **Category:** Chemistry and geochemistry

- **Definition**

Carbon monoxide (CO) is a colorless, odorless, tasteless, and highly toxic gas composed of an atom of carbon and an atom of oxygen chemically bonded together. It is useful in the production of a wide variety of chemicals in various industries, including the automotive, construction, agrochemical, cosmetics, pharmaceutical, plastics, and textile industries. Environmental CO is primarily produced from the incomplete combustion of carbon-containing materials.

Anthropogenic (human) sources of CO include incomplete combustion of fossil fuels in internal combustion engines, from which it is released in automobile exhaust; industrial plant exhaust, including exhaust from industry oxidation of hydrocarbons; cigarette smoke; burning of biomass; and various fuel-burning household appliances, including wood-burning stoves, water heaters, clothes dryers, furnaces, fireplaces, generators, and space heaters. CO released in automobile exhaust accounts for about 60 percent of all U.S. CO emissions. Moreover, such automobile exhaust can represent up to about 95 percent of all CO emissions in U.S. cities. Natural sources of CO include coal mines, forest fires, volcanoes, vegetation, soil (including water-saturated areas such as wetlands), the ocean, and atmospheric oxidation of hydrocarbons.

In the United States, CO is considered to be the leading cause of death from poisoning. CO is toxic in that it interferes with delivery of oxygen in the body. Normally, oxygen binds to a blood protein called hemoglobin, which then transports the oxygen throughout the body. CO has a higher affinity for hemoglobin than does oxygen. Therefore, when CO is inhaled, it binds to hemoglobin, displacing oxygen or preventing it from binding and thereby preventing the hemoglobin from delivering the oxygen to the cells that need it.

- **Significance for Climate Change**

CO affects global warming through its ability, either directly or indirectly, to increase the levels of other gases in the atmosphere. Such other gases, including carbon dioxide (CO_2), methane (CH_4),

The Conch Cement Company's Kiln Number 3, site of a carbon monoxide poisoning incident that left one person dead and twelve injured in January, 2009. (Li Jian/Xinhua/Landov) and ozone (O_3), directly affect global warming. After the Earth is heated by the Sun, some terrestrial heat normally leaves the planet, escaping into outer space. This process allows the Earth to maintain a constant temperature, rather than growing steadily warmer as more solar energy impinges upon it. CO_2, methane, and ozone have the ability to trap the terrestrial heat attempting to leave the Earth, thereby preventing this heat from escaping into outer space. Although such gases, known as greenhouse gases (GHGs), play a role in maintaining a stable and moderate temperature on Earth, an excess of GHGs results in a terrestrial buildup of heat and an elevation of the Earth's temperature. The atmospheric concentrations of many GHGs have significantly increased since the advent of industrialization, around 1750.

Although CO is not a GHG, it acts directly or indirectly to increase the levels of Earth's GHGs—including methane, tropospheric ozone (the troposphere is the lowest portion of the Earth's atmosphere), and CO_2—by participating in various chemical reactions in the atmosphere. For example, CO indirectly affects the levels of methane and tropospheric ozone by reacting with the hydroxyl radical. The hydroxyl radical is a reactive molecule, consisting of an oxygen atom chemically bonded to a hydrogen atom, that is responsible for decreasing the levels of many atmospheric pollutants, including methane and tropospheric ozone. When atmospheric carbon monoxide reacts with the hydroxyl radical, it decreases the amount of this radical available to react with and remove methane and tropospheric ozone. As a result, methane and ozone build up in the atmosphere.

CO also indirectly affects the levels of tropospheric ozone by its involvement in reactions producing substances that can generate tropospheric ozone. For example, when CO reacts with the hydroxyl radical, one of the products formed in a series of reactions is the hydroperoxyl radical (a reactive molecule consisting of an atom of hydrogen and two atoms of oxygen). The hydroperoxyl radical can participate in reactions that form tropospheric ozone. Finally, CO directly affects the levels of atmospheric CO_2 through its reaction with the hydroxyl radical. When CO reacts with the hydroxyl radical in the atmosphere, it forms CO_2. CO_2 is one of the most potent GHGs.

Jason J. Schwartz

• Further Reading

Houghton, John. *Global Warming: The Complete Briefing*. 4th ed. New York: Cambridge University Press, 2009. Discusses the science of global warming, the effects of climate change on society, and ways these effects can be mitigated.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. A multi-article scientific assessment of information related to climate change, including discussion of the role of greenhouse and other gases, including carbon monoxide, and an evaluation of the environmental and economic consequences of climate change.

Kroschwitz, Jacqueline I., and Arza Seidel, eds. *Kirk-Othmer Encyclopedia of Chemical Technology*. 5th ed. Hoboken, N.J.: Wiley-Interscience, 2004-2007. Provides detailed information on chemical compounds (including CO), including their physical and chemical properties, the reactions they participate in, their uses, and related information.

Van Ham, J., et al., eds. *Non-CO_2 Greenhouse Gases: Scientific Understanding, Control, and Implementation*. Amsterdam, the Netherlands: Kluwer Academic, 2000. Discusses the sources of non-CO_2 GHGs, including chemical reactions occurring in the troposphere and methods to control emission of such gases.

See also: Carbon dioxide; Greenhouse effect; Greenhouse gases; Methane; Oxygen, atmospheric; Ozone.

Carbon taxes

- **Category:** Laws, treaties, and protocols

- **Definition**

In the narrowest sense, carbon taxes are governmentally mandated fees levied on entities engaged in activities that cause carbon-containing greenhouse gases (GHGs), such as carbon dioxide (CO_2) and methane, to be emitted into the atmosphere. Such activities would include the combustion of fossil fuels, changes in land use that increase CO_2 emissions from soils, livestock propagation, solid-waste burial, and the production and disposal of goods that release carbon-containing GHGs to the environment when they decay. More broadly, as the phrase is used in political discourse, carbon taxes are fees levied on activities that lead to the emission of any of the major anthropogenic GHGs—CO_2, methane, nitrous oxide, sulfur hexafluoride, hydrofluorcarbons (HFCs), and perfluorocarbons (PFCs)—whether the emitted gases contain carbon or not.

The amount levied by a carbon tax is determined based upon how many units of carbon dioxide equivalent (CO_2e) are released into the atmosphere by a given activity. The CO_2e of a GHG is calculated using the gas's global warming potential (GWP), which is based on the potency and longevity of the gas. In theory, carbon taxes could also be levied on people for inactions, such as failing to suppress a fire in a tree farm that functions as a carbon reservoir or failing to recycle carbon-containing materials.

Carbon taxes may be thought of as a type of consumption tax, as they are based on the consumption or reduction of a finite good (the atmosphere's ability to tolerate GHG emissions). In a pollution-control context, carbon taxes represent taxes on the environmental damages inflicted by GHG emissions upon current and future generations by the production and sale of commodities. The difference between the market price of a good or activity and the overall cost that the good or activity inflicts on society is called the "externality cost" of the activity. If such externality costs are not "internalized" into the price of a good or activity, there is said to be a market failure, which many economists believe should be remedied by government action. The resulting taxes are often called Pigovian taxes in recognition of economist Arthur Pigou, who first developed the concept of taxing activities to compensate society for damages not priced into the activity in the free market.

- **Significance for Climate Change**

Carbon taxes have been proposed as a means to control the emission of GHGs. Economic theory predicts that increasing the cost of emitting GHGs will lead emitters to curtail their activities. The size of the resulting reduction would depend upon the elasticity of demand, or the relative value that people place on activities that emit GHGs compared to activities that emit less gases or none. Carbon taxes would have a broad variety of effects in addition to reducing GHG emissions.

By raising the price of goods and services throughout the economy, carbon taxes would reduce economic efficency. This would create what economists call "deadweight loss," a general consequence of all taxation. The result of accumulating deadweight losses is a reduction of wealth, productivity, and employment across the economy.

Like other taxes, carbon taxes redistribute wealth. The tax collected from GHG emitters is paid to the government, and the cost is passed on to consumers. The government can use collected revenues in many ways. For example, the government could use carbon tax revenues to administer government programs, compensate government employees, compensate contractors, or subsidize other forms of economic activity (such as the production of non-fossil-fuel-based energy). Alternatively, the government could rebate some or all of the tax to taxpayers, with or without regard for their income levels or for how much tax they have paid. Such revenue rebates are called "revenue recycling" in carbon tax discussions. Depending on the nature of the redistribution, carbon taxes could be proportional, progressive, or regressive. That is, they could place an economic burden on people in proportion to their incomes (proportional); increase the share of rebated revenue to poorer people (progressive); or impose a higher burden on poorer people than on wealthier people (regressive).

Carbon taxes are considered a price-based control measure, as their effectiveness is based on increasing the price of activities that lead to GHG emissions. Other forms of GHG control include quantity-based controls, such as carbon emission trading, and regulatory controls, such as vehicle emission standards. Among economists, both carbon taxes and carbon emission trading are considered to be more efficient than regulatory controls. Recent economic research suggests what then the ultimate cost of an externality is uncertain, as is the case for climate change, and when the ultimate cost of reducing GHG emissions is uncertain, carbon taxes are superior to both emission trading and regulatory approaches.

Kenneth P. Green

• **Further Reading**

Congressional Budget Office. *Policy Options for Reducing CO_2 Emissions.* Washington, D.C.: Author, 2008. This report summarizes the economic and environmental impacts of alternative carbon control regimes.

Green, Kenneth P., Steven F. Hayward, and Kevin A. Hassett. *Climate Change: Caps vs. Taxes.* Washington, D.C.: American Enterprise Institute, 2007. A short policy article that outlines the limitations of emissions trading and the potential benefits of carbon taxes.

Kaplow, Louis, and Steven Shavell. "On the Superiority of Corrective Taxes to Quantity Regulation." *American Law and Economics Review* 4, no. 1 (2002): 1-17. Makes the case for the superiority of carbon taxes in situations where there is uncertainty about control costs.

Nordhaus, William D. *Life After Kyoto: Alternative Approaches to Global Warming Policies.* Washington, D.C.: National Bureau of Economic Research, 2005. Nordhaus's economic modeling of the impacts of carbon taxes are prominent in academic discussions of carbon taxation.

Repetto, Robert, et al. *Green Fees: How a Tax Shift Can Work for the Environment and the Economy.* Washington, D.C.: World Resources Institute, 1992. An early publication that lays out the case for replacing taxes on goods (productivity) with taxes on bads (carbon dioxide emissions).

See also: Air quality standards and measurement; Baseline emissions; Certified emissions reduction; Ecotaxation; Polluter pays principle.

Carbon 3 plants

• **Category:** Plants and vegetation

• **Definition**

During photosynthesis, plants absorb carbon dioxide (CO_2) from the atmosphere and convert it into a variety of organic molecules that can be used to provide energy to cells or to provide the raw materials to build more cells and tissues. The process of converting CO_2 to organic molecules is called carbon fixation. The oldest and most common carbon fixation pathway is the carbon 3 pathway. Most trees and agricultural crops, including rice, wheat, soybeans, potatoes, and vegetables, use carbon 3 metabolism. In the carbon 3 pathway, the first organic molecule formed from CO_2, phosphogylcerate (PGA), contains three carbon atoms. Essential to this process is a five-carbon molecule called ribulose bisphosphate (RuBP) that has an affinity for CO_2. The enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) binds water and a single CO_2 molecule to RuBP and immediately splits the six-carbon intermediate molecule into two PGA molecules, one of which includes the original CO_2 molecule from the atmosphere.

• **Significance for Climate Change**

Although RuBisCO has an affinity for CO_2, it also binds molecular oxygen (O_2), depending on the relative ratio of the concentrations of CO_2 to O_2. When CO_2 levels are low, O_2 begins to out-compete CO_2 for the binding site on RuBisCO, and the rate of photosynthetic carbon fixation decreases. In fact, as more O_2 is taken up by RuBisCO, a photosynthesizing plant begins to produce CO_2 through a process called photorespiration. This competition between CO_2 and O_2 is temperature dependent. At contemporary levels of atmospheric CO_2, about 380 parts per million, temperatures above

25° Celsius are unfavorable for carbon 3 plants, because CO_2 levels are suboptimal.

Some greenhouse growers speed up production of many crops by adding supplemental CO_2. This suggests that the rising levels of CO_2 associated with global warming should stimulate carbon 3 photosynthesis in most plants, which should help reduce CO_2 levels. However, it may not be so simple. For atmospheric gases to get into plants, they must diffuse through microscopic openings in the surfaces of leaves and green stems called stomata. Warming causes plants to lose water vapor through their stomata, a process called transpiration, which leads to wilting and even death. Plants respond to water loss by closing their stomata, thus reducing gas exchange with the atmosphere. If the stomata remain closed for very long, CO_2 contained in plant tissues' intercellular spaces soon is depleted enough that photorespiration begins to outpace photosynthesis.

Marshall D. Sundberg

See also: Agriculture and agricultural land; Carbon cycle; Carbon dioxide; Carbon dioxide fertilization; Carbon 4 plants; Photosynthesis.

Carbonaceous aerosols

- **Category:** Chemistry and geochemistry

- **Definition**

Aerosols are fine solid or liquid particles suspended in a gas. Carbonaceous aerosols are fine, solid carbon particles suspended in the atmosphere. They result from burning fossil fuels, which are not completely consumed in the combustion process. Sometimes, these aerosols are referred to as "soot." They can affect the global climate, as well as causing problems for people who breathe the air: They are associated with allergies and respiratory diseases, as they interfere with breathing by clogging the air sacs in a person's lungs. These aerosols are also a major cause of pollution-related mortality.

- **Significance for Climate Change**

Carbonaceous aerosols are made up of two parts: Organic carbon (OC), which scatters light, and black carbon (BC), which absorbs light. These particles can block radiation from the Sun and scatter light, so they can affect Earth's climate in several ways. They can scatter and absorb radiation from the Sun. They can reflect light back into space, increasing Earth's albedo directly, and they can also make clouds more reflective, increasing it indirectly. OC in particular is able to do this, offsetting the warming that greenhouse gases (GHGs) cause. Carbonaceous aerosols, particularly BC, can also heat the atmosphere by absorbing sunlight.

Carbonaceous aerosols can block light from reaching the Earth's surface. BC also does this, which can lead to cooling the Earth's surface. They can affect the amounts of trace gases in the atmosphere, which may affect warming or cooling of the atmosphere depending on which type of gas is affected. They can combine with each other and other particles to interact in different ways that lead to unusual, and sometimes perplexing, effects on the global climate.

Thus, carbonaceous aerosols can affect both the warming and cooling of the Earth and its atmosphere. Scientists are still trying to understand the complexities of how these aerosols affect global climate change, though some estimate that black carbon particles may be responsible for 15 to 30 percent of global warming.

Tihomir Novakov and his research group at Lawrence Berkeley National Laboratory have been leaders in performing significant research on carbonaceous aerosals since the 1970's, and it is mostly due to this work that these particles are now accepted as being common in the atmosphere. (Previously, scientists thought that fossil fuels burned completely and left no fine solid particles in the atmosphere.)

The effect that carbonaceous aerosols have on the environment can be influenced by the number of these particles contained in the total volume of air, the size of the particles, and the proportion of organic versus black carbon composing each particle. Studying aerosols can be difficult. Carbonaceous aerosols do not last long and do not mix in the same way in all areas across the Earth, which

A snowmobile trail cuts through the volcanic ash covering the snow in Skwentna, Alaska, following the eruption of Mount Redoubt in March, 2009. (Bonnie Dee Childs/MCT/Landov)

makes analyzing their effects difficult. The way these particles interact with water, particularly salt water, and over areas covered with snow and ice is not well understood and is a subject of scientific inquiry. Previous major studies, such as the Asian-Pacific Regional Aerosol Characterization Experiment (ACE-Asia) in 2001 and the Indian Ocean Experiment (INDOEX) in 1991, relied on large teams of scientists using aircraft, balloons, ships, and surface stations to help analyze these effects.

Carbonaceous aerosols can affect the hydrologic cycle by cutting down the amount of sunlight that is able to reach the ocean, affecting how quickly seawater evaporates into the air. They may also affect how clouds are formed. Both these actions can reduce the amount and frequency of rainfall. Carbonaceous aerosols can also affect plants by coating their leaves and affecting their ability to photosynthesize or use light to break down chemical compounds, thus also contributing to global climate change.

Marianne M. Madsen

• Further Reading

Gelencsér, András. *Carbonaceous Aerosol*. Dordrecht, the Netherlands: Springer, 2004. Contains thirty-one pages of references, a helpful index, and a list of abbreviations referring to carbonaceous aerosols.

Jacobson, Mark. "Strong Radiative Heating Due to the Mixing State of Black Carbon in Atmospheric Aerosols." *Nature* 409 (February 15, 2001): 695-697. Discusses studies of black carbon in aerosols and its variations in mixing in the atmosphere, describing external and internal mixing.

Novakov, T. "The Role of Soot and Primary Oxidants in Atmospheric Chemistry." *The Science of the Total Environment* 36 (1984): 1-10. Explains how soot in the atmosphere affects atmospheric chemistry and describes a methodology for estimating primary and secondary carbon particulate concentrations.

Ramanathan, V., and G. Carmichael. "Global and Regional Climate Changes Due to Black Carbon." *Nature Geoscience* 1 (2008): 221-227. Describes how black carbon mixes with other aerosols to form atmospheric brown clouds, especially over snow and ice surfaces, to affect the hydrologic cycle.

Rosen, H., T. Novakov, and B. Bodhaine. "Soot in the Arctic." *Atmospheric Environment* 15 (1981): 1371-1374. One of Novakov's early publications describing soot in Arctic ice. Describes how drilling into the Arctic ice and extracting cores led to the scientific acceptance of carbonaceous aerosols in the atmosphere and how their concentration has increased over time.

Wolff, G. T., and R. L. Klimisch, eds. *Particulate Carbon-Atmospheric Life Cycle*. New York: Plenum, 1982. This classic book on the carbon cycle includes Novakov's article "Soot in the Atmosphere."

See also: Aerosols; Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Albedo feedback; Carbon equivalent; Clouds and cloud feedback; Hydrologic cycle; Sulfate aerosols.

Carson, Rachel

American naturalist, ecologist, and writer

Born: May 27, 1907; Springdale, Pennsylvania
Died: April 14, 1964; Silver Spring, Maryland

Although at the time of her writing Rachel Carson did not attribute global warming to human causes, she was well aware of climate change and held the view that humans were the one part of nature distinguished largely by their power to alter it, perhaps irreversibly.

• Life

Rachel Carson, the youngest of three offspring of Robert Warden and Maria McLean Carson, was born near Springdale, Pennsylvania, and was brought up in a simple farmhouse there and in nearby Parnassus, where she graduated from high school. She graduated with honors in 1929 from the Pennsylvania College for Women (later Chatham College); a scholarship enabled her to earn an M.A. degree in zoology from Johns Hopkins University in 1932. As a child, she was encouraged by her mother to appreciate nature, and, although her goal was to become a writer, she changed her college major from English to biology after taking a required biology course. Increasingly, she developed a passion for the world of nature, especially for the ocean.

After teaching at Johns Hopkins and the University of Maryland, Carson did postgraduate work at the Marine Biological Laboratory in Woods Hole, Cape Cod, Massachusetts, then wrote a radio show, "Romance Under the Waters," for the Bureau of Fisheries in Washington, D.C. In 1936, after becoming the first woman to take and pass the civil service test, she became a junior aquatic biologist and moved up the ranks to become the chief editor of publications for the U.S. Fish and Wildlife Services. Carson began writing about her observations of life under the sea, and she published *Under the Sea-Wind: A Naturalist's Picture of Ocean Life*, the first book of a trilogy, in 1941. It was followed by *The Sea Around Us* (1951) and *The Edge of the Sea* (1955), a *New York Times* best seller for twenty weeks.

Carson's best-known book, *Silent Spring*, appeared in 1962. Documenting the dangers of pesticides and herbicides and thereby bringing on a storm of assault from the agricultural chemical industry, the book was ultimately instrumental in action being taken to regulate these substances at the national level. Carson has been called the mother of the modern environmental movement. *The Sense of Wonder*, encouraging the young to appreciate nature, was published posthumously in 1965. After an extended battle with cancer, Carson died on April 14, 1964, at her home in Silver Spring, Maryland.

• Climate Work

When *The Sea Around Us* was published, it brought Carson international acclaim and awards, including the Gold Medal of the New York Zoological Society, the John Burroughs Medal, the Gold Medal of the Geographical Society of Philadelphia, and the National Book Award. The book remained on the *New York Times* best-seller list for eighty-six weeks, thirty-nine at the number one position.

"A Fable for Tomorrow"

In 1962, Rachel Carson's Silent Spring *painted a bleak picture of a not-too-distant future in which unrestricted use of chemical pesticides had upset the balance of nature, resulting in a sterile, dead landscape:*

There was once a town in the heart of America where all life seemed to live in harmony with its surroundings. The town lay in the midst of a checkerboard of prosperous farms, with fields of grain and hillsides of orchards.

Along the roads laurel, viburnum and alder, great ferns and wildflowers delighted the traveller's eye through much of the year. Even in winter the roadsides were places of beauty, where countless birds came to feed on the berries and on the seed heads of the dried weeds rising above the snow. The streams flowed clear and cold out of the hills and contained shady pools where trout lay.

Then a strange blight crept over the area and everything began to change. . . . Everywhere was a shadow of death. . . .

There was a strange stillness. The birds, for example—where had they gone? Many people spoke of them, puzzled and disturbed. The feeding stations in the backyards were deserted. The few birds seen anywhere were moribund; they trembled violently and could not fly. It was a spring without voices. . . . The apple trees were coming into bloom but no bees droned among the blossoms, so there was no pollination and there would be no fruit. . . . Even the streams were now lifeless. Anglers no longer visited them, for all the fish had died.

In the gutters under the eaves and between the shingles of the roofs, a white granular powder still showed a few patches: some weeks before it had fallen like snow upon the roofs and the lawns, the fields and the streams.

No witchcraft, no enemy action had silenced the rebirth of new life in this stricken world. The people had done it themselves.

Source: Excerpted from Rachel Carson, "A Fable for Tomorrow," chapter 1 in *Silent Spring* (Boston: Houghton Mifflin, 1962).

Selling over 200,000 copies, the book and its reception enabled Carson to leave the Fish and Wildlife Service and devote herself full time to writing. Its popularity was due in part to Carson's ability to condense huge amounts of scientific information into terms that nonspecialists could understand.

Although Carson did not attribute global warming to human causes, she was well aware of a trend toward a warmer Earth. *The Sea Around Us* contains three sections. The first, "Mother Sea," focuses on the origin of Earth and the sea and analyzes the nature of the sea from its surface to the ocean floor. It explains the intricacy of the food chain in the ocean, the seasonal changes in surface waters, and the development and death of islands. Part 2, "The Restless Sea," explains the forces that affect the ocean: the wind, the Sun, the Moon, Earth's rotation, waves, tides, and currents, as well as the gravitational pull that affects every drop of water in the ocean.

The book's final section, "Man and the Sea About Him," is of particular importance. A chapter entitled "The Global Thermostat" explains how the ocean dominates the world's climate, poses the question of whether the ocean is an agent in bringing about the lengthy climate swings that have occurred throughout Earth's history, and cites a theory of Swedish oceanographer Otto Pettersson that supports an affirmative answer: The theory predicts that a tidal effect that prevailed about 500 C.E. will occur again about the year 2400, bringing global warming. Carson says that it is established beyond question that a change in arctic climate set in around 1900, became marked about 1930, and is still spreading. Acknowledging that there are undoubtedly other agents at work in bringing about climate changes in the Arctic regions, she concludes that, if the Pettersson theory is valid, there is no doubt that the pendulum is swinging toward a warmer Earth.

Victoria Price

• Further Reading

Brooks, Paul. *The House of Life: Rachel Carson at Work*. Boston: Houghton Mifflin, 1972. Provides selections of Carson's writing and reminiscences of Brooks and other friends of Carson to show how she achieved what she did.

Carson, Rachel. *The Sea Around Us*. New York: Oxford University Press, 1961. A special edition in which Carson's description of the ocean as part of the Earth's ecological system, which makes life on Earth possible, is supplemented by a chapter by Jeffrey Levinton, a leading marine ecologist, who updates the scientific side of her book.

Freeman, Martha, ed. *Always Rachel: The Letters of Rachel Carson and Dorothy Freeman, 1952-1964*. Boston: Beacon Press, 1995. The exchange of letters between Carson and her summer house neighbor provides a sense of Carson's philosophy comparable to that of a biography.

Lear, Linda. *Rachel Carson: Witness for Nature*. New York: Henry Holt, 1997. Considered the definitive biography of Rachel Carson. Herself an environmental historian, Lear brings to the account of Carson's life and work insightfulness and accuracy.

See also: Environmental economics; Environmental movement; Pesticides and pest management.

Catalytic converters

• **Categories:** Economics, industries, and products; transportation

• Definition

A catalytic converter is a device to reduce the amount of toxic emissions in the exhaust of an internal combustion engine. It was developed in response to efforts in the early 1970's by the Environmental Protection Agency (EPA) to tighten regulations on emissions from internal combustion engines. The 1975 model cars were produced with catalytic converters. The first converter, a two-way converter, oxidized carbon monoxide (CO) to carbon dioxide (CO_2) and oxidized unburnt hydrocarbons to CO_2 and water. The hydrocarbons were molecules of gasoline that escaped a car's pistons without being burned. Beginning in 1981, catalytic converters also had a third component that reduced nitrogen oxides to nitrogen and oxygen.

Catalytic converters are composed of three parts. There is a core or substrate honeycomb constructed of either ceramic material or stainless steel. The honeycomb design provides maximum surface area. A washout of silica and alumina is added to the substrate to increase the surface area. The catalyst is a precious metal attached to the washout. Platinum or rhodium is usually used as the reducing catalyst, and platinum or palladium is usually used as the oxidizing catalyst.

Exhaust gas reaches the reducing catalyst first. Nitrogen oxides attach to the catalyst, and the reaction to separate nitrogen from oxygen is aided by the nitrogen being bound. After the oxygen is removed, nitrogen atoms can combine to form diatomic nitrogen gas. Carbon from the CO in the exhaust is held in the oxidizing area, where oxygen reacts with it to form CO_2. Similarly, hydrocarbons are held to be oxidized to CO_2 and water.

• Significance for Climate Change

Catalytic converters drastically reduce the amount of nitrogen oxides, hydrocarbons, and carbon monoxide emitted into the atmosphere. Nitrogen oxides and hydrocarbons are two of the main reactants, along with sunlight, producing photochemical smog. The catalytic converter has been a major factor, along with reformed gasoline, in reducing smog in many places. For example, in 1975, the air

A catalytic converter on a 1996 Dodge Ram.

in Los Angeles exceeded the ozone standard 192 out of 365 days. By 2005, Los Angeles air exceeded ozone standards on only 27 days of the year. Los Angeles's air quality improved consistently over the thirty years between 1975 and 2005. Smog in the city was cut by two-thirds. In 1977, the city experienced 121 stage 1 smog alerts, the most severe designation denoting a day when air quality is particularly unhealthy. In 1980, there were 79 stage 1 smog alerts in Los Angeles, and there were only 7 such alerts in 1996.

The deployment of catalytic converters is not the only factor in achieving this significant improvement in air quality. It is, however, a major factor. By reducing the smog-related emissions from motor vehicles, the catalytic converter prevented a great deal of pollutants from being released into the atmosphere. Contemporary automobiles emit 90 percent less CO, hydrocarbons, and nitrogen oxides than did 1970 models.

The effects of catalytic converters have not all been positive, however. The devices oxidize CO and hydrocarbons, converting them to CO_2. CO_2 is a greenhouse gas (GHG) that may contribute to global warming. The transportation industry is one of the major sources of CO_2. In addition to transforming other pollutants into CO_2, catalytic converters often reduce fuel efficiency, increasing a vehicle's output of CO_2 per kilometer. Moreover, nitrogen oxides are not always reduced completely to nitrogen gas by catalytic converters. Instead, they may be reduced to nitrous oxide (N_2O), a GHG whose global warming potential is three hundred times that of CO_2. As the number of vehicles with catalytic converters has increased, the N_2O in the atmosphere has also increased. It now constitutes over 7 percent of the GHGs in the atmosphere.

Catalytic converters function well only after they are warmed up. Thus, they do not effectively reduce the emissions of the first gasoline burned after starting a motor vehicle. Catalytic converters can deteriorate if exposed to intense heat. Lead and some other elements will contaminate the catalyst. For this reason, it is illegal to use leaded gasoline in a vehicle with a catalytic converter. Contaminated and deteriorated converters may increase, rather than decrease, the pollution emitted from a car. Catalytic converters have helped clean the air of smog, but they have come to represent a new problem by generating GHGs.

C. Alton Hassell

- **Further Reading**

Bode, H. *Material Aspects in Automotive Catalytic Converters.* Weinheim, Germany: Wiley-VCH, 2002. Based on the second international conference on materials aspects in automotive catalytic converters, Munich, 2001. Illustrations, biography, index.

Kubsh, Joseph Edward. *Advanced Three-Way Catalysts.* Warrendale, Pa.: Society of Automotive Engineers, 2006. Describes the new generation of catalysts, both reducing and oxidizing. Illustrations, biography.

Society of Automotive Engineers. *Advanced Catalysts for Emission Control.* Warrendale, Pa.: Author, 2003. Covers the topics discussed at the Society of Automotive Engineers 2003 World Congress in Detroit. Illustrations, biography.

_______. *Emission: Advanced Catalysts and Substrates, Measurement and Testing, and Diesel Gaseous Emissions.* Warrendale, Pa.: Author, 2003. Covers the testing of catalytic converters, the emission of nitrogen oxides, and diesel motor exhaust gas. Illustrations, biography.

See also: Automobile technology; Greenhouse effect; Greenhouse gases; Motor vehicles.

Catastrophist-cornucopian debate

- **Category:** Environmentalism, conservation, and ecosystems

- **Definition**

Many people are pessimistic about Earth's future when they consider the myriad environmental problems facing today's world. In the early nineteenth century, Thomas Robert Malthus predicted a dismal future of overpopulation and mass starvation; neo-Malthusian environmentalists foresee a catastrophic future in which too many humans battle for ever-dwindling resources, leading to vice, misery, and the collapse of civilization.

On the other hand, optimists believe that technology is a cornucopia that, like the mythical horn of plenty, will provide an abundance of ingenious new cures for the world's environmental problems. This promethean environmentalism, named for the Greek titan who created humans and gave them the gift of fire, argues that past innovative technologies have repeatedly averted predicted disasters with new inventions. It asserts that this historic pattern of progress and abundance will continue indefinitely into the future.

• Significance for Climate Change

According to catastrophists, the disasters accompanying global warming are inevitable unless drastic changes in human society and behavior are implemented immediately. Even then, it may already be too late to avoid an impending doom. Although excessive dwelling on future disasters can become a self-fulfilling prophecy, if nothing is done, the feared consequences are more likely to occur. It is not unreasonable for environmentally concerned people to feel moral indignation over abundant excesses, abuses, and needless waste, but attempting to shock or shame people into altering such behaviors is often futile. Progressive, positive action is seldom motivated by fear alone. If a predicted disasters fail to materialize, the public may assume a false sense of complacency.

On the other hand, prometheans tend to emphasize historical precedents for the solution of environmental problems. Although this approach is comfortable, it can lead the public into a false sense of security by causing people to expect technology to fix all problems. Blind faith in technology then becomes an excuse for continuing behavior that exacerbates existing problems.

A balanced viewpoint also exists between these two extremes. This viewpoint recognizes that there are serious environmental problems facing the world but asserts that obstacles can be conquered when faced openly and creatively. Such a viewpoint embraces the cornucopian belief that solutions to all problems are possible, but it also embraces the catastrophist belief that the cooperation of nearly every human society and individual will be necessary to achieve those solutions. It rejects the inevitability of environmental doom, but it also rejects the belief that anonymous scientists or inventors will solve problems on humanity's behalf, a belief that excuses individuals from working to solve those problems themselves.

George R. Plitnik

See also: Ecocentrism vs. technocentrism; Environmental movement; Skeptics.

Cato Institute

- **Category:** Organizations and agencies
- **Date:** Established 1977
- **Web address:** http://www.cato.org/

• Mission

Classified as a nonprofit, tax-exempt 501(c)3 educational foundation, the Cato Institute deploys an extensive program of reports, books, press releases, and speeches. Since at least 1998, Cato has disputed the scientific evidence of climate change and its human causes, the urgency of taking action, and the efficacy of large expenditures to mitigate greenhouse gas (GHG) emissions.

The Cato Institute was cofounded by Edward H. Crane, a libertarian, and Charles Koch, the chief executive officer of Koch Enterprises, a vast, privately held company engaged in oil refining, forest production, and commodities trading, among other ventures. Cato's stated purpose is to broaden public policy debate by advocating for individual liberty, limited government, dynamic market capitalism, and peaceful relations among nations. An annual study of mainstream media citations of public policy think tanks conducted by Fairness and Accuracy In Reporting (FAIR) ranked Cato ninth in 2006, with 1,265 citations.

• Significance for Climate Change

In 2008, the Cato Institute employed 104 full-time employees, 72 adjunct scholars, and 23 fellows. Cato has released several books and reports on

What to Do About Climate Change

The following quotation, from Indur M. Goklany's 2008 policy analysis What to Do About Climate Change, *illustrates the Cato Institute's small-government philosophy.*

If future well-being is measured by per capita income adjusted for welfare losses due to climate change, the surprising conclusion using the Stern Review's own estimates is that future generations will be better off in the richest but warmest (A1FI) world. This suggests that, if protecting future well-being is the objective of public policy, governmental intervention to address climate change ought to be aimed at maximizing wealth creation, not minimizing CO_2 emissions.

global warming, including *Climate of Fear: Why We Shouldn't Worry About Global Warming* (1998), issued shortly after the Kyoto Protocol was adopted, and *The Improving State of the World: Why We're Living Longer, Healthier, More Comfortable Lives on a Cleaner Planet* (2007).

Patrick J. Michaels, Cato's senior fellow in environmental studies, is their most visible and prolific spokesperson on global warming. The institute's 2004 annual report states that Michaels's book *Meltdown* "formed the scientific basis" for Michael Crichton's 2004 best-selling mystery thriller, *State of Fear*. Michaels was a keynote speaker at the 2008 International Conference on Climate Change, giving a lecture entitled "Global Warming: Truth or Swindle" that was attended by around five hundred global warming skeptics. A Cato scholar, Jonathan Adler, wrote an amicus brief for the Supreme Court case *Massachusetts v. EPA* (2007) in late 2006, arguing on behalf of the U.S. Environmental Protection Agency that the Clean Air Acts (1963-1990) do not grant the agency the authority to regulate vehicular emissions of greenhouse gases.

Glenn Ellen Starr Stilling

See also: Cooler Heads Coalition; Libertarianism; Skeptics.

Cement and concrete

- **Category:** Chemistry and geochemistry

- **Definition**

Concrete, at its most basic, is composed of aggregates and a binding material (cement). Concrete aggregates are coarse, greater than 4.75 millimeters; fine aggregates are less than 4.75 millimeters in size. Aggregates—which are free of silt, organics, sugars, and oils—include sand, gravel, crushed stone, and iron blast-furnace slag. By volume, they make up about 75 percent of a concrete-cement mixture. The aggregates' size plays an important role in achieving maximum particle packing. Optimum packing reduces the amount of cement needed; with less cement, the durability and mechanical properties of the concrete are improved.

Compressive strength, the measured maximum resistance to axial loading, is one of the outstanding properties of cement. Tensile strength, a measure of resistance to stretching, is much lower for concrete, so it is often reinforced with steel bars to provide additional tensile strength. The durability of concrete is high, because it can be designed and manufactured for resistance to freeze-thaw cycles, seawater exposure, chemicals, and corrosion.

Cement, in the broadest sense, binds concrete elements together in the presence of water. Cement is instrumental in determining the quality of concrete. In properly manufactured concrete, every particle of aggregate must be surrounded by cement, and all voids must be filled with cement.

Early cements, known as soft lime cements, were prepared by burning slabs of limestone in a vertical kiln. After burning, the crumbly slabs were used immediately; slaked to produce a powder form that, when combined with sand and water, created soft lime mortars used for brickwork/masonry; or packed into barrels for later use.

There are three classes of hydraulic cement: Pozzolana (Pozzola or Trass), natural cement, and Portland cement. Pozzolana, a volcanic deposit, is finely ground then mixed with lime, sand, and water, creating strong cement that hardens underwater (hydraulic) and is impervious to salt water. Natural cement is produced by low-temperature burning of clay- or magnesium-rich limestone; upon completion of the burn, the limestone is crushed into smaller fragments, then pulverized, producing very strong cement.

Portland cement, patented by Joseph Aspdin in England in 1824, combines limestone and clay, then grinds them with water into fine slurry. The dried slurry is burned in a kiln and the calcined material is again ground to a fine powder. By the 1850's, the strength and setting qualities of Portland cement were improved by burning the mixture at very high temperatures—close to the fusion point within the kiln. This improvement and the ability to chemically analyze successful cement products allowed the Portland cement industry to grow. Portland cement began production in the United States between 1875 and 1890, with mills in Texas, Oregon, Michigan, New York, Maine, and the Lehigh District of Pennsylvania.

• Significance for Climate Change

The basic makeup of Portland cement is lime (CaO) from limestone and cement rock, silica (SiO_2) from clay and fly ash, alumina ($A1_2O_3$) from aluminum ore refuse, and iron oxide (Fe_2O_3) from iron ore. The proportions of these crushed elements are closely defined by industry standards. A mix or slurry of limestone and shale or clay is prepared for burning and final cooling in an inclined, rotating kiln. The dry cement mix slowly heats to 1,260° Celsius, and the carbonates (limestone and cement rock) burn and lose carbon dioxide (CO_2). Lime, alumina, and iron oxide fuse between 1,427 and 1,482° Celsius to complete the cement. Approximately 60 percent of all CO_2 emissions are from the lime-burning process; the remaining 40 percent of CO_2 emissions originate from fossil fuels used for combustion.

Originally, oil was used to heat kilns; the use of pulverized coal began in the late 1890's and has continued. Electricity, used in plant operation, is often generated by coal, and diesel or gasoline is used for quarrying raw materials. All are fossil fuels—all release CO_2 into the atmosphere. U.S. CO_2 emission data from the Energy Information Agency (EIA) for cement manufacture show that atmospheric CO_2 has risen from 33 million metric tons in 1990 to 46.1 metric tons in 2005, an increase of

Cement factories such as this one emit carbon dioxide and other pollutants into the atmosphere. (Reuters/Landov)

13.1 percent in fifteen years. Projected data beyond 2005 continue the increasing CO_2 emissions trend. It is estimated that 5 percent of all global atmospheric CO_2 is derived from cement manufacturing.

According to most climate scientists, elevated levels of CO_2 increase the Earth's temperature. CO_2 and other greenhouse gases absorb and prevent the longer wavelength heat radiation from leaving Earth's surface. This heat builds up and warms Earth's surface, atmosphere, and climate. This warmer climate may substantially melt glaciers and polar ice sheets, causing sea-level rise, increased evaporation, drought, flooding, and heat waves.

Mariana L. Rhoades

• Further Reading

"Concrete as a CO_2 Sink?" *Environmental Building News* 4, no. 5 (September/October, 1995): 5. Addresses CO_2 emission of cement manufacture, explains why the process releases CO_2, and details CO_2 sequestering during the curing process and after concrete is fully cured.

Energy Information Administration. *Emissions of Greenhouse Gases in the U.S.* Washington, D.C.: U.S. Department of Energy, 2006. Full set of industry-wide data on CO_2 emissions and fossil fuels consumed. Part of a series that is updated yearly and includes future projections.

Kosmatka, S. H., B. Kerkhoff, and W. C. Panares. *Design and Control of Concrete Mixtures.* Skokie, Ill.: Portland Cement Association, 2002. Complete manual of concrete and cement manufacture. Includes easily understood descriptions with useful graphics and photographs, a large section on concrete applications, a list of regulations, and research resources.

Long, Douglas. *Global Warming.* New York: Facts On File, 2004. Confronts global warming on all levels, including science community input (addressing skeptics) and international efforts and protocols to understand and mitigate global warming. Provides a large research resource base, including periodicals, books, and Web sites.

See also: Carbon dioxide; Greenhouse gases; Industrial ecology; Industrial emission controls; Industrial greenhouse emissions.

Center for the Study of Carbon Dioxide and Global Change

- **Category:** Organizations and agencies
- **Date:** Established 1998
- **Web address:** http://www.co2science.org/

• Mission

The Center for the Study of Carbon Dioxide and Global Change is an independent, nonprofit, science-based educational organization that provides regular reviews and commentary on new research findings about the climatic and biological significance of the continuing rise atmospheric carbon dioxide (CO_2) concentrations. The center reviews peer-reviewed scientific journal articles, original research, and other educational materials relevant to the debate over CO_2 and global change. Material is published weekly on the center's Web site.

The center's main aim is to separate research findings based on solid science and empirical data from the rhetoric in the emotionally charged debate over global climate change. Its stated commitment is to empirical evidence and real-world solutions, as opposed to speculation and information from untested hypothetical numerical models. Its position on global warming may be summarized as follows: There is little doubt that the CO_2 concentration in the atmosphere has risen significantly over the past 100 to 150 years as a result of humanity's use of fossil fuels and that the Earth has warmed slightly over the same period; however, there is no compelling reason to believe that the rise in temperature was caused primarily by the rise in CO_2. Moreover, real-world data provide no compelling evidence to suggest that the ongoing rise in the CO_2 concentration of the atmosphere will lead to harmful changes in Earth's climate. The center was founded in 1998 and is run by a father and two sons, all of whom have Ph.D's in fields directly related to the study of CO_2, climate, and global warming.

• Significance for Climate Change

Since its creation in 1998, the center has published over three thousand reviews of scientific journal articles on both the biological and climatological effects of atmospheric CO_2 enrichment. Accompanying each review is the full journal reference for the article reviewed, so users may access the articles and assess the information themselves. Reviews are archived in one or more topical categories inside a large subject index that includes more than eight hundred topics and subtopics relative to CO_2 and global change. The material is listed in detailed subject index summaries, which are continually updated as newer material is added. Web site users may use a keyword search engine for locating reviewed articles or summaries.

The center also provides Web site users with access to various air-temperature and precipitation databases, from which they may calculate and plot trends for the entire globe or for selected regions of the globe. Output includes a graphical representation of temperature or precipitation anomalies over a user-selected time interval, as well as access to these data in tabular form. A linear regression line of the temperature or precipitation trend over time is also displayed, along with its associated statistics. The site includes four global data sets and 1,221 individual station locations in the conterminous United States where users may calculate and plot climate data.

Two other important services provided by the center may be found in its plant-growth database and Medieval Warm Period Project. The plant-growth database is an ongoing project to build an archive of the results of peer-reviewed scientific studies that report the growth responses of plants to atmospheric CO_2 enrichment. Results are updated weekly and posted according to two types of growth response (dry weight and photosynthesis). The data are listed alphabetically according to plant names (both scientific and common) in individual tables. Each table begins with an abbreviated reference, followed by a brief description of the experimental growing conditions and the percentage increase in plant growth due to a 300, 600, or 900 part-per-million increase in the atmospheric CO_2 concentration. Full reference citations for each experiment are also available in linked files. The center has archived thousands of CO_2-enrichment studies.

The Medieval Warm Period Project is an ongoing project to document the magnitude and spatial and temporal extent of a significant period of warmth that occurred in Europe approximately one thousand years ago, when the atmosphere's CO_2 concentration was approximately 30 percent lower than it is currently. The purpose of this project is to show that Earth's near-surface air temperature was equally as high as, or even higher than, it is today during a period of lower CO_2 concentration. Thereby, the center reasons that current air temperatures are not unusual and need not be due to the recent rise in the CO_2 content of the atmosphere. Updates of new scientific studies documenting the climate of the Medieval Warm Period are provided weekly, and Web site users may graphically view individual study locations and attributes on an interactive map.

Students and teachers may use material found in the center's Global Change Laboratory, where instructions are given on how to conduct simple experiments that illustrate the effects of atmospheric CO_2 enrichment and depletion on vegetative growth and development. Utilizing the so-called Poor Man's Biosphere experimental technique pioneered by center president Sherwood B. Idso, plants are grown inside sealed aquariums or other containers maintained at different CO_2 concentrations, from which students can watch and plot growth progression data over the course of time. Several experiments have been developed, and these experiments can be performed by nearly anyone anywhere in the world at very little expense.

The center expanded its activities in 2008 to include the production of documentary digital video discs (DVDs) covering a wide range of topics in the global warming debate, including *Carbon Dioxide and the Climate Crisis: Reality or Illusion?*; *Carbon Dioxide and the Climate Crisis: Avoiding Plant and Animal Extinctions*; and *Carbon Dioxide and the Climate Crisis: Doing the Right Thing*. In addition, the center produces short two- to four-minute video segments on YouTube that highlight the findings of important research papers that have appeared in international science journals. Since 2001, the center has provided a professional service to assist U.S. companies in filing their greenhouse gas emission reports under the U.S. Voluntary Reporting of Greenhouse Gases Program—section 1605(b) of the Energy Policy Act of 1992.

C R de Freitas

• **Further Reading**

Essex, Christopher, and Ross McKitrick. *Taken by Storm: The Troubled Science, Policy, and Politics of Global Warming*. Rev. ed. Toronto: Key Porter Books, 2008. Thought-provoking skeptical analysis of aspects of key global warming issues that are widely misunderstood.

Idso, Sherwood B. *Carbon Dioxide and Global Change: Earth in Transition*. Tempe, Ariz.: IBR Press, 1989. Analyzes the climatic and biological implications of the rise in the atmosphere's CO_2 concentration. The author is the center's founder.

________. *Carbon Dioxide—Friend or Foe? An Inquiry into the Climatic and Agricultural Consequences of the Rapidly Rising CO_2 Content of Earth's Atmosphere*. Tempe, Ariz.: IBR Press, 1982. The first substantial critique of anthropogenic global warming.

Kininmonth, William. *Climate Change: A Natural Hazard*. Brentwood, Essex, England: Multi-Science, 2004. Argues that global climate models represented by the Intergovenmental Panel on Climate Change are deficient as a basis for future planning for global warming.

Michaels, Patrick J., ed. *Shattered Consensus: The True State of Global Warming*. Lanham, Md.: Rowman & Littlefield, 2005. Collection of ten critical accounts of important global warming themes by eleven internationally known climate scientists.

See also: Scientific credentials; Scientific proof; Skeptics.

Certified emissions reduction

• **Category:** Laws, treaties, and protocols

• **Definition**

A certified emissions reduction (CER) is a unit of greenhouse gas (GHG) emissions reduced by sources or removed by sinks and achieved under a clean development mechanism (CDM) project. Under the CDM, developed countries can invest in or finance projects in developing countries. These projects must result in a reduction of emission or removal of GHGs from the atmosphere additional to any that would have occurred in the absence of the projects. The difference between the emissions that would have been released without the project (referred to as the baseline emissions) and what was actually released is validated and certified by an independent body and confirmation is issued by the CDM Executive Boards as a CER. Developed countries that have quantified emission limitation and reduction commitments (QELRCs) under the Kyoto Protocol can use CERs to contribute to meeting their targets. These QELRCs are set out in Annex B of the protocol, and developed countries are allowed to use CERs to achieve part, but not all, of their commitments. CERs are also known as carbon credits.

A CER represents 1 metric ton of carbon dioxide equivalent (CO_2e) GHG emissions, either removed from the atmosphere or prevented from being released into the atmosphere. The amount of CERs issued for 1 metric ton of GHG reduction or removal depends on the type of gas and its global warming potential (GWP). The GWP of a gas refers to an estimation of its contribution to climate change or the effect it has on the climate. All gases are defined relative to carbon dioxide (CO_2), whose GWP is 1, so for 1 metric ton of CO_2 reduced or removed, one CER or carbon credit can be issued. The GWP of other gases may vary depending on the time horizon over which the impact of the gas is being determined—for most gases, the impact reduces as the time horizon increases. The GWP of methane, for example, ranges from 56 for a time horizon of 20 years, to 21 for 100 years, to 6.5 for 500 years. This means that for 1 metric ton of methane reduced or removed from the atmosphere, 56, 21, or 6.5 CERs can be generated, depending on the relevant time horizon.

• **Significance for Climate Change**

As of October, 2008, about 227 million metric tons of CERs were being generated annually from registered CDM projects. The total CERs from all roughly 1,184 registered CDM projects are expected to amount to about 1.3 billion metric tons by the end of 2012. By the end of 2012, it is expected that the CDM will have generated approximately 3 billion metric tons of CERs. This represents 3 billion metric tons of CO_2e removed or reduced from the atmosphere. The purpose of the CDM includes assisting developing countries in their efforts to stabilize the amount of GHGs in the atmosphere at a safe level and assisting developed countries to meet their commitments to reduce their GHG emissions. The aim of the CDM therefore is to support the mitigation of climate change.

The quantity of CERs generated from CDM projects represents how successful the CDM has been in achieving this goal. In particular, the CER system is the only streamlined means for developing countries to participate in the CDM, because under the Kyoto Protocol, developing countries have no set emission-reduction targets. Since all CERs are generated from projects implemented in developing countries, they represent emission reductions achieved in developing countries, in addition to those achieved in developed countries. In addition, the CDM is expected to assist developing countries in achieving sustainable development, helping them move to a more climate-friendly development path.

CERs can also be traded on the carbon market. Some developed country entities invest in CDM projects in order to use the CERs generated to meet their reduction targets under the Kyoto Protocol. Other entities invest in projects in order to obtain CERs from the projects and sell them on the carbon market. In addition, developing-country entities also finance or invest in projects and trade the CERs generated from them in the carbon market. Trade in CERs has helped create a market for trade in carbon, thereby increasing the number of entities, especially private entities, interested in carbon credits, and potentially in efforts to reduce GHG emissions.

The issuance of CERs could also potentially have a negative impact on climate change. Developed countries with reduction targets can use CERs to meet these targets. If the emission reductions generated by a CDM project are overestimated and too many CERs issued for the project, this would result in no decrease, or even a net increase, in GHG emissions, as these CERs would count toward developed country targets, and these countries could in fact theoretically increase their emissions by this amount.

Tomi Akanle

• **Further Reading**

Ali, Paul A. U., and Kanako Yano. *Eco-Finance: The Legal Design and Regulation of Market-Based Environmental Instruments.* New York: Kluwer Law International, 2004. Chapter 3 of this book provides a legal analysis of the carbon market, carbon finance, and carbon trading.

Lecocq, Franck. *State and Trends of the Carbon Market, 2004.* Washington, D.C.: International Bank for Reconstruction and Development/World Bank, 2005. Uses case studies of carbon market transactions to examine the status and trends of the carbon market.

Yamin, Farhana, ed. *Climate Change and Carbon Markets: A Handbook of Emissions Reductions Mechanisms.* London: Earthscan, 2005. Provides a comprehensive description of the carbon market, including its rules and operation.

See also: Annex B of the Kyoto Protocol; Baseline emissions; Carbon dioxide; Carbon dioxide equivalent; Clean development mechanism; Emission scenario; Emissions standards; Kyoto mechanisms; Kyoto Protocol.

Charcoal

• **Category:** Chemistry and geochemistry

• **Definition**

Charcoal is the residue of biomass charring, or the burning of animal or vegetable substances such as wood (usually beech, birch, oak, or willow), peat, nut shells, bark, or bones into a hard material used for fuel. Chemically, it is mainly carbon (85 to 98 percent), with small amounts of oxygen and hydrogen. Microscopically, it retains some of the texture typical of plant structures.

Charcoal is formed when trees or other organic matter are burned in the absence of oxygen (usually in a kiln-type structure), preventing the plant material from turning into ash. The burned material forms charcoal, a hardened material that burns with little or no flame or smoke. Charcoal provides a greater amount of heat in proportion to its volume than the wood or other biomass material from which it is formed. This quality makes it a much sought after type of fuel, particularly in nonindustrialized countries.

• Significance for Climate Change

Charcoal and Carbon Dioxide Production. Charcoal historically has been a major source of fuel for cooking. It is still used in many countries every day in this way. When charcoal is burned for fuel, the carbon stored in it is released in the form of carbon dioxide (CO_2) back into the atmosphere. If this occurs at a greater rate than the rate at which the oceans or plants and other trees are able to convert the CO_2 back into oxygen and energy, more CO_2 is left in the atmosphere than is removed. CO_2 acts as an insulator; it keeps heat from evaporating into the atmosphere, causing the Earth to be warmer. Thus, the release of CO_2 from burning charcoal can affect global climate change if it changes the composition of the atmosphere. In addition, creating charcoal involves burning wood in a kiln very slowly for long periods of time, which also releases CO_2 into the air.

Charcoal and Deforestation. Cutting down trees and other plants to produce charcoal may also affect the global climate. As wood is removed and burned to create charcoal, fewer trees are left to grow, and deforestation occurs. Deforestation affects the global climate, and nonforested areas have a degraded environmental structure and result in less biodiversity in an area that was previously covered in forest.

In addition, denuding the land of forest materials decreases the amount of oxygen released into the atmosphere, as trees and other plants that remove CO_2 from the air during photosynthesis are removed. Deforestation also affects the amount of moisture in the atmosphere (trees take water up through their roots and release it into the atmosphere), which affects clouds and how much protection they are able to give the Earth from the Sun, as well as the amount of water that is retained in soil (trees, especially in their roots, keep water in the soil and discourage erosion, keeping an area cooler and increasing soil fertility).

Currently, Central America, South Asia, and Southeast Asia lead the world in deforestation rates. Some alternatives that may help reduce the amounts of charcoal burned for fuel in these countries include providing people with stoves that retain heat better than an open fire and creating briquettes that will fully combust out of other biomass materials. These technologies are often expensive or unavailable to the full population that would need to use them to reduce the amount of deforestation and CO_2 production often found with the use of charcoal as fuel. Ultimately, charcoal pro-

Pyrolysis, Charcoal, and Climate Change

Water-saturated charcoal can be used as a soil supplement, increasing fertility; it can be produced in pyrolyzers, which rapidly heat biomass, charring rather than burning it. This process produces three substances, each of which can be put to sustainable use:

- Bio-oil (60 percent): Can be used as an alternative fuel. 1 megagram of biomass will produce enough bio-oil to replace about 1.7 barrels of oil.
- Synthesis gas, or syngas (20 percent): Can be used to power the pyrolyzer, obviating the need for any outside energy source to drive production.
- Charcoal (20 percent): Can be buried in agricultural fields, increasing crop yields and sequestering carbon. Carbon buried as charcoal will remain sequestered for thousands of years.

duction and burning may lead to a downward spiral of producing much more CO_2 that escapes into the atmosphere, while leaving fewer trees to take CO_2 out of the atmosphere.

Marianne M. Madsen

• Further Reading

Anderson, L. E., et al. *The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon.* New York: Cambridge University Press, 2003. Discusses the economics of deforestation in the Amazon Basin, including the sources and agents of deforestation and carbon emissions.

Johns, A. G., and J. Burley. *Timber Production and Biodiversity Conservation in Tropical Rain Forests.* New York: Cambridge University Press, 2004. Gives an overview of how deforestation affects the environment in rain forests, including how charcoal production affects deforestation and how charcoal burning affects air quality.

Lomborg, Bjørn. *The Skeptical Environmentalist: Measuring the Real State of the World.* New York: Cambridge University Press, 2001. Discusses traditional fuels, including charcoal and wood, and how they contribute to energy production and consumption.

Raven, P. H., and L. R. Berg. *Environment.* New York: Wiley, 2006. Includes discussions on energy, including burning charcoal for cooking fuel, and resources, including how deforestation occurs when wood is burned for charcoal.

Rosen, L. *Climate Change and Energy Policy: Proceedings of the International Conference on Global Climate Change—Its Mitigation Through Improved Production.* Edited by R. Glasser. New York: American Institute of Physics Press, 1992. These conference proceedings discuss charcoal burning in underdeveloped countries and give an overview of better production methods.

Thomas, P., and J. Packham. *Ecology of Woodlands and Forests: Description, Dynamics, and Diversity.* New York: Cambridge University Press, 2007. Provides an overview of forest structures and the dynamic changes in wooded areas. Includes an index, references, and illustrations.

See also: Carbon cycle; Carbon dioxide; Deforestation; Fossil fuels.

Chemical industry

• Category: Economics, industries, and products

As a major user of fossil fuels, the chemical industry contributes to global warming, and its processes and products that generate GHGs exacerbate this problem. Some chemical companies are developing environmentally friendly products and technologies that reduce or eliminate GHG emissions.

• Key concepts

fossil fuels: hydrocarbon materials formed from carboniferous organic life in geologic deposits of natural gas, petroleum, and coal

greenhouse effect: an atmospheric warming phenomenon by which certain gases act like glass in a greenhouse, allowing the transmission of ultraviolet solar radiation but trapping infrared terrestrial radiation

greenhouse gases (GHGs): gases such as carbon dioxide, chlorofluorocarbons (CFCs), methane, water vapor, and nitrous oxide that cause the greenhouse effect

ozone layer: a region of the stratosphere with high concentrations of triatomic oxygen, which absorbs much solar ultraviolet radiation that would be harmful to life if it reached Earth's surface

petrochemical industries: businesses that refine crude oil to create raw materials needed in the manufacture of most chemicals, from fertilizers and pesticides to plastics, synthetic fibers, and medicines

• Background

Before the nineteenth century, chemical industries were relatively modest in size and their releases of carbon dioxide (CO_2) and other pollutants tended to have local, rather than global, effects. As these industries expanded, processes in their factories and the uses of their products led to escalating emissions of CO_2, methane, and nitrous oxide that began influencing global temperatures. However, because of annual temperature fluctuations, the resulting rise in temperature was not clear until the second half of the twentieth century.

• How Chemical Industries Contribute to Climate Change

Chemical industries have been vital to the economies of developed and developing nations, but, particularly in the late twentieth and early twenty-first centuries, environmentalists have criticized these industries for their unsustainable use of raw materials and for their polluting products and by-products that, among other things, have contributed to global warming. In the late twentieth century, some scientists estimated that about one-third of the world's total energy consumption could be attributed to the chemical industry. The American chemical industry, the world's largest, manufactures over seventy thousand different products and employs over one million people, but in doing so it generates about 3.5 percent of U.S. CO_2 emissions.

In both developed and developing countries, chemical industries produce greenhouse gases (GHGs) not only directly through the manufacture of various products but also indirectly when these products are used. For example, a major product of the petrochemical industry is gasoline, whose use in automobiles is a significant source of CO_2 emissions. In the United States, automobiles discharge more of this gas than the total output of all but four countries. Chlorofluorocarbons (CFCs) are more potent GHGs than CO_2, and, because of their effect on the ozone layer, they have a more complex relationship to global warming than does CO_2. CFCs' phenomenal success as refrigerants and in aerosols led to a 500 percent increase in their manufacture by chemical companies from 1960 to 1985. By the late 1980's, scientists knew that CFCs depleted the ozone layer, resulting in dangerous ultraviolet radiation reaching Earth's surface, but CFCs also accelerated stratospheric cooling. Therefore, it was the radiation effect rather than global warming that, in 1988, led DuPont, the largest manufacturer of CFCs, to stop making them.

By this time, computerized general-circulation models of the atmosphere had become sufficiently sophisticated that the role of GHGs in global warming had been accepted by most scientists. Environmental activists criticized chemical companies for accelerating climate change. In his writings, Barry Commoner contended that the only reason the chemical industry was so successful was that it had failed to pay its "environmental bill." He also acknowledged that, if the chemical industry were to eliminate all pollutants, including GHGs, from their discharges into the environment, the costs would probably make these companies unprofitable. Environmental organizations such as Greenpeace attacked various companies such as ExxonMobil for their intransigence in accepting responsibility for adding GHGs to the atmosphere. Some of these chemical companies responded by claiming that circulation models failed precisely to predict specific rises in global temperatures, so chief executive officers should postpone policy decisions on global warming until scientific studies were deemed sufficiently mature to assign responsibility correctly.

• National and International Regulations

When, in the late twentieth century, consensus among climatologists developed that anthropogenic GHG emissions from various industries and the use of certain products influenced climate change, national and international actions were taken to reduce concentrations of these molecular culprits. Following the pattern set by laws designed to force chemical companies to reduce or eliminate toxic chemicals from their discharges, several nations passed laws whose purpose was to reduce GHG emissions. In developed countries, many chemical companies claimed that this "overregulation" and "increased environmental costs" would inevitably lead to the decline of their global competitiveness and the loss of many jobs. On the other hand, certain developed nations, such as the United States and the United Kingdom, were leaders in enacting international regulations that resulted in the gradual phase-out of CFCs. In 1987, at a meeting of industrialized nations in Montreal, Canada, an agreement known as the Montreal Protocol was achieved, despite protests from some chemical companies. This treaty was later amended, and eventually over 175 nations became signatories.

Because of controversies over global warming, consensus among climatologists about GHG emissions came later than the CFC consensus, but in 1997 more than twenty-two hundred delegates from 161 nations met in Kyoto, Japan, to formulate a treaty to help slow global warming. A central provision of the Kyoto Protocol required thirty-nine

Louisana Petrochemical plants line the Mississippi River in St. Charles Parish, Louisiana. (Brett Duke/The Times-Picayune/Landov)

developed countries to reduce GHG emissions by about 5 percent below 1990 levels by 2012. By 2008, over 180 nations had ratified the Kyoto Protocol, but the United States had neither ratified nor withdrawn from the treaty. President George W. Bush argued that the treaty was basically unfair, since it exempted such developing countries as China and India from restrictions on their GHG emissions, which were becoming significant as these populous countries industrialized. Bush's stance had the support of many American chemical companies, which had dramatically slowed the construction of U.S. chemical facilities and relocated many of their enterprises in developing countries.

- **How Chemical Industries Attempt to Mitigate Global Warming**

Despite criticisms of the Kyoto Protocol and the recognition that new and better international climate treaties were needed, an increasing number of chemical companies came to realize that it was in their best interest to reduce GHG emissions. In the United States, companies such as Dow Chemical and DuPont understood that they could increase their profits by making their operations more energy-efficient, with the concomitant benefit of a reduction in GHG emissions. By 2004, DuPont had cut its GHG emissions by 65 percent from their 1990 levels and simultaneously saved hundreds of millions of dollars. Dow Chemical, using ideas developed by its subsidiaries, invested $1.7 million in GHG reductions and received a 173 percent return on its investment. Similarly, chemical industries in Europe made significant improvements by reducing energy use per unit of product by 40 percent from 1990 to 2004. In Asia, several Japanese chemical companies formed the Global Warming Countermeasure Council to decrease substantially their GHG emissions. These and other countries used a variety of methods to achieve these gains in energy efficiency, including emissions-trading arrangements, combining heat and power plants, and the use of powerful catalysts to make products more efficiently and reduce harmful by-products.

Besides reducing their dependence on fossil fuels, many chemical companies have promoted climate protection by developing environmentally friendly products and technologies, and a number of these have even started their own environmental businesses. Some chemical companies have developed improved insulation for buildings, while others have created renewable products based on new biopolymers and enzymes. Some factories began making more efficient materials for solar and fuel cells, new ceramics for power plants, and new chemicals for removing GHGs before their discharge into the atmosphere. DuPont has created more than ten environmental businesses, and those that provide environmental remediation services are expected to grow by $4 billion over ten years. Many chemists working for various industries are engaged in research on sequestration, using nanotechnology, mineralization, and other methods to remove CO_2 from the atmosphere. Optimists believe that what the chemical industry has done, with its modest impact on global warming, can be multiplied and intensified, whereas pessimists claim that what has been done is "too little, too late."

• Context

Because of its influence on so many fields, chemistry has often been called the "keystone science," and, similarly, chemical industries play such vital roles for so many other industries that they have become essential to the success of the global economy. These industries have helped lift impoverished nations to prosperity and prosperous nations to even greater levels of wealth. These gains have not come without costs, particularly to the environment, and these negative environmental effects have resulted in the chemical industry becoming one of the world's most regulated. Chemical companies are required to spend billions of dollars in operating costs to meet national and international regulations, with the lion's share of the costs borne by those companies that convert such raw materials as petroleum into basic chemicals for commercial uses.

Compliance with the growing regulations on GHG emissions will entail heavy financial burdens, and chemical companies in the developed world have lobbied for flexibility in how these goals are achieved, to avoid not only business failures but also the collapse of national economies. Because the stakes are so high, between the Scylla of world economic collapse and the Charybdis of the flooding of major coastal cities, the scientifically correct diagnosis of and solution to the problem of global warming are imperative. Just as the chemical industry has had an important part in creating this problem, so, too, will it have to be deeply involved in its solution.

Robert J. Paradowski

• Further Reading

Begg, Kathryn, Frans van der Woerd, and David Levy, eds. *The Business of Climate Change: Corporate Responses to Kyoto*. Sheffield, South Yorkshire, United Kingdom: Greenleaf, 2005. Analyzes how industries have responded to the challenge of climate change. Chapter 12 in the "Sector Analysis" section deals with the chemical industry's response to climate change.

Fineman, Stephen, ed. *The Business of Greening*. New York: Routledge, 2000. Collection of articles written by scholars in several fields who investigate the relationship between businesses, including chemical companies, and environmental problems, including global warming. Bibliographic references, index.

Hoffman, Andrew J. *From Heresy to Dogma: An Institutional History of Corporate Environmentalism.* 1997. Expanded ed. Palo Alto, Calif.: Stanford Business Books, 2001. Emphasizes the dramatic changes that have taken place in American companies, including chemical industries, as a result of ever-increasing requirements for environmental protection.

Matlack, Albert S. *Introduction to Green Chemistry*. New York: Marcel Dekker, 2001. With its several thousand references, this book is more a treatise than a textbook, though it can serve as both an introduction to the field and a reference source. Index.

Spitz, Peter H., ed. *The Chemical Industry at the Millennium: Maturity, Restructuring, and Globaliza-*

tion. Philadelphia: Chemical Heritage Foundation, 2003. Some scholars in this compendium analyze the influence of environmental regulations on the chemical industry, including the future challenges posed by global warming.

See also: Aerosols; Chlorofluorocarbons and related compounds; Clean energy; Emissions standards; Fossil fuels; Greenhouse gases; Industrial ecology; Industrial emission controls; Kyoto Protocol; Montreal Protocol; Ozone.

China, People's Republic of

- **Category:** Nations and peoples
- **Key facts**

Population: 1,330,000,000 (2009 estimate)

Area: 9,826,630 square kilometers (several border areas are in dispute)

Gross domestic product (GDP): $7.8 trillion (purchasing power parity, 2008 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 6,100 in 2004

Kyoto Protocol status: Ratified, 2002

• Historical and Political Context

The major factor in the global production of greenhouse gases (GHGs) and in general environmental degradation is the massive growth in the world human population, and China is home to a substantial portion of that population. From 400 million people before World War II, China's population has grown to over 1.3 billion. Following the establishment of the People's Republic of China in 1949, the new government focused on rebuilding the nation and growing the population. In the face of Mao Zedong's philosophy of controlling and shaping the environment to serve a new generation, it was difficult at first for population scientists to convince the government that there was a need to constrain growth.

It soon became obvious, however, that progress in literacy, food production, and modernization was undermined by uncontrolled population growth. Mao agreed first to a two-child policy and then to a one-child policy, limiting the number of offspring allowed to each family. These policies are enforced only for the Han Chinese; ethnic minorities have never been limited in their number of children. It is estimated that without the one-child policy, China's population would be greater by over 300 million—a number approximately equal to the population of the United States: The Chinese standard of living would be dramatically lower, and severe stresses would be placed on food supplies, living conditions, and energy. The nation would have added over 1 billion metric tons of carbon dioxide (CO_2) to its annual emissions.

Management of environmental issues in China has modified and expanded since the first National Environmental Protection Meeting in 1973. In 1982, the Ministry of Urban and Rural Construction and Environmental Protection was established. The State Environmental Protection Administration (SEPA) was established in 1988 and upgraded to ministry level in 1998. The Ministry of Environmental Protection (MEP) was established in 2008. On March 28, 2008, the MEP established five regional inspection offices with a total staff numbering under twenty-fix hundred, compared with the U.S. Environmental Protection Agency's seventeen thousand personnel.

The State Council of the People's Republic of China issued the *China National Environmental Protection Plan in the Eleventh Five-Years, 2006-2010*. That five-year plan set forth a goal of achieving 20 percent greater energy efficiency and a 10 percent decrease in pollutants. China's officials acknowledged that the need for sustaining economic growth could take precedence over environmental concerns and weaken enforcement of environmental regulations. Lu Xuedu, deputy director of the Chinese Office of Global Environmental Affairs, explained that "You cannot tell people who are struggling to earn enough to eat that they need to reduce their emissions." Economic arguments are not restricted to China. Because coal is much cheaper than oil and natural gas, Japan and Europe also make greater use of coal.

While the economic health of the population takes priority, China's officials are not hesitant to

address the problems of climate change. *China's National Assessment Report on Climate Change (I)* (2007) notes that sea levels have risen 2.5 millimeters annually over fifty years. Glaciers have retreated, and air temperatures have increased 0.5°-0.8 ° Celsius over the last century, mostly in the last fifty years. The report predicts rural agricultural output will drop by 5 to 10 percent by 2030.

China's Scientific and Technological Actions on Climate Change further details that from 1986 to 2006, "China experienced 21 warm winters nationwide in succession." China is putting together large-scale observation networks and has laid out targets for very aggressive research in emission controls.

• Impact of Chinese Policies on Climate Change

The *China National Environmental Protection Plan in the Eleventh Five-Years, 2006-2010* by the State Council of the People's Republic of China has directed over one percent of gross domestic product (GDP) to environmental protection but considers the environmental situation "still grave." It laments that there were no breakthroughs in areas that should have been addressed before and directly blames ongoing problems on the lack of observation of laws, minimal punishments for lawbreakers, and poor enforcement of environmental laws. The most successful controls have been those cutting sulfur emissions, which ironically reflected sunlight back into space and therefore counteracted global warming. Thus, by decreasing acid rain, China has increased the greenhouse effect.

In contrast to American trends, China has avoided the rush to develop corn ethanol and other biofuels that could in any way displace foodstuffs for human consumption. China has concerns over food security originating in the nation's history of hunger and famine. Biofuels from nonfood plants, oilseeds, and an experimental *Jatropha curcas* plant are being considered, but great caution is being exercised to avoid soil erosion or reducing the number of food crops.

China recently completed the world's largest hydroelectric dam, a source of clean energy. Its twenty-six generators produce 700 megawatts of energy each. The dam's total 18,200 megawatt output is equal to that of fifteen of the largest nuclear power plants. It was designed to generate up to 10 percent of the country's power needs at the time of construction, but China's energy needs are rapidly increasing. The World Bank refused to fund the dam, and the United States led a boycott of bank funding for the project. China nevertheless built the massive dam based on the need to control devastating floods, generate clean power, and also bring ocean freighters to the interior industrial city of Chongqing.

China has provided subsidies to companies producing solar photovoltaic systems. Photovoltaics, or solar panels, are carbon neutral once they have been produced. However, as a source of electrical power, their costs have not yet dropped to a level where they can compete with natural gas or coal, a point called "grid parity" in China, and many solar units are shipped to Germany and other countries. General estimates are that solar power would have to drop to 14 cents per kilowatt hour to be economical in China. Contemporary costs run near 40 cents per kilowatt hour. The 2008 surge in oil prices provided the expectation that the cost of such alternative fuels would soon come close to competing with fossil fuels. However the subsequent global economic downturn also dramatically reduced the price of fossil fuels. The point at which solar power would become as cheap as fossil fuels, once optimistically thought to be as early as 2012, was deferred.

Many companies that make photovoltaics are located in China in order to take advantage not only of cheaper labor but also of cheaper land and materials. New buildings in Guangdong and other developed areas are being designed to use solar panels to provide their complete energy needs. The main market for Chinese solar panel production is in Europe, where regulations and subsidies promote the use of this more expensive power source. China itself remains cost conscious and is not ready to substitute more expensive power sources for cheaper coal plants. The need to serve the poorer population in the less developed countryside takes precedence.

Silicon, a central ingredient in solar cells, is also critical to the semiconductor industry. The solar industry has exceeded the semiconductor industry in its use of silicon. China has provided various electrical engineers with millions of dollars in start-up funds to establish state-of-the-art solar photovoltaic system factories in Wuxi and several other cities. Research has reduced the amount of silicon needed to produce solar cells. The economic downturn has also decreased the costs of silicon. Improved technology, much developed in China, is increasing the efficiency of silicon electricity production.

- **China as a GHG Emitter**

China was the first developing country to establish a national policy for addressing global warming, releasing its National Action Plan on Climate Change in June, 2007. According to the International Energy Agency, China surpassed the United States in CO_2 emissions in 2009. China's dramatic economic expansion since 1980 has pulled 400 million of its citizens out of poverty, but it has likewise increased per capita use of energy, especially visible in the nation's rapid adoption of automobiles. The increase in energy demand in developed regions has required China to enter the global market as a major player, negotiating the purchase of major shares of oil from Kazakhstan and other nearby fields.

According to the *World Energy Outlook, 2008*, produced by the Organization for Economic Cooperation and Development and the International Energy Agency, China's energy demand is expected to grow to such an extent that China will produce double the emissions of India and more than triple the emissions of other developed economic regions by 2030. This expected growth is a function not only of China's productive potential but also of the size of its markets.

While China is the second-largest consumer of oil at 7 million barrels per day, the United States leads at 21 million barrels per day. As is true of the United States, China has limited and rapidly declining domestic oil reserves. Oil imports account for 40 percent of Chinese consumption. By comparison, 60 percent of U.S. consumption is of imported oil.

With substantial coal reserves, China has used many smaller power plants located near population centers to deliver power locally with less lost to transmission. The nation has began requiring, however, that larger plants be built that are more efficient and use less coal per kilowatt-hour produced. China's main strategic energy reserve is coal. National energy consumption is so great that it also imports coal from Canada and Australia.

While scrubber technology reduces some emissions, burning coal is still a major CO_2 generator. China has begun thirty large-scale coal-to-liquid (CTL) projects using the Fischer-Tropsch process, which produces methanol for end users. Methanol is added to gasoline to produce a cleaner-burning fuel, and the country has committed to substantial use of methanol in 2011-2013. When oil prices are above $35 per barrel, coal-derived methanol is cost-effective for automobile fuel. China seeks to produce the methanol equivalent of 20 percent of its current oil consumption, although because its consumption is expected to double, this production level would amount to about 10 percent of the country's future needs.

China's largest joint venture with Royal Dutch/Shell is a project in Ningxia that would produce 70,000 oil barrels equivalent of methanol per day. The National Development and Reform Commission established standards for CTL methanol, allowing the fuel to be used and projects such as the one in Ningxia to go forward. China was the first country in the world to develop methanol as an alternative fuel. The Chinese employ oxygenated gasification, a process developed with some U.S. government funding in earlier years, to isolate CO_2. This allows China to either sequester the CO_2 or use it to increase oil production from older wells.

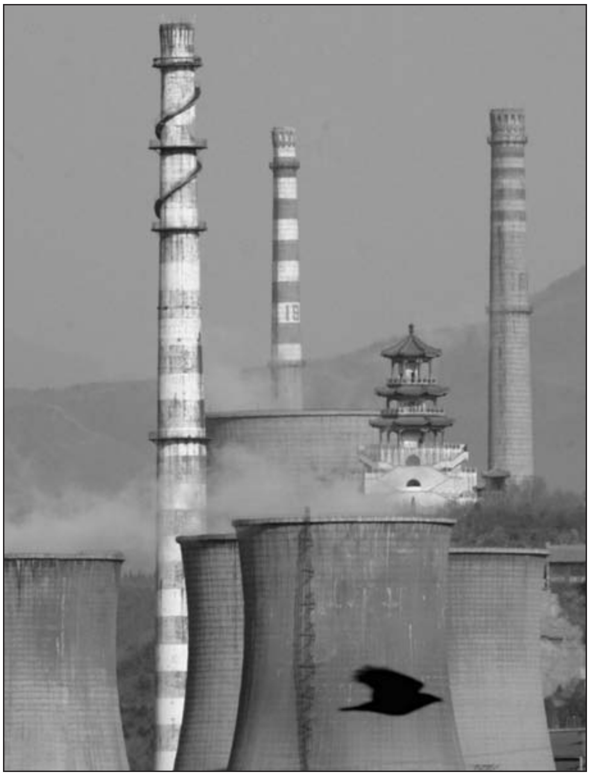
A growing source of Chinese carbon emissions is the increase in motor vehicles. In the last few decades, government policy has promoted automobile production and encouraged the growing Chinese middle class to buy cars. The initial rationale was that the production, repair, and maintenance of cars would drive economic growth and reduce poverty; pollution control was deferred until after economic benefits had been realized. However, China has since established fuel-economy requirements for new car production that are more rigorous than those of the United States.

Compared to over-the-road trucking, rail is far more efficient for moving products on cost-per-mile and carbon emission bases. China has 72,500 kilometers of rail network compared to 228,500 kilometers still operable in the United States. China plans to invest $242 billion by the year 2020 in modernizing its railroad infrastructure, expanding the rail network and separating passenger and freight transport.

• Summary and Foresight

China's rapid economic growth has generated concern that the energy demands of such a huge population, if it grew to the per capita usage of the United States, would produce sufficient pollution and GHG emissions to represent an ecological disaster. However, the lifestyle of the new Chinese middle class retains a conservation ethic that may prevent runaway consumption. China combines economy and conservation of energy by using passive solar water heaters and has a long history of employing public transportation, bicycles, and electric bicycles to travel. In addition, the crowding of a large population requires severe limitations on pollution and provides a public awareness of the need to conserve and protect the environment. As a result, the government has begun aggressively recognizing and responding to the problems of global warming. China's ability to implement such policies is tempered by the need to pull half of its population, primarily in the countryside, out of poverty.

At the international level, under the Kyoto Protocol, the People's Republic of China is considered a developing country and therefore not required to meet emission timetables and targets. However, it can earn emission-reduction credits under the clean development mechanism. China's admission into the World Trade Organization and its leading



Smokestacks and cooling towers frame a pagoda outside the Chinese capital of Beijing. (Reinhard Krause/Reuters/Landov) role as a major nation have moved it to the position of needing to provide leadership in controlling GHGs.

John Richard Schrock

• **Further Reading**

Ding Yihui, et al. *Advances in Climate Change Research.* Supplement 3 to Vol. 1 of *China's National Assessment Report on Climate Change.* Beijing: National Climate Commission of China, 2007. Details the state of Chinese climate research in the early twenty-first century.

Economy, Elizabeth C. *The River Runs Black: The Environmental Challenge to China's Future.* Ithaca, N.Y.: Cornell University Press, 2004. This Council on Foreign Relations book examines the extent to which China's spectacular commercial advancement has depleted resources and challenged governmental regulatory agencies at all levels. Discussion extends to health problems, migration, economics, and social stability.

People's Republic of China. Ministry of Science and Technology, et al. *China's Scientific and Technological Actions on Climate Change.* Beijing: Author, 2007. Official state overview; candidly addresses the severity of climate change in China and the need to set strict targets.

People's Republic of China. State Council. *China National Environmental Protection Plan in the Eleventh Five-Years, 2006-2010.* State Council Document 39. Beijing: Author, 2005. China sets goals for all governmental issues in five-year plans. This official report details the failure to achieve major targets under the previous Tenth Five-Year Plan for National Environmental Protection and the necessity to emphasize environmental protection equally with economic goals.

Shapiro, Judith. *Mao's War Against Nature: Politics and the Environment in Revolutionary China.* New York: Cambridge University Press, 2001. Overview of the early years of the People's Republic under Mao; takes a negative view of the environmental degradation that accompanied the restructuring of Chinese society immediately after 1949.

See also: Coal; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Hydroelectricity; Kyoto Protocol; Motor vehicles; United Nations Framework Convention on Climate Change.

Chlorofluorocarbons and related compounds

• **Category:** Chemistry and geochemistry

CFCs are useful as refrigerants, solvents, and aerosol propellants, but they can act as catalysts for the destruction of stratospheric ozone. These compounds also contribute directly to global warming by acting as GHGs.

• **Key concepts**

Freon: trade name for CFCs made by DuPont chemical company

greenhouse effect: a phenomenon in which gases trap solar heat within Earth's atmosphere, preventing it from radiating away into space

halocarbons: the general family of compounds that includes CFCs, HCFCs, HFCs, and other molecules in which carbon bonds with halogen atoms

halon: a compound containing bromine, carbon, chlorine, and fluorine

Kyoto Protocol: a 1997 international agreement to limit greenhouse gas emissions

Montreal Protocol: a 1987 international agreement to phase out the manufacture and use of ozone-depleting chemicals

ozone layer: the portion of the Earth's stratosphere (10-50 kilometers high) where ozone has formed and absorbs dangerous ultraviolet radiation from the Sun

• **Background**

Developed in the 1930's as refrigerants, chlorofluorocarbons (CFCs) gained rapid acceptance in the 1940's. New uses were found for them as aerosol propellants, blowing agents, solvents, fire suppressants, and inhalation anesthetics. Production climbed, reaching as high as 566,591 metric tons in the United States by 1988. In 1971, it was shown that CFCs had accumulated in the atmosphere, and by 1974 a relationship was demonstrated between

Aerosol spray cans release a fine mist of chemicals suspended in liquid. CFCs used to propel this mist out of the can cause depletion of Earth's ozone layer. (©iStockphoto.com/Picsfive)

atmospheric CFCs and depletion of the ozone layer. Over the next twenty years, manufacture and use of CFCs were drastically reduced to protect the ozone layer from further harm.

• Fate of Halocarbons in the Atmosphere

CFCs, although denser than air, mix throughout the atmosphere and eventually reach the stratosphere (10-50 kilometers in altitude). Although CFCs have low chemical reactivity (and hence long lifetimes) in the lower atmosphere, in the stratosphere they encounter and absorb energetic ultraviolet radiation, resulting in their chlorine atoms being set free. These chlorine atoms can act as catalysts for the destruction of stratospheric ozone molecules. Because of the catalytic process, each chlorine atom can destroy thousands of ozone molecules. Other volatile chlorine compounds such as methyl chloroform and carbon tetrachloride can also form destructive chlorine atoms. Bromine atoms are also destructive of ozone, and bromine-containing compounds include the halons, used as fire suppressants and inhalation anesthetics, and methyl bromide, a soil fumigant and natural product of sea organisms.

In 1971, James E. Lovelock, using a sensitive detector, found traces of CFCs in air samples from different parts of the world. F. Sherwood Rowland and Mario Molina realized the potential ozone destructiveness of CFCs and stirred up concern among industrialists and politicians that led to the signing of the Montreal Protocol in 1987. Because of the long lifetimes of CFCs, however, even in the absence of further production it will take years for the existing pollutants to dissipate and allow the ozone layer to recover.

• Substitutes for CFCs

Phasing out CFCs meant that substitutes were needed for applications in refrigeration, air conditioning, and aerosols. The ideal substitute would be nontoxic, nonflammable, noncorrosive (like a CFC), and of suitable physical properties (such as boiling point and heat of vaporization), but without the ozone destructiveness of the CFCs. Attention naturally focused on the related compounds hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). The HCFCs, although they contain chlorine, tend to be destroyed by chemical reactions in the lower atmosphere before they reach the ozone layer. HFCs, which contain no chlorine, have negligible ozone destructiveness even should they reach the stratosphere. In addition to adopting these new compounds, the existing stocks of CFCs in abandoned equipment had to be trapped and either recycled or disposed of in an environmentally acceptable manner, rather than being vented into the atmosphere.

• Context

The impact of CFCs and their related compounds is mainly on the ozone layer, because of their catalytic effect. CFCs are also potent greenhouse gases but are present in the atmosphere at such low levels (0.1-0.5 parts per billion) that their contribution to the total greenhouse effect is relatively small. Loss of ozone in the stratosphere also affects temperature in complex ways, warming some parts of the atmosphere and cooling others. Nevertheless, the sheer numbers of individual halocarbons, even at low levels individually, add up to a warming potential that is worth controlling. Atmospheric levels of substances controlled by the Montreal Protocol have declined appreciably, but, not surprising, the levels of their substitutes have risen. This trade-off is good for the ozone layer, but it leaves much to be accomplished on the global warming front.

John R. Phillips

• **Further Reading**

Benedick, Richard E. *Ozone Diplomacy: New Directions in Safeguarding the Planet.* Enlarged ed. Cambridge, Mass.: Harvard University Press, 1998. Detailed discussion of the negotiations that led to the Montreal Protocol and its London Amendments.

Bily, C. A., ed. *Global Warming: Opposing Viewpoints.* Farmington Hills Mich.: Greenhaven Press, 2006. Collection of individual short essays arguing either pro or con regarding some aspect of global warming science and environmentalism.

Finlayson-Pitts, B. J., and J. N. Pitts, Jr. *Chemistry of the Upper and Lower Atmosphere.* San Diego, Calif.: Academic Press, 2000. Very thorough technical discussion of global warming, ozone depletion, and other topics. Hundreds of references to peer-reviewed literature. A graduate-level text.

Hiyama, T. *Organofluorine Compounds.* New York: Springer, 2000. A survey of the chemistry of organofluorine compounds, with a chapter on CFCs detailing their manufacture, uses, and fate in the environment.

Howe-Grant, M. *Fluorine Chemistry: A Comprehensive Treatment.* New York: Wiley, 1995. Contains basic information on the properties, manufacture, and uses of chlorofluorocarbons, hydrofluorocarbons, and perfluorocarbons.

Lomborg, B. *Cool It.* New York: Knopf, 2007. Lomborg, a social scientist, feels that some of the dire predictions about the consequences of global warming have been exaggerated. He concludes that huge sums spent for reducing carbon emissions are not cost-effective and would be better spent on clean water, treating AIDS, and other problems.

McNeill, J. R. *Something New Under the Sun.* New York: Norton, 2000. A comprehensive environmental history of the twentieth century. Considers global warming, ozone depletion, and many other topics with regard to various world regions.

Malmström, Bo G., ed. *Nobel Lectures: Chemistry, 1991-1995.* Singapore: World Scientific, 1997. Includes a lecture by F. Sherwood Rowland, who shared the 1995 Nobel Prize in Chemistry, in which he gives a technical discussion of atmospheric chemistry involving CFCs and ozone.

Midgley, Thomas, IV. *From the Periodic Table to Production: The Biography of Thomas Midgley, Jr., the Inventor of Ethyl Gasoline and Freon Refrigerants.* Corona, Calif.: Stargazer, 2001. Biography of Midgley (1889-1944), a chemist working for General Motors who pioneered the use of chlorofluorocarbons as refrigerants in the 1930's. Written by his grandson.

Walker, G., and D. King. *The Hot Topic: What We Can Do About Global Warming.* Orlando, Fla.: Houghton-Mifflin Harcourt, 2008. States the evidence for global warming in layperson's terms and proposes technological and political steps that should be taken. Includes a chapter on myths and misconceptions.

See also: Aerosols; Air conditioning and air-cooling technology; Carbonaceous aerosols; Chemical industry; Halocarbons; Halons; Montreal Protocol; Ozone; Sulfate aerosols.

Cities for Climate Protection

- **Category:** Organizations and agencies
- **Date:** Established 2005
- **Web address:** http://www.icleiusa.org/

• **Mission**

Greg Nickels, Seattle's mayor, launched the U.S. Conference of Mayors Climate Protection Agreement in 2005, after a season of unusually mild winter weather ruined the Pacific Northwest's skiing season. By mid-2008, 850 U.S. cities from Boston to Portland, Oregon, representing a total population of more than 85 million, had pledged to meet Kyoto Protocol standards. Many municipal leaders took action, because they believed the federal government during the administration of George W. Bush had failed to do so.

At the Seattle Climate Protection Summit of November, 2007, more than one hundred U.S. mayors called for a federal partnership to address energy dependence and global warming. Nickels said,

> We are showing what is possible in light of climate change at the local level, but to reach our goal of 80 percent reductions in greenhouse gases by 2050, we need strong support from the federal government.

The call for federal action occurred alongside the commitments of a large number of U.S. cities to reduce their residents' greenhouse gas (GHG) emissions.

Cities for Climate Protection organizes and coordinates efforts to combat global warming in U.S. towns and cities, coordinates action on a national level, and encourages efforts undertaken by individual urban areas. There is no limit on the size of a municipal district that may take part. The organization also works with cities and towns to improve air quality and enhance urban livability, coordinating with groups that have similar missions around the world.

• Significance for Climate Change

Cities for Climate Protection's street-level impact can be measured by programs in several affiliated urban areas. For example, in Los Angeles, Mayor Antonio Villaraigosa, in partnership with the Los Angeles City Council and environmental leaders,

The Five Milestones

Cities joining the Cities for Climate Protection are given five milestones to measure their progress toward implementing the organization's program.

Milestone 1. ***Conduct a baseline emissions inventory and forecast.*** Based on energy consumption and waste generation, the city calculates greenhouse gas emissions for a base year (e.g. 2000) and for a forecast year (e.g. 2015). The inventory and forecast provide a benchmark against which the city can measure progress.

Milestone 2. ***Adopt an emissions reduction target for the forecast year.*** The city establishes an emission reduction target for the city. The target both fosters political will and creates a framework to guide the planning and implementation of measures.

Milestone 3. ***Develop a Local Action Plan.*** Through a multi-stakeholder process, the city develops a Local Action Plan that describes the policies and measures that the local government will take to reduce greenhouse gas emissions and achieve its emissions reduction target. Most plans include a timeline, a description of financing mechanisms, and an assignment of responsibility to departments and staff. In addition to direct greenhouse gas reduction measures, most plans also incorporate public awareness and education efforts.

Milestone 4. ***Implement policies and measures.*** The city implements the policies and measures contained in their Local Action Plan. Typical policies and measures implemented by CCP participants include energy efficiency improvements to municipal buildings and water treatment facilities, streetlight retrofits, public transit improvements, installation of renewable power applications, and methane recovery from waste management.

Milestone 5. ***Monitor and verify results.*** Monitoring and verifying progress on the implementation of measures to reduce or avoid greenhouse gas emissions is an ongoing process. Monitoring begins once measures are implemented and continues for the life of the measures, providing important feedback that can be used to improve the measures over time.

Source: ICLEI—Local Governments for Sustainability.

has unveiled GREEN L.A., described as "an action plan to lead the nation in fighting global warming." Villaraigosa pledged to reduce his city's carbon footprint to 65 percent of its 1990 level by 2035, the most ambitious goal set by a major American city. Los Angeles also planned to increase its use of renewable energy to 35 percent of total energy usage by 2020, much of it through changes to its municipal electrical utility, the largest in the country.

In Austin, Texas, energy efficiency standards were raised for homes, requiring a 60 percent reduction in energy use by 2015. Chicago has attempted waterless urinals and planted several thousand trees. Philadelphia has been replacing black tarpaper roofs atop old row houses with snow-white, highly reflective composites. Keene, New Hampshire, requires parents waiting to pick up their children at schools to turn off their car engines. In Portland, Oregon, carbon emissions had been reduced to 1990 levels by 2007. Water flowing through Portland's drinking-water system also generates hydroelectricity. Mayors of at least 134 U.S. cities by 2007 were using more energy efficient lighting in public buildings, streetlights, parks, traffic signals, and other places. Many city governments' auto fleets had converted to alternative fuels or hybrid-electric technology.

The Chicago Climate Action Plan, announced in September, 2008, aimed to cut GHG emissions to 25 percent below 1990 levels by 2020. The plan required retrofitting of commercial and industrial buildings, increased energy efficiency in residences, and more use of renewable sources of electricity to reduce Chicago's emissions to 80 percent of 1990 levels by 2050. Buildings, which emit 70 percent of Chicago's carbon dioxide, are the major target of the Climate Action Plan. Chicago City Hall already has a green roof, designed as a model for as many as six thousand buildings citywide. Chicago's Smart Bulb Program by 2007 had distributed 500,000 free compact fluorescent light bulbs to residents.

The Dallas, Texas, municipal government decided early in 2008 to purchase 40 percent of its power from renewable energy sources, primarily wind power, which has been expanding rapidly in Texas. The city government also was reducing its energy use 5 percent per year by using lighting upgrades, solar panels, highly efficient heating and air-conditioning systems, and automated building temperature controls.

Using the AlbuquerqueGreen program, that city reduced natural-gas consumption 42 percent and cut GHG emissions 67 percent between 2000 and 2006. AlbuquerqueGreen promotes growth of green-tech companies, bicycle use, and pedestrian-friendly streets. Albuquerque requires that all new buildings be designed to be carbon neutral, with architecture suitable for 100 percent renewable energy use by 2030.

Several cities have targeted poor neighborhoods with subsidies and grants for insulation of older homes that often leak heat in winter. Such programs also allow some people to acquire insulation and energy-efficient compact fluorescent light bulbs as they replace older, inefficient basic electrical appliances, such as refrigerators, washers, and dryers.

With encouragement from Cities for Climate Protection, several major U.S. cities have launched sizable tree-planting programs, including Washington, D.C., Baltimore, Minneapolis, Chicago, Denver, and Los Angeles. Even so, an ongoing decline in urban tree cover has been accelerating since the 1970's in the United States, especially on private property and new development, according to American Forests, an environmental group that uses satellite imagery to document tree cover across the United States. Washington, D.C., is among the cities with the largest reduction in dense tree cover, with a 64 percent decline from 1973 to 1997, according to American Forests.

Bruce E. Johansen

• Further Reading

Cohen, Stuart, et al. *Cities for Climate Protection Policy and Practice Manual—Green Fleets: A Guide to Increasing Efficiency for Reducing Emissions from Municipal Fleets.* Toronto: International Council for Local Environmental Initiatives, [1996?]. Practical guide to city-level initiatives that can be undertaken to reduce motor-vehicle emissions.

U.S. Communities Acting to Protect the Climate: Achievements of ICLEI's Cities for Climate Protection—U.S., 2000. Berkeley, Calif.: International Council for Local Environmental Initiatives, 2000. Thirty-two-page pamphlet, published by Cities for Climate Protection's parent organization, detailing the program's accomplishments.

Young, Abby. "Forming Networks, Enabling Leaders, Financing Action: The Cities for Climate Protection Campaign." In *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, edited by Susanne C. Moser and Lisa Dilling. New York: Cambridge University Press, 2007. Detailed case study of the formation and activities of Cities for Climate Protection.

See also: Megacities; Urban heat island; U.S. energy policy.

Civilization and the environment

• **Category:** Nations and peoples

In a world where the map of global climate change is always shifting, the conditions that once made a civilization flourish can never be taken for granted. There is a constant ebb and flow of migration and return-migration, as changes in weather patterns modify a people's environment and sources of sustenance. These changes have often proven so drastic as to contribute to the demise of previously stable civilizations.

• Key concepts

deforestation: the process by which areas are stripped of forests and tree cover, exposing the underlying soil to erosive forces

desertification: the process by which once semi-arable lands are converted into desert

El Niño-Southern Oscillation: a climatic phenomenon wherein the normally cold ocean currents off the Pacific Coast of South America reverse, affecting global weather patterns

Little Ice Age: time period from around 1250 to 1850 characterized by cooling global temperatures

Medieval Warm Period: time period from around 800 to 1250 when European and possibly global temperatures were generally warming

• Background

The extent to which climatic change has affected the genesis, development, location, nature, rise, and fall of civilizations throughout history has been a matter of long-standing debate. The issue has gained a sharper edge and assumed a greater urgency, however, in an era of increasing environmental awareness. Any agreement among scholars seems to be on a broad scale, rather than on specifics. The wider view is that the globe has been in a predominantly warming trend for the last seventeen thousand years. This thaw in the wake of the last major ice age has been proposed as the main factor that started, propelled, and then sustained the spectacular advance of human civilization, notably from around 3000 B.C.E. to the present. However, when historians attempt to determine causal factors contributing to the success and failure of particular cultures, multiple factors other than climate have to be taken into account.

• Indus River Valley Culture

A long-standing debate has raged over what might have caused the demise of the Indus River Valley culture. Sprawled along the alluvial plain of the Indus River in what later became Pakistan, it was the largest in terms of land area of the four earliest cradles of civilization. Dependent on the agricultural productivity of the fertile soil along the riverbanks, it was highly urbanized and had strong trade links with Mesopotamia. The cities were painstakingly planned; buildings were constructed of oven-baked brick; spacious streets were almost perfectly laid out in modern grid fashion; and the cities employed advanced drainage and sewage disposal mechanisms.

The Indus culture flourished beginning around 2500 B.C.E. then declined and became depopulated by no later than 1200 to 1100 B.C.E. Different theories have been advanced to explain its downfall, none of which has proven conclusive. Increasing evidence indicates, however, that climatic and environmental factors brought about the downturn in the culture's fortunes, rather than theorized attacks by Aryan invaders. According to one scenario, a climatic change seems to have triggered increased rainfall, leading to massive flooding. The demand for wood to fire the kilns used to produce bricks had denuded the forests, and this deforestation had eroded the soil, rendering it vulnerable to the flooding. Another climate change theory has it that drought, warmer temperatures, and anthropogenic deforestation resulted in desertification, which caused the large-scale abandonment of the Indus cities.

• Egypt, Mesopotamia, and Greece

The Old Kingdom civilization of Egypt, 3100-2200 B.C.E., was renowned as the era of pyramid construction and exemplary of strength and prosperity. However, there is some evidence that global climate change possibly caused the disruption of the annual flooding of the Nile River—perhaps augmented by El Niño-Southern Oscillation (ENSO) effects—and thus might have brought about a devastating drought cycle that led to the termination of the Old Kingdom. The kingdom's demise was followed by a chaotic 150 years known as the First Intermediate Period.

The climatic vulnerability of Mesopotamia has been amply attested to in the cuneiform texts of its various civilizations, as well as being evidenced by the archaeological record. The Akkadian Empire (2400-2200 B.C.E.), which encompassed Mesopotamia and the Fertile Crescent up to the Levantine Coast, was apparently brought low by a series of very severe winters combined with drought conditions that were perhaps occasioned by volcanic eruptions. Another such massive drought cycle around 1200 B.C.E. is also believed to have contributed to the ending of the Hittite Empire and Mycenaean Greece.

• The Americas: Anasazi and Maya

Lack of documentation makes it exceptionally difficult to gauge the scale of the impact that climate may have had on pre-Columbian Native American cultures. The Maya of Mexico and Central America, whose civilization was the most advanced and probably the best documented, suffered the nearly wholesale destruction of their books by Spanish missionaries. The Anasazi, who dwelled in present-day portions of the southwestern United States from around 700 to 1150, had no such documentation to begin with, so their abrupt collapse has proven even more puzzling.

The Navajo term "Anasazi," or "Ancient Ones," has been used to denote the Pueblo cultures known variously in different regions as the Hohokam, Mogollon, and Patayan. These peoples inhabited the area around the modern Four Corners—where Utah, Colorado, Arizona, and New Mexico converge—and southward into the greater part of the modern state of Chihuahua, Mexico. They constructed the spectacular cliff dwellings that still dot the regions they once inhabited, including Mesa Verde, Chaco Canyon, and Canyon de Chelly. Around 1150, a particularly severe and prolonged period of drought drove the Anasazi to nearby areas where water was slightly more accessible, and the descendents of the Anasazi can be found among the present-day Pueblo.

Deriving, most likely, from the more ancient cultures of the Olmec and Teotihuacan in southern Mexico, the people known as the Maya flourished in the region of the Mexican Yucatán Peninsula and the modern countries of Guatemala, Belize, El Salvador, and Honduras around 200 to 900 C.E. Massive and sophisticated in their architectural designs and elaborate pyramids, Mayan city-states burgeoned into mini-empires under autocratic kings who claimed to serve as conduits to the gods to ensure their people's prosperity. The once-baffling collapse of these city-states is now thought to have been caused by a series of droughts; the resulting crop failures drove the Maya to abandon both their faith in these kings and the city-states themselves, which became isolated ruins.

• The Andes and Oceania

The enigmatic Moche culture of the Andes lasted from about 100 to 750 C.E. along the northern coastline of Peru and coincided with the Nazca culture to the south. Both ended abruptly, leaving little more than their major artifacts (Moche pottery and the Nazca lines in the Nazca Desert). There is some disputed evidence that extensive ENSO episodes set off alternating patterns of flooding and drought, causing both civilizations to crumble. The more extensive Tiahuanaco culture, centered around an urban site in Bolivia, flourished from about 700 to 1150, left giant stonework ruins, and seems to have perished from the effects of the same massive drought period that destroyed the Anasazi.

The more isolated islands of Pacific Oceania could be expected to offer more examples of vulnerability: Because of their remoteness, the scarcity of land and resources, and the potential capriciousness of nature, they have been home to some of the most frail of human societies. These societies, however, met with different outcomes. For example, the native culture of Easter Island seems to have come to an end in part through a murderous civil war brought on by deforestation and social unrest. It is possible that an ENSO episode exacerbated conditions of drought and scarcity, thus bringing about the culture's final destruction.

• Norse Greenland

The fate of the Norse settlements in Greenland offers the most readily documented example of the negative impact of climate change. In 968, the Viking warlord Eric the Red sailed from Iceland to establish a Scandinavian colony in Greenland. During the Medieval Warm Period, the colony thrived and expanded, concentrating into two major settlements. An eastern settlement was located on the island's extreme southern coast, and a less significant settlement was founded 320 kilometers up the western coast. In its heyday, each settlement may have had a population of five thousand. Their economic mainstays were cattle and sheep grazing, as well as trade, mainly with the Icelanders and Norwegians.

Around 1250, as the Medieval Warm Period gave way to the Little Ice Age, glaciers advanced dramatically across Greenland. (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.) Growing seasons shortened; temperatures plummeted; and hunting, grazing, and agricultural land became scarce. The Greenlanders, always in an isolated position, became even more cut off as ice packs began blocking the passage routes to and from Iceland and Norway. Increasingly harsh conditions also drove the Inuit (Eskimos) south and west, and almost immediately, armed clashes broke out between them and the Norse, as both groups competed for dwindling sources of sustenance. The Inuit proved to be the more readily adaptable to change, while the Norse were reluctant to alter their ways. Thus, by 1400, the western and eastern settlements lay abandoned as the Vikings either starved, died at the hands of the Inuit, or fled.

• Context

Though there now exists little doubt that climate change and environmental factors have affected the course of civilization, there remains an element of debate over their relationship to other causal factors such as outside encroachment and internal dissension. It may well be different in each case. The ability of climate to influence history may affect contemporary politics and public policy decision making. If the correlation between climatic or environmental events and the decline of civilizations could be conclusively established, then it would logically follow that governments should work to prevent or to alleviate the effects of such events in the interests of self-preservation.

Raymond Pierre Hylton

• Further Reading

Avari, Burjor. *India—The Ancient Past: A History of the Indian Subcontinent from c. 7000 B.C. to A.D. 1200.* New York: Routledge, 2007. Evenhanded account that examines both major theories for the collapse of the Indus Valley culture, with the logical preponderance of evidence supporting environmental or climatic calamity, rather than outside invasion.

Diamond, Jared. *Collapse: How Societies Choose to Fail or Succeed.* New York: Penguin Books, 2006. Though the author concedes that climatic change is a significant factor in the demise of several civilizations, he emphasizes the impact of ill-advised decisions by the leaders and populaces as necessary contributing elements.

Fagan, Brian. *The Long Summer: How Climate Changed Civilization.* New York: Basic Books, 2005. Advances the theory that all the major developments of human civilization may be seen as coinciding with the lengthy warming period that followed the last global ice age.

Henderson, John S. *The World of the Ancient Maya.* Ithaca, N.Y.: Cornell University Press, 1997. Sets out unhesitatingly the probable role of climate-related subsistence crisis in triggering the abandonment of Mayan city-states.

Jones, Gwyn. *A History of the Vikings.* New York: Oxford University Press, 1969. Seminal study that establishes the pivotal role of Greenland's isolation and the onset of extreme global cooling to the subsistence crisis that overtook the westernmost Viking outposts.

Pike, Donald G. *Anasazi: Ancient People of the Rock.* Illustrated by David Muench. Palo Alto, Calif.: American West, 1974. Blames the Anasazi's decline in part on drought, but asserts that the depredations of nomads were a more significant factor.

Schele, Linda, and David Freidel. *A Forest of Kings: The Untold Story of the Ancient Maya.* New York: William Morrow, 1990. Extremely detailed description of the complexity of Mayan culture, including its language and religion. Scant and inconclusive discussion of the culture's decline.

Wheeler, Sir Mortimer. *The Indus Civilization.* 3d ed. New York: Cambridge University Press, 1968. Downplays the idea of climate change and human environmental blunders as causes for the decline of the Indus culture; strongly advocates the view that Aryan aggression was more decisive.

See also: Arctic peoples; Deforestation; Desertification; Easter Island; El Niño-Southern Oscillation; Greenland ice cap; Little Ice Age; Medieval Warm Period; Paleoclimates and paleoclimate change.

Clathrates

- **Category:** Chemistry and geochemistry

• Definition

A clathrate is a chemically constructed lattice structure in which one type of molecule traps and contains another type of molecule without forming a chemical bond. Clathrates may also be called gas hydrates (sometimes using the name of the gas, such as "methane clathrate"), host-guest complexes, or molecular compounds. They are sometimes referred to as "marsh gas."

The most common types of clathrates are those involving water trapping a gas, such as methane, ethane, propane, isobutene, butane, nitrogen, carbon dioxide (CO_2), or hydrogen sulfide. Methane trapped in water is the most common type of naturally occurring clathrate. Methane clathrates usually occur when organic matter in a low-oxygen environment is degraded by bacteria. This situation usually occurs under ice sheets in the ocean; usually, these structures are found in sediments. A clump of methane hydrate looks like a snowball, but at room temperature, the ball dissolves. It can even be lit on fire, as the methane inside the lattice structure burns.

• Significance for Climate Change

Because methane is one of the greenhouse gases (GHGs), gases that trap warmth on Earth's surface, the release of large amounts of methane could cause the Earth to become warmer. In the geologic past, sudden releases of large amounts of methane may have triggered abrupt climatic events. Geologists believe that about 635 million years ago, a large quantity of methane was released into the atmosphere from ice sheets that covered Earth. This release caused an abrupt, global warming, taking Earth from a cold, relatively stable climate to a very warm, still relatively stable climate. Scientists think this event quickly warmed the Earth by tens of degrees Celsius.

Sudden releases of methane could occur if either the temperature rises or the pressure falls on the sediment above the methane clathrate structure. Often, sediment continues to accumulate over the methane clathrate until the weight of the sediment causes the clathrate structure to become unstable, when it disintegrates into water and gas. The covering sediments then become unstable and release methane into the atmosphere. The methane reacts with oxygen to form CO_2, which can kill any animals that need oxygen.

The U.S. Geological Survey estimates that up to 8.5 million cubic kilometers of methane clathrate exist in the seafloor worldwide, more than in all other fossil energy resources combined, so methane clathrates are being investigated as a potential source of natural gas energy. However, getting to this energy source is dangerous, as the accidental release of methane into the atmosphere could be deadly in and of itself. In addition, a release of this sort could affect the global temperature or even cause tsunamis if landslides under the ocean were triggered. Safe methods of harvesting this resource will need to be developed, as methane can be very explosive. Deadly methane explosions have occurred in the past in mines in Harlan County, Kentucky, in 2006, and in Ulyanovskaya, Russia, in 2007. Methane can also cause an "exploding lake," such as Lake Kivu in Africa. There, the lake water interacts with volcanic gases to produce methane and CO_2, which are potentially deadly when released.

Harvesting methane from under ice sheets for fuel requires two different approaches, both of which are potentially dangerous. With the depressurization method, holes are drilled into a layer of methane hydrate just under the ice, which releases pressure and causes the methane to flow up a pipe. This approach uses less energy than the other approach, that of thermal injection. Thermal injection involves pumping hot water into a deposit of methane, which destabilizes the structure of the methane clathrate. A promising future approach involves injecting CO_2 into the hydrate formation, displacing the methane in the structure.

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- **Further Reading**

"Clathrate Hydrates: Icy Fuel Thawed with Antifreeze Proteins." *Canadian Chemical News*, May 1, 2006. Explains in detail what clathrate hydrates are and how they affect the environment. Includes illustrations and photos.

Kennedy, M., D. Mrofka, and C. von der Borch. "Snowball Earth Termination by Destabilization of Equatorial Permafrost Methane Clathrate." *Nature* 453 (May 29, 2008): 642-645. Describes how a large methane release in the past affected climate; explains how another such release could affect climate change now.

Kennett, J. P., ed. *Methane Hydrates in Quaternary Climate Change: The Clathrate Gun Hypothesis.* Washington, D.C.: American Geophysical Union, 2002. Uses varied sciences, such as paleoceanography, climate dynamics, paleobotany, biogeochemical cycling, analysis of methane hydrates (clathrates), and marine geology, to explain abrupt global warming.

Maynard, B. "Methane Hydrates: Energy Source of the Future?" *Popular Mechanics*, April, 2006. Explains methods of extracting methane as fuel. Includes maps and graphs.

Sloan, E. Dendy, Jr. *Clathrate Hydrates of Natural Gases.* Boca Raton, Fla.: CRC Press, 2008. Provides a historical overview of clathrate hydrates and discusses their structure and properties. Includes tables and illustrations.

Weber, E. *Molecular Inclusion and Molecular Recognition: Clathrates I.* New York: Springer, 1987. Classic textbook discussing clathrates and their chemical structure.

Weitemeyer, K. A., and B. A. Buffett. "Accumulation and Release of Methane from Clathrates Below the Laurentide and Cordilleran Ice Sheets." In *Global and Planetary Change.* Amsterdam, the Netherlands: Elsevier, 2006. Describes how ice-age cycles are associated with large fluctuations of methane, possibly due to clathrates, and how methane clathrates accumulate below ice sheets.

See also: Fossil fuel reserves; Fossil fuels; Greenhouse gases; Ice shelves; Methane.

Clean Air Acts, U.S.

- **Category:** Laws, treaties, and protocols
- **Date:** Enacted 1963, 1970, 1977, and 1990

The Clean Air Act of 1963 and its subsequent amendments have mandated reductions in various atmospheric pollutants, with Congress imposing increasingly stringent standards over time. Some of the provisions of the laws have limited anthropogenic contributions to climate change as well.

- **Background**

Air pollution has long been recognized as a problem in the United States. The passage of the Clean

Air Act (CAA) in 1963 provided federal support for efforts to reverse and control air pollution. In 1970, Congress passed the Clean Air Act Extension, amending the CAA to provide for strict national ambient air quality standards (NAAQSs) and their enforcement. The 1970 and later amendments have sought to reduce atmospheric ozone, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), hydrocarbons, lead, and particulate matter. The 1990 amendments also set provisions for toxic air pollutants. The legislation has been primarily aimed at protecting human health and preventing or reducing acid rain, rather than mitigating climate change.

• Summary of Provisions

The CAA of 1963 provided for federal help in dealing with air pollution but indicated few specifics and no standards for enforcement. The 1970 and 1990 CAA amendments have been the most important in establishing specific air pollution policies. Dating from the 1970 amendments, the Environmental Protection Agency (EPA) identified six air pollutants in the United States (and, by extension, worldwide): ozone, sulfur dioxide, nitrogen oxides, carbon monoxide, lead, and particulates. The EPA divided the United States into regions and established acceptable levels for each pollutant in each region in order to reduce pollutant levels nationwide. Some of these pollutants are generated by industries, such as the electric power industry, while others are generated by automobiles. Some of the pollutants, such as SO_2 and NO_x, lead to the production of acid rain, which harms human health, bodies of water into which the rain falls, buildings, and crops. The 1970 and 1977 amendments to the CAA led to reductions in electric power plants' production of SO_2 and NO_x, as the plants turned to low-sulfur coal or adopted technological fixes, such as scrubbers, that removed these gases from their emissions. Automobile makers modified their engines to burn unleaded gasoline, reducing lead emissions. Decreasing ozone and CO levels proved to be more difficult.

Because of the high cost of reducing emissions, the EPA adopted standards that enabled utilities with low SO_2 emissions to trade some of their polluting capacity to utilities that were unable to meet EPA standards codified in the 1977 amendments. The 1990 CAA went farther and allowed utilities to sell some of their excess capacity on the open market. This approach has led to overall reductions in SO_2 in the United States, although levels remain high in some areas.

Congress tightened standards for automobile emissions of the various pollutants with the 1977

Time Line of U.S. Clean Air Acts

Year	*Law*	*Provisions*
1955	Air Pollution Control Act	First U.S. law addressing air pollution and funding research into pollution prevention.
1963	Clean Air Act of 1963	First U.S. law providing for monitoring and control of air pollution.
1967	Air Quality Act	Established enforcement provisions to reduce interstate air pollution transport.
1970	Clean Air Act Extension of 1970	Established first comprehensive emission regulatory structure, including the National Ambient Air Quality Standards (NAAQS).
1977	Clean Air Act Amendment of 1977	Provided for the prevention of deterioration in air quality in areas that were in compliance with the NAAQS.
1990	Clean Air Act Amendment of 1990	Established programs to control acid precipitation, as well as 189 specific toxic pollutants.

Source: U.S. Environmental Protection Agency.

and 1990 amendments and directed that the EPA should continue to develop even more stringent standards if ambient air pollution was not reduced. The 1990 amendments to the CAA provided for new enforcement standards for 189 toxic air pollutants such as asbestos, benzene, mercury, or cadmium compounds, as well as providing for the phasing out of stratospheric ozone-depleting substances by 1996. These standards affected various aspects of American life, from oil refineries that emitted numerous toxins to building demolition.

The CAA has been directed toward improving the health of the American people through removing or reducing various air pollutants that have been judged to be harmful to human health and by extension harmful to the environment. It has been a top-down approach that mandated ambient air quality standards and that left it up to industry to achieve the technological means to meet these standards. The record of the CAA has been mixed, but there have been some notable successes, such as the reduction of lead in the atmosphere.

• Significance for Climate Change

The CAA in its various iterations has been directed toward improving human health, not dealing with climate change. Nonetheless, some of the standards of the CAA have also had an impact on the climate. In particular two greenhouse gases (GHGs), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs)—which deplete stratospheric ozone—have been regulated by the CAA.

With the 1970 amendments to the CAA, Congress mandated a reduction in NO_x in the atmosphere, which helps reduce nitrous oxide. Automobile exhaust and fertilizer containing nitrogen are major contributors of nitrous oxide to the atmosphere, and coal-burning power plants contribute other nitrogen oxides. Control of NO_x has been more difficult to achieve than has control of SO_2. The 1970, 1977, and 1990 CAA amendments have provided for progressively tougher standards for the emission of NO_x. The 1990 amendments, for example, provided for cutting nitrogen oxide emissions by an additional 1.8 million metric tons below the 1980 levels. Although N_2O has a lower presence in the atmosphere than do other GHGs such as carbon dioxide or methane, it is estimated to contribute slightly over 6 percent of the greenhouse effect worldwide, so reductions are important.

Nitrogen oxide compounds have long been products of industrial society, but production of CFCs has been of more recent vintage. CFCs are composed of chlorine, fluorine, and carbon atoms and are chemically almost inert. Because of this property, they came to be used as refrigerants, as well as propellants for aerosols such as deodorants. CFCs are also long-lived in the atmosphere, so once produced they will remain for a long time. When exposed to ultraviolet radiation in the upper atmosphere, CFC molecules break apart and free up chlorine atoms that, combined with oxygen in the stratosphere, help deplete the ozone layer.

Dating from the late 1970's, one CFC, CFC-11, was banned from use as a propellant. Because of the attractiveness of CFCs as refrigerants and solvents and the difficulty in obtaining substitutes, CFC-11 and two other CFC compounds (CFC-12 and CFC-113) continued in use in refrigerants, air conditioners, and industrial mechanisms. As the severity of the damage to the ozone layer became recognized, pressure built to ban or curtail the use of all CFCs. The 1990 amendments to the CAA mandated the elimination of new CFCs in the United States and provided for careful handling of CFCs in existing refrigerants and air conditioners so as to limit their escape into the atmosphere. Although some countries continue to make use of CFCs, the position of the United States as a major user made American reduction quite important. Although it will be quite some time before the holes in the Arctic and Antarctic ozone layers no longer exist, the reduction of additional CFC production has decreased further damage to the ozone layer.

In sum, the Clean Air Act and its various amendments have helped in dealing with climate change, although that generally was not their intent. The CAA has regulated two GHGs, limiting their production and use. In addition, the CAA has provided a precedent for congressional action dealing with other GHGs. Because the United States is a major producer of GHGs, any reduction in the production of these gases by that nation will have a large impact on climate change globally.

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• **Further Reading**

Blatt, Harvey. *America's Environmental Report Card*. Cambridge, Mass.: MIT Press, 2005. Provides a summary of the impact of U.S. policy on reducing air pollution and global warming.

Rosenbaum, Walter A. *Environmental Politics and Policy*. 7th ed. Washington, D.C.: CQ Press, 2008. Includes a chapter that places the CAA in the context of command-and-control environmental proctection.

Somerville, Richard C. J. *The Forgiving Air*. Berkeley: University of California Press, 1996. Useful discussion of the impact of the CAA on air pollution and climate change.

See also: Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Air quality standards and measurement; Chlorofluorocarbons and related compounds; Environmental law; Nitrous oxide; U.S. legislation.

Clean development mechanism

• **Category:** Laws, treaties, and protocols

The CDM allows industrialized nations to fund climate-friendly development in developing nations. It fosters cooperation between the industrialized and developing world, but by giving industrialized nations credit for their actions abroad, it allows them to do less to reduce emissions at home.

• **Key concepts**

Annex I parties: industrialized nations listed in Annex I of the UNFCCC

CDM project cycle: the registration and issuance process all CDM projects must go through in order to generate CERs

certified emissions reductions (CERs): credits for contributing to reduced emissions in developing nations that Annex I nations can substitute for domestic reductions

quantified emission limitation and reduction commitments (QELRCs): Annex I parties' reduction targets, as set out in Annex B of the Kyoto Protocol

• **Background**

Article 3 of the Kyoto Protocol commits developed countries identified in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC) to reduce their emissions of six greenhouse gases (GHGs). These reduction commitments, termed quantified emission limitation and reduction commitments (QELRCs), are spelled out in Annex B of the protocol. To help Annex I parties meet their commitments, three mechanisms were established: joint implementation, emissions trading, and the clean development mechanism (CDM). Under the CDM, developed countries can invest in or finance projects in developing countries that reduce or remove GHG emissions and use the reductions achieved toward meeting their own emissions targets.

• **The CDM Regime**

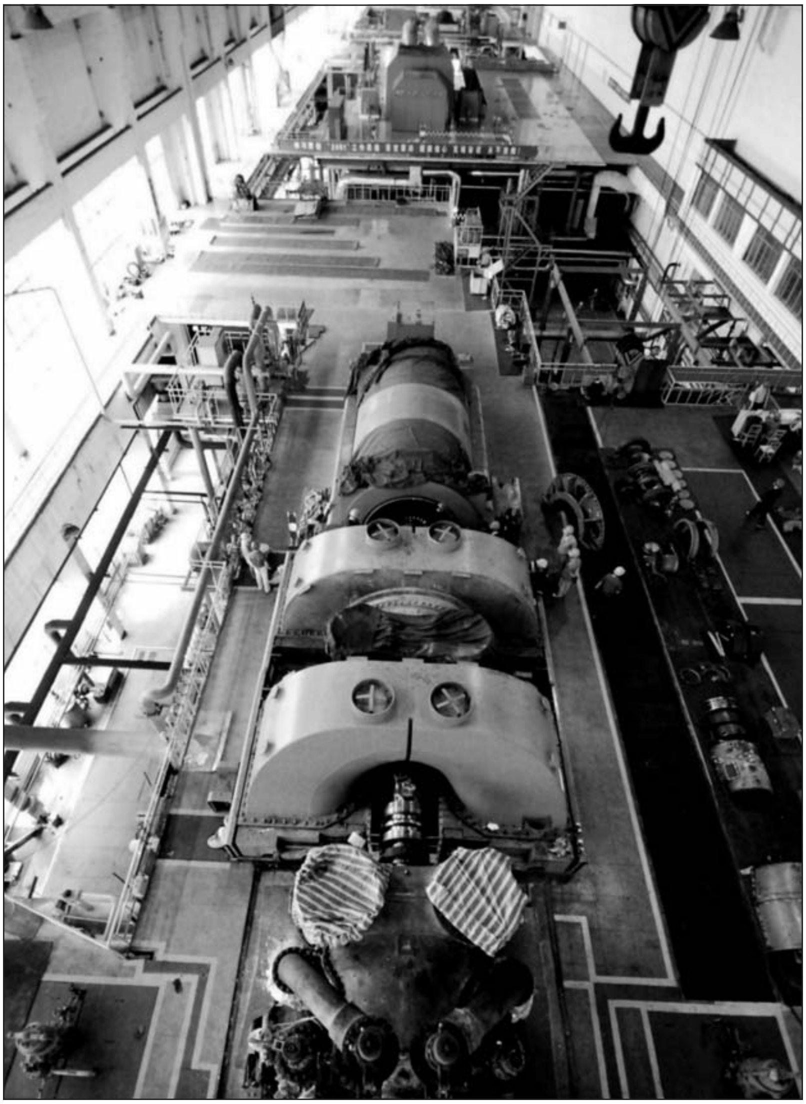
The CDM is a project-based mechanism under which projects in developing countries that result in lowered GHG emissions can generate certified emissions reductions (CERs), which developed countries can use to contribute to meeting their QELRCs. The mechanism was established by Article 12 of the Kyoto Protocol. That article sets out the aims of the CDM, which are to assist developing countries to achieve sustainable development and to contribute to the ultimate goal of the UNFCCC, as well as to assist developed countries to meet their QELRCs. The CDM is therefore intended to provide a dual benefit to the climate change regime: sustainable development benefits to developing countries and cost-effective emission reductions to developed countries. In addition to these, 2 percent of the proceeds of CDM projects are to be put into the Kyoto Protocol Adaptation Fund, to finance adaptation activities in developing countries.

Both public and private entities are allowed to participate in the CDM, but to do so they must be authorized by parties to the protocol. The CDM is overseen by an executive board, and under the authority and guidance of the Conference of the Parties to the Framework Convention on Climate

Change serving as the meeting of the Parties to the Kyoto Protocol (COP/MOP, or CMP).

- **Operation of the CDM**

Under the CDM, developed countries can invest in or finance projects in developing countries. These projects must result in a reduction or removal of emissions from the atmosphere additional to any that would have occurred in the absence of the projects. The difference between the emissions that would have been released (referred to as the baseline emissions) and those actually released, that is, the reductions or removals achieved by the project, are validated and certified by an independent body and issued by the CDM executive boards as CERs. Each CER represents 1 metric ton of carbon dioxide equivalent (CO_2e) reduction or removal achieved. That is, it represents either the reduction of 1 metric ton of atmospheric CO_2 or an amount of another GHG that has the same global warming potential (GWP) as 1 metric ton of CO_2.



In a clean development mechanism project, these generators in China's Jiujiang Power Plant were made more efficient, allowing them to burn less coal to generate the same amount of electricity. (Hu Guolin/Xinhua/Landov)

CERs, also referred to as carbon credits, can then be used by Annex I parties to contribute toward achieving their QELRCs. A CDM project can also be implemented unilaterally. In that case, the investment or financing for the project is provided by an entity in the host country itself, without the involvement of a developed country. The CERs generated by the project can then be sold on the carbon market by the investing entity. Again, Annex I parties can buy and use these CERs to contribute to meeting their targets.

- **An Example of a CDM Project**

An example of a registered CDM project is the West Nile Electrification Project, hosted by Uganda, with Finland, the Netherlands, and the International Bank for Reconstruction and Development as the investor entities. The project inter alia involves the installation and operation of a hydroelectric power plant to provide energy and displace the use of diesel-based electricity, as well as the installation and operation of a high-efficiency generator to displace low-efficiency diesel generators at isolated diesel stations and privately owned diesel generator sets. The project is expected to eliminate 36,210 metric tons of CO_2e annually.

• Operation and Provisions of the CDM

To participate in the CDM, countries must be parties to the Kyoto Protocol. In addition to this basic requirement, Article 12 of the protocol and Decision 3/CMP.1 (the third decision of the First Conference of the Parties serving as the meeting of the Parties, 2005) provide more detailed participation requirements that parties and projects must fulfill to be eligible for participation. Countries must designate national authorities, who serve within those countries as points of contact for information on the CDM. Developed countries have further requirements, including the need to comply with their methodological and reporting obligations under Articles 5 and 7 of the protocol. In addition, a CDM project must provide real, measurable, and long-term benefits related to climate change mitigation, including emission reductions or removals that exceed any that would occur in the absence of the project. For a project to be registered as a CDM project and generate CERs, it must go through a registration and issuance process, referred to as the CDM project cycle, to ensure that it satisfies these and other criteria.

• Participation in the CDM

There are 182 parties to the Kyoto Protocol. Of this number, around 135 have designated their national authorities, thus fulfilling the basic participation requirements of the CDM. As of October, 2008, 51 developing countries were hosting CDM projects and 16 developed countries had invested in the CDM, bringing the total participation to 67 parties. There were a total of 1,184 registered CDM projects.

• Status and Trends

Most of the 1,184 registered projects were hosted in Asia and the Pacific region, which had a total share of 65 percent of registered projects. This was followed by Latin America and the Caribbean region, with a total of 32 percent, and Africa, with less than 3 percent of the total. On a country-by-country basis, this distribution sees four countries accounting for about 70 percent of all registered projects. These are, in order of portfolio size, India, China, Brazil, and Mexico. This distribution of projects has been termed inequitable, and discussions are ongoing on ways of addressing this inequity. Several actions have been instituted to this end, such as the launch of the Nairobi Framework to catalyze the CDM in Africa.

• Context

The CDM arose from a proposal made by the government of Brazil for a clean development fund. This fund was to be replenished through compulsory contributions by developed countries that were in noncompliance with their emission reduction targets under the Kyoto Protocol. Countries welcomed this aspect of the fund for the flexibility it provided to developed countries unable to meet their targets and the potential financial benefits it provided to developing countries. Further negotiations led to agreement on the CDM, and its two core elements remain flexibility and cost-effectiveness for developed countries and financial investment and sustainable development benefits for developing countries.

Tomi Akanle

• Further Reading

Streck, Charlotte, and Jolene Lin. "Making Markets Work: A Review of CDM Performance and the Need for Reform." *European Journal of International Law* 19, no. 2 (2008): 409-442. Analyzes the operation of the CDM, highlighting some of its problems and suggesting ways of overcoming these problems.

United Nations Development Programme. *The Clean Development Mechanism: A User's Guide*. New York: Author, 2003. Examines the CDM and its rules and modalities; constitutes a guide on how to implement the CDM effectively.

Werksman, Jacob. "The Clean Development Mechanism: Unwrapping the Kyoto Surprise." *RECIEL* 7, no. 2 (1998). Describes the negotiations and circumstances leading up to the establishment of the CDM and examines the CDM's conceptual roots and basic provisions.

See also: Annex B of the Kyoto Protocol; Basel Convention; Baseline emissions; Certified emissions reduction; Emission scenario; Industrial emission controls; Kyoto lands; Kyoto mechanisms; Kyoto Protocol.

Clean energy

- **Category:** Energy

- **Definition**

Clean energy refers to any energy source whose use does not emit carbon dioxide (CO_2), or other pollutants or greenhouse gases (GHGs) that contribute to global warming. Examples of clean energy include solar energy, wind power, and hydroelectric power. Nuclear power is considered by some to be clean energy (it does not emit CO_2), but opponents point to the risk of radioactive contamination that it carries. Natural gas is essentially nonpolluting but emits CO_2 when burned. (Because methane has a much greater global warming potential than does CO_2, burning it reduces the total amount of CO_2 equivalent GHG in the world, despite generating a GHG.)

Solar power (or solar energy) is energy given off by the Sun. Humans harness only a tiny fraction of this energy (less than 0.0001 percent), as it is diffuse, is very difficult to trap, and can vary with seasonal and weather conditions. Photovoltaic and solar thermal technologies are the solar technologies most widely used for contemporary power generation. In a photovoltaic process, solar energy is used to generate electricity. Photovoltaic cells, or solar batteries, can be found in many home appliances, including calculators and watches. Each photovoltaic cell consists of two layers. When sunlight strikes the solar cell, electrons from the lower layer move toward the upper surface, creating an electrical potential between the layers. This potential provides an electrical current. Electrons from the upper layer flow through an electrical device (for example, a small motor) back to the lower layer, thus providing energy for the device. These cells can be arranged into panels that generate enough electricity to power an entire family house.

Another solar technology, known as a solar thermal system, uses sunlight to generate heat. These systems are very popular in warm, sunny climates and have been used to provide hot water for homes and factories for decades. A typical solar collector for heating water consists of a shallow box with a plastic top and a black bottom. Glass or plastic tubes filled with water run through the inside of the box. The black bottom absorbs light and conveys the heat to the water within the tubes; the clear top of the box prevents heat from escaping. This technology can also be used to generate electricity, using a technology called concentrating solar power. This technology deploys thousands of dish-shaped solar concentrators attached to an engine that converts heat to electricity.

Wind power is the conversion of wind energy into useful forms of energy, mainly electricity. The design of wind turbines is based on wind-driven propeller blades. Turbine design has recently improved, allowing much more electricity to be generated at competitive prices. Europe is the world's number one user of wind power, followed by the United States. Hydropower is the most widely used form of clean energy. In hydropower dams, water under high pressure flows through turbines and generates electricity.

- **Significance for Climate Change**

In order to reduce global warming, the United States and other countries are making a major commitment to develop clean energy sources that generate little or no CO_2. For decades, clean energy technologies were too expensive to compete with fossil fuels. Concerns about global warming, coupled with the high prices of oil, have pushed forward the use of clean (or green) energy technologies. In the first years of the twenty-first century, clean energy supplied less than 7 percent of the world's energy consumption, but the potential of such technologies was enormous. The amount of solar energy reaching Earth exceeds by six thousand times humanity's global energy consumption. In the United States, the potential for the expansion of wind power is enormous as well, especially in the windy Great Plains area. Hydropower already

From left: Former White House chief of staff John Podesta, Senate Majority Leader Harry Reid, former senator Timothy Wirth, and energy executive T. Boone Pickens speak to the press about the need to develop clean energy technologies. (Jonathan Ernst/Reuters/Landov)

generates about 17 percent of the electricity used around the world.

The operation of wind turbines and solar power stations does not consume fossil fuels and does not produce GHG emissions. However, wind turbines and solar panels require the use of some fossil energy during construction and transportation. These initial CO_2 emissions are not significant compared to the environmental benefits of using clean wind and solar power. Wind turbines and solar panels do not require deforestation of land, so they do not interfere with forests' ability to sequester CO_2. In addition, land beneath wind turbines can be used for farming. Turbines may also be placed offshore.

Solar photovoltaic cells and collectors can be installed on the roofs and walls of homes and offices, as well as in the desert. Wind power is one success story involving the use of clean energy to reduce CO_2 emissions; the number of wind turbines used for the generation of electricity increased dramatically in the first decade of the twenty-first century. Prices for wind power decreased until they were very close to the price of electricity generated by burning coal, a major CO_2 producer. This decrease in price may allow replacing coal power with wind-generated power in the future. Some data indicate microclimate change around big wind farms, but these findings require additional studies.

Hydropower is also ideal for clean electricity generation. It does not produce CO_2 directly. However, hydropower stations are criticized, because they change the environment indirectly, in a way that may produce substantial amounts of both CO_2 and methane, a very powerful GHG. The water trapped in flooded areas directly upstream of hydropower dams contains a large amount of decaying plant material. This plant material is metabolized by microorganisms, leading to the formation of CO_2 and methane. However, hydropower technologies such as tidal energy exist that do not generate GHG emissions during use. Tidal power uses the energy generated by the daily ebb and flow of ocean tides. This energy is derived directly from the gravitational pull of the Moon and, to a lesser extent, the Sun. Large tidal power plants exist in France, Canada, and the United States.

Sergei Arlenovich Markov

• **Further Reading**

Kammen, Daniel M. "The Rise of Renewable Energy." *Scientific American* 295, no. 3 (September, 2006): 84-93. Describes different clean energy technologies and their future.

Nebel, Bernard J., and Richard T. Wright. *Environmental Science: Towards a Sustainable Future*. Englewood Cliffs, N.J.: Prentice Hall, 2008. Several chapters portray clean energy, its real-world applications, and its future.

Touryan, Ken J. "Renewable Energy: Rapidly Maturing Technology for the Twenty-first Century." *Journal of Propulsion and Power* 15, no. 2 (March/April, 1999): 163-174. Comprehensive review article that explains different types of clean energy technologies.

See also: Biofuels; Coal; Energy from waste; Energy resources; Ethanol; Fossil fuels; Fuels, alternative; Geothermal energy; Hydroelectricity; Hydrogen power; Nuclear energy; Renewable energy; Solar energy; Tidal power; Wind power.

Climate and the climate system

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Climate is an aggregation of near-surface atmospheric conditions and weather phenomena over an extended period in a given area. It is characterized by statistical means and such variables as air temperature, precipitation, winds, humidity, and frequency of weather extremes. The time period is typically thirty years, as described by the World Meteorological Organization (WMO).

World climate is classified by either the empirical method, focusing on the effects of climate, or the genetic method, emphasizing the causes of climate. The empirical Köppen system, based on annual mean temperature and precipitation combined with vegetation distribution, divides world climate into five groups: tropical, dry, temperate, continental, and polar. Each group contains subgroups, depending on moisture and geographical location.

The genetic Bergeron, or air-mass, classification system is more widely accepted among atmospheric scientists, as it directly relates to climate formation and origin. Air-mass classification uses two fundamental attributes—moisture and thermal properties of air masses. Air masses are classified into dry continental (C) or moist maritime (M) categories. A second letter is assigned to each mass to describe the thermal characteristic of its source region: P for polar, T for tropical, and (less widely used) A for Arctic or Antarctic. For example, the dry cold CP air mass originates from a continental polar region. Sometimes, a third letter is used to indicate the air mass being cold (K) or warm (W) relative to the underlying surface, implying its vertical stability.

• **Climate System**

In a broad sense, climate often refers to an intricate system consisting of five major components: the atmosphere, hydrosphere, cryosphere, land surface (a portion of the lithosphere), and biosphere, all of which are influenced by various external forces such as Earth-Sun orbit variations and human activities. The atmosphere, where weather events occur and most climate variables are measured, is the most unstable and rapidly changing part of the system. The Earth's atmosphere is composed of 99 percent permanent gases (nitrogen and oxygen) and 1 percent trace gases, such as carbon dioxide (CO_2) and water vapor. All weather and climate phenomena are associated with the trace gases called greenhouse gases (GHG). Long-term increases in GHG concentration warm the climate, while day-to-day variations in atmospheric thermal and dynamic structures are responsible for daily weather events.

The hydrosphere comprises all fresh and saline waters. Freshwater runoff from land returning to the ocean influences the ocean's composition and circulations, while transporting a large amount of chemicals and energy. Because of their great thermal inertia and huge moisture source, oceans regulate the Earth's climate. The cryosphere consists of those parts of the Earth's surface covered by permanent ice in polar regions, alpine snow, sea ice, and permafrost. It has a high reflectivity (albedo), reflecting solar radiation back into space, and is critical in driving deep-ocean circulations.

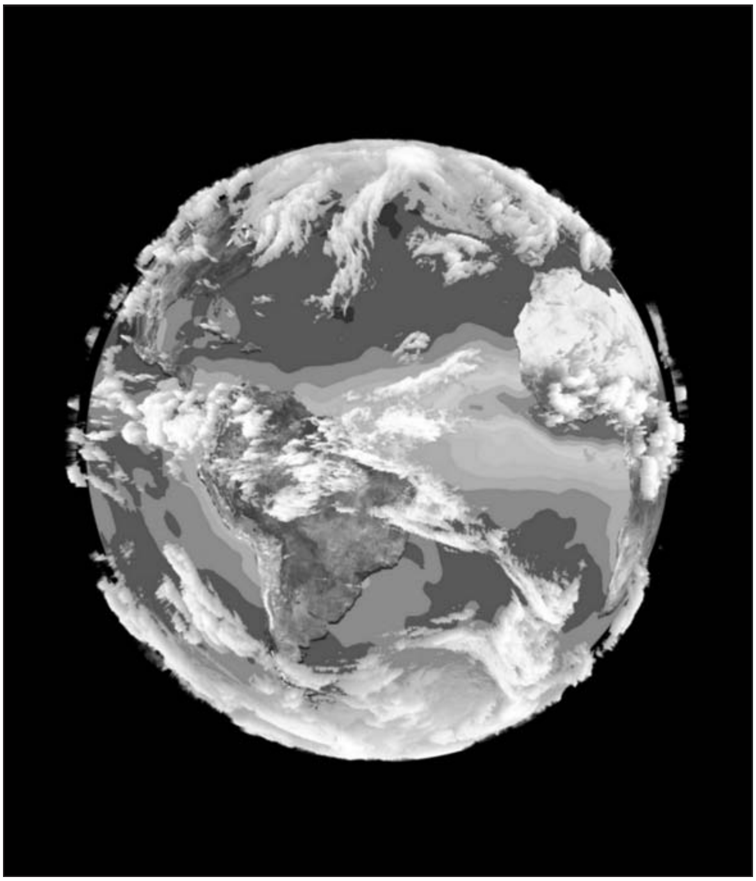
Land surfaces and the terrestrial biosphere control how energy received at the surface from the Sun is returned to the atmosphere, in terms of heat and moisture. The partitioning between heating and moistening the atmosphere has profound implications for the initiation and maintenance of convection and thus for precipitation and temperature. Marine and terrestrial biospheres have major impacts on the atmosphere's composition through the uptake and release of GHG during photosynthesis and organic material decomposition.

- **Interactions Among Climate System Components**

The individual components of the climate system are linked by physical, chemical, and biological interactions over a wide range of space and time scales. The atmosphere and oceans are strongly coupled by moisture and heat exchange. This coupling is responsible for El Niño, the North Atlantic Oscillation, and the Pacific Decadal Oscillation, resulting in climate swings on interannual to interdecadal scales. The terrestrial biosphere and atmosphere exchange gases and energy through transpiration, photosynthesis, and radiation reflection, absorption, and emission.

These interactions form the global water, energy, and carbon cycles. The hydrologic cycle leads to clouds, precipitation, and runoff, redistributing water among climate components. Oceans and land surfaces absorb solar radiation and release it into the atmosphere by diffusion and convection. Global carbon and other gas cycles are completed by photosynthesis fixing CO_2 from the atmosphere and depositing it into the biosphere, soil, and oceans as organic materials, which are then decomposed by microorganisms and released back into the atmosphere.

Any change or disturbance to the climate system can lead to chain reactions that may reinforce or suppress initial perturbation through interactive feedbacks. If the climate warms, melting of glaciers and sea ice will ac-



A composite satellite image depicting Earth's interrelated climate systems. (NASA) celerate, and the surface will absorb more solar radiation, further enhancing warming. On the other hand, warmer air temperatures result in more moisture in the atmosphere, increasing cloud cover, which increases albedo and reduces the absorbed solar radiation. This leads to cooling, compensating for the initial warming. There exist many such positive and negative feedback mechanisms, which makes the causality of climate change complex.

Zaitao Pan

• Further Reading

Ahrens, Donald C. *Meteorology Today: An Introduction to Weather, Climate, and the Environment*. 9th ed. Belmont, Calif.: Brooks/Cole, 2009. Textbook with many colorful illustrations of how climate and weather systems work. The last two chapters present concise summaries of the climate system and changes.

Bridgman, Howard A., and John E. Oliver. *The Global Climate System: Patterns, Processes, and Teleconnections*. New York: Cambridge University Press, 2006. Covers regional climate anomalies, global teleconnections, recent climate change, and human impacts upon the climate system.

Hartmann, Dennis L. *Global Physical Climatology*. San Diego, Calif.: Academic Press, 1994. Rigorous presentation of the physical principles that govern the energetics and gas exchanges within the climate system; focuses on the atmosphere.

McKnight, Tom L., and Darrel Hess. *Physical Geography: A Landscape Appreciation*. 9th ed. Upper Saddle River, N.J.: Prentice Hall, 2008. Covers all five components of the climate system; chapter 8 is devoted to climatic zones and types.

Oliver, John E., and John J. Hidore. *Climatology: An Atmospheric Science*. 2d ed. Upper Saddle River, N.J.: Prentice Hall, 2002. A descriptive textbook mainly for nonscientists who have a basic working understanding of the climate system.

See also: Abrupt climate change; Climate change; Climate feedback; Climate lag; Climate models and modeling; Climate prediction and projection; Climate sensitivity; Climate variability; Climate zones; Climatology; Continental climate; Global climate.

Climate change

• Category: Meteorology and atmospheric sciences

While Earth's climate is constantly changing in various ways, the planet tends to experience long-term trends toward either warming or cooling. The potential or actual contribution of postindustrial human activity to climate change, the consequences of that contribution, and the proper response to those consequences remain matters of crucial importance and signficant controversy.

• Key concepts

anthropogenic: caused by human activity

climate: long-term, average, regional or global weather patterns

emission scenario: a set of posited conditions and events, involving climatic conditions and pollutant emissions, used to project future climate change

greenhouse gases (GHGs): trace atmospheric gases that trap heat on Earth, preventing it from escaping into space

proxy: an indirect indicator of past climate conditions

weather: the set of atmospheric conditions obtaining at a given time and place

• Background

Climate is characterized by mean air temperature, humidity, winds, precipitation, and frequency of extreme weather events over a lengthy period of time, at least thirty years. Global warming is an example of climate change, and so are increases in the magnitude or frequency of floods and droughts experienced in many parts of the world during the past several decades. Climate change includes both natural variability and anthropogenic changes.

Although climate changes on longer than millennial timescales are natural, the global warming of the past 150 years or so is likely anthropogenic, according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) of the United Nations. The United Nations is concerned primarily with anthropogenic climate change, both because it poses a threat to global security and because it can be altered by altering human and governmental behavior. For this reason, the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as

> a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

• Climate Change Detection

Earth's atmosphere is chaotic, and weather can change dramatically in a matter of days or even hours. Temperature in some places may rise or fall by 20° Celsius or more in one day. On the other hand, climate, as the average of years of weather conditions, changes on a much smaller scale. For example, the global mean surface air temperature increased by only 0.6° Celsius during the twentieth century. By the same token, such a seemingly small increase can have extremely significant effects.

The climatic increase in mean surface air temperature is computed from tens of thousands of weather station records spanning decades. The difficulty of ensuring data continuity in time, uniformity in space, and constancy in observational methods poses serious challenges to climatologists. To discern slight trends amid diverging data, scientists use advanced mathematical tools to synchronize all observations, adjust discontinuities, and filter out local influences such as heat island effects.

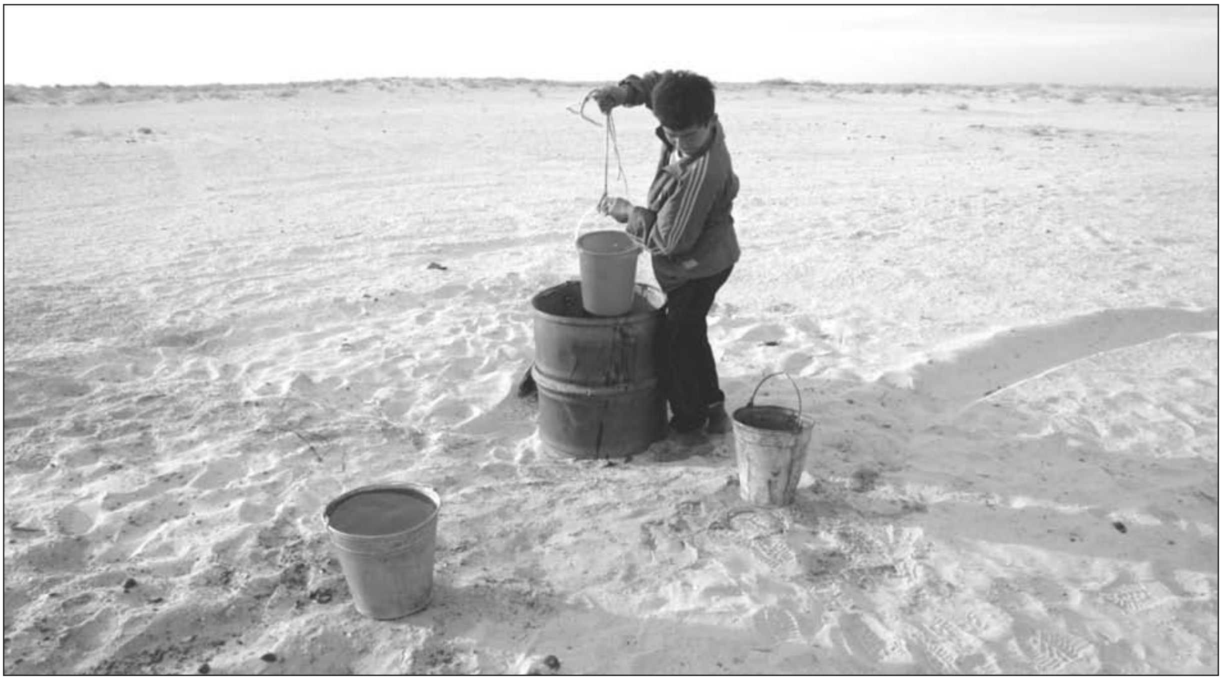
Modern climate change has generally been observed with in situ thermometers and, later, with remote sensing devices. Paleoclimate change (change before about 1850) is inferred from proxy climate data. Tree rings can provide evidence of temperature and precipitation history for two to three thousand years, while tiny air bubbles trapped in the Antarctic ice deposits provide data on ice ages hundreds of thousands of years in the past. Pollen and zooplankton cells in river and sea sediments also contain useful proxy climate data.

Detecting climate change depends on individual variables. Temperature change is the most reliable such variable, because its internal variability is small and it is more widely observed than other variables. Long-term precipitation changes are more difficult to discern, because rain- and snowfall vary so greatly from one year to the next. The intensity and frequency of extreme weather events such as hundred-year floods are even more difficult to detect, because these events are rare, so a significant data set must cover many years.

Instrument records from land stations and ships indicate that the global annual mean surface air temperature rose during the twentieth century. The warming occurred more quickly in high latitudes than it did in the tropics. It was also faster over land than it was over the ocean and faster in the Northern Hemisphere than in the Southern Hemisphere. Winters warmed more than did summer, and nights warmed more than did days. Contemporary daily temperature ranges have narrowed, precisely because nights have warmed more than have days.

Extensive heat waves and intense floods have become more frequent in recent decades. Globally, the average number of tropical storms (about ninety per year) changed little during the twentieth century, although historical data are poor for some regions. In the North Atlantic, where the best records are available, there has been a clear increase in the number and intensity of tropical storms and major hurricanes. From 1997 to 2006, there were about fourteen tropical storms per year, including about eight hurricanes in the North Atlantic, compared to about ten storms and five hurricanes between 1850 and 1990.

On timescales of thousands of years or greater, the Earth's climate has been both warmer and much colder than it is today, although temperatures around the turn of the twenty-first century were the warmest in the past two thousand years. Based on ice-core proxy data, four major global glaciations occurred in past 450,000 years, about one every 100,000 years, correlating well with the cyclical variations in Earth's orbit known as the Milanković cycles. Various ice ages occurred, with the most recent one ending about 11,500 years ago. Before that, much of North America was covered in permanent ice. Over the course of Earth's history, its temperature has swung more than 10° Celsius between cold and warm modes.



In the bed of what was once the Aral Sea, a Kazakh villager pulls water from a well sunk into the sandy, desert ground. (Shamil Zhumatov/Reuters/Landov)

• Climate Change Scenario

Future climate changes are predicted by climate models based on assumed greenhouse gas (GHG) emission scenarios. The scenarios range from high fossil fuel consumption, resulting in atmospheric carbon dioxide (CO_2) concentration of 800 parts per million, to low consumption, with CO_2 concentration reaching 550 parts per million. The reliability of these predictions depends on future global environmental, energy, and climate policy, as well as the accuracy of the models.

Most models project that climate change will accelerate during the twenty-first century and that the global average temperature will increase by between 1.8° Celsius and 4.0° Celsius by 2100. As in the past, warming will be more pronounced in the polar Northern Hemisphere during winter. Precipitation amounts are likely to increase in high latitudes and to decrease in most subtropical lands. Heat waves and heavy precipitation events will very likely increase in frequency. With warmer oceans, future tropical storms will become more intense, with greater peak wind speeds and heavier precipitation.

• Context

Climate change may be attributed to natural processes or to human activity. Natural factors include the Earth's internal processes, such as volcanic eruptions, as well as external parameters, such as solar luminosity and Earth's orbital pattern around the Sun. Anthropogenic activity includes GHG and aerosol emission and, to a lesser degree, changes in land use. Separating natural and anthropogenic causes of climate change is challenging, if it is possible at all. Since no controlled laboratory setting exists in which to conduct climate change experiments, climate scientists have developed computer models based on the laws governing climate systems. By altering model settings, one can simulate natural and anthropogenic effects on climate, separately or in combination, thereby tracing the causes of climate change. In general, on scales of a decade to a century, climate change is attributable to atmosphere-ocean interaction and to human activity. On scales of millennia to hundreds of thousands of years, the variations in Earth's orbit directly controls the planet's climate. This orbit is described by the Milanković cycles, which repeat every 20,000 to 100,000 years. Beyond the million-year timescale, tectonic drift is likely the main driver of climate change.

Zaitao Pan

- **Further Reading**

Easterling, David R., et al. "Maximum and Minimum Temperature Trends for the Globe." *Science* 277 (July 18, 1997): 364-367. Pioneering work on asymmetric warming between day and night.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Pools and synthesizes the most authoritative opinions on climate change from thousands of scientists worldwide. Reviews extensively past observations and future scenarios published in the early twenty-first century.

Mann, Michael E., Raymond S. Bradley, and Malcolm K. Hughes. "Global-Scale Temperature Patterns and Climate Forcing over the Past Six Centuries." *Nature* 392 (April 23, 1998): 779-787. The source of the famous and controversial "hockey stick" plot of the global warming trajectory, arguing for a sudden increase in temperature in the twentieth century.

Nakicenovic, N., et al., eds. *Special Report on Emission Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.* New York: Cambridge University Press, 2000. Provides the baselines for GHG emission scenarios that are used globally to conduct climate change simulations.

National Research Council. *Abrupt Climate Change: Inevitable Surprises.* Washington, D.C.: National Academies Press, 2002. Comprehensive review of scientific theory and evidence for abrupt climate change.

United Nations Framework Convention on Climate Change, Article 1: Definitions. Geneva, Switzerland: United Nations, 1992. Gives specific definitions of climate-change-related terminology.

See also: Abrupt climate change; Climate and the climate system; Climate feedback; Climate models and modeling; Climatology; Global climate; Global dimming; Greenhouse effect; Hockey stick graph.

Climate Change Science Program, U.S.

- **Category:** Organizations and agencies
- **Date:** Established 2002
- **Web address:** http://www.climatescience.gov/

- **Mission**

The U.S. Climate Change Science Program (CCSP) is an interagency U.S. government program established by President George W. Bush that coordinates and publishes thirteen federal agencies' research related to the Earth's climate and to human impacts on climate change. The CCSP facilitates communication among the thirteen agencies, as well as coordinating their publications. The CCSP was established in 2002 to bring together scientific research from agencies including the Environmental Protection Agency, the National Science Foundation, the Smithsonian Institution, the Department of Energy, and the Department of Agriculture.

- **Significance for Climate Change**

The CCSP has been criticized as an effort by the Bush administration to delay practical responses to global warming. The program's integrity was questioned when, in 2005, a CCSP scientist accused White House officials of editing draft reports before they were made public in order to downplay references to global warming. However, in 2006, the CCSP published a final report that resolved inconsistencies created by scientific research that seemed to disprove global warming. The report confirmed that the Earth's temperature was measurably increasing and that human activity contributed to climate change.

The 1990 Global Change Research Act requires the White House to provide Congress with an assessment of climate change every four years. Through the CCSP, the Bush administration opted instead to produce twenty-one synthesis and assessment reports. In November, 2006, environmental groups sued the administration for failing to comply with the 1990 law, and White House officials agreed to publish all twenty-one reports by May, 2008. By that date, however, only six reports had been completed. These reports provided scientific analyses of temperature measurements, the possible effects of increased or stabilized amounts of greenhouse gases in the atmosphere, North American production of carbon dioxide, methods for protecting ecosystems from the effects of climate change, anticipated extreme weather conditions, and the effects of climate change on natural resources and energy production.

The CCSP confirmed that global warming was a scientifically provable phenomenon, documented trends in global warming, and predicted its large-scale effects. In 2008, the Senate called for the CCSP to shift its focus away from global trends, data collection, and scholarly communication. Instead, the program was tasked with developing practical ways local governments and policy makers across various climatic regions of the United States could plan for and respond to climate change.

Maureen Puffer-Rothenberg

See also: Center for the Study of Carbon Dioxide and Global Change; Energy Policy Act of 1992; National Climate Program Act; National Research Council; U.S. energy policy; U.S. legislation.

Climate engineering

- **Category:** Science and technology

- **Definition**

Climate engineering is a species of geoengineering, an expansive field that ranges over a wide variety of subjects, combining the study of Earth's atmosphere, lithosphere, and biospheres with practical engineering principles. Also termed planetary engineering or macro engineering, the practice was suggested in the 1970's by Cesare Marchetti, who envisioned mitigating climatic impacts from burning fossil fuels by injecting carbon dioxide (CO_2) deep into the ocean. The term geoengineering then started to appear in publications by the National Academies of Science and entered the conventional climate change debate.

Practitioners of geoengineering or climate engineering develop technologies for the large-scale, intentional manipulation of the global environment. The threat represented by the greenhouse effect has generated international concern among politicians, policy makers, scientists, and engineers, who are continuously trying to fight global climate change and control warming. Climate engineering has gained a great deal of attention worldwide as a result of its potential to combat global warming. Goals of such engineering are to reduce the amount of solar radiation absorbed by the Earth, control the atmosphereic concentration of CO_2, and maneuver the ocean-atmospheric system by redirecting heat.

- **Methods of Climate Engineering**

Important climate engineering technologies and goals include use of atmospheric aerosols, CO_2 sequestration, re-icefication of the Arctic, use of ocean-cooling pipes, cloud seeding, genetically modified CO_2-eating trees, space mirrors, and glacier blankets. Use of atmospheric aerosols and CO_2 sequestration have gained the greatest reputation in the scientific community.

Aerosols are microscopic particles floating in the atmosphere. The chemical composition of aerosols can vary widely; however, the sulfate aerosols have aroused particular concern. There are two main types of atmospheric aerosols that influence the Earth's climate. Natural aerosols result from volcanoes, wildfires, desert dust, and terrestrial and marine biogenic activity. Anthropogenic aerosols include smoke particulates from burning fossil fuels and tropical forests, as well as by-products from industrial activity. Sulfate aerosols influence the global climate by scattering and absorbing solar radiation, increasing the albedo, and modifying the size and duration of clouds, which in turn produce a global cooling effect.

Research suggests that it might be possible to increase Earth's albedo and compensate for global warming by adding aerosols to the atmosphere. Mikhail I. Budyko for the first time proposed injecting sulfate aerosols into the atmosphere to create an artificial volcano effect. David W. Keith's analysis has indicated that about 1.5 to 10.0 teragrams of sulfate per year would balance the effect of a doubled atmospheric CO_2 concentration. The most serious potential side effects of Budyko's proposal would be alteration of atmospheric chemistry, ozone layer depletion, and whitening of the daytime sky, which would all destabilize Earths ecosystems in ways both predictable and unpredictable.

The enhanced greenhouse effect due to fossil fuel combustion can be reduced by capturing CO_2 emissions from industrial power plants and sequestering them. Contemporary climate engineering studies focus on technologies that will extract and compress CO_2 from power plants and store them in carbon reservoirs or carbon sinks. The CO_2 extraction and capture technologies, which involve precombustion, postcombustion, oxyfuel combustion, and industrial separation (such as natural gas processing and ammonia production), are expensive, require substantial energy, and remain mostly in the research and development phase.

Carbon sinks can be classified as biological, geologic, or oceanic. Carbon from fossil fuel combustion can be sequestered in geologic sinks such as coal, oil, and gas fields and saline aquifers. The Intergovernmental Panel on Climate Change (IPCC) estimates that there is enough capacity worldwide permanently to store as much as 1.1 trillion metric tons of CO_2 underground in geological formations. CO_2 can be removed biologically from the atmosphere via photosynthesis, afforestation, or changes in farming practices, as well as restoration of phyto-

In a modest example of climate engineering, Chinese farmers plant wheat straw at the edge of the Mu Us Desert. Since the 1970's, farmers in this area have transformed more than 470,000 hectares of desert. (Xinhua/Landov) plankton by seeding the ocean surface with micronutrients such as nitrates, phosphates, silica, and iron. Conversely, such increased photosynthesis could increase CO_2 emissions, deplete oxygen, and trigger climate warming.

The third and greatest carbon sink on Earth is the ocean, which balances atmospheric CO_2 levels. About 80 percent of atmospheric CO_2 is absorbed by the oceans on an exponential timescale of about three hundred years. This timescale can be reduced by direct disposal of CO_2 in the deep ocean (via pipelines or through dumping from ships) or in geological formations beneath the ocean bed. Accomplishing such sequestration requires a thorough understanding of the feasibility, efficiency, and environmental consequences of such a project.

• Significance for Climate Change

Climate engineering appears to be a potential solution to the global warming crisis. However, great caution needs to be taken before attempting any large-scale manipulation of the global climate, as the climate system is extremely complex and chaotic. Moreover, the nations or powers that engage in climate engineering are not necessarily the ones that will suffer the greatest damage should that engineering go awry. Thus, various political and ethical debates arise over whether geoengineering should be considered as a viable option to ameliorate the effects of climate change.

Arpita Nandi

• Further Reading

Brovkin, Victor, et al. "Geoengineering Climate by Stratospheric Sulfur Injections: Earth System Vulnerability to Technological Failure." *Climatic Change*, September 17, 2008. Uses a climate-carbon-cycle model of intermediate complexity to investigate situations in which injected stratospheric sulfur was used as a measure to balance CO_2-induced global warming.

Intergovernmental Panel on Climate Change. *Carbon Dioxide Capture and Storage: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Edited by Paul Freund et al. Geneva, Switzerland: Author, 2005. This extensive report discusses the options for capturing and storing anthropogenic CO_2 emissions.

Keith, David W. "Geoengineering and Carbon Management: Is There a Meaningful Distinction?" In *Greenhouse Gas Control Technologies: Proceedings of the Fifth International Conference*, edited by D. Williams et al. Collingwood, Vic.: CSIRO, 2001. Discusses attempts to manage and mitigate CO_2 production from a geoengineering perspective.

Marchetti, Cesare. "On Geoengineering and the CO_2 Problem." *Climatic Change* 1, no. 1 (March, 1977): 59-68. Prevention of CO_2 emissions through physical capture of CO_2 from fuel power plants was first proposed by Marchetti. He argues here that CO_2 can be sequestrated into suitable sinking thermohaline currents that would carry and spread it into the deep ocean.

Rasch, Philip J., Paul J. Crutzen, and Danielle B. Coleman. "Exploring the Geoengineering of Climate Using Stratospheric Sulfate Aerosols: The Role of Particle Size." *Geophysical Research Letters* 35 (2008). Investigates how the amount and size of atmospheric sulfur aerosols affect the climate system.

See also: Anthropogenic climate change; Human behavior change; Reservoirs, pools, and stocks; Sequestration; Sinks; Sulfate aerosols; Technological change.

Climate feedback

• **Category:** Meteorology and atmospheric sciences

Negative climate feedback helps preserve the Earth's climate in its existing state, whereas positive feedback accelerates changes, creating potential tipping points beyond which global warming or cooling becomes extremely difficult to reverse. Understanding both types of feedback is necessary to develop adequate climate policies.

• Key concepts

aerosols: tiny particles or liquid droplets suspended in the atmosphere; some, such as sea salt, are natural, while others, such as soot from power plants, are of human origin

albedo: the extent to which an object reflects radiation; the reflectivity of objects with regard to incoming solar radiation

climate forcing: factors that alter the radiative balance of the atmosphere (the ratio of incoming to outgoing radiation)

greenhouse gases (GHGs): gases (or vapors) that trap heat in the atmosphere by preventing or delaying the outward passage of long-wavelength infrared radiation from the Earth's surface out to space

infrared radiation: radiation with wavelengths longer than those of visible light, felt by humans and animals as heat

lapse rate: the change in a variable with height, often used to discuss changes in temperature with altitude in a context of climate change

radiative balance: the balance between incoming and outgoing radiation of a body in space, such as Earth

• Background

Like all planets, the Earth is bombarded by radiation from the Sun, stars, and other space-based sources of energy. Eventually, that energy is returned to space. Incoming and outgoing radiation must ultimately balance out, in conformity with the first law of thermodynamics, the law of conservation of energy. In the case of the Earth, which has a significant atmosphere and varied surface geography, the pathways by which radiation reaches the surface and is radiated back out to space are somewhat convoluted. Some incoming radiation is reflected back to space by clouds and particles in the atmosphere before it reaches the ground, some is reflected back toward space at ground level, and some is absorbed and then reradiated away in the form of long-wave, or infrared, radiation. Some of this reradiated infrared radiation is bounced back toward the ground by atmospheric gases or water vapor before it eventually makes its way back into space. Still, over time, the total Earth-atmosphere system is said to be in radiative balance.

Factors that can alter Earth's radiative balance are called "climate forcings" and "climate feedbacks." Understanding climate forcings and feedbacks is at the heart of understanding how greenhouse gases emitted into the atmosphere might affect future temperature trends. Climate feedbacks are particularly important to understand because computer models projecting future warming incorporate assumptions about such feedbacks (especially water vapor) that significantly elevate predicted temperature increases due to greenhouse gas emissions.

• Climate Forcing

One cannot understand climate feedbacks without understanding climate forcings. A climate forcing (technically a "radiative forcing") is something that exerts a direct effect on the radiative balance of the Earth's atmosphere—that is, something that changes the balance of incoming versus outgoing radiation either permanently or transiently. Forcings include incoming solar radiation, the heat-retaining ability of greenhouse gases present naturally in the atmosphere, human greenhouse gas emissions and conventional air pollutants, changes in land use that might alter the reflectivity of the Earth's surface, and more. The Intergovernmental Panel on Climate Change (IPCC) identifies nine major radiative forcing components, some of which are considered well understood, and others less so. Forcings identified by the IPCC include the greenhouse gases, ozone, stratospheric water vapor, surface albedo, aerosols, contrails, and solar irradiance.

• Climate Feedback

Climate feedbacks are secondary changes to the radiative balance of the climate stemming from the influence of one or another climate forcing. Such climate feedbacks may be either positive or negative; a positive feedback would amplify the effect of a change in a given climate forcing, while a negative feedback would damp down the effect of a change in a given climate forcing. Thus, a change in the atmosphere's water vapor content could cause greater cloudiness, which could, depending on the type of clouds, constitute a positive or negative feedback.

According to the National Research Council (part of the U.S. National Academies of Science), climate feedbacks that primarily affect the magnitude of climate change include clouds; atmospheric water vapor; the lapse rate of the atmosphere (defined as the change in temperature with altitude); the reflectivity, or albedo, of ice masses; biological, geological, and chemical cycles; and the carbon cycle. Feedbacks that primarily affect temporary responses of the climate include ocean heat uptake and circulation feedbacks. Finally, feedbacks that mostly influence the spatial distribution of climate change include land hydrology and vegetation feedbacks, as well as natural climate system variability.

When used in projecting future temperatures stemming from greenhouse gas emissions, estimates of some climate feedbacks are incorporated into computerized models of the climate system. These climate feedbacks—clouds, water vapor, surface albedo, and the lapse rate—are expected to contribute as much (or more) warming to the atmosphere as changes in the greenhouse gases do by themselves.

• Context

The extent to which climate feedbacks might increase or decrease the heat-trapping effects of humanity's greenhouse gas emissions is an important factor in public policy development. If computer models understate the extent of positive feedbacks, future warming could be worse than projected, and actions undertaken to combat climate change might be insufficient to the challenge. By contrast, if computer models overstate positive feedbacks, or underestimate negative feedbacks, projected future warming scenarios could be too high. In this case, massive resources spent on controlling greenhouse gas emissions could be wasted, leaving society less able to deal with other challenges, environmental or otherwise.

Kenneth P. Green

An iceberg melts in the Jokulsarlon glacier lake in Iceland. Melting icebergs decrease Earth's albedo, increasing warming in the region, which causes further melting of icebergs. (©Dreamstime.com/36clicks)

• **Further Reading**

Houghton, John. *Global Warming: The Complete Briefing*. New York: Cambridge University Press, 2009. A leading textbook on climate change, updated to reflect findings of the IPCC's most recent assessment reports.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. The first volume of the IPCC Fourth Assessment Report, focusing on the quantification of climate change, atmospheric greenhouse gas concentrations, climate forcings and feedbacks, and the fundamental science underlying the theory of climate change. This volume includes a summary for policy makers, a technical summary, and a "frequently asked questions" section accessible to the interested lay audience.

National Research Council. *Understanding Climate Change Feedbacks*. Washington, D.C.: National Academies Press, 2003. A publication examining the question of climate feedbacks and their roles in understanding and predicting climate change.

North, Gerald, and Tatiana Erukhimova. *Atmospheric Thermodynamics: Elementary Physics and Chemistry*. New York: Cambridge University Press, 2009. A textbook coauthored with a climate modeler deeply steeped in the study of climate forcings and feedbacks. Suitable for an undergraduate audience.

Spencer, Roy. *Climate Confusion: How Global Warming Hysteria Leads to Bad Science, Pandering Politicians, and Misguided Policies That Hurt the Poor*. New York: Encounter Books, 2006. Spencer, an expert in the satellite measurement of the climate, argues that a misunderstanding of climate feedbacks, particularly water vapor feedbacks, has led to an overestimation of potential climate change due to greenhouse gas emissions.

See also: Albedo feedback; Amazon deforestation; Carbon cycle; Climate lag; Climate sensitivity; Clouds and cloud feedback; Ecosystems; Forcing mechanisms; Industrial Revolution; Paleoclimates and paleoclimate change; Radiative forcing.

Climate lag

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Climate lag denotes a delay in the climate change prompted by a particular factor. This can occur when the system is influenced by another, slower-acting, factor. For example, when carbon dioxide (CO_2) is released into the atmosphere, its full effect may not be recognized immediately, because some of the CO_2 may be partially absorbed, and much later released, by the oceans. The considerable amount of lag in geophysical systems can be seen in the delay between actions that increase or decrease climate forcings (changes that affect the energy balance of Earth) and their consequent impacts on the climate. Lag can be accounted for in several ways: Some occurs because of the length of time it takes for certain chemicals to cycle out of the atmosphere, some results from the effects of warming upon natural cycles, and some comes from the slow pace of oceanic temperature change. Many climate scientists estimate climate lag to be between twenty and thirty years; thus, even if all additional carbon emissions were to cease, Earth would still experience two to three decades of warming before the cessation took effect.

• **Significance for Climate Change**

If, during a two- to three-decade lag, rising temperatures begin to trigger climate feedback effects—such as a reduction of the polar ice cap, allowing more heat to be absorbed by the dark water, or large emissions of methane from melting permafrost—the lag time could be extended. The longer some kinds of climate disruption are delayed, and the more climate commitment is built up, the more likely it is that feedback effects will be seen. "Climate commitment" refers to the fact that climate reacts with a delay to influencing factors. For example, an increase in the concentration of greenhouse gases (GHGs) will influence Earth's climate over time, rather than all at once. There are at least three responses to this situation: prevention, mitigation, and remediation. The potential for dangerous feedback effects drives a prevention response, that is, action that reduces the global warming risk. Since it is not yet known how damaging to the environment feedback effects could be, it seems prudent to do everything possible to start eliminating the anthropogenic sources of GHGs and thereby keep the level of committed warming to a minimum. A mitigation response takes a practical approach: Climate disaster is already imminent, and the best prevention efforts may be too little, too late, but there is still the need to reduce the worst of the threats. A remediation approach would not look at ways to change greenhouse emissions and their consequences; instead, efforts would be made to use geoengineering, that is, to alter the core geophysical processes that relate to global warming.

Victoria Price

See also: Abrupt climate change; Climate change; Climate feedback; Climatology; Paleoclimates and paleoclimate change.

Climate models and modeling

• **Category:** Meteorology and atmospheric sciences

Earth's climate is a system of vast complexity, and modeling that system in useful ways poses significant challenges. Understanding the hierarchy of climate models, however, allows scientists to create models using the minimum complexity necessary for the specific climatic problem under investigation.

• Key concepts

albedo: the fraction of incident light reflected from a body such as Earth

convection: vertical transfer of heat by movement of warm parcels of air

emissivity: a measure of the ability to radiate absorbed energy

greenhouse gases (GHGs): atmospheric trace gases that trap heat, preventing it from escaping into space

Navier-Stokes equation: an equation describing the flow of air (or any other fluid)

parameterization: the approximation of processes

• Background

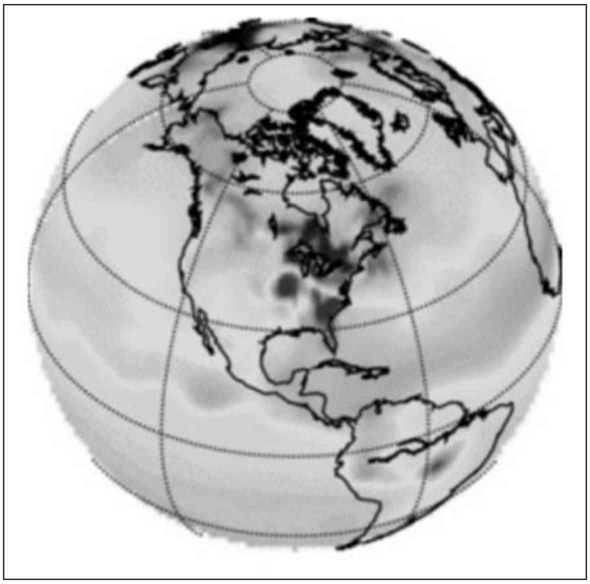
Climate models are the most important tools for quantitatively estimating how natural and anthropogenic forces affect different aspects of the climate system. A climate model is a numerical representation of the climate system, including the physical, chemical, and biological properties of its components and the interactions between those components. It consists of a large number of mathematical equations that quantitatively describe the processes occurring within the climate system. Climate models span the entire range from very simple models that can be solved on paper to very complex models that require large supercomputers.

• Hierarchy of Climate Models

Climate model equations describe the conservation and transport of atmospheric heat, moisture, and momentum along three directions: latitude, longitude, and vertical altitude. For simplicity, climate models are often averaged along one or more of these directions. Depending on the nature of averaging, the following hierarchy of climate models develops.

Zero-dimensional energy-balance models. The simplest form of climate model is averaged along all three directions. It consists of a single equation describing the balance of incoming and outgoing energy at the top of the atmosphere. These models calculate the temperature of the Earth as a function of incoming solar radiation, Earth's albedo, and emissivity.

The advantage of zero-dimensional models is their simplicity. These are the only type of climate models that can be solved by hand using a simple calculator. They have been widely used to study how global temperature may change in response to changes in solar radiation (during the eleven-year and longer solar cycles), in Earth's albedo (resulting from changes in cloud cover or sea-ice extent), and in emissivity.



A computer model of global carbon dioxide emissions. (NOAA)

One-dimensional models. Radiative-convective (RC) models are averaged along latitude and longitude, but not along the vertical direction. They include the two most important processes of vertical energy transport in the atmosphere: upward and downward transport of radiation and upward transport of heat from Earth's surface by convection. The inclusion of vertical transport is important for climate modeling. Because gases in the atmosphere are unevenly distributed vertically, the impact of climate change varies with altitude. RC models can accurately simulate the vertical profile of temperature and temperature change in the atmosphere.

In contrast with RC models, energy balance (EB) models are averaged along the longitudinal and vertical directions. Thus, they may be used to account for equator-pole heat transport that arises because the equator receives more solar energy than do the poles. Unlike RC models, which use very sophisticated and realistic heat transport equations, the transport in EB models is described through relatively simple parameterizations that have limited applicability. EB models have been used to study the mechanisms of poleward heat transport, ice age climates, and ocean-atmosphere interactions.

Two-dimensional models. Two-dimensional RC models are averaged along the longitudinal direction. They thus combine one-dimensional RC and EB models. They account for the climate system's two most important heat transport processes, vertical and poleward. These models have been widely used to study atmospheric general circulation patterns such as the Hadley cell. Because of their relative simplicity, these models have also been coupled with chemistry and radiation models to study stratospheric chemical-radiative-dynamical interactions.

Two-dimensional EB models average atmospheric properties and processes over the height of the atmosphere to describe the energy balance over Earth's entire surface. These models have limited applicability and have been used to study ice-age climates.

- **Three-Dimensional General Circulation Models**

General circulation models (GCMs) are the most complex climate models. They solve the full set of Navier-Stokes equations for atmospheric flow and thermodynamic and microphysical equations for conservation of energy and moisture along all three cardinal directions. The three-dimensional nature of the models allows them realistically to handle the transport of energy, moisture, and momentum in the horizontal as well as vertical dimensions. Hence, GCMs are very useful for investigating regional aspects of climate and climate change.

Sometimes these models are coupled with dynamic ocean models, atmospheric chemistry models, or ecosystem dynamics models. Such multi-model coupling allows scientists to study the interactions between all three components of the climate system (atmosphere, biosphere, and hydrosphere).

The major disadvantage of GCMs, especially coupled atmosphere-ocean GCMs (AOGCMs), is that they are computationally very expensive. Only well-funded research groups have access to the supercomputers needed to run simulations with GCMs. Because of their size and complexity, it takes a long time, often weeks, to complete each simulation. Another drawback of these models is their coarse resolution. Each grid cell in a GCM is at least 1° latitude by 1° longitude. GCMs therefore cannot explicitly resolve fine-scale processes such as boundary-layer turbulence or cumulus clouds. The models do not completely ignore such fine-scale processes, however. Rather, these processes are approximated by subgrid parameterizations.

Earth systems models of intermediate complexity (EMICs) are another very powerful tool in climate studies. These models bridge the gap between complex GCMs and simpler models. EMICs simulate all the physical and dynamical processes contained in GCMs, but they use simpler parameterizations and coarser resolution, making them much faster to run than GCMs. Because of their computational efficiency, EMICs are becoming very popular in the climate policy field. They are widely used to study the feasibility of different adaptive and mitigation policies on climate change.

• Context

Climate models in general form the basis for nearly all rational argumentation as to the causes and severity of climate changes of the past and present, as well as the effects of human actions on climate in the future. They are thus crucial to both climate science and climate policy. However, different climate modeling systems—and different deployments of the same systems—have yielded different results, rendering it difficult thus far to come to definitive conclusions as to the optimal course of action in either the near term or the long term. Hierarchizing climate models can help reduce some of the uncertainty by deploying the most appropriate model for a given purpose, but precise, definitive predictions of climate change remain elusive.

Somnath Baidya Roy

• Further Reading

Harvey, D., et al. "An Introduction to Simple Climate Models Used in the IPCC Second Assessment Report." IPCC Technical Paper 2. Edited by J. T. Houghton, L. G. Meira Filho, D. J. Griggs, and K. Maskell. Geneva, Switzerland: Intergovernmental Panel on Climate Change, 1997. Surveys low-order climate models and modeling methods used by the foremost international scientific body working on climate change.

Held, Issac. "The Gap Between Simulation and Understanding in Climate Modeling." *Bulletin of American Meteorological Society* 86, no. 11 (November, 2005): 1609-1614. Held is a well-known climate modeler based in the NOAA Geophysical Fluid Dynamics Laboratory at Princeton, New Jersey. This article describes why even very simple models are essential for climate studies.

Intergovernmental Panel on Climate Change. *Climate Change, 2001—The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by J. T. Houghton et al. New York: Cambridge University Press, 2001. Provides a scientific assessment of past, present, and future climate change. Chapter 8 contains a thorough discussion of climate models and modeling hierarchy. Illustrations, references, index.

_______. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Revisits and expands the modeling discussion of the third report.

Kiehl, Jeffrey T. "Atmospheric General Circulation Modeling." In *Climate System Modeling*, edited by K. Trenberth. New York: Cambridge University Press, 1992. Discusses the different kinds of averaging of atmospheric dynamic and thermodynamic equations and the different kinds of climate models they produce.

See also: Bayesian method; Climate prediction and projection; General circulation models; Parameterization; Slab-ocean model.

Climate prediction and projection

• **Category:** Meteorology and atmospheric sciences

The methodology and databases accumulated over several decades to monitor and predict normal cyclical variations in climate provide a base against which to assess whether, *and to what extent, current global warming is anthropogenic and to what extent it may be self-correcting.*

• Key concepts

anthropogenic climate change: changes in overall long-term weather patterns in a region due to human activity

extreme weather events: natural disasters caused by weather, including floods, hurricanes, drought, and prolonged severe hot and cold spells

proxies: measurable parameters, correlated with climate, that are preserved in the geologic record (for example, oxygen isotope ratios and fossil pollen)

• Background

Weather is the sum of the atmospheric conditions we experience on a daily basis; climate is what produces those conditions in a given geographical area. Climatology has been described as "geographical meteorology." The principal purpose of studying a region's climate is to discover measurable factors that accurately predict, months or years in advance, what the general weather regime will be like in a given area. In making their predictions, climatologists first look at established historical patterns, both recorded in writing and documented through proxies. Increasingly they also investigate whether there are systematic perturbations in established historical patterns, and they also incorporate the effects of events whose probability is low or unknown.

• History

Attempts by humans to forecast climate date back several millennia, at least to the days of ancient Babylon, when astrologers used the motions of the Sun, Moon, and planets to predict whether the coming season would be favorable for agriculture. The practice may be even older. Anthropologist Johannes Wilbert recorded a religiously based system of climate prediction among the Warao Indians of Venezuela, a group of primitive Stone Age agriculturalists. The biblical story of Joseph (c. 1800 B.C.E.) relates how Joseph interpreted Pharaoh's dream of seven lean cattle devouring seven fat cattle as a prediction of impending drought and famine, enabling the Egyptians to prepare in advance.

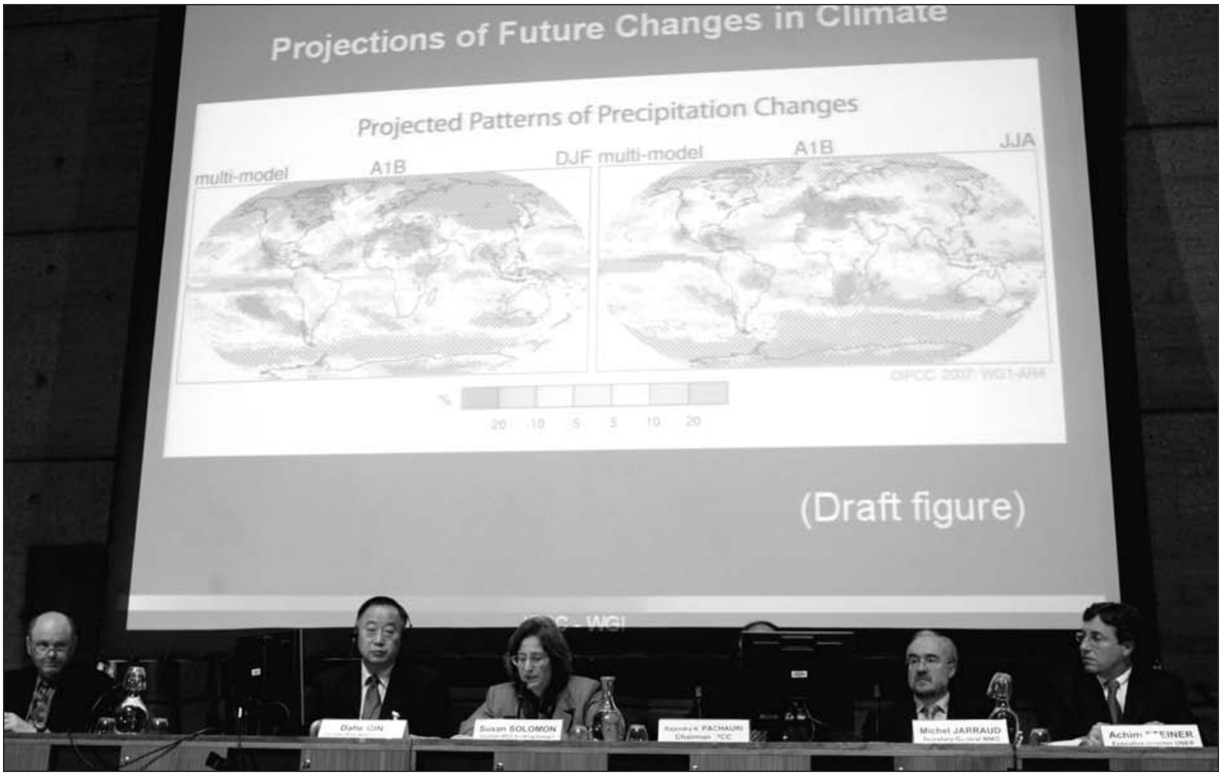
Climate prediction for agricultural purposes remained a major function of astrology, and later astronomy, from Babylon to the pioneer European astronomer Tycho Brahe in the sixteenth century. Even today, many successful American farmers follow the *Farmers' Almanac*, with its astrologically based recommendations for planting crops. The practice persists in part because it has some basis in fact: The phases of the Moon, and to a lesser extent the orbits of Jupiter and Saturn, do affect climate.

Interest in a more scientific and systematic approach to climate prediction gained impetus in the late nineteenth century in response to expansion of Europeans into regions that experience more extreme and variable climatic conditions than Europe. The eleventh edition of the *Encyclopedia Britannica* (1911) divides the globe into climatic zones, describes the variability of each, and discusses evidence for a general warming trend, which the author of the encyclopedia article was inclined to dismiss as unproven.

A decade later, Sir Gilbert Walker began publishing his pioneering work on fluctuations in the Indian monsoons, their relationship to periodic famines, and the correlation between them and oscillation of high- and low-pressure areas between the Indian Ocean and the tropical Pacific. This Southern Oscillation, later shown to be linked to the El Niño phenomenon in the eastern Pacific, is the most important determinant of cyclical global weather patterns.

• Building a Global Climate Prediction Network

Climate prediction depends upon having large numbers of accurate measurements of many different variables, which can then be correlated mathematically. Correlation is an uncertain process at best, rarely yielding unequivocal results. For example, all of the complex hurricane-predicting machinery of the United States' National Oceanic and Atmospheric Administration (NOAA) produced, as of the beginning of June, 2009, the prediction that the upcoming August-October Atlantic hurricane season would have a 50 percent chance of being average and a 25 percent chance of being above or below average. Vague predictions such as this are one reason that skeptics such as Marcel Leroux,



In February, 2007, members of the Intergovernmental Panel on Climate Change sit in front of a projection of future changes in precipitation patterns caused by global warming. (AP/Wide World Photos)

of the University of Adelaide, can plausibly question that scientists have demonstrated any general global warming effect.

Global meteorological monitoring, coordinated through national weather services and the United Nations, involves a network of satellites capable of measuring physical parameters including surface temperatures, wind speeds, cloud cover, and barometric pressure, at points 50 kilometers apart, at hourly intervals. National weather centers are well apprised, for example, of the exact status of El Niño on any given day and how it has been developing, but unless it has recently exhibited extraordinary features, these data give only a general picture of what the climate will do in affected regions.

The main thrust of global climate prediction was, and to a large extent still is, extreme weather events, including droughts, floods, and cyclonic storms. Predictions impact disaster preparedness and help nations minimize mortality. Knowing in advance that El Niño is likely to produce drought in Australia and South Africa in a given year helps those countries stockpile grain, devote more acreage to drought-resistant crops, and prepare for wildfires. In the United States and elsewhere, projections for hurricane and tornado activity affect insurance policies and land-use decisions. For extreme weather projections, a decadal time frame is sufficient. Beyond that, only a few cyclical phenomena can be projected with yearly accuracy, and the number of unknown variables becomes too large to allow useful prediction.

• Climate Projection

All of the models used in predicting decadal climate variability were developed using historical data and assume that variables are constant, oscillate in a regular manner around a mean, or are increasing or decreasing at a constant rate. With respect to the carbon dioxide content of the atmosphere, none of these conditions is currently met. However, once a model is developed, climatologists can use a computer simulation to project, for example, how atmospheric carbon dioxide and global temperatures would respond if there were a large increase or decrease in emissions. Because of complexities, uncertainties, and unknown variables, such projections often prove to be far off track.

- **Context**

With respect to the controversy over global warming—whether is is occurring and to what it is attributable—input from climatologists associated with NOAA and other agencies suffers from distortion between laboratory and the media. When scientists correctly project from their models that a massive eruption of the Yellowstone supervolcano such as occurred 200,000 years ago would produce abrupt catastrophic cooling, completely dwarfing any anthropogenic warming, it implies neither that such an eruption is expected in the near future nor that efforts to curtail emissions and environmental degradation are futile in the face of overwhelming nature—yet that is the lesson many people would derive from their findings. The high resolution, global coverage, and international cooperation among climatology centers ensure that no event or trend of significance escapes attention. If media attention does not translate into action, it is not the fault of the climatologists.

Martha A. Sherwood

- **Further Reading**

Leroux, Marcel. *Global Warming: Myth or Reality? The Erring Ways of Climatology*. New York: Springer, 2005. A skeptical view focusing on the limitations of climate prediction; good nontechnical description of data and issues.

Mayewsky, Paul, et al. "Holocene Climate Variability." *Quaternary Research* 62 (2004): 243-255. A technical summary of high-resolution proxy records from many parts of the globe; offers some discussion of correlation with human history.

Saltzman, Barry. *Dynamical Paleoclimatology: Generalized Theory of Global Climate Change*. San Diego, Calif.: Academic Press, 2002. Treats interactions between abiotic, biotic, and anthropogenic variables; discusses controversies about the magnitude of human impact.

Thompson, Russell D., and Allen Perry, eds. *Applied Climatology: Principles and Practice*. New York: Routledge, 1997. This volume, aimed at professionals, offers a collection of papers emphasizing decadal-scale disaster prediction.

See also: Climate change; Climate feedback; Climate models and modeling; Extreme weather events; Famine; General circulation models; Global monitoring; Hockey stick graph; Parameterization; Seasonal changes; Skeptics; Weather forecasting; WGII LESS scenarios.

Climate Project

- **Category:** Organizations and agencies
- **Date:** Established 2006
- **Web address:** http://www.theclimate project.org

- **Mission**

The mission of the Climate Project is to increase "public awareness of the climate crisis at a grassroots level in the United States and abroad." It was founded in June, 2006, by Nobel laureate Al Gore, a former vice president of the United States (1993-2001) and an environmental activist and author.

The project grew out of a slide-show presentation that Gore, an early activist on the issue of preventing global warming, had been giving around the United States and internationally. In the slide show, Gore summarized the scientific arguments supporting the causes and dangers of global warming and described the political and economic consequences of ignoring the issue. The presentation was filmed, becoming the Academy Award-winning 2006 documentary *An Inconvenient Truth*, and a companion book became a *New York Times* best seller. Requests for showings of the film and presentations about global warming, and questions about Gore's next step in spreading his message, reached such a high level that Gore formed the Climate Project to help "educate, encourage, and promote dialogue about climate change as well as potential solutions." On the film's Web site, he sent out a call for one thousand "Climate Change Messengers," whom he would train to help deliver his message about global warming.

In Nashville, Gore himself began training hundreds of volunteers to deliver a version of the popular slide show. Volunteers in Australia, Canada, India, Spain, and the United Kingdom were also trained. The project expanded to include a special faith community training session, helping members of churches and other faith communities deliver the presentation, organize other faith-based activities to educate about global warming, and talk about global warming in the context of their faiths. Through the Climate Project Web site, anyone interested can request a presentation in the local community, delivered by a volunteer at no charge. Volunteers pay their own expenses to travel to training sessions, but donations to the Climate Project help support their travel as they make presentations, and pay for the brochures and other materials they distribute.

• Significance for Climate Change

Presenters, who commit to making at least ten presentations in a year, hope to alert citizens to the dangers of global warming, and to affect local and national policy decisions. For their programs, volunteers typically combine slides from Gore's presentation with new slides showing the local effects of global warming. In Australia, those who are uncomfortable with the idea of speaking at length in public can instead become "connectors," who commit to showing a digital video disc (DVD) called *Telling the Truth*, leading a discussion about global warming, and asking members of the audience to sign a statement that supports the Climate Project.

Volunteers, who must apply and be selected by the Climate Project, come from a variety of age groups and professions. They include a former Australian professional rugby player, a Canadian railroad executive, a French fashion model (who urged celebrity friends to design T-shirts to raise money for the project), a former member of the Canadian national women's hockey team, a mother and massage therapist, an astrophysicist, an eleven-year-old girl, and a woman in her nineties. Critics have objected that many of the presenters are not scientifically knowledgeable enough to make intelligent arguments about an issue as technically complex as global climate change. Others have praised the Climate Project for encouraging so many people to think seriously about an important issue. Public presentations, which run less than an hour, typically draw audiences of twenty to thirty people, but some draw a hundred or more.

Gore himself inspires and attracts volunteers. Most of the volunteers are trained by Gore, who has conducted two- and three-day training sessions in Nashville, Tennessee; Montreal, Canada; and Melbourne, Australia. After he spoke in Montreal, Canada, in April, 2008, the number of Canadian volunteers grew from 20 to more than 250 in six months. As of October, 2008, the Climate Project had trained more than 2,500 volunteer presenters, whose programs had reached audiences totaling more than four million people.

Cynthia A. Bily

• Further Reading

Adams, David. "Global Warming, Meet Your New Adversary." *St. Petersburg Times*, January 23, 2007, p. 1A. A history of Gore's founding of the Climate Project, focusing on Florida volunteer Roberta Fernandez.

Della Caca, Marco R. "Al Gore Trains a Global Army: Soldiers March Forth with Environmental Message." *USA Today*, April 25, 2007, p. 1D. A history of Gore's founding of the Climate Project, focusing on Texas volunteer Gary Dunham.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It.* Emmaus, Pa.: Rodale, 2006. A clearly written book based on Gore's slide show lectures on global warming. These presentations were captured in the film *An Inconvenient Truth* and are the basis of the Climate Project's presentations.

Meacham, Steve. "Standing Up for the Planet: The Messengers." *Sydney Morning Herald*, December 10, 2008, p. 19. Describes the activities of soccer player Al Kanaar, one of the first Australian Climate Project presenters.

See also: Gore, Al; *Inconvenient Truth, An.*

Climate reconstruction

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Scientists use a combination of techniques to reconstruct and describe aspects of past climates, such as temperature, precipitation, and atmospheric carbon dioxide (CO_2) concentration, using historical accounts and proxies. These methods include analysis of preserved pollen, tree rings, and ice-core oxygen isotope ratios and CO_2 concentrations, as well as paleobotanical methods.

• **Significance for Climate Change**

To develop accurate climate-prediction models, scientists require data that predate modern science, forcing them to rely on historical records and a variety of climate proxies to reconstruct the climate of hundreds, thousands, and even millions of years ago. Climate factors that can be reconstructed include local and global temperature, precipitation, sea level and salinity, atmospheric pressure, atmospheric CO_2 concentration, ice volume, and ocean circulation.

Many studies use a combination of proxies in an attempt to minimize error. Data from these proxies can be combined with modern climate data to create models that infer past climate as well as predict future climate. Paleoclimatology and climate reconstruction are important for explaining current ecosystems and understanding factors that affect climate change. Climate reconstruction data also are important for improving models that help predict the effects of possible climate change scenarios, such as the potential effect of increased atmospheric CO_2.

Two of the most crucial sources of paleoclimatic data are ice and sediment cores. Deep ice cores preserve atmospheric gases, water, and pollen. Scientists analyze isotope ratios, CO_2 concentrations, and pollen assemblages to infer information about past climates. Perhaps the most famous ice core was taken from Lake Vostok in Antarctica. Data from this core has shown that East Antarctica was colder and drier and atmospheric circulation was more vigorous during glacial periods than they are now. Scientists can also correlate atmospheric CO_2 and methane with temperature.

Deep-sea sediment cores provide similar information about past climate through marine microorganisms such as diatoms and foraminifera, which preserve isotope ratios in their shells. These isotopes allow scientists to infer past water temperature, while community makeup of microorganisms can be used to make other inferences about their environments. Scientists also take sediment cores from lakes. Charcoal layers in sediment can indicate fires, and pollen can also provide climate information.

Pollen is extremely tough and holds up well for millions of years in the fossil record. Pollen assemblages from cores can be used to infer climate by comparison with modern plants and their climate tolerances, although scientists must be careful not to assume that plants today live exactly as their ancestors did. Pollen records are often correlated with records from other sources, such as marine plankton and ice cores, to minimize error.

Pollen records can have very high resolution, on the order of a single year when taken from annually deposited lake sediments. For example, researchers at the Faculte de St. Jerome in France were able to estimate climatic range and variability in the Eemian interglacial period, approximately 130,000 to 120,000 years ago. They found that the warmest winter temperatures occurred in the first three millennia of the period, followed by a rapid shift to cooler winter temperatures between 4,000 and

Sources of Climate Reconstruction Data

Years Ago	*Available Data Sources*
1,000	Written records, tree rings
10,000	Varved and lake sediments
50,000	Lake levels, mountain glaciers
250,000	Polar ice cores
1,000,000+	Ocean sediments, cave deposits

Source: National Ice Core Laboratory, U.S. Geological Survey.

5,000 years after the beginning of the Eemian. After that, annual variations of temperature and precipitation were slight, only 2-4° Celsius and 200-400 millimeters per year.

Tree-ring analysis is usually employed within the timespan of the historical record, although it can be employed on fossilized trees. The thickness of tree rings is affected by temperature, precipitation, and other environmental factors—trees grow thicker rings in years with optimal conditions. Scars and burn marks can also be used to identify fires and other events. These events can often be correlated with historical records to establish precise dates. Slices of different trees can also be correlated with one another to construct records stretching back hundreds and even thousands of years.

In areas with good tree records, such as the dry American Southwest, tree-ring analysis has extremely fine resolution. In the White Mountains, the bristlecone pine tree chronology goes back ten thousand years, to 7,000 B.C.E., almost to the end of the last ice age. Bristlecone pine chronologies have been used to recalibrate the carbon 14 dating process. Tree-ring analysis can also provide information about the effects of pollution. Using similar methods with coral, scientists have reconstructed sea surface temperatures and salinity levels for the last few centuries.

Several other methods of climate reconstruction are used to infer temperature and precipitation from millions of years ago. These methods often rely on the fossil record, particularly that of plants. Leaf physiognomy methods rely on physical characteristics of leaves thought to be independent of species in order to estimate precipitation and temperature. For example, leaf-margin analysis compares the ratio of leaves with smooth margins to leaves with toothed margins. Tropical environments have a higher percentage of smooth-margined leaves than do temperate environments. The stomatal index—the ratio of the tiny holes in a given area of a leaf to the overall number—can provide information about atmospheric CO_2. Scientists have used many other proxies to reconstruct aspects of past climates, and they develop new methods every year, further refining their understanding of the past and improving their models of the future.

Melissa A. Barton

• Further Reading

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Author and geoscientist Alley, who has studied ice cores from Greenland and Antarctica, covers what ice cores reveal about past climate and about the climate challenges faced today. Illustrated.

Levenson, Thomas. *Ice Time: Climate, Science, and Life on Earth.* New York: HarperCollins, 1990. Good introduction to the causes of weather and climate and the history of climate science. Discusses the last ice age.

Redfern, Ron. *Origins: The Evolution of Continents, Oceans, and Life.* Norman: University of Oklahoma Press, 2001. Profusely illustrated history of the Earth, including the movement of continents, the rise and fall of oceans, and the fluctuations of temperature. Illustrated.

See also: Carbon isotopes; Climate models and modeling; Climate prediction and projection; Dating methods; Ice cores; Oxygen isotopes; Pollen analysis; Sea sediments; Tree rings.

Climate sensitivity

• Category: Meteorology and atmospheric sciences

• Definition

Global climate is a complex system that reacts to changes in its components, such as atmospheric carbon dioxide (CO_2) concentration. A change in the atmospheric concentration of CO_2 may cause a change in the radiation balance of the Earth; such a change is called "radiative forcing." Many changes can cause radiative forcing, including changes in greenhouse gas (GHG) concentration, the output of the Sun, ice cover, and aerosol concentration. In response to a change in the Earth's radiation balance, the planet's temperature will change until global energy balance is restored. How much the global temperature changes depends on internal feedbacks in the Earth's climate system that cause net amplification of the initial radiative forcing. Internal climate feedbacks include changes in water vapor, lapse rate, albedo, and clouds.

Equilibrium climate sensitivity (ECS) is a useful summary statistic of the behavior of the Earth's climate system. ECS is defined as the change in equilibrium of global average surface temperature in response to a doubling of the atmospheric concentration of CO_2 from preindustrial levels (from 280 parts per million to 560 parts per million). A doubling of atmospheric CO_2 causes radiative forcing of about 3.7 watts per square meter by increasing long-wave radiative absorption. ECS is not a simple measure of the amount of thermal energy added to Earth's climate system by the CO_2 alone, because climate changes cause feedback loops. For example, melting ice decreases Earth's albedo, causing the planet's surface to absorb more heat and to further increase thermal energy. If there were no internal climate feedbacks, then ECS would be about 1.2° Celsius. However, because of internal climate feedbacks, ECS is likely between 2° Celsius and 4.5° Celsius.

ECS allows scientists to assess the change in average global temperature after the Earth has reached equilibrium over several thousand years. However, it is computationally intensive to run complex global climate models to equilibrium. Thus, a modified concept, effective climate sensitivity, has been developed as an approximation of ECS. Effective climate sensitivity is calculated by estimating the climate feedback parameter at a specific point in time during transient climate conditions (not at equilibrium) using estimates of ocean heat storage, radiative forcing, and surface temperature change. Some studies find that effective climate sensitivity calculations underestimate the true ECS of a given model.

• Significance for Climate Change

ECS is used to summarize and compare different climate models, as well as to combine information from models, historical records, and paleoclimate reconstructions. It is immensely important for making, understanding, and reacting to projections of future climate change. Every 1° Celsius difference in ECS can imply vastly different impacts on the planet over the long term.

A large number of studies have estimated ECS using a variety of methods, models, and data. There are four main categories of strategies used to estimate ECS. One method is to estimate ECS directly from observations of past climate changes. Another is to compile expert opinions. A third is to take a single climate model, create multiple versions by varying its parameters, and then compare the climate simulated by each version with climate observations to determine which is most likely. A final strategy is to combine the results of multiple methods into a single probability distribution. There are two main sources of climate observations used in this type of research: modern instrumental observations (after 1850), and paleoclimate reconstructions over the past thousands or millions of years.

After considering all the available research, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that ECS is likely (with a probability of greater than 66 percent) to be between 2° Celsius and 4.5° Celsius, very likely (greater than 90 percent probability) to be larger than 1.5° Celsius, and most likely to have a value of about 3° Celsius. The estimated range of ECS has been relatively stable over a thirty-year period: A range of 1.5° Celsius to 4.5° Celsius was proposed in 1979 in a report by the National Academy of Sciences. Scientists have improved the certainty of their estimates of the lower limit of climate sensitivity and of the transient climate response. The upper limit of ECS, however, remains difficult to quantify as a result of nonlinearities that cause a skewed probability distribution. The persistence of such large uncertainty in the value of ECS is a significant barrier to narrowing the range of projections of future climate change.

There are several important limitations to the concept of ECS. It is potentially dependent upon the state of the climate system and upon the rate and magnitude of radiative forcing: A doubling of CO_2 versus a halving of CO_2 may not cause the same magnitude of temperature change. Additionally, different forcing mechanisms can have different sensitivities to radiative forcing, so ECS values may be specific to changes in CO_2. Lastly, ECS quantifies equilibrium temperature change over thousands of years, so it does not give direct projections for future climate changes over periods of hundreds of years. A separate summary statistic, transient climate response (TCR), was developed to compare the transient responses of climate models and provide shorter-term projections.

Carolyn P. Snyder

- **Further Reading**

Edwards, T. L., et al. "Using the Past to Constrain the Future: How the Palaeorecord Can Improve Estimates of Global Warming." *Progress in Physical Geography* 31, no. 5 (October, 2007): 481-500. Provides an accessible overview of ECS research, with useful tables categorizing studies and a focus on the role of paleoclimate reconstructions in ECS estimations.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. The IPCC provides an extensive overview of the scientific literature on ECS. Chapters 6, 8, 9, and 10 are most relevant.

Knutti, R., and G. C. Hegerl. "The Equilibrium Sensitivity of the Earth's Temperature to Radiation Changes." *Nature Geoscience* 1, no. 11 (November, 2008): 735-743. Provides an updated technical overview of the scientific literature on ECS, with useful figures comparing different estimates.

See also: Climate and the climate system; Climate feedback; Climate models and modeling; Climate prediction and projection; Climate reconstruction; Climate variability; Paleoclimates and paleoclimate change.

Climate variability

- **Category:** Meteorology and atmospheric sciences

A stable climate is not necessarily a static climate: Climates can vary within limits over time, and it is important to distinguish between this climate variability and genuine climate change in evaluating climatic history and making future projections.

- **Key concepts**

climate change: alterations in long-term meteorological averages in a given region or globally

climate fluctuations: changes in the statistical distributions used to describe climate states

climate normals: averages of a climatic variable for a uniform period of thirty years

climatic oscillation: a fluctuation of a climatic variable in which the variable tends to move gradually and smoothly between successive maxima and minima

climatic trend: a climatic change characterized by a smooth monotonic increase or decrease of the average value in the period of record

- **Background**

Climate is an abstraction, a synthesis of the day-to-day weather conditions in a given area over a long period of time. The main climate elements are precipitation, temperature, humidity, sunshine, radiation, wind speed, wind direction, and phenomena such as fog, frost, thunder, gales, cloudiness, evaporation, and grass and soil temperatures. In addition, meteorological elements observed in the upper air may be included where appropriate. The climate of any area may also be described as a statistical analysis of weather and atmospheric patterns, such as the frequency or infrequency of specific events.

In the most general sense, the term "climate variability" denotes the inherent tendency of the climate of a specific area to change over time. The time period considered would normally be at least fifty years, but a period of at least one hundred years is usually more appropriate. Instrumental climatic observations have been taken in most areas of the world for at least one hundred years, and in some areas for more than two hundred years, and any analysis of climate variability over time should utilize the full record of those observations. Longer time periods, from one thousand years to a geological period, may also be studied using proxies.

• Magnitude of Climate Variability

The degree or magnitude of climate variability can best be described through the statistical differences between long-term measurements of meteorological elements calculated for different periods. In this sense, the measure of climate variability is essentially the same as the measure of climate change. The term climate variability is also used to describe deviations of the climate statistics over a period of time (such as a month, season, or year) from the long-term statistics relating to the same calendar period. In this sense, the measure of climate variability is generally termed a climate anomaly.

• Climate Properties

Three basic properties characterize the climate of an area. Thermal properties include surface air temperatures above water, land, and ice. Kinetic properties include wind and ocean currents, which are affected by vertical motions and the motions of air masses, aqueous humidity, cloudiness, cloud water content, groundwater, lake lands, and the water content of snow on land and sea ice. Finally, static properties include pressure and density of the atmosphere and oceans, composition of the dry air, salinity of the oceans, and the geometric boundaries and physical constants of the system. These three types of properties are interconnected by various physical processes, such as precipitation, evaporation, infrared radiation, convection, advection, and turbulence. The climate is a complex system, and any consideration of climate variations, especially in terms of global warming, must be carefully evaluated.

• Climate Variability Over the Last Thousand Years

One thousand years ago, some—and possibly many—parts of the Earth were warm and dry. The Atlantic Ocean and the North Sea were almost free of storms. This was the time of the great Viking voyages. Vineyards flourished in England; in contrast, some frosts occurred in the Mediterranean area, and rivers such as the Tiber in Rome and the Nile in Cairo occasionally froze. This suggests that a shift occurred in the pattern of large-scale European weather systems. However, by about 1200, the benign climate in Western Europe began to deteriorate, and climate extremes characterized the next two centuries. From about 1400 to 1550, the climate grew colder again, and about 1550 a three-hundred-year cold spell known as the Little Ice Age began. (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.) Around 1850, the cold temperatures began to moderate, and from about 1900 a relatively steady warming trend (with a few intervening cold periods) occurred in many areas of the world. However, since the peak warmth of the year 1998 for the world as a whole, global temperatures have remained relatively stable, with some cooling trends in a few areas.

• Context

The climate has always varied and will continue to vary, but it is important to differentiate internal variations, or changes that do not imply instability, with external variations, which are attributable to forcing. Changes in the intensity of seasons or of rainfall may presage global warming, or they may simply be temporary oscillations within an existing system. The longer the time period under discussion, moreover, the more difficult it is to tell where unidirectional climate change begins or ends.

Climate variability, when seen as an inherent characteristic of Earth's atmosphere, can be treated as a reason to accept global changes as natural and beyond human control. When seen as a result of human activity, the same variability can be treated as a call to action to reverse global warming. Evaluations of the limits of natural variability are therefore crucial precursors of evaluations of climate change itself. What will prove to be the correct argument remains for the future, but irrespective of the truth of the two arguments, it is evident that people and societies must adapt to climate changes, and those communities that adapt to the varying climate will be in a better position to withstand the climatic variability of the future.

W. J. Maunder

• Further Reading

Broecker, W. S. "Does the Trigger for Abrupt Climate Change Reside in the Ocean or the Atmosphere?" *Science* 300 (2003): 1519-1522. Good example of a discussion on some aspects of the natural causes of climate change.

Kininmonth, William. *Climate Change: A Natural Hazard*. Brentwood, Essex, England: Multi-Science, 2004. Kininmonth's career in meteorological and climatological science and policy spans more than forty-five years. His suspicions that the science and predictions of anthropogenic global warming have extended beyond sound theory and evidence were crystallized following the release of the 2001 IPCC report.

Maunder, W. J. *The Human Impact of Climate Uncertainty: Weather Information, Economic Planning, and Business Management*. New York: Routledge, 1989. Provides an overview of the economic dimensions of climate and human activities; explains how the variable nature of the atmosphere must be accepted as an integral part of the management package.

See also: Abrupt climate change; Climate change; Climate models and modeling; Climate prediction and projection; Climate sensitivity; Climatology; Intergovernmental Panel on Climate Change; Weather vs. climate.

Climate zones

• **Category:** Meteorology and atmospheric sciences

• Definition

Climate, the average weather conditions over a period of at least thirty years, is determined by various factors, the most important of which are the amount of precipitation and the temperature of the air. Climate controls the major ecological community types, or biomes; that is, the climate in a given region determines the flora and fauna that will thrive in that region. In 1900, Wladimir Köppen, a German climatologist, developed what has become the most widely used system for classifying world climates. The Köppen system identifies five major climate zones: tropical moist climates (A zone), dry climates (B zone), humid middle latitude climates (C zone), continental climates (D zone), and cold climates (E zone). Köppen also used two subgroups to more specifically describe the zones.

Tropical moist climates are characterized by year-round high temperatures and large amounts of rain. Rainfall is adequate all year round, and there is no dry season. This zone is typical of northern parts of South America, central Africa, Malaysia, Indonesia, and Papua New Guinea. The dry climate zone has little rain and a wide range of daily temperatures. There is a dry season in the summer and winter, with a mean annual temperature over or under 18° Celsius, as in the western United States, northern and extreme southern Africa, parts of central Asia, and most of Australia.

The humid middle latitude climate, or temperate zone, has hot-to-warm, dry summers and cool, wet winters, but no dry season as such. Southeastern sections of the United States and South America, westernmost Europe, and the southeast corner of China fit this category. The continental climate zone, in interior regions of large land masses such as Canada and northern Europe and Asia, experience varied seasonal temperatures and moderate rainfall. The cold climate zone, characterized by permanent ice and ever-present tundra, occupies Greenland and the most northerly parts of Asia.

• Significance for Climate Change

While acknowledging some unknowns and uncertainty, researchers predicts that, if global warming caused by carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions continue at the current rate, some of the climate zones recognized in the early twenty-first century could disappear entirely by the end of the century, giving way to new climate zones on up to 39 percent of the world's land surface. Major areas that could be affected are tropical highlands and polar regions. Broad strips of areas labeled tropics and subtropics at the beginning of the twenty-first century could develop new climates that do not resemble any of the zones in categories assigned in the Köppen Climate Classification System. Researchers predict that heavily populated areas such as the southeastern United

An Adelie penguin leaps over a crack in the thinning sea ice off Ross Island. The polar climate zone is among the most susceptible to global warming. (Chris Walker/MCT/Landov)

States, southeastern Asia, parts of Africa such as its mountain ranges, the Amazonian rain forest, and South American mountain ranges are likely to be the most severely affected.

Climate change patterns could affect ecosystems on a global scale. For example, major changes in the forests of North America could result: Four species of tree—the yellow birch, the sugar maple, the hemlock, and the beech—are expected to move northward up to 1,000 kilometers while abandoning entirely their present-day locations. Animals could also be affected. Temperature and rainfall patterns could change breeding and migration patterns.

For humans, a grave concern is global food production. One model predicts that the corn belt in North America will move northward, possibly as far as Canada; winter wheat may replace corn in parts of the present corn belt. Within several decades, the Swiss Alps could become a Mediterranean climate, with wet winters and long, dry, warm summers. Within one hundred years, the climate zone in southern Switzerland may move northward by as much as 500 kilometers. In the western Alps, the climate may come to resemble that found in southern France in the early twenty-first century.

Biodiversity in South Africa is expected to be affected substantially by shifting climate zones: Species will experience extinction on a wide scale; up to half the country will see a climate not known before; succulent karoo, a globally important arid-climate hotspot, and biomes in the *fynbos* (a Mediterranean-climate thicket) will suffer. While the degree of this change remains speculative, availability of food could affect sub-Saharan West Africa, as vegetation zones move southward.

Deforestation will continue in the Amazonian forest areas of South America, and new climates are expected to be created near the equator. Some researchers predict that mountainous areas such as those found in Peru and the Colombian Andes, as well as regions in Siberia and southern Australia, could experience the disappearance of climates completely. Devastation of critical ecosystems and changes in agricultural patterns could severely affect Australia, New Zealand, and the developing island nations of the Pacific. With so many factors still undetermined or speculative, however, it remains to be seen how climate zone changes will play out in the future.

Victoria Price

• Further Reading

Burroughs, William James. *Climate Change: A Multidisciplinary Approach.* 2d ed. New York: Cambridge University Press, 2007. Discusses climate change's natural and anthropogenic causes, effects and consequences, methods of measurement, and contemporary predictions.

Diaz, Henry F., and Richard J. Murnane, eds. *Climate Extremes and Society.* New York: Cambridge University Press, 2008. Two parts discuss definitions and models of weather extremes and the impact of weather and climate extremes on the insurance industry.

Ennis, Christine A., and Nancy H. Marcus. *Biological Consequences of Global Climate Change*. Sausalito, Calif.: University Science Books, 1996. Explains the links between living organisms and climate; examines direct and indirect effects of GHGs on physical climate. Stresses uncertainties and challenges that affect future research and suggests that the most challenging aspect of climate change is that predicted changes will be occurring at the same time.

See also: Continental climate; Global climate; Holocene climate; Maritime climate; Mediterranean climate; Polar climate; Regional, local, and microclimates; Tropical climate.

Climatology

- **Category:** Meteorology and atmospheric sciences

• Definition

Climatology can be defined as the synthesis of weather studies over a time interval long enough to determine statistical properties. In other words, meteorology plus time equals climatology. Climatology differs from meteorology in that meteorology describes the atmospheric conditions at present, what are most often called "the weather." Meteorology also involves forecasting the weather for the very near future. Climatology involves studying the weather and its trends over a long period of time. Usually, the study of climate is limited to a particular area and, rather than providing a short-term forecast, can give an idea of the broad meteorological parameters in the area at any given time. The climate of a specific area can vary from year to year, decade to decade, or even century to century, and climatologists track these trends. Climatologists often use a thirty-year average to determine the normal climate for an area based on average humidity, precipitation, sunshine, and temperature. Meteorologists concentrate on the short term, studying and predicting weather systems that last only a few weeks.

• Significance for Climate Change

Climatologists study the climate, how it changes, and how those changes over time may affect the Earth, humans, and other forms of life. There are several different branches of climatology, such as paleoclimatology (reconstructing past climates by examining evidence such as ice cores or tree rings), paleotempestology (determining the frequency of hurricanes over thousands of years in order to understand their patterns), and historical climatology (focusing on climate changes that occurred on the Earth after humans appeared).

Climatologists study the way five different climate systems interact with one another. These systems include:

- *Atmosphere:* the gases that surround the Earth, including water vapor
- *Biosphere:* the Earth's ecosystems and all living organisms and dead organic matter on land and in water
- *Cryosphere:* any frozen water, such as floating ice, glaciers, permafrost, or snow
- *Hydrosphere:* all liquid surfaces, such as lakes, oceans, rivers, as well as underground water
- *Lithosphere:* the solid parts of the Earth

Based on the interactions between and among these systems and the way weather is created by them, climatologists are able to predict the changes in these systems that will affect the climate and, to a certain extent, what kinds of changes in the climate may occur as a result of these interactions and disturbances to them.

Climatologists study both broad issues (such as the circulation of ocean currents and how they affect the Earth) and seemingly small issues (such as how minor differences in the amounts of sunlight between urban and rural areas affect the overall climate of each area). Both these types of phenomena may affect the climate of a certain area; for example, the amount of heat retained in concrete may cause an area's climate to change dramatically if the area is urban.

Climatology can be a difficult science because of the long time periods involved and the complexity of the processes and interactions that must be dissected to arrive at any type of conclusion. Climatologists break these complexities down into mathematical differential equations that can be used to integrate different climate observations and help piece them together. Climatologists often use statistical or mathematical models to test how their hypotheses about climate will play out. These models simulate the interactions of climate systems in order to project future climate changes.

In the past, climatology was seen as a static field of study, one that changed little over time and involved compiling statistics about weather conditions. Concerns about global climate change beginning in the 1960's helped highlight this science as a field that could help explain the changes in climate that occurred in the distant past and predict how climate would affect the Earth and its living organisms in the future.

Marianne M. Madsen

• **Further Reading**

Barry, R. G. *Synoptic and Dynamic Climatology.* New York: Routledge, 2001. Discusses climate dynamics and mechanisms and synoptic-scale weather systems.

Bonan, G. *Ecological Climatology: Concepts and Applications.* New York: Cambridge University Press, 2008. Focuses on interactions between the climate and ecosystems; reviews basic meteorological, hydrological, and ecological concepts.

Critchfield, H. J. *General Climatology.* Englewood Cliffs, N.J.: Prentice Hall, 1998. Discusses all aspects of weather and climate as well as past and possible future climate changes. Includes charts, graphs, and black-and-white photos.

Hartmann, D. L. *Global Physical Climatology.* San Diego, Calif.: Academic Press, 1994. A textbook approach to physical climatology including the climate system. Includes a comprehensive index.

Oliver, J. E., ed. *The Encyclopedia of World Climatology.* New York: Springer, 2005. Discusses the subfields of climatology. Includes graphs, charts, drawings, and citations to other important climatology works.

Oliver, J. E., and J. J. Hidore. *Climatology: An Atmospheric Science.* 2d ed. Upper Saddle River, N.J.: Prentice Hall, 2002. Discusses why recent climate changes have occurred and explains the science behind those changes. Describes how basic processes operate in the atmosphere.

Perry, A. *Applied Climatology: Principles and Practice.* New York: Routledge, 1997. Emphasizes the effects of climate changes on life-forms.

Rayner, John N. *Dynamic Climatology: Basis in Mathematics and Physics.* Malden, Mass.: Blackwell, 2001. Discusses how statistics, dynamics, and thermodynamics affect the study of climate. Includes historical accounts.

Robinson, P., and A. Henderson-Sellers. *Contemporary Climatology.* Englewood Cliffs, N.J.: Prentice Hall, 1999. Covers topics such as the water cycle and use of satellite observations to track climate changes.

Rohli, R. V., and A. J. Vega. *Climatology.* Sudbury, Mass.: Jones & Bartlett, 2007. Provides a basic foundation in climatic processes. Discusses climatology versus meteorology.

See also: Atmospheric dynamics; Climate and the climate system; Climate models and modeling; Climate prediction and projection; Climate reconstruction; Ocean-atmosphere coupling; Weather forecasting; Weather vs. climate.

Clouds and cloud feedback

• **Category:** Meteorology and atmospheric sciences

Clouds are important components of Earth's life-sustaining greenhouse effect. Alterations in cloud density, prevalence, or altitude caused by global temperature increases may have far-reaching consequences for Earth's temperature equilibrium.

• **Key concepts**

aerosols: tiny particles suspended in Earth's atmosphere

enhanced greenhouse effect: increased retention of heat in the atmosphere resulting from anthropogenic atmospheric gases

global radiative equilibrium: the maintenance of Earth's average temperature through a balance between energy transmitted by the Sun and energy returned to space *greenhouse gases (GHGs):* atmospheric gases that trap heat, preventing it from escaping to space

• Background

Clouds have a profound influence on local and global climate. Scientists have known for many years that clouds are a major component of the greenhouse effect, which makes life possible on Earth. What is not well understood is what effect clouds may have on global warming and cooling trends. Of the many variables that factor into global warming, clouds present the greatest uncertainty in predicting climate change.

• Clouds

Clouds are composed of droplets or ice crystals that form around aerosols in the atmosphere. These droplets accumulate until they become visible. The many shapes and sizes of clouds are divided into three basic types: cirriform (wispy and transparent), stratiform (layered), and cummuliform (mounded and fluffy). Three altitude divisions are also used for classification: high (more than 5,000 meters above sea level), middle (between 2,000 and 5,000 meters above sea level), and low (less than 2,000 meters above sea level). The terms are combined, with the upper and middle altitudes given the prefixes cirro- and alto-; a midlevel stratus cloud is called altostratus, for example.

Clouds reflect solar radiation back to space, and they reflect Earth's radiation back to the surface. Thus, all other factors being equal, nights are warmer and days are cooler when clouds are present. The amount of reflection back to space depends on cloud thickness, with a low of approximately 20 percent for cirrus clouds and a high of 90 percent for cumulonimbus clouds. Clouds contribute significantly to global radiative balance, or radiative equilibrium, an overall balance between solar radiation received by the Earth and heat reflected back to space. If the Earth absorbed all the radiation it receives, it would be much too hot to sustain life.

• Greenhouse Effect and Feedback

However, the Earth does not absorb all the solar energy it receives, but instead reflects visible radiation and emits infrared radiation. Without an atmosphere, the total return of energy to space would make the Earth much colder than it is—the average surface temperature would be approximately –18° Celsius. Clouds and other greenhouse gases (GHGs) absorb some of the energy, trapping it and sending some of it back to the Earth's surface. This is the greenhouse effect.

"Feedback" is a term that applies to any multipart system in which a change in one part produces a change in the other part, which then affects the original part, and so on. A simple example is a thermostat, which responds to a drop in temperature by turning on a furnace. The furnace raises the air temperature, which then causes the thermostat to turn off the furnace. Feedback systems can affect changes in cloud thickness and prevalence as a response to climate changes, particularly temperature. The greenhouse effect creates a state of equilibrium, and cloud feedback disturbs that equilibrium.

Cloud feedback can be either positive or negative. Positive feedback increases the enhanced greenhouse effect, while negative feedback lowers global temperatures. Most clouds provide both positive feedback (transmitting energy down toward the Earth) and negative feedback (transmitting solar radiation back to space). Determining whether the net feedback is positive or negative is a complicated process.

• Clouds and Climate Change

Climate change can increase both positive and negative feedback. Studies have shown that cold water

Types of Clouds

Name	*Altitude (km)*
Altocumulus	2-7
Altostratus	2-7
Cirrocumulus	5-13.75
Cirrostratus	5-13.75
Cirrus	5-13.75
Cumulonimbus	to 2
Cumulus	to 2
Nimbostratus	2-7
Stratocumulus	to 2
Stratus	to 2

Source: National Oceanic and Atmospheric Administration.

produced by the melting polar ice cap causes phytoplankton to release chemicals that produce more and brighter clouds, thereby increasing negative feedback. Aerosols may produce either positive or negative feedback, depending on the source of the aerosols. Volcanic eruptions and pollution from technologically advanced countries, consisting of sulfates and nitrates, generate clouds that produce negative feedback. However, the developing world produces pollution that contains these substances as well as large amounts of black carbon, the by-product of incomplete combustion of carbon-based fuels. Black carbon aerosols generate positive feedback. The net feedback of pollution is very difficult to determine.

A long-held belief is that if the Earth's climate warms, water vapor amounts in the atmosphere will increase, creating more low-level thick clouds that will generate negative feedback. That belief is being called into question by recent studies that have shown that turbulence created by rising warm air currents will actually lead to fewer clouds being formed overall.

• A Source of Uncertainty

The impact of clouds on climate change is extremely difficult to model. Most of the important climate modeling systems represent clouds with a small number of variables, masking the subtleties of cloud dynamics. This is due to the extremely complicated mathematics required to model clouds realistically. While analyzing the results of some large-scale climate studies, scientists have concluded that neither the magnitude nor the sign of cloud feedback can be relied upon.

When weather data are entered into climate models, the resulting pictures of cloud cover and thickness often do not match actual conditions. Further complicating matters, studies done with live data collection also show contradictory results. For example, some studies indicate that decreasing cloud cover over China (resulting from large amounts of pollution) may be responsible for increasing temperatures there. However, other studies performed in other parts of the world indicate that temperatures have increased as cloud cover has increased.

• Context

The impact of clouds on global climate cannot be overstated. Clouds are extremely sensitive to fluctuations in solar radiation, Earth's surface temperature, and many other environmental factors, including pollution levels. It is this sensitivity, combined with nearly infinite variations in cloud size, make-up, and altitude, that make predicting cloud feedback so difficult. Since clouds may either mitigate or increase global warming, it is imperative that scientists intensify their efforts to produce better predictive climate modeling systems, as well as promote studies that analyze data collected in the field. Throughout the world, decisions are being made using climate predictions that may be flawed as a result of the uncertainty presented by cloud behavior. As these decisions will have a considerable impact both economically and sociologically, minimizing the uncertainty presented by clouds in a warming climate may become a priority in environmental agendas.

Kathryn Rowberg and Gail Rampke

• Further Reading

Combs, Peter. "Clouds and Climate Change." *Focus* 46, no. 1 (Spring, 2000): 35-36. Examines ground-level data collection of actual clouds, rather than modeling.

Mlynczak, M. G., et al. "A Detailed Evaluation of the Statospheric Heat Budget and Global Radiation Balance and Diabatic Circulations." *Journal of Geophysics Research* 104 (1999): 6039-6066. This study of global radiative balance uses satellite data from two time periods (1978-1979 and 1991-1993), the second of which includes the Pinatubo eruption. The conditions existing during the two time periods make this worthwhile reading for those interested in cloud feedback.

Soden, Brian J., and Issac M. Held. "An Assessment of Climate Feedbacks in Coupled Ocean-Amospheric Models." *Journal of Climate* 19 (2006): 3354-3360. Examines global climate modeling systems, focusing on cloud feedback results and their interpretation.

Stephens, G. L. "Cloud Feedbacks in the Climate System: A Critical Review." *Journal of Climate* 18 (2005): 237-273. Excellent overview of cloud feedback systems and the difficulties they pre-

sent when one is trying properly to parameterize them in climate modeling.

See also: Albedo feedback; Climate feedback; Noctilucent clouds; Polar stratospheric clouds.

Coal

- **Categories:** Fossil fuels; energy

Coal burning accounts for a large share of global anthropogenic CO_2 output. Net carbon emissions per unit energy produced by coal exceed those of any other major energy source. The relative cheapness of coal, enormous reserves, and the concentration of those reserves in countries that are among the top energy consumers make continued growth likely—and make reducing carbon output from coal an urgent priority.

• Key concepts

carbon budget: the total amount of CO_2 emissions that can be sustained, given a target atmospheric CO_2 concentration, and the way in which those emissions are apportioned

carbon-capture-and-storage (CCS) systems: processes that remove CO_2 from combustion products and sequester it—typically in underground storage

fossil fuels: combustible products of ancient photosynthesis

integrated gasification combined cycle (IGCC) systems: electrical generation technology that converts coal to combustible gas before burning it

• Background

Coal was the first fossil fuel to be used by humans, and it will likely be the last. Known world coal reserves are projected to last for another 250 years. Unlike petroleum and uranium, which must be transported great distances to reach oil burners and nuclear reactors, the largest concentrations of coal deposits exist within populous countries with high energy requirements.

Most coal is used in contemporary society for generating electricity. Historically, solid coal also fueled transportation and industry. Inefficient energy conversion, the weight of coal-fired steam engines, and massive pollution all encouraged conversion to petroleum products for most purposes other than electrical power generation in the twentieth century. These factors also constitute powerful arguments against reviving the older technologies. However, both fuel gas and oil can be produced from coal, eliminating much of the bulk and pollution associated with coal-based energy—but not the problem of carbon dioxide (CO_2) emissions. According to one estimate, if early twenty-first century trends continue, the CO_2 emissions from burning coal in 2030 alone will equal about 50 percent of the total emissions from 1750 through 2000.

Most of the world's coal reserves accumulated during the Carboniferous ("coal-bearing") age. This age, ocurring between 354 and 290 million years ago, was a very warm period when land-plant productivity greatly exceeded herbivore consumption and decomposition. The Chinese were already burning coal in the thirteenth century. The use of coal for cooking and heating in cities was well established by the middle of the eighteenth century in England, when a series of inventions enabled manufacturers to replace human and animal labor with increasingly sophisticated coal-fired steam engines. This Industrial Revolution enabled an individual worker greatly to increase productivity, leading to an overall increase in per capita consumption of the Earth's renewable and nonrenewable resources at a time when population was also beginning to increase at an exponential rate.

• History of Coal Consumption

Coal consumption in Great Britain increased from 2.45 million metric tons per year in 1700 to 45 million metric tons per year in 1850 to 227 million metric tons per year in 1900. Annual consumption in the United States was 36 million metric tons in 1870 and 469 million metric tons in 1913. Total world consumption of coal on the eve of World War I was roughly one-tenth of its 2006 level of 5.44 billion metric tons.

Global warming as an environmental concern of coal utilization is a relatively recent phenomenon. Pollution and environmental degradation due to unsound mining practices dominated discussions of coal until the 1980's. At first, efforts to curb rampant urban air pollution consisted of moving heavy industry away from population centers, building taller smokestacks to divert pollutants elsewhere, and removing soot and other particulates from emissions. These brought sulfur dioxide (SO_2) and acid rain to the forefront of the environmental consciousness.

To address the SO_2 problem, industry developed the integrated gasification combined cycle (IGCC) system, which subjects superheated pulverized coal to steam to produce coal gas, which is then used to fuel electrical generation or other industrial functions. Coal gasification converts sulfur to hydrogen sulfide, which is removed before combustion. Startup costs for an IGCC plant are high, but some of the operating expenses are recouped from industrial use of hydrogen sulfide.

In terms of carbon output, IGCC systems exacerbate coal's already unfortunate profile. The process itself requires large energy inputs, which increase the fuel's carbon footprint, and the gas produced includes a high proportion of carbon monoxide, a carbon-intensive fuel source. While in many respects equivalent to natural gas, coal gas is inferior to that gas in terms of its carbon emissions. Its toxicity is also a drawback for domestic use.

There is evidence that efforts to combat pollution have actually increased the greenhouse effect caused by coal burning, because the dirtier and more polluting a coal-fired plant is, the more soot and SO_2 it spews into the atmosphere. Both pollutants block incoming solar radiation directly and serve as nuclei for cloud formation. In contrast, soot on surfaces, especially snow and ice, has a positive warming effect. Coal mining also contributes to greenhouse gas (GHG) buildup by releasing methane stored in coal seams. This was once a significant source of atmospheric methane, but most mines now have recovery systems, using the gas for operations.

Coal Consumption Increase During the Industrial Revolution

Year	*British Consumption (mmt)**	*U.S. Consumption (mmt)*	*Global Consumption (mmt)*
1700	2.45		
1850	45		
1870		36	
1900	227		
1913		469	
1914			~550
2006			5,440

*mmt = millions of metric tons.

- **Carbon Capture and Storage**

In order to continue using coal as an energy source while avoiding escalating global warming, some practical method must be devised to remove CO_2 at the source, either storing it or converting it into nongaseous compounds. In practice, the energy costs of building and operating a system for sequestering the amounts of carbon emitted by a modern electrical generating plant are daunting. A very effective mechanism for using solar energy to convert CO_2 to organic compounds has existed for several billion years: photosynthesis. There have been proposals to couple CO_2 emissions with intensive algae farms, but it would unfortunately require thousands of square kilometers of surface area and hundreds of years to convert a large power plant's annual emissions into biomass fuel.

The most promising plans for carbon-capture-and-storage (CCS) systems call for using pure oxygen rather than air in IGCC plants, eliminating a large admixture of environmentally neutral nitrogen. The gas would then be injected into depleted petroleum reservoirs. Geologic formations suitable for CO_2 sequestration are typically far removed from coal-producing areas, requiring a delivery network for the waste gas comparable in cost and extent to that used for distribution of natural gas. The costs of retrofitting an IGCC plant for CCS, delivering the waste product to its destination, and maintaining ongoing operating costs make CCS commercially unviable in the absence of government subsidies and tax incentives. There have been many proposals and a few pieces of legislation addressing this dilemma, but none so far has stimulated investment in this technology.

The Fiddlers Ferry coal-fired power station in Liverpool, England. (Phil Noble/Reuters/Landov)

• Context

Electrical power plants have huge startup costs, very long half-lives, and limited capacity for adaptation. Many U.S. power plants date from the 1950's and even before, supplying cheap electricity in competition with costlier, newer plants built to more stringent environmental standards. Until these older plants are retired, the potential of the new technology cannot be realized. Reducing carbon emissions from coal-fired power plants will require massive public investment, either from government subsidies or sharply higher electricity costs. Neither alternative is likely to find an effective advocate in a shaky economy. Depending on the extent to which global markets contract, a deep recession could also reduce electrical demand and halt efforts to convert coal to other uses to reduce petroleum dependence. Such a reduction would temporarily dampen the escalating curve of coal consumption and CO_2 output.

Martha A. Sherwood

• Further Reading

Flatow, Ira. *Present at the Future: From Evolution to Nanotechnology—Candid and Controversial Conversations on Science and Nature*. New York: Collins, 2007. Chapter 14, "Is Coal Still King," discusses the merits of some new technologies.

Freese, Barbara. *Coal: A Human History*. Cambridge, Mass.: Perseus, 2003. Nontechnical; provides a narrative of coal use through history, a discussion of current environmental issues including global warming, and an assessment of future prospects.

Krupp, Fred. *Earth, the Sequel: The Race to Reinvent Energy and Stop Global Warming*. New York: W. W. Norton, 2008. Provides an extensive discussion of new, environmentally friendly technologies, most in the early experimental phase.

See also: Carbon cycle; Carbon equivalent; Clean energy; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Greenhouse gases.

Coastal impacts of global climate change

• **Category:** Environmentalism, conservation, and ecosystems

Coastal environments include three of the four habitats on Earth that are most productive of biomass. Each of these habitats is directly affected by sea level and sea-level rise. Increasing concentrations of dissolved gases in the oceans will affect these ecosystems as well.

• Key concepts

brackish: having an intermediate salt concentration between freshwater (less than 5 parts per thousand) and seawater (35 parts per thousand)

primary production: the conversion of CO_2 into organic compounds, primarily by photosynthesis

salinity: the concentration of salts in water

• Background

The biomass productivity of marshes, estuaries, and coral reefs is comparable to that of tropical rain forests. This high productivity is due in part to the extreme range of environmental conditions at transitions between major habitats: terrestrial to marine, freshwater to seawater, and from the surface to considerable depths. These ecosystems not only are critical for the organisms whose entire lives are restricted to that ecosystem but also serve as nurseries for many of the fish and invertebrate species commercially harvested for human consumption.

• Coastal Wetlands

Coastal wetlands usually consist of a fringing border of marshlands grading through four general types, from open water toward land: salt marshes, brackish marshes, intermediate marshes, and freshwater marshes. The principal determinants of each grade are soil salinity and elevation. Soil salinity is slightly higher than the salinity of the surrounding water, so salt marsh plants, which are flooded by high tide, must be very salt tolerant. Such plants include salt grass and mangrove. Moving inland, soil elevation increases slightly with a consequent decrease in seawater influence versus freshwater input. The wetlands are integral to the coastal ecosystem. They filter freshwater runoff, trapping nutrients and sediments and thus extending the land seaward. Marshes protect the shore from wave action and storm damage by binding the soil and reducing wave energy. They serve as a nursery for many commercially important species such as shrimp, oysters, and crabs.

• Estuaries

Estuaries are semi-enclosed bodies of water where freshwater runoff from land mixes with seawater in a shifting gradient of brackish water with freshwater layered over denser seawater. Depending on the rate of freshwater flow, a wedge of salt water can intrude far upstream. For instance, in dry years with low river flow, salt water can intrude up the Mississippi River as far as New Orleans, threatening the city's water supply. During low water, an underwater sand sill is constructed across the river bottom a few kilometers downstream of the city to prevent this catastrophe. Major estuaries in the United States include Chesapeake Bay, Puget Sound, San Francisco Bay, and much of the Gulf Coast. Estuaries are one of the world's most productive natural environments and serve as the nursery areas for many commercial and sport fisheries. Typically, adult animals spawn at sea, and their eggs and larvae are carried by tide and currents to estuaries, where the young animals grow and develop.

• Intertidal Zone

Sea level is not uniform. On most coasts, sea level fluctuates between high tide and low tide twice a day. The extent of these tides also fluctuates on a monthly cycle. Once a month, there is a highest high tide, the spring tide, and two weeks later there follows the lowest low tide of the month, the neap tide. Between the levels of the spring tide and the neap tide is a gradient of conditions that are constantly varying. The intertidal zone is often subdivided into high, middle, and low subzones, each with its characteristic species. Organisms in the high intertidal zone are exposed to air virtually daily. In the low intertidal zone, organisms are exposed only a few days a month. Above the high intertidal zone is a splash zone, where terrestrial organisms must be tolerant of salt water. Below the level of low tide is the subtidal zone, which is further stratified by salinity tolerance and depth of light penetration. The consequences of tidal fluctuation are most dramatic on rocky shorelines, where the stratification of algal and invertebrate animal communities is clearly visible at low tide.

• Marine Zones

Oceans are the largest reservoir of carbon in the carbon cycle and readily dissolve carbon dioxide (CO_2) from the atmosphere. As such, they were thought to provide a buffer against global warming, with algal productivity increasing in proportion to carbon uptake from the atmosphere. However, when CO_2 dissolves in water, it forms carbonic acid, which lowers pH to the detriment of marine organisms. In addition, increasing oceanic nitrogen levels from fertilizer runoff and sewage washed by rivers into the sea and from nitrous oxide produced by burning fossil fuels is having a negative impact on marine life. Again, initial thought was that adding nitrogen to the oceans would be a good thing, fertilizing the sea and promoting algal growth. In many places, however, the resulting algal blooms deplete dissolved oxygen in the water, forming extensive dead zones, where fish cannot survive. For instance, every year a dead zone forms off the mouth of the Mississippi River, extending from Louisiana to Texas.

• Coral Reefs

Coral reefs are important coastal habitats in tropical waters, such as off the coasts of Hawaii and southern Florida. They are highly productive and, like estuaries and marshes, serve as a nursery for many marine animals. A reef itself is produced largely by calcium deposition from coral animals and coralline algae. The organisms secrete calcium carbonate, or limestone, around themselves for protection against predators, slowly building new reef upon older, dead layers. Coral animals have a narrow range of optimal temperatures, and scientists think that warming is responsible for some of the bleaching and death occurring on reefs worldwide, but particularly in the Caribbean Sea. Coral animals require symbiotic unicellular algae for calcium secretion, and animals that lose their symbionts quickly beach and die. In addition to temperature change, gradual acidification of the water due to dissolved CO_2 also may be a critical factor in coral death. As corals die, they often are replaced by carpets of algae that completely change the community composition of the reef.

Although reef walls may extend to great depths, their most productive zones are just below the surface. Fringing and barrier reefs are often visible from shore because of waves forming breakers as the water suddenly becomes shallower. As a result, the reef crest dissipates wave energy and protects the shoreline from the power of wave and storm action. A shallow lagoon,

Toxic algae, known collectively as a "red tide," threaten the coast of Dubai, United Arab Emirates, in April, 2009. (Matthias Seifert/Reuters/Landov) with its own characteristic species, typically forms between the reef and the shore.

• Context

All coastal ecosystems are characterized by gradients of temperature and salinity that are directly related to water depth and distance from freshwater sources. Temperature-induced sea-level rise has an impact on seawater intrusion into freshwater and terrestrial habitats, changing the nature of the ecosystem. Higher temperatures also increase the rate of evaporation, concentrating salts and further raising salinity levels.

Marshall D. Sundberg

• Further Reading

Bertness, Mark, Brian Reed Silliman, and Robert Jefferies. "Salt Marshes Under Siege." *American Scientist* 92, no. 1 (2005): 54-61. Global warming is a long-term threat, but this article concentrates on some of the more immediate anthropogenic threats to this productive ecosystem.

Ricketts, Edward F., and Jack Calvin. *Between Pacific Tides*. Stanford, Calif.: Stanford University Press, 1962. Classic introduction to marine life on the shore by a friend and companion of novelist John Steinbeck. Ricketts was the model for Doc in Steinbeck's *Cannery Row*.

Silver, Cheryl Simon, with Ruth S. DeFries. *One Earth, One Future: Our Changing Global Environment*. Washington, D.C.: National Academy Press, 1990. One of the first warning calls concerning climate change. One chapter addresses coastlines and rising seas.

Wolanski, Eric, et al. "Mud, Marine Snow, and Coral Reefs." *American Scientist* 91 (2005): 44-51. Coral reefs are one of the most productive ecosystems on Earth, but they have been in noticeable decline for several decades. The authors elaborate on some of the causes, including warming oceans.

See also: Alliance of Small Island States; Barrier islands; Estuaries; Louisiana coast; New Orleans; Ocean acidification; Ocean life; Reefs; Sea-level change; Sea sediments; Sea surface temperatures.

Coastline changes

• **Categories:** Geology and geography; oceanography

• Definition

The term "coastline" is used to describe those places where the land and the water of the world's oceans meet. These are dynamic parts of the globe that are daily shaped by tides, winds, waves, changing sea levels, and human activities. Large river discharges may dominate them entirely, or they may be ice covered much of the time; cities may border them with their polluting activities, or they may be remote with no human presence at all. Oceanographers generally classify coastlines as being in one of two categories: either erosional or depositional.

Erosional coastlines are found where wave action is actively removing bedrock or sediment exposed along a coast, or where rivers or glaciers eroded the coast in past times when sea levels were lower than they are today. Some of the distinctive features found along erosional shorelines include rocky headlands separated by bays and coves, sea cliffs, sea caves, sea arches, sea stacks, and uplifted wave-cut terraces. Additional features such as fjords, old glacial moraines, drowned river valley systems, faults, and volcanoes may also be present.

Depositional coastlines are places where the shoreline grows outward because of the accumulation of sediment or the action of organisms such as mangroves and corals. Important features found along these coasts include beaches, sand bars, cusps, spits, sand hooks, and offshore barrier islands with long, narrow lagoons behind them. In addition, coral reefs, deltas, mangrove swamps, and salt marshes may be present. The term "coastal zone" is used in legal and legislative documents to describe the shoreline area. The landward boundary of the coastal zone is defined as the distance inland from a chosen reference point, usually the high water mark. This distance is frequently 60 meters. The seaward boundary of the coastal zone is variously defined by local, state, or federal laws.

Dauphin Island, off the coast of Alabama, has been split in two, but its halves may be growing back together. Coastal features such as these barrier islands can change relatively rapidly as a result of maritime events. (Bill Starling/The Press-Register/Landov)

• Significance for Climate Change

As sea levels rise as a result of the thermal expansion of seawater and the addition of new water from ice melting on land, a variety of coastline changes can be anticipated to take place. Areas that were previously above wave action will be subject to vigorous wave attack, and storm surges should intensify and extend farther toward the poles as a warming ocean generates more lethal storms. While cliffs made of resistant rock may remain unaffected, those coastlines built of loose sedimentary materials, such as sand or gravel, may be eroded back as much as a few meters in a single storm. Coastal areas that were never flooded before may be covered with seawater during severe storms and high tides; finally, they will be flooded by the ocean on a permanent basis. Low-lying urban areas would be particularly affected. The flooding of New Orleans during Hurricane Katrina in 2005 is an example, and already the city of Venice experiences periodic floods when tides are extremely high.

Ultimately, the people who live in high-risk areas such as these will be forced to move, and millions of people will be displaced. The Nile and Mississippi deltas are examples of high-risk places with large urban populations, as are the low-lying coastal areas in Bangladesh and the adjoining countries of Southeast Asia. As seas rise because of global warming, beaches will be forced to migrate inland or drown in place. Those in important tourist areas, such as Miami Beach and the Gulf Coast of the United States, will require expensive nourishment programs. Estuaries, which are critical for commercial fish stocks during spawning and early life stages, will gradually change from brackish to saline or in time may become part of the sea itself. The coastal wetlands behind them, which filter out pollution from the land and act as sponges for storm surges, will become saline too. These, along with the mangroves that protect the shoreline from wave attack and are also part of the nutrient system, will eventually have to migrate inland, provided the areas behind them are not already developed.

Even the offshore coral reefs that provide protection to the shoreline from wave erosion may be affected, because corals have a very low tolerance to elevated water temperatures. It can also be anticipated that salt water will gradually intrude upon coastal aquifers, making their supplies of drinking water unfit for humans, and that expensive structures such as dikes and seawalls will have to be built to protect most of the urban areas. Infrastructure, such as highways, bridges, waterways, ports, mass transit systems, airports, water supply facilities, and waste storage systems, may be threatened as well, and some of the nuclear power plants that have been built next to the ocean to make use of seawater for their cooling towers will have to be moved. Even lowly storm drains, built to carry rainwater off the land, will play a significant role in coastal flooding by providing conduits to send the seawater onshore.

Donald W. Lovejoy

• Further Reading

Bird, Eric. *Coastal Geomorphology: An Introduction.* Hoboken, N.J.: Wiley, 2008. Definitive survey of the classic shoreline types, with excellent photographs showing examples of each of these features throughout the world.

Davis, Richard A., and Duncan M. Fitzgerald. *Beaches and Coasts.* Malden, Mass.: Blackwell Science, 2004. Provides a good overview of beach and coastal features with useful information on the steps humans are taking to protect themselves from rising sea levels.

Glick, Daniel. "The Big Thaw." In *Global Climate Change,* edited by Paul McCaffrey. New York: H. W. Press, 2006. A sampling of firsthand reports illustrating the ways in which rising sea levels are affecting shorelines in many parts of the world.

See also: Bangladesh; Barrier islands; Coastal impacts of global climate change; Floods and flooding; New Orleans; Storm surges.

Collapse

- **Category:** Popular culture and society
- **Date:** Published 2005
- **Author:** Jared Diamond (1937-)

• Background

Collapse: How Societies Choose to Fail or Succeed was published in 2005 by Jared Diamond, who previously won the Pulitzer Prize for *Guns, Germs, and Steel: The Fates of Human Societies* in 1998. Diamond's central theme is that environmental mismanagement and failure to confront emerging environmental problems have repeatedly led to the collapse of societies, even when the problems were obvious.

Collapse consists of four parts. Part 1 examines contemporary Montana, which saw the collapse of once-lucrative industries like mining and logging, and which is struggling with the need to adapt to change while grappling with ingrained hostility toward regulation and restraints on individual freedom. Part 2 is an examination of historical examples of societal collapse: Easter Island and other Polynesian examples, the Anasazi of the American Southwest, the Maya, and the Norse settlements in Iceland and Greenland. Diamond describes two contrasting paths taken by successful societies, the decentralized approach of New Guinea tribal societies and the top-down style of Japan under the Tokugawa regime (1603-1867). Part 3 is a study of several contemporary societies: Rwanda, the contrasting examples of Haiti and the Dominican Republic, China, and Australia. Finally, in Part 4, Diamond attempts to catalog the reasons some societies fail to respond to environmental threats, discusses environmental practices of several large industries, and finally attempts to apply his analysis to contemporary society. Although Diamond is critical of many Western attitudes and practices, the tone of the book is not apocalyptic. In fact it closes on a rather hopeful note by enumerating ways that modern societies have deliberately changed.

Societies may fail to deal with environmental threats for many reasons. They may not recognize the threat. The problem may be recognized, but attempts to solve it may be inappropriate. There may be no attempts to solve the problem, because certain interest groups may be adversely affected by the solution, the benefits of solving the problem may not seem to outweigh the costs, or the problem may be seen as diffuse or remote. Some environments, like Greenland or the American Southwest, may simply be unsuited for intensive human use. In contrast to errors that can be termed "rational," that is, attempts to cope with problems using what seem to be sound reasoning and methods, Diamond discusses "irrational failures," courses of action that are harmful to all. For example, many of the collapses discussed by Diamond were driven in part by maintaining the status of ruling elites, or unwillingness to abandon cultural prejudices.

• Significance for Climate Change

Several of the collapses discussed by Diamond were related directly to climate change, particularly the Anasazi, the classical Maya, and the Norse of Greenland. None of those societies was scientifically capable of recognizing the change in time or devising suitable strategies for coping with it. The relevance of *Collapse* is not in its use of past case studies of climate change, but its discussion of ways that societies have dealt with environmental degradation and either averted catastrophe or succumbed to it. Many of the patterns Diamond discusses can be seen at work in the climate change controversy.

Societies may be unaware of an emerging problem, because the onset of the problem is gradual, like the deteriorating climate of Norse Greenland. The onset of the problem may also be concealed by short-term random fluctuations, like the intermittent droughts that led to the collapse of Anasazi and Classical Maya society, which were interspersed with more normal years. In contemporary Western society, skeptics point to unusually cold episodes as evidence against climate change, while believers point to increasingly frequent evidence of warming. The "noisiness" of climate data is a major reason climate change is so controversial.

Environmental problems may be recognized but attempts to solve them may be inappropriate—for example, introduction of exotic species to control pests or total fire suppression in the American West. Similarly, some proposals for dealing with climate change may have unintended negative effects. Other attempted solutions may be costly but ineffective, impairing economic productivity and quality of life but not appreciably affecting climate change. There may be no attempts to solve the problem, because certain interest groups may be adversely affected by the solution, or because the problem is seen as diffuse or remote.

Many of the choices made by failed societies involve deep internal conflicts—for example, immediate survival needs versus long-term survival needs, or survival needs versus other deeply held values. Some of the collapses discussed by Diamond were partly caused by practices for maintaining the status of ruling elites, such as the way Easter Island society collapsed because resources were exhausted in building progressively larger statues in a prestige race among chiefs. Other fatal decisions involved unwillingness to abandon cultural prejudices. For example, the Norse settlements in Greenland died out because the Norse never adopted Inuit survival techniques, even as the climate deteriorated. Diamond notes that many of the values so-

The Metaphor of Easter Island

In Collapse, *Jared Diamond asserts that Easter Island and its tribal culture represent a useful metaphor for Earth and its inhabitants. In the excerpt below, he explains why.*

Thanks to globalization, international trade, jet planes, and the Internet, all countries on Earth today share resources and affect each other, just as did Easter's dozen clans. Polynesian Easter Island was as isolated in the Pacific Ocean as the Earth is today in space. When the Easter Islanders got into difficulties, there was nowhere to which they could flee, nor to which they could turn for help; nor shall we modern Earthlings have recourse elsewhere if our troubles increase. Those are the reasons why people see the collapse of Easter Island society as a metaphor, a worst-case scenario, for what may lie ahead of us in our own future.

cieties are most reluctant to change are often the very values that made the society successful in the past. These examples may have parallels in contemporary society, where much of the opposition to the idea of climate change is motivated by concern over impacts on lifestyle and where environmentally inefficient choices such as overly large homes and vehicles are often motivated by desire for social status.

Steven I. Dutch

See also: Arctic peoples; Carson, Rachel; Civilization and the environment; Displaced persons and refugees; Maldives; Megacities; Population growth; Preindustrial society.

Colorado River transformation

• **Category:** Water resources

Major reservoirs, constructed along the Colorado River to capture and more efficiently use annual river flow, promote evaporative water loss that concentrates the mineral salts washed into the river. Global warming will exacerbate this problem.

• Key concepts

aqueduct (irrigation canal): a human-made channel or pipe to carry water for consumption or industrial or agricultural use

desalination: the process of removing dissolved salts and minerals from water to produce freshwater for consumption or irrigation

evaporation: transformation of liquid water to water vapor, which is absorbed into the air

reservoir: a body of water that forms behind a dam

watershed: the area of land drained by a river and all of its tributary streams

• Background

The Colorado River is the major source of freshwater for a watershed of seven southwestern U.S. states and the adjacent nation of Mexico. In the early twentieth century, California was growing rapidly and the other states realized that their future development depended upon water allocation from the river. A series of compacts, laws, and court rulings legally parceled out more water than annually flows down the river, so the river no longer reaches the sea.

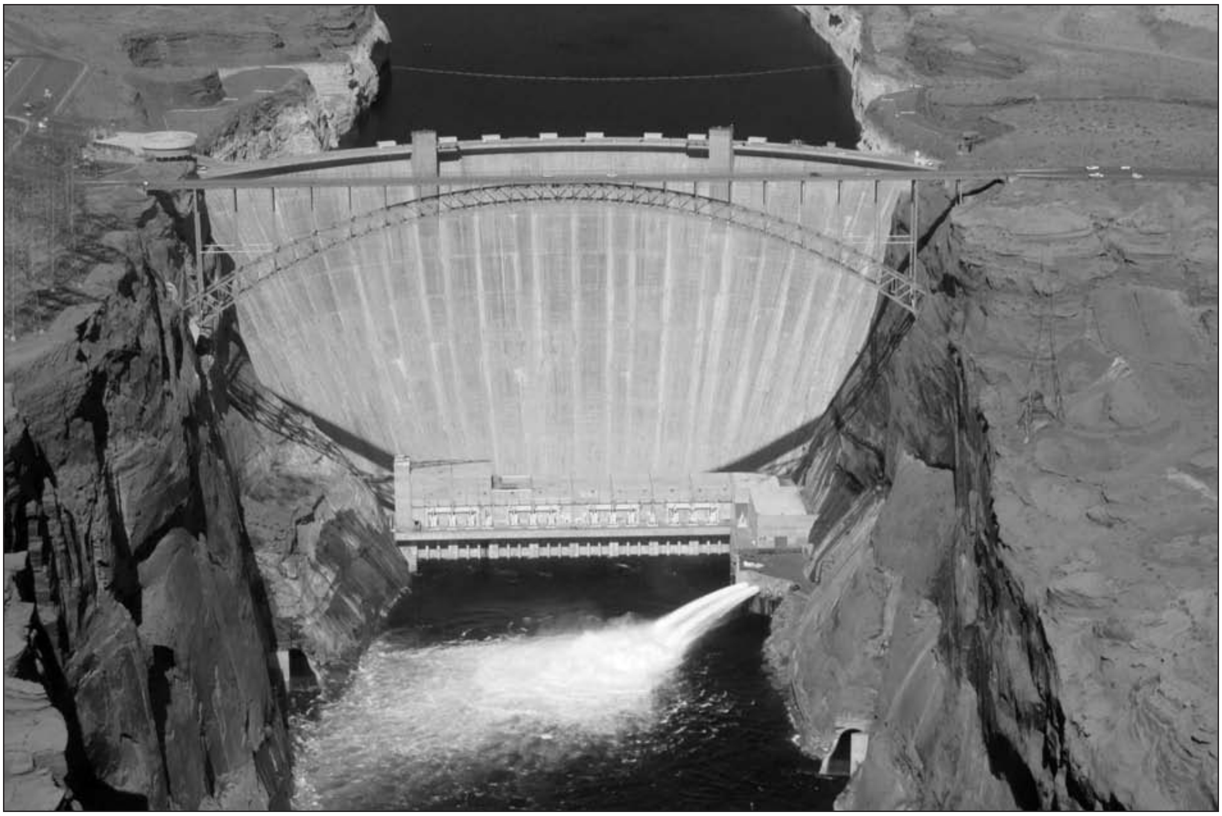
• Law of the River

In 1902, the Reclamation Act provided for development of irrigation projects throughout the West, including projects in California, Arizona, Utah, and Colorado in the Colorado River Basin. The Colorado River Compact (1922), the first of a series of laws and agreements specific to the Colorado River, divided the river into an upper and lower basin and allocated 9.25 cubic kilometers of water to each. The lower basin was given priority, so in dry years the upper basin allocation must be cut back to ensure that 9.25 cubic kilometers flows to the lower basin. The states in each basin negotiated a share of the water.

In a "good year," state allocations of Colorado River water are as follows: Colorado, 4.76 cubic kilometers; New Mexico, 1.04 cubic kilometers; Utah, 2.11 cubic kilometers; Wyoming, 1.28 cubic kilometers; Nevada, 0.37 cubic kilometer; Arizona, 3.45 cubic kilometers; and California, 5.43 cubic kilometers. In 1944, Mexico was granted an allocation of 1.85 cubic kilometers, and a subsequent agreement specified allowable salinity. The courts have allocated 1.11 cubic kilometers to Native Americans in the lower basin, and Native American rights in the upper basin are pending.

• Dams and Reservoirs

In the late 1800's, agricultural development of the Imperial Valley of California was watered by a canal from the Colorado River running mostly though Mexico. A major flood in 1905 caused a breach in the canal, and for two years the river emptied into the valley, creating the Salton Sea. Another major flood in 1910 stimulated planning for a flood-control dam upstream: The Hoover Dam was completed in 1935, and Lake Mead formed behind it. The Colorado River Compact between the states was made in response to plans to build the Hoover Dam, which would primarily benefit California.



Water is released from the Glen Canyon Dam in March, 2008, in an effort to restore depleted ecosystems downstream. (Tami Heilemann/UPI/Landov)

The dam provided flood control and generated electricity for Las Vegas and Los Angeles.

There are now seven major dams on the Colorado River, from Glen Canyon Dam, just north of Lees Ferry (the divide between the upper and lower basins), to the Mexican border. An additional thirty-five dams are built on tributaries within the watershed. The four largest reservoirs expose a tremendous surface area to evaporation: Lake Powell, 658 square kilometers; Lake Mead, 640 square kilometers; Lake Mojave, 114 square kilometers; and Lake Havasu, 83 square kilometers. This evaporation has driven an increase in the river's salinity. Indeed, river salinity levels have increased so much that in 1973 an agreement was reached between the United States and Mexico to mandate maximum salinity levels in the water crossing the border. The following year, Congress authorized construction of a desalination plant on the U.S. side of the border to ensure that water flowing into Mexico achieved treaty salinity specifications.

In addition to affecting water quality, dams and reservoirs change the physical characteristics of the river. Sediments normally deposited along the river banks during floods are now captured behind the dams. Absence of annual scouring by floods, with additional deposition of new sediments, has greatly altered habitat along the banks of much of the river.

• Human Uses

Shortly after completion of the Hoover Dam, plans were made to build additional dams, aqueducts, and canals. The Parker Dam, creating Lake Havasu, was completed in 1938, and within three years the Colorado River Aqueduct was supplying water to Los Angeles, 400 kilometers to the west. The following year, the Imperial Diversion Dam was completed to divert water through the All-American Canal, which replaced the old irrigation canal through Mexico. The new canal provided reliable irrigation water to the Imperial Valley and water to the city of San Diego.

Today, the Colorado River provides irrigation water for more than 809,000 hectares of agricultural land, as well as water for consumption by more than 24 million people in Denver, Phoenix, Salt Lake City, Las Vegas, Los Angeles, San Diego, and hundreds of other cities and towns. Almost from the beginning, California had been using more than its allocation of 5.43 cubic kilometers. By 1990, California had to begin reducing its consumption, as other states used greater and greater amounts of their allocations. In 1963, Denver completed the Harold D. Roberts Tunnel under the continental divide to divert water from the Colorado River watershed to the city. The Central Arizona Project, whose backbone is an aqueduct from Lake Havasu through Phoenix to Tucson, was essentially complete by 1993.

Today, California's use is still greater than its allocation at about 5.92 cubic kilometers, and further increases by any other state will require additional cutbacks by California. For more than a decade, the complete allocation of Colorado River water has been used; the river no longer reaches the sea. This situation has additional consequences in the former delta region in Mexico, where freshwater input has been cut off.

- **Context**

Early in the twentieth century, politicians realized the importance of achieving an equitable allocation of Colorado River water for the future development of their states and the region. Their agreements were based on available data suggesting an annual flow of 20.23 cubic kilometers per year. It would later be discovered that the average flow is considerably less, about 16.65 cubic kilometers. Future disputes over Colorado River water rights will continue to be shaped by that initial overestimation.

Marshall D. Sundberg

- **Further Reading**

Diamond, Jared. *Collapse: How Societies Choose to Fail or Succeed.* New York: Viking Press, 2005. Diamond's hypothesis about why five different human cultures, including the Anasazi in the American Southwest, collapsed.

Pearce, Fred. *When the Rivers Run Dry: The Defining Crisis of the Twenty-first Century.* Boston: Beacon Press, 2006. The Colorado is just one overused river that no longer reaches the sea.

Reisner, Marc. *Cadillac Desert: The American West and Its Disappearing Water.* New York: Viking Press, 1986. Overview of the history and ecology of Western water and water rights in the United States. Rated number sixty-one in the Modern Library Top 100 works of nonfiction of the twentieth century.

See also: Aral Sea desiccation; Desalination of seawater; Freshwater; Siberian river diversion proposal; Water quality; Water resources, global; Water resources, North American; Water rights.

Competitive Enterprise Institute

- **Category:** Organizations and agencies
- **Date:** Established 1984
- **Web address:** http://cei.org

- **Mission**

The Competitive Enterprise Institute (CEI) is a nonprofit public policy organization that promotes the principles of free enterprise and limited government. The institute contends that individuals are best served free of government intervention, allowing for unfettered progress through a free marketplace. It accepts no government funding; among its principal sponsors are Amoco, Exxon Mobil, Texaco, the Ford Motor Company, Phillip Morris Companies, and the Pfizer drug company.

CEI describes itself as a think tank and an advocacy organization. While it contends its policy positions are science based, it disputes all evidence pointing to greenhouse gases (GHGs) as the driving force behind global warming. Consistent with the CEI philosophy, the institute opposes vehicle fuel efficiency standards and calls for the elimination of the Superfund—using property rights as an argument against government regulation.

• Significance for Climate Change

CEI opposes any government action that would mitigate global warming, including mandated limits on GHGs. Consistent with this stand, it supports constitutional challenges that would impede the government's ability to intrude on corporate polluters. In an effort to garner public support, in 2006 CEI ran television ads trivializing the effects of climate change with the line: "Carbon dioxide: They call it pollution; we call it life." It insists that pollution-generated global warming is a scientific fallacy and embraces carbon dioxide as "a life-giving force" rather than a noxious waste. Consistent with its postilion, which denies the connection between GHGs and climate change, CEI participated in the opposition to the 1997 international global warming negotiations in Kyoto, insisting that global warming is a "theory not a fact."

Unlike many academic think tanks, CEI aggressively enforces its positions through the courts. It argues that climate change would create a "milder, greener, more prosperous world." A quote taken from the CEI Web site best illustrates the organization's philosophy and potential impact on climate change.

> Although global warming has been described as the greatest threat facing mankind, the policies designed to address global warming actually pose a greater threat. Luckily, predictions of the extent of future warming are based on implausible scientific and economic assumptions, and the negative impacts of predicted warming have been vastly exaggerated. In the unlikely event that global warming turns out to be a problem, the correct approach is not energy rationing, but rather long-term technological transformation and building resiliency in societies by increasing wealth. CEI has been a leader in the fight against the global warming scare.

Richard S. Spira

See also: Pseudoscience and junk science; Skeptics.

Composting

• Category: Plants and vegetation

• Definition

Composting is a natural biological process that breaks down organic materials into a stable organic substance called compost. Compost is created by combining organic wastes, such as yard trimmings, food wastes, and manures, in piles or containers. Microorganisms, primarily bacteria and fungi, decompose organic matter and form compost, a nutrient-rich material that is also called humus. Humus is dark brown or black in color and is free of most pathogens and weed seeds. Compost can either be added to soil as fertilizer or be used to support plant growth. Composting is used in landscaping, horticulture, and agriculture as an organic fertilizer to enrich soils. Compost is also used for erosion control, wetland construction, and as landfill cover. Industrial composting systems are increasingly being utilized as landfill alternatives, making them an important tool for waste management.

Composting methods range from simple backyard or onsite systems to large, commercial-scale agricultural and worm-composting centers. Composting can be either aerobic (occurring in the presence of oxygen) or anaerobic (without oxygen). Aerobic methods are generally more efficient at decomposing organic matter. Homeowners and other small-quantity generators use backyard composting systems to degrade such wastes as yard trimmings and food scraps. Larger operations utilize aerated, or turned, windrow composting, in which organic waste is piled in rows called "windrows" and aerated by periodically turning the piles. Windrow composting is suited for large quantities of waste, such as that generated by food-processing businesses including restaurants, cafeterias, and packing plants. The process can accommodate diverse wastes, including animal by-products.

In aerated, static-pile composting, organic waste is placed in one large pile rather than rows and is aerated by layering the pile with bulking agents, such as wood chips or shredded newspaper. This method is suitable for large quantities of yard waste, food scraps, and paper products, but not animal by-products or grease. It is often used by landscapers or on farms. In-vessel composting uses a container—such as a drum, silo, or similar vessel—and can be used to process large amounts of waste in a limited area. Most organic waste, including meat, manure, biosolids, and food scraps, can be decomposed using this method. Worm composting, or vermicomposting, uses worms in a container to break down organic matter. Red worms, rather than nightcrawlers or garden worms, break down food scraps, paper, and plants and generate rich compost called "castings." Vermicomposting also produces "worm tea," a nutrient-rich liquid fertilizer that can be used in gardens or for houseplants. Vermicomposting is well suited for apartments or small offices.

- **Significance for Climate Change**

Composting organic material has many environmental benefits, including some that mitigate some of the harmful effects associated with climate change. In general, composting leads either directly or indirectly to a reduction in the amount of greenhouse gases (GHGs) released into the atmosphere. Composting reduces the use of inorganic fertilizers and pesticides, diverts wastes from landfills, restores soil quality, and increases carbon content in soils. By regenerating nutrient-poor soils, compost increases the water-hold capacity of soils and decreases the amount of inorganic fertilizer required to grow healthy crops.

Inorganic fertilizers require a great deal of energy to produce, so reducing the demand for such fertilizers reduces energy production and consumption. Composting, moreover, slows down the depletion of existing organic matter from soils while simultaneously adding organic matter and carbon to the soil. Increasing carbon sequestration within soils contributes substantially to reduced GHG emissions. Composting also helps decrease plant diseases and pests, which reduces the amount

Tom Szaky's company, TerraCycle, uses earthworms to turn garbage into compost. (Jonathan Wilson/MCT/Landov) of pesticides required. Composting also diverts organic wastes that would otherwise end up in landfills or other disposal sites. Reducing organic wastes in disposal sites reduces the amount of methane, a very potent GHG, emitted from such sites.

Although composting decreases methane emissions from landfills, some GHGs, including carbon dioxide, methane, and nitrous oxide, are produced during composting. During the intense microbial activity that occurs during composting, a significant loss of nitrogen as nitrous oxide and other nitrogen-based gases occurs. Although the worms used in composting decompose organic material very efficiently, nitrous oxide is emitted during digestion. Large, commercial-scale worm-composting plants generate GHGs in amounts comparable in global warming potential to those generated by landfills of the same scale. Nitrous oxide is believed to be many times more powerful than carbon dioxide or methane in contributing to global warming. At present, there is little research on the management of these gases during composting.

C. J. Walsh

• Further Reading

Campbell, Stu. *Let it Rot! The Gardener's Guide to Composting*. 3d ed. North Adams, Mass.: Storey, 1998. Introduction to composting for general readers. Includes descriptions of how composting works and different composting methods.

Culen, Gerald R., et al. *Organics: A Wasted Resource? An Extended Case Study for the Investigation and Evaluation of Composting and Organic Waste Management Issues.* Champaign, Ill.: Stipes, 2001. Written for students, this text provides information related to composting and waste management for a foundation in environmental science. Includes case studies and student activities.

Ebeling, Erich, ed. *Basic Composting: All the Skills and Tools You Need to Get Started.* Mechanicsburg, Pa.: Stackpole Books, 2003. A complete guide to tools and techniques of composting written by composting experts, including information on different composting methods and how to build composting bins.

Lens, Piet, Bert Hamelers, and Harry Hoitnik, eds. *Resource Recovery and Reuse in Organic Solid Waste Management.* London: IWA, 2007. Provides information on solid waste management using composting to reduce greenhouse effects and other environmental damage. Written at an advanced scientific level.

Scott, Nicky. *Composting: An Easy Household Guide.* White River Junction, Vt.: Chelsea Green, 2007. Contains a plethora of basic information about how to begin composting and was written by a chair of a Community Composting Association.

See also: Agriculture and agricultural land; Land use and reclamation; Nitrogen fertilization; Soil erosion.

Conservation and preservation

• Category: Environmentalism, conservation, and ecosystems

The history of conservation in the United States may be divided into three successively evolving stages: utilitarian conservation, nature preservation, and modern environmentalism. In the twenty-first century, as a result of global warming, environmentalism has adopted a more inclusive, planetary view.

• Key concepts

anthropocentric: treating human beings and human concerns as the primary source of value

biocentric: treating all living things as equal in value

natural area: a region where organisms and geological processes are undisturbed by humans, with as few controls as possible

• Background

Human abuse of nature is almost as old as recorded history. Plato lamented land degradation due to hills being denuded for lumber. Eighteenth century French and British colonial administrators understood the link between deforestation, soil erosion, and local climate change. Stephen Hales, a British plant physiologist, instigated the practice of reserving 20 percent of all green plants to preserve rainfall on the Caribbean island of Tobago. Pierre Poivre, French governor of Mauritius, appalled by forest and wildlife devastation, ordered one-fourth of the island to be preserved in woodlands. In America, conservation commenced as a pragmatic response to the excesses imbued by the nineteenth century limitless frontier mentality.

• Utilitarian Resource Conservation

George Perkins Marsh, who had witnessed the damage caused by excessive grazing and deforestation around the Mediterranean, became alarmed by the profligate waste of resources occurring on the American frontier in the mid-nineteenth century. In 1864, he published *Man and Nature*, warning of the unfortunate ecological consequences of this wanton destruction. This book had several lasting impacts, including the establishment of the National Forest Service in 1873 to protect dwindling timber supplies and endangered watersheds. In 1905, President Theodore Roosevelt, influenced by Marsh's book, moved the Forest Service from the Department of the Interior to the Department of Agriculture, and made his chief conservation adviser, Gifford Pinchot, the new head. This decision situated resource management on a straightforward, rational, and scientific basis.

Together with naturalist John Muir, first president of the Sierra Club, Roosevelt and Pinchot passed game protection laws, restructured the national park system, and reconstituted forest and wildlife refuge systems. These policies were primarily pragmatic. They believed that forests should be saved, not for aesthetic reasons or out of concern about wildlife, but to provide homes and jobs for people. Resources should be used for the greatest good for the greatest number for the longest time. Utilitarian conservation is not concerned about saving resources for future generations, but about wisely developing and using the resources for the benefit of humans now living. According to this viewpoint, there is as much waste in neglecting to develop and utilize natural resources as there is in their wanton destruction. This approach is still evident in the multiple-use policies of the Forest Service.

Protesters in March, 2009, demand that the power plant providing electricity to the U.S. Capitol building stop burning coal. The modern environmental movement has broadened to address the issue of climate change. (Roger L. Wollenberg/UPI/Landov)

• Nature Preservation

Muir, believing utilitarian conservation to be too anthropocentric, strenuously opposed Pinchot's influence and policies. Muir espoused the more biocentric viewpoint that all living organisms are imbued with intrinsic rights and deserve to live in nature, whether or not they are useful to humans. Every organism, as part of an ecological web, is not only entitled to continuance, but is essential to the integrity and stability of the biotic community. According to this viewpoint, humans are a miniscule component of nature; as such they have no right to value themselves above other species with whom they coexist. Humans are primarily a negative influence on nature.

In order to preserve its pristine wilderness, John

Muir fought for and achieved the establishment of Yosemite as a State Park in 1864, later incorporating additional land to become a National Park in 1890. He was also instrumental in having King's Canyon preserved until it also achieved National Park status. When the National Park Service was established in 1916, it was headed by one of Muir's disciples, guaranteeing that his ideals of attempting to preserve pristine wildernesses in their purest, unaltered state would become a guiding principle. This philosophy is often at odds with the Forest Service.

• Modern Environmentalism

Contemporary environmentalists have moved beyond the simple preservation of nature to embrace problems adversely affecting the health and well-being of all species, particularly humans. Air and water pollution began to become problematic during and particularly after World War II as a result of industrial expansion, greater use of toxic chemicals, and increased automotive traffic. One of the first books to awaken public awareness to the deleterious effects of noxious chemicals in the environment was *Silent Spring* by Rachel Carson, published in 1962. This led to an environmental movement as concerns broadened from preserving nature and using resources wisely to controlling and reducing pollution.

Two pioneers of the environmental movement were David Brower and Barry Commoner. Brower, while serving as the executive director of the Sierra Club, introduced many of the techniques now characteristic of modern environmentalism. These include litigation, intervention in regulatory hearings, and using the mass media for publicity campaigns. Commoner, a biologist, used scientific research to reveal connections among science, technology, the ecosphere, and society. Both activism and research remain defining characteristics of the modern environmental movement. By the 1970's, the movement had expanded from wilderness protection and pollution problems to include human population growth, nuclear power, fossil fuel extraction and use, and recycling. With the first Earth Day in 1970 environmentalism created public awareness and concern about health and ecological damage from pollution.

• Context

Because modern humans are interconnected in a myriad of ways, the Earth has become a global village of people sharing a common planetary environment. Attention has shifted from preserving particular landscapes or preventing pollution of a specific watershed to concern about the life-support systems of the entire world. Humans are changing planetary weather systems, increasing the extinction rate of species, and degrading ecosystems; without drastic remediation the ultimate consequences will be catastrophic. Protecting the planetary environment must become an international cause since it will take worldwide cooperation to effect the many changes necessary. Preliminary steps in this direction have been taken with the Montreal Protocol, adopted by most industrial nations in 1987, which phased out the use of ozone-depleting chlorofluorocarbons. The fledgling Kyoto Protocol is another international effort attempting to mandate carbon dioxide reduction. The agreement is still weak because the United States and Australia, two of the world's greatest emitters, refuse to sign.

Twenty-first century humans have begun to comprehend that human societies can no longer act in isolation because the Earth is an interconnected whole. Pollution and environmental problems are inextricably linked to poverty, injustice, oppression, and the exploitation of underdeveloped nations by greedy capitalists in industrialized countries. Only by working together to correct these historic wrongs and actively pursuing sustainable lifestyles can the planetary environment be conserved.

George R. Plitnik

• Further Reading

Brown, Lester R. *Plan B 3.0: Mobilizing to Save Civilization.* 3d ed. New York: W. W. Norton, 2008. Presents a worldwide plan to stabilize climate and control population. An excellent example of global environmentalism.

Commoner, Barry. *Making Peace with the Planet.* New York: Pantheon, 1990. A handbook of modern ecological conservation that treats the failures of modern environmentalism and prescribes actions that must be taken to live in harmony with the Earth.

Humphrey, Mathew. *Preservation Versus the People?* New York: Oxford University Press, 2002. Discusses humanity's interaction with nature and how one's political philosophy determines one's environmental worldview.

See also: Carson, Rachel; Civilization and the environment; Ecological impact of global climate change; Environmental economics; Environmental movement; Forestry and forest management; Marsh, George Perkins; Sierra Club; Sustainable development; Thoreau, Henry David.

Conservatism

- **Category:** Popular culture and society

Conservatism is a loosely defined political philosophy that places great emphasis on tradition, continuity, and gradualism in the development of public policy. There are many streams of conservatism, the best known of which are religious conservatism, cultural conservatism, and fiscal conservatism.

• Key concepts

Burkean conservatism: promulgated by the father of Anglo-conservatism, Edmund Burke, especially in his 1790 pamphlet *Reflections on the Revolution in France*, the classic tenets of conservatism—such as its distrust of utopian, revolutionary social reform—that laid the philosophical foundations of modern conservatism

conservationism: also known as the conservation ethic, the idea, originating in the late 1800's, that society should conserve natural resources for the purpose of ensuring continued abundance for maximum sustainable use

conservatism: a political philosophy located to the right of center on the classic political spectrum, marked by an emphasis on tradition and skepticism about radical ideas or social planning

invisible hand: an economic principle, promulgated by Scottish philosopher and author of *An Inquiry into the Nature and Causes of the Wealth of Nations* Adam Smith (considered the father of modern economics), that free markets are the best means by which to allocate goods in a society, as if guided by an "invisible hand"

• Background

The root of the term "conservatism" is "to conserve," which derives from the Latin verb *conservare,* meaning "to keep, preserve, or save." The term arose in the early 1800's, beginning in France with the writings of François-René Chateaubriand. The term then migrated to England in the writings of British statesman John Wilson Croker and was imported into America by John C. Calhoun, an early defender of states' rights.

The modern form of conservatism, however, largely derives from the works of Edmund Burke, who repudiated revolutionary government reforms in his 1790 book *Reflections on the Revolution in France.* Burke was critical of the French Revolution for its chaotic nature, though he supported the American Revolution.

Rather than being a set of strictly defined tenets, conservatism is a loose cluster of general principles which embrace nationalism and sovereignty, individual merit, free enterprise, reverence for tradition in the evolution of human institutions, strong respect for law and order, respect for family values such as the traditional nuclear family, respect for the wisdom of religious institutions, aversion to social planning, and an aversion to pure rationalism.

Conservatives are considered to be economic liberals, following the tradition of economist Adam Smith, which places great emphasis on the importance of well-defined property rights and the strict enforcement of contracts. Economic liberals (hence, conservatives) disapprove of government intervention in economic affairs beyond the provision of a highly limited set of "public goods," which the "invisible hand" of free markets would not be expected to produce but which are considered necessary for social welfare.

• Conservationism and Environmentalism

Conservatism is infused by a conservation ethic, which is distinct from the ethics of modern environmentalism. The attitude of conservatives toward the environment differs in fundamental ways from those of the modern environmental movement. Conservatives have long embraced "conservationism," which is the idea that society should conserve natural resources for the purpose of ensuring continued abundance for maximum sustainable use. Beginning with Theodore Roosevelt (1858-1919), twenty-sixth president of the United States, conservatives and many Republicans have been strong proponents of conservationism. Roosevelt's confidant and the first head of the U.S. Forest Service, Gifford Pinchot (1865-1946), was highly influential in shaping conservationism and emphasized the importance of using the greatest amount of natural resources that can be used sustainably, arguing that underutilization is just as wasteful as overutilization.

Conservationism rejects several of the ecocentric tenets of modern environmentalism, which seek to minimize natural resource use and human influences on the environment, ecosystems, biodiversity, air, water, soil, and climate. As Pinchot wrote,

> . . . the use of the natural resources now existing on this continent [is] for the benefit of the people who live here now. There may be just as much waste in neglecting the development and use of certain natural resources as there is in their destruction. . . . The development of our natural resources and the fullest use of them for the present generation is the first duty of this generation.

Pinchot further wrote:

> Without natural resources life itself is impossible. From birth to death, natural resources, transformed for human use, feed, clothe, shelter, and transport us. Upon them we depend for every material necessity, comfort, convenience, and protection in our lives. Without abundant resources prosperity is out of reach.

Pinchot's words remain at the core of the conservation ethic that infuses the philosophy of conservatism.

Major Conservative Think Tanks and Climatological Organizations

- Advancement of Sound Science Center
- American Enterprise Institute
- Cato Institute
- Competitive Enterprise Institute
- Cooler Heads Coalition
- Fraser Institute
- Friends of Science
- George C. Marshall Institute
- Heartland Institute
- Heritage Foundation
- High Park Group
- Information Council on the Environment
- International Policy Network
- Lavoisier Group
- National Center for Policy Analysis
- Nongovernmental International Panel on Climate Change
- Reason Public Policy Institute
- Science and Environmental Policy Project
- Science and Public Policy Institute
- Scientific Alliance

• Context

The conservative values mentioned above, combined with the conservation ethic, have shaped the responses of modern conservatives to the issue of climate change. In keeping with their rejection of pure rationalism, conservatives have been wary of absolutist claims regarding climate science and are inclined toward a more skeptical view, particularly of scientific pronouncements that elevate scientific rationalism above other conservative values. Averse to social planning, the expansion of government, and redistribution of wealth, conservatives have generally rejected programs to reduce greenhouse gas emissions such as the Kyoto Protocol, emissions trading, carbon taxes, and regulatory regimes.

With regard to fossil fuel consumption, the conservation ethic held by many conservatives leads them to oppose greenhouse gas control regimes on the grounds that such controls would result in the underutilization of affordable fossil fuels to the detriment of society. As explained above, this theme of maximizing sustainable utilization of natural resources differs significantly from modern environmentalism, which seeks to end the use of fossil fuels in favor of alternatives such as wind or solar power and generally to minimize human consumption of natural resources.

Finally, fiscal conservatism leads conservatives to oppose measures that they believe carry costs that will exceed their benefits, and that might compromise the economic prosperity and competitiveness of the United States.

Kenneth P. Green

• Further Reading

Pinchot, Gifford. *The Fight for Conservation*. 1910. Reprint. Whitefish, Mont.: Kesser, 2004. Pinchot makes the case for a conservation ethic in this booklet, which would later infuse the conservative philosophy as the central principle for managing natural resources and the environment.

Schneider, Gregory. *Conservatism in America Since 1930: A Reader*. New York: New York University Press, 2003. This collection of writings won great acclaim from conservative scholars and was a selection of the Conservative Book Club.

Scruton, Roger. *The Meaning of Conservatism*. Chicago: St. Augustine's Press, 2002. Scruton, an economic philosopher and leading conservative intellectual, explores the philosophical underpinnings of conservatism, such as an aversion to social planning and redistribution of wealth.

Smith, Adam. *An Inquiry into the Nature and Causes of the Wealth of Nations*. 1776. Reprint. New York: Bantam, 2003. In this successor to *The Theory of Moral Sentiments*, Smith fleshes out the economic theories that would evolve into modern economics. Smith's general thesis is that free markets are the best institution for allocating goods and services in an economy, while governmental intervention in markets leads to suboptimal outcomes and should be undertaken only reluctantly.

See also: American Association of Petroleum Geologists; American Enterprise Institute; Conspiracy theories; Cooler Heads Coalition; Falsifiability rule; Fraser Institute; George C. Marshall Institute; Heritage Foundation; High Park Group; Liberalism; Libertarianism; Media; National Center for Policy Analysis; Religious Right; Skeptics; U.S. and European politics.

Conspiracy theories

• **Category:** Popular culture and society

Each side in the climate change debate has accused the other of ulterior motives and of being part of a conspiracy to advance a hidden agenda.

• Key concepts

ad hominem argument: a logical fallacy that attempts to discredit an idea by discrediting the person espousing it

conspiracy: a secret effort by a group to achieve a (usually illegitimate) purpose

fallacy: a false belief or an argument that looks superficially convincing but is based on logical errors

hidden agenda: an ulterior motive

non sequitur: a fallacy based on an erroneous claim that a piece of evidence proves a given point

• Background

Many people believe that historic or present-day events are the work of conspiracies. Some conspiracy theories claim that specific groups are secretly working to control society. Other theories claim that major historical events were plotted by conspiracies. Finally, many people claim that unorthodox ideas, such as revolutionary inventions or medical cures, are suppressed by entrenched vested interests, although they may not identify any specific people or groups as responsible. In general, any belief that there are secret, organized efforts working behind the scenes to manipulate events can be termed a conspiracy theory.

• When Are Conspiracy Theories Valid?

There have been real conspiracies in history, such as the plot to assassinate President Abraham Lincoln, and there are real conspiracies today, such as criminal cartels and terrorist movements. In order for a conspiracy theory to be valid, a first requirement must be that the goals of the covert group be unethical or criminal. Someone who is prosecuted for selling a worthless medical remedy may claim that he is the victim of a conspiracy between the medical establishment and the government, but removing worthless remedies from the market is a legitimate goal. The efforts during World War II to keep the American landing at Normandy and the atomic bomb project secret involved large organizations acting secretly, but their objectives were legitimate. Not all secret movements are conspiracies.

Most important, for a theory to be valid, the conspiracy it describes must exist in reality. It is very hard to prove the existence of a conspiracy, unless its cloak of secrecy is removed. It may be infiltrated by law enforcement, be betrayed by a member, or be defeated and its secrets revealed. Most believers in a given conspiracy claim that the conspiracy is ongoing and therefore secret. They resort to indirect arguments in support of their theories, pointing to unusual coincidences, reasons why certain people might benefit from a conspiracy, and unanswered questions about events as evidence of their beliefs. While those lines of evidence might be consistent with a conspiracy, they are not sufficient to prove the existence of the conspiracy.

• Why Conspiracy Theories Are Faulty Reasoning

Some climate change skeptics have claimed that the idea of global climate change is part of a movement to destroy capitalism and personal freedom. Climate change activists, by contrast, claim that many skeptics are allied with front groups funded by industry or political movements. The climate change controversy is a good example of why conspiracy theories have no place in science.

In any debate, the only relevant question is whether ideas are true or false. The overriding issue in the climate change controversy is whether or not human activities are changing the climate in a dangerous fashion. The fact that someone has a personal motivation, or a hidden agenda, for supporting or opposing an idea does not make the idea true or false. This is an example of a fallacy called a non sequitur. The fact that many supporters of climate change hold liberal political beliefs and many opponents have ties to industry proves nothing about the correctness of their ideas. Merely calling something a conspiracy does not make it one.

Many people use conspiracy accusations to imply that their opponents are unethical or wrong or use conspiracy theories to explain why others reject their ideas. This is a fallacy known as an ad hominem argument. Criticism or opposition, by themselves, do not constitute a conspiracy. If an idea is generally rejected by the scientific community, that is evidence that the theory is wrong, not that scientists are conspiring against it.

• Dealing with Conspiracy Theories

There are real conspiracies in the world, so the mere fact that someone believes in a conspiracy does not make the person wrong. However, using a conspiracy argument to justify a belief commits several logical fallacies. Conspiracy allegations show that the person making them uses faulty logic. It is not logically correct to dismiss conspiracy beliefs as automatically wrong, but it is legitimate to reject them as evidence and to insist that the person using them debate ideas on their own merits rather than resorting to conspiracy claims. It is never legitimate to use conspiracy arguments to justify the acceptance or rejection of an idea.

• Context

In scientific debates, the only relevant issue is whether ideas are right or wrong. Using the idea of a conspiracy to discredit a position is a logical fallacy and, worse yet, poisons the climate of debate. For example, the title of Al Gore's celebrated documentary *An Inconvenient Truth* (2006) hints that critics of global warming are motivated not by the scientific data but by personal motives. Likewise, the name of the skeptic organization, Cooler Heads Coalition, implies that their opponents are acting irrationally and rashly. Knowing that someone has a personal motivation for a belief can certainly justify giving the person's arguments very close scrutiny, but it never constitutes scientific evidence.

Steven I. Dutch

• **Further Reading**

Hofstadter, Richard. *The Paranoid Style in American Politics, and Other Essays.* Cambridge, Mass.: Harvard University Press, 1996. Hofstadter is a prominent historian and author of a major work on anti-intellectualism in America. In this book, he explores conspiracy theories with emphasis on politically conservative conspiracy theories.

Jameson, Fredric. "Totality as Conspiracy." In *The Geopolitical Aesthetic: Cinema and Space in the World System.* Bloomington: Indiana University Press, 1995. An explication of the ideological work done by conspiracy narratives and the reason those narratives are so powerful in postmodern societies.

Newton, Michael. *The Encyclopedia of Conspiracies and Conspiracy Theories.* New York: Facts On File, 2006. Provides short articles on about five hundred persons, organizations, and historical events, arranged alphabetically. Discusses documented conspiracies (such as the Iran-Contra affair), as well as those with little or no supporting evidence.

Parish, Jane, and Martin Parker, eds. *The Age of Anxiety: Conspiracy Theory and the Human Sciences.* Oxford, England: Blackwell, 2001. Academic treatment of conspiracy theories, exploring how people use such theories to respond to anxiety and crisis.

Pipes, Daniel. *Conspiracy: How the Paranoid Style Flourishes and Where It Comes From.* New York: Free Press, 1997. Emphasizes theories revolving around secret societies and Jews and discusses conspiracy theories across the political spectrum.

Roeper, Richard. *Debunked! Conspiracy Theories, Urban Legends, and Evil Plots of the Twenty-first Century.* Chicago: Chicago Review Press, 2008. Popular discussion of about two dozen widespread conspiracy theories by a columnist for the *Chicago Sun-Times.*

See also: Gore, Al; *Inconvenient Truth, An*; Journalism and journalistic ethics; Popular culture; Skeptics.

Consultative Group on International Agricultural Research

• **Category:** Organizations and agencies
• **Date:** Established 1971
• **Web address:** http://www.cgiar.org

• **Mission**

The Consultative Group on International Agricultural Research (CGIAR) supports scientific projects at affiliated centers worldwide to address concerns regarding the detrimental impacts of extreme temperatures, altered precipitation cycles, and other erratic climatic factors on crops and livestock. The CGIAR oversees scientists' efforts to provide information, technology, seeds, plants, and resources to assist farmers, especially in developing countries. Prior to CGIAR, researchers had independently conducted plant-breeding projects to ease famines, working at the International Center for Tropical Agriculture (CIAT) in Colombia, the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, the International Institute of Tropical Agriculture (IITA) in Nigeria, and the International Rice Research Institute (IRRI) in the Philippines.

Interested in centralizing their efforts, representatives of those research centers and the United Nations Food and Agriculture Organization (FAO) and Development Programme (UNDP) met at the World Bank at Washington, D.C., in May, 1971, to establish the CGIAR. By 2008, fifteen CGIAR research centers, including the initial four, were operating in Africa, Asia, Europe, the Middle East, and North and South America. Approximately one thousand researchers and seven thousand staffers pursue sustainable agricultural methods at centers for staple crops, such as wheat, rice, and maize; forestry; fisheries; and livestock. Several centers focus on agriculture in deserts or the tropics. Some centers specialize in such issues as food policy research, genetic resources, and water waste management. An alliance of governmental, public, and private groups funds the CGIAR's programs.

The CGIAR promotes scientific methods to cultivate and protect ample, nutritious food supplies and ease impoverishment in developing countries for both producers and consumers of agricultural goods. That group encourages researchers to preserve natural resources against pollution and other threats. The CGIAR hosts an annual conference, issues publications, and distributes information electronically on the Internet. CGIAR leaders adjust their research goals in response to urgent problems, such as global warming, that threaten to disrupt agriculture.

• Significance for Climate Change

The CGIAR emphasizes preparation to sustain agriculture against global warming. Since the organization's creation, CGIAR representatives have recognized the influence of weather upon agriculture, which is vulnerable to variations in temperature and precipitation. In the late twentieth century, the CGIAR stressed the dangers that changing climates posed to agriculture, particularly crops and livestock raised in developing countries. CGIAR centers initiated research to counter the detrimental impact of global warming on agriculture, highlighting the need for plants and livestock that can survive climate fluctuations. Scientists explained how increased temperatures and excess or insufficient precipitation can alter crop growth patterns and seasons by hindering photosynthesis and pollination. Increased knowledge regarding climate changes enabled people, ranging from agriculturists to government officials, to plan strategies and policies, using CGIAR resources to deal with global warming.

CGIAR scientists compile agricultural, demographic, climatic, and socioeconomic data relevant to areas being studied in order to simulate with computer models possible future conditions as climates change. Geographical-information-system (GIS) maps enhance this modeling. CGIAR researchers have used computer modeling to determine that wheat and maize crops are particularly at risk as the twenty-first century progresses. Models prepared through 2055 indicated that maize yields could decrease by 10 percent in developing countries without intervention. Also, temperature increases may cause maize cultivation to shift to highlands. The CGIAR study "Can Wheat Beat the Heat?" stated that India might lose 51 percent of its wheat fields by the mid-twentieth century. Scientists hypothesized warming climates could impede frost, enabling farmers to grow wheat near the Arctic Circle.

CGIAR research centers pursued genetic engineering in the 1970's to create more compatible and productive plants for famine-stricken countries. Changing climates resulted in revised efforts to make plants more resilient to temperature changes in air and soil and to inconsistent precipitation conditions. CGIAR scientists identified wild species of plants that exhibited resistance to heat, pests, diseases, salt, drought, or flood and evaluated samples to understand physiologically why some species are more tolerant than others. Scientists isolated genes associated with traits resistant to climate change in order to bioengineer stronger varieties of traditional crops and livestock or create hybrids for altered climates. Often, researchers determined that several genes in combination were linked to resistance to specific climate changes.

The CGIAR's successes have included the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria, which used wild *Hordeum spontaneum* to create drought-resistant barley. The IRRI produced rice resistant to high temperatures and flooding, submerging plants for several weeks and studying leaf evaporation processes to reduce temperatures. CGIAR researchers examined how to achieve successful maize pollination during drought conditions. They designed maize that grew bigger ears with more kernels than previous types.

Global warming is a catalyst for migration of some wild plant species to ecosystems where they are considered exotic. In their new habitats, these species compete for resources, crowding established species and detrimentally affecting cultivated crops. Climate change also causes insects and diseases to move to new areas, and the CGIAR has conducted research to assess how these invaders affect agriculture and how they might be controlled. When El Niño altered Peru's climate during the late 1990's, a previously unknown blight fungus attacked potato crops. The CGIAR's International Potato Center developed a hybrid that resisted blight, and it distributed those hybrid plants to farmers.

Promoting biodiversity, the CGIAR includes gene banks at its centers to preserve genetic material from agricultural resources worldwide, because computer models have indicated that many wild and domestic plant species may become extinct as a result of climate changes. Scientists estimate that one-fourth to one-half of all plant species could be extinct by 2055. CGIAR gene banks store millions of plant specimens, assuring that diverse agricultural crops from varied geographical locations will survive despite climate-provoked losses.

CGIAR scientists hypothesize 67 percent of people worldwide will experience water shortages by 2050, because changing climates will alter precipitation and melt glaciers, affecting long-term water supplies. CGIAR researchers develop water management techniques for arid locations, including techniques for storing precipitation and irrigating land. CGIAR representatives teach agriculturists techniques for dealing with inconsistent precipitation, such as applying phosphorus fertilizers to increase plants' root growth, allowing the roots to reach subsoil water. CGIAR workers also suggest agricultural adjustments to respond to depleted or eroded soil caused by climate changes. The CGIAR encourages farmers to diversify, planting alternative crops to counter climate impacts on their production and marketing possibilities.

CGIAR researchers note that some developing countries' agricultural methods, particularly the clearing of forests for fields, contribute to climate change. The CGIAR seeks ways to control global warming by urging farmers to use such agricultural techniques as limiting tillage manipulation of fields in order to retain carbon in soils. Center representatives educate agriculturists regarding forest management and biofuels, emphasizing the need to minimize emissions.

Elizabeth D. Schafer

• **Further Reading**

Ceccarelli, Salvatore, et al. "Breeding for Drought Resistance in a Changing Climate." In *Challenges and Strategies for Dryland Agriculture*, edited by Srinivas C. Rao and John Ryan. Madison, Wisc.: Crop Science Society of America, 2004. CGIAR researchers in Syria describe their work bioengineering barley for arid climates and suggest strategies to create resilient crops for diverse environments.

Fuccillo, Dominic, Linda Sears, and Paul Stapleton, eds. *Biodiversity in Trust: Conservation and Use of Plant Genetic Resources in CGIAR Centres*. New York: Cambridge University Press, 1997. Chapters feature numerous crops and forages CGIAR has identified as essential to include in its gene banks to protect agricultural variety as climate changes threaten species' survival.

Lele, Uma J. *The CGIAR at Thirty-One: An Independent Meta-evaluation of the Consultative Group on International Agricultural Research*. Washington, D.C.: World Bank, 2004. Critique by the World Bank's Operations Evaluation Department that suggests CGIAR shapes its climate change research to appease donors and should assist developing world farmers with global warming concerns not analyze its causes.

Varma, Surendra, and Mark Winslow. *Healing Wounds: How the International Centers of the CGIAR Help Rebuild Agriculture in Countries Affected by Conflicts and Natural Disasters*. Washington, D.C.: CGIAR, 2005. Profiles climate-change-related CGIAR projects. Photographs depict farmers, CGIAR representatives, and crops. Appendix provides centers' contact information.

See also: Agriculture and agricultural land; Animal husbandry practices; Composting; Food and Agriculture Organization; Land use and reclamation; Nitrogen fertilization; Pesticides and pest management; Soil erosion.

Continental climate

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Defining a climate is difficult. The accuracy of weather observations and the length of time over which these data have been recorded can seriously affect the statistical understanding of a climate. Additionally, having data to produce statistical averages is no assurance that a climate's classification can accurately describe its conditions. Consider Chicago's humid, continental climate: The average temperature of the city is near 10° Celsius, but the nature of the climate in the region lends itself to extremes. Chicago's daily temperatures are usually either well above or well below the average.

The average precipitation in Chicago is about 84 centimeters per year. This is equal to the precipitation level in Seattle, which has a west coast marine climate. Precipitation in Seattle is mostly rain, however, while Chicago experiences a mix of rain and snow. Rain in Chicago falls mostly in the summer, during violent convective storms. Rain in Seattle continues through the year, with a slight increase during the winter. Seattle's maritime influence moderates the tendency toward convective storms.

Continental climates are characterized by extreme temperatures, and they are unique in that they have a global Northern Hemispheric distribution. In fact, to understand the potential impact that climate change might have on a continental climate, one must first consider its unique geographic character. Humid continental climates are found in North America, Europe, and Asia. In North America, they bound on the humid, subtropical climates of the southern and southeastern United States, and they encompass all of the northeastern quarter of the country.

The North American continental climate extends northward into Canada at a line of latitude that marks the extent of viable agricultural production. It extends westward into southern portions of the Prairie Provinces of Canada and north of the middle-latitude, dry climates that prevail just east of the Rocky Mountains. In Europe, the humid continental climate begins directly east of the marine-climate boundaries, along the west coast of the continent. It stretches into Russia, Germany, southern Sweden, and Finland, and is also found in Romania and Poland. Parts of Asia are also included in this climate. Almost all of northern China, the northern part of Japan, and North Korea fall within the humid continental climate zone.

The Köppen classification system places these climates in a group of midlatitude climates. Such climates include the west coast marine climate, the middle latitude dry climate, the humid continental-warm (long) summer climate, and the humid continental-cool (short) summer climate. The term "continental" has significance from the standpoint of the climate's paleoclimatic character. Continental climates exist presently in only the Northern Hemisphere as a result of the movement of tectonic plates, which have concentrated Earth's landmass in the northern half of the globe. The Southern Hemisphere lacks a sufficient continental landmass to form a continental climate. The Southern Hemisphere is more ocean (71 percent) than land. Most important, this region is agriculturally productive. Many soils in the region result from glaciation in the recent Pleistocene, 2 million years ago.

• Significance for Climate Change

The continental climate sustains a global breadbasket. The climate can be divided further by the growing regions of corn (maize) or wheat. An imaginary line running east through the southern half of South Dakota, and as far east as New England, defines the margin zones of the humid continental long (warm) summer climate (to the south of this line) and the humid continental short (cool) summer climate (to the north of it). A similar line divides the climate in Europe and Asia. Thus, global climatic change within this zone has the potential to affect world food supplies.

In a warming scenario affecting the continental climate zone, ancillary problems for farming may emerge. Some models suggest that warming will increase annual precipitation. The humid continental climate averages 76 centimeters of precipitation per year, with snow being the predominant form of precipitation in the winter. Precipitation in this climate zone can vary from about 51 centimeters near drier areas to 127 centimeters near the oceans. An increase in precipitation in the continental climate zone could lead to increased flooding, noxious weeds, and plant diseases. In contrast, some suggest that warming would lead to a longer growing period and a shift of the temperature toward the north.

Conversely, in a global cooling scenario, the continental climate zone might experience shorter summers, and the temperature line between warm and cool summers could move south. Drier conditions and drought would prevail. The region might expect to see more rainfall relative to snowfall, as rain might continue further into the winter months. The continental short (cool) summer climate zone is characterized by cyclonic storms in winter that can bring huge snowfalls.

During the summer, convectional storms, many of them severe with lightning, are normal in continental short (cool) summer climate zones. The temperature average during summer is 24° Celsius. During the winter, average temperatures fall below freezing, down to –12° to –11° Celsius. With the influence of cold northern air, it is not uncommon to experience temperature extremes well below –18° Celsius. With increasing temperatures, the possibility for a prolonged period of convective storms might exist. Dry-land crops, such as wheat, would need to be modified to accommodate warmer and moister conditions. More rainfall might increase erosion in already tenuous soils, especially in highly productive löess soils. New farming methods to accommodate these changes would have to be implemented.

M. Marian Mustoe

- **Further Reading**

Aguado, Edward, and James E. Burt. *Understanding Weather and Climate*. 4th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. The formation of midlatitude storms is surveyed. Continental climates and the structure of climate are discussed.

Ahrens, C. Donald. *Meteorology Today*. 9th ed. Pacific Grove, Calif.: Thomson/Brooks/Cole, 2009. Discusses global climates, climate change, and classification.

Critchfield, Howard J. *General Climatology*. Englewood Cliffs, N.J.: Prentice-Hall, 1998. Considers climate classification and discusses how climate affects agricultural productivity.

See also: Climate and the climate system; Climate change; Climate models and modeling; Climate prediction and projection; Climate zones; Climatology; Polar climate.

Contrails

- **Category:** Transportation

- **Definition**

Condensation trails, or contrails, are long, narrow cirrus clouds composed of ice crystals that form behind aircraft or rocket engines flying in the upper atmosphere. When fuels containing hydrogen, such as hydrocarbons, burn in air, the engine exhaust contains water vapor. The vapor in the hot exhaust rapidly condenses and freezes when it mixes with cold, humid atmospheric air, forming a trail of ice crystals. Contrails typically form where the air temperature is 4° to –60° Celsius and relative humidity exceeds 100 percent, with low wind turbulence. Favorable conditions typically occur above 8,530 meters. Contrails have been reported since 1915, but they became much more common as jet aircraft traffic increased. Geese flying in cold air have been seen to leave small contrails as they exhale moist air.

The condensation engendered by contrails starts to form on microscopic dust particles. Contrails become visible approximately 0.1 second after leaving an engine, as the ice particles grow large enough to scatter sufficient light for them to be seen. Although contrails start as one exhaust behind each engine, they often merge into one wingtip vortex from each wing tip. The lower pressure and temperature in the core of each tip vortex also helps accelerate condensation. Contrails move down in reaction to the aircraft's lift and the higher density of ice. During daytime ice crystals absorb sunlight. The warming air around them can convect the contrails several hundred meters up.

When the air is dry, the ice particles sublimate to vapor quickly, resulting in a short contrail. In humid air, contrails can persist for several hours or thousands of kilometers, given the speed of aircraft, and they grow into cirrus clouds as thick as 500 meters and several kilometers wide. Ice-particle size in such clouds is on the order of 200 micrometers, and their density is on the order of 1 to 50 particles per cubic centimeter of air. Many trails are over two hours old, and they continue to accumulate moisture from the air during that time. Indeed,

A plane with four jet engines leaves four contrails in its wake. (AP/Wide World Photos)

ing to the greenhouse effect. Some argue that long-wave infrared radiation is absorbed more by ice crystals than by air or water vapor, so that cirrus clouds have a net warming effect.

Others studies suggest that night flights, which constitute only 20 to 25 percent of air traffic, may contribute to 60 percent of contrails' greenhouse effect. Published data project that a fivefold increase in air traffic would cause a net global warming effect due to contrails of 0.05° Celsius. Some argue that any detectable anthropogenic change is a cause for concern. Others point to a more severe localized effect due to the heavy traffic over industrialized nations in the temperate zone, where the air is moist and cold for a greater part of the year compared to equatorial regions.

Changing from hydrocarbon to hydrogen fuel will not reduce water vapor, but may reduce dust particles in the exhaust. A different aspect is the deposition of carbon dioxide and heat in the upper atmosphere. Aircraft emissions are believed to contribute 2 to 3 percent of all anthropogenic global warming. Contrails are highly amplified reminders of that problem.

Narayanan M. Komerath

little of such a cloud comes from the original jet exhaust. A contrail cloud may contain one thousand to ten thousand times the water released by the aircraft engine itself.

• Significance for Climate Change

The cirrus cover due to contrails has been estimated to cover as much as 0.1 percent of the Earth's surface. The most famous experiment on contrails was conducted by the National Aeronautics and Space Administration (NASA) in the days following the terrorist attacks of September 11, 2001. U.S. civil air traffic was grounded for three days. During those three days, the difference between daytime high and nighttime low temperatures over the continental United States increased by roughly 1° Celsius when compared to the thirty-year average. At the same time, the trails left by six military aircraft persisted and eventually covered over 19,700 square kilometers.

The increase in cirrus cloud cover due to contrails has been studied as an anthropogenic factor in global warming. Ice crystals absorb, scatter, and reflect radiant heat. Some studies indicate that contrail cloud cover inhibits outward radiation from the Earth's surface and lower atmosphere more than it reflects incoming solar radiation, contribut-

• Further Reading

Atlas, David, Zhien Wang, and David P. Duda. "Contrails to Cirrus: Morphology, Microphysics, and Radiative Properties." *Journal of the American Meteorological Society*, January, 2006, 5-19. LIDAR, satellite, and aircraft flight track data are used to study how contrails evolve into cirrus clouds, along with their particle density, sizes, fall rates and ice content.

Hoyle, C. R., B. P. Luo, and T. Peter. "The Origin of High Ice Crystal Number Densities in Cirrus Clouds." *Journal of the Atmospheric Sciences* 62, no. 7 (July, 2005): 2568-2579. Reports measured particle size and number density in cirrus clouds. Presents hypotheses on how cirrus clouds form and evolve, including the role of wind fluctuations.

Jensen, E. J., et al. "Spreading and Growth of Contrails in a Sheared Environment." *Journal of Geophysical Research* 103, no. D24 (1998): 31,557-31,567. Compares computational predictions of how contrails evolve as a result of winds with satellite and in situ measurements. Also discusses the formation and growth of ice crystals and updrafts due to solar heating.

Penner, J. E., et al. "Aviation and the Global Atmosphere." *Intergovernmental Panel on Climate Change, Special Report.* New York: Cambridge University Press 1999. Chapter 6 includes a discussion of contrail effects. Reports global air traffic, carbon dioxide emission, and other data to estimate overall effects.

See also: Air travel; Clouds and cloud feedback; Motor vehicles; Noctilucent clouds; Polar stratospheric clouds; Transportation.

Convention on Biological Diversity

- **Category:** Laws, treaties, and protocols
- **Date:** Opened for signature June 5, 1992; entered into force on December 29, 1993

The CBD seeks to conserve Earth's biodiversity and biological resources. Climate change can affect the rate of biodiversity loss, which in turn affects the capacity of human and nonhuman biological systems to adapt to the effects of climate change.

- **Participating nations:** *1992:* Albania, Canada, Maldives, Marshall Islands, Mauritius, Monaco, Seychelles; *1993:* Antigua and Barbuda, Armenia, Australia, Bahamas, Barbados, Belarus, Belize, Burkina Faso, China, Cook Islands, Czech Republic, Democratic People's Republic of Korea, Denmark, Ecuador, European Community, Fiji, Germany, Guinea, Japan, Jordan, Mexico, Mongolia, Nauru, Nepal, New Zealand, Norway, Papua New Guinea, Peru, Philippines, Portugal, Saint Kitts and Nevis, Saint Lucia, Spain, Sweden, Tunisia, Uganda, Uruguay, Vanuatu, Zambia; *1994:* Argentina, Austria, Bangladesh, Benin, Bolivia, Brazil, Cameroon, Chad, Chile, Colombia, Comoros, Costa Rica, Cote d'Ivoire, Cuba, Democratic Republic of Congo, Djibouti, Dominica, Egypt, El Salvador, Equatorial Guinea, Estonia, Ethiopia, Finland, France, Gambia, Georgia, Ghana, Greece, Grenada, Guyana, Hungary, Iceland, India, Indonesia, Italy, Kazakhstan, Kenya, Kiribati, Kyrgyzstan, Lebanon, Luxembourg, Malawi, Malaysia, Micronesia (Federated States of), Myanmar, Netherlands, Nigeria, Pakistan, Paraguay, Republic of Korea, Romania, Russian Federation, Samoa, San Marino, Senegal, Sierra Leone, Slovakia, Sri Lanka, Swaziland, Switzerland, United Kingdom of Great Britain and Northern Ireland, Venezuela, Vietnam; *1995:* Algeria, Bhutan, Botswana, Cape Verde, Central African Republic, Guatemala, Guinea-Bissau, Honduras, Israel, Jamaica, Lao People's Democratic Republic, Latvia, Lesotho, Mali, Morocco, Mozambique, Nicaragua, Niger, Oman, Panama, Republic of Moldova, Singapore, Solomon Islands, South Africa, Sudan, Togo, Trinidad and Tobago, Ukraine, Uzbekistan; *1996:* Bahrain, Belgium, Bulgaria, Cambodia, Congo, Croatia, Cyprus, Dominican Republic, Eritrea, Haiti, Ireland, Lithuania, Madagascar, Mauritania, Niue, Poland, Qatar, Rwanda, Saint Vincent and the Grenadines, Slovenia, Suriname, Syrian Arab Republic, Turkmenistan, United Republic of Tanzania, Yemen; *1997:* Burundi, Gabon, Liechtenstein, Namibia, The former Yugoslav Republic of Macedonia, Turkey; *1998:* Angola, Tonga; *1999:* Malta, Palau, Sao Tome and Principe; *2000:* Azerbaijan, Liberia, United Arab Emirates; *2001:* Libyan Arab Jamahiriya, Saudi Arabia; *2002:* Afghanistan, Bosnia and Herzegovina, Kuwait, Serbia, Tuvalu; *2004:* Thailand; *2006:* Montenegro; *2007:* Timor-Leste; *2008:* Brunei Darussalam

- **Background**

Conservation biologists do not always agree on a common definition of biological diversity, or biodiversity. The term, however, generally refers to the breadth of variation of life on Earth at all levels of biological organization. It includes the genetic diversity within species, the species diversity within ecosystems, and the diversity of ecosystems on the planet.

Other, more specialized biodiversity protection treaties predate the Convention on Biological Diversity (CBD). These include, for example, the Ramsar Convention and the Convention on International Trade in Endangered Species (CITES). The CBD, however, is the first such broad and overarching biodiversity treaty. Pre-negotiations on the treaty began in 1987 under the auspices of the United Nations Environment Programme (UNEP). The resulting negotiated text was opened for signature in 1992 in Rio de Janeiro at the United Nations Conference on Environment and Development, where over 150 countries signed it. By 2008, the CBD had near universal membership, with 191 party nations.

• Summary of Provisions

The CBD's forty-two articles contain many provisions broadly aimed at encouraging member countries to develop national plans for protecting biodiversity and for integrating biodiversity conservation and sustainable use into sectoral or cross-sectoral plans, programs, and policies. The CBD's rules and norms overlap with those of the earlier biodiversity agreements, but they are much broader in scope. Other biodiversity protection treaties tend to focus on the protection of specific habitats (for example, the Ramsar Convention focuses on wetlands) or a specific group of species (for example, the Convention on Migratory Species focuses on species that migrate from one geographical location to another). The CBD encompasses all such conservation objectives and expands them. This breadth of focus is clearly articulated in the three stated goals of the convention: biodiversity conservation, sustainable use of biodiversity components, and equitable sharing of biodiversity benefits.

• Significance for Climate Change

Discussions about the links between biodiversity loss and climate change are not new to the CBD forum. This linkage has been a topic of discussion since 1998, when the Fourth Conference of the Parties (COP-4) to the CBD passed a decision recognizing the effect of climate change on coral bleaching. The relationship between the CBD and climate change has remained on the CBD agenda since that time, resulting in various scientific and technical papers on the issue and four key decisions relating to specific CBD work programs.

Discussion of climate change within the CBD forum also led to the creation of the Joint Liaison Group between the CBD, the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Convention to Combat Desertification (UNCCD). The scientific and technical reports that have emerged from the CBD process have discussed various aspects of the biodiversity-climate change relationship. They have emphasized that climate change is an increasingly important driver of biodiversity loss and have identified other aspects of the relationship between biodiversity loss and climate change. For example, although some reports emphasize these issues more than others, they discuss the role that biodiversity conservation can play in climate change mitigation and adaptation, as well as the capacity of ecosystems to adapt to changing climates.

The CBD Conference of the Parties has passed

Objectives of the Convention on Biological Diversity

Article 1 of the Convention on Biological Diversity sets out the convention's objectives, which guide all of its specific provisions and define the fundamental obligations of its signatories.

The objectives of this Convention, to be pursued in accordance with its relevant provisions, are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding.

five key decisions related to the relationship between the CBD and climate change. These decisions have addressed issues including the risks climate change presents to coral reefs (Decision V/3) and forests (Decision V/4), measures to help mitigate and adapt to climate change (Decision VII/15), and attempts to promote synergy among activities related to biodiversity conservation and climate change adaptation and mitigation (Decision VIII/30). The most comprehensive decision on this topic was taken at COP-9 in May, 2008. Among other things, the conference established a new ad hoc technical expert group to develop scientific and technical advice on biodiversity as it relates to climate change.

Finally, the CBD secretariat, along with those of the UNFCCC and UNCCD, has participated in the Joint Liaison Group. Created in 2001 by parallel decisions by the CBD, UNFCCC, and UNCCD, the Joint Liaison Group provides a forum for information exchange, particularly as it relates to enhancing synergies between the three conventions.

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• **Further Reading**

Gitay, Habiba, et al., eds. *Climate Change and Biodiversity*. Technical Paper 5. [Geneva, Switzerland]: Intergovernmental Panel on Climate Change, 2002. This technical report was developed in response to a request from the CBD's scientific body. It addresses the relationship between climate change on biodiversity with respect to impacts, mitigation measures, sustainable use, and adaptation.

Le Prestre, Philippe G., ed. *Governing Global Biodiversity: The Evolution and Implementation of the Convention on Biological Diversity*. Burlington, Vt.: Ashgate, 2002. This edited volume contains a variety of academic perspectives discussing the evolution and effectiveness of the CBD. Provides a foundation for exploring more complex issues, such as the relationship between the CBD and climate change.

Lovejoy, T., and L. Hannah, eds. *Climate Change and Biodiversity*. New Haven, Conn.: Yale University Press, 2005. Collects commentaries from a variety of leading experts that address the impacts of climate change on biological diversity.

Secretariat of the Convention on Biological Diversity. *Interlinkages Between Biological Diversity and Climate Change: Advice on the Integration of Biodiversity Considerations into the Implementation of the United Nations Framework Convention on Climate Change and Its Kyoto Protocol*. CBD Technical Series 10. Montreal: Author, 2003. This technical report explains various ways to use biodiversity conservation to enhance mitigation of and adaptation to climate change.

See also: Amazon deforestation; Biodiversity; Convention on International Trade in Endangered Species; Endangered and threatened species; Invasive exotic species.

Convention on International Trade in Endangered Species

• **Categories:** Laws, treaties, and protocols; animals; plants and vegetation
• **Date:** Opened for signature March 3, 1973; entered into force on July 1, 1975

CITES addresses unsustainable exploitation through international trade. As such, climate change is significant to CITES to the extent that such change affects populations of species that are traded internationally.

• **Participating nations:** *1975:* Brazil, Canada, Chile, Costa Rica, Cyprus, Ecuador, Madagascar, Mauritius, Morocco, Nepal, Niger, Nigeria, Peru, South Africa, Sweden, Switzerland, Tunisia, United States of America, Uruguay; *1976:* Australia, Democratic Republic of Congo, Finland, Germany, Ghana, India, Iran, Norway, Pakistan, Papua New Guinea, United Kingdom of Great Britain and Northern Ireland; *1977:* Denmark, Gambia, Guyana, Paraguay, Senegal, Seychelles; *1978:* Botswana, Egypt, France, Malaysia, Monaco, Panama, Venezuela; *1979:* Bahamas, Indonesia, Italy, Jordan, Kenya, Sri Lanka, Togo; *1980:* Central African

Republic, Guatemala, Israel, Japan, Liechtenstein, United Republic of Tanzania; *1981:* Argentina, Belize, Cameroon, China, Colombia, Guinea, Liberia, Mozambique, Philippines, Portugal, Rwanda, Suriname, Zambia, Zimbabwe; *1982:* Austria, Bangladesh, Malawi; *1983:* Congo, Saint Lucia, Sudan, Thailand; *1984:* Algeria, Belgium, Benin, Luxembourg, Netherlands, Trinidad and Tobago; *1985:* Honduras, Hungary; *1986:* Afghanistan, Somalia, Spain; *1987:* Dominican Republic, El Salvador, Singapore; *1988:* Burundi; *1989:* Chad, Ethiopia, Gabon, Malta, New Zealand, Saint Vincent and the Grenadines, Vanuatu; *1990:* Brunei Darussalam, Burkina Faso, Cuba, Guinea-Bissau, Poland, United Arab Emirates; *1991:* Bulgaria, Mexico, Namibia, Uganda; *1992:* Djibouti, Equatorial Guinea, Estonia, Russian Federation; *1993:* Barbados, Czech Republic, Greece, Republic of Korea, Slovakia; *1994:* Mali, Romania, Saint Kitts and Nevis, Vietnam; *1995:* Belarus, Comoros, Côte d'Ivoire, Dominica, Eritrea, Sierra Leone; *1996:* Georgia, Mongolia, Saudi Arabia, Turkey; *1997:* Antigua and Barbuda, Cambodia, Fiji, Jamaica, Latvia, Myanmar, Swaziland, Uzbekistan, Yemen; *1998:* Mauritania; *1999:* Azerbaijan, Grenada; *2000:* Croatia, Iceland, Kazakhstan, Slovenia, the Former Yugoslav Republic of Macedonia, Ukraine; *2001:* Moldova, Sao Tome and Principe, Qatar; *2002:* Bhutan, Ireland, Kuwait, Lithuania; *2003:* Albania, Lesotho, Libyan Arab Jamahiriya, Syrian Arab Republic; *2004:* Lao People's Democratic Republic, Palau; *2005:* Cape Verde, Samoa, San Marino; *2006:* Montenegro, Serbia; *2007:* Kyrgyzstan, Solomon Islands; *2008:* Oman

• Background

International trade in wildlife, wildlife components, and their derivatives (including pets, hunting trophies, skins, bark, food products, medicines, exotic leather goods, and timber) is estimated to be worth billions of dollars per year. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international treaty that regulates wildlife trade through a licensing system in order to ensure that trade in wild plants and animals does not threaten those species' survival. CITES is one of the oldest international environmental treaties in the world, and it enjoys almost universal membership, with 173 parties as of 2008.

Species Protected by the CITES

Species Type	*Species*	*Subspecies*	*Populations*
Mammals	617	36	26
Birds	1,455	17	3
Reptiles	657	9	10
Amphibians	114	0	0
Fish	86	0	0
Invertebrates	2,179	5	0
Total fauna	5,108	67	39
Plants	28,977	7	3
Total	34,085	74	42

• Summary of Provisions

CITES aims to conserve biodiversity and contribute to its sustainable use by delimiting acceptable trade practices. The treaty seeks to ensure that no species of wild animal or plant is subject to unsustainable exploitation through international trade. It thereby contributes to a significant reduction in the rate of global biodiversity loss. CITES identifies species that are or may be affected by international trade and lists them in a set of three appendixes, each affording a different level of protection. It then provides mechanisms for tracking trade in the listed species through an extensive system of trade permits and certificates. CITES's appendixes contain over thirty thousand plant and animal species.

CITES trade must generally satisfy two preconditions: scientific confirmation that trade in the species will not be detrimental to its survival and a finding that the specimens in trade were acquired legally. Within that rubric, Appendix 1 provides the most stringent level of protection. It lists those species that are both threatened with extinction and either currently or potentially affected by international trade. Appendix 1 species include the great apes, humpback whales, sea turtles, tigers, and the monkey-puzzle tree. Generally speaking, these species cannot be traded internationally for "primarily commercial" purposes, and noncommercial trade is permissible only when authorized by import-export permits.

Appendix 2 includes species such as bigleaf mahogany, queen conch, bottle-nosed dolphins, and sharks. It lists species that, although not currently threatened with extinction, may become threatened in the future unless trade in those species is strictly controlled. Commercial international trade in Appendix 2 species is allowed under an export permit, again subject to the general requirement of scientific confirmation that trade in the species will not threaten its survival and a finding that the specimen in trade was acquired legally. Finally, Appendix 3 lists species based on the input of specific member nations. Appendix 3 species are protected by law in at least one country, and that country has asked other CITES parties for assistance in controlling trade in that species.

- **Significance for Climate Change**

Unlike some other biodiversity conventions, such as the Convention on Biological Diversity (CBD) and the Convention on the Conservation of Migratory Species of Wild Animals (CMS; also known as the Bonn Convention), CITES does not directly address climate change issues. The CBD and CMS address drivers of biodiversity loss that are heavily influenced by a changing climate, such as habitat destruction and change. The scope of CITES, by contrast, is limited to a single driver of species loss that is not directly related to climate change: unsustainable international trade.

Thus, the relationship between CITES and climate change is limited to the potential role that CITES can play in protecting those species that are affected by climate change, but it can protect only those species that are also threatened by international trade. Thus, if there is no market in specimens or derivatives of a given species, CITES can do nothing to protect it. However, if a species is simultaneously threatened by climate change and international trade, CITES can help reduce the latter threat.

Sikina Jinnah

- **Further Reading**

Lovejoy, T., and L. Hannah, eds. *Climate Change and Biodiversity*. New Haven, Conn.: Yale University Press, 2005. This edited volume contains commentaries from a variety of leading experts that address the impacts of climate change on biological diversity.

Reeve, R. *Policing Trade in Endangered Species: The CITES Treaty and Compliance*. London: Earthscan, 2002. This assessment of CITES's national-level implementation and compliance provides one perspective on how CITES operates on the ground.

Wijnstekers, W. *The Evolution of CITES: A Reference to the Convention on International Trade in Endangered Species of Wild Fauna and Flora*. Geneva, Switzerland: CITES Secretariat, 2006. This guidebook, written by the CITES secretary-general, provides an introduction to the various provisions of CITES and its political process; available in electronic form via the CITES Web site.

See also: Amazon deforestation; Biodiversity; Convention on Biological Diversity; Endangered and threatened species; Invasive exotic species.

Convention on Long-Range Transboundary Air Pollution

- **Categories:** Laws, treaties, and protocols; pollution and waste
- **Date:** Signed November, 1979

LRTAP is one of the oldest international environmental treaties and one whose success has made it a model for later agreements. It addresses air pollution, including GHG emissions, and creates structures for gathering and assessing data.

- **Participating nations:** *1980:* Belarus, Hungary, Portugal, Russian Federation, Ukraine; *1981:* Bulgaria, Canada, Finland, France, Norway, Sweden, United States; *1982:* Austria, Belgium, Denmark, European Community, Germany, Ireland, Italy, Luxembourg, Netherlands, Spain, United Kingdom; *1983:* Greece, Iceland, Liechtenstein, Switzerland, Turkey; *1985:* Poland; *1991:* Cyprus, Romania, Bosnia and Herzegovina, Croatia, Slovenia; *1993:* Czech Republic, Slovakia; *1994:* Latvia, Lithuania; *1995:* Republic of Moldova; *1997:* Armenia, Malta, the Former Yugoslav Republic of Macedonia; *1999:* Georgia, Monaco; *2000:* Estonia, Kyrgyzstan; *2001:* Kazakhstan, Serbia; *2002:* Azerbaijan; *2005:* Albania; *2006:* Montenegro

• Background

In the 1960's, scientists proved for the first time that the acidification of lakes in Scandinavia was the result of industrial emissions of sulfur dioxides and nitrogen oxides throughout Europe. In 1972, the year the term "acid rain" was first used, the United Nations convened the Conference on the Human Environment, also known as the Stockholm Conference, the U.N.'s first conference on international environmental issues. This conference led to increased public awareness of air pollution and to research that confirmed the theory that air pollution could travel large distances and cause harm far away from its source.

It was clear that air pollution generated in one country could damage the environment in another and that only through international cooperation could the environment be protected. After five more years of research and diplomacy, the Economic Commission for Europe convened a meeting in Geneva, Switzerland, during which the Convention on Long-Range Transboundary Air Pollution (LRTAP) was signed. Thirty-four governments and the European Community signed the treaty between November 13 and 16, 1979, and it went into effect in 1983. The Holy See and San Marino were signatories to the convention in 1979, but they have not ratified it. Of the industrialized nations in the Northern Hemisphere, only China and Japan are not parties to the convention.

• Summary of Provisions

The convention was based on the principles that individual nations have

> the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States.

Contracting parties agreed to share research and other information and to gradually reduce air pollution. They agreed to hold talks between those nations most affected by air pollution and those generating the highest levels of it and to fully implement the work of the Cooperative Programme for the Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (generally referred to as EMEP). Finally, the convention created an executive body, which would meet annually, and a secretariat, which would convene meetings and direct the dissemination of information.

Most important, the parties agreed to take reasonable steps to reduce air pollution:

> Each Contracting Party undertakes to develop the best policies and strategies including air quality management systems and, as part of them, control measures compatible with balanced development, in particular by using the best available technology which is economically feasible.

The original convention addressed levels of sulfur dioxide only, but it recognized that further research could indicate a need to consider other pollutants.

Between 1984 and 1999, the convention was extended with eight additional agreements, or protocols, each signed by between twenty-one and forty-two parties. The first addressed financing of EMEP, but the others addressed specific pollutants and targets for their reductions: sulfur (1985 and 1994), nitrogen oxides (1988), volatile organic compounds (1991), heavy metals (1998), persistent organic pollutants (1998), and pollutants leading to acidification, eutrophication, and ground-level ozone (1999). Several of these protocols established reduction targets based on the concept of critical load.

• Significance for Climate Change

Several targets established under LRTAP have been met. The 1985 Protocol on Sulfur Emissions, for example, was entered into force in 1987, and its target of reducing emissions by 30 percent by 1993 was met or exceeded by all twenty-one parties. This success encouraged the signatories to agree to the

1994 Protocol on Further Reduction of Sulfur Emissions, which used the concept of critical load, rather than strict percentages, to establish targets. Overall, the levels of sulfur in the air decreased some 60 percent in Europe, and almost 50 percent in the United States and Canada, between 1979 and 2004. In addition, nineteen of the twenty-five parties to the 1988 Protocol Concerning the Control of Nitrogen Oxides met their targets of freezing and then reducing their emissions of nitrogen oxides and ammonia.

The success of LRTAP led the UNECE to press for four more environmental agreements: the Convention on Environmental Impact Assessment in a Transboundary Context (1991; also known as the Espoo Convention); the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992); the Convention on the Transboundary Effects of Industrial Accidents (1992); and the Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters (1998; also known as the Aarhus Convention).

Although preventing global warming was not the impetus for LRTAP, several of the pollutants regulated by the convention have direct and indirect effects on global warming. Nitrous oxide, for example, is itself a greenhouse gas (GHG). Emissions of nitrogen oxide and VOCs create ozone, another GHG. Parties to LRTAP, therefore, had already made some progress toward reducing anthropogenic emissions of GHGs before treaties such as the Kyoto Protocol (1992) were drafted.

By funding EMEP, LRTAP put into place structures for monitoring and assessing air quality, and for disseminating research findings. These structures have provided useful data for the study of global warming. As scientists study the relatively new questions about the effects of global climate change on the processes of acidification and eutrophication, they will draw on data already

Fundamental Principles of the Convention on Long-Range Transboundary Air Pollution

Articles 2 through 5 of the Convention on Long-Range Transboundary Air Pollution set out the fundamental principles of the agreement, by which all contracting parties agree to be bound.

Article 2:

The Contracting Parties, taking due account of the facts and problems involved, are determined to protect man and his environment against air pollution and shall endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution.

Article 3:

The Contracting Parties, within the framework of the present Convention, shall by means of exchanges of information, consultation, research and monitoring, develop without undue delay policies and strategies which shall serve as a means of combating the discharge of air pollutants, taking into account efforts already made at national and international levels.

Article 4:

The Contracting Parties shall exchange information on and review their policies, scientific activities and technical measures aimed at combating, as far as possible, the discharge of air pollutants which may have adverse effects, thereby contributing to the reduction of air pollution including long-range transboundary air pollution.

Article 5:

Consultations shall be held, upon request, at an early stage between, on the one hand, Contracting Parties which are actually affected by or exposed to a significant risk of long-range transboundary air pollution and, on the other hand, Contracting Parties within which and subject to whose jurisdiction a significant contribution to long-range transboundary air pollution originates, or could originate, in connection with activities carried on or contemplated therein.

gathered under the terms of the 1999 LRTAP protocol. Similarly, researchers will use data gathered under LRTAP to develop methodologies for determining the most cost-effective emissions reduction targets.

Cynthia A. Bily

• Further Reading

Kuokkanen, Tuomas. "The Convention on Long-Range Transboundary Air Pollution." In *Making Treaties Work: Human Rights, Environment, and Arms Control*, edited by Geir Ulfstein, Thilo Marauhn, and Andreas Zimmermann. New York: Cambridge University Press, 2007. An overview of the negotiations leading up to the passage of LRTAP, the treaty's terms and structures, and the efforts of the governing committee to encourage compliance.

Sliggers, Johan, and Willem Kakebeeke. *Clearing the Air: Twenty-Five Years of the Convention on Long-Range Transboundary Air Pollution.* New York: United Nations, 2005. A look back on the successes of the convention by scientific and political experts, many of whom participated in the original convention negotiations and drafting.

Soroos, Marvin S. *The Endangered Atmosphere: Preserving a Global Commons.* Columbia: University of South Carolina Press, 1997. Examines global public policy related to the atmosphere, with extensive discussion of the LRTAP convention and climate change.

United Nations Economic Commission for Europe. *Handbook for the 1979 Convention on Long-Range Transboundary Air Pollution and Its Protocols.* New York: United Nations, 2004. A history of the convention, and its protocols and activities, and a collection of all the major documents produced during the first twenty-five years of the convention.

See also: Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Air quality standards and measurement; United Nations Conference on Environment and Development; United Nations Conference on the Human Environment; United Nations Framework Convention on Climate Change; Water quality.

Cooler Heads Coalition

- **Category:** Organizations and agencies
- **Date:** Established May 6, 1997
- **Web address:** http://www.globalwarming.org

• Mission

Originally a project of the National Consumer Coalition, which was itself a project of the nonprofit group Consumer Alert, the Cooler Heads Coalition strives to dispel the "myths of global warming by exposing flawed economic, scientific, and risk analysis." The coalition, consisting of about twenty-five groups, was established in May, 1997, in response to a concern that Americans were not being adequately informed about the economic impact of reductions of greenhouse gas emissions and about the pros and cons of global warming. A major focus of the group is the consumer impact of global warming policies that restrict energy use drastically and that would raise consumer costs. Cooler Heads also maintains that the science of global warming is uncertain and that global warming policies have a negative impact on consumers.

The Cooler Heads Coalition publishes a biweekly newsletter, *The Cooler Heads Newsletter*, which provides updates on scientific, economic, and political issues relating to global climate change. The coalition maintains a global warming Web site as a clearinghouse for information on global warming science and policy proposals. *The New York Times* listed this site among fifteen top environmental Web sites; it was the only market-oriented site listed.

• Significance for Climate Change

Members of the Cooler Heads Coalition hold the view that the science of global warming is uncertain, while the negative impacts of policies addressing global warming are not. One statement on the issue maintains that "global warming may or may not be a problem" and that "man may or may not be driving it." Members of the Cooler Heads Coalition publish reports, research studies, and briefs on scientific, economic, and political aspects of global warming policy and sponsor press conferences, hold rallies, conduct consumer surveys, participate in debates, make television and radio talk show appearances, and write newspaper and magazine articles. Several of its groups involve themselves in the global warming treaty negotiations at the United Nations.

The primary focus of the coalition is economic rather than environmental, as evidenced by comments by the executive director of Consumer Alert:

> Policies disguised as middle-of-the-road instead will be leading us down the road to national industrial policy and a planned economy. The losers will be American consumers, who will bear the brunt of restrictions on energy use in their everyday lives. They'll have to pay the costs, not just in higher prices, but in a drastically lower standard of living.

Victoria Price

See also: Cato Institute; Skeptics.

Coriolis effect

• **Category:** Physics and geophysics

• **Definition**

The Coriolis effect is an apparent acceleration of a moving object as seen in a rotating system. The acceleration is not a true change in velocity, but an illusion caused by the rotation of the system beneath the moving object.

An unconscious tendency to regard the Earth as a fixed frame of reference generates an unrecognized expectation on the part of many people that objects free of forces will move with unchanging direction and speed. That is, they will be unaccelerated. This expectation is consistent with Sir Isaac Newton's First Law of Motion, which states that a body in motion will remain in motion, in a constant direction, with constant speed, unless acted on by an outside force.

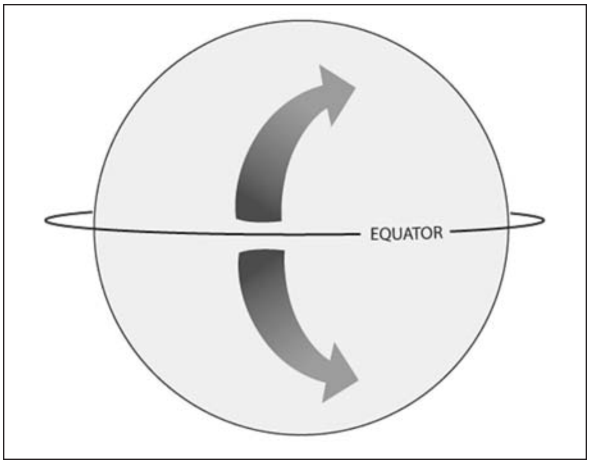
Newton's First Law of Motion, however, applies only in frames of reference that are themselves not accelerating. These so-called inertial frames must be moving in a constant direction with constant speed. This condition is not met by rotating frames, such as the surface of the Earth, where every point in the frame (though traveling at a constant speed) is constantly changing direction as it completes a circular path around the axis of rotation.

The farther an object is from the axis of rotation, the faster it will travel on its circular path. An object on the equator, for example, completes a path of 40,000 kilometers in one day, while an object at 60° north latitude travels only half that distance in the same time. Thus, the object at 60° north latitude travels at half the speed of the object on the equator.

Wind and water that leave the equator headed due north carry their equatorial speed with them. As they move north, they pass over territory that is traveling eastward more slowly than they are. As a result, the wind and water move eastward relative to the ground or the seafloor. Conversely, wind and water starting at northern latitudes and moving due south will cross ground that is moving eastward faster than they are; they will move westward relative to the ground or seafloor. This deflection from the original direction of motion is the Coriolis effect.

• **Significance for Climate Change**

Convection-driven currents carry warm water and air poleward from the equator and carry cool air and water from the polar regions toward the tropics. Both the tropical and the polar currents are de-



The Coriolis effect causes moving fluids to be deflected to their right in the Northern Hemisphere and to their left in the Southern Hemisphere. (NOAA) flected to the right, relative to their direction of motion, in the Northern Hemisphere and to the left, relative to their direction of motion, in the Southern Hemisphere. In regions where the currents converge, the deflections merge into circular rotations about the point of convergence. In the Northern Hemisphere, these rotations move counterclockwise; in the Southern Hemisphere, they move clockwise.

A low-pressure weather system in the Northern Hemisphere, for example, draws in air from the surrounding terrain in all directions. The wind flowing in from the north is deflected to the west. The wind from the west is deflected to the south, the wind from the south is deflected to the east, and the wind from the east is deflected to the north. In combination, the winds form a vortex rotating counterclockwise about the center of the low-pressure area. A high-pressure system, by contrast, repels winds, creating a clockwise vortex. In the Southern Hemisphere, these directions are reversed. Similar effects occur in ocean currents.

The magnitude of the deflection caused by the Coriolis effect is proportional to the distance from the point of deflection to the rotation axis. For that reason, the Coriolis effect is most prominent at the equator. It is also proportional to the speed of the currents involved. High winds associated with hurricanes readily display the effect, generating the characteristic circular wind pattern with a calm eye at the center.

The Coriolis effect establishes the circulation pattern of major storms, trade winds, jet streams, and large-scale ocean currents. All of these convection currents transport thermal energy from the warm tropics to the temperate and polar regions, moderating the global difference in temperatures. The Gulf Stream, for example, keeps Great Britain, Ireland, and the North Atlantic coast of Europe substantially warmer than other regions of the Northern Hemisphere that are located at the same latitude. Air currents also transport large amounts of water evaporated from tropical oceans to temperate and polar regions, where the water precipitates as rain and snow.

The rate at which convection currents transport mass and heat poleward from the tropics is a function of the temperature difference between the two regions. If climate change raises average temperatures in the tropics more than it raises them at the poles, it will create more energetic and powerful currents. If climate change raises polar temperatures more than it raises equatorial temperatures, it will dampen these currents. The resulting effects on the number, type, and destructive power of storms in either case would be complex and difficult to model.

Billy R. Smith, Jr.

• **Further Reading**

Mayes, Julian, and Karel Hughes. *Understanding Weather: A Visual Approach.* New York: Oxford University Press, 2004. This introduction to the science of meteorology instructs primarily through pictures, graphs, and maps. The Coriolis effect is explained within the larger context of atmospheric movements (winds, fronts, storms, and so on).

Stommel, Henry, and Dennis Moore. *An Introduction to the Coriolis Force.* New York: Columbia University Press, 1989. Requires some understanding of basic physics and familiarity with calculus through differential equations. Includes an appendix devoted to the construction of a laboratory demonstrator of the Coriolis effect.

Walker, Gabrielle. *An Ocean of Air: Why the Wind Blows and Other Mysteries of the Atmosphere.* Orlando, Fla.: Harcourt, 2007. The Coriolis effect is included as part of a discussion of winds and storms.

See also: Atmospheric dynamics; Atmospheric structure and evolution; Earth motions; Gulf Stream; Jet stream; Ocean-atmosphere coupling; Ocean dynamics.

Cosmic rays

• **Category:** Physics and geophysics

• **Definition**

Cosmic rays are energetic particles that travel through space. Of those that strike the Earth's atmosphere, about 90 percent are protons, 9 percent are helium nuclei (also called alpha particles), and 1 percent are electrons. When high-energy protons collide with atoms in the Earth's atmosphere, they produce showers of secondary particles, such as lower-energy protons, neutrons, electrons, and various mesons. Secondary particles generally have enough energy to form positive ions by knocking electrons away from atoms. These ions can attract atoms from the air and form tiny balls that serve as nucleation sites for water vapor, known as cloud condensation nuclei. Water vapor may then condense into water droplets on the ion balls to form clouds.

- **Significance for Climate Change**

Thus, scientists have theorized that cosmic rays form nucleation sites that promote cloud formation, so increases or decreases in cosmic ray bombardment of the Earth would correspond with increases or decreases in Earth's cloud cover. High clouds increase Earth's albedo, reflecting sunlight back into space and cooling the planet. Lower-energy cosmic rays come from the Sun, but high-energy particles originate elsewhere in the galaxy. When the Sun's activity increases, its magnetic field pushes further outward, partly blocking galactic cosmic rays from reaching the Earth. Thus, increased solar activity should lead Earth to experience fewer high-energy cosmic rays, less cloud cover, and increased global warming.

The theory may be tested by comparing records of cosmic ray intensity to past global temperatures. The ratio of the isotopes oxygen 18 to oxygen 16 in rocks and fossils provides a proxy indicator of past temperatures, while the amount of carbon 14 and beryllium 10 found in ice cores from Greenland provides similar evidence of past cosmic-ray flux. Carbon 14 is formed when a secondary neutron collides with nitrogen 14 and exchanges a proton for a neutron. Beryllium 10 is one of the possible by-products when a high-energy proton slams into either a nitrogen nucleus or an oxygen nucleus, and knocks out several neutrons and protons. This is the only source of beryllium 10.

Supporters of the cosmic ray theory note that during the Medieval Warm Period (roughly 1100 to 1300) cosmic ray intensity seems to have decreased, based on a decrease in carbon 14 and beryllium 10 at that time. On the other hand, during the part of the Little Ice Age from about 1600 to 1800, cosmic ray intensity increased and temperatures decreased. However, the temperature rise of the past fifty years has not been accompanied by a significant increase in cosmic ray intensity. Global warming is a complex phenomenon, because it may have many different causes, and the dominant cause may be different at different times. A reasonable assessment today is that 25 percent of current warming may be due to greater solar activity, but the remaining 75 percent is most likely due to greenhouse gas concentrations, with human activities being the major contributor to those concentrations.

Charles W. Rogers

See also: Albedo feedback; Clouds and cloud feedback; Noctilucent clouds; Polar stratospheric clouds; Ultraviolet radiation.

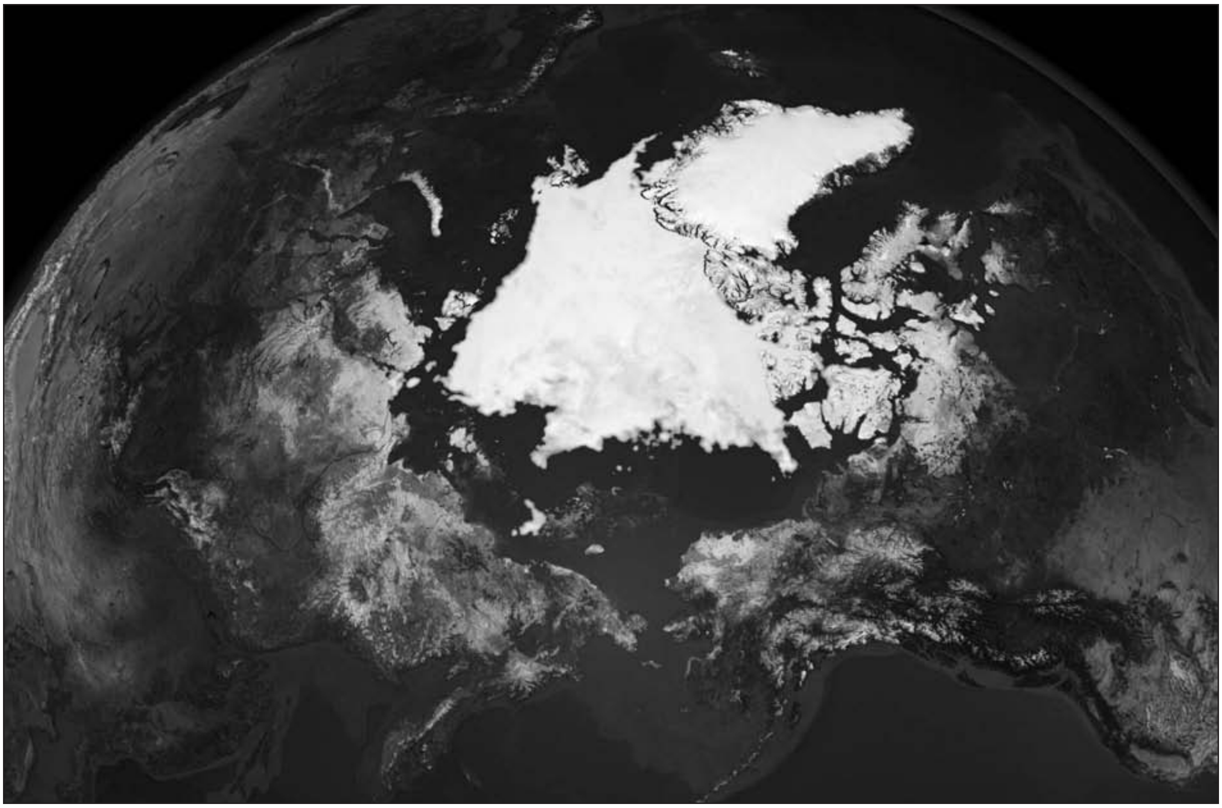
Cryosphere

- **Category:** Cryology and glaciology

- **Definition**

The cryosphere (from the Greek *kryo,* meaning "too cold") refers to those parts of the Earth's surface where temperatures are sufficiently low that water is frozen solid, in the form of either snow or ice. The conditions that freeze the available water within a particular area can be seasonal or can last for years or centuries. The cryosphere includes land covered with snow in the winter; freshwater lakes and river systems that freeze over seasonally; glaciers that freely move about larger water systems and are thus prone to melting and reshaping; and permafrost, or frozen soil and rock that remains frozen year round. The places most associated with the cryosphere are the North and South Poles, but frozen surfaces are found in many high-elevation regions of both the Northern and Southern Hemispheres.

Scientists distinguish two types of formations



Earth's Arctic ice cover in September, 2008. Polar ice accounts for a large proportion of both the planet's cryosphere and its albedo. (Reuters/Landov)

that make up the cryosphere: land ice and sea ice. Land ice is formed slowly by compressed snow that becomes layers of ice. Land ice is thus freshwater. Perhaps the most familiar examples of land ice are glaciers, great slow-moving ice masses that store at any one time close to 70 percent of the world's available freshwater. Other examples of land ice are ice shelves left where glaciers break off and head into the open oceans as icebergs; ice shelves are found in coastal areas of Greenland, northern Canada, northern China, lower South America, southern Australia, and, of course, both poles.

Conversely, the polar oceans, both north and south, are covered with sea ice, or frozen seawater. Sea ice floats on the surface of the water and has an average thickness of 1 meter in the Antarctic and nearly 3 meters in the Arctic. Because this ice exists within a dynamic environment—that is, one subject to temperature changes, wind, and ocean currents—sea ice can be measured by its duration (generally one year or multiyear). Because navigation depends on charting these fluid conditions, climatologists measure the sea ice as it cracks and even splits into huge moving parts, particularly as it inevitably diminishes during the abbreviated summer seasons at the poles. In the most extreme reaches of both poles, sea ice survives summer melting and becomes far thicker and can measure up to 381 centimeters.

• Significance for Climate Change

Although seasonal fluctuations in mean temperatures in polar regions are to be expected and do not affect the general dynamic of the cryosphere, long-term climate shifts resulting from decades of burning fossil fuels have contributed to a significant rise in the Earth's average air temperature. This global warming, in turn, affects the thousands of square kilometers that make up the cryosphere. As that fragile environment undergoes radical changes over a relatively brief period of time, such changes, in turn, affect a variety of climate and meteorological conditions around the globe. Interest in the cryosphere has greatly increased over the last generation, as climatologists see this frozen environment as the earliest indicator of rising global temperatures. The National Snow and Ice Data Center at the University of Colorado monitors the cryosphere.

Most dramatically, the diminishing of the snow and ice cover and the shortening of the winter season at the poles means that the planet's natural insulation from the direct bombardment of solar energy is diminishing. The bright surface of the snow and ice of the cryosphere contributes to Earth's albedo and is responsible for reflecting back into space 70 percent of the Sun's energy. As that protection recedes, the Earth absorbs more solar energy, resulting in an increase in mean air temperature.

The global warming trend causes inland waterways to thaw earlier than they otherwise would, disrupting navigation lines and storm patterns and affecting the ecosystems of indigenous wildlife and plants. Groundwater levels in turn decline. Glaciers melt, and scientists must confront the possibility of significant impacts on the Earth's water system and the need for global water management. There is cause for concern: Scientists estimate that global sea levels have risen over the last two decades by 7.5 to 10 centimeters, but the loss of significant ice in the endangered Antarctic could raise ocean levels a catastrophic 9 meters in the next century, making the nearly 15 percent of the world's population who live along shorelines climate refugees.

The sea-ice shelves—which protect coastlines in both poles, Alaska, Canada, and Russia from wave erosion—are disappearing, upending peoples who have worked in that difficult environment for centuries. In turn, under the impact of rising air temperatures, the permafrost loses its integrity, a process further complicated by the drilling into the rich deposits of fossil fuels. But loss of the permafrost has a greater significance. Trapped within its thousands of frozen kilometers are centuries of decayed plant and animal detritus. As the permafrost thaws, carbon dioxide and methane, themselves greenhouse gases, are released in great volume to further influence global air temperature.

Joseph Dewey

• Further Reading

Archer, David. *The Long Thaw: How Humans Are Changing the Next 100,000 Years of Earth's Climate.* Princeton, N.J.: Princeton University Press, 2008. Accessible description of the consequences of cryosphere loss. Pitched to a nonscientific audience, resisting alarmist argument, and generally objective.

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming.* Rev. ed. London: Penguin, 2007. Investigates the widest implications of global warming. Essential for understanding how the cryosphere affects a broad range of climate phenomena across the globe.

Michaels, Patrick J. *Climate of Extremes: Global Warming Science They Don't Want You to Know.* Washington, D.C.: Cato Institute, 2009. Important conservative corrective to growing alarmist projections about crysophere damage. Moderates the predictions and indicates progress in monitoring the cryosphere.

Slaymaker, Olav, and Richard Kelly. *The Cryosphere and Global Environmental Change.* Hoboken, N.J.: Wiley-Blackwell, 2007. Groundbreaking textbook on the specific issues facing the cryosphere. Explains causes of cryosphere damage. Helpfully illustrated.

See also: Glaciations; Glaciers; Greenland ice cap; Ground ice; Ice shelves; Permafrost; Sea ice.

Damages: market and nonmarket

• **Categories:** Economics, industries, and products; environmentalism, conservation, and ecosystems; popular culture and society

• **Definition**

Climate change has the potential to inflict significant social, financial, and environmental damages. Some of these damages will be market damages, measurable as negative influences on gross domestic product (GDP), and some will be nonmarket damages, not accounted for in GDP. A clear example of a market damage that could be attributed to climate change is the loss of tourism associated with the destruction of coral reefs by sea-level rise or temperature change. An example of nonmarket damage is the loss of the ecosystem service of storm protection provided by coastal wetlands in a sea-level-rise scenario. Perhaps ironically, the value of the storm protection services of coastal wetlands increases with climate-induced increases in storm frequency and intensity.

Some impacts of climate change fall into even murkier territory with respect to assigning phenomena as net benefits or costs. Suppose increasing global temperatures cause an increased use of air conditioning around the world, which boosts GDP via increased energy revenues and increased air-conditioner sales and service. This increased use of air conditioning exacerbates climate change, however, through increased carbon dioxide (CO_2) emissions. Does this situation represent a market benefit or cost? Does it represent a nonmarket benefit or cost? Traditional economic paradigms are increasingly challenged by environmental problems, and assessing the costs of climate change from a strictly economic perspective is particularly problematic.

• **Significance for Climate Change**

Assessing the market and nonmarket damages of climate change is an active, diverse, and contested area of economic and social science research. Climate change presents many complex and problematic market-failure potentials in the categories of public goods, common property, and negative externalities. A public good is an acknowledged market failure, in that a free market will not provide appropriate supplies of it, because it is nonexcludable and nonrival in consumption. A commonly used example is lighthouses. Society benefits from lighthouses, because they prevent damage to life and property in cost-effective ways. However, the private sector will not build lighthouses, because owners of lighthouses cannot charge for their services effectively, nor can they exclude nonpayers from using those services. Governments typically provide public goods, such as street lighting and national defense, for this reason.

Institutions that provide conservation services, such as the U.S. Fish and Wildlife Agency and the Environmental Protection Agency, could be considered public goods. Climate change may necessitate the creation of new institutions that monitor and enforce policies related to various phenomena associated with global warming. Public goods such as ecosystem services are an example of a nonmarketed public good that are threatened in myriad ways by global warming. Common property is another market failure well described in Garrett Hardin's famous paper "The Tragedy of the Commons." Communally owned properties are often not used in economically optimal ways because of conflicts between public and private interests. The atmosphere is a global common property that is used as a greenhouse-gas dumping ground to varying extents by the nations of the world.

Externalities are another market failure that occurs when all of the costs or benefits of an activity are not accounted for. When a university improves its campus with new and appealing buildings and improves its reputation, raising the property values of nearby residential real estate, that represents a positive externality. When a manufacturer pollutes the environment but does not account for the resulting environmental costs by reimbursing the affected community, that represents a negative externality. Climate change will probably involve both positive and negative externalities; nonetheless, the growing consensus is that in the aggregate it will be negative.

Climate change produces negative externalities via sea-level rise, increased frequency and intensity of extreme weather events, and reduced soil moisture. As with much environmental damage, the community responsible for climate change is not necessarily the one that suffers as a result. Greenhouse gas (GHG) emissions of the developed world could cause sea-level rise that swamps small, poor, island nations. If so, serious human and environmental damage will have occurred, and it will be difficult if not impossible to put a dollar value on these damages, or to determine who should be compensated, in what way, and with whose resources. The intra- and intergenerational equity questions raised by the impacts of climate change present the global community with profound ethical questions and institutional challenges.

Monitoring and enforcement of GHG emissions will necessitate the establishment of institutions that are regarded as fair, just, accurate, and effective by the global community in order to be accepted. The establishment and maintenance of these institutions will inevitably require expenditures. These costs may be recouped in the form of improvements to the human economy, such as preventing damage to accrued and inherited wealth, rather than in the form of increased GDP. Wars, wildfires, and extreme weather events such as Hurricane Katrina all increase economic activity and consequently GDP, yet no one would recommend disasters of this nature to create market benefits. An economic paradigm that values current economic activity (GDP) over established wealth (both marketed and particularly nonmarketed) is increasingly inadequate to many of the most pressing policy questions in relation to climate change. The scale, scope, and costs of this global institutional challenge are unprecedented.

Paul C. Sutton

• **Further Reading**

Costanza, R., et al. "The Value of the World's Ecosystem Services and Natural Capital." *Nature* 387 (May 15, 1997). Economic analysis of natural resources and the damage to their value done by ecological degradation.

Daily, Gretchen, ed. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, D.C.: Island Press, 1997. Looks at ecosystems as part of a global anthropomorphic service economy that includes nonhuman entities.

Heal, Geoffrey. *Nature and the Marketplace: Capturing the Value of Ecosystem Services*. Washington, D.C.: Island Press, 2000. Market analysis of natural resources.

See also: Carbon footprint; Conservation and preservation; Deforestation; Economics of global climate change; Employment; Environmental economics; Global economy; Sustainable development.

Dating methods

• **Categories:** Chemistry and geochemistry; science and technology

Reliable dating methods permit scientists to describe past climate change quantitatively and to establish connections between known astronomical cycles and climate cycles.

• **Key concepts**

cosmogenic isotope: an isotope—possibly radioactive—produced when a cosmic ray strikes the nucleus of an atom

decay constant: a measure of how radioactive an isotope is, determined with a Geiger counter

half-life: the time needed for half of a quantity of a radioactive isotope to decay; it is calculated from the decay constant, not measured directly

isotopes: variants of an element that are chemically identical but have different atomic mass numbers and vary in radioactivity

primordial isotope: an isotope that has been present on Earth since the planet formed 4.5 billion years ago

varve: an annual layer in a sediment, usually the result of seasonal variation in inputs

• **Background**

Because the geological and climatological history of Earth began long before recorded history, scientific dating methods are necessary to determine when many climatic events occurred. For example, such methods could be used to determine when glacial deposits formed or when a boulder was dropped on top of those deposits by a melting glacier.

• Primordial Isotopes

When the Earth formed, it inherited an inventory of radioactive elements that have been decaying ever since. The decay constant for a particular isotope can be determined by measuring the rate at which disintegrations occur in a sample of known mass. Half-lives are calculated from decay constants. Known half-lives of radioactive isotopes enable scientists to determine the age of some objects that contain those isotopes.

For example, water moving through the ground will often dissolve small amounts of uranium. A stalagmite may form from this water in a cave as the water evaporates, incorporating any uranium 238 (U^{238}) present. The uranium will decay to produce thorium 234 (Th^{234}). Thorium is insoluble in water, so it can be assumed that the stalagmite initially contained no thorium. Thorium, too, is radioactive, and may decay into U^{234}, which decays to Th^{230}, which is also radioactive. Using the decay constants and the amounts of U^{238}, U^{234}, and Th^{230} present in a specimen, scientists can calculate how long it has been since the uranium came out of solution. This technique is limited to ages less than 500,000 years.

• Cosmogenic Isotopes

Cosmic rays are subatomic particles traveling at very high velocities. When they strike the nucleus of an atom, they can eliminate nucleons, altering the identity of the atom. An atom of nitrogen 14 (N^{14}), for instance, might become carbon 14 (C^{14}), or atoms of silicon or oxygen might become beryllium 10 (Be^{10}) or aluminum 26 (Al^{26}). C^{14}, Be^{10}, and Al^{26} are all radioactive, and their decay constants are known, so they provide a means of dating organic material and the surfaces of boulders.

On Earth, C^{14} is generally created only as a result of cosmic ray bombardment in the atmosphere, so only atmospheric carbon replenishes its C^{14} level. Nonatmospheric C^{14} decays over time without replenishment. An organism will interchange carbon with the atmosphere while it is alive, maintaining a relatively constant ratio of C^{14} to carbon 12 (C^{12}), but once it dies that interchange will cease and the ratio will decrease. By assuming a historically constant ratio of C^{14} to C^{12} in the atmosphere (and thus in living organisms) and by comparing that ratio to the ratio in a sample of tissue from a deceased organism, it is possible to determine how many half-lives of C^{14} have passed since the organism died. The assumption of a constant ratio is known to be invalid, but it will produce the same errors in all samples, giving the same results for samples of the same age. If the goal of analysis is to compare different samples with one another and there is little need for actual calendar years, samples' ages are often reported in C^{14} years.

To convert results accurately to calendar years, corrections are made using calibration curves derived from other dating techniques such as may produce different calibrated ages from the same C^{14} age. The effective limit of this technique is about forty-five thousand years.

Cosmic rays also cause reactions in the outer layers of quartz-rich rocks. Be^{10} and Al^{26} accumulate in these layers at small but relatively constant rates. These isotopes are produced slowly, at a rate of about 100 atoms per gram of rock per year, requiring accelerator mass spectrometry (AMS) techniques to detect them. Cosmic rays do not penetrate solids by more than a few meters, so the exposure age of a surface can reveal when glacial ice melted away above that surface.

• Nonradiometric Methods

Dendrochronology. Dendrochronology is a method for determining the age of wood by counting and examining annual tree rings. The thickness of a given ring in a tree is determined by environmental factors obtaining during the year in which the ring was formed. Such factors as temperature and rainfall affect the rate of growth and overall health of trees. As a result, patterns of ring thickness in trees that were alive at the same time in the same area tend to resemble one another. Matching patterns of ring thickness between trees of known and unknown age can thus provide evidence that the trees were alive at the same time. The reliability of this method has been extended back to about ten thousand years.

Varves. Just as trees have annual growth cycles, so do sediments deposited in lakes in regions near glaciers. In the summer, rains bring coarse sediments into the lake. In the winter, fine clays have time to settle out. The banded sediments that result from this seasonal alternation are called varves. Just as with tree rings, patterns of thick and thin layers can be correlated in different varved sequences. Some sequences cover more than thirteen thousand years.

Lichenometry. Lichens grow at fairly constant rates in a given area. In a given area, rocks covered by larger lichens have surfaces that have been exposed longer than have the surfaces of rocks covered by smaller lichens of the same type. By calibrating measurements using tombstones and other objects of know age, the absolute exposure age of lichen-covered surfaces can be estimated.

• Context

Understanding climate change requires knowledge of Earth's climatological history, which in turn requires methods capable of dating events of climatic significance over the last few million years. As technology has improved, the precision and accuracy of these methods has increased dramatically, and the size of the samples required for accurate dating has decreased by orders of magnitude.

Scientists looking at isotope-ratio records in marine sediment cores have sometimes found that different radiometric techniques indicate different dates for the same climatic excursion. As the climatic excursions were found to be global and strongly correlated with known astronomical cycles, it became possible to determine their age with greater accuracy, validating some results over others. This correlation with astronomical cycles could also be used to calibrate radiometric dating methods, just as counting tree rings was used to calibrate C^{14} dating methods. As methods developed, it became possible to date specific geologic and climatic events, such as the encroachment or retreat of ice from a given area, the speed of uplift of a surface, or the rate of development of a valley.

Otto H. Muller

• Further Reading

Cremeens, David L., and John P. Hart, eds. *Geoarchaeology of Landscapes in the Glaciated Northeast: Proceedings of a Symposium Held at the New York Natural History Conference 6*. Albany: State University of New York: State Education Deptartment, 2003. Contains an outstanding example of dating, using the New England varve sequence, uranium-thorium calibrations, C^{14} dates, and calendar C^{14} dates; shows how all these methods can be used in concert to reinforce one another. Figures, maps, bibliography.

Ruddiman, William F. *Earth's Climate Past and Future*. 2d ed. New York: W. H. Freeman, 2008. This elementary college textbook has several sections concerning dating methods, their limitations, errors, and resolution. Illustrations, figures, tables, maps, bibliography, index.

Thurber, David L., et al. "Uranium-Series Ages of Pacific Atoll Coral." *Science* 149, no. 3679 (1965): 55-58. An early paper describing the uranium-thorium method; uses graphs to illustrate the viability of the technique. Figures, tables, bibliography.

See also: Carbon cycle; Carbon dioxide; Carbon isotopes; Climate reconstruction; Cosmic rays; Deglaciation; Earth history; 8.2ka event; Holocene climate; Medieval Warm Period; Oxygen isotopes; Paleoclimates and paleoclimate change; Pleistocene climate; Sea sediments; Tree rings; Younger Dryas.

Day After Tomorrow, The

- **Category:** Popular culture and society
- **Date:** Released 2004
- **Director:** Roland Emmerich (1955-   )

• Background

The motion picture *The Day After Tomorrow* is a fictional depiction of the advent of a modern ice age. Brandishing elaborate special effects and generic political characters who ignore the warnings of prominent scientists that a global climate change is coming upon them, the movie attempts to explain how a rapid climate change can occur. Based on the concept of the Younger Dryas period, a much-debated dramatic cooling that occurred in northern Europe approximately ten thousand years ago, *The Day After Tomorrow* attempts to engage with modern global warming concerns.

The movie begins with a slice of reality—the thawing of the glaciers. A massive chunk of the arctic ice shelf breaks away from the continent. Scientists monitoring the temperatures in the ocean note a thirteen-degree drop in water temperatures in multiple locations off Greenland. Events go awry on a worldwide scale shortly thereafter. A critical desalination of the ocean's water occurs, shifting ocean currents and wreaking havoc on the world's climate. The planet is besieged by bizarre weather changes. Snowstorms, brick-sized hail, massive wind sheers, and tornadoes begin to affect regions where such meteorological events had never occurred before. Scientists quickly develop a climate model based on these occurrences that predicts the arrival of a new ice age within six to eight weeks. Politicians ignore this prediction, thereby dooming millions.

• Significance for Climate Change

The events depicted in *The Day After Tomorrow*, while based on solid theories and conjectures, are presented in a sensationalized way. One gigantic storm covers the globe and plunges the world into a new ice age. These events take place in a matter of days, not months or years.

Most scientific experts agree that a cataclysmic climate change would not happen so quickly. Even the Younger Dryas period, with its radical climate change, is speculated to have taken seventy years to develop. Ice-core samples confirm that the changes to the climate took a significant period of time to occur. According to widely accepted beliefs, a climate change of the magnitude depicted in *The Day After Tomorrow* would be gradual by human temporal standards, evolving over the course of ten to fifty years. An increase in atmospheric carbon dioxide (CO_2) from industrialization and poor regulation is expected to double the levels of CO_2 over the course of the next century. A slow warming trend is expected, but it unlikely to lead to the type of rapid climate change depicted in the film.

Even with the realization that *The Day After Tomorrow* is more a work of fiction than of fact, one is left with the fear that the events depicted in the film are possible. A widely publicized research study on the ocean's thermohaline circulation—the flow of tropical waters to the Earth's northern polar region—has indicated that, if the water's flow should abruptly cease, it could lead to rapid and severe climate change in Great Britain and western Europe. Such an occurrence could cause a miniature ice age to befall that region in only a matter of years.

There is speculation and conjecture to both support and debunk the notion that the thermohaline circulation could stop. Climate models, such as the ones depicted in the film, cannot take into account the millions of variables required accurately to predict what will occur given specific stimuli. The Earth's climate and oceanic flows are just too complex for such accuracy.

This image from The Day After Tomorrow *shows New York City after the sudden onset of a new ice age.* (AP/Wide World Photos)

Still, *The Day After Tomorrow* does represent in stylized fashion actual risks to the environment. Unlike the Younger Dryas period, during which nature alone created a climate change, human intervention into the delicate balance of atmospheric and oceanic concerns can only upset the equilibrium further. Greenhouse gases in the atmosphere have the potential to raise the Earth's temperature, causing the polar ice caps to melt and drop billions of tons of freshwater into the ocean, thereby causing the desalination depicted in the film. It is conjectured that such events are already occurring and are interfering with polar ecosystems.

As was true during the Younger Dryas period, life-forms—both animal and plant—are the first indicators that something is wrong with the ecosystem. Plant life, acclimated to specific temperatures and climates, will slowly diminish and die when climate changes occur. Animals that feed on the plant life either have to adjust to the loss of a food source or perish as well. *The Day After Tomorrow* fails to denote this fact, although it could certainly be implied from the events depicted in the film that animal life perished on the same scale as human life.

As a piece of entertainment, *The Day After Tomorrow* is an engaging and thought-provoking film. It depicts a future no one wants to come to fruition—a new ice age. This ice age occurs in a matter of days, throwing the world into chaos and killing billions. While an effective argument against the horrors of global warming and environmental abuse, *The Day After Tomorrow* depicts a rapid descent into a new ice age that is highly unlikely. It is more probable that slow change will occur and that humankind will be able to take the necessary steps to ensure its survival.

Roger Dale Trexler

• **Further Reading**

Fagan, Brian M. *The Little Ice Age: How Climate Made History, 1300-1850.* Jackson, Tenn.: Basic Books, 2001. A discussion of how climate change altered European history.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change.* Boston: Beacon Press, 2008. A critical study of anthropogenic climate change written by a journalist for *New Scientist* magazine.

Weart, Spencer R. *The Discovery of Global Warming.* Rev. and expanded ed. Cambridge, Mass.: Harvard University Press, 2008. An informed history of the concept of global warming.

See also: Abrupt climate change; Little Ice Age; Media; Popular culture; Speculative fiction; Younger Dryas.

Deforestation

• **Category:** Plants and vegetation

• **Definition**

Deforestation is the long-term or permanent conversion of forested land to another use. Deforestation can be a natural phenomenon: floods, hurricanes, wildfires, landslides, and droughts, for example, can all cause widespread damage and destruction to a forest. However, deforestation is frequently anthropogenic. Such anthropogenic deforestation results from destructive logging; the transformation of forest to cropland, pasture, or developed areas; and overutilization of forest resources past the point where the ecosystem can recover. Road building, oil extraction, mining, and hydroelectric dam construction also involve deforestation.

Humankind has cleared forests since its earliest days to build shelter, obtain fuel, and make way for crops and livestock. Deforestation has inevitably accompanied human settlement, development, and commerce. Rates of forest loss are highest in developing nations, where trees are harvested in response to an international demand for wood products. They are also cut down to meet domestic needs for fuel, as wood and charcoal are still widely used for cooking and heating. Tropical forests are eliminated and the land reworked to provide more profitable, exportable commodities such as beef cattle, biofuel crops, sugar, palm oil, rubber, tea, and coffee.

In its 2005 Global Forest Resources Assessment, the Forestry Department of the United Nations

A deforested portion of the Amazon rain forest near Tailandia, Brazil. (Jack Chang/MCT/Landov)

Food and Agriculture Organization (FAO) reported a global deforestation rate of about 13 million hectares per year between 2000 and 2005. Although forest restoration efforts, afforestation (establishing forest plantations in historically unforested areas), and natural forest expansion offset part of the destruction, the net loss remained substantial: Every year during the study period, an estimated 7.3 million hectares of forest—an area roughly the size of Panama—disappeared. (This represents an improvement over the years from 1990 to 2000, when the annual net loss was 8.9 million hectares.) Forests in Africa and South America were hardest hit; North and Central America and Oceania also experienced a net loss. Europe showed a slow expansion of forested area, and China reported a net gain due to large-scale afforestation. As of 2005, the total global forested area was just under 4 billion hectares and covered about 30 percent of the planet's land area.

- **Significance for Climate Change**

Living plants take in carbon dioxide (CO_2) during photosynthesis and retain, or sequester, it. The carbon is returned to the atmosphere when the plant decomposes or burns. The FAO's 2005 Global Forest Resources Assessment estimates that forests worldwide store 283 billion metric tons of carbon in their biomass alone; the carbon stored in that biomass, together with that in forest deadwood, litter, and soil, is about 50 percent more than the amount of carbon in the atmosphere.

Because of the role trees and other forest plants play in the carbon cycle, deforestation is regarded as a major source of greenhouse gas (GHG) emissions. When a forest's trees are harvested or cleared, they can no longer pull carbon from the atmosphere. Furthermore, as they burn or decompose, they release their stored carbon to the atmosphere. The FAO reports that global carbon stocks retained in forest biomass dropped by 1.1 billion metric tons annually between 1990 and 2005 in response to deforestation and forest degradation.

According to *Land Use, Land-Use Change, and Forestry* (2000), a report by the Intergovernmental Panel on Climate Change (IPCC), an estimated net release of 121 billion metric tons of carbon resulted from the expansion of agriculture through conversion of forest and grasslands during the 140-year period between 1850 and 1990. Approximately 40 percent of that was emitted from middle- and high-latitude areas in the Northern Hemisphere, primarily before the middle of the twentieth century; the remaining 60 percent came from low-latitude tropical forests, mostly during the latter half of the twentieth century. The IPCC attributes more than 90 percent of net carbon emissions during the 1980's to land-use changes (chiefly deforestation) in the tropics.

It was during the 1980's that international concern about the widespread liquidation of forests mounted. At the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, the nonbinding Statement of Forest Principles was developed and made several recommendations for responsible and sustainable forestry. Since then, most of the world's countries have adopted forestry laws and policies that integrate environmental, economic, and social considerations. Some countries, including Paraguay, Costa Rica, China, Thailand, the Philippines, and much of Europe, have implemented deforestation bans or moratoria.

Deforestation is largely driven by economic considerations: The financial advantages of harvesting or clearing a forest are clear, while the benefits the forest provides in terms of carbon storage, biodiversity, water purification, and erosion control are less evident. Tax credits, subsidies, incentive programs, and carbon trading have been proposed to encourage forest conservation and preservation. In Costa Rica, forest loss has been halted through a combination of tax incentives and a program of payment for environmental services. In 2008, the United Nations launched the Reduced Emissions from Deforestation and Forest Degradation (REDD) Program, in which developed nations will pay developing nations to slow climate change by protecting and planting forests.

Karen N. Kähler

- **Further Reading**

Food and Agriculture Organization of the United Nations. *State of the World's Forests, 2007.* Rome: Author, 2007. Includes tables summarizing forest areas and area change; forest growing stock, biomass, and carbon; and the ratification status of international conventions and agreements. Figures, photographs, acronyms list, references.

Gay, Kathlyn. *Rainforests of the World: A Reference Handbook.* 2d ed. Santa Barbara, Calif.: ABC-CLIO, 2001. Chapter 2 is devoted to the causes and impacts of deforestation. Chapter 5 includes the text of the 1992 Statement of Forest Principles. Bibliographic information, glossary, index.

Williams, Michael. *Deforesting the Earth: From Prehistory to Global Crisis.* Chicago: University of Chicago Press, 2003. A survey of humanity's ten-thousand-year history of clearing forests. Part 3 looks at the acceleration of global deforestation during the twentieth century. Figures, tables, plates, notes, bibliography, index.

See also: Agroforestry; Amazon deforestation; Forestry and forest management; Forests; Intergovernmental Panel on Forests; Tree-planting programs.

Deglaciation

- **Category:** Cryology and glaciology

- **Definition**

Deglaciation is the uncovering or exposure of a land surface that was previously covered by glacial ice. It results from ice melting or subliming (transforming from solid directly into vapor). Deglaciation, therefore, accompanies the end of a glacial stage. As deglaciation occurs, several processes take effect. Among these processes are meltwater stream flow, development of meltwater lakes, addition of water to the world's oceans (raising the global sea level), exposure of the land, and rebound of the land (lifting of the land's elevation as a result of the removal of the weight of the overlying ice). In addition, faunal and floral changes accompany deglaciation in response to changes in landscape and ecology.

Glaciers have a seemingly infinite capacity to entrain and transport sedimentary material, from tiny clay particles to giant rock boulders. Glaciers move these materials within and upon the ice, but when they melt all this sediment is deposited in the area where the ice melts. For this reason, areas that have experienced deglaciation are typically covered by glacially transported sediment. Alternatively, glaciers may sweep an area clean of loose material, creating deglaciated areas of bare bedrock. Where deglaciation has formed modern shorelines, those shorelines tend either to be laden with glacial sediment or to present bare bedrock to the waves. In some places, rebound has lifted the land along the modern shore, forming sea cliffs.

Deglaciation accompanies the transition from a glacial stage to an interglacial or warm stage. There have been several such transitions over the past two million years. In addition, deglaciation—to a lesser extent—accompanies minor warming events that occur during glacial stages. Prior to the current epoch of glacial and interglacial stages, the Earth experienced several periods during which glaciers episodically covered large parts of its surface. There have been at least four such glacial periods during the past one billion years.

An Antarctic mountain is reflected in the surface of a bay that was once covered by a glacier. (Stuart McDill/Reuters/Landov)

• **Significance for Climate Change**

Deglaciation accompanies climate change and can be a cause of climate change. The geological record indicates that, when deglaciation commences, there is typically a climatic turn toward global warming. In other words, after climatic warming initiates deglaciation, the deglaciation itself can create a positive feedback loop engendering further warming. Glaciers are highly reflective of sunlight, contributing to Earth's albedo (the percentage of sunlight reflected back into space from the planet's surface). As glaciers melt, white ice and snow are replaced with darker surface elements. Earth's albedo decreases, and more solar radiation is absorbed and retained by the planet. As the planet warms, more glaciers melt, the albedo decreases even further, and the process continues. Melting glaciers also contribute water to lakes and oceans, which help retain atmospheric heat. Rising sea levels due to glacial meltwater contribute to global climate change as well.

Using the modern deglaciation as an example, loss of glacial ice cover on the land has had and continues to have profound consequences for global climate change. For example, release of water locked up in glaciers has affected the amount of water in the oceans as well as on land, in rivers and streams, and in the form of groundwater. This has affected coastal and interior ecosystems, which are dependent upon water for life. Changing patterns in the distribution of water cause both climates and ecosystems to change.

Deglaciation, as compared to glaciation, can be a relatively rapid process, once the melting triggers feedback mechanisms that increase its pace. The rapid nature of this change has led to disequilibrium conditions on land, such as unstable slopes, high gradients in rivers and streams, and unstable lakes that drain catastrophically. In the biotic realm, rapid deglaciation has led to mass death and mass extinction among plant and animal groups, as well as mass migration of animal populations.

Deglaciation leaves behind profound physical effects of ice movement, such as landscapes altered by the erosive forces of massive ice sheets, depositional landforms created by sediment released from melting ice, and lakes created by the meltwater—including waters from marooned blocks of ice that melt long after the main glacial mass is gone. The resulting altered landscapes generally have low levels of vegetation (at least initially), as well as areas of low elevation where water can accumulate. This type of landscape has a higher capacity to retain radiated heat from the Sun and therefore also contributes to atmospheric warming.

David T. King, Jr.

• **Further Reading**

Alley, R. B., and P. U. Clark. "Deglaciation of the Northern Hemisphere." *Annual Reviews* 28 (2000): 149-182. One of the best references for a complete understanding of the current deglaciation, its chronology, and its overall effects. Well illustrated.

Ehlers, J., and P. L. Gibbard, eds. *Quaternary Glaciations: Extent and Chronology.* 3 vols. San Diego, Calif.: Elsevier, 2004. Massive, comprehensive compendium of studies of the glaciations and deglaciations of the Quaternary period. Includes five CD-ROMS of digital maps and other supporting material.

Stanley, Steven. *Earth Systems History.* 3d ed. New York: W. H. Freeman, 2009. Lays out the history of Earth, including the factors affecting global climates and climate change, over the vastness of geological time. Selected chapters focus on climate change in terms of glaciation and deglaciation.

See also: Albedo feedback; Climate feedback; Cryosphere; Glaciations; Glaciers; Ground ice; Ice shelves; Interglacials; Sea ice; Sea-level change.

Desalination of seawater

• **Categories:** Water resources; science and technology

Desalination of water is an often-disputed subject where climate change is concerned. Scientists are unsure whether desalination will have a major effect on Earth's climate.

• Key concepts

distillation: use of evaporation and condensation to remove solutes from a liquid; one of the earliest forms of artificial desalination

passive vacuum technology: method that utilizes gravity and atmospheric pressure, rather than pumps, to create a vacuum, which enables evaporation to occur at lower temperatures, requiring less energy

reverse osmosis: forced passage of a liquid through a membrane to remove solutes

• Background

The removal of salt from seawater is an ages-old process that has become a multimillion-dollar industry. The demand for freshwater, especially in arid regions, has driven people to create and implement new and more effective ways to remove salt from water. Desalination occurs naturally as part of the hydrologic cycle. The Sun evaporates water from the ocean. The vapor, condensed by cooler air in the atmosphere, forms rain clouds. The rain from these clouds reaches the ground as pure liquid water. Earth's ecosystems are dependent upon this process.

All artificial desalination processes are based on the natural hydrologic cycle. For the most part, the energy requirements to desalinate seawater are heavy, making the process expensive. Still, it is estimated that 30 percent of the world's irrigated areas suffer from salinity problems that prevent crops from flourishing as they would if freshwater were available. The need for desalinated water for human and crop consumption is critical in the Middle East and other regions where freshwater is not abundant.

• Distillation

The most fundamental form of desalination is distillation, one of the earliest forms of water treatment. Ancient mariners used this process to convert seawater into drinking water on long voyages. By heating salt water and capturing the vapors, then letting them condense back into a liquid, they removed salt and other impurities. The same process is used to separate alcohol from fermented grains.

• Passive Vacuum Technology

Passive vacuum technology is used to decrease the energy requirements of desalination. By elevating a container, a partial vacuum can be created by the difference between air pressure inside and outside the container. The vacuum in turn allows water directed through the container to evaporate at a lower temperature, making it feasible to heat the water to its evaporation point with solar power. The temperature requirement for this system is less than for other methods, in part because it represents a closed system, so heat and vapors remain within it.

As pure water evaporates from salt water, the salinity of the remaining water increases, thereby decreasing its evaporation rate. Fresh salt water needs to replace the remaining brine at a rate equal to the rate of evaporation in order to maintain the overall salinity of the system. A tube-in-tube heat exchanger is used to inject new salt water while simultaneously drawing off the concentrated brine. The freshwater produced is reconstituted to its liquid state through a series of condenser coils similar to that of a moonshiner's still. The freshwater is delivered to a storage tank, while the concentrated brine can be sent to a solar tank and condensed further.

This method has the advantage of using far less energy than do typical solar evaporators, and the vacuum effect produced within the enclosed system makes a pump unnecessary. Internal pressure is developed within the closed system that is sufficient to push water through the system. It is a continuous system, yet it has its shortfalls as well. The system needs to be cleaned and restarted on a periodic basis, lest the noncondensable gases produced from the process build up and destroy the vacuum.

• Reverse Osmosis

Another method of desalinating seawater is reverse osmosis. A reverse osmosis system has four major steps: pretreatment, pressurization, membrane separation, and post-treatment stabilization. In this method, saltwater is pumped into an enclosed system, building pressure that forces it through a water-permeable membrane. The membrane prevents dissolved salts and other impurities from passing through it, thereby purifying the water. The re-

Interior of the world's largest seawater reverse osmosis desalination plant, in Ashkelon, Israel. (Yael Tzur/Israel Sun/Landov)

sulting brine is pushed through the pressurized side of the reactor and stored. The concentrated salts are then discharged in an effort to minimize the pressure build-up. Without discharging the build-up of salts and other impurities, more energy would have to be input into the system to achieve purification. The main energy expenditure of reverse osmosis is thus in the initial pressurization of the feedwater through the membrane.

The key advantage to reverse osmosis is its simplicity. The only difficulties that the process presents are in minimizing the need to clean the membrane by producing enough clean feedwater to keep the system running at top capacity and in the need to remove particulates in that feedwater by pretreating the water. The technology is viable for regions with a readily available supply of brackish groundwater or seawater.

- **The Purity of Ice**

Yet another way to desalinate water that is seldom used is freezing. This technique is based on the simple fact that freshwater will freeze before salt water will. By allowing water to freeze and crystallize, separating the crystals from the salty slurry, then applying heat, freshwater may be obtained from salt water. Northern states and territories are the most likely to find this method viable, because they experience more months of cold weather and harsher climates than do more southern states. The harsh climate can be harnessed to freeze water without energy input.

This method has its benefits. At freezing temperatures, scaling—the build-up of elements other than salt within the water—is minimized. Also, equipment does not suffer the corrosion it does when water vapor is involved. Corrosion is a major drawback in methods involving heating the water that, in general, does not exist when freezing is involved.

Icebergs have been considered as a potential source of a massive supply of freshwater because of their purity. Icebergs contain water that is almost as pure as distilled water. They are abundant and can be easily procured. Large towing ships could, in theory, remove an iceberg from the polar region and tow it to an area where the already desalinated water within the iceberg could be easily thawed and put to use. Because arctic icebergs are irregularly shaped, antarctic icebergs are the more suitable for transport. A suitable iceberg would not only have to be shaped correctly, but it would also need to weigh somewhere around 91 million metric tons to retain enough frozen pure water by the time it reaches its destination. The drawbacks of this method include the requisite time, erosion of the iceberg during transport, financial concerns, and the uncertainty of the ecological and climatic effects of removing icebergs from an already decaying environment.

• Context

The advantages of desalination are many and varied. In regions where freshwater is not readily available, desalination and purifying water could provide an economic and population boom. Arid regions could be irrigated, and crops could be sown to increase the food supply. Desalination will play a part in the future of mankind, and it will be up to humans to create new and improved methods of providing freshwater. Different methods are required to desalinate water in different regions of the world, but fresh, potable water is a necessity everywhere.

Roger Dale Trexler

• Further Reading

Army Corps of Engineers, U.S. *Water Desalination.* Honolulu: University Press of the Pacific, 2005. Explores and creates guidelines that are useful in both military and civilian settings for selecting a method to produce potable water from seawater and brackish water.

Lauer, William C., ed. *Desalination of Seawater and Brackish Water.* Denver: American Waterworks Association, 2006. Collection of articles taken from AWA conference proceedings, periodicals, and previously unpublished sources. Topics include seawater, brackish water, osmosis-membrane softening, disposal, and the cost involved in desalination.

Wilf, Mark, et al. *The Guidebook to Membrane Desalination Technology: Reverse Osmosis, Nanofiltration, and Hybrid Systems Process, Design, Application, and Economics.* Rehovot, Israel: Balaban, 2007. Encompassing the latest membrane desalination technology, this book provides a thorough overview of the latest systems. Explores all facets and processes in the field of membrane desalination.

See also: Ekman transport and pumping; Estuaries; Freshwater; Groundwater; Hydrologic cycle; Ocean acidification; Sea ice; Water quality; Water resources, global; Water resources, North American.

Desertification

• **Category:** Environmentalism, conservation, and ecosystems

Expansion and intensification of agriculture in dryland environments can lead to land degradation. When drought occurs in such environments, further land degradation is so severe that the ecosystem cannot recover fully after the rains return, and the region becomes a desert. Should drought frequency increase in the future, vulnerability to desertification will also increase.

• Key concepts

Inter-Tropical Convergence Zone: a meandering zone of convergence of the northeast and southeast trade winds adjacent to the equator

salinization: accumulation of soluble salts in the soil, greatly reducing fertility

soil structure: the size of soil particles and their tendency to combine in lumps or clusters

stable air: air that resists convectional mixing and uplifting and in which precipitation is unlikely to occur *summer monsoon:* a summertime influx over a continent of unstable, rain-bearing air from over the ocean

unstable air: air that is readily susceptible to convectional mixing and uplifting, which often results in precipitation

winter monsoon: a wintertime, large-scale wind system that extends cool, dry, stable air from a continental interior over a large area

• Background

Desertification is a process of land degradation in arid and semiarid areas resulting from climatic variations and human activities. Degradation results from pressure from expansion of agriculture and livestock numbers, which make the land increasingly vulnerable to the impact of drought. Also, rising human populations have led people to farm on increasingly marginal land, which is even more at risk. The pressure on the land is such that, when drought occurs, the land degrades to the point that it is unable fully to recover.

• Characteristics of Desertification

Manifestations of desertification include a breakdown of soil structure, accelerated soil loss to wind and water erosion, an increase in atmospheric dust, a reduction in soil moisture-holding capacity, an increase in surface-water runoff and streamflow variability, salinization of soils and groundwater, and reductions in species diversity and plant biomass. The net result is a reduction in the overall productivity of dry-land ecosystems. This reduction leads to the impoverishment of human communities that are dependent on the land for survival.

The best examples of desertification are to be found in the Sahel region of Africa and the Rajasthan state of India, vulnerable areas on the borders of the Sahara and Thar Deserts, respectively. The underlying problem is poverty, which means few resources are available for managing the environment. Most of the people are subsistence farmers whose food supply is dependent on an adequate harvest each year. Farmers rely on summer monsoon rains. If one rainy season fails, people have very little in the way of stored food or money to see them through. The most vulnerable are the pastoralists, whose animals rapidly weaken and perish when there is nothing left to graze. Those animals that do survive will have stripped the land of vegetation so intensively that it may fail fully to recover when the rains eventually return.

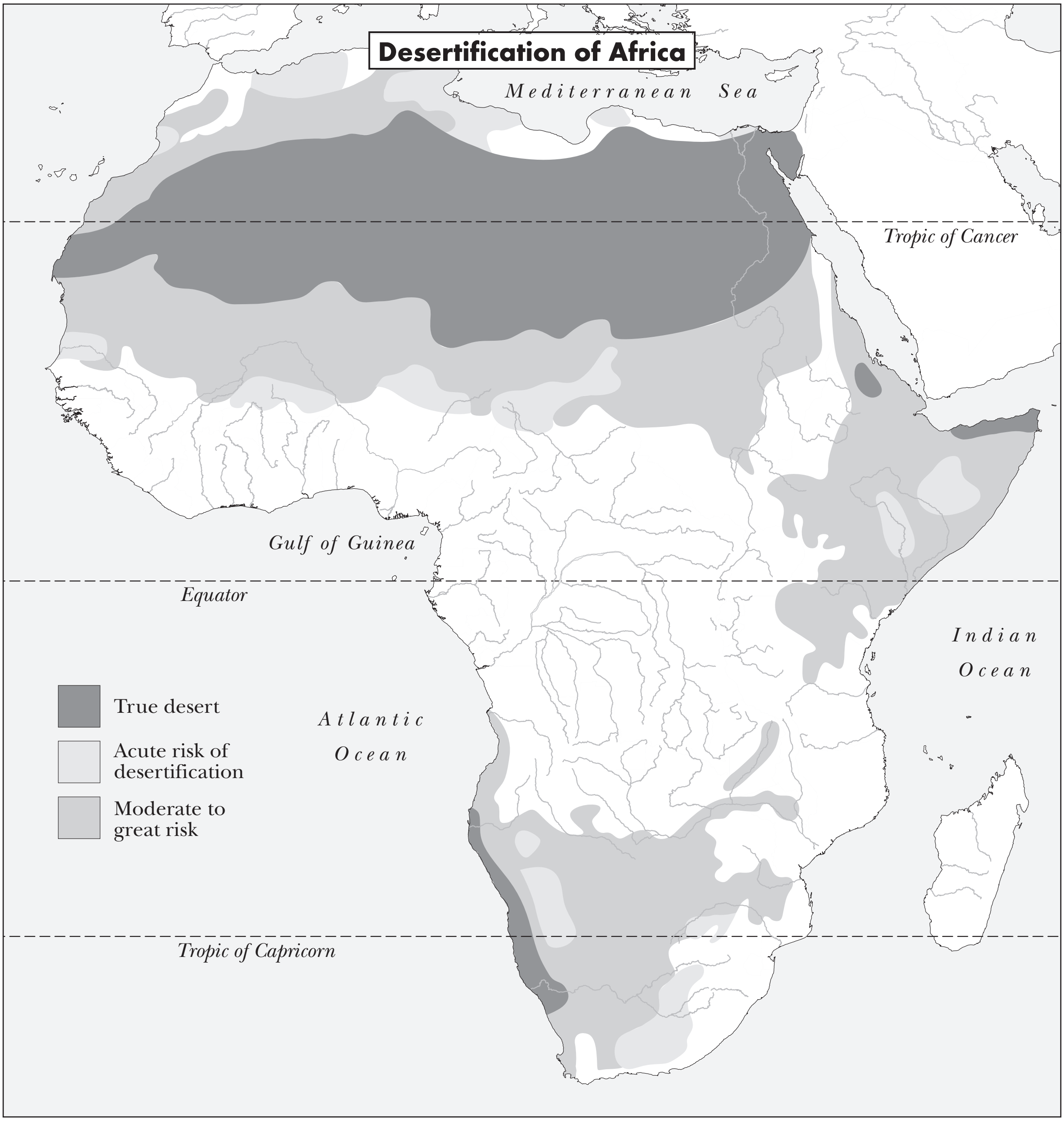
• Climatic Feedback Processes

The impact of drought is in some cases linked to feedback processes between the atmosphere and a land surface that is modified and used by the very population that is at risk. Stress on the land is not the sole cause of desertification, but it weakens an ecosystem's ability to withstand drought. It is an important part of the feedback chain. In wet years, there is often an expansion and intensification of grazing and cultivation of land that is otherwise marginal. Following a relatively dry year, excessive demands may be placed on the water stored in the soil. The soil will then dry, become susceptible to wind erosion, and eventually blow away. Even if the rains were to return, what soil remains would be washed away by sheet erosion and gullying. Most important, if such changes affect a large area, positive feedback processes to which localized climate is highly sensitive are set in motion, which accentuates existing anomalies in climate.

A key factor in the role of climate is stability of air. When the atmosphere is stable, upward motion of air is suppressed. Even in humid airstreams, rainfall will not occur unless stability is overcome. Subtropical high-pressure belts at about 30° latitude on either side of the equator are associated with masses of stable air. This air accounts for most of Earth's large areas of arid and semiarid climate. Rain occurs when the air in these high-pressure belts is displaced by the advance of unstable, rain-bearing oceanic air moving with the Inter-Tropical Convergence Zone (ITCZ). This movement of rain-bearing air is known as the summer monsoon. The Sahel and Rajasthan are at the northern edge of an area that experiences drought when the summer monsoon does not reach far enough north.

Earth's atmospheric pressure systems migrate with the seasons. Should the ITCZ advance north only a few degrees of latitude less than normal, large areas of the desert borderlands will experience a reduction in rainfall. If climate changes so that the norm is redefined and the northward movement of the rain-bearing air is frequently below the previous norm, the desert would expand southward. There are various theories as to how this expansion could come to pass.

One popular theory asserts that overgrazing of the land by livestock leads to loss of vegetation, resulting in bare soil being exposed to wind erosion. Large quantities of windblown dust in the atmosphere reduce the amount of solar radiation reaching and heating the land surface. Overgrazing also increases the land surface's albedo—that is, it causes the surface to reflect more incoming energy from the Sun compared with a vegetated surface.



This additional reflection of solar energy results in land cooling. Thus, overgrazing has multiple consequences that increase cooling and air stability, which effectively adds to the extent of the stable air of the subtropical high-pressure belt and erodes the northern edge of the advancing rain-bearing air of the summer monsoon. The dry conditions result in a further loss of vegetation, causing increased reflectivity and subsidence of dry air even further to the south, and so on in a cycle of positive feedbacks.

• Desertification and Climate Change

The Intergovernmental Panel on Climate Change (IPCC) has commented on the possibility of increased frequency of droughts in certain areas. If the vulnerable desert borderlands are among the regions affected, then desertification may be intensified. However, connections between anthropogenic increases in greenhouse gases (GHGs) in the atmosphere and changed drought frequency and intensity are only speculative, as climate models that are used to assess these connections have not been shown to be reliable. The level of scientific uncertainty and the existence of conflicting results are such that reliable predictions of future climate are not possible at this time.

• Context

Owing to the uncertainty surrounding scientists' understanding of the global climate, neither the trends in drought occurrence nor the interannual variability of droughts can be simulated reliably in global climate models. Despite this, projections have been made about future trends in precipitation extremes linked to increases in GHGs. Vulnerability will decline if drought frequency and intensity are reduced. The salient point is that there is no clear answer to the question of what will happen to trends in drought occurrence.

C R de Freitas

• Further Reading

Delville, Philippe L. *Societies and Nature in the Sahel.* London: Taylor & Francis, 2007. Explores the links between environmental and social systems that lead to desertification across sub-Saharan Africa.

Geist, Helmut. *The Causes and Progression of Desertification.* Burlington, Vt.: Ashgate, 2005. Examines desertification on the local and international scales and assesses the role of causal processes.

Middleton, N. *Global Desertification: Do Humans Cause Deserts?* Amsterdam, the Netherlands: Elsevier, 2004. Explores and assesses various possible causes of desertification.

Williams, M. A. J., and Robert C. Balling, Jr. *Interactions of Desertification and Climate.* London: Arnold, 1996. Comprehensive account of the interactions between desertification and climate.

See also: Agriculture and agricultural land; Albedo feedback; Climate feedback; Climate prediction and projection; Deserts; Drought; Dust storms; Sahara Desert; Sahel drought; Soil erosion; United Nations Convention to Combat Desertification.

Deserts

• **Category:** Environmentalism, conservation, and ecosystems

Deserts cover some 26.2 million square kilometers, or about 20 percent, of the Earth's land surface, mainly in the subtropical to midlatitudes. The importance of water to human and natural systems in deserts makes those systems very sensitive to climate changes affecting the amount, type, timing, and effectiveness of precipitation.

• Key concepts

drought: an extended period of months or years during which a region experiences a deficit in its water supply, mainly as a result of low rainfall

dune mobility index: a measure of potential sand mobility as a function of the ratio between the annual percentage of the time the wind is above the sand transport threshold and the effective annual rainfall

subtropical anticyclonic belts: a series of high-pressure belts situated at latitudes 30° north and south of the equator

• Background

Deserts are fragile environments, easily affected by natural and human disturbance. They are being affected by a rapidly growing and increasingly urban population that is dependent on scarce surface- and groundwater. The historical and observational record indicates the great natural variability of climates in these regions, including the occurrence of periodic severe and multi-decadal droughts.

• Causes of Deserts

Desert climates are characterized by low humidity (except in cool, foggy coastal deserts such as the Namib and Atacama), a high daily range of temperatures, and precipitation that is highly variable in time and space. The most extensive deserts lie astride the tropics. Solar heating in equatorial latitudes gives rise to rising moist air, which then condenses, loses moisture as tropical rainfall, cools, and descends away from the equator. As the air descends, it warms and becomes very dry. This descending, dry air in the subtropical anticyclonic belts maintains arid conditions throughout the year. The effects of stable air masses are reinforced in some areas by mountain barriers, which block moist air masses (for example, the Himalaya and other mountain ranges prevent the penetration of the southwest monsoon to the Gobi and Takla Makan Deserts of central Asia). Deserts located on the west coasts of South America and southern Africa (the Atacama and Namib) owe their hyperarid climates to the influence of cold oceanic currents offshore. These currents reinforce the subsidence-induced stability of the atmosphere by cooling surface air and creating a strong temperature inversion.

• Effects of Climate Change

The effects and potential effects of past and future climate change on deserts are many and are influenced by the topographic and climatic diversity of desert regions. Global climate models differ in their predictions of the direction and magnitude of future change in arid regions. In some areas—such as China, southeastern Arabia, and India—increased monsoon precipitation is predicted, but its effects may be offset by higher evaporation as a result of increased temperatures. In the Sahara Desert, there is support in many climate-model predictions for increased rainfall in the southern and southeastern areas (including the Sahel), but strong drying in the northern and western areas. Some models, however, suggest a strong drying throughout the region.

The differences between varioius models' predictions for the Sahara demonstrate the complexity of forcing factors in the region, as well as the possible influence of feedbacks between land-surface conditions and the atmosphere. Such feedbacks could affect rainfall total, effectiveness, and spatial distribution. Most of the interior of southern Africa is also predicted to become drier, leading to the mobilization of sand dunes in the Kalahari Desert, as well as severe impacts on surface and groundwater resources.

In the southwestern United States, higher temperatures are predicted to increase the severity of droughts. Some models indicate that the region may already be in transition to a new, more arid state as a result of anthropogenically influenced climate change. The economies of many desert regions (including Atacama, the American Southwest, Iran, western China, and southwest Asia) depend on runoff derived from winter snow in mountain areas for domestic use and irrigated agriculture. Higher temperatures are already reducing

Deserts and Climate Change

Likely effects of climate change upon deserts include but are not limited to:

- changes in the amount, type, and seasonal distribution of precipitation
- changes in the magnitude and frequency of extreme events such as dust storms, floods, wildfires, and periods of extended drought
- changes in the mobility of sand dune areas, including reactivation of vegetation-stabilized dunes
- vegetation change, including increased vulnerability to invasive species

the amount of snowpack and changing the timing and duration of spring runoff. More precipitation is falling as rain, leading to less natural storage and an increased risk of flooding. Such changes, if continued into the future, will require costly upgrades of water management systems and possibly a reduction in available water supply.

Many desert areas experienced significant increases in temperature and reductions in rainfall during the 1990's and early twenty-first century. During that time period, droughts occurred in the Colorado River Basin, Australia, southern Africa, Iraq, and Afghanistan. Sand dunes occupy up to one-third of the area of many desert regions. Dune mobility is a function of the ratio between wind strength and effective rainfall and is measured by the dune mobility index. Increased temperatures, accompanied by decreased rainfall, are predicted to lead to remobilization of vegetated sand dunes in the Kalahari and drier areas of the Australian desert.

The effects of climate change on vegetation patterns in desert regions is difficult to separate from anthropogenic disturbance. Increased levels of atmospheric carbon dioxide (CO_2) may increase plant productivity in arid regions. Higher CO_2 levels may also favor invasive exotic species such as cheat grass, with possible effects on fire regimes in the Great Basin Desert. Models that incorporate CO_2 fertilization of vegetation indicate a reduction in desert areas in the next century, introducing an additional level of uncertainty about the future of desert ecosystems.

• Context

The great natural variability of climatic conditions, especially the distribution of rainfall in space and time, presents challenges for the prediction of the response of desert regions to future climate change. However, the experience of recent drought episodes indicates that the natural and human systems of deserts and desert margin areas are highly susceptible to soil moisture deficits. Climate change is expected to decrease water availability in all desert regions, through increased temperatures, changes in the amount of precipitation, or a combination of both. The result will be increased pressure on existing water resources for human and ecosystem use, possibly leading to higher levels of conflict over scarce resources.

Nicholas Lancaster

• Further Reading

Ezcurra, E., ed. *Global Deserts Outlook.* Nairobi, Kenya: United Nations Environment Programme, 2006. A comprehensive and well-illustrated interdisciplinary overview of desert environments, their issues, and their problems, as well as challenges and opportunities for the future.

Goudie, A. S. *Great Warm Deserts of the World: Landscapes and Evolution.* New York: Oxford University Press, 2002. Provides basic information on the physical environment of low- and midlatitude deserts, from a geomorphological perspective.

See also: Desertification; Drought; Dust storms; Sahara Desert; Sahel drought; United Nations Convention to Combat Desertification.

Dew point

• Category: Meteorology and atmospheric sciences

• Definition

Dew point is the critical temperature at which a parcel of air will become saturated with water vapor if it is cooled at constant pressure and constant water vapor content. Dew point is a measure of humidity, or atmospheric vapor content, since the higher the dew point temperature of an air mass, the greater the water vapor content. Compared to warm air masses, cold air masses have smaller water-holding capacities and therefore lower dew points. Dew point is also related to evaporation and condensation. The closer the dew point is to actual air temperature, the lower the rate of evaporation. When actual air temperature cools to the dew point, condensation will occur.

- **Significance for Climate Change**

A rise in the concentration of greenhouse gases (GHGs) in the atmosphere makes available more energy at the Earth's surface. This additional energy could heat the atmosphere by way of the sensible heat flux, increasing temperature, or it could evaporate water at the Earth's surface via the latent heat flux, increasing humidity. The latter course of events would lead to higher dew points. When water is freely available, the latent heat flux will always dominate, meaning that energy otherwise available to heat the atmosphere will be used in the evaporative transpiration of moisture from the surface to the atmosphere.

Most of Earth's surface is either water (approximately 70 percent is occupied by oceans, seas, and lakes) or land that is well supplied with precipitation. Thus, most of the additional energy at the surface due to an increased concentration of GHGs in the atmosphere will enhance the latent heat flux. The resulting warming of the atmosphere would be less in this case than if all the additional available energy were accounted for by an increase in the sensible heat flux alone. Dew point would then rise accordingly.

Water vapor is by far the most important GHG in the atmosphere, so a rise in global dew point would add significantly to the greenhouse effect, leading to enhanced warming and further enhanced evaporation and transpiration, and so on. This self-reinforcing cycle is known as a positive feedback effect. On the other hand, a rise in dew point could result in increased cloudiness as moisture is added to the Earth's atmosphere. Clouds, especially low clouds, act to reflect incoming energy from the Sun, energy that would otherwise be absorbed at the Earth's surface. The result is to reduce the energy available for heating the air and for evaporation and transpiration of moisture. This negative feedback, or stabilizing effect, would only partially compensate for the warming effect of higher dew points.

C R de Freitas

See also: Greenhouse effect; Greenhouse gases; Humidity; Hydrologic cycle; Hydrosphere; Ocean-atmosphere coupling; Ocean dynamics; Water vapor.

Diatoms

- **Category:** Plants and vegetation

- **Definition**

Diatoms are ubiquitous, microscopic, golden-colored algae. The most distinctive characteristic of a diatom is its rigid cell wall. The cell wall is formed in two halves, with one half fitting inside the other as a shoebox fits its lid. This rigid, glassy wall containing silica is patterned with pores, variable thicknesses, and spine-like extensions projecting from its surface.

Once a diatom dies, its cell walls either dissolve into the water or fall to the bottom of the sea or lake, where they become part of its sediments. When large numbers of diatoms are present in a body of water, their cell walls tend to accumulate in the sediments. Large deposits of diatom cell walls have been found on land in areas that were once covered by seas. This material is mined as diatomaceous earth and is used commercially as a fine abrasive material or filtering agent.

The classification system for diatoms is based on two key features, the pattern of the cell wall and the shape of the cell. Two major groups are often distinguished: Pennate diatoms are typically bilaterally symmetrical, while radially symmetrical diatoms are known as centric diatoms.

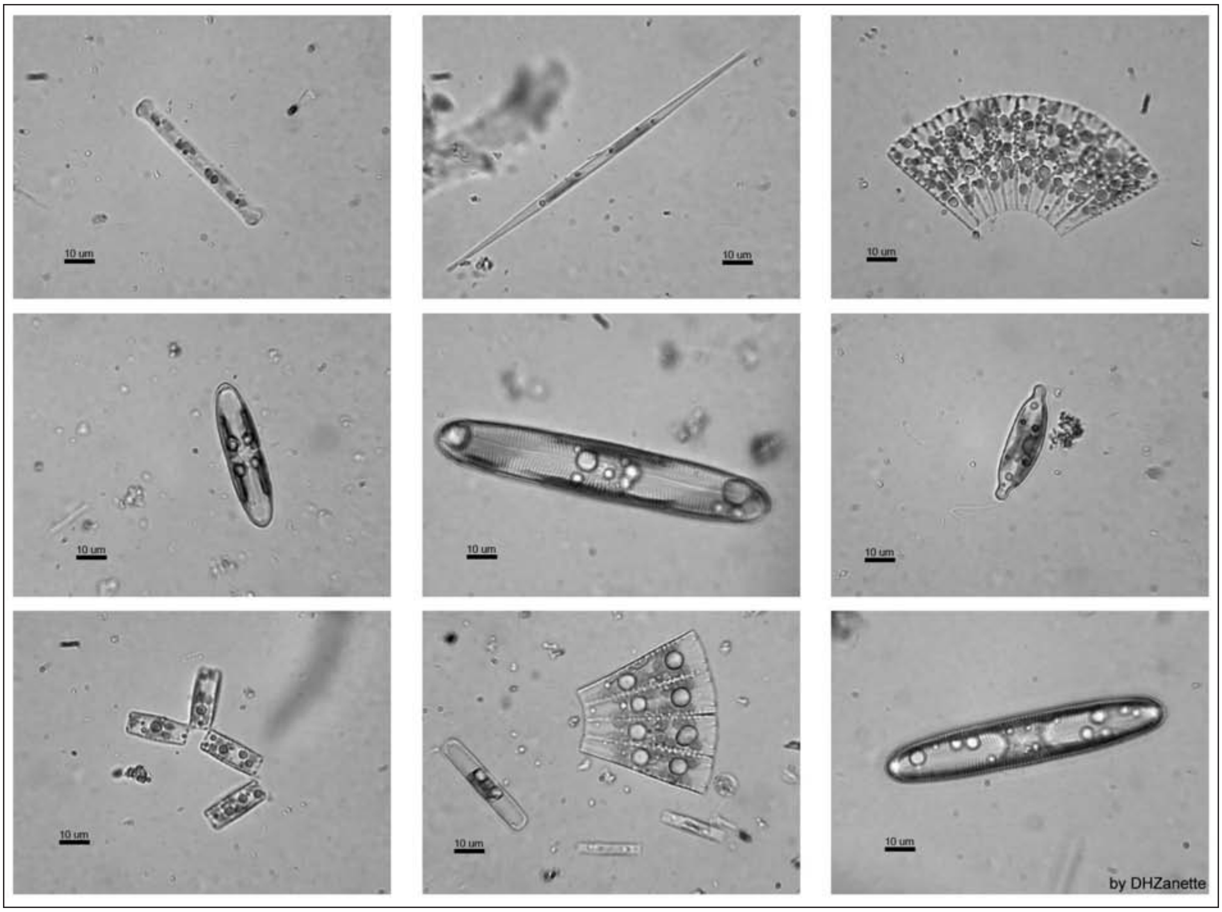
Although diatoms are found in most environments, these organisms are very important members of marine and freshwater ecosystems. As photosynthesizers, these tiny organisms harvest energy from the sun, fixing carbon dioxide (CO_2) into organic compounds that are used by the diatom and by organisms that consume the diatom. In this capacity, diatoms are at the first trophic level of the food chain, providing energy and organic compounds for the heterotrophic organisms in that ecosystem.

- **Significance for Climate Change**

Researchers have estimated that 20 to 25 percent of all carbon fixed on Earth via photosynthesis is fixed by planktonic marine organisms. In some oceans, diatoms are the most numerous members of the phytoplankton; in other areas, they are significant but not dominant. Through photosynthesis, diatoms also play a significant role in the carbon cycle, removing carbon from the atmosphere. The carbon may be made available to other organisms within the ecosystem, or it could be removed from the carbon cycle for millions of years as the dead diatoms become a part of the sediments.

Numerous environmental factors influence the growth of diatoms, including light, wind, currents, temperature, and available nutrients. The nutrients that most commonly limit growth of diatoms in aquatic environments are nitrogen, phosphorus, silicon, and iron. Since numerous factors affect the metabolism, growth, and reproduction of these organisms, the impact of climate change is likely to be complex and difficult to predict. It is unlikely that all environment factors would work in either a negative or a positive manner, so the end result is likely to be cumulative. Given the vital importance of diatoms to the local ecosystem and to the carbon cycle, it will be critical to monitor these organisms as changes occur.

Climate changes affecting diatoms could through them have a profound effect on the carbon cycle. Any factor that affects the rate of photosynthesis, the health, or the reproduction of these organisms would affect the role they play in the cycle. If there were a drastic decrease in the number of diatoms or a drop in their photosynthetic rates, less CO_2 would be removed from the air, ultimately resulting in warmer atmospheric conditions and contributing to global warming. On the other hand, massive



Microscopic images of diatoms. Despite their small size, these phytoplankton play a crucial role in Earth's carbon cycle. (DHZanette) blooms of these organisms could lead to more CO_2 being removed via both photosynthesis and greater sedimentation rates, resulting eventually in a cooler atmosphere. Using historical evidence, researchers have suggested that such changes in atmospheric CO_2 levels during the glacial periods were correlated with changes in diatom abundance and carbon fixation.

Some of the best evidence linking diatoms and climate change has come from research in Antarctica. Diatoms are the dominant photosynthetic organisms in the cool southern ocean and on the ice shelves at the edges of the continent. Researchers have found that these organisms produce a compound known as dimethyl sulfide (DMS). Once airborne, DMS can serve as a nucleus for water condensation to form clouds or be converted to sulfuric acid and return to the ground as acid rain. Changes in numbers of diatoms in these areas could result in changes in cloud and moisture patterns in the Antarctic.

At least one aspect of climate change has generated concern regarding diatoms in Antarctica. These organisms are being exposed to increasing amounts of ultraviolet (UV) radiation, as the ozone layer in this part of the world continues to thin. Laboratory studies have shown that diatoms suffer damage to their photosynthetic pigments and deoxyribonucleic acid (DNA) when exposed to UV radiation.

Changes in the number or photosynthetic activity of diatoms due to climate change could have significant effects on ecosystems where diatoms contribute significantly to the first trophic level of the food chain. Areas most likely to be affected are those where diatoms tend to dominate, such as in the open ocean. The impact of climate change to shoreline marine ecosystems or to freshwaters could be less significant, as these ecosystems tend to contain a greater diversity of photosynthetic organisms that contribute to the primary productivity of the system.

Joyce M. Hardin

- **Further Reading**

Amsler, Charles D., ed. *Algal Chemical Ecology*. Berlin: Springer, 2008. Reviews the production and role of secondary metabolites by micro- and macroalgae. Illustrations, figures, tables, bibliography, index.

Graham, Linda E., and Lee W. Wilcox. *Algae*. Upper Saddle River, N.J.: Prentice Hall, 2000. Reviews the major groups of algae and the interactions of algae with other organisms and the environment. Illustrations, figures, tables, bibliography, index.

Miller, G. Tyler, Jr., and Scott Spoolman. *Environmental Science: Problems, Concepts, and Solutions*. 12th ed. Belmont, Calif.: Brooks Cole, 2008. Provides an overview of environmental issues, including information on the sulfur and carbon cycles. Illustrations, figures, tables, bibliography, index, maps.

Stoermer, Eugene, and John P. Smol, eds. *The Diatoms: Applications for the Environmental and Earth Sciences*. New York: Cambridge University Press, 1999. Explicates the use of diatoms as indicators of environmental change in aquatic and extreme environments. Illustrations, figures, tables, bibliography, index, maps.

See also: Antarctica: threats and responses; Carbon cycle; Carbon dioxide; Carbon dioxide fertilization; Ocean life; Photosynthesis; Plankton; Sea sediments; Sequestration.

Diseases

- **Category:** Diseases and health effects

Climatic conditions that support the successful colonization of geographical locations by human societies also tend to support the populations of pests and pathogens associated with human diseases. Abrupt climate change can destabilize trends in the distribution of diseases in populations, as well as society's ability to cope with emerging pathogens and shifting demographic patterns.

- **Key concepts**

air quality: normal atmospheric constituencies, such as levels of particulate matter, elements, and toxins *disability-adjusted life years (DALYs):* a time-based quantitative measure of the burden of disease in a population that combines years of life lost to premature mortality and years of life lost to poor health or disability

heat wave: a long period of exceedingly hot, uncomfortable weather

pathogens: viruses, bacteria, protozoa, or other chemical or biological agents that can infect a human host to produce disease

vector-borne diseases: illnesses associated with pathogenic microorganisms whose transmission from an infected host to a new host is mediated by an insect or other agent (vector)

waterborne diseases: illnesses caused by pathogens that are transmitted through contaminated drinking water or contact with environmental waters

• Background

The most important factor in the emergence and proliferation of pathogens is the availability of susceptible hosts. Therefore, many pathogens have coevolved, not only with human biological constraints against disease, but also with socially developed constraints such as climate-controlled domiciles and disinfection. In the event of abrupt climate change, leading to excessive fluctuations in extreme weather conditions, there occurs a selection process that affects the microbial diversity of ecosystems, with some organism declining, whereas other organisms increase in population density. In addition, long-term climate change may forge new interactions among different organisms. When these biodiversity changes coincide with increasingly dynamic relocation of people in response to climatic events, epidemics can result from the resurgence of old diseases, emergence of new diseases, or exacerbation of preexisting disease conditions.

• Emergence of Climate Change as a Threat to Public Health

Seasonal trends in morbidity and mortality have long been understood by human societies. Such understandings have formed the basis of preventive health care plans in many countries. For example, preparation for the influenza (flu) season means massive vaccination campaigns during the months of September, October, and November. Similarly, respiratory conditions with no clear involvement of pathogenic agents, such as asthma and allergies, are known to follow seasonal patterns. Humans have, more or less, adapted to such seasonal inconveniences until they become so extreme to the extent that population migrations can occur. Outbreaks of contagious disease associated with scarce water supplies can destabilize communities or force local extinctions in human habitats. However, it has not been straightforward to project health impacts as part of the consequences of anthropogenic climate change.

In 1990, a World Health Organization (WHO) task group issued one of the early reports on the potential health effects of climate change. The group based its assessments on the scenario that global average temperature could increase by 3° Celsius by the year 2030; that sea level could rise by 0.10-0.32 meter; and that ultraviolet radiation, mainly UV-B, is expected to increase by a maximum of 20-25 percent in the same period. Based on these conditions, the task group anticipated both direct and indirect effects of climate change on human health.

The direct effects include those associated with thermal factors (heat disorders) and the effects of UV radiation on the incidence of skin cancer, immune response, eye function, and air quality. Indirect effects of climate change on human health are expected to include impacts on food production and nutrition, on wildlife and biodiversity, and on communicable diseases through effects on disease vectors and the incidence of infectious diseases that are not associated with specific vectors. In addition, indirect impacts of climate on health include the repercussions of human migration.

In 1997, responding to a request from the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC), Working Group II of the Intergovernmental Panel on Climate Change (IPCC) published a special report on the assessment of vulnerability in the regional impact of climate change. The Conference of the Parties (COP) to the UNFCCC needed information on the degree to which human conditions and the natural environment are vulnerable to the potential effects of climate change, but the regional assessment approach adopted by the IPCC revealed wide variation in the vulnerability of different populations, especially in the health sector. Different levels of vulnerability exist under similar climate and pathogen distribution patterns because of local economic, social, and political conditions, as well as the level of dependence on resources sensitive to climate variability. Therefore, instead of producing quantitative predictions of the impacts of climate change for each region, the IPCC took the approach of assessing regional sensitivities and vulnerabilities.

The adoption of "Weather, Climate, and Health" as the theme of the 1999 World Meteorological Day signified the convergence of global issue-framing strategies with the health impacts of climate change. This event emerged after more than a decade of policy formulation and scientific assessment activities by the WHO, the IPCC, and the World Meteorological Organization (WMO). Following the progress made by WHO researchers during the 1990's toward the development of quantitative methods for assessing the global burden of disease, it became possible to compare or project into the future the disease burden associated with specific risk factors such as climate change. Composite measures of disease burden such as disability-adjusted life years (DALYs) account for both mortality and morbidity, and are particularly suitable for evaluating risk factors with a broad range of disease end points. For example, in 2004, WHO estimated that global climate change accounts for approximately 5.5 million DALYs lost directly, but exacerbation of disease conditions associated with the creation of unsanitary conditions could result in a lot more DALYs lost. Not surprisingly, children younger than five years are particularly vulnerable.

To cap the evolution of health effects as a dominant frame of reference for the threats associated with climate change, in May 2008, the 193 member countries represented at the World Health Assembly adopted a resolution to protect public health from impending global climate change. This event signaled a much higher level of commitment from the health sector to strengthen the evidence for anthropogenic climate change and to better characterize the risks to public health at the regional and global levels.

• Diseases Associated with Climate Change

Communicable diseases. Vector-borne diseases, such as malaria, have dominated research on the impacts of climate change on public health. The rationale behind these studies is that increases in temperature and rainfall would support the proliferation of mosquito vectors and their ability to incubate disease-causing protozoa, leading to more infections. According to WHO, malaria infects 400 to 500 million, killing approximately 2 million people annually. Although the rate of morbidity and mortality associated with malaria in endemic zones might intensify, the real fear associated with climate change is that malaria zones will expand toward the temperate regions that have hitherto been free of the parasite. There is spotty evidence of recent incidences of malaria in Europe and North America, but it is not clear that these cases are not associ-

A swampy area in Thailand with a high rate of malaria transmission. If global warming increases the number of such areas, the global malaria-transmission rate will increase accordingly. (AP/Wide World Photos) ated with population migration, which has led to the coining of the phrase "airport malaria." Nonetheless, a Roll Back Malaria initiative was launched in 1998 by the WHO, the United Nations Children's Fund (UNICEF), the United Nations Development Programme (UNDP), and the World Bank to provide a coordinated global approach against malaria, including scenarios associated with the influence of climate change. The IPCC predicted in 2007 that under certain climate change scenarios, the global population at risk from vector-borne malaria will increase by between 220 million and 400 million in the next century.

Other vector-borne diseases that are of concern with respect to climate change include lymphatic filariases, which are also transmitted through tropical mosquitoes, typically in urban slums. The geographical zone of these diseases may expand with increasing average global temperature, but good urban planning and hygienic conditions can limit the impact of the diseases on society. This scenario is expected to be similar for other climate-sensitive vector-borne diseases such as onchocerciasis (vector: African black fly, *Simulium damnosum*), schistosomiasis (vector: water snails such as *Biomphalaria glabrata*), African trypanosomiasis (vector: tsetse flies, *Glossina palpalis gambiensis*), leishmaniasis (vector: sandfly, *Phlebotomus* species), and dracunculiasis (vector: waterborne copepods such as *Mesocyclops leuckarti*).

Incidences of bacterial diseases that are transmitted through ticks and body lice (tick-borne relapsing fever caused by several species of spiral-shaped bacteria; tularemia, caused by *Francisella tularensis*; and louse-borne relapsing fever, caused by *Borrelia recurrentis*) are also considered to be sensitive to climate change, primarily because of the well-defined ecological conditions that support the proliferation of the vectors. Arboviral diseases also represent a major category of potentially climate-sensitive communicable diseases that can change from endemic to epidemic forms, given favorable environmental conditions. These diseases include dengue/hemorrhagic fever (caused by *Flavivirus*), Rift Valley fever (*Phlebovirus*), and Japanese encephalitis and St. Louis encephalitis (caused by viruses in the family *Flaviviridae*).

Finally, waterborne diseases that are not clearly associated with vectors have also been linked to climate change. Diarrheal diseases are at the forefront in this category that includes bacterial (for example, *Vibrio cholera*) viral (for example, Norwalk virus), and protozoan (for example, amebic dysentery) causes. Together, these diseases account for a large portion of the global burden of diseases that disable or kill children younger than five years in developing countries. The association with climate change is that in cases of drought, people tend to use contaminated sources of water, and in the absence of reliable disinfection programs, the incidence of these diseases will increase. In addition, natural disasters such as floods, hurricanes, and earthquakes can damage water supply and sewage treatment infrastructures in developed countries, leading to the contamination of potable water supplies that can increase the incidence of waterborne diseases. Hence emergency public health preparedness is a major category of planned adaptation to climate change.

Noncommunicable diseases. Heat-related diseases are the most researched category of noncommunicable diseases that have been associated with climate change. During the summer season, the frequency of extreme heat waves is predicted to increase. For example, the IPCC predicted in 2007 that the cities of Chicago and Los Angeles will experience up to 25 percent more frequent heat waves and a fourfold to eightfold increase in heat wave days by the year 2100. Based on current estimates of morbidity and mortality associated with prolonged periods of extreme heat, people with preexisting conditions such as heart problems, asthma, the elderly, the very young and the homeless will be more vulnerable. In contrast, it is also likely that under certain climate change scenarios, warmer temperatures will prevail during the winter months, leading to fewer cases of death and disability from hypothermia.

Climate change is also expected to adversely affect air quality, especially in urban areas where higher temperatures may increase the concentrations of respirable particulate matter (smaller than 2.5 micrometers) and the concentration of tropospheric ozone, which can be especially dangerous for people suffering from asthma and other chronic pulmonary diseases.

- **Context**

Motivating action around climate changes requires framing the issue in ways that command attention. Linking climate change to public health impacts continues to be one of the most cogent framings that have engendered research and policy questions about societal preparedness and adaptation. Ultimately, morbidity and premature mortality represent the crucial end points of most scenarios of climate change impacts. Most people are afraid of contracting diseases that were previously unknown in their communities, or for which there are no known cures. Many of the tropical diseases associated with climate change fall in these fearsome categories. However, it is also becoming increasingly clear that many of the diseases associated with climate change are preventable through well-known public health approaches, but these approaches require economic resources that may not be available to the most vulnerable populations across the world. Therefore, the roles of international organizations such as the WHO and its supporting agencies are crucial in global assessments of disease burden and future projections of climate-sensitive diseases, and in building capacity for adaptation in vulnerable societies.

Oladele A. Ogunseitan

- **Further Reading**

Campbell-Lendrum, Diarmid, and Rosalie Woodruff. *Climate Change: Quantifying the Health Impacts at National and Local Levels.* Environmental Burden of Disease 14. Geneva: World Health Organization, 2007. Provides comprehensive estimates of the disease burden associated with the impacts of climate change, based on WHO composite measures, including DALYs.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Martin Parry et al. New York: Cambridge University Press, 2007. The IPCC Working Group II assesses the scientific evidence linking climate to health impacts, describes vulnerable populations, and suggests strategies for adaptation.

Ogunseitan, Oladele A. "Framing Environmental Change in Africa: Cross-Scale Institutional Constraints on Progressing from Rhetoric to Action Against Vulnerability." *Global Environmental Change* 13 (2003): 101-111. Assesses the state of knowledge about health support systems and identifies impediments to the development of policies that can protect the most vulnerable populations from climate change.

See also: Asthma; Health impacts of global warming; Skin cancer; World Health Organization.

Displaced persons and refugees

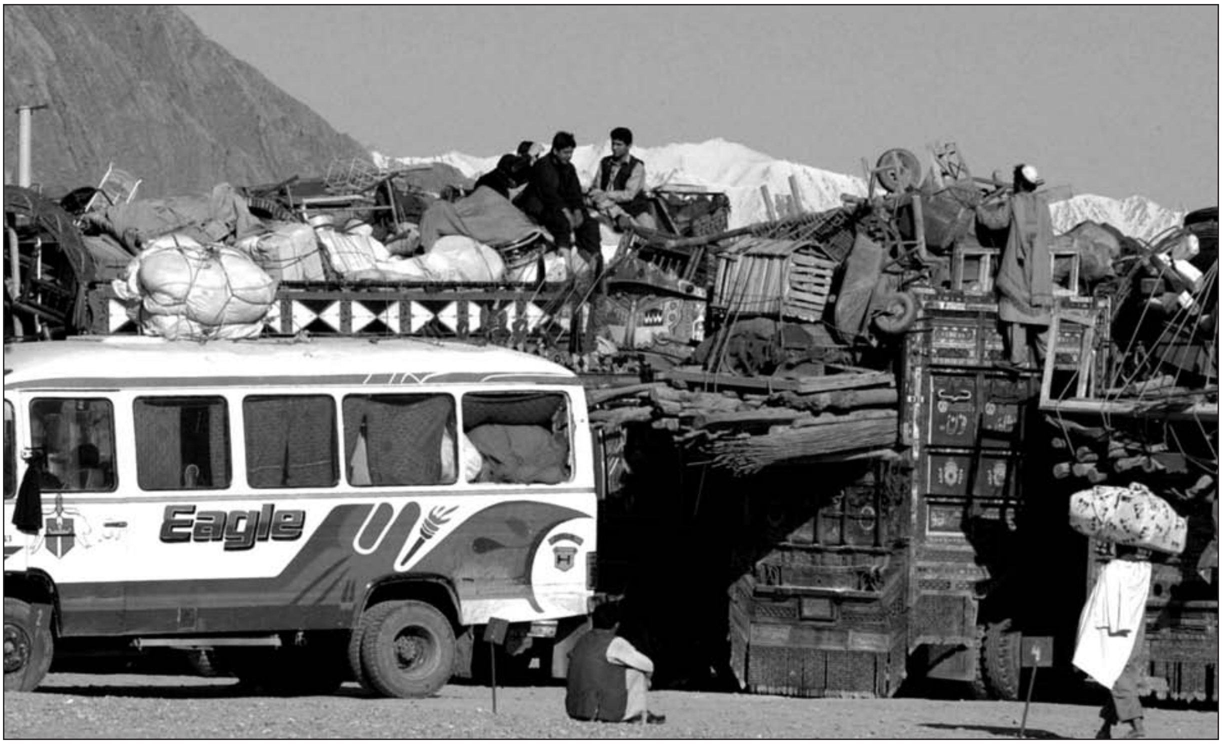
- **Category:** Ethics, human rights, and social justice

- **Definition**

Humans have always migrated in response to climatic changes, and a rapid global climate change in the twenty-first century would be no exception. In some parts of the world, climate change may make the environment inhospitable or unsuitable for human habitation, leading to exodus of the affected populations.

People who migrate for climatic reasons are sometimes referred to as "climate refugees." However, refugees, as defined by the 1951 U.N. Refugee Convention, are those who flee their home country under justified fear of persecution due to their religion, ethnicity, nationality, or social or political affiliation. Migrants fleeing the effects of climate change do not usually fit this definition. Rather, they fall into the broader category of displaced persons, those who migrate internally or internationally to escape intolerable conditions such as civil strife, economic collapse, or land degradation. Such movement is termed "forced migration."

Climate change can cause forced migration in several different ways. Perhaps the most obvious is sea-level rise, which can obliterate homes, communities, and entire countries. Climate-related natural disasters such as hurricanes and floods can also



Afghani refugees, who had been driven from their country by drought and warfare, wait to return home. If drought becomes more common, it will displace more people globally. (AP/Wide World Photos)

necessitate permanent migration. "Slow disasters," such as drought, desertification, and glacier loss, may gradually render an area uninhabitable. Finally, violent conflict may arise from climate-induced resource scarcity.

- **Significance for Climate Change**

International law confers refugee status only upon those who cross international borders to flee violent persecution. Climate "refugees" who are internally displaced, and those who are escaping nonviolent conditions, currently have no formal recourse to international aid. However, many countries and organizations have begun to acknowledge the need for a concerted response to climate-induced migration.

An impending problem with no legal precedent is the disappearance of an entire country due to sea-level rise, leaving the citizens of that country stateless. With projected rates of sea-level rise, several island states will lose their entire territory within the twenty-first century. One such country is Tuvalu, from which citizens have already begun evacuating. Although other countries have no legal obligation to accept Tuvaluan migrants, New Zealand has formally invited them since 2001 (at the rate of 75 per year). Australia has declined to enter into a similar agreement. Tuvalu Overview, a Japanese NGO, has sought to call attention to Tuvalu's plight—and that of other small island states—by documenting the life of each of Tuvalu's ten thousand citizens in photos and stories.

Other climate-related causes of human migration—such as floods, droughts, storms, and land degradation—are even more ambiguous in their legal implications, since these events cannot be definitively attributed to climate change. The Office of the United Nations High Commissioner for Refugees (UNHCR) has expressed concern about the impending problem of populations displaced by climate change, but its mandate does not extend to most of those populations. New legal and humanitarian arrangements may prove necessary. Since attribution of blame will often be difficult or impossible, the best solution may be voluntary aid from nations that have the resources to assist.

The number of people likely to migrate because of climate change is highly uncertain. Predictions of such migration over the next century vary from a few tens of millions of people (mainly due to the direct effect of sea-level rise) to over a billion people (due to drought, crop failure, storms, conflict, and other indirect effects). More accurate estimates are needed to help institutions prepare for the likely consequences.

Despite the great uncertainties surrounding climate-related forced migration, there is a general consensus that developing countries will be the most negatively affected. This is due to their greater climatic vulnerability, their lower adaptive capacity, and the fact that they already host most of the world's displaced persons and refugees. However, vigorous adaptation efforts may be able to prevent the most serious consequences of climate change and reduce the need for migration. There will still be instances of unavoidable migration, such as disappearance of a country below sea level, in which case strengthened institutional and legal frameworks will be needed to help resettle the affected population as promptly and equitably as possible.

Amber C. Kerr

• Further Reading

Black, Richard. "Forced Migration and Environmental Change: The Evidence." Chapter 2 in *Refugees, Environment, and Development.* New York: Addison Wesley Longman, 1998. Discusses the evidence for and controversies surrounding environmental causes of forced migration, including natural disasters, desertification, and sea-level rise.

Reuveny, Rafael. "Climate Change-Induced Migration and Violent Conflict." *Political Geography* 26 (2007): 656-673. Reviews thirty-eight case studies of climate-related migration, concluding that climate and other environmental factors can catalyze violent conflict, especially in the developing world.

Salehyan, Idean. "From Climate Change to Conflict? No Consensus Yet." *Journal of Peace Research* 45, no. 3 (May, 2008): 315-326. Urges pursuit of adaptation efforts to forestall potential conflicts and rejects the notion that climate change will inevitably cause political violence.

United Nations High Commission for Refugees. "Climate Change, Natural Disasters and Human Displacement: A UNHCR Perspective." Geneva, Switzerland: Author, 2008. Outlines UNHCR's role in tackling the problem of climate-induced displacement, asserting that "refugee" is often the wrong term for these displaced persons.

Unruh, Jon D., Maarten S. Krol, and Nurit Kliot, eds. *Environmental Change and Its Implications for Population Migration.* Dordrecht, the Netherlands: Kluwer Academic, 2005. Based on 2001 workshop proceedings, this book includes overview chapters and topic-specific chapters on technical, legal, and economic aspects of environmentally induced migration.

See also: Coastline changes; Islands; Sea-level change; Tuvalu.

Dolphins and porpoises

• Category: Animals

• Definition

Dolphins and porpoises are aquatic, carnivorous mammals found worldwide from polar to tropical waters. Most species are marine, with a few having freshwater populations, but only the Indian River dolphin (*Platanista gangetica*), La Plata River dolphin (*Pontoporia blainvillei*), and the Yangtze River dolphin (*Lipotes vexillifer*) are strictly relegated to freshwater habitats.

The term dolphin can be used to refer to the Odontoceti (toothed whales), but here it will be used to refer to the dolphin family Delphinidae (approximately thirty-six species), the four families of river dolphins (one species apiece), and the porpoise family Phocoenidae (six species). Taxonomic uncertainty makes the exact number of species an open question.

Dolphins and porpoises face a variety of threats, including targeted hunting, entanglement in fishing gear, pollution, disease, habitat degradation, water diversion, acoustic disturbance, and competition with fisheries. The 2008 IUCN Red Lists identify twenty-three of forty-eight species and subspecies of dolphins and porpoises as threatened, and extensive surveys suggest that the Yangtze River dolphin is almost extinct.

• Significance for Climate Change

Global warming is expected to induce biogeographic range shifts in dolphins and porpoises, as water temperature is often a good predictor of the presence of these species. For example, off the coast of Scotland an increase in the number of warm-water species since the 1980's was coincident with an increase in water temperatures over the same period, while the abundance of cold-water species diminished. Around the British Isles in general, the white-beaked dolphin (*Lagenorhynchus albirostris*) prefers colder waters, and the short-beaked common dolphin (*Delphinus delphis*) prefers warmer waters. If these waters warm further, the short-beaked dolphin could expand its range at the expense of the white-beaked dolphin.

On global scales, the diversity of whales (including dolphins and porpoises) in deep water is maximum at sea surface temperatures of 21° Celsius, which occur commonly at midlatitudes. When applied to warming scenarios for the next few decades from the Intergovernmental Panel on Climate Change, these results suggest that biogeographic ranges would shift so that the diversity of whales in the tropics would decline while the diversity in higher latitudes would increase.

Climate change could induce range shifts in dolphins and porpoises by affecting species lower in the food web and thereby making preferred food items less abundant. This could also change competitive relationships between species. For instance, the 1982-1983 El Niño-Southern Oscillation event caused a reduction in squid off of California and coincided with the displacement of short-finned pilot whales (*Globicephala macrorhynchus*) by Risso's dolphins (*Grampus griseus*), which are able to dive more deeply to obtain scarce prey.

Climate change might also fragment dolphin and porpoise populations, which has implications for genetic diversity and generally reduces population persistence. For instance, water diversions for shipping and irrigation have already fragmented the populations of the three freshwater river dolphins. If precipitation patterns change, so too could the demand for water withdrawals and impoundments, meaning that the ranges of these species could become further fragmented. Climate change could also fragment marine populations. For example, warming could enhance the degree to which the warm-water current flowing through the Bay of Biscay divides northern and southern

Three dolphins await a postmortem examination after becoming stranded and dying in a river creek in Cornwall, England. (Barry Batchelor/PA Photos/Landov) populations of the harbor porpoise (*Phocoena phocoena*).

Ocean acidification, a result of carbon dioxide (CO_2) dissolving into marine waters, could affect the food supply of dolphins and porpoises. Dolphins and porpoises are often the top predators in food webs based on organisms that have calcium carbonate ($CaCO_3$) body structures, which are susceptible to dissolution in acidified waters. For example, the pantropical spotted dolphin (*Stenella attenuata*) consumes pteropods, which are known to be sensitive to acidification. Moreover, many species of fish that are prey to dolphins and porpoises are dependent on coral reef habitats, which are susceptible to warming-induced bleaching and decalcification from acidification.

Another consequence of ocean acidification is that acidified water absorbs sound less effectively, making the environment "noisier." Dolphins and porpoises depend upon echolocation to locate prey, discern their environment, and locate one another. Many species already suffer from acoustic disturbances caused by boat traffic, seismic exploration, and military exercises which can propagate tens of kilometers underwater, and such disturbances are associated with behavioral changes, strandings, internal injury, and death. Deep water and waters at high latitudes are expected to be especially affected since the acidification reaction is temperature-dependent.

Global warming could exacerbate the threats of disease and pollution. Warmer temperatures and shifting currents are expected to extend the range of disease-causing agents. For example, warmer temperatures are associated with outbreaks of the bacterium *Vibrio* known to infect dolphins. Climate change might also influence the frequency and severity of harmful algal blooms.

Adam B. Smith

• Further Reading

Burns, William C. G., and Alexander Gillespie, eds. *The Future of Cetaceans in a Changing World.* Ardsley, N.Y.: Transnational, 2003. Collection of twelve essays on current and future threats to whales and on international organizations and conventions designed to manage and ameliorate these threats.

Culik, Boris M. *Review of Small Cetaceans: Distribution, Behavior, Migration, and Threats.* Bonn, Germany: United Nations Environment Programme/Convention on Migratory Species Secretariat, 2004. Review, illustrations, and range maps of almost all toothed whales, including dolphins and porpoises. Each species is described in an essay detailing its conservation status, distribution, and behavior.

Reeves, Randall R., et al., comps. *Dolphins, Whales, and Porpoises: 2002-2010 Conservation Action Plan for the World's Cetaceans.* Gland, Switzerland: International Union for Conservation of Nature, 2003. A detailed account of conservation actions and research required to address threats to many species of small whales.

Soulé, Michael E., Elliot A. Norse, and Larry B. Crowder. *Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity.* Washington, D.C.: Island Press, 2005. Twenty-five essays on conservation of marine species, including issues germane to small cetaceans, such as pollution, algal blooms, fisheries, and synergy of threats.

See also: El Niño-Southern Oscillation; Maritime climate; Ocean acidification; Ocean life; Whales.

Downscaling

- **Category:** Science and technology

• Definition

Downscaling is a technique for applying information derived from larger-scale models or data analyses to smaller-scale models. In the context of global warming research, downscaling is used to link large-scale atmospheric variables with local climates. Global climate models, also known as general circulation models (GCMs), are data-rich, three-dimensional computer models of the climate mapped on a grid. GCMs employ variable atmospheric data to make estimates of future climate change on a global, hemispheric, or continental scale. Their resolution is generally about 150 to 300 kilometers by 150 to 300 kilometers. However, smaller-scale, local models require data at scales of 10 to 100 kilometers. To translate the larger-scale information to a regional scale requires downscaling into higher spatial and temporal resolution grids. With this finer resolution, the effect of subgrid topographical features such as clouds, mountain ranges, and wetlands can be incorporated. There are two main methods of downscaling: dynamical downscaling and statistical, or empirical, downscaling.

- **Significance for Climate Change**

Downscaling is an important tool for the study of anthropogenic climate change caused by increased carbon dioxide (CO_2) emissions. GCMs allow for predictions of large-scale climate change based on assumed patterns of greenhouse gas (GHG) emissions and other impacts. However, this scale can lack accuracy for regional and sub-regional models where differences in climate occur at a scale below GCM resolutions. Downscaling is used to make more accurate predictions at this local-to-regional scale.

Downscaling has been used in atmospheric forecasting for several decades. In dynamical downscaling, limited area models (LAMs) and regional climate models (RCMs) are nested into GCMs using GCM data as boundary conditions. In statistical downscaling, statistical relationships are calculated between factors simulated by the GCM at the large-scale level and variable data measured at the local level, such as rainfall occurrences and surface air temperatures. Dynamical techniques produce more data but are computationally expensive and depend on the accuracy of the GCM grid-point data used to calculate boundary conditions.

Dynamical downscaling has been used, for example, to calculate the number of extreme temperature days per year, as well as changes in their distribution. Such data can then be used to calculate the increased drought risk in dry climate areas, such as prevail in Australia and New Zealand. Statistical downscaling has been used, for example, to chart projected temperature ranges in various regions through the remainder of the twenty-first century, as well as mean monthly temperatures and precipitation. A combination of dynamical and statistical methods will probably obtain the best results in the future, allowing local planners to better adapt strategies and policies for coping with climate changes in their regions.

Howard Bromberg

See also: Bayesian method; Climate models and modeling; Climate prediction and projection; General circulation models; Parameterization.

Drought

- **Categories:** Meteorology and atmospheric sciences; environmentalism, conservation, and ecosystems

Many parts of the world are expected to suffer more frequent, more widespread, and more severe droughts as a result of climate change. Drought will likely be one of the most significant impacts of climate change on ecosystems and human society, but adaptation can lessen its effects.

- **Key concepts**

agricultural drought: lack of sufficient soil moisture for crop growth, leading to partial or total loss of yield

El Niño-Southern Oscillation (ENSO): a periodic fluctuation in Pacific sea surface temperatures, causing an alternating pattern of above- and below-average precipitation on either side of the Pacific

hydrologic drought: significantly below average water levels in lakes, rivers, reservoirs, and aquifers

megadrought: a drought lasting for years, decades, or centuries, often leading to permanent changes in ecosystems and human societies

meteorological drought: prolonged deficiency of precipitation in an area, as compared to the historical average

socioeconomic drought: a drought severe enough to cause disruption to human societies and economies

• Background

A drought is a period when the water supply of a given area is insufficient for the needs of humans or of ecosystems, usually resulting from below-normal precipitation. If defined simply as a precipitation deficit, such an event is called a meteorological drought. If a drought depletes soil moisture and harms crops, it is an agricultural drought. Eventually, lack of precipitation will diminish water levels in lakes, rivers, and aquifers; this is a hydrological drought. If a drought affects human well-being, it can be called a socioeconomic drought. These categories overlap, and there are many other ways to define droughts based on their causes or effects.

• Causes and Effects of Drought

Precipitation patterns result from large-scale atmospheric and oceanic processes, which in turn are affected by solar forcing, atmospheric composition, land-surface characteristics, and other factors. Scientific understanding of these processes is imperfect but improving; for example, in the 1980's, it was discovered that a cyclical variation in Pacific sea surface temperature called the El Niño-Southern Oscillation (ENSO) has a profound effect on rainfall around the world. Paleoclimate records show that short- and long-term rainfall fluctuations are common and predate human history, though the causes are often unclear.

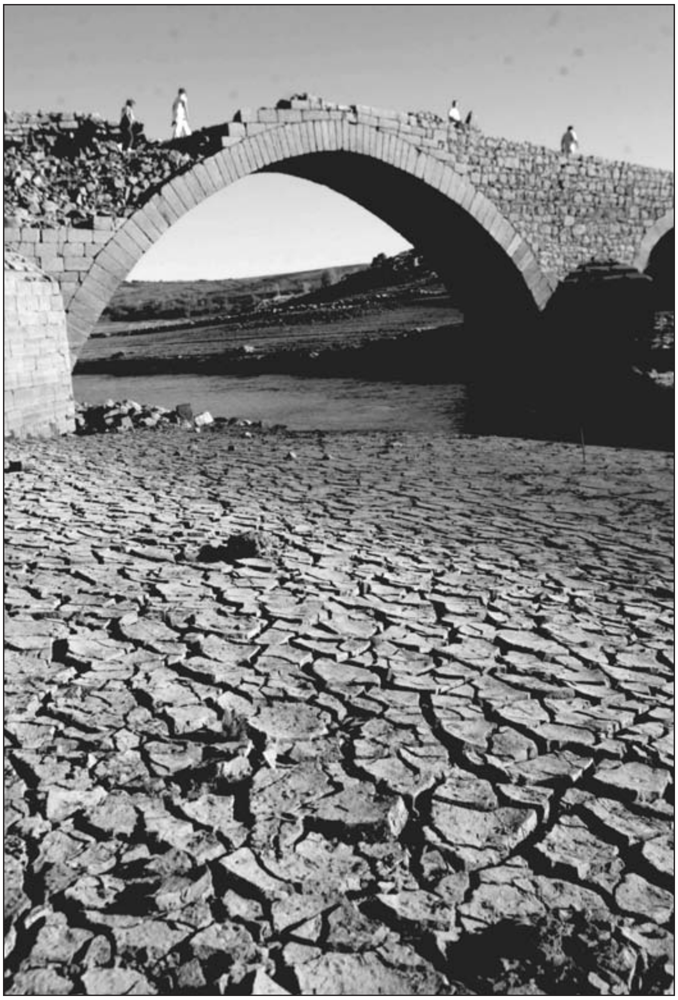
Another important cause of drought is above-average temperatures, which increase evaporation and hasten loss of soil moisture. Warm temperatures can also cause precipitation to fall as rain instead of snow, causing it to run off rather than being stored and gradually released. Human land use, such as deforestation or poor soil manage-

A Time Line of Historic Droughts

1270-1350	SOUTHWEST: A prolonged drought destroys Anasazi Indian culture.
1585-1587	NEW ENGLAND: A severe drought destroys the Roanoke colonies of English settlers in Virginia.
1887-1896	GREAT PLAINS: Droughts drive out many early settlers.
1899	INDIA: The lack of monsoons results in many deaths.
1910-1915	SAHEL, AFRICA: First in a series of recurring droughts.
1933-1936	GREAT PLAINS: Extensive droughts in the southern Great Plains destroy many farms and create the Dust Bowl during the worst U.S. drought in more than 300 years.
1968-1974	SAHEL, AFRICA: Intense period of drought; 22 million affected in four countries, 200,000-500,000 estimated dead, millions of livestock lost.
1977-1978	WESTERN UNITED STATES: Severe drought compromises agriculture.
1981-1986	AFRICA: Drought in 22 countries, including Angola, Botswana, Burkina Faso, Chad, Ethiopia, Kenya, Mali, Mauritania, Mozambique, Namibia, Niger, Somalia, South Africa, Sudan, Zambia, and Zimbabwe, results in 120 million people in 22 countries affected, several million forced to migrate, significant loss of life and of livestock.
1986-1988	MIDWEST: Many farmers are driven out of business by a drought.
1986-1992	SOUTHERN CALIFORNIA: Drought brings increased water prices, loss of water for agricultural production, water rationing.
1998	MIDWEST: Drought destroys crops in the southern part of the Midwest.
1999	LARGE PART OF UNITED STATES: Major drought strikes the Southeast, the Atlantic coast, and New England; billions of dollars in damage to crops.
Beg. 2006	WESTERN UNITED STATES: Drought-induced wildfires cause significant property and environmental damage in both urban and rural areas.

ment, can contribute to drought. Droughts may have multiple causes; for example, the 1930's Dust Bowl event in the U.S. Great Plains was a result of both meteorological drought and erosion-prone farming techniques.

Drought has both direct and indirect effects. The direct effects most relevant to human well-being include reduced water supply (both in quantity and quality); crop failure, especially of rainfed crops; loss of livestock; soil degradation, such as through dust storms and desertification; death of forests, often resulting in wildfires; and electricity shortages (if hydropower is used). These effects, in turn, can have profound consequences for human society, including mortality (due to starvation, thirst, fire, or dust); large-scale migration, often to urban centers; economic depression and entrenchment of poverty; and, under very adverse conditions, violent conflict. Ecosystems can usually survive and may even benefit from periods of drought; however, an especially severe drought may cause biodiversity loss and long-term disruption of ecosystem processes.



This bridge in northern Spain, shown in the midst of a severe drought in October, 2005, is normally submerged in the Pisuerga River. (AP/Wide World Photos)

• Effects of Climate Change on Drought Patterns

There is general agreement that climate change is likely to worsen droughts worldwide, but the location, timing, and magnitude of these effects are highly uncertain. Averaged globally, climate change will increase precipitation by speeding ocean evaporation. However, rising temperatures will affect oceanic and atmospheric circulation patterns, changing the global distribution of rainfall. Some regions will become wetter; others, drier. Even in regions where total precipitation does not decrease, drought risk may increase as a result of faster land-surface evaporation, loss of water stored in snow and ice, and greater variability of precipitation events (causing not only droughts but also floods).

Climate models generally agree that several regions of the world are likely to suffer from decreased precipitation and increased drought risk under future climate. These regions include the Mediterranean (southern Europe and northern Africa); southern Africa, especially its southwest corner; the southwestern United States; parts of Central America; and southern Australia. Semiarid and arid regions will probably be hardest hit by drought, with subsistence farmers in developing countries being especially vulnerable. In addition, climate change may cause water shortages wherever populations depend upon glaciers or snowmelt for their water supply, such as the Andes in South America, the Himalayas in central Asia, and the Sierra in California.

• Drought Monitoring, Response, and Adaptation

Close monitoring of atmospheric conditions can reveal an impending drought before its agricultural or socioeconomic symptoms become severe, allowing protective measures to be taken. This is the basis of drought early-warning systems, for which there are several regional and global networks. Once a drought has begun, relief efforts may be necessary. Such efforts may include allocation of water to communities and farms, cash payments to farmers, and relocation assistance. However, the availability of relief can ultimately increase vulnerability to drought by encouraging inappropriate settlement and farming practices.

Although drought cannot be prevented, its effects can be minimized through adaptation. Examples of drought adaptation include selecting drought-tolerant crops; improving agricultural soil management; reducing the size of livestock herds; controlling fuel loads in forests; building dams and reservoirs; and encouraging water conservation. A society can insulate itself against drought (or any hazard) by reducing poverty, diversifying its economy, and building strong social institutions.

• Context

Humans have always needed to cope with drought; it has been a cause of hardship, conflict, and migration throughout recorded history. Megadroughts may have led to the disappearance of some civilizations, such as the Maya. More than 10 million people are thought to have been killed by drought during the twentieth century. Climate change will likely not only increase the incidence of drought but add other stresses to human society as well.

Drought is a natural phenomenon, and a given drought cannot be attributed definitively to climate change. Furthermore, there is much uncertainty about when and where climate change will increase drought incidence. This does not, however, imply that adaptation efforts should be delayed. Many drought-adaptation actions will have benefits in the present as well as the future.

Amber C. Kerr

• Further Reading

Boken, Vijendra K., Arthur P. Cracknell, and Ronald L. Heathcote, eds. *Monitoring and Predicting Agricultural Drought: A Global Study*. New York: Oxford University Press, 2005. Technical volume discussing drought monitoring and its use in different world regions. Includes a chapter on climate change. Figures, tables, maps, index.

Botterill, Linda C., and Melanie Fisher, eds. *Beyond Drought: People, Policy, and Perspectives*. Collingwood, Vic.: Commonwealth Scientific and Industrial Research Organisation, 2003. Evaluates the social, cultural, political, and economic aspects of drought and drought relief. Focuses on Australia. Figures, tables, maps, index.

Cooley, Heather. "Floods and Droughts." Chapter 4 in *The World's Water, 2006-2007: The Biennial Report on Freshwater Resources*, edited by Peter Gleick. Washington, D.C.: Island Press, 2006. Discusses causes and effects of drought; provides statistics on historical droughts; distinguishes between drought management, mitigation, and response. Figures, tables.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Forecasts weather and climate, including precipitation and drought, for each region of the world; provides an integrated overview of the most likely severe effects worldwide. Figures, maps, tables.

Kallis, Giorgos. "Drought." *Annual Review of Environment and Resources* 33 (2008): 85-118. Concise review of all aspects of drought. Provides definitions and metrics; discusses natural science and social science perspectives; emphasizes climate change. Tables, glossary.

Trenberth, K. E., J. T. Overpeck, and S. Solomon. "Exploring Drought and Its Implications for the Future." *Eos* 85, no. 3 (January 20, 2004): 27. This brief article reviews evidence that severe droughts have increased in the past century, compares contemporary climates to the paleoclimate record, and discusses effects of climate change on drought severity.

See also: Desertification; Floods and flooding; Freshwater; Glaciers; Hydrosphere; Rainfall patterns; Sahel drought; Water resources, global; Water resources, North American.

Dust storms

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Dust storms are meteorological events in which visibility is reduced to 1 kilometer or less as a result of blowing dust (defined as material less than 63 microns in size—the size of silt and clay). In many areas, wind conditions conducive to dust storms are associated with the passage of frontal systems (especially cold fronts) and downdrafts from convectional storms. Elsewhere, strengthened pressure gradients give rise to sustained high wind speeds capable of raising dust. Examples include the Shamal and Hundred Days winds in the Arabian Gulf and Seistan regions of Iran and Afghanistan and the Santa Ana winds of Southern California.

The dust emission process involves both the horizontal transport of coarse, sand-sized material and the vertical flux of fine, silt- or clay-sized particles. Coarse particles abrade fine materials (as, for example, on the surfaces of dry lake beds) and eject the fine particles into the air, where atmospheric turbulence transports them in suspension, often for many tens or hundreds of kilometers. Plumes of dust from the Sahara Desert regularly reach southern Europe, and they occasionally cross the Atlantic Ocean to reach the Caribbean Sea and South America. Dust plumes from China reach Japan on a regular basis and occasionally cross the Pacific Ocean to North America.

• **Significance for Climate Change**

Dust emitted and transported from deserts represents a major linkage between deserts and other environments. Dust deposition has important effects on ocean and terrestrial productivity by contribut-

A massive cloud of dust blows over Griffith, Australia, in November, 2002. (AP/Wide World Photos) ing nutrients to ecosystems (especially iron, which is limiting to marine productivity). Air quality is affected by particulate loading. Atmospheric radiative properties are changed through the scattering and absorption of solar radiation by mineral aerosols. Such processes may result in either warming or cooling effects, depending on the size and composition of the dust particles. Dust is trapped by vegetation and adds to soils on desert margins and elsewhere. Saharan dust is a major component of soils throughout the Mediterranean Basin and even as far afield as the Caribbean. Human health is affected by high dust concentrations, which can lead to respiratory disease. Changes in the dust loading of the atmosphere have also been linked to rainfall changes in areas adjacent to the Sahara and to the intensification of drought conditions.

Most dust source areas are located in arid climate zones and are associated with topographic lows, flat surfaces, finely textured soils, and sparse or no vegetation cover. Such areas have been identified by orbital sensors, particularly the Total Ozone Mapping Spectrometer Aerosol Index (TOMS AI), as well as ground observations. The majority of mineral dust is derived from natural surfaces; the contribution of human activities (such as agriculture) to the dust loading of the atmosphere is uncertain; global estimates vary from anywhere between 50 percent to less than 10 percent. Major dust source areas include the Bodelé Depression in Tchad, the Aral Sea area, southeast Iran, the Taklamakan Desert of China, Inner Mongolia, and the loess plateau of China. The Sahara region is believed to be the largest single dust source, accounting for as much as 690 million metric tons of dust per year. Satellite data show that three of the world's most important dust source areas lie in this region.

The interannual frequency and magnitude of dust storms is strongly linked to climatic variability: In many areas, dust emissions are inversely correlated to rainfall, although in a complex nonlinear manner, in part because a supply of fine sediment is required for dust emission. For example, periods of increased rainfall cause runoff that may flood playas and contribute sediment that is mobilized by wind in subsequent dry periods. In this way, dust emissions appear to correlate with El Niño-Southern Oscillation (ENSO) cycles in the southwestern United States. Elsewhere, there are strong anti-correlations between the flux of dust from the Sahara and rainfall.

On a longer time scale, important millennial and centennial variations in global and regional dust loadings are recorded by dust deposits in marine sediments and ice cores. For example, dust flux from the Sahara and many other desert regions (such as Australia) was high during the Last Glacial Maximum, as a result of increased aridity and wind strength at this time. Dust flux also increased sharply following the desiccation of the Sahara some five thousand years ago.

Future changes in dust emissions are therefore likely to be influenced by climate change, most notably as the effect of vegetation-cover change, with human activities affecting conditions locally. The direction of change in dust emissions, as predicted by different models, is, however, uncertain. In one model, Saharan dust emissions are predicted to increase by 11 percent as a result of higher wind speeds. Other simulations predict a decrease of 4 percent as a result of increased monsoonal rainfall and vegetation cover.

Nicholas Lancaster

• Further Reading

Christopher, Sundar A., Donna V. Vulcan, and Ronald M. Welch. *Radiative Effects of Aerosols Generated from Biomass Burning, Dust Storms, and Forest Fires.* Springfield, Va.: National Technical Information Service, 1996. The contribution of dust storms to radiative forcing is compared to those of natural and anthropogenic conflagrations.

Engelstaedter, S., I. Tegen, and R. Washington. "North African Dust Emissions and Transport." *Earth Science Reviews* 79 (2006): 73-100. Review of the processes of dust emissions and transport for the Saharan region.

Goudie, A. S., and N. J. Middleton. *Desert Dust in the Global System.* New York: Springer, 2006. Comprehensive overview of dust processes and their relation to environmental conditions.

See also: Aerosols; Desertification; Deserts; Sahara Desert; Sahel drought; Soil erosion; Sulfate aerosols.

Earth history

• **Categories:** Geology and geography; astronomy

The key to understanding present-day climate change lies in interpreting the geologic past. Present in the rocks of the Earth's crust is a continuous record of change. Scientists use the evidence found in those rocks to help understand current Earth processes.

• Key concepts

accretion: the final process of planetary formation, in which smaller objects are pulled into the nascent planet

continents: large sections of an earthlike planet's surface with high elevations and lower-density rocks

core: the central part of a planetary body, usually composed of high-density metal alloys

crust: the outer portion of an earthlike planet, consisting of lower-density silicate minerals and rocks

magnetic field: the flow patterns of magnetism that surround a celestial body as a result of an electrodynamo effect

mantle: the middle section of an earthlike planet, consisting of higher-density silicate minerals and rocks

ocean basins: large sections of an earthlike planet's surface with low elevations and higher-density rocks

planetary nebula: the gas and dust that is required to form a star and its family of planets

plate tectonics: the mechanisms responsible for creating movement in large sections of a planet's surface

radiometric dating: an analytical technique using radioactive isotopes to determine the age of rocks and minerals

• Background

The Earth is one of eight major planets and a host of minor planets that circle a fairly average, middle-aged, main-sequence star. It formed from the accretion of residual material from the gravitational collapse of the solar nebula that produced the Sun. Based on their specific distances from the Sun, the planets formed into groups of similar chemical compositions, sizes, and densities. The four smaller inner planets are of higher density and are composed of a mixture of rock and metal. In contrast, the next four planets are massive gas giants with lower densities and larger sizes. The final grouping consists of small, low-density, icy worlds. Unlike the other inner planets, the Earth has remained a geologically active planet and has undergone continuous change since its formation. It is a planet dominated by the presence of liquid water. Throughout its long history, the Earth has evolved from a lifeless world into one that is populated by an uncountable number of species.

• Early History of the Earth

Based on radiometric dating analyses of moon rocks and meteorites, the Earth is believed to be about 4.5 billion years old. Many scientists believe that the Earth originated as a cold, undifferentiated body that internally heated up from the energy released through giant impacts, radioactive isotope decay, and the mass of the Earth itself. Once the appropriate melting temperatures were reached, heavy metallic elements sank to the planet's center of gravity, as lighter elements were displaced upward toward the surface. This process may have taken place in as little as 50 million years. It is fairly certain that the present core-mantle-crust structure was in place by 4 billion years ago.

Earth's core consists of both solid and liquid metal, presumably of nickel-iron composition. The outer, liquid metallic core revolves around the inner, solid metallic core and, in the process, generates an electric current. This electric current is responsible for the Earth's magnetic field. Sandwiched between the core and the crust is the mantle, a region of high-density iron- and magnesium-rich silicate rock material. Depending upon specific temperatures and pressures, this material can behave either as a solid or as a liquid.

Scientists closely link the history of the Earth to that of the Moon. The Earth and Moon are geologically similar in many ways, but there are significant differences in their respective elemental abundances, and lunar specimens exhibit an apparent lack of certain volatiles. One origin theory suggests

In a graphic illustration of Earth's geologic history, the Creteceous-Tertiary boundary is clearly visible in this rock formation near Drumheller, Alberta. The transition from light to dark rock marks the point at which dinosaurs became extinct, probably as a result of abrupt climate change. (G. Larson)

that the Moon is the product of a huge collision between a Mars-sized object and the primordial Earth. The resulting debris from this impact later accreted and formed the Moon. This theory mainly draws its support from computer impact simulations and a great mnany assumptions, but it lacks the physical evidence necessary to support it.

Finding a common theory of origin for the Earth and Moon has proven to be quite difficult. In fact, when comparing size, density, and internal structure, the Moon seems to have more in common with Mars than it does with the Earth. What is certain is that the Moon has a definite influence on the Earth's environment. The Moon's daily tidal effects on the world's oceans are obvious, but the Moon also has a gravitational influence on the Earth's axial rotation. Without the gravitational pull of the Moon, the Earth's axial tilt would fall outside of its normal range of between 21° and 25° and literally fall over. Without the Moon "holding the Earth in place," the equator of today could easily become the polar regions of tomorrow.

• Evolution of the Atmosphere and Oceans

The primitive Earth did not have the same atmosphere that it does today. Many scientists believe that the Earth's original atmosphere may have been a very dense, hot mixture of ammonia and methane. This is consistent with the conditions present during Earth's proto-planetary stage that probably dissipated during the Sun's T-Tauri phase. The first "permanent" atmosphere formed as a product of volcanic degassing. Through this process, carbon dioxide (CO_2) gradually became the dominant gas, along with a significant amount of water vapor. As the Earth cooled, water vapor condensed and fell as rain. This rain later filled the lowlands and created the first primitive oceans. Chemical reactions occurring in seawater slowly began to extract CO_2 from the atmosphere and form large amounts of carbonate rocks. Somehow, during the first 500 million years of Earth history, life crossed over the threshold between being a collection of complex organic molecules and living organisms. With life-forms such as blue-green algae at work, the CO_2-rich atmosphere slowly transformed into a nitrogen and oxygen-rich atmosphere that could support animal life. This transition is clearly marked in the Earth's geological record when previously dark, iron-bearing sediments turned red from oxidation. It is shortly after this geological benchmark that the first marine animals appear in the fossil record.

• Supercontinents and Continental Drift

The formation of supercontinents and continental drift is essentially tied to the internal mechanisms of the Earth's upper mantle. There, convection cells provide the energy necessary to split apart the crust into both large and small sections that can move relative to one another. The direct evidence for the effects of this convective energy is the large number of volcanoes and earthquakes that occur along plate boundaries. No one is certain how long plate tectonics has been a part of Earth history, but it is certainly responsible for the continent-ocean basin relationship, which forms the present crust.

In the geologic past, supercontinents have existed only to be broken apart and distributed across the face of the Earth. This movement is continuous, and the formation of supercontinents seems to be inevitable, as is their eventual breakup. The formation of the world's great mountain chains is the direct result of colliding continents transforming marine sediment into hard rock. New crustal rock is created by volcanic activity at mid-oceanic ridges that pushes plates apart from one another. Such plate movement can also carry older, crustal rock to its destruction in an oceanic trench or be welded together into a new continental mass.

• The History of Life

There is strong evidence to support the hypothesis that life has existed on Earth for more than 4 billion years. Initially, single-celled life-forms dominated the planet, and they gradually evolved into more complex forms. Scientists theorize that life could have originated on Earth in two possible ways: either as an indigenous form, created from the organic compounds and conditions present in the primordial Earth, or from organic compounds or even living bacteria that were transported to Earth by comets or meteorites. This later "panspermia" theory suggests that organic compounds and living bacteria may have come to Earth from space and served as the seeds for life.

Regardless of its origin, life has flourished on Earth for billions of years and has adapted to an ever-changing variety of environmental conditions. For over 2.5 billion years, cyanobacteria were the dominant life-forms and were responsible for the gradual buildup of an oxygen-rich atmosphere. In the Cambrian geological period, there was an explosion in the diversity of marine animal life. Various species seem to have come and gone as if they were the products of some biological experiment to see which could survive best. The survivors continued to evolve into more complex organisms that gradually found their way to land.

It seems that the end of one species's dominance and the beginning of another's is usually marked by a dramatic change in global climate. The best evidence to support such a theory occurs at the Cretaceous-Tertiary boundary, approximately 65 to 70 million years ago. An iridium-rich layer of sediment, attributed to the impact of an asteroid, marks the boundary between the two geological periods. Dinosaur fossils are found below this layer but are notably missing from the layers above. Scientists interpret this as evidence for global climate change that led to the mass extinction of a large number of species. An event such as this is not limited to the Cretaceous-Tertiary periods but may also be responsible for several other mass extinctions.

• Ice Ages and Interglacial Periods

There are many scientific theories that suggest the Earth is usually a cold planet covered by vast amounts of ice. Periodically, warm periods emerge that last for several thousand years and eventually phase back into long ice ages. It is during these warm periods that land animals flourish and perhaps even speed up their evolutionary processes. There are no certainties as to when ice ages begin or end. Global climate change is the underlying reason, but what initiates this change? Scientists have suggested such possibilities as changes in the Earth's axial tilt, increased volcanic activity blocking incoming sunlight, shifts in the world's ocean currents, impact debris from collisions with comets or asteroids, and the effects of human pollution. No one is certain which of these possibilities holds the answer, and the truth is probably found in some combination of factors. What is certain is that ice ages and their interglacial warm periods are features inherent to planet Earth, and they will continue to occur with or without human influence.

• Context

Astronomers have presented evidence to support the existence of hundreds of other planets orbiting distant and even exotic stars. These planets range from massive gas giants to a few with nearly earthlike masses. All evidence tends to indicate, however, that Earth is a very unusual planet. It has evolved from a hot gaseous world to one that is dominated by liquid water. Its atmosphere changed from one that was poisonous to animal life to one that is oxygen-rich and supports uncountable species of life, both on land and in the oceans. In the geological past, the processes of plate tectonics may have been beneficial to the evolution of life, while at other times they may have caused mass extinctions. Perhaps the one constant throughout Earth's history has been that change is inevitable. Present-day humans are the result of the ever-changing conditions of the Earth's surface. Adaptation to climatic changes means survival for some species, while others that cannot change face extinction. Unique to this period in Earth history is the fact that a particular species, human beings, possesses the ability to have either a positive or a negative effect on the environment. One path may lead to a better world, while the other may lead to extinction.

Paul P. Sipiera

• Further Reading

Canup, R. M., and K. Righter, eds. *Origin of the Earth and Moon.* Tucson: University of Arizona Press, 2000. A compilation of twenty-nine scientific papers dealing with terrestrial planetary formation with emphasis on the Earth-Moon system. Excellent reference source for undergraduate and graduate students.

Hartmann, William K. *Moons and Planets.* 5th ed. New York: Brooks/Cole-Thomson Learning, 2005. A comprehensive examination of the solar system from the planetary geologist's perspective. Suitable for advanced high school and undergraduate students.

McSween, Harry Y., Jr. *Meteorites and Their Parent Planets.* 2d ed. New York: Cambridge University Press, 1999. A concise yet comprehensive work on the importance of meteorite studies to understanding planetary formation. Chapter 9 is particularly relevant to Earth history.

Russell, Michael. "First Life" *American Scientist* 94, no. 1 (2006): 32-39. A detailed and well-illustrated description of the emergence of life on the early Earth. Brings together all of Earth's dynamic processes as vital contributors to the origin of life. Suitable for a general readership and science students alike.

Schubert, Gerald, Donald L. Turcotte, and Peter Olsen. *Mantle Convection in the Earth and Planets.* New York: Cambridge University Press, 2001. An essential reference for the serious student of Earth history. Clearly explains how tectonic mechanisms in the Earth's upper mantle affect all Earth processes, including the evolution of life.

See also: Atmospheric structure and evolution; Climate reconstruction; Dating methods; Deglaciation; Earth motions; Earth structure and development; Earthquakes; Global energy balance; Paleoclimates and paleoclimate change; Planetary atmospheres and evolution; Plate tectonics; Sun.

Earth motions

• **Category:** Astronomy

• **Definition**

Earth is not fixed in space. Rather, Earth orbits the Sun in a nearly circular orbit once every 365.26 days, a period of time called the sidereal year. As Earth orbits the Sun, it rotates once every 23 hours 56 minutes about a rotational axis that is tilted at approximately 23.5° with respect to its orbital motion. This axial tilt is called obliquity, and Earth's daily rotation is called diurnal motion.

Earth's orbit is nearly circular, but it is not a perfect circle. The measure of how far an orbit deviates from being circular is called its eccentricity. Earth's orbital eccentricity is about 0.017, meaning that its orbital distance from the Sun deviates by 1.7 percent from its average distance of 149,597,871 kilometers. Interactions between the Sun, Earth, and other planets can cause the Earth's eccentricity to change somewhat. The entire orbit shifts a little each time around, causing the point in the orbit where the Earth is closest to the Sun to shift a little each year. This motion is called precession.

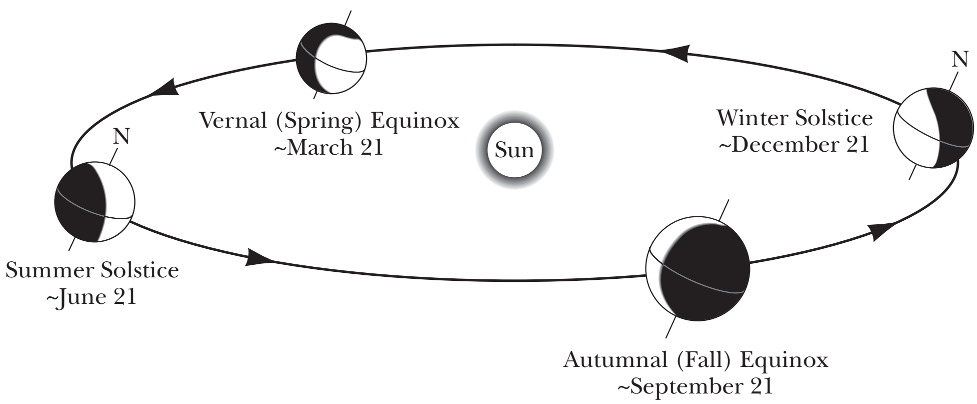
Though the Earth's orbit is slightly elliptical, it is the planet's obliquity that is responsible for the seasons. That obliquity, however, is not constant. The tilt, or inclination, varies somewhat over time, increasing and decreasing. This change in inclination is called nutation. There are many causes for nutation, with the largest being tidal interactions between the Earth, Sun, and Moon. These interactions create an 18.6-year nutation cycle, shifting Earth's obliquity by up to 9 arcseconds. Other causes of nutation also exist, with periods ranging from days to thousands of years. Furthermore, Earth's rotational axis, too, gradually shifts the direction of its obliquity. This shift, also called precession, takes about twenty-six thousand years to go through a complete circle. The combination of the precession of the orbit and the precession of the poles causes the seasons to repeat every 365.24 days, a period of time known as the tropical year, instead of repeating in a sidereal year.

• **Significance for Climate Change**

Earth's climate is governed by the interaction between the Earth and the Sun. Sunlight warms the Earth, and Earth radiates heat into space. Anything that affects this process can have an effect on Earth's climate. Thus, some long-term climate change can be attributed to the motion of the Earth as a planet.

Changes in Earth's obliquity can affect seasons by changing the angle of the sunlight reaching

Earth's Orbit Around the Sun



Earth's surface. However, these changes in obliquity change only the distribution of solar energy reaching Earth, not its total amount. As the obliquity decreases, the difference between summer and winter decreases. Conversely, as obliquity increases, the difference between summer and winter becomes more pronounced. This represents a change in climate, but it does not directly result in global warming or cooling.

At present, about two weeks before Earth reaches its aphelion, its greatest distance from the Sun, Earth's Northern Hemisphere is tilted most toward the Sun, creating summer in the Northern Hemisphere and winter in the Southern Hemisphere. Likewise, Earth's Southern Hemisphere is pointed most toward the Sun, creating summer in the Southern Hemisphere and winter in the Northern Hemisphere, about two weeks before Earth reaches its perihelion, its closest distance to the Sun. Because of this, the Southern Hemisphere receives more intense solar radiation during its summer and less intense solar radiation during its winter than does the Northern Hemisphere.

Normally, this difference in radiation intensity would be expected to produce more extreme seasons in the Southern Hemisphere than in the Northern Hemisphere. However, the Northern Hemisphere has a larger landmass than does the Southern Hemisphere. The large bodies of water in the Southern Hemisphere act, in part, as a heat sink to moderate the effects of the differences in solar radiation. Over time, though, the difference between the sidereal year and the tropical year causes seasons to shift the point along Earth's orbit at which they occur. This process is called the precession of the equinoxes. Eventually, the seasons will reverse, with the Northern Hemisphere experiencing the more intense differences in summer and winter solar radiation. Without the buffering effect of the large bodies of water of the Southern Hemisphere, this shift will result in more extreme seasons. These changes, though, do not result in a change in the total solar radiation incident upon Earth, only in how that radiation is distributed.

Eccentricity changes, however, can change the total solar energy incident upon Earth, and such changes can have a dramatic impact on Earth's climate. Furthermore, global warming or cooling can result in a decrease or increase in ice on the planet. Ice and snow reflect sunlight rather than absorbing it, amplifying the effects of orbital changes. Warming results in less ice, causing more solar energy to be absorbed by the planet's surface and warming Earth more. Cooling results in more ice and less solar energy absorbed, cooling Earth more. All of these effects, though, are expected to occur on fairly long timescales compared with human experience.

Raymond D. Benge, Jr.

• Further Reading

Drake, Frances. *Global Warming: The Science of Climate Change*. London: Arnold, 2000. Excellent introduction to the principles of climatology and climate change. Contains a good description of the role of the planetary motions of the Earth and how they affect climate. Each chapter is well referenced.

Leroux, Marcel. *Global Warming: Myth or Reality? The Erring Ways of Climatology*. Chichester, West Sussex, England: Praxis, 2005. Good description of both natural and anthropogenic climate change, with many references. Some discussion is given to the role of changes in Earth's motions in producing climate change.

Mathez, Edmond A., and James D. Webster. *The Earth Machine: The Science of a Dynamic Planet*. New York: Columbia University Press, 2004. Introduction to Earth as a planet, with a good description of the motions of the Earth. Three chapters are dedicated to climate and climate change.

See also: Albedo feedback; Climate and the climate system; Climate change; Climate feedback; Earth history; Earth structure and development; Global energy balance; Planetary atmospheres and evolution; Seasonal changes; Sun.

Earth structure and development

• **Categories:** Astronomy; geology and geography

Climate depends strongly on the geometry of the Earth's surface: Where the continents are, and where the mountain ranges are within them, controls winds, currents, and continental glaciers. The Earth's surface geometry is a result of its structure and development.

• Key concepts

asthenosphere: the ductile layer of the Earth, beneath the lithosphere, defined by mechanical behavior; although solid, it deforms horizontally over tens of millions of years

crust: the uppermost layer of the Earth as defined by seismic properties inferred to represent composition

inner core: the innermost layer of the Earth, extending from 5,150 kilometers to 6,370 kilometers below ground and composed mostly of solid iron

lithosphere: the uppermost layer of the Earth, about 150 kilometers thick, as defined by mechanical behavior; it does not deform horizontally

mantle: the layer beneath the crust, known to be solid and defined by seismic properties inferred to represent composition

outer core: a liquid region extending from the base of the mantle at a depth of 2,900 kilometers down to the inner core, at a depth of 5,150 kilometers; mostly molten iron

• Background

The Earth is a dynamic planet. Heat from its formation and radioactive decay moves to the surface and radiates to outer space. In the process, pieces of the surface are moved around, and mountain ranges are produced. The result is a mosaic of plates, some with continents and mountain ranges on them, that shift around over geologic time periods. The pattern of oceans, continents, and mountains controls ice-sheet formation, ocean currents, and atmospheric circulation patterns that, in turn, control the climate.

• Layers Based on Composition

By studying the waves generated by earthquakes, seismologists have been able to determine the elastic properties and density of the Earth as a function of depth. This technique has revealed four major layers: the crust (5 to 70 kilometers thick), the mantle (2,900 kilometers thick), the outer core (2,300 kilometers thick), and the inner core (1,200 kilometers thick). The outer core is liquid; all the other layers are solid. These layers are thought to represent differences in composition.

The continental crust, typically 30 to 70 kilometers thick, is made of granitic rocks, while the somewhat denser oceanic crust, typically 0 to 7 kilometers thick, is made of basaltic rocks. The mantle, a silicate rock called peridotite, is denser than the crust. The core, both inner and outer, is mostly iron, and is about twice as dense as the mantle. The inner core is solid, because it is subjected to higher pressure than the outer core.

• Layers Based on Behavior

When Alfred Wegener struggled to convince his skeptics that the continents drifted around, he assumed that the compositional layering described above would also be important mechanically and that the continents moved like giant ships through the mantle and oceanic crust. At the temperatures present in the crust and upper mantle, however, horizontal deformations like this are not possible.

As the evidence for drifting continents accumulated in the 1960's, a different approach developed. Although the peridotite is denser than granite or basalt, the mechanical behavior of these materials is similar. This behavior depends on temperature, which is known to increase with depth. The cooler, outer part of the Earth (about 150 kilometers thick), which does not deform horizontally, was defined as the lithosphere, and the hotter, deeper part, which does deform horizontally, as the asthenosphere. The theory of continental drift became the theory of plate tectonics, where the continents were seen to be passively riding on much thicker, "rigid" plates of the lithosphere. Plates deform vertically beneath glacial loads, but not horizontally when pushed by convection, because they are only about 150 kilometers thick but thousands of kilometers wide. There are about a dozen major lithospheric plates, and their interactions produce most of the mountains on Earth.

- **Mantle Convection**

In the Earth, heat moves from the hot interior to the surface. Heat from the core enters the lower mantle, expanding some of it, making it buoyant. The mantle is solid, but, because of its immense size, it behaves like silicon putty, deforming to permit the rise of this buoyant, heated rock. As the rock approaches the crust, tens of millions of years later, it spreads out, cools, and sinks. This process is called convection.

The convection cells on Earth rise at mid-ocean ridges, where lithospheric plates grow, and descend at subduction zones. The presence of plates influences the convection and limits the movements it can produce at the surface.

- **Plate Tectonics and Climate**

As convection moves the continents around, their latitude will change, making it more or less likely that continental glaciers will form on them. Currently, glaciers can only form at high latitudes, above 45°. If the rate of convection changes, the atmospheric carbon dioxide (CO_2) concentration is likely to change. Volcanism transfers CO_2 from within the Earth to the atmosphere; faster convection will result in more volcanism and thus higher levels of atmospheric CO_2.

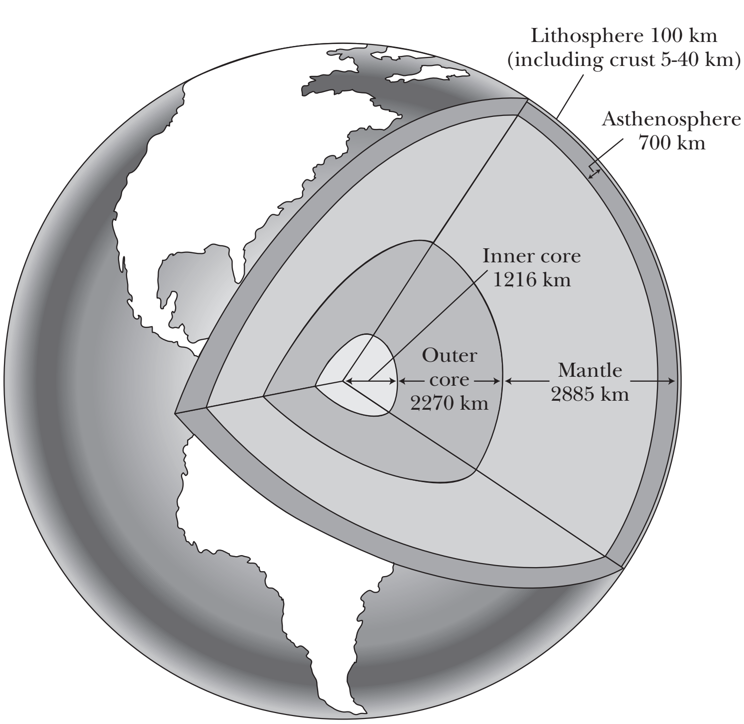
Ocean circulation patterns depend on the shapes of the ocean basins. Before the closing of the Isthmus of Panama, warm, salty water from the Atlantic Ocean was flushed into the Pacific Ocean. After the isthmus's closure, this water remained in the Atlantic Basin, changing circulation patterns.

Collision of the Indian subcontinent with Asia caused the uplift of the Himalayan plateau, which led to the development of the monsoon winds. These are likely to have resulted in an unusually high rate of weathering, removing CO_2 from the atmosphere. The Rocky Mountains have been shown to deflect prevailing westerlies as they move across North America, bringing great quantities of heat to western Europe.

- **Context**

Scientists' confidence in being able to predict future climate change depends on their understanding of past climate change. Inputs that vary too slowly to affect the historical record, such as the locations of continents and mountain ranges, need to be evaluated from a geological perspective. These formations affect global climate, and their changes in the future will affect the evolution of Earth's climate on a geological timescale. One way to gauge the accuracy of existing models of geological history is to compare climate signals from times

Earth's Interior



when the elevation and location of a geological formation are known to have differed from their current values. Knowledge of the structure and development of the Earth provides a path to obtain this information.

Otto H. Muller

• Further Reading

Fowler, C. M. R. *The Solid Earth: An Introduction to Global Geophysics*. 2d ed. New York: Cambridge University Press, 2005. Excellent discussion of current plate motions, plate rheology, and so on, but somewhat technical in approach. Illustrations, figures, tables, maps, bibliography, index.

Grotzinger, John. *Understanding Earth*. New York: W. H. Freeman, 2007. Introductory college-level textbook. Good overview of the plate tectonic paradigm. Illustrations, figures, tables, maps, bibliography, index.

Ruddiman, William F. *Earth's Climate Past and Future*. 2d ed. New York: W. H. Freeman, 2008. Chapter 6 of this elementary college textbook describes how the locations of continents and mountain ranges may have been responsible for ice ages. Illustrations, figures, tables, maps, bibliography, index.

Seager, R. "The Source of Europe's Mild Climate: The Notion That the Gulf Stream Is Responsible for Keeping Europe Anonymously Warm Turns Out to Be a Myth." *American Scientist* 94 (2002): 340-41. Good description of how the mountains in the American West control the climate of Europe by deflecting prevailing westerlies. Illustrations, maps.

Van der Pluijm, Ben. *Earth Structure: An Introduction to Structural Geology and Tectonics*. New York: W. W. Norton, 2004. The second half of this book concerns tectonics and describes in detail the formation of many mountain ranges on Earth. Illustrations, figures, tables, maps, bibliography, index.

See also: Continental climate; Earth history; Earth motions; Earthquakes; Plate tectonics; Volcanoes.

Earth Summits

• **Category:** Conferences and meetings

The Earth Summits held by the United Nations have presented forums for the creation and maintenance of important international treaties and agreements relating to climate change. They bring with them both the strengths and the weaknesses of the United Nations as a body for organizing international cooperation among nations with very different interests and agendas.

• Key concepts

greenhouse gases (GHGs): gases that trap heat in the atmosphere, preventing it from escaping into space and increasing the temperature of the planet

Kyoto Protocol: a treaty that established specific and legally binding limits on GHG emissions for the global community, ratified by 182 nations

sustainable development: the growth of population, industry, and agriculture in a fashion that does not deplete global resources

U.N. Framework Convention on Climate Change (UNFCCC): the agreement underlying the Kyoto Protocol and all other subsequent U.N. agreements relating to climate change

• Background

During the twenty years following the 1972 United Nations Conference on the Human Environment, in Stockholm, Sweden, the global environment continued to deteriorate, as the ozone layer and natural resources were depleted, while global warming and pollution increased. Importantly, little had been done to integrate environmental issues with economics and development. In 1983, Gro Harlem Brundtland of Norway, head of the World Commission on Environment and Development, put forth a report that defined sustainable development as "the growth of population, industry, and agriculture occurring in a manner that allows the current generation to fulfill its own needs without jeopardizing those of future generations." A sustainable way of life was said to depend on "equitable economic growth, conservation of natural resources, and the environment," in addition to social development.

As a result of the Brundtland Report, the United Nations requested that a conference be convened that focused equally on the environment and development. The First Earth Summit (formally, the United Nations Conference on Environment and Development, or UNCED) was held in 1992. It served as the foundation for U.N. activities to coordinate sustainable development and resist global climate change. Two subsequent summits, Earth Summit +5 and Earth Summit +10, functioned as reviews of the progress made since UNCED after five and ten years, respectively.

• The First Earth Summit

Held in Rio de Janeiro, Brazil, from June 3 to 14, 1992, UNCED set out to provide a basis for global collaboration between the developed and the developing nations so as to bolster socioeconomic development and halt the deterioration of the planet's environment. Some 108 participating countries adopted five significant agreements with the aims of improving the environment and redefining the traditional concept of development to one that included sustainability.

Agenda 21 was the sole product of UNCED that covered all aspects of sustainable development, from goals and responsibilities to financing. It included proposals for social and economic action, such as fighting poverty and balancing production with consumption, while integrating environmental and developmental concerns. The Rio Declaration on Environment and Development was a statement of principles in support of Agenda 21, designed to guide nations in their efforts to protect the environment. It proclaimed that humans are entitled to life in harmony with nature via sustainable development and that reducing global disparities and eradicating poverty are essential for such development. The Rio Declaration also emphasized the importance of strengthening the role of women, youth, farmers, and indigenous peoples in contemporary society.

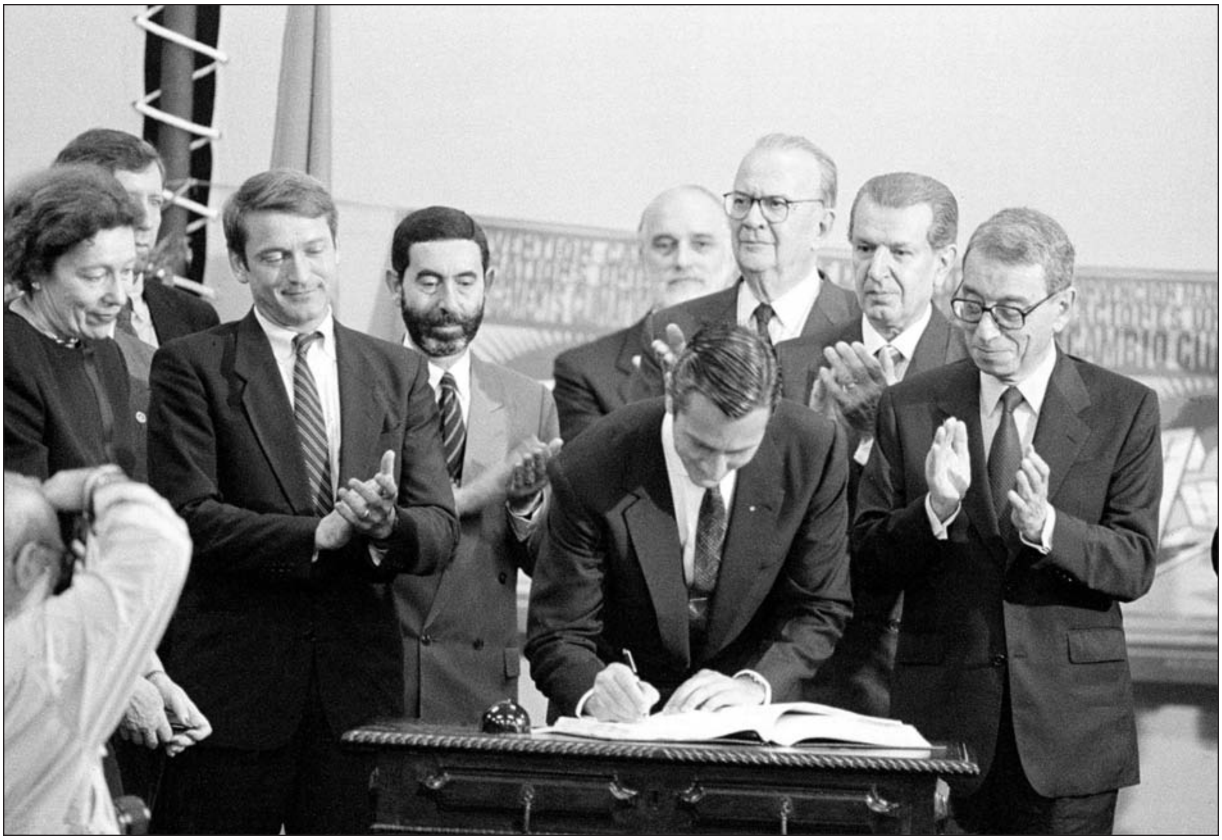
The Statement of Forest Principles described the principles that underlie the sustainable management of forests. The Convention on Biodiversity focused on sustaining and conserving the plethora of species inhabiting the planet. Finally, the United Nations Framework Convention on Climate Change (UNFCCC), a nonbinding treaty on the environment, was ratified on June 12, 1992, by 154 countries with the intent of stabilizing their greenhouse gas (GHG) emissions at 1990 levels by 2000. The principle of "common but differentiated responsibilities" for developed and developing countries was agreed upon, with the developed countries bearing the greater burden of accountability.

• Earth Summit +5

From June 23 to 27, 1997, delegates from 165 nations, including over 53 heads of state, attended a special session of the U.N. General Assembly at the U.N. headquarters in New York City to "review and appraise" the implementation of Agenda 21 and to assess whether there had been global progress toward sustainable development. The participants of Earth Summit +5 determined that the global environment had deteriorated since UNCED, concluding that while some progress had been achieved in forestalling climate change and the loss of forests and freshwater, global poverty continued its downward spiral, and there were few commitments from the global community to reduce GHG emissions and help fund sustainable development. The north-south divide between developed and developing nations was seen as largely to blame for these problems.

• Earth Summit +10

Earth Summit +10 was held in Johannesburg, South Africa, from August 26 to September 4, 2002, ten years after UNCED, in order to explore the progess made in promoting sustainable development. Known as the World Summit on Sustainable Development (WSSD), the meeting gathered leaders from the business sector, nongovernmental organizations (NGOs), and other concerned groups with the goal of enhancing the quality of life for all humankind and conserving Earth's natural resources. During Earth Summit +10, a number of parallel activities were simultaneously held by independent organizations and groups that believed that agreements reached by WSSD were full of good intentions concerning access to potable water, biodiversity, and fishing resources, but were devoid of objectives for promoting renewable ener-



Fellow world leaders and diplomats applaud as Brazilian president Fernando Collor de Mello signs the United Nations Framework Convention on Climate Change at the first Earth Summit in June, 1992. (AP/Wide World Photos)

gies, and lacking specific commitments for funding. These groups echoed similar concerns expressed following Earth Summit +5. Some believe that the most positive outcome of Earth Summit +10 was the commitment garnered from several governments to ratify the Kyoto Protocol.

- **Significance for Climate Change**

The First Earth Summit, UNCED, set the tone for the two Earth Summits that followed by emphasizing sustainability as vital for environmental progress in the fight to contain climate change and forestall global warming. In addition, UNCED produced the most important treaty for achieving this goal, the UNFCCC, with a goal of stabilizing GHG emissions at a level that might prevent anthropogenic disruption of the Earth's climate. Originally a legally nonbinding document, because it set no mandatory limits on GHG emissions, the treaty included provisions for updates called "protocols," the best known being the Kyoto Protocol, which established specific, enforceable limits on GHG emissions. Parties to the UNFCCC were asked to adopt legally binding targets for developed countries.

The UNFCCC created a "national GHG inventory" to keep track of GHG emissions and their removal from the atmosphere. It was ratified by the United States in October, 1992, when it was opened for signing. While the UNFCCC was ratified by 166 countries, few developed countries met the goal of reducing GHG emissions to 1990 levels by 2000. However, since the UNFCC entered into force in 1994, the parties to the treaty have been meeting yearly in the Conferences of the Parties (COP) in order to evaluate their progress and to establish and implement legal obligations for developed nations to decrease their GHG emissions under the terms of the Kyoto Protocol.

Cynthia F. Racer

• Further Reading

Bradbrook, A. J., et al., eds. *The Law of Energy for Sustainable Development.* New York: Cambridge University Press, 2005. Based upon lectures given at a conference on sustainable energy; focuses on the legal implications of employing energy resources required for sustainable development.

Gagain, J. R., Jr. "The United Nations and Civil Society: A New Step in the Right Direction." *UN Chronicle* 40 (June, 2003). Argues that UNCED demonstrated the need for countries to interact with the United Nations framework, particularly on borderless issues such as the environment and sustainable development.

Strong, Maurice. *Where on Earth Are We Going?* London: TEXERE, 2001. Strong, a major organizer of the Rio Earth Summit, describes his pivotal role in various environmental movements and speaks about what has to be done to save the planet in an historical context.

See also: Annex B of the Kyoto Protocol; Kyoto lands; Kyoto mechanisms; Kyoto Protocol; Sustainable development; United Nations Conference on the Human Environment; United Nations Division for Sustainable Development; United Nations Framework Convention on Climate Change.

Earthquakes

• **Category:** Geology and geography

• Definition

An earthquake is a shaking or trembling of the ground caused by energy coming from volcanic eruptions or from rocks breaking during the geologic process known as faulting. This process takes place as a result of differential movements of segments of the Earth's crust known as plates. The plate tectonics theory has identified seven major crustal plates, as well as several minor plates, which are thought to be colliding with one another, separating from one another, or sliding past one another like books on a tabletop. The sudden movements of these plates, as they separate, collide, or slide past one another, are believed to cause most of the planet's earthquakes.

Volcanoes can cause earthquakes too, but these earthquakes are generally minor and occur only during periods of heightened volcanic activity. Some additional causes of earthquakes include landslides that drop large quantities of earth suddenly on underlying surfaces, and human activities, such as blasting during surface or underground mining operations. The shock waves from underground nuclear tests can generate vibrations similar to earthquakes as well.

• Significance for Climate Change

Concerns have been raised that climate change may lead to earthquakes in Alaska, or elsewhere, and these concerns may not be entirely unwarranted. Many glaciers and ice sheets are located in regions of past or continuing geologic activity, where crustal movements are still taking place. Removal of ice cover during periods of global warming might be sufficient to activate ancient faults in these areas and set off earthquakes of considerable magnitude. The rate at which the ice melts may not need to be rapid to cause such activity. Rocks can build up strains over a period of years without breaking at all, until the tension is suddenly released in a devastating shock. Scientists describe this process as elastic rebound. While the rocks on either side of a fault slowly slide past each other, the fault itself may remain "locked," with no movement taking place. Meanwhile, the rock masses on both sides of the fault begin to stretch, in a fashion similar to the stretching of an elastic band. When the strain in the rocks becomes too great, the fault will break, and the rocks on either side will snap back to their original dimensions.

There is clear evidence that the removal of ice from the Earth's surface following the ice ages is causing significant upward movement of the crust in several places. In parts of Scotland, Scandinavia, and Canada, the amount of rise has been dramatic. Interior Scandinavia has risen as much as 250 meters since the ice disappeared, and elevated beaches around Hudson Bay in northern Canada indicate the land there has risen more than 330 meters during the same period. Scandinavia is still rebounding at a rate of one meter per century, and some coastal cities have been uplifted so rapidly that docks constructed several hundred years ago are now inland, while harbors have grown so shallow that they can no longer accommodate the ships that once docked there.

Scientists refer to this uplifting process as isostatic rebound. When the weight of a continental ice sheet is added to the Earth's crust, the crust responds by subsiding. When the ice is removed, the crust begins to rise again, just as a cargo ship that sank lower in the water when it was loaded floats higher after its cargo is removed. The weight of the three-kilometer-thick ice sheets that once covered North America and Europe apparently caused down-warping of the crust by hundreds of meters. Now that the ice has been removed, the crust is rebounding to its original height.

Whether faults that were once active can be reactivated sufficiently by this rebounding process to cause earthquakes is difficult to determine, but such rebounding may well explain a series of mysterious earthquakes that plagued upper New York State during the late 1900's, as well as earthquakes that rattled Boston at the same time. Both areas were once buried beneath the North American ice sheet, and Boston's jolts have continued into the twenty-first century. By contrast, the continent of Antarctica still has its ice cover, and Antarctica's continental shelves, which would normally be found 120 meters below sea level, are now found 330 meters down. Presumably, the shelves were formed in water depths of 120 meters when Antarctica was ice free, and they will rise again to normal

A woman mourns her relatives at the site of a devastating 2009 earthquake in Sichuan, China. (Aly Song/Reuters/Landov) depths if the weight of the ice now covering the continent is someday removed.

Donald W. Lovejoy

• **Further Reading**

Anderson, David E., Andrew S. Gaudie, and Adrian G. Parker. *Global Environments Through the Quaternary: Exploring Environmental Change.* New York: Oxford University Press, 2007. Analysis of environmental changes during the last two million years of Earth history, with particular attention to the post-glacial uplift of Scotland, Scandinavia, and North America.

Hough, Susan Elizabeth. *Earthshaking Science: What We Know and Don't Know About Earthquakes.* Princeton, N.J.: Princeton University Press, 2002. Excellent basic description of how the various kinds of plate movements can cause earthquakes and a helpful explanation of the elastic rebound theory.

Zeilinga de Boer, Jelle, and Donald Theodore Sanders. *Earthquakes in Human History: The Far-Reaching Effects of Seismic Disruptions.* Princeton, N.J.: Princeton University Press, 2005. Summarizes ways in which earthquakes affect human lives; includes an important section on "induced earthquakes," which are caused when weight is added to the Earth's crust.

See also: Coastline changes; Deglaciation; Earth structure and development; Ice shelves; Lithosphere; Mass balance; Plate tectonics; Volcanoes.

Easter Island

• **Category:** Nations and peoples

• **Definition**

Easter Island is a small island, occupying 163 square kilometers in the Eastern Pacific Ocean. It is considered to be the most remote place on Earth—it is the spot furthest away from any other populated landfall. The island is perhaps most famous for the stone megaliths found there, huge heads with impassive faces called "moai" carved for unknown reasons by the islanders. The island was named Easter Island by a Dutch explorer who landed there on Easter Sunday, 1722. It is called Rapa Nui in the language of those who inhabited the island (who are also called the Rapa Nui) and Isla de Pascua in Spanish. The island is currently Chilean territory.

Some historians believe that Polynesian islanders were the first humans to populate Easter Island in about 700 C.E., while others argue that the island was inhabited as early as 300 C.E. It has had a turbulent history involving European visitors who brought smallpox, the plague, slave raids, and war to the island, decimating the population and contributing to the collapse of its culture and economy. The island's history is complex and subject to ongoing archaeological interpretation.

• **Significance for Climate Change**

Easter Island is often given as an example of a societal collapse that was due, in part, to mismanagement of natural resources. The population of the island has risen and fallen in conjunction with the fluctuations in its ecosystem. Seafaring people from Polynesia arrived on Easter Island perhaps as early as the fourth century, coming to an island that is believed to have been covered in forest. The land was very fertile, and the ease with which food grew led to a rapid increase in the island's population. The Easter Island palm, part of the island's subtropical forest, was tall enough to provide timber suitable for homes and canoes and was also available for fuel.

Present-day Easter Island is deforested; many of its unique tree species are now extinct. Competing theories abound as to how the deforestation occurred—some blame the islanders for using trees to erect their statues or for firewood; others speculate that the Little Ice Age, which occurred between 1650 and 1850, may have affected the island's forests. (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.) Perhaps because of deforestation, the island's soil

Some of the famous megaliths of Easter Island. (©Galina Barskaya/Dreamstime.com)

has eroded over the years. This erosion may have also been sped along by agricultural development, including sheep farming.

As the island became deforested and the soil became less fertile, the islanders' entire community structure disintegrated. Resources were consumed steadily with no conservation plan. People began to live in caves rather than in homes, because wood was no longer available, and it is thought that the islanders were also unable to build canoes, although they may have built canoes out of reeds rather than trees.

As deforestation and soil erosion led to extinction of the trees and reeds, the Rapa Nui people were unable to build new canoes, so they began to eat birds and mollusks rather than fish and sea mammals. Eventually, the birds on the island, both native and migratory, neared extinction. With no birds to pollinate the trees and other forest plants, the deforestation of the island increased. With food and fuel diminishing rapidly, the islanders' quality of life suffered dramatically.

By the time of European contact, Easter Island was nearly completely deforested, and the islanders were malnourished by their limited diet. The ships that arrived from Europe brought smallpox, which led to a severe decline in the island's population. European contact also led to slave raids on the islanders. Interisland wars over food and other resources may have contributed to the island's population decline as well. These factors, in addition to the mismanagement of the island's ecosystem, eventually led the island's population to shrink dramatically. In 1877, Easter Island was home to only

111 humans. In 2002, the population had rebounded to 3,700.

European ships also contained rats, which helped destroy many of the native seabird and landbird species on the island. They also brought chickens, which helped destroy many of the insect and plant species. Rats also contributed to the extinction of the Easter Island palm by eating its seeds.

Marianne M. Madsen

• **Further Reading**

Arnold, C. *Easter Island: Giant Stone Statues Tell of a Rich and Tragic Past.* New York: Clarion Books, 2004. Includes information about decimation of natural resources on the island. Includes color photos, maps, a complete glossary, a chronology, a bibliography, and a pronunciation guide.

Bahn, P. *The Enigmas of Easter Island.* New York: Oxford University Press, 2003. Discusses Easter Island as an example of "eco-stupidity"; includes analysis of destruction of the ecosystem.

Fischer, S. R. *Island at the End of the World: The Turbulent History of Easter Island.* London: Reaktion Books, 2006. Discusses social and cultural history of the island.

Loret, J., and J. Tanacredi, eds. *Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm.* New York: Springer, 2003. Discusses the effects of human population growth and climate change on the island on its ecology.

Routledge, Mrs. Scoresby. *The Mystery of Easter Island.* Reprint. New York: Cosimo Classics, 2007. An account by an archeologist studying the island in 1913. Includes native folklore, culture, and traditions.

Van Tilburg, J. *Easter Island: Archaeology, Ecology, and Culture.* London: British Museum Press, 1994. Offers an account by the current leading authority on Easter Island. Discusses the cultural, ecological and archaeological history of the island and its people.

See also: Alliance of Small Island States; Coastal impacts of global climate change; Islands; Maldives; Mean sea level; Sea-level change; Sea surface temperatures.

Eastern Europe

• **Category:** Nations and peoples

• **Key facts**

Population: 120,154,616 (2008-2009 estimates)

Countries: Albania, Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, and the former Yugoslavia (now consisting of Bosnia-Herzegovina, Croatia, Kosovo, Macedonia, Montenegro, Serbia, and Slovenia)

Area: 1,166,322 square kilometers

Gross domestic product (GDP): $1.919 trillion (purchasing power parity, 2008-2009 estimates; several countries in the former Yugoslavia have large informal economies up to 50 percent as large as their official economies)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 955.6 in 2006 (excluding former Yugoslavian nations)

Kyoto Protocol status: Accepted or ratified by Czech Republic (2001), Hungary (2001), Romania (2001), Bulgaria (2002), Poland (2002), Slovakia (2002), Slovenia (2002), Albania (2005), Bosnia-Herzegovina (2007), Croatia (2007), Macedonia (2005) Montenegro (2007), and Serbia (2007); not signed by Kosovo as of 2009

• **Historical and Political Context**

Prior to the twentieth century, most of Eastern Europe, with the exception of Poland, was part of the Austro-Hungarian or Ottoman (Turkish) Empire. Bulgaria, Romania, and Serbia gained their independence from the Ottoman Empire during the nineteenth century. Following the defeat of Austria-Hungary during World War I (1914-1918), the Austro-Hungarian Empire was broken into several countries by the victors. Some of the resulting nations, such as Austria itself and Hungary, are defined by fairly natural and stable cultural and geographic boundaries. The Slavic portions of the empire were grouped into two collective countries, Czechoslovakia (reflecting its Czech and Slovak ethnicity) and Yugoslavia ("land of the southern Slavs," from the Slavic root *yug,* meaning "south"). Neither of these two entities remained intact.

A further legacy of imperial rule in Eastern Europe is that there are many cultural minorities living in enclaves surrounded by other ethnic groups. When these regions were ruled from a distant imperial capital, an ethnic patchwork made little difference. However, when the empires dissolved, many ethnic groups found themselves in countries ruled by hostile groups, or outside their ethnic homelands. In Czechoslovakia, ethnic differences led to peaceful division, but in the former Yugoslavia, ethnic tensions erupted in civil war. The tendency of countries in the Balkan region (the portion of Eastern Europe between the Adriatic and Black Seas) to fragment has been noted for a long time and has given rise to the term “Balkanization.”

All the Eastern European countries were either allied with or occupied by Nazi Germany during World War II. The Soviet counterattack led to Soviet military occupation of most of Eastern Europe. Yugoslavia and Albania expelled German forces on their own and were not occupied, but installed their own communist regimes. By 1948, communist governments had been established in all Eastern European countries. Communism was an attempt to implement the political and economic theories of Karl Marx. Under communism, the state owned all means of industrial production, though in practice varying degrees of legal and extralegal private enterprise existed as well. As an economic system, communism proved to be inefficient, since there were few incentives for efficiency. Moreover, there were no adequate means of accurately determining market needs or setting appropriate prices. Ultimately, however, the most destructive feature of communism was its stifling of dissent, which served to conceal corruption and poor environmental practices. More important, the suppression of criticism prevented communist governments from knowing how urgently reform was needed until it was too late.

Since most of the Eastern European governments were highly subservient to the Soviet Union, they were commonly called “satellites.” In 1955, all the countries of Eastern Europe except Yugoslavia joined the Soviet Union in a military alliance commonly called the Warsaw Pact. Albania later left the alliance as well. An attempt by Hungary to overthrow its communist government was crushed by Soviet invasion in 1956, and Czechoslovakia was occupied by the Soviet Union in 1968, when reforms by the Czech government were seen as threatening. Nevertheless, countries such as Poland, Czechoslovakia, and Hungary tried to liberalize their economies within the limits set by Soviet tolerance. Hungary, in particular, instituted economic policies that accommodated a great deal of capitalism. The Cold War—the name given to the period of tension between the United States and the Soviet Union—ended with the dissolution of the Soviet Union in 1991. Over the next few years, communist governments were dissolved in all the countries of Eastern Europe.

• Impact of Eastern European Policies on Climate Change

Because Eastern Europe was economically and militarily dominated for decades by the Soviet Union, its policies during the Cold War were largely dictated by the Soviet Union. The economic emphasis in the years after World War II ended (in 1945) was on reconstruction, followed by an emphasis on heavy industry. With repression of dissent and little opportunity for public participation in government, environmental issues received little attention; greenhouse gas (GHG) emissions began to be seen as an important issue only about the time of the breakup of the Soviet Union, in 1991. Since 1991, the countries of Eastern Europe have tended to adopt Western European practices and policies.

In 1997, Poland, the Czech Republic, Slovakia,

Ranking Eastern European Corruption

Nation	*Corruption Perceptions Index*
Czech Republic	45
Hungary	47
Slovakia	52
Poland	58
Croatia	62
Romania	70
Bulgaria	72
Macedonia	72
Albania	85
Montenegro	85
Serbia	85
Bosnia-Herzegovina	92

Source: Transparency International.

Hungary, Slovenia, Romania, and Bulgaria applied for admission to the European Union. All except Romania and Bulgaria were admitted in 2004. Romania and Bulgaria were admitted in 2007. Macedonia and Croatia have applied for admission. All Eastern European countries, except Kosovo, have ratified or accepted the Kyoto Protocol.

• Eastern European Nations as GHG Emitters

The Kyoto Protocol calls for signatories to reduce their GHG emissions relative to 1990 emissions—that is, relative to levels before the dissolution of the Soviet Union. The economic turmoil following the breakup of the Soviet Union caused all countries of the former Soviet Union and the countries of Eastern Europe to suffer serious economic declines. The former Yugoslavia, though not a Soviet satellite, nevertheless suffered its own breakup in the 1990's and also experienced serious economic decline. As a result, despite having a great deal of inefficient and antiquated infrastructure, the nations of Eastern Europe are well below their Kyoto emissions targets. Their total emissions, roughly the equivalent of a billion tons of carbon dioxide, are approximately a third lower than their targets, which are about 1.3 billion tons. The economic cloud over Eastern Europe has its silver lining: Eastern European countries have large emissions allowances that can be traded, as well as a substantial margin for growth.

• Summary and Foresight

Eastern Europe is characterized by several themes. First is the legacy of domination by the Soviet Union: inefficiency, corruption, and in some areas organized crime. Inexperience with market economies has led to conditions such as severe inflation in Bulgaria in 1997 and the collapse of the Albanian economy through pyramid investment schemes that same year. Transparency International, which publishes a Corruption Perceptions Index based on a variety of reports by business, government, and human rights groups, gave Slovenia the highest (least corrupt) ranking, at number 26 of 180 countries surveyed in 2008—comparable to some Western European countries. Several other Eastern European countries had much lower ratings. Nevertheless, all Eastern European countries had substantially less corruption than Russia, which ranked 147th.

Unresolved ethnic tensions continue to be important in Eastern Europe. Ethnic Albanians are split between Albania itself and the neighboring region of Kosovo in former Yugoslavia. Kosovo, in turn, contains Serbian enclaves that object to separation from Serbia. There is a significant Hungarian population in northern Serbia and southern Slovakia. The independent country of Moldova is a former slice of Romania annexed by the Soviet Union. Greece objects to the name Macedonia out of concern that it might serve to justify claims on territory in Greece that is also called Macedonia. As a result, the nation of Macedonia is officially called by the cumbersome title Former Yugoslav Republic of Macedonia.

Some Eastern European countries, especially those that had democratic and capitalist traditions before Soviet domination, have successfully resumed their previous courses. Considering the repressive governments of the Cold War era, the countries of Eastern Europe have made remarkable progress toward democratization. The Czech Republic, Poland, Slovakia, Slovenia, and Hungary are all rated 1 for political and civil liberty by Freedom House, the highest rating. Bulgaria, Croatia, and Romania are rated 2, that is, highly free but with some restrictions. Albania and the countries of former Yugoslavia are mostly rated 3 in each area, that is, partly free. The lower ratings in these countries stem from weak democratic traditions and the aftereffects of strife during the breakup of Yugoslavia. In contrast, Russia in 2009 rated 6 in political freedom and 5 in civil liberties.

All the Eastern European countries, except disputed Kosovo, have signed and ratified the Kyoto Protocol. They are less developed than the countries of Western Europe, and as they seek to grow economically they will face the interlocking problems of meeting increased consumer demand while simultaneously attempting to replace inefficient infrastructure and reform environmental safeguards. However, like Russia, the comparatively low level of industry in Eastern Europe, plus the drop in productivity during the transition from communist to capitalist economies, gives these countries a significant buffer zone that will enable them to grow but still remain within their Kyoto targets. Eastern Europe is about one-third below its

Kyoto emissions target. Also, replacement of aging and obsolete infrastructure will enable the nations of Eastern Europe to install more environmentally friendly infrastructures rather than having to grapple with modifications of existing ones. Finally, membership in the European Union gives the member countries of Eastern Europe access to funding for development.

Steven I. Dutch

• Further Reading

Bideleux, Robert, and Ian Jeffries. *A History of Eastern Europe: Crisis and Change*. New York: Routledge, 2007. Traces the history of Eastern Europe from Greco-Roman times to the present. Roughly a quarter of the book deals with the Cold War and its aftermath.

Douma, W. Th., L. Massai, and M. Montini, eds. *The Kyoto Protocol and Beyond: Legal and Policy Challenges of Climate Change*. West Nyack, N.Y.: Cambridge University Press, 2007. Includes chapters on the Russian Federation and on non-Annex I Eastern European nations.

United Nations Industrial Development Organization. *Regional Forum on Industrial Cooperation and Partnership in Central and Eastern Europe and the Newly Independent States*. [Vienna]: Author, [2006]. The second of the three sessions documented here addressed environmental management, climate change, and industrial energy efficiency.

See also: Europe and the European Union; Kyoto Protocol; Poland; Ukraine.

Ecocentrism vs. technocentrism

• Category: Environmentalism, conservation, and ecosystems

• Definition

"Ecocentrism" is a label for views that place at the center of moral concern the relationship of human beings to the Earth. "Technocentrism" is a label for views that explicitly or implicitly locate the center of moral concern in human technical and technological capabilities. Technocentrists see the solution for woes brought on by human ingenuity as more ingenuity, while ecocentrists in contrast believe that humans must find and respect their proper place in the world, rather than seeking to use technology to transcend it. Technocentric ambitions seem to ecocentrists to be expressions of arrogance or hubris, and ecocentric pieties seem to technocentrists to acquiesce in mysticism and passivity in the face of nature's hard challenges.

• Significance for Climate Change

In the light of the prospect of global climate change, ecocentrists tend to seek solutions that involve changing destructive practices and undoing the lifestyle choices that have brought humans to the present crisis. Technocentrists, on the other hand, tend to look for a technical fix. Julian Simon is an example of a technocentric enthusiast. For him, human beings are the ultimate resource, so the more of them there are, the better the prospects for solving the world's problems, including environmental challenges. For those who agree with Simon, popular claims about resource scarcity—and, accordingly, calls for scaling back enterprise—sell short the fecundity of human powers of imagination and invention. To technocentrists, calls to sacrifice ambitions of development are premature, because they ignore the likelihood that seemingly overwhelming problems will yield to unforeseeable technical innovations.

The value of civilization, if not the skills that make society itself possible, has been in question at least since the reaction to the Enlightenment of the Romantic movement (growing out of the work of the Swiss-French philosopher Jean-Jacques Rousseau and the English poet William Blake, among others). The German philosopher Martin Heidegger traces the woes of the modern worldview, which he refers to as "the enframing," back to Plato and other ancient Greek thinkers. In more recent times, such thinkers as Henry David Thoreau, Aldo Leopold, Wendell Berry, Arne Naess, and various other exponents of deep ecology have called for a radical reconsideration of the place of human experience, and even of animal sentience itself, in the vast, interconnected web of nature.

Though their call for a better relation to nature predates concern with global warming, the dire consequences of climate change constitute for ecocentrists an object lesson in human arrogance and exploitation. On this view, salvation from human folly is to be found only in a pared-down existence: a life simpler, closer to the soil, and more local in scale and scope. What is wrong can only be fixed by relinquishing human presumption and acquiescing in limits that are natural, if not divine. This view accordingly holds that "small is beautiful," and urges people to reduce their carbon footprint.

For their technocentric opponents, such attitudes not only underestimate human creativity in meeting challenges and solving problems but also sacrifice too readily the prospects of socially disadvantaged individuals and groups: Economic opportunity and social justice, they believe, will require continuation on the path of development and discovery. Moreover, it may seem presumptuous to believe humans could possibly encompass within their time-bound minds all of the relevant aspects and possibilities. For technocentrists, the imperative is to continue to re-create the world in humanity's own, reasonable image, while for the ecocentrists, it is to rethink fundamentally humanity's place in the world.

Edward Johnson

• Further Reading

Ehrenfeld, David. *The Arrogance of Humanism.* New York: Oxford University Press, 1978. A sweeping critique of human-centered (including technocentric) attitudes.

Kunstler, James Howard. *The Long Emergency: Surviving the Converging Catastrophes of the Twenty-first Century.* New York: Atlantic Monthly Press, 2005. Bleak and sobering forecast of the collapse of the world's "cheap-oil fiesta" and of the ensuing postindustrial constraints and disasters.

Naess, Arne. *The Ecology of Wisdom: Writings by Arne Naess.* Edited by Alan R. Drengson. New York: Counterpoint, 2008. Collection of essays by the Norwegian philosopher often regarded as the founder of the deep ecology movement.

O'Riordan, Timothy. *Environmentalism.* London: Pion Books, 1981. The original application of the specific terms "ecocentric" and "technocentric" to the contrasting views described.

Ponting, Clive. *A New Green History of the World: The Environment and the Collapse of Great Civilizations.* Rev. and expanded ed. New York: Penguin, 2007. Provides a stunning long-term view of human history that sees the original wrong turning as the development of agriculture.

Quinn, Daniel. *Beyond Civilization: Humanity's Next Great Adventure.* New York: Crown, 2000. The famous ecocentric novelist proposes that the human future lies in a rejection of civilization and the embrace of a "new tribal revolution."

Rodman, John. "The Liberation of Nature." *Inquiry* 20, no. 1 (1977): 83-145. An early philosophical examination of what an alternative to sentience-based ethics might look like.

Simon, Julian. *The Ultimate Resource 2.* Princeton, N.J.: Princeton University Press, 1998. Upbeat, technocentric assessment of environmental problems, including a skeptical approach to global warming, in light of the author's conviction that having more people means better prospects for discovering ingenious solutions to human problems.

Zerzan, John. *Twilight of the Machines.* Port Townsend, Wash.: Feral House, 2008. A radical ecocentric comparison of productionism and the primitive future as fates for the human species, which argues for voluntary abandonment of the industrial mode of existence.

Zimmerman, Michael. *Contesting Earth's Future: Radical Ecology and Postmodernity.* Berkeley: University of California Press, 1994. A Heideggerian philosopher's sympathetic critique of deep ecology and other ecocentric approaches to environmental issues.

See also: Anthropogenic climate change; Civilization and the environment; Conservation and preservation; Economics of global climate change; Environmental economics; Environmental movement; Human behavior change; Technological change.

Ecological impact of global climate change

• **Category:** Environmentalism, conservation, and ecosystems

Anthropogenic climate changes, especially global warming, have affected terrestrial, freshwater, and marine ecosystems in the past few centuries. If the Earth's average global temperature continues to increase, these ecosystems will change even more radically in the future.

• Key concepts

anthropogenic: caused by humans

biodiversity: the entire variety of living organisms in a given location, from the local to the global

biosphere: the ecological zones on Earth where life is found, whether on land, in the water, or in the air

ecological niche: the relational position of a species in an ecosystem with respect to all other species, resources, and physical and chemical factors affecting life and reproduction within that ecosystem

ecosystem: a community of different species interacting with each other and with the nonliving environment

extinction: the total disappearance of a species from the Earth

greenhouse gases (GHGs): lower atmospheric gases, such as water vapor and carbon dioxide, that trap heat radiated from the Earth's surface

• Background

Long before the appearance of *Homo sapiens*, periodic momentous climate changes had devastating effects on Earth's ecosystems. For example, 245 million years ago, a colossal effusion of greenhouse gases (GHGs) from massive volcanoes raised average global temperatures by 5° Celsius, leading to the demise of over 90 percent of living things in the great Permian-Triassic extinction. Humans, in the few million years they have lived on Earth, have not had as cataclysmic an effect on the biosphere as have natural climatic catastrophes. However, over time and particularly since the development of advanced industrialized societies, they have been having an increasingly potent effect on the Earth's climate, which in turn has led to the decline and even the extinction of many species.

• Effects of Global Climate Change on Plants

The response of the Earth's land and water vegetation to anthropogenic climate change is extremely complex and varied, extending from photosynthesis in relatively simple microscopic plants to the global distributions of highly variegated plant species. Scientists researching climate-induced environmental changes and the effects of those changes have concentrated on a careful selection of flora in the distant and recent past. They have then extrapolated from those focused studies of the past to draw conclusions about present and future time periods, mainly through computer models. Paleobotanists have discovered how some large ecosystems dominated by plants responded to global climate changes in prehistoric ages, but this understanding has not been easily applicable to modern conditions. More secure understanding has resulted from studies of how vegetation responded to the climate changes during the ice ages: Migration proved a means for many species to survive glacial and interglacial climates.

While, in recent centuries, the greatest threat to plant species has been from their unsustainable harvesting by humans and the elimination of their habitats, anthropogenic global warming has also had an influence on certain plant distributions. For example, with a temperature rise of nearly 2° Celsius in the boreal zone of North America, conifer forests have moved closer to polar regions. Certain computer models relating global warming and plant survival have predicted future changes in the species composition and locations of forests, while still other forests may desiccate, burn, and disappear completely. In tropical rain forests, certain orchids are rare, because they have highly unusual ecological niches. If their environments are climatically transformed, these orchids often prove to be mediocre migrants. Some plant species, unable to tolerate warmer fresh and salt waters, will become extinct, while climate-caused habitat loss will lead to other plant extinctions. Flooding of coastal estuaries and wetlands may further the destruction of plants unable to adapt to the changed conditions.

• Effects of Global Climate Change on Animals

The abundance, distribution, and ecological niches of animal species will continue to be affected by changing climatic factors. As the climate warmed at the end of the ice ages, some species expanded their ranges while other species migrated to new regions. This postglacial warming resulted in the extinction of many species of large mammals, including the wooly mammoth. Many scientists believe that climate played a role in these extinctions. Analogously, many scientists believe that in the past few centuries, when human activities have contributed to global warming, elevated global temperatures have affected certain animal species.

The declining numbers of amphibians is an important example of this phenomenon. From 1975 to 2000, certain Costa Rican forests warmed significantly, causing shifts in the habitats of birds, reptiles, and amphibians. Some frogs, unable to adapt to these changes, became extinct, while others became endangered or critically threatened. Not all scientists are convinced that climate change is to blame for amphibian declines, however. Some cite pollution and fungus as possible alternate causes. Another often-cited example of a declining species is the polar bear. From 1975 to 2005, Arctic sea ice shrank by about 20 percent, reducing the bears' access to seals, their main prey. In the two decades from 1985 to 2005, polar bear populations fell by over 20 percent.

Because of the many variables contributing to the decline of various animal species, it has been difficult to determine with precision the role that global warming has played in these declines. Nevertheless, certain scientists have used computer models to issue warnings that accelerated global warming will inevitably lead to the extinction of many animal species. In 2004, the United Nations published a report based on the expertise of many scientists that estimated a million species of plants and animals could become extinct by 2050, unless global warming can be stopped. Environmentalists think that the ecosystems most likely to experience the greatest species loss are polar seas, arctic tundra, and coastal wetlands.

• How Species Cope with Climate Change

Nature has provided species of plants and animals with a powerful mechanism of coping with environmental changes, including climate changes. Charles Darwin, who discovered this mechanism and showed how it could account for the origin and evolution of species, called it natural selection. Throughout the long history of life on Earth, plants and animals have had to adapt to changing environmental conditions, often gradually, sometimes dramatically. After the appearance of *Homo sapiens* and human technology, plants and animals were forced to accommodate themselves to various anthropogenic changes, chief of which were habitat destruction and global climate change.

After the period of the ice ages, many species of plants and animals had to adjust to warmer climates, and paleobotanists, paleozoologists, and paleoclimatologists have studied how various species responded. In general,

A polar bear stands on summer pack ice, hunting for seals. As such pack ice becomes sparse, the bears have difficulty finding their prey. (B & C Alexander/Photoshot/Landov) because of shifting climate zones, species often migrated to live in ecological niches similar to those to which they had become accustomed. Temperate-zone species moved north, and polar species migrated more deeply into arctic regions. By studying numerous species, scientists have been able to quantify the extent of migration as zonal temperatures rose. Specifically, pollen records from northern Europe and eastern North America have revealed migration rates between 0.02 and 2 kilometers per year, with an average of about 0.4 kilometer per year, though scientists note that migration rates differed widely from species to species. These variations are evidence that some species were unable to keep up with climate change, and this probably played a role in their extinction rates.

Although migration routes for species other than trees are not so well known, the evidence that has been gathered and studied indicates that such organisms as snails, mayflies, and beetles responded to climate changes much faster than did trees. During the past few centuries of anthropogenic climate warming, examples of both range expansions and range contractions have occurred. Ornithologists have observed range extensions for some bird species, and zoologists have found rates of nearly 50 kilometers per year for certain mammals. Those species that are able to expand their midlatitude ranges may be able to cope with the future rise of global temperatures.

On the other hand, some plants and animals have experienced problems in adapting to warming temperatures, especially when new conditions have exceeded their physiological limits or destroyed their ecological niches. For example, multiyear droughts in the southern United States have caused the contraction and destruction of various salt marshes along the southeast and Gulf coasts, precipitating the loss of many species (though some species, such as certain snails, increased their numbers when their predators declined). Anthozoan polyps of coral reefs, which are very sensitive to increases in ocean temperatures, have experienced widespread declines. For example, in 1998, a 1° rise in the Indian Ocean's temperature led to the destruction of over 80 percent of the coral reefs. Nearly all the reefs surrounding the Maldives and Seychelles disappeared.

• Possible Future Scenarios

Scientists who use computer models to predict the possible ecological effects of global warming generally issue caveats about the uncertainty of their predictions, since these models necessarily involve gross oversimplifications. Nonetheless, this practice has not prevented some researchers from warning of massive extinctions produced by rising sea levels and rapidly transformed ecological zones. There are also more hopeful scientists, who, basing their models on the abilities of ancient plants and animals that adapted to disastrous climate changes, believe that global warming may bring about the flourishing of many species, particularly plants that will find high carbon dioxide levels and warm temperatures favorable to their development. Between these extremes are scientists who, like medical doctors employing the principle of *primum non nocere* ("first, do no harm"), urge their fellow humans to be very careful as they modify the Earth's temperature, since living things will most likely continue to interact in complex and unexpected ways.

In constructing their scenarios for the future, scientists have used the growing body of evidence about how plants and animals have responded to climate change in the distant as well as recent past. Several scenarios predict that global warming will inevitably lead to large elevations of sea level and the massive melting of ice in the polar regions. This would lead in turn to both habitat destruction and habitat creation, during which some species adapt and increase in numbers, while others, because they fail to adapt, become extinct. If global warming continues to accelerate, some scientists predict, extinction rates will increase, leading to a loss of plants and animals second only to the gargantuan extinctions during the Cretaceous-Tertiary cataclysm of 65 million years ago. Some pessimists contend that this massive extinction cannot be halted, only slowed. Optimists, however, point out that extraordinary changes also create extraordinary opportunities for adaptive innovations.

• Context

Much of the analysis of the effect of global warming on biodiversity has taken place in the context of a human population whose numbers have dramatically increased in the past few centuries and may continue to increase in the future. If certain plant species (such as trees used for lumber and paper) expand their ranges, then humanity may benefit, but if habitats for edible fish are destroyed by warmer ocean temperatures, then the effects on humanity will be negative. Physicians at the Center for Health and the Global Environment at Harvard Medical School have shown how human health profoundly depends on biodiversity. For example, many important drugs derive directly or indirectly from plant species. Furthermore, if global warming increases the numbers of insects that carry such viral diseases as dengue, encephalitis, and yellow fever, this would seriously endanger human health. Ecosystems have served humanity well throughout its history, but many concerned scientists now believe that numerous plant and animal species in these ecosystems are threatened by human activities that these scientists feel sure have been definitely linked to global warming. However, what humans have done, humans can undo.

Robert J. Paradowski

• Further Reading

Chivian, Eric, and Aaron Bernstein, eds. *Sustaining Life: How Human Health Depends on Biodiversity*. New York: Oxford University Press, 2008. This lavishly illustrated, oversize book is aimed at both general readers and scholars. One of its themes is the threat posed by global warming to plants and animals that are beneficial to humans. Appendixes, references, index.

Cowie, Jonathan. *Climate Change: Biological and Human Aspects*. New York: Cambridge University Press, 2007. This introductory text has sections on the past, present, and future effects of climate change on plants and animals. Illustrations, figures, tables, references, appendixes, index.

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming*. Rev. ed. London: Penguin, 2007. A scientist and conservationist surveys the history of climate change for the general reader. Beside dealing with its effects on plants and animals, Flannery also offers specific suggestions for politicians and citizens to reduce global warming. Illustrations, chapter notes, index.

Woodward, F. I., ed. *Global Climate Change: The Ecological Consequences*. San Diego, Calif.: Academic Press, 1992. Collects articles by climatologists, atmospheric scientists, and ecologists that discuss the interconnections between climatic and biological systems. Though written by academics for academics, the articles are sufficiently general to be understandable by readers with modest scientific backgrounds. Maps, charts, graphs, references, index.

See also: Amphibians; Convention on International Trade in Endangered Species; Endangered and threatened species; Invasive exotic species; Polar bears.

Economics of global climate change

• **Category:** Economics, industries, and products

Policy makers rely on natural scientists to explain the causes and likely physical consequences of climate change, but they also need economists to provide estimates of the costs of mitigation strategies and to offer guidance on balancing costs in the present against potential damages in the future.

• Key concepts

cap and trade: a system in which the government limits total carbon dioxide emissions but allows individual emitters to buy and sell permits giving legal permission to portions of the total cap

carbon tax: a tax on activities that lead to carbon dioxide emissions, designed to “internalize the externalities” of such emissions

discount rate: the percentage discount to be applied per unit of time in order to account for the higher weight given to costs and benefits that occur sooner

inefficiency: preventable waste in the use or distribution of resources

leakage: the shortfall in targeted greenhouse gas emissions reduction caused by industries relocating to jurisdictions with weaker regulation *negative externality:* a situation in which market prices do not reflect the full social costs of some behavior

• Background

Many scientists argue that human activities release greenhouse gases (GHGs) that cause climate changes that will impose harms on future generations. Economists classify such activities as negative externalities that may require corrective policies. Measures that reduce carbon dioxide (CO_2) emissions will cause economic hardship in the present, but their benefit will be lower damages from climate change in the future. Economists already have tools to analyze trade-offs between present costs and future benefits.

• Benefits of Reducing GHG Emissions

The primary benefit of reducing GHG emissions is the expected reduction in damages from climate change in the future. In order to combine various types of damage—such as increased mortality from heat stress, reduction in crop yields, and loss of coastal property—economists must reduce the impacts to a common denominator, namely money.

The monetary damages from future climate change can be quite broad. For example, if climate change leads to more intense hurricanes, the total damages could include not just the money spent rebuilding damaged property, but also the monetary value of the lives lost and even an estimate of the psychological harm suffered by people living with a greater fear of hurricanes. In general, economists prefer cost estimates tied to objective measures, to limit the bias of an individual analyst.

Many economists would not include the creation of new, green industries and jobs to be a net benefit from policies that reduce GHG emissions. While a tax on CO_2 may create jobs in the manufacture of electric cars and solar panels, it would also destroy jobs in the manufacture of SUVs and coal-fired power plants.

• Costs of Reducing GHG Emissions

The costs of climate change policies are the reduced outputs of various goods and services. For example, if the government levies a tax on every ton of CO_2 emitted by a factory, this will increase the cost of production, leading to smaller output and higher prices for the goods produced in the factory. If the factory produces components used in other processes, then the tax will ultimately lead to higher prices for those goods as well.

When a carbon tax or a cap-and-trade program is put in place, the economy will adjust to the new incentives. Producers will strive to maximize their profits, workers will flock to the jobs with the highest salaries, and consumers will shop for the cheapest products. However, any new policy that causes GHG emissions to be lower than they otherwise would have been will necessarily impose economic hardship in the near term. In the absence of such climate policies, the economy would have produced goods and services that emitted a greater amount of GHGs.

Unregulated business does not purposely seek to cause climate damage; it rather seeks to maximize profits by providing consumers with the products they desire at the lowest prices. If government policies force businesses to change their behavior, this results in a lower quantity or quality of output. For example, if it truly were more efficient (disre-

Economics of Climate Change Mitigation

Below is a table of the reduction levels in GHG emissions that have been projected by the Intergovernmental Panel on Climate Change (IPCC) to be achievable in a cost-effective manner: These are the levels of reduction that the IPCC believes can be achieved at a cost of no more than $50 per metric ton of CO_2 equivalent.

Source Sector	*Reduction*
Buildings	5.50
Industry	3.50
Energy supply	3.25
Agriculture	2.75
Forestry	2.00
Transportation	1.75
Waste	0.75

Source: Intergovernmental Panel on Climate Change.

*Amounts are expressed in billions of metric tons of CO_2 equivalent, rounded to the nearest 0.25 billion metric tons.

garding climate change issues) for African nations to build an infrastructure reliant on solar and wind power, then industry would not need special incentives to cause this outcome. The present costs of policies to mitigate climate change may well be justified, in light of the future benefits (reduced climate change damages). Even so, policies leading to lower GHG emissions are costly.

- **Proper Discount Rate to Compare Future Benefits with Present Costs**

In order to determine the relative merits of various climate change policies, including the policy of doing nothing about climate change, economists can first reduce the varied and often qualitative harms of future climate change into an aggregate figure of total monetary damage at each future date. They can perform a similar calculation for the total expected monetary costs of compliance with a given policy for every time period. At each interval of time (for example, every year or every decade) from the onset of the new policy into the future, an economist would then have an estimate of the net costs or benefits from the proposed policy.

Typically, climate change policies impose net costs in the beginning, but at some point in the future yield net benefits, because technology allows for easier compliance with low emission targets, and also because the benefits from reduced climate change grow larger as time passes. The more aggressive the policy—in other words, the harsher the penalties it places on GHG emissions—the higher the net costs in the earlier years, but also the higher the net benefits in later years. By definition, a baseline laissez-faire policy imposes no compliance costs, but eventually yields the largest damages from climate change because of unrestricted GHG emissions. The problem of choosing the most efficient or optimal policy can thus be reduced to choosing the most preferred stream of net costs and net benefits accruing at respective time intervals.

A central concept in economics is the discount rate, which allows one to translate costs and benefits accruing at a future date into their present value. For transactions in the marketplace, the relevant market rate of interest is often used. For example, the owner of a building might consider the installation of insulation that will cost $10,000 up front, but that will reduce heating expenses by $1,200 per year for the next ten years, after which time the insulation will have to be replaced. If there were no discount on future dollars, the insulation would clearly be profitable; it would yield a lifetime savings of $12,000, in contrast to its initial expense of $10,000. However, if the owner could alternatively invest his money in low-risk bonds earning 3.5 percent or more per year, then the insulation would be a poor investment, based purely on monetary considerations. In general, the higher the discount rate, the more present-oriented investors will be; projects that require large upfront expenses, or that do not yield benefits until distant dates in the future, will be penalized, because the early expenses will weigh more heavily than the later benefits.

Once the appropriate discount rate is selected, the various climate change policies can be ranked according to their present value. The lower the discount rate used, the more aggressive will the optimal policy be. This is because aggressive GHG reductions impose higher upfront costs in exchange for greater future benefits, and so their present value increases as a lower discount rate is applied. In contrast, if a high discount rate is adopted, then the optimal policy typically will involve only modest GHG reductions in early years, gently increasing over time as the atmosphere becomes more concentrated with GHGs and climate change damages become less distant in the eyes of policy makers in those time periods.

There are two major controversies among economists regarding this framework for analyzing climate change policies. The first involves adequately dealing with the problem of risk or uncertainty. Unlike stylized scenarios involving cost-saving insulation, the case of climate change involves many unknowns. Many economists argue that the method described above of selecting the best policy may be too risky, and instead they would recommend erring on the side of caution by implementing a more aggressive policy to reduce GHG emissions.

A second controversy lies in the choice of discount rate to be used in the context of climate change trade-offs. Many economists believe market interest rates are inappropriate for matters of public policy, especially ones involving future generations. After adjusting for inflation and specific risks, the "real" rate of return on capital investment in Western economies is estimated at roughly 4 percent per year. This discount rate implies that a climate change policy that imposes compliance costs of $21,000 to people living in the year 2020, but that reduces environmental damages for the people in the year 2120 by $1 million, will be dismissed as too expensive by the earlier generation. Outcomes such as this strike many as selfish.

On the other hand, many economists defend the use of market discount rates. Some discount must be applied, because future generations may be far wealthier than people in the present; it strikes some analysts as unethical to impose compliance costs on developing nations today where many do not have clean water or electricity, in order that (the equivalent of) multimillionaires in the year 2120 might live in a slightly cooler world. There is also the remote possibility that an asteroid collision, nuclear war, or other catastrophe unrelated to climate change could reduce future populations, in which case the total benefits to future humans from reduced GHG emissions would be much lower. In light of these considerations and others, a future dollar in benefits must be weighed less heavily than a present dollar of compliance costs. Many economists favor the choice of the market's discount rate, despite its possible flaws, because it is objectively measurable.

• Context

One of the earliest yet comprehensive works on the economics of climate change was William Nordhaus' 1979 book, *The Efficient Use of Energy Resources.* Since its publication, a growing number of economists have devoted their attention to the many issues involved, ranging from estimates of compliance costs and future damages to fairly technical issues of modeling uncertainty.

Economists can generally be divided into three broad groups in terms of their attitude to climate change. The first group believes that GHG emissions constitute a negative externality, and they recommend a modest carbon tax or other penalty on emissions, which grows over time as climate change damages become more severe. A second group of economists believes the situation is far more serious, and they therefore urge more drastic penalties on emissions. The difference could be due to their reliance on more severe forecasts of future damages or their use of a lower discount rate than the first group. Finally, a third group of economists does not believe the government should take any particular actions regarding climate change, either because they dispute the science underlying the policies or because they believe that politicians cannot be trusted to implement an efficient solution. For example, these skeptics might argue that without worldwide controls on GHG emissions, industries will simply move to unregulated regions, a process known as leakage.

Robert P. Murphy

• Further Reading

Bradley, Robert. *Climate Alarmism Reconsidered.* London: Institute of Economic Affairs, 2003. Bradley holds a Ph.D. in political economy but shows a command of the scientific literature on climate change. He is not a "denier" but argues that a wise understanding of government behavior and unintended consequences should lead to a "look before you leap" attitude regarding massive new programs to combat climate change. Bibliography.

Mendelsohn, Robert, and James Neumann, eds. *The Impact of Climate Change on the United States Economy.* New York: Cambridge University Press, 1999. This collection represents a more optimistic forecast of the impacts of climate change, suggesting that there will be net benefits from a modest warming of 1° or 2° Celsius. The editors argue that other, more pessimistic forecasts make very limiting assumptions on humans' adaptability to climate change.

Nordhaus, William. *The Efficient Use of Energy Resources.* New Haven, Conn.: Yale University Press, 1979. Nordhaus is a pioneer in the economics of climate change, and this is an early yet comprehensive economic analysis of climate change externalities.

_______. *A Question of Balance: Weighing the Options on Global Warming Policies.* New Haven, Conn.: Yale University Press, 2008. Summarizes the latest results of his DICE model of the global climate and economy. Nordhaus favors a carbon tax at an initially modest level that increases over time. Graphs, charts, bibliography.

Stern, Nicholas. *The Economics of Climate Change: The Stern Review.* New York: Cambridge University Press, 2007. Former chief economist for the World Bank, Stern was commissioned by the British government in 2005 to assess the economics of climate change. His aggressive recommendations for rapid reductions in GHG emissions gained worldwide attention and criticism because they deviated from most previous economic analyses. Charts, bibliography.

See also: Air pollution and pollutants: anthropogenic; Basel Convention; Baseline emissions; Carbon dioxide; Carbon footprint; Carbon taxes; Certified emissions reduction; Emissions standards; Employment; Environmental economics; Greenhouse gases; Industrial emission controls; Offsetting; Polluter pays principle.

Ecosystems

• **Category:** Environmentalism, conservation, and ecosystems

Ecosystems influence climate in at least three ways: altering energy balance, regulating water-vapor dynamics via evapotranspiration, and changing GHG cycling in the atmosphere. The ecosystem processes that influence climate change are also influenced by climate, forming ecosystem-climate feedback systems on local, regional, and global scales.

• Key concepts

albedo: the percentage of the solar radiation of all wavelengths reflected by a body or surface

biome: a geographically defined area of similar plant community structure shaped by climatic conditions

canopy: the upper layers of vegetation or uppermost levels of a forest, where energy, water, and greenhouse gases are actively exchanged between ecosystems and the atmosphere

evapotranspiration: processes through which water on surfaces or in plants is lost to the atmosphere

greenhouse gases (GHGs): atmospheric gases that trap heat, preventing it from escaping into space

latent heat flux: the flux of thermal energy from land surface to the atmosphere that is associated with evaporation and transpiration of water from ecosystems

photosynthesis: a metabolic pathway that absorbs inorganic carbon dioxide from the atmosphere and converts it to organic carbon compounds using sunlight as an energy source

respiration: metabolic reactions and processes to convert organic compounds to energy that release CO_2 as a by-product

sensible heat flux: the flux of thermal energy that is associated with a rise in temperature

stoma: a pore in the leaf and stem epidermis that is used for gas exchange

• Background

An ecosystem is a functional system, encompassing all organisms (plants, animals, and microorganisms) and all elements of the nonliving physical environment that interact together in a given area. Organisms extract chemical elements (including water, carbon dioxide, and nutrients) as substrates from the physical environment, using these substrates for their own survival, growth, and reproduction. Physical processes and chemical reactions in the environment are catalyzed by organisms so as to influence energy balance and to form biogeochemcial cycles of carbon, water, and other elements within the system. Ecosystems can be bounded on various scales, from a microcosm to the entire planet.

• Climate and Geographical Distributions of Ecosystems

Various types of ecosystems exist on Earth, including ocean ecosystems, land ecosystems, and freshwater ecosystems on a broad scale. Within land ecosystems, vegetation displays different patterns, forming different ecosystems at regional scales, such as forests, deserts, grasslands, and croplands. Except for artificial ecosystems, patterns of natural ecosystems are primarily shaped by climate conditions (such as temperature and precipitation).

Aldabra, in the Indian Ocean, is the world's largest raised coral atoll and constitutes a unique and fragile ecosystem. (Reuters/Landov)

Along a precipitation gradient from wet to dry regions, ecosystem types change from forests, woodlands, and grasslands to deserts. Along a temperature gradient from the equator to the polar region, ecosystems vary from tropical forests, subtropical forests, temperate deciduous forests, temperature mixed forests, and boreal forests to tundra. In polar climate zones with average temperatures below 10° Celsius in all twelve months of the year, ecosystems include tundra and ice cap in Antarctica and in inner Greenland. Thus, climate and other physical environmental characteristics determine the distribution of ecosystems on the globe.

- **Ecosystem Responses to Climate Change**

Ecosystems are very sensitive to changes in temperature, atmospheric carbon dioxide (CO_2), and precipitation. Rising atmospheric CO_2 primarily stimulates carbon influx, leading to increases in carbon sequestration and thus potentially mitigating climate change. Rising atmospheric CO_2 concentration has relatively minor impacts on canopy energy balance and water exchange at the surface. Climate warming influences ecosystem feedback related to climate change in several ways, such as exchange of greenhouse gases (GHGs), surface energy balance, and water cycling. It is generally assumed that warming affects carbon release more than carbon uptake, leading to net carbon loss from land ecosystems to the atmosphere. Temperature also affects phenology and length of growing seasons, nutrient availability, and species composition. All these processes influence carbon balances, potentially leading to the net carbon uptake from the atmosphere and negative ecosystem feedback to climate warming.

Increasing temperature also stimulates evapotranspiration, resulting in cooler land surfaces in wet regions and thus negative feedback to climate change. The ecohydrological feedback to climate warming via altering land surface energy balance is weak in dry regions. Altered precipitation regimes (that is, alterations in amount, seasonality, frequency, and intensity) under climate change modify ecosystem carbon cycling, energy balance, and water exchange with the atmosphere. Increased precipitation, for example, usually stimulates plant productivity and ecosystem carbon uptake from the atmosphere. Decreased precipitation generally causes land surfaces to be warmer and generates a higher albedo than does ambient precipitation. Impacts of altered precipitation seasonality, frequency, and intensity are complex and region-specific. In addition, precipitation regimes have long-term impacts on soil development, nutrient availability and vegetation distributions, which can be different from short-term impacts of precipitation on ecosystem processes. Moreover, climate change involves a suite of changes in temperature, precipitation, and GHGs. Those global change factors can interactively influence ecosystem processes and their feedback to climate change.

- **Ecosystem Regulation of Climate Change Via Energy Balance**

Land surface energy balance influences the climate system by causing fluctuations in temperature, winds, ocean currents, and precipitation. The surface energy balance, in turn, is determined by fractions of absorbed, emitted, and reflected incoming solar radiation. One of the key parameters to determine the energy balance at the land surface is albedo, which regulates differences between the amount of absorbed shortwave radiation (input) and the outgoing longwave radiation (output). Different vegetation covers have different albedo values. When land use and land cover changes occur due to either climate change or anthropogenic activities, land surface energy balance is altered. Overgrazing, for example, may increase albedo. As a consequence, evapotranspiration decreases with associated decline in energy and moisture transfer to the atmosphere. In general, vegetation absorbs more solar energy, transpires more water, drives more air circulation, and results in more local precipitation in a region with low than high albedo. Thus, ecosystems influence energy balance in the atmosphere and feed back to climate change.

- **Ecohydrological Regulation of Climate Change**

Water vapor exchange at the land surface significantly affects climate dynamics at local, regional, and global scales. Ecosystems receive water input via precipitation and lose water via evapotranspiration. Plant vegetation is the primary regulator of evapotranspiration. Thus, types of ecosystems significantly affect energy and water transfers from ecosystems to the atmosphere.

Because water transpired through leaves comes from the roots, rooting systems play a critical role in ecohydrological regulation of climate. Woody encroachment to grasslands, for example, can accelerate the ecosystem hydrologic cycle and then influence climate dynamics because trees usually have deep taproots to take up water from deep soil layers. Conifer forests can transpire water from the soil to the atmosphere in early spring and late fall and have longer seasons of transpiration than deciduous forests. Conversion of grasslands to winter wheat croplands accelerates evapotranspiration in winter and early spring when wheat actively grows and grasses are dormant. However, evapotranspiration is lower in fallow fields after wheat harvest than in grasslands in summer and fall. In addition, rooting systems are highly adaptive to climate change. When climate warming increases soil temperature and water stress, plants grow more roots to take up water. The adaptive rooting systems can significantly regulate climate change.

- **Carbon-Climate Feedback**

Ecosystems can regulate climate change via changes in uptake and releases of GHGs. The GHGs involved in ecosystem feedbacks to climate change include CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Their uptakes and releases are modified by changes in temperature, precipitation, atmospheric CO_2 concentration, land use and land cover changes, and nitrogen deposition. For example, ecosystems absorb CO_2 from the atmosphere by photosynthesis and release it back to the atmosphere via respiration. Photosynthetically fixed carbon from the air is converted to organic carbon compounds. Some of the carbon compounds are used to grow plant tissues while others are used for plant respiration. Plant tissues die, adding litter to soil. Litter is partly decomposed by microorganisms to release CO_2 back to the atmosphere and partly incorporated to soil organic matter. The latter can store carbon in soil for hundreds and thousands of years.

Many factors and processes can alter the carbon cycles and then influence carbon-climate feedback. For example, deforestation usually results in net release of carbon from ecosystems to the atmosphere, enhancing climate change. Rising atmospheric CO_2 usually stimulates plant growth and ecosystem carbon sequestration, mitigating climate change. Climate warming can stimulate both photosynthesis and respiration. Most models assume that respiration is more sensitive than photosynthesis to climate warming and predict a positive feedback between terrestrial carbon cycles and climate warming. Field experiments, however, suggest much richer mechanisms driving ecosystem responses to climate warming, including extended growing seasons, enhanced nutrient availability, shifted species composition, and altered ecosystem-water dynamics. The diverse mechanisms likely define more possibilities of carbon-climate feedbacks than projected by the current models.

• Context

Ecosystems are basic units of the biosphere. The latter is the global ecological system integrating all living organisms and their interaction with the lithosphere, hydrosphere, and atmosphere. Biosphere-atmosphere interactions occur via exchanges of energy, water, and GHGs in ecosystems. Specifically, ecosystems interact with the atmosphere via emission and absorption of GHGs so as to influence energy balance in the atmosphere; variations in albedo to influence the amount of heat transferred from ecosystems to the atmosphere; and changes in evapotranspiration to cool the land surface, to influence water vapor dynamics, and to drive atmospheric mixing. In addition, ecosystems can influence climate dynamics by changes in production of aerosols and surface roughness and coupling with the atmosphere. Thus, understanding ecosystem processes that regulate energy balances, water cycling, and carbon and nitrogen dynamics is critical to Earth-system science.

Yiqi Luo

• Further Reading

Chapin, F. Stuart, III, et al. "Changing Feedbacks in the Climate-Biosphere System." *Frontiers in Ecology and the Environment* 6 (2008): 313-320. Provides an overview of interrelationships between ecosystems and the climate system in terms of energy balance, water cycling, and greenhouse gas release and uptake in ecosystems.

Chapin, F. Stuart, III, Harold A. Mooney, and Pamela Matson. *Principles of Terrestrial Ecosystem Ecology*. New York: Springer, 2002. Written by three prominent ecologists, this text provides a good introduction for beginners in ecosystem ecology. Comprises four major sections: context, mechanisms, patterns, and integration.

Field, C. B., D. B. Lobell, and H. A. Peters. "Feedbacks of Terrestrial Ecosystems to Climate Change." *Annual Review of Environmental Resources* 32 (2007): 1-29. Reviews major ecosystem processes that potentially result in either negative or positive feedbacks to climate change. Discusses regional differences between those ecosystem-climate feedback processes.

Luo, Y. Q. "Terrestrial Carbon-Cycle Feedback to Climate Warming." *Annual Review of Ecology Evolution and Systematics* 38 (2007): 683-712. Provides an overview of modeling results and experimental evidence regarding carbon cycle-climate change feedback. Summarizes major regulatory mechanisms underlying the carbon-climate feedbacks, including extended growing seasons, enhanced nutrient availability, shifted species composition, and altered ecosystem-water dynamics in response to climate warming.

See also: Coastal impacts of global climate change; Deserts; Estuaries; Evapotranspiration; Islands; Tundra; Wetlands.

Ecotaxation

• **Category:** Laws, treaties, and protocols

• **Definition**

Ecotaxation is the use of tax policy to discourage economically inefficient behavior that harms the environment. According to most economists, an unregulated market economy would fail to provide socially ideal or efficient outcomes because of negative externalities. A negative externality is the harm caused to unrelated third parties when two people engage in a market transaction, such as a customer buying a car made in a factory that releases pollution. To deal with negative externalities, most economists endorse a tax on the behavior causing the harm, referred to as a Pigovian tax after economist Arthur Pigou (1877-1959). If correctly calibrated, a Pigovian tax causes the producer to "internalize the externality." A Pigovian tax is thought to promote economic efficiency, because the tax forces individuals to take into account the full consequences of their behavior. After imposing the correct Pigovian tax, the government can allow citizens to make their own decisions without further regulations. Further measures to achieve environmental goals are unnecessary, because market prices, corrected by the Pigovian tax, guide individuals' behavior and lead to a socially desirable outcome.

• **Significance for Climate Change**

If industrial processes and land-use changes are causing climate change that imposes harm on people in the present or future, then these activities suffer from large negative externalities. For example, when motorists drive vehicles with poor gas mileage or when an electric utility builds a coal-fired power plant, they are not adequately accounting for the extra climate change damages that others will suffer because of their behavior. But if the government raised taxes on gasoline or imposed a tax on utilities based on the amount of carbon dioxide (CO_2) released into the atmosphere, then motorists and utilities would alter their behavior in ways that ultimately reduced anthropogenic climate change. People would still act in their own interest, but the new incentives would ensure that their selfish interests did not jeopardize the welfare of others or of future generations.

Because taxation discourages an activity, most economists favor a policy of "taxing bads, not goods." For example, if the government raised taxes on activities that emit CO_2, and used the new revenues to reduce personal income taxes, then citizens would have the incentive to produce more output but in an environmentally friendlier way. Most economists believe that a correctly calibrated Pigovian tax on environmentally harmful activities, accompanied by dollar-for-dollar tax cuts on economically productive activities, would promote economic efficiency. Many proponents of ecotaxation recommend such offsetting tax cuts on other activities in order to overcome political opposition to tax hikes.

Robert P. Murphy

See also: Air quality standards and measurement; Carbon taxes; Clean Air Acts, U.S.; Emissions standards; Environmental law.

Ecoterrorism

• **Category:** Environmentalism, conservation, and ecosystems

Ecoterrorists commit crimes, primarily arson and vandalism, against entities that they think are harming the environment. Such acts have generally represented reactions to local problems. Because climate change is a global problem, however, there is concern that ecoterrorism could also become a global problem.

• **Key concepts**

Earth Liberation Front: a loosely organized movement often claiming or associated with ecoterrorism acts in the United States

ecotage: vandalism and direct action taken against corporate polluters

environmental terrorism: acts of violence intended to harm the environment or deprive people of environmental benefits or resources *tree spiking:* a form of vandalism that involves hammering a metal or ceramic spike into a tree to discourage logging

• Background

Ecoterrorism refers collectively to a variety of criminal acts undertaken in the name of protecting nature while specifically not intending to harm humans. In response to a series of high-profile acts of arson connected to the Earth Liberation Front (ELF), in 2002 the U.S. Federal Bureau of Investigation (FBI) created a new definition of ecoterrorism: "the use or threatened use of violence of a criminal nature against innocent victims or property by an environmentally oriented, subnational group for environmental-political reasons, or aimed at an audience beyond the target, often of symbolic nature."

• Evolution of Ecoterrorism

The contemporary construct of ecoterrorism evolved from three terms: ecotage, environmental terrorism, and terrorism. Environmental terrorism has come to mean acts of terrorism against the environment, whereas ecoterrorism refers to terrorist acts undertaken in the perceived interests of the environment. Ecotage entered the American national lexicon in 1972, with the publication of the book *Ecotage!* (1972). The book, published by the national environmental group Environmental Action, was based on a 1971 national contest in which suggestions of ecotage were elicited to make "corporate polluters shape up," garnering the attention of the national media. Ecotage dissipated and fell out of favor, in part because a series of landmark federal antipollution laws were enacted between 1972 and 1975. Prior to 1971, few federal environmental laws existed.

In 1975, Edward Abbey's book *The Monkey Wrench Gang* was published, describing the exploits of the fictional character George Washington Hayduke III, who returns from Vietnam to the desert to find his beloved wilderness threatened by development. Hayduke and a cast of characters join to wage war on construction equipment, dam construction, and road builders. The publication of this book fueled a growth in ecotage, then referred to as "monkeywrenching," especially in the southwestern United States through the vandalizing of billboards and construction equipment. In the early 1980's, tree spiking, a form of vandalism that involves hammering a metal or ceramic spike into a tree to discourage logging, became popular in response to logging old-growth trees in national forests. Although originally the realm of individuals, ecotage began to be seen as a legitimate organizational philosophy through such groups as Earth First!, Greenpeace, and the Sea Shepard Conservation Society.

Beginning in 1990, a number of high-profile events changed the construct of ecotage and monkeywrenching into a more radical, violent, and socially unacceptable act. This included the arrest of Dave Foreman, cofounder of Earth First! In 1991, during the Gulf War, Saddam Hussein intentionally ordered two large oil spills in the Gulf and the detonation of more than twelve hundred oil wells, resulting in numerous fires. In response, President George H. W. Bush branded Saddam Hussein's actions as ecoterrorism. In the mid-1990's, the infamous Unabomber, Ted Kaczynski, received national attention as a labeled ecoterrorist resulting from his mailing of bombs to various corporate offices for anti-environmental actions. His bombing campaign resulted in three deaths and multiple injuries.

Time Line of Ecoterror Incidents

Year	*Incident*
1998	Arson of a U.S. Department of Agriculture animal damage control building near Olympia, Washington, resulting in $2 million in damages
1998	Arson of a Vail, Colorado, ski resort, resulting in $12 million in damages
1999	Arson at a genetic-engineering research office at Michigan State University
2003	Arson at a HUMMER dealership in West Covina, California, destroying 125 SUVs and resulting in an estimated $1 million in damages
2005	Arson of five townhouses under construction in Hagerstown, Maryland
2008	Arson at the Street of Dreams housing development in Woodinville, Washington, resulting in $12 million in damages

Types of Ecoterrorism

Category of Ecoterrorism	*Percent of Incidents, 1993-2004*
Vandalism	77
Arson	12.6
Assault and bodily harm	2
Bombings	1.1
Other	7.3

- **Earth Liberation Front**

Also during this period, the ELF was founded in Brighton, England, and began engaging in violent and destructive acts increasingly referred to as ecoterrorism. These acts included the 1998 burning of the Vail Resort in Colorado, which garnered the attention of the FBI and the Bureau of Alcohol, Tobacco, and Firearms, who focused on eliminating the ELF. In February, 2002, the FBI declared that the Earth Liberation Front was one of the country's greatest domestic terrorism threats. According to the FBI, between 1996 and 2002, the ELF and the Animal Liberation Front (a violent, direct action animal rights group) committed more than 600 criminal acts in the United States, resulting in damages in excess of $43 million.

- **Context**

The ELF is the primary entity associated with ecoterrorism; however, it is not an organization, but a movement. It has been very difficult to eliminate because of a lack of organization and hierarchy. A 2008 arson in Woodville, Washington, has raised concern that a resurgence in ELF-associated violent activity is a potential. Although ecoterrorist targets related specifically to global climate change have been limited, primarily SUVs and SUV dealerships, as the concern over the effects of global climate change increases, there is a potential for acts of ecoterrorism to increase.

Travis Wagner

- **Further Reading**

Abby, Edward. *The Monkeywrench Gang*. New York: Avon, 1975. This novel about a cast of characters performing acts of ecotage to reclaim the wilderness is the most influential book on the subject of ecoterrorism.

Long, Douglas. *Ecoterrorism*. New York: Facts On File, 2004. Well-written reference resource and useful research guide that provides useful background information, definitions, and concepts.

Taylor, Bron R., ed. *Ecological Resistance Movements: The Global Emergence of Radical and Popular Environmentalism*. Albany: State University of New York Press, 1995. Compilation of writings related to the examination and analysis of contemporary movements of ecological resistance.

Wagner, Travis. "Reframing Ecotage as Ecoterrorism: News and the Discourse of Fear." *Environmental Communication: A Journal of Nature and Culture* 2, no. 1 (2008): 25-39. Discusses the evolution of the concept of ecoterrorism as viewed in the mass media.

See also: Amazon deforestation; Anthropogenic climate change; Biodiversity; Civilization and the environment; Human behavior change.

Education about global climate change

- **Category:** Popular culture and society

Evidence for climate change is found in the geologic record well before the emergence of human beings. However, the notion of anthropogenic influences upon climate has led government policy makers to educate the public about human impacts upon and potential control of Earth's climate.

- **Key concepts**

anthropogenic climate change: changes in climate due to human activities

Environmental Protection Agency (EPA): the U.S. agency charged with enforcement and regulation of environmental policies

Intergovernmental Panel on Climate Change (IPCC): an international organization of government leaders and scientists

International Journal of Climatology: a professional journal published by the Royal Meteorological Society

International Union for Quaternary Research (INQUA): an international scientific organization devoted to research on climate change during the Quaternary period, the last 2.6 million years of the Earth's history

National Research Council (NRC): a private, nonprofit organization, founded by congressional charter in 1916, that functions under the auspices of the National Academy of Sciences and provides policy information

National Resources Defense Council (NRDC): a nonprofit environmental action group established in 1970

nonprofit organizations (NPOs): organizations that use their profit for a particular cause or goal

scientific journal article: a report written for a scientific journal and reviewed by a panel of peers

United Nations Environment Programme (UNEP): the official U.N. educational and informational outlet for environmental concerns

World Meteorological Organization (WMO): the official voice on climate and weather issues within the United Nations

• Background

Educating the public regarding the notion of global warming somewhat evolved with the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. Since then the dissemination of the idea of global warming has occurred through the news media, via Internet sites, and through the publishing of formal and informal literature, along with other forms of media. Formal academic sources such as the International Union for Quaternary Research (INQUA) and the *International Journal of Climatology* are examples of scientific information sources. In contrast, books and films such as Al Gore's *An Inconvenient Truth* (2006) are popular vehicles used to educate the public on the issue. Getting the word out about climate change and in particular global warming has transcended a variety of media and organizations.

• Bringing the Issue to the Forefront

In 1962, before the notion of "global warming" was an environmental concern, Senator Gaylord Nelson, during the Kennedy administration, conceived a way to bring public attention to environmental issues. The idea ultimately came to fruition in 1970 as the first official Earth Day. Earth Day began as a grassroots movement bringing environmental concerns such as water and air pollution as well as the impact of population on the environment to an agenda at the national level. Since then Earth Day has evolved as a vehicle for educating the public about a wide range of environmental concerns, including the notion of anthropogenic influences on climate change. Earth Day, celebrated in the United States on April 22, and its U.N. counterpart, celebrated worldwide in March on the date of the spring equinox, have been among the best examples of successful environmental campaigns to promote awareness of global warming issues. Earth Day has served as a rallying point, especially for students, from the elementary to the university levels, concerned about environmental issues.

• Governmental Sources

The responsibilities of the U.S. Environmental Protection Agency (EPA) include addressing environmental issues, setting environment policy, and providing public information on the environment through hearings, press releases, and Web resources. Additionally, the EPA is an example of a U.S. government agency concerned with informing citizens about environmental policy and the impacts these laws may have on the environment. The EPA publishes a wide range of information on climate change, greenhouse gas emissions, climate and health issues, and climate economics via the Internet. It also provides curricular materials on climate change for educators and students and disseminates advance notices to the public regarding new regulations.

• Intergovernmental Panels

The agency best known for its dissemination of climate change information is no doubt the Intergovernmental Panel on Climate Change (IPCC). The IPCC emerged from the World Meteorological Organization and United Nations Environment Programme and is composed of scientists and government officials. It has been suggested that the concept of the IPCC was born from concerns first expressed by Swedish meteorologist Bert Bolin at an environmental meeting held in Stockholm in 1972. At that meeting, Bolin presented a hypothesis suggesting that an apparent rise in CO_2 levels from 1850 to 1970 had contributed to global warming. Ultimately in 1988 the IPCC, with Bolin as its first president, was established. Today, as an environmental organization concerned with informing the public about global warming issues, the IPCC acts as an intergovernmental clearinghouse assessing and disseminating scientific and other forms of research regarding natural and anthropogenic climate change.

- **Scientific Sources**

An example of an organization producing research and publishing professional literature on issues surrounding climate change is the International Union for Quaternary Research (INQUA). This organization, established in 1928, is a nonprofit council of scientists from around the world, publishing and supporting research in areas such as sea-level change and the evaluation of paleoclimatic environments. The research published in INQUA's scientific journal and newsletter is distributed to a wide range of readers.

Based on the peer-evaluated scrutiny they endure, professional journal articles are the voice of scientific research and disseminate information to both the scientific and nonscientific communities. The *International Journal of Climatology*, published under the direction of the Royal Meteorological Society of the United Kingdom, provides articles on the research on climate in general, including themes dealing with climate change. Journals such as this provide the reader with a source of objective climate research. Additionally, it is through journals such as the *International Journal of Climatology* that further evaluation of the research can be made through review of the methods used and replication of the scientific investigations reported on within these articles.

- **Sources Serving Public Policy**

The intent of the United States' National Research Council (NRC) is to assist in educating the public and to help facilitate the government in establishing public policy around a variety of issues pertaining to science. The NRC has established a set of studies entitled "America's Climate Choices" to help assist the public in anticipating problems arising as a result of climate change. Additionally, the NRC sponsors the Summit on America's Climate Choices, an open meeting to help establish a dialogue on climate change. The NRC has been successful in disseminating its information via the Internet, with podcasts and Web sites.

- **Nonprofit Organizations**

The National Research Defense Council (NRDC) is one example of an environmental action group. The NRDC was established in 1970 by law students and attorneys. Its membership exceeds one million. In addition to drawing attention to global warming issues, it provides its members with information pertaining to the establishment of environmental policy and news. Addressing such issues as energy efficiency, health, and pollution, the NRDC's Web site educates the public on global warming and suggests steps for preventing or ameliorating it.

- **Alternative Sources**

The Pennsylvania Council of Churches might sound like an unlikely source for climate education, but its Interfaith Climate Campaign is an example of one of many grassroots attempts at the community level to educate its members and the general public about the impacts of climate change. The campaign instructs members on climate topics through a Web site and community workshops. It also encourages outreach to public officials and governmental agencies and disseminates its program through videotapes and in-church bulletin papers.

- **Global Warming Cinema**

In 2006, the award-winning film *An Inconvenient Truth*, presented by former U.S. vice president Al Gore and directed by Davis Guggenheim, was released as a documentary on global warming. Although the film has undergone much scrutiny and criticism from school boards, scientists, and global warming skeptics, and in the classrooms of the United Kingdom, it is shown with a disclaimer and continues to be made available as an influential educational source on the impacts of global warming. Regardless of the scientific debate over some of the data presented, the film and book have served to increase public awareness of climate change and mobilize public opinion.

• Literature

An amazing array of literature has emerged from both the positive and negative perspectives on global warming and climate change. During the 1970's, popular nonfiction such as John Gribbin's *What's Wrong with Our Weather? The Climatic Threat of the Twenty-first Century* (1979) described the potential for the return of ice-age conditions—global cooling.

Publications for the general audience since the beginning of the twenty-first century, however, have emphasized the climatic warming trend, reflecting concerns over the growth of air pollution (CO_2 and other greenhouse gas emissions), world population, and anecdotal experience of increasing temperatures, borne out by meteorological records, albeit short-lived. Notable contemporary titles include *Greenhouse: The Two-Hundred-Year Story of Global Warming*, by Gale E. Christianson (1999) and Al Gore's *Earth in the Balance: Ecology and the Human Spirit* (2006).

The counter viewpoint also persists in the popular literature. Books such as Christopher Horner's *Red Hot Lies: How Global Warming Alarmists Use Threats, Fraud, and Deception to Keep You Misinformed* (2008) and Thomas Moore's *Climate of Fear: Why We Shouldn't Worry About Global Warming* (1998) are examples of critiques and criticisms of popular views of global warming.

• Educating with a Theme

Additionally, the theme of global warming has entered science-fiction literature and film. Films such as *The Day After Tomorrow* (released 2004), directed by Roland Emmerich, and books such as Jay Kaplan's *A Chilling Warmth: A Tale of Global Warming* (2002) continue to keep the theme of climate change active in the minds of the public.

M. Marian Mustoe

Education specialist C. J. Rea of Kenain Fjords National Park instructs a bipartisan group of thirty U.S. mayors about Alaska's experience of climate change. (AP/Wide World Photos)

• Further Reading

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Alley is a climate research specialist. Details research he completed in Greenland and discusses the process of ice-core drilling.

Christianson, Gale E. *Greenhouse: The Two-Hundred-Year Story of Global Warming*. New York: Walker, 1999. Christianson is a history professor of the College of Arts and Sciences at Indiana State University. Reviews the foundations of the thought behind global warming by describing and characterizing the historical scientific personalities tied to the sciences surrounding the phenomena of climate.

Douglass, D. H., et al. "A Comparison of Tropical Temperature Trends with Model Predictions." *International Journal of Climatology* 28, no. 13 (2007): 1693-1701. Compares atmospheric temperatures derived from models with those observed in the upper atmosphere. Exemplifies the process of validating and checking scientific data and procedures within a study or experiment. Finds a statistical difference between model predictions and observed temperatures in the troposphere above the tropics.

Gribbin, J. *What's Wrong with Our Weather*. New York: Charles Scribner's and Sons, 1978. Describes some of the climate concerns, both warming and cooling, coming to the forefront of the public's attention during the 1970's. Includes reviews of climate patterns and data during these years and discusses some of the research up to that time.

Kench, P., and P. Cowell "Erosion of Low-Lying Reef Islands." *Tiempo* 46 (December, 2002). Geographers Kench and Cowell discuss the dynamics of sea-level rise as it pertains to small islands in the Pacific. They introduce an evaluation instrument that considers the sedimentation and erosion of islands and consider some of the management issues surrounding sea-level rise in small island nations.

Lovelock, J. *The Rough Guide to Climate Change*. 2d ed. London: Rough Guides, 2008. Guide to major themes in global warming. Considers the mechanism behind the process and details its human implications.

Mörner, Nils-Axel. *The Greatest Lie Ever Told*. Stockholm, Sweden: Author, 2007. Mörner, professor emeritus of palegeophysics and geodynamics from Stockholm University, is internationally known as a sea-level expert. Describes research in sea-level measurements and provides a detailed description of the variables that control sea level. Concludes that sea level is not rising as suggested by global warming models.

See also: Basel Convention; Bennett, Hugh Hammond; Brundtland Commission and Report; Canaries in the coal mine; Carson, Rachel; Catastrophist-cornucopian debate; Civilization and the environment; Climate Project; Conspiracy theories; Environmental movement; Falsifiability rule; Friends of Science Society; Friends of the Earth; Gore, Al; *Inconvenient Truth, An*; Human behavior change; Journalism and journalistic ethics; Peer review; Popular culture; Scientific proof; Skeptics; United Nations Climate Change Conference.

8.2ka event

- **Category:** Climatic events and epochs

- **Definition**

The 8.2 kiloyear (8.2ka) event was a sudden decrease in mean global temperatures that started approximately eighty-two hundred years ago. The 8.2ka event lasted between two hundred and four hundred years. This cooling event was not as cold as the previous strong cooling event in Earth's history, the Younger Dryas (spanning the period between 12,800 and 11,500 years ago). The 8.2ka event was, however, colder than the strong cooling event that followed it, the Little Ice Age (approximately 400 to 150 years ago). (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.)

Periodic cooling events such as the 8.2ka event have left a geologic record of sediments in the northern Atlantic Ocean. These sediments are gravelly sand layers, which were laid down by numerous icebergs as they melted and the icebergs released trapped sediments, which then fell to the seafloor. The 8.2ka event was first discovered by European scientists. When ice cores were drilled in Greenland and studied for their climate record, the occurrence of the 8.2ka event was confirmed.

- **Significance for Climate Change**

The 8.2ka event appears to be one occurrence of global cooling within a repeating pattern of cooling events that have occurred periodically in the Northern Hemisphere. These cooling events started after the end of the last glacial cycle on Earth, about thirteen thousand years ago. The genesis of these events is thought to be related to changes in solar output, changes in circulation patterns in the atmosphere, or other atmospheric and oceanic factors. There have been at least eight such cooling events since the end of the last glacial cycle; however, there is evidence that such cooling events also occurred during the interglacial cycle that preceded the most recent glacial cycle. Cooling events like the 8.2ka event are spaced at intervals of five hundred to two thousand years.

The significance for global climate change of these events is that even though the Earth is in an interglacial or post-glacial warming cycle, there is a history of periodic cooling events superimposed on this current warming trend. It remains to be seen if the current trend of global warming will continue and thus prevent or delay the recurrence of such a cooling event as the 8.2ka or if the future return of such a global cooling event will temporarily reverse the trend of global warming effects.

David T. King, Jr.

See also: Alleroed oscillation; Climate reconstruction; Dating methods; Deglaciation; Holocene climate; Little Ice Age; Medieval Warm Period; Paleoclimates and paleoclimate change; Pleistocene climate; Younger Dryas.

Ekman transport and pumping

- **Category:** Oceanography

• Definition

When the wind blows over a body of water, it exerts a force that causes the water on and near the surface to move. Each layer of moving water pulls or drags the layer immediately underneath it. This continues into the depth of the body of water, until the drag reaches the bottom or becomes vanishingly small, whichever occurs first. This process is known as Ekman transport, and it is related to the so-called Ekman spiral. Although this spiral had been observed earlier by Fridtjof Nansen (1861-1930), the Norwegian explorer, diplomat, scientist, and 1922 Nobel Peace laureate, both the transport and the spiral were named after Vagn Walfrid Ekman (1874-1954), the Swedish oceanographer. It was the latter who conducted the first scientific study of this phenomenon and published his results. The research project itself was identified and assigned to Ekman by his mentor and teacher, Vilhelm Bjerknes (1862-1951), the Norwegian physicist and meteorologist.

The Ekman spiral is a twisting structure of liquid or gas currents that arises near a horizontal boundary. The net effect is that, as the flow moves away from the horizontal boundary, its direction rotates, thereby creating the physical structure of a spiral. The Ekman spiral is related to the Coriolis effect (named for Gaspard-Gustave de Coriolis, 1792-1843), a phenomenon that is due to the rotation of the Earth and used to explain why it is that objects moving on the surface of the Earth, or in its atmosphere, do so at an angle to the forces that one applies directly to them. Theory and experiment show that, in the Northern Hemisphere, objects move to the right of applied forces, while in the Southern Hemisphere, they move to their left. The Coriolis effect helps explain part of the Ekman spiral.

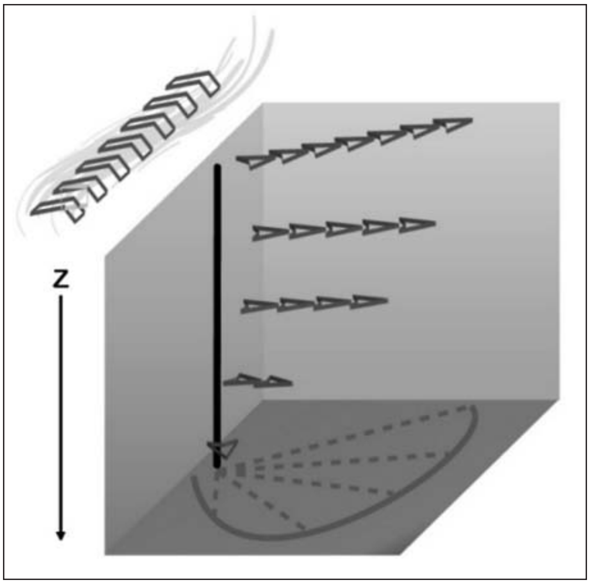
When a wind that blows on the surface of the sea varies in the horizontal direction, it induces horizontal variability in the Ekman transports, which creates vertical velocities at the top of the Ekman layer. The creation of vertical velocities is necessary, because the mass of ocean water that flows through a fixed region of space must be conserved (displaced water is replaced). This effect forces water to move up the Ekman layer, against the downward pull of gravity. That action is known as Ekman pumping. In other words, the existence of horizontal divergence in the Ekman transports creates vertical velocities in the upper boundary layer of the ocean.

• Significance for Climate Change

When the wind blows on the ocean's surface, the direction of surface currents that are so created do not line up with the direction of the wind. Instead, they move at an angle to it: In the Northern Hemisphere, they move to the right of the wind, and in the Southern Hemisphere, they move to its left. As the effect of the wind moves deeper and deeper into the water, the angle between the direction of the wind and that of the water current of each succeeding layer increases in size.

Consequently, if the currents at the different levels of depth could the viewed from above the ocean surface in the time sequence of their occurrence, then, in the Northern Hemisphere, one would see a water current twisting itself progressively to the right with deeper and deeper penetration, while in the Southern Hemisphere, a similar current would twist itself progressively to the left with deeper and deeper penetration of the ocean. In each hemisphere, the average angle across all depths between the direction of the wind and that of the water current is 90°. Given that the surface of the Earth is covered mostly by oceans, these large-scale movements of ocean water have an influence on the climate.

Patterns of large-scale climate variability in each hemisphere of the Earth are studied using annular modes: a Northern annular mode (NAM) and a Southern annular mode (SAM). They are used to explain the variance in atmospheric flow with time that is not associated with the changes in seasons. The El Niño-Southern Oscillation (ENSO) is a third example of a large-scale pattern of climate variability that is historically tied to the interactions between the ocean and the atmosphere in the tropical Pacific. All three patterns are affected by what happens in the oceans, as well as in the atmosphere, and they particularly reflect the sea surface temperature fields of their respective hemispheres, which are affected by the surface fluxes of latent heat, sensible heat, and heat due to Ekman pumping.



Ekman pumping results from a combination of ocean surface winds, drag, and the Coriolis effect, which cause seawater to move in a spiral pattern.

Ekman transport and pumping are very important in the study of general circulation in the world's oceans, because they create upwelling and downwelling of ocean water. Upwelling occurs when water from below the surface of the ocean is forced to come to the top. Downwelling is the reverse of upwelling. Spatial variability in wind current leads to upwelling near the shore. In the open ocean, it leads to both upwelling and downwelling, which redistribute the mass of water in the ocean. Therefore, upwelling and downwelling due to Ekman transport and pumping are leading mechanisms in the variability of the heat contents in the upper oceans.

Furthermore, simulations indicate that Ekman pumping and oceanic wind-driven circulations respond to increases in atmospheric carbon dioxide (CO_2), one of the greenhouse gases. These simulations have shown that modest increases in CO_2 in the atmosphere have several effects on wind-driven circulations in the oceans in the Southern Hemisphere. They change and intensify the distribution of wind stresses; increase the rate of water circulation, Ekman pumping, and deep-water upwelling in the southern oceans; and expand the subtropical gyres toward the poles in both hemispheres.

Josué Njock Libii

• Further Reading

Ahrens, C. Donald. *Meteorology Today*. 9th ed. Pacific Grove, Calif.: Thomson/Brooks/Cole, 2009. A general introduction to the meteorological sciences. Chapters 10, 16, and 17 are particularly pertinent to oceanographic studies.

Price, James F., Robert A. Weller, and Rebecca R. Schudlich. "Wind-Driven Ocean Currents and Ekman Transport." *Science* 238, no. 4833 (1987): 1534-1538. Technical discussion of the topic that is accessible to the general reader.

Sverdrup, Keith A., Alison Duxbury, and Alyn C. Duxbury. *Fundamentals of Oceanography*. New York: McGraw-Hill, 2006. A general introduction to oceanography that covers Ekman transport.

See also: Atlantic heat conveyor; Atlantic multidecadal oscillation; Coriolis effect; El Niño-Southern Oscillation; Gulf Stream; La Niña; Meridional overturning circulation; Ocean-atmosphere coupling; Ocean dynamics; Sea surface temperatures.

El Niño-Southern Oscillation

• **Categories:** Oceanography; meteorology and atmospheric sciences

El Niño and the Southern Oscillation are linked atmosphere-ocean phenomena that occur in the tropical Pacific, but their influence on climate can be seen globally. They represent a cyclical recurrence of warm ocean currents that cause large-scale changes in Earth's weather.

• Key concepts

Hadley cell: an atmospheric circulation system of air rising near the equator, flowing poleward, descending in the subtropics, and then flowing back toward the equator

La Niña: the cooling half of the cycle of which El Niño is the warming half

ocean-atmosphere coupling: the interaction between the sea surface and the lower atmosphere that drives many patterns and changes in Earth's weather systems

paleoclimates: climates of the distant past

Walker circulation: an atmospheric circulation pattern in the Pacific and elsewhere in which hot, moist air rises, travels eastward, cools and dries, descends, and returns westward

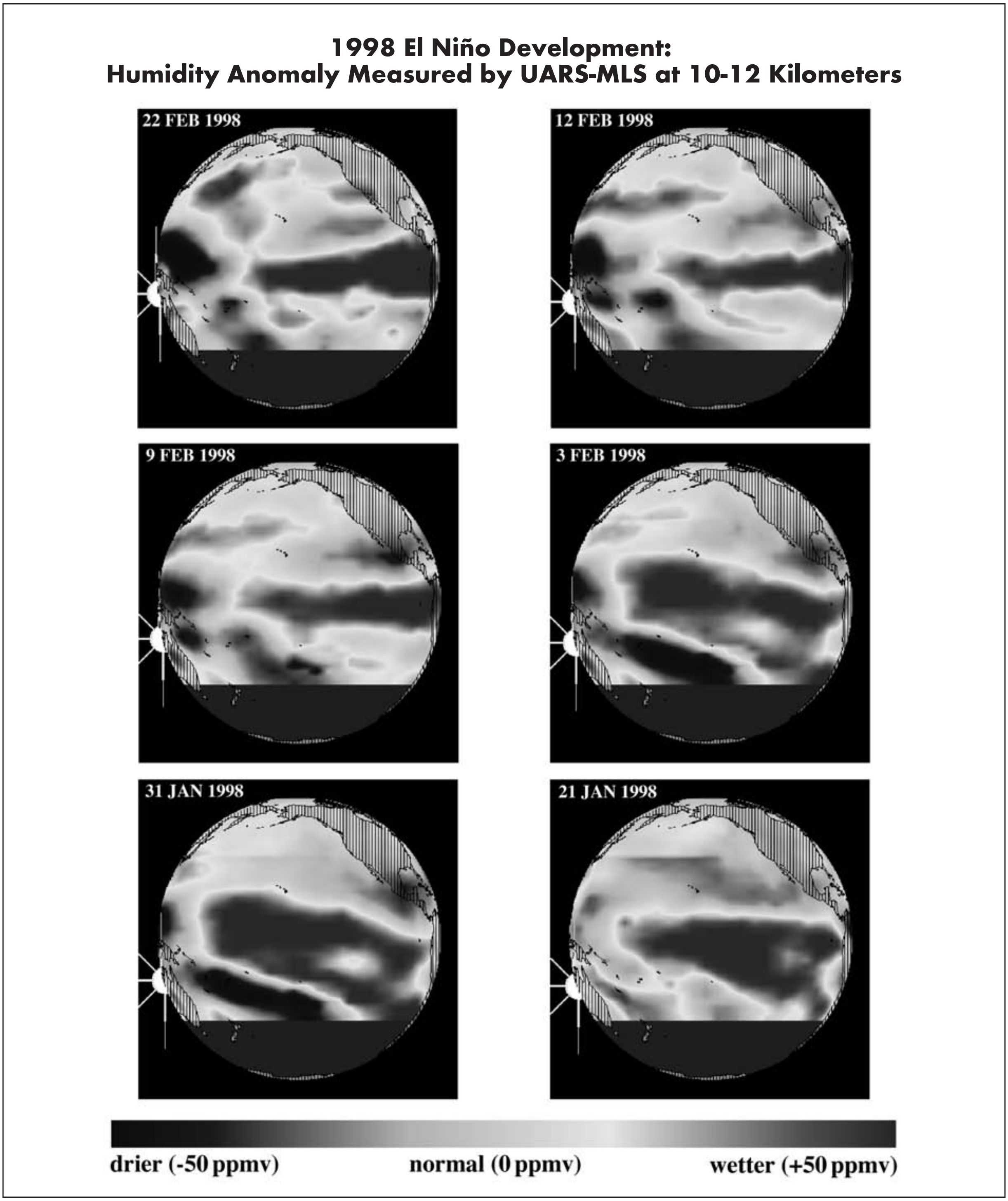
• Background

El Niño is a sporadic warming of sea surface water in the central and eastern equatorial Pacific Ocean, adjacent to the Peruvian coast. This warming is part of a cycle, and the cycle's opposite, cooling phase is called La Niña. The Southern Oscillation (SO) is a "seesaw" of air pressure and air circulation between the eastern Pacific and the Indonesian region. The terms El Niño and La Niña are used to denote the extremes of the oscillation. The hyphenate El Niño-Southern Oscillation (ENSO) describes the range of atmospheric and oceanic processes and their accompanying changes. Although ENSO is based in the tropics, it influences weather throughout the Northern Hemisphere and possibly the globe as a whole.

• Characteristics of ENSO

Definitions of ENSO vary, but a common aspect of El Niño is the irregular warming of sea surface water off the coasts of Ecuador, northern Peru, and occasionally Chile. This warming is linked to irregular changes in air pressure at sea level across the Pacific Ocean. During El Niño conditions, the westward-flowing trade winds slacken. During La Niña conditions, by contrast, the westward-flowing trade winds are stronger than normal. A common measure of the SO is the Southern Oscillation Index (SOI), which is usually based on changes in sea-level air pressure at locations on opposite sides of the tropical Pacific. The most common basis for the SOI is the mean sea-level air pressure difference between Tahiti and Darwin, expressed as the long-term difference of their monthly pressures.

Normally, there is a low-pressure zone of warm air in the western Pacific and a high-pressure zone of cool air in the eastern Pacific. This pressure differential drives a loop of warm air from over the western Pacific that rises just east of Indonesia, travels eastward, and descends over the eastern Pacific. The loop then flows in a westerly direction at the surface back toward the west. The strength of this circulation, known as the Walker circulation, is heavily influenced by the seesaw-like sea-level pressure differences between the eastern and western Pacific. The pattern is named after Gilbert Walker, whose work led to the discovery of the Southern Oscillation.



This series of images shows the development of water vapor over the Pacific Ocean during the El Niño event of January and February, 1998. Warmer water temperatures result in greater-than-normal water evaporation, warmer, moister air, and finally altered global weather patterns. (NASA/JPL/Caltech)

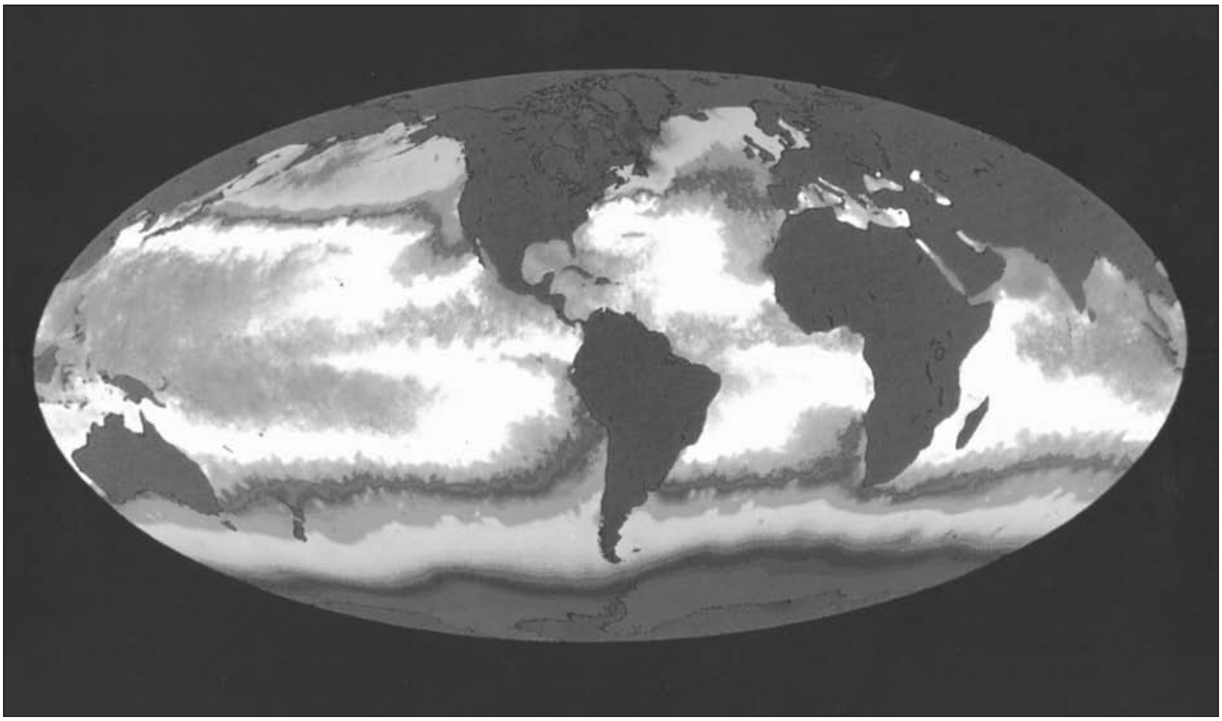
The formation and breakdown of the Walker circulation cell is reflected in the pressure difference across the Pacific: When pressure is low in Tahiti, it is high in Darwin, and vice versa. This periodic yearly-to-decadal seesaw of atmospheric and oceanic circulation is the SO. When the SOI is negative, sea surface temperatures (SSTs) are warmer than usual in the eastern equatorial Pacific, off the coats of Ecuador and northern Peru (and occasionally Chile). A negative SOI is associated with El Niño conditions. When the SOI is positive, SSTs are cooler than usual in the eastern equatorial Pacific. A positive SOI is associated with La Niña conditions. During La Niña events, the east-west movement of air in the Walker circulation is enhanced with well-defined and vigorous rising and sinking branches.

- **Links to Global Climate Change**

During El Niño events, there is an increase in Hadley cell circulation, the circulation cell of air that rises over the equator and descends in the subtropical latitudes on both sides of the equator. A more vigorous overturning of the Hadley cell circulation leads to an increase in heat transfer from tropical to higher latitudes in both hemispheres. Often, the climatic effects of increased Hadley circulation can be seen globally as above-average temperatures and extreme precipitation. Various other climatic consequences of ENSO events have been reported: Warmer ocean waters have bleached coral, and vigorous atmospheric circulation has driven ocean currents northward, warming the Arctic Ocean and decreasing the amount of sea ice there.

- **Assumptions About ENSO and Anthropogenic Global Warming**

The Intergovernmental Panel on Climate Change (IPCC) has commented on the possibility of connections between ENSO and anthropogenic increases in atmospheric greenhouse gases. Based on the output of complex but unvalidated global climate models, the IPCC indicates that as tempera-



This satellite image depicts the average variation in sea surface temperatures (lighter is warmer), which alter in El Niño years. (NASA) tures increase, the average Pacific climate could more consistently emulate El Niño conditions. However, the IPCC accepts that some climate models point to a more La Niña-like response to global warming, because Hadley cell circulation may decrease with increasing global temperature. Paleoclimatic studies support the view that global warming is likely to foster weaker and less frequent El Niño events. However, the level of scientific uncertainty and the existence of conflicting results are such that reliable prediction of future climate is not possible at this time.

• Context

Owing to the complexity and uncertainty surrounding global climate and climate change, neither the mean annual values of ENSO nor the interannual variability of ENSO can be reliably simulated in global climate models. Despite this, projections have been made about future trends in precipitation extremes linked to ENSO. ENSO has a noticeable influence on mean global temperature, and shifts in temperature are consistent with shifts in the SOI, but the relationship between temperature and ENSO effects has not been consistently strong. On one hand, strong El Niño events create significant spikes in mean global air temperature. On the other hand, there is evidence that long-term warming depresses El Niño activity. For this reason, the mutual effects of climate change and ENSO upon each other remain difficult to predict.

C R de Freitas

• Further Reading

Couper-Johnston, R. *El Niño: The Weather Phenomenon That Changed the World*. London: Hodder and Stoughton, 2000. The author is a wildlife and science documentary maker who has examined impacts of ENSO around the world. Presents a historical perspective on the topic in a popular form. Focuses mainly on the historical impacts of ENSO on human society and civilization. Illustrations, maps.

D'Aleo, J. S., and P. G. Grube. *El Niño and La Niña*. Westport, Conn.: ORYX Press, 2002. Two climate scientists describe what is known about ENSO phenomena and underlying processes in twelve short chapters. Themes dealt with include a history of ENSO, how scientists study and track ENSO phenomena, and how ENSO information is used. Glossary, large bibliography, charts, maps, and diagrams and color plates.

Glantz, M. H. *Currents of Change: Impacts of El Niño and La Niña on Climate and Society*. 2d ed. New York: Cambridge University Press, 2001. The author, a climate scientist, describes in an easily understood fashion what ENSO is and what its negative and positive consequences on weather and climate are around the world. Written for the lay audience; covers the increases in information and knowledge gained from the major El Niño event of 1997-1998. Illustrations, figures, tables, maps, bibliography, index.

See also: Average weather; Drought; Extreme weather events; La Niña; Monsoons; Tropical storms; Weather vs. climate.

Elton, Charles Sutherland

English ecologist

Born: March 29, 1900; Withington, Manchester, England
Died: May 1, 1991; Oxford, England

Elton was the first person to describe ecosystem invasions by animals and plants. As the climate changes, all indications are that such invasions will be more frequent and have greater effects.

• Life

Charles Sutherland Elton was the youngest of three sons born to Oliver Elton, a professor of English literature at Liverpool University, and Letitia Maynard Elton (nee MacColl), a children's writer. Charles attended Liverpool College and graduated from Oxford University with a degree in zoology in 1922. In 1921, he had the opportunity to join an Arctic expedition to Spitsbergen to study Arctic vertebrates. He returned to the Arctic in 1923, 1924, and 1930 to continue the study. From 1926 to 1931, Elton was a consultant with the Hudson's Bay Company, studying species that affected the fur trade. In 1923, he was appointed departmental demonstrator at Oxford.

Elton married Rose Montagne in 1928. After five years, they separated and divorced amicably. His second marriage, a few years later, to Edith Joy Scovell was happy. He found great pleasure in his family life. In 1932, Elton established the Bureau of Animal Population at Oxford and became the editor of the new publication *Journal of Animal Ecology*. He would continue as editor for nineteen years. He was appointed reader in animal ecology at Oxford University and senior research fellow at Corpus Christi College in 1936. During World War II, the Bureau of Animal Population was given the task of controlling the loss of foodstuff to rats, mice, and rabbits. For twenty years after the war, Elton studied the animals on the Wytham estate of Oxford University. He retired in 1965, but he remained active, managing a study of tropical America in his retirement.

• Climate Work

Elton did not publish a large number of research papers, but his books left a dynamic legacy. In *Animal Ecology* (1927; rev. ed., 1946), his clear, concise writing defined ecology for future scientists. He was one of the first people to apply scientific methods to the study of animals in the wild, their interrelationships, and their relationship with the environment. He discussed ecological niches and their relationship to larger ecosystems, particularly the pyramid of numbers—the notion that each level up the food chain has a smaller population than the one below it.

Voles, Mice, and Lemmings: Problems in Population Dynamics (1942) discussed the subject of population fluctuation. Elton felt that understanding the rodent population was a major factor in controlling human plague. In his studies of the population fluctuations of animals, he came to the conclusions that the population of wild animals is never constant, that the change in number is also neither constant nor periodic, and that the ever-changing population of one species has both direct and indirect effects on the populations of other species. Elton was very concerned with conserving biodiversity. He felt that preserving biodiversity established the correct relationship of humanity with nature, provided greater opportunities for people to experience nature, and increased ecological stability.

The Ecology of Invasions by Animals and Plants (1958) brought together many different fields—such as biogeography, human history, epidemiology, population ecology, and conservation biology—to show how important the concept of invasions can be. Elton predicted that in the future there would be a smaller total number of species because some of the native species would be eliminated by invading species. Increasing human travel, he believed, would facilitate the transportation of invasive species. Invasive species in general are likely to experience explosive population growth in a new ecosystem, because they will have fewer natural predators and parasites.

The Pattern of Animal Communities (1966) was published about the time Elton retired, and the work's greatest impact on the field of ecology may still lie in the future. Some of Elton's ideas have been ahead of their time. For example, Elton posited that, when a species is under stress, it will often search for a new environment. Thus, the selection of environment by animal is more likely than the selection of animal by environment. This proposition has significant implications for climate change, which will cause major changes in the animal and plant populations of specific ecosystems. These changes may cause some species to migrate in search of new habitats, turning them into invasive species.

C. Alton Hassell

• Further Reading

Crowcroft, Peter. *Elton's Ecologists: A History of the Bureau of Animal Population.* Chicago: University of Chicago Press, 1991. Informal history of the group who worked at the Bureau of Animal Population with Elton. Illustrations, index.

Elton, Charles S. *The Ecology of Invasions by Animals and Plants.* Reprint. Chicago: University of Chicago Press, 2000. Elton's classic book on invasions by nonnative species. Illustrations, maps, bibliography.

_______. *Voles, Mice, and Lemmings: Problems in Population Dynamics.* Oxford, England: Clarendon

Press, 1942. Another of Elton's classic books that define ecology. Illustration, maps, bibliography.

Elton, Charles S., Mathew A. Leibold, and J. Timothy Wootton. *Animal Ecology*. Reprint. Chicago: University of Chicago Press, 2001. Leibold and Wootton have added introductions to each chapter of this reprint, elucidating the scientific and historical context of the chapter. Illustrations, bibliography.

See also: Budongo Forest Project; Carbon dioxide fertilization; Forestry and forest management; Invasive exotic species.

Emiliani, Cesare

Italian Ameican paleoceanographer

Born: December 8, 1922; Bologna, Italy
Died: July 20, 1995; Palm Beach Gardens, Florida

Emiliani developed the oxygen isotopic abundance method to study the history of the oceans and their climate changes.

• Life

Cesare Emiliani was born to Luigi Emiliani and Maria Manfredidi Emiliani. Cesare studied geology at the University of Bologna, and in 1945 he received a doctorate in micropaleontology from the same university. From 1946 to 1948, he worked for the Societa Idrocarburi Nazionale in Florence as a micropaleontologist. In 1948, he moved to the University of Chicago, where he had been awarded the Rollin D. Salisbury Fellowship. He received a second doctorate in 1950 from the University of Chicago, this time in geology (isotopic paleoclimatology). In Chicago, he met and, on June 28, 1951, married his wife, Rosita. They had two children: Sandra and Mario. Emiliani's family was important to him. He was a wonderful husband, father, and grandfather.

Emiliani worked in Harold Urey's geochemisty laboratory at the Enrico Fermi Institute for Nuclear Studies at the University of Chicago as a research associate from 1950 to 1956. In 1957, he moved to the University of Miami's Institute of Marine Science, which would later become the Rosenstiel School of Marine and Atmospheric Sciences. There, he developed programs in marine geology and geophysics. In 1967, he became chair of the Department of Geological Sciences, which he had organized. He remained the chair until his retirement in 1993. He was at home in 1995 when he was felled by a sudden heart attack.

• Climate Work

In Urey's lab, Emiliani learned how the two stable isotopes of oxygen were related to temperature change. He used isotopic analysis to study the carbonate remains of foraminifera, microscopic protists that live close to the ocean's surface, falling to the seafloor only after they die to become part of the sedimentary layer. Emiliani found foraminifera remains both on the ocean floor and in cores drilled into the floor. From the data he acquired, he determined that the ocean had been much warmer in the early Tertiary period, about 65 million years ago. The discovery that the ocean was not always the same temperature opened up the new field of paleoceanography to study changes in what had previously been thought to be a constant environment.

The isotopic abundance method of comparing ratios of oxygen isotopes is based on the fact that, when in thermodynamic equilibrium, calcite and seawater differ in their ratios of oxygen 18 (O^{18}) to oxygen 16 (O^{16}). Calcite forms a part of the body of foraminifera that is preserved in fossilized remains of the creatures. The ratio of O^{18} to O^{16} in these creatures and their remains increases with cooler water temperatures and with increasing volumes of ice, so it is an indicator of temperature changes.

Looking at the oxygen abundance ratio of fossilized calcite, Emiliani found a sawtooth pattern in deep-sea cores indicating that there had been periodic ice ages. His work also showed that the Pleistocene period had experienced several ice ages, at a time when most scientists believed there had been only four. Emiliani found evidence of seven ice ages in Caribbean deep-ocean bed cores, and in Pacific cores, he found evidence of fifteen ice ages.

His work introduced the notion that ice ages were cyclic phenomena.

Emiliani concluded that cycles of glaciers were caused by several different factors. The albedo of, or the amount of light reflected by, surface ice affected how much heat the ice and its surroundings absorbed and thus the amount of ice that melted. (Ice surrounded by heat-absorbing dark water will melt faster than ice surrounded by more heat-reflecting ice.) Glacier cycles also seemed to be affected by changes in the stress placed on the ocean floor by the weight of ice on land, by orogenic (mountain-forming) uplift, and by changes in the amount of solar radiation reaching Earth. Emiliani's research transformed the study of the oceans and their history.

Emiliani also discovered that different species of plankton live at different levels of the ocean. The temperature of the ocean drops quickly with increasing depth, so species living at different depths have different ratios of O^{18} to O^{16}. Emiliani's assertion that different species live at different depths was initially ridiculed but has since been proven to be true.

Emiliani's move to the University of Miami was motivated by his belief that deep-sea drilling cores provided the best evidence of ocean history. He was disappointed when one core-drilling project, the Mohole project, folded, so he sent a proposal to the U.S. National Science Foundation to fund the Long Cores project (LOCO). The cores drilled by this project produced enough data to motivate the creation of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). Its three subsequent projects operated continuously from 1966 until 2003. The data from deep-sea cores not only provided evidence of ocean history but also proved the theory of seafloor spreading and plate tectonics.

C. Alton Hassell

• Further Reading

Elderfield, Harry. *The Oceans and Marine Geochemistry.* Amsterdam, the Netherlands: Esevier Pergamon, 2006. Dedicated to Emiliani, among others. Shows how impotant his work was and is in understanding the oceans and ocean geology. Illustrations, bibliography, index.

Emiliani, Cesare. *Planet Earth: Cosomology, Geology, and the Evolution of Life and Environment.* New York: Cambridge University Press, 1992. Emiliani's synthesis of different sciences to describe how the world was formed.

_______. *The Scientific Companion: Exploring the Physical World with Facts, Figures, and Formulas.* New York: Wiley, 1988. Emiliani uses his vast knowledge of different topics to correlate what is known of today's world.

Hill, Maurice N., et al. *The Sea: Ideas and Observations on Progress in the Study of the Seas.* Reprint. New York: Wiley, 2005. Reissue of an earlier series of books cowritten by Emiliani and demonstrating his influence upon his coauthors. Illustrations, graphs.

See also: Climate reconstruction; Dating methods; Deglaciation; Earth history; Paleoclimates and paleoclimate change.

Emission scenario

• **Categories:** Meteorology and atmospheric sciences; pollution and waste

• Definition

An emission scenario is a means of assessing the future impact of global greenhouse gas (GHG) emissions through different story lines that use a variety of assumptions. The Intergovernmental Panel on Climate Change (IPCC), established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), uses various emission scenarios to periodically review the science, impacts, and socioeconomics of climate change. The IPCC developed the projected scenarios using a variety of sources including literature searches, alternative modeling approaches, and feedback from informed groups and individuals. These models include emissions from all types of GHGs and their driving forces.

• **Significance for Climate Change**

The Special Report on Emissions Scenarios (SRES) allows a forward-looking assessment of the causes and impact of emissions as viewed from demographic, technological, and economic developments. Armed with information provided by the emission scenarios, the IPCC is able to advise the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The SRES team included fifty members from eighteen countries representing a range of scientific disciplines. In order to provide the UNFCCC with useful information covering a variety of possibilities, the IPCC used forty different scenarios; each scenario makes different assumptions for future GHG pollution. Included in the report are assumptions about possible technological and future economic development for each scenario, as well as options to reduce the predicted environmental hazards.

The reports come in the form of story lines, with each story line representing a different future possibility. For example, one of the story lines allows for a future of rapid economic growth, advanced technologies and global population peaking in mid-century and then declining. Another story line presents continuously expanding global population with slower economic growth, while another assumes the introduction of cleaner, more efficient technologies that are environmentally friendly and assumes growth of service and information technologies. A fourth story line presents variations on the other three possible outcomes.

As with any attempt to divine the future, emission scenarios have their critics. The critics argue that the scenarios don't include climate-specific initiatives and that they miss the mark on their assessment of economic growth and degree of future GHG emissions. For example, overestimating economic growth might point to higher GHG emissions than reality would suggest. Also, the scenarios do not assume implementation of the UNFCCC or the emissions targets of the Kyoto Protocol. However, emission scenarios are a useful tool used throughout the world, and many models exist independent of the IPPC model.

Richard S. Spira

See also: Climate models and modeling; Climate prediction and projection; WGII LESS scenarios.

Emissions standards

• **Category:** Pollution and waste

Emissions standards seek to protect the environment and the climate by setting limits on the amount of pollutants and GHGs that may be emitted by motor vehicles, factories, and other sources of anthropogenic air pollution.

• **Key concepts**

catalytic converters: devices that reduce vehicular carbon monoxide exhaust by converting it into carbon dioxide

emissions trading: a practice in which the right to pollute is turned into an exchangeable commodity, motivating polluters to reduce their emissions so they can profit by selling the right to others

Kyoto Protocol: a binding international agreement that includes a detailed plan to reduce greenhouse gas emissions

maximum achievable control technology (MACT) standards: standards designed to limit air pollution from stationary sources (usually heavy industries)

smog: the noticeable brown haze created by vehicular and industrial emissions and other fossil emissions, especially prevalent in large cities

volatile organic compounds: carbon-based substances that can easily enter the atmosphere through vaporization

• **Background**

The evolution of emissions standards began largely in response to the heavy vehicular traffic and industrialization of major urban areas. At the beginning of the twentieth century, the word "smog" was used to describe the grim atmospheric haze created by smoke and sulfur dioxide from burning coal. This haze was especially noticeable in large cities such as

London, which had already suffered from the effects of burning coal for centuries. As automobiles became popular, pollutants from coal were joined by photochemical smog, created by emissions from gasoline engines and other sources, releasing volatile organic compounds that were acted upon by sunlight.

Over time, with increased scientific research, the global scope and long-range impact of air pollution became more apparent, and local efforts to prevent further damage were joined by national and international policies and agreements. In the United States, the Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards, which regulate carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur dioxide. These key pollutants are measured by both volume and weight, and measurements are made based on the amount of fuel input. Regulations based on fuel input have been criticized as being less relevant to overall energy efficiency than regulations based on output.

One of the most significant international agreements regulating emissions is the Kyoto Protocol of 1997, which implemented the suggestions of the 1992 United Nations Framework Convention on Climate Change. An important feature of the protocol is that industrialized nations agreed to cover more of the initial costs of reducing greenhouse gases (GHGs) than did developing nations. Also, the Kyoto Protocol promoted emissions trading and other viable economic incentives that make international cooperation in combating global warming more practical.

• Stationary Emissions Standards

Factories and power plants have been subject to varying emissions standards, with a focus on regulating major sources. In the United States, the Clean Air Act Extension of 1970 was amended in 1990 to define major sources as individual or grouped stationary sources with the capacity to release 9 metric tons or more per year of a single pollutant, or 23 metric tons or more per year of combined pollutants. Coal, which is still used all over the world, is a significant source of dangerous mercury pollution, and many nations, including China, are still heavily dependent on coal for power. In 2005, the EPA issued the Clean Air Mercury Rule in an attempt to reduce mercury emissions from coal-burning power plants in the United States.

• Road-Based Vehicular Emissions Standards

One of the most significant sources of global air pollution is the exhaust from cars and trucks. While the image of factory smokestacks is often used as a symbol for air pollution, the cumulative effect of millions of vehicles, even with catalytic converters, is potentially catastrophic. In 2004, carbon dioxide emitted by personal vehicles in the United States alone reached 314 million metric tons. Within the European Union, emissions standards differentiate between diesel and gasoline fuel, as well as between vehicles of different weights and sizes. Testing also takes the temperature of an engine into account. Europe's standards have been adopted in some Asian countries, including India and China.

• Nonroad Vehicular Emissions Standards

Locomotives, boats, aircraft, and farm and lawn equipment are also sources of air pollution, and attempts have been made to control their toxic emissions. Along with particulate matter and other byproducts of combustion, diesel engines used in locomotives and boats emit sulfur, and the piston engines in aircraft emit lead. In 2007, tougher emissions standards for marine diesel engines that had been set by the EPA began to take effect, with the goal of reducing the level of sulfur in fuel by 99 percent, and stricter standards were set for newly constructed engines. Smaller boats often use gasoline engines similar to those found in cars and trucks, and although not as prevalent, they release the same pollutants as road-based vehicles. Engine emission standards for aircraft have been set by the United Nations International Civil Aviation Organization, and there is a trend toward greater regulation of this mode of transportation.

• Context

The creation and enforcement of emissions standards is one of several long-term strategies for reducing GHGs and combatting global climate change. Other strategies reject the use of fossil fuels altogether and seek to find and promote alternative sources of energy. Many legal and political complexities have arisen in determining which corporate entities or governments are responsible for preventing environmental damage to the air in another community, since the the air is not restricted by political borders of any kind.

Alice Myers

• Further Reading

Ellerman, A. Denny. *Markets for Clean Air: The U.S. Acid Rain Program.* New York: Cambridge University Press, 2000. Details the first three years of the program, including its political and economic background and its impact on the problem. Illustrated. Bibliography and index.

Hansjürgens, Bernd, ed. *Emissions Trading for Climate Policy: U.S. and European Perspectives.* New York: Cambridge University Press, 2005. Includes economic analysis and theory, as well as consideration of options for future policies. Bibliography, index.

Reed, Alan. *Precious Air: The Kyoto Protocol and Profit in the Global Warming Game.* Overland Park, Kans.: Leathers, 2006. Comprehensive study describing the United Nations' efforts to deal with global warming, the Kyoto Protocol's effects on world economics, and the development of the emissions trading industry. Illustrations, bibliography.

Sperling, Daniel, and James S. Cannon, eds. *Driving Climate Change: Cutting Carbon from Transportation.* Boston: Academic Press, 2007. An outgrowth of the 2005 Asilomar Conference on Transportation and Energy in California, this book discusses strategies for reducing GHG emissions. Illustrated. Bibliography, index.

Tietenberg, T. H. *Emissions Trading: Principles and Practice.* Washington, D.C.: Resources for the Future, 2006. Classic study of the use of transferable permits or economic incentives to control pollution. Illustrated. Bibliography, index.

See also: Carbon dioxide; Emission scenario; Greenhouse gases; Industrial emission controls; Motor vehicles; U.S. legislation.

Employment

• **Category:** Economics, industries, and products

As Earth's climate changes, some workers may leave adversely affected regions and migrate to other areas. Other workers will remain in place but may be forced to seek different employment as industries become less viable or are damaged by extreme weather events. In some cases, new economic opportunities will arise from mitigation and adaptation efforts.

• Key concepts

environmental refugees: people forced to move because of climate change

extreme weather events: major, potentially damaging weather occurrences, such as hurricanes, snowstorms, or floods

Intergovernmental Panel on Climate Change (IPCC): a group of scientists charged by the United Nations to develop various scenarios examining the impact of climate change

migration: the movement of people from place to place

scenario: outline of the impact of climate change under certain conditions

• Background

At present, human communities are more vulnerable to extreme weather events than to gradual change. Nonetheless, over time communities will be affected by global warming. As is usually the case, poorer communities will be more vulnerable than wealthier ones. Agriculture will be more affected than industry by gradual climate change, because industry is more adaptable. Extreme weather events, a likely product of global warming, will often negatively affect industries. Workers will often be forced to seek employment in new jobs when their old employers lose their viability. In some regions, workers may be forced to migrate from severely affected regions to those less affected, even when this means crossing national borders.

• Extreme Weather Events and Employment

Global warming is expected to produce several impacts. Some, such as increasingly warmer weather or decreased precipitation, would be gradual. Most scientists agree, however, that global warming is also likely to produce more extreme weather, particularly in the tropics. The scenarios produced by the working group of the Intergovernmental Panel on Climate Change (IPCC) indicate that warmer weather will likely produce more and larger hurricanes and cyclones in the tropics, as well as more intense rainstorms or droughts in some areas. The occurrence of specific extreme events is difficult to predict on a long-term basis, so it will be difficult to plan for such events in any one specific area. Nonetheless, it is possible to indicate some regions that will be likely to experience more extreme weather events, such as Category 5 hurricanes (those with wind speeds over 241 kilometers per hour).

In the United States, for example, the IPCC scenarios indicate that Florida and the Gulf Coast will experience more hurricanes and, more important, hurricanes of greater magnitude. Worldwide, several cities, such as Miami in the United States and Mumbai in India, are situated along coasts vulnerable to hurricanes and cyclones; consequently, industries in these cities are vulnerable to the flooding and wind damage produced by large storms. It may be possible to adapt to stronger storms, especially in the industrial nations, but they will often produce short-term disruption that leads some businesses to close temporarily or eventually to move elsewhere. Even in industrialized countries, increased insurance costs may lead some businesses to move from coastal areas to inland locations. Businesses in less industrialized countries may simply close or move elsewhere rather than trying to rebuild when faced with major devastation. When manufacturing plants close because of extreme weather, skilled workers are forced to mi-

In March, 2007, European Union commissioner for employment and social affairs Vladimir Spidla, left, observes a discussion between European Commission president Jose Manuel Barroso and German chancellor Angela Merkel, who is pushing her fellow E.U. members to improve the European economy by embracing clean energy initiatives. (AP/Wide World Photos) grate elsewhere, although they may be able to find comparable jobs.

The increase in number and intensity of hurricanes will have a negative impact on low-wage employers in hurricane-prone areas in both industrial and less industrialized nations, as these businesses often do not have the capital to rebuild. Also, some people who are forced to relocate by severe weather events never return to their old homes. Hurricane Katrina, which hit New Orleans in 2005, left many people without jobs or homes. Some of the people who left New Orleans returned to the city, but many moved elsewhere, never to return.

Climate change and extreme weather events are likely to harm the tourist industry in several areas. The presence of more powerful storms in the tropics (a likely event in most climate scenarios) may deter some tourists from visiting beachfront resorts. Resorts often will be faced with added costs of operation, such as insurance costs, that will force some to close. In mountain areas, higher temperatures that come from gradual warming will affect snowpack, making it difficult to sustain ski resorts. Already, some ski resorts in the North Carolina mountains are being forced to close by the lack of enough snow to sustain their business. Many resort workers are seasonal and will be able to find work elsewhere, but many are permanent residents who will have to relocate in order to find work.

• Gradual Climate Change and Employment

Even when regions do not suffer from extreme weather, warming can lead to a gradual rise in sea level, flooding some coastal areas. In other cases, increased precipitation or snow melt will cause rivers to flood, affecting nearby communities. When combined with extreme events, this pattern can lead to substantial migration. Already, this is beginning to happen in Bangladesh. Farmers are losing productive land to water incursions and are crossing the border into the neighboring Indian province of Assam. These new immigrants often cause a reduction in wage levels, producing hostility between natives and the new arrivals. More extreme climate change scenarios indicate that some Pacific Islanders, such as those on Nauru, may be forced to evacuate their home islands before the end of the century when increases in sea level and more powerful storms make the low-lying islands uninhabitable. These migrants will have an impact on labor supplies wherever they settle. Inundations by seawater are already having an impact on the parishes south of New Orleans. Fishermen and fur trappers are being forced to move elsewhere in search of work as their livelihoods are being destroyed.

In some cases, it is the lack of water rather than too much water that leads to environmental migration. As desert regions in northern Africa become drier, herding people are finding it difficult to maintain their herds with decreased water supplies. In some areas, drought conditions are preventing farmers from growing crops, and some scenarios indicate increasing drought for parts of Africa, as well as the American Southwest. Some cities, such as Las Vegas, may have to face the possibility of water shortages under some climate change scenarios. In the case of Las Vegas, this situation would have a potentially negative impact on casino employment. As some lakes, such as Lake Chad in Africa, dry up, people who earned their livelihood from fishing in those lakes will be forced to move. In many cases, these people become desperate, as they move to cities or across borders looking for employment. In some cases, such as Darfur, this situation is already contributing to economic and political distress, as climate-based migration is being coupled to other, long-standing points of dispute. Although not as severe, the migration from Bangladesh into Assam is beginning to lead to problems, as some natives fear the potential changes occurring because of the new arrivals.

As countries try to find means to adapt to global warming and mitigate its impact, some industrial sectors will be affected in both negative and positive fashions. Various critics of the impact of carbon dioxide (CO_2) on the atmosphere call for the curtailment of the use of oil and coal (both sources of CO_2) for energy and a concomitant decrease in production. If oil and coal production decreases, there will be fewer jobs in these industries, as well as those that supply equipment or expertise such as oil well drilling. On the other hand, energy demand is likely to remain high, so new industries will grow to provide energy or old industries such as the nuclear power industry will begin to grow once again.

• Climate Change Fosters Employment Growth

Global warming does appear to be creating employment opportunities in some industries and regions. As annual temperatures rise in some temperate areas, such as northern Europe and Canada, new crops will become viable as growing seasons become longer. For the most part, this will mean simply an exchange of one sort of job for another for agricultural workers. As it becomes easier to navigate in the Arctic, companies are beginning to eye various opportunities to exploit natural resources there. The Arctic seabed is believed to hold several minerals, as well as having the potential for oil field development. Exploiting both of these resources will provide opportunities for skilled workers, and sailors will be needed to navigate the Northwest Passage from the Atlantic Ocean to the Pacific Ocean.

• Context

As countries strive to adapt to global warming, new industries will develop, creating jobs, at least in the industrial countries. Solar panel and wind turbine fabrication and construction are two new industries that are beginning to take shape in several countries as people turn to renewable energy sources. In some countries, infrastructure projects, such as the construction of higher seawalls in the Netherlands, are already under way. Unfortunately, poorer countries will share less in this sort of job creation because of lack of capital. People in less industrialized nations will simply be forced off the land into the cities, where few jobs exist. Even so, there will be some potential for low-wage jobs in cleaning up storm damage in all regions.

These sorts of impacts of global warming appear to be quite straightforward, yet as the IPCC panel of scientists indicates, the reality is more complex. People may also move from one area to another in search of higher wages or better working conditions. Climate change plays a role in their decision, but so do other factors, making it difficult to assign an impact to climate change alone.

Predicting the impact of climate change on global employment patterns will continue to be of interest but will be exceedingly difficult to do. There are no neat trade-offs from one industry to another that can be assigned to climate change. Because people move for a variety of reasons, it is hard to assign values to the impact of climate change on population movement.

It is apparent that people in developing countries will bear a large share of the employment (and other) costs of climate change. The economies of industrial nations are more adaptable, but they too will face some employment dislocations by the end of the twenty-first century. As always, the more extreme climate change scenarios (those predicting average global warming of 5° to 7° Celsius) will lead to larger impacts on the world economies, including employment patterns.

John M. Theilmann

• Further Reading

Agnew, M. D., and D. Viner. "Potential Impact of Climate Change on International Tourism." *Tourism and Hospitality Research* 3 (2001): 37-60. Examines the impact of climate change on several tourist areas worldwide.

Faris, Stephan. *Forecast.* New York: Henry Holt, 2009. Several chapters deal with the economic impacts of climate change, especially population migration.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Martin Parry et al. New York: Cambridge University Press, 2007. Comprehensive analysis of the impact of climate change worldwide by a group of leading climate scientists.

Jorgenson, Dale W., et al. *U.S. Market Consequences of Global Climate Change.* Washington, D.C.: Pew Center on Global Climate Change, 2004. Focuses on the effects of climate change on the U.S. economy.

Stern, Nicholas. *The Economics of Climate Change: The Stern Review.* New York: Cambridge University Press, 2007. Excellent analysis of the economic impact of climate change, sponsored by the British government. Some of Stern's assumptions are questioned by some other economists.

Unruh, J., M. Krol, and N. Kliot. *Environmental Change and Its Implications for Population Migra-*

tion. New York: Springer, 2004. Useful treatment of the impact of climate change on population movements.

See also: Human migration; Poverty; Renewable energy; Solar energy; Wind power.

Endangered and threatened species

- **Categories:** Animals; plants and vegetation

Climate change has overtaken other threats such as deforestation and pollution as a primary danger to the survival of plant and animal species.

• Key concepts

biodiversity: the variety of species in a given location

biome: a major biological community adapted to a particular climate or area

ecosystem: all living organisms within an area, as well as the nonliving area's environment, understood as a coherent functioning unit

endangered species: a species that is in danger of extinction throughout all or a significant portion of its range

habitat: the place where a biological population normally lives

threatened species: a species likely to become endangered within the foreseeable future

• Background

Although the endangerment and extinction of species has taken place continuously since life on Earth began, human activities have intensified the process. In the past century, an increasing human population has built more cities, towns, and roadways; sacrificed forests for agricultural land; increased pollution; and produced other trends that disrupt stable ecosystems. In addition, symptoms of the Earth's gradual warming have been evident since the mid-1970's. An number of plant and animal species unprecedented on the human timescale faces conditions that threaten their survival.

• Identifying the Dangers

The U.S. Endangered Species Act was enacted in 1973 in an effort to protect wildlife and counter those processes that endanger the survival of various animal and plant species. The World Conservation Union issues its Red List of species deemed to be at risk. Its 2008 report classified 16,928 species as threatened, out of a total of 44,838 surveyed. Half of all the mammal species surveyed were in decline. The report listed one in eight bird species, one in three amphibians, and 70 percent of all plant species as likely to perish in the foreseeable future.

Because so many anthropogenic hazards threaten the planet's life-forms, proof of the prime role of climate change has been difficult to establish. As time goes on, though, the effects of warming temperatures and related weather phenomena become more clear. Startling events in several different biomes bear this out.

• Extinction Observed in a Costa Rican Rain Forest

Climate change leading to extinction probably has taken place many times, but out of the view of biologists or of any human observer. Zoologist Tim Flannery recounts a series of events in the Monteverde Cloud Forest Preserve in Costa Rica which, in retrospect, demonstrate a species suddenly dying out as a result of climate change.

The preserve is a mountain area whose forests are typically cloaked in mist. It is the home of an intriguing variety of rain-forest species. Among these was the golden toad, whose bright orange-gold males were so spectacular they became a symbol for happiness in tribal legends. These toads were seen gathered in their forest pools to mate in April, 1987. Then, the pools rapidly dried up, along with the golden toad eggs just deposited there. It was an El Niño year. The dry conditions were the culmination of a decade when, each year, the cloud cover drifted higher up the mountainside. As a result of this drift, the toads lost the mist in which they thrived.

The higher cloud levels were later traced to a rise in sea surface temperatures of the central Pacific over the preceding decade. In May, 1987, more toad eggs were laid, perhaps an instinctual effort to replace the dried-up ones. Few tadpoles

An exhibition of sixteen hundred panda sculptures in Nantes, France, draws attention to the plight of endangered species. (Bertrand Bechard/Maxppp/Landov)

hatched or survived, however. During the next two years (1988 and 1989), the researcher found only one lone toad where many had lived before. Since that time, no toads have been seen. Because the golden toads live only in this region and have been meticulously studied, their disappearance became the first documented case of extinction from climate change.

Golden toads were not the only victims of this quiet catastrophe. The Cloud Forest Preserve, a relatively accessible rain-forest area, was home to some fifty species of frogs and toads. At the end of the disastrously dry 1987 season, thirty of the fifty species had vanished. Among these was the Monteverde harlequin frog. Its demise was also connected to shifting climatic conditions, via the outbreak of a fungus that thrived only as the surrounding weather became drier and warmer. In fact, the continual decline of amphibians has been a worldwide occurrence. It seems likely that these animals' sensitivity to changes in temperature and humidity has been a significant factor in their decline. Their loss is an early warning of the ravages of a warming world.

Other animal life in the preserve also suffered. Several species of lizards living there have disappeared or become rarer. The keel-billed toucan, a lowland bird, has moved onto the mountainside, where it threatens the eggs of the quetzal, a spectacular bird famous in Mayan folklore. Altogether, this one small area, crowded with species adapted to its unique climatic conditions, has been an object lesson in what happens when these conditions abruptly change.

• The Warming of Polar Regions

Among Earth's most rapidly changing habitats are those in the Arctic. For some time, each Arctic winter has been milder than the winter before. Sea ice in Hudson and Baffin Bays, for example, typically broke up in the early twenty-first century some three weeks earlier than it did in the 1970's. This trend disrupts the polar bears' annual trek onto ice to find their main food, the ringed seals that live there. There are now malnourished adult polar bears, and fewer cubs are being born.

Large stretches of the sea lack ice chunks big enough to support a bear. There have been reports of polar bears marooned on ice 640 kilometers away from any land or food source. The higher winter temperatures bring rains, which collapse the bears' birthing dens, killing the mothers and cubs inside. In short, each season of the polar bears' life cycle is threatened by a warmer Arctic, and this region has been warming almost twice as rapidly as most of the world.

The ice is home to some four species of seals that are equally threatened. The Gulf of Saint Lawrence has had several years when, because of the scarcity of ice, no harp seal pups were born. In fact, the whole Arctic biosphere is at risk. Walruses, caribou, and other animals all are threatened as winters average four to five degrees warmer than in generations past. Caribou herds, for instance, have drastically decreased in size. The main factor seems to be newly occurring autumn rains, which freeze their lichen supply so it is hard to browse. The rains also create swollen rivers which are fatal to many caribou cubs.

• Endangered Coral Reef Communities

Coral reefs flourish in shallow tropical seas. Known for their intricate, many-colored forms and their role in island formation, the reefs also serve as a sort of nursery for fish and other marine organisms. A typical reef in the Indian Ocean may contain over five hundred coral species and provide food and shelter for more than two thousand different fish species. Coral itself is a phylum of invertebrate animals. The coral formations are an exoskeleton built out of calcium carbonate which supports a tiny animal living inside, called a polyp. Corals live in symbiosis with algae, the zooxanthellae. The algae give the reefs their spectacular color. They provide the polyp with food produced from photosynthesis.

Coral reefs require a delicate balance of temperature, water chemistry, and sunlight to stay healthy. When the surrounding sea's temperature rises above a certain level, the algae-polyp partnership breaks up. Extended warm spells make the algae disappear, and the coral polyps starve. The reef becomes bleached and dead. In the two El Niño years of 1998 and 2002, this happened on Australia's Great Barrier Reef, damaging a total of 60 percent of the reef's area in whole or in part. Many coral reefs on the outskirts of civilization have been damaged by surface runoff of silt, sewage, and trash and by harvesting of the coral. The added destruction from warming tropical waters means the loss not only of the reef structures themselves, but also of the habitat and breeding grounds of much marine life. Fish, crustaceans, anemones, and other creatures, some not even known to science, lose their home. Coral reefs are a complex ecosystem in delicate balance, susceptible to ruin from small changes in the planet's weather patterns.

• Habitat Loss in Slow Motion

The foregoing scenarios are notable for their exotic settings and fauna, and for the rapid pace with which global warming took a toll on the species involved. However, no part of the Earth is unaffected. Even nonscientists living in temperate regions have noticed such symptoms as the scarcity of butterflies, which in the earlier twentieth century were abundant.

One of the markers of ecosystem threat is the earlier occurrence of spring. University of Texas biologist Camille Parmesan examined nearly two thousand studies showing this happening on six continents and in all of the world's oceans. In the majority of cases, life cycles were disrupted. Insects and animals in a given ecosystem regulate their dormancy, reproduction, and growth in tandem with the growth and blossoming of plants. Temperature and day length appear to be the two signals which key their life cycle events. When the two become de-synchronized, the web of interactions involving food availability, pollination, seed dispersal, and other daily events does not stay intact.

When this happens, animals tend to migrate when they can. Shifts of habitat northward have been documented for multiple species of birds and butterflies since 1960, in both Europe and America. Red foxes have expanded their range northward, driving the arctic fox further toward the Arctic Ocean. This can be a successful survival strategy, but it also disrupts existing ecosystems and may displace native species that filled the same ecological niche. Eventually a species may run out of spaces to migrate to, or exceed its own ability to adapt.

Migrating to higher elevations is a variant of this strategy, and it is subject to the same risks. The Edith's Checkerspot butterfly in California has shifted its range upward some 100 meters in the Sierra Nevada. A closely related species, the Quino Checkerspot, has become endangered because it is unable to cross the Los Angeles metropolis and establish itself in cooler, wetter environment.

Past experience in reversing the plight of endangered species is not always relevant to the global warming situation. The Endangered Species Act emphasizes using law and human efforts to counter damage threats from hunting, disruption of habitats by urbanization or agriculture, and pollution. It has had notable successes in the recovery or reestablishment of species such as the gray wolf, the peregrine falcon, and the humpback whale. But there are still eighteen hundred species on its list, and thousands of other threatened species needing protection. Moreover, the act was not designed to counter threats to an entire biome, much less those of planetwide scope.

An officer of the Kenyan Wildlife Services displays ivory seized from travelers seeking to smuggle it out of the country. Trade in the materials of endangered species increases the threat of their extinction. (Reuters/Landov)

• Context

There have been five great extinctions in Earth's geologic past in which most existing species vanished. Their causes appear to be varied, but rapid climatic change is implicated in most. The most recent, culminating with the dinosaurs' extinction and the slow ascendancy of the age of mammals, happened 55 million years ago. The immediate cause was probably Earth's collision with an asteroid, but it was the aftereffects that affected the climate so drastically as to overturn all existing ecosystems. By colliding with limestone-rich rock, the asteroid created an explosion that put enough carbon dioxide into the air to warm the planet by an estimated 4° to 10° Celsius. No creatures that weighed over 35 kilograms survived; there were also major changes in the vegetation.

A case can be made that ever since human activity began to alter the planet, Earth's other fauna and flora have been threatened. In the past decades, however technologies have been developed that can document and measure the planet's warming trend, and these technologies may prove sufficient to convince humanity to alter its behavior. Still, unless humans find ways systematically to counter the trend toward anthropogenic climate change and environmental degradation, the survival of threatened species can be accomplished only on a piecemeal basis.

Emily Alward

• Further Reading

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming*. Rev. ed. London: Penguin, 2007. Wide-ranging survey of the ways human life impinges upon the rest of nature. The author, director of the South Australian Museum, ranges back through time and across the globe, and urges action to slow global warming.

McGavin, George C. *Endangered: Wildlife on the Brink of Extinction*. Buffalo, N.Y.: Firefly Books, 2006. Lavishly illustrated coffee-table type book showing the diversity of animal life on Earth. Climate change is discussed as one among several threats to diverse species. Excellent charts and explanations.

Spicer, John. *Biodiversity: A Beginner's Guide*. Oxford, England: Oneworld, 1996. Topical guide to the interaction of life-forms. Contains hard-to-find nuggets of information on many topics, from extinction cascades to the place of the biosphere in religious and secular value systems.

Ward, Peter D. *Under a Green Sky*. New York: HarperCollins, 2007. Highly personalized account of the search for extinctions of the past, and consideration of what they mean for the present climate change.

See also: Amazon deforestation; Budongo Forest Project; Convention on International Trade in Endangered Species; Extinctions and mass extinctions; Fishing industry, fisheries, and fish farming; Invasive exotic species; Whales.

Energy efficiency

• **Category:** Energy

• Definition

The efficiency of an energy-producing system is defined as the benefit derived from operating the system divided by the cost necessary to operate it. It can theoretically vary between 0 and 100 percent. The benefit is the net amount of work produced by the system during its operating time, while the cost is determined by how much energy must be provided in order to generate this work. According to the laws of thermodynamics, only part of the input energy will be converted into work, so the energy efficiency will always be less than 100 percent.

• Significance for Climate Change

Market strategies, economic policies, and political interests have generally assigned a lower priority to the implementation of energy-efficiency measures to reduce global warming than they have to increased energy production. If energy efficiency were properly addressed, promoted, and increased, world demands for energy production could be decreased and climate change stabilized. By increasing the energy efficiency of homes, vehicles, and industries, fossil fuel usage and global warming could be reduced, and the energy security of a nation could be increased by decreasing the demand for imported petroleum. About 75 percent of the electricity consumed in the United States could be saved by implementing energy-efficiency measures that cost less than the electricity itself.

As an example, energy-efficient strategies that have continually been implemented in California since the mid-1970's are projected to reduce greenhouse gas (GHG) emissions to at least 1990 levels by 2020 while keeping per capita energy consumption approximately the same. The top priority in California's energy policy is to reduce fossil fuel usage by promoting and providing more energy-efficient homes, vehicles, and businesses, which will reduce GHG emissions that generate climate change. High-performance windows, properly installed insulation, and energy-efficient cooling, heating, and lighting systems can reduce energy use in a standard home by at least 15 percent. Similar policies could be adopted worldwide.

In 1992, the Energy Star program was created in the United States by the Environmental Protection Agency in an effort to reduce energy consumption and GHG emissions. Initially established to identify and promote energy-efficient products, the program was expanded to include energy-efficiency labels for residential heating and cooling systems, new homes, and commercial and industrial buildings. Energy Star has also promoted the use of more efficient power supplies, home appliances, electronic systems, light-emitting-diode (LED) traffic lights, efficient fluorescent lights, and energy management equipment for office systems in order to reduce energy consumption, global warming effects, and air pollution.

Alvin K. Benson

See also: Biofuels; Carbon taxes; Clean energy; Energy from waste; Energy resources; Ethanol; Fossil fuels; Fuels, alternative; Renewable energy; U.S. energy policy.

Energy from waste

• **Categories:** Energy; environmentalism, conservation, and ecosystems

Energy-from-waste technologies are designed to reduce or eliminate waste that otherwise contributes to global warming, while simultaneously generating energy and reducing the need to consume nonrenewable resources.

• Key concepts

incinerator: a facility used to burn waste until it is reduced to ash

landfill: a site where municipal or industrial wastes are buried in the ground

methane: a greenhouse gas with the molecular formula CH_4

microalgae: photosynthetic microorganisms similar to plants

municipal solid waste (MSW): the trash, refuse, and garbage thrown away from homes and commercial establishments

• Background

Energy from waste, or waste-to-energy, refers to any waste treatment that generates energy from a waste source. Most waste-to-energy technologies make electricity directly through combustion, or they produce fuels, such as methane, hydrogen, biodiesel, or ethanol. These technologies reduce the amount of waste on the planet and also reduce the need to produce energy using technologies that create more waste.

• Refuse-to-Energy Conversion

As human populations and industrialization have increased, the amount of generated municipal solid waste (MSW) has grown steadily. In the early twenty-first century, the United States produced around 1.8 kilograms of such waste per person per day. Because it has high energy content, refuse material can be burned to release energy. The amount of energy generated by burning waste is about half that produced by burning the same mass of coal.

Several cities around the world use incinerators to convert refuse to electricity. Incinerators are huge furnaces, capable of handling 15 metric tons of waste per hour, in which temperatures are high enough to allow waste to be burned completely. The value of the electricity generated by these incinerators offsets the costs of MSW handling and burning. However, incineration has serious environmental consequences, including the production of greenhouse gases (GHGs). Burning MSW produces nitrogen oxide as well as carbon dioxide (CO_2), the primary GHG. There is a worldwide awareness that CO_2 emissions contribute to global warming. Some of the CO_2 produced in incinerators is biomass-derived and is considered to be part of the Earth's natural carbon cycle, however.

Incineration is particularly popular in countries where land is a scarce resource. Sweden and Denmark have been leaders in using the energy generated from incineration for more than a century. Although incinerators reduce the volume of the original waste by 95-96 percent, the ash produced after incineration must still be disposed of in landfills. Ash often contains high concentrations of hazardous heavy metals, such as lead or cadmium. Ash may also include precious metals, such as aluminum, gold, copper, and iron. These metals are recycled before ash deposition into the landfills. Alternatively, ash can be used for road work or building construction, provided that it does not contain hazardous substances.

- **Methane Production**

Buried in landfills, wastes do not have access to oxygen. The resulting anaerobic waste decomposition produces biogas, which is 30 percent methane. Methane is a very powerful GHG, but it is also a very good fuel. In order to avoid releasing methane into the atmosphere, a number of cities install "gas wells" in landfills to capture the methane they generate and use it as fuel. There are several such landfill gas facilities in the United States that generate electricity.

Biogas can also be generated from wastewater and from animal waste. Domestic wastewater consists of substances such as ground garbage, laundry water, and excrement. All these components are biological molecules that microbes can eat. Thus, one of the most common treatments of wastewater and manure employs microbial anaerobic digestion. Such digestion is very similar to the process of landfill waste decomposition, and it yields biogas.

In this process, wastewater or manure is fed into digesters (bioreactors), where microorganisms metabolize it into biogas. Biogas can be used to fuel engines connected to electrical generators to produce electricity. The nutrient-rich sludge remaining after digestion can be used as fertilizer. In many countries, millions of small farmers maintain simple digesters at home to generate energy. The only side effect of this technology is that burning methane in combusting engines produces CO_2. Because methane has a greater global warming potential than does CO_2, however, the process potentially results in a net decrease in GHG emissions.

A worker feeds waste into an incinerator in Aargau, Switzerland. (Alessandro Della Bella/Keystone/Landov)

• Agricultural Waste to Energy

Where energy is generated as a by-product of waste disposal, agricultural waste may have considerable merit. A great number of cellulosic wastes result from the cultivation of crops such as corn. This waste can be turned into ethanol. Use of ethanol as fuel has been vigorously promoted. Ethanol is mainly produced by fermentation of sugars derived from food crops with the help of baker's yeast. However, making ethanol from leftover materials such as corn stover is highly desirable, because such materials consist largely of sugars but they have no direct food use. Other cellulosic waste material such as sawdust, wood chips, cane waste (bagasse), and wastepaper can be converted into ethanol as well. In contrast to food-to-ethanol conversion, converting farm waste to ethanol involves little or no contribution to the greenhouse effect.

Plant waste material may also be gasified to produce syngas, a mixture of carbon monoxide (CO) and hydrogen (H_2). Syngas is considered an alternative fuel, because it generates electricity with co-production of water and CO_2 when burned. Syngas can also be converted by certain microbes into other alternative fuels, such as ethanol and H_2.

• Harnessing Photosynthesis

Exhaust streams from power plants and other manufacturing units contain high levels (up to 20 percent) of CO_2. Typical coal-fired power plants account for up to 13 percent of anthropogenic CO_2 emissions. Researchers are exploring the application of photosynthetic microalgae to remove CO_2 from the emissions of power stations and other industrial plants. Algae utilize CO_2 and, at the same time, produce oil and H_2 as part of their growth process. Therefore, they can be used to generate environmentally friendly biofuels such as biodiesel and H_2.

The biological potential of photosynthetic microalgae for CO_2 removal and biofuel generation is determined by their cultivation techniques. Current industrial production of microalgae is achieved in open "raceway" ponds of some thousand square meters in size. These systems suffer from severe limitations, such as lack of temperature control, low attainable cellular concentrations, and difficulty in preventing contamination. The need to overcome these limits led to design and development of photobioreactors.

Photobioreactors are closed systems that are made of an array of tubes or tanks, in which microalgae are cultivated and monitored. The main challenge in photobioreactor design is to create a simple, inexpensive, high-cell-density, energy-efficient reactor that is scalable to meet the needs of industrial production. Several U.S. companies (GreenFuel Technologies, GreenShift, Solix, and Valcent Products) have created pilot-scale photobioreactors for CO_2 mitigation and biofuel production by microalgae.

• Context

Contemporary society generates significant amounts of waste that affect the climate on Earth as the result of GHG release, as well as polluting the environment generally. One of the solutions to this situation is to turn this waste into energy. Energy-from-waste technologies are valuable for energy generation and may represent efficient means for removing waste while minimizing environmental and climatological side effects. However, energy-from-waste technologies should be used under strict environmental regulations to avoid generating additional pollutants or otherwise exacerbating the problems they seek to solve. For instance, responsible application of energy-from-waste technology would require recycling the CO_2 released from incinerators.

Another solution to waste management is recycling. Making products such as paper from recycled materials requires 65 percent less energy and generates 75 percent less CO_2 and methane emissions than does similar production using virgin raw materials. Therefore, waste recycling, although it does not generate energy, saves considerable amounts of energy and reduces GHG emissions.

Sergei Arlenovich Markov

• Further Reading

Haag, Amanda L. "Algae Bloom Again." *Nature* 447 (May 31, 2007): 520-521. An introductory review on algal biotechnology for CO_2 removal from the atmosphere and biofuel generation.

Nebel, Bernard J., and Richard T. Wright. *Environmental Science: Towards a Sustainable Future.* Englewood Cliffs, N.J.: Prentice Hall, 2008. Introductory environmental education textbook. Several chapters describe waste management and energy-from-waste issues.

Williams, Paul T. *Waste Treatment and Disposal.* Chichester, West Sussex, England: John Wiley and Sons, 1998. Comprehensive book on waste-treatment technologies.

See also: Carbon dioxide; Clean energy; Energy efficiency; Energy resources; Fuels, alternative; Greenhouse gases; Methane; Renewable energy.

Energy Policy Act of 1992

- **Category:** Laws, treaties, and protocols
- **Date:** Signed into law October 24, 1992

The Energy Policy Act of 1992 covers numerous resource conservation initiatives, but Title 16 in particular puts into place mechanisms for monitoring and addressing climate change and global warming.

• Background

The 1973 oil crisis in the United States created a sense of urgency for action to reduce America's dependence on foreign oil while simultaneously reducing carbon dioxide (CO_2) emissions. The 1975 Energy Policy and Conservation Act (EPCA) established corporate average fuel economy (CAFE) standards. In 1978, the Public Utility Regulatory Policies Act (PURPA) promoted development of alternative energy sources. The National Appliance Energy Conservation Act (NAECA) of 1987 envisioned a 21.6 million metric ton reduction in carbon emissions by the year 2010. Title VI of the 1990 Clean Air Act Amendments responded to the domestic ozone depletion issue, which is related to reducing greenhouse gas (GHG) emissions. Then, in 1992, the United States ratified the United Nations Framework Convention on Climate Change (UNFCCC), which challenged industrialized countries to become leaders in reducing GHGs. The Energy Policy Act (EPACT) of 1992 represents the major initial response to that initiative.

• Summary of Provisions

The Energy Policy Act of 1992, an extensive and varied act with twenty-seven titles, addresses various aspects of overriding issues such as improving energy efficiency, implementing measures to reduce GHG generation, and incentives to increase renewable energy and clean coal technology. Title XVI of the act, however, contains specific stipulations that address global climate change and global warming and provides partial fulfillment of obligations which the United States incurred upon ratification of the UNFCCC. The act contains four main mandates.

The act directed the secretary of energy to submit a report to the Congress by October 24, 1994, that was to assess a wide variety of implications for implementing policies that would enable the United States to comply with its obligations under the UNFCCC. These include potential implications relating to the economy, energy, society, the environment, and competition. The report was also to assess the feasibility and implications for jobs and of stabilizing GHG generation in the United States by the year 2005; of stabilizing GHG generation by the year 2005; of reducing the generation of GHGs; and of successfully reducing 1988 levels of CO_2 by 20 percent by the year 2005.

Section 1602 of Title XVI of the act required that each National Energy Policy Plan that the president submitted to Congress include a least-cost energy strategy prepared by the secretary of energy. The strategy had to consider economic, energy-related, social, environmental, and competitive costs and benefits. The strategy design had to be one that could achieve specific things at least cost to the country: federal energy production; utilization and energy conservation priorities; stabilization and eventual reduction in GHG generation; an increase in the efficiency of the total energy use in the United States by 30 percent over 1988 levels by the year 2010; an increase of 75 percent over 1988 levels in the percentage of energy derived from renewable resources by the year 2005; and a reduction in U.S. oil consumption from about 40 percent (1990 level) of total energy use to 35 percent by the year 2005. The strategy also had to identify federal priorities to include policies that implemented standards for more efficient use of fossil fuels, increased the energy efficiency of existing technologies, and encouraged new ones that included such things as clean coal technologies and others that lower GHG levels.

The secretary of energy was directed to establish a director of climate protection within the Department of Energy who would have three major responsibilities: to serve as the secretary's representative for global change policy discussions, including activities of the Committee on Earth and Environmental Sciences and the Policy Coordinating Committee Working Group on Climate Change; to monitor domestic and international policies as to their effects on GHG generation; and to have the authority to participate in planning activities of relevant programs of the Department of Energy.

Section 1609 of the 1992 Energy Policy Act directed the secretary of the treasury, in consultation with the secretary of state, to set up the Global Climate Change Response Fund to be used for American contributions toward global efforts to effect global climate change. Management and uses of the fund were clearly stipulated: No fund deposits would be made before the United States had ratified the UNFCCC; the money was to be used by the president as authorized and appropriated under the Foreign Assistance Act of 1961, exclusively for matters related to the UNFCCC; and $50 million was to be appropriated for deposit for fiscal year 1994, with amounts as deemed necessary for fiscal years 1995 and 1996.

Title XVI: Global Climate Change

Title XVI of the Energy Policy Act of 1992 addresses efforts to mitigate climate change. Section 1601, reproduced below, calls for the production of a report on the ability of the United States to respond to climate change and to limit greenhouse gas emissions.

Not later than 2 years after the date of the enactment of this Act, the Secretary shall submit a report to the Congress that includes an assessment of—

(1) the feasibility and economic, energy, social, environmental, and competitive implications, including implications for jobs, of stabilizing the generation of greenhouse gases in the United States by the year 2005;

(2) the recommendations made in chapter 9 of the 1991 National Academy of Sciences report entitled 'Policy Implications of Greenhouse Warming', including an analysis of the benefits and costs of each recommendation;

(3) the extent to which the United States is responding, compared with other countries, to the recommendations made in chapter 9 of the 1991 National Academy of Sciences report;

(4) the feasibility of reducing the generation of greenhouse gases;

(5) the feasibility and economic, energy, social, environmental, and competitive implications, including implications for jobs, of achieving a 20 percent reduction from 1988 levels in the generation of carbon dioxide by the year 2005 as recommended by the 1988 Toronto Scientific World Conference on the Changing Atmosphere;

(6) the potential economic, energy, social, environmental, and competitive implications, including implications for jobs, of implementing the policies necessary to enable the United States to comply with any obligations under the United Nations Framework Convention on Climate Change or subsequent international agreements.

• Significance for Climate Change

The Energy Policy Act of 1992 began a debate which resulted first in developing a process for deregulating the electric industry. The act mandated open access for transmitting energy to wholesale customers, but not to retail customers. It addressed disposal standards for nuclear waste so as to protect individuals from abnormal amounts of exposure, specifically those in the Yucca Mountain repository site area. It initiated increased research on the production of alternative-fuel vehicles (electric, ethanol, natural gas, and propane) as well as on hybrid electric and hydrogen fuel cell vehicles. The act further resulted in new efficiency standards for faucet fixtures, commercial air conditioning and heating equipment, electric motors, and lamps. Modifications were made in commercial and residential building energy codes. A program for federal support for renewable energy technologies was established, and standards were revised for long-term power purchases, in addition to a host of other provisions.

While some of the energy efficiency measures indirectly affected climate change and global warming—for example, reduction of GHG emissions—as a whole, performance reports on the Title XVI provisions (those concerning climate control and global warming) were disappointing; implementation deadlines, for one thing, were not met. Also, a number of measures were to be voluntary, thus weakening the impact of the law. The act did, however, provide a framework for pursuing its mandates and result in subsequent amendments that could enhance the odds of future realization.

Victoria Price

• Further Reading

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It.* New York: Hill and Wang, 2008. Explains why climate change may be getting out of control, but offers possibilities for reversing the trend.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It.* Emmaus, Pa.: Rodale, 2006. The climate crisis is seen as an opportunity for a generational mission and moral purpose. Addresses the numerous areas in which Americans, in particular, have contributed to a global warming crisis.

Leroux, Marcel. *Global Warming, Myth or Reality? The Erring Ways of Climatology.* New York: Springer, 2005. Outlines the history of global warming. Discusses climate models and their limitations, and postulates alternative causes of climate change.

See also: Air pollution and pollutants: anthropogenic; Clean Air Acts, U.S.; Clean energy; U.S. energy policy; U.S. legislation.

ENCYCLOPEDIA OF
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Abbreviations and Acronyms

AMO: Atlantic multidecadal oscillation
AQI: Air Quality Index
C^{14}: carbon 14
CCS: carbon capture and storage
CDM: clean development mechanism
CER: certified emissions reduction
CFCs: chlorofluorocarbons
CH_4: methane
CITES: Convention on International Trade in Endangered Species
CMP: Conference of the Parties to the United Nations Framework Convention on Climate Change, functioning as the meeting of the Parties to the Kyoto Protocol
CO: carbon monoxide
CO_2: carbon dioxide
CO_2e: carbon dioxide equivalent
COP: Conference of the Parties [to a treaty, such as the Framework Convention on Climate Change or the Convention on Biological Diversity]
COP/MOP: Conference of the Parties to the United Nations Framework Convention on Climate Change, functioning as the meeting of the Parties to the Kyoto Protocol
COP-1: First Conference of the Parties
CSD: Commission on Sustainable Development
DNA: deoxyribonucleic acid
EEZ: exclusive economic zone
ENSO: El Niño-Southern Oscillation
EPA: Environmental Protection Agency
ERU: emission reduction unit
FAO: Food and Agriculture Organization
GCM: general circulation model
GDP: gross domestic product
GHG: greenhouse gas
GWP: global warming potential
H_2: hydrogen (molecular)
HCFCs: hydroclorofluorocarbons
HFCs: hydrofluorocarbons
IAEA: International Atomic Energy Agency
IGY: International Geophysical Year
IMF: International Monetary Fund
INQUA: International Union for Quaternary Research
IPCC: Intergovernmental Panel on Climate Change
ITCZ: Inter-Tropical Convergence Zone
IUCN: International Union for Conservation of Nature
LOICZ: Land-Ocean Interactions in the Coastal Zone
MOC: meridional overturning circulation
MOP: meeting of the Parties [to a treaty, such as the Kyoto Protocol]
MOP-1: first meeting of the Parties
N_2O: nitrous oxide
NAAQS: National Ambient Air Quality Standards
NAM: Northern annular mode
NAO: North Atlantic Oscillation
NASA: National Aeronautics and Space Administration
NATO: North Atlantic Treaty Organization
NGO: nongovernmental organization
NOAA: National Oceanic and Atmospheric Administration
NO_x: nitrogen oxides
NRC: National Research Council
O^{16}: oxygen 16
O^{18}: oxygen 18
O_2: oxygen (molecular)
O_3: ozone
OECD: Organization for Economic Cooperation and Development
OPEC: Organization of Petroleum Exporting Countries
PFCs: perfluorocarbons
QELRCs: quantified emission limitation and reduction commitments
RuBisCO: Ribulose-1,5-bisphosphate carboxylase/oxygenase
SAM: Southern annular mode
SCOPE: Scientific Committee on Problems of the Environment
SF_6: sulfur hexafluoride
SO_2: sulfur dioxide

SSTs: sea surface temperatures
SUV: sports utility vehicle
THC: Thermohaline circulation
UNCED: United Nations Conference on Environment and Development
UNDP: United Nations Development Programme
UNEP: United Nations Economic Programme
UNESCO: United Nations Educational, Scientific, and Cultural Organization
UNFCCC: United Nations Framework Convention on Climate Change
UV: ultraviolet
VOCs: volatile organic compounds
WHO: World Health Organization
WMO: World Meteorological Organization

Common Units of Measure

Common prefixes for metric units—which may apply in more cases than shown below—include *giga-* (1 billion times the unit), *mega-* (one million times), *kilo-* (1,000 times), *hecto-* (100 times), *deka-* (10 times), *deci-* (0.1 times, or one tenth), *centi-* (0.01, or one hundredth), *milli-* (0.001, or one thousandth), and *micro-* (0.0001, or one millionth).

Unit	*Quantity*	*Symbol*	*Equivalents*
Acre	Area	ac	43,560 square feet 4,840 square yards 0.405 hectare
Ampere	Electric current	A *or* amp	1.00016502722949 international ampere 0.1 biot *or* abampere
Angstrom	Length	Å	0.1 nanometer 0.0000001 millimeter 0.000000004 inch
Astronomical unit	Length	AU	92,955,807 miles 149,597,871 kilometers (mean Earth-Sun distance)
Barn	Area	b	10^{-28} meters squared (approx. cross-sectional area of 1 uranium nucleus)
Barrel (dry, for most produce)	Volume/capacity	bbl	7,056 cubic inches; 105 dry quarts; 3.281 bushels, struck measure
Barrel (liquid)	Volume/capacity	bbl	31 to 42 gallons
British thermal unit	Energy	Btu	1055.05585262 joule
Bushel (U.S., heaped)	Volume/capacity	bsh *or* bu	2,747.715 cubic inches 1.278 bushels, struck measure
Bushel (U.S., struck measure)	Volume/capacity	bsh *or* bu	2,150.42 cubic inches 35.238 liters
Candela	Luminous intensity	cd	1.09 hefner candle
Celsius	Temperature	C	1° centigrade
Centigram	Mass/weight	cg	0.15 grain
Centimeter	Length	cm	0.3937 inch
Centimeter, cubic	Volume/capacity	cm^3	0.061 cubic inch
Centimeter, square	Area	cm^2	0.155 square inch

Unit	*Quantity*	*Symbol*	*Equivalents*
Coulomb	Electric charge	C	1 ampere second
Cup	Volume/capacity	C	250 milliliters 8 fluid ounces 0.5 liquid pint
Deciliter	Volume/capacity	dl	0.21 pint
Decimeter	Length	dm	3.937 inches
Decimeter, cubic	Volume/capacity	dm^3	61.024 cubic inches
Decimeter, square	Area	dm^2	15.5 square inches
Dekaliter	Volume/capacity	dal	2.642 gallons 1.135 pecks
Dekameter	Length	dam	32.808 feet
Dram	Mass/weight	dr *or* dr avdp	0.0625 ounce 27.344 grains 1.772 grams
Electron volt	Energy	eV	$1.5185847232839 \times 10^{-22}$ Btus $1.6021917 \times 10^{-19}$ joules
Fermi	Length	fm	1 femtometer 1.0×10^{-15} meters
Foot	Length	ft *or* ′	12 inches 0.3048 meter 30.48 centimeters
Foot, cubic	Volume/capacity	ft^3	0.028 cubic meter 0.0370 cubic yard 1,728 cubic inches
Foot, square	Area	ft^2	929.030 square centimeters
Gallon (British Imperial)	Volume/capacity	gal	277.42 cubic inches 1.201 U.S. gallons 4.546 liters 160 British fluid ounces
Gallon (U.S.)	Volume/capacity	gal	231 cubic inches 3.785 liters 0.833 British gallon 128 U.S. fluid ounces
Giga-electron volt	Energy	GeV	$1.6021917 \times 10^{-10}$ joule
Gigahertz	Frequency	GHz	—
Gill	Volume/capacity	gi	7.219 cubic inches 4 fluid ounces 0.118 liter

Unit	*Quantity*	*Symbol*	*Equivalents*
Grain	Mass/weight	gr	0.037 dram 0.002083 ounce 0.0648 gram
Gram	Mass/weight	g	15.432 grains 0.035 avoirdupois ounce
Hectare	Area	ha	2.471 acres
Hectoliter	Volume/capacity	hl	26.418 gallons 2.838 bushels
Hertz	Frequency	Hz	$1.08782775707767 \times 10^{-10}$ cesium atom frequency
Hour	Time	h	60 minutes 3,600 seconds
Inch	Length	in *or* ″	2.54 centimeters
Inch, cubic	Volume/capacity	in^3	0.554 fluid ounce 4.433 fluid drams 16.387 cubic centimeters
Inch, square	Area	in^2	6.4516 square centimeters
Joule	Energy	J	$6.2414503832469 \times 10^{18}$ electron volt
Joule per kelvin	Heat capacity	J/K	$7.24311216248908 \times 10^{22}$ Boltzmann constant
Joule per second	Power	J/s	1 watt
Kelvin	Temperature	K	–272.15 Celsius
Kilo-electron volt	Energy	keV	$1.5185847232839 \times 10^{-19}$ joule
Kilogram	Mass/weight	kg	2.205 pounds
Kilogram per cubic meter	Mass/weight density	kg/m^3	$5.78036672001339 \times 10^{-4}$ ounces per cubic inch
Kilohertz	Frequency	kHz	—
Kiloliter	Volume/capacity	kl	—
Kilometer	Length	km	0.621 mile
Kilometer, square	Area	km^2	0.386 square mile 247.105 acres
Light-year (distance traveled by light in one Earth year)	Length/distance	lt-yr	5,878,499,814,275.88 miles 9.46×10^{12} kilometers

Unit	*Quantity*	*Symbol*	*Equivalents*
Liter	Volume/capacity	L	1.057 liquid quarts 0.908 dry quart 61.024 cubic inches
Mega-electron volt	Energy	MeV	—
Megahertz	Frequency	MHz	—
Meter	Length	m	39.37 inches
Meter, cubic	Volume/capacity	m^3	1.308 cubic yards
Meter per second	Velocity	m/s	2.24 miles per hour 3.60 kilometers per hour
Meter per second per second	Acceleration	m/s^2	12,960.00 kilometers per hour per hour 8,052.97 miles per hour per hour
Meter, square	Area	m^2	1.196 square yards 10.764 square feet
Metric. *See* unit name			
Microgram	Mass/weight	mcg *or* µg	0.000001 gram
Microliter	Volume/capacity	µl	0.00027 fluid ounce
Micrometer	Length	µm	0.001 millimeter 0.00003937 inch
Mile (nautical international)	Length	mi	1.852 kilometers 1.151 statute miles 0.999 U.S. nautical miles
Mile (statute or land)	Length	mi	5,280 feet 1.609 kilometers
Mile, square	Area	mi^2	258.999 hectares
Milligram	Mass/weight	mg	0.015 grain
Milliliter	Volume/capacity	ml	0.271 fluid dram 16.231 minims 0.061 cubic inch
Millimeter	Length	mm	0.03937 inch
Millimeter, square	Area	mm^2	0.002 square inch
Minute	Time	m	60 seconds
Mole	Amount of substance	mol	6.02×10^{23} atoms or molecules of a given substance

Unit	*Quantity*	*Symbol*	*Equivalents*
Nanometer	Length	nm	1,000,000 fermis 10 angstroms 0.001 micrometer 0.00000003937 inch
Newton	Force	N	x 0.224808943099711 pound force 0.101971621297793 kilogram force 100,000 dynes
Newton meter	Torque	N·m	0.7375621 foot-pound
Ounce (avoirdupois)	Mass/weight	oz	28.350 grams 437.5 grains 0.911 troy or apothecaries' ounce
Ounce (troy)	Mass/weight	oz	31.103 grams 480 grains 1.097 avoirdupois ounces
Ounce (U.S., fluid or liquid)	Mass/weight	oz	1.805 cubic inch 29.574 milliliters 1.041 British fluid ounces
Parsec	Length	pc	30,856,775,876,793 kilometers 19,173,511,615,163 miles
Peck	Volume/capacity	pk	8.810 liters
Pint (dry)	Volume/capacity	pt	33.600 cubic inches 0.551 liter
Pint (liquid)	Volume/capacity	pt	28.875 cubic inches 0.473 liter
Pound (avoirdupois)	Mass/weight	lb	7,000 grains 1.215 troy or apothecaries' pounds 453.59237 grams
Pound (troy)	Mass/weight	lb	5,760 grains 0.823 avoirdupois pound 373.242 grams
Quart (British)	Volume/capacity	qt	69.354 cubic inches 1.032 U.S. dry quarts 1.201 U.S. liquid quarts
Quart (U.S., dry)	Volume/capacity	qt	67.201 cubic inches 1.101 liters 0.969 British quart
Quart (U.S., liquid)	Volume/capacity	qt	57.75 cubic inches 0.946 liter 0.833 British quart
Rod	Length	rd	5.029 meters 5.50 yards

Unit	*Quantity*	*Symbol*	*Equivalents*
Rod, square	Area	rd^2	25.293 square meters 30.25 square yards 0.00625 acre
Second	Time	s *or* sec	$\frac{1}{60}$ minute $\frac{1}{3600}$ hour
Tablespoon	Volume/capacity	T *or* tb	3 teaspoons 4 fluid drams
Teaspoon	Volume/capacity	t *or* tsp	0.33 tablespoon 1.33 fluid drams
Ton (gross or long)	Mass/weight	t	2,240 pounds 1.12 net tons 1.016 metric tons
Ton (metric)	Mass/weight	t	1,000 kilograms 2,204.62 pounds 0.984 gross ton 1.102 net tons
Ton (net or short)	Mass/weight	t	2,000 pounds 0.893 gross ton 0.907 metric ton
Volt	Electric potential	V	1 joule per coulomb
Watt	Power	W	1 joule per second 0.001 kilowatt $2.84345136093995 \times 10^{-4}$ ton of refrigeration
Yard	Length	yd	0.9144 meter
Yard, cubic	Volume/capacity	yd^3	0.765 cubic meter
Yard, square	Area	yd^2	0.836 square meter

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ENCYCLOPEDIA OF
GLOBAL WARMING

Energy resources

• **Category:** Energy

Most energy consumed by humans currently comes from fossil fuels, a source that will be exhausted within decades to centuries. Burning these fuels adds CO_2 to the atmosphere, which affects the climate.

• Key concepts

extraction: removing a resource from its natural location

Hubbert's peak: the point at which the rate of production or extraction of an energy resource ceases to increase and begins to decrease

processing: changing a resource into a marketable commodity by milling, refining, and so on

transportation: movement of a resource from its place of origin to its market or processing location

• Background

Many of the greenhouse gases (GHGs) in the atmosphere result from humans burning energy resources. The type of resource being burned depends on the value given to different properties of different fuels. The need for lowest cost and an ability to stockpile supplies favors coal, the need to minimize air pollution favors natural gas, and the need to be easily transported favors fuels derived from petroleum. As the need to limit emissions of GHGs becomes more pressing, it is reasonable to assume that other changes will occur.

• Early American Settlers

Before agriculture, humans used fire to keep warm, cook their food, make their hunting more efficient, and promote the growth of wild plants they could eat or that would attract their preferred game. Their population density was low, and they moved frequently, so they were probably not limited by access to firewood.

As agriculture developed, it became necessary to remain in one location for extended periods. Initially, because the forests had to be cleared anyway, firewood was plentiful, and prodigious amounts were burned. A typical colonial family in New England burned 100 to 145 cubic meters of wood each year, translating to about 23 kilowatts of annual energy use. As the average colonial household contained about six people, the per capita energy use was about 4 kilowatts. For comparison, the United States today has a per capita use of about 11 kilowatts, whereas the global average is about 2.5 kilowatts per capita.

Another energy source available to early settlers was water power. In a new settlement the first major building to be constructed was usually a sawmill, often before churches or schools were built. By 1840, over sixty-five thousand water-powered mills had been operating in the United States. In particularly favorable locations such as Niagara Falls, Rochester, and Minneapolis, large flows over waterfalls permitted many large mills to coexist. Dependent on rainfall, removed by floods, and usually limited in scale by available hydraulic head and river flows, water-powered mills lost out to steam power, produced from coal.

Energy from coal did not fluctuate with the seasons, factories could grow, and they could be located where infrastructure existed to transport resources and products. Furthermore, they could become concentrated in those locations, providing jobs for thousands of city dwellers, rather than being stretched out along often unnavigable rivers.

• The Industrial Revolution

By the middle of the nineteenth century the Industrial Revolution had begun, largely as a result of the steam engine. In addition to the large steam engines powering factories, smaller ones were adapted to pull trains, and with this development it became easier to transport an energy resource from where it occurred naturally to where it was needed.

To be valuable, resources need to bring in a profit when and where they are sold. The costs of bringing a resource to market, including extraction, processing, and transportation, as well as the market price, will determine whether that resource can be utilized. For example, abandoned gold dredges sit near the headwaters of dozens of streams in Alaska, intact except for their copper wires. The costs of dismantling and transporting the other parts are greater than their market value.

Coal requires little processing, so the cost of

A worker manipulates a valve on the pipeline from Iraq's Zubair Moshrif oil field. (AP/Wide World Photos)

bringing it to market entails only a trade-off between extraction and transportation. More expensive mining techniques can be used where transportation costs are lower. Coal quality (heat content, sulfur content, and so on) varies, and long-term contracts may also distort prices, resulting in remarkable discrepancies. In 2006, for example, the open market value of a ton of coal mined in Wyoming was $9.03, with a delivered price in Wyoming of $17.61; the open market value of a ton of coal mined in Pennsylvania was $37.42, with a delivered price in Massachusetts of $68.02.

The railroads and the coal industry have had a mutually beneficial relationship: Before the advent of diesel locomotives trains were a major coal user, and coal has always been a major fraction of the freight moved by trains. In addition to powering factories and trains, coal was used to heat homes. It had gradually replaced wood and by 1885 it heated more homes than wood did. Basement furnaces replaced stoves and fireplaces, and the low cost of coal meant that homes could be heated even with windows open in the middle of winter. The combined effect of hundreds of coal-burning furnaces, however, polluted the air, and the shipping, handling and storing of coal were very dirty operations.

Because it is a sedimentary rock, formed in swamps hundreds of millions of years ago, coal does not burn cleanly, but forms ash and clinker that need to be disposed of. Much less labor-intensive than wood stoves, coal furnaces still needed people to attend to them, to make sure coal was getting to the furnace and ash was being removed. As soon as oil or gas could be used, it quickly replaced coal for home heating.

Oil became an energy resource after ways were discovered to extract kerosene from it, which was used for lighting. By the beginning of the twentieth century large reliable supplies had been developed, largely in Texas, and railroads and barges transported it to markets elsewhere. The invention of the automobile and the oil burner during the first decades of the twentieth century made oil the most important energy resource in Europe and America. Crude oil must be extracted from the ground, transported to a refinery, processed, and then transported again before its useful components, gasoline and other fuels, can be used. Before this, it must be discovered.

• Estimating Oil Reserves

An economic resource must be sufficiently abundant so that the costs needed to develop it can be paid off before it runs out. When a company invests in refineries and distribution systems it should know that it has sufficient reserves on hand to justify those expenses. These are called "proven reserves." To exploit these reserves, the resource must be extracted, processed, and transported and still return a profit to the company. The amount of proven reserves is a function of all of these costs as well as the market price of the final product. A company which is neither finding new resources nor selling old resources can still see change in the amount of proven reserves it owns as these costs and prices change. As the price of oil rose in 2007, the vast oil sands in Alberta, Canada, became profitable to extract and so were, in many tabulations, added to the list of proven reserves. When they are included they put Canada second, after Saudi Arabia, in total proven reserves.

In 1949 M. King Hubbert suggested that production of a nonrenewable resource would follow a bell-shaped curve, reaching a peak when about half of the resource had been consumed. Since then there has been considerable discussion about whether or not some region, defined geologically or politically, has reached its "Hubbert's peak" with respect to some resource. Although details vary, emotions run high, and apocalyptic predictions sprout up like weeds, a consensus is gradually developing that the world peak for conventional oil will have been, or will occur, sometime between 2005 and 2050.

As is the case with coal, natural gas requires transportation to a market before it has value. When it is encountered in oil fields with no access to pipelines, transportation costs often exceed market prices, so the natural gas is burned off, or "flared." Technological developments in the 1940's permitted the construction of extensive pipeline systems to distribute natural gas in developed countries. By 2008, there were over 480,000 kilometers of pipelines in the United States. Where pipeline infrastructure exists, much of the cost of natural gas is still in its transportation. In 2007 in the United States, for example, the average price for 28.3 cubic meters at the wellhead was $6.39, while residential users paid $13.01.

Renewables face similar distribution requirements. Solar- or wind-generated energy needs to be shipped to a market, and ideally needs to be stored until it is most needed. As each conversion step has inefficiencies, this will add to the costs of renewable energy resources.

• Context

Climate change scenarios rely on estimates of the total amount of carbon-containing fuels which will be burned and the rate at which this will occur. Neither estimate is known well; however, guidance is provided by exploring resource utilization history. As reserves of petroleum are depleted, it is reasonable to expect prices to rise and alternative fossil fuel resources, such as oil sands and oil shales, to be developed. Whether or not such unconventional fossil fuels are included in climate model projections can make a substantial difference in the predicted CO_2 levels in the atmosphere.

For renewable energy resources to compete, means must be developed to store their energy and transport it to markets when and where it is needed. For example, wind energy is unlikely to be directly available during hot spells, which are usually accompanied by still, high-pressure air—yet, that is just when peak electric loads to run air conditioners are greatest. If wind energy could be stored in batteries, hydrogen, pumped-storage facilities, and other repositories, then it would be available when most needed. If it could be shipped and stockpiled safely and efficiently, then huge installations of windmills could be developed, far from populated or scenic areas, perhaps in developing countries.

Otto H. Muller

• Further Reading

BP. *BP Statistical Review of World Energy, June, 2008.* London: Author, 2008. One of the industry standards for assessing energy resources, this publication consists of a wide variety of tables and charts, including data from all of 2007. Written by an oil company, its biases are different from those of a government agency. Charts, tables.

Campbell, C. J., and J. H. Laherrere. "The End of Cheap Oil." *Scientific American* 278, no. 3 (1998): 60-65. An easily understood description of Hubbert's peak, the difficulties involved in reporting proven reserves, and some of the possible effects of depleting petroleum resources. Graphs, charts.

Cloud, P. *Resources and Man.* San Francisco: W. H. Freeman, 1969. A report by the National Academy of Sciences; the last third concerns energy resources. Of interest is how well the predictions have held up over time. Tables, charts, graphs.

Energy Information Administration, U.S. *Annual Energy Review, 2006*. Washington, D.C.: Government Printing Office, 2007. One of the industry standards for assessing energy resources, this publication consists of a wide variety of tables and charts, including data from all of 2006. Written by a government agency, its biases are different from those of an oil company.

Wolfson, Richard. *Energy, Environment, and Climate*. New York: W. W. Norton, 2008. An excellent treatment of environmental energy issues; Wolfson is able to construct quantitative explanations without using intimidating math. In addition to showing how the variables relate, he includes current values for global estimates of many of the important variables. Illustrations, figures, tables, maps, bibliography, index.

See also: Biofuels; Clean energy; Coal; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Geothermal energy; Hubbert's peak; Nuclear energy; Renewable energy; Solar energy; Wind power.

Engineers Australia

- **Category:** Organizations and agencies
- **Date:** Established 1919
- **Web address:** http://www.engineersaustralia.org.au/

• Mission

Engineers Australia advocates a comprehensive, coordinated governmental approach to counter environmental degradation. It particularly wants to recast infrastructure, such as transportation, energy, and greenhouse gas (GHG) management, in order to ensure security, prosperity, and social harmony while fostering sustainability.

Its royal charter naming it as the Institution of Engineers, Australia, the eighty-thousand-member nonprofit organization is best known simply as Engineers Australia. It is governed by its National Council and Congress chaired by its president, has a national office in the capital (Canberra) headed by its chief executive, and maintains nine state and territorial divisions. It is affiliated as well with colleges, national committees, technical societies, and engineering interest groups.

Engineers Australia serves as a national forum for promoting all engineering disciplines. Specifically, it seeks to advance engineering science, set standards for chartering engineers, cultivate educational development among its members, instill professional ethics and integrity, and recognize achievements through awards. Its National Engineering Registration Board, established in 1994, is a consumer-protection measure to ensure that enrolled engineers use their knowledge in the public interest.

• Significance for Climate Change

Engineers Australia issued a media statement in June, 2007, defining its support for a GHG reduction effort that progressively decreases annual emissions. The statement quotes the group's national president, Rolfe Hartley:

> The collective science and ongoing research firmly point to the need to reduce global greenhouse emissions by 2050 by between 40 and 80 percent. Any further delays in determining a target, rather than getting on with solutions, is more wasted time that we don't have. A target in this range requires only a minimal reduction in emissions of about 1 percent per year.
>
> While we need to balance the impact of meaningful action on global warming on our economy and employment opportunities, the fact remains that a slightly slower growth of the Australian economy stands in stark contrast to what may happen if the economy becomes smaller under the impacts of climate change. . . .
>
> While it would be naïve to expect global consensus on emission reduction programs in the short-term, it would be equally dangerous for Australia to continue to procrastinate and then opt for emissions reduction programs that lack substance and rigour.
>
> Until wider agreement on a global emissions strategy is achieved, Australia could go a long way

towards meeting a meaningful emissions target through vigorously pursuing energy efficiency approaches which the International Energy Agency believes could achieve almost half of the needed emissions.

Roger Smith

See also: Climate engineering.

Enhanced greenhouse effect

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Greenhouse gases (GHGs) in the atmosphere—such as carbon dioxide (CO_2), methane, nitrous oxide, water vapor, and ozone—absorb infrared radiation from the Sun and reradiate some of it at the surface, warming Earth's atmosphere. The average temperature of the atmosphere has been estimated to be more than 30° Celsius warmer than it would be without these gases. The natural greenhouse effect occurs when this process is the result of nonhuman activities; the enhanced greenhouse effect denotes increases in the effect caused by GHGs emitted into the atmosphere by human activities.

• **Significance for Climate Change**

The concentrations of CO_2 and, to a lesser extent, other GHGs have gradually increased in the atmosphere, especially during the twentieth century. For instance, the CO_2 content of the atmosphere in the Hawaiian Islands has increased from 313 parts per million in 1960 to 375 parts per million in 2005. Arctic ice-core samples indicate that the CO_2 content of the atmosphere has also gradually increased over longer timescales. Much of this increase in atmospheric CO_2 concentration appears to be due to human activity, although the importance of human activity relative to natural processes such as in volcanism is not clear. It is known, however, that CO_2 is released to the atmosphere by human activity, such as the burning of fossil fuels (petroleum, natural gas, and coal). Deforestation of tropical and other forests—such as the Amazon rain forest in Brazil—produces a great deal of CO_2 as the plants decay, and it also reduces an extremely important carbon sink, increasing the amount of CO_2 that remains in the atmosphere rather than being converted to biomass and oxygen. CO_2 is also liberated in cement production.

A continued increase in GHGs will likely cause a continued increase in the average temperature of the atmosphere. The greatest increase in temperature will likely be over polar landmasses. For example, a doubling of the amount of CO_2 in the atmosphere has been predicted to cause an average increase of 3° to 4° Celsius at high northern latitudes, resulting in much less snow and ice. Summer conditions might last an extra two months with a correspondingly shorter winter.

Warmer air holds more water vapor than cooler air, so global warming will likely cause the evaporation rate to increase. This increase in evaporation may result in increased drought, desertification, and water shortages in some regions. Although water availability may decrease, greater levels of atmospheric CO_2 will mean more CO_2 is available to drive photosynthesis, so some plants may benefit from this increase. Warmer temperatures at higher latitudes should also allow some crops such as wheat to be grown further to the north than at the present.

Robert L. Cullers

See also: Carbon dioxide; Climate change; Emissions standards; Greenhouse effect; Greenhouse Gas Protocol; Greenhouse gases; Methane.

Environmental economics

• **Category:** Economics, industries, and products

Environmental economics seeks to quantify present and future losses from damaged health and depleted natural resources that are due to environmental degradation. The *most efficient way to reduce these losses is determined by comparing the cost of environmental damage to the cost of mitigation options.*

• Key concepts

abatement cost: cost incurred when reducing a nuisance such as pollution

Coase theorem: assertion that when property rights are properly defined, people are forced to pay for the negative externalities they impose on others and market transactions will produce efficient outcomes

discount rate: percentage by which measured economic effects occurring in the future are transformed into present values

emission charges: a fixed-rate tax calculated per unit of emissions

option value: potential benefits of the environment not derived from actual use

Pareto optimum: a situation in which it is impossible to make improve any individual's condition without worsening that of another individual

willingness to accept (WTA): minimum amount of money one would accept to forgo some good or to bear some harm

willingness to pay (WTP): maximum amount of money one would give up to buy some good

• Background

Environmental economics emerged as a discipline in the 1950's and 1960's, when its primary focus was on natural resource economics as concern over environmental degradation began to develop. Environmental economics borrows heavily from the theories of its precursors and is couched in many neoclassical economics assumptions. Environmental economics has evolved to address ever-emerging issues, such as pollution and fishery issues. Currently, efficiently mitigating and adapting to climate change, which is a multidiscipline issue, is a main focus.

• Monetary Valuation of the Environment

Environmental economics is predicated on the concept that natural resources and environmental health can be valued monetarily, which is contested by some environmentalists. Economic value is determined by people's preferences and the intersection of supply and demand for the valued entity. Money is a convenient and familiar metric to decision makers determining "optimal" environmental policies. Monetary valuation has been established as a precedent by legally mandated economic reparations in major environmental disasters, such as the 1989 *Exxon Valdez* oil spill off Alaska.

The economic value of an environmental good is assessed subjectively, is relative to the value of other goods, and is marginal (that is, it is altered by changes in the broader state of affairs). There is no formal market for environmental goods; therefore, economists have developed methods to elicit individuals' valuation. "Revealed preferences" methodology deduces valuation based on people's observed behaviors. Alternatively, "stated preference" methodology techniques directly ask people their valuation of environmental goods.

Monetary valuation of the environment remains an ethical question. This brand of valuation is based upon a utilitarian philosophy, which is anthropocentric and consequentialist. It can be argued that individual preferences are a poor guide for social decision making. To appropriately weigh all aspects of a decision, the environment should not be ignored; some monetary valuation is arguably better than none at all. In 1997, researchers estimated that the worldwide flow of environmental services was $33 trillion, demonstrating that the environment is a larger provider of economic goods and services than conventional economic estimates reflect.

• Cost-Benefit Analysis

Economic valuation allows comparison of diverse benefits and costs associated with ecosystem conservation. In this way, the wider array of benefits and costs associated with a project can be considered in deciding which alternative produces the largest net benefit to society. Economists study how people make decisions when faced with scarcity. Scarcity implies that resources devoted to one end are not available to meet another; hence, there is opportunity cost associated with any action. For example, funds used by a municipality to retrofit a sewage treatment plant cannot also be used to improve the local community center. Pareto improvements are an important consideration in this process.

Cost-benefit analysis (CBA) is the economist's applied tool for assessing the efficiency of alternative public choices and policies. Economists favor the use of CBA because it requires transparency and encourages objectivity by the analyst. CBA provides an organizational framework for identifying, quantifying, and comparing benefits and costs of a proposed action. Generally, economists suggest policies providing greater benefits than costs; CBA allows ranking of alternatives in this manner.

• Market-Based Instruments

The Coase theorem states that under ideal circumstances, when polluters and polluttees bargain, the equilibrium level of pollution is independent of the allocation of property rights. Ideal circumstances include perfect information about costs and benefits and assume no transaction costs. In the real world, externalities can lead to market failures, and the use of market-based instruments can provide more equitable outcomes. The optimal level of pollution is determined where the marginal cost of emissions and marginal benefits are equal. The target level of the policy is then calculated, taking into account the potential for gaming and principal-agent problems.

The four main economic instruments used are pollution taxes, clean technology subsidies, tradable permits, and hybrid schemes. Pollution (Pigovian) taxes and clean technology subsidies are price instruments; issuance of tradeable emissions permits is a quantity instrument.

Pigovian taxes are levied to correct negative externalities. The tax shifts the marginal private cost (MPC) curve up by the amount of the tax, thus providing incentive for producers to reduce output to the socially optimum level. Subsidies are useful when taxes are politically unrealistic, though they run contrary to the polluter pays principle and can result in efficiency losses. Emissions trading guarantees that the pollution quantity reached is optimal (unlike taxes) but does not cap the costs of achieving the target. The European Union Emission Trading Scheme (EUETS) is the largest multinational emission trading scheme in the world.

• Climate Change Economics

Environmental economics is increasingly involved in climate change mitigation strategies, which present unique problems due to their global nature and the long time-horizons affected.

Estimating abatement costs can be achieved through two different approaches: resource cost estimates (RCE) and macroeconomic cost estimates (MCE). RCE rely on deriving the marginal abatement cost (MAC) curve by estimating and ranking the technologies and their emissions potential. MCE models examine behavioral responses to carbon price increases.

Economic estimation of potential global warming damages necessitates an integrated assessment (IA) approach, considering scientific findings and socioeconomic forcings. IA models differ considerably in impact representations, which are especially sensitive to the discount rate and applied elasticity of marginal utility.

• Context

Environmental economists are tasked with recommending policies that reflect appropriate division of scarce resources on the societal level. However, there is controversy over the correct manner of nonmarket good and services valuation and whether environmental economics is overly anthropocentric. When dealing with environmental issues, ethical considerations are necessary. For instance, climate change economics is currently dealing with the ethical dimension of discount rate valuation. The long-term nature of climate change coupled with the complexity of climate systems complicates economic analyses by producing inherently high uncertainty as to potential outcomes.

Jennifer Freya Helgeson

• Further Reading

Diamond, P., and J. Hausman. "Contingent Valuation: Is Some Number Better than No Number?" *Journal of Economic Perspectives* 8, no. 4 (Autumn, 1994): 45-64. Argues that monetary valuation of environmental goods can be misleading and inaccurate.

Hanneman, M. "Valuing the Environment Through Contingent Valuation." *Journal of Economic Perspectives* 8, no. 4 (Autumn, 1994): 19-43. Supports the use of monetary valuation of environmental goods.

Pizer, W. "Combining Price and Quantity Controls to Mitigate Global Climate Change." *Journal of Public Economics* 85, no. 3 (2002): 409-434. Discusses the economics of hybrid mechanisms.

Stern, N., et al. *Stern Review on the Economics of Climate Change.* New York: Cambridge University Press, 2006. This report, headed by Lord Stern for the British government, discusses the effect of climate change on the world economy. Not the first economic report on climate change, but its approach and level of detail are novel.

Tietenberg, Tom, and Lynne Lewis. *Environmental and Natural Resource Economics.* 8th ed. Boston: Pearson Addison Wesley, 2009. An introduction to environmental policy problems through an integrated discussion of economic theory and empirical evidence.

See also: Anthropogenic climate change; Damages: market and nonmarket; Deforestation; Ecological impact of global climate change; Economics of global climate change; Environmental movement; Extinctions and mass extinctions; Human behavior change; Kyoto Protocol.

Environmental law

• **Category:** Laws, treaties, and protocols

Federal environmental laws such as the Clean Air Acts, although formulated before the modern scientific study of climate change, have become the chief vehicle for attempting to reduce GHG emissions. Several states have passed climate change initiatives, as has the international community in the Kyoto Protocol.

• Key concepts

cap-and-trade agreements: transaction-based agreements that make the right to emit greenhouse gases or other pollutants a fungible commodity

greenhouse effect: increased warming of the Earth caused by absorption of heat energy by gases in the atmosphere

greenhouse gases (GHGs): gaseous constituents of the atmosphere, such as carbon dioxide, that contribute to the greenhouse effect

legal standing: eligibility to bring a civil lawsuit in a specific case, usually as a result of suffering damages

litigation: disputes in court between parties regarding the meaning and execution of laws

• Background

For most of human history, the environment was to all intents and purposes unprotected by law. In Anglo-American law, the near-absolute dominion that was accorded to owners of property put little restraint on the right to consume, exhaust, or pollute resources at will. A nuisance lawsuit could be pursued if a neighbor deprived a property owner of the ability to enjoy such essentials as light, air, and water. The public trust doctrine restrained landowners from monopolizing access to navigable waters. Other than these impediments, American law left the environment open to even the most rapacious use. The preservationist movement of John Muir and Gifford Pinchot focused on conserving public lands and parks; it had little effect on private uses of land.

• Environmental Law

This situation changed in the United States with the introduction of environmental laws in the twentieth century. The first environmental laws were an extension of nuisance laws and health and safety laws: protecting against environmental threats to the safety of the population, rather than the environment itself. But by the 1970's, laws to protect the environment had found broad acceptance in American political and popular culture. The National Environmental Policy Act of 1970 (NEPA) established federal guidelines for protecting the environment. In the same year, Congress established the Environmental Protection Agency (EPA) as the federal authority to oversee enforcement of the environmental laws, and the Clean Air Act Extension to control air pollution.

The Clean Water Act was enacted in 1972 to protect the purity and drinkability of water and to preserve wetlands. The Energy Policy and Conservation Act of 1975, as amended by the Alternative Fuels Act of 1988, mandated automobile fuel economy standards and encouraged the development of alternative fuels in vehicle use. The Comprehensive Environmental Response Compensation and Liability Act of 1980 provided a superfund program to clean up hazardous wastes.

In November, 2006, Carol Browner, future assistant to President Barack Obama for energy and climate change, speaks to reporters outside the Supreme Court building following oral arguments in Massachusetts v. EPA. (AP/Wide World Photos)

• Global Climate Change and the Law

In 2009, the United States contemplated legislation aimed directly at global warming; previously, legal controversies over global warming focused on the extension of existing environmental laws to greenhouse gases (GHGs). For example, the landmark case of *Massachusetts v. EPA* (2007) concerned the question of whether motor vehicular emissions of GHGs are air pollutants and thus subject to regulation under the Clean Air Acts (1963-1990). A major barrier in all environmental law litigation is the question of legal standing—who is permitted to bring a lawsuit on behalf of the environment. Normally a plaintiff must show a concrete and immediate harm.

In *Massachusetts v. EPA*, the U.S. Supreme Court allowed a coalition of environmental groups and state attorney generals to bring the lawsuit. After hearing evidence from both sides, the Court required the EPA to determine if carbon dioxide (CO_2) emissions satisfy the definitions of an air pollutant under the Clean Air Acts and are thus subject to EPA regulation. Likewise, in *Border Power Plant Working Group v. Department of Energy* (2003), the federal government was required to consider power plant CO_2 emissions in regulating the construction of power lines and grids. The administration of George W. Bush, however, did not believe administrative action was required as to climate change. The 2008 election of President Barack Obama signaled a change in executive enforcement. On April 17, 2009, the EPA announced that it had determined that CO_2 and other gas emissions were indeed dangers to public health and welfare and thus subject to its mandate.

Several U.S. states took legislative action on climate change before the U.S. Congress. California in particular passed legislation to restrict GHG emissions. As specific carbon emission legislation is passed by the states, there may be less reliance on older, more general environmental laws to address global warming concerns. The Regional Greenhouse Gas Initiative is a joint cap-and-trade program of ten northeastern states to reduce CO_2 emissions from power plants while pursuing clean energy programs. Globally, the 1992 United Nations Framework Convention on Climate Change launched the international effort to reduce carbon emissions. It found legal force in the Kyoto Protocol of 1997 establishing binding targets for reducing GHGs. However, upon taking office in 2001, President Bush renounced American participation in the protocol.

• Context

Environmental legislation enacted since the 1970's has provided some basis for regulation and litigation concerning CO_2 emissions that many believe contribute to global warming. Environmentalists have made use of such historic legislation as the Clean Air Acts to try to compel the EPA to include reduction of GHGs under its regulatory mandate, a step resisted by President George W. Bush but revisited by the Obama administration. States, particularly in the northeast and California, have been more aggressive in enacting frameworks designed to reduce CO_2 emissions in a cap-and-trade system.

Given the exclusive authority that the federal government retains over national environmental questions and interstate commerce, it is hard to know how effective state legislation can be. The industrialized nations have been active in enacting frameworks, initiatives, and treaties addressing climate change, but, given the nature of international competition and national sovereignty, the future of such essentially voluntary restrictions is uncertain. One of the largest questions facing Congress is how to integrate federal policy with both state and international initiatives.

Howard Bromberg

• Further Reading

Aspatore Book Staff, eds. *The Legal Impact of Climate Change: Leading Lawyers on Preparing for New Environmental Legislation, Assessing Green Programs for Clients, and Working with Government Agencies on Climate Change Issues.* Boston: Thomson West, 2008. Includes essays by lawyers on developments in regulating GHG emissions.

Gerrard, Michael, ed. *Global Climate Change and U.S. Law.* Chicago: American Bar Association, 2008. Provides comprehensive, in-depth essays examining all major aspects of U.S. law as it bears on global climate change.

Kushner, James. *Global Climate Change and the Road to Extinction: The Legal and Planning Response.* Durham, N.C.: Carolina Academic Press, 2009. Written by a law professor; examines broad-ranging economic, social, educational, technological, and legal strategies for reversing climate change. With helpful tables of relevant statutes, regulations, executive orders, and court cases.

Salzman, James, and Barton Thompson. *Environmental Law and Policy.* 2d ed. New York: Foundation Press, 2007. Summarizes the regulatory scheme of U.S. environmental law while emphasizing the policies and controversies underlying the law in a concise and compact manner.

See also: Clean Air Acts, U.S.; Environmental movement; U.S. and European politics; U.S. energy policy; U.S. legislation.

Environmental movement

• **Category:** Environmentalism, conservation, and ecosystems

The organizations and individuals that make up the environmental movement have been instrumental in bringing the issue of climate change into the mainstream and to the attention of the general public. By raising public awareness, the environmental movement has helped pressure politicians and the private sector to take action.

• Key concepts

direct action: nonconventional political activity, including protests and demonstrations

environmental paradox: the tendency of the environmental movement to work within the system that may be responsible for the problems the movement seeks to address

individualization of responsibility: placing responsibility for climate change on individuals rather than on businesses, corporations, or the government

precautionary principle: a policy rule that one should act to prevent severe harm, even if the likelihood of that harm occurring is unknown or potentially low

• Background

The environmental movement began in the 1960's as a grassroots effort to address local and regional environmental issues. With increasing public support throughout the 1970's, it became highly professionalized and began focusing mostly on federal politics. The environmental movement became concerned with global warming in the late 1980's. Since then, the movement has employed a combination of direct action and traditional lobbying methods to prompt action by the public and private sectors to address climate change.

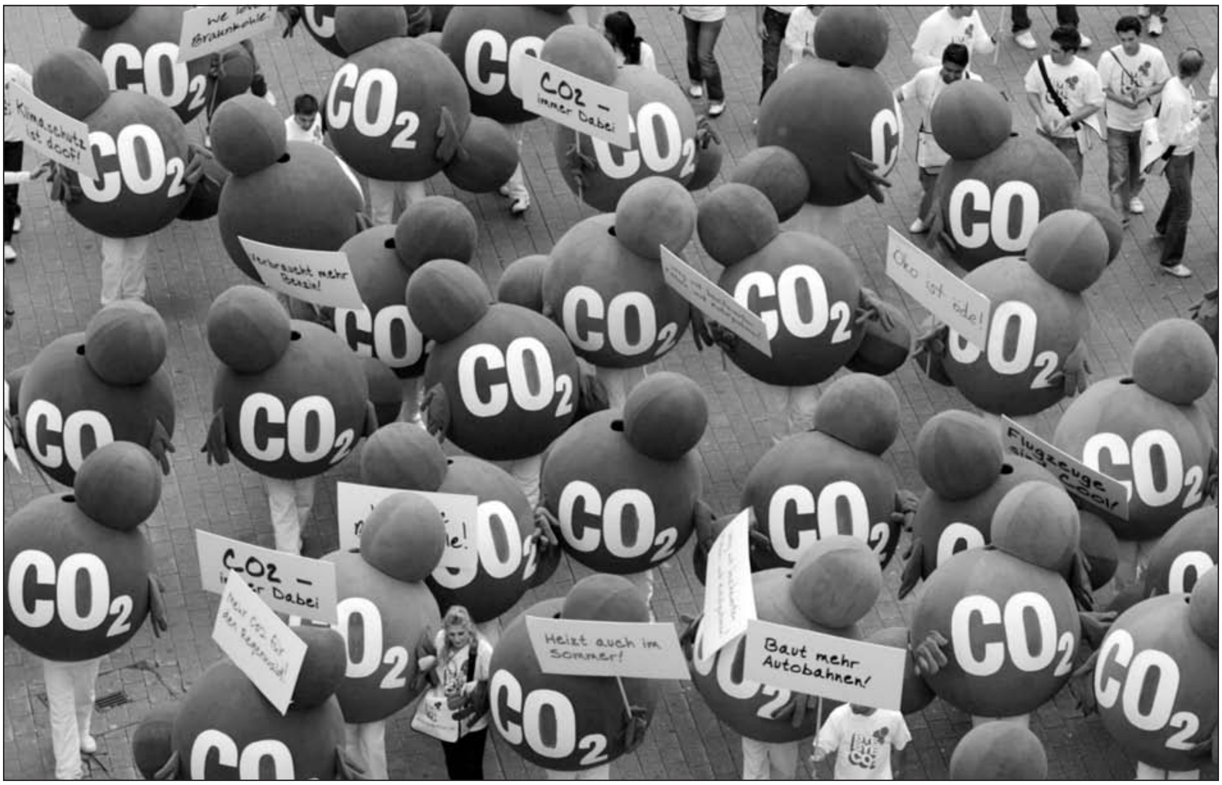
• Promoting Awareness of Climate Change

The environmental movement has promoted both awareness and action in response to climate change through educational and motivational campaigns. These campaigns have targeted the general public, all levels of government, businesses, and international civic society. They have encouraged civic and personal responsibility, made elected officials aware of public opinion, and sought to hold them accountable for responding to it with appropriate legislation. There have been several campaigns in the early twenty-first century, including Step It Up, a grassroots effort to encourage people to lobby their congressional representatives to take action on climate change, and the Climate Change Solutions Campaign, which connects thousands of national and international members of the environmental movement. Both of these campaigns and many others rely on the Internet to reach and educate people. Another method of bringing about awareness is through films. *An Inconvenient Truth* (2006), the U.S. documentary on climate change presented by Al Gore, is a good example of this tactic.

- **Sponsoring Public and Private Solutions**

Traditionally, the environmental movement focused on federal legislation to combat global warming. However, this strategy has proven fruitless for almost two decades. In 2005, major environmental groups began to target state and local governments, some of which are more willing than Congress to address climate change. The Cool Cities Campaign is an example of the environmental movement encouraging action at the local level. This campaign aims to persuade cities to sign the U.S. Conference of Mayors Climate Protection Agreement, a commitment started in 2005 to advance the initiatives of the Kyoto Protocol at the local level. Additionally, the movement has targeted the federal government through litigation related to the Clean Air Acts (1963-1990) in an attempt to force the Environmental Protection Agency to regulate carbon emissions.

The environmental movement has also targeted the private sector through a variety of campaigns, including efforts to discourage the production of sports-utility vehicles (SUVs). In 2004, the Apollo Alliance was established as a large-scale attempt to



Protesters dressed as carbon dioxide molecules march in Essen, Germany, in June, 2007. (Ina Fassbender/Reuters/Landov) address climate change by forging a coalition between environmental groups and labor unions. The alliance is working on the Apollo Project, an effort to create 1 million new jobs in the renewable energy sector and reduce U.S. dependence on foreign oil.

• Dealing with the Opposition

The environmental movement has used a variety of strategies to overcome opposition to action on climate change. A major argument against acting on climate change is that the lack of total scientific consensus does not warrant the economic investment needed. The environmental movement has advocated the use of the precautionary principle in making decisions about climate policy. The principle is popular in other industrial countries, particularly European Union member countries, and holds that even if the risk of climate change is uncertain, the potential for catastrophe is great enough to warrant immediate action to avoid it: Certainty of the risk of severe consequences may come only when it is too late to prevent them.

• Criticisms

Despite the efforts of the environmental movement to address climate change, several critiques have emerged of the movement's dominant climate-related strategies. Kirkpatrick Sale notes that there is an "environmental paradox" that has resulted from the movement's tendency to work within the system that is causing environmental degradation rather than confront the actors and encourage changes to the system itself.

Michael Maniates provides a critique of the "individualization of responsibility," a tendency of environmental groups to encourage individuals to take on responsibility by reducing their own carbon footprints rather than confronting corporate or government entities: Environmental groups, for example, encourage people to use less fossil fuels by biking, carpooling, or driving more efficient vehicles. The argument against this tactic is that alleviating the global warming problem requires much more than individual action, and by focusing on campaigns on individuals, environmentalists implicitly absolve bigger entities that generate large amounts of greenhouse gas emissions of their responsibility. The most notable critique was presented in 2004 by Ted Nordhaus and Michael Shellenberger in their essay, "Death of Environmentalism." The essay criticizes the movement for relying on tactics that worked for issues like acid rain but are inadequate to combat a global environmental problem such as climate change. Environmental organizations responded by revamping their strategies in 2005 to include a more grassroots approach.

• Context

Global warming has become a unifying issue for the environmental movement. It provides an overarching concern that covers all of the issues that environmental organizations deal with, such as biodiversity, preservation, and human health. The ability of the movement to promote the radical changes necessary to mitigate climate change has been called into question. As the organizations and individuals within the movement increase their efforts, some scientists warn that climate change may soon become irreversible. It is yet to be determined whether the sort of concerted effort of all levels of government, consumers, and individuals in nations throughout the globe will agree to implement the sorts of changes that environmentalists believe to be necessary to respond to global warming.

Katrina Darlene Taylor

• Further Reading

Maniates, Michael F. "Individualization: Plant a Tree, Buy a Bike, Save the World." *Global Environmental Politics* 1, no. 3 (2001): 31-52. Reviews the emerging strategy of the environmental movement to place responsibility for solving global warming on individuals. Shows that this may be happening at the expense of seeking political solutions and policies.

Sale, Kirkpatrick. *The Green Revolution: The American Environmental Movement, 1962-1992.* New York: Hill and Wang, 1993. Presents one of the first critiques of the environmental movement's increasing neglect of grassroots organizing and solutions since the 1970's in favor of more professional lobbying and litigation tactics like those used by the for-profit community.

Schellenberger, Michael, and Ted Nordhaus. "Death of Environmentalism." n.p.: Authors, 2004. Argues that the environmental movement is failing

to effect change on global warming and that a new and bolder strategy is needed. Focuses on the need to move away from traditional tactics through the reformation of liberalism, the main political position of the environmental movement.

See also: Biodiversity; Carson, Rachel; Catastrophist-cornucopian debate; Civilization and the environment; Conservation and preservation; Deforestation; Ecological impact of global climate change; Ecosystems; Environmental law; Friends of the Earth; Greenpeace; International Union for Conservation of Nature; Sierra Club; Sustainable development.

Estuaries

• **Categories:** Geology and geography; water resources

• **Definition**

Oceanographer Gerardo Perillo has crafted perhaps one of the most well-considered definitions of an estuary from the dozens that had been put forward previously:

> An estuary is a semi-enclosed coastal body of water that extends to the effective limit of tidal influence within which seawater entering from one or more free connections to the open sea, or other saline body of water, is significantly diluted with freshwater.

This definition encompasses seven geomorphic types of estuary in three categories of salinity stratification. The geomorphic types are: high relief estuaries, such as fjords; moderate-relief, winding valleys, such as rias; low-relief, drowned river valleys, or coastal plain estuaries; deltaic estuaries; tectonic estuaries; bar-built estuaries; and seasonally blocked bar-built estuaries, or blind estuaries. In terms of salinity stratification, estuaries can be salt-wedge, partially mixed, or homogeneous.

• **Significance for Climate Change**

Coastal systems in general and estuaries in particular exert a control over biogeochemical cycles and, therefore, play an important role in regulating global climate. In the face of a changing climate, sea-level rise, sediment supply, the persistence of barrier beaches and salt marshes, water temperature changes, and freshwater supply will all alter estuaries. Changes in the magnitude of freshwater flow or in its seasonal distribution will immediately shift the stratification of existing estuaries. For instance, greater spates will drive existing estuaries toward more stratified end members. Under extreme conditions, salinity gradients could be driven out onto the shelf. At high latitudes, the reduction or elimination of permafrost and sea-ice cover will redefine the freshwater budget of local estuaries.

A transgressive shoreline creates space for estuaries, but it may be inimical to them in some situations. Bar-built estuaries, in particular, rely on the maintenance of a barrier beach. A too rapid rise in sea level could make it impossible for the barriers to maintain themselves, drowning the former estuaries. In other situations, stronger seasonality of freshwater discharge may open formerly blind estuaries or turn ephemeral estuaries into permanent, bar-built estuaries. The condition will depend on the rate of sea-level rise and on the supply of littoral sand by processes that allow barrier beaches to maintain their integrity and to migrate shoreward in the face of rising seas.

In the geological perspective, estuaries are ephemeral features, prevalent at times of high sea-level stands, especially along coasts of low relief. Rising sea levels will shift isohalines inland, possibly turning formerly true-estuarine environments into marginal seas or merely arms of the ocean. At the same time, high-energy environments will shift toward the outer part of the coast. However, because estuaries are sediment traps, their continued existence is a balance between flooding associated with rising sea level and infilling.

Estuaries disappear when they eventually fill with sediment. Climate-induced changes in the amount and seasonality of rainfall, temperature, humidity, and vegetation over wide areas will all influence the rate of infilling of estuaries newly fighting for existence. Any increased sedimentation will

A great egret takes off in the Tijuana Estuary in Imperial Beach, California. (AP/Wide World Photos)

compete with increased sea-level rise to shorten the life of future estuaries. For example, increased rainfall and more intense spates may enhance soil erosion, and changes in both temperature and humidity may accelerate chemical weathering. Northern estuaries might be expected to be exposed to higher sediment supplies more typically associated with semitropical regions.

Human responses to climate change will exert another influence on estuaries, especially because so much human development is concentrated around estuarine shorelines. Shoreline hardening can squeeze out salt marsh development, as well as arresting shoreline transgression. Human control of flooding—such as that provided by the Thames storm-surge barriers, those at Rotterdam and St. Petersburg, and that under construction in Venice—would limit the expansion of estuaries in some regions. The construction of dams to control flooding and water supply could force some estuaries to cope with decreases in both freshwater flow and nutrient fluxes. Changes in forestation and agricultural land-use must further alter the delivery of both nutrients and sediments to estuaries.

Although the physical shifts in estuarine conditions may be as yet poorly resolved, the potential and realized impacts on marine ecosystems are well recognized. Increasing stratification, coupled with elevated temperature, exacerbates problems of hypoxia that already plague many temperate estuaries. Freshening and warming will also change nutrient delivery to the estuary, perhaps increasing total nutrient delivery while simultaneously shifting higher concentrations seaward. Pelagic species will be forced into new patterns of larval transport and recruitment and changes in foraying. Changes in one or two key, leverage species may cause broad, community-level changes. Harmful algal blooms, invasive species and the spread of diseases will alter estuarine ecology further. In Long Island Sound, for example, a crash of the American lobster population has been suggested to result from immunodepression caused by the stress of warming water temperatures.

Henry Bokuniewicz

• Further Reading

Crossland, Christopher J., et al., eds. *Coastal Fluxes in the Anthropocene.* Berlin: Springer-Verlag, 2005. Synthesizes a decade of international research by the Land-Ocean Interactions in the Coastal Zone (LOICZ) project to assess the impacts on coastal ecosystems of climate change and human activity. Focuses on biogeochemical fluxes and key habitats.

Fairbridge, Rhodes W. "The Estuary: Its Definitive and Geodynamic Cycle." In *Chemistry and Biogeochemistry of Estuaries*, edited by E. Olausson and I. Cato. New York: Wiley, 1980. Classic article by a renowned scientist that lays a foundation for the global study of estuaries, including the ephemeral nature of individual estuaries in geological time.

Harley, Christopher D. G., et al. "The Impact of Climate Change in Coastal Marine Systems." *Ecology Letters* 9 (2006): 228-241. Discusses the importance of a few key, "leverage" species in maintaining marine ecosystem services and the potential impacts of temperature changes and changes in ocean chemistry.

Perillo, Geraldo M. E. "Definition and Geomorphic Classifications of Estuaries." In *Geomorphology and Sedimentology of Estuaries*, edited by G. M. E. Perillo. Amsterdam: Elsevier, 1997. Reviews physical, geochemical, and biological characteristics of estuaries and crafts a new definition in the context of multidisciplinary studies as required for coastal management.

See also: Barrier islands; Coastal impacts of global climate change; Coastline changes; Freshwater; Ocean acidification; Ocean life; Sea sediments; Venice.

Ethanol

- **Category:** Energy

- **Definition**

Ethanol (ethyl alcohol, or grain alcohol) is a transportation fuel that is used as a gasoline substitute. Henry Ford's first car, the Model T Ford, was designed to run on pure ethanol. Ethanol is a colorless liquid with the chemical formula C_2H_5OH. It is produced through a biological process based on fungal or bacterial fermentation of a variety of materials. In the United States, most ethanol is produced by yeast (fungal) fermentation of sugar from cornstarch. Sugar is extracted using enzymes, then yeast cells convert the sugar into ethanol and carbon dioxide (CO_2). The ethanol is separated from the fermentation broth by distillation.

Ethanol can also be produced chemically from petroleum. Ethanol produced by fermentation is commonly referred to as bioethanol to differentiate it from chemically produced ethanol. Brazil, the second largest bioethanol producer after the United States, generates bioethanol from sugarcane. Brazilian production of ethanol from sugarcane is more efficient than is the U.S. corn-based production method. Several factors contribute to that efficiency, including climate and cheap labor. In addition, sugarcane has much a higher sugar content than corn, and no enzymes are necessary to extract cane sugar. Therefore, sugarcane yields of ethanol are twice as great as corn yields.

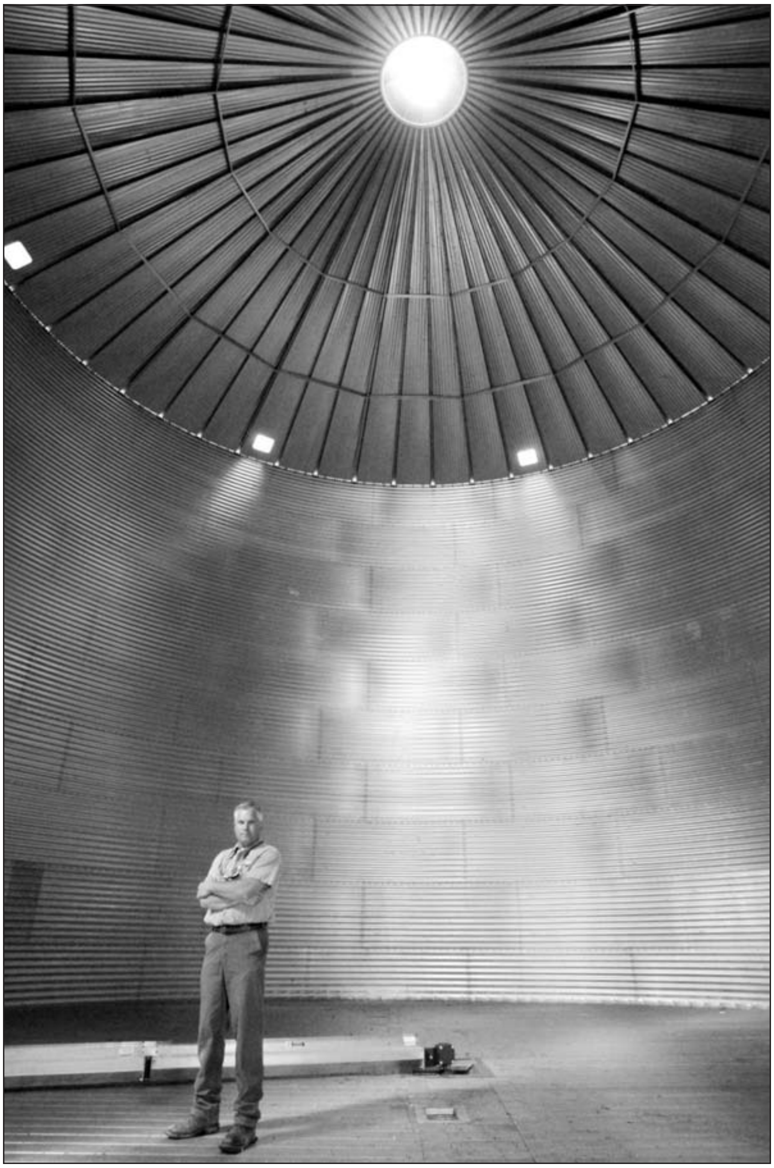
When energy demands and oil prices increase, ethanol becomes a valuable option as an alternative transportation fuel. In 2005, the U.S. Congress passed an energy bill that required gasoline sold in the United States to be mixed with ethanol in order to decrease the nation's dependence on oil. There is a limit to the amount of ethanol that can be mixed with gasoline in the American market, however. Nearly all modern automobiles can use E10, fuel that contains 10 percent ethanol. By contrast, E85, containing 85 percent ethanol and only 15 percent gasoline, requires specially equipped flexible-fuel engines. In the United States, only a fraction of motor vehicles use such engines. Most cars in Brazil have a flex engine, however, as ethanol use in vehicle fuels has been mandatory in that country since 1977. Brazil's ethanol policy allowed the nation to achieve energy independence in 2006.

Blending ethanol with gasoline oxygenates the fuel mixture, which then burns more completely and emits less carbon monoxide. However, ethanol has about two-thirds the energy content of gasoline by volume, so vehicles can travel less far on a gasoline-ethanol mixture than they can on pure gasoline. Ethanol also tends to be more expensive than gasoline. In addition, carcinogenic aldehydes, such as formaldehyde, are produced when ethanol is burned in internal combustion engines.

- **Significance for Climate Change**

Burning ethanol in internal combustion engines produces carbon dioxide (CO_2), a major greenhouse gas (GHG). However, vehicles that run on pure ethanol or ethanol/gasoline mixtures can produce 20 percent less CO_2 than vehicles that burn gasoline alone. Emissions of nitrogen oxide (another GHG) are about equal for both ethanol and gasoline.

In order fully to evaluate ethanol's carbon footprint, it is necessary to determine how much CO_2 is emitting during production of the fuel. Such determinations depend on the method of ethanol manufacturing employed. For example, ethanol can be manufactured from various feedstocks, including starch (cornstarch), sugarcane, and lignocellulose. Lignocellulose is a combination of lignin, cellulose, and hemicellulose that strengthens plant cell walls. Cellulose and hemicellulose are made of sugars that can be converted into ethanol. Many energy-intensive steps are required to sustain this conversion. These steps include growing, transporting, and processing the feedstock.



Stuart Sanderson stands in a 60,000 bushel grain silo, which he intends to fill with corn for use in ethanol production. (Joe Songer/Newhouse News Service/Landov)

Manufacturing ethanol from cornstarch requires considerable amounts of energy, usually obtained by burning fossil fuels. Burning these fossil fuels releases significant amounts of CO_2. In addition, allocating corn crops to ethanol production leads to increases in food prices, because a great number of food items in the United States include corn-based ingredients, such as corn syrup and cornstarch. Corn-based ethanol is thus not a viable long-term biofuel, but it may help smooth the transition from a petroleum-based economy into a biofuel-based economy that utilizes ethanol from other sources.

Increasing corn ethanol use will help reduce U.S. reliance on foreign oil, but it will not do much to slow global warming and will lessen the availability of corn for food. By contrast, net emissions of CO_2 during lignocellulose ethanol production can be nearly zero. Burning the lignin itself can provide enough energy to power ethanol production, alleviating the need for fossil fuels. Burning lignin does not add any net CO_2 to the atmosphere, because the plants that are used to make the ethanol absorb CO_2 during their growth. Most important, lignocellulose may be obtained from nonedible plants, such as switchgrass and poplar, or nonedible parts of other plants, such as corn stalks and wood chips. Thus, lignocellulose ethanol does not compete for food resources.

Lignocellulose is a very attractive ethanol fuel feedstock because it is in abundant supply. On a global scale, plants produce almost 90 billion metric tons of cellulose per year, making it the most abundant organic compound on Earth. In addition, cultivation of nonedible plants for ethanol production requires fewer nutrients, fertilizers, herbicides, acres of cultivated land, and energy resources.

Methods of processing the cellulosic parts of plants into simple sugars in order to ferment them into ethanol have so far been costly. The cost of ethanol generation from lignocellulose can be reduced substantially, however, by using a biorefinery-based production strategy. Similar in function to a petroleum refinery, a biorefinery utilizes every component of lignocellulose to produce useful products, thereby increasing revenues and cost-effectiveness. These products include ethanol fuel, electrical power, heat energy, animal feed, and chemicals such as succinic acid and 1,4-butanediol. The latter can be used to manufacture plastics, paints, and other products. Major research and development efforts are under way to improve the conversion cost of lignocellulose to ethanol.

Sergei Arlenovich Markov

• Further Reading

Demain, Arnold L., Michael Newcomb, and J. H. David Wu. "Cellulase, Clostridia, and Ethanol." *Microbiology and Molecular Biology Reviews* 69, no. 1 (March, 2005): 124-154. Review article about making ethanol from plant cellulose.

Glazer, Alexander N., and Hiroshi Nikaido. *Microbial Biotechnology: Fundamentals of Applied Microbiology*. New York: Cambridge University Press, 2007. In-depth analysis of ethanol for fuel application.

Wald, Matthew L. "Is Ethanol for the Long Haul?" *Scientific American*, January, 2007, 42-49. Excellent discussion about the future of ethanol fuel.

See also: Agriculture and agricultural land; Biofuels; Fossil fuel reserves; Fossil fuels; Hubbert's peak.

Europe and the European Union

- **Category:** Nations and peoples
- **Key facts**

Population: European Union: about 497.5 million; the rest of Europe: about 236 million

European Union Member States (EU27): Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Area: 10,180,000 square kilometers

Gross domestic product (GDP): European Union: $14.82 trillion (purchasing power parity, 2008 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 4,762 in 1995; 4,696 in 2005

Kyoto Protocol status: Ratified by the European Union and all member states in 2002

• Historical and Political Context

After World War II, many European governments agreed on the basic understanding that there never should be a war on European territory again. Shocked by the devastation of the war and by the Holocaust, Winston Churchill soon after the war's conclusion proposed the idea of the establishment of "United States of Europe" (1946). Several institutions and organizations, including the Western Union Treaty (Brussels Treaty, 1948)—signed by Belgium, France, Luxembourg, the Netherlands, and the United Kingdom—the Organization for European Economic Cooperation (OEEC), coordinating the initiatives undertaken by the Marshall plan, and the Council of Europe (1949) were established. Based on a concept by French minister for foreign affairs Robert Schuman, regarding the integration of the Western European coal and steel industry, the Treaty of Paris establishing the European Coal and Steel Community (ECSC) was signed by Belgium, France, Germany, Italy, Luxembourg, and the Netherlands in 1951. The basic idea behind the ECSC was to prevent future wars by economically integrating the two main economic sectors with which a war can be fought, coal and steel. In 1953, all trade barriers regarding these two economic goods were removed within a common market.

The European Communities, the ECSC together with the European Economic Community (EEC) and the European Atomic Energy Community (Euratom), were founded in Rome in 1957. The Treaty of Rome entered into force in 1958, and it established a Parliamentary Assembly and a Court of Justice. In 1958, the Economic and Social Committee (ESC) was founded. Agricultural policies were integrated from 1962 onward by means of the Common Agricultural Policy, and in 1967, a treaty was signed to establish a joint European Commission and a European Council for all three communities. While the 1970's brought much discussion but little progress toward European integration, in 1987, the Single European Act developed the European Economic Community including the European Monetary System (representing further progress for a system of exchange rates).

With the Maastricht Treaty of 1992 and several other commitments, the Common Market, with the free movement of goods and services, financial capital, and labor, was fully established, together with the joint European currency (the euro). Many policy fields fall within the competence of the European Council, the European Commission, and the European Parliament. The majority of policy fields (for example, economic and environmental policy) are treated at the European level, with aims further to integrate tax and social policies of member states and to pass a European Constitution.

Environmental policy is an especially important topic for European integration, since environmental problems (air and water pollution, waste management, land use, climate change) do not follow national boundaries but are often truly international problems. The European Union has therefore established a dense system of environmental regulations touching upon, among other issues, air pollution, water quality standards, agricultural subsidies, transport policies, product and production standards, and the regulation and registration of chemicals.

• Impact of European Policies on Climate Change

The European Union ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1993. After the adoption of the Kyoto Protocol in 1997, the European Union signed the protocol in 1998 and ratified it in 2002, with the obligation that all EU member states had to ratify the Kyoto Protocol by 2002 at the latest.

The European Union and its member states have committed themselves to a reduction of greenhouse gas (GHG) emissions by 8 percent during the observation period of 2008 to 2012, compared to the base years (1990, 1995). The EU member states follow different national policies, including different national base years and reduction scenarios. Some of the newer EU member states do not have reduction targets according to the Kyoto Protocol, since they were transition countries at the time of the setting up of the Kyoto Protocol.

The European Union's Climate Change Strategy quantified the union's policy objective to limit the rise of global temperatures to 2° Celsius above preindustrial levels in 2005, confirming policy objectives already formulated in 1996. The elements of this strategy include differentiated national climate change policies, increase in energy efficiency, efficient policy instruments such as emission trading, and support for climate change adaptation policies.

A major policy instrument for reducing the European Union's GHG emissions is the scheme for GHG-emission-allowance trading based on a mechanism for monitoring GHG emissions. Within the emission trading system, GHGs emitted by certain sources (including energy companies and major industrial emitters) can be traded in order to reduce emissions at sources where reduction is most effi-

European Union commissioner for environment Stavros Dimas, left, and Czech environment minister Ladislav Miko speak at the beginning of Green Week, June, 2009, at the E.U. Commission headquarters in Brussels, Belgium. (AP/Wide World Photos)

cient. EU member countries had to submit national allocation plans for the distribution of emission allowances with many recent positive results regarding the control of CO_2 emissions.

- **Europe and the European Union as GHG Emitters**

The European Union member countries emit huge quantities of GHGs into the atmosphere. Carbon dioxide (CO_2) emissions amounted to 3.778 billion metric tons in 1995 and to 3.873 billion metric tons in 2005; GHG emissions were 4.762 billion metric tons of CO_2 equivalent in 1995 and 4.696 billion tons of CO_2 equivalent in 2005 in EU27. The EU15 countries, falling under the reduction scenarios according to the Kyoto Protocol, create about 3.6 trillion metric tons of CO_2 emissions per year. These emissions exhibit a major impact on global climate change, since the EU15 countries are responsible for 12 percent of global CO_2 emissions. While China (24 percent) and the United States (21 percent) have the largest share in worldwide CO_2 emissions, India (8 percent) and Russia (6 percent) emit smaller amounts of CO_2. While some small oil-producing countries such as Qatar and the United Arab Emirates have the highest per capita emissions, annual U.S. per capita emissions amount to about 17.8 metric tons, which is roughly twice the EU15 per capita emission. China's and India's per capita emissions are comparatively small, at 3.5 and 1.0 metric tons, respectively. However, it is estimated that the sustainable level of per capita emission is at the most 1.8 metric tons per year, indicating that industrialized countries are largely off track from a sustainability perspective.

Regarding the importance of the different economic sectors and activities emitting GHGs, energy use (excluding the transport sector), in particular electricity consumption and the use of energy for heating buildings, is the largest emitter by far (59 percent), followed by the transport sector (21 percent). The agricultural sector emits 9 percent of EU27's GHGs emissions; industrial processes follow with 8 percent.

The European and national strategies have been successful in various degrees. While the EU15 target of reducing GHG emissions is -8 percent until 2008-2012, the EU15 countries managed to reduce CO_2 emissions by 2 percent until 2005. Ten EU27 member states increased their GHG emissions, while the remaining seventeen member states managed to reduce their emissions. Among those that contributed to EU's reduction in GHG emissions, Germany, Finland, the Netherlands, and Romania did the most to combat climate change. For instance, Finland reduced its emissions by 14.6 percent, while Germany reported a fall by 2.3 percent, the largest reduction in absolute terms (21.3 million metric tons). Spain recorded the largest absolute increase in GHGs, 14.0 million metic tons or 3.7 percent, while Austria fell short of its Kyoto reduction target by about 30 percent. Instead of reducing its emissions by 13 percent, emissions were about 20 percent above base year emissions.

• Summary and Foresight

GHG emissions of European Union countries are among the largest in the world. Strong action is therefore needed to decrease CO_2 emissions substantially. The European Union has issued proposals for reduction targets for the post-Kyoto period until 2020. The European Commission proposed to cut GHG emissions by 20 percent until 2020, to increase the share of renewable energy sources from currently around 6.5 percent to 20 percent by 2020, to increase the share of biofuels to 10 percent of all transport fuels, and to reduce energy consumption by 20 percent based on increased energy efficiency. Additionally, the European Council discussed a reduction target of 30 percent based on 1990 emissions, provided that other developed and industrialized countries committed themselves to similar targets and efforts. Critics argue that the European Union's efforts may only slightly decelerate the increase of the CO_2 content in the atmosphere, since reductions in energy use and CO_2 emissions in Europe are—without other comparable international efforts—easily offset by increases in emissions of large countries such as the United States, China, India, and Russia.

Even if the European Union's commitments are realized and the impact on the Earth's climate is small, the economy may largely benefit. Research in new energy-efficient technologies can significantly increase the competitiveness of the European economy, and lower energy costs also increase the disposable income of households.

Regarding the instruments for further emission reduction, the emission trading system will have to be developed further, Europe-wide standards for energy efficiency will have to be set into force, and national policies with respect to energy taxation will have to be coordinated on the European level.

Michael Getzner

• Further Reading

Commission of the European Communities. "An Energy Policy for Europe." *COM(2007)* 1, January 10, 2007. This energy strategy statement describes future EU efforts for increasing energy efficiency, increasing the share of renewables, and technological progress, and includes an "action plans" to achieving EU energy goals.

_______. "Limiting Global Climate Change to 2 Degrees Celsius: The Way Ahead for 2020 and Beyond." *COM(2007)* 2, January 10, 2007. Communication paper of the European Commission addressed to the European Council in order to discuss EU's new targets regarding combating climate change by reducing GHG emissions significantly.

_______. "Proposal for a Decision of the European Parliament and the European Council on the Effort of Member States to Reduce Their Greenhouse Gas Emissions to Meet the Community's Greenhouse Gas Emission Reduction Commitments up to 2020." *COM(2008)* 17, January 23, 2008. The European Commission proposed an "effort-sharing" decision in order to implement GHG emission reduction policies in a differentiated way among EU member countries.

_______. "Proposal for a Directive of the European Parliament and the Council Amending Directive 2003/87/EC So As to Improve and Extend the Greenhouse Gas Emission Allowance Trading System of the Community." *COM(2008)* 16, January 23, 2008. A Commission proposal to account for the 20 percent reduction scenario by means of developing and strengthening EU's emission allowance trading system.

European Communities. *Europe in Figures: Eurostat Yearbook, 2008*. Luxembourg: Office for Official Publications of the European Communities, 2008. Includes statistical information (text, figures, tables) on the demography, economy, environment, and social issues of the European Union and EU member countries; it is also most valuable for details on GHG emissions and country-specific obligations and achievements.

Jordan, Andrew. *Environmental Policy in the European Union*. London: Earthscan, 2005. Describes EU's environmental policies from the viewpoint of processes, actors, and institutions, and presents case studies of EU environmental policies such as climate change; special emphasis is also laid on policy challenges due to globalization and EU enlargement.

Knill, Christoph, and Duncan Liefferink. *Environmental Politics in the European Union*. Manchester, England: Manchester University Press, 2007. Comprehensive and easy-to-read introduction to the European Union's environmental policies presenting the establishment of environmental policies as a European issue, institutions and actors, policy processes and policy fields, and country case studies; discusses EU's capacity for environmental solutions.

Peeters, Marjan, and Kurt Deketelaere, eds. *EU Climate Change Policy: The Challenge of New Regulatory Initiatives*. Cheltenham, England: Edward Elgar, 2006. Collective and comprehensive volume presenting EU's climate change policies and frameworks. Discusses the European Union's emission allowances trading system from various perspectives, explores the links between energy policies and climate change policies, and summarizes policy principles such as good governance.

See also: Annex B of the Kyoto Protocol; Carbon dioxide; Greenhouse effect; Greenhouse gases; Industrial emission controls; Kyoto lands; Kyoto mechanisms; Kyoto Protocol; United Nations Framework Convention on Climate Change.

Evapotranspiration

• **Category:** Meteorology and atmospheric sciences

• **Definition**

In the hydrologic cycle, two processes—evaporation and transpiration—are responsible for returning water to the atmosphere. Evapotranspiration is the sum of these processes. Evaporation is the loss of water vapor from the surface of objects containing liquid water, such as lakes and streams, soil, and organisms. Temperature is a major factor controlling evaporation. In general, the higher the temperature, the faster the rate of evaporation. Other major factors influencing evaporation rate include the amount of water vapor already held by the air (humidity) and air movement. Low humidity and high wind speed promote evaporation.

Transpiration is the loss of water vapor primarily through the stomata of leaves and green stems of plants. All above-ground parts of plants are covered by a waxy cuticle that helps prevent water loss. As a result, the internal spaces within the plant are nearly saturated with water vapor. Stomata are microscopic pores in plants' surface layers that open or close to allow gas exchange for photosynthesis while regulating water loss to prevent desiccating the plant. Cottonwoods near Dallas, Texas, can transpire up to 120 liters of water per tree per day. In the Amazon rain forest, a single large tree can transpire up to 1,180 liters of water per tree per day.

Transpiration provides the force necessary to pull water and dissolved nutrients up from the roots to the tips of the highest branches. Within the plant, water and dissolved minerals travel in specialized xylem cells that are arranged end to end in long files. Xylem cells are programmed to die once they mature; they then form hollow tubes to transport water. When filled with water, the xylem acts like a straw, and transpiration from the top draws water up from the bottom. Transpiration provides enough suction force that water could be pulled through the xylem to the top of a tree much taller than the tallest living redwood, higher than a forty-story building.

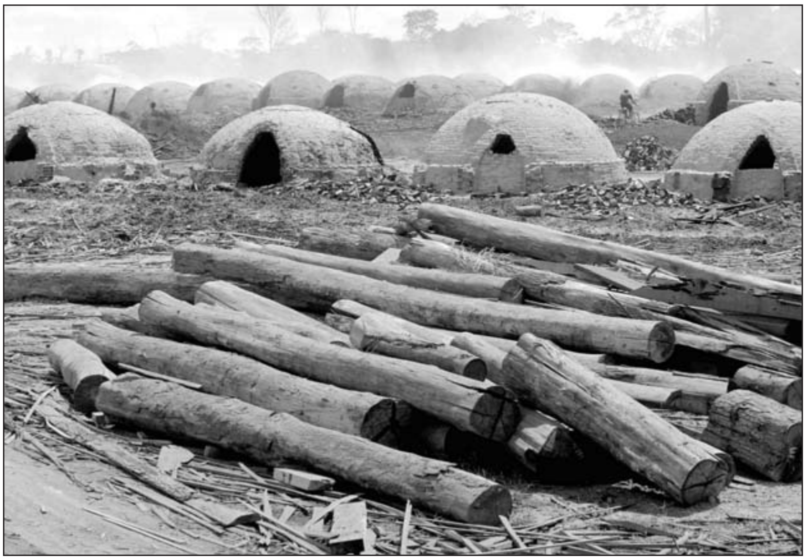
- **Significance for Climate Change**

Air temperature directly affects evapotranspiration; any increase in temperature will increase evapotranspiration as long as adequate water is available. In tropical rain forests, transpiration increases beginning at sunrise, and the released water vapor rises in the heated air until it condenses in cooler air at high elevation, thus forming clouds. These clouds deliver afternoon rain showers that replenish soil moisture to repeat the process the next day.

Some studies suggest that extensive clear-cutting of the forest has decreased transpiration sufficiently to decrease local rainfall. If enough water is not available during the hot daytime, stomata of the remaining trees close and transpiration is shut down. Less water vapor is returned to the atmosphere, and the daily water cycle is broken. Less water returned to the atmosphere can exacerbate drought conditions and have a snowballing effect on climate. Some scientists predict that even the Amazon rain forest could be transformed to a savanna if too many trees are cut down and there remains too little evapotranspiration to sustain regular rainfall. Similar changes can occur in temperate grasslands and in temperate forests, making them more arid.

Decreasing rates of transpiration that are due to global warming and local drying also affect photosynthesis. Some plants, classified as carbon 4 plants, are more efficient at photosynthesizing at higher temperatures and in drier conditions. These plants, which are most common in the southern United States, will spread northward as temperatures rise. By contrast, carbon 3 plants, including most trees and vegetable crops, tend to be less drought tolerant and will not cope as well with increasing temperatures. Carbon 3 plants can be expected to migrate toward cooler latitudes if their existing locations become untenable. Plant migration is generally slow, and it is questionable if a poleward migration of biomes and plant types could keep pace with a global warming trend. Even if plants could migrate fast enough, the soils of higher latitudes are not as fertile and productive as those in current temperate areas, the "breadbaskets" of the world, because they have not supported extensive plant growth for millennia.

Water loss from transpiration often can exceed evaporative water loss from a water surface of the same area. For instance, a sugarcane field in Hawaii can transpire 120 percent as much water vapor as a similar area of open water. This is due not only to the amount of leaf surface area containing stomata but also to extensive root



Logs cut from the Amazon rain forest lie next to the ovens that will turn them into charcoal. The large-scale logging of the Amazon may decrease evapotranspiration rates in the forest, modifying regional and global climate. (Paulo Santos/Reuters/Landov) systems that can tap soil water in excess of the flat surface area of water. Some studies predict that such natural pumping of soil water, in response to a warming environment, will deplete soil water in the same way that pumping irrigation water from underground aquifers depletes groundwater.

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• Further Reading

Angelo, Claudio. "Punctuated Disequilibrium." *Scientific American* 292, no. 2 (February, 2005): 22-23. Describes how deforestation and global warming in the eastern Amazon rain forest may be tipping the scale toward development of a savanna ecosystem.

Huxley, Anthony. *Green Inheritance: The World Wildlife Fund Book of Plants.* New York: Anchor Press, 1985. A botany textbook written for the general public with a concise, well-illustrated section explaining transpiration.

Pimm, Stuart L. *The World According to Pimm: A Scientist Audits the Earth.* New YorK: McGraw-Hill, 2001. Pimm uses an engaging style to describe human impacts on the Earth.

See also: Amazon deforestation; Atmospheric dynamics; Carbon 4 plants; Carbon 3 plants; Clouds and cloud feedback; Dew point; Hydrologic cycle; Rainfall patterns; Water vapor.

Extinctions and mass extinctions

• Categories: Animals; plants and vegetation

Climate change, particularly global warming, has been correlated with past extinction events. Any future short- or medium-term global warming would likely contribute to further extinctions.

• Key concepts

anthropogenic: resulting from human actions

extinction: species loss; the death of the last member of a particular species

extinction event: an unusually large number of extinctions occurring in a relatively short period of time

methane hydrate: also known as methane clathrate; an extremely abundant, solid, ice-like form of methane that occurs at or beneath the ocean floor in especially deep or cold waters

• Background

Although consensus about categorization is lacking, five major mass extinctions (the "Big Five") and numerous smaller extinction events are generally recognized. Mass extinctions involve global losses of at least 30 percent of species of various types and sizes occupying various habitats. Less severe extinction events involve fewer species losses (less than 25 percent) and fail to meet one or more additional criteria defining mass extinctions. Their scope may be regional rather than global, for example. Background extinctions occur between extinction events, at relatively low rates, and affect only one or a very few species at a time. Thus, they reflect the mean duration—or "life span"—of species in general as reflected in the fossil record. Although background extinctions occur infrequently, because they accumulate over very long periods of time they account for far more species losses than do mass extinctions.

• Extinction, Mass Extinction, and Global Warming

It is generally impossible to identify a single cause for an extinction. By way of example, imagine that global warming allows a pathogen to extend its range from the tropics into what was formerly a temperate region. Imagine further that the pathogen's new range overlaps that of a bird that has become highly endangered by habitat loss. The pathogen causes 90 percent mortality among the birds, and the remainder dies off shortly thereafter during a series of severe storms. It would be an oversimplification to state that only habitat loss, global warming, infectious disease, or severe weather caused the extinction. Habitat loss represents the ultimate, underlying cause, although additional proximate stressors subsequently eliminated the species. Relative to single-species extinctions, extinction events typically involve far more complicated chains of causation.

Global warming is thought to have contributed to numerous extinctions—including the Permian-Triassic and Triassic-Jurassic events, as well as less severe events during the early Jurassic (around 183 million years ago) and the Paleocene-Eocene boundary (around 55 million years ago). If global warming were to occur again, it would likely contribute to future extinctions via several main mechanisms. First, warming conditions would reduce or degrade the habitats of high-latitude, high-altitude, and temperate species. For example, polar bears rely for food on the formation of winter ice in which their seal prey dens, so they would be threatened by a decrease in such ice formation. Similarly, rising sea levels resulting from melting glaciers would flood coastal areas and reduce Earth's overall island area, threatening the disproportionately high levels of biodiversity occupying these relatively small landmasses.

Although rising sea levels might increase the total volume of aquatic habitat, global warming would also place important, interrelated stresses on aquatic species. The first of these would be thermal stress. Because of water's ability to absorb and retain heat, aquatic environments experience less temperature variation than do terrestrial environments. As a consequence, aquatic species are generally adapted to a narrower range of temperature tolerances than are terrestrial species. Thus, any change in sea temperature is liable to threaten aquatic species. Because excessive heat poses a greater physiological threat to most organisms than does excessive cold, global warming would represent an especially serious stress. Contemporary coral die-offs resulting from warming oceans provide a noteworthy example.

A second threat to aquatic species relates to the fact that as water's temperature increases, it holds less dissolved oxygen, while warming waters tend to increase organismal metabolism and oxygen demand. Consequently, warmer water can support relatively fewer aerobic organisms than can colder water. Hypoxia (oxygen scarcity) and anoxia (absence of oxygen) in warming waters have been linked to a variety of extinctions. Although these factors would most directly affect aquatic species, they would also exert significant indirect effects on species dependent on aquatic organisms, such as fish-eating birds.

Warming oceans pose an additional threat to marine species, since warmer seawater would likely melt extensive seafloor deposits of methane hydrate. Melted methane hydrate reacts with the dissolved oxygen in seawater to form carbon dioxide, and the release of large quantities would greatly reduce oceanic oxygen levels, placing considerable stress on both marine and marine-dependent species by exacerbating the effects of the reduced oxygen levels associated with increased water temperature. Such a scenario is thought to have occurred during the Paleocene-Eocene extinction, when high-latitude and deep-sea temperatures may have increased by as much as 7° Celsius. It has been predicted that contemporary global warming could cause similar effects.

• Modern Versus Paleoextinctions

The fossil record's limitations make detailed characterizations of the biodiversity losses associated with extinctions difficult. Paleontologists estimate that fossils preserve less than 4-5 percent of all species that have ever lived. The fossil record's incompleteness results from numerous factors. First, species vary in composition and habitat. Hard tissue such as shell, tooth, and bone is much more prone to fossilization than is soft tissue such as muscle and skin. Since fossilization occurs only in environments where dead organisms can be preserved in sediment, species occupying habitats where sediments were routinely deposited are more common as fossils. By contrast, in areas such as mountain tops, where erosional processes dominated, fossils are rare or unknown. Thus, the fossil record reveals far more about shelled marine mollusks (which had hard parts and occupied depositional environments) than about small, delicately built uplands birds (which had fragile bones and occupied erosional environments).

Since fossilization is a rare outcome, species that were rare in life are correspondingly rare in the fossil record. As a consequence, while complete or nearly complete fossils of some marine invertebrates are common, most dinosaurs are known from one or a very few specimens, many of them fragmentary. Because marine fossils are much more common than terrestrial fossils, they are frequently used in computing extinction rates.

The final key factor limiting the fossil record's completeness is erosion, which eventually reduces fossil-bearing rock to sediment, destroying any fossils it contains. The longer fossil-bearing rock is in existence, the more opportunity there is for erosion to act on it. As a result, the fossil record of more recent extinctions is far more complete than that of older extinctions. Consequently, the details of the Cretaceous-Tertiary extinction are better understood than those of the much earlier Ordovician-Silurian extinction.

The Big Five Mass Extinction Events

Event	*Occurrence (millions of years ago)*	*Percent of Marine Species Extinct*
Ordovician-Silurian	c. 440	up to 85
Late Devonian	c. 360	up to 83
Permian-Triassic	c. 250	up to 95
Triassic-Jurassic	c. 200	up to 80
Cretaceous-Tertiary (K/T)	c. 65	up to 76

Because the fossil record is so often imprecise at the species level, paleontologists often assess extinctions on the basis of the persistence or disappearance of higher taxa, such as genera, families, or orders. The extinction of even one order, family, or genus would likely involve the loss of numerous species, although the vagaries of fossilization preclude precise estimates of species losses.

Although contemporary biologists face logistical difficulties in locating and cataloging existing biodiversity, they clearly have significant advantages over paleontologists attempting to characterize the biodiversity of vanished ecosystems. It would be highly unlikely for relatively small, rare, and delicately boned species analogous to today's black-footed ferrets and ivory-billed woodpeckers to be abundant or well-preserved in the fossil record. However, some of the same traits that make such creatures rare in the fossil record place them in danger of extinction in the modern world, where an ability to study their distant ancestors through fossil records could help scientists better understand their ecological and evolutionary roles.

• Possibility of Anthropogenic Mass Extinction

Despite the difficulties paleontologists face in providing detailed characterizations of vanished life, they can render informative sketches of lost biological communities. In comparing estimates of present-day extinction rates, whose main cause is habitat loss, to those computed from the fossil record, ecologists have concluded that recent human history, including the present, probably qualifies as a period of mass extinction.

Mass extinctions are generally thought to have resulted from nonbiological causes, such as climate change, sea-level shift, intense volcanism, or meteor impact. Current extinctions, linked as they are to the activities of a single species, humans, appear unprecedented: Collectively, they represent the first mass extinction with a biotic cause. The rate of extinction might also be unusually high, at least fifty to one hundred times greater than background extinction rates. Although often referred to as "events," mass extinctions are generally thought to have been protracted by human standards, occurring over thousands or, in many cases, millions of years. By contrast, the spike in extinction rates associated with human activities may be unprecedentedly high, occurring as it has over only several thousand years.

• Context

The fossil record provides invaluable insights into extinction, but it may prove insufficient for use in predicting future extinction risks. For instance, it has been noted that few North American extinctions are associated with climate change during the roughly two-million-year duration of the Pleistocene. During periods of Pleistocene cooling and warming, species simply shifted their ranges. The assumption that species would do the same globally under near-term warming conditions ignores a complicating factor: Humans now occupy and modify a far larger percentage of the Earth's habitats. While Pleistocene species could readily shift their ranges in response to climate change, they did not face the challenge of doing so across such large areas of potentially inhospitable human-modified habitats. Vulnerability to human barriers would vary from species to species. While many birds could simply fly to preferred habitats and shift their migratory patterns in response to changing conditions, less-mobile species—particularly those with specialized habitat requirements—would be at greater risk. Just as important, anthropogenic stressors could interact both with global warming and with other abiotic stressors such as drought or volcanism to increase extinction risk.

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• **Further Reading**

Benton, Michael J., and Richard J. Twitchett. "How to Kill (Almost) All Life: The End-Permian Extinction Event." *Trends in Ecology and Evolution* 18 (2003): 358-365. Semi-technical review of potential causal factors—including global warming—and their likely interactions in Earth's largest mass extinction.

Botkin, Daniel B., et al. "Forecasting the Effects of Global Warming on Biodiversity." *BioScience* 57 (2007): 227-236. A broad survey of attempts to model global warming's effects on biodiversity.

Gibbs, W. Wayt. "On the Termination of Species." *Scientific American*, November, 2001, 39-49. A nontechnical review of extinctions, mass extinctions, and extinction rates written by an able science journalist; does not focus on global warming.

Hallam, Tony. *Catastrophes and Lesser Calamities: The Causes of Mass Extinctions.* New York: Oxford University Press, 2004. An accessible overview of mass extinction phenomena that covers global warming and climate change in the context of other causal factors.

Huey, Raymond B., and Peter D. Ward. "Hypoxia, Global Warming, and Terrestrial Late Permian Extinctions." *Science* 308 (2005): 398-401. A simulation-based assessment of how two particular extinction stressors would have interacted to affect terrestrial species.

Quammen, David. *The Song of the Dodo: Island Biogeography in an Age of Extinction.* New York: Scribner, 1996. An engaging account of factors other than global warming that are contributing to species extinctions.

Raup, David M. *Extinction: Bad Genes or Bad Luck?* New York: W. W. Norton, 1991. An excellent, readable overview of extinction phenomena that emphasizes the difficulties of determining their causes; covers both current extinctions and those in the geological record.

Wilson, Edward O. *The Diversity of Life.* 2d ed. New York: W. W. Norton, 1999. An accessible assessment of biodiversity and discussion of methods for estimating contemporary extinction rates.

See also: Climate reconstruction; Dating methods; Earth history; 8.2ka event; Endangered and threatened species; Holocene climate; Paleoclimates and paleoclimate change; Pleistocene climate.

Extreme weather events

• **Category:** Meteorology and atmospheric sciences

Scientists continue to debate the effects of global warming upon both the intensity and the frequency of extreme weather events. It is possible that one or both of these factors may increase as global temperature increases, causing increased loss of life and property.

• **Key concepts**

cyclone: a storm system that rotates about a low pressure area

drought: a long period of no or scarce precipitation

extratropical cyclone: a cyclone originating and subsisting outside the tropics

heat wave: an extended period of abnormally high temperatures

hurricane: a cyclone originating in the tropics

severe thunderstorms: mostly summer convective storms involving microscale rotating winds

tornado: a narrowly focused, funnel-shaped violent windstorm

wildfire: spontaneously ignited, naturally occurring fire

• **Background**

Extreme weather events are weather systems that become abnormally severe and have high impacts on human life, property, and the environment. In the last hundred years, especially in the latter half of the twentieth century, global surface temperature have experienced a rapid increase. This rapid warming may cause significant changes in Earth's weather patterns, including affecting the frequency and intensity of extreme weather events.

- **Heavy Precipitation and Floods**

One of the possible consequences of global warming is that it will enhance evaporation and transpiration of water vapor from oceans, rivers, lakes, and vegetated lands. Temperature is the main factor determining the moisture-holding capacity of air. The higher the temperature, the more moisture an air parcel can hold. Although global warming may not occur uniformly across the globe, the averaged temperature increase in the atmosphere should give rise to a corresponding increase of average humidity. More water content in the atmosphere will increase the probability of heavy precipitation, which can lead to floods.

Another global warming-related factor that influences heavy precipitation and flooding is a convection-related increase in the severity of storms. In addition to increased temperatures, global warming may involve a higher extension of Earth's troposphere. Both of these processes can lead to more and stronger convection, which can in turn produce more violent convective storms and heavier precipitation.

- **Droughts**

Since global warming is not uniform, a strong warming can occur in some parts of the world while other parts of the world cool. In response to such non-uniform conditions, different patterns of atmospheric circulation can be realized in different parts of the globe. As a result, in some areas air may be enriched by moisture, and in other areas the air may lose moisture, depending on the general atmospheric circulation patterns and moisture transport in each region. Therefore, while global warming may increase the intensity and frequency of heavy precipitation and floods in some locations, it may also increase the severity and frequency of drought conditions in others.

- **Heat Waves**

Global warming increases air temperature in both average and extreme contexts. That is, it results in an increase not only in average temperature but also in daily, monthly, and yearly maximum temperatures. The increase in temperature extremes suggests an increase in the number of hot days as well. Therefore, global warming will most likely increase both the severity and frequency of heat waves. Such heat waves, along with drought, may increase the occurrence of wildfires.

Although wildfire is not a weather phenomenon, its occurrence is closely related to weather conditions. In particular, warm temperatures and low humidity are the two necessary conditions for wildfires. Because global warming can generate warm surface temperatures and frequent drought conditions, it will increase the likelihood of wildfires.

- **Tropical Storms**

One of the necessary conditions for tropical-storm formation is high sea surface temperature (SST). Tropical storms typically develop over the ocean when SSTs exceed 26°-27° Celsius. Based on this criterion, recent global warming trends seem to suggest an increase in the number of tropical storms. Furthermore, tropical storms derive energy from latent heat brought by water vapor evaporated from oceans. Higher SSTs promote greater evaporation of water into the atmosphere. This factor suggests that future warm climates may also produce more powerful hurricanes and typhoons. However, the question of whether global warming would cause an increase in storm frequency is unre-

Years of Greatest Accumulated Cyclone Energy (ACE)

Year	*ACE*	*Year*	*ACE*	*Year*	*ACE*
2005	248	1995	227	1933	213
1950	243	2004	224	1961	205
1893	231	1926	222	1955	199
				1887	182

Note: ACE is equal to the sum of the squares of the maximum sustained wind speed of each tropical storm measured in knots every six hours solved, and different studies have produced conflicting results.

• Extratropical Cyclones

Unlike tropical storms, extratropical cyclones derive energy from a non-uniform temperature distribution, or a temperature contrast between locations in the northern and southern latitudes. In meteorology, such a condition is called a "temperature gradient." Strong temperature gradients will generate unstable atmospheric conditions, which will initiate large-scale cyclones. These cyclones typically occur in the cool season, and they are enforced by upper-level jet streams and also characterized by surface fronts.

A general consensus exists that global warming will decrease temperature gradients and also decrease the intensity of jet streams. The combined effect of these changes would tend to decrease the intensity and frequency of extratropical cyclones. However, some scientists argue that, because global warming tends to increase humidity, extratropical cyclones may gain extra energy from latent heat flux due to water vapor condensation.

• Severe Thunderstorms and Tornadoes

Severe thunderstorms and tornadoes are convective-scale and microscale weather systems. They are different from extratropical cyclones, which are forced by large-scale temperature gradients. Thunderstorm development strongly depends on convection, which is influenced by surface radiative heating, convergence of surface flows, and topographic forcing. In a future warm climate, increase of global surface temperatures may provide favorable conditions for convection to occur. The number of both annual tornado sightings and annual tornado warning days increased over the second half of the twentieth century, but the number of the most severe tornadoes (F2-F5) exhibited a slight decrease.

• Context

A 2007 report by the Intergovernmental Panel on Climate Change (IPCC) predicted that global warming would likely increase the number and frequency of extreme weather events. These increased extreme weather events would generate profound impacts on global socioeconomic development. Such impacts include, among many other things, increased risks to human life and health, increased property and infrastructure losses, increased cost and pressure on government's disaster relief and mitigation resources, and increased costs of private insurance.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Widely used introductory textbook on atmospheric science; covers a wide range of topics on weather and climate.

Diffenbaugh, N. S., R. J. Trapp, and H. Brooks. "Does Global Warming Influence Tornado Activity?" *Eos* 89, no. 53 (2008). Discusses the impact of global warming on tornado activity in the United States.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Comprehensive overview of global climate change published by a network of the world's leading climate change scientists under the auspices of the World Meteorological Organization and the United Nations Environment Programme.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Introductory textbook that covers a wide range of atmospheric sciences.

Tebaldi, C., J. M. Arblaster, K. Hayhoe, and G. A. Meehl. "Going to the Extremes: An Intercomparison of Model-Simulated Historical and Future Changes in Extreme Events." *Climate Change* 79: 185-211 (2006). Discusses model-based assessment of global warming's effects on extreme climate conditions.

See also: Average weather; Drought; Dust storms; Meteorology; Rainfall patterns; Sahel drought; Storm surges; Thunderstorms; Tornadoes; Tropical storms; Tsunamis.

Faculae

- **Category:** Astronomy

- **Definition**

The word facula (*plural:* faculae) derives from the Latin word for torch. Faculae are bright spots on the Sun's visible surface or photosphere. Faculae might be thought of as the opposite of sunspots. Sunspots are dark areas on the Sun's surface caused by the solar magnetic field deflecting energy coming up from within the Sun. Faculae are bright areas on the Sun's surface that are also caused by the solar magnetic field. However, for faculae, the magnetic field concentrates rather than deflects energy from the interior. Because both sunspots and faculae result from solar magnetic activity, the numbers of both increase and decrease together as they follow the Sun's activity cycle.

Faculae are most easily observed near the "edge" of the Sun. A phenomenon called limb darkening causes the edge of the Sun's disk to appear fainter from Earth, even though it emits just as much energy. Limb darkening increases the contrast between faculae and the Sun's surface, so faculae show up more clearly near the edge of the Sun.

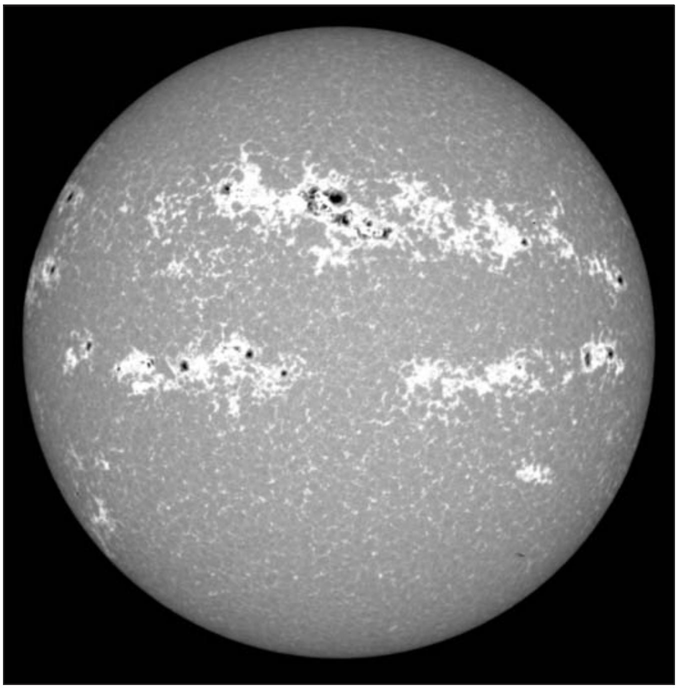
Faculae can extend upward from the Sun's photosphere into the Sun's chromosphere, the layer directly above the photosphere. These extensions of faculae into the chromosphere are called plages. Both faculae and plages are always found around sunspots or sunspot groups. They can also occur on unspotted regions of the Sun's surface.

Near the Sun's surface, energy is transferred from the interior by convection currents similar to those that heat a room containing a radiator on one side but no fan. These convection currents make the Sun's surface very turbulent, and the turbulence causes granules, which are higher regions at the top of convection-current cells. Faculae form in the lower regions along the boundaries between granules.

- **Significance for Climate Change**

Bright faculae and dark sunspots both increase and decrease in time with the Sun's eleven-year sunspot cycle. Accurate satellite measurements over the course of these sunspot cycles show that during maximum sunspot activity, the Sun emits about 0.15 percent more energy than during minimum sunspot activity. Thus, the total extra energy emitted by faculae is slightly greater than the total energy blocked by sunspots. The effect of the eleven-year sunspot cycles is too small and rapid noticeably to affect Earth's climate; however, there are also longer, less regular, and poorly understood cycles in the Sun's activity.

During the Maunder Minimum, from about 1645 to about 1715, there were very few sunspots and correspondingly few faculae. If the observation that, during the eleven-year cycle, the Sun is fainter during sunspot minimum holds for longer cycles, then the Sun should also have emitted less energy during the Maunder Minimum. Accurate instruments for measuring the Sun's total energy output did not exist in the seventeenth century, so this hy-



The solar disk, covered with faculae (bright areas) and a few sunspots (dark areas). (NASA) pothesis could not be tested directly. However, it is known that this time period was the coldest portion of the Little Ice Age. Thus, circumstantial evidence indicates that the Sun did emit less total energy during the Maunder Minimum.

During the period from about 1000 to about 1200, the Medieval Grand Maximum, the Sun had many more sunspots and faculae than normal. If the hypothesis that the Sun emits more energy during periods of high sunspot activity is correct, then the Sun should have been more luminous than normal during these centuries. Climate research shows that, excepting the latter portion of the twentieth century, this period was the warmest of the last one thousand years. For example, a Viking colony flourished on Greenland during this period, but it was abandoned when the climate cooled again.

Climate studies combined with solar-activity studies over the last millennium show that during extended sunspot maxima Earth's climate is warmer and during extended sunspot minima Earth's climate is cooler. Faculae play an important role in these climate changes. As the bright areas on the Sun's surface, they contribute to the Sun's increased energy output during periods of high solar activity. Their lack also contributes to decreased energy output during periods of lower solar activity.

Many of the eleven-year solar-activity cycles during the late twentieth century had higher levels of maximum solar activity, so John Eddy and a few other scientists have suggested that the Sun might be entering a period of increased activity. The increased solar activity to date is probably not sufficient to have caused the current global warming. However, it might have contributed to the trend on a small scale. Understanding faculae, sunspots, and their relation to the total solar energy output is important to completely understanding long-term climate changes on Earth.

Paul A. Heckert

- **Further Reading**

Eddy, J. A. "The Maunder Minimum." *Science* 192 (1976): 1189-1192. In this seminal article, Eddy demonstrates that the Maunder Minimum is real and argues both that the Sun's energy output varies with long-term activity cycles and that this variation causes climate changes.

Foukal, P., C. Fröhlich, H. Spruit, and T. M. L. Wigley. "Variations in Solar Luminosity and Their Effect on Earth's Climate." *Nature* 443 (2006): 161-166. Reviews the current state of knowledge of solar variability and its role in climate changes. The role of faculae is specifically discussed.

Golub, Leon, and Jay M. Pasachoff. *Nearest Star: The Surprising Science of Our Sun.* Cambridge, Mass.: Harvard University Press, 2001. This well-written book provides a detailed summary of scientific knowledge of the Sun. Includes solar surface features such as faculae and solar variability.

Hoyt, Douglas V., and Kenneth H. Schatten. *The Role of the Sun in Climate Change.* New York: Oxford University Press, 1997. Well-written and extensively documented coverage of solar variability and possible associated climate changes, as well as of the role of faculae and sunspots in causing solar variability.

Soon, Willie Wei-Hock, and Steven H. Yaskell. *The Maunder Minimum and the Variable Sun-Earth Connection.* River Edge, N.J.: World Scientific, 2003. Explores surface features such as faculae, the Maunder Minimum, long-term solar variability, and the role this variability plays in Earth's climate changes.

See also: Little Ice Age; Medieval Warm Period; Solar cycle; Solar energy; Sun; Sunspots.

Falsifiability rule

- **Category:** Science and technology

The falsifiability rule asserts that for a theory to count as scientific, it must be logically capable of being disproven. The falsifiability of climate change theories has been contested by some of their critics.

- **Key concepts**

falsifiability: testability of a scientific theory by performing experiments or collecting observations that might potentially disprove the theory

falsification: disproof of a scientific theory using experiments or observations that contradict the theory
naïve falsification: erroneous claims that a scientific theory has been falsified based on isolated anomalies, poor data, or faulty observation
replicability: the ability of an experiment or observation to be repeated and confirmed

• Background

Science covers such a broad range of subjects that it is very hard to come up with a simple definition of scientific proof. Many scientific ideas cannot be tested by simple experiments. Sometimes, even well-established scientific ideas require revision when new data are discovered, so scientists generally believe it is impossible to prove a theory to be absolutely true. Austrian-born British philosopher Karl Popper proposed that ideas could be regarded as legitimate science if they could be falsified—that is, if there were some test that might possibly prove the idea wrong. Falsifiability separates science from subjects such as philosophy, religion, and political ideology, for which either there is no way to disprove ideas or believers are unwilling to admit their ideas can be falsified.

• Types of Falsification

The simplest form of falsification is to compare a theory with the results of an experiment or an observation in nature. If the theory does not agree with the experiment or observation, it has been falsified. Of course, the experiment or observation must be performed correctly. If there is any doubt, the test can be repeated. Therefore, replicability, the ability to repeat observations or experiments, is considered a vital part of the scientific method and is one aspect of falsification. Events outside the laboratory such as earthquakes, hurricanes, and epidemics are never exactly repeatable, but they all have features in common from one occurrence to the next.

Theories about events in the remote past or physically inaccessible events can be falsified in several ways. For example, one can compare ancient features in rocks with features forming now to test whether processes on Earth have changed over geologic time. One can develop theories of how stars develop and compare the results with actual stars. If the theories fail to match observations, they have been falsified.

Popper also noted that tests must be "risky." There must be a real possibility of the test failing. If one knows that a theory will always pass a given test, it is not a real test. A test in which someone dismisses or evades the falsification is also not a real test. Although many people claim their religion or ideology is scientific, very few are willing to submit to a risky test and abide by the results.

• Problems with Falsification

Sometimes falsifications are wrong. A famous example is that of astronomer Simon Newcomb, who "proved" that powered flight was impossible only a few months before Wilbur Wright and Orville Wright successfully flew, because he made overly conservative assumptions about the weight and power of engines. Erroneous falsifications are common enough that author Arthur C. Clarke described them in his First Law: "When a distinguished but elderly scientist says that something is possible, he is very likely right. When he says that something is impossible, he is very probably wrong." Generally, erroneous falsifications stem from overly strict assumptions or failure to anticipate new discoveries.

One of Popper's own errors, frequently cited by anti-evolutionists, was to say "Darwinism is not a testable scientific theory, but a metaphysical research program." In fact, Charles Darwin himself proposed one test of evolution. He stated that evolution would be falsified if it could be shown that some change could not have occurred in a series of gradual steps. In 1978, Popper retracted his statement, saying "I have changed my mind about the testability and logical status of the theory of natural selection; and I am glad to have an opportunity to make a recantation."

• Misapplications of Falsification

The more tests a theory has passed, the more confident one can be in its validity. For long-established theories, it is hard to imagine any additional test that might falsify them. However, many of the best-established ideas in science are the basis of modern technology and can be said to face the riskiest of all tests: producing practical results. If the theories ever fail to produce the expected results, they will have failed.

Many people equate falsifiability with experiment, but there are many other ways scientific ideas can be falsified. They can be shown to be contradicted by other scientific findings, or shown to be logically inconsistent. Some people believe ideas cannot be falsified simply because they are unaware of the possible tests. For example, study of light from distant galaxies shows clearly that the same laws of physics apply throughout the universe. The idea that the laws of nature are constant in space and time is falsifiable and so far has survived every test.

Many people, seeking to justify disbelief in some scientific idea, engage in naïve falsification—the use of evidence that seems to contradict established science, even if the evidence is of poor quality or supported by bad reasoning. Whenever an observation is claimed to contradict a theory, there are two possibilities: Either the theory is wrong, or the observations are wrong. If a single observation is claimed to disprove a well-tested theory, almost certainly the observation is wrong. In addition, if the results are reported in popular media, the observation may be inaccurately reported or even a deliberate hoax. Finally, unsolved problems or unanswered questions do not disprove a theory.

• Context

There probably is no single, all-purpose definition of science, but falsifiability is one of the most widely useful. In the case of climate change, falsifiability must be understood and applied properly. Isolated cases of unusually warm or cold weather do not prove or disprove climate change. Long-term climate trends, unprecedented changes such as large-scale melting of Arctic sea ice, and the physics of heat absorption by greenhouse gases count much more than individual weather events.

Steven I. Dutch

• Further Reading

Clarke, Arthur C. *Profiles of the Future: An Inquiry into the Limits of the Possible.* New York: Harper & Row, 1962. Includes the essay "Hazards of Prophecy: The Failure of Imagination," the source of Clarke's First Law.

Godfrey-Smith, Peter. *Theory and Reality: An Introduction to the Philosophy of Science.* Chicago: University of Chicago Press, 2003. A survey of the philosophy of science for nonspecialists. The ideas of Karl Popper, as well as those of Thomas Kuhn on scientific revolutions, are prominently featured, along with the work of later thinkers.

Popper, Karl. *The Logic of Scientific Discovery.* 1959. Reprint. New York: Routledge, 2002. Popper's pivotal book, widely viewed as one of the most important philosophical works of the twentieth century.

_______. "Natural Selection and the Emergence of Mind." *Dialectica* 32, nos. 3/4 (1978): 339-355. The essay in which Popper retracted his earlier description of evolution as untestable.

Tesh, Sylvia Noble. *Uncertain Hazards: Environmental Activists and Scientific Proof.* Ithaca, N.Y.: Cornell University Press, 2000. Surveys the problems of ambiguity and scientific proof in the environmental sciences. Explores the different assumptions that scientists and environmental activists bring to environmental debates.

See also: Gaia hypothesis; Level of scientific understanding; Peer review; Scientific credentials; Scientific proof.

Famine

• **Category:** Diseases and health effects

There is considerable evidence that global climate change is taking place, and floods, droughts, and other extreme weather events precipitated by these changes are likely to reduce food production and distribution significantly, resulting in famine in various parts of the world.

• Key concepts

climate canaries: the first victims of world climate change, who serve as early warnings to others

climate change scenario: a physically consistent set of changes in meteorological variables based on accepted projection of carbon dioxide and other trace gas levels *desertification:* the gradual transformation of habitable land into desert due to climate change or destructive land use

drought: an extended period of months or years when a region experiences a deficiency in its water supply

greenhouse gas (GHG): any atmospheric gas that absorbs radiation, contributing to warming of the Earth's atmosphere

• Background

Some groups deny that continuing global warming will lead to famine, arguing that the warmer climate exerts beneficial effects on food production and that the increased carbon dioxide (CO_2) production from global warming serves as a fertilizing agent for plants, The majority of research, however, paints a very different picture. Numerous researchers associated with respected organizations conclude that climate change is real and that it is possible to predict when and where the most severe famines are likely to occur.

• Findings of the Hadley Centre for Climate Prediction and Research

Established in 1990, the Hadley Centre has been located in Exeter, England, since 2003 and has been recognized for the quality of the research on climate change carried out by its more than 150 scientists. In 2006, it predicted that about one-third of the Earth will become desert by 2100, as a result of drought and its consequent desertification. Those areas of the world that are already victims of drought, such as Africa, will likely experience the most severe effects. The people predicted by the Hadley Centre to be the first victims of world climate change, called "climate canaries," will be about three million pastoral nomads in northern Kenya. A way of life that has been sustained for thousands of years therefore faces eradication. Myriad herders have forsaken their traditional way of life to settle in Kenya's northeastern province after their livestock were decimated. The situation is not limited to Kenya: At least eleven million people are affected from Tanzania to Ethiopia, Eritrea, and Somalia.

• Predictions of the U.N. Food and Agriculture Organization

The Food and Agriculture Organization (FAO) likewise predicts the most severe impact of diminished food production and resulting famine to occur in African countries below the Sahara Desert. Desertification could result in an increase of as many as 90 million hectares of arid land, an area almost four times the size of Britain. The FAO's predictions are not limited to Africa: Sixty-five developing countries, including more than half of the total population of the developing world in 1995, are expected to lose around 254 million metric tons of potential grain production because of climate change. Nor are the "extreme weather events" limited to drought and desertification. Flooding will bring devastating effects as well. During the first decade of the twenty-first century, more than six hundred floods have caused $25 billion in damage, a substantial amount of which includes the loss of some 254 million metric tons of potential cereal production. Another FAO study reported that at least ten million people in Malawi, Zimbabwe, Lesotho, and Swaziland are threatened with starvation; even at harvest time, a serious food crisis persists.

• Scholze's Predictions

Mark Scholze of Bristol University has conducted research for the organization Quantifying and Understanding the Earth System (QUEST) involving world climate simulation predictions through the twenty-first century based on sixteen climate models. He poses several scenarios regarding fire, flood, and famine by the year 2100 and predicts that effects of an average of 2° Celsius in global temperature rise are inevitable and will cause deforestation of up to 30 percent in parts of Europe, Asia, Canada, Central America, and Amazonia. Freshwater shortages, likely due to drought, can be expected with a rise of between 2° and 3° Celsius in parts of West Africa, Central America, southern Europe, and the eastern United States. As trees are lost, tropical Africa and South America will be subject to flooding.

Should a 3° temperature increase occur, an even more dangerous scenario is likely: As temperatures rise, plants may begin to grow more vigorously and take up more carbon oxide from the air. When sat-

A single seedling pokes through a drought-ridden field in Ulsan, South Korea. Drought contributes significantly to famine throughout the world. (Xinhua/Landov)

urated, the ecosystem begins to respire more than it is taking up. Scholze's data, which are in line with findings of the Hadley Centre, indicate that this tipping point could arrive by mid-century. These phenomena would cause a decrease in worldwide cereal crop production of between 18 million and 363 million metric tons and put 400 million more people in famine conditions. Scholze insists that fossil fuel combustion must be significantly curtailed before 2040.

• Context

During the past two million years, the climate on Earth has alternated between cooling and warming. Thus, one might question the concern during the latter twentieth and early twenty-first centuries over global warming. The concern arises, because the Earth is growing warmer faster than it has in the past, as more greenhouse gases (GHGs) are released into the atmosphere. Over one hundred years ago, people worldwide began using more coal and oil for homes, factories, and transportation, thereby releasing CO_2 and other GHGs into the atmosphere. Scientific data reveal that during the past century, the world's surface air temperature increased an average of 0.6° Celsius. Even one degree can affect Earth's climate.

Heavier rainfall is causing flooding in some areas, while there is extreme drought in others, resulting in famine. The first half of the twentieth century was not unusual: The period of 1900 to 1939 brought mild winters, characteristic of a high North Atlantic Oscillation (NAO) condition. However, in the 1950's, the global average temperature fell, and some thought an ice age was imminent. Then, the NAO suddenly flipped to high, and some scientists declared that the warming was a permanent phenomenon because of humans' promiscuous use of fossil fuels. If so, the likelihood of famine remains a constant.

Victoria Price

• Further Reading

Bazzaz, Fakhri, and Wim Sombroek. *Global Climate Change and Agricultural Production.* New York: John Wiley & Sons, 1996. Thirteen essays address various aspects of global warming and their effects on agriculture. Numerous tables and charts.

Cline, William R. *Global Warming and Agriculture: Impact Estimates by Country.* Washington, D.C.: Center for Global Development, 2007. Introduction identifies the risk to agriculture as an important effect of global warming. Surveys global warming literature. Discusses the key issues of carbon fertilization, irrigation, and trade and makes numerous climate projections at the country level in addition to providing tables of impact estimates.

McCaffrey, Paul, ed. *Global Climate Change*. New York: H. W. Wilson, 2006. Divides discussion into four sections that address the greenhouse effect, rising tides and other effects of global warming, future prospects, and possible amelioration. Explores the science supporting global warming, as well as the arguments of skeptics. Includes the text of the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Bibliography and index.

See also: Abrupt climate change; Agriculture and agricultural land; Desertification; Deserts; Drought; Food and Agriculture Organization; Fossil fuel emissions; Fossil fuels; United Nations Convention to Combat Desertification.

Fire

• **Categories:** Meteorology and atmospheric sciences; environmentalism, conservation, and ecosystems

Forests sequester carbon, and fires return it to the atmosphere. Huge fires may account for as much as 40 percent of the anthropogenic contribution of CO_2 to Earth's atmosphere. Early humans used fire in their agriculture. When specific human populations collapsed, the absence of these fires resulted in reforestation and the removal of CO_2 from the atmosphere.

• Key concepts

carbon sequestration: removing CO_2 from the atmosphere and storing it, or the carbon within it, somewhere else

gigaton C: one billion metric tons of carbon, equivalent to 1 petagram (10^{15} grams)

hectare: an area of 10,000 square meters

natural succession: changes in the types of plants that grow in an area over time, starting with grasses and moving through shrubs to trees

slash and burn: an agricultural practice of clearing the land whereby trees are girdled, left to die, and then burned

wildland/urban interface: a region where residential housing is embedded within, or abuts against, a wild or nearly wild environment

• Background

Fire is an important factor in climate, whether it is stopping or starting. Study of charcoal deposits has shown that before 1500 C.E., indigenous populations in the Amazon Basin used fire to clear forests and maintain extensive agricultural enterprises. After European plagues killed 90 percent of the Amazon population, the rain forest grew back, sequestering 10 gigatons of carbon. This may have lowered atmospheric carbon dioxide (CO_2) concentration by 2 parts per million by volume, contributing to the development of the Little Ice Age. In 1997-1998, forest fires in Indonesia are thought to have added between 0.81 and 2.57 gigatons of carbon to the atmosphere, out of the total 6.0 gigatons.

• Wildfires and Public Policy

Wildfires are natural. Many habitats exist because wildfires occur and would disappear in the absence of fires. Fires occur when there is fuel, oxygen, and a source of ignition. Lightning and oxygen will always exist in the wild, so the principal variable is the fuel load. Nature limits the supply of fuel with frequent small fires, which burn through an area, removing accumulated deadwood and forest litter. Long periods of fire suppression interfere with this process, permitting large quantities of fuel to accumulate. The subsequent fires are then larger and more intense.

CO_2 is sequestered in the wood of the forest, removing it from the atmosphere and preventing it from affecting the Earth's climate. As the natural succession results in shrubs replacing grasses and being replaced in turn by slightly larger trees, which are replaced by even larger trees, and so on, the amount of CO_2 being stored in the forest increases. When the forest reaches its climax state, the species making up the forest will stabilize. Eventually, new growth will only replace older, dying growth, and no additional CO_2 will be removed from the atmosphere. How rapidly this all occurs will vary with the climate, soil, and other factors, but it is generally thought to take fifty to one hundred years.

• Early Human Burning Practices

Early humans may have observed beavers. These creatures prefer foods such as aspens, which grow fairly early in the succession. If they encounter hickories or oaks, they will frequently girdle them, chewing away a strip of bark a few centimeters wide, all the way around the tree. The trees will die, standing where they are, eventually falling over, or being burned in a lightning-caused fire, and the area in which they were standing will revert to meadow to begin the process of succession again.

If early humans wanted to create a meadow, they could emulate this behavior of beavers, using blades to girdle the trees and, after the trees had died, starting fires to speed things along. This technique is called "slash and burn," and it is still a major cause of deforestation. It causes the CO_2 that was sequestered in a forest to move into the atmosphere, where it contributes to the greenhouse effect. Some 3.5 to 4.5 million square kilometers of forest are burned in fires every year. Over 99 percent of these fires are set intentionally by humans, usually for agricultural purposes. Most are in Africa.

If agriculturalists abandon their fields, the opposite effect, reforestation, will occur. In the case of the Americas, scientists estimate that 35-90 million people died shortly after the European plagues were introduced. If each of these farmers had been keeping one hectare clear, and after regrowth to

Wildfires raged through Southern California in November of 2008, destroying this mobile home park in Sylmar. (Jim Ruymen/UPI/Landov) rain forest each hectare of land supported an additional 100 metric tons of carbon, the increase in the amount of carbon sequestered would have been on the order of 3.5-9 gigatons.

- **Context**

Climate change will alter precipitation patterns in time and space. Some areas will become more fire prone, others less. The makeup of forests will change along with the climate, and eventually the plants growing in an area will be those that are best suited for that environment. Some will require fires and will thrive in areas that burn frequently. Sound fire management practices should permit this. As changes occur, however, those places that are drying up will have more combustible fuel available, and wildfires can be expected until this fuel is consumed. Thinning, controlled burns, and other means of reducing this fuel should be used to avoid uncontrollable conflagrations.

For the foreseeable future, fire will be used as an agricultural tool. If done on a small scale, this is unlikely to contribute substantially more CO_2 to the atmosphere than the oxidation performed by microbes. However, it should not be permitted on a large scale, particularly as part of lumbering operations, as under such circumstance the contribution of burning to atmospheric CO_2 concentrations may be large and long lasting.

Otto H. Muller

- **Further Reading**

Nevle, Richard J., and Dennis K. Bird. "Effects of Syn-pandemic Fire Reduction and Reforestation in the Tropical Americas on Atmospheric CO_2 During European Conquest." *Palaeogeography, Palaeoclimatology, Palaeoecology* 264, nos. 1/2 (2008): 25-38. Argues that before Columbus much of the Amazon Basin was farmland, abandoned as the farmers tending it died off in the pandemics resulting from the arrival of Europeans, and that the reforestation was at least partially responsible for the Little Ice Age. Map, tables, bibiliography.

Omi, Philip N. *Forest Fires: A Reference Handbook.* Santa Barbara, Calif.: ABC-CLIO, 2005. As a handbook, this text is not intended to be read in a linear fashion, but it contains a wealth of information about wildfires and their management. It contains details about many famous forest fires in the United States and data showing how fire fighting and forest management practices have changed over time. Illustrations, figures, tables, maps, bibliography, index.

Page, Susan E., et al. "The Amount of Carbon Released from Peat and Forest Fires in Indonesia During 1997." *Nature* 420, no. 6911 (2002): 61-65. Describes how between 13 and 40 percent of the average anthropogenic contribution of CO_2 was added to the atmosphere by these fires. Maps, tables, diagrams.

Pyne, Stephen J. *Vestal Fire: An Environmental History, Told Through Fire, of Europe and Europe's Encounter with the World.* Seattle: University of Washington Press, 1997. An erudite treatment of the role of fire in the history of the world, this book is exhaustive in its scope. Illustrations, charts, tables, bibliography, index.

Ruddiman, William F. *Plows, Plagues, and Petroleum: How Humans Took Control of Climate.* Princeton, N.J.: Princeton University Press, 2005. Written for the lay public, this book provides the background and thinking behind the theory that humans have influenced the climate for the last nine thousand years, primarily through agriculture. Illustrations, figures, tables, maps, bibliography, index.

See also: Amazon deforestation; Deforestation; Forestry and forest management; Forests.

Fishing industry, fisheries, and fish farming

- **Categories:** Animals; economics, industries, and products

- **Definition**

Fish have been a protein source throughout history. Early fishing primarily involved individuals capturing fish near their communities for consumption or trade. Ships gave fishers access to

Top Ten Inland Fishing Nations

Nation	*Fishery Production, 1998 (thousands of metric tons)*	*Percentage of Global Production**
China	2,280	28.5
India	650	8.1
Bangladesh	538	6.7
Indonesia	315	3.9
Tanzania	300	3.7
Russian Federation	271	3.4
Egypt	253	3.2
Uganda	220	2.8
Thailand	191	2.4
Brazil	180	2.3

Source: Food and Agriculture Organization.
*The top ten countries accounted for 65 percent of global inland fisheries production.

ocean-based fisheries. Commercial fishing became industrialized by the late nineteenth century, as technological innovations helped locate, catch, and process fish. In addition to fish living in natural freshwater or saltwater fisheries, fish cultivated in fish farms' ponds or tanks represented approximately one-fourth of the fish eaten in the world. Countries benefited economically with domestic trade and by exporting valuable fish. In the early twenty-first century, fisheries generated billions of dollars globally with approximately 42 million people employed to catch fish and several hundred millions more working in related industries. Fisheries reinforced food security when climate changes caused shortages of other agricultural products.

• Significance for Climate Change

For centuries, fishers realized that weather affected fish populations, but they lacked the scholarly resources to investigate their observations. During the nineteenth century, fishery researchers began applying scientific methodology to study diverse factors affecting fish health, reproduction, and habitats. They contemplated reasons for decreased fish populations besides overfishing. U.S. Environmental Protection Agency representatives voiced concerns that climate deviations affected the quantity and quality of fisheries to the U.S. Congress in 1988. The American Fisheries Society promoted research examining how climate change might affect fisheries. Scientists consulted ships' logs and records documenting fish-catch statistics and meteorological patterns to evaluate hypotheses about the climate's possible role in fish population losses. Researchers used computer simulations to consider future climatic factors that could potentially harm fish.

Fish are exceptionally vulnerable to habitat changes. The World Wildlife Federation emphasizes that temperature increases of 2° Celsius or more are dangerous for fish. Healthy water temperatures differ according to species. Scientists link increased water temperatures to global warming, because water absorbs heat trapped by greenhouse gases (GHGs). The Intergovernmental Panel on Climate Change (IPCC) states that abnormally high ocean temperatures have occurred as deep as 3,000 meters below sea level. Water-temperature increases can interfere with fishes' oxygen supply and the physiological processes associated with maturation, digestion, and spawning. High temperatures also weaken fishes' resistance to toxic substances and pathogens that invade their habitats. Scientists evaluate fish otoliths (ear bones), which indicate growth, to study how temperatures at varying depths influence development.

Researchers have correlated temperature deviations in oceans with fish displacement due to reduced growth of food sources, such as plankton. Melting glaciers caused by global warming raise water levels and dilute the oceans, decreasing salinity. This surplus water disrupts currents crucial for transporting food and removing pollutants, including from such human sources as fishing vessels and fish-factory emissions. Fish migrate to waters with more compatible temperatures and ample food supplies, but they often fail to thrive if they are unable to adapt. Since the late 1980's, Massachusetts fishermen reported an 80 percent decline in cod catches. Fisheries managers aware of areas where wild fish have relocated can adapt management practices to minimize additional climate change damage and to replenish fisheries.

Temperature increases of almost 3° Celsius in some locations have caused freshwater in streams, rivers, and lakes to evaporate, reducing habitat size and stressing fisheries, particularly trout and salmon species in the western United States. In Montana, grayling fish in the Big Hole River decreased from ninety-six fish per kilometer of river in the 1990's to as few as eight in the early twenty-first century because of temperature changes. Some hardier species, such as smallmouth bass, sought warmer habitats, competing for resources and displacing indigenous fish. Scientists warned that loss of diverse fish genetic material diminishes fisheries and some species will become extinct. Fishery experts estimated reductions of approximately 90 percent of bull trout and 40 percent of salmon populations by 2050 if extreme heat and arid climate conditions persist.

Climate changes alter fish ecosystems in lakes, resulting in fishery populations being reduced by as much as 30 percent, as has been reported in Africa's Lake Tanganyika. In addition to temperature and precipitation deviations, climate changes slow wind velocities needed to stir nutrients from deeper lake water to the surface. Changing climates might force fish farmers to relocate stock from ponds to protected sites where hot temperatures do not threaten fish health.

Oceans become more acidic when water absorbs carbon dioxide (CO_2) in the atmosphere, bleaching coral reefs, which many fish need for habitats and nurseries. A January 16, 2009, *Science* article reported researchers' discovery that calcium carbonate in fish fecal material can control some ocean acidity. CO_2 circulating in fish blood stimulates production of calcium carbonate. Ironically, as GHG emissions increase, the amount of fish-produced calcium carbonate might too, helping counter climate change's impact on fisheries.

Elizabeth D. Schafer

• Further Reading

Marine Resources Service, Fishery Resources Division, FAO Fisheries Department. *Review of the State of World Marine Fishery Resources.* Rome, Italy: Food and Agriculture Organization of the United Nations, 2005. Illustrated sections feature diverse regional fisheries. Climate chapter discusses scientific investigations that question whether climate changes have caused population fluctuations in fisheries.

Nelleman, Christian, Stefan Hain, and Jackie Alder, eds. *In Dead Water: Merging of Climate Change with Pollution, Over-Harvest, and Infestations in the World's Fishing Grounds.* Arendal, Norway: United Nations Environment Programme, GRID-Arendal, 2008. Comprehensive examination of global warming issues relevant to fisheries. Photographs, figures, and maps displaying past and projected climate changes supplement the text.

Robbins, Jim. "As Fight for Water Heats Up, Prized Fish Suffer." *The New York Times,* April 1, 2008, p. F4. Scientists explain how temperature changes and diversion of water for agricultural uses combined to harm fish habitats in western U.S. rivers. Includes suggestions for restoring fish populations.

Sharp, Gary D. *Future Climate Change and Regional Fisheries: A Collaborative Analysis.* Rome, Italy: Food and Agriculture Organization of the United Nations, 2003. Fisheries expert differentiates between global change and warming and how they have continually shaped ecosystems supporting fish throughout the Earth's history. Figures, glossary, bibliography, list of recommended Web sites.

Wilson, R. W., et al. "Contribution of Fish to the Marine Inorganic Carbon Cycle." *Science* 323, no. 5912 (January 16, 2009): 359-362. Highlights the contribution of fish excretions to the carbonate content of seawater; argues that, because the magnesium content of these excretions allows them to be dissolved more readily than other carbonates, they may have a disproportionate effect on ocean alkalinity.

See also: Dolphins and porpoises; Ocean acidification; Ocean disposal; Ocean life; Whales.

Flood barriers, movable

- **Category:** Science and technology

- **Definition**

People have innovated technology and methods to divert floodwater throughout history. Devices to block excess water from inundating land include dikes, levees, and seawalls which are primarily rigid structures. In the twentieth century, extreme floods overwhelmed many of those structures, prompting people to seek better protection to withstand future deluges. Engineers designed large movable floodgates placed at intervals in rivers and lagoons adjacent to seas. These barriers, which could be quickly maneuvered into place for specific flooding threats, were constructed from more durable materials and in greater sizes than previous flood walls. When sea levels rose, producing surges, operators raised and closed movable barriers to keep rising seawater from flooding communities. After conditions improved, barriers were opened or lowered to enable water traffic to pass unimpeded.

- **Significance for Climate Change**

Raised seawater levels associated with global warming often results in severe flooding in coastal communities. European floods in 1953 were especially catastrophic. Government leaders in England and the Netherlands, which both suffered vast losses, sought more effective ways to control flooding. The 1953 floods resulted in engineers in the Netherlands developing the innovative Delta Project to control flooding with a complex system of heightened dikes, connected seawalls and dams, and movable floodgates which could be shut into position when storms occurred to block tidal surges from the North Sea.

The Delta Works consists of some of the Earth's biggest movable flood barriers. Beginning service in 1986, the Oosterschelde Storm Surge Barrier, built in an estuary, contains sixty-two steel gates which move on concrete piers. Saltwater necessary to sustain the estuary's ecosystem can advance through the opened gates. Built by 1997 at Rotterdam, the Maeslant Storm Surge Barrier on the Nieuwe Waterweg incorporates computer sensors which sense rising water levels from tidal surges and activates the two curved triangle-shaped gates to pivot from their home bank to meet in the river's center. The movable Hagestein Weir near Hagestein, Holland, has curved gates resembling visors which can be shut to control water flow.

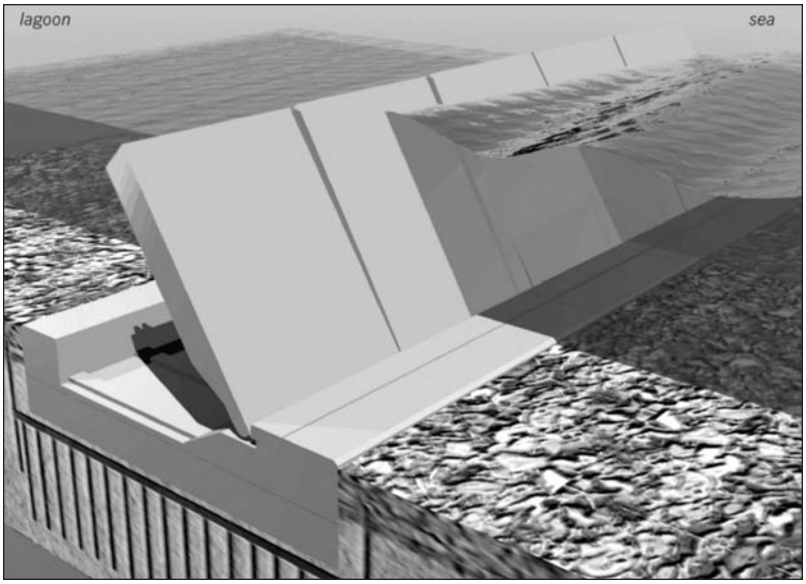
In England, the Thames River represented that country's greatest flood concern, particularly in London. Officials considered reports suggesting building a river-wide barricade consisting of gates which could be moved to impede floodwater. They passed the 1972 Thames Barrier, and Flood Protection Act. Construction of a movable flood barrier started in 1974 at an east London site located in the Thames Estuary. By 1982, builders finished the Thames Barrier, which consists of ten hood-shaped steel gates mounted on concrete sills secured to the river floor. Environment Agency personnel oversee the Thames Barrier and evaluate tidal threats based on Storm Tide Forecasting Service data and computer models.

Engineers estimated the Thames Barrier can handle possible flooding conditions through 2030 and perhaps through 2070, but due to intensified global warming, that barrier has been activated more often than estimated. Since 1982, operators have shut the Thames Barrier in more than one hundred incidents, with at least fifty percent of those closings happening after the year 2000. If climate change is not slowed and sea levels rise more quickly than projected, the Thames Barrier will become insufficient before engineers envisioned, necessitating plans for construction of another barrier in the Thames Estuary.

The Italian city of Venice, located adjacent to barrier islands bordering the Adriatic Sea, often experiences flooding. Global warming contributes to rising sea levels, causing excess water to inundate Venice's lagoon and St. Mark's Square, which flooded more than one hundred times annually in the twenty-first century compared to six times yearly in the early twentieth century. Extreme floods in 1966 motivated Italian officials to consider more effective flood-control techniques. Concerned climate changes might result in tidal floods destroying Venice, engineers recommended installing movable flood barriers and by 1990 presented a prototype of the *modulo sperimentale elettromeccanico*

(MOSE), also known as the Moses Project.

In 2002, government leaders decided to fund the Moses Project to build seventy-nine hollow steel gates for placement in the lagoon's Chioggia, Lido, and Malamocco inlets. Chief engineer Alberto Scotti oversaw construction starting in spring, 2003. According to plans, the gates, lowered on their hinges, are to be submerged in underwater cement structures. Operators will lift gates by pumping compressed air into them when needed. Because of the project's complexity, its completion date was shifted from 2010 to 2014.



An artist's rendering of Venice's Moses Project movable flood barriers, which are expected to be completed around 2014. (AP/Wide World Photos)

Moses Project construction provoked controversy. Opponents stated the barriers will damage the lagoon environmentally. Continued flooding provoked by global warming, especially high waters in 2008, emphasized the need for flood control. Projections for sea level increases of a few meters by 2100 caused engineers to recognize the Moses Project might need reinforcements to block surges into Venice's lagoon.

Elizabeth D. Schafer

• Further Reading

Bijker, Wiebe E. "The Oosterschelde Storm Surge Barrier: A Test Case for Dutch Water Technology, Management, and Politics." *Technology and Culture* 43, no. 3 (July, 2002): 569-584. University of Maastricht professor whose civil engineer father worked on Dutch flood-control projects provides insights regarding construction, politics, public opinion, and environmental issues relevant to this movable barrier.

Donadio, Rachel. "Floodwaters, Worst Since '86, Begin to Recede in Venice." *The New York Times*, December 3, 2008, p. A12. Examines the impact of global warming on Venice and public reaction to the Moses Project, commenting that those barriers could have stopped this flood. Remarks that the barriers' opponents suggest that limiting carbon emissions can solve Venice's flooding concerns.

Hoeksema, Robert J. *Designed for Dry Feet: Flood Protection and Land Reclamation in the Netherlands.* Reston, Va.: American Society of Civil Engineers Press, 2006. Discusses historical Dutch floods, the twentieth century Delta Project, and Delta Works technology. Illustrations depict the construction and use of movable flood barriers. Glossaries.

Keahey, John. *Venice Against the Sea: A City Besieged.* New York: Thomas Dunne Books/St. Martin's Press, 2002. Incorporates climate change information in chapters focusing on efforts to protect Venice with movable flood barriers, as well as on disagreements regarding those plans. Illustrations include a Moses Project diagram.

See also: Coastal impacts of global climate change; Estuaries; Floods and flooding; Venice.

Floods and flooding

• **Categories:** Meteorology and atmospheric sciences; oceanography

Floods along rivers and storm surges along ocean shorelines may become more severe on average as a result of higher sea levels and greater precipitation associated with global warming.

• Key concepts

base flow: the normal amount of discharge in a river
discharge: the volume of water that passes a point in a river in a certain interval of time
evaporation: the absorption of liquid water into the air as water vapor
flood: unusually high levels in bodies of water, causing some water to leave those bodies and pour onto land
latitude: the distance of a point on Earth from the equator, measured in degrees of the planet's curvature
precipitation: rainfall, hail fall, or snowfall
storm surge: an abnormal rise of the ocean along a shoreline as a result of storm winds

• Background

Floods along rivers occur when large amounts of precipitation, often combined with melting snow, cause the discharge of a river to increase far beyond its base flow. The floods may be even higher in cities because of rapid runoff of water from cement into storm sewers. Global warming may increase the intensity and variability of precipitation in many regions, causing more intense flooding. Floods along maritime coastlines can result from storm surges. Higher sea levels due to glacial melting during global warming and more frequent and intense hurricanes may result in more coastal flooding.

• Warming of the Earth's Climate

The average temperature of the atmosphere of Earth near its surface is variable, and it has been estimated in a number of ways. Nevertheless, the average temperature before 1920 is estimated to have been about 0.2° to 0.4° Celsius lower than it was from about 1940 to 1980. The average temperature from about 1980 to the early twenty-first century was about 0.4° Celsius higher than that from 1940 to 1980. A major reason for this increase in average temperature is likely the 33 percent measured increase of the atmospheric concentration of the greenhouse gas (GHG) carbon dioxide (CO_2) between about 1958 and the early twenty-first century. Much of this increase in CO_2 was likely due to burning coal, oil, and natural gas.

Predictions of warming of the atmosphere in the future are much more difficult to make. For instance, a doubling of the CO_2 content of the atmosphere from that of the present has been predicted to cause an increase in temperature of about 2° to 3° Celsius. Warming of the atmosphere to the year 2100 has been predicted, depending on the model, to increase the temperature by as little as 2° Celsius to as much as 8° Celsius.

• Predicted Influence of Climate Change on Precipitation and Floods

The gradual increase of temperature is likely to lead to more frequent warm periods, such as the extreme heat wave that occurred in Europe in the summer of 2003. Also, snow should, on the average, melt sooner in the spring and melt more rapidly and further to the northern and southern latitudes than it does now.

The increase in temperature of the atmosphere and oceans during global warming will also likely increase the amount of water that evaporates into the atmosphere. Thus, more intense precipitation should occur in some regions. On a regional scale, this effect is most likely to transport more water from the subtropics to higher latitudes. Thus, higher local rainfall may occur in some areas, causing more discharge into rivers and producing more flooding. This precipitation may be quite variable in different areas. For instance, some drainage basins in the northwestern United States have been predicted to have increased flood risk as a result of global warming. By contrast, drainage basins that receive much of their precipitation as snow have been predicted to have less flood risk in the spring as a result of there being less snow to melt.

In the aftermath of a deadly flood in Ecuador, survivors attempt to save their belongings. (Xinhua/Landov)

- **Predicted Influence of Climate Change on Maritime Coasts**

Hurricanes have been predicted to become more numerous and destructive as a result of global warming. For instance, there has been an increase in Type 4 and 5 hurricanes since 1970. This increase should result in more and greater storm surges along coastlines.

The gradual increase in temperature over time should result in more glacial melting and an increase in the volume of liquid water on the planet. Some predict that even modest increases in GHGs in the atmosphere could melt the ice sheet on Greenland and much of the Antarctic ice sheet. These effects would lead gradually to a rise in sea levels. Estimates of this rise have varied from an increase of 0.1 meter to 0.9 meter by the year 2100. This increase in sea level should result in more flooding of flat-lying areas along oceanic coastlines and an increased influence of storm surges.

This problem could be made worse in areas in which the land surface is gradually sinking, such as in southeastern England or in Venice, Italy. Venice is located at sea level, and a series of water canals inundate much of the city. The sea level has risen relative to the land surface by about 25 centimeters from about 1900 to 2000, mostly as a result of the land subsiding because of the removal of groundwater for industry. Thus, Venice risks being submerged into the ocean if the sea level rises.

- **Context**

Some of the changes expected to result from global warming are difficult to predict. For instance, changes to the Gulf Stream associated with global warming could potentially be very important, causing vast changes in the climate. The Gulf Stream is the flow of warm, salty water from the subtropical Atlantic Ocean northward toward polar regions. The Gulf Stream loses heat to the atmosphere in cooler areas, so it becomes denser and sinks. The cooler water then flows to the south, along the eastern coast of North America. Warming of the atmosphere and ocean as a result of climate change could potentially keep the Gulf Stream warmer further to the north, making the water less dense. This lower density might keep the surface waters from sinking and partially or even completely shut down this circulation cycle in the Atlantic Ocean, drastically affecting the climate. Northern latitudes might become wetter, much of the midlatitudes could become dry, and tropical rainfall could shift. Thus, flooding and drought areas may shift drastically if the global climate continues to change.

Robert L. Cullers

• Further Reading

Mitchell, John, Jason Lowe, Richard Wood, and Michael Vellinza. "Extreme Events Due to Human-Induced Climate Change." *Philosophical Transactions of the Royal Society* 364 (2006): 2117-2133. Describes the causes of global warming and its effects on rain and flooding, as well as other potential catastrophic effects on the Earth.

Overpeck, Jonathon T., and Julia E. Cole. "Abrupt Change in the Earth's Climate System." *Annual Reviews of Environmental Resources* 31 (2006): 1-31. Explains how the Earth's climate has changed rapidly in the past and how it may change abruptly in the future.

Ruddiman, William F. *Earth's Climate Past and Future*. 2d ed. New York: W. H. Freeman, 2008. Ruddiman specializes in climate research, and he summarizes the background of climate science and what may happen to the climate as a result of global warming. There are many colored figures to support the discussion.

Valsson, Trausti. *How the World Will Change with Global Warming*. Reykjavik: University of Iceland Press, 2006. The causes and potential effects of global warming are described in this book. Some of the predictions are controversial. There are numerous tables and figures to support the discussion.

See also: Coastal impacts of global climate change; Coastline changes; Flood barriers, movable; Islands; Mean sea level; Sea-level change.

Florida

• **Category:** Nations and peoples

Florida is one of the U.S. states most vulnerable to sea-level rise because of the low elevation of its land surface. The major cities along the coast, as well as Everglades National Park, are at greatest risk.

• Key concepts

Category 5 storm: the most severe hurricane possible, with winds of at least 250 kilometers per hour and a storm surge of at least 5.5 meters

Everglades: a vast sawgrass marsh with occasional wooded "tree islands"

groundwater table: the upper surface of the underground zone saturated with water

St. Louis encephalitis: a form of sleeping sickness

storm surge: an abnormally large sea-level rise occurring during a severe storm

subtropics: a climate zone found just poleward of the tropics

tropics: a climate zone found close to the equator that lacks a winter season

• Background

Located in the southeastern corner of the United States, Florida is the nation's fourth most populous state. The state's land surface consists largely of a peninsula extending southward, bordered by the Gulf of Mexico on the west, Florida Bay on the south, and the Atlantic Ocean on the east. A panhandle that trends west from the peninsula is bordered by Georgia and Alabama on the north. The highest point in Florida is only 105 meters above sea level; the rest of the state is low-lying, with a fairly level surface.

• Flooding

Flooding is a potential hazard for all of Florida's coastal areas, because the land is so flat and the ground surface is only a few meters above sea level. Heavy downpours cause serious problems. Storm drains and canals are designed to carry off excess water by gravity flow, but most of them empty into the ocean or lagoons behind the barrier islands, so a future sea-level rise would reduce the effectiveness of these drains and canals, aggravating flooding problems.

- **Beach Erosion**

Florida beaches experience severe erosion during storms and hurricanes, and this erosion will continue and increase if sea levels rise. Erosion along undeveloped sections of the coast is already cutting beaches back by as much as 0.5 meter per year. In developed areas, preventing beach erosion is a costly process. Property owners must armor their beachfront property with protective sea walls, or groins, while cities have to undertake dredge-and-fill projects, known as "beach renourishment" projects. Not only do the latter cost millions of dollars per kilometer, but also sand dredged from offshore

is often the same fine-grained sand that was washed away in the first place. Once it is replaced on the beaches, it is as easily washed away again, so the life expectancy of renourished beaches is just a few years or even less.

Florida's population is concentrated in the coastal zone, where the amount of residential and commercial development has steadily increased. Owners have torn down their oceanfront cottages to replace them with two-story mini-mansions, and, where single-family houses once stood, multi-story condominiums have risen. The vegetated sand dunes that once protected the coastline from beach erosion have been largely replaced by concrete structures, but many of these have proven to be just as vulnerable to wave attack as the dunes were, and some have even had to be torn down.

• Hurricane Damage

Hurricanes are intense storms that form over warm ocean waters. Because of its southerly location, Florida may experience several of these each year. With continued warming of the oceans, Florida's hurricanes will probably occur more frequently and with greater intensity. The hurricane season lasts from June 1 until November 30, with two periods of peak activity. The first such period comes in June, when smaller storms form in the Caribbean Sea and the Gulf of Mexico, because the waters there warm first. The second activity peak comes in September, when the normally cool waters off the coast of Africa start to warm up and severe Category 5 storms may develop. The damage caused by hurricanes results from high winds as well as from the accompanying storm surges. The lower, southeastern coast of Florida has been most affected by hurricane damage over the years, but no part of Florida has gone untouched. The 2004 hurricane season was particularly stressful: Four major hurricanes hit the state during a five-week period. Following those storms, property-insurance rates for coastal dwellers skyrocketed.

• Infrastructure Damage

Rising sea levels will affect Florida's highways, bridges, houses, factories, waterways, ports, airports, mass transit systems, sewage treatment plants, and water supply facilities. Unfortunately, many of these systems are already under stress as a result of long-term deferral of maintenance. In addition, the productivity of the coastal lands for agriculture, residences, tourism, recreation, and industry will be affected by rising sea levels, as will Florida's estuaries, wetlands, and coastal groundwater tables. Worse still, as salt water from the ocean intrudes along the coast, the well fields from which many Florida cities get their drinking water will become contaminated.

• Environmental Changes

South Florida is classified as subtropical because of its mild winter season. Central and North Florida have more severe winters, with frequent freezing temperatures. However, global warming could cause South Florida to become tropical and cause Central Florida to develop the subtropical characteristics South Florida now has. These temperature changes would result in longer growing seasons and a poleward shift of certain plant and animal ranges. Mangroves would grow farther north, for example, and cypress, which are not tolerant of salt water, would decline and eventually die, as the rising ocean waters extended inland. Humans would be affected as well: Heat-related deaths could increase, and tropical diseases could spread. South Florida already has occasional cases of St. Louis encephalitis and malaria. The numbers of these cases would probably increase as temperatures warmed, and dengue fever could appear as well.

• Context

Florida is low-lying and has one of the longest coastlines of any U.S. state. As a result, it would be severely affected should sea levels rise as a result of global warming. Geologists believe that, prior to the last ice age, worldwide sea levels stood some 95-125 meters higher than present levels. As the highest point in Florida is only 105 meters above sea level, the entire state must have been submerged at that time. Evidence for this can be found in the old sand bars and sea shells scattered everywhere on the Florida land surface. A rise in sea level of only 15 meters would submerge all of South Florida, including the Everglades. If all the ice on the planet melts, the entire state of Florida will disappear beneath the waves.

Donald W. Lovejoy

• **Further Reading**

Braasch, Gary. *Earth Under Fire: How Global Warming Is Changing the World.* Berkeley: University of California Press, 2007. This handsomely illustrated book surveys the changes that global warming is bringing to the planet, how these changes are caused, and what can be done about them.

Bush, D., et al. *Living with Florida's Atlantic Beaches: Coastal Hazards from Amelia Island to Key West.* Hong Kong: Duke University Press, 2004. Identifies shoreline areas that are safe or unsafe for development and the steps that coastal dwellers should take to reduce the hazards they face.

Warrick, R. A., E. M. Barrow, and T. M. L. Wigley, eds. *Climate and Sea Level Change: Observations, Implications, and Projections.* New York: Cambridge University Press, 1993. This classic book specifically addresses the regional effects of sea-level rise in terms of land loss, flooding, saltwater intrusion, and environmental and socioeconomic impact.

See also: Coastal impacts of global climate change; Coastline changes; Damages: market and nonmarket; Flood barriers, movable; Floods and flooding; Mean sea level; Saltwater intrusion; Sea-level change; Storm surges; Tropical storms.

Fog

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Fog is a cloud near the ground. Fog forms as the temperature of air falls below its dew point and condensation occurs. Fog also forms and dissolves rapidly depending on whether the temperature is higher or lower than the dew point. Fogs are named based on the specific process through which the humidity has reached its saturation point, causing the fog to form.

Radiation fog forms as air temperature falls below the dew point by a rapid radiation cooling through a clear, calm night. The cool and heavy air containing this type of fog often settles in low-lying areas, such as mountain valleys. Most inland fogs are radiation fogs. Advection fog usually forms in coastal regions as warm air blows over a cold surface and loses heat to the underlying surface. Upslope fog forms as air blows over mountain slopes, becomes cool, and reaches saturation.

Evaporation fog occurs as a cold, dry air blows over warm, moist surfaces. Thermal and humidity gradients between the two entities facilitate rapid evaporation from the surface. As the warmer, moist air from the ground mixes with cold, dry air above, it reaches saturation and forms fog. Steam fog over lakes during late fall and early winter is a typical form of evaporation fog.

• **Significance for Climate Change**

Fog, as a surface-level cloud, has roughly the same climatic effects as low-level clouds. Fog dictates air and surface temperature patterns by controlling the amount of radiation that enters and leaves the surface. High moisture content imparts fog with great thermal inertia. Thus, once a fog has formed, it will prevent air temperature from changing. In the morning, fog's high albedo allows less incoming solar radiation to reach the surface. Thus, morning fogs keep air temperatures low, allowing only gradual increases until the fog evaporates. As a result, fogs decrease daytime high temperatures.

In the night, fog traps outgoing longwave radiation and prevents air temperature from dropping as it would on a clear night. Fog also potentially warms the air near the surface, because condensation is a warming process. Overall, however, fog has a greater cooling effect than warming effect on Earth. As global warming continues, greater incidences of fog and lower clouds are expected, because warmer air can contain more water vapor. This increased fog may affect humans by reducing visibility and by trapping air pollutants to form smog. Fog can also produce precipitation, in the form of rain drizzle and light snow.

Jongnam Choi

See also: Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Albedo feedback; Clouds and cloud feedback; Dew point; Water vapor.

Food and Agriculture Organization

- **Category:** Organizations and agencies
- **Date:** Established 1945
- **Web address:** http://www.fao.org

• Mission

A United Nations agency, the Food and Agriculture Organization (FAO) gathers information about climate change that affects agricultural resources. Emphasizing food security and economic stability, the organization advises government leaders regarding policy strategies for agriculturists to adjust farming methods to continue production despite altered climatic conditions.

Food shortages and malnutrition during World War II motivated international leaders to establish the FAO on October 16, 1945. By the early twenty-first century, the FAO, headquartered in Rome, Italy, consisted of 189 member nations. The FAO supports nutritional humanitarian work by assisting agriculturists in developing and developed countries to increase cultivation of essential crops and livestock. Concerned about securing abundant food supplies worldwide, FAO consultants study agricultural conditions in diverse geographical locations, prepare publications, and present findings at meetings. They communicate with government leaders, who decide whether to incorporate FAO programs in policies.

• Significance for Climate Change

FAO reports and conferences discussed climate change when addressing other issues but did not focus on that subject until 1988. At that time, FAO leaders, recognizing that global warming endangered food security, established a climate group to assess scientific activity investigating climate change to shape the FAO's objectives. By 2001, the FAO's Interdepartmental Working Group on Climate Change and integrated climate change program benefited from FAO departments representing such specific issues as animal husbandry, bioenergy, and forestry sharing climate-related work.

The FAO acquired and distributed information and funding to assist members' governments to encourage agriculturists, especially in developing countries, to utilize alternative techniques to keep farming and sustain yields despite temperature, precipitation, and other climatic deviations affecting agriculture. FAO representatives advocated conservation and recommended methods which eased climate change stresses on crops and livestock. The FAO coordinated endeavors with the United Nations Environment Programme (UNEP) and Framework Convention on Climate Change (UNFCCC).

FAO researchers utilized satellite technology to evaluate water and land resources needed for agriculture and observe climate-related disasters such as droughts and floods. They promoted biotechnology efforts to create resilient crops that could survive

The FAO Mandate

The Food and Agriculture Organization provides the following statement of its institutional mandate.

Achieving food security for all is at the heart of FAO's efforts—to make sure people have regular access to enough high-quality food to lead active, healthy lives.

FAO's mandate is to raise levels of nutrition, improve agricultural productivity, better the lives of rural populations and contribute to the growth of the world economy.

FAO provides the kind of behind-the-scenes assistance that helps people and nations help themselves. If a community wants to increase crop yields but lacks the technical skills, we introduce simple, sustainable tools and techniques. When a country shifts from state to private land ownership, we provide the legal advice to smooth the way. When a drought pushes already vulnerable groups to the point of famine, we mobilize action. And in a complex world of competing needs, we provide a neutral meeting place and the background knowledge needed to reach consensus.

such climate extremes as excess or insufficient water availability. The FAO established programs with universities to prepare experts for field assignments to assist agriculturists and show them how to adapt farming procedures to withstand climate change. FAO representatives encouraged farmers to plant trees to absorb carbons and reduce agricultural contributions to global warming by decreasing emissions from livestock and machinery used to harvest, process, and transport crops.

The FAO chaired UN Water, a program coordinating work and research concerning water resources impacted by climate change. The FAO helped governments with various water issues associated with global warming, including melting glaciers, and distributed reports such as the December, 2008, *Climate Change and Food Security in Pacific Island Countries*. The FAO stressed that solutions must be appropriate for each location and encouraged government officials from nations simultaneously using a large water resource, such as Lake Chad, to work together to address climate problems, instead of complicating situations with contradictory approaches.

The FAO studied how climate change affected indigenous populations, noting that lands they farmed often were threatened by deforestation and they were denied access to resources. FAO representatives also investigated how climate change impacted agriculturists according to gender, with males often leaving rural areas to secure consistent income.

FAO's annual World Food Day events emphasized how climate change hazards to agriculture interfered with food security. The FAO's 2006 *State of Food Insecurity in the World* report stated hunger affected 854 million people internationally. The FAO warned that climate change was the greatest threat to interfering with populations acquiring nourishment. World Food Day in October, 2008, featured a forum for participants to share ways they countered climate change.

In December, 2007, the FAO food price index indicated a forty percent price increase since 2006 due to climate changes and other factors causing shortages. The food price crisis diverted climate change discussion at a June, 2008, conference, and FAO leaders urged agriculturists to focus on crops for food, not biofuels. The 2008 FAO Initiative on Soaring Food Prices helped agriculturists in ninety countries.

In November, 2008, FAO members decided to reform that agency as a result of an independent assessment. Beginning in 2009, the FAO determined to concentrate its time and funds on several issues, including improved and expanded climate change work. FAO leaders stated they would request diplomats to incorporate food security provisions in climate change treaties. In January, 2009, FAO ideas resulted in the International Treaty on Plant Genetic Resources for Food and Agriculture, which advanced biodiversity by preserving and sharing genetic material from sixty-four crops to adapt plants impacted by climate change.

The FAO's Web site includes a climate change section, providing digital databases and publications. In 2008, the FAO initiated its electronic newsletter *Food-Climate*.

Elizabeth D. Schafer

• Further Reading

Bruinsma, Jelle, ed. *World Agriculture—Towards 2015/2030: An FAO Perspective*. London: Earthscan, 2003. Chapter 13, prepared by geographer David Norse and FAO climatologist René Gommes, focuses on how agriculture both affects and is affected by climate change; projects potential food security concerns.

Food and Agriculture Organization of the United Nations. *FAO: The First Forty Years*. Rome, Italy: Author, 1985. Illustrated historical overview describes FAO programs, referring to weather issues and desertification, depicted on a map of Africa, prior to that agency initiating climate change projects.

Martin, Andrew. "U.N. Food Meeting Ends With a Call for 'Urgent' Action." *The New York Times*, June 6, 2008, p. A13. Discusses why a conference initially organized to focus on climate change and biofuels instead concentrated on food prices. Participants' comments reveal diverse attitudes toward climate policies.

Rosenthal, Elisabeth. "World Food Supply Is Shrinking, U.N. Agency Warns." *The New York Times*, December 18, 2007, p. 5. Provides examples of climate change's contributions to re-

duced agricultural production and of FAO's adaptation strategies for farmers. Includes statistics and quotations by FAO director-general Jacques Diouf and climate scientists.

See also: Agriculture and agricultural land; Agroforestry; United Nations Environment Programme; United Nations Framework Convention on Climate Change.

Forcing mechanisms

• **Category:** Meteorology and atmospheric sciences

Forcing mechanisms alter climate by changing the balance between incoming solar radiation and radiative energy loss. They may occur on human or geologic timescales and be anthropogenic or natural. The unpredictability of some large-scale forcing events has been used as an argument against modifying human policies to reduce the greenhouse effect.

• Key concepts

astronomical forcing: climatic change triggered by changes in solar luminosity, variation in the Earth's orbit, and bolide impact

Milanković cycles: variations in the eccentricity of the Earth's orbit, the tilt of the Earth's axis, and the precession of equinoxes that result in climatic variation on the scale of tens of thousands of years

planetary albedo: reflectivity of the Earth's surface to light

• Background

Examining fossils, evidence from archaeological sites, and the historical record indicates that climate fluctuates markedly on timescales ranging from decades to tens of millions of years. One age's tundra may have been another age's temperate forest. Solar energy drives the Earth's climate. The amount of solar energy available depends on the balance between the amount reaching the Earth and the amount radiated back into space, both of which are variable. In addition to solar energy, Earth also receives input from gravitation and radioactive decay; these sources are dwarfed by solar input and have been essentially constant throughout the Phanerozoic era.

• The Geologic Record: Evidence for Forcing

The geologic record spans of millions of years during which global climate was relatively uniform, divided by much briefer spans characterized by climatic extremes and elevated extinction rates. This record is punctuated by five recognized episodes of catastrophic extinction, believed to correlate with external climatic forcing mechanisms. The best-known of these is the end-Cretaceous event marking the end of the dinosaurs 65 million years ago. Most biologists accept that the precipitating factor was an asteroid collision that (among other effects) abruptly lowered global temperatures by ejecting massive amounts of dust into the atmosphere.

• Types of Forcing Mechanisms

Climatic forcing mechanisms can be classified according to whether they are external or internal, whether their effect is to increase or decrease net energy available to the system, and the timescale on which they operate.

External Mechanisms. External forcing mechanisms include variations in the Earth's orbit, variation in solar output, impacts by comets and meteorites, and radiation from nearby supernovas. No effect attributable to the last two extremely rare, unpredictable events is evident in the Holocene. The only such event for which there is firm geological evidence is the end-Cretaceous asteroid impact that destroyed the dinosaurs. The predicted climatic effects of an asteroid impact include a short-lived global winter due to obstruction of incoming radiation, followed by a spike in temperatures from carbon dioxide (CO_2) released by burning and decaying vegetation. Oceanic currents would also be severely disrupted.

Total solar radiation varies by approximately 3 percent over the course of the eleven-year sunspot cycle. There is evidence for a ninety-year cycle in addition, and longer-term ones probably exist as well. The latter part of the Little Ice Age corresponds to the Maunder Minimum, a two-hundred-year period of reduced sunspot activity documented by historical records and proxy measurements. Whether similar extended periods of low sunspot activity contributed to global cooling at other times is uncertain. The Sun reached a low point in its cycle at the beginning of 2008.

Variations in Earth's orbit affect both total insolation and its distribution on Earth's surface. The relevant parameters are degree of eccentricity of the orbit, tilt of the Earth on its axis, and precession of the equinoxes. All of these vary in a predictable way on timescales of thousands of years, with a maximum periodicity of ninety thousand years. The entire orbital pattern is called the Milanković cycles, after its discoverer. These cycles correlate well with Pleistocene glaciation episodes, and studies of Triassic-age lake sediments suggest the pattern is ancient. Earth is currently at an intermediate point in this long-term cycle.

Internal Forcing Mechanisms. Internal mechanisms include geologic events and large-scale biological changes. The timescales of such events vary from weeks, in the case of massive volcanic eruptions, to hundreds of millions of years, in the case of continental drift. The effects of changes in the Earth's magnetic field on climate are a matter of controversy. This field, generated by currents in the Earth's molten core, fluctuates on a timescale of 2,300 years and reverses polarity every 780,000 years. When the field is at its weakest, climatic variability is highest. The current weakening of Earth's magnetic field and the southward drift of the magnetic pole predict a cooling trend that Earth is not experiencing.

Plate tectonics and continental drift drive volcanic eruptions, which are major determinants of climate. Eruptions spew quantities of ash and sulfur dioxide into the atmosphere, blocking sunlight and reducing ground temperatures. There are several historical examples, most notably the Tambora eruption in 1815. Massive eruptions may also destroy enough vegetation to increase planetary albedo. On very long timescales, continental drift alters the ratio of land to water surface and distribution relative to the equator.

Oceanic Forcing. Small changes in sea surface temperature create large-scale climatic effects by altering the circulation of oceanic currents. Changes in oceanic currents may be cyclical and relatively predictable, for example those involved in the El Niño-Southern Oscillation, or they may be externally driven, unpredictable, and of longer duration. The cessation of Gulf Stream circulation in the North Atlantic during the Younger Dryas provides an example of the latter category.

Biological Forcing. Changes in the balance between photosynthesis and heterotrophic consumption alter the CO_2 content of the atmosphere. The present rise in CO_2 levels due to fossil fuel burning by humans mirrors ancient CO_2 depletion. Two episodes of massive global glaciation in the Precambrian follow periods of algal reef building and may represent global cooling due to photosynthetic carbon fixation.

• Context

On a human timescale of hundreds or thousands of years, the most important forcing mechanisms are changes in atmospheric CO_2 content, the solar cycle, and volcanic eruptions. Of these, only the CO_2 content can be regulated by human activity. Sunspot cycles, volcanic eruptions, and some of the shorter Milanković cycles have the potential to either reinforce or cancel out present anthropogenic global warming. Understanding and tracking forcing mechanisms is an important step in formulating rational global warming policy.

Martha A. Sherwood

• Further Reading

Chambers, Frank, and Michael Ogle. *Natural Forcing Factors for Climate Change on Time Scales 10^{-1} to 10^5 Years.* Vol. 2 in *Climate Change: Critical Concepts in the Environment.* New York: Routledge, 2002. Detailed and technical; good coverage of the research upon which conclusions are based.

Cronin, Thomas M. *Principles of Paleoclimatology.* New York: Columbia University Press, 1999. A standard textbook explaining methodology in detail, with an extensive discussion of the implications of recent discoveries for global energy policies.

Pap, Judit M., and Peter Fox, eds. *Solar Variability and Its Effects on Climate.* Washington, D.C.: American Geophysical Union, 2004. In addition

to Milanković cycles, discusses sunspots and changes in solar output in geologic time.

See also: Abrupt climate change; Albedo feedback; Carbon dioxide; Earth motions; Holocene climate; Milanković, Milutin; Radiative forcing; Solar cycle; Sun; Volcanoes; Younger Dryas.

Forestry and forest management

• **Categories:** Plants and vegetation; environmentalism, conservation, and ecosystems

• Definition

Forests are both sources and sinks for carbon. Forest management therefore has the potential to be a means to either increase or decrease forest-based carbon storage. Forestry is a practical science concerned with creating, managing, using, and conserving forests and associated resources in a sustainable manner that meets societal goals. Forest management involves the regeneration, management, utilization, and conservation of forests to meet goals and objectives of society while maintaining the productive potential of the forest. The products, services, and values obtained from a forest include wood, water, wildlife, recreation opportunities, food products, aesthetic beauty, and many others.

A central tenet of forestry is sustainability—ensuring that the products, services, values, and inherent productivity of the resources are sustained over time. An old concept in forestry is sustained yield, meaning that the amount of resources removed from a forest is equal to the amount grown or produced in that forest. This concept has traditionally been most used to define the limits of sustainable timber production: No more timber should be removed from the forest than is grown in any given cycle. Similar concepts apply to the production of wildlife, grasses for forage or livestock, and nontimber ecosystem services such as berries, floral greenery, mushrooms, and so on.

Forest stands in which trees are roughly the same age are typically managed over rotations of twenty to over one hundred years, depending on species, site quality, and specific management objectives. Multiaged stands—which include multiple age classes of trees—are managed over cutting cycles that may range from five to over fifty years. Ideally, stands are maintained at different stages of development, so the forest as a whole may include a variety of stand ages and stand structures.

Many stands are managed to form simple structures that consist of a single tree species planted at consistent spacings and possibly with similar genotypes. Other stands are grown to have many species and multiaged structures. A regulated forest has an arrangement of stand structures that yields a constant production over time. This arrangement represents an ideal that is rarely met, because, over the long time span of forest growth, there are often changes in land ownership patterns, management directives, and regulations that affect how and which lands are managed, as well as disturbances such as fire.

• Significance for Climate Change

Forestry also involves the management of fuels and their arrangement in forest stands. Forest fires occur over broad areas every year in both temperate and tropical forests and result in massive carbon emissions. Insects and pathogens represent another potential hazard to forests that may increase fuels and fire hazards, lead to large-scale carbon emissions, and reduce the ability of the forest to meet other needs. Forests that are resistant to disturbance present an opportunity to conserve carbon on a large scale. Forests with natural functions and processes, endemic levels of insects and pathogens, and normal levels of biodiversity are said to be healthy. Regardless of specific objectives for any forest land, maintenance of forest health is a common, overriding objective for managed forests.

Forests store large amounts of carbon in living, above-ground stems, branches, and foliage; below-ground root structures and fine roots; dead, woody objects, such as logs, decomposing foliage, and twigs; and soil. Forest management activities affect these components and therefore affect a site's carbon balance. A clear-cut harvest will remove all stems but will typically not remove branches, foliage, some stemwood, or any below-ground components. A selection treatment to create a multiaged stand structure would remove a smaller number of trees. Other regeneration methods that remove intermediate amounts of trees produce intermediate results.

In addition to these direct effects on forest carbon, treatments and related soil disturbance may affect the rate of decomposition of plant materials and soil carbon. Disturbances such as fire, wind, or insect or pathogen attack can cause similar effects. Following treatment or disturbance, stands regrow, replacing trees and carbon. A forest managed on a sustainable basis would have a relatively constant level of carbon present, as well as wood fiber and other resources. Permanent removal of forests, or deforestation, generally results in reduced carbon storage. When wood and other forest products are removed and put into long-term use in a sustainable manner, however, they represent an additional source of carbon storage that supplements the forests. Likewise, wood biomass used for energy production results in temporary carbon loss in the forest but in a net carbon savings through offsets of nonrenewable fuels.

Forests represent both a source and a sink for atmospheric carbon. Under global warming climate scenarios, forests will experience greater concentrations of atmospheric carbon dioxide (CO_2), rising temperatures, and altered precipitation patterns. These changes may result in greater growth rates in some cases. Given the long life span of trees, however, they may have poor evolutionary adaptability to changing climatic conditions in their native ranges. Species can be moved to more suitable climates, but species are adapted to both climate and photoperiod.

Future forests are likely to receive greater pressure to produce wood and other ecosystem services including using wood as energy. Deforestation remains another threat to global carbon balance, as forests are replaced with agricultural lands or converted to other uses. Forests are an integral part of

This pine forest in Walden, Colorado, is infested with bark beetles. Climate change presents a challenge to forestry, as pests migrate into warming areas that were previously outside of their habitat. (Gary Caskey/UPI/Landov) the global carbon equation and heavily subject to human influence. Management of forests to offset carbon losses, meet demands for wood and other forest products, cultivate ecosystem services, reduce losses to fire, provide biodiversity, and promote healthy forests all indicate the continued great importance of forestry in the future.

Kevin L. O'Hara

• **Further Reading**

Freer-Smith, P. H., M. S. J. Broadmeadow, and J. M. Lynch, eds. *Forestry and Climate Change*. Oxfordshire, England: CABI International, 2007. An edited volume of twenty-eight chapters covering carbon sequestration, policy issues, climate change effects on forests, soil carbon, and implications for forest policy.

Kohm, K. A., and J. F. Franklin, eds. *Creating a Forestry for the Twenty-first Century*. Washington, D.C.: Island Press, 1997. Twenty-nine chapters present ecological foundations for forest ecosystem management and the concepts related to its silvicultural, landscape-level, and human dimensions.

Puhe, J., and B. Ulrich. *Global Climate Change and Human Impacts on Forest Ecosystems*. Ecological Studies 13. Berlin, Germany: Springer, 2001. A fundamental treatment of climate change effects, covering a range of ecological issues and including a chapter on forest management.

See also: Amazon deforestation; Budongo Forest Project; Carbon dioxide; Carbon dioxide fertilization; Carbon 4 plants; Carbon 3 plants; Deforestation; Fire; Forests; Intergovernmental Panel on Forests; Tree-planting programs.

Forests

• **Category:** Plants and vegetation

Forests, covering about one-third of the Earth's ground surface, are a major carbon sink. Manipulating the amount of surface area in forests arguably offers the best chance for mitigating anthropogenic climate change.

• **Key concepts**

afforestation: creating forests on lands not previously forested

carbon sink: vegetation that incorporates carbon into its structure

dormancy: the portion of the year during which no growth occurs

growing season: the portion of the year during which photosynthesis occurs

reforestation: replacing lost forests

• **Background**

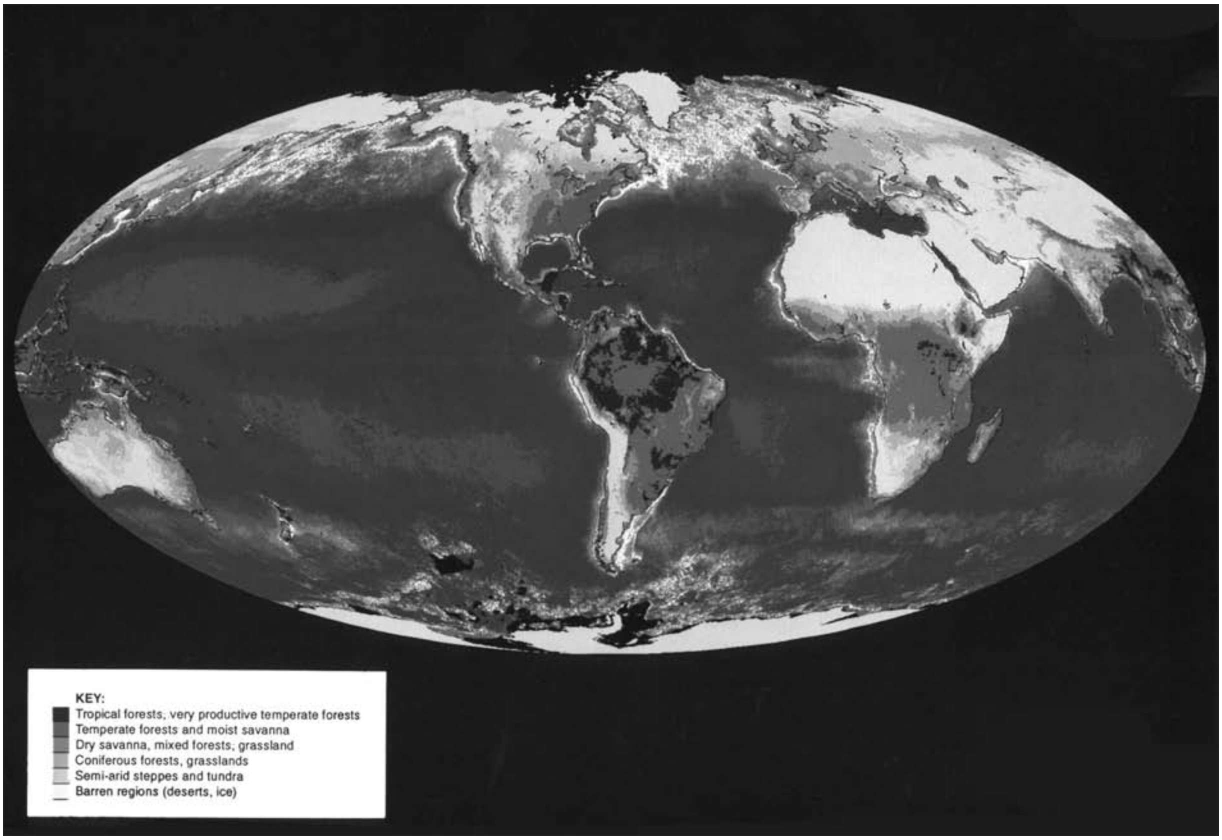
Eight thousand years before the present, before the rise of human civilization, one-half of the Earth's surface was covered by forest. In the intervening years, 20 percent of previously forested land has lost its forest cover, resulting in the loss of a major carbon sink. One of the easiest ways for humans to prevent further carbonization of the atmosphere is to prevent further deforestation and to maintain existing forests intact.

• **Distribution of Forests**

The forests of the world fall into three primary zones: tropical, temperate, and boreal. These zones are defined by their climate and precipitation. Trees require a minimum of 25 centimeters of rainfall per year to grow; land that, by virtue of its location, does not attract the minimum rainfall annually will not support trees. Such land will be either grassland, shrubland, or desert. Trees also require a frost-free part of the year for a growing season. Generally, the longer the growing season, the greater the annual growth.

The tropical rain forests on either side of the equator support tree growth that continues virtually all year long. About half of the world's forests are tropical forests, and they contain the greatest biological diversity of species. Because trees through photosynthesis convert atmospheric carbon to contained carbon, the half of the world's forests in tropical areas are of vital importance.

The temperate forest does not grow all year long. The falling temperatures reach a point at which growth is no longer supported, and the trees go into dormancy for part of the year. The temperate zone has a less varied collection of tree species than the tropics, but it contains a mix of coniferous



An image produced by NOAA's Polar Orbiting Environmental Satellite, showing the distribution of Earth's forests. (NASA)

and broad-leaved species, the latter of which generally lose their leaves during the dormant period.

The forest closest to the north pole is the boreal forest, composed very largely of coniferous species. It grows more slowly than the other forests, because its growing season is the shortest, and it exists in dormancy for a major part of each year. While the true polar regions may have enough precipitation to support trees, their growing season is too short for trees to grow enough to support the needles that provide respiration.

• Twentieth Century Changes

The conversion of formerly forested land to other land uses was greater in the twentieth century than in any previous century. This conversion was driven in large part by the growth in human populations in all parts of the world, but especially during the latter half of the century, primarily in the tropical regions. Between 1950 and 2000, the world's population more than doubled, from 2.5 billion to 6 billion, and the developing world, largely located in the same area where tropical forests are found, contained three-fourths of that larger population. Since forests provide the largest carbon sink, the loss of many forests, especially the tropical forests, is mainly responsible for the rising proportion of carbon in the atmosphere.

The chief driver of deforestation during the twentieth century has been the demand for additional agricultural land to support the growing population. The conversion of forestland to agricultural land adds to atmospheric carbon in several ways. In many cases, the trees that are cut down to release the land for agriculture are burned, and the carbon stored in them is released into the atmosphere. Second, the carbon contained in forest soils over time is also released into the atmosphere when the trees are no longer there to prevent its release. Third, the trees that had been on the land are no longer there to capture future carbon as they grow.

Beside the need for agricultural land to grow crops to feed the growing world population, that population has experienced a change in dietary demand, particularly to include meat products. Some of the land freed up by deforestation is converted not to cropland but to pasture land. Specialized crops such as sugar or soybeans have a market price that poor populations seek to realize by converting forestland to agricultural land. In many areas, the production of specialized crops with major markets in the developed world, such as rubber, has also promoted deforestation.

• Locations of Deforestation

The loss of forestland to agriculture has occurred in most parts of the world adapted to tropical forests. The Amazonian forest in Brazil and the forests in central America have been subject to important depletion since the mid-twentieth century. The deforestation has also been substantial in Southeast Asia, notably on many of Indonesia's islands, as well as in Malaysia and Thailand. The forest in Africa has been less affected.

The temperate forest that was heavily deforested in the nineteenth century has started to bounce back as urbanization and the mechanization of agriculture have reduced the demand for agricultural land. Thus where the population is heavily urbanized, former agricultural land is being gradually reforested, as in the United States and Europe.

Much of the world's sawtimber comes from the coniferous trees in the temperate forest and from the coniferous trees that cover the boreal forest. The Russian forest constitutes one-fifth of the total forestland of the world, but in recent years much cutting to supply sawtimber to the developed world has depleted some of that forest. Combined with softwood coming from Canada's boreal forests, these two sources have supplied a major portion of the dimensional lumber used by the developed world for the construction of houses. Lumber production peaked in the United States in 1906, at 46 billion board feet, but since then lumber production supplied by U.S. forests has gone down. However, wood remains the third most productive commodity in world trade, behind petroleum and natural gas. A substantial proportion becomes fuelwood.

• Context

At the Rio Conference in 1992, 158 countries agreed to try to prevent further deforestation. It has, however, proved difficult to accomplish partly because market forces are working against it, and partly because definition has proved elusive. The Kyoto Protocol of 1999 identified "reforestation" and "afforestation" as processes that could mitigate deforestation, but compensation to those who carry out such measures has not found widespread acceptance. No way has yet been found to value existing forests such that their preservation could be financially rewarded.

Nancy M. Gordon

• Further Reading

Humphreys, David. *Logjam: Deforestation and the Crisis of Global Government.* London: Earthscan, 2006. Highly critical of the failure of international organizations to take on the task of preventing deforestation.

Malmesheimer, R. W., et al. "Preventing GHG Emissions Through Avoided Land-Use Change." *Journal of Forestry* 106, no. 3 (April/May, 2008). This special issue is devoted entirely to the Society of American Foresters' task force report on forest management solutions for mitigating climate change.

Stern, Nicholas. *The Economics of Climate Change: The Stern Review.* New York: Cambridge University Press, 2007. This famous report tackles the charges of those who claim that the economic costs of attempting to prevent climate change are too great.

Williams, Michael. *Deforesting the Earth: From Prehistory to Global Crisis.* Chicago: University of Chicago Press, 2003. This massive account by an author already well known for his careful evaluation of forest history is definitive.

See also: Amazon deforestation; Deforestation; Fire; Forestry and forest management; Intergovernmental Panel on Forests; Tree-planting programs.

Fossil fuel emissions

• **Categories:** Energy; pollution and waste

With the exception of CO_2, the effluents of fossil fuel combustion devices such as automobile engines and thermoelectric power plants do not seem to have a direct effect on climate change. These pollutants are important, however, because of their deleterious effects upon the environment and human health.

• Key concepts

exo: a prefix indicating 10^{18}

fossil fuel: any combustible deposit of carbon of biological origin created over millions of years of geologic history

ozone: a very reactive form of oxygen consisting of three oxygen atoms bound together loosely

particulate matter: small particles, such as fly ash and soot, emitted during the combustion of a carbon-based fuel

• Background

Fossil fuels are combustible geologic deposits of carbon created from plant and animal remains subjected to high temperatures and pressures in the Earth over hundreds of millions of years. Coal, oil, and natural gas are the primary fossil fuels. When any carbon-based fuel is burned, the carbon unites with oxygen in the atmosphere to produce carbon dioxide (CO_2), the main culprit responsible for anthropogenic global warming. In addition, sulfur dioxide, nitrogen oxides, ozone, and particulate matter are often by-products of fossil fuel combustion. These pollutants detrimentally affect plants, aquatic life, and human respiratory health.

• Consumption Modes

In the contemporary United States, 86 percent of all energy consumed is derived from fossil fuels, primarily oil (39 percent), natural gas (24 percent), and coal (23 percent). Some 8 percent comes from nuclear power, with the remaining 6 percent equally divided between wood and hydroelectric plants.

The energy consumed by each U.S. economic sector is as follows: residential and commercial, 35 percent; industry, 23 percent; direct transportation, 27 percent; and transportation-related uses, such as highways and other infrastructure construction, 15 percent. Some 69 percent of the petroleum consumed is for transportation, with another 9 percent for transportation-related uses. Industry accounts for 16 percent of U.S. petroleum consumption, while the residential and commercial sectors account for only 6 percent. Of the 9 percent used for transportation, automobiles consume 40 percent, trucks 33 percent, railroads and buses 3 percent, aircaft 9 percent, water craft 6 percent, and all others 9 percent.

• Environmental Impacts

Fossil fuels provide energy when carbon, the backbone of all fossil fuels, unites with oxygen in the air to produce that energy, as well as CO_2—a combustion by-product. Other elements occurring with fossil fuels, most notably sulfur, are also combusted, releasing emissions toxic to plants and animals. Nonnegligible environmental impacts also result from the extraction, processing, transportation, and waste disposal involved with fossil fuels. The two most important ecological impacts of combusting fossil fuels are the effects on climate of CO_2 emissions and the effects on health of particulate matter and the gaseous by-products of combustion.

Coal mining is accomplished through either strip mining or deep mining. Strip mining renders scores of hectares of land unusable unless they are later reclaimed and has led to mudslides when the removed overburdens are piled too high. Deep mining is prone to cave-ins and fires, and virtually all career deep miners eventually succumb to pneumoconiosis (black lung disease). Abandoned mines often leach acidic effluents into local streams, decimating the local ecology and ruining scenic vistas.

Drilling for oil leads to environmental degradation at the drill site, but even more problematic are the minor leaks and major oil spills that occur during transportation of the oil. These accidents have contaminated shorelines and estuaries, fouling beaches and killing waterfowl and aquatic life. Natural gas is prone to drilling accidents as well and is also subject to pipeline leaks during gas transportation.

Annual Global CO_2 Emissions from Burning Fossil Fuels

Year	Total (mmt)*	Gas (mmt)	Liquids (mmt)	Solids (mmt)	Cement Production (mmt)	Gas Flaring (mmt)	Per Capita (metric tons)
1751	3	0	0	3	0	0	—
1775	4	0	0	4	0	0	—
1800	8	0	0	8	0	0	—
1825	17	0	0	17	0	0	—
1850	54	0	0	54	0	0	—
1875	188	0	1	187	0	0	—
1900	534	3	16	515	0	0	—
1925	975	17	116	842	0	0	—
1950	1,630	97	423	1,070	18	23	0.64
1975	4,615	623	2,132	1,673	95	92	1.13
2000	6,745	1,291	2,838	2,348	226	43	1.10
2005	7,985	1,484	3,096	3,032	315	58	1.23

Data from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.
*mmt = millions of metric tons.

• Public Health Impacts

All fossil fuels emit CO_2, which is a greenhouse gas but not a direct health hazard. In addition, coal typically contains from 1 to 10 percent sulfur and many other trace elements, some of which are radioactive. When sulfur is burned with the coal, it produces sulfur dioxide, which converts to sulfuric acid in the atmosphere. Rain containing the dissolved acid (known as acid rain) will adversely affect forests, and when the acid contaminates bodies of water, fish and aquatic plants are likely to die.

Whenever a carbon-containing fuel is burned, nitrogen oxides are also created; these chemicals react with atmospheric water vapor to create nitric acid, another component of acid rain. In addition, atmospheric nitrogen oxides, as well as sulfur oxides, raise mortality rates and morbidity, particularly among those with respiratory problems. Another gaseous pollutant associated with combusting fossil fuels is ozone, a highly reactive form of oxygen, formed when nitrogen oxides combine with volatile organic compounds in automotive exhaust. Ozone, in addition to increasing morbidity in those with respiratory problems, detrimentally affects forests and reduces crop yields.

Particulate matter released when fossil fuels are burned causes respiratory illness when particles between 0.2 and 3 microns in size coat the lining deep inside the lungs. For those already burdened by respiratory ailments, increased morbidity is a likely result.

• Context

In the past 150 years, the U.S. population has increased by a factor of ten, and the per capita consumption of energy has increased by a factor of five. The United States is thus consuming fifty times the energy it consumed in 1860. Over this time period, the use of wood for fuel has remained relatively constant at about 3 exojoules annually. Water was not harnessed for energy until about 1906, when Niagara Falls became the site of the first hydroelectric power plant. After World War II, the available energy from new hydroelectric plants increased to about 3 exojoules, where it has remained.

The use of coal began around 1840 and grew exponentially until 1920, when it reached 15 exojoules per year. Although the rate of increase has slowed, total annual coal use continues to increase; it is about 22 exojoules today. The use of oil, relatively minimal in the nineteenth century, reached 2 exojoules by 1900. With the twentieth century increase in automobiles, annual oil use rapidly increased to 15 exojoules in 1950, 35 exojoules in

1980, and 40 exojoules at the end of the century. Natural gas was used for lighting in the late nineteenth century at an annual rate of about 1 exojoule. As gas was increasingly used for heating, this rate increased to 5 exojoules by 1940 and 17 exojoules by 1960; it leveled off at 35 exojoules per year from 1980 through 2000.

George R. Plitnik

• **Further Reading**

Bent, R., L. Orr, and R. Baker, eds. *Energy: Science, Policy, and the Pursuit of Sustainability.* Washington, D.C.: Island Press, 2002. An accessible introduction to crucial questions concerning energy use, consumption, and pollution.

Freese, Barbara. *Coal: A Human History.* New York: Penguin, 2004. A comprehensive survey covering in great detail the social, environmental, and political history of coal.

Hyne, Norman J. *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production.* 2d ed. Tulsa, Okla.: Pennwell, 2001. Details, among other items, the location, discovery, mapping, exploration, drilling, production, and reserves of oil and natural gas.

See also: Biofuels; Clean energy; Coal; Energy resources; Ethanol; Fossil fuel reserves; Fossil fuels; Gasoline prices; Hubbert's peak; Oil industry; Renewable energy.

Fossil fuel reserves

• **Categories:** Fossil fuels; energy

• **Definition**

Fossil fuel reserves represent the total quantity of hydrocarbon fuels—such as coal, oil, and natural gas—estimated to be economically recoverable from a specified region. In order to aggregate the different physical units commonly used for each type of fuel, the reserves may be expressed in terms of energy content, using a measurement such as joules.

Calculated fossil fuel reserves are based on estimates of the physical deposits that may exist in a region. These estimates have several sources of potential inaccuracy. Even for a given oil well already in operation, geologists and engineers cannot be certain how many barrels will be extracted before it is shut down. To quantify the uncertainty of the estimates, there are three common categories of reserves. Proved reserves are those reserves that can be developed with reasonable certainty, usually taken to be 80 to 90 percent confidence, using known techniques and with prevailing market conditions. Probable reserves are those that can be developed with 50 percent confidence. Possible reserves may be developed with 10 percent confidence—for example if market conditions change or extraction technology improves.

Estimates of fossil fuel reserves rely not just on geological and engineering factors, but on economic factors as well. The operators of an oil well do not extract the entire reservoir of oil lying beneath the surface; at some point, production is discontinued because it costs more money to extract an additional barrel from the deposit than the barrel can be sold for on the market. This means that, as oil and other fossil fuel prices change, estimates of reserves will also change. The Energy Information Administration has estimated that, as of December 31, 2006, the United States had proved reserves of 21 billion barrels of crude oil, 6 trillion cubic meters of dry natural gas, and 17 billion metric tons of recoverable coal reserves.

• **Significance for Climate Change**

Estimates of fossil fuel reserves at a local level are important in the oil industry. Company officials and shareholders need such estimates in order responsibly to invest in future projects. Estimates of fossil fuel reserves on a worldwide scale have many implications for the debate over climate change and energy policies.

If M. King Hubbert's theory of peak oil is correct, then the rate of worldwide oil production has reached a maximum level or will do so in the near future. According to this theory, as existing deposits are exhausted, it will become more and more difficult to locate new deposits. Over time, it will become costlier to bring a barrel of oil to market, and

World Proved Fossil Fuel Reserves, 2003

Region	*Oil*	*Coal*	*Natural Gas*
Far East	8,041	140,362	16,317
Middle East and North Africa	105,662	1,322	71,385
Europe	11,845	135,783	48,433
Sub-Saharan Africa	6,500	33,348	4,497
North America	6,493	125,311	6,209
Central America and West Indies	2,550	690	1,037
South America	14,120	8,601	5,608
Oceania	611	41,748	2,679
Total	156,700	501,172	158,198

Source: International Energy Agency.

Note: In millions of metric tons of oil equivalent.

production will not be able to keep up with growth in demand. Those who subscribe to the peak oil theory often favor government policies that encourage the development of renewable forms of energy (such as solar and wind power), because they believe the era of conventional fossil fuel use is ending.

Other analysts dispute the peak oil theory and blame government regulations for hampering the growth in supply to meet the growing worldwide demand for energy. According to this view, production of oil (as well as other fossil fuels) would grow significantly if the U.S. federal government lifted restrictions on energy companies for the development of the Arctic National Wildlife Refuge (ANWR) and offshore areas.

Optimists for the future of fossil fuels also argue that it only makes economic sense to look for additional reserves when the relative supply begins to dwindle. For example, in the early twentieth century, many official forecasts declared that the United States would soon run out of oil, based on known reserves at the time and the rate of oil consumption. In retrospect, these warnings were unfounded, because the oil industry explored and found new deposits as the older ones diminished. Some analysts believe the same will prove true regarding more modern warnings and that fossil fuels will continue to be an economical source of energy for decades into the future.

The role of the Organization of Petroleum Exporting Countries (OPEC) in the world oil and natural gas markets affects the treatment of fossil fuel reserve estimates. Many critics of OPEC argue that the lack of transparency applicable to national oil companies—in contrast to Western-based, private companies owned by shareholders—casts doubt upon the official reserve estimates of nations such as Saudi Arabia. For example, many analysts worry that the ministers of Saudi Arabia's vast deposits exaggerate the nation's reserves in an effort to keep the world complacent with its dependence on conventional fuels.

Robert P. Murphy

• Further Reading

BP. *BP Statistical Review of World Energy, June, 2007.* London, England: Author, 2007. This annual summary, which draws on many primary sources, is a standard reference in the industry. Tables, charts.

Bradley, Robert, Jr., and Richard Fulmer. *Energy: The Master Resource.* Dubuque, Iowa: Kendall/Hunt, 2004. Bradley and Fulmer apply Julian Simon's view of the powers of the creative human mind to the area of nonrenewable resources. They offer a strong case for optimism over conventional energy supplies, which could last for centuries if no other option appeared preferable in the meantime. Tables, charts.

Simmons, Matthew. *Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy.* Hoboken, N.J.: John Wiley & Sons, 2005. Simmons is one of the leading proponents of peak oil theory. His presentations to the layperson stress the implausibility of official estimates of Saudi oil reserves.

See also: Biofuels; Clean energy; Coal; Energy resources; Fossil fuel emissions; Fossil fuels; Fuels, alternative; Gasoline prices; Hubbert's peak; Oil industry; Organization of Petroleum Exporting Countries; Renewable energy; U.S. energy policy.

Fossil fuels

- **Category:** Energy

The coal-burning steam engine stimulated the Industrial Revolution, leading to the nineteenth century's vast commercial productivity. The invention of affordable automobiles in the twentieth century created a huge market for oil, which became America's dominant energy source. When a fossil fuel is burned, its emissions include CO_2, the main anthropogenic contributor to global warming.

• Key concepts

fossil fuel: any combustible deposit of carbon of biological origin created over millions of years of geologic history

kerogen: complex compounds with large molecules consisting of carbon, hydrogen, oxygen, nitrogen, and sulfur

methane hydrates: small bubbles of natural gas trapped in a crystalline ice matrix

oil shale: a fine-grained sedimentary rock rich in kerogen

tar sands: sands containing highly viscous asphalt-like oil that can be extracted by mixing the sands with hot water or steam

• Background

Fossil fuels store the chemical energy created over hundreds of millions of years as accumulated layers of plant and animal remains were subjected to heat and pressure. These organic residues transformed into coal beds, pools of oil, and pockets of gas. They include coal, oil, natural gas, oil shale, and tar sands. Since these fuels are no longer being created, they are nonrenewable resources. Equally important, when burned, the carbon unites with oxygen in the atmosphere to produce carbon dioxide (CO_2), the main culprit responsible for anthropogenic global warming.

People search a cinder dump in Changzhi, China, for bits of usable coal. (Reuters/Landov)

• Coal

Coal is fossilized plant material, deposited 300 million years ago when Earth was warmer and wetter. Preserved and altered by geological forces over eons of time, this material was compacted into carbon-rich fuel.

Coal mining is dirty and dangerous, because underground mines are subject to cave-ins, accumulations of carbon monoxide, and fires caused by explosive gases such as methane. In the United States alone, tens of thousands of miners have died in accidents over the past century, and even more have died or been disabled by respiratory diseases caused by the accumulation of fine dust particles in the lungs. Although strip mining is a safer and less expensive alternative, the land remaining after the overburden is removed is rendered unfit for any other use. Restoration and reclamation are now mandated by U.S. law, but the efforts expended by mining companies are often superficial and ineffective. Coal mining also contributes to water pollution, because sulfur and other soluble minerals in mine drainage and runoff from mine tailing are acidic and highly toxic.

Coal burning releases, in addition to CO_2, many toxic metals and radioactive elements formed into gaseous compounds. Coal combustion is responsible for about 25 percent of all atmospheric mercury pollution in the United States.

• Oil, Oil Shale, and Tar Sands

Oil is formed from phytoplankton, microorganisms that lived in warm, shallow seas hundreds of million of years ago. When they died, they sank to the bottom and were buried in sediments. Over eons of time heat from the Earth and the pressure of overlying layers of sedimentary rocks transformed this into kerogen deposits containing a mixture of oil, gas, and solid tarlike substances.

Drilling for oil leads to environmental degradation at the drill site, but even more problematic are water pollution due to leaks during transportation and the major oil spills caused by accidents. Such accidents have been known to contaminate shorelines and estuaries, fouling beaches and murdering waterfowl and aquatic life.

Oil shale and tar sands are unconventional resources with a large potential if they can be recovered with reasonable social, economic, and environmental costs. Western Canada has an estimated 270 billion cubic meters of tar sands from which liquid petroleum can be extracted, but the process is expensive and the environmental problems severe. A typical site yielding 125,000 barrels daily leaves 15 million cubic meters of toxic sludge and contaminates billions of liters of water each year.

Vast deposits of oil shale, rich in kerogen, are located in the United States' intermountain west. When heated to about 482° Celsius, the kerogen liquefies and can be separated from the stone. If the deposits could be extracted at a reasonable price and with acceptable environmental impact, the amount would be the equivalent of several trillion barrels of oil. The mining and extraction requires huge amounts of water (a scarcity in the west), creates air pollution, contaminates water, and leaves mountains of loose, rocky waste.

• Natural Gas

After oil and coal, natural gas is the world's third largest commercial fuel, accounting for 24 percent of global consumption. It is also the most rapidly increasing fossil fuel energy source because it is convenient, inexpensive, and cleaner burning than coal or oil. When combusted it releases half the CO_2 as an equivalent amount of coal; substituting gas for coal thus helps reduce global warming. Although it is difficult to ship across oceans, the U.S. has an abundant easily available supply and the pipelines to transport it from source to end user. Natural gas, often released when oil is extracted, is burned off when no easy mechanism exists to deliver it to a user. Although transportation is problematic for some recoverable natural gas deposits, the world resources are estimated to be about 300 trillion cubic meters, a sixty-year supply at current rates of use.

An unconventional and as yet untapped source of natural gas is the methane hydrate deposits located in arctic permafrost and beneath deep ocean sediments. At least fifty ocean deposits and a dozen land deposits, containing about 9 trillion metric tons of methane, are known to exist. This is twice the combined amount of all coal, oil and natural gas reserves. Although this is a possible future energy source, the complex technologies required to extract, store, and ship the methane hydrates are formidable.

• Context

Fossil fuels promoted the Industrial Revolution, increased industrial productivity, contributed to capitalizing industry and farming, and still provide 85 percent of the world's energy. These resources, however, are nonrenewable; eventually the production rate will decline to the point where it is no longer economically feasible to extract the remaining fuel. When a production peak occurs and decline begins, about half of the total resource has been recovered. Assuming a modest 1 percent or 2 percent annual increase in consumption, the number of years remaining until production peaks for the three main fossil fuels is hundreds of years for coal, up to sixty years for natural gas, and no more than forty years for oil. Given the eminent end of fossil fuel dependence, the contamination of air and water caused by their extraction and combustion, and the hazards posed by global warming, alternate renewable resources must be developed and incorporated into the energy mix expeditiously.

George R. Plitnik

- **Further Reading**

Berkowitz, Norbert. *Fossil Hydrocarbons.* San Diego, Calif.: Academic Press, 1997. Exposition of all major fossil fuels, including their composition, chemical properties, processing requirements, environmental aspects, and conversion technologies.

Hinrichs, Roger. *Energy: Its Use and the Environment.* 2d ed. New York: Saunders, 1996. An introductory text that explains the physical principles involved in energy use and its effects on the biosphere.

Jaccard, Mark. *Sustainable Fossil Fuels.* New York: Cambridge University Press, 2006. Presents the unusual hypothesis that, if means can be developed efficiently to extract energy from fossil fuels without harming the biosphere, fossil fuels can continue to provide energy almost indefinitely.

See also: Biofuels; Clean energy; Coal; Energy resources; Ethanol; Fossil fuel emissions; Fossil fuel reserves; Gasoline prices; Hubbert's peak; Oil industry; Renewable energy.

France

- **Category:** Nations and peoples
- **Key facts**

Population: Metropolitan France: 62,150,775; total population, including overseas departments: 64,057,792 (July, 2008)

Area: Metropolitan France: 547,030 square kilometers; total area, including overseas departments: 643,427 square kilometers

Gross domestic product (GDP): $2.067 trillion (purchasing power parity, 2007 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 566.4 in 1990; 559.9 in 2000; 546.5 in 2006

Kyoto Protocol status: Ratified, May 31, 2002

- **History and Political Context**

Charlemagne (742-814) united the Frankish kingdoms and ushered in a mini-renaissance, encouraging education and the arts. After Charlemagne, France remained only nominally unified under titular kings who held little power compared to local princes such as William the Conqueror. France was eventually united under strong centralized leadership by Louis IX (1214-1270). For the next five hundred years, the country was periodically torn by internal religious conflict, as well as being threatened by foreign powers including England, Spain, and Germany. Nevertheless, France was a major contributor to the Age of Enlightenment of the sixteenth and seventeenth centuries.

In the 1700's, an egalitarian and humanistic movement culminated in the French Revolution (1789-1794), which became a dominating theme in French thought and government. In 1871, the last remnants of the monarchies disappeared, and the government became a republican parliamentary democracy. The government survived many parliamentary crises from 1871 to 1958—a period that encompassed two world wars. In 1958, Charles de Gaulle assumed power under a new constitution that included a strong presidency. This structure stabilized the government and allowed France to concentrate on its goals of fostering a strong and united Europe, as well as encouraging innovation in the arts and sciences. In 1992, France signed the Maastricht Treaty, which created the European Union. Since that time, France has worked to balance its own national interests with increased involvement in agencies and projects intended to unify and centralize Eastern and Western Europe.

- **Impact of French Policies on Climate Change**

French environmental ideology has two fundamental roots: a devotion to intellectual innovation and a profound appreciation for the natural world. France has been the initiator or advocate of the creation of European environmental agencies beginning in 1948 with the International Union for Conservation of Nature. France was a driving force behind the Kyoto Protocol, galvanizing the 1997 conference and increasing the number of signatory nations. France has signed 130 European and worldwide agreements focused on the environment.

In February, 2005, France ratified the Charter

for the Environment and added it to the preamble of the French constitution, thus assigning environmental rights and responsibilities an importance equal to that of civil liberties and economic and social rights. The charter's ten articles include assertions that declare individuals must participate in conservation, that promote sustainable development, and that ensure the public is educated about environmental concerns. Article 5 supports the controversial precautionary principle, which states that action may be taken regarding an environmental issue even if there is disagreement in the scientific community over the severity of the problem or the best way to address it.

In addition to the charter, in 2004 France instituted a climate plan more aggressive than the Kyoto Protocol, with the goal of reducing carbon dioxide (CO_2) emissions by 54 million metric tons by 2010. This plan includes procedures to effect change at every level of French society, from large corporations to individual citizens. For both industry and consumers, those who choose lower emission technologies receive rebates, bonuses, or price reductions. Those who do not choose such technologies must pay additional fees or taxes or face punitive legal action. Examples include a measure to mitigate property taxes for energy-efficient buildings and an initiative to increase the use of biofuels. The French climate plan also includes funding for public education.

• France as a GHG Emitter

According to data reported to the Climate Change Secretariat of the United Nations, the total amount of CO_2 emitted by France in 1990—the benchmark year to which levels were to be reduced—was 395.6 billion metric tons. Ten years later, the amount was 406.1 billion metric tons, an increase of 2.6 percent. In 2006, the amount was 408.7 billion metric tons, an increase from 1990 of 3.3 percent. However, all other greenhouse gas (GHG) emissions, including those of methane and hydrofluorocarbons (HFCs), have decreased 19 percent from 1990 to 2006. Thus, from 1990 to 2006, total French GHG emissions decreased by 3.5 percent.

Even with this decrease, unless more stringent controls are implemented, France will miss its Kyoto Protocol target of an 8 percent decrease in 2012 from 1990 levels. The French reliance on nuclear power—the last coal mine in France was closed in 2004—has contributed to lowering the rate of increase of CO_2 emissions, but the remaining increases, small as they are, are still troubling. One of the more difficult sectors to control is transportation, which is responsible for 26 percent of the increase in France's CO_2 emissions. The second-largest contributor to the increase is home heating, at 12 percent.

• Summary and Foresight

The French desire to show leadership in environmental concerns seems to clash with the nation's ambition to also be a technologically advanced society. This has led France to attempt to integrate policies that are pro-environment with those that encourage technological competition and innovation. The French people favor measures such as green belts within industrial areas and the high-speed *train à grande vitesse* (TGV), a train that provides low-emission, energy-efficient transportation. The French citizenry seems willing to tolerate taxes and fees on ecologically unfriendly consumer goods, although occasionally there is strong opposition, as there was to a so-called "picnic tax," a tax on disposable items such as plates and tableware. The government provides incentives as well as fees, including a rebate of as much as $7,000 on cars that are particularly fuel efficient.

Although it appears that France is making great strides in improving air quality, some issues remain troubling. GHG emissions increased late in the first decade of the twenty-first century, in spite of controls and fines, and a worldwide recession generated pressure on the government to repeal or mitigate some previously established limits on GHG emissions. France was particularly concerned that some countries that were under extreme economic pressures or burdened with Soviet-era industries and power plants might rebel against EU agreements on limiting emissions. In an attempt to keep international accords from disintegrating, France has softened its stance on upholding those limits, and in 2008 it used its occupancy of the presidency of the European Union to mediate among EU member nations when conflicts arose over emissions standards and related issues.

Kathryn Rowberg and Gail Rampke

• Further Reading

Bess, Michael. *The Light-Green Society: Ecology and Technological Modernity in France.* Chicago: University of Chicago Press, 2004. This award-winning book explores the conflict and eventual mediation between French beliefs in the sanctity of nature and what Bess calls "technological Darwinism"—a determination that France will not be left behind as technology advances.

International Energy Agency. *Energy Security and Climate Policy: Assessing Interactions.* Paris: Author, 2007. Close study of the relationship between the pursuit of national energy security and attempts to mitigate global warming in five example nations, one of which is France.

Prendiville, Brendan. *Environmental Politics in France.* Boulder, Colo.: Westview Press, 1994. Thorough examination of the influence of the "Green Movement" on French politics for the watershed years of 1970 through 1996.

See also: Europe and the European Union; International agreements and cooperation; Kyoto Protocol; Precautionary approach; United Nations Framework Convention on Climate Change.

Fraser Institute

- **Category:** Organizations and agencies
- **Date:** Established 1974
- **Web address:** http://www.fraserinstitute.org

• Mission

Based in Canada and grounded in conservative and libertarian philosophies, the independent economic and social research and education organization the Fraser Institute espouses free market principles. This think tank is highly critical of scientific claims that support human contributions to global warming. It focuses on advocating for freedom and competitive markets and on opposing public policy solutions such as spending, taxation, and regulation for economic problems.

• Significance for Climate Change

The Fraser Institute seeks to illustrates how complex economic problems should and can be solved with innovative market solutions. The institute was established by a group of academics and business executives in order to study the impact of markets and government interventions on individuals and society. Membership includes high-profile figures and individuals from a wide range of backgrounds such as Michael Walker, an economist from the University of Western Ontario; former Reform Party leader Preston Manning; former Ontario Conservative premier Michael Harris; and Barbara Amiel, wife of columnist Conrad Black. The institute is highly critical of some widely accepted scientific evidence on climate change. Its February 1, 2007, publication titled *The Independent Summary for Policymakers: IPCC Fourth Assessment Report*, links directly to discussions included in the U.N. Intergovernmental Panel on Climate Change (IPCC) draft report.

The institute seeks to rebut popular scientific views on climate change by pointing to various studies. The basis of its claim includes data collected by weather satellites indicating that no significant warming is occurring in the tropical troposphere (the portion of the atmosphere that accounts for half of the world's atmosphere), as well as a lack of global-warming-related perturbations in long-term precipitation trends, total snow-covered area, snow depth, or arctic sea ice thickness. The institute also argues that considerable natural climatic variation exists and that greenhouse gas emissions cannot be correlated to climate change. Finally, it asserts that computer simulations tend to be inherently uncertain and inaccurate at the regional level.

The Fraser Institute has published information dedicated to specific countries. In *A Breath of Fresh Air: The State of Environmental Policy in Canada* (2008), the Fraser Institute addresses Canadians' concern for the environment and frustration with costly and intrusive environmental policies. The book outlines several market-based environmental policy solutions geared to improve the state of the environment and includes chapters dedicated to the discussion of air-pollution policy; water, forests, and fisheries management; and waste and recycling systems in Canada.

Rena Christina Tabata

See also: Canada; Conservatism; Libertarianism; Skeptics.

Freshwater

- **Category:** Water resources

Freshwater is essential to support human life and Earth's biodiversity. Freshwater resources are under pressure from climate change and other sources, so policy makers must understand how climate affects freshwater and the importance of water resources.

Key concepts

base flow: the portion of stream flow that comes from groundwater
drainage basin: an area bounded by a continuous and topographically higher divide where water from precipitation drains downhill into a body of water
evaporation: the process by which water changes from liquid to vapor
evapotranspiration: the sum of evaporation and transpiration
groundwater: water stored beneath the land's surface
hydrologic cycle: the continuous circulation of solid, liquid, and gaseous water among the oceans, atmosphere, and continents
precipitation: the condensation of atmospheric water vapor that deposits hail, mist, rain, sleet, or snow on the Earth's surface
surface runoff: water from precipitation that flows over land surfaces to bodies of water
surface water: water found on land in such bodies as ponds, lakes, streams, rivers, wetlands, and inland seas
transpiration: the process through which water evaporates from the aerial parts of plants, especially leaves

Background

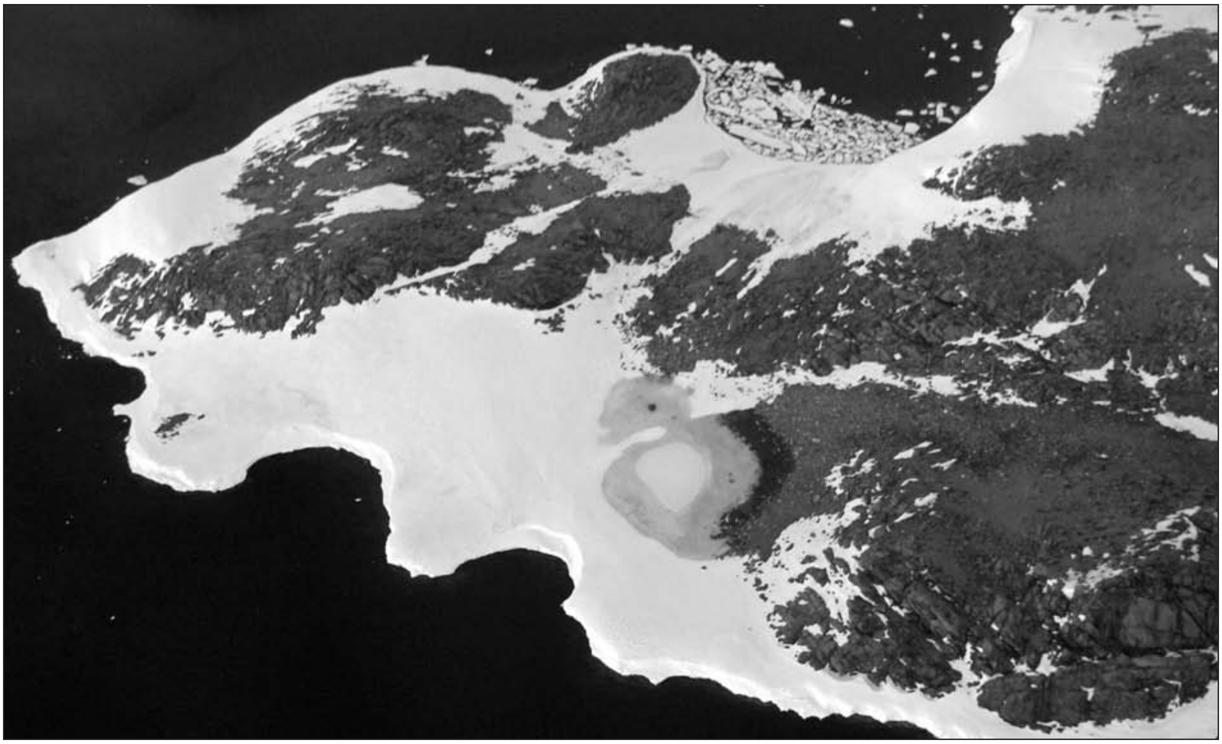
Freshwater is water that contains low concentrations of dissolved solids, such as salts. Water containing less than 1 gram per liter of dissolved solids is considered fresh, whereas water containing more than 1 gram per liter of such solids is saline. Ocean water has a salinity of approximately 35,000 parts per million. Some 97.2 percent of the total volume of the Earth's water is seawater. The majority of the Earth's freshwater is sequestered in glaciers. More than 98 percent of available freshwater is groundwater, and less than 2 percent of available freshwater is in lakes, running water, and wetlands.

Freshwater and the Hydrologic Cycle

Freshwater storage and migration are essential components of the Earth's hydrologic cycle. The ocean receives less water through precipitation than it loses through evaporation. Earth's land surface receives more water through precipitation than it loses through evapotranspiration. Surface runoff and base flow of freshwater from the land surface to the ocean are critical to maintain the balance of the hydrologic cycle, preserving sea levels and preventing permanent surface flooding.

Human Reliance on Surface Water

Even though most freshwater exists as groundwater and glacier ice, surface water—such as running water and lakes—is more important to human life, because it is readily accessible. In ancient culture, fresh surface water was mainly used as drinking water. With the development of civilization, more



A lake of freshwater forms from the melting snow of the Antarctic Budd Coast. Most of Earth's freshwater is sequestered in glaciers. (Reuters/Landov)

and more surface water was used for irrigation and industry. Water usage in modern society varies among nations. Water resources in developing countries are mainly employed for irrigation and municipal uses. On the other hand, developed countries use most of their water for industry.

Water use by households, businesses, and communities is classified as municipal water use. Basic municipal water use includes drinking, washing, bathing, cooking, and sanitation. In addition, municipal water is used—especially in developed nations—for swimming pools, recreational parks, firefighting, street and car washing, and gardening. The largest use of surface water worldwide is for agriculture. Because of the increasing demand for water to grow crops, most of agricultural water use is for irrigation, or the controlled application of water to foster crop growth. As the human population grows, greater quantities and more efficient use of freshwater is necessary to meet the increasing demand for food. In addition, since the Industrial Revolution water has been used to drive almost every aspect of industry, including mining, automobile and other manufacturing, and energy production.

• Impact of Climate Change on Rivers, Streams, and Lakes

Any climate change, and particularly global warming, will have a significant impact on the Earth's freshwater supply. However, the precise effect of increasing temperatures on the water supply is uncertain. Higher air temperatures can generate more precipitation, but they also increase evaporation. More precipitation and improved plant water-use efficiency due to increased atmospheric carbon dioxide (CO_2) would increase water supply. However, more precipitation and warmer temperatures could potentially extend the growing season of plants, which could result in greater transpiration and reduce water supply. The net effect of increasing temperature on water supply is thus unclear, especially on a global scale.

Studies have revealed other potential sources of dramatic climate-change-related impact on surface freshwater. Shrinking alpine glaciers would significantly reduce water supplies for many rivers and streams that originate from melting snow and glaciers while simultaneously releasing excess floods of water into glacial lakes. Even the world's largest freshwater lake, Lake Baikal, responds strongly to the Earth's warming temperature.

- **Context**

The availability of surface water varies among continents and countries. Today, more than 1 billion people lack access to safe drinking water. Approximately two-thirds of the world's population will be living in water-stressed areas by 2025, if no serious actions are taken to control climate change, water pollution, and water usage. Climate change has a significant impact on surface water resources. Globally, many policies have been established to reduce greenhouse gas emissions and promote the usage of renewable or alternative energy. However, a significant amount of water has been used to produce energy, and energy has been increasingly used to process water. With the pressure of population growth and limited energy and water resources, all governments and communities need to work together to develop a plan to integrate water and energy policy making. Communities and individuals need to conserve water and energy resources, and they must control pollution and mitigate climate change to ensure safe access to freshwater in the future.

Yongli Gao

- **Further Reading**

Barnett, T. P., J. C. Adam, and D. P. Lettenmaier. "Potential Impacts of a Warming Climate on Water Availability in Snow-Dominated Regions." *Nature* 438 (2005): 303-309. Report of a research team led by Timothy Barnett at the Scripps Institution of Oceanography on the impact of climate change on snow-dominated runoff. Demonstrates that the Earth's warming temperature is likely to disrupt freshwater resources in regions that rely on snowmelt for water supply.

Cyranoski, David. "Climate Change: The Long-Range Forecast." *Nature* 438 (2005): 275-276. *Nature*'s Asia-Pacific correspondent explains how melting glaciers are threatening the livelihoods of millions of people in the Tibetan Plateau.

Hampton, S., et al. "Sixty Years of Environmental Change in the World's Largest Freshwater Lake—Lake Baikal, Siberia." *Global Change Biology* 14 (2008): 1947-1958. Details the effect of global warming on the world's largest freshwater lake.

Milly, P. C. D., K. A. Dunne, and A. V. Vecchia. "Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate." *Nature* 438 (2005): 347-350. U.S. Geological Survey researchers compare the results of twelve climate models to project future annual stream flows worldwide.

Thomson, A. M., et al. "Climate Change Impacts for the Conterminous USA: An Integrated Assessment. Part 4—Water Resources." *Climatic Change* 69, no. 1 (2005): 67-88. Applies a suite of twelve potential climate change scenarios that could occur over the next century to simulate alterations to water supply in the coterminous United States.

Webber, M. E. "Catch-22: Water vs. Energy, September, 2008." *Scientific American Earth 3.0* 18, no. 4 (2008). A leading expert on the integrated study of water and energy explains the mutual dependencies between water and energy and advocates a government plan for integrated water and energy policy making.

See also: Desalination of seawater; Groundwater; Hydrologic cycle; Water quality; Water resources, global; Water resources, North American; Water rights.

Friends of Science Society

- **Category:** Organizations and agencies
- **Date:** Established 2002
- **Web address:** http://www.friendsofscience.org

- **Mission**

An independent, education-based, nonprofit organization that provides regular scientific and factual commentary on the causes and impacts of climate change, the Friends of Science Society aims

> to encourage and assist the Canadian Federal Government to re-evaluate the Kyoto Protocol by engaging in a national public debate on the scientific merit of Kyoto and the global warming issue, and to educate the public through dissemination of relevant, balanced and objective technical information on this subject.

The organization, through its Internet Web site, offers "critical evidence that challenges the premises of [the] Kyoto [Protocol]" and highlights alternative causes of global climate change.

The Friends of Science Society is run by volunteers comprising mainly active and retired Earth and atmospheric scientists, engineers, and other professionals concerned about the abuse of science displayed in some of the interpretations of the Intergovernmental Panel on Climate Change and the politically inspired Kyoto Protocol. The organization uses a scientific advisory board made up of international climate scientists from around the world to "offer a critical mass of current science on global climate and climate change to policy makers, as well as any other interested parties." On its Web site, the organization declares "We do not represent any industry group, and operate on an extremely limited budget. Our operational funds are derived from membership dues and donations."

• Significance for Climate Change

The stated objectives of the Friends of Science Society are to "work to educate the public through the dissemination of relevant, balanced and objective information on Climate Change, and to support real environmental solutions" and "to spark a national and international debate on global warming." Members as well as non-members conduct literature research on scientific subjects related to global warming, the results of which are communicated to the public via its Web site and by means of newsletters.

The organization's major environmental concern is the significant shift in recent years away from the important emphasis of previous decades on continual reductions in air and water pollution, to focus almost exclusively on global warming. It claims climate fluctuations are natural phenomena and suggests that adaptation should be emphasized rather than misguided attempts at control. Substantial funds could be saved or deployed toward more urgent needs of humanity.

C R de Freitas

See also: Level of scientific understanding; Pseudoscience and junk science; Scientific credentials; Scientific proof; Skeptics.

Friends of the Earth

- **Categories:** Organizations and agencies; environmentalism, conservation, and ecosystems
- **Date:** Established 1969
- **Web address:** http://www.foe.org/

• Mission

Founded in San Francisco by David Brower, Friends of the Earth (FoE) is a volunteer organization that raises public awareness about activities environmentally destructive to the Earth's climate and that initiates legal action to address threats from global warming. FoE is affiliated with grassroots activist organizations in more than seventy countries that together form Friends of the Earth International.

FoE has been involved in previous initiatives against environmentally destructive activities and technologies including campaigns to stop construction of the Trans-Alaskan Pipeline and efforts to limit the growth of nuclear power. During the mid-1980's, FoE initiated a media campaign against products harmful to Earth's ozone layer such as air conditioning coolants and aerosols that contained chlorofluorocarbons. FoE has also worked to increase public awareness about human activities contributing to global warming. FoE advocates conservation, improvements in energy efficiency, and sustainable and environmentally friendly sources of alternative energy. In addition to pushing for corporate responsibility and accountability, FoE has called for changes in public policy and has taken direct action through lawsuits filed against large polluters and government regulatory agencies.

• Significance for Climate Change

As a part of its campaign to raise awareness about climate change, FoE has publicized research showing evidence of a 30 percent increase in atmospheric carbon dioxide (CO_2) over the past two hundred years and predicting increases in average surface temperature of 1.4° to 5.8° Celsius by the year 2100. FoE notes that increasing global temperatures contribute to the melting of glaciers and permafrost, rising sea levels, severe flooding, heat waves, and damaging weather, all of which have disproportionate impacts on persons in developing countries. In September, 2007, FoE and thirty other organizations submitted a letter to the U.S. Congress urging its members to provide assistance to developing countries coping with global warming.

In pushing for corporate responsibility, FoE notes that many companies underreport the climate-related impacts of business ventures. To address this issue, FoE has increased pressure on automobile makers, petrochemical corporations, and electric utilities to provide information to customers and shareholders about climate-related risks associated with their activities. Under pressure from environmental groups such as FoE, the Ford Motor Corporation announced in 2005 that it would increase output of hybrid vehicles to 250,000 annually by 2010.

In addition to influencing public opinion, FoE has taken direct action to address public policies on climate change. FoE notes that industrialized countries are largely responsible for greenhouse gas (GHG) emissions that contribute to global warming. Therefore, FoE believes that these countries must take immediate and aggressive steps to reduce their carbon emissions. Among industrialized nations, Japan, the United States, Canada, and New Zealand are most resistant to implementing policies to address the problem of climate change. With about 4 percent of the world's population, the United States is responsible for 25 percent of GHG emissions. FoE maintains that a country's production of GHGs should be tied to its population and that developing countries should not be required to sacrifice economic growth by having to institute the same reductions in emissions as industrialized countries.

In 2005, FoE filed a lawsuit in U.S. federal court to require enforcement of standards for CO_2 emissions. Working in conjunction with other environmental organizations and twelve state and local governments, FoE helped win a 2007 Supreme Court ruling that required the U.S. Environmental Protection Agency to regulate GHGs emitted by automobiles. FoE has also worked to demonstrate problems in proposed climate legislation such as the Lieberman-Warner Climate Security Bill (introduced in 2007). According to FoE, the bill fails to penalize companies that pollute and ignores recommendations made by leading scientists on ways to address global warming. In addition, FoE argues that the Lieberman-Warner Climate Security Bill's proposed targets for emissions are inadequate. Instead of endorsing the provision of pollution permits to corporations at no charge, FoE advocates the sale of such permits, with revenues used to support clean sources of energy such as wind, solar, and geothermal power.

FoE argues against increased production of biofuels and the expansion of nuclear power facilities to address the global warming crisis. It notes that growing reliance on biofuels such as corn ethanol may encourage the destruction of forests and can lead to higher food prices. Nuclear power is not viewed as a viable solution, because it remains a dangerous source of energy and produces large amounts of radioactive waste that will become a burden to future generations.

At the international level, FoE opposes a provision of the Kyoto Protocol allowing countries to meet targets for reductions in carbon emissions using a system that acknowledges benefits of carbon sinks. Carbon sinks include forests and ocean areas that absorb CO_2 produced by the burning of fossil fuels. FoE has pointed out that fast-growing monoculture plantations created as carbon sinks are harmful to biodiversity.

Thomas A. Wikle

• Further Reading

Friends of the Earth. *Climate Change: Voices from Communities Affected by Climate Change*. Washington, D.C.: Author, 2007. Contains testimonials from persons in nine communities impacted by climate change.

_______. *Climate Debt: Making Historical Responsibility Part of the Solution*. Washington, D.C.: Author,

2005. A call for industrialized nations to accept responsibility for past contributions to greenhouse emissions.

Porritt, Jonathan. *Friends of the Earth Hand Book.* London: Macdonald Optima, 1989. Explains how each person can limit his or her impact on the environment.

Smith, Joseph, and David Shearman. *Climate Change Litigation.* Adelaide, S.Aust.: Presidian, 2006. Examines legal issues surrounding climate change including a discussion of environmental advocacy groups.

See also: Biofuels; Carbon dioxide; Environmental movement; Greenhouse gases; Sinks; U.S. legislation.

Fronts

• **Category:** Meteorology and atmospheric sciences

• Definition

A front is a band of low-pressure systems and marks the transition from one weather regime to another. It is typically formed at the boundary of two distinct air masses. In most cases, fronts are associated with a type of large-scale weather system called a midlatitude cyclone, which has a low-pressure center and causes winds to blow cyclonically (that is, in a counterclockwise direction). Midlatitude cyclones are the largest weather systems on Earth and generate most of the winter storms over the midlatitude continents. A front is a part of the midlatitude cyclone system, which trails a band of low-pressure air extending outward from the low-pressure center of the cyclone. Therefore, various weather systems, such as thunderstorms, heavy precipitation, snowstorms, and tornadoes, are also formed along the frontal band.

Different air masses are characterized by different physical properties of atmosphere, such as density, temperature, pressure, winds, and moisture. Because a front is a line that separates two different air masses, the atmosphere exhibits different physical properties on either side of a front. For example, air can change from warm to cold or from cold to warm, winds can blow from northerly to southerly or from westerly to easterly, and air can vary from dry to moist or from moist to dry across the frontal zone. Based on the movement of the frontal band and the temperature and humidity differentials, fronts can be classified as cold fronts, warm fronts, stationary fronts, and occluded fronts.

A cold front is formed when a cold and dry air mass advances and replaces a warm and moist air mass. In this case, the cold and dry air pushes and undercuts the warm and moist air ahead of it. The temperature will generally decrease in an area where a cold front is passing through. Because the cold front will lift the warm and moist air, clouds and precipitation can form at or behind the cold front.

A warm front is formed when a warm and moist air mass advances and replaces a cold and dry air mass. In this case, the warm and moist air pushes and overrides the cold and dry air, and the cold and dry air retreats. The temperature will generally rise in an area where a warm front is passing through. Because of the overriding of warm and moist air over the cold and dry air ahead of it, clouds and precipitation typically form ahead of a warm front.

An occluded front forms when a cold front catches up to and overtakes a warm front. In this case, a warm and moist air sector between the cold and warm fronts disappears, causing a complete convection of warm air in the storm center. This stage marks the full maturity of a midlatitude cyclone. Further dynamic and thermodynamic supports for the storm no longer exist, and the storm will dissipate from this time on.

A stationary front can form when a cold and a warm front move in opposite directions. When they meet, they can be locked in location. The cold and warm air mix together, so that there is no dominant overtake and apparent movement from either warm or cold air. This kind of situation often arises when fronts interact with the surface topography beneath them.

• Significance for Climate Change

Fronts are important weather systems affecting people's daily lives. They mainly occur in middle

A squall line marks the leading edge of a cold front. (NOAA National Weather Service Collection)

latitudes, where large landmasses and dense human populations are located. A midlatitude cyclone, fronts, an upper-level jet stream, and specific storm tracks are all related from one to another and constitute a complete synoptic weather system (a weather system that can be analyzed on a weather map). Thus, a change in one part of the atmospheric environment will result in a change of the entire weather system. Studies show that global warming tends to widen the tropics and extend the troposphere vertically. There are many consequences of these changes. One of them is a poleward shifting of future jet streams. This shift would cause climatologic locations for midlatitude cyclones, fronts, and storm tracks to change accordingly.

The current global warming trend may also suggest a decrease of surface temperature gradient, since many observations and atmospheric model simulations indicate that a larger warming tends to occur in the colder regions. Since the horizontal temperature gradient is the key mechanism for the development of midlatitude cyclones, global warming might decrease the occurrence and intensity of midlatitude cyclones and associated fronts. On the other hand, because global warming tends to increase water content in the atmosphere, midlatitude cyclones may derive more energy from latent heat release and become more violent. There are no definite answers so far for how midlatitude cyclones and fronts are affected by these competing mechanisms.

Finally, frontal dynamics provides an important mechanism to cause convection and to form clouds. Precipitation related to fronts is a major process removing water from the midlatitude atmosphere. A potential change in frontal climatology in a future warm climate, regardless of whether it is an increase or decrease, will result in redistribution of snow and rain, changing the distribution of Earth's hydrosphere, especially in middle and high latitudes.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. One of the most widely used introductory books on atmospheric science; covers a wide range of topics on weather and climate.

Archer, Cristina L., and Ken Caldeira. "Historical Trends in the Jet Streams." *Geophysical Research Lett*ers 35, no. 24 (2008). Reports an investigation of the change of location of the jet stream in response to global warming.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Provides the most authoritative general report on climate change and global warming.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Elementary introductory text that covers a wide range of atmospheric sciences.

Yin, Jeffrey H. "A Consistent Poleward Shift of the

Storm Tracks in Simulation of Twenty-first Century Climate." *Geophysical Research Letters* 32 (2005). Investigates poleward shifting of storm tracks in relation to the jet stream under global warming conditions.

See also: Average weather; Extreme weather events; Hydrosphere; Meteorology; Monsoons; Rainfall patterns; Seasonal changes; Thunderstorms; Tropical storms.

Fuels, alternative

- **Category:** Energy

Alternative fuels are sustainable, nonfossil fuels that do not duplicate the environmental and climatic damage caused by fossil fuels or nuclear power.

• Key concepts

biodiesel: fuel with the chemical structure of fatty acid alkyl esters

biomass: plant and other organic material that can be used as fuel

ethanol: a colorless liquid alcohol with chemical formula C_2H_5OH

molecular hydrogen (H_2): a flammable, colorless, odorless gas

• Background

The world is facing a potential energy crisis due to continuous fossil fuel energy demand and population increase. Pollution from fossil fuels, including carbon dioxide (CO_2) release, affects public health and causes global climate change. One way to solve this problem is to use alternative fuels, which provide renewable energy and generate little or no CO_2. Another reason to switch to alternative fuels is to reduce dependence on foreign oil. Some of the most commonly used alternative fuels are hydrogen, ethanol, biodiesel, and biomass.

• Hydrogen

Molecular hydrogen is an ideal alternative fuel to be used for transportation, since the energy content of hydrogen is three times greater than that of gasoline by weight. It is also virtually nonpolluting and a renewable fuel. Using H_2 as an energy source produces only water; H_2 can be made from water again. A growing number of automobile manufacturers around the world are working on prototype hydrogen-powered vehicles. Only water is emitted from the tailpipe, not greenhouse gases (GHGs). These cars' motors run on electricity generated in fuel cells by chemical reactions between H_2 and oxygen (O_2). Many problems remain to be overcome before hydrogen cars become commercially viable, however.

One of the reasons for the delayed acceptance of H_2 is the difficulty of producing it on a cost-effective and climate-friendly basis. H_2 is obtained mainly from natural gas (methane and propane) via steam reforming. Although this approach is practically attractive, it is not GHG emission free. Molecular hydrogen can also be produced by electrolysis. In this case, electric energy is required to split water into H_2 and O_2. However, the process is not efficient; it requires significant expenditure of energy and purified water. One promising green method of H_2 production is biological: A great number of microorganisms produce H_2 from inorganic materials such as water or from organic materials such as sugar in reactions catalyzed by enzymes. Hydrogen produced by microorganisms is called biohydrogen. There is currently no commercial biohydrogen production process available.

The most attractive hydrogen production method for industrial applications is using photosynthetic microbes. These microorganisms, such as microscopic algae, cyanobacteria, and photosynthetic bacteria, use sunlight as an energy source and water to generate hydrogen. Hydrogen production by photosynthetic microbes holds the promise of generating a renewable hydrogen fuel, because there are large amounts of available sunlight and water. One exciting opportunity, with the potential for near-term practical applications of photosynthetic bacteria, is to use them as catalysts in the dark conversion of carbon monoxide (CO) and H_2O into H_2. This type of process is called a microbial shift reaction. The effluent gas from the experimental shift-reaction apparatus has been directly injected into small fuel cells and shown to be capable of generating enough electricity to power small motors and lamps. CO for use in the shift reaction can be produced by other microorganisms.

- **Ethanol**

Ethanol is an alternative fuel that is mainly produced by microbial fermentation of starch crops (such as corn, wheat, and barley) or sugarcane. In the United States, most ethanol is produced by yeast (fungal) fermentation of sugar from cornstarch. With increasing energy demands and oil prices, ethanol becomes a valuable option as an alternative transportation fuel. In 2005, Congress passed an energy bill that required gasoline sold in the United States to be mixed with ethanol. Nearly all cars can use fuel that is 10 percent ethanol (E10). Blending ethanol with gasoline oxygenates the fuel mixture, which as a result burns more completely and produces fewer harmful CO emissions. However, ethanol has about two-thirds the energy content of gasoline by volume, so vehicles running on an ethanol-gasoline mixture must be refueled more often. Ethanol is also more expensive than gasoline.

Carcinogenic aldehydes such as formaldehyde are produced when ethanol is burned in internal combustion engines. Moreover, an 85 percent/15 percent ethanol/gasoline mix (E85), which is also widely used, requires specially equipped "flexible fuel" engines. Only a fraction of the cars driven in the United States are equipped with such engines. Ethanol produced from cornstarch will help transition smoothly from an oil-based economy to an alternative-fuel-based economy. This transition will help reduce U.S. reliance on foreign oil, but it will not do much to slow global warming, will compete with food sources, and, therefore, does not represent a potential long-term energy solution. Ethanol

Mass Biofuel worker Steve MacDougall loads his truck with soybean-derived biofuel for delivery to home heating customers in Needham, Massachusetts. (Brian Snyder/Reuters/Landov) derived from the cellulosic portion of plants offers a better alternative to cornstarch-based fuel. Cellulosic plant matter is the most plentiful biological material on Earth. Polysaccharides made of sugars can be fermented into ethanol. However, current methods of converting cellulosic material into ethanol are inefficient, so intensive research and development efforts are required.

- **Biodiesel**

Biodiesel is a fuel obtained mainly from vegetable oil, such as soybean oil or restaurant greases. It is produced by transesterification of oils, a simple chemical reaction with alcohol (ethanol or methanol) that is catalyzed by acids or bases (such as sodium hydroxide). Transesterification produces alkyl esters of fatty acids, as well as glycerol. Biodiesel performs similarly to diesel and can be used in unmodified diesel engines of trucks, tractors, and other vehicles. Rudolf Diesel designed his first diesel engine to run on such materials, and he himself used peanut oil to power it. Biodiesel is often blended with petroleum diesel in percentages of 2, 5, or 20 percent biodiesel. It can be used as a pure fuel, but it is not suitable for such use in winter, because it thickens in cold temperatures.

Europe is the world's number one producer of biodiesel, which it generates primarily from canola oil. In the United States, biodiesel comes mainly from soybean plants. Other vegetative oils that have been used in biodiesel production are corn, sunflower, cottonseed, and rapeseed oils.

When petroleum prices increase, there is an increase in crop-based biodiesel production. Even if all crops were used as fuel, however, only a small percentage of petroleum-derived diesel fuels would be replaced. Changing from food crops to fuel crops would lead to serious food shortages and increased poverty. Moreover, production of biodiesel from crops would not significantly reduce GHG emissions so long as crop production is itself driven by burning fossil fuels. Emissions are produced by applying fertilizers to feedstock crops, transporting the feedstock to factories, processing the feedstock into biodiesel, and transporting the biodiesel to its point of use.

From the point of view of global warming, it makes the most sense to produce biodiesel from waste oil, grease, or other noncrop and nonfood sources. Waste vegetable oil is a good choice for biodiesel production, but its availability is problematic. Biodiesel from waste oil can be produced and used only locally. Another possible source for biodiesel production is microscopic algae. Research conducted by the U.S. Department of Energy Aquatic Species Program from the 1970's to the 1990's demonstrated that many species of algae produce sufficient quantities of oil to become economical feedstock for biodiesel production. The oil productivity of many microalgae species greatly exceeds the productivity of the highest-yielding oil crops. Thus, microalgal oil content can exceed 80 percent per cell dry weight, and oil levels of 20-50 percent are quite common.

Algae use oil (lipids) as a storage material. They are species of diatoms, golden algae, haptophates, and some green algae. For example, oil content in species of the green alga *Chlorella* is 28-55 percent. Compared to other crops, these green algae can grow their mass within hours. They can grow everywhere: in oceans, rivers, lakes, the snow of mountaintops, forests, and desert soils, and on rocks. They do not need much for growth, just sunlight, water, CO_2, and small quantities of mineral salts. Because—like plants—they use CO_2 to grow, algae can remove CO_2 from Earth's atmosphere, reducing the concentration of GHGs.

Cropland and potable water are not necessary for microalgae cultivation, since microalgae can grow in wastewater. Industrial production of microalgae has been achieved in open "raceway" ponds of some thousand square meters in size. These systems suffer from severe limitations, such as lack of temperature control, low attainable cellular concentrations, and difficulty in preventing contamination. Some companies concentrate on building algal photobioreactors.

Photobioreactors are named for the fact that light is the essential component for growing algae. They are closed systems comprising an array of transparent tubes or tanks in which microalgae are cultivated and monitored. The main challenge in photobioreactor design is to create a simple, inexpensive, high-cell-density, energy-efficient photobioreactor that is scalable to industrial capabilities. Photobioreactors should also provide the most efficient utilization of solar energy and allow the monitoring of culture purity and basic process parameters.

Photobioreactors can be as simple as plastic bags floating on water or thin PVC tubes allowing deep light penetration. To be used outdoors, such photobioreactors require a cooling system (such as a water sprinkler or heat exchanger) during summer and early fall, and algal cultures must be mixed to achieve uniform illumination of all cells. The future of algal biodiesel is a bright one. Therefore, development of biodiesel from algae is among the most popular energy alternatives.

• Biomass

Plants and algae convert the energy of the Sun and CO_2 into energy, which they store in their biomass. Biomass burning in the form of wood is among the oldest forms of energy used by humans. Using biomass as a fuel source does not result in net CO_2 emissions, since burning biomass will only release the amount of CO_2 it absorbed during plant growth (providing its production and harvesting are sustainable). One example of biomass as a modern alternative energy source is biogas (mainly methane) production by microbial digestion of biological waste material. In India, over one million biogas plants of various capacities have been installed. China has millions of small household digesters, which are used mainly for cooking and lighting.

• Context

Alternative fuels became popular as a result of the oil embargo in the 1970's. Then, when oil prices dropped, alternative energy technologies were removed from the national agenda. As concerns about global warming have increased, however, the interest in alternative fuels has become reignited. Moreover, high oil and natural gas prices have made the need to develop alternative fuels all the more urgent. Alternative fuels under development will help protect the global climate and reduce U.S. reliance on foreign oil. These fuels still require long-term scientific, economical, and political investments, but clean, alternative fuels could become humanity's main energy source by the end of the twenty-first century.

Sergei Arlenovich Markov

• Further Reading

Chisti, Yusuf. "Biodiesel from Microalgae." *Biotechnology Advances* 25 (2007): 294-306. Review on biodiesel generation from microalgae.

Nebel, Bernard J., and Richard T. Wright. *Environmental Science: Towards a Sustainable Future*. Englewood Cliffs, N.J.: Prentice Hall, 2008. Several chapters describe alternative fuels.

Service, Robert F. "The Hydrogen Backlash." *Science* 305, no. 5686 (August 13, 2004): 958-961. Good discussion about future hydrogen economy and the maturity of hydrogen power.

Wald, Matthew L. "Is Ethanol for the Long Haul?" *Scientific American* (January, 2007): 42-49. Comprehensive article about the future of ethanol fuel.

See also: Biofuels; Clean energy; Energy from waste; Energy resources; Ethanol; Fossil fuels; Hydrogen power; Renewable energy; Solar energy; Wind power.

Gaia hypothesis

• **Category:** Environmentalism, conservation, and ecosystems

• **Definition**

In 1979, British atmospheric chemist James E. Lovelock and his collaborator, University of Massachusetts, Amherst, microbiologist Lynn Margulis, postulated that the chemical composition of the Earth's atmosphere and oceans was actively molded and maintained by living organisms on the Earth. Up to this point, scientists assumed that life adapted to the changing terrestrial environment as needed but did not mold the Earth into a life-supporting planet. Lovelock's hypothesis turned this assumption around and asserted that biological organisms not only had actively transformed the Earth into a life-friendly place but also continued to make the Earth a life-friendly planet. Novelist William Golding suggested that Lovelock call his hypothesis the "Gaia hypothesis" in deference to the Greek goddess who gave birth to the gods.

Lovelock went further, describing the Earth and its associated biosphere as one large, living, self-regulating organism. While many scientists ridiculed this characterization as a kind of neopagan, New Age religion, some environmental activists found in it a powerful metaphor. Speaking of the Earth as alive and even sentient provided a strong emotional appeal for environmental causes. Describing environmental degradation as "wounding" the Earth conveyed a strong moral impetus for ecological concerns.

• **Significance for Climate Change**

The Gaia hypothesis proposes that biologically mediated, negative feedback mechanisms contribute to environmental homeostasis and make the environment suitable for life. Perhaps most controversially, the Gaia hypothesis further argues that these negative feedback mechanisms arise by means of neo-Darwinian selection.

The surface temperature of the Earth provides an example of one such mechanism. The global surface temperature has remained relatively constant, even though the energy output of the Sun has increased by 25 to 30 percent since life began on the planet. Temperature regulation results from a decrease in the atmospheric concentration of the greenhouse gas (GHG) carbon dioxide (CO_2). CO_2 reduction is due to bacteria and plants, which metabolize CO_2 into biomass. Furthermore, increased atmospheric CO_2 levels increase plant carbon sequestration and removal of CO_2 from the atmosphere. Increased carbon utilization also increases the number of marine, carbon-utilizing algae called coccolithophores. When coccolithophores die, they release dimethyl sulfide, which nucleates cloud formation. Increased cloud cover, which was initially induced by increased atmospheric CO_2, further cools the Earth. Other life-dependent homeostatic processes are also thought to regulate the composition of Earth's atmosphere and the salinity of the oceans.

Some climate scientists favor the Gaia hypothesis, while others are highly critical of it. Virtually all Earth scientists recognize that living organisms have significant effects on the physical and chemical aspects of the environment. However, biologically mediated feedbacks are not intrinsically homeostatic, since some of them can destabilize the environment and are deleterious to life. For example, increased warming increases respiration rates of soil-based organisms, which increases CO_2 release from soils. Increased soil carbon release increases the greenhouse effect and global warming. This positive feedback system destabilizes the terrestrial environment. Furthermore, genomic studies of plants and animals have failed to reveal Gaian global feedback mechanisms. Likewise, natural selection affects individual organisms and is not a global process. Similarly, natural selection does not act with foresight.

With respect to global climate change, the Earth, according to the Gaia hypothesis, should use a series of feedback mechanisms to regulate global temperatures. Thus, the freezing of the poles covers them with ice, which reflects the rays of the Sun and cools the planet. Likewise, increases in atmospheric CO_2 cause increased marine algal growth, which removes CO_2 and decreases greenhouse warming.

However, human intervention has short-circuited these negative feedback mechanisms. Industrial pollution of the oceans has introduced increased amounts of mercury, which prevents algal growth and destroys the primary means of regulating atmospheric CO_2 levels. Increased CO_2 levels cause increase greenhouse-based heating of the planet, which in turn melts the polar ice caps and decreases the reflectivity of the Earth's surface, further heating the Earth.

In one sense, the Gaia hypothesis is strongly optimistic, since it strongly asserts that the Earth and at least some of its resident life will adapt and survive. However, this optimism does not include humanity, since the environment of the Earth after such dramatic climate change will probably be highly inhospitable to human life.

Michael A. Buratovich

• Further Reading

Lovelock, James. *The Ages of Gaia: A Biography of Our Living Earth.* New York: W. W. Norton, 1995. A second presentation of the Gaia hypothesis that adjusts the theory to several criticisms of the original proposal and is consequently better researched and more nuanced.

_______. *Gaia: A New Look at Life on Earth.* New ed. New York: Oxford University Press, 2000. Lovelock's first book detailing the Gaia hypothesis and several of its consequences.

_______. *The Revenge of Gaia: Earth's Climate Crisis and the Fate of Humanity.* New York: Basic Books, 2007. Human activity has short-circuited many of the negative feedback mechanisms that would normally allow the Earth to adjust to climate changes, and positive feedback mechanisms are in play amplifying global warming. In this book, Lovelock advocates the use of nuclear power to mitigate the effects of human activity.

Margulis, Lynn. *Symbiotic Planet: A New Look at Evolution.* New York: Basic Books, 1999. A renowned Amherst microbiologist discusses the role of endosymbiosis in the evolution of life on Earth and concludes that evolution is sometimes cooperative rather than competitive.

Schneider, Stephen H., et al., eds. *Scientists Debate Gaia: The Next Century.* Cambridge, Mass.: MIT Press, 2008. A fascinating collection of articles by a distinguished group of scientists who debate the merits and problems of the Gaia hypothesis.

See also: Albedo feedback; Carbon dioxide; Carbon dioxide fertilization; Climate feedback; Global surface temperature; Greenhouse effect; Greenhouse gases.

Gasoline prices

• Categories: Fossil fuels; economics, industries, and products

It is unclear what effect climate policy will have on gasoline prices. In order to limit the atmospheric CO_2 concentration, gasoline would most likely have to be made more expensive in order to reduce consumption.

• Key concepts

gasoline: a fuel, refined from oil, that is used to power automobile and other engines

oil embargo: a refusal on the part of oil-producing nations to sell oil to other nations

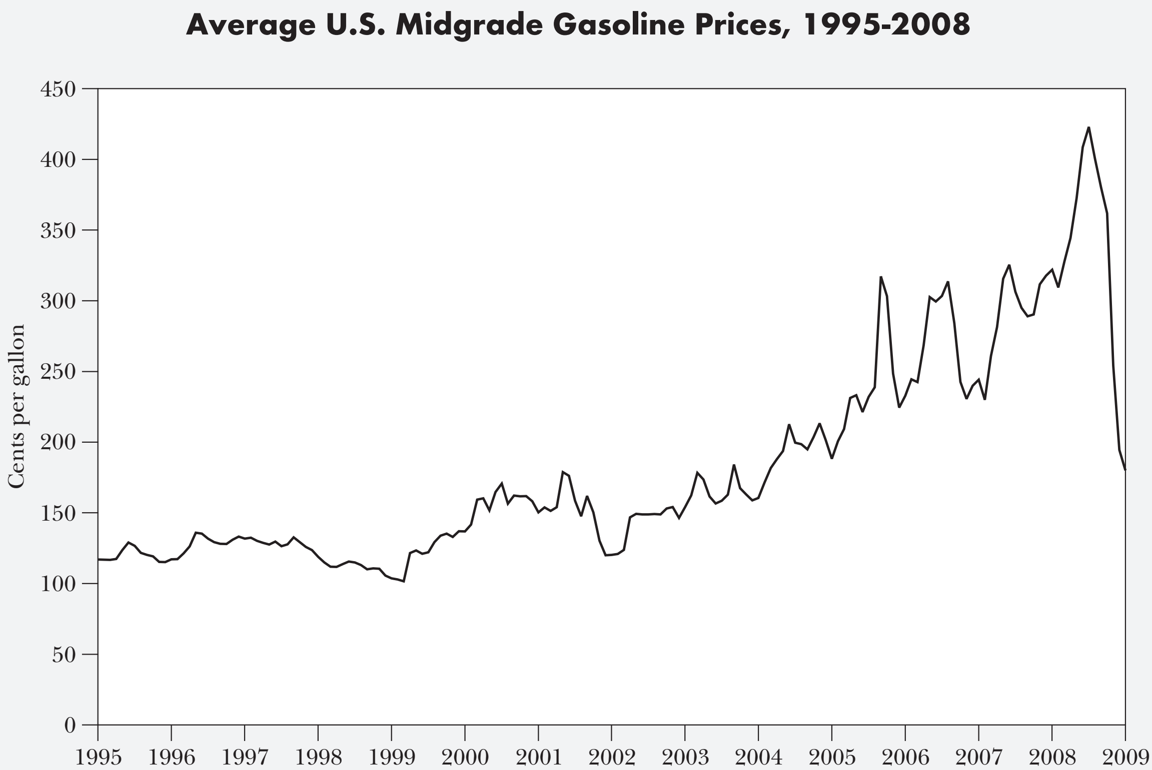
Organization of Petroleum Exporting Countries: group of major oil-producing nations that acts in concert to set oil prices and trade policy

peak oil: the point at which oil availability and production reaches its zenith, before the Earth's oil resources begin either to dwindle or to become prohibitively expensive to exploit

• Background

In the early 1900's, when gasoline was first finding use as an automotive fuel, the inflation-adjusted cost of a gallon of gasoline was approximately $3.00. Save for a temporary rise in fuel prices during World War II, the price of gasoline generally declined from 1919 to 1973, when the price per gallon of regular gasoline stood at $1.20 per gallon.

The post-1973 history of gasoline prices has been considerably more volatile. Prices began trending upward in 1973 in response to an oil embargo by the Organization of Petroleum Exporting Countries (OPEC), with prices peaking at approximately $2.00 in 1982. After that nearly ten-year increase, there was an additional price spike corresponding to unrest in Iran, during the Iranian



Data from U.S. Energy Information Administration.

Revolution, when prices soared above their previous historical high of $3.00 per gallon. Subsequently, prices declined throughout the 1990's, bottoming out at $1.10 per gallon in 1998.

Prices rose sharply after 1998, nearly quadrupling to approximately $4.00 per gallon by June, 2008, then fell once again. Despite the rise in the real cost of gasoline, gasoline expenditure as a share of household income actually declined between 1950, when it was approximately 5 percent, to 4 percent in 2007.

• Effects of the 1973 OPEC Embargo

In 1973, the Arab members of OPEC, as well as Egypt and Syria, stopped shipping oil to Israel and countries that were supporting Israel in the Yom Kippur War (October 6-26, 1973), including the United States, some countries in Western Europe, and Japan. In addition, OPEC reduced the production of crude oil sharply, driving up world oil prices. The world price for a barrel of oil nearly doubled in real terms from 1972 to 1974, with gasoline prices following suit.

Contrary to popular belief, long lines and gasoline shortages in the years of the OPEC embargo were not caused by a shortage of crude oil, which is a fungible commodity traded on a world market. Rather, gas lines and shortages were the result of price controls on gasoline emplaced by President Richard Nixon earlier in 1973, which prevented the rising price signal from reducing demand for refined gasoline.

With the nominal price of oil quadrupling from 1973 to 1974, oil-producing countries significantly increased their revenue, while oil-importing countries, particularly the United States, saw their economies decline. The U.S. economy shrank in 1974 and 1975, and growth in gross domestic product

(GDP) also decreased significantly in Western Europe during that time, hitting negative growth rates in France, Germany, Italy, and other nations.

• Causes and Effects of Price Changes

Major shifts in the price of gasoline have generally corresponded to the level of unrest in the oil-producing countries of the Middle East. Prior to OPEC's emergence in 1960 as an oil cartel, prices were generally kept low by Western-owned oil companies, particularly in Texas.

Changes in the price of gasoline lead to changes in consumer behavior, especially as it relates to automobile selection. After the 1973 oil crisis, American consumers began buying smaller cars, and Congress mandated fleet efficiency standards for American car companies in 1974 that further expanded small car offerings in the U.S. market. By contrast, the period of low gasoline prices in the late 1980's and 1990's allowed consumers to purchase larger vehicles, including pickup trucks and sport-utility vehicles.

High gasoline prices have also spurred governmental and market investment in nongasoline alternatives, such as electric vehicles and vehicles powered with natural gas, propane, and biofuels.

• Peak Oil

The peak oil hypothesis is the idea that because oil is a nonrenewable resource, global oil resources will ultimately be depleted, and oil production will pass its peak and enter a permanent decline. The concept that conventional oil resources are finite is not controversial; the arguments surrounding peak oil relate not to whether but to when oil will peak and what the effects will be. Some believe that oil production has peaked or soon will, and that technology will not progress fast enough to allow people to maintain their standard of living. Others point to significant oil reserves and technological advances that allow development of nonconventional petroleum-based fuels, such as those from tar sands, which may make declining conventional resources potentially less economically damaging.

Several oil companies have commented on when they think oil resources will peak and what the implications will be. Exxon executives have argued that the oil resource base is constantly changing as resources become exploitable via new technology, and the company ran a public relations campaign in 2006 declaring that "[w]ith abundant oil resources still available peak production is nowhere in sight." Other executives and campaigns have been less optimistic. Chevron executives have said that peak oil will happen (that is, oil production will, eventually, be forced to decline permanently), but that event does not need to be a disaster. Still other executives have voiced opinions ranging from the alarmist to the sanguine.

• Climate Change and Global Warming

The burning of fossil fuels is a major producer of carbon dioxide (CO_2), which most scientists believe is a contributor to global climate change. There are two major sets of proposals to mitigate CO_2 emissions: One involves limiting the amount of CO_2 emissions permissible and selling emissions rights; the other involves taxing CO_2 emissions. Both of these strategies, in order to be effective, would have to raise the price of emitting CO_2 emissions significantly, which would also raise the price of gasoline.

It is unclear at this point what effect climate-change-related policy will have on gasoline prices. In order to keep the amount of CO_2 in the atmosphere under levels that many scientists think would be dangerous, gasoline would most likely have to be made more expensive in order to reduce consumption. However, it is unknown whether policies to do so will become widespread. Also, if affordable, carbon-neutral fuels are developed, demand for gasoline (and its price) will likely decline, stimulating consumption.

Kenneth P. Green

• Further Reading

Bryce, Robert. *Gusher of Lies: The Dangerous Delusions of Energy Independence*. New York: PublicAffairs, 2008. Bryce, an energy journalist and editor, examines whether or not calls for energy independence stand up to scrutiny. Systematically breaks down such claims, paying special attention to biofuels, which he argues are little more than a con game.

Deffeyes, Kenneth S. *Beyond Oil: The View from Hubbert's Peak*. New York: Hill and Wang, 2006. Deffeyes, a geologist, is a leading proponent of the idea that oil production is peaking and will soon enter a terminal decline as existing oil fields run dry and large new finds become increasingly scarce.

Green, Kenneth P. "Bringing Down Gas and Oil Prices." *Environmental Policy Outlook* 3 (May, 2006). Short article that discusses why gasoline and oil prices rose to new heights in 2006 and what can be done to bring such prices down.

Huber, Peter W., and Mark P. Mills. *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and Why We Will Never Run Out of Energy.* New York: Basic Books, 2005. Argues that, contrary to those who subscribe to the peak oil theory, the world will not run out of affordable oil, since the steady move toward electrification will reduce demand for oil.

Smil, Vaclav. *Energy at the Crossroads: Global Perspectives and Uncertainties.* Cambridge, Mass.: MIT Press, 2005. Authoritative text on the history of energy use, the challenges attendant on that use, and potential solutions to the environmental impacts of energy use.

See also: Fossil fuel reserves; Fossil fuels; Fuels, alternative; Hubbert's peak; Oil industry; Organization of Petroleum Exporting Countries.

General circulation models

• **Categories:** Meteorology and atmospheric sciences; oceanography; science and technology

• Definition

The dynamics and physics that govern the atmosphere and oceans are the result of many cycles and processes interacting. A general circulation model (GCM) is a collection of mathematical equations that represent these cycles and processes using computational algorithms that can be solved on a supercomputer. In general, the components of the model, such as the atmosphere and ocean, are modeled separately and interact only at their boundaries—for instance, at the interface between the atmosphere and the ocean. GCMs include equations to solve the dynamics (motions) of the atmosphere and ocean, as well as equations and parameterizations to represent atmospheric, oceanic, sea-ice, and terrestrial physics. Processes represented by parameterizations combine equations with proportionality constants, correlations, and table lookups based on observational and experimental data.

In order to be solved on a computer, the equations and variables incorporated in a GCM must be discretized, which is typically accomplished by dividing up the atmosphere and ocean on a grid and defining the key variables such as temperature and humidity at defined points on this grid. Using variable values and the governing and parameterization equations, one can compute new variable values a relatively short time in the future. This integration process is repeated to generate longer time sequences. Validation studies that compare the results of the model computation to experimental and observational data are required to acquire confidence in the accuracy of the simulation.

• Significance for Climate Change

GCMs are the fundamental tools for predicting the future evolution of Earth's climate and the impact that anthropogenic greenhouse gas (GHG) emissions or other environmental effects will have on future temperatures, rainfall, and other climatic conditions. GCMs arose from efforts at numerical weather prediction (NWP). The English mathematician Lewis Fry Richardson is credited with making the first NWP calculation when he attempted to predict the weather six hours into the future during World War I. Because he lacked computers, the calculations took six months to complete, but the basic approach was the same that would be used four decades later in NWP. The first working GCM is attributed to Normal Phillips, who completed a two-layer hemispheric atmospheric model in 1955. The late 1960's and the 1970's saw the introduction of coupled atmosphere-ocean models and the first use of a GCM to study the effects of carbon dioxide (CO_2) and pollutants in the atmosphere. From that point forward, GCMs were recognized as critical components in the study of climate change.

Four-component models (comprising atmosphere, ocean, sea ice, and land) are often referred to as atmosphere-ocean general circulation models (AOGCMs). The highest-resolution AOGCM grids have horizontal spacings of 1° (roughly 100 kilometers) and up to sixty vertical layers in the atmosphere. A typical use of these models takes an average of current conditions as the initial conditions then integrates the GCM computationally through future decades, while different parameters and boundary conditions are changed to account for different scenarios. Based on the results of these computations, the likely range of future temperatures and other future climatic conditions is determined to the extent possible given the accuracy of the model and the related inputs.

GCM simulations are also used to compute the magnitude of anthropogenic versus natural forcing of the environment in order quantitatively to isolate the human contribution to climate change. They are also used to assess the future impact of plans to reduce global GHG emissions. Key statements about global warming, such as the anticipated rise in temperature and sea level and changes in precipitation and storm patterns due to the release of anthropogenic GHGs over the next century, are the product of general circulation models.

Given their importance in the debate over global warming, GCMs are subject to much scrutiny. These models are not complete, with some physical processes generally not implemented in the models and other representations being the source of argument and uncertainty. Critical points of contention include the parameterization of cloud-radiation feedbacks and cloud microphysics, including precipitation; the impact of changes in incoming solar radiation; and the general variability of results when using different GCMs. A notable missing process in most GCMs is an explicit numerical treatment of the carbon cycle, causing most global warming studies to rely on predetermined changes in atmospheric GHG content. Ongoing work to improve modeling of physical processes, achieve higher-resolution simulations on more powerful computing platforms, and increase the use of validation studies will generate the mechanisms by which these concerns will be addressed. Even with their limitations, GCMs remain the primary tool for analyzing the future of Earth's climate.

Raymond P. LeBeau, Jr.

• **Further Reading**

Houghton, John. *Global Warming: The Complete Briefing*. 4th ed. New York: Cambridge University Press, 2009. This overview of global warming by a leading scientist in the field includes an introductory discussion of climate modeling. Figures, references, glossary, index.

Leroux, Marcel. *Global Warming: Myth or Reality? The Erring Ways of Climatology*. New York: Springer, 2005. French climatologist Leroux, a skeptic of current global warming theory, presents criticisms of current general circulation models as part of this text. Figures, bibliography, index.

Randall, David A., ed. *General Circulation Model Development*. San Diego, Calif.: Academic Press, 2000. Collection of papers prepared for the 1998 Retirement Symposium of UCLA professor Akio Arakawa, a leading researcher in the development of GCMs. Figures, references, index.

Randall, David A., et al. "Climate Models and Their Evaluation." In *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Susan Solomon et al. New York: Cambridge University Press, 2007. IPCC assessment of the current state of general circulation models. Figures, tables, references.

See also: Bayesian method; Climate models and modeling; Climate prediction and projection; Ocean-atmosphere coupling; Parameterization.

Geographical information systems

• **Categories:** Geology and geography; science and technology

• **Definition**

A geographical information system (GIS) is, fundamentally, a map that can be queried. It is what a map becomes when computer technology enables users to make individualized choices relating to its mode of representation and the data upon which it is based. In an electronic, digital world, it becomes possible to access, represent, and analyze information in multiple, integrated ways, and geographical information systems bring these options to bear on spatial and related data. Complex relationships and processes occurring in space are thereby subject to display and investigation. GIS makes it easier to discover facts about how large-scale processes, such as weather and climate change, work and to visualize the causal roles of location (both proximity and relative distance). GIS thus serves as an interface between the basic physical sciences, such as physics, chemistry, biology, and geology, and the sciences of human social development. As Lee Chapman and John E. Thornes remark, "the assessment and monitoring of the effects of climate change is truly a multidisciplinary exercise of which GIS provides a pivotal unifying role."

GIS is usually regarded as having six principal components. First, people make and use the system and ask the questions. Second, data are identified as relevant for answering the questions. Third, computer software programs provide for display and analysis of the data. This includes not only GIS software but also databases and programs that permit imaging, drawing, statistical manipulation, and so on. Fourth, computer hardware runs the software. Hardware capabilities affect processing speed, ease of use, and the type of output available. Fifth, procedures define how the information is processed, interpreted, and used. Finally, a network links together all these elements and their real-world applications. The Internet permits GIS applications to draw upon data warehouses of all kinds regardless of their physical location.

Because GIS involves the use of data drawn from many different sources, obtained and organized in many different ways, issues of quality control arise. For this reason, GIS must include information about its information—so-called metadata. Metadata provide answers to the traditional journalist's questions—who, what, where, when, why, and how—and thereby enable users to assess the relevance, reliability, and comparability of different data sets. The manner in which concepts are defined, operationalized, and measured can affect how data are recorded and what the data mean.

• Significance for Climate Change

Geographical information systems play an increasing role in all fields that employ spatial data, including agriculture, ecology, forestry, health and medicine, weather forecasting, hydrology, transportation, urban planning, energy generation and policy, and climatology. By utilizing concepts such as adjacency, area, direction, coincidence, connectivity, containment, direction, length, location, and shape, the properties of geographical entities and their relationships (indeed, any data that can be mapped) can be represented in simplified models by mathematical coordinates. Geographical information systems provide ways of discovering, organizing, and presenting data about past and current climate conditions relevant to such models. These data thus comprise the basis on which competing climate models project possible future climate-change scenarios; they also provide part of the basis for assessing the accuracy of the models.

The planet as a whole can be represented as an integrated series of boxes in a stack of checkerboards, or of layers in an onion, and the data relating to each component can serve as input into mathematical algorithms representing the constraints of physical laws and the operation of natural processes. The results can then be interpreted as showing something about how these data and processes interact to produce the phenomena represented. Representations of aspects of atmosphere, land, and ocean can be combined to model meterological processes in general circulation models. Running such models repeatedly, with different assumptions about inputs and processes, results in different outcomes, and these form the basis for projections about the climate's future. Syukuro Manabe, of the National Oceanic and Atmospheric Administration (NOAA), was a pioneer of such modeling. The Goddard Institute for Space Studies (GISS) also has been a leader in the field, and its head, James E. Hansen, has played a leading role in the debate about global warming.

As geographical information systems and the remote-sensing data they so often rely on play an ever-larger role in understanding the planet's dynamic processes, it is important to remember the many ways in which data can be misleading. Joseph Farman's 1985 discovery of the Antarctic ozone hole can serve as an object lesson in this regard: As related by science journalist Fred Pearce,

> satellites had seen the ozone hole forming and growing over Antarctica all along, even before Farman had spotted it. But the computers on the ground that were analyzing the streams of data had been programmed to throw out any wildly abnormal readings.

Critics of GIS and other modeling technology emphasize the limitations of the climate-modeling process as a basis for reliable long-term climate forecasting. Models must include representations of natural processes that may be understood only approximately, and they must incorporate simplified parameters to stand for complex interactions in large areas of atmosphere, land, and ocean. When models that were originally developed to cover discrete phenomena are integrated, further uncertainties are introduced. Skeptics sometimes even suggest that models are designed in a way that insures desired outputs through the manipulation of parameters.

Proponents of computer modeling, in contrast, view limitations as temporary, representing natural steps in scientific progress, as models are revised in the light of researchers' improved understanding of salient factors. Such proponents often urge, however, that policy makers cannot wait patiently for the modeling process to achieve perfection, since by the time scientists can provide unassailable data, it may be too late for action. Thus, decisions, like computer models themselves, must be based on the best data and procedures available at the time.

Rebecca S. Carrasco

• Further Reading

Chapman, Lee, and John E. Thornes. "The Use of Geographical Information Systems in Climatology and Meteorology." *Progress in Physical Geography* 27, no. 3 (2003): 313-330. A survey of GIS applications in climatology and meteorology; extensive bibliography.

Green, David, and Terry Bossomaier. *Online GIS and Spatial Metadata.* New York: Taylor & Francis, 2002. Discussion of GIS, Web-based technology, and environmental informatics.

Kasianchuk, Peter, and Marnel Taggart, eds. *GIS Education Solutions from ESRI: Introduction to ArcGIS I.* Redlands, Calif.: ESRI Press, 2000-2004. A technical introduction to the use of GIS.

Kolbert, Elizabeth. *Field Notes from a Catastrophe: Man, Nature, and Climate Change.* New York: Bloomsbury, 2006. A popular treatment of the evidence for global warming; provides a good brief account of how climate models work.

Longley, Paul A., et al. *Geographic Information Systems and Science.* 2d ed. Hoboken, N.J.: John Wiley and Sons, 2005. An influential textbook on both GIS and its underlying mechanisms.

Maslin, Mark. *Global Warming: A Very Short Introduction.* New York: Oxford University Press, 2004. A concise introduction to global warming issues, particularly helpful on climate models.

Monmonier, Mark. *How to Lie with Maps.* 2d ed. Chicago: University of Chicago Press, 1996. A basic introduction to the complexities of data representation.

Ormsby, Tim, et al. *Getting to Know ArcGIS Desktop.* Redlands, Calif.: ESRI Press, 2001. An introductory workbook for the Environmental Systems Research Institute's GIS software.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change.* Boston: Beacon Press, 2007. A leading science journalist surveys the scientific case for rapid, rather than gradual, global warming and its alarming consequences.

See also: Climate models and modeling; General circulation models; Manabe, Syukuro.

Geoid

• **Category:** Geology and geography

• Definition

The geoid is a mathematical model of the Earth in which the geoid surface coincides exactly with the average elevation of the surface of the planet's oceans. This model surface is extended over the globe, even through the continents, to form the geoid. This surface is smooth and is defined by mathematical calculations and numerous gravitational measurements. The geoid is a physical representation of the body of the Earth and is different from other representations of the Earth, for example the Earth's reference ellipsoid. Only since the advent of modern geomathematical computing has the geoid been calculated with high precision.

The geoid is sometimes referred to as an equipotential surface, which means that the force of gravity is everywhere the same on the geoid and that the force of gravity is everywhere perpendicular to the surface of the geoid. The form of the geoid is slightly irregular but is everywhere very smooth. The geoid has a history dating to the nineteenth century, when several scientists worked on the problem of computing a mathematical description of the Earth, or computing the shape of the geoid. Since that time, more precise measurements and better means of computing have permitted progressively more precise definitions and understandings of the geoid and its complexity.

For the average person, the geoid's most notable impact on daily life is the precision of handheld and vehicle-mounted global positioning satellite (GPS) receivers. The modern geoid allows these devices to provide extremely accurate physical locations on the Earth's surface, sometimes including elevation. However, there are more applications for the geoid than personal GPS devices, including applications that are related to environmental and climate change. The word "geoid" is the root word for the term "geodesy," which is the study of the shape of the Earth, including ways to describe that shape and practical applications incorporating it.

• Significance for Climate Change

The significance of the geoid for climate change lies in its potential for very precise calculation of elevation and elevation changes on Earth. These precise calculations are made with the aid of GPS systems, which are used to compute elevations in reference to the geoid. These satellites are part of the global navigation satellite system (GNSS) operational around the world. GPS elevation readings are taken in reference to an Earth-centered reference ellipsoid, because satellites orbit about the center of gravity of the Earth. Using corrections, GPS elevations are computed within GPS receivers in reference to the geoid.

Knowing precise elevations is very important in studies of climate and environmental change. For example, measurements of sea-level rise or fall are important in such studies. Also, changes in elevation of ice-covered regions of Earth may help scientists understand the broader range of changes occurring there. The elevation of the surface of the ocean may vary from place to place as a result of changes in the temperature and volume of moving water masses. All these data are useful in assessing the degree, rate, and extent of climate and environmental change on Earth.

The Gravity Recovery and Climate Experiment (GRACE) is a geoid-referencing project that involves two orbiting spacecraft that were launched by the United States in 2002. In addition to detailed measurements of Earth's gravity, GRACE has conducted several environmental and climate-related studies, including studies of the new, rapid melting of the Antarctic ice sheet. The ice sheet is melting at a rate, according to GRACE, that is 75 percent faster than it was at the end of the twentieth century. These results show that Antarctic ice loss rivals the ice loss in Greenland, which was studied and documented by GRACE data in 2006.

GRACE has studied the freshwater storage patterns and human activity of many continental areas on Earth, including China's Yangtze River, Australia, and parts of North America and Africa. In particular, GRACE data show that most continental areas are drying up or losing net stored water, findings that have long-term climatic implications affecting the future of human society. The location and distribution of water on Earth has a profound effect upon the distribution of life.

The more precisely defined the geoid becomes, the more Earth parameters can be measured precisely against it. For example, a more precisely defined geoid will help scientists understand better even very small changes in the elevation of the ocean surface, which can be useful in measuring changes in circulation patterns, tides, and heat transfer in the oceans. A precisely defined geoid is useful for hydrological and glaciological modeling, which in turn provides for enhanced climate modeling and analysis. Geoid definitions are dependent upon time-variable effects, which are an integral part of the definition. Modern geoid approximations are computer models based on numerous complex variables.

David T. King, Jr.

• Further Reading

Hofmann-Wellenhof, Bernhard, and Helmut Moritz. *Physical Geodesy.* 2d ed. Berlin: Springer-Verlag, 2006. Primary textbook in the field of geodesy and the geoid. Very well illustrated with problems and solutions. The second edition contains an updated discussion of the modern geoid definition.

Hooijberg, Maarten. *Geometrical Geodesy: Using Information and Computer Technology.* New York: Springer, 2008. Details both the mathematics and the computer science principles behind geodesy.

National Geodetic Survey. *Geodesy: Imagine the Possibilities.* Washington, D.C.: U.S. Department of Commerce, 2000. A short book that introduces the reader to geodesy and the geoid. Can be downloaded at the National Geodetic Survey Web page at no cost. Discusses various applications now and in the future.

See also: Climate models and modeling; Climate prediction and projection; General circulation models; Mean sea level; Sea-level change; Slab-ocean model.

Geological Society of America

• Categories: Organizations and agencies; geology and geography
• Date: Established 1888
• Web address: http://www.geosociety.org

• Mission

The Geological Society of America is a global professional society whose members are academicians, scholars, and experts in the geosciences. The mission of the society is to be a leader in the advancement of the geosciences, to enhance the professional growth of its members, and to promote the geoscieness in the service of humankind. To implement its mission, the society holds an annual meeting, organizes numerous conferences, publishes the research of geoscientists, and fosters dialogue with the public and with decision makers on relevant geoscience issues. The society has a growing membership of more than twenty-one thousand residing in eighty-five different counties. It also has a professional staff at its headquarters in Boulder, Colorado, officers elected from among leading scientists, six regional sections that are spread throughout North America and also meet annually, numerous committees, seventeen special-interest divisions that meet in conjunction with the Annual Meeting of the Society, and forty-five affiliated societies with which it works in partnership.

• Significance for Climate Change

At their October, 2006, annual meeting in Philadelphia, members of the Geological Society of America adopted the following position statement as a reflection of their institutional and individual commitment to the subject of global climate change:

> The Geological Society of America (GSA) supports the scientific conclusions that Earth's climate is changing; the climate changes are due in part to human activities; and the probable consequences of the climate changes will be significant and blind to geopolitical boundaries. Furthermore, the potential implications of global climate change and the time scale over which such changes will likely occur require active, effective, long-term planning. GSA also supports statements on the global climate change issue made by the joint national academies of science (June, 2005), American Geophysical Union (December, 2003), and American Chemical Society (2004). GSA strongly encourages that the following efforts be undertaken internationally: (1) adequately research climate change at all time scales, (2) develop thoughtful, science-based policy appropriate for the multifaceted issues of global climate change, (3) organize global planning to recognize, prepare for, and adapt to

the causes and consequences of global climate change, and (4) organize and develop comprehensive, long-term strategies for sustainable energy, particularly focused on minimizing impacts on global climate.

A public forum on the topic of climate change was also held at this meeting, allowing the GSA to engage with laypersons to discuss the implications of climate change. The major speakers at the forum were Dr. Richard B. Alley of Pennsylvania State University and Dr. Robert Jackson of Duke University.

Donald W. Lovejoy

See also: American Association of Petroleum Geologists; American Chemical Society; American Geophysical Union; Earth structure and development.

George C. Marshall Institute

- **Category:** Organizations and agencies
- **Date:** Established 1984
- **Web address:** http://www.marshall.org

• Mission

The George C. Marshall Institute is a nonprofit organization supported by foundations, industry, and the public to improve the use of science in making public policy. Its major emphasis is on issues of the environment and national security.

The mission of the George C. Marshall Institute (GMI) is to encourage the use of science in making public policy when science and technology are major components of that policy. The institute was founded in 1984 by two respected scientists, Frederick Seitz, the former president of the National Academy of Sciences, and Robert Jastrow, an astronomer and author. The institute differs from most other think tanks, because its board of directors includes a large proportion of leading scientists and the assessments it undertakes have a strong focus on the science used in making public policy. The activities of GMI in the environmental field include civic environmentalism and climate change and, in the national defense field, bioterrorism and missile defense.

GMI carries out its mission through published reports, workshops, roundtables, and collaboration with other organizations with similar goals, such as the Hoover Institution, Doctors for Disaster Preparedness, and Physicians for Civil Defense. It has a staff that organizes workshops and roundtables and also prepares assessments of issues connected to its mission.

The Washington Roundtable on Science and Public Policy was established by GMI to bring together scientific experts and government leaders to explore policy options connected to scientific and technological questions. Its aim is to insure that policy makers are aware of the science and the uncertainties involved in these questions.

GMI has a conservative bent and has been skeptical about many mainstream scientific assessments, including those of global warming. It was a strong supporter of the Strategic Defense Initiative and emphasized the uncertainties about the negative impacts of secondhand smoke. It gives more weight to the uncertainties in the scientific basis underlying public issues than do other think tanks. Many liberal organizations and the media have attacked GMI for the stands it has taken on these controversial policies.

• Significance for Climate Change

Since it was established in 1984 GMI has published more than one hundred books, reports, roundtable discussions, and other documents on the science of climate change and its policy implications. Among these are assessments of the validity of some scientific measurements of global warming; policy implications of climate change, including arguments against the cap-and-trade policy supported by some members of Congress; and critiques of the reports of the Intergovernmental Panel on Climate Change (IPCC). Its emphasis on science and the limits of knowledge led GMI to cosponsor the Petition Project, through which more than thirty thousand scientists have signed a petition urging the United States government to reject the Kyoto Protocol on global warming.

GMI reports have been instrumental in pointing out the scientific and statistical difficulties with the hockey stick model of global temperatures used in the third IPCC report. The model indicates that the global temperatures have risen in the shape of a hockey stick since the middle of the twentieth century and are expected to continue this rapid rise. A reevaluation by GMI shows that there are serious questions about both the data and the statistics used in this model.

The cap-and-trade policy would allow Congress to set an overall cap on greenhouse gases and allow industries to auction their allotments among themselves to meet the cap. The Marshall Institute has argued against this policy, because it would distort the economy by letting Congress arbitrarily set emission values for industries, and it could be susceptible to fraud.

Because many of these reports point out difficulties and uncertainties in the science and the policies advocated by other groups, GMI has been called a denier of global warming. GMI argues that before making catastrophic and possibly irreversible policy changes, the relevant science should be improved and its uncertainties reduced. It points out that there is no consensus among scientists about either the data or the models of global warming. There could be great danger to the economy and well-being of the world posed by setting controversial policies while the uncertainties remain high.

Raymond D. Cooper

• **Further Reading**

Ball, Timothy. *The Science Isn't Settled: The Limitations of Global Climate Models*. Washington, D.C.: George C. Marshall Institute, 2007. GMI Washington Roundtable Report in which the limitations of climate models are discussed. Points out that many of the assumptions used in the models are questionable, with biases that tend to increase predicted warming. Twenty figures.

George C. Marshall Institute. *Climate Issues and Questions*. 3d ed. Washington, D.C.: Author, 2008. Addresses twenty-nine questions about climate change, bringing to bear the best available scientific evidence. Discusses the IPCC process and results, scientific facts about climate change that are well established, and uncertainties about these issues. Figures, tables, endnotes.

Gough, Michael. *Politicizing Science: The Alchemy of Policymaking*. Palo Alto, Calif.: Hoover Institution Press, 2003. Describes how the manipulation of science has been used to advance particular political agendas, resulting in burdens on the economy and missed opportunities. Index.

Michaels, Patrick J., ed. *Shattered Consensus: The True State of Global Warming*. Lanham, Md.: Rowman & Littlefield, 2006. Collection of ten rather technical essays by the editor and nine other experts on climate change. Reviews and highlights the differences between what has been predicted and what has actually been observed about global warming. Figures, index.

See also: Air pollution and pollutants: anthropogenic; Hockey stick graph; Offsetting; Skeptics; U.S. legislation.

Geothermal energy

• **Category:** Energy

As an alternative to fossil fuels, geothermal energy resources may be developed where conditions warrant. This technology requires proximity to resources and the infrastructure to ship energy to market. Unlike wind and hydropower, however, availability of geothermal energy does not depend on weather or precipitation.

• **Key concepts**

heat: thermal energy, often measured in calories or joules

heat flow: the rate at which thermal energy flows through a surface

watt: a unit of power, frequently associated with electricity, equivalent to 1 joule per second

• **Background**

Volcanic activity heats rock, imbuing it with thermal energy. Where such activity is recent or ongoing, naturally occurring water moving through hot rock may produce natural hydrothermal systems that need only a little engineering to generate electricity. Often there is enough energy for major commercial development. Other locales may have hot rock but little water. The technology needed to produce energy commercially from these systems has not yet been developed. If the cost of producing energy from other sources gets high enough, this technology may be pursued.

• Geothermal

Heat flows from hot to cold. As a result of radioactive decay, as well as some residual heat from Earth's formation, the interior of the planet is hot compared to outer space, so heat flows upward from depth through the surface of the Earth. By measuring how rapidly temperature increases with depth and determining the thermal conductivity of rocks, scientists can determine the rate of Earth's heat flow: The planet's average heat flow is about 87 milliwatts per square meter, so the total heat loss from Earth is about 44×10^{12} watts. To put this in perspective, total human energy consumption is about 15×10^{12} watts, and total solar energy reaching the Earth is about 240 watts per square meter, or 12.65×10^{15} watts.

Heat flow varies with location, and in some places it is high enough to generate usable power. In Italy, geothermal resources have been used since 1913, when a 250-kilowatt power station was constructed. Iceland produces over one-quarter of its electricity and over 80 percent of its home heating and hot water from geothermal resources. The Geysers geothermal field in Northern California produced 2×10^{9} watts at its peak in 1987, with output generally declining since then but leveling off at about 8.5×10^{8} watts. In these locations, naturally occurring water migrating through hot rocks turns to steam in sufficient volumes to power a steam turbine and to heat homes. Such conditions are uncommon and are even less commonly situated in locations near significant human populations. Un-

Olkaria KenGen Geothermal Energy Power station in Naivasha, Kenya. (Antony Njuguna/Reuters/Landov) like some energy sources, however, geothermal energy at the locations where it exists is available at any time.

• Hot Dry Rock

There are many areas with high geologic heat flow but no naturally occurring steam. Efforts to develop these hot dry rock (HDR) resources began in 1970 at the Los Alamos National Laboratory. The project involved drilling a 4-kilometer-deep well at Fenton Hill, New Mexico, then injecting water under pressure to produce cracks in the hot rock at that depth. The cracks were expected to be penny shaped, and another well was drilled down to where the top of the penny was expected to be. Many technological challenges were successfully met; however, the vagaries of fracture propagation within a complex geological terrain were not adequately anticipated. After thirty years of work by some of the country's top geologists and engineers and over $180 million spent, the site was closed and the wells were cemented in. Many lessons were learned, including the realization that huge investments of human and financial capital may not be sufficient to harness a "free" source of energy.

• Low-Temperature Geothermal Energy

Even where heat flow is not particularly high, geothermal systems can heat and cool buildings. These low-temperature systems pump fluids through the subsurface, absorbing heat in the winter and dispensing it in the summer. This is possible because the Sun and atmosphere are responsible for heating the surface of the Earth, and at a depth of a few meters the temperature is close to the median surface temperature for a given location. Electricity is needed to operate the fluid pumps and the heat pumps, but a well-designed system can be considerably more efficient than one based on fossil fuels or electricity alone.

• Context

Huge quantities of energy move through the Earth's systems, providing tempting possibilities for environmentally sound, sustainable energy production. Geothermal energy is one such avenue. In places where high heat flow and naturally occurring water coexist, this resource has often already been developed. In places where there is high heat flow but no water, the risks inherent in trying to put the thermal energy to use are great, as the investments required are enormous and there is no certainty of success.

Low-temperature geothermal systems for space heating and cooling present the same problems on a smaller scale. If there were a good chance that the investment costs of such systems would be paid back quickly in fuel savings, they would be extremely popular. Design improvements, manufacturing efficiencies, and economies of scale will bring down the cost of these systems, while resource depletion and environmental costs will increase the cost of fossil fuel systems. At some point, in some areas, the former may become more economical than the latter.

Otto H. Muller

• Further Reading

Decker, Robert W., and Barbara Decker. *Volcanoes.* New York: W. H. Freeman, 2005. An elementary-level college textbook; chapter 15 provides a good overview of geothermal energy. Illustrations, figures, tables, maps, photos, bibliography, index.

Duffield, W. A., J. H. Sass, and M. L. Sorey. *Tapping the Earth's Natural Heat.* Washington, D.C.: U.S. Geological Survey, 1994. With plenty of color photographs, this circular shows what the potential is for geothermal energy development in the United States, but it also warns of some of the threats to the environment posed by geothermal development.

Pahl, Greg. *The Citizen-Powered Energy Handbook: Community Solutions to a Global Crisis.* White River Junction, Vt.: Chelsea Green, 2007. Includes good descriptions of low-temperature systems, both municipal and residential. Photos, figures.

Tester, J., et al. "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the Twenty-first Century." *Final Report to the U.S. Department of Energy Geothermal Technologies Program.* Cambridge, Mass.: MIT Press, 2006. Written in a way that a general reader will find understandable, but with sufficient technical detail to satisfy scientists and engineers, this thorough 372-page report covers

everything from heat flow maps to economic forecasts based on predicted learning curves. Maps and charts.

See also: Clean energy; Energy efficiency; Energy resources; Fossil fuels; Fuels, alternative; Renewable energy; Solar energy.

Germany

- **Category:** Nations and peoples
- **Key facts**

Population: 82,329,758 (July, 2009, estimate)
Area: 357,021 square kilometers
Gross domestic product (GDP): $2.863 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 1,226 in 1990; 981.3 in 2007
Kyoto Protocol status: Ratified April 26, 2002

• Historical and Political Context

Because of its central location in Europe, no other country shares more borders with European countries than Germany. Germanic people were fragmented by a number of large tribes. Following the Thirty Years' War (1618-1648), which devastated German lands and killed about 30 percent of the people, the Peace of Westphalia divided the Holy Roman Empire of the German nation into numerous independent principalities, with the Austrian Habsburg monarchy and the Kingdom of Prussia as the largest players. The long road to unification included the foundation of the German Confederation in 1814, the tariff union (*Zollverein*), the Revolution of 1848, and the first establishment of the German nation state in 1871 amid the Franco-Prussian War. Being a latecomer, Germany pursued an aggressive path in its quest for power in Europe and abroad, leading to two lost world wars, with comprehensive devastation and unspeakable crimes committed by Nazi Germany.

Being forced to learn its lesson under Allied occupations, Germany was divided in 1949 into a socialist Eastern and a capitalist Western state, both of which became the battleground (and almost the nuclear battlefield) for the Cold War antagonists the United States and Soviet Union. After the spectacular fall of the Berlin Wall in 1989, triggered by Soviet premier Mikhail Gorbachev's reforms, Germany was reunified in 1990. United Germany took a leading role in the further establishment of the European Union, adopting the European currency, the euro in 1999.

In 2009, Germany had the largest population in the European Union and had sixteen federal states. It was home to a large number of international migrants. Germany is a federal parliamentary republic with the world's third largest economy by nominal GDP and is the world's leading exporter of goods, partly because of its scientific and technological advancements. The country has a comprehensive system of social security and the second biggest budget of development aid in the world. While military expenditure ranks sixth, Germany is an influential partner in the North Atlantic Treaty Organization and took part in military interventions in the Balkans and Afghanistan that became controversial because of a strong anti-war attitude in the population.

• Impact of German Policies on Climate Change

Concerns about the environment and sustainable development are high on the agenda in Germany. Policies have contributed to reducing air pollution and acid rain from sulfur dioxide emissions, limiting pollution from industrial effluents into water bodies, and increasing nature preservation areas. There is significant attention among the Germany public and media to the threat of global warming, including shrinking glaciers in Alpine regions, and natural hazards such as river flooding and storms.

The national government has put great emphasis on climate policy and is committed to supporting the Kyoto Protocol and other agreements for reducing greenhouse gas emissions. Germany is trying to phase out nuclear power and has taken a lead in renewable energy sources, including bioenergy and wind and solar power (such as the "100,000 roofs" solar electricity program). While the country's CO_2 emissions per capita are among the highest in the European Union (still significantly lower than those of Australia, Canada, or the United States), overall emissions are falling thanks to wide-ranging emission reduction activities.

In June, 1990, the Interministerial Working Group on CO_2 Reduction was established to develop climate protection policies and report to the federal cabinet. Germany's national climate-protection strategy addresses the specifics of the economic sectors (industry, energy and transportation, commerce, trade and services) and is oriented toward achieving a sustainable energy supply by improving energy efficiency, balancing energy mix, and expanding renewable energy sources. Germany has a leading role in international climate negotiations; for example, it directed the 1995 Conference of the Parties to the UNFCCC and it hosted the U.N. Climate Secretariate in Bonn. The federal government plans to achieve its Kyoto target by implementing climate-policy instruments and measures.

The Ecological Tax Reform established a set of energy taxes (mineral oil, heating fuel, coal, electricity) and prevented 20 million metric tons of CO_2 emissions; it also created up to 250,000 jobs and additional tax revenues of 17.8 billion euros in 2005 used for the public social security system. Special regulations help to ensure the competitiveness of energy-intensive processes. The Renewable Energy Sources Act (EEG) of 2000 and the 2004 and 2009 EEG amendments granted priority to renewable energy sources. In 2006, a total of 73.8 terrawatt hours of electricity based on renewable sources was generated, corresponding to 12 percent of total German electricity consumption. At the end of 2006, 5.8 percent of primary energy requirements and 12.0 percent of electricity requirements came from renewable sources. Through 2020, the EEG is expected to reduce emissions by about 45 million metric tons of CO_2.

Since 2005, emissions trading in the European Union has created economic incentives for reducing CO_2 emissions, including large energy installations and energy-intensive industrial systems. The German Bundestag (legislature) has passed several related laws: the Greenhouse Gas Emissions Trading Act, the National Allocation Plan, and the Act on Project-based Mechanisms. The initial upper emissions limit of 499 million metric tons is to be reduced to 453.1 million metric tons by 2012, including new installations.

• Germany as a GHG Emitter

When it ratified the Kyoto Protocol, the European Union (with fifteen member states at that time) committed to reducing its greenhouse gas (GHG) emissions by 8 percent by the 2008-2012 period, compared to their base-year levels (1990 and 1995). Under the EU burden-sharing agreement, Germany has agreed to reduce its emissions by 21 percent compared to 1990. German reunification was a key factor in the sharp decrease beginning in the early 1990's. Numerous fossil-fired power stations were modernized, and production in the new German state decreased considerably. According to the National Inventory Report, Germany has fulfilled a large part of its obligations. In 2007, German emissions declined by roughly 24 million metric tons compared to 2006 (-2.4 percent), bringing emissions down to below the one billion threshold for the first time, an overall reduction of 20.4 percent compared to 1990. Reasons for the steep decline were high gasoline prices, a mild winter, a tax increase, and the increase of renewable energy sources by 15 percent.

In 2006, CO_2 accounted for 87.6 percent of all

GHG emissions, mostly related to stationary and mobile combustion. Methane (CH_4) emissions from animal husbandry, fuel distribution, and landfills contributed 4.6 percent, and nitrous oxide (N_2O) from agriculture, industrial processes, and transport, 6.3 percent of greenhouse gas releases. Fluorocarbons accounted for about 1.6 percent of total emissions. Emissions changes were -14.7 percent for CO_2 by 2006, -53.8 percent for methane, and -25.3 percent for nitrous oxide.

• Summary and Foresight

To achieve its Kyoto obligations and move to lower numbers beyond Kyoto, setting a target of reducing GHG emissions by 40 percent by 2020, the federal government continually reviews and refines measures already taken. There are no plans for state purchase of emissions allowances from clean development mechanism (CDM) and joint implementation (JI) projects. Instead, Germany helps to develop the EU emissions trading system by enhancing energy efficiency, renewable energy use, and additional regulatory measures. With the Project Mechanisms Act of 2005, the legal basis exists for carrying out CDM and JI projects, with the Federal Environmental Agency as the competent authority.

Jürgen Scheffran

• Further Reading

Solsten, Eric, ed. *Germany: A Country Study*. 3d ed. Washington, D.C.: Federal Research Division, Library of Congress, 1996. Reviews Germany's history and dominant social, political, economic, and military aspects. Comprehensive assessment of Germany in historical and cultural context.

Umwelt Bundes Amt. *Climate Change in Germany: Vulnerability and Adaptation of Climate Sensitive Areas*. Dessau, Germany: Author, 2008. Discusses climate impacts and adaptation strategies.

_______. *National Report for the German Greenhouse Gas Inventory, 1990-2006*. Dessau, Germany: Author, 2008. Official report on German GHG emissions.

_______. *Progress of German Climate Change Policies Until 2020*. Dessau, Germany: Author, 2008. Puts German climate strategy in context.

See also: Clean development mechanism; Greenhouse effect; Greenhouse gases; Kyoto Protocol; United Nations Framework Convention on Climate Change.

Glacial Lake Agassiz

• **Categories:** Geology and geography; cryology and glaciology

• Definition

The ice constituting mountain glaciers and continental ice sheets is derived from ocean water. During the Pleistocene epoch, the sea level dropped 100 meters, supplying sufficient water to cover about 30 percent of the Earth with glacial ice. As climatic conditions change and deglaciation begins, ice melts; meltwaters flow into the oceans or remain on land as glacial lakes. Lake Agassiz, the largest lake in North America during Pleistocene deglaciation, was dammed to the north by the Laurentide ice sheet (LIS). This proglacial lake (a glacial lake directly in contact with glacier ice) and its drainage basin covered, at maximum, 2 million square kilometers, extending from the Rocky Mountains in Alberta to the Lake Superior basin, into South Dakota, and north to the LIS in Hudson Bay. Maximum volume was 163,000 cubic kilometers.

First recognized by W. H. Keating in 1823 and named by Warren Upham in 1880, Lake Agassiz honors Louis Agassiz, a promoter of continental ice theory. Lake Agassiz is known for its fluctuating size, shape, and depth; multiple large-volume outbursts (drawdowns); and differing meltwater outlets. Physical evidence documenting these variations include former beaches and wave-cut cliffs, lake outlets, and ancient—now dry—lake marshes.

The maximum elevation of the lake's surface was determined by a lake outlet at 70 meters above sea level. Lake outlets were controlled by the vacillating LIS. Lake Agassiz water would rise until it reached an outlet, at which point it would abruptly

NADW moves cold, salty, deep-ocean water south from North America. The same studies reveal that within a glacial-interglacial transition, a freshwater outburst of less than 10,000 cubic kilometers brought significant changes to ocean circulation, as well as colder temperatures. An outburst from Lake Agassiz of 9,500 cubic kilometers through the Great Lakes-St. Lawrence drainage system initiated the Younger Dryas cooling event 12,900 to 11,600 years ago.

Another cooling episode, the 8.2ka event, was preceded by an outburst of 163,000 cubic kilometers in one year from the Lake Agassiz-Lake Ojibway system. Near the end of the existence of Lake Agassiz, the waters of Lake Ojibway commingled with Lake Agassiz. The exit route for this enormous interglacial outburst was through a weakened LIS, then northward

overflow. Runoff routes were the Mackenzie River Valley to the Arctic Ocean, Hudson Bay to the North Atlantic Ocean, the St. Lawrence River to the North Atlantic Ocean, and the Mississippi River Valley to the Gulf of Mexico. As deglaciation continued, the level of Lake Agassiz fell below the level of the eastern outlets; lands south of 53° north latitude were above the level of the lake about eighty-five hundred years ago. Approximately one thousand years later, Lake Agassiz drained into the Tyrrell Sea, an area somewhat larger than today's Hudson and James bays. The lake existed for about five thousand years.

• **Significance for Climate Change**

Short-term, often abrupt changes of climate are driven by reorganization of ocean circulation. Studies have shown that a freshwater influx of less than 100,000 cubic meters per second may slow or shut down the North Atlantic deep water (NADW). Part of the thermohaline circulation (THC), the

into the Hudson Strait. The Hudson Strait is 2,000 kilometers north of the Atlantic Ocean. It has been suggested that, despite the distance from the Atlantic Ocean, the rapid influx of cold freshwater brought about the 8.2ka event, the last major cooling event of the Pleistocene deglaciation.

Global warming may introduce large fluxes of cold freshwater to the North Atlantic Ocean. As the climate warms, Greenland glaciers could melt, and increased rain could fall, producing a high volume of freshwater that could slow or stop the NADW. Freshwater outbursts from Lake Agassiz during the past deglaciation document perturbations of the NADW and the THC, resulting in cold temperatures, especially in North America and northern Europe.

In addition, once highly reflective snow and ice have melted, the less reflective land surface will absorb more solar radiation and add more heat to Earth. Along with reduced snow cover is the loss of tundra—areas habitated by scrubby, often snow-covered vegetation located on vast regions of Europe and North America. Snow-covered tundra reflects sunlight, but, if typical tundra vegetation is replaced by taiga vegetation (the dark, evergreen forests of subarctic regions), more sunlight would be absorbed and more warming would occur.

Mariana L. Rhoades

• Further Reading

Alley, R. B. *The Two-Mile Time Machine*. Princeton, N.J.: Princeton University Press, 2000. Explains climate records extracted from ice cores, as well as the human imprint on future climates.

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It*. New York: Hill and Wang, 2008. Text on climate science, glaciations, and abrupt climate change. Details consequences of global warming; concluding chapters describe remedies.

Clark, P. U., et al. "Freshwater Forcing of Abrupt Climate Change During the Last Glaciation." *Science* 293 (July 13, 2001): 283-287. Research reporting on the relationship between increased freshwater flow and the NADW, providing a mechanism for climate variability and global ice volume.

Teller, J. T., and L. Clayton, eds. *Glacial Lake Agassiz*. Geological Association of Canada Special Paper 26. Toronto: University of Toronto Press, 1983. Major research detailing Lake Agassiz history, biota, geology, hydrologic basins, and post-glaciation geology.

Teller, J. T., D. W. Leverington, and J. D. Mann. "Freshwater Outbursts to the Oceans from Glacial Lake Agassiz and Their Role in Climate Change During the Last Deglaciation." *Quaternary Science Reviews* 21 (2002): 879-887. Research comparing the volumes, fluxes, routings, and timings of ten different Lake Agassiz outbursts and relating the outburst to the history of climate change.

See also: Agassiz, Louis; Cryosphere; Deglaciation; 8.2ka event; Glaciations; Glaciers; Interglacials; Last Glacial Maximum.

Glaciations

• **Category:** Cryology and glaciology

Discovering glaciations and trying to understand them have occupied scientists for over a century. In the process, great progress has been made in understanding the drivers of climate change in the past and the likely drivers in the future.

• Key concepts

glaciation: the advance of a continental ice sheet
ice age: a period of time during which major continental ice sheets advanced and retreated
interglacial: the warm period between glaciations
marine isotope stage: half of a glacial cycle, as identified in the oxygen isotope data from ocean cores
Milanković cycle: period of variation in Earth's orbital parameters, including axial inclination, climatic precession, and orbital eccentricity

• Background

Glaciations presented a challenge to climate science. With ice sheets today only on Greenland and Antarctica, huge continental glaciers were difficult even to imagine. As the idea took root, however, evidence for glaciations throughout geologic history became apparent. What controls the timing of glaciations is now largely understood, but how they grow or retreat—and why—continue to be important subjects of research.

• Global Factors

The temperature of the surface of the Earth is a function of how much energy it receives from the Sun and how much of this energy is radiated back into space. The atmosphere plays an important role, as its clouds and aerosols limit how much light energy reaches the surface and its greenhouse gases (GHGs) limit how much infrared energy escapes. Geologic evidence suggests that average global surface temperatures have remained within a limited range over the past two billion years, and GHGs, particularly carbon dioxide (CO_2), may have been responsible for this consistency.

CO_2 is produced by volcanism and removed by weathering. Weathering is temperature dependent, so it represents a negative feedback system: Higher temperature results in more weathering, which removes more CO_2, resulting in lower temperatures, or vice versa. Although over periods measured in hundreds of millions of years this feedback loop seems to have maintained a relatively constant temperature, its effects are not instantaneous, and perturbations have occurred. When these perturbations produce colder conditions, ice ages can result.

Evidence of a number of ice ages has been identified in rocks more than one billion years old. Little is known about these ice ages, as data are sparse and difficult to interpret. Between 750 and 550 million years ago, there were several major ice ages, usually lumped together and called Snowball Earth, as there is evidence that glaciers then existed at sea level near the equator. Although they are of academic interest, at the time these ice ages occurred, there were no land plants, and the atmosphere had far less oxygen, so it is not clear that efforts to understand them will help in the study of contemporary climate change.

Other ice ages, including a short one 440 million years ago and the Permo-Carboniferous ice age between 325 and 240 million years ago, provide insight into what conditions are required for ice ages. These occurred when the land on which the continental glaciers formed was over the South Pole. As continents were also over the South Pole in the time period between these two ice ages and Antarctica sat over the South Pole for 90 million years before its current glaciers formed, this location seems to be a necessary but not a sufficient condition for ice age formation.

• Pleistocene Glaciations

About 50 million years ago, the Earth began to cool. Deep-ocean temperatures gradually dropped from 13° Celsius to the present 1° Celsius. Study of ocean sediment cores has identified some minor ice ages around 40 million years ago, another ice age formed the East Antarctica Ice Sheet 34 million years ago, and a third ice age around 13 million years ago left evidence in Alaska. Orbital factors probably influenced these advances, perhaps by affecting the carbon cycle, but the details remain obscure.

A thawed glacier in Valais, Switzerland, demonstrates the role of glaciation in shaping Earth's surface topography. (Francoise Funk-Salami/Keystone/Landov)

Starting about three million years ago, the climate developed two different states. Since then, it has oscillated between them, causing glaciations—with continental glaciers extending down to the 40° north parallel of latitude—and interglacials such as the current period, some with temperatures even higher than those of the present. Geologists identified glacial deposits, determined that some were on top of others, and gave names to each, but the names were not standardized internationally. The name of the most recent glaciation is Valdaian on the Russian Plains, Devensian in Britain, Weichselian in Scandinavia, Würm in the Alps, and Wisconsinan in North America. The deposits of one glacier are easily removed by subsequent glaciers, so there might be some for which no evidence remains on the continents.

Oxygen isotope ratios of marine sediments, which are not removed by later glaciations, show that there have actually been around fifty glaciations. Because these ratios indicate how much water is tied up in ice, this record is now seen as the best way of delineating when an advance ended and a retreat began. Each marine isotope stage (MIS) is given a number (odd ones for interglacials, even ones for glaciations) starting with the most recent. Interglacial MIS 103 occurred 2,580,000 years ago.

Once all these additional glaciations were known, analysis showed that astronomical cycles controlled their timing, as had been suggested by James Croll in 1864 and Milutin Milanković in 1941. These results are so robust that geologists now use these cycles to calibrate the more recent part of the geologic time scale.

That Milanković cycles control the timing of glaciations is beyond dispute. How they do so, however, is not well understood. Feedback systems in the oceans, the atmosphere, the biosphere, or perhaps elsewhere are needed to amplify the tiny signal produced astronomically. Identifying and understanding these systems will help scientists understand current climate change.

• Context

Skeptics who wonder if the climate is changing should consider glaciations. Doomsayers, who fear the human race is threatened by global warming, should also consider glaciations. Much of geologic history concerns things that happened so long ago that it is easy to dismiss or ignore them, but glaciations are recent history. *Homo erectus* was on the planet and using fire twenty or so glaciations ago. All of human evolution has taken place as glaciers ebbed and flowed. Human migration to North America occurred 14,600 years ago, just after the peak of the last glaciation. Ice sheets then, although they were getting smaller, still covered most of Maine and northern parts of New York, Vermont, and New Hampsire. They are not there now. Climate changes.

Otto H. Muller

• Further Reading

Imbrie, J., and K. P. Imbrie. *Ice Ages: Solving the Mystery.* Short Hills, N.J.: Enslow, 1979. An excellent history of the efforts to understand what caused the ice ages. Full of personal anecdotes, it gives a sense of the excitement and frustrations experienced by cryologists. Many diagrams, including some now classic ones.

Macdougall, J. D. *Frozen Earth: The Once and Future Story of Ice Ages.* Berkeley: University of California Press, 2004. Easily understood by a general reader, this book explains how glaciations were discovered and understood. Chapter 10 focuses on the role glaciations played in evolution in general, and in human evolution in particular. Photos, diagrams, maps, an annotated bibliography of general-interest books.

Ruddiman, William F. *Earth's Climate Past and Future.* 2d ed. New York: W. H. Freeman, 2008. This elementary college textbook has several sections concerning glaciations and their causes, with particular attention paid to how they can elucidate climate change. Illustrations, figures, tables, maps, bibliography, index.

See also: Cryosphere; Deglaciation; Glaciers; Greenland ice cap; Ground ice; Ice cores; Ice-out studies; Ice shelves; Interglacials; Last Glacial Maximum; Little Ice Age; Milanković, Milutin.

Glaciers

• Category: Cryology and glaciology

Glaciers are very sensitive to global temperature changes, retreating and growing as the Earth warms and cools. Because of this sensitivity, geologists have made careful measurements of the changes in benchmark glaciers in order to monitor the effects of global climate change and have studied the history of glaciers as a means of reconstructing the sequence of temperature fluctuations in Earth's past.

• Key concepts

alpine glaciers: large masses of ice found in valleys, on plateaus, and attached to mountains

cryosphere: the portion of the Earth's surface that is composed of frozen water
firn: the intermediary stage between snow and ice
glacial ice: ice created by the compression of snow, sometimes saturated with meltwater that is refrozen
ice caps: masses of ice covering areas smaller than 50,000 square kilometers
ice sheets: masses of ice covering large landmasses

• Background

Of the freshwater ice of the world, 99 percent is located in Antarctica and in Greenland: 90 percent of the ice is located in Antarctica (an area of 14 million square kilometers containing 27.6 million cubic kilometers of ice); 9 percent is in Greenland (an area of 1.726 million square kilometers containing 2.85 million cubic kilometers of ice), and 1 percent exists in the glaciers and ice caps scattered throughout the world. The two ice sheets of Antarctica and Greenland represent about 10 percent of the Earth's land area and contain more than three-quarters of its freshwater.

• Glacial Landscape

Geologists can provide useful information about the history of glaciation by studying the geographic features left by glaciers that have long since melted away. When alpine glaciers form, they produce an amphitheater-like depression called a "cirque" at their highest point. When the compression of snow produces ice in a depth of about 20 meters, the ice begins to flow downward along the valleys of former streams. The ice deepens and widens the stream valley to produce a glacial trough. Valleys of tributary streams are filled with ice as well, but the shorter length of the tributary glaciers and the lesser discharge produce less deepening of the channel. Typically, these tributary glaciers erode their channels only down to the current ice surface of the main glacier, resulting in distinctive "hanging valleys" that end in a precipice at their juncture with the valley produced by the main body of the glacier. The height of these hanging valleys indicates the depth of the ice in the main glacier.

Materials the glacier erodes are pushed to its side, creating lateral moraines, or to its lower end, creating a frontal or end moraine, or accumulate under the glacier, creating a ground moraine, or till. These features identify the greatest breadth (lateral moraines) and furthest extent (terminal moraine) of ancient glaciers. The sediments deposited in glacial lakes—called varves—can be used to determine the length of the deposition process. Distinctive small hills called drumlins are formed under an advancing glacier and, because of their teardrop shape, indicate the direction of the ice and water flow. Meltwater accumulates in lakes found in the cirques; these lakes are called tarns. Other lakes occupy the depressions in the glacial troughs. When the glacier retreats, it uncovers a U-shaped valley instead of the V-shaped valley it had prior to the glaciation.

Continental ice sheets transform the landscape differently. When they retreat, they leave a multitude of lakes, many of which are round (kettle lakes). Others are elongated in the direction of the ice flow—such as the Finger Lakes in New York. By reconstructing the history of glaciation from these alterations made to the landscape, glaciologists and geologists have been able to contribute greatly to the understanding of the nature of Earth's climatic changes.

• Ice Formation and Location

Glaciers are masses of ice that are produced where the summer temperatures fail to melt the snow that fell during the preceding winter. Over time, this snow is compressed by overlying layers of more recent snow, forcing out some of the air that exists around snow crystals. This air escapes toward the surface; the density of this older snow steadily increases, until the snow turns into ice. At that point, the density of the ice varies from 0.85 to 0.91. Ice therefore floats on liquid water, whose density is 1. The transformation of snow into ice is slower in polar areas, where compression is the major mechanism at work, because air temperatures remain low all year round, producing very little, if any, meltwater to be refrozen. In temperate climates, ice forms more rapidly than in the polar areas because there are periods of melting when the temperature is above the freezing point of water. The meltwater soaks the snow and refreezes during the next colder period. This process is much faster than compression to achieve the density of ice.

A glacier melts during the Patagonian winter in July, 2008, releasing massive ice splinters into Lago Argentino. (Reuters/Landov)

Glaciers can exist at any latitude, even along the equator. They are present on every continent except Australia. The necessary condition for glaciers is that the air temperature remains low enough to prevent melting of the last winter snow. Because temperature decreases with increasing elevation, glaciers are found on high mountains or volcanoes. In Africa, Mounts Kenya, Kilimanjaro, and Ruwenzori have small glaciers (though they are retreating rapidly). In South America, there are many small tropical glaciers located in the Andes as well. In North America, Europe, and Asia, small glaciers dot the summits of high mountain ranges and volcanoes. Glaciers gain mass—called "accumulation"—by the deposition of snow in the highest elevation, called the cirque—a large amphitheater at the summit of glaciers.

Glaciers lose mass (a process called "ablation") by melting, sublimation, and calving. Melting takes place in a glacier where the temperature is greater than 0° Celsius. This can occur where the air temperature reaches this value or at the underside of the glacier, where friction of the ice on the ground beneath the glacier causes the temperature to increase, producing meltwater. This water lubricates the underside of the glacier, resulting in faster movement.

The second component of ablation is sublimation. Sublimation is the transformation of ice directly into water vapor, without an intermediate liquid stage. In Antarctica, sublimation is a major contributor to the ablation of ice because the ice sheet is affected by very strong winds which enhance the process. The third form of ablation is calving. It involves the breaking of the end of the glacier when it reaches an ocean or a lake. Calving produces icebergs—masses of ice that float because of the lower density of ice (0.85-0.91) compared to that of water (1). Calving is responsible for about

Glaciation Time Line

Glaciation	*Millions of Years Ago*	*Era*
Karoo	360-260	Paleozoic
Andean-Saharan	450-420	Paleozoic
Cryogenian	800-635	Neoproterozoic
Huronian	2,400-2,100	Paleoproterozoic

40 percent of ablation in Greenland and 80 to 90 percent in Antarctica.

The term "mass balance" refers to the difference in mass between accumulation and ablation. A glacier will grow longer if accumulation is greater than ablation over a period of time. This is called a glacial advance. A glacier will get shorter if the amount of ice removed by ablation exceeds the amount of snow that accumulates in the coldest part, the cirque. When glaciers become shorter they are said to retreat. This does not mean that the ice stops moving downward from the cirque to the lower end of the glacier, called the front. Glacial retreat indicates only that the front of the glacier will be found closer to the cirque.

Today, most glaciers in the world are retreating. Although there are a few exceptions where glaciers are advancing, the worldwide trend is a steady retreat in response to the general raising of the Earth's temperatures.

• Glaciology and Paleoclimates

The science that studies the cryosphere is called glaciology. One of the first important glaciologists was Louis Agassiz, a native of Switzerland, who studied the glaciers of the Alps in the nineteenth century. Building on Agassiz's work, modern glaciologists discovered that glaciers not only are a good source of information about the global impact of recent environmental changes but also provide valuable data about the long history of climate change on this planet. Modern study of ice cores, cylinders of ice retrieved from glaciers, has shown that ice records the temperatures of the Earth atmosphere at the time the snow fell. The paleotemperatures are inferred from the composition of the water that makes up the ice.

In nature, water is made of two atoms of hydrogen and one atom of oxygen; however, oxygen has three isotopes (elements that have the same number of protons but different numbers of neutrons). The lightest and most abundant of the three is O^{16}. O^{18} is the heaviest but exists in much smaller quantities. Higher Earth temperatures make it easier for the heavier O^{18} molecule to evaporate, resulting in snow—and therefore glacial ice—that has an increased proportion of it. During glaciations, the lower temperatures lead to a depletion of O^{18} in the ice of glaciers. The same principle is applied to ice when two isotopes of hydrogen are measured. Because the ice sheets of Antarctica and Greenland are very thick, ice cores obtained by drilling into these ice sheets are very long. They therefore provide a very long record of the climates of the past (known as "paleoclimates"). Based on the cores retrieved so far, scientists have been able to identify a sequence of glacial and interglacial cycles that covers the last 800,000 years.

The Earth has had many ice ages in its 4.5-billion-year history. Most recently, beginning about one million years ago, the Great Ice Age occurred during a time period called the Pleistocene. This glacial period formed an ice sheet in North America, Northern Europe, Northern Asia, and Antarctica that expanded until it reached its maximum extent about twenty thousand years ago. The Pleistocene Glaciation was not uniformly cold; short interglacial periods of warming occurred several times. Finally, about ten thousand years ago, the warming trend continued, melting the ice sheets and uncovering the northern continents. The northern part of Canada became free of ice about six thousand years ago. The mountain glaciers attached to the high mountain ranges of the American West are remnants of the Pleistocene period. In more recent centuries, the Earth experienced a shorter period of cold temperatures, called the Little Ice Age, beginning about 1650 and ending approximately in 1850, during which the Earth cooled by about 1° Celsius. (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.) The mountain glaciers that advanced during this period are currently retreating in response to today's higher temperatures.

• Context

At their present rate of melting and retreating, glaciers are having a major impact on the populations living in their vicinity. The increase in meltwater can increase the production of hydroelectricity for a short while but at the same time may impact the population's well-being in the very near future by decreasing the amount of available water for irrigation or electricity production when the glaciers will have completely disappeared. Monitoring glacier changes and drawing scientific conclusions about their retreat is not something new. As early as 1894 scientists began cataloging glaciers and their changes. These findings were published by the World Glacier Monitoring Service. Maximum extents of glaciers were computed by using the position of their terminal moraines, and their volumes were estimated by measuring the height of their lower end since it corresponds to the height of ice that used to occupy the glacial trough.

In the 1970's, during the International Hydrological Decade declared by United Nations Educational, Scientific, and Cultural Organization, the Temporal Technical Secretariat for the World Glacier Inventory was created and began making a comprehensive inventory of more than 100,000 glaciers worldwide. Since then, with the help of satellite instruments, it has been determined that there are about 160,000 glaciers, thousands of whose outlines, retreats, and advances are readily mappable. These measurements allow scientists to rapidly assess the impact of the warming of the Earth on the cryosphere, and their study has proven a valuable tool in monitoring their reaction to the warming of the Earth's atmosphere.

The work of the Intergovernmental Panel on Climate Change and the research conducted for the Fourth International Polar Year (2007-2008) organized by the International Council for Science in conjunction with the World Meteorological Organization are focused on understanding the extremely complex relationships between glaciers and climates. One of the goals of the United States National Committee for the International Polar Year is the creation of a network of observation platforms to monitor glaciers in order to provide reliable data by which scientists will be able to assess the impact of global warming both on the glaciers themselves and upon the global ecosystem of which they are an essential part.

Denyse Lemaire and David Kasserman

• Further Reading

Benn, Douglas I., and David J. A. Evans. *Glaciers and Glaciation.* New York: Arnold, 1998. Provides a complete description of the effects of glaciers on landscapes. The text is concise and clear, and artwork and photographs are superb.

Bennet, Matthew, and Neil Glasser. *Glacial Geology: Ice Sheets and Landforms.* New York: Cambridge University Press, 1997. Overview of the cryological earth sciences.

Hambrey, Michael, and Jurg Alean. *Glaciers.* New York: Cambridge University Press, 2006. Describes all types of glaciers with excellent illustrations.

Trewby, Mary. *Antarctica: An Encyclopedia from Abbott Ice Shelf to Zooplankton.* Toronto: Firefly Books, 2002. General encyclopedia of Antarctica. Explains all the features found on the continent, using clear and simple language.

See also: Cryosphere; Deglaciation; Glaciations; Greenland ice cap; Ice cores; Ice-out studies; Ice shelves; Interglacials; Mass balance; Permafrost.

Glacken, Clarence J.

American geographer and historian

Born: March 30, 1909; Sacramento, California
Died: August 20, 1989; Sacramento, California

An environmental historian who specialized in studying the relationships between culture and nature, Glacken was one of the first twentieth century scientists to recognize the connection between human activities and the environment.

• Life

For most of his career, Clarence J. Glacken was a faculty member at the University of California, Berkeley, in the Geography Department, although his academic post followed many varied types of employment. He was a native of California and attended Berkeley as an undergraduate student. There he was profoundly influenced by Frederick Teggart, author of *The Theory of History* (1925) and other works, experiences that first introduced Glacken to broad interdisciplinary scholarship which he later cultivated. He graduated during the Great Depression, however, and spent most of the 1930's and 1940's working not as an academic but in public service, for various government agencies, to provide relief to farmworkers entering California after fleeing the Dust Bowl. These experiences significantly influenced his life and increased his awareness of the interactions between humans and the environment.

In 1937, Glacken took almost a year off to travel the world, including Europe, the Mediterranean, and East Asia. When he returned to the United States, he continued to work with displaced farmworkers until 1941, when he was drafted into the U.S. Army during World War II. During his service, he was trained as a specialist in Japanese languages and culture and was posted to Korea. On his discharge, Glacken served in Korea as deputy director of the Bureau of Health and Welfare in the military government, where he studied deforestation. Later, the Pacific Science Board invited him to do an ethnographic study of three villages in Okinawa, which resulted in a highly regarded book, *The Great Loochoo: A Study of Okinawan Village Life*, published in 1955.

Glacken's varied experiences in different worlds fueled his interest in studying the history of ideas about nature and culture. Consequently, in his forties, Glacken began work on a Ph.D. in geography at The Johns Hopkins University, where he completed a thesis titled *The Idea of the Habitable World*. After he graduated in 1952, he was appointed to the faculty in the geography department at the University of California, Berkeley, where he joined Carl Sauer. He was a faculty member there for thirty-seven years—the duration of his career.

• Climate Work

Glacken was an environmental historian who specialized in the relationships between culture and nature. Climate scientists have only recently begun to rely on environmental historians to enhance their understanding of the dynamics of climate change impacts. Although the effects of expanding civilization and industrialization on climate was intensely debated worldwide during the nineteenth century, Glacken was probably the first twentieth century scientist to be concerned with these issues. As a faculty member and through his writings, he inspired many generations of students of the history of geographical ideas and contributed to historical and intellectual foundations for the environmental and conservation movement. The current understanding of how scientists throughout the ages have considered the interactions between nature and humankind was greatly enhanced by Glacken's scholarship.

Glacken wrote many books and papers about the history of ideas about nature and man. In 1955, he presented a paper titled "Changing Ideas of a Habitable World" at the conference Man's Role in Changing the Face of the Earth, a symposium that brought together the historical and current knowledge of these issues that was available at the time. This symposium represented a changing awareness among American scientists and indicated the beginning of a new era in which people began to realize that their actions affected nature and the physical world.

Glacken's most influential and prominent contribution was a book on nature and culture in Western thought from ancient times to the end of the nineteenth century, titled *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century*. This widely appreciated work brought together ideas in a manner that transcended geography as a discipline. Published in 1967, this text predated the resurgence of environmentalism in America. It originally was meant to be only an introductory chapter to a larger work. Glacken's primary purpose in this book was to uncover the variety and complexity of thinking on nature and culture in the Western tradition and to show how contemporary interests in conservation have long histories. Although he had accumulated a significant amount of material for a sequel that covered the modern period and included art, science, and philosophy, he was unable to finalize it for publication.

C. J. Walsh

• **Further Reading**

Agnew, John A., David N. Livingstone, and Alisdair Rogers. *Human Geography: An Essential Anthology.* Hoboken, N.J.: Blackwell, 1996. Part 3 of this five-part book is concerned with interactions between nature, culture, and landscape; includes a chapter on Glacken.

Glacken, Clarence J. *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century.* Berkeley: University of California Press, 1967. Glacken's most influential work, which helped redefine the discipline of geography.

Oakes, Timothy S., and Patricia L. Price, eds. *The Cultural Geography Reader.* New York: Routledge, 2008. Suitable for students, this reader includes discussions of history and its relationship to cultural geography, as well as a chapter on the works of Clarence Glacken.

See also: Anthropogenic climate change; Human behavior change.

Global climate

• **Category:** Meteorology and atmospheric sciences

The global climate system is complex and dynamic, greatly complicating attempts to evaluate or predict long-term alterations to Earth's climate. However, physical measurements of specific parameters can be made, rendering climate change quantifiable.

• **Key concepts**

chinook/foehn wind: a warm, dry wind on the eastern side of the Rocky Mountains or the Alps

climate controls: the relatively permanent factors that govern the general nature of the climate of a region

evaporation: the process by which a liquid changes into a gas

Hadley circulation: an atmospheric circulation pattern in which a warm, moist air ascends near the equator, flows poleward, descends as dry air in subtropical regions, and returns toward the equator

Inter-Tropical Convergence Zone (ITCZ): a low-pressure belt, located near the equator, where deep convection and heavy rains occur

Köppen climate classification system: a system for classifying climate based mainly on average temperature and precipitation

monsoon: a seasonal climate system characterized by wind and precipitation patterns

precipitation: liquid or solid water particles that fall from the atmosphere to the ground

rain shadow: the region on the lee side of a mountain where precipitation is noticeably less than on the windward side

subtropical high belt: a high-pressure belt where warm, dry air sinks closer to the surface

transpiration: the process by which water in plants is transferred as water vapor into the atmosphere

• **Background**

Climate is a general characterization of long-term weather and environment conditions for a specific location. Several major factors influence climate in a given region, including latitudinal position, the distribution of land and water, and elevation. Ocean currents, prevailing winds, and the positions of high- and low-pressure areas also have significant climatic effects.

Heterogeneous distributions of heat and water result in rich and varied climates. In particular, the tropical regions receive more energy from solar radiation than they emit in the form of infrared heat. The polar regions, by contrast, receive less energy from the Sun than they emit as heat. As a result, the tropics are regions of heat surplus, while polar regions are deficient in heat. Moreover, because tropical regions include large expanses of ocean, there is more water stored in the tropical atmosphere than is stored in the atmosphere at high latitudes.

The imbalance in the heat and water budget in the tropical and polar regions often leads to circulations that transport heat and water from and to these regions. These transports are typically carried out by both atmosphere and oceans. The weakening or strengthening of heat and water transports is an important signal for climate change.

Several methods have been developed to classify global climate. The most widely used method is based on the Köppen classification system. Designed by the German climatologist Wladimir Köppen (1846-1940), this method uses the average annual and monthly temperature and precipitation to describe a global climate for various climate zones. In this method, global climate is divided into the following six major groups, and each group is divided into subgroups.

- **Tropical Moist Climate (Group A)**

Tropical moist climate is typical of most of Earth's tropical regions (from the equator to about 20° latitude into each hemisphere). The climate of these regions is characterized by year-round warm temperatures and abundant rainfall. In the tropics, the annual mean temperature is typically above 18° Celsius, and typical annual average rainfall exceeds 150 centimeters. Tropical moist climate is divided based on rainfall characteristics into three subtypes of climate: tropical wet, or tropical rain-forest climate (Af); tropical monsoon climate (Am); and tropical wet-and-dry climate (Aw).

The tropical rain-forest climate exhibits constant high temperatures and abundant year-round rainfall. As a result, it is marked by dense vegetation, typically composed of broadleaf trees, jungles, and evergreen forests. A large number of diversified plants, insects, birds, and animals inhabit the tropical rain forests. Many lowlands near the equator are in this type of climate, which includes the Amazon River Basin of South America, the Congo River Basin of Africa, and the East Indies, from Sumatra to New Guinea.

Unlike the tropical wet climate, the tropical wet-and-dry climate has distinctive wet and dry seasons. Although the annual precipitation usually exceeds 100 centimeters, during the dry season the average monthly rainfall can be less than 6 centimeters. The dry season lasts more than two months. The tropical wet-and-dry climate dominates most of tropical Africa, tropical South America, and South Asia. The variations of dry and wet seasons in these regions are closely associated with the migration of the Inter-Tropical Convergence Zone (ITCZ) in the tropics.

The tropical monsoon climate exists between the tropical rain-forest and wet-dry climates: It has abundant rainfall, in excess of 150 centimeters per year, but the rains do stop briefly, typically for one or two months. Tropical monsoon climate can be seen along the coasts of Southeast Asia and India and in northeastern South America. In contrast to the wet-dry climate, the rain and the pause of rain in these areas are related to monsoonal circulation.

- **Dry Climate (Group B)**

Just outside the tropics, most of the continental land located between approximately 20° and 30° latitude in both the Northern and the Southern Hemispheres is in arid or semiarid climates. Precipitation in these areas is scarce most of the year, and evaporation and transpiration exceed precipitation.

The arid climate (BW) is the true desert climate and can be found in the Sahara Desert in Africa, a large portion of the Middle East, much of the interior of Australia, Central Asia, and the west coasts of South America and Africa. These areas are located in the subtropical high belt, which is caused by descending air from the Hadley circulation.

Around the margins of the arid regions, semiarid (BS) areas enjoy a slightly greater rainfall. The light rains of semiarid climes support the growth of short bunch grass, scattered low bushes, trees, and sagebrush. This climate can be found in the western United States, southern Africa, and the Sahel.

- **The Moist Subtropical Midlatitude Climate (Group C)**

Most subtropical midlatitude regions are farther poleward from the major dry-climate latitudes. These areas extend approximately from 25° to 40° latitudes in both the Northern and the Southern Hemispheres. This climate has distinct summer and winter seasons. Winter is mild, with average temperatures for the coldest month of between -3° and 18° Celsius. The regions in this climate belt are typically humid and have ample precipitation.

There are three major subtypes in the group C climate: humid subtropical (Cfa); west coast marine (Cfb); and dry-summer subtropical, or Mediterranean (Cs). The humid subtropical climate typically presents hot and muggy summers, but mild winters. Summers experience heavy rains, while winters are slightly drier. This climate type can be found principally along the east coasts of continents, such as the southeastern United States, eastern China, southeastern South America, and the southeastern coasts of Africa and Australia.

The west coast marine climate has cool summers and mild winters and produces more precipitation in winter than in summer. The largest area with this climate is Europe. Finally, the dry-summer, or Mediterranean, climate is distinctively characterized by extreme summer aridity and heavy rains in winter. Countries surrounding the Mediterranean Sea and the U.S. West Coast, including Northern California and Oregon, are in this type of climate.

- **Moist Continental Climate (Group D)**

The moist continental climate is located farther north of the moist subtropical midlatitude climate zone, from 40° to 50° north latitudes. This climate mostly occurs in North America and Eurasia. The general characteristics of the moist continental climate are warm-to-cool summers and cold winters. The average temperature of the warmest month exceeds 10° Celsius, and the coldest month's average temperature generally drops below -3° Celsius. Winters are severe, with snowstorms, blustery winds, and bitter cold. The climate is controlled by a large landmass.

The group D climate is further divided by summer temperature into three major subtypes: humid continental with hot summers (Dfa), humid continental with cool summers (Dfb), and subpolar (Dfc). Both winter and summer temperatures in the Dfa climate are relatively severe. That is, winter

The Tibetan Plateau is among the most prominent examples of a highland climate zone, which is characterized by rapid changes in climate type with altitude. (Xinhua/Landov) is cold and summer is hot. Farther north is the Dfb climate, which experiences long, cool summers and long, cold, windy winters. The subpolar climate presents severely cold winters and short summers. In the subpolar region, moisture supply is limited. Therefore, precipitation is low.

• Polar Climate (Group E)

The polar climate exists over the northern coastal areas of North America and Eurasia, Greenland, the Arctic, and Antarctica. It is characterized by low temperatures year-round. Even during the warmest month, the temperature is below 10° Celsius. Precipitation is scarce in these parts of the Earth.

The polar climate can be divided into two subtypes: the polar tundra (ET) climate and the polar ice-cap (EF) climate. The tundra climate occupies the coastal fringes of the Arctic Ocean, many Arctic islands, and the ice-free shores of northern Iceland and southern Greenland. In these regions, the ground is permanently frozen to depths of hundreds of meters, a condition known as permafrost. In summer, the temperature can remain above freezing, allowing tundra vegetation to grow. The monthly mean temperature under the ice-cap climate is mostly below 0° Celsius. The ice cap occupies the interior ice sheets of Greenland and Antarctica. The growth of plants is prohibited, and the landscape is perpetually covered with snow and ice. Many studies show that these regions are most sensitive to global warming and have experienced rapid snow and ice melting in recent decades.

• Highland Climates (Group H)

The distribution of global mountain ranges and plateaus creates another type of climate. Climate in highland regions is unique. Highland climates are characterized by a great diversity of conditions. Because air temperature decreases with altitude, climatic changes corresponding to those from group B to group E will be experienced when ascending mountain slopes. In general, every 300 meters of mountain elevation will correspond to a change of climate type.

In addition to the drop of temperature with increased altitude, orography modifies precipitation and wind patterns in many ways. For example, a mountain's windward slopes typically receive more precipitation than its leeward slopes. Therefore, more dense vegetation grows on the windward slopes of large mountains, such as the western slope of the Rockies, than on the leeward slopes, such as the eastern slope of the Rockies. Often, the leeward foot of a mountain receives very little precipitation. These areas are often called "rain shadows." Leeward mountain foots are also subject to downslope mountain winds from time to time, especially during winters. These winds are called "chinook wind" in North America, or "foehn wind" in Europe.

The most prominent highland climate occurs over the Tibetan Plateau, where the average elevation is over 4,000 meters. In North America, highland climates characterize the Rockies, Sierra Nevada, and Cascades. In South America, the Andes create a continuous band of highland climate. Many of these mountains and highlands play central roles in monsoonal circulation, an important global climate system in various parts of the world.

• Context

Global climate is a complex system that involves interactions among Earth's atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. In an even larger context, the global climate is just a part of the Sun-Earth system. For a particular place on Earth, the formation of the local climate pattern is dependent upon a set of climate controls. Despite its complexity, the global climate can be classified according to two basic physical parameters: mean temperature and precipitation. Future climate change can be measured and quantified by closely monitoring the change of these parameters in various parts of the world.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. One of the most widely used introductory books on atmospheric science; covers a wide range of topics on weather and climate.

Geer, Ira W., ed. *Glossary of Weather and Climate*. Boston: American Meteorological Society, 1996. Collection of terms, concepts, and definitions related to weather and climate.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Elementary introductory text that covers a wide range of atmospheric sciences.

U.S. Climate Change Science Program. *Our Changing Planet: A Report by the Climate Change Science Program and the Subcommittee on Global Change Research for Fiscal Year 2007*. Washington, D.C.: Author, 2006. A report of the Climate Change Science Program, established in 2002 to empower the U.S. national and global communities with sufficient science-based knowledge to manage risks and opportunities for change in the climate and related environmental systems.

See also: Climate and the climate system; Climate models and modeling; Continental climate; Maritime climate; Mediterranean climate; Monsoons; Ocean-atmosphere coupling; Polar climate; Weather vs. climate.

Global Climate Coalition

- **Category:** Organizations and agencies
- **Date:** Established 1989; disbanded 2002
- **Web address:** http://www.globalclimate.org/ (deactivated)

• Mission

The Global Climate Coalition (GCC) is a defunct industry group that worked to set the climate change agenda of the United States. This organization was influential and successful in its endeavors. The GCC dissolved amid increased understanding in climate science and the rise of public opinion in support of public policy to address climate change. The coalition met many of its goals prior to its dissolution.

The GCC was formed by representatives of multinational corporations reliant on the use of fossil fuels, particularly in the energy and transportation sectors. Prominent members of the GCC included BP, Royal Dutch Shell, Dupont, Ford Motor Company, Daimler Chrysler, Texaco, General Motors, and Exxon (now ExxonMobil). The mission of the GCC was to influence U.S. public policy regarding climate change.

The GCC was organized in reaction to the findings of the Intergovernmental Panel on Climate Change (IPCC). A GCC representative argued at the libertarian think tank the Cato Institute that the IPCC report was flawed and represented the views of pro-climate-change activists. The GCC rejected all government-mandated reductions of greenhouse gas (GHG) emissions in the United States. The GCC was against U.S. participation in the Kyoto Protocol. The coalition argued that climate science and the human impact on climate change were both too uncertain to justify coercive government policy intended to lessen GHG emissions. The GCC conducted lobbying and public relations campaigns to spread the skeptical view of climate change to the public.

• Significance for Climate Change

The GCC was an influential factor in setting the U.S. climate change agenda. The GCC pressured the Bill Clinton administration to reject command-and-control environmental regulations intended to address climate change. The coalition argued that burdensome regulations designed to address climate change would decrease economic growth and hinder the economic competitiveness of U.S. companies. The GCC was an influential actor in preventing U.S. ratification of the Kyoto Protocol. In 1998, the Senate voted to reject the Kyoto Protocol 95-0.

The demise of the GCC began with the withdrawal of BP, a major multinational oil company. BP broke ranks with the GCC in May, 1997. The GCC lost members as increasing scientific evidence and rising consensus alarmed governments, and people across the world demanded action on climate change. In 2002, the GCC disbanded, stating, "At this point, both Congress and the Administration (Bush II) agree that the United States should not accept mandatory cuts in emissions required by the Protocol." The GCC claimed its mission had been accomplished, so there was no reason to maintain an active presence to shape the climate change agenda.

The skeptical view of climate change found representation in the George W. Bush administration. The administration took the view that climate science was uncertain and asked the National Academy of Sciences (NAS) for assistance in determining if IPCC reports had been tampered with by pro-climate-change-policy activists.

Although the GCC has dissolved as an organization, its activities made a lasting impact in setting the climate policy agenda in the United States. Many in the business sector continue to insist that there is no need to transform the global economy to address climate change. In June, 2008, National Aeronautics and Space Administration climatologist James E. Hansen argued that corporate executives who promote contrarian arguments against climate change theory should be held liable for their actions. Hansen contends such activities are "crimes against humanity and nature" and that executives from many fossil-fuel-intensive corporations consciously attempt to confuse the public on the state of understanding and agreement among climate scientists.

Justin Ervin

- **Further Reading**

Bellamy Foster, John. *Ecology Against Capitalism.* New York: Monthly Review Press, 2002. Argues that climate change is an issue ill addressed by capitalist institutions and is caused by the drive for unending economic growth. Sees organizations such as the GCC as unsurprising given that global capitalism is reliant on the combustion of fossil fuels.

Brown, Lester R. *Eco-Economy: Building an Economy for the Earth.* New York: W. W. Norton, 2001. Documents the decline of the GCC as members began to define their corporate interest in terms of the need to address climate change.

Lewis, Paul. "U.S. Industries Oppose Emission Proposals." *The New York Times*, August 22, 1995. Documents GCC resistance to U.S. participation in climate change negotiations. The GCC called on the U.S. government to study the impact that reductions in greenhouse gas emissions would have on the U.S. economy.

Pilkington, Ed. "Put Oil Firm Chiefs on Trial, Says Leading Climate Change Scientist." *The Guardian*, Monday, June 23, 2008. Discusses James E. Hansen's return to Congress after he first warned of climate change in 1988. Hansen claims industry groups have been consciously spreading misinformation on climate change that has slowed government reaction to address climate change.

See also: American Enterprise Institute; Brundtland Commission and Report; Catastrophist-cornucopian debate; Cato Institute; Competitive Enterprise Institute; Conservatism; Economics of global climate change; Skeptics.

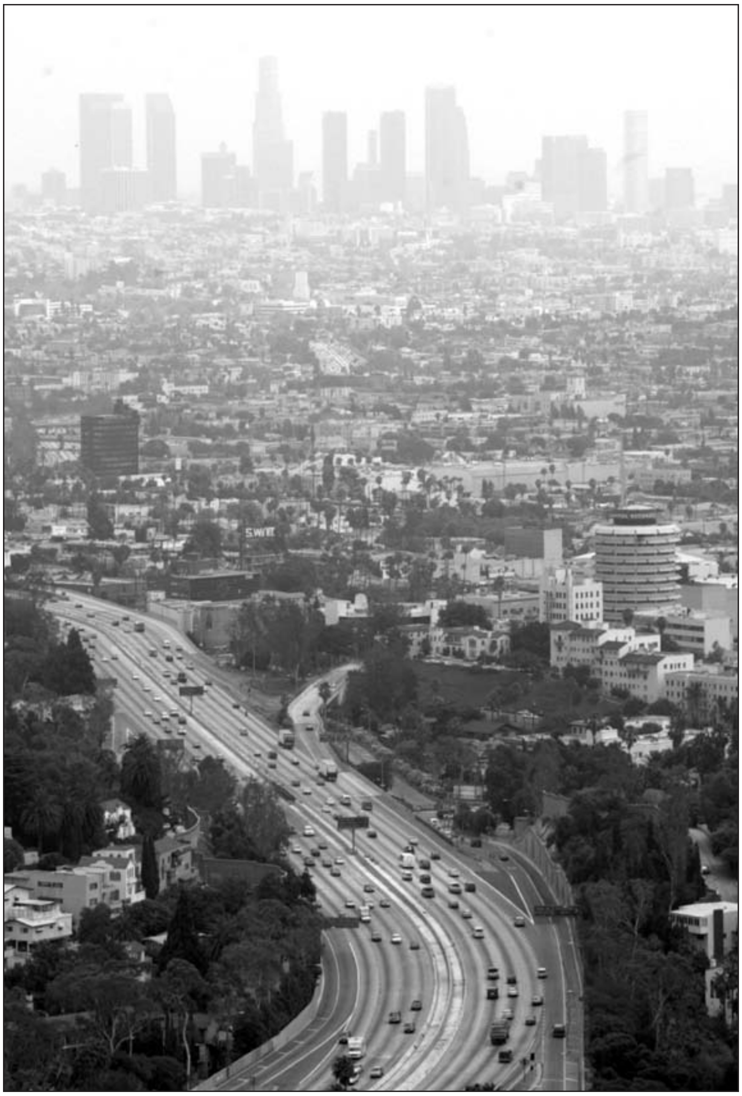
Global dimming

- **Category:** Physics and geophysics

- **Definition**

The first widespread effort to measure solar radiation began during the 1957-1958 International Geophysical Year (IGY), when a global network of radiometer stations was established to measure the Earth's radiation budget. In the following years, scientists discovered that the amount of solar radiation reaching the Earth's surface was not constant. From 1960 to 1990, measurements of solar radiation decreased worldwide by 4 to 6 percent. The greatest rates of decline were in the heavily populated, industrialized regions of the Northern Hemisphere; smaller decreases were measured over the Arctic and Antarctic. The term "global dimming" was coined during the 1990's to describe this observed reduction in surface solar radiation.

Many scientists contend that global dimming results from the release of anthropogenic aerosols, or air pollution. Aerosols are solid particles or liquid droplets, typically 0.01 to 10 micrometers in size, that are produced by natural or anthropogenic sources and remain suspended in the atmosphere. Anthropogenic sources include the release of sulfur dioxide (SO_2) and black carbon from the combustion of fossil fuels. Some scientists contend that aerosols cause dimming by absorbing solar radiation or scattering it back into space and by modifying the optical characteristics and coverage of clouds. In clouds, anthropogenic aerosols act as cloud condensation nuclei. Their presence significantly increases the number of sites on which clouds droplets can form, leading to the formation of clouds with many more small droplets than would occur naturally. This process leads to the formation of clouds that reflect greater amounts of solar radiation because of their higher albedos, expanded coverage, and longer lifetimes.



The Los Angeles skyline is obscured by a mix of fog and smog. Such air pollution may contribute to global dimming. (AP/Wide World Photos)

• **Significance for Climate Change**
Global dimming is important to the broader discussion of climate change for many reasons. For one, it has fostered a more focused discussion of the global impacts of anthropogenic aerosols. While scientists have long observed the large-scale impacts of aerosols, such as the global cooling that followed the eruption of Mount Pinatubo in 1991, air pollution was often regarded as a small-scale problem confined to urban and industrialized regions. Observations of global dimming have fostered a broader consideration of how aerosols impact the global climate system.

Some scientists hypothesize that global dimming may have masked the effects of global warming from the 1960's to the present. They suggest that observations of increased global temperature, often attributed to GHG emissions, may be more significant than observed, because global dimming was simultaneously acting to cool surface temperatures. This theory provides a basis to explain why surface temperatures rose by 0.3° Celsius from 1960 to 1990, while the amount of solar radiation reaching the Earth's surface declined by 4 to 6 percent.

Since 1990, the hypothesized impact of global dimming has raised concerns among global warming experts, because measurements of solar radiation suggest that dimming has waned in many parts of the world, a phenomenon that has earned the label "global brightening." Some scientists hypothesize that focused efforts to reduce air pollution, such as the United States' 1990 Clean Air Act Amendments, along with changes in the global economy, have fostered a worldwide reduction in aerosol emissions. Since aerosols have a much shorter residence time in the atmosphere than

GHG emissions, there is a concern that continued efforts to reduce anthropogenic aerosols will cause global warming to proceed more rapidly over the next century than had been predicted.

In addition to its impact on global temperature, some scientists hypothesize that global dimming affects the hydrologic cycle by reducing the rate of evaporation and precipitation worldwide. Evidence for this hypothesis was originally uncovered from pan evaporation data collected over the latter half of the twentieth century, when scientists observed an annual decrease in the amount of water evaporated at many sites in the Northern Hemisphere. This result was unexpected, as it was generally thought that higher temperatures associated with global warming would increase rates of evaporation. Subsequent research, however, suggested that solar radiation may be a more important factor than originally believed in determining evaporation rates.

Provided this context, the reduction in solar radiation observed since the 1950's is viewed by many scientists as additional evidence for global dimming. It provides a basis to explain why evaporation rates decreased from 1960 to 1990 while global temperatures increased on average. In addition to the impacts outlined above, atmospheric scientists are investigating the broader impacts of global dimming on global circulation patterns, the distribution of rainfall worldwide, the vertical temperature profile, and the ability of plants to conduct photosynthesis under changing solar conditions.

Jeffrey C. Brunskill

- **Further Reading**

Hansen, James, et al. "Earth's Energy Imbalance: Confirmation and Implications." *Science* 308, no. 5727 (June 3, 2005): 1431-1435. Presents a detailed discussion of how anthropogenic emissions of GHGs and aerosols affect the global climate system. Provides an important basis for reasoning about the response of the global climate system to changes in surface solar radiation and the ability of atmospheric models to predict future trends.

Roderick, Michael L., and Graham D. Farquhar. "The Cause of Decreased Pan Evaporation over the Past Fifty Years." *Science* 298, no. 5597 (November 15, 2002): 1410-1411. Discusses the pan evaporation paradox, the unexpected observation that evaporation rates decreased worldwide from 1950 to 2000 while global temperatures increased. The results of this study are regarded by many as evidence of global dimming.

Stanhill, Gerald. "Global Dimming: A New Aspect of Climate Change." *Weather* 60, no. 1 (January, 2005): 11-14. Stanhill was one of the first scientists to publish observations of decreasing surface solar radiation. This article summarizes the evidence for global dimming since the 1960's and discusses many of the causes and consequences of the phenomenon.

See also: Aerosols; Air pollution and pollutants: anthropogenic; Albedo feedback; Clouds and cloud feedback; Evapotranspiration; Hydrologic cycle; Rainfall patterns.

Global economy

- **Category:** Popular culture and society

The global economy and climate change are two interrelated processes of globalization. As the economy grows, so do factors associated with climate change, which can both drive and impede economic growth.

- **Key concepts**

capitalism: an economic system in which the means of production are privately owned and operated with the goal of increasing wealth

commodity: anything that has commensurable value and can be exchanged

economic interdependency: a state of affairs in which the economic processes of a group of nations are mutually dependent

globalization: the worldwide expansion and consequent transformation of socioeconomic interrelationships

industrialization: the process of transformation from an agrarian society based on animal and human labor to an industrial society based on machines and fossil fuels *liberal institutionalism:* a school of thought that focuses on cooperation between countries derived from agreements and organizations

neoliberalism: a school of economic thought that stresses the importance of free markets and minimal government intervention in economic matters

• Background

The global economy is the result of a process of increasingly global economic integration that began in the sixteenth century. European powers spread capitalism to colonies that provided cheap labor (including slaves), abundant natural resources, and vital new markets for goods and services. The expansion of European capitalism led to the export of industrialization in the nineteenth and twentieth centuries. The United States worked to reorganize the global economy following the instability of the early twentieth century that culminated with World War II. This reorganization was negotiated at Bretton Woods, New Hampshire, in 1944. The International Monetary Fund (IMF) and the World Bank were created at the Bretton Woods Conference. The General Agreement on Tariffs and Trade (GATT) was signed in 1947. Together, these institutions and agreements were designed to include as much of the world's people and territory as possible under a global capitalist economy. The Soviet Union and China limited this vision at the time. Members of the former Soviet Union and China have since become vital actors in the global economy.

• Economic Globalization

The global economy represents a central process of globalization. As such, it increases economic interdependency. Economic globalization is made possible through advances in information and transportation technology. With the rise of technology, many of the world's countries have become interconnected through complex networks of economic production and consumption.

Economic globalization is composed of many actors. Countries legalize rules regarding international economic transactions. Multinational corporations dominate international economic production and the global trade in goods and services. International financial institutions finance the global flow of goods and services and provide money capital for foreign investment.

• The Global Economy and Climate Change

The spread and growth of the global economy increases the energy intensity of the world's countries. The increase in the volume of exchange of goods and services, over greater distances, has increased the use of fossil fuels. More people drive more kilometers in automobiles and fly longer distances in airplanes. More people use increasing amounts of electricity, most of which is produced by fossil fuels. The expansion of global economic activity requires a continuing increase in the consumption of fossil fuel. The consumption of fossil fuel is the major factor causing climate change.

Economic globalization increases the human transformation of the environment. Deforestation results from the human need for lumber for construction and land for agriculture. Rising living standards lead to increased construction and the increase of the consumption of meat. Deforestation decreases the Earth's ability to remove carbon dioxide from the atmosphere. Increased meat consumption increases the concentration of the greenhouse gas (GHG) methane in the atmosphere.

Problems associated with the global economy and climate change have gained the attention of powerful actors within the global economy. The IMF and the World Economic Forum (WEF) agree that climate change, if left unchecked, is likely to destabilize the global economy. The Stern Report, produced by the United Kingdom in 2006, announced that climate change would likely cause a 5 to 20 percent decrease in global GDP. This could lead to a global economic depression and violent conflict. Climate change could dissolve global economic networks, creating shortages of vital economic inputs, leading to global economic decline.

• Political Economic Theory and Climate Change

The impact the global economy has on climate change is addressed by theories of political economy. One's adherence to a particular theory greatly impacts the way one interprets the relationship between the global economy and climate

A Coca-Cola vendor hawks his wares in the middle of Moscow's Red Square, a former symbol of communism, August, 2002. (AP/Wide World Photos)

change. For example, neoliberal economic theorists argue that global markets will distribute the technologies needed to address climate change. New technologies, such as wind generators, photovoltaic solar panels, hybrid automobiles, and fuel cells will circulate across the globe under free market capitalism. Liberal institutionalist theorists agree with neoliberals about technological transfer. They argue, however, that the global economy requires active public management to address climate change. Liberal institutionalists cite the importance of cooperation among countries to address climate change. This cooperation is best realized in the form of international governmental organizations and agreements, such as the Kyoto Protocol.

Some theorists argue the global economy is unsustainable. These theorists propose dramatic transformations for the economy. Ecological economists argue environmental problems such as climate change are symptoms of the Earth no longer being able to assimilate human economic activity. Ecological economists argue that the global economy is unsustainably depleting Earth's natural capital at an ever-increasing rate. This condition cannot last indefinitely, because the Earth is a finite system. Ecological economists argue the global economy must attain an optimal scale or face devastating consequences.

• Context

The global economy has created unprecedented opportunities and problems for humanity. The global economy has created unprecedented wealth, but it has also increased social instability while contributing to environmental problems such as climate change. Climate change transcends the ability of individual countries to create solutions. To confront climate change, countries of the world will have to cooperate at unprecedented levels. Rich countries will have to promote policies to help poor countries address climate change. Those living in rich countries and enjoying energy-intensive lifestyles have little right to demand economic sacrifices from the poor.

Humanity faces a serious economic paradox with climate change. In order to remain stable, the global economy must grow. However, to address climate change, this growth must be achieved while diminishing the factors responsible for climate change. Given a global economy that is based on the combustion of fossil fuels, this will be no easy feat. The global economy and climate change are interconnected but contradictory functions. As the global economy grows, the dangers of climate change increase. As the dangers of climate change increase, global economic growth is threatened. This relationship is critically important and offers no easy solutions.

Justin Ervin

• Further Reading

Brown, Lester R. *Plan B 3.0: Mobilizing to Save Civilization.* 3d ed. New York: W. W. Norton, 2008. Lays out an extensive plan to transform the global economy to meet ecological limits.

Daly, Herman E. "Sustainable Growth: An Impossibility Theorem." In *Valuing the Earth: Economics, Ecology, and Ethics,* edited by Herman E. Daly and

Kenneth N. Townsend. Cambridge, Mass.: MIT Press, 1996. Argues that "sustainable growth" is an irrational economic concept and that global warming and environmental problems in general are expressions of this proposition. Rather than growth, the global economy should focus on maintaining an optimal scale, or size.

Ervin, Justin, and Zachary A. Smith. *Globalization: A Reference Handbook*. Santa Barbara, Calif.: ABC-CLIO, 2008. Focuses on the economic, environmental, and security dimensions of globalization from different political worldviews.

Wallerstein, Immanuel *The Modern World System*. New York: Academic Press, 1974. Asserts that global capitalist society began in Western Europe in the sixteenth century, and that the modern world system is composed of core, periphery, and semi-periphery countries that each play specific roles within the global economy.

See also: Agriculture and agricultural land; Anthropogenic climate change; Carbon footprint; Damages: market and nonmarket; Economics of global climate change; Employment; Energy resources; Enhanced greenhouse effect; Environmental economics; Fossil fuels; Renewable energy; Sustainable development.

Global energy balance

- **Category:** Astronomy

• Definition

The global energy balance is the overall inflow and outflow of energy to and from Earth. The different processes that control this balance are atmospheric reflectance, absorption by the atmosphere and Earth's surface, and reradiation of energy to space by Earth itself. Electromagnetic energy arrives in the form of solar radiation that passes through the atmosphere and interacts with the surface.

When electromagnetic energy hits an object, such as Earth, three processes can occur. Transmission occurs when the energy passes through an object without affecting it. Reflection occurs when the energy bounces off the object, and absorption occurs when the energy is taken up by the object. Incoming solar radiation exists at all wavelengths, but the dominant intensity is within the visible band (400-700 nanometers), at 550 nanometers. Of this energy, 30 percent is reflected from the atmosphere back into space, 25 percent is absorbed by the atmosphere, and the remaining 45 percent is absorbed by Earth's surface.

The energy absorbed by Earth's surface is converted to thermal energy and raises the surface temperature. Because the Earth itself is a warm object, it also emits electromagnetic energy to space. The energy emitted by Earth occurs in longer wavelengths than incoming solar radiation, with the maximum intensity at 10 millimeters. Of this energy, 70 percent passes through the atmosphere and is transmitted to space. However, 30 percent is reabsorbed by atmospheric greenhouse gases (GHGs), including carbon dioxide (CO_2), methane, nitrous oxide, and water vapor. This reabsorbed energy contributes to further warming of Earth. The balance between the amount of incoming solar radiation and the amount of reflected, absorbed, and transmitted energy controls global wind patterns and oceanic circulation. Shifts in this balance determine the overall warming and cooling of the planet.

• Significance for Climate Change

Changes to the global energy balance, which is affected by both natural and anthropogenic processes, are a fundamental cause of climate change. Processes that affect the global energy balance are often intertwined with one another, resulting in various feedback mechanisms that can enhance or reduce the effects of the original change. Natural changes in the global energy balance can be caused by variations in Earth's orbit or in the output of solar radiation—both of which affect the amount of energy coming into Earth.

The shape of Earth's orbit and the tilt of Earth's axis change slightly over timescales ranging from 11,000 to 100,000 years. These changes can cause the Earth to be somewhat closer to or further away from the Sun, leading to a relative increase or decrease in the amount of solar radiation that reaches Earth. In the geologic past, these types of changes are manifested as climate shifts on timescales of millions of years, known as greenhouse and icehouse conditions. During greenhouse times, Earth is ice-free because of high concentrations of GHGs. During icehouse times, Earth is covered by variable proportions of ice, and the climate shifts between interglacial times (less ice) and glacial times (larger continental ice sheets) on timescales of tens of thousands of years. The most recent ice age peaked at the Last Glacial Maximum, approximately 20,000 years ago. Approximately 850-630 million years ago, Earth may have been completely covered by ice, creating a so-called Snowball Earth. This hypothesis, however, remains highly controversial among scientists. Blocking some proportion of incoming solar radiation remains a goal of certain geoengineering proposals as a means to prevent future global warming.

Changes in GHG concentrations also affect the global energy balance—and therefore, global temperature—because of changes in the amount of reradiated energy trapped on Earth. Volcanoes are natural sources of GHGs, and geologic evidence suggests that there is a correlation between widespread volcanism and greenhouse times in the past. Anthropogenic changes in the global energy balance are thought to be caused by the addition of GHGs to the atmosphere. The most notable of these is the production of CO_2 through the burning of fossil fuels, although the production of methane should not be discounted. Increased concentrations of GHGs in the atmosphere lead to increased absorption of energy radiated from Earth, which, in turn, leads to further warming of the surface. The Intergovernmental Panel on Climate Change (IPCC) estimates that anthropogenic changes in atmospheric CO_2 concentrations have resulted in a global temperature increase of 0.74° Celsius between 1905 and 2005. Removing CO_2 from the atmosphere and sequestering it in reservoirs such as the deep ocean, ocean sediments, or rock formations constitutes a second geoengineering approach to reduce future global warming.

Anna M. Cruse

• Further Reading

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Comprehensive treatment of the causes of climate change, written for a wide audience. Figures, illustrations, glossary, index, references.

Kunzig, Robert. "A Sunshade for Planet Earth." *Scientific American* 299, no. 5 (November, 2008): 46-55. Explains the basic premises of geoengineering and discusses the potential pros and cons of a variety of geoengineering approaches. Figures.

Rapp, Donald. *Assessing Climate Change: Temperatures, Solar Radiation, and Heat Balance*. New York: Springer, 2008. Presents evidence for climate change—both natural and anthropogenic. Rapp is a systems engineer who attempts to consider the Earth system as a whole. Figures, tables, index, references.

Walker, Gabrielle. *Snowball Earth: The Story of the Great Global Catastrophe That Spawned Life as We Know It*. New York: Crown, 2003. A presentation of the Snowball Earth hypothesis, as developed by Paul Hoffman, for nongeologists. Combines geological theory and data with stories of Hoffman's travels to remote locations to conduct his research. Index, references.

See also: Climate and the climate system; Climate engineering; Earth history; Earth motions; Glaciations; Greenhouse effect; Greenhouse gases; Interglacials.

Global Environment Facility

- **Category:** Organizations and agencies
- **Date:** Established 1991
- **Web address:** http://www.gefweb.org

• Mission

The Global Environment Facility (GEF) provides grants and concessional funds to recipient countries for projects and activities that protect the global environment. GEF programs focus on environmental problems involving climate change, biological diversity, international waters, and depletion of the ozone layer.

Jointly implemented by the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank, the GEF was launched as a pilot program in 1991. The GEF secretariat, which is functionally independent from the three implementing agencies, reports to the Council and Assembly of the GEF. The council is the main governing body and consists of representatives from thirty-two countries, eighteen of which receive GEF funds and fourteen of which are nonrecipient nations. Since 1994, any country that is a member of the United Nations or one of its specialized agencies has been able to become a GEF participant by filing a notification of participation with the GEF secretariat. By 2007, 178 countries were participating in the GEF program; Somalia became the 178th participant nation in that year.

Countries may be eligible for GEF project funds in one of two ways: by meeting the eligibility requirements to borrow from the World Bank or to receive technical assistance funds from the UNDP or by meeting the eligibility requirements for financial assistance through either the Convention on Biological Diversity or the U.N. Framework Convention on Climate Change (UNFCCC). In either case, the country must also be a participant in the Convention on Biological Diversity or the UNFCCC to qualify for GEF funds.

The organizing principle of the GEF is that no new bureaucracy will be created to support it. The UNDP is responsible for technical assistance activities and helps identify projects and activities consistent with the GEF's Small Grants Program, which awards nongovernmental organizations (NGOs) and community groups around the world. Responsibility for initiating the development of scientific and technical analysis and for advancing environmental management of GEF-financed activities rests with the UNEP, as does the management of the Scientific and Technical Advisory Panel, which provides scientific and technical guidance to the GEF. The World Bank serves as the repository of the GEF trust fund and is responsible for investment projects. It also seeks resources from the private sector in accordance with GEF objectives.

GEF resources aim to facilitate projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants. Projects and activities must be approved by the GEF Council. If at least four council members request a review of the final project documents, the council will conduct the review prior to granting approval of GEF funds.

• Significance for Climate Change

As of 2008, the GEF was supporting more than six hundred climate-change-related projects and programs in scores of developing nations around the world. These projects help those nations to contribute to the objective of the UNFCCC by supporting measures to reduce the risk or minimize the adverse effects of climate change. The climate-related projects GEF supports center on lowering greenhouse gas (GHG) emissions through adopting renewable energy sources, energy-efficient technologies, sustainable transportation methods, and clean energy sources.

The GEF also supports adaptation to climate change through programs that attempt to cope with the negative impacts of climate change faced by countries, regions, and communities at particular risk. In addition to allocating approximately $250 million per year for such projects, the GEF oversees several funds under the UNFCCC: the Least Developed Countries Fund (LDCF), the Special Climate Change Fund (SCCF), and the Special Priority on Adaptation (SPA). The latter supports programs and projects that may be integrated into national policies and sustainable development planning. The GEF also assists member nations in their communications with and reporting to the UNFCCC, including reports on GHG inventories.

Finally, the GEF sponsors outreach to educate the public. In December, 2007, for example, the GEF joined forces with UNEP, the World Bank, Global Initiatives, and Artists' Project Earth to create *Fragile Planet*, a video about human impact on climate change.

Alvin K. Benson

• Further Reading

Axelrod, Regina S., David Leonard Downie, and Norman J. Vig, eds. *The Global Environment: Insti-*

tutions, Law, and Policy. 2d ed. Washington, D.C.: CQ Press, 2004. Essays address the history of interational environmental organizations and treaties as well as the dynamics of their implementation. Devotes several pages to the GEF.

Global Environment Facility. *Valuing the Global Environment: Actions and Investments for a Twenty-first Century*. Washington, D.C.: Author, 1998. A foreword by Brazilian president Fernando Henrique Cardoso and an introduction by GEF chair Mohamed T. El-Ashry introduce thirty-three essays from more than twenty nations, with authors such as biologist E. O. Wilson and Queen Noor of Jordan, on environmental challenges and the need for international solutions.

Horta, Korinna, and Robin Round. *The Global Environment Facility—The First Ten Years: Growing Pains or Inherent Flaws?* Sterling, Va.: Pluto Press, 2002. A critique of the GEF by authors associated with the International Program of Environmental Defense and the Halifax Initiative.

Young, Zoe. *A New Green Order? The World Bank and the Politics of the Global Environment Facility*. Sterling, Va.: Pluto Press, 2002. Explores the GEF from a political perspective by reference to documents and interviews. Young considers the GEF as a product of Western governments seeking to use funding to control U.N. treaties on global resource use and the environment.

See also: Agenda 21; Asia-Pacific Partnership; United Nations Division for Sustainable Development; United Nations Environment Programme; United Nations Framework Convention on Climate Change; World Bank; World Trade Organization.

Global monitoring

• **Category:** Meteorology and atmospheric sciences

To know what is happening with global climate, researchers must be able to determine exactly what has happened in the past, which requires good data taken at the same place over a period of several decades. Global monitoring is a collective term used in relation to the measurement of a wide variety of atmospheric and surface properties on a global or regional scale at frequent intervals.

• Key concepts

global: relating to the whole Earth

homogeneous climate data: a sequence of values of a climate variable, such as precipitation, which have been observed under the same or similar conditions and with the same or similar measuring equipment; the combination of climate data from two localities that are near each other is often made when considering climate change

monitoring: the systematic observation of an element such as precipitation, sea surface temperatures, or wind speed; such observations are usually made every six hours and sometimes every three hours, hourly, or (conversely) only once daily

observing systems: systems of collectively gathering and analyzing temperature and other atmospheric observations, particularly (in modern times) through the World Meteorological Organization

regional: relating to areas such as the Pacific, the Atlantic, the tropics, and large land areas, such as North America or Australia

• Background

The monitoring of the climate and related variables on global and regional scales is essential if correct analyses of what has happened, and what is happening, to the atmospheric climate are to be made. For example, it is often mentioned, especially by the media, that the climate is getting warmer, or cooler, or drier, or wetter, or more humid, or windier, and so on. What the true situation is, however, cannot be determined without rigorous and ongoing collection and examination of data. For example, are the polar ice areas increasing or deceasing, and are glaciers advancing or retreating? Are these trends different from what happened a few decades ago? The correct monitoring of the global climate and related variables is clearly necessary to advance our knowledge of the true situation.

Global Monitoring Principles

According to the GCOS Web site, "effective monitoring systems for climate should adhere to the following principles":

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems. Furthermore, operators of satellite systems for monitoring climate need to:
    (a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
    (b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

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• Global Climate Monitoring System

Temperature and other atmospheric observations have been made in many parts of the world for more than a century, and in some places for more than two hundred years. Initially these observations were made by single entities, but during the last hundred years, particularly during the last fifty years, there has been an effort to centralize and consolidate these data.

The World Meteorological Organization (WMO) and its forerunner, the International Meteorological Organization (IMO), have, for more than one hundred years, been at the forefront of organizing research on and monitoring the world's climate. In particular, since 1992 the Global Climate Observing System (GCOS) has supported this research according to several key principles: operation of historically uninterrupted stations and observing systems should be maintained; high priority for additional observations should be focused on data-poor regions, poorly observed parameters, and regions sensitive to change; and operators of satellite systems for monitoring climate need to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

• Regional Monitoring

A good example of "regional monitoring" is the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP), which was developed in 1991 as the Australian government's response to con-

(continued from p. 507)

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.

12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.

13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.

14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.

15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.

16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.

17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.

18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.

19. Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.

20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

Source: Global Climate Observing System.

cerns raised by member countries of the South Pacific Forum over the potential impacts of human-induced global warming on climate and sea levels in the Pacific region. The first three phases of the project established a network of twelve high-resolution Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) sea-level and climate-monitoring stations throughout the Pacific.

- **U.S. National Climate Center**

Another example of "regional monitoring" is the Climate Prediction Center (CPC) of the National Weather Service (part of the National Oceanographic and Atmospheric Administration, NOAA). The CPC collects and produces daily and monthly data, time series, and maps for various climate parameters, such as precipitation, temperature, snow cover, and degree days for the United States, the Pacific islands, and other parts of the world. The CPC also compiles data on historical and current atmospheric and oceanic conditions, the El Niño-Southern Oscillation (ENSO) Index, and other climate patterns, such as the North Atlantic and Pacific Decadal Oscillations, as well as stratospheric ozone and temperatures.

- **U.K. Climate Research Unit**

A significant global center for compiling temperature and other climate data sets is the Climate Research Unit (CRU) of the University of East Anglia in the United Kingdom. Some of the data produced are available online, and other sets are available on request. CRU endeavors to update the majority of the data pages at timely intervals. Data sets are available in the following categories: temperature, precipitation, atmospheric pressure and circulation indices, climate indices for the United Kingdom, data for the Mediterranean and alpine areas, and high-resolution gridded data sets.

• World Data Center System

A good example of a "global center" is the World Data Center (WDC) system, which was created to archive and distribute data collected from the observational programs of the 1957-1958 International Geophysical Year (IGY). Originally established in the United States, Europe, Russia, and Japan, the WDC system has since expanded to fifty-two centers in twelve countries. Its holdings include a wide range of solar, geophysical, environmental, and human dimensions data. The WDC is maintained by Model and Data (M&D), which is hosted at the Max Planck Institute for Meteorology, located in Germany.

• Context

In terms of climate change, the monitoring of the climate is extremely important. A number of internationally recognized groups collect, analyze, and publish—mainly through Web sites—climate and other data for various areas of the world, including the globe as a whole, the land as a whole, the ocean as a whole, and regions such as the tropics and polar areas. In addition to the climate variables, a wide variety of other variables are monitored on a global or regional scale, such as the extent of sea ice, sea surface temperatures, carbon dioxide, and methane. All of these values, when correctly analyzed, provide important indicators of what changes have occurred during the past (weeks to many decades) in the broader atmospheric environment. Such information is essential if correct answers to questions relating to the changing climate are to be obtained.

W. J. Maunder

• Further Reading

Kininmonth, William. *Climate Change: A Natural Hazard*. Brentwood, Essex, England: Multiscience, 2004. Kininmonth has a career in meteorological and climatological science and policy spanning more than forty-five years. His suspicions that the science and predictions of anthropogenic global warming extend beyond sound theory and evidence were crystallized following the release of the 2001 IPCC assessment report. His book gives information about global and regional monitoring on various scales.

National Aeronautics and Space Administration. "Solar Physics." Available at http://solarscience.msfc.nasa.gov/SunspotCycle.shtml. Presents data on the solar cycle, the Maunder Minimum, and other Earth-Sun interactions.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years*. Lanham, Md.: Rowman and Littlefield, 2008. This book is dedicated to those thousands of research scientists who have documented evidence of a fifteen-hundred-year climate cycle over the Earth. Refers throughout to various aspects of monitoring of the global climate.

University of Colorado at Boulder. "Sea Level Change." Available at http://sealevel.colorado.edu/results.php. Presents tables, maps, time series, and other data on global sea level.

University of East Anglia. "Climatic Research Unit." Available at http://www.cru.uea.ac.uk/. The CRU presents data, information sheets, and the online journal *Climate Monitor*.

University of Illinois. "The Cryosphere Today." Available at http://arctic.atmos.uiuc.edu/cryosphere/. Offers frequently updated data on the current state of Earth's cryosphere.

U.S. National Space Science and Technology Center. Available at http://www.nsstc.org/. The mission of the NSSTC, an arm of NASA, is "to conduct and communicate research and development critical to NASA's mission in support of the national interest, to educate the next generation of scientists and engineers for space-based research, and to use the platform of space to better understand our Earth and space environment and increase our knowledge of materials and processes."

See also: Air quality standards and measurement; Geographical information systems; Ice cores; Industrial emission controls; Mauna Loa Record; Tree rings.

Global surface temperature

- **Category:** Meteorology and atmospheric sciences

- **Definition**

Global surface temperature is an estimate of global mean air temperature at the Earth's surface, based on thermometer measurements made at land-based weather stations. Because about 70 percent of the Earth's surface is covered by water, land-based data are supplemented by sea-surface-temperature (SST) measurements. Estimates of air temperature are based on the assumption that there is a simple link between the SST and that of the air above. Usually, SST measurements are based on measurements of the temperature of sea-water that is taken aboard ships for use as an engine coolant. In the past, SST measurements were made of water taken from buckets tethered to ropes and thrown overboard. Supplementary SST data are gathered from data buoys, small island stations, and shipboard, nighttime measurements of marine air temperatures.

- **Significance for Climate Change**

Three agencies have taken responsibility for the combined global surface temperature record: the Climate Research Unit of the University of East Anglia; the U.S. National Aeronautics and Space Administration's Goddard Institute for Space Studies; and the Global Historical Climate Network of the U.S. National Oceanographic and Atmospheric Administration. To determine global surface temperature changes over time, these agencies locate and analyze anomalous departures from thirty-year temperature averages. These analyses are most commonly based on the area-weighted global average of sea-surface-temperature anomalies and land-surface-air-temperature anomalies. Based on these analyses, the mean global surface temperature of the Earth shows a warming in the range of 0.3°-0.7° Celsius over the past century, or a statistical average of about 0.003°-0.007° Celsius per year. Global data sets from the various agencies show slightly dissimilar trends, as the data are processed in different ways.

Deviations in Mean Global Surface Temperature

The following table lists deviations in average global surface temperature from the baseline temperature average set during the period between 1951 and 1980.

Year	*Deviation (in 0.01° Celsius)*	*Year*	*Deviation (in 0.01° Celsius)*
1880	−12	1960	−2
1890	−21	1970	+4
1900	−6	1980	+28
1910	−21	1990	+48
1920	−17	2000	+42
1930	−4	2005	+76
1940	+14	2008	+54
1950	−17		

Data from Goddard Institute for Space Studies, National Aeronautics and Space Administration.

Questions arise as to the representative nature of the data on which global surface temperature calculations have been based. These data come from weather stations unevenly distributed over the Earth's surface, mostly on land, close to towns and cities, and predominantly in the Northern Hemisphere. Land use can have significant effects on local climate. The best-documented examples of such effects are urban heat islands, which are significantly warmer than their rural surroundings. Cities replace natural vegetation with surfaces such as concrete and asphalt that can warm them by several degrees Celsius. Thus, a disproportionate number of weather stations being located in urban environments may skew data regarding global averages. Many weather stations are located at airports, which were originally located in rural areas that have since been developed. Thus, while the data collected at such stations remain reliable measurements of the local, urban environment, they may no longer be equally reliable indicators of global trends.

C R de Freitas

See also: Albedo feedback; Atmospheric dynamics; Climate and the climate system; Climate change; Heat vs. temperature; Sea surface temperatures.

Global warming potential

- **Category:** Pollution and waste

- **Definition**

Global warming potential (GWP) is an index based upon radiative (infrared-absorbing) properties of well-mixed greenhouse gases (GHGs). It can be used to estimate the relative potential future impacts of GHG emissions on the global climate. Specifically, the GWP of a given GHG is the time-integrated global mean radiative forcing from the instantaneous release of 1 kilogram of that GHG, relative to that of a reference GHG, usually carbon dioxide (CO_2). The GWP is a function of a gas's lifetime, concentration, and effectiveness at absorbing thermal infrared radiation.

- **Significance for Climate Change**

GWP is the index used by parties to the United Nations Framework Convention on Climate Change (UNFCCC) to quantify the greenhouse-enhancing potential of trace atmospheric gases. The GWP is used to evaluate the effects of anthropogenic interference in the climate system and of GHG emission reductions. GWP is a purely physical index and does not take into consideration the costs and benefits of climate policy initiatives, cost discounting, or the location of emissions or regional climates, among other factors. Thus, GWP does not measure economic, cultural, or regional factors useful in determining climate- and GHG-related policies.

Other limitations of the GWP index exist. The choice of time horizon for integration ranges from short-term changes (such as responses of cloud cover to surface temperature changes) to long-term effects (such as changes in ocean level). For purposes of the first commitment period under the Kyoto Protocol, the parties to the UNFCCC agreed to a one-hundred-year time horizon for integration of GWPs as a mid-term balance between long-term (five-hundred-year) and short-term (twenty-year) climate effects. The current one-hundred-year GWPs for select GHGs are listed in *Climate Change, 2007*, a report prepared by the Intergovernmental Panel on Climate Change (IPCC).

The mid-term time horizon favors reductions in GHGs whose GWP is greatest over one-hundred-year periods, while diminishing the importance of reducing short-lived GHG emissions in the near future and long-lived GHGs over the long term. For example, GWPs for methane over twenty-year, one-hundred-year, and five-hundred-year time horizons are 72, 25, and 7, respectively. The value of reducing methane under analyses based on the short-term time horizon is nearly three times that of reducing it according to analyses employing the mid-term time horizon. Short-term analyses, however, have motivated the United States to create the Methane to Markets initiative, which seeks to capture or reduce methane emissions to address near-term climate change cost-effectively.

Uncertainties in the GWP arise from assuming a linear radiative forcing function under a small emission pulse (1 kilogram). That is, GWP calculations assume that 100 kilograms of a GHG will have a GWP one hundred times that of 1 kilogram of that GHG. This is not necessarily the case, as emissions of a GHG may build on or interfere with each other, cause positive or negative feedback loops, or otherwise increase or decrease their effects on climate in a nonlinear manner. As more information on radiative forcing is gathered, confidence in GWP values will increase.

Kathryn Rowberg

See also: Annex B of the Kyoto Protocol; Carbon dioxide; Carbon dioxide equivalent; Certified

Global Warming Potentials of Major Greenhouse Gases

Greenhouse Gas	*Global Warming Potential**
CO_2 (carbon dioxide)	1 (reference)
CH_4 (methane)	25
N_2O (nitrous oxide)	298
HFC-23 (hydrofluorocarbon-23)	14,800
SF_6 (sulfur hexafluoride)	22,800

*One-hundred-year time horizon.

emissions reduction; Emissions standards; Greenhouse Gas Protocol; Greenhouse gases; Kyoto Protocol; United Nations Framework Convention on Climate Change.

Gore, Al

American statesman and environmental activist

Born: March 31, 1948; Washington, D.C.

A longtime congressional and administrative governmental advocate for environmental issues, Gore was awarded the 2007 Nobel Peace Prize for his work in raising awareness about such issues, particularly global warming.

• Life

Al Gore was born on March 31, 1948, in Washington, D.C., the son of then-congressman, later U.S. senator, Albert Arnold Gore, Sr., of Carthage, Tennessee, and his wife, Pauline LaFon Gore. Gore attended Harvard University from 1965 to 1969, earning a bachelor of arts in government. He saw military service in Vietnam with the Twentieth Engineers from 1970 to 1971 and spent a year in the divinity school at Vanderbilt University before landing a position as a reporter for *The Tennessean*, Nashville's largest daily newspaper. After two years at Vanderbilt Law School, Gore was elected to the U.S. House of Representatives in 1976.

He was re-elected three times; in 1984, he ran successfully for the Senate, where he served until 1993. In 1988, he announced his intention to enter the race for the Democratic Party's presidential nomination. Failing to overtake front-runner and eventual nominee Michael Dukakis of Massachusetts, Gore dropped from the race after losing heavily in the New York State primary election. Apart from his environmental efforts, Gore's most notable legislative activity lay in the field of informational technology. As chair of the House Committee on Science and Technology, he was the most active legislative advocate for promoting the Internet. While in the Senate, he sponsored the High Performance Computing and Communication Act of 1991. His contribution in the crafting of this piece of legislation was so pervasive that it was dubbed the Gore Act.

Gore initially decided against involvement in the 1992 presidential campaign, citing family concerns arising from his son's near-fatal traffic accident and lengthy recuperation. However, when Democratic nominee Bill Clinton offered him the vice presidential slot on the party ticket, the Tennessee senator accepted. His strong performance in the television debate with Republican vice presidential candidate Dan Quayle and independent candidate Admiral James B. Stockdale is seen by some as a factor in the Democratic electoral victory in November, 1992. He served as vice president for the duration of the Clinton administration, 1993-2001.

Breaking somewhat with Clinton in the wake of the Monica Lewinsky scandal, Gore easily secured the Democratic presidential nomination in 2000, selecting U.S. senator Joseph Lieberman of Connecticut as his running mate. Though Gore won the popular vote over George W. Bush, it was the Republican candidate who took the presidency by tallying a margin of 271-266 votes in the Electoral College in a campaign marred by a ballot recount controversy in Florida.

• Climate Work

Gore himself attributes the genesis of his interest in the environment to listening to his mother reading from the groundbreaking book *Silent Spring* (1962) by Rachel Carson. Then, while studying at Harvard, he was much influenced by the lectures and research of Roger Revelle, one of the world's first academics to monitor atmospheric carbon dioxide levels scientifically and to tie them to global temperature increases. So active was Gore at taking the lead in advocating green causes during his congressional and senatorial tenures that he earned the nickname Mr. Ozone. In 1992, Gore published *Earth in the Balance*, wherein he pressed for what he termed a "global Marshall Plan" comprising a united effort by the more technologically advanced nations to set aside specific funding in order to assist underdeveloped countries in coping with their own ecological crises. However, apart from raising awareness about the global warming issue through committee hearings and publications, Gore was able to push through little in the way of far-reaching ecological legislation.

It would not be until his vice presidential term that some of his ideas would effectively permeate through higher governmental circles, generating some interest from the Clinton administration. Even at that, efforts in that direction would be hampered by conservative Republican electoral gains that resulted in Republican control of Congress. Increasingly focused on the 2000 presidential campaign, Gore began drawing criticism from environmental groups for his apparent inactivity. Even his greatest effort in the cause of alleviating the threat to global warming posed by greenhouse gases—his intervention to save the Kyoto Protocol on Climate Change—elicited mixed reactions. Negotiations almost broke down over the question of whether developing countries could be held to the same gas emission standards as the more technologically advanced nations. The U.S. Senate threatened to sabotage the treaty if Third World nations were not equally accountable. In December, 1997, Gore traveled personally to Kyoto and, probably putting his political career on the line, was able to devise a compromise calling for accountability, but also for lower emission standards.

During the course of his post-vice presidential years, Gore has worked for environmental policy change through the Alliance for Climate Protection, a nonprofit educational and lobbying organization dedicated to reversing global warming, and Generation Investment Management, a business corporation he founded in 2004 to encourage investment in firms that demonstrate environmental consciousness. In 2006, Gore gained his greatest international fame through the simultaneous release of a film and book titled *An Inconvenient Truth*. The DVD recording of the film, especially, in which Gore himself adroitly lectured upon and explained global warming at the popular level, was so acclaimed that it earned the former vice president the 2007 Nobel Peace Prize, which he shared with the Intergovernmental Panel on Climate Change, and a share of the credit for the 2006 Academy Award for Best Documentary Feature.

Raymond Pierre Hylton

Things Fall Apart

In Earth in the Balance, *Al Gore describes the societal breakdown that occurred in the early nineteenth century in response to climate anomalies caused by a volcanic eruption. He suggests that such breakdowns will be repeated and worsen as Earth's climate systematically alters.*

Beginning in 1816, "the year without a summer," widespread crop failures led to food riots in nearly every country of Europe, producing a revolutionary fervor that swept the continent for three years.

In France, for example, the existing government fell and the conservative Duc de Richelieu was asked to form a new one. Everywhere governments struggled to maintain social order as an unprecedented crime epidemic surged in the cities. The Swiss were stunned by the wave of criminal activity. Even the number of suicides increased dramatically, along with executions of women for infanticide. . . .

Although no one realized it at the time, the proximate cause of this suffering and social unrest was a change in the composition of the global atmosphere following an unusually large series of eruptions of the Tambora volcano, on the island of Sumbawa, Indonesia, in the spring of 1815. Scientists estimate that 10,000 people were killed in the initial eruption and approximately 82,000 more died of starvation and disease in the following months. However, the worst effects on the rest of the world were not felt until a year later, by which time the dust ejected into the sky had spread throughout the atmosphere and had begun to dramatically reduce the amount of sunlight reaching the surface of the earth and to force temperatures down.

• Further Reading

Gore, Al. *Earth in the Balance: Ecology and the Human Spirit.* New York: Rodale Books, 2006. The first major expression of Gore's assessment of the environmental crisis and his earliest "blueprint" for action focused on solutions.

________. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. Reprint. New York: Rodale Books, 2006. The fine tuning, expansion, and elaboration of Gore's ideas as initially expressed in *Earth in the Balance*. This book—in conjunction with the film of the same title—brings the issues to a more popular level and is generally considered to depict Gore at his most engaging and articulate.

Maraniss, David, and Ellen Nakashima. *The Prince of Tennessee: The Rise of Al Gore*. New York: Simon & Schuster, 2000. Reveals Gore's considerable prior involvement in environmental matters, its extent and nature, and its role in his formation as a political figure.

Turque, Bill. *Inventing Al Gore: A Biography*. New York: Houghton Mifflin, 2000. Takes the sweeping view that Gore's environmental focus derives from a religious zeal born out of formative childhood experiences.

Zelnick, Bob. *Gore: A Political Life*. Washington, D.C.: Regnery, 1999. Categorizes Gore's commitment to global warming issues as not only long-standing but also quasi-religious in nature.

See also: Carson, Rachel; Environmental movement; *Inconvenient Truth, An*; U.S. legislation.

Greenhouse effect

- **Category:** Meteorology and atmospheric sciences

• Definition

The greenhouse effect warms the lower portion of a planet's atmosphere when heat is trapped there by gases—such as water vapor, carbon dioxide (CO_2), methane, and nitrous oxides—that prevent it from escaping into space. As a result of their molecular structure, these gases are dominant absorbers and emitters of infrared radiation. They absorb infrared energy from a planet's surface and reemit it in all directions. A significant fraction of this reradiated energy is directed back to the planet's surface, resulting in an increase in average temperatures. This effect is somewhat analogous to the trapping of heat by a greenhouse, but the retention of heat in a greenhouse is due mostly to reduced cooling caused by the prevention of convection: Only a small amount is due to trapped infrared radiation.

• Significance for Climate Change

The greenhouse effect is a natural phenomenon that has been occurring on Earth and other planets for millions of years. It allows Earth to support life. If heat were not trapped in Earth's atmosphere, the planet would be approximately 33° Celsius cooler than it is now. A large percentage of Earth's natural greenhouse warming is caused by water vapor. If the greenhouse effect were enhanced, the Earth would become warmer, which could cause problems for humans, plants, and animals.

In the mid-1950's, an enhanced greenhouse effect was recognized as a concern. As a result of anthropogenic (human-induced) activities, atmospheric concentrations of the greenhouse gases (GHGs) were on the rise. This trend was associated with an increasing global atmospheric temperature. Industrialization resulted in an increase in the use of fossil fuels, which increased GHG emissions. The global mean annual temperature rose by approximately 0.5° Celsius between 1890 and 2000. Most of that increase occurred after 1970.

In addition to rising global temperature, observations of glaciers indicate that more of them are retreating than are growing. For example, eight glaciers that were advancing on Mount Baker in the northern Cascades in 1976 were all melting back at their termini by 1990. Observed climate changes associated with rising global temperatures, retreating glaciers, and increased polar ice melting are consistent with the effects that might be produced by an enhanced greenhouse effect accelerated by burning more fossil fuels. Verification of this connection depends primarily on computer-generated climate models. Existing models must be improved by addressing the coupled, nonlinear, dynamic nature of climate and by expanding the climatological database to include additional factors that influence the greenhouse effect, such as volcanic production of GHGs and the emission of methane from landfills and melting tundra.

Alvin K. Benson

See also: Atmosphere; Atmospheric chemistry; Atmospheric dynamics; Atmospheric structure and evolution; Carbon dioxide; Climate and the climate system; Climate change; Enhanced greenhouse effect; Greenhouse gases; Industrial greenhouse emissions; Methane.

Greenhouse Gas Protocol

- **Category:** Economics, industries, and products
- **Date:** Published September, 2001; revised March, 2004

• Definition

Prior to 2001, there was not a tool for corporations to assess greenhouse gas (GHG) emissions. To remedy this void, the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) began work on a method for corporations to account for and report their GHG emissions. The result was the Greenhouse Gas Protocol. WBCSD is a coalition of 170 international companies whose shared interest is sustainable development guided by growth economically balanced with ecology and social progress. Members come from more than thirty-five countries. WRI is a nonprofit organization of over one hundred people from many different occupations who work toward protecting the Earth while improving people's lives. There were five ideals controlling the production of the protocol: relevance (that the program provide accurate information to those needing the information, both inside and external to the company), completeness (that the program account for all sources of emissions), consistency (that the program produce meaningful and useful data year after year), transparency (that the procedures be apparent to anyone interested), and accuracy (that emissions are measured correctly with the smallest possible degree of uncertainty). The protocol was published in September, 2001, and in March, 2004, a revised version was published.

• Significance for Climate Change

The accounting tool consists of three modules: The first one is for corporations to use in calculating and reporting GHG emissions, the second is for calculating indirect emissions, and the third is used to calculate the effect of reduction projects. The GHGs covered by this protocol are the gases covered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

There were five objectives used in the design of this accounting tool. First, it would be a tool that would aid companies in making a true and accurate measure of their GHG emissions. Second, the procedure would be simpler and less expensive than current practices. Third, it would provide the means to acquire the information needed to control and reduce GHG emissions. Fourth, the protocol would provide the information to allow companies to join GHG programs, both voluntary and required. Fifth, the protocol is to increase communication between companies and provide a standard method to report emissions. The procedures are divided into three scopes. Scope 1 is derived from emissions that are produced by equipment or machinery owned or controlled by the company. Most of these emissions are direct emissions; some activity of the company causes the emission. Scope 2 is the electricity indirect GHG emissions. These are the emissions generated in producing the electricity used by the company in its equipment or machinery. This includes electricity that is lost during transport or distribution. Scope 3 is the emissions due to the exploration, production, and transportation of the fuel used to generate electricity.

The 2004 revised edition added more guidelines to the procedure, more case studies, and appendixes on indirect emissions. Information in the revised edition is also designed to aid companies in setting a target for future emissions now that they know their current values. The protocol is also set up to allow the companies to more easily evaluate and trade GHG offsets. Offsets increase the amounts of GHGs that can be emitted without breaking governmental rules. A company with low rates of emissions may sell offsets to a company with high output to allow the second company to stay within the rules.

The Greenhouse Gas Protocol is designed to allow companies to evaluate their current emissions and set targets for reduction of GHGs. It even allows a company to assess different reduction procedures to determine which might be best. Countries can now set standards for companies in an effort to control the emission of GHGs. By the use of this standard accounting system, one company will not have an advantage over another company when meeting the standards. It will also be easier for the government to monitor companies' emissions with the new accounting system.

C. Alton Hassell

• Further Reading

Gerrard, Michael B., ed. *Global Climate Change and U.S. Law.* Chicago: American Bar Association, Section of Environment, Energy, and Resources, 2007. Discusses from a legal viewpoint the different initiatives—regional, state and local—undertaken to control GHGs. Illustrations, bibliography, index.

World Business Council for Sustainable Development, World Resources Institute. *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard.* Geneva, Switzerland: Author, 2001. The first edition of the protocol to assess greenhouse gases. Illustrations, bibliography.

_______. *The Greenhouse Gas Protocol: The GHG Protocol for Project Accounting.* Geneva, Switzerland: Author, 2005. The 2005 edition of the protocol to assess GHGs. Illustrations, bibliography.

See also: Carbon dioxide; Environmental economics; Greenhouse effect; Greenhouse gases; Hydrofluorocarbons; Kyoto Protocol; Methane; Nitrous oxide; Perfluorocarbons; Sulfur hexafluoride.

Greenhouse gases

• Categories: Meteorology and atmospheric sciences; pollution and waste

GHGs are trace atmospheric gases that trap heat in the lower atmosphere, causing global warming. Such warming has been associated with droughts, tornadoes, ice melting, sea-level rise, saltwater intrusion, evaporation, and other climatic changes and effects.

• Key concepts

aerosols: small particles suspended in the atmosphere

anthropogenic: deriving from human sources or activities

fossil fuels: fuels (coal, oil, and natural gas) formed by the chemical alteration of plant and animal matter under geologic pressure over long periods of time

global dimming: reduction of the amount of sunlight reaching Earth's surface

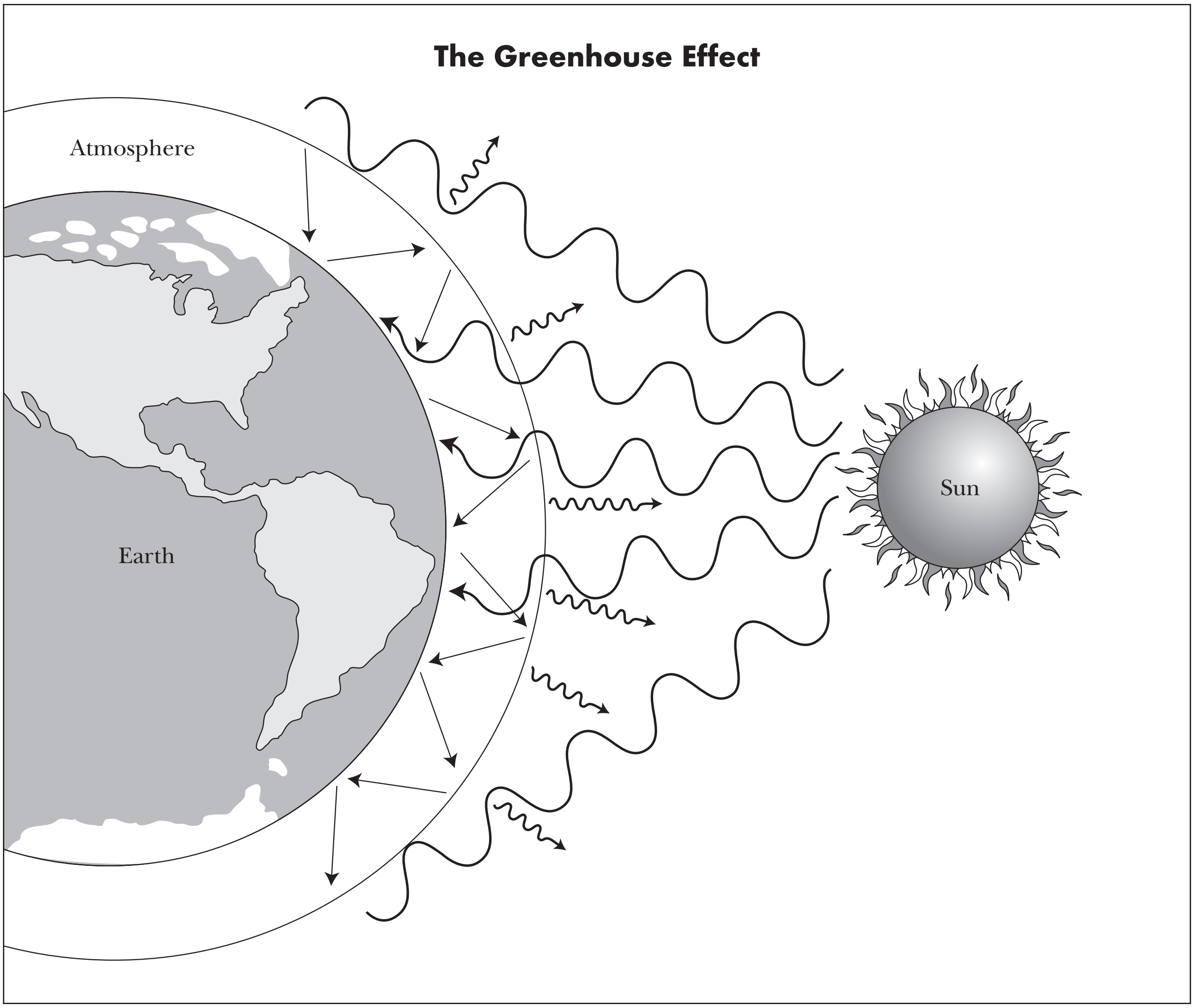
global warming: an overall increase in Earth's average temperature

greenhouse effect: absorption and emission of radiation by atmospheric gases, trapping heat energy within the atmosphere rather than allowing it to escape into space

greenhouse gases (GHGs): atmospheric trace gases that contribute to the greenhouse effect

• Background

Greenhouse gases (GHGs) have both natural and anthropogenic sources. They allow sunlight to pass through them and reach Earth's surface, but they trap the infrared radiation released by Earth's surface, preventing it from escaping into space. These trace atmospheric gases thus play an important role in the regulation of Earth's energy balance, raising the temperature of the lower atmosphere. GHG concentrations in the atmosphere have historically varied as a result of natural processes, such as volcanic activity. They have always been a small fraction of the overall atmosphere, however, exhibiting significant effects on the climate despite their low concentrations. Thus, small variations in GHG concentration may have disproportionate effects on



The greenhouse effect is aptly named: Some heat from the Sun is reflected back into space (squiggled arrows), but some becomes trapped by Earth's atmosphere and reradiates toward Earth (straight arrows), heating the planet just as heat is trapped inside a greenhouse.

Earth's climate. Since the Industrial Revolution, humans have added a significant amount of GHGs to the atmosphere by burning fossil fuels and cutting down trees. Scientists estimate that the Earth's average temperature has already increased by 0.3° to 0.6° Celsius since the beginning of the twentieth century.

- **GHG Sources and Atmospheric Physics**

The atmosphere comprises constant components and variable components. It is composed primarily of nitrogen (78 percent) and oxygen (21 percent). Its other constant components include argon, neon, krypton, and helium. Its variable components include carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), sulfur dioxide (SO_2), ozone (O_3), and nitrous oxide (N_2O). The variable components affect the weather and climate because they absorb heat emitted by Earth and thereby warm the atmosphere. In addition to the variable natural atmospheric GHGs, anthropogenic halocarbons, other chlorine- and bromine-containing substances, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons contribute to the greenhouse effect.

CO_2, composed of two oxygen atoms and one carbon atom, is a colorless, odorless gas deriving from carbon burning in the presence of sufficient oxygen. It is released to the atmosphere by forest fires, fossil fuel combustion, volcanic eruptions, plant and animal decomposition, oceanic evaporation, and respiration. It is removed from the atmosphere by CO_2 sinks, seawater absorption, and photosynthesis.

Methane is a colorless, odorless, nontoxic gas consisting of four hydrogen atoms and one carbon atom. It is a constituent of natural gas and fossil fuel. It is released into the atmosphere when organic matter decomposes in oxygen-deficient environments. Natural sources include wetlands, swamps, marshes, termites, and oceans. Other sources are the mining and burning of fossil fuels, digestive processes in ruminant animals, and landfills. Methane reacts with hydroxyl radicals in the atmosphere, which break it down in the presence of sunlight, shortening its lifetime.

Nitrous oxide is a colorless, nonflammable gas with a sweetish odor. It is naturally produced by oceans and rain forests. Anthropogenic sources include nylon and nitric acid production, fertilizers, cars with catalytic converters, and the burning of organic matter. Nitrous oxide gas is consumed by microbial respiration in specific anoxic environments.

Sulfur dioxide is released during volcanic activities, combustion of fossil fuel, transportation, and industrial metal processing. This gas is more reactive than is CO_2, and it rapidly oxidizes to sulfate. It produces acidic gases and acid rain when it reacts with water and oxygen.

Ozone (triatomic oxygen) is a highly reactive, gaseous constituent of the atmosphere. A powerfully oxidizing, poisonous, blue gas with an unpleasant smell, it helps create smog. It is produced in chemical reactions of volatile organic compounds or nitrogen oxide with other atmospheric gases in the presence of sunlight. Oxygen and ozone absorb a critical range of the ultraviolet spectrum, preventing this dangerous radiation from reaching Earth's surface and making possible life on Earth.

Halocarbons have global warming potentials (GWPs) from three thousand to thirteen thousand times that of CO_2; they remain in the atmosphere for hundreds of years. These compounds were commonly used in refrigeration, air conditioning, and electrical systems, but their use has been regulated as a result of their environmental and climatic effects.

• Effect on Climate Change

The Working Groups of the Intergovernmental Panel on Climate Change (IPCC) presented a synthesis report in 2007, providing an integrated view of climate change from multiple perspectives. The report observed an increase of global air and ocean temperatures, melting of snows, and rising sea levels. The report estimated the one-hundred-year linear trend of Earth's average temperature between 1906 and 2005 at an increase of 0.74° Celsius, significantly greater than the trend from 1901 to 2000 (0.6° Celsius). The increase of temperature contributed to changes in wind patterns, affecting extratropical storm tracks and temperature patterns.

Global average sea level has risen between 1961 and 2001 at an average rate of 1.8 millimeters per year and between 1993 and 2008 at an average rate of 3.1 millimeters per year. The increase is due largely to melting glaciers and polar ice sheets. Satellite data between 1978 and 2008 show that average annual extent of Arctic sea ice shrank by an average of 2.7 percent per decade. The average summertime extent shrank far more, an average of 7.4 percent per decade.

Increases have been reported in the number and size of glacial lakes and the rate of change in some Arctic and Antarctic ecosystems. Runoff and earlier spring peak discharge in many glacier- and snow-fed rivers have also increased. These increases have in turn had effects on the thermal structure and water quality of the rivers and lakes fed by this runoff. Both marine and freshwater systems have been associated with rising water temperatures and with changes in ice cover, salinity, oxygen levels, and circulation patterns. These ecological changes have affected algal, plankton, and fish abundance.

Precipitation has increased in the eastern parts of North and South America, northern Europe, and northern and central Asia. It has decreased in the Mediterranean and southern Africa. These patterns also have affected algal, plankton, and fish abundance. Globally, since 1970, a greater area of Earth's surface has been affected by drought.

Changes in atmospheric GHG and aerosol concentration, as well as solar radiation levels, affect the energy balance of Earth's climate system. Global GHG emissions increased by 70 percent over preindustrial levels between 1970 and 2004. CO_2 emissions increased by 80 percent, but they began to decline after 2000. The global increase in CO_2 and methane emissions is due to fossil fuel and land use, particularly agriculture.

Coastlines are particularly vulnerable to the consequences of climate change, such as sea-level rise and extreme weather. Around 120 million people on Earth are exposed to tropical cyclone hazards. During the twentieth century, global sea-level rises contributed to increased coastal inundation, erosion, ecosystem losses, loss of sea ice, thawing of permafrost, coastal retreat, and more frequent coral bleaching.

Anticipated future climate-related changes include a rise in sea level of up to 0.6 meter by 2100, a rise in sea surface temperatures by up to 3° Celsius, an intensification of tropical cyclones, larger waves and storms, changes in precipitation and runoff patterns, and ocean acidification. These phenomena will vary on regional and local scales. Increased flooding and the degradation of freshwater, fisheries, and other resources could impact hundreds of millions of people, with significant socioeconomic costs. Degradation of coastal ecosystems, especially wetlands and coral reefs, affects the well-being of societies dependent on coastal ecosystems for goods and services.

• Context

In response to global warming, changes are being implemented to reduce GHG emissions. The United Nations Framework Convention on Climate Change prepared the 1997 Kyoto Protocol. Under the protocol, thirty-six states, including highly industrialized countries and countries undergoing transitions to a market economy, entered into legally binding agreements to limit and reduce GHG emissions. Developing countries assumed nonbinding obligations to limit their emissions as well.

In the energy sector, fuel use is slowly transitioning from coal to natural gas and renewable energy (hydropower, solar, wind, geothermal, tidal, wave, and bioenergy). In the transport sector, fuel-efficient, hybrid, and fully electric vehicles are being designed and marketed, and governments are attempting to motivate commuters to use mass-transit systems. More efficient uses of energy, including low-energy lightbulbs, day lighting, and efficient electrical, heating, and cooling appliances are being developed and deployed.

Industrial manufacturers have implemented electrical efficiency measures as well, and they have begun recycling, as well as capturing and storing CO_2. Crop and land management techniques have also improved, leading to an increase in soil carbon storage and the restoration of peaty soils and degraded land. Rice cultivation techniques have been improved, and livestock management techniques are being developed to reduce methane and nitrogen emissions. More controversially, dedicated energy crops are being grown to replace fossil fuels.

Afforestation, reforestation, forest management, reduced deforestation, and harvested wood product management are also being geared toward reducing GHG emissions. Forestry products are in use for bioenenergy to replace fossil fuels. Improvements are being made in tree species, remote sensing for analyses of vegetation and soil carbon, and mapping of land use. In the waste industry, methane is being recovered from landfills and energy is being recovered from waste incineration. Organic waste is more widely used for composting, wastewater is minimized, and the wastewater produced is treated and recycled. Biocovers and biofilters are being developed to optimize methane oxidation.

Ewa M. Burchard

• Further Reading

Dlugokencky, E. J., et al. "Continuing Decline in the Growth Rate of the Atmospheric Methane Burden." *Nature* 393 (1998): 447-450. Presents analyses and measurements of methane in the atmosphere and shows a decreasing trend.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It.* Emmaus, Pa.: Rodale, 2006. Gore, the former vice president of the United States, presents documentary examples of global warming's effects on Earth.

Le Treut, H., et al. "Historical Overview of Climate Change." In *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Contains an evaluation of climate change as an effect of the temperature increase at the Earth's surface.

Walker, Gabrielle. *An Ocean of Air: Why the Wind Blows and Other Mysteries of the Atmosphere*. Orlando, Fla.: Harcourt, 2007. Informative book about air, processes in the atmosphere, and the climate.

See also: Carbon dioxide; Chlorofluorocarbons and related compounds; Enhanced greenhouse effect; Greenhouse effect; Greenhouse Gas Protocol; Hydrofluorocarbons; Industrial greenhouse emissions; Kyoto Protocol; Methane; Ozone; Perfluorocarbons; Sulfur hexafluoride; Water vapor.

Greening Earth Society

- **Category:** Organizations and agencies
- **Date:** Established 1998
- **Web address:** http://www.greeningearthsociety.org/ (deactivated)

• Mission

The Greening Earth Society (GES), created by the Western Fuels Association, is a public relations organization promoting the idea that higher levels of greenhouse gases (GHGs), particularly of carbon dioxide (CO_2), are beneficial because they promote plant growth. GES was founded on Earth Day, 1998, by Frederick Palmer, chief executive officer of the Western Fuels Association, a group of coal-based rural electric cooperatives and municipal utilities. The purpose of GES is to promote the benefits of "moderate" global warming. The group is based in Arlington, Virginia, where both Palmer and Ned Leonard, director of communications and government affairs of GES and of the Western Fuels Association, worked as registered lobbyists. After 2000, Bob Norrgard, general manager of Western Fuels, assumed the directorship of GES. Its scientific advisers include Patrick J. Michael, professor of environmental sciences at the University of Virginia; Robert E. Davis, professor of climatology at the University of Virginia's Department of Environmental Sciences; Robert C. Balling, director of the Laboratory of Climatology at Arizona State University; and Sallie Baliunas and Willie Soon of the Harvard-Smithsonian Center for Astrophysics.

GES was founded in response to attempts by the Environmental Protection Agency to regulate CO_2 as a pollutant. Higher concentrations of CO_2, GES argues, not only are not harmful, but also at moderate levels actually "increase plant productivity, water use efficiency, and their resistance to a variety of environmental stresses including heat, drought, cold, pests, deficient nutrients, and air pollution." In a 1999 ad in *The Washington Post*, GES articulated its position that CO_2 is a nutrient, not a pollutant, explaining,

> Carbon Dioxide (CO_2) levels have risen in direct proportion to human population since the 15th century. The good news is that today's higher CO_2 levels are producing more abundant plant life and greater agricultural yields. Unfortunately, good news like this doesn't command the same attention as news about catastrophic climate change.

According to GES, there is no scientific consensus about the anthropogenic causes of climate change, contrary to media reports. Environmentalists who argue that global warming represents a looming catastrophe, it argues, are merely alarmists who either misunderstand or intentionally misrepresent scientific data.

• Significance for Climate Change

Until 2003, GES published the *World Climate Report*, a biweekly newsletter intended to point out "the weaknesses and outright fallacies in the science that is being touted as 'proof' of disastrous warming." The group's Web site described the newsletter as "the perfect antidote against those who argue for proposed changes to the Rio Climate Treaty, such as the Kyoto Protocol, which are aimed at limiting carbon emissions from the United States." Since 2004, the newsletter has been published by New Hope Environmental Services, still under the direction of editors Michael, Davis, and Balling. The international science journal *Nature* recognized *World Climate Report* as presenting a "mainstream skeptic" view of global warming.

From 2000 to 2003, GES also issued Virtual Climate Alerts, brief press releases whose titles included "Emissions Trend Doesn't Support Claim of Ecological and Economic Disaster," "More Cold Truth Dispels Hot Air," and "How Popular Coverage of Melting Arctic Sea Ice Overlooks Relevant Long-Term Research." In addition, GES issued annual State of the Climate Reports; scientific reports, including "In Defense of Carbon Dioxide: A Comprehensive Review of Carbon Dioxide's Effect on Human Health, Welfare, and the Environment" (1998) and "The Internet Begins with Coal: A Preliminary Exploration of the Impact of the Internet on Electricity Consumption" (1999); and the videos *The Greening of Planet Earth* (1992) and *The Greening of Planet Earth Continues* (1998). The group is named as a sponsor of the Web site www.co2and climate.org, an annotated collection of links, and it has funded research through the Arizona State University Climate Data Task Force. By the end of 2008, the Greening Earth Society Web site had been suspended, many of its publications were available only on other sites, and the Western Fuels Association Web site no longer provided a link to GES.

Cynthia A. Bily

• Further Reading

Goodell, Jeff. *Big Coal: The Dirty Secret Behind America's Energy Future*. Boston: Mariner, 2007. Goodell, an editor of *Rolling Stone*, presents a lively analysis of America's dangerous reliance on coal and its hidden costs in the forms of global warming and lung disease.

Michael, Patrick J., and Robert C. Balling. *The Satanic Gases: Clearing the Air About Global Warming*. Washington, D.C.: Cato Institute, 2000. Two Greening Earth Society members argue, in accessible prose, that environmentalists and politicians have exaggerated the causes and dangers of global warming.

Poole, Steven. *Unspeak: How Words Become Weapons, How Weapons Become a Message, and How That Message Becomes Reality*. New York: Grove Press, 2007. Poole's witty analysis of the politics of language includes a discussion of the loaded term "global warming" and of the language of industry-funded propaganda groups.

Rampton, Sheldon, and John Stauber. *Trust Us, We're Experts! How Industry Manipulates Science and Gambles with Your Future*. New York: Jeremy P. Tarcher/Putnam, 2001. Explores the deceptive practices used by industry, including employment of public relations front organizations and the misuse of data, to influence public opinion on issues including global warming.

See also: Carbon dioxide; Carbon dioxide fertilization; Skeptics.

Greenland ice cap

• Category: Cryology and glaciology

The largest mass of ice in the Northern Hemisphere resides atop Greenland, which is home to 10 percent of the world's ice. This ice has been melting at an accelerating rate, especially in coastal areas.

• Key concepts

albedo: the fraction of radiation reflected by a surface

ice cores: cylindrical samples of ice taken from glaciers or ice caps that are used by scientists to determine atmospheric composition in the past

Jakobshavn glacier: a major outlet glacier in Greenland whose movement toward the sea has been accelerating

tipping point: point at which feedbacks take control and propel a climatic forcing past a point where control or mitigation is possible

upwelling: a rising of warm water to the surface, displacing colder water and potentially melting coastal ice

• Background

Greenland's ice is only a fraction of Antarctica's, but it is melting more rapidly, in part because summers are warmer, allowing for more rapid runoff. The amount of ice lost by Greenland during 2007 was equivalent to two times all the ice in the Alps, or a layer of water more than 0.8 kilometer deep covering Washington, D.C., according to Konrad Steffen, a professor of geography at the University of Colorado, who also directs the Cooperative Institute for Research in Environmental Sciences.

• Six Meters of Sea-Level Rise

Philippe Huybrechts, a glaciologist and ice-sheet modeler at the Free University of Brussels, has modeled the behavior of Greenland's ice sheet, finding that, with an anticipated annual temperature increase of 8° Celsius, the ice sheet would shrink to a small glaciated area far inland and the worldwide sea level would rise by 6 meters. Erosion of the Greenland ice sheet due to prolonged warming would be irreversible.

Upon close examination of paleoclimatic proxies, scientists examining ice cores from Greenland have found that its climate can change very quickly. The island's climate altered to a different state within one to three years at the onset of the present interglacial period, for example. Other scientists have found evidence that Greenland's surface has been covered with pine forests within a few hundred thousand years of the present, with the ice mass a fraction of today's size.

Ice melt in Greenland has accelerated significantly since 1990, according to a report in the *Journal of Climate* coauthored by Steffen. A scientific team surveyed the rate of summer melting there between 1958 and 2006, and found that the five largest melting years occurred after 1995. The year 1998 was the biggest (454 cubic kilometers), followed by 2003, 2006, 1995, and 2002. Melting in

A section of the Greenland ice cap. (AP/Wide World Photos)

2007 exceeded that of all previous years. Scientists have been keeping close watch on many glaciers, one of the most notable being the Jakobshavn glacier (the probable source of the iceberg that sank the *Titanic*), which has been accelerating toward the ocean.

• Melting Acceleration

Greenland is largely an artifact of the last ice age, held in place by the albedo (reflectivity) of its massive ice sheet. Once the ice melts, present-day climatic conditions will not allow its re-creation. Greenland's coastal ice often melts with a boost from the sea, warm water upwelling, flowing from below. Scientists have been debating the amount of additional warming that could cause Greenland's ice cap to cross a "tipping point," beyond which continued melting will be inevitable. During the winters between 2003 and 2007, Greenland lost two to three times as much ice in summer melt as it regained during winter snows.

Greenland's ice loss is accelerating irregularly year by year as well. During the 2007 melting season, with temperatures 4° to 6° Celsius higher than the previous thirty years' average, 450 billion metric tons of ice vanished, 30 percent more than the previous year and 4 percent more than the previous record, in 2005. During years of record melting, such as 2005 and 2007, high-pressure systems over Greenland keep storms away, clearing skies, allowing the Sun to shine for extended hours. Greenland's ice-mass loss between 2004 and 2006 was two and a half times the loss between 2002 and 2004.

While increases in the rate of ice loss to date have been greatest in southern Greenland, melting has been spreading northward, especially along the coastline. By the summer of 2007, the ice cap was studded by more than one thousand shallow meltwater lakes, some as wide as 5 kilometers. Tens of millions of cubic meters of water swirl from these lakes to the base of the ice sheet within a matter of days, opening huge waterfalls where none had previously existed.

• Context

Melting of the Greenland ice sheet's western reaches increased by about 30 percent from 1979 to 2006. Ice is melting most rapidly at the edges of the ice sheet. Although Greenland's ice sheet has been thickening at higher elevations due to increases in snowfall (warmer air holds more moisture, thus more snow), the gain is more than offset by an accelerating mass loss, primarily from rapidly thinning and accelerating outlet glaciers.

Scientists using pollen records from marine sediment off southwest Greenland have deduced that much of the Greenland ice sheet has melted relatively quickly during sharp natural warming in Earth's climate, some warming as recent as 400,000 years ago, when carbon dioxide levels were lower than they are today. During these spells, boreal coniferous forest covered much of the island. These spells of abrupt warming (abrupt, that is, in geologic time) reduced the ice sheet to about one-quarter of its present size and by themselves have raised world sea levels 4 to 6 meters.

Bruce E. Johansen

• Further Reading

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future*. Princeton, N.J.: Princeton University Press, 2000. A popular version of Alley's scientific work on climate change in the Arctic, with special attention to rapid climate change in Greenland.

Appenzeller, Tim. "The Big Thaw." *National Geographic*, June, 2007, 56-71. Survey of ice melt in the Arctic, Antarctic, and mountain glaciers, with explanations describing why the process has been speeding up.

Hanna, Edward, et al. "Increased Runoff from Melt from the Greenland Ice Sheet: A Response to Global Warming." *Journal of Climate* 21, no. 2 (January, 2008): 331-341. The article, coauthored by Konrad Stephen, that details the acceleration of Greenlandic ice melt between 1990 and 2007.

Murray, Tavi. "Greenland's Ice on the Scales." *Nature* 443 (September 21, 2006): 277-278. Provides ice-mass measurements for Greenland and discusses how they have changed in the years surrounding the turn of the century.

Paterson, W. S. B., and N. Reeh. "Thinning of the Ice Sheet in Northwest Greenland over the Past Forty Years." *Nature* 414 (November 1, 2001): 60-62. Greenland ice losses are presented in historical context.

Steffensen, Jørgen Peder, et al. "High-Resolution Greenland Ice Core Data Show Abrupt Climate Change Happens in Few Years." *Science* 321 (August 1, 2008): 654-657. A description of how quickly Greenland's climate has changed in the past.

See also: Abrupt climate change; Antarctica: threats and responses; Arctic; Cryosphere; Deglaciation; Glaciations; Glaciers; Ice shelves; Polar climate.

Greenpeace

- **Categories:** Organizations and agencies; environmentalism, conservation, and ecosystems
- **Date:** Established 1971
- **Web address:** http://www.greenpeace.org

• Mission

An independent international activist and research organization, Greenpeace is funded almost entirely by contributions from its members. It works to produce and distribute educational and advocacy materials, support grassroots activism, encourage pressure on legislatures and other national and international bodies, and conduct original research on global warming, clean energy, and other issues.

Greenpeace's first action in 1971 was to protest U.S. nuclear testing off the Alaskan coast at the island of Amchitka, attempting to stop a test by steering a fishing boat named *Greenpeace I* into the path of military vessels. In 1974, the organization launched its first environmental effort with the Save the Whales campaign, capturing the attention and imagination of people worldwide. These first activities illustrated what would become Greenpeace trademarks: well-publicized actions of nonviolent resistance based on solid science, attracting widespread public attention to pacifist and environmental causes.

As of 2008, Greenpeace had expanded to become an international organization with a presence in forty-two countries and a wide-ranging, six-part mission. Its Web site identifies climate change as the single most serious global threat, and it lists working to support new forms of energy as the first action in the mission statement. The other goals of the organization include defending oceans and forests, reducing the use of hazardous chemicals by finding alternatives, encouraging more responsible agriculture, and the original goal of stopping nuclear proliferation and working for peaceful disarmament.

To combat global warming, Greenpeace takes a multipronged approach. Its Project Hot Seat campaign targets individual members of the U.S. Congress, encouraging supporters to pressure legislators to support global warming bills. Greenpeace also conducts and publishes research projects, engages in legal action against large emitters of greenhouse gases (GHGs), and campaigns actively to sway opinions of participants in United Nations climate conferences. Its Web site and publications attempt to reach a broad audience with information about global warming, refutation of arguments made by skeptics, and opportunities for activism.

• Significance for Climate Change

Greenpeace has an international headquarters in Amsterdam, as well as regional offices in more than thirty countries. It has more than 250,000 contributing members in the United States and 2.5 million worldwide. With a small paid staff and thousands of volunteers, Greenpeace works to increase awareness of global warming among the general population, and it targets particular experts and officials at opportune moments, as it did when it lobbied participants in the United Nations Climate Conference in Bali in 2007.

Greenpeace publishes research reports with titles such as *False Hope: Why Carbon Capture and Storage Won't Save the Planet* (2008) and *Impacts of Climate Change on Glaciers Around the World* (2004), legislative and press briefings including *Kyoto and the Bali Mandate: What the World Needs to Do to Combat Climate Change* (2007), and a 2004 activists' guide for students interested in organizing to help their college campuses switch to clean energy, as well as brochures, videos, and blogs. Two of its most significant climate change campaigns are the research project ExxonSecrets, which targets scientists and lobbyists employed by the Exxon Corporation to downplay the importance of global warming, and Energy [R]evolution, whose name is a combination of the words "revolution" and "evolution," suggesting the need for a massive overhaul of the way the world produces and consumes energy.

Through the project Greenpeace Solutions, the organization collaborates with business, technology, financial, and government organizations to help individual consumers make good purchasing decisions. The group developed and marketed the GreenFreeze refrigerator, which does not use dangerous hydrofluorocarbons (HFCs), a GHG. Though the product is not widely known in North America, more than 150 million units have sold in Europe and Asia. Greenpeace has also cooperated with European and United Nations groups to develop the SolarChill battery-free solar refrigerator, and it has worked in the United States to develop and promote wind power.

The Greenpeace ship Rainbow Warrior *attempts to block a coal ship at the port of Newcastle, Australia, the largest coal port in the world, in July, 2005.* (AP/Wide World Photos)

In August, 2002, Greenpeace filed suit, along with the environmental organization Friends of the Earth and the city of Boulder, Colorado, against the U.S. Export Import Bank and the U.S. Overseas Private Investment Corporation, accusing them of helping to fund dangerous fossil fuel projects with taxpayer money. The suit claims that these government agencies should have studied the potential climate change effects of these projects before granting funding.

Cynthia A. Bily

• Further Reading

Bohlen, Jim. *Making Waves: The Origins and Future of Greenpeace*. Montreal: Black Rose Books, 2001. This memoir by a research scientist who became one of Greenpeace's founders focuses on the organization's early years but concludes with a call for a Global Green Constitution to address contemporary problems including global warming.

Ferguson, Christy, Elizabeth A. Nelson, and Geoff G. Sherman. *Turning up the Heat: Global Warming and the Degradation of Canada's Boreal Forest.* Washington, D.C.: Greenpeace, 2008. A collaboration between Greenpeace and the University of Toronto, this report examines how Canada's boreal forest helps slow global warming and how logging of the forest increases the release of GHGs.

Weyler, Rex. *Greenpeace: How a Group of Journalists, Ecologists, and Visionaries Changed the World*. Emmaus, Pa.: Rodale, 2004. Written by one of the group's founders, this volume traces the early history of Greenpeace, from a small group of committed pacifists working for nuclear disarmament to one of the largest and best-known environmental activist organizations in the world.

See also: Environmental law; Environmental movement; Friends of the Earth; Gore, Al; U.S. legislation.

Ground ice

- **Category:** Cryology and glaciology

• Definition

Ground ice is found in cavities, voids, pores, and other openings in frozen or freezing ground. It is a feature of a permafrost region, but the two terms are not interchangeable. A permafrost region is defined as an area where the soil and rocks making up the land remain below the freezing point for two or more consecutive years and can include areas with little or no water content. Permafrost regions account for nearly one-quarter of the landmass of the Northern Hemisphere, and some of these areas have been frozen since the Pleistocene ice age. Ground ice differs from glacier ice as well. Glaciers are created when fallen snow compresses into thick ice masses over long periods of time, and they are capable of riverlike movement, albeit at a pace so slow as to be imperceptible to the human eye.

Ground ice is formed once the temperature drops below 0° Celsius, when most of the moisture in the soil freezes. There are two different types of ground ice: structure-forming ice and pure ice. Structure-forming ice, which holds sediment together, comes in multiple varieties, including ice crystals, intrusive ice, reticulate vein ice, segregated ice, and icy coatings on soil particles. Pure, or massive, ice exists primarily toward the surface and is found as ice wedges, massive icy beds, and pingo cores. Massive ice beds are those with a minimum ice-to-soil ratio of 2.5 to 1.

Ancient ground ice, known as fossil ice, is a valuable source of historical information for geologists, paleontologists, and climatologists. Fossil ice preserves organic material and provides a measurable history of sediment and air quality covering hundreds of thousands of years. Cores drilled from fossil ice are studied to learn about the climates of the distant past.

In 2002, the National Aeronautics and Space Administration reported that the Odyssey orbiter had identified ground ice on Mars, a find that was confirmed by the Phoenix lander in June, 2008. The extreme cold and thin atmosphere on Mars would cause surface water to vaporize as dry ice does on Earth, but ground ice buried under the surface remains frozen and should prove invaluable to studies of the planet's history.

• Significance for Climate Change

Ground ice and permafrost play crucial roles in the industrial development of a region's energy and mining industries, as well as in the infrastructure needed to support such enterprises. It is possible to build in the presence of ground ice in its structure-forming state, so long as its properties are taken into consideration.

The presence of ground ice is closely linked to a region's climate, especially to the temperature at ground level. Its impact varies based on a variety of factors, including drainage, snow cover, soil composition, and vegetation. Ground ice affects both topography and vegetation, as well as a region's response to changes in climate and population.

In regions where the temperature remains close to freezing, a change of only a few degrees can be enough to cause ground ice to start melting. Changes can occur naturally, with normal temperature fluctuations, or as a result of ground clearing through construction or forest fire. When structure-forming ground ice melts, the surrounding terrain is significantly weakened, creating slope instabilities and thaw settlement.

Scientists predict that as much as 90 percent of the permafrost in the Northern Hemisphere could melt by the end of the twenty-first century, with most of the thaw taking place in the top 3 meters of terrain. Some regions in Alaska and Siberia have already experienced collapsed infrastructure and increased rock fall in the high elevations. The resulting meltwater would eventually reach the oceans, causing sea levels to rise around the world. Since the 1930's, Arctic water runoff has increased by 7 percent, and it is projected to reach a 28 percent increase by 2100.

Permafrost traps and holds approximately 30 percent of Earth's carbon, sequestering it from the atmosphere. Melting ground ice will release the trapped carbon into the atmosphere, contributing to the greenhouse effect, which in turn will cause even more ice to melt.

Coastlines in permafrost regions become more vulnerable to erosion as the ice retreats. The Alaskan island of Shishmaref, home to a native population whose ancestors have lived there for more than four thousand years, lost 7 meters of coastline annually between 2001 and 2006.

P. S. Ramsey

- **Further Reading**

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Overview of the study of ice cores and how scientists use them to determine historical weather and geological data.

Davis, Neil. *Permafrost: A Guide to Frozen Ground in Transition.* Fairbanks: University of Alaska Press, 2001. Study of permafrost and the various ways in which humans have lived with it and changed it throughout history.

Gosnell, Mariana. *Ice: The Nature, the History, and the Uses of an Astonishing Substance.* Chicago: University of Chicago Press, 2007. Examines in detail ice and its impact on Earth and its inhabitants.

MacDougall, Doug. *Frozen Earth: The Once and Future Story of Ice Ages.* Berkeley: University of California Press, 2004. A scientific look at the ice ages and their geological impact.

Pielou, E. C. *After the Ice Age: The Return of Life to Glaciated North America.* Chicago: University of Chicago Press, 1991. Surveys the impact of the last ice age and North America's evolution after the ice retreated.

See also: Cryosphere; Glaciers; Greenhouse effect; Groundwater; Permafrost; Sea-level change; Sequestration.

Groundwater

- **Category:** Water resources

- **Definition**

There are approximately 1.385 billion cubic kilometers of water on, above, and in the Earth. However, the vast majority of the Earth's water (around 97 percent) is found in its oceans. Groundwater, though constituting less than 2 percent of the world's water, accounts for more than 98 percent of its available freshwater resources. In the United States, more than half of the population depends on groundwater, while in semiarid to arid regions the percentage of people using groundwater is almost 100 percent.

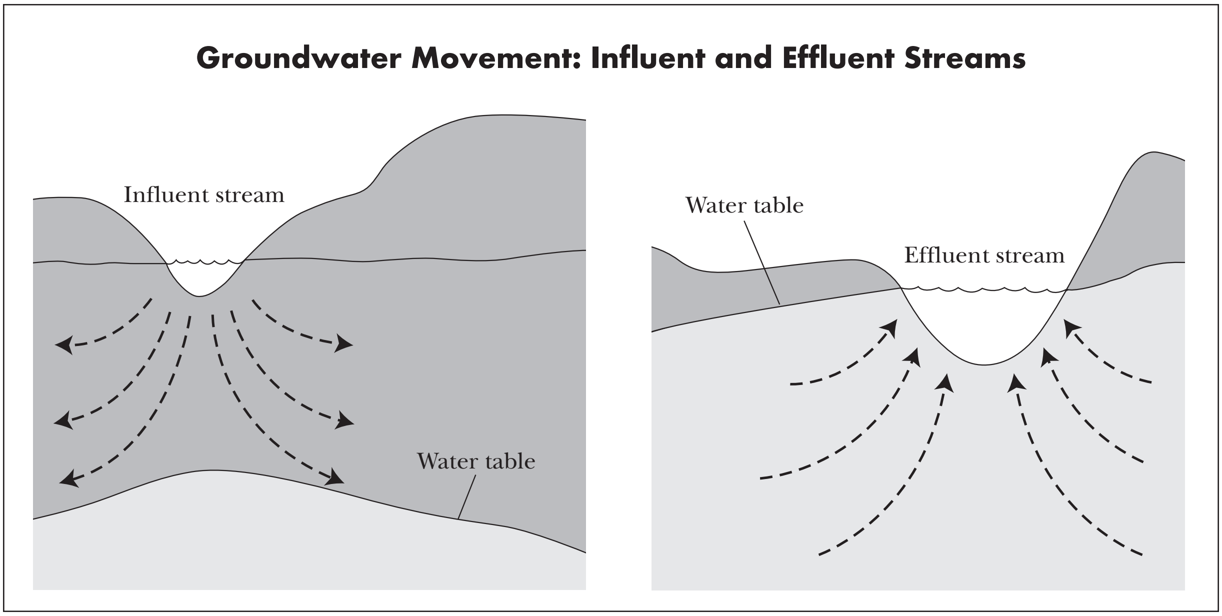
Groundwater is water found in pore spaces (pores) in soil and rocks. It differs from soil water in that groundwater is found below a water table—the demarcation separating saturated pores from unsaturated pores. Soil or rock that is saturated with water and is capable of supporting a well is called an aquifer. An aquifer can comprise one or multiple rock or sediment layers, ranging in size from a few meters to several hundred kilometers long, several meters thick, and meters to kilometers in width. An aquifer could be unconsolidated material, such as sand, or consolidated material, such as sandstone and other rocks. Limestone also makes good aquifers.

Aquifers may be divided into two main types. Open aquifers enjoy direct access to surface water. Closed aquifers sit underneath confining layers of semi- or nonpermeable material, which prevent such access. Water recharges aquifers by infiltration or seepage through permeable materials, and the recharge rate depends on the type of surface material, land cover, slope, and amount and intensity of precipitation melt.

- **Significance for Climate Change**

The effect of global warming on groundwater varies from place to place, with differing effects on water quality and quantity. In semiarid to arid regions, the higher rate of evaporation increases the concentration of dissolved salts in the groundwater, as is the case in Lake Chad, in Africa, where the surface water in some closed areas is becoming more saline. This saline water may recharge the African groundwater system, making the water saline.

With global warming, snow and ice caps will melt, resulting in rapid sea-level rise. This rise may force saline waters into aquifers, reducing the water's suitability for human and ecological use. Already, such seawater intrusion has occurred along some coastal aquifers, including one in El Paso, Texas.



Two examples of groundwater movement: Influent streams, found in dry climates, cause an upward bulge in the water table as water from the stream migrates downward. Effluent streams, found in wet climates, are produced by a high water table that migrates water into channels in the ground's surface.

Global temperature rise will lead to an increase in precipitation in the Northern Hemisphere. As snow and glaciers melt, the groundwater table will rise in most places. Sinkhole numbers may increase in limestone terrains with higher rates of solution weathering resulting from acid rain. These sinkholes could become conduits through which contaminants from the land surface could reach the groundwater.

Groundwater resident time (the length of time water stays in an aquifer) varies from a few days to several thousand years. Generally, the shorter the resident time, the greater the infiltration rate or the shallower the aquifer. In areas such as Libya, where resident time can stretch to hundreds or thousands of years, drought-induced demands for groundwater can cause faster depletion of that water. In areas where the land surface is highly permeable and where rainfall or snowmelt is heavy, the resident time may be low; such areas may experience a dramatic rise in groundwater level. Assuming the anthropogenic effect upon groundwater is minimized or maintained at its current rate, a reduction in rainfall would lead to the lowering of water tables. Such lower water tables could cause ground compaction, loss of permeability of the land surface, and an increased runoff that could lead to flooding. Groundwater withdrawal could also lead to ground subsidence, as has occurred in Texas and California. Heavy cracks, rills, or gullies may develop on the surface, as in Lake Chad, where the soil is clayey.

Global warming is likely to increase flood and drought conditions in different parts of the world. This in turn would affect the rate of evaporation, lowering water levels in rivers and lakes during the summer months. Some of these water bodies could become groundwater recharging zones. Near-surface water tables will lose increasing amounts of water to evaporation as surface temperatures increase. In addition, surface water infiltration will lead to a reduction of groundwater flows to lakes.

Solomon A. Isiorho

• Further Reading

Anderson, M. P. "Introducing Groundwater Physics." *Physics Today* 60, no. 5 (May, 2007): 42. Good, succinct summary of the principles of groundwater.

Fetter, C. W. *Applied Hydrogeology*. 4th ed. Upper Saddle River, N.J.: Prentice Hall, 2001. An easy-to-read textbook on hydrogeology. Presents several case studies and includes student versions of modflow, flownet, and aqtesolv software.

Hudak, Paul F. *Principles of Hydrogeology*. 3d ed. Boca Raton, Fla.: CRC Press, 2005. A simple book on hydrogeology that assumes readers have some geology and algebra skills.

Todds, David Keith, and Larry W. Mays. *Groundwater Hydrology*. Hoboken, N.J.: Wiley, 2005. Covers the basics of groundwater hydrology and includes modeling methods.

Younger, P. L. *Groundwater in the Environment: An Introduction*. Malden, Mass.: Blackwell, 2007. This is a good book for those interested in groundwater that does not require a geology background.

See also: Freshwater; Hydrologic cycle; Hydrosphere; Saltwater intrusion; Water quality; Water resources, global; Water resources, North American; Water rights.

Group of 77 and China

- **Categories:** Organizations and agencies; nations and peoples
- **Date:** Established June 15, 1964
- **Web address:** http://www.G7.org

• Mission

In the early 1960's, at the height of the Cold War, the agenda at the United Nations reflected a world divided between East and West. As part of the United Nations mission to offer a forum for the representation of the global community, efforts began as early as 1962 to organize the developing countries of the nonaligned Third World into a coalition within the United Nations. The original protocol for establishing the network of less influential nations was to address questions of trade. The interests of the United States and its allies and the Soviet Union and its satellites threatened smaller countries, which demanded relaxed trade barriers and stabilized commodity prices. "Solidarity" was seen as the only way to promote the economic interests of this diverse international community of nations.

The coalition was officially chartered with the Joint Declaration of the Developing Countries in October, 1963, and first convened on June 15, 1964, at the close of the first session of the United Nations Conference on Trade and Development in Geneva. Originally, the charter included seventy-seven nations that represented six continents. The group endorsed the central vitality of the United Nations as the forum most appropriate for presenting—and addressing—trade problems. Given the wide range of cultural and religious elements among the group's membership, the Group of 77 became a paradigm for the mission of the United Nations itself: forging community from diversity.

The first meeting of the Group of 77 was held in Algiers in September, 1967. That assembly adopted a superstructure for the organization, a protocol for annual meetings to be held in conjunction with the opening of the General Assembly in New York. Currently member nations number 130, although the name of the organization was retained for its historical importance. The Republic of China has been recognized as a conditional invitee since 1981. In 1971, a separate chapter-entity, the Group of 24, was established to work specifically on international monetary issues.

• Significance for Climate Change

After more than three decades of monitoring the economic development, trade growth, health care, and technological development of developing countries, the Group of 77 in the mid-1990's shifted its agenda to consider the ramifications of the growing alarming data that projected dire consequences for global climate patterns should the emission of greenhouse gases (GHGs) fail to be significantly curbed. Global warming accelerated by the burning of oil, gas, and coal—the primary energy resource of the powerful dominant world economies—created a frustrating problem for those less industrial countries. Many of these countries were largely agricultural and most lacked the developed industrial grid that produced GHGs; hence, these countries were not part of the GHG emission problem. Yet, as climatologists began to gather data, it was increasingly clear that impoverished countries would bear the initial brunt of any catastrophic change in the Earth's climate patterns.

The ambitious and controversial 1997 Kyoto Protocol called for thirty-eight developed countries to reduce fossil fuel emissions by an average of 5.2 percent by 2012. Since that agreement, the Group of 77 has become aggressive in its efforts to represent the impact of global warming on developing countries. Each successive chair of the powerful caucus has endeavored to stress that the economies of developing countries are most vulnerable to the earliest effects of global warming. The Group of 77, in a series of communiqués issued through its agencies, has argued that the strategy proposed by the Kyoto Protocol to help smaller nations—transferring to these nations cutting-edge technology as a way to minimize the production of GHGs from their obsolete facilities—would not sufficiently address the magnitude of the fast-approaching problems.

The Group of 77 pointed out the need for an international water management strategy to handle diminishing water supplies; the need to chart the catastrophic impact of irregular weather patterns (most notably the increase in droughts, heat waves, and cyclones); the need to assess the impact of dropping of sea levels on trade and navigation routes and the economies that rely on them; the need for strategies to handle the sharp increase in food riots in areas stricken by droughts; and the impact on previously stable governments as countries struggle to address these concerns. Given the reluctance of entrenched dominant world economies to reduce fossil fuel emissions, the Group of 77 aggressively pursued its role as agitator, arguing that the crisis of global warming will demand the cooperation of developing nations as the only way to make their interests part of the international dialogue on addressing the crisis.

Joseph Dewey

• **Further Reading**

Aldy, Joseph E., and Robert N. Stavins. *Architectures for Agreement: Addressing Global Climate Change in a Post-Kyoto World*. New York: Cambridge University Press, 2007. Assesses the relationship between dominant economies and developing countries necessary to address the threat of

From left: U.N. secretary-general of the Conference on Trade and Development Rubens Ricupero, Brazilian minister of external relations Celso Amorim, and Qatar minister of economy and commerce Sheikh Mohammed Bin Ahmed Bin Jassin Al-Thani speak at the ceremony commemorating the fortieth anniversary of the Group of 77 in June, 2004. (AP/Wide World Photos)

global warming. Argues the central role of the United Nations in developing a workable framework for enforcing the Kyoto Protocol.

Mingst, Karen A., and Margaret P. Karns. *The United Nations in the Twenty-first Century*. Boulder, Colo.: Westview Press, 2006. Informed analysis of the role of the United Nations in a variety of pressing issues, including global warming.

Northcutt, Michael. *A Moral Climate: The Ethics of Global Warming*. Phoenix, Ariz.: Orbis, 2007. Fascinating and accessible argument that examines the moral dimension of the conflicting interests of industrialized and developing nations in addressing global warming.

Sauvant, Karl P. *Group of 77: Evolution, Structure, Organization*. New York: Oxford University Press, 1980. Still the most comprehensive and reliable history of the organization's mission; emphasizes trade inequities and the need for solidarity.

See also: Annex B of the Kyoto Protocol; China, People's Republic of; International agreements and cooperation; Kyoto Protocol; Poverty; United Nations Framework Convention on Climate Change.

Gulf Stream

• **Category:** Oceanography

The Gulf Stream moves huge amounts of water, salt, and heat around the Atlantic Ocean. Many scientists have argued that the position of the Gulf Stream has shifted at times in the geologic past, causing significant changes in the climate of Greenland and northern Europe.

• Key concepts

Coriolis effect: the deflection of moving objects caused by Earth's rotation

geostrophic current: a current driven by horizontal gradients in pressure that are balanced by the Coriolis effect

North Atlantic drift: a current that diverges from the Gulf Stream, moving warm water northward to areas where it will cool and sink

subtropical gyre: a gigantic lens of warm water, usually occupying a substantial portion of an ocean basin, that rotates because of geostrophic currents

thermohaline circulation: circulation driven by differences in density

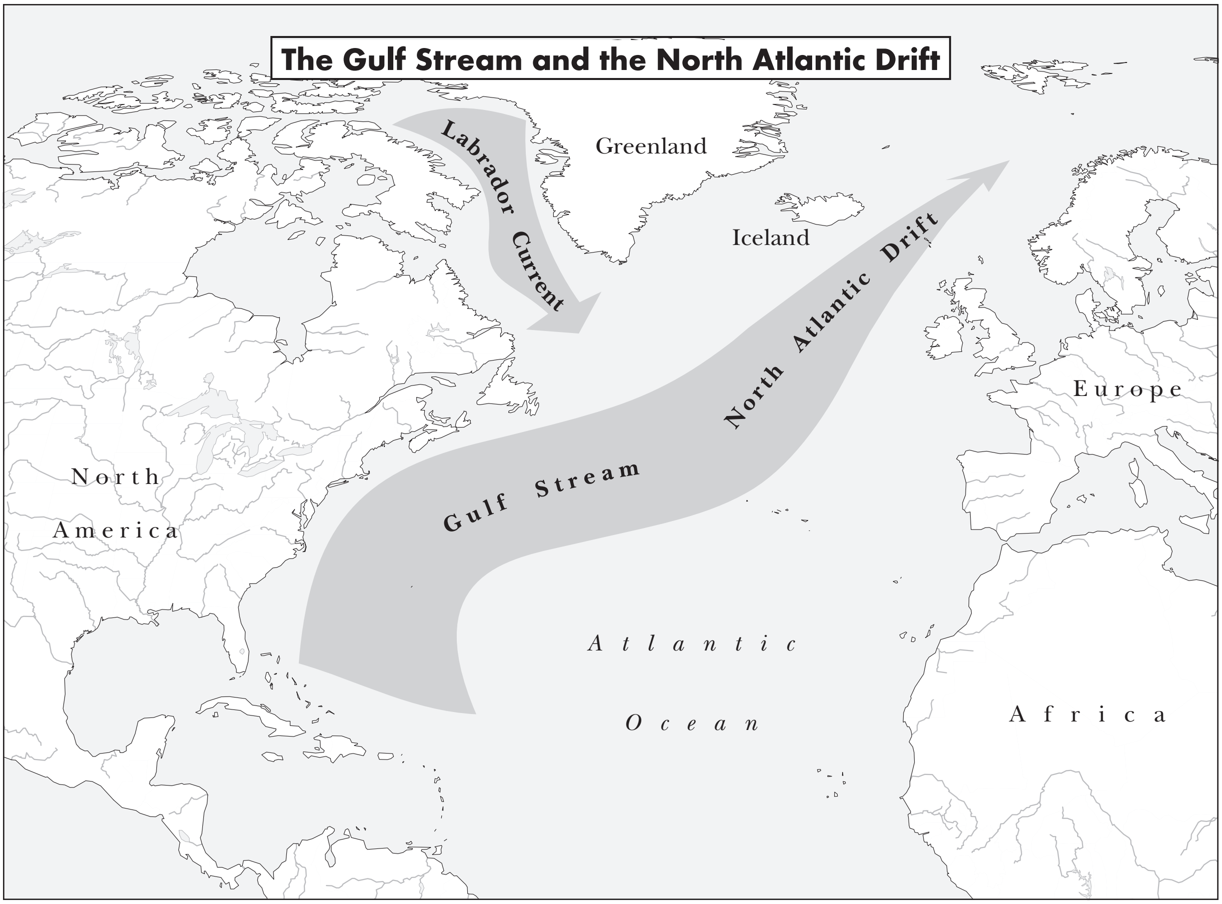
westerlies: the prevailing winds in the midlatitudes, resulting from a combination of vertical circulation patterns in the atmosphere and the rotation of the Earth

• Background

The Gulf Stream has a peak flow of more than a hundred times that of all the rivers and streams on Earth, combined. Much of this is warm water from the Gulf of Mexico or the Caribbean, being transported to the North Atlantic, transferring a great amount of heat. A strong belief has developed that this ocean current is responsible for the mild climate of Europe. Recent data and global climate models indicate, however, that it is only one of several factors, as the heat transported by winds is several times greater.

• Geostrophic Flow and the North Atlantic Gyre

The Sun warms the surface waters of the oceans, expanding them and reducing their density. The prevailing wind patterns in the subtropics (near 20° latitude) pile up these surface waters into hills, which are actually lens-shaped water masses floating on denser, cooler water, and bounded in part by continents. These hills have "peaks" no more than two meters higher than their edges, thousands of kilometers away. As the water at the surface tries to flow down this slope, the Coriolis effect, which is a consequence of the Earth's rotation, causes it to be deflected. In the Northern Hemisphere this deflection is to the right, so the circulation actually follows the hill contours, forming a rotating gyre. In the North Atlantic and North Pacific, subtropical gyres rotate in a clockwise sense. Constraints of flow on a rotating planet require that gyres are asymmetric, with a very steep slope on the western side. The rate at which these geostrophic currents flow is proportional to the slope. The Gulf Stream is a result of this steep slope, produced by a combi-



nation of solar heating, basin geometry, prevailing wind directions, and the rotation of the Earth.

The magnitude of this flow is prodigious. Peak flows are about 150×10^6 cubic meters per second. Put another way, a mass of ocean water, equivalent to the mass of the entire human population, flows by in less than four seconds. In a year the Gulf Stream moves 4.71 million cubic kilometers of water, which is huge compared to the annual runoff from all the continents (40,000 cubic kilometers) or even the total water moving between the surface of the Earth and the atmosphere (489,000 cubic kilometers).

- **Heat Transport**

Along with all the water, the Gulf Stream moves a great deal of heat to the north. At the northern end of its range (near 50° north latitude), the North Atlantic Drift, with a flow of 14×10^6 cubic meters per second, diverges from it, moving this water farther north, where it cools and sinks. If it loses 20° Celsius in the process, or 20 calories per gram, about 1×10^{15} watts are released. This is fifty times the total human energy use of 0.018×10^{15} watts, and about half of the total poleward ocean heat transport on the planet. However, the heat transported by the atmosphere is about four times greater.

The cause of this disparity lies in the heat of vaporization of water. Every gram that evaporates moves at least 540 calories of heat from the ocean to the atmosphere. Of the 413,000 cubic kilometers of water evaporated from the sea every year, perhaps 56,000 cubic kilometers, evaporate near the equator in the Atlantic and precipitate farther north. That would release 4×10^{15} watts.

The Gulf Stream may not be directly responsible for the mild climate of Europe, but it probably is responsible for the warm temperatures of the North Atlantic. If these temperatures fall, the ocean surface may become covered with ice, the wind will not be warmed, and Europe will surely chill. Furthermore, the strength of the North Atlantic Oscillation (NAO) may well depend on these warm temperatures, and hence on the Gulf Stream.

• Context

Intuitively, it would seem that a current that brings about 1×10^{15} watts of heat into the North Atlantic should be a dominant player in the climate of Europe. Since its discovery, many people have thought so and have written about it. Recent studies indicate, however, that the heat brought by the Gulf Stream is only a tenth of the heat transported, it is responsible for only a few degrees of warming, and it does nothing to explain why Europe is 15°-20° Celsius warmer, in winter, than places at similar latitudes on the East Coast of North America. Most of the heat, and all of the heat producing the contrast between Europe and North America, comes from atmospheric transport and the heating of the surface waters during the summer. Because the myth is so entrenched in the collective understanding of climate science, changing the way people think about it has proven to be extremely difficult. The strength of the NAO may be more important to Earth's climate than the strength of the Gulf Stream; however, the Gulf Stream may control the NAO.

Otto H. Muller

• Further Reading

Fagan, Brian M. *The Little Ice Age: How Climate Made History, 1300-1850.* New York: Basic Books, 2000. Although it does contain some scientific errors, this book shows how significant the North Atlantic Oscillation has been over the last seven hundred years. It is written in an engaging, easily accessible style. Illustrations, maps.

Gaskell, Thomas Frohock. *The Gulf Stream.* New York: John Day, 1973. Although he does not repudiate the myth that the Gulf Stream is primarily responsible for Europe's mild climate, Gaskell emphasizes the role of the wind. An early source of warnings about the warming effects of a buildup of CO_2 in the atmosphere. Illustrations, photographs, maps.

MacLeish, William H. *The Gulf Stream: Encounters with the Blue God.* Boston: Houghton Mifflin, 1989. Provides a fascinating personal account of the Gulf Stream. MacLeish points out that to most oceanographers, the notion that the Gulf Stream was responsible for the mild climate of Europe has generally been treated with derision. Illustrations, maps.

Seager, R. "The Source of Europe's Mild Climate: The Notion That the Gulf Stream Is Responsible for Keeping Europe Anonymously Warm Turns out to Be a Myth." *American Scientist* 94 (2002): 340-31. An accessible treatment of the research conducted by Seager and others to debunk the myth. Illustrations, photographs, maps.

Seager, R., et al. "Is the Gulf Stream Responsible for Europe's Mild Winters?" *Quarterly Journal of the Royal Meteorological Society* 128, no. 586 (2002): 2563-2586. Somewhat technical, this work describes the details of the work done by Seager and others to debunk the myth.

See also: Atlantic heat conveyor; Atlantic multidecadal oscillation; Ekman transport and pumping; El Niño-Southern Oscillation; Gyres; La Niña; Maritime climate; Meridional overturning circulation; Ocean-atmosphere coupling; Ocean dynamics; Sea surface temperatures; Thermohaline circulation.

Gyres

• Category: Oceanography

• Definition

The oceans' gyres are basin-scale circulation patterns in which the net flow of water occurs in a circular pattern around the basin. Each gyre is generally made up of four distinct currents that are driven by wind stresses, and its circulation direction is governed by the Coriolis effect. The major, subtropical gyres in the Atlantic and Pacific Oceans are located between the equator and approximately 45° north latitude, while the smaller, subpolar gyres lie north of that latitude. The Antarctic Circumpolar Current is a gyre that flows continuously around Antarctica, because there are no landmasses to impede it.

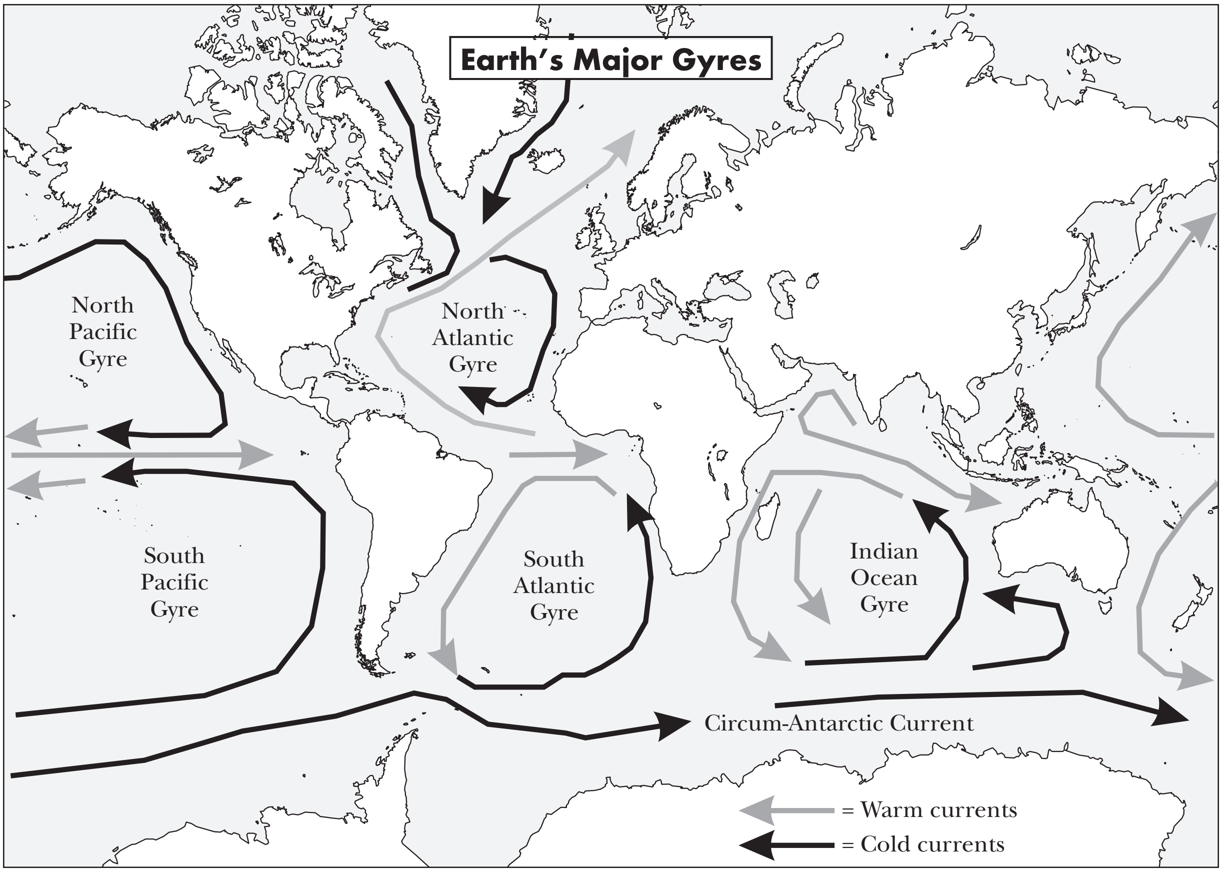
Individual currents that make up a gyre have different characteristics. Because of the Coriolis effect and resulting differences in sea surface elevation, the western boundary currents (currents that flow on the western side of the ocean basins and flow northward from the equator) are narrow, are relatively deep (up to 1,200 meters), and have velocities of up to 178 kilometers per day. Examples of western boundary currents include the Gulf Stream in the Atlantic Ocean and the Kuroshio Current in the Pacific Ocean.

Eastern boundary currents have widths of up to almost 1,000 kilometers but are only 500 meters deep. Examples of eastern boundary currents include the California Current in the Pacific Ocean and the Canary Current in the Atlantic Ocean. Offshore Ekman transport associated with the eastern boundary currents leads to upwelling and high levels of productivity in these surface waters. Circulation of the gyres is completed by transverse currents that flow east and west across the ocean basins, connecting the western and eastern boundary currents.

The subtropical gyres are associated with persistent high-pressure regions in the atmosphere, which leads to a net motion of surface water to the center of the gyre—a process known as convergence. These regions of high pressure are associated with low annual rainfall totals, so the salinity of water in the center of the gyres is somewhat elevated. Elevated salinity and convergence lead to downwelling, so the central gyres are regions of low productivity.

• Significance for Climate Change

The gyres transfer large amounts of heat from the equator to the poles. For example, the Gulf Stream carries heat north from the Caribbean Ocean, trav-



els along the East Coast of the United States, and then curves eastward toward Europe. The heat released from the Gulf Stream may lead to warmer average temperatures in Europe than those found at similar latitudes in North America. It has been hypothesized that global warming will lead to an increased influx of freshwater to the Arctic Ocean, which could block the northward flow of the warm, salty water of the Gulf Stream. In turn, this could prevent heat transport from the equator and could lead to cooling of the Northern Hemisphere.

The strength of the gyral currents can vary on decadal timescales, such as is observed in the Atlantic Multidecadal Oscillation (AMO), which manifests as cycles in average sea surface temperatures (SSTs), as lesser or greater amounts of warm water are transported from equatorial regions. The intensity of hurricanes is strongly dependent on SST, with stronger, more frequent hurricanes occurring when SSTs are higher. Thus, if global temperatures increase, the amplitude of the AMO will increase, leading to the circulation of warmer water and increased hurricane intensity.

Decadal variations in gyral flow can also affect the extent of coastal upwelling, salinity, and nutrient concentrations. Scientists from the Georgia Institute of Technology have discovered the existence of the North Pacific Gyre Oscillation. Variations in the mode of the oscillation are thought to cause historical variations in fish populations that are critical to Pacific fisheries. While such oscillations are part of the natural climate cycle, evidence indicates that the amplitude of the oscillations may increase with global warming.

Water in the center of the gyres is isolated from the rest of the world's oceans. An important consequence of this isolation is the low levels of phytoplankton productivity of the water—a situation described as "oligotrophic." The major source of nutrients to support productivity in the central gyres is upwelling of deep waters. However, downwelling, not upwelling, occurs in the central gyres, making these waters the equivalent of large, open-ocean deserts. As global temperatures have increased, the size of these ocean deserts has increased. Scientists from the National Oceanic and Atmospheric Administration and the University of Hawaii have examined a nine-year series of remotely sensed ocean color data from the SeaWiFS satellite and concluded that these open-ocean deserts have expanded by up to 15 percent. The expansion of the oligotrophic regions is consistent with computer models of oceanic vertical stratification in the gyres, but the rate of expansion exceeds all model predictions.

Anna M. Cruse

• Further Reading

Di Lorenzo, Emanuele, et al. "North Pacific Gyre Oscillation Links Ocean Climate and Ecosystem Change." *Geophysical Research Letters* 35, no. 108607 (April, 2008). Overview of the discovery of the North Pacific Gyre Oscillation and its consequences for Pacific ecosystems and fisheries industries.

Open University. *Ocean Circulation*. 2d ed. Boston, Mass.: Elsevier Butterworth-Heinemann, 2005. This introductory oceanography textbook covers atmospheric circulation, surface currents, and thermohaline circulation. The theory of fluid flow throughout the ocean is developed with a minimum of mathematics (knowledge of algebra and trigonometry is assumed). Illustrations, figures, tables, maps, references, index.

Polovna, Jeffrey J., Evan A. Howell, and Melanie Abecassis. "Ocean's Least Productive Waters Are Expanding." *Geophysical Research Letters* 35, no. 103618 (February, 2008). Presents the SeaWiFS data, showing that the ocean's oligotrophic regions in the subtropical gyres are expanding at rates exceeding those predicted by computer models.

Trenberth, Kevin E. "Warmer Oceans, Stronger Hurricanes." *Scientific American* 297, no. 1 (July, 2007): 44-51. Describes how warmer oceans and variations in gyral currents such as the Gulf Stream affect decade-scale circulation patterns and the formation of hurricanes.

See also: Atlantic heat conveyor; Atlantic multidecadal oscillation; Ekman transport and pumping; El Niño-Southern Oscillation; Gulf Stream; La Niña; Mean sea level; Meridional overturning circulation; Ocean dynamics; Plankton; Sea surface temperatures; Thermocline; Thermohaline circulation.

Hadley circulation

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Named for eighteenth century meteorologist George Hadley, who explained how it worked, the Hadley circulation is a loop of air that starts near the equator. The hot air in the equator region rises to the troposphere level and is carried toward the poles. At about 30° latitude, the air drops back to the surface, creating a high-pressure area. The air is pulled back toward the equator, completing the loop and generating the trade winds. Because the Earth is spinning, the air traveling back to the equator goes toward the southwest in the Northern Hemisphere and is called the Northeast Trades. In the Southern Hemisphere, the air movement generates the Southeast Trades. The low-pressure area where the Northeast Trades meet the Southeast Trades and where the hot air rises is called the Inter-Tropical Convergence Zone (ITCZ). The ITCZ does shift with the seasons.

The Hadley circulation is caused by solar heating. The intensity of the Hadley circulation is related to the sea surface temperature. The hot air will carry moisture aloft, but as the air rises, it cools and is able to contain less moisture, causing the large amount of rainfall in the equatorial region. Still, it is moist hot air that travels toward the poles and drier cool air that blows back toward the equator.

The Hadley circulation is one of the major regulators of the Earth's energy budget. It spreads heat collected at the equator to the northern and southern subtropical areas. It also carries heat into the troposphere, where it can radiate into space. Hadley's ascending limb controls the rainfall in the tropical areas, where large amounts of rain occur. The descending limb controls the dryness of the subtropical area. Although the Hadley circulation covers only part of the Earth, it covers the area where a large percentage of the people of the world live.

• **Significance for Climate Change**

A difference in the patterns of the sea surface temperature would force a change in precipitation and cause a change in the Hadley circulation. A change in that system would cause a change in the flow of heat, momentum, and humidity along the meridians. The Earth's overall radiative balance, along with the monsoon systems and the ocean circulation, are also affected by a change in Hadley circulation. Different climate models diverge when they project the effect of an increase in greenhouse gases (GHGs) on the Hadley circulation. Some models indicate an increase of the intensity of the Hadley circulation, causing a more arid subtropical region to develop as the rising GHG concentration causes an increase in sea surface temperature. Other models indicate a weakening of the Hadley circulation.

Since 1950, there has been a more intense Hadley circulation, with a consequential increase in rainfall in the equatorial oceanic region and a drier tropical and subtropical landmass. This increase has accompanied a stronger westerly stratospheric flow and an increase in cyclones in the middle latitudes. The driving force behind these changes has been identified as the warming of the Indo-West Pacific tropical waters. The increased sea surface temperature difference between the winter and summer hemisphere tropics causes a stronger Hadley circulation.

Models indicate that the solar forcing of the increased Hadley circulation is more intense with GHGs than without. It is not clear from the models proposed whether the more intense Hadley circulation is due to a natural fluctuation, is anthropogenic, or is the combined result of natural and human factors. Solar forcing models indicate more evaporation and thus more moisture carried aloft. This causes less cloud cover and more solar heating. Thus, solar forcing seems to represent a positive feedback loop. The more solar heating, the less cloud cover and more solar heating.

Models of past data indicate that the ITCZ may have shifted over time by more than just the annual summer-to-winter position shift. Another shift would cause different areas of the Earth to be dry or to be rain-soaked. The extent of the Hadley circulation is influenced by several different factors according to models. One factor that was shown not to be related is the mean global temperature. Just increasing the Earth's temperature will not change the area covered by the Hadley circulation. The

Hadley circulation can be likened to El Niño-Southern Oscillation events. Since 1976, the increase in number and strength of El Niño events has caused an increase in the strength of the winter Hadley circulation.

C. Alton Hassell

• Further Reading

Diaz, Henry F., and Raymond S. Bradley, eds. *The Hadley Circulation: Present, Past, and Future.* Dordrecht, the Netherlands: Kluwer Academic, 2004. Essay collection that grew out of a conference examining the Hadley circulation from several different viewpoints. Illustrations, maps, references.

Hadley, G. "Concerning the Cause of the General Trade-Winds." *Philosophical Transactions of the Royal Society of London* 39 (1735): 58-62. George Hadley takes Halley's concept and expands on it.

Halley, E. "An Historical Account of the Trade Winds, and Monsoons, Observable in the Seas Between the Tropicks, with an Attempt to Assign the Physical Cause of the Said Winds." *Philosophical Transactions of the Royal Society of London* 16 (1686): 153-168. The original article explaining the Hadley circulation. Illustrations.

O'Hare, Greg, John Sweeney, and R. L. Wilby. *Weather, Climate, and Climate Change: Human Perspectives.* Harlow, England: Pearson Prentice Hall, 2005. Comprehensive review of weather and its causes, including the Hadley cell. Illustrations, references, index.

Watterson, Ian Godfrey, and Edwin K. Schneider. "The Effect of the Hadley Circulation on the Meridional Propagation of Stationary Waves." *Quarterly Journal of the Royal Meteorological Society* 113, no. 477 (July, 1987): 779-813. Based on Watterson's doctoral dissertation of the same name, this article distills one of the only extended studies of Hadley circulation, presenting its most salient insights and conclusions.

See also: Atmospheric dynamics; Climate and the climate system; Climate models and modeling; Climate zones; Evapotranspiration; Inter-Tropical Convergence Zone; North Atlantic Oscillation; Ocean-atmosphere coupling.

Halocarbons

• **Category:** Chemistry and geochemistry

• Definition

The halocarbons are a group of partially halogenated organic compounds, in which carbon atoms link with halogen atoms by a covalent bond. (The halogen atoms include bromine, chlorine, fluorine, and iodine.) The most common type of halocarbon contains chlorine and belongs to the subclass of chlorocarbons, which includes substances such as carbon tetrachloride and tetrachloroethylene. The other common subclass of halocarbon, the fluorocarbons, contains fluorine and includes polytetrafluoroethylene (Teflon) and perfluorocarbons (PFCs). Some of the Freons, though not all, are halocarbons. Halocarbons are produced and valued because of their nonflammability, low chemical reactivity, and low toxicity.

The halocarbons include several compounds that affect the environment, compounds such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), halons, methyl chloride, and methyl bromide. Though it is possible for halocarbons to form naturally, from volcanic activity or by the interaction of halogen and plant matter, most halocarbons are produced by humans for industrial and chemical use and include substances used as refrigerants and fire extinguishants.

• Significance for Climate Change

Many halocarbon compounds have a high global warming potential (GWP). Of these compounds, three (CFC-11, CFC-12, and CFC-113, all created by human activity) are the worst offenders. These gases are not reactive, so they are able to remain in the stratosphere for hundreds of years.

How Halocarbons Affect the Earth's Heat Retention. As light from the Sun enters the atmosphere, some of that light is scattered by molecules in the air or is reflected from clouds back into space. Some of the light that reaches Earth's surface is also reflected back into space, such as light that hits snow or ice. However, much of the light that reaches Earth is absorbed and retained as heat.

The Earth's surface warms and emits infrared photons, which make several passes between the Earth and the atmosphere, warming the atmosphere and the Earth as they go back and forth. Eventually, these infrared photons return to space.

The greenhouse gases (GHGs), which include many halocarbons, are able to absorb infrared photons, transferring their energy from the photons to gas molecules and thereby trapping thermal energy that would otherwise be released into space. Eventually, this absorption of energy causes a net change in the Earth's energy balance, increasing the overall amount of thermal energy held within the system. Different GHGs have different GWPs and lifetimes, measurements of the amount they contribute to global warming and the duration of that contribution, respectively. Both the GWP and the lifetime of halocarbons are unusually high. They may remain in the atmosphere for up to four hundred years, for example, continuing to affect the global climate long after their initial release.

How Halocarbons Deplete the Ozone Layer. Halocarbons containing chlorine and bromine also deplete the ozone layer. Until the 1970's, CFCs, perhaps the best known of the halocarbons, were used as propellants, solvents, and cleaners. Realizing that these compounds were depleting the ozone layer, many nations agreed to control halocarbon emissions when they signed the Montreal Protocol.

Ozone is a form of oxygen; it is formed of three atoms of oxygen bound together. Ozone in the stratosphere blocks harmful solar radiation. Halocarbons help speed the natural destruction of ozone. For example, CFCs are able to break down ozone when they combine with it in high-frequency ultraviolet (UV) light. During this breakdown, ozone molecules are destroyed, but chlorine reforms and is able to take part in the breakdown again. In this way, just one chlorine atom in the stratosphere is thought to be able to destroy about 100,000 ozone molecules.

Ozone depletion can have serious effects. The less ozone is available to shield the Earth, the more UV-B rays are able to penetrate the atmosphere and reach the planet's surface, where they cause skin cancer and cataracts in humans. Moreover, the disruption of the normal wavelengths of light reaching Earth's surface affects plants and their growth rates. It is also possible that the change in atmospheric radiation affects global wind patterns and therefore climate.

Halocarbons do not disintegrate easily and may become corrosive agents when burned, which makes them difficult to dispose of safely. Halocarbons are also implicated in liver disease, eye cataracts, and skin cancer, and they may affect the human immune system.

Marianne M. Madsen

• Further Reading

Forster, P., and M. Joshi. "The Role of Halocarbons in the Climate Change of the Troposphere and Stratosphere." *Climatic Change* 71, no. 1 (July, 2005): 249-266. Discusses how halocarbons containing chlorine and bromine affect atmospheric temperature and ozone-layer depletion.

Middlebrook, Ann M., and Margaret A. Tolbert. *Stratospheric Ozone Depletion*. Sausalito, Calif.: University Science Books, 2000. Describes how human activities affect ozone destruction.

Ozone Depletion, Greenhouse Gases, and Climate Change. Washington, D.C.: National Academy Press, 1989. Proceedings of a 1988 conference on atmospheric contributors to climate change. Includes a chapter entitled "The Role of Halocarbons in Stratospheric Ozone Depletion."

World Meteorological Organization. *Scientific Assessment of Ozone Depletion, 1994*. Global Ozone Research and Monitoring Project Report 37. Geneva, Switzerland: Author, 1995. Overview of the state of the ozone layer and factors contributing to its depletion.

See also: Aerosols; Chemical industry; Chlorofluorocarbons and related compounds; Cosmic rays; Greenhouse effect; Halons; Hydrofluorocarbons; Ozone; Perfluorocarbons.

Halons

• **Category:** Chemistry and geochemistry

• **Definition**

Halons are gaseous compounds of carbon, bromine, and another halogen (such as hydrogen, chlorine, or fluorine). These gases, also known as bromofluorocarbons, include the chlorofluorocarbon (CFC) family. They are classified by the U.S. Environmental Protection Agency as Group II of the Class I ozone-depleting substances.

Halons were first used during World War II as fire-extinguishing agents. They are particularly useful in extinguishing electrical fires, because they are covalently bonded and thus do not react with electrical equipment. They continued to be used through 1994, when they were banned by the Montreal Protocol as ozone-depleting substances.

• **Significance for Climate Change**

Halons are members of the class of halogenated hydrocarbons, which have been shown to deplete the ozone layer. By some estimates, halons are three to ten times more destructive of the ozone layer than are other substances in this family, including CFCs, because they contain bromine. The bromine radicals in halons react with ozone particles and remove them from the stratosphere. They sometimes react with atmospheric chlorine as well, magnifying their effects on ozone. The bromine-containing halons are much more destructive of atmospheric ozone than are other compounds, such as those containing chlorine, because bromine compounds are much more likely to disassociate in ultraviolet light, so many more ozone molecules are destroyed before the bromine molecules diffuse.

Halon use worldwide has historically been less than CFC use, so halons are not as widely known as ozone-destruction agents. However, halons are more destructive than some other ozone-depleting compounds, because their concentration in the atmosphere is still rising as a result of their long lifetimes.

Less environmentally destructive fire-extinguishing agents have been found to replace halons. These include halocarbon-based agents that absorb heat and inert gas agents that deplete oxygen, smothering fires. Both of these agents are less threatening to the ozone layer than are halons.

Marianne M. Madsen

• **Further Reading**

Miziolek, Andrzej W., and Wing Tsang, eds. *Halon Replacements: Technology and Science.* Washington, D.C.: American Chemical Society, 1995. A seminal source on research, development, and testing of substances to replace halons. Arose out of a symposium on the subject and provides a summary of that symposium in addition to collected papers. Includes author index and detailed topical index.

Schwarzenbach, René P., Philip M. Gschwend, and Dieter M. Imboden. *Environmental Organic Chemistry.* 2d ed. Hoboken, N.J.: Wiley, 2003. Discusses environmental factors and how they affect organic compounds. Includes problems and case studies.

Taylor, Gary. *Eliminating Dependency on Halons: Case Studies.* Paris: United Nations Environment Programme, 2000. Case studies describing successful removal of halons according to the Montreal Protocol.

See also: Aerosols; Chemical industry; Chlorofluorocarbons and related compounds; Cosmic rays; Greenhouse effect; Halocarbons; Hydrofluorocarbons; Ozone; Perfluorocarbons.

Health impacts of global warming

• **Category:** Diseases and health effects

Ambient temperature in general, and systematic temperature changes in particular, have both direct and indirect impacts on human health. Direct effects include increases or decreases in heatstroke, hypothermia, and metabolic and physiological disorders. Indirect effects include increases or decreases in drought, famine, severe weather events, and disease.

• Key concepts

cardiac diseases: heart diseases, including those of relevant blood vessels (cardiovascular) and those caused by decreased blood supply (ischemic)

cerebrovascular disease: illness caused by abnormality in blood vessels supplying the brain

hemoconcentration: increased concentration or thickening of the blood resulting from dehydration or cooling of the body

mortality and morbidity: statistics on death and illness in population groups

pulmonary disease: illness of the lungs or affecting the breathing process

• Background

The threat of possible severe climate change, including predictions of global warming from politicians, media leaders, and scientists, has aroused worldwide concern about the potential effects of such change on human health. The United Nations' Intergovernmental Panel on Climate Change (IPCC) reported in 2007 that multiple computer-model predictions were consistent with significant climate warming occurring by 2050 and potentially disastrous warming occurring by 2100. These predictions depended on various scenarios of increasing greenhouse gases (GHGs), especially carbon dioxide (CO_2), in the atmosphere and were based on the anthropogenic hypothesis, which holds that the most important variable in climate predictions is the human contribution of atmospheric CO_2 from burning fossil fuels. Less significant contributing factors include methane production by farm animals.

There is significant scientific dissent on the causation of climate change, since human historical records show temperature variation profoundly affecting agriculture and worldwide human activity for centuries before the Industrial Revolution. Fur-

Two-year-old Nicholas Pollock, who suffers from allergies and asthma, rides past a sign for the Learn Green, Live Green conference being organized in Akron, Ohio, by his mother. (Ed Suba Jr./MCT/Landov) thermore, ice cores and other paleontological records show violent variations of temperature, CO_2, and methane for hundreds of thousands of years before human civilization.

The IPCC computer models predict increases in average global surface temperatures of 1.0 to 1.9° Celsius by 2050. These models calculate temperature rises of 2.0 to 4.5° Celsius by 2100, depending on whether CO_2 emissions stabilize downward at 5 gigatons per year or increase to as much as 28 gigatons per year by the end of the century.

Prior temperature records show that humans have been exposed to temperature shifts of similar magnitudes. The cooling that occurred from 1940 to 1970 was estimated at about 0.2° Celsius, and the warming from 1970 to 1998 is estimated at 0.5° to 0.7° Celsius. The average surface temperature in the decade following the 1998 El Niño did not increase significantly, and physicists who study solar effects on climate have predicted possible cooling because of the decrease in solar activity (such as sunspots).

S. Fred Singer and Dennis Avery have compiled extensive reports on prior temperature fluctuations, with examples of past climate cycles showing increased temperatures of more than 1° Celsius during the Medieval Warm Period and decreases of 0.3° Celsius during the Little Ice Age. South African data from stalagmite temperature proxies indicate temperature increases of up to 4° Celsius in the Medieval Warm Period.

• Urban Heat Island Effects

As Earth's population continues to migrate from rural areas to more densely concentrated suburbs and cities, more people become exposed to urban heat islands. Cities are warmer than surrounding countryside, because traditional roofs and paving surfaces absorb more solar heat than do dirt and vegetation, and significant heat is generated by industry, power plants, residential heating, and air conditioning. Large cities have shown average temperature increases of as much as 3° Celsius (Tokyo, 1876-2004) to 4° Celsius (New York City, 1822-2000). These data are relevant, because potential health effects may be evaluated by comparing the effects of these localized temperature changes to projected future temperature changes.

Global Deaths Due to Climate-Related Disasters, 1900-1999

Decade	*Deaths (thousands)*	*Death Rate (per million people)*
1900's	128	79
1910's	25	14
1920's	485	242
1930's	446	209
1940's	180	76
1950's	211	71
1960's	167	49
1970's	74	19
1980's	66	14
1990's	32	6

Data from: Indur M. Goklany, *The Improving State of the World.* Washington, D.C.: Cato Institute, 2007.

• Historical Context

Scientists have been speculating about the health effects of climate change since the concept of global warming became widespread. In 1992 and 1995, IPCC members expressed concern that increases in the number and severity of heat waves could cause a rise in deaths. The 1992 report found that temperature increases were more prevalent in the winter and at night, diminishing the health effects of extreme cold weather; summer temperature increases have fallen, which diminishes deaths from heat waves. This could explain the IPCC's 1995 statement that global warming could result in fewer cold-related deaths.

In 1995, Thomas Gale Moore published the first of his pioneering efforts, "Why Global Warming Would Be Good for You," followed in 1998 by "Health and Amenity Effects of Global Warming." He estimated that a temperature increase of 2.5° Celsius in the United States would cause a decrease of forty thousand deaths per year from respiratory and circulatory disease, based on U.S. mortality statistics as a function of monthly climate change.

In 1997, the Eurowinter Group published "Cold Exposure and Winter Mortality from Ischaemic Heart Disease, Cerebrovascular Diseases, Respiratory Diseases, and All Causes in Warm and Cold Regions of Europe." This was a landmark study that elucidated the mechanisms of serious illness from cold, which are dominated by hemoconcentration, which increases blood viscosity ("sludging"). Hemoconcentration can cause death from blockage of vessels serving the heart and brain tissue, and it accounts for half of all excess cold-related mortality.

The 1997 Eurowinter Group study was followed by "Heart Related Mortality in Warm and Cold Regions of Europe: Observational Study," which was published in the *British Medical Journal* in 2000. These two studies provided data on mortality rates as a function of mean daily temperature in Athens, Greece; London, England; and Helsinki, Finland, providing the most comprehensive collection of evidence that mortality decreases as temperature increases, over most of the current climate range in Europe.

In 2005, Robert E. Davis furnished a survey on climate change and human health, published in *Shattered Consensus: The True State of Global Warming*. He predicted that human adaptation "will be key in determining the ultimate impacts of climate change." He demonstrated that some adaptations are already taking place that effectively mitigate negative impacts of global warming. His data, for example, show that excess mortality due to heat waves in many U.S. cities dropped to essentially zero in the three decades following 1964. This decline in heat mortality was especially evident in Southern cities, where high heat and humidity are common, but also spread northward. This happy trend could be attributed to air conditioning, better health care, architectural changes, and public health measures such as shelters. The salutary result, however, is prevention of major death events that were previously associated with heat waves and diminution of negative effects of climate warming.

In 2006, A. J. McMichael and his colleagues published "Climate Change and Human Health: Present and Future Risks." This was an attempt at a comprehensive evaluation of the direct and indirect health risks associated with warming, including infections and vector-borne diseases such as malaria. The evaluation assumes that the maximum daily mortality in higher-temperature periods will be equal to or greater than the maximum mortality in colder periods, resulting in heat-related deaths increasing far more than the lives saved by warming of the cold periods. This hypothesis does not stand up to previous data from the United States that showed that mortality in winter due to cardiac, vascular, and respiratory disease is seven times greater than summer. This ratio is about 9 to 10 in Europe.

The most comprehensive data on daily mortality, from all causes, as a function of the day of the year, show a clear relationship, with maximum mortality in January and minimum mortality in the warmest months of July and August. These data strongly indicate that warming of average daily temperatures would cause a decrease in mortality in winter far greater than the slight increase of mortality from summer heat.

• Current Findings

In early 2008, the British Department of Health released "Health Effects of Climate Change in the U.K., 2008," an update of previous reports from 2001-2002 edited by Sari Kovats. It used IPCC models that predicted an increase of mean annual temperatures in the United Kingdom between 2.5 and 3° Celsius by 2100. They found that there was no increase in heat-related deaths from 1971-2002, despite warming in summers, suggesting that the British population is adapting to warmer conditions. Cold-related mortality fell by more than one-third in all regions. The overall trend in mortality for the warming (from 1971-2002) was beneficial. The report states, in summary, that "winter deaths will continue to decline as the climate warms."

• Quantitative Estimates of Benefit

The data from the Eurowinter Group on mortality versus temperature can be used to estimate mortality benefits from climate warming. The authors actually drew "straight-line" fits to the slope of the data. The slopes for Athens, Helsinki, and London vary between 1 and 2 percent decreased mortality per degree Celsius increased temperature. This would lead to an estimated decrease of twenty-five to fifty thousand deaths per year in the United States for a 1° Celsius temperature rise. This can be compared to thirty thousand deaths per year from breast cancer, thirty thousand for prostate cancer, and about forty thousand from motor-vehicle accidents.

Bjørn Lomborg, a distinguished Danish environmental economist, has estimated 1.7 million fewer deaths in the world per year from moderate warming, or 17 million by year 2100. (He also notes that deaths from cold are nine times greater than deaths from warmth.) Note that the converse is also true; that is, cooling would cause similar increases in death rates. Heat deaths often represent "displacement"; that is, weakened people die a few days or weeks before prior expectation. Deaths due to cold, on the other hand, usually result in months to years of life lost. Thus, the benefits in life expectancy from warming in cold periods may be much more than nine times greater than lifespan lost in warm periods.

• More Severe Climate Change

The slopes of the data on mortality versus temperature are fairly linear over temperature variations of more than 20° Celsius. Thus, the benefit of warming (and the risk of cooling) should be fairly proportional to the temperature change, for climate shifts of more than 2-4° Celsius. Increasingly urbanized populations have already been exposed, and presumably adapted, to warming of 2-4° Celsius, because of the urban heat island effect. A major drop in climatic temperatures could be more devastating, especially in rural and less developed societies.

• The Developing World

Unfortunately, there is a dearth of data on mortality versus temperature in the developing world, especially by comparison to Europe and the United States. Lower standards of living and health care could decrease technological response to climate change, but less developed societies have already evolved adaptation techniques and behaviors that promote survival under potentially adverse conditions such as daily and seasonal climate changes.

The most prominent variable affecting health and survival of less advanced societies is the amount and variety of food available. Food crop production is enhanced by increased CO_2 in the atmosphere, which promotes photosynthesis. Increased CO_2 also allows plants to flourish with less water, giving them greater resistance to drought. It is estimated that the current increase in CO_2 has already caused increased food production by about 10 percent, independent of other factors. If CO_2 continues to increase as expected, significant improvements in nutrition may benefit populations in developing nations, no matter how the climate changes.

There are data on global death rates on climate-related disasters, however. Goklany has shown that death rates fell between 1930 and 2004. It is not possible to separate the decreasing mortality from storms, floods, drought, and so on from deaths due to heat and cold, but the overall trend is extremely beneficial and is taking place during a period of multiple climate changes and increasing GHG emissions.

• Context

The direct effects of possible climate warming on mortality are likely to be beneficial and of substantial magnitude by comparison to mortality from disease and accidents. The impact on human life expectancy may be proportionally more significant because of the different characteristics of death due to cold versus heat.

Quality of life and health may also improve. Large populations have migrated from the northern to the southern United States, experiencing an increase in average temperature of more than 5° Celsius, resulting in improved health and life expectancy. There are similar effects beginning in Europe.

It is reasonable to expect better health and better health statistics in the industrialized world, with moderate climate warming. Better nutrition and human adaptation can be expected in the developing world. The consequences of widespread climatic cooling are likely to be much more threatening.

Howard Maccabee

• Further Reading

Baer, Hans A., and Merrill Singer. *Global Warming and the Political Ecology of Health: Emerging Crises and Systemic Solutions.* Walnut Creek, Calif.: Left Coast Press, 2009. A reading of global warming as a condemnation of capitalism that includes significant discussion of the health effects of climate change.

Goklany, Indur M. *The Improving State of the World.* Washington, D.C.: Cato Institute, 2007. Well-researched and graphically documented book on economic development, technological change, and environmental effects on the human condition. Concludes optimistically that reconciling human well-being with climate change, sustainable development, and population trends is possible.

Lomborg, Bjørn. *The Skeptical Environmentalist: Measuring the Real State of the World.* New York: Cambridge University Press, 2001. Lomborg is a world-leading pioneer in environmental economics, with path-breaking arguments, backed with data, on improvements in human welfare and prosperity despite perceptions of global warming, pollution, and other environmental changes. This is a profound and comprehensive masterwork.

Musil, Robert K. *Hope for a Heated Planet: How Americans Are Fighting Global Warming and Building a Better Future.* New Brunswick, N.J.: Rutgers University Press, 2009. Comprehensive approach to global warming through the lens of public health policy.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years.* Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008. Explains multiple natural cycles that affect climate, especially the variations of the solar and cosmic-ray effects. Shows how data are developed to measure climate variation in the distant past and how historical events such as the Medieval Warm Period are not consistent with the anthropogenic hypothesis.

See also: Asthma; Carbon dioxide fertilization; Coastal impacts of global climate change; Diseases; Extreme weather events; Famine; Floods and flooding; Poverty; Skin cancer; World Health Organization.

Heartland Institute

- **Category:** Organizations and agencies
- **Date:** Established 1984
- **Web address:** http://www.globalwarmingheartland.org

• Mission

An American, libertarian, free-market-oriented, tax-exempt 501(c)(3) nonprofit organization, the Heartland Institute researches and develops free market solutions to social and economic problems, including environmental problems. The institute was established in 1984 and is based in Chicago, Illinois. Its activities are directed by a fifteen-member board of directors that meets quarterly. As of 2008, thirty full-time staff, including editors and senior fellows, oversee the organization's day-to-day activities. The think tank focuses on issues such as government spending, taxation, education, health care, free market environmentalism, and global warming.

• Significance for Climate Change

The Heartland Institute asserts that there are no reliable data supporting the notion that global warming mechanisms or trends have ever taken place or are taking place presently. Furthermore, it claims that a moderate degree of global warming is beneficial to the environment and humans worldwide. The institute has partnered with other global warming skeptic organizations such as the Cooler Heads Coalition, which has itself been widely criticized for its work against penalizing big carbon dioxide (CO_2) emitters.

At the Heartland Institute's March, 2008, conference, global warming skeptics from around the world were brought together in New York. At the meeting, participants collectively criticized the Intergovernmental Panel on Climate Change, as well as proponents of any scientific studies that reported positive correlation between human activities and global warming. The organization's numerous publications and conferences have all shared a similar theme and tone.

The Heartland Institute received extensive scrutiny of its publication procedures in April, 2008, after environmental journalist Richard Littlemore revealed that it engaged in questionable practices. In compiling a list of "Five Hundred Scientists with Documented Doubts of Man-Made Global Warming Scares," the organization included over forty-five scientists as coauthors on various articles with which they had no affiliation, that they did not agree to coauthor, or that made claims with which they disagreed. Following this scandal, when scientists came forward to demand removal of their names from the list, the Heartland Institute claimed that they had no legal or ethical grounds to remove or amend the original list of names.

The institute has also been criticized for its policies on appointing and recruiting members of its board of directors. In the past, executives from such corporations such as ExxonMobil, an oil company, and Philip Morris, a tobacco company, have served on the Heartland Institute's steering committee.

Rena Christina Tabata

See also: American Enterprise Institute; Catastrophist-cornucopian debate; Cato Institute; Competitive Enterprise Institute; Cooler Heads Coalition; Friends of Science Society; Heritage Foundation; Journalism and journalistic ethics; Libertarianism; Nongovernmental International Panel on Climate Change; Pseudoscience and junk science; Reason Public Policy Institute; Skeptics.

Heat capacity

- **Category:** Physics and geophysics

- **Definition**

The total heat capacity of an object is the amount of energy needed to raise its temperature one degree Celsius. Heat capacity is usually measured in joules per Celsius degree. Thus, if an object has a heat capacity of 500 joules per Celsius degree, adding 500 joules of thermal energy will increase its temperature by 1° Celsius. Adding 1,500 joules will increase its temperature by 3° Celsius, and so forth. Removing the same amount of thermal energy will decrease the object's temperature by the same amount.

An object's heat capacity is related to both its composition and its mass. Scientists divide heat capacity by mass to determine an object's specific heat capacity, or specific heat, which is a property of composition alone. Heat capacity and specific heat are thus closely related, but heat capacity is a property of a particular object, while specific heat is a more general property of a type of material.

Particularly for gases or liquids, the heat capacity and specific heat can differ under different conditions, such as pressure or volume. Hence, specific heat capacity tables often list specific heats at constant pressure and at constant volume.

- **Significance for Climate Change**

Using various climate change computer models, climate researchers try to predict changes in global surface temperature. One of the many input parameters for these calculations is the change in the energy content of Earth's climate system. Energy sources can include incoming solar radiation, energy trapped by greenhouse gases, waste energy from machines or industrial processes, and so forth. After scientists determine the net energy change in Earth's climate system, they need to calculate the total heat capacity of the climate system, including Earth's atmosphere, oceans, and surface.

Using the calculated change in thermal energy contained in Earth's climate system and its total heat capacity, scientists can calculate the net change in Earth's temperature. The idea is relatively simple, but it is very difficult to calculate both the total thermal energy and the heat capacity for Earth's climate system. Therefore, it is difficult to make accurate predictions about changes in Earth's average temperature.

These complexities make global warming models very uncertain. Different global warming models will make different predictions as a result of these uncertainties.

Paul A. Heckert

See also: Bayesian method; Climate models and modeling; Climate prediction and projection; General circulation models; Heat content.

Heat content

- **Category:** Physics and geophysics

- **Definition**

Touch a fluorescent light bulb. It may feel pleasantly warm, but it will not feel extremely hot. However, the gas inside a working fluorescent bulb is usually at a temperature of more than 10,000° Kelvin. For comparison, the Sun's surface temperature is 5,800° Kelvin. If the gas inside a fluorescent light bulb is at such a high temperature, why is the surface of the bulb relatively cool?

The key is heat content. The gas inside the bulb is at a high temperature, but, because the gas is so thin and there are relatively few gas atoms inside the bulb, relatively little total heat energy is contained within the gas. Heat content is the total thermal energy an object contains. The gas inside the bulb has a high temperature but a low heat content, so there is not enough thermal energy to burn one's hand.

A key related concept is heat capacity, which is the amount of heat energy needed to raise the temperature of an object. The gas in a fluorescent bulb has a low heat capacity, so the total amount of thermal energy needed to raise its temperature is small. Thus, it required relatively little heat energy to raise the temperature of the gas, which also contributes to explaining why the system contains relatively little energy.

- **Significance for Climate Change**

The total heat content of Earth's climate system, including its atmosphere, oceans, and surface, can change through a variety of processes. For example, the amount of direct solar radiation striking Earth's surface can change, either by the Sun's energy output changing or by the atmosphere's transparency changing. Changes in the concentration of greenhouse gases in Earth's atmosphere change the amount of thermal energy trapped within the atmosphere rather than radiated back into space. Industrial processes and waste heat from all types of engines pump thermal energy into Earth's climate system. These and many other processes change the total heat content of the planetary climate system.

As this total heat content changes, Earth's average temperature changes. Predictions of changes in Earth's temperature depend upon knowledge of the planet's current total heat content, as well as of all processes affecting Earth's climate system. Such comprehensive knowledge is elusive, so predicting future temperature changes is extremely difficult, and vastly divergent predictions are common.

Paul A. Heckert

See also: Bayesian method; Climate models and modeling; Climate prediction and projection; General circulation models; Heat capacity.

Heat vs. temperature

- **Category:** Physics and geophysics

- **Definition**

The concepts of heat and temperature are closely related, so these quantities are often confused, and the terms are sometimes used interchangeably (but incorrectly) by laypersons. Temperature is a measurement of the average kinetic energy—that is, physical motion—of the atoms in a substance. The kinetic energy of an object is calculated according to the following formula:

$$E_K = \frac{1}{2}MV^2$$

where E_K is kinetic energy, M is mass, and V is velocity. The kinetic energy of atoms is generally due to a combination of their directional velocity and vibrational motion. This energy may be measured by a thermometer.

The two most common temperature scales in use are the Fahrenheit and Celsius (formerly centigrade) scales. In the Fahrenheit scale, the freezing point of water is defined as 32° and the boiling point is defined as 212°. In the Celsius scale, the freezing point of water is defined as 0° and the boiling point is defined as 100°. In science and engineering, the Rankine and Kelvin temperature scales are used. These are called absolute temperature scales, because their zero reference level is absolute zero, the lowest temperature that can theoretically exist. At absolute zero, the total kinetic energy of all the atoms in a substance is zero.

Heat is the form of energy transferred across the boundary of an object as a result of a temperature difference across that boundary. Consider what happens across a pane of window glass on a cold winter day. The air inside the heated house is warmer than the air outside. This temperature difference across the window pane causes an energy flow through the glass from the warm air inside to the cold air outside: The outer air next to the glass is warmed, while the air inside the house cools, requiring a heating system to maintain a constant, comfortable temperature. There are three types of heat transfer: conduction, convection, and radiation. All result from a temperature difference between an object and its surroundings.

Conduction is the primary mechanism of heat transfer in solids. It occurs because of molecular activity in the solid. Convection is the primary mechanism of heat transfer through fluids and results from bulk mixing between fluid layers. Radiation, the third type of heat transfer, is the only mechanism that can transfer heat through a vacuum. When the Sun heats the Earth, there is no solid between them through which heat can be conducted, nor is there is any fluid through which heat can be convected. The temperature difference between the Sun and the Earth still causes heat transfer to the Earth by means of electromagnetic waves. Electromagnetic waves can also transfer energy in the form of light, X rays, or radio waves.

Heat is measured as a function of the temperature change of a substance when heat transfer occurs. The commonly used units for heat are the calorie, the joule, and the British Thermal Unit (BTU). A calorie is the amount of heat required to raise the temperature of one gram of water by one degree Celsius. A BTU is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. One joule is equal to 0.239 calorie.

• Significance for Climate Change

Heat transfer to the Earth's oceans and atmosphere is the first step in, and at the very heart of, climate change. Most of the industrial or mechanical processes in which humans engage release heat as a waste by-product. For example, all fossil fuel and nuclear power plants generate waste heat as a by-product of producing power. A typical power plant may have an efficiency of between 35 percent and 50 percent, meaning that this percentage of the stored energy in a fuel is converted to useful energy, while the remaining energy is discharged to the atmosphere or some body of water as waste heat. This heat transfer to the environment causes a temperature increase of the environment. This temperature increase is a contributor to global warming. Even a degree or two increase in the average temperature of the oceans or the atmosphere can cause profound effects upon Earth's biosphere. All combustion engines also dissipate waste heat to the environment, as do heating and cooking appliances. Only power produced by wind, water, or geothermal energy does not directly contribute to global warming, although these types of power production can have other effects.

Eugene E. Niemi, Jr.

• Further Reading

Cengel, Yunus A., and Michael Boles. *Thermodynamics: An Engineering Approach.* 5th ed. New York: McGraw-Hill, 2006. Sophomore- or junior-level college textbook dealing with heat and energy. Includes a simplified discussion of global warming and the greenhouse effect.

Holman, Jack P. *Heat Transfer.* 9th ed. New York: McGraw-Hill, 2002. College engineering textbook dealing with the various mechanisms of heat transfer.

Thurman, Harold V., and Elizabeth Burton. *Introductory Oceanography.* 9th ed. Upper Saddle River, N.J.: Prentice Hall, 2001. Includes a section on air-sea interaction and its relationship to global warming.

See also: Atlantic heat conveyor; Global surface temperature; Heat capacity; Heat content; Latent heat flux; Sea surface temperatures; Urban heat island.

Heritage Foundation

- **Category:** Organizations and agencies
- **Date:** Established 1973
- **Web address:** http://www.heritage.org

• Mission

The Heritage Foundation is a conservative public policy research organization, or think tank, based in Washington, D.C. It is widely supported, with more than 390,000 individual, foundation, and corporate donors, and it promotes conservative ideas and principles as solutions to current problems. The foundation maintains a database of policy experts, including those with expertise in global warming issues, and publishes summary statements and analyses of proposed climate change legislation. Its stated mission is to "formulate and promote conservative public policies based on the principles of free enterprise, limited government, individual freedom, traditional values, and a strong national defense."

Using an executive summary format more likely to be read by government officials than are other formats, the Heritage Foundation distills complicated topics into shorter policy papers. Historically, the foundation has had considerable political influence; it became prominent during the conservative era of Ronald Reagan's presidency. Reagan's policies were influenced by a foundation-published book, *Mandate for Leadership* (1981), that provided policy, budget, and administrative action recommendations and advocated limited government. The foundation continues to play a significant role in public policy and is considered one of the most influential research organizations in the United States.

• Significance for Climate Change

The Heritage Foundation researches a broad range of policy issues, including issues related to the environment and global warming. It maintains a searchable online database of policy experts at www.policyexperts.org that includes several renowned climate change skeptics. The foundation's policy statements and legislative analysis related to climate change have included documents on greenhouse gas emission and other issues related to global warming. Most statements published by the foundation argue against mainstream views of the severity and extent of global warming and downplay its potential impacts.

Policy statements issued by the Heritage Foundation suggest that proposed legislation directed toward mitigating global warming may be prohibitively expensive. The foundation concluded that the proposed Climate Security Bill of 2007 would have resulted in substantial costs for little gain. The foundation maintains that global warming is neither unprecedented nor a cause for major concern. A statement published on its Web site reads, "Global warming is a concern, not a crisis. Both the seriousness and imminence of the threat are overstated." The foundation's viewpoint is that anthropogenic emissions contribute little to greenhouse gases and that climate variability has been present throughout the ages, with current temperatures within the range of natural variability rather than evidence of anthropogenic warming.

C. J. Walsh

See also: American Enterprise Institute; Conservatism; Economics of global climate change; Skeptics; U.S. energy policy.

Heterotrophic respiration

• **Categories:** Animals; plants and vegetation

• Definition

Heterotrophic respiration is a set of metabolic processes through which organisms produce carbon dioxide (CO_2) and release energy from organic compounds that they have ingested or otherwise incorporated from outside themselves. It may be differentiated from autotrophic respiration, in which energy-bearing compounds are produced by the organism through processes such as photosynthesis. Heterotrophic organisms include animals, fungi, and many types of bacteria.

• Significance for Climate Change

CO_2 is a greenhouse gas (GHG), meaning that its increased atmospheric concentration may trap more heat on Earth and raise global temperatures. The amount of carbon in the top meter of Earth's soil has been estimated to be twice that present as CO_2 in the planet's atmosphere. Consequently, increased decomposition of organic matter in the soil—a type of heterotrophic respiration—could make a substantial contribution to global atmospheric CO_2 and thus to global warming.

As a result of these relationships, factors that increase heterotrophic respiration could affect global climate. Certain types of land use are reported to affect heterotrophic respiration in soil. For example, deforestation increases CO_2 release from soil. In addition, CO_2 released into the atmosphere from other sources, such as fossil fuel, can increase global temperatures, which in turn increases the rate of soil heterotrophic respiration, releasing more CO_2. The effect of temperature on heterotrophic respiration may be more pronounced in temperate climates than in tropical ones, in which the effect of temperature may already be at or near maximal.

The soil organisms involved in heterotrophic respiration include macro fauna, such as earthworms, insects, and burrowing mammals; micro and meso fauna, such as protozoa and nematodes; and microscopic fauna, such as bacteria and fungi. The major soil heterotrophs are bacteria, in terms of numbers, and fungi, in terms of mass. Cellulose is a major molecule that is transformed into CO_2 by the process, and fungi, termites, and bacteria are the main types of organisms that produce enzymes that break down cellulose into simpler compounds.

Oluseyi Adewale Vanderpuye

• Further Reading

Bardgett, Richard D. *The Biology of Soil: A Community and Ecosystem Approach.* New York: Oxford University Press, 2005. Covers the diversity of organisms that live in soil, including how their ecology and decomposition activities relate to climate change.

Luo, Yiqui, and Xuhui Zhou. *Soil Respiration and the Environment.* New York: Elsevier, 2006. Discusses the roles and significance of soil respiration and its involvement in the global carbon cycle; includes a description of the carbon substrates and heterotrophic organisms.

Schlesinger, William H. *Biogeochemistry: An Analysis of Global Change.* New York: Academic Press, 1997. Extensive analysis of the effects of human activities and those of other forms of life on biogeochemical cycles. This multidisciplinary book places heterotrophic respiration in a wide context along with other factors affecting global temperatures.

See also: Amazon deforestation; Animal husbandry practices; Carbon cycle; Carbon dioxide; Deforestation; Ecosystems; Nitrogen cycle; Soil erosion.

High global warming potential

• Category: Meteorology and atmospheric sciences

• Definition

High global warming potential (HGWP) is a term assigned to industrially produced gases that have extremely high global warming potentials (GWPs). There are three major groups of HGWP gases: perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6). Emissions of a given mass of one of these gases contribute significantly more to the greenhouse effect than does an equivalent mass of carbon dioxide (CO_2) or other, more common gases.

• Significance for Climate Change

Measurement of GWP was developed as a tool to quantify and compare the efficiency of different gases to trap heat in the atmosphere. GWP depends on both the potency of the substance as a greenhouse gas (GHG) and its atmospheric lifetime and is measured relative to the equivalent mass of CO_2 and described for a set time period. HGWP gases operate in a manner similar to all other GHGs, by absorbing and emitting radiation within the thermal infrared range. However, HGWP gases are hundreds to thousands of times more potent than is CO_2 with respect to their atmospheric heat-trapping properties over a set time period. For example, the most potent GHG, SF_6, has an atmospheric lifetime of thirty-two hundred years and a GWP of 16,300 over twenty years, 22,800 over one hundred years, and 32,600 over five hundred years (relative to CO_2, which is defined to have a GWP of 1 over all time periods).

There are few natural sources of HGWP emissions. The majority of anthropogenic emissions result from the decision to use HGWP chemicals in-

Global Warming Potentials of Major HGWP Gases

Gas	*GWP*
HFC-152a	140
CF_4	6,500
C_2F_6	9,200
HFC-23	11,700
SF_6	23,900

Source: U.S. Environmental Protection Agency.

stead of ozone-depleting substances for equivalent functions. Preventing ozone depletion is a higher priority than preventing increases in the greenhouse effect, as outlined in authoritative publications such as the Kyoto Protocol and the Montreal Protocol. HGWP gases are also emitted during industrial processes, such as aluminum and magnesium production, and from commercial products such as automobile air conditioning.

In the early twenty-first century, nitrogen trifluoride (NF_3) began receiving increased attention due to its initial marketing as a green alternative in the technological manufacturing sector. Subsequent data indicated that it is seventeen thousand times more potent as a GHG than is CO_2, but by the time this was known, NF_3 was used to produce a wide range of household products, including computer chips, flat-screen televisions, and thin-film solar photovoltaic cells. HGWP emissions are relatively low in developed countries, accounting for less than 2 percent of total emissions in the United States in 2001, for example. They are so potent, however, that even small amounts can have significant effects, especially given that very few sinks exist for these gases. There is therefore a global movement to reduce HGWP emissions by improving industrial processes.

Rena Christina Tabata

See also: Carbon dioxide; Carbon dioxide equivalent; Carbon footprint; Global warming potential; Hydrofluorocarbons; Kyoto Protocol; Montreal Protocol; Ozone; Perfluorocarbons; Sulfur hexafluoride.

High Park Group

- **Category:** Organizations and agencies
- **Date:** Registered January 22, 2003
- **Web address:** http://www.highpark group.com

- **Mission**

The High Park Group (HPG) is a public affairs and policy consulting group in Toronto and Ottawa that represents many energy industry clients. The firm appears to support skepticism of anthropogenic climate change.

The group claims to work in a wide range of areas, but its primary areas are energy, environment, and ethics. Among its services are policy and strategic consulting, direct lobbying, media relations, and issues management. In 2009 the president was Timothy M. Egan. One of the directors was Kathleen McGinnis. The director of regulatory affairs was Julio Legos. The Ottawa director until September, 2006, was Tom Harris. The High Park Group is registered as lobbying for several energy clients, including Areva Canada Inc., the world's largest nuclear power company; ARISE Technologies Corporation, a solar technology company; the Canadian Electricity Association; and the Canadian Gas Association. Harris was a lobbyist for the Canadian Electricity Association and Canadian Gas Association. McGinnis was registered to represent the Canadian Electricity Association to lobby government agencies regarding activities of the National Energy Board related to electric transmission. Egan was senior adviser to the Canadian Electricity Association and monitored U.S. policy as it related to the electricity industry of Canada.

In September, 2006, Harris became head of the Natural Resources Stewardship Project (NRSP), a group that describes itself as "promot[ing] responsible environmental stewardship." Two of the three directors of the board of the Natural Resources Stewardship Project are Egan and Legos of the High Park Group. NRSP promotes global warming skepticism. Tom Harris wrote in the June 7, 2006, *National Post* that "the hypothesis that human release of CO_2 is a major contributor to global warming is just that—an unproven hypothesis, against which evidence is increasingly mounting." Critics have claimed that the Natural Resources Stewardship Project allows the High Park Group to lobby against climate change regulations on behalf of its energy clients without the clients being identified.

Although not trained in climatology, Harris has bachelor's and master's degrees in mechanical engineering. Even before the formation of High Park Group, he made statements such as

> I think most investors would sensibly conclude that until the science is more mature, pressuring companies to do something, or not to do something, about GHG emissions is a costly gamble and that they should wait until the verdict is in before deciding what to do (if anything).

In a March 8-14, 2001, *European Voice* article coauthored with geologist Tim Patterson, Harris asked, "Is the UN guilty of exaggerating fears over climate change?" In November, 2002, Harris was one of the organizers of an event in Ottawa at which climate change skeptics were "to reveal the science and technology flaws of the Kyoto Accord."

In the June 8, 2006, *Vancouver Sun*, Harris wrote an editorial titled "Environmental Heresy." The subtitle read: "Failing to question the scientific assumptions underlying Kyoto isn't fair to citizens concerned about climate change." After his associations with the High Park Group and the Natural Resources Stewardship Project, he became executive director of the International Climate Science Coalition (ICSC), in March, 2008. This coalition describes itself as an association of scientists, economists, and energy and policy experts working to promote better understanding of climate change science and policy. Patterson is chairman.

• Significance for Climate Change

Some skepticism is good when considering conclusions made from scientific data, especially when different scientists reach conclusions that do not agree. Skepticism can also be used to confuse people. Critics of HPG, NRSP, and ICSC claim that they lobby against regulation to protect their clients' profits. They emphasize that the registered lobbyist HPG directs the flow of skepticism from NRSP and ICSC, so that government decision makers will be so confused as to make no changes or the wrong change. If the wrong decision is made, then the world and its climate could be drastically changed.

C. Alton Hassell

• Further Reading

Harris, Tom. "Scientists Call for 'Reality Check' on Climate Change." *The Winsor Star*, June 5, 2006. Attempts to refute theories of anthropogenic climate change. Typical of the skeptic viewpoint, which is usually expressed in newspapers or Internet sources and seldom in books.

McCaffrey, Paul, ed. *Global Climate Change*. Bronx, N.Y.: H. W. Wilson, 2006. Collection of essays by different authors on climate change. Nonskeptical treatment of facts and results. Bibliography, index.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change*. Boston: Beacon Press, 2008. Study of climate change that includes a section addressing the concerns of skeptics. Bibliography, index.

See also: Canada; Canadian Meteorological and Oceanographic Society; Skeptics.

Hockey stick graph

• **Categories:** Meteorology and atmospheric sciences; climatic events and epochs

The hockey stick graph, named for its shape, represents a thousand-year period of essentially stable average temperatures in the Northern Hemisphere, followed by an upward spike around 1900. The graph, which suggests the impact of industrial activity on global warming, has been cited to support arguments that global warming has anthropogenic causes, but its accuracy has been questioned; it has thus been both prominent and controversial.

• Key concepts

Medieval Warm Period: a period of warmer-than-average temperatures between the tenth and fourteenth centuries

multiproxy reconstruction: a method of estimating prehistoric climate conditions using a combination of proxy indicators
paleoclimatology: the study of prehistoric climate conditions
proxy indicators: tree rings, fossils, and other artifacts that provide indirect evidence of past temperatures

• Background

The "hockey stick" is a nickname given to a dramatic graph of historic average temperatures in the Northern Hemisphere. The graph became a prominent—and controversial—symbol in the debate over whether or not recent global average temperatures are historically abnormal and thus more likely to have been caused by human activities. The graph gets its nickname from its shape, which represents a flat, thousand-year period of stability (the stick) followed by a sudden upward spike (the blade). The nickname is generally attributed to Jerry Mahlman, head of the Geophysical Fluid Dynamics Laboratory, part of the National Oceanographic and Atmospheric Administration.

The hockey stick graph was first published in *Nature* magazine in 1998 by a research team of Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes and was featured prominently in the 2001 Second Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC). Mann and Bradley were researchers with the University of Massachusetts, while Hughes was a specialist in dendrochronology (tree-ring dating), working at the University of Arizona in Tucson. The scientists engaged in a type of historical temperature reconstruction generally referred to as "multiproxy" reconstruction. That is, they combined a broad set of measured temperatures with estimates based on several proxy temperature indicators, such as tree-ring growth, fossilized leaf stomata, boreholes, lake sediments, and tree pollen.

The graph published in *Nature* was a radical departure from previous temperature reconstructions, which had depicted a period of significant warmth (equal to or greater than current temperatures) during the Medieval Warm Period, which lasted from the tenth to the fourteenth century. Controversy over the hockey stick graph arose when two Canadian researchers—Steven McIntyre, a policy analyst with a background in mathematics and mineral exploration, and Ross McKitrick, an economist at the University of Guelph—sought to examine the underlying data and programming used by Mann and his colleagues in creating the graph.

• The Criticism

McIntyre and McKitrick examined the data and attempted to reproduce the hockey stick model using the same methodology Mann's team had employed. They then published an article in the European journal *Energy and Environment* asserting that the earlier team's data set contained significant errors, omissions, and duplicated data. They also claimed that the computer program used to analyze the data gave undue importance to a single proxy series of dubious value. In later analyses, published outside of the scientific literature, McIntyre and McKitrick asserted that the analytical program had a built-in bias that would produce a hockey-stick shape even if it was analyzing completely random data. A continuing bone of contention was the resistance that Mann's group demonstrated to sharing its data or providing sufficient information about its computer program to facilitate others' efforts to reproduce the hockey stick.

• Mann's Response

The claims made by McIntyre and McKitrick have been sharply rejected by Mann, Bradley, Hughes, and other members of the academic paleoclimatology community. In addition to questioning McIntyre and McKitrick's ability to understand the development of multiproxy temperature reconstructions, Mann and other paleoclimatologists argue that what McIntyre and McKitrick found were only trivial data errors that did not alter the fundamental shape of the graph. Claims regarding bias in the analytical program have also been disputed and attributed to improper mathematical analysis techniques, as well as to failures properly to use the program.

• Third-Party Referees

The controversy over the hockey stick graph led several high-level review panels to be convened. One such panel was created by the National Academy of Sciences' National Research Council at the request of U.S. representative Sherwood Bohlert, chair of the House Committee on Science. It was led by climate modeler Gerald North. Another committee, assembled at the request of two other Republican members of the House, was directed by statistician Edward Wegman, head of the National Academy of Sciences' Committee on Applied and Theoretical Statistics. Both of these committees upheld many of the findings of McIntyre and McKitrick, although the North panel was slightly less critical of the hockey stick model than was the Wegman panel.

• Context

Despite the findings of the two review panels, the hockey stick controversy continued to rage with considerable rancor. It was conducted primarily via claims and counterclaims about various elements of the debate on blogs such as that of Steven McIntyre (www.climateaudit.org) and Real Climate, a collective blog operated by a group of climate researchers (www.realclimate.org). Areas of contention involved assumptions regarding the accuracy and global representativeness of individual proxy data sets.

The hockey stick controversy affected public opinion and the methodology of climate reconstruction, as well as the representation of such reconstructions in scientific publications. It became a rallying point for climate change skeptics, especially those doubting that greenhouse gas emissions and other anthropogenic factors play a role in global warming. These skeptics saw the controversy as evidence that climate researchers were intentionally exaggerating recent warming by erasing warmth from prior centuries. They produced a huge number of publications proclaiming the "breaking" of the hockey stick and, with it, the refutation of the idea that recent temperatures are historically abnormal.

Many believe that the controversy over the hockey stick also led to changes in the way that the IPCC chose to represent historical temperature reconstructions in its Fourth Assessment Report on the science of climate change. Rather than relying on a single historical climate reconstruction, the report presented the results of an ensemble of reconstructions. Some of these reconstructions included the Medieval Warm Period; others did not.

Kenneth P. Green

• Further Reading

Intergovernmental Panel on Climate Change. *Climate Change, 2001—The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by J. T. Houghton et al. New York: Cambridge University Press, 2001. The first volume in the IPCC's Third Assessment Report on climate change, in which the hockey stick graph features prominently.

_______. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Discusses paleotemperature reconstruction with reference to a greater range of reconstructions.

Kerr, Richard A. "Politicians Attack, but Evidence for Global Warming Does Not Melt." *Science* 313, no. 5786 (July 28, 2006): 421. This short article summarizes the events at the House Committee on Energy and Commerce testimony in which the Wegman report was discussed.

McIntyre, Steven, and Ross McKitrick. "Corrections to the Mann et al. (1998) Proxy Data Base and Northern Hemisphere Average Temperature Series." *Energy and Environment* 14, no. 6 (November 1, 2003): 751-772. The first peer-reviewed publication in the debate over the hockey stick reconstruction.

National Academy of Sciences. *Surface Temperature Reconstructions for the Last Two Thousand Years*. Washington, D.C.: National Academies Press, 2006. This report by the committee headed by climate modeler Gerald North upheld many of the criticisms that McIntyre and McKitrick raised regarding the hockey stick graph, while still affirming the general correctness of the graph over the last nine hundred years.

Wegman, Edward, et al. *Ad Hoc Committee Report on the "Hockey Stick" Global Climate Reconstruction*. Washington, D.C.: House Committee on Energy and Commerce, 2006. In many ways the strongest criticism of the hockey stick graph, the

Wegman report consists of two parts: an analysis of statistical problems in creating paleoclimate reconstructions and a social networking analysis showing that the modeling community is too tightly linked for its members to be able to review one another's work objectively.

See also: Bayesian method; Climate models and modeling; Climate reconstruction; Dating methods; Industrial Revolution; Medieval Warm Period; Paleoclimates and paleoclimate change; Parameterization; Peer review; Preindustrial society; Scientific credentials; Skeptics.

Holocene climate

- **Category:** Climatic events and epochs

Understanding climatic fluctuations since the last ice age provides a context for evaluating the extent to which the present global warming trend is an anthropogenic phenomenon. Correlation of archaeological and historical records allows projections of the impact of global warming on human society.

Key concepts

positive feedback loops: self-accelerating processes, such as increased snow cover increasing planetary albedo and promoting additional cooling, leading to more snow cover

proxies: preserved, measurable parameters that correlate with climate and serve as evidence of past climatic conditions

thermohaline circulation: the rising and sinking of water caused by differences in water density due to differences in temperature and salinity

Background

Climatic changes since the end of the last ice age form the backdrop for much of human prehistory and are viewed by some as a driving force in the rise and fall of civilizations. The retreat of continental glaciers began in earnest 13 million years ago, with a gradual warming trend that reached its peak around 6,000 years ago during a period known as the Hypsithermal or Holocene climatic optimum. Proxy records, supplemented by historical data in more recent times, suggest six periods of abrupt cooling in the Holocene, 9,000-8,000, 6,000-5,000, 4,200-3,800, 3,500-2,500, 1,200-1,000, and 650-150 years before the present. Within warm periods and cold periods, there is considerable fluctuation on scales ranging from decades to centuries. Temperature variations as measured by a variety of proxies are more dramatic near the poles, while variations in rainfall associated with temperature-induced fluctuations in oceanic currents predominate in the tropics. Overall, climatic variability in the Holocene is considerably less than it was in the Pleistocene, and what fluctuations have occurred in the Holocene have decreased over the course of the period.

Climatologists are continually modifying the prevailing picture of climate change in the Holocene as more high-resolution studies become available from areas other than Europe and eastern North America. Climatic shifts typically appear earlier in the Southern Hemisphere than in the Northern Hemisphere. Signs of the 8.2ka event, a period of dramatic European cooling due to disruption of currents in the Atlantic Ocean, are much less evident in western North America and are absent in New Zealand.

Measuring Holocene Climate

Systematic instrumental records of weather in parts of Europe and North America exist for the last 150 years. Agricultural records, historic narratives, and even legendary sources chronicle catastrophic events throughout human history.

Until recently, much of the available information about climate in prehistoric times came from archaeological investigations. The study of artifacts and settlement patterns reveals a great deal about the climate in which ancient people lived. For example, prolonged drought in the American Southwest, corresponding to the culturally benign Medieval Warm Period in Europe, is evident in shifting patterns of cultivation, declining population, skeletal deformities due to malnutrition, compressed tree rings in construction timbers, and eventual abandonment of cliff dwellings.

Vegetation is a good climatic indicator. Leaves, woody material, and particularly pollen occur in abundance in bogs, lake sediments, and areas of human settlement. Pollen analysis is a powerful tool, because pollen is extraordinarily decay-resistant. Many pollen grains can be identified to genus, and relative abundance provides a fairly complete picture of a region's flora. Wind-pollinated plants with narrow ecological niches are particularly useful. In Europe, the arctic-alpine herb *Dryas octopetala* indicates arctic-alpine conditions, spruce (*Picea*) indicates a cold, humid climate, and oak (*Quercus*) provides evidence of a drier, warm climate. Pollen of *Plantago*, a weed in grain fields, suggests cultivation. In marine sediments, relative abundance of planktonic types serves as a proxy for water temperature.

Various geological formations permit high-resolution analysis of local climate. Moraines and scouring document the advance and retreat of glaciers. Varves, which are layers of sediment in lakebeds, provide a record of stream flow into lakes. When precipitation is high, increased runoff and sediment load create thick varves and rapid deposition of alluvial fans at the mouths of rivers. Terraces along lake and ocean shores document rises and falls in water level. In some areas, the land may also be rising or subsiding relative to sea level.

Ice cores taken from glaciers in Greenland and Antarctica provide evidence of climate over the last 400,000 years, including rates of precipitation, amounts of atmospheric dust, and concentrations of carbon dioxide (CO_2) in trapped air. Analysis of the ratios of carbon and oxygen isotopes in carbonates and of oxygen isotopes in ice also provides clues to climate, since both biotic and abiotic processes use isotopes selectively. Isotope ratios can also be used as proxies for sunspot activity, a suspected factor in warming and cooling trends.

• Climatic Change in Human Prehistory

The tenure of modern humans on Earth encompasses the last Pleistocene glaciation and the ten thousand years of the Holocene, during which the Earth's climate has fluctuated, with a temperature maximum roughly six thousand years ago. There are many studies correlating prehistoric cultural changes with climatic changes. For agricultural societies, the droughts associated with colder periods are more devastating than are lower temperatures themselves. The Holocene historical and geologic records contain no compelling evidence of rapid rises in temperature such as the Earth is currently experiencing: Global warming in geologic time appears to be a gradual process to which life adapts. Cooling, on the other hand, can be extremely rapid and catastrophic.

Gradual warming can also produce catastrophic results, when rising waters overwhelm a natural dam, unleashing a flood of biblical proportions. Indeed, a controversial theory postulates that the biblical flood was just such an event, and that the fertile agricultural land surrounding the Black Sea was suddenly inundated when rising waters in the Mediterranean breached the Bosporus roughly seven thousand years ago. Similar floods occurred in the lower reaches of the Tigris and Euphrates rivers and the northern Red Sea at about the same time.

In North America, rapid draining of Glacial Lake Agassiz through the St. Lawrence River caused local devastation, as well as disrupting oceanic currents. The Missoula floods in the Columbia River basin resulted from periodic breaching and reforming of an ice dam at the glacial margin. The widespread occurrence of devastating warming-induced floods in prehistoric times holds a lesson for the present. If there is a dam protecting a city from rising waters, whether it is natural or artificial,

Holocene Climate Time Line

Years Before Present	*Climate Trend*
9,000 to 8,000	Cooling
8,000 to 6,000	Warming
6,000 to 5,000	Cooling
5,000 to 4,200	Warming
4,200 to 3,800	Cooling
3,800 to 3,500	Warming
3,500 to 2,500	Cooling
2,500 to 1,200	Warming
1,200 to 1,000	Cooling
1,000 to 650	Warming
650 to 150	Cooling
150 to present	Warming

every incremental temperature rise increases the likelihood of disaster.

The causes of cooling episodes are various. They include changes in solar radiation levels, volcanic aerosol concentration, greenhouse gas (GHG) concentration, the hydrologic cycle, sea level, sea ice extent, and forest cover. The six defined periods of cooling in the Holocene most probably all derive from several such factors acting in concert.

The rapid cooling that occurred between nine thousand and eight thousand years ago took place during a decline in insolation and a high level of volcanic SO_2 production. A massive infusion of glacial meltwater into the North Atlantic disrupted thermohaline circulation. A weakening Afro-Asian monsoon contributed to tropical aridity. Atmospheric methane concentrations declined because of the drought; this depletion of GHGs created a feedback loop prolonging cooling conditions.

Proxy records based on isotope ratios suggest a decline in solar radiation during the four subsequent cooling periods. The cooling corresponds to lows in solar radiation that correspond to variation in the Earth's orbit. In the case of the 8.2ka event and the onset of the Little Ice Age, there is also evidence of increased volcanic activity. Massive volcanic eruptions cause global cooling by ejecting fine ash and sulfates into the atmosphere. However, in the absence of reinforcement from orbital forcing, this effect dissipates in about three years.

• Cultural Effects of Holocene Climate Change

As several analysts have pointed out, climate has helped shape civilization, but not by being benign. Human technological and social advances appear in the archaeological and historical record as responses to climate change that rendered older ways of life maladaptive. The general pattern appears to involve a buildup of population and associated infrastructure during periods characterized by warm temperatures, adequate rainfall, and low variability, such as the Hypsithermal or the Medieval Warm Period. This is followed by a population crash due to famine, war, and pestilence when the climate changes, and a period of rapid technological and social innovation as the population adapts to the new conditions.

In the Middle East, the 8.2ka event, which occurred at a time when agriculture had not yet entirely supplanted the hunter-gatherer economy, spurred the transition to a permanently settled mode of life, more intensive methods of cultivation, and the rise of towns. The 6ka cooling period corresponds to the beginnings of civilization in the Middle East, China, and Southeast Asia. The need to coordinate a large population base over a wide area to manage irrigation during a prolonged drought has been postulated as a key factor in the rise of city-states in Mesopotamia.

During the Hypsithermal, large portions of the Sahara Desert were savanna dotted with seasonal lakes, supporting abundant game and hunters who left rock art and artifacts in areas that are completely barren today. The present aridity of the Sahara and much of the Middle East was well established in classical times (twenty-five hundred to fifteen hundred years ago) and has persisted through warm periods of increased rainfall, in part as a result of human activities such as overgrazing. Global warming could increase rainfall in regions such as the Sahel. Although this would ultimately be beneficial, immediate effects would include flash flooding, erosion, and the proliferation of invasive species.

The cultural pattern is less clear-cut in the humid tropics, but studies of the rise and fall of lowland Mayan civilization in Central America suggest that, contrary to expectation, the peak of this civilization corresponded to the cooling period that occurred twelve hundred to one thousand years ago. Its subsequent decline came during the Medieval Warm Period. In the tropics, cold conditions at the poles cause a weakening of monsoons. Seasonally dry conditions advance toward the equator. Climates with strongly marked wet and dry seasons are more favorable to intensive, highly productive agriculture than is a permanently wet tropical rain forest.

Modern Western civilization is the product of the Little Ice Age. (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.) The abrupt drop in temperatures that occurred in 1315 produced first a famine, then war, and finally a pestilence that wiped out one-third of Europe's population. Without a famine-weakened population and the disruptions of war, the bubonic plague might well have remained localized, as it did in North Africa in the eighteenth century. Temperatures remained low during the recovery period. Thus, a return to the population levels and living standards of the thirteenth century required first technological innovation and later exploitation of warmer areas through colonialism. For reasons not clearly understood, the Little Ice Age did not produce increased drought in the tropics.

• Context

Probably the most important global warming lesson to be learned from the Holocene record is that of the disruption of North Atlantic currents and resulting deep freeze in Europe eighty-two hundred years ago. Very rapid melting of the Greenland ice cap and release of freshwater into the Atlantic could well produce a similar effect. Short-lived episodes of warming and cooling are documented in the climate proxy record. On a local level, such episodes undoubtedly produced dramatic effects, but they left no lasting impression on the world's flora and fauna, nor on human culture as a whole. In today's overpopulated and environmentally degraded world, the consequences of a temporary drop in global temperatures due to either massive volcanism or a disruption of thermohaline circulation in any of the Earth's oceans present a much grimmer prospect than they did at any other time in history. Both scenarios have sufficiently high probability to attract the attention of Pentagon analysts.

Martha A. Sherwood

• Further Reading

Alverson, Keith D., Raymond S. Bradley, and Thomas Pedersen, eds. *Paleoclimate, Global Change, and the Future*. Berlin: Springer Verlag, 2003. Collection of scholarly papers comparing past climate changes with present anthropogenic trends; discusses ancient civilizations.

Fagan, Brian. *The Long Summer: How Climate Changed Civilization*. New York: Basic Books, 2004. Argues that civilization has evolved in response to climatological challenges and obstacles that had to be overcome. Semipopular, with a focus on the Middle East and the rise of agriculture.

Mayewsky, Paul, et al. "Holocene Climate Variability." *Quaternary Research* 62 (2004): 243-255. Technical summary of high-resolution proxy records from many parts of the globe; includes some discussion of the correlation of these records with human history.

Saltzman, Barry. *Dynamical Paleoclimatology: Generalized Theory of Global Climate Change*. New York: Academic Press, 2002. Treats interactions between abiotic, biotic, and anthropogenic variables; discusses controversies about the magnitude of human impacts on climate.

Stipp, David. "The Pentagon's Weather Nightmare." *Fortune*, February 9, 2004. Posits a plausible chain of events leading from a climatic shift comparable to the 8.2ka event to World War III.

See also: Abrupt climate change; Civilization and the environment; Climate reconstruction; Dating methods; 8.2ka event; Little Ice Age; Medieval Warm Period; Pleistocene climate.

Hubbert's peak

• **Categories:** Fossil fuels; energy

Geophysicist Hubbert's prediction that American oil production would peak in 1972 proved accurate and presaged the rise of energy independence and security as crucial national and international issues.

• Key concepts

fossil fuels: fuels, including coal, oil, and natural gas, produced by chemical alteration of organic matter under pressure

greenhouse gases (GHGs): atmospheric trace gases that trap heat, preventing it from escaping into space

nonrenewable resource: a resource that, once consumed, cannot be renewed

reserves: the estimated amount of a nonrenewable resource remaining to be consumed

• Background

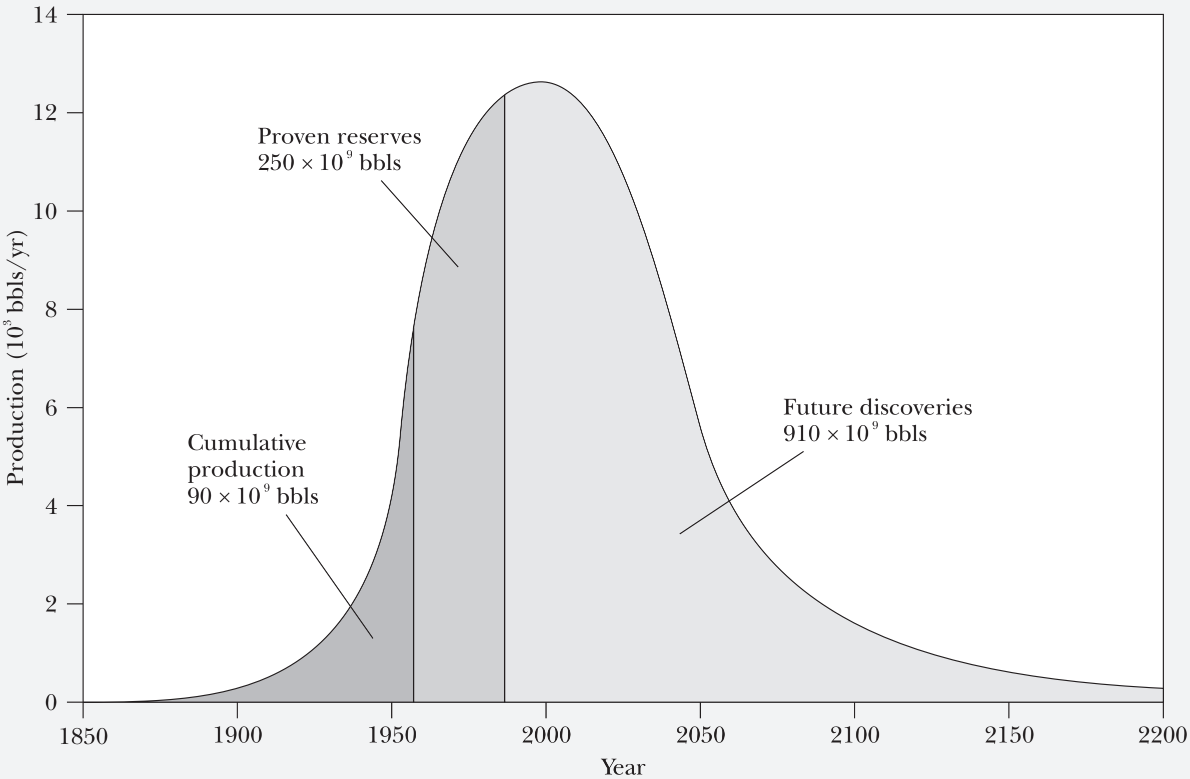
In 1956, Shell Oil Company geophysicist M. King Hubbert predicted that U.S. oil production in the lower forty-eight states would peak in 1972; it peaked in 1970. Other scholars have extended Hubbert's work to predict that world oil production would peak sometime between 2005 and 2011. Although there are critics of Hubbert's approach, most geologists and geophysicists agree with the basic premises of his work. World demand would exceed production capacity about the time of peak production, driving up the cost of oil. Burning oil is a major producer of carbon dioxide (CO_2), a greenhouse gas (GHG). The impending oil shortage and resulting increases in the price of oil may help spur people to turn to alternative energy sources, many of which do not produce CO_2.

• Hubbert's Predictions

Basing his analysis on proven oil reserves in the United States and on an analysis of production patterns in the anthracite coal industry, Hubbert produced a bell curve that showed the growth, peak, and eventual decline in American oil production. He described what has come to be called Hubbert's peak, the one-hundred-year period in which oil was the driving force of the economy. Hubbert tied his analysis to patterns of production for other fossil

Hubbert's Peak

Reproduced below is a graph of M. King Hubbert's original 1956 prediction of global oil production over two and one-half centuries.



bbls = billions of barrels.

fuels, most notably anthracite coal in the eastern U.S. Because fossil fuels are a nonrenewable resource, they cannot be re-created once used. The model that Hubbert produced contained two scenarios, one predicting that U.S. oil production would peak in 1965, and a more optimistic one indicating 1972. Actual U.S. oil production peaked in 1970, giving additional weight to Hubbert's approach.

Hubbert's bell curve indicated that there would continue to be significant American oil production after the early 1970's, as has occurred. However, as easily accessible reserves are consumed, oil producers are forced to turn to increasingly expensive means to produce oil. This has meant drilling in unlikely places, often at great expense and to no avail; expensive recovery processes that try to obtain what oil remains in an underground reservoir; and increased emphasis on offshore drilling, in some cases through 3,000 meters of water and then 6,000 meters below the ocean floor.

Several scholars, such as Kenneth Deffeyes, have extended Hubbert's approach and predicted the peak for world oil production would occur some time during the first decade of the twenty-first century. Because the United States has come to rely on foreign oil, a decline in world oil production will have a significant impact on the American economy as well as climatic conditions. This second peak production point will lead to increasingly expensive means of trying to obtain oil.

• A Question of Reserves

Hubbert's analysis was based on his knowledge of proven oil reserves taken from several sources. Oil is generally found in particular types of geologic formations between 2,300 and 4,600 meters beneath the surface of the Earth. These oil-bearing formations are found in both the land and beneath the ocean. In the past oil companies and government bodies have often overstated oil reserves for political and economic reasons. This situation may be changing, as Shell Oil sharply decreased its reserve predictions early in the twenty-first century. Although further exploration has led to higher estimates for reserves, by the early twenty-first century only the South China Sea region had not been fully explored, and most geologists do not expect any oil fields approaching the magnitude of the Saudi Arabian fields to be found there.

Economists often raise the principle of substitutability in dealing with oil reserve predictions. They indicate that as it becomes more expensive to drill for oil in one area, oil companies will drill elsewhere distorting reserve predictions as oil still remains in the ground in the old fields. This was true for a time, but now oil companies are using new technologies to extract oil from old fields in places such as east Texas and Mexico. The criticism of Hubbert that he ignored substitutability may have been somewhat true at one point, but it is less true at present.

Oil is a finite resource, and as oil fields are depleted oil companies turn to more expensive means of production. For example, in 2008 some oil companies were paying more than $600,000 a day to lease drill ships for offshore drilling. In addition, some oil reserves are now found in politically unstable locations, such as off the east coast of Africa, a condition likely to drive up the costs of obtaining oil. Oil is also found in tar sands in Canada, but extraction is expensive and causes several environmental problems. Moreover, oil is used for more than energy. It is also the feedstock for the chemical industry for such products as plastics.

• Context

Burning fossil fuels such as oil is a major source of GHGs such as CO_2. It is estimated that CO_2 generated by burning fossil fuels represents 57 percent of the GHGs emitted into the atmosphere. Although oil- and gasoline-burning comprise only parts of this figure (coal-burning is also a major source of CO_2), decreasing the burning of oil will help to reduce this source of CO_2 emissions. Oil consumption is so ingrained in industrial society in the use of oil for industrial and home energy and for transportation that simply turning to another source is not likely in the short run without the impetus of a steep price increase. With the exception of coal most other, cleaner energy sources have been more expensive than fossil fuels, so there has been little economic incentive to adopt them.

It is likely that the assumptions concerning world oil production derived from Hubbert's model are correct and the production of oil will become increasingly expensive in the next few years. The increasing cost of oil predicted by Hubbert's model may help to lower consumption of oil. Confronted by sharp increases in the prices of gasoline and fuel oil in 2008, more industries and consumers were searching for alternative fuels, fuels that often produced a smaller carbon footprint than oil.

John M. Theilmann

• Further Reading

Adelman, M. A., and Michael C. Lynch. "Fixed View of Resource Limits Creates Undue Pressure." *Oil and Gas Journal*, April 7, 1997, pp. 56-60. Denies the validity of Hubbert's analysis. Written from an economist's perspective.

Deffeyes, Kenneth S. *Beyond Oil*. New York: Hill and Wang, 2005. Places oil production in the wider context of the energy industry in general and argues that the impact of a coming oil shortage will force a turn to other energy sources.

_______. *Hubbert's Peak*. Princeton, N.J.: Princeton University Press, 2001. Excellent explanation of Hubbert's model that extends it to examine world oil production.

Goodstein, David. *Out of Gas*. New York: W. W. Norton, 2004. Good description of energy and the coming depletion of oil that accepts the validity of Hubbert's model.

Hubbert, M. King. "The World's Evolving Energy System." *American Journal of Physics* 49 (1981): 1007-1029. Useful and comprehensible presentation of Hubbert's views concerning petroleum production and the implications of his model.

See also: American Association of Petroleum Geologists; Biofuels; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Gasoline prices; Oil industry.

Human behavior change

• **Category:** Popular culture and society

Climate change will affect human welfare, and changing behavior may mitigate the threat. Technologies exist to facilitate the development of proactive behavior and problem solving, as well as the reduction of human contributions to global warming.

• Key concepts

adaptation: the process through which entities adjust in response to external circumstances

altruism: behavior intended to benefit others rather than the self

behavioral economics: the study of the combined economic and psychological principles affecting human behavior and decision making

environmental psychology: the study of the interaction between behavior and the environment among individuals, groups, organizations, and systems

negative reinforcement: deployment of stimuli to decrease a given behavior

positive reinforcement: deployment of stimuli to increase a given behavior

punishment: a type of negative reinforcement incorporating a moral component

systems theory: approaches to understanding interdependent behavior within and among groups or systems

• Background

Humans regularly adapt their behavior to daily and seasonal weather changes with ease. With global climate change, however, the adaptation demands facing humans are expected to be extraordinary. There is scientific consensus that human activities will need to adapt substantially to meet the anticipated changes of the near future and beyond. Such changes will demand local and regional adaptations in daily individual and community functioning, as well as sustained behavior changes by individuals, organizations, and systems to reduce or cease activities affecting the climate deleteriously in a more global and persisting way. Behavioral economics and environmental psychology provide tools for making such change occur.

• Preparing for Climate Change Through Behavior Change

Global climate change will demand different preparation activities from different people. This variation is partly a function of the varied effects of climate change experienced by different regions of

Vivian deZwager shows off the newly planted green roof on her garage. Such roofs help reduce carbon dioxide, as well as heating and cooling costs. Treating the planting as an artistic project may help motivate others to follow suit. (Janet Jensen/MCT/Landov)

the globe. Some regions may become hotter or cooler, drier or wetter, or may have more or less seasonal variation in weather than previously known. Necessary individual, organizational, and systems-level preparations vary by location. Relevant factors include latitude, longitude, elevation above sea level, and the time span considered.

People may adapt by adjusting where and how they live, making home improvements to meet new climate challenges, and developing personal climate disaster plans. Assessment and acquisition of skills needed in the event of a climate-related crisis also will be necessary. Community organizations may seek to protect whole communities and neighborhoods. Organizations such as businesses and governments may adapt by changing locations for headquarters, road systems, and other construction, as well as arrangements for food, medical, and other natural resource distribution. They also may prepare on the systems level by engaging with other governments to coordinate responses to challenges should they arrive, such as dispersing aid and assistance and ensuring vital communications.

• Lessening the Impact of Climate Change Through Behavior Change

Individuals, organizations, and governments must consider what they can do to lessen the continued development and ultimate impact of global climate change using available knowledge and technologies. For individuals, education about carbon footprints, water-use habits, use of natural space, and resource use related to climate change will be a first step. After understanding their personal behavior, people may need to alter their lifestyles, travel patterns, and consumption of goods to lessen their carbon footprints and other environmental impacts. Such proactive and altruistic behavior will lessen the overall burden on those expected to be most affected by climate changes and will perhaps lessen the overall damage that may occur.

Individuals also may consider changing how they influence other individuals and the relevant organizations and systems in which they interact. They may examine their work and governmental behavior and policies affecting climate. They may advocate for change to initiate and reinforce larger systems adjustments, as well as smaller change in local communities, such as within a family or among friends and neighbors. Climate change is not affected only by individuals, however; organizational and systems behavior matters too.

Governments and businesses are the largest global consumers of energy, having much greater carbon footprints and environmental impacts than individuals. Therefore, attempts to lessen the overall impact of climate change must incorporate organizational and systems-level adjustment. For families, this may mean assessing the overall impact of living far away from schools and workplaces. Businesses and government could similarly assess their employees' air travel and consider ways to minimize or replace such travel. At a systems level, efforts such as the Montreal Protocol and Kyoto

Protocol may need to be updated and expanded, encouraging greater coordinated efforts across larger systems of human behavior.

- **Climate Change, Behavioral Economics, and Managing Human Behavior**

Individuals, organizations, and systems do not enact behavior merely based on morals, principles, or theories. Incentives, such as positive and negative reinforcement, as well as costs, such as punishments, pay a role. In effect, human behavior is subject to behavioral economics—a valuable tool for changing human behavior. Examination of key behaviors needing change among individuals, organizations, and systems, coupled with identification of key incentives and costs, can be used to encourage change. Rebates, taxes, credits, budgets, fines, barter, and allowances for different climate-related behaviors are examples of how behavioral economics may be applied for both businesses and individuals. Similarly, organizations such as governments can be subject to incentives, such as basing the right to import or export goods on climate-related practices within a particular country. At the systems level, governments can develop agreements with one another that suit the goals of preparing for climate change and enacting behavior to lessen its impact.

- **Context**

Scientific advances allow humans to predict, shape, and respond to future change by adapting both individual and collective behavior. The ability of humans to communicate globally, cooperatively, and quickly has increased dramatically as a function of modern communications technologies. These technologies facilitate the communication of complex environmental and behavioral information, along with insights into the dynamics of human behavioral economics, market forces, and the connectedness of people across the globe. Such abilities may be combined with psychological technology to affect and shape human behavior at the individual, organizational, and systems levels, and thoughtful and sustained leadership can provide solutions to the pressing climate problems ahead.

Nancy A. Piotrowski

- **Further Reading**

Brown, Lester B. *Plan B 3.0: Mobilizing to Save Civilization.* 3d ed. New York: W. W. Norton, 2008. A leading social scientist engagingly describes global warming and its associated problems in a sociological context and proposes socioecological strategies to address them.

Camerer, Colin F., George Lowenstein, and Matthew Rabin, eds. *Advances in Behavioral Economics.* Princeton, N.J.: Princeton University Press, 2003. Introduces behavioral economics; describes the integration of psychological and economic theories in order to understand and predict human behavior.

Gifford, Robert. *Environmental Psychology: Principles and Practice.* 4th ed. Colville, Wash.: Optimal Press, 2007. Presents the scope and principles of environmental psychology, how the environment shapes human behavior, and how human behavior can be managed to achieve goals such as sustainability.

See also: Anthropogenic climate change; Climate and the climate system; Economics of global climate change; Environmental economics.

Human migration

- **Category:** Ethics, human rights, and social justice

- **Definition**

Most literature uses the term "environmental refugees" or "climate refugees" to conceptualize the complex relationships between human migration and climate change. In the 1970's, Lester Brown of the Worldwatch Institute defined environmental refugees as people forced to leave their traditional habitats, temporarily or permanently, because of marked environmental disruptions.

- **Significance for Climate Change**

Migration caused by environmental degradation is not a new phenomenon. People throughout history have migrated in order to seek new opportunities and resources for survival. What makes climate-change-related displacement different is the scale of the problem and the size of the population affected by them. Both the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Environment Programme warn that human mass migration caused by climate change can turn into humanitarian crises and a global security threat, because the change of settlement may cause conflict over resources within nations or in host communities.

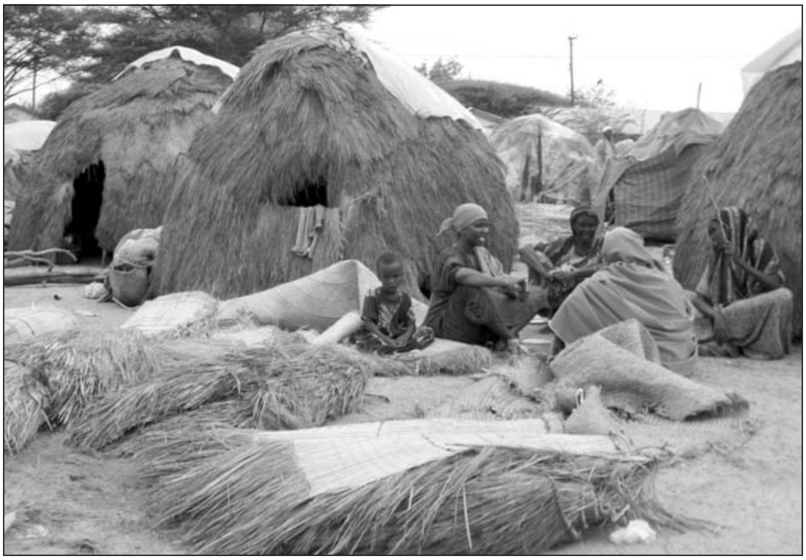
The Office of the United Nations High Commissioner for Refugees estimates that 24 million people around the world will be displaced because of floods, famines, and other environmental factors by 2050. The *Stein Review* and Friends of the Earth both predict that by that year 200 million people will become climate change migrants worldwide, including one million from small island states affected by shoreline erosion, coastal flooding, and severe drought resulting from rising sea levels, deforestation, dry-land degradation, and natural disasters. Christian Aid makes the most extreme prediction: One billion people will be forcibly displaced by 2050.

The impact of global warming is twofold: First, climate change increases the variability of extreme weather events associated with the changes in surface temperature and precipitation. This results in floods, droughts, and a high incidence of diseases that affect both human and animal health. Second, rising sea levels mean loss of farmland, accelerating shoreline erosion, and disruption of agricultural production. For example, in Egypt, the anticipated rise in sea level could cause 12 to 15 percent loss of arable land by 2050, and consequently 14 million people would be forced to disperse. In Bangladesh, a 1 meter increase in sea level would inundate half of Bangladeshi rice land, forcing the relocation of 40 million people.

Studies show that climate-change-related displacement has a negative impact on the well-being of migrants. The process may cause severe long-term stress and psychological effects. Prolonged uprooting may result in culture and identity loss. Displaced people become landless, homeless, and unemployed, and they are restricted from getting access to common property resources in new areas. The weakening of community ties will reduce their social networks and further reinforce social marginalization.

The IPCC warns that climate-related migration may increase the risk of group-identity conflict and political instability within states. Reduced water availability, for example, may induce conflict between different water users, such as pastoralists and farmers. People may resort to violence to gain dominant control over limited natural resources. The grievance could increase recruitment opportunities for rebel movements and lead to civil war. Environmental scarcity could also bring about conflict across borders. Water scarcity can cause transboundary disputes.

Migration would also bring problems to host communities or nations, especially if they are not well prepared for the influx of migrants. The rising numbers of migrants will exert pressure on resources and social services. The migrants them-



An encampment of Somalian refugees who have been displaced from their homes by flooding. (Daud Yussuf/Reuters/Landov) selves will compete for jobs, and that competition may increase social tensions and intergroup clashes. In order to curb the influx of migrants, host societies may change their immigration laws and restrict asylum. International law does not require states to provide asylum to those displaced by environmental degradation.

The literature suggests that the impact of climate change on human migration is complex. The causes of migration are multiple, and many problems created by climate change build on existing development problems, such as socioeconomic vulnerability, political suppression, and institutional weakening. The consequences of climate-change-induced migration also depend on the rate of recovery, adaptive capability, preparedness for disasters, and effectiveness of conflict resolution mechanisms. Questions as to whether the deterioration of environmental conditions by climate change is sudden or gradual, whether the displacement is temporary or permanent, and whether migrants are victims or strategists who choose to migrate because of foreseeable opportunities in a new environment need to be carefully examined.

To address these problems, disaster preparedness must be improved; this includes building better adverse-weather advance-warning systems for vulnerable areas. Effective conflict resolution mechanisms can be developed to settle disputes. Governments can increase community resilience by reducing soil erosion and deforestation and enhancing awareness about sustainable use of resources. Better coordinated assistance is needed to reconstruct the livelihoods of the displaced. Land-based resettlement, rehousing, social inclusion, improved health care, and building community assets and services are a few strategies to reduce the impact of migration.

Sam Wong

• Further Reading

Forced Migration Review 31 (2008). This special issue titled "Climate Change and Displacement" offers updated discussion of the relationships between climate change and human migration. Highlights the differences between voluntary and involuntary displacement, as well as their different impacts on climate change policies.

Friends of the Earth Australia. *A Citizen's Guide to Climate Refugees*. Melbourne, Vic.: Author, 2007. Offers a critical examination of the concept of climate refugees, as well as recommendations to address migration problems.

Vine, David. "The Other Migrants: Cause and Prevention in Involuntary Displacement and the Question of 'Environmental Refugees.'" In *International Migration and the Millennium Development Goals*. New York: United Nations Population Fund, 2005. Offers a critical examination of the concept of environmental refugees. Questions whether the term is critically conceptualized and whether it is relevant to climate change.

See also: Displaced persons and refugees; Intergovernmental Panel on Climate Change; United Nations Environment Programme.

Humidity

• Category: Meteorology and atmospheric sciences

• Definition

Humidity is the amount of water present in the atmosphere in the form of vapor. As a gas, water vapor contributes to the local atmospheric pressure in accordance with Dalton's law of partial pressures: In any mixture of gases, the partial pressure of any one component is equal to the total pressure of the mixture multiplied by the fraction of the gas present in the mixture. For example, molecular oxygen constitutes 20 percent of the atmosphere, so the partial atmospheric pressure of oxygen is 20 percent of Earth's total atmospheric pressure. The total pressure is about 1.03 kilograms per square centimeter, so the partial atmospheric pressure of oxygen is about .20 kilograms per square centimeter.

Water normally exists in liquid and solid as well as vaporous form. Its vapor pressure is the pressure at which pure water vapor coexists in equilibrium with either the liquid or the solid state. At equilibrium, the liquid would not evaporate, the solid would not sublimate, and the vapor would not condense. By contrast, if the local partial pressure of water vapor is greater than its vapor pressure, the vapor condenses; if the local partial pressure is less than the vapor pressure, then the liquid evaporates and the solid sublimates. Vapor pressure is not a constant but rather is a function of temperature.

If the local partial pressure of water is exactly equal to its vapor pressure, the air is said to be saturated. This state is defined as 100 percent humidity, and the corresponding temperature is water's dew point. If the vapor pressure of water is equal to the total local atmospheric pressure, the water will evaporate without limit, and the corresponding temperature is water's boiling point. Relative humidity is the ratio, expressed as a percentage, of the local partial pressure of water vapor to the vapor pressure associated with the local temperature.

Humidity can exceed 100 percent, a condition known as supersaturation. In supersaturation, water vapor's partial pressure exceeds the theoretical vapor pressure at that temperature. Condensation cannot take place, however, unless condensation nuclei are present. Water droplets exceeding a certain critical size act as such nuclei, absorbing water vapor and growing; water droplets below the critical size evaporate. If no droplets larger than the critical size exist and no other condensation nuclei are present, then the supersaturated vapor is stable. Fine, dry particles, such as dust or pollutants, also act as condensation nuclei in supersaturated air.

Evaporation is an endothermic process, or one that requires an input of energy in order to occur. The change of phase from liquid to gas takes place at constant temperature. The energy consumed by the process is stored in the water vapor in the form of latent heat of vaporization. When the vapor condenses, all of the latent heat is released, which means that condensation is exothermic. Water has a latent heat of vaporization of 2,256,000 joules per kilogram, an unusually high value for such a simple compound.

• Significance for Climate Change

Water vapor is the most abundant greenhouse gas (GHG) in Earth's atmosphere, exceeding the amount of CO_2 by a factor of one thousand. It is transparent to visible radiation but opaque to infrared radiation of 5.25 to 7.5 micrometers in wavelength, which is a lower frequency range than that of visible light. Incoming solar radiation peaks in the visible spectrum. Energy re-emitted by the Earth peaks in the infrared portion of the spectrum. Thus, incoming energy is better able to penetrate water vapor than is outgoing energy.

In order for the Earth to maintain thermal equilibrium, radiating as much energy back to space as it receives from the Sun, the global average temperature must rise higher than it would if there were no humidity in the atmosphere. The balance of the amounts of radiation received from the Sun and emitted back into space is called the radiation budget.

No simple statements about the effect of total atmospheric water vapor on climate change are possible, because the atmosphere is a nonequilibrium system. Water vapor resides in the air for fairly short periods before precipitating out as rain, snow, or dew. As a result, the amount of water vapor in the atmosphere itself responds quickly to changes in climate. Water vapor in turn affects Earth's radiation budget and, through it, surface temperatures, closing the loop and generating feedback. Layers of air near the planet's surface are warm enough and close enough to the oceans to stay relatively saturated. Their effect on the radiation budget is small, because they are nearly as warm as the surface itself. Upper layers of the atmosphere are cooler and moistened only by the water vapor that convects or diffuses upward from the layers below. Small quantities of water in these upper layers can have a disproportionate effect on the radiation budget, trapping enough infrared energy to significantly warm the climate.

This feedback is complicated, however, by the presence of water in the air as suspended droplets in the form of clouds and fog. These droplets scatter visible radiation in all directions, preventing an appreciable fraction of the incident solar energy from reaching the ground and contributing to Earth's albedo (the fraction of incident solar energy reflected back into space). Ice and snow have the same effect. Increases in albedo have a cooling effect and act to moderate any global average temperature increases.

Billy R. Smith, Jr.

• Further Reading

Colman, B. R., and T. D. Potter, eds. *Handbook of Weather, Climate, and Water*. Hoboken, N.J.: Wiley-Interscience, 2003. Concise and thorough treatment of the hydrologic cycle and its effect on climate. Illustrations, figures, tables, references, index.

Schneider, T., and A. H. Sobel, eds. *The Global Circulation of the Atmosphere*. Princeton, N.J.: Princeton University Press, 2007. Chapter 6, "Relative Humidity of the Atmosphere," may be difficult for the nonexpert to read in depth, but there is value in skimming it to understand the authors' positions on the subject. Figures, tables, and references.

Taylor, F. W. *Elementary Climate Physics*. New York: Oxford University Press, 2005. Readers without significant prior knowledge of climate science should consult this book for help in understanding difficult topics. Illustrations, figures, tables, bibliography, index.

See also: Clouds and cloud feedback; Dew point; Greenhouse effect; Noctilucent clouds; Polar stratospheric clouds; Rainfall patterns; Water vapor.

Hybrid automobiles

• Categories: Economics, industries, and products; energy

Hybrid automobiles derive their energy from two or more sources, such as gasoline and electricity. They are low- or zero-emission vehicles and greatly reduce or eliminate the toxic carbon emissions that are by-products of gasoline-powered internal combustion engines.

• Key concepts

aerodynamic: designed to minimize drag from the air

compressed air: air that is forced into a small space under high pressure

fossil fuels: fuels derived from decayed plants and animals under geologic pressure over millions of years

hydrogen automobiles: vehicles that use electricity generated from combining hydrogen and oxygen to produce water

lithium-ion batteries: long-lasting, lightweight batteries made from lithium

prototype: a trial model of a product a manufacturer is considering mass-producing

regenerative braking: process that uses the friction caused by applying a car's brakes to produce energy to help power the vehicle

zero-emission automobiles: motor vehicles that do not produce toxic pollutants

• Background

Hybrid vehicles combine electric motors and internal combustion engines in such a way that their drive shafts can be powered by the gasoline engine, by the lithium-ion batteries of their electrical engines, or by a combination of the two. Although such vehicles existed as experimental prototypes as early as the late nineteenth century, they did not become commercially viable until the last quarter of the twentieth century, when fuel shortages, problems with air pollution, and concern over global warming converged to make fuel-efficient, nonpolluting vehicles attractive to the public.

The Japanese automobile company Toyota launched the first mass-produced hybrid, the Prius, in 1997. Although this vehicle was not expected to attract many buyers, its initial American reception after it was introduced to the U.S. market in 2000 was enthusiastic. Toyota increased production and moved toward the manufacture of an aerodynamic Prius the size of Toyota's Corolla that would travel more than 21 kilometers on a liter of gasoline. Soon, Honda was producing comparable hybrids.

People who wanted to buy a Prius often had to wait four to six months to have their orders filled. Prius sales in the United States doubled between 2003 and 2004, and they doubled again in 2005. By 2007, some 250,000 hybrids were sold in the United States.

• Hybrid Technology

Hybrids generate much of their own power and are essentially low- or zero-emission vehicles. Although their internal combustion engines can provide power in ways comparable to those of more conventional vehicles, these vehicles derive much of their power from a lithium-ion battery pack that is continuously charged and recharged while the vehicle is operated by its gasoline-powered engine and by the friction caused in normal braking. This regenerative process permits hybrids to deliver higher mileage in stop-start, urban driving than in long-distance, highway driving.

The key to producing hybrid vehicles that will deliver over 40 kilometers to a liter of gasoline is the development of increasingly light, rechargeable lithium-ion batteries. Toyota and other manufacturers have already developed lithium-ion batteries that do not encroach upon the vehicle's interior space, as earlier versions of such batteries did.

Some hybrid automobiles are capable of recharging their batteries by plugging into charging stations such as this one in Berkeley Square, London. (Getty Images)

• Other Kinds of Hybrids

A number of automobile manufacturers have produced electric cars, "plug-in" vehicles that usually have ancillary gasoline-powered engines. Most of these vehicles must be plugged in for periods of from four to six hours for recharging. Most of them have a limited range, generally at best about 160 kilometers, and some are incapable of operating at interstate speeds. Despite these limitations, many such vehicles are in service with the United States Postal Service and other groups. They are practical if they are required to be in service for eight or ten hours a day, after which they can be plugged in to have their batteries recharged before the next work day.

Hydrogen vehicles have also been developed. These carry hydrogen in their fuel tanks, where it combines with oxygen taken in from the air and produces electricity to power the vehicle. The by-product of this technology is water vapor, which results in zero emissions.

The Tata Motor Company of India has developed automobiles that will retail for under five thousand dollars and are directed toward buyers in India and China. It is doubtful that the initial Tata vehicles could meet U.S. safety standards. One of the most exciting Tata hybrids is being produced for developing nations. These vehicles, equipped with auxiliary gasoline engines, operate on compressed air using a technology developed by Guy Nègre, a French engineer. They are extremely economical to operate.

• Context

The rapid development of hybrid vehicles has been stimulated by a number of compelling forces, not the least of which is the problem of the worldwide pollution being caused by the burning of fossil fuels. The toxic residues that the burning of such fuels produces are poisoning the environments of every nation in the world.

Even if one ignores the threat posed by burning fossil fuels, society worldwide is exhausting the supplies of such fuels. In a world dependent for its transportation upon vehicles powered by various sources of energy, it is crucial that these sources must be both nonpolluting and renewable. It is unrealistic to assume that the contemporary world will drastically reduce its consumption of energy in the foreseeable future. Thus, the development of technologies that will make optimal use of renewable energy is perhaps society's greatest hope for the future.

R. Baird Shuman

• Further Reading

Bethscheider-Kieser, Ulrich. *Green Designed Future Cars: Bio Fuel, Hybrid, Electrical, Hydrogen, Fuel Economy in All Sizes and Shapes.* Los Angeles: Fusion, 2008. Useful account of the various contemporary hybrid automobiles, with specifics about how each type works.

Boschert, Sherry. *Plug-In Hybrids: The Cars That Will Recharge America.* Gabriola Island, B.C.: New Society, 2006. Contends that electric automobiles that plug into conventional electrical sources are likely to be available commercially before hydrogen automobiles are.

Ehsani, Mehrdad, et al. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design.* Boca Raton, Fla.: CYC Press, 2005. Comprehensive, explicit account of the evolution of hybrid motor vehicles, replete with illustrations.

Juettner, Bonnie. *Hybrid Cars.* Chicago: Norawood House Press, 2009. Directed at young adult readers, this overview of the development of hybrid automobiles, clear and thorough, is easily accessible to newcomers to the field.

Povey, Karen. *Our Environment: Hybrid Cars.* Farmington Hills, Mich.: KidHaven, 2006. Aimed at young adult readers, this slim volume discusses intelligently the role that hybrid cars can serve in protecting the environment and reducing global warming.

Walker, Niki. *Hydrogen: Running on Water.* New York: Crabtree, 2007. Explains how a technology that separates the two elements of water, hydrogen and oxygen, may eventually enable motor vehicles to run on water, whose exhaust would not be toxic.

See also: Automobile technology; Motor vehicles; Transportation.

Hydroelectricity

• Category: Energy

Because hydroelectricity uses falling water rather than fossil fuels for its production, it does not contribute GHGs to the atmosphere. It is both a clean and a renewable energy source.

• Key concepts

fossil fuels: fuels, such as coal, gas, or oil, created during early geologic eras

generator: a mechanical device whose rotational movement around magnets produces an electrical current

head: the fall of the water at a site selected for production of hydroelectricity

reservoir: a gathering place for water held in reserve for later hydroelectric production

turbine: an enclosed vessel containing rotating parts turned by the passage of a fluid, such as water or air

• Background

Hydroelectricity is a twentieth century phenomenon. Although the use of moving water for the production of mechanical energy is ancient (water wheels go back to ancient times), the use of falling water to create electricity awaited knowledge about using electricity as a motive power. Although Michael Faraday invented a dynamo that produced an electric current in 1831, the concept of using an electric current to move energy from one place to another awaited the appearance of Thomas Alva Edison and the electric light in the 1870's. Critical for hydroelectricity were the understanding that electricity could be produced by other kinds of mechanical energy, the development of machines that could use mechanical energy to induce an electric current (generators), and knowledge of the transmission systems that made it possible to move electricity across significant distances.

• Early History of Hydroelectricity

The invention of the turbine allowed water run through a containing vessel to produce mechanical energy that could, in turn, generate an electrical current. The turbine designed by James Francis was the earliest to appear, but modifications made by Lester Allan Pelton and later Viktor Kaplan adapted the turbine to use in situations involving falls of significant distance. Generally, hydraulic installations are classified into either low-head facilities, where the drop is on the order of 15 meters, and high-head facilities, with a drop of more than 60 meters. The height of the head determines whether a vertical- or horizontal-impulse turbine is used. The determining factor is the continuous volume of water passing through the turbine.

Initially, use was made of sites that both were close to manufacturing facilities and involved large volumes of water falling substantial distances. The most notable example was Niagara Falls. Sites with this combination of features are relatively rare, however. Most suitable sites tend to be located at the base of chains of mountains, where they can make use of the water generated by large amounts of melting snow. The drawback to such sites is that the amount of water they generate is seasonally variable. The very high capital costs of constructing such installations make it essential that they be sited where the flow of water is steady, allowing them to operate year-round. Thus, in the twentieth century, operators of hydroelectric facilities began to build holding ponds or reservoirs. These structures allowed them to collect water when its flow was great and store it for later use during drier seasons.

- **Major Facilities**

The common preference, especially among governments, for economies of scale has led to the development of a number of very large hydroelectric facilities, of which the largest, in China, is the Three Gorges Dam in Hubei province. Governmental priorities also entailed building a large reservoir to ensure that there would always be sufficient water to operate the facility's generators. This construction in turn flooded some 100,000 of China's towns and villages, forced one million peo-

The Sayano-Shushenskaya hydroelectric power station in Khakassia, Siberia, Russia. (Sergei Karpukhin/Reuters/Landov) ple to move, and submerged about 400 square kilometers of farmland.

Other large facilities include the Itaipu, serving both Paraguay and Brazil; the Yacyreta, serving Argentina and Brazil; the Krasnoyarsk, the Bratsk, the Ust-Ilim, and the Volgograd in Russia; the Minamiaiki in Japan; and the Chief Joseph in the United States. The United States also has a number of facilities built during the 1920's and 1930's, notably the Hoover Dam, the Glen Canyon Dam, the Grand Coulee, and the Bonneville facility. Although many of these were built in sparsely inhabited areas, they have had an effect on the human populations in their area, though perhaps none so much as the Three Gorges Dam in China.

• Environmental Effects of Hydroelectricity

Although the construction of large hydroelectric projects has had some benefit for the population served by the electricity they produce, the heavy use of hydroelectricity in some parts of the world has also had some negative effects. Among the advantages are the production of low-cost electricity without burning fossil fuels (although many hydroelectric plants have back-up fossil fuel generators so as to keep the generation steady); the creation of dams that can also be used for flood control, controlling water supply in urban areas with large populations; and the creation of artificial lakes that can provide many recreational opportunities.

The disadvantages include high construction costs, conflicting demands for flood control and hydroelectric generating capacity, the withdrawal of substantial amounts of land from agricultural use (as in China), degradation of fish habitat, and the elimination of trees on the flooded land. In several cases, aboriginal communities have lost the land that they traditionally used for their sustenance.

• Context

The steadily growing need of human populations for electricity has created a continuing demand for large facilities that appear to place little burden on the environment. By producing electricity without burning fossil fuels and at low cost, hydroelectric plants are seductive, especially to the politicians who make public policy. Although the best sites have already been taken, there are still a number of lesser locations that may yet be claimed. For many countries in the developing world, hydroelectricity has a large attraction, especially if those countries lack local sources of fossil fuels.

Nancy M. Gordon

• Further Reading

Hausman, William, Peter Hertner, and Mira Wilkins. *Global Electrification: Multinational Enterprise and International Finance in the History of Light and Power, 1878-2007.* New York: Cambridge University Press, 2008. Comprehensive survey from a contemporary standpoint of the advance of electrification throughout the world.

International Energy Agency/OECD. *Projected Costs of Generating Electricity: Update, 1998.* Paris: Author, 1998. Contains a lot of statistical information about electricity, including hydroelectricity, worldwide.

Manore, Jean. *Cross-Currents: Hydroelectricity and the Engineering of Northern Ontario.* Waterloo, Ont.: Wilfrid Laurier University Press, 1999. Although dealing only with the province of Ontario, this study shows how the ever-rising demand for electricity has affected a single part of Canada, among the world's largest users of hydroelectricity.

Smil, Vaclav. *Energy at the Crossroads.* Cambridge, Mass.: MIT Press, 2003. A comprehensive account of the growth of energy during the twentieth century.

_______. *Transforming the Twentieth Century: Technical Innovations and Their Consequences.* New York: Oxford University Press, 2006. Broader look at some of the issues raised in Smil's earlier book, particularly some of the negative effects of the ever-growing demand for electricity.

See also: Clean energy; Energy resources; Fossil fuels; Renewable energy; Tidal power; Wave power.

Hydrofluorocarbons

• **Category:** Chemistry and geochemistry

• **Definition**

Hydrofluorocarbons (HFCs) are a family of organic chemical compounds composed entirely of hydrogen, fluorine, and carbon. They are generally colorless, odorless, and chemically unreactive gases at room temperature. HFCs fall under the broader classification of haloalkanes. While HFCs do not harm the ozone layer, they contribute to global warming as greenhouse gases (GHGs) and are considered one of the major groups of high global warming potential (HGWP) gases.

• **Significance for Climate Change**

Many of the HFCs were developed for use in industrial, commercial, and consumer products as alternatives to ozone-depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Common HFCs, in order of atmospheric abundance, include HFC-23 (fluoroform), HFC 134a (1,1,1,2-Tetrafluoroethane, tetrafluoroethane, R-134a, Genetron 134a, or Suva 134a), and HFC-152a (1,1-Difluoroethane, difluoroethane, or R-152a). HFC-23 is used in a wide range of industrial processes and is a by-product of Teflon(TM) production. HFC-134a is primarily used as a refrigerant for domestic refrigeration and automobile air conditioners. HFC-152a is commonly used in refrigeration, electronic cleaning products, and automobile applications as an alternative to HFC-134a.

The global warming potentials (GWPs) of HFCs range from 140 (for HFC-152a) to 11,700 (for HFC-23). These GWPs are significantly lower than those of the gases the HFCs are designed to replace. The atmospheric lifetimes of the same two HFCs are just over 1 year and 260 years, respectively. HFCs are one of two groups of haloalkanes targeted in the Kyoto Protocol. HFC emissions are projected to increase in the coming years, as industry continues to strive to decrease CFC and HCFC production.

HFCs are preferred over CFCs and HCFCs, because HFCs lack chlorine. When CFCs are emitted into the atmosphere, chlorine (Cl) atoms contained in those CFCs become disassociated through interaction with ultraviolet light. The resulting free Cl atoms decompose ozone into oxygen, and regenerated Cl atoms go on to degrade more ozone molecules. This reaction continues for the atmospheric lifetime of the Cl atom, which ranges from one to two years. On average, a single Cl atom destroys 100,000 ozone molecules. Thus, the lack of Cl in HFCs makes them a desirable alternative.

Some studies indicate that excessive exposure to HFCs may affect the brain and heart. However, this has only been established for concentrations higher than those found in the atmosphere.

Rena Christina Tabata

See also: Aerosols; Air conditioning and air-cooling technology; Chemical industry; Chlorofluorocarbons and related compounds; Kyoto Protocol; Ozone.

Hydrogen power

• **Category:** Energy

• **Definition**

Molecular hydrogen (H_2) is an ideal fuel to be used for transportation, since the energy content of hydrogen is three times greater than that of gasoline and four times greater than that of ethanol. Hydrogen power powered rockets launched by the National Aeronautics and Space Administration (NASA) for many years. Today, a growing number of automobile manufactures around the world are making hydrogen-powered vehicles. Because of depleting supplies and growing demand for oil, H_2 may become an alternative to gasoline.

The idea of hydrogen as the fuel of the future was expressed long ago by Jules Verne in his novel *L'Île mystérieuse* (1874-1875; *The Mysterious Island*, 1875). However, compared to oil, H_2 is not abundant on Earth. Its atmospheric concentration is only 0.00001 percent, and there is even less of it in the oceans. Though many microorganisms pro-

A hydrogen-powered car sits in front of a fueling station at New York's JFK International Airport on the station's first day of operation, July 14, 2009. (Shannon Stapleton/Reuters/Landov)

duce H_2 during fermentation, it is such a good source of energy that it is used almost immediately by other microbes. Thus, in order for humans to use hydrogen as fuel, it must be generated using other energy sources.

While molecular hydrogen is rare, the chemical element hydrogen is the most basic and plentiful element in the universe. It also forms a part of the most abundant chemical compound on Earth, water. Therefore, the challenge posed is to find a cost-effective and environmentally friendly way to generate H_2 from water or other chemical compounds. At present, H_2 is obtained mainly from natural gas (methane and propane) via steam reforming. Although this approach is practically attractive, it is not sustainable. Molecular hydrogen can be also produced by electrolysis. In this process, electric energy is employed to split water into H_2 and O_2. The requisite electricity can be obtained using clean, sustainable energy technologies such as wind and solar power. However, the process is not efficient, requiring significant expenditure of energy and purified water.

There are other technological and economic obstacles to hydrogen power. These obstacles include safety issues, as well as the lack of effective solutions for storage and distribution of H_2. Hydrogen has gained an unwarranted reputation as a highly dangerous substance among the general public. Like all fuels, H_2 may produce an explosion, but it has been used for years in industry and earned an excellent safety record when handled properly.

Hydrogen is the lightest chemical, so it has a much lower energy density by volume than do other fuels. As a gas, it requires three thousand times more space for storage than does gasoline. Thus, hydrogen storage, especially in cars, represents a challenge for scientists and engineers. For storage, H_2 is pressurized in cylinders or liquefied in cryotanks at −253° Celsius. Both processes require a significant expenditure of energy and generate large quantities of waste carbon dioxide (CO_2). In most contemporary hydrogen-powered vehicles, H_2 is stored as compressed gas. Because compressed gas cannot be delivered in the same fashion as liquid fuel, gasoline stations and pumps cannot simply be converted into hydrogen stations. Thus, the distribution system for the new fuel would have to be constructed from scatch, requiring considerable monetary investment.

- **Significance for Climate Change**

Fossil fuels generate CO_2, contributing to the greenhouse effect. Switching from fossil fuels to H_2 would eliminate that source of greenhouse gas (GHG) emissions, provided that the new fuel could be produced without carbon-emitting technologies. Burning H_2 for an energy source produces only water as a by-product, and H_2 is also a renewable fuel, since it can be made from water again. Unfortunately, current methods of H_2 production from natural gas also generate CO_2. The ultimate goal is to generate H_2 without emitting GHGs into the atmosphere, perhaps by using wind or solar power.

One promising green method of H_2 production is a biological approach: A great number of microorganisms produce H_2 from inorganic materials, such as water, or from organic materials, such as sugar, in reactions catalyzed by the enzymes hydrogenase and nitrogenase. Hydrogen produced by microorganisms is called biohydrogen. The most attractive biohydrogen for industrial applications is that produced by photosynthetic microbes. These microorganisms, such as microscopic algae, cyanobacteria, and photosynthetic bacteria, use sunlight as an energy source and water to generate hydrogen. Hydrogen production by photosynthetic microbes holds the promise of generating a renewable hydrogen fuel using the plentiful resources of solar light and water.

It is possible to use hydrogen to fuel internal combustion engines. Doing so produces at least one GHG, nitrogen oxide, because the burning of hydrogen requires air, which is almost 80 percent nitrogen (N_2). To use hydrogen power in climate-friendly ways, it will be necessary to replace the internal combustion engine with fuel cells, which would produce electricity to power vehicles without motors. Fuel cells are like batteries: They generate electricity via chemical reactions between H_2 and O_2. Fuel cells emit water and heat, not CO_2 or other GHGs. In addition, fuel cells are 2.5 to 3 times more efficient in converting H_2 energy than are internal combustion engines. Hydrogen fuel-cell cars could even provide power for homes and offices if necessary.

For hydrogen power to become a reality, tremendous research and investment efforts are necessary. The fate of hydrogen power technology will also depend on consumers' willingness to spend money on climate-friendly technologies.

Sergei Arlenovich Markov

- **Further Reading**

Ogden, Joan. "High Hopes for Hydrogen." *Scientific American*, September, 2006, 94-99. Describes hydrogen cars, fuel cells, and a hydrogen economy.

Service, Robert F. "The Hydrogen Backlash." *Science* 305, no. 5686 (August 13, 2004): 958-961. Provides a good discussion of a future hydrogen economy and the maturity of hydrogen power.

Zaborsky, Oskar R., ed. *Biohydrogen.* New York: Plenum Press, 1998. Collection of articles on biological hydrogen production by bacteria and algae.

See also: Biofuels; Clean energy; Energy efficiency; Energy resources; Ethanol; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Hubbert's peak; Oil industry; Renewable energy; Solar energy; Wind power.

Hydrologic cycle

- **Category:** Environmentalism, conservation, and ecosystems

- **Definition**

The hydrologic cycle comprises the movement of water on Earth: It evaporates from the oceans, precipitates back to the surface, flows in the form of runoff to bodies of water, and infiltrates and is stored underground. A warming climate affects this cycle and therefore all life on the planet.

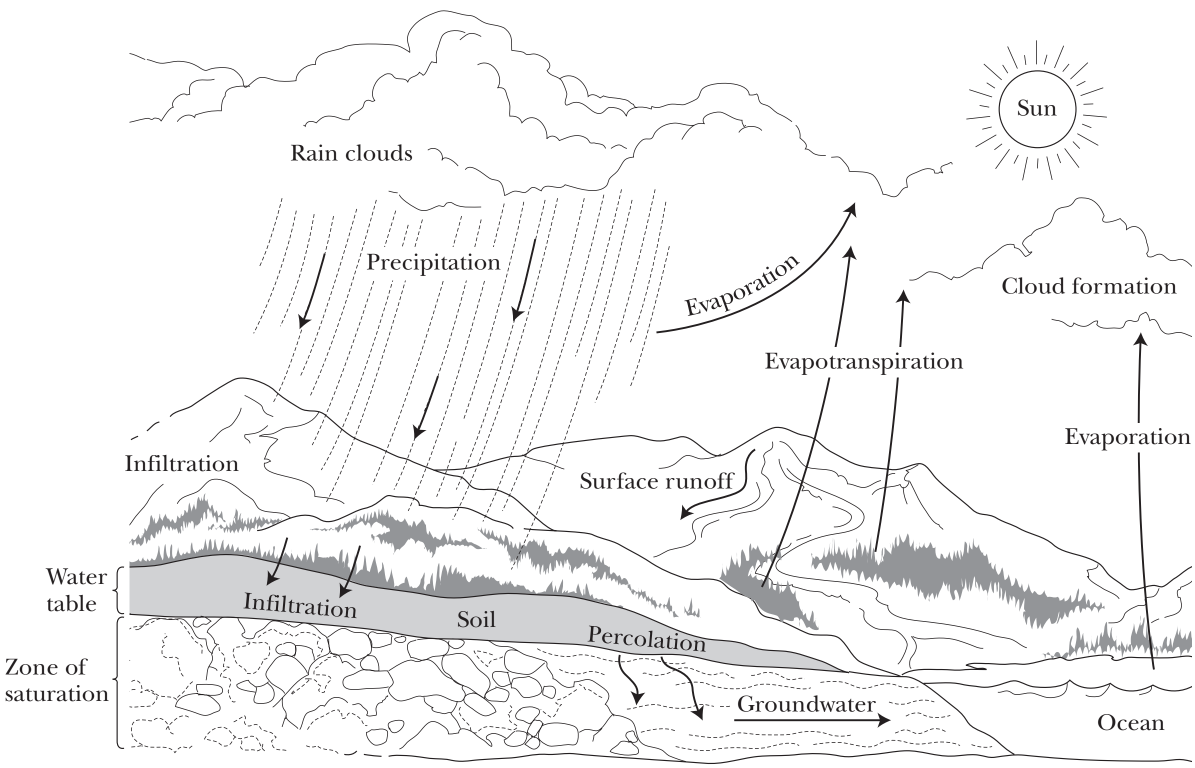
Steady warming increases the atmosphere's moisture-holding capacity, altering the hydrologic cycle and the characteristics of precipitation, most notably intensity. Changes in the global rate and distribution of precipitation may have a greater direct effect on human well-being and ecosystem dynamics than do changes in temperature. While temperature increases in a linear fashion, scientific research indicates that the hydrologic cycle may change exponentially, according to David Easterling of the U.S. National Climatic Data Center.

Atmospheric moisture increases rapidly as temperatures rise; over the United States and Europe, atmospheric moisture increased by 10 to 20 percent from 1980 to 2000. Studies of tree rings have provided a reconstruction of precipitation variability in the high mountains of northern Pakistan going back one thousand years that indicates a large-scale intensification of the hydrologic cycle coincided with the onset of industrialization and global warming. The unprecedented amplitude of this change strongly suggests a human role. This study suggests that an unprecedented intensification of the hydrologic cycle in western Central Asia occurred during the twentieth century.

• Significance for Climate Change

Theory as well as an increasing number of daily weather reports strongly indicates that changes in precipitation patterns may vary widely across time and space. Such changes will be highly uneven, episodic, and sometimes damaging. Both droughts and deluges are likely to become more severe. They may even alternate in some regions. By 2007, the hydrologic cycle seemed to be changing more rapidly than temperatures. With sustained warming, usually wet places often seemed to be receiving more rain than before; dry places often were experiencing less rain and becoming subject to more persistent droughts. Some drought-stricken regions occasionally were doused with brief deluges that washed away cracking earth.

The Hydrologic Cycle



In many places, the daily weather increasingly was becoming a question of drought or deluge. Paradoxically, the intensification of the hydrologic cycle due to a warming climate may provoke both drought and deluge—sometimes alternately in the same location. The behavior of this cycle also figures into a lively debate regarding whether a generally warming climate may cause hurricanes to intensify, as well as the impact of climate change on the worldwide spread of deserts, which may contribute to the number of "environmental refugees," and on disaster relief generally.

By 2000, the hydrologic cycle seemed to be changing more quickly than temperatures. In 2005, for example, India's annual monsoon brought a 94-centimeter rainfall in 24 hours to Mumbai (Bombay). India is accustomed to a drought-and-deluge cycle because of its annual monsoon, but the rains have become more intense, as well as more variable. Excessive rain has deluged parts of Europe and Asia, swamping cities and villages and killing many people, while drought and heat have scorched other areas. Unprecedented precipitation events have occurred recently in the Arctic, where temperatures have risen rapidly. Winter rains with thunder and lightning have been experienced on Southern Baffin Island, the Alaskan North Slope, and southwestern Greenland. Climate-change skeptics argued that weather is always variable, but other observers noted that extremes seemed to be more frequent than before.

Violent weather has been hitting unusual areas with increasing frequency. Major tornadoes, for example, have been sighted in Michigan and Japan. At least nine people were killed, at least twenty injured, and others trapped under rubble when a tornado hit northern Japan on November 6, 2006, in a location where such storms had been all but unknown. The tornado demolished two prefabricated buildings at a construction site, about eight private houses, and a factory, according to an official at the fire department in Engaru, on the northeastern part of Japan's northern island of Hokkaido. Fire engines and ambulances were at the site, where crushed cars could be seen along with lumber and other scattered debris. Several houses were reduced to rubble.

Bruce E. Johansen

- **Further Reading**

Barnett, Tim P., et al. "Human-Induced Changes in the Hydrology of the Western United States." *Science* 319 (February 22, 2008): 1080-1083. Discusses human influences on the hydrologic cycle.

Barringer, Felicity. "Precipitation Across U.S. Intensifies Over Fifty Years." *The New York Times*, December 5, 2007. A description of studies indicating that precipitation intensity is increasing across the continental United States.

Del Genio, Anthony D., Mao-Sung Yao, and Jeffrey Jonas. "Will Moist Convection Be Stronger in a Warmer Climate?" *Geophysical Research Letters* 34, no. 16 (August 17, 2007). Describes the theoretical basis of changes in the hydrologic cycle in a warmer climate.

Trenberth, Kevin E., Aiguo Dai, Roy M. Rassmussen, and David B. Parsons. "The Changing Character of Precipitation." *Bulletin of the American Meteorological Society*, September, 2003, 1205-1217. Scientifically solid treatment of how warming conditions influence intensity of rain and snowfall.

See also: Aral Sea desiccation; Desertification; Deserts; Ekman transport and pumping; Freshwater; Groundwater; Hydrosphere; Ocean-atmosphere coupling; Saltwater intrusion; Sea surface temperatures; Water resources, global; Water vapor.

Hydrosphere

- **Categories:** Water resources; oceanography; cryology and glaciology

The hydrosphere, the collective designation of all water on Earth, significantly affects Earth's greenhouse effect and global temperatures generally. Atmospheric water vapor is the major GHG, and the oceans are major storage sites for water, heat, and CO_2.

- **Key concepts**

cryosphere: water on the Earth's surface in solid form, especially as snow, glaciers, ice caps, and ice sheets

evaporation: the transformation of liquid water into water vapor
hydrologic cycle: water's movement among the spheres of the climate system
thermal expansion: the increase in water volume as its temperature increases and density decreases
water vapor: water in the gaseous state

• Background

The range of Earth's surface temperatures and atmospheric pressures permits water to occur naturally as a solid, liquid, and vapor. Water is present in all Earth's climate subsystems. In broadest terms, the hydrosphere includes liquid water at the Earth's surface, water in the atmosphere in all its forms, and water in the cryosphere stored as ice. It extends several kilometers below Earth's surface and reaches 12 kilometers into the atmosphere.

• Distribution of Water

The hydrosphere contains an estimated 1.36 billion cubic kilometers of water, and liquid water covers about 71 percent of the Earth's surface. Most of the world's water is contained in the oceans as salt water; only 2.5 percent is freshwater. Ice sheets and glaciers concentrated on about 10 percent of the Earth's land area, mainly in Antarctica and Greenland, constitute less than 2 percent of all water, but they account for 69 percent of freshwater. Groundwater and soil water constitute the subsurface water storage, which is important as a water supply for humans in arid regions and as a moisture source for plants. Groundwater and soil water together account for 0.5 percent of all water, but 30 percent of freshwater. Rivers, lakes, and streams contain 0.02 percent of all water and 0.3 percent of freshwater. Water vapor and cloud droplets in the atmosphere account for 0.0001 percent of all water and 0.04 percent of freshwater, but water vapor and cloud droplets contribute between 66 and 85 percent of the greenhouse effect, which traps heat in the atmosphere, preventing it from escaping into space.

• Formation of the Hydrosphere

The hydrosphere's formation required a series of steps occurring over millions of years to reach the sequence of energy and moisture transfers currently linking the hydrosphere and Earth's climate. Water from outgassing by volcanic eruptions and possibly from incoming comets collected in the early atmosphere as water vapor along with other gases. Eventual cooling of the Earth's surface and the atmosphere caused the water vapor to condense into droplets and fall as rain to the Earth's surface. The rain collected in topographic depressions in the Earth's crust and formed rivers, lakes, and oceans. Some water drained vertically through the rocks and collected in large underground reservoirs, and some water was held by the soil that developed as rocks disintegrated.

The Earth's original hydrosphere probably was freshwater exclusively, with the hydrologic cycle as the centerpiece. Water cycling was sustained by evaporation mainly from the oceans that returned water vapor to the atmosphere to fall as rain. Dissolved gases fell with the rain from the early atmosphere, and the oceans absorbed large amounts of atmospheric carbon dioxide (CO_2). The transition to today's salt-dominated oceans spanned hundreds of millions of years and involved crustal differentiation, life processes, and a series of mineral equilibriums. Rain on the land dissolved minerals from rocks; rivers and streams carried the minerals to the oceans; chlorine leached from the oceanic crust accumulated in seawater; and dissolved carbonates were gradually removed. During periods of global cooling, snow accumulated on the continents, forming glaciers and ice sheets, and sea levels were lowered.

• Effects of a Warmer Climate

Evidence of warmer temperatures exists in all the hydrosphere's components, but it is most apparent in the oceans. Oceans store more than 90 percent of the heat in the Earth's climate system, and they buffer the effects of climate change. Sea surface temperatures since 1860 show essentially the same trends as land temperatures, and ocean temperature changes contribute about one-half Earth's net temperature gain. Ocean circulation transfers energy from warm tropical regions toward the poles and brings colder water back to the tropics. Ocean circulation is accomplished by powerful, wind-driven surface currents coupled with deep-ocean currents responding to density differences produced by temperature and salinity variations. British oceanographers have reported that circulation in a section of the Atlantic Ocean has slowed 30 percent in the past five decades, which raises concern that the global transfer of energy by the oceans may be weakening.

Warmer oceans produce thermal expansion, which is a major contributor to rising sea levels of 15-20 centimeters over the last century. Observed twentieth century melting of glaciers and ice sheets contributed to sea-level rise, but the volume of melting accounts for about 20 percent of the observed increase. An observed 10 percent per decade decrease in Arctic sea ice probably contributes more to radiation balance changes and warming the air and water than to sea-level rise.

Oceans are the source for 85 percent of the water vapor transferred into the atmosphere, and warmer temperatures increase evaporation. Increased atmospheric water vapor supports greater precipitation, an intensification of the greenhouse effect, increased cloud cover, and increased global albedo. Changes in the timing, amount, and location of precipitation and runoff are occurring as global temperatures increase, and these changes alter water availability and quality and the duration and intensity of floods and drought.

CO_2 in the oceans increases as atmospheric CO_2 increases, but warm oceans are a less efficient absorber of CO_2. About half of the known CO_2 produced by fossil fuel consumption over the past fifty years has been absorbed by the oceans.

• Context

Water is essential for humans and for natural ecosystems, but the relatively small proportion of Earth's total water represented by freshwater is unevenly distributed globally. Approximately one-third of the world's population lives in regions where the freshwater supply is less than the recommended per capita minimum, and 70 percent of all freshwater withdrawals are used for crop irrigation. The freshwater resource relies on precipitation delivered by the hydrologic cycle. Precipitation is sustained through the conversion of ocean water into freshwater by a complex system responding to global-scale climatic influences. Hydrological processes, related energy exchanges, and interactions of these exchanges with clouds and the radiation balance are highly variable at the regional scale where the global warming impact on the freshwater resource is greatest. Quantifying regional temperature and precipitation patterns and the effects of altered evaporation, transpiration, soil moisture storage, and runoff on the freshwater supply is a great challenge facing scientists as they strive to understand global warming at the regional scale.

Marlyn L. Shelton

• Further Reading

Barnett, Tim P., David W. Peirce, and Reiner Schnur. "Detection of Anthropogenic Climate Change in the World's Oceans." *Science* 292, no. 5515 (April 13, 2001): 270-274. Observed ocean heat content and estimates from a global climate model are analyzed for evidence of global temperature change in deep ocean water. Both data sets indicate increases in heat content in the major ocean basins, but vertical temperature changes are markedly different.

Bigg, Grant R. *The Oceans and Climate*. New York: Cambridge University Press, 1996. Emphasizes the complex links between the atmosphere and oceans in driving climate and climate change, as well as interactions with other planetary spheres. By a highly regarded researcher in marine climate change. Illustrations, tables, glossary, bibliography, index.

Ernst, W. G., ed. *Earth Systems: Processes and Issues*. New York: Cambridge University Press, 2000. Integrated overview of Earth systems, from a process-oriented perspective, written by twenty-eight international scientists. The hydrosphere section contains four chapters focused on the hydrologic cycle and the oceans. Illustrations, tables, glossary, index.

See also: Evapotranspiration; Freshwater; Glaciers; Groundwater; Hydrologic cycle; Ice shelves; Ocean-atmosphere coupling; Water resources, global; Water resources, North American; Water vapor.

Ice cores

• **Category:** Cryology and glaciology

Ice cores contain evidence of an orderly sequence of changes that occurred in the Earth's atmosphere, including changes in temperature and trace gases. They therefore provide a history of the Earth's climates.

• Key concepts

Dome C: the Antarctic Plateau location of the Concordia Research Station
glacial ice: ice created by the compression of snow into glaciers
paleoclimatology: the study of past climates
Vostok: a Russian Antarctic research station built in 1957 during the First Geophysical Year

• Background

An ice core is a cylinder of ice measuring 10 centimeters in diameter and obtained by drilling vertically into a glacier. Glacial ice is produced by the natural, gradual transformation of snow into ice. Snow is made of fragile ice crystals surrounded by air. In the process that transforms snow into ice, this air is trapped in tiny bubbles that are identical in composition to the atmosphere that produced the snowfall. As snow falls year after year and is compacted into ice, each layer can be identified visually or electronically. In this way, glaciers preserve a record of atmospheric changes that have occurred over time, and ice cores can be drilled to retrieve that record.

• Variation in the Atmosphere's Composition

Because they contain a chronologically ordered record of atmospheric composition, ice cores can be used to reconstruct the history of both natural and anthropogenic pollution. The chemical composition of Earth's atmosphere varies over time. It reacts to volcanic eruptions, for instance, which add carbon monoxide, carbon dioxide (CO_2), and sulfur dioxide to its normal content of nitrogen, oxygen, argon, CO_2, and methane. Thus, changes in the chemical composition of the air trapped in ice cores make it possible to date past volcanic eruptions.

In the same way, some human activities can be identified and dated. Analysis of ice cores from the Alps and Greenland has identified the pollution resulting from the smelting of lead ore by the Romans more than two thousand years ago. More recently, traces of chemicals linked to nuclear explosions or to the Chernobyl nuclear reactor meltdown have been detected in glacial ice. Today, at a time when issues of climate change and pollution are uppermost in the minds of many, glaciologists have sought to retrieve the longest possible ice cores in order to produce a substantial historical record to contextualize current atmospheric trends.

• The Longest Ice Cores

The first giant ice core was drilled in Vostok, the Russian base in Antarctica. The region of Antarctica in which Vostok is located is extremely cold and dry. The advantage of low precipitation in glaciology is that, because each year produces less ice, a large number of years is recorded relative to core length. The disadvantage of such low precipitation is that, because each annual layer of ice is extremely thin, it can be very difficult to produce an accurate count. When all analyses were complete, Vostok glaciologists concluded that the 3,623-meter core drilled in 1996 represented the last 420,000 years of the Earth's history.

The normal analysis of an ice core consists of analyzing the content of the ice for the presence of deuterium (an isotope of hydrogen) and the presence of oxygen 18 (O^{18}; an isotope of oxygen), because both are reliable indicators of the Earth's temperature at the time of the snowfall. The temperature records obtained thanks to the Vostok ice core compare well with cores obtained in the center of Greenland. Since the Greenland ice sheet is smaller and thinner (1,600 meters deep on average) than the Antarctic ice sheet (2,400 meters deep on average), the paleoclimatic record derivable from Greenland ice cores is shorter. However, that record is consistent with the Vostok ice core record. Greenland also receives more precipitation than does Vostok, resulting in thicker annual layers of ice; a layer as old as 100,000 years can still be as much as 1 centimeter thick. Greenland ice cores therefore are outstanding at establishing a chronol-

Cryologist Hideaki Motoyama displays a million-year-old ice core drilled from 3 kilometers underneath Antarctica. (AP/Wide World Photos)

ogy for the last glacial period for which the estimated error does not exceed 2 percent for the first forty thousand years.

In an effort to increase the length of the paleoclimatic record, scientists from Europe have drilled in two other regions of the East Antarctic Ice Sheet under the European Project for Ice Coring in Antarctic (EPICA). A site on Dome C located at 75°06′ south latitude and longitude 123°21′ east was selected. There, where the ice sheet is thicker while both the ice and the air remain extremely cold, a permanent research base, Concordia, was built by France and Italy (partly financed by the European Union). Dome C is ideal for the thickness of its ice and its low precipitation; it initially provided a 3,140-meter ice core, revealing 740,000 years of climatic history. Since then, even deeper ice has been retrieved, extending knowledge of climatic history to over 800,000 years.

- **Testing Theories of Climate Change**

In order to analyze the ice core samples that have been retrieved, scientists crush the ice in a vacuum, releasing the air trapped within the sample without allowing it to mix with the modern atmosphere. They can then analyze these air samples, compute the proportion of greenhouse gases (GHGs) such as CO_2 and methane in the air, and compare their proportions to the temperature record derived from the deuterium and O^{18} analyses. The goal is to see if an increase of GHGs in ice always leads to an increase in the Earth's temperature or, conversely, if an increase in the Earth's temperature releases CO_2 and methane into the atmosphere.

- **Context**

Scientists continue to search for deeper deposits of ice from which even longer historical sequences can be identified. The Dome C site holds the promise of ice cores that will extend the scientific record to more than one million years into the past. Meanwhile, research also continues on ways to recover more, and more precise, information from ice cores. Analysis of core samples containing volcanic dust taken at Dome C, for instance, has demonstrated that the magnetic polarity of the Earth reversed about 780,000 years ago. As ice cores get longer and scientists find ways to learn more from them, the historical record will become more detailed over longer periods of time.

Denyse Lemaire and David Kasserman

• Further Reading

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future.* Princeton, N.J.: Princeton University Press, 2000. Provides ice coring research information and discusses the work of geoscientists in relation to the cryosphere. The text is concise and clear, with superb artwork and photographs.

Trewby, Mary. *Antarctica: An Encyclopedia from Abbott Ice Shelf to Zooplankton.* Toronto: Firefly Books, 2002. General encyclopedia of Antarctica. Explains all the features found on the continent using a clear and simple language.

Turney, Chris. *Ice, Mud, and Blood: Lessons from Climates Past.* New York: Macmillan, 2008. Describes the discoveries derived from ice cores and how these discoveries led to a better understanding of paleoclimates.

See also: Climate reconstruction; Dating methods; Glaciers; Greenland ice cap; Oxygen isotopes; Paleoclimates and paleoclimate change.

Ice-out studies

• **Categories:** Arctic and Antarctic; cryology and glaciology

• Definition

Across the northern United States, a popular tradition for many decades has been guessing the date of ice breakup ("ice-out") on local lakes. Not only is it a local news story and harbinger of spring, but ice-out has numerous practical ramifications as well. It marks the end of winter activities on the lake, such as ice fishing and travel across the ice, and the beginning of summer activities, such as open-water fishing.

In earlier days, ice-out was important for commercial activities such as log drives and steamship navigation. As a result, for many lakes ice-out data are available since the middle of the nineteenth century. Moosehead Lake, the largest lake in Maine, has continuous data since 1848; Sebago Lake in southern Maine has sporadic data since 1807. Areas outside New England also maintain ice-out statistics. Minnesota has at least four lakes with more than 100 years of data, and the longest record is 139 years. Lakes Mendota and Monona, which flank the city of Madison, Wisconsin, have records extending back more than 150 years.

Ice-out dates are quite variable from year to year and depend on air temperature, the flux of meltwater into the lake, and the discharge of the outlet stream. For example, the earliest and latest ice-out dates for Moosehead Lake differ by forty-five days. Nevertheless, scientists from the U.S. Geological Survey analyzed ice-out dates for New England lakes and found that the average date of ice-out was nine days earlier in 2000 than it was in 1850. Generally, ice-out data are tabulated in terms of day of the year (the Julian date) rather than the calendar date. For example, February 20 is Julian day 51. The data indicate generally steady ice-out dates until 1900, decreasing (earlier) dates until roughly 1950, a slight increase in ice-out dates until about 1970, and decreasing dates thereafter. Despite the wide variability from year to year, the overall pattern is consistent across numerous lakes.

• Significance for Climate Change

There are many complexities in the use of ice-out data, largely due to variations in what defined "ice-out." Sometimes a marker placed on the ice has been used to signal ice breakup. In some places the marker was even a junked car (an environmentally dubious practice). In other places the criterion has been the ability to cross the lake by boat without being blocked by ice. Still other places have used visual estimates of ice cover. Such estimates can be quite subjective. It may take several days for ice to clear out, and ice may persist in restricted coves long after most of a lake is ice-free.

Unfortunately, it is not always clear what criterion was used for many early records. Also, ice-out data are extremely "noisy"—that is, the range in the data is much larger than the long-term change in average date. For example, for Maine's Moosehead Lake, the best-fit trend line for the ice-out data shows a nine-day decrease in ice-out day between 1849 and 2005, but the variation between earliest and latest ice-out is forty-five days. Even from year to year, the variations can be quite large: In 2001 ice-out occurred on day 124, dropping to day 110 in 2002 and increasing to day 127 in 2003.

Ice-out data for any individual lake are usually so variable that there is a significant possibility that the data, just by chance, happen to show a decrease over time. For example, if one flips a coin and keeps score of the difference between heads and tails, even though the flips are completely random there may be long runs where the difference increases or decreases steadily. However, when data from many lakes, especially those separated by large distances, show the same pattern, the statistical significance of the data becomes far greater.

Taking all these considerations into account, ice-out data for lakes across the northern United States show a broad trend of earlier ice breakup. Climate change skeptics have not paid much attention to ice-out data. Their most common approach has been to use anecdotal data—that is, point to unusually late ice-out on some particular lake, rather than examine long-term trends.

Steven I. Dutch

• Further Reading

Hodgkins, Glenn A., and Ivan C. James. "Historical Ice-Out Dates for Twenty-nine Lakes in New England." U.S. Geological Survey Open-File Report 02-34. Denver, Colo.: U.S. Geological Survey, 2002. Listings of ice-out dates for all years with data and discussion of methods and interpretation. The data listings enable users to perform their own analyses of the data.

Hodgkins, Glenn A., Ivan C. James, and T. G. Huntington. "Historical Changes in Lake Ice-Out Dates as Indicators of Climate Change in New England, 1850-2000." U.S. Geological Survey Fact Sheet FS 2005-3002. Available online at http://pubs.usgs.gov/fs/2005/3002/. A summary of ice-out trends in New England lakes, with graphs of data trends but no data.

U.S. Geological Survey. "Lake Ice-Out Data for New England." 2007. Available online at http://me.water.usgs.gov/iceout.html. Contains links to other articles and an interactive map that links to data for each lake. The data are in simple columnar format, making it easy to copy and paste into a spreadsheet.

Wisconsin State Climatology Office. "Wisconsin Lake Ice Climatologies: Duration of Lake Ice." 2004. Available online at http://www.aos.wisc.edu/~sco/lakes/WI-lake_ice-1.html. Links to data for twenty-seven Wisconsin lakes. The links show duration of ice cover rather than specific dates of freezing and breakup. Lakes Mendota and Monona, with more than 150 years of data, show clearly decreasing trends, as do numerous other lakes.

See also: Arctic; Cryosphere; Deglaciation; Glaciations; Glaciers; Greenland ice cap; Ground ice; Hydrosphere; Ice cores; Last Glacial Maximum; Little Ice Age; Mass balance; Permafrost; Polar climate; Sea ice.

Ice shelves

• **Category:** Cryology and glaciology

The debate over global warming has prompted a renewed interest in the study of ice shelves, particularly after the collapse of the Larsen A and Larsen B shelves in 1995 and 2002, respectively. These collapses have been seen not only as products of global warming but also as part of a process by which the movement of Antarctic ice toward the ocean has been accelerated.

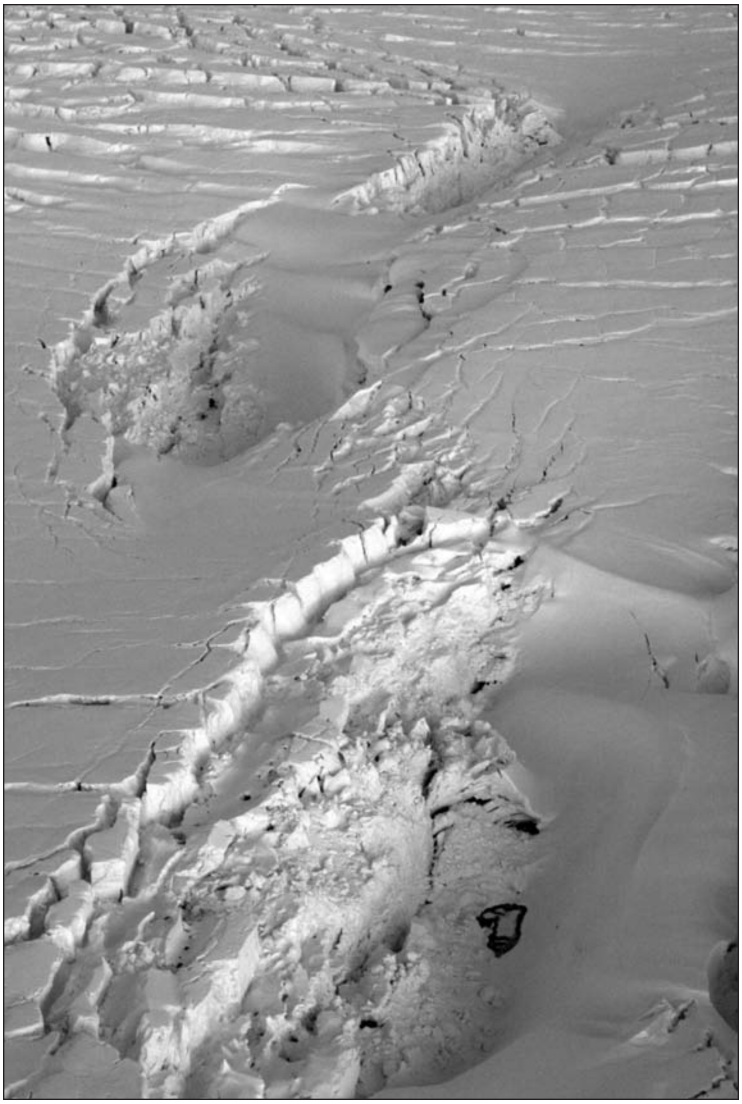
• Key concepts

glacier: a mass of ice that flows downhill, usually within the confines of a former stream valley

ice sheets: masses of ice covering large areas of land
ice shelf: a platform of freshwater ice floating over the ocean
West Antarctic ice sheet: the smallest ice sheet in Antarctica, located west of the Transantarctic Mountains

• Background

Ice shelves are the seaward extensions of continental ice sheets. They are found extending from 50 percent of the coast of Antarctica and account for 11 percent of the mass of ice of the Antarctic Ice Sheets. The two largest ice shelves—Ross (472,960 square kilometers) and Ronne-Filchner (422,420 square kilometers)—together represent 67 percent of the total area of Antarctic ice shelves. Ice shelves are typically thinner at their seaward edge; the largest shelves reach a depth of 1,300 meters near the grounding line (the location where the ice begins to float), but thin to 200 meters at the leading edge.



A gigantic iceberg separates from the ice shelf on the Knox Coast of Australia's Antarctic territory in January, 2008. (Reuters/Landov)

• Formation of Ice Shelves

Ice shelves gain mass in three different ways. The primary source is the ice sheet that moves off the land surface onto the water, but accumulated snow on their upper surface and the freezing of seawater to the lower one also contribute. On the other hand, ice shelves lose mass in five ways: by calving of icebergs, by the melting of ice in contact with the sea, by snow blowing off the edge of ice shelves, by enhanced sublimation of ice under the very strong Antarctic winds, and by superficial melting. Since surface melting in Antarctica is negligible, and since wind ablation is limited in general, nearly all mass loss is the result of either iceberg calving at the seaward margin or bottom melting of ice in contact with the sea.

• Ice Shelves of the West Antarctic Peninsula

With the widespread availability of video clips on the Internet, many people have observed the breaking of very large tabular icebergs off the Antarctic Peninsula. The calving of icebergs is a natural phenomenon that occurs regularly under normal climatic conditions. This calving should not be interpreted as a sure sign of global warming. In the extreme north of the Antarctic Peninsula, ice shelves are called Larsen A, B, C, and D, named in sequence from north to south. The

Larsen A ice shelf began to retreat at a very rapid pace in January, 1995. The breakup of Larsen A was irrefutably a response to the rise in ocean temperature. South of Larsen A, Larsen B calved large tabular icebergs beginning in 1995, prior to a larger disintegration that occurred in the first three months of 2002. More recently, in 2008, the Wilkins Ice Shelf that had broken up in 1998 partially disintegrated. The culprit seemed to be the presence of warm ocean waters melting ice shelves from beneath and destabilizing the ice shelf at the grounding line.

• Ice Shelves as Buttresses

Because ice shelves may be very thick, they are often anchored on the continental shelf, where they begin to float. The grounding of these ice shelves allows them to slow down the outward movement of ice sheets by acting as a buttress if they are thick enough. This effect is lost if the ice shelf disintegrates. In the case of the Larsen B Ice Shelf, its disintegration in 2002 led to an acceleration of the outward flow of ice from the glacier that feeds it.

• Context

Although there is no doubt that ice shelves in the West Antarctic Peninsula have decreased in size over the last three decades, their complete melting would not raise sea level by more than a few millimeters. Their destruction could, however, contribute significantly to rising sea level if the glaciers feeding these ice shelves were to speed up once the ice shelf stops being grounded. A 2004 study by researchers from the National Snow and Ice Data Center and NASA described accelerations of such glaciers reaching four to six times their normal speed.

Interestingly, the ice shelves of the southern part of the West Antarctic ice sheet and those of the East Antarctic ice sheet do not seem to be affected by global climate change. Their temperature remains below freezing, probably because they are surrounded by abundant sea ice that acts as a buffer, protecting them from the advection of warmer water.

Denyse Lemaire and David Kasserman

• Further Reading

Copeland, Sebastian. *The Global Warning*. San Rafael, Calif.: Earth Aware Editions, 2007. This abundantly illustrated book about Antarctica tends to focus on the potential calamitous effects of global climate change using a clear and simple language.

McGonigal, David. *Antarctica: Secrets of the Southern Continent*. Richmond Hill, Ont.: Firefly Books, 2008. Describes the discoveries of the International Polar Year, 2007-2008, in various fields, including geology, geography, and climatology. Discusses potential effects of global warming.

Trewby, Mary. *Antarctica: An Encyclopedia from Abbott Ice Shelf to Zooplankton*. Toronto: Firefly Books, 2002. General encyclopedia of Antarctica that explains all major features of the continent.

Turney, Chris. *Ice, Mud, and Blood: Lessons from Climates Past*. New York: Macmillan, 2008. Examines various discoveries derived from ice cores and how these discoveries led to a better understanding of paleoclimates.

See also: Antarctica: threats and responses; Glaciers; Greenland ice cap; Sea ice.

Inconvenient Truth, An

- **Category:** Popular culture and society
- **Dates:** Book published and film released 2006
- **Author:** Al Gore (1948-)
- **Director:** Davis Guggenheim (1963-)

An Inconvenient Truth *emphasizes the need to stop global warming in order to prevent the destruction of Earth's natural resources and the accompanying loss of biodiversity. A centerpiece of Al Gore's work on climate change, it was the primary factor behind Gore's receipt of the 2007 Nobel Peace Prize.*

• Key concepts

carbon dioxide (CO_2): a greenhouse gas produced by burning fossil fuels

climate change: a lasting, significant change in the average weather of a given area

fossil fuels: hydrocarbon deposits, such as petroleum or coal, that have been derived from the remains of ancient plants and animals and are useful sources of energy

global warming: a significant increase in the mean temperature of the Earth's air and water over time

greenhouse effect: the ability of certain gases in the atmosphere to trap heat emitted from the surface of the Earth, resulting in the insulation and warming of the planet

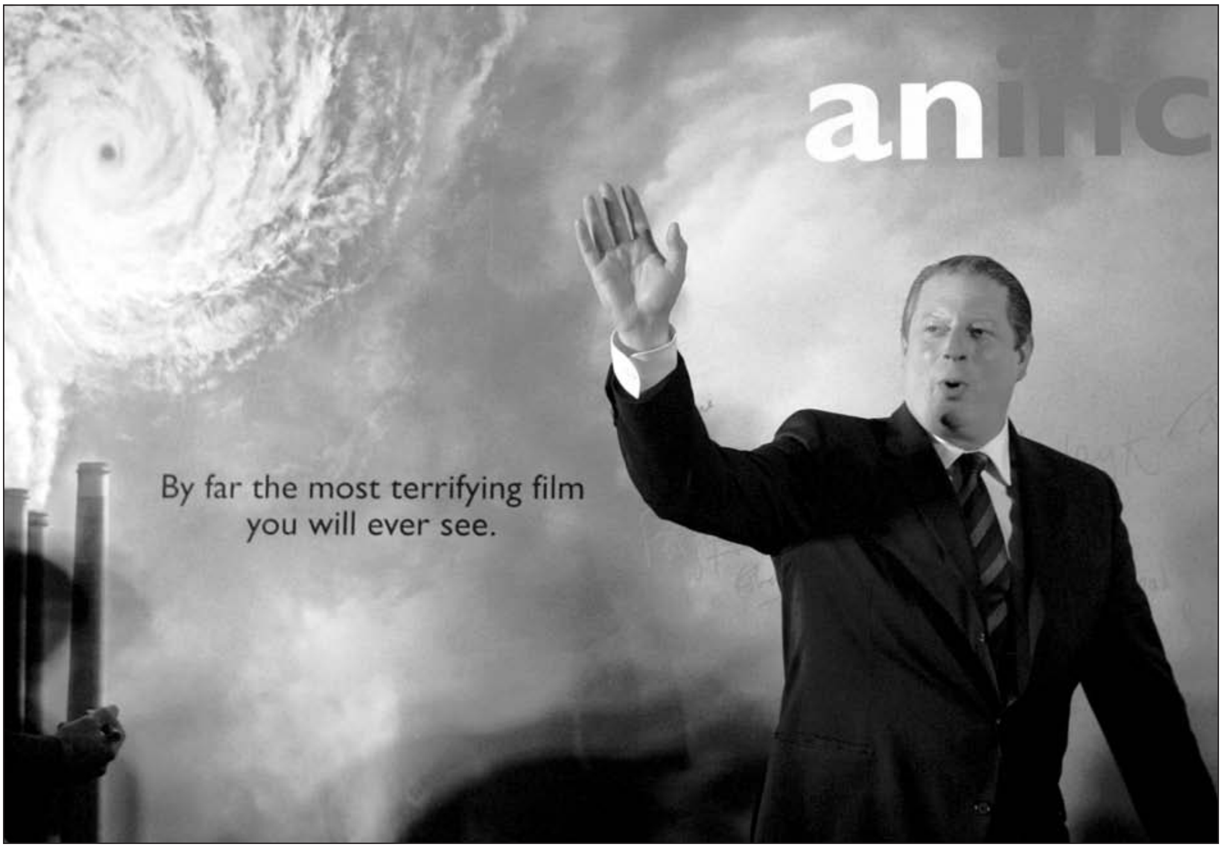
greenhouse gases (GHGs): gases present in the Earth's atmosphere that reduce the loss of heat into space, thereby contributing to global warming through the greenhouse effect

• Background

Throughout his time as vice president of the United States, and for many years before, Al Gore advocated for changes in environmental policies, especially as they related to the climate, most notably global warming. Over the years, he had prepared and worked to perfect a slide show dealing with the problem of global warming. This slide show, which he presented many times, became the basis for the movie *An Inconvenient Truth.*

• The Film

The one-hundred-minute documentary film made its debut on May 24, 2006, in New York and Los Angeles. Directed by Davis Guggenheim, the movie features Gore. In the slide show within the movie, Gore presents scientific evidence of Earth's changing climate and looks at the economic and political impact of global warming on the planet. Gore goes on to discuss likely consequences of global warming if society does not find a way to reduce the production of greenhouse gases (GHGs). Throughout the film, Gore makes an impassioned plea to society to take the steps necessary to halt global warming in



Al Gore arrives at the Hong Kong premiere of An Inconvenient Truth. (Paul Yeung/Reuters/Landov) order to stop a worldwide crisis. The film garnered the 2007 Academy Award for Best Documentary.

• The Book

Titled *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*, Gore's book was published by Rodale Press in conjunction with the release of the movie. The 328-page book highlights most of the scientific evidence concerning GHGs and global warming, and it issues the same plea for major environmental changes to avoid global crisis. In 2007, Gore and Rodale Press in conjunction with Viking Press published a version of the book aimed at adolescents and young adults, *An Inconvenient Truth: The Crisis of Global Warming*. Gore believed that the younger generation would have to be involved in bringing about the technological and policy changes necessary to halt devastating climate change.

• Origins of Gore's Interest in Climate Change

Gore's interest in global warming began when, as a student at Harvard University, he took a course dealing with climate change and the greenhouse effect. When he became a congressman, he introduced the first congressional hearings on global warming. When congressional response was slow, Gore responded by writing his first book dealing with environmental issues, *Earth in Balance* (1992), published the year he was elected vice president. As vice president, Gore encouraged passage of a tax designed to decrease the use of fossil fuels, which would thereby decrease carbon dioxide (CO_2) buildup and global warming. In 1997, he was also instrumental in the development of the Kyoto Protocol, an international treaty aimed at decreasing the emission of GHGs.

When he ran for president in 2000, Gore made saving the environment one of his platform issues, as he hoped to convince the Senate to ratify the Kyoto treaty. After losing the presidential election in 2000, Gore began to focus his attention fully on environmental concerns, revising his slide show and lecturing on global warming around the world. This slide show evolved into the basis for *An Inconvenient Truth*. For his work focused on the prevention of global warming, Al Gore was nominated for and received the Nobel Peace Prize in October of 2007.

• Context

According to the Nobel Prize committee, Al Gore is probably the one man who has done the most to create an understanding of global warming and its potential planetary impact. By promoting this understanding and advocating for the changes that need to be made to avoid further climate change, Gore is leading the march against planetary destruction. This battle against global warming is one Gore believes must be won if society is to continue.

When people are exposed to *An Inconvenient Truth* (either the movie or book), they are made aware of the problems of climate change and are urged to focus on means that can be used to prevent the greenhouse effect and global warming. Since the first showing of the movie, Gore has run hundreds of training sessions, in which he has taught thousands of people to be ambassadors to the planet for *An Inconvenient Truth*. These ambassadors, known as climate project presenters, have traveled the planet, giving abridged versions of Gore's slide show and answering any questions that arise from the audience. Thanks to Gore and those that have been trained by him, many more people are aware of the problems of global warming and are taking steps to prevent it.

Robin Kamienny Montvilo

• Further Reading

Gore, Al. *Earth in the Balance: Ecology and the Human Spirit*. Boston: Houghton Mifflin, 2000. In this book, the precursor to *An Inconvenient Truth*, Gore focuses attention on the environment and the danger of its imminent destruction unless humankind changes its behavior.

_______. *Our Purpose: The Nobel Peace Prize Lecture, 2007*. New York: Rodale, 2008. Gore's speech upon accepting the Nobel Prize, presenting his thoughts on the nature and obligations of humanity.

Maraniss, David, and Ellen Nakashima. *The Prince of Tennessee: Al Gore Meets His Fate*. New York: Simon & Schuster, 2001. Political biography of Gore, following his career and the place of environmentalism within it.

See also: Gore, Al; Greenhouse effect; Greenhouse gases.

India

- **Category:** Nations and peoples
- **Key facts**

Population: 1,148,000,000 (2008)
Area: 3,287,590 square kilometers
Gross domestic product (GDP): $3.267 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 1,000-1,300 in 2001
Kyoto Protocol status: Ratified August, 2002

• History and Political Context

Great Britain's colonial occupation of India destroyed and replaced the region's traditional, cottage-based textile, metal, and crafts industries with plantations and infrastructure to export raw materials and mined ores through a few ports to the factories of the British Empire. By the early 1900's, India had a desperately poor subsistence economy that was dependent on the monsoons and experienced frequent famines when crops failed. The world wars necessitated steel plants to be located in India to build railways and armaments to supply the war effort, and a few entrepreneurs such as the Tatas and Birlas won access to the capital needed to create heavy industry.

Upon independence in 1947, India boosted irrigation, agriculture, education, public transport, and heavy industry through a series of central five-year plans. Capital and technology came from the United Kingdom, United States, West Germany, and the Soviet Union. Public-sector plants produced steel, cement, fertilizers, chemicals, aluminum, titanium, railway equipment, heavy electricals and electronics, aircraft, ships, and refined oil. Democratic governments tried to invest scarce resources in education and to improve the desperately poor standard of living of the entire population, with the result that a socialist economy with top-tier tax rates as high as 90 percent and many restrictions on private enterprise evolved and stagnated. Free primary schooling was instituted in many states, and central institutes imparted essentially free, world-class scientific and technical education to students selected on merit.

The investments in education and broad-based opportunity paid off. By 1980, Indian agriculture had outpaced population growth and turned the famine nation into a net exporter of food. Even as the rupee plunged in the 1980's as a result of rising energy costs and the inability of government enterprises to compete in the world market, remittances from skilled expatriates in the Middle East oil economies and the West boosted the foreign exchange reserves and the demand for good housing and consumer goods. In 1991, as the nation was facing a debt crisis, the Indian economy was opened to free enterprise and began to advance rapidly.

Globe-trotting Indian software engineers and entrepreneurs led competitive knowledge-based and global service industries and drove explosive growth in information technology, communications, consumer goods, manufacturing, and construction. Investment in space research spawned a thriving remote sensing, educational, communications, and weather satellite system leap-frogging the terrestrial communications grid to the villages. Today there is growing industry and export in chemicals, food processing, steel, transportation equipment, cement, mining, petroleum, machinery, and software. Automobile manufacturing is expanding for the domestic and export markets. Indian-owned steel manufacturing is among the leaders in the world. Modernization is creeping into the hinterland, with rising land values, education, food prices, and expectations.

• Impact of Indian Policies on Climate Change

Energy shortage and Akshay Urja (inexhaustible energy). As of 2007, India had proven resources of 668 billion liters of oil and 1 trillion cubic meters of natural gas. National consumption was 98 billion liters of oil and 31 billion cubic meters of gas per year, mostly imports. Recoverable coal reserves were 92 billion metric tons, consumed at 434 million metric tons per year. Installed electric capacity in 2004 was 131 gigawatts, consumed at 588 billion kilowatt-hours per year. Total energy consumption was 16.3 quadrillion kilojoules. Coal accounted for 53 percent of energy consumption, oil accounted for 33 percent, natural gas 8 percent, and hydroelectricity 5 percent. Kerosene, a staple fuel for cooking and lighting of rural and lower-income homes, and diesel fuel for trucks were heavily subsidized. Over 56 percent of Indian homes and some 112,000 villages still lacked grid access to electric power.

India has a central ministry for renewable energy (RE). In 2008, the RE industry turnover was $500 million, with about $3 billion in investments. The government aimed to electrify eighteen thousand villages by 2012, with a 10 percent RE contribution. Micro-hydel plants of 2 to 25 megawatts exploit mountain streams and account for 2,500 megawatts, lighting many remote villages. By 2008, 3.94 million family-level biogas plants and over 2.15 million square meters of solar collectors had been installed, and 617,000 solar cookers were in use. Some 3,365 villages and 830 hamlets had been electrified using renewable off-grid sources. Renewable power installation totaled over 11 gigawatts. India had become fourth in the world in installed wind power capacity, with 7.8 gigawatts. Large solar thermal plants operate in Rajasthan. Wind farms of 500 kilowatt turbines, limited by Indian roads, were coming up in Tamil Nadu, Gujarat, and Karnataka and along the Western Ghat mountain range. Indian Railways cultivates the jatropha plant along its right-of-way to generate biodiesel.

Indian nuclear energy. Since 1955, India has developed a series of nuclear power plants. In 2007, nuclear power supplied 15.8 billion kilowatt-hours (2.5 percent of the total) from 3.7 gigawatt-hours of capacity. In 2008, with approval from the International Atomic Energy Agency (IAEA) and the Nuclear Supplier Group cartel, India signed civilian nuclear cooperation agreements with the United States, France, and Russia to embark on 40 gigawatt-hours of civilian nuclear power by 2030. This would form the core of clean baseload generation for advanced industry and critical services. The ultimate aim was a three-stage cycle to use vast indigenous reserves of thorium, before uranium was depleted.

CDM projects and GHG alleviation. The energy sector accounts for 61 percent of Indian greenhouse gas (GHG) emissions. As of 2008, India has 815 projects under the clean development mechanism (CDM), of which 536 deal with renewable energy. Other projects focus on sequestering carbon dioxide (CO_2) by creating green spaces in urban areas and replanting forests. Pollution-control laws in major cities such as New Delhi have converted

buses and taxis to compressed natural gas fuel. The competition to build a small, cheap automobile has excited public interest, opening the market for hybrid and electric cars suited to regenerating power from the frequent braking needed on Indian roads. Mandatory rainwater collection for most new construction is making a huge impact on urban water supply and helping alleviate the flood-drought cycle and soil erosion. Tube wells must be supplemented with replenishment tubes.

• India as a GHG Emitter

Home to more than 16 percent of the world's population, India accounts for only 4.9 percent of the world's GHG emissions. This places it in fifth place, behind the United States (22.2 percent), China and Taiwan (18.4 percent), the European Union (14.7 percent), and Russia (5.6 percent) and followed by Japan (4.6 percent) and Germany (3.1 percent). The average Indian's carbon footprint is 0.87 metric ton per year, compared to the average American's 18.1 metric tons, the average Australian's 25.5 metric tons, and the average Chinese's 2.5 metric tons. The Indian carbon footprint is growing rapidly and expected to reach the level of today's China by 2030.

Low carbon footprint but high air pollution. Southern and central India are in the tropical climate zone, and even in the northern plains winter home heating is rarely needed. Residential air conditioning is generally impractical because of power shortages in summer. Houses built to resist summer heat and monsoon rains have efficient throughflow ventilation. Windows are kept open.

Most Indians live in small villages. The cities are densely populated, with few zoning restrictions. Many people can walk or ride bicycles or scooters to work. Commuters use public transportation heavily. Long-distance travel is mostly by rail or bus. The Indian staple diet is organically grown, mostly in small farms, and consists of grain, vegetables, fish, and meat products marketed and consumed locally, minimizing energy use in processing, packaging, and transportation. Few homes have large appliances. Much Indian clothing is made from cotton, suited for the hot, humid climate, rather than from synthetic petroleum products. For these reasons, the personal and discretionary parts of the Indian carbon footprint are minimal.

The primary power resource in India is coal, powering much of Indian industry with thermal plants. With heavy industry near cities, GHG emissions and urban air pollution are severe. Much of the population uses open, wood-burning stoves or other biomass burners for cooking. Composting and outdoor burning generate GHGs, fumes, and particulates. Fleets of two- and three-wheelers powered by two-stroke engines and ancient diesel trucks that survive vehicle emission laws generate noxious fumes in gridlocked traffic on narrow, monsoon-damaged roads.

Scenarios for GHG emission growth. Moderate economic growth is likely to double GHG emissions by 2030. Assuming that the population reaches 1.3 billion, the Indian CO_2 footprint will reach 2.4 metric tons. Scenarios assuming sustainable technologies and clean coal burning reduce the growth rate of emissions by roughly 50 percent, leveling it off at a much lower footprint.

• Summary and Foresight

India has signed and ratified most of the United Nations treaties related to climate change, including the Kyoto Protocol, but understanding Indian progress requires a deeper perspective. This vast, densely populated nation has a common culture but a diverse population. The vibrant democracy holds regular, free elections and frequent, vociferous, and even violent protests. In every city, dozens of newspapers in English and Indian languages present diverse viewpoints, and hundreds if not thousands of political parties span the entire spectrum. The Internet has caught on rapidly. The transistor radio and newspaper are now supplemented by satellite television even in the villages, and Indians are connected to a worldwide diaspora through bicycle-delivered email, but also cell phones, text messaging, and voice-over-Internet.

In the 1980's, the Panchayati Raj law devolved many powers from the central government to elected village Panchayats (originally meaning an assembly of five or more wise people). Grassroots movements draw power partially from an ancient native respect for nature, partially from a fear of foreign enslavement, and partially from the class war ambitions of the communist parties. Skepticism about big corporations has evolved into critical examination of large-scale development and its effects on the environment. Intense and sophisticated opposition ostensibly based on concern for people displaced from fertile areas by dam reservoirs or large industrial plants has raised public awareness and interest in climate change and sustainable development issues all over India. This situation creates unique opportunities for game-changing developments.

Middle-class initiatives may revolutionize renewable power and sustainable development far beyond government targets, adapting advanced technology to Indian needs and preferences. Millions of Indian homes and businesses, forced by the abysmally unreliable power grid, already have grid-connected inverters, battery storage, voltage regulators, and auxiliary generators, and they are ready to incorporate renewable sources and perhaps a hydrogen economy. Highly efficient light emitting diodes are becoming popular for home lighting. Cell phones have rendered the landline telephone network obsolete, and beamed power may do the same to the power grid. Clean-burning liquefied petroleum gas (LPG) delivered in cylinders has become popular in Indian urban homes, but rising fossil fuel prices may replace these with biomass natural gas. Family-level solar thermal and biomass system installations are reaching critical mass numbers for explosive growth. With these, India has the potential rapidly to become a leader in sustainable development.

Padma Komerath

• Further Reading

Abdul Kalam, A. P. J., and Y. S. Rajan. *India, 2020: A Vision for the New Millennium.* New York: Penguin Books, 1998. Former president Dr. Abdul Kalam, an aerospace engineer, sets out his ambitious dream of India becoming a developed nation by 2020. A must-read for anyone who wants to understand Indian aspirations and plans.

Lala, R. M. *Beyond The Last Blue Mountain: A Life of J. R. D. Tata.* New York: Penguin Books, 1993. Through the biography of a leading industrialist, this book lays out the history of Indian technological development and heavy industry from the insider perspective of the largest industrial house in India.

Sharma, S., S. Bhattacharya, and A. Garg. "Greenhouse Gas Emissions from India: A Perspective." *Current Science* 90, no. 3 (February 10, 2006): 326-334. Deals with the methods and data used in estimating inventory of greenhouse gas emissions, and hence the results on growth rate of GHG emissions in India.

Shukla, P. R. "India's GFG Emission Scenarios: Aligning Development and Stabilization Paths." *Current Science* 90, no. 3 (February 10, 2006): 384-396. Gives different scenarios of economic growth and incorporation of sustainable technologies. The values used are very conservative, with carbon footprints well beyond those reported by U.S. or Indian sources in 2008.

Srinivasan, M. R. *From Fission to Fusion: The Story of India's Atomic Energy Programme.* New York: Penguin Books, 2002. A view of the development of the Indian nuclear energy program, from an insider who started with the program. Gives a detailed view of how such projects get done in India.

See also: Greenhouse gases; Kyoto mechanisms; Kyoto Protocol; Sustainable development.

Industrial ecology

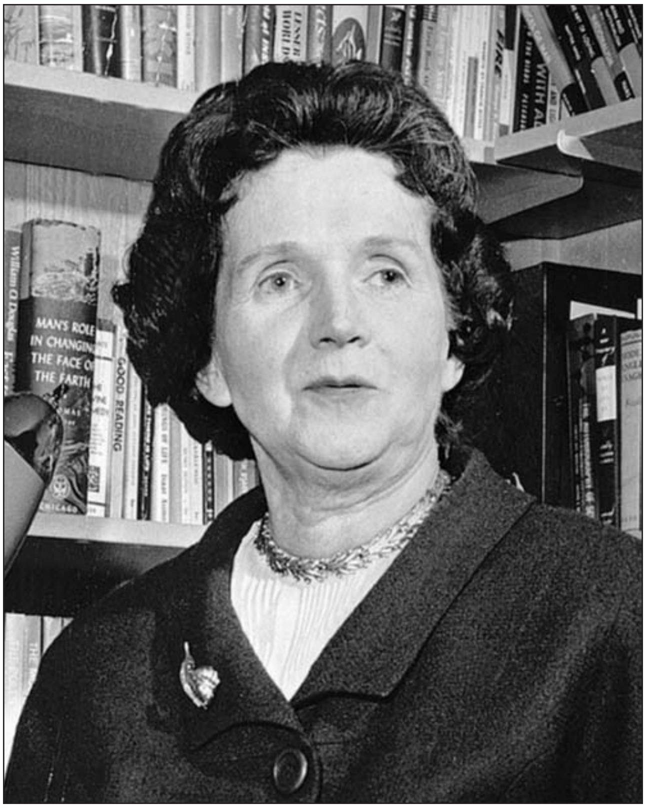
• **Categories:** Economics, industries, and products; environmentalism, conservation, and ecosystems

• Definition

Industrial ecology is the study of the flows of materials and energy in industrial and consumer activities and their impact on the environment. It includes the effects of economic, political, and social factors bearing on those flows and their environmental consequences. The discipline is an adaptation of the concept of a biological ecosystem, which has been at the core of environmental studies for many decades, applying the same analysis to the human-created world as had been applied to the biological world. It is also an adaptation of the idea of materials flow, which has been applied to geologic and industrial evaluations, applying the concept to industrial production and to the consumption of industrial products.

The roots of industrial ecology go back to the "tragedy of the commons," defined by Garrett Hardin in 1968 in an article of the same name. Hardin pointed out that while humans are very sensitive to the costs of generating income from producing goods that they personally own, they are largely insensitive to the costs of production that derive from assets owned in common. That same self-centered approach has been adapted to industrial production, particularly in the framework of a market-based economy (though the unraveling of the Soviet system in the late 1980's and the 1990's arguably showed that it also applied in systems of collective ownership).

The result of this self-centered approach has been that environmental assets have not enjoyed the kind of value recognition that has gone into private ownership. The reevaluation of those assets' value has been driven by those who maintain that failure to maintain and protect the environment has caused environmental assets to lose a great deal of value. This loss of value has been documented by individuals such as Rachel Carson, whose paradigm-changing work on the effects of DDT pointed out that environmental damage can harm humans



Rachel Carson, whose groundbreaking work on the effects of pesticides on humans transformed understandings of industrial ecology. (Library of Congress)

as well. Industrialists responding to such studies applied the methodology of systems analysis to industrial and ecological processes, producing "materials flow assessments." The techniques involved came to be called "life cycle assessment," or LCA.

In the 1990's, scientists began to observe what looked like systemic changes to the atmosphere and began looking for causes and defining the consequences through the absorption of carbon into the atmosphere. As a result, people began to realize that the human-created world might have a very important part to play in climate. The conclusions of the Intergovernmental Panel on Climate Change, that atmospheric changes were to a substantial extent caused by human activities, put a focus on evaluating those activities, especially those carried out by industry. Industrial ecology offered a method of analysis that, by tracing the flow of materials through the industrial system, could provide detailed information on the anthropogenic influences on global climate.

Because of the multiplicity of industries that convert various materials into saleable products, performing LCAs for the manufactured world involves several kinds of disciplinary expertise. Raw materials, very often taken from the ground, are subjected to a number of alterations to convert them into a form that humans need, so geologists play a significant part in the analysis, as they have specialized knowledge that reveals how the raw materials can be altered. Very often, chemical processes are employed in this alteration, and for this to be fully understood requires sophisticated knowledge of those processes. Moreover, in most cases, industrial production involves the application of forces generated by energy, for which an understanding of the physics of energy use is essential. Finally, most manufacturing processes create waste by-products. Indeed, life in the industrialized world in general generates enormous amounts of waste, and its disposition, without harming the environment or generating environmental changes that affect the climate, is a major political and social concern requiring knowledge of ecology and biogeochemistry to achieve.

• Significance for Climate Change

Since anthropogenic changes to the environment have been identified as major contributors to the changing climate, ways need to be found to minimize this impact. Full knowledge of the effects of the various parts of industrial production is essential to changing those effects. Industrial ecology, a specialized branch of environmental studies, has its own journal, the *Journal of Industrial Ecology*, edited at the Yale School of Environmental Studies. It draws on contributions from academics, members of the business community, and government officials. Through this journal and in other academic, private, and public forums, ideas and processes that can serve to modify industrial production and thereby reduce its negative impact on the climate are spread.

Nancy M. Gordon

- **Further Reading**

Ayres, Robert U., and Leslie W. Ayres, eds. *A Handbook of Industrial Ecology*. Cheltenham, Gloucestershire, England: Edward Elgar, 2002. A collection of chapters by experts in many of the fields that contribute to industrial ecology, covering the broad range of disciplines that industrial ecology employs, including economics, national policy, and applications.

Graedel, Thomas, and B. R. Allenby. *Industrial Ecology*. 2d ed. Upper Saddle River, N.J.: Pearson Education, 2003. The standard text in industrial ecology.

Lifset, Reid. "Industrial Ecology and Forestry." *Journal of Forestry* 98, no. 10 (October, 2000). Special inset provides a very concise explanation by the editor of the *Journal of Industrial Ecology*.

See also: Carson, Rachel; Civilization and the environment; Conservation and preservation; Ecological impact of global climate change; Ecosystems; Environmental economics; Environmental movement; Industrial emission controls; Industrial greenhouse emissions; Industrial Revolution; Sustainable development.

Industrial emission controls

- **Category:** Pollution and waste

Governmental regulations and technological innovations have helped reduce the amount of environmental pollutants and GHGs emitted into the environment as byproducts of industrial manufacturing.

- **Key concepts**

capture: to secure and contain harmful particles and chemicals
combustion: the burning of fuels to produce energy
emissions: gases and particulates released by industrial and other processes
filtration: separation or removal of contaminants from emissions
industrial: related to large-scale manufacturing or energy production
neutralization: elimination of harmful characteristics or properties to render contaminants benign
scrubbers: liquids that remove pollutants from emissions
sequestration: isolation of hazardous emissions to prevent them from polluting the atmosphere

- **Background**

Since the Industrial Revolution began in the mid-nineteenth century, factories using combustion to power machinery manufacturing products have released chemicals detrimental to the environment in their emissions. By the twentieth century, power plants generating energy through burning fuels such as coal and natural gas added to this pollution, and industrial greenhouse gases (GHGs) accelerated climate change. Motivated by economic, legislative, and environmental incentives, many industry operators sought ways to control industrial emissions. Engineers and scientists innovated and devised technology or methods to minimize, remove, convert, or store chemicals emitted during industrial combustion activities.

- **Industrial Emissions and Control Strategies**

Turbines, boilers, generators, engines, and furnaces powered by burning fuels release GHGs produced during combustion. Emissions frequently associated with industries include nitrogen oxides, sulfur dioxide, carbon dioxide (CO_2), and methane. The U.S. Environmental Protection Agency identified petrochemical, ammonia, aluminum, steel, iron, and cement manufacturers as emitters of large amounts of GHGs.

Political and social demands to reduce emissions resulted in many industry leaders evaluating how to alter production methods and technology in order to satisfy laws limiting emissions while not experiencing profit losses. Intergovernmental Panel on Climate Change (IPCC) reports discussed how to control industrial emissions, recommending industry managers seek control strategies and technology appropriate for manufacturing processes and fuels their factories utilized.

- **Carbon Capture and Storage**

Industries have successfully controlled emissions with carbon-capture-and-storage (CCS) methods by securing carbons released during combustion and then compressing and sequestering them in remote areas, usually underground, distant from the Earth's atmosphere. CCS is especially effective for minimizing CO_2 released in emissions from petroleum, iron, cement, and ammonia industrial processes and refineries.

Norwegian industries were early users of CCS because Norway's government began taxing carbon emissions in 1991. Norwegian engineers and scientists created CCS technology and procedures to store CO_2 in sandstone approximately 1,000 meters beneath the North Sea. Starting in 1996, the Norwegian industry StatoilHydro sequestered almost one million metric tons of carbon emissions annually.

Experts emphasized CCS technology is essential to achieve projected emission reductions by 2100. Researchers collaborated on CCS projects. Scientists experimented using chemicals to enhance CCS effectiveness and burning biomass to power equipment used to capture CO_2. In 2007, researchers demonstrated how algae capture carbon.

• Scrubbers

Scrubber technology cleans exhaust and emissions from industrial sources by removing particulates from acidic gases. A typical scrubbing procedure results in chemicals in emissions being altered, sometimes undergoing reactions to transform into other compounds, or lessening their strength.

Scrubbing equipment designs incorporate a tank and recirculation system cycling liquid scrubbers into the presence of emissions. The basic particulate scrubbing process involves the swift movement, from 45 to 120 meters per second, of emissions inside a tank constructed from fiberglass or metals that will not corrode. In this vessel, a liquid, often water, serving as the scrubber impacts the fast moving emissions and transforms into small drops that absorb particles in emissions.

Engineers designed scrubbers to meet specific industrial needs. Scientists identified chemical solutions, including chlorine dioxide, hydrogen peroxide, sodium chlorate, and sulfuric acid, effective as scrubbers to minimize sulfur oxides, nitrogen oxides, and heavy metals, such as mercury, in flue gas emissions.

• Filtration

Industrial emissions can be controlled by filtering contaminants produced during combustion. Filtration technology consists of an insulated metal chamber, usually made from stainless steel or an alloy, and mesh filters, mostly constructed with copper, silicon, or aluminum. Tanks store water before and after filtration. Sprayers and pipes transport water during filtration.

Water and temperatures control industrial emissions during filtration. Inside the chamber, sprayers coat water that has been cooled to 2° Celsius in an adjacent refrigerator tank on one or more mesh filters near the top of the chamber prior to hot emissions rising beneath the filter in the chamber. The dripping water hits the emissions, cooling them, and capturing particulates or liquefying such gases as sulfur dioxide and CO_2 when they reach the filter. The water containing particulates and gases is expelled into a dump tank.

• Neutralization and Absorption

Some industrial emissions are managed by neutralizing them. Researchers innovated methods to extract toxic chemicals prior to combustion. Engineers developed technology to impede nitrogen oxidization during combustion. In selective catalytic reduction (SCR), the reaction of ammonia with flue gases, aided by use of a catalyst such as tungsten oxide, breaks nitrogen oxides into nitrogen molecules and water. SCR effectively reduces emissions by 80 to 90 percent but is costly due to catalyst expenses.

Fluidized bed combustion (FBC) keeps nitrogen oxides from being produced because chamber temperatures are lowered to 750° to 950° Celsius by water tubes in the bed absorbing heat. FBC control methods used when burning coal achieve 80 to 90 percent reduction of sulfur oxides. Various flue gas desulfurization (FGD) methods utilize chemicals or minerals such as limestone that absorb emission contaminants, particularly sulfur dioxide.

• Context

Images of smoke rising from industrial parks often are used to symbolize global warming. Endeavors to control industrial emissions exemplify international focus on enhancing and promoting the use

London's Eggborough Power Station emits pollutants including GHGs into the atmosphere. (AP/Wide World Photos)

of clean technology, particularly due to the expansion of industry because of economic incentives to produce more goods and energy to support expanding populations. Legislation such as the U.S. Clean Air Acts (1963-1990) outlined requirements for industries to control emissions. The Kyoto Protocol addressed industrial emissions control and suggested reductions. As global warming worsened into the twenty-first century, governments worldwide, such as the European Union, revised limits previously set for GHGs produced by industries.

Many industrial leaders recognized their environmental responsibilities and willingly limited emissions from factories and acquired updated equipment, trained operators, and enforced stricter procedures to minimize the impact of industrial emissions on climate change. Other industries, however, continued to release excessive GHGs because of apathy, ignorance, or inability to afford or attain access to emissions control technologies.

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• Further Reading

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Beth Metz et al. New York: Cambridge University Press, 2007. Chapter 7 of this IPCC report focuses on industry. Addresses industrial GHGs and the technology and techniques industries use to control emissions. Bibliography.

Maroto-Valer, M. M. Mercedes, John M. Andrésen, and Yinzhi Zhang. "Toward a Green Chemistry and Engineering Solution for the U.S. Energy Industry: Reducing Emissions and Converting Waste Streams into Value-Added Products." In *Advancing Sustainability Through Green Chemistry and Engineering*, edited by Rebecca L. Lankey and Paul T. Anastas. Washington, D.C.: American Chemical Society, 2002. Recommends using low-nitrogen-oxides burners to decrease emissions, in addition to disposing of any unburned carbonaceous ash.

Wald, Matthew L. "In a Test of Capturing Carbon Dioxide, Perhaps a Way to Temper Global Warming." *The New York Times*, March 15, 2007, p. C3. Describes American Electric Power's strategies for sequestering CO_2 using chilled ammonia to absorb it, a technique using less energy than do other carbon-capture methods.

Wilson, Elizabeth J., and David Gerard, eds. *Carbon Capture and Sequestration: Integrating Technology, Monitoring, and Regulation*. New York: John Wiley and Sons, 2007. Energy policy experts present technical descriptions of CCS processes, engineering concerns (including seepage), and legalities such as storage-site ownership.

See also: Carbon dioxide; Emission scenario; Emissions standards; Greenhouse gases; Motor vehicles; U.S. legislation.

Industrial greenhouse emissions

• **Categories:** Pollution and waste; economics, industries, and products

Since the Industrial Revolution, increased amounts of anthropogenic industrial GHG emissions from factories and power plants have combined with emissions from other sources to raise the global temperature and change the climate. Modern technology has accelerated the global warming process with the production of new industrial GHGs.

• Key concepts

albedo: the fraction of incident light reflected from a body such as Earth

anthropogenic: derived from human sources or activities

biodiversity: the variety of organisms at a particular geographic location

biosecurity: measures required or taken to protect organisms from risk or danger

fossil fuels: fuels formed by the chemical alteration of plant and animal matter under geologic pressure over long periods, including coal, oil, and natural gas

greenhouse gases (GHGs): gaseous constituents of the atmosphere, both natural and anthropogenic, that contribute to the greenhouse effect

industrial: related to large-scale manufacturing or energy production

Intergovernmental Panel on Climate Change (IPCC): a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP)

ozone layer: a region of the upper atmosphere with high concentration of ozone (a gaseous form of oxygen) that protects the Earth by absorbing solar ultraviolet radiation

• Background

Industrial greenhouse gases (GHGs) are anthropogenic gaseous constituents of the atmosphere produced by human industrial processes that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation, emitted by the Earth's surface, the atmosphere, and by clouds. This phenomenon causes the greenhouse effect, which contributes to global warming. The concentrations of carbon dioxide (CO_2) among such emissions are now more than one-third higher than they were before the Industrial Revolution. The Earth is artificially made even warmer by hydrofluorocarbons (HFCs) from industrial activities that trap extra heat from the sun, causing changes in weather patterns around the globe.

• The Sources and Levels of Industrial Greenhouse Emissions

CO_2, the most abundant GHG, is emitted from products and by-products of manufacturing sites, and from burning fossil fuels at large industrial facilities. Natural gas, coal, and oil are the three types of polluting power plants, and they produce 40 percent of CO_2 in the United States, coal being the biggest contributor. Brown coal produces more CO_2 than black coal. In the United States, industrial CO_2 emissions, resulting both directly from the combustion of fossil fuels and indirectly from the generation of electricity that is consumed by industry, accounted for 28 percent of CO_2 from fossil fuel combustion in 2006.

Industrial processes are among the six major sources of pollution in the United States and are responsible for over 60 percent of Canada's total emissions. In the United States, energy-related activities account for over three-quarters of anthropogenic GHG emissions, more than half of which comes from power plants and industrial processes. When emissions from electricity were distributed among various sectors, industry accounted for the largest share of U.S. GHG emissions (29 percent) in 2006. Overall, emission sources from industrial processes accounted for 4.5 percent of U.S. GHG emissions in 2006.

The six major industrial GHGs are CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The major industrial greenhouse gases are released from manufacturing and production processes related to iron ore pelletizing, lime, iron and steel, titanium, pulp and paper, aluminum and alumina, cement, petroleum refining, chemicals and fertilizers, electricity (produced with oil, coal, and gas), natural gas pipelines, potash, base metal smelters, silicon carbide, nitric acid, ammonia, urea, limestone and dolomite use (such as flux stone, flue gas desulfurization, and glass manufacturing), soda ash, ferroalloy, zinc, phosphoric acid, titanium dioxide production, lead, coal mining, wastewater treatment, stationary combustion, composting, manure management, semiconductors, magnesium, and adipic acid.

At present, electric power generation is the largest contributor to industrial GHG emissions. Industrial methane comes from petroleum systems and coal mining. Unintentional fugitive industrial methane emissions come from equipment leaks, natural gas distribution, and storage facilities. Nitrous oxide is generated during the production of nitric acid and adipic acid. The manufacture of liquid crystal display (LCD) screens releases nitrogen trifluoride. Reports in 2008 indicated a rise in airborne levels of nitrogen trifluoride from flat-panel screen technology (manufacture of LCD screens).

Industrial activities also produce several classes of greenhouse halogenated substances that contain fluorine, chlorine, or bromine, such as potent greenhouse HFCs, PFCs, and SF_6 gases. Sulfur hexafluoride is the most potent GHG the IPCC has evaluated. Chlorofluorocarbons, or CFCs, are wholly human-made, new to the atmosphere, and widely used in aerosols, foam manufacture, air conditioning, and refrigeration. Other industrial sources include HCFC-22 production, semiconductor manufacturing, aluminum production, and magnesium production and processing.

• Capacity of Industrial Emissions to Affect Climate Change

Industrial emissions form a significant percentage of anthropogenic sources of GHGs that are blanketing the Earth and increasing the average global air temperature near the Earth's surface. Industrial processes can chemically transform raw materials, which often release waste gases such as CO_2, CH_4, and N_2O, gases that can influence the atmospheric lifetimes of other gases. These emissions can affect atmospheric processes that alter the radiative balance of the Earth, such as cloud formation or albedo. The IPCC reported in 2007 that methane is twenty times as effective as CO_2 at trapping heat in the atmosphere, and its concentration in the atmosphere has increased by 148 percent over the last 250 years.

Nitrous oxide is over three hundred times more powerful than CO_2. Nitrogen trifluoride is thousands of times stronger at trapping atmospheric heat than CO_2. Human industrial activity has produced very potent GHGs such as hydrofluorocar-

Contribution of Anthropogenic GHG Emissions to Earth's Greenhouse Effect

GHG	*Recent Enhanced Greenhouse Effect*
Carbon dioxide	69.6
Methane	22.9
Nitrous oxide	7.1
HGWP gases	0.4

Data from U.S. Environmental Protection Agency.

bons that trap more heat from the Sun than CO_2 and other GHGs, making the Earth artificially warmer. As a result, extreme weather events will become more frequent, more widespread, and more intense in the times ahead. In addition to having high global warming potentials, SF_6 and PFCs have extremely long atmospheric lifetimes, resulting in their irreversible accumulation in the atmosphere once emitted.

• How Industrial Greenhouse Emissions Affect Climate and Global Events

Industrial greenhouse emissions play a major role in the gaseous blanketing effects that create higher temperatures around the Earth. Chlorofluorocarbons emitted from factories destroy the protective ozone layer, causing more intense solar radiation to bombard the Earth. Increasing global temperature is expected to cause sea levels to rise, increase the intensity of extreme weather events, and create significant changes to the amount and pattern of precipitation, likely leading to an expanse of tropical areas, loss of biodiversity, and increased pace of desertification.

The effects of climate change have serious implications for the economy and environment of nations. Winters are becoming milder, and summers are becoming hotter. Snowpacks are shrinking, and unseasonably warm temperatures are leading to rapid spring melts, depleting the supply of summer water for agriculture and stream flows for wildlife. Storms and forest fires are becoming more severe while the risk of coastal flooding is increasing. These climatic changes will potentially affect native ecosystems, industries, infrastructure, health, biosecurity, and the economy.

Industrial smog emissions provoke responses of the atmosphere that cause health hazards, and affect agricultural as well as drinking water supplies. Other expected effects include modifications of trade routes, glacier retreat and disappearance, mass species extinctions, increases in the ranges of disease vectors, changes in quantity and quality of agricultural yields, and impacts on land use due to significant alterations in temperature and rainfall patterns. The health of livestock and other animals will be affected, as pests, pathogens, and diseases become modified or multiply. Land erosion and impoverishment will abound, with increase in soil infertility and proliferation of weeds. All these factors will have poverty impacts on people and jeopardize the global economy.

• Direct and Indirect Industrial Emission Impacts on the Atmosphere and Environment

Direct radiative effects of industrial GHGs occur when the gases themselves absorb radiation and warm the Earth. Strong industrial greenhouse emissions such as CFCs directly contribute significantly to the depletion of the protective ozone layer around the Earth.

The IPCC reported in 2007 that from the preindustrial era (ending about 1750) to 2005, concentrations of CO_2, CH_4, and N_2O have increased globally by 36, 148, and 18 percent, respectively. Their emissions from industrial sources directly pollute groundwater after rainfall has washed the pollutants into the soil. Toxins from the pollutants directly affect the health, growth, and reproduction of plants and animals.

Indirect atmospheric modification occurs when chemical transformations of the substances emitted from industrial processes produce other GHGs. Industries contain by-product or fugitive emissions of GHGs from industrial processes not directly related to energy activities. Industrial gases can also indirectly influence the atmospheric lifetimes of other gases. There are several gases that do not have a direct global warming effect but indirectly affect terrestrial and solar radiation absorption by causing some GHGs to persist longer in the atmosphere, and influencing the formation or destruction of other GHGs, including tropospheric and stratospheric ozone depletion. These gases include carbon monoxide (CO), oxides of nitrogen (NOx), and non-CH_4 volatile organic compounds (NMVOCs).

• Context

Today, Earth is hotter than it has been in two thousand years. The global temperature will rise higher, to destructive levels, than at any time in the past two million years if industrial emissions are not reduced. The IPCC predicts a further rise of 1.1° to 6.4 ° Celsius in the average global surface temperature. According to the *Science Daily* of September 17, 2008, the Earth will warm about 2.4° Celsius above preindustrial levels even under extremely conservative GHG emission conditions and under the assumption that efforts to clean up pollution continue to be successful. Although most studies focus on the period up to 2100, warming and sea-level rise are expected to continue for more than a thousand years even if GHG levels are stabilized. The delay in reaching equilibrium is due to the large heat capacity of the oceans.

As a result of the 1987 Montreal Protocol to curb CFCs, the IPCC reported in 2007 that the production of ozone-depleting substances (ODS) is being phased out, as CFCs and HCFCs are replaced by ODS substitutes such as HFCs and PFCs. Unfortunately, the substitutes, while being relatively harmless to the ozone layer, are equally potent GHGs, and at present their phase-out dates are not due for another 20 to 30 years.

Technological advancement and innovation are critical to achieving significant, long-term reductions in industrial GHG emissions. Investments in biofuels and alternative energy sources would promote clean electricity. Cement producers could use waste material from other industries in place of emission-intensive clinker. Some industries have installed new technology to cut emissions, and use filters that improve the quality of the air released into the atmosphere.

Samuel V. A. Kisseadoo

• **Further Reading**

Clarke, A. G. *Industrial Air Pollution Monitoring: Gaseous and Particulate Emissions.* Environment Management Series 8. New York: Springer, 1997. Provides details of the types, effects, and emission rates of industrial pollutants.

Friedrich, R., and S. Reis, eds. *Emissions of Air Pollutants: Measurements, Calculations, and Uncertainties.* New York: Springer, 2004. Provides information intended to guide efforts to reduce and mitigate air pollution and to design experiments related to specific pollution sources.

Hardy, John T. *Climate Change: Causes, Effects, and Solutions.* New York: John Wiley, 2003. Emphasizes and explains potential global effects of anthropogenic climate change and provides scientific findings, case studies, and discussions of the broader issues of the ecological, economic, and human effects of such change.

Quigley, John T., Howard E. Hesketh, and Frank L. Cross, Jr. *Emission Control from Industrial Boilers.* Lancaster, Pa.: Technomic, 1995. Provides in-depth treatment of industrial production related to the Clean Air Act, boiler systems, combustion fundamentals, scrubbers, filters, disposal of residuals, and emission monitoring.

Reay, Dave. *Climate Change Begins at Home: Life on the Two-Way Street of Global Warming.* New York: Palgrave Macmillan, 2006. Analyzes case studies, emissions trends, lifestyle comparisons, and calculations describing climate change as a great twenty-first century human threat.

See also: Aerosols; Carbon dioxide; Chlorofluorocarbons and related compounds; Emissions standards; Environmental law; Greenhouse effect; Greenhouse gases; Hydrofluorocarbons; Methane; Sulfur hexafluoride.

Industrial Revolution

• **Category:** Economics, industries, and products

The Industrial Revolution involved a shift from human and animal power to reliance on coal for manufacturing and transportation, and it was marked by an escalating rate of population increase. The early industrial period saw global cooling rather than warming.

• **Key concepts**

carrying capacity: the number of people the environment can support

climate feedback loops: self-reinforcing and self-negating processes that accelerate or retard climatic trends

fossil fuels: combustible products of ancient photosynthesis, such as coal

planetary albedo: the relectiveness of the Earth's surface, including cloud cover, to sunlight

• Background

The Industrial Revolution began around the middle of the eighteenth century in England. Increasingly sophisticated power-driven machines augmented and replaced human and animal labor, greatly increasing individual worker productivity. This led to an overall increase in per capita resource consumption at a time when population was also beginning to increase at an exponential rate.

Some economic historians speak of three or four separate Industrial Revolutions. The first, roughly 1750-1850, centered on mechanization of the textile and metallurgical industries. Mechanization of transportation in the form of railroads and steamships dominated the second phase. The United States overtook Britain as the world's leading consumer of fossil fuels, and Japan became the first non-Western nation to embrace industrialization. The post-World War II era of globalization and rapid growth in information technology has been called a third Industrial Revolution. Finally, some economists call for a fourth Industrial Revolution that would drastically reduce depletion of nonrenewable resources.

Of the revolutions that convulsed Europe and North America in the last quarter of the eighteenth century, the Industrial Revolution arguably had the most profound effect on the mass of people who experienced it. Most of its environmental effects, however, were either local or indirect. Compared with the first half of the eighteenth century and the latter half of the nineteenth, temperatures were cooler. Industrial carbon and sulfur emissions, smoke, and deforestation probably contributed, but their importance relative to other factors is uncertain.

Drax Power Station in Yorkshire, England. The Industrial Revolution radically transformed both the landscape and the air of England and other Western nations. (John Giles/PA Photos/Landov)

• The Process of Industrialization

The roots of Europe's industrialization must be sought in population fluxes and changing agricultural practices of the preceding centuries. Plague caused Europe's population to crash in the mid-fourteenth century. By 1700, the population again reached carrying capacity, supporting urban growth and creating pressure to improve agricultural productivity. Rapid rural population growth also allowed colonial expansion, which in turn provided a source of raw materials for industry.

By 1719, when Isaac Watt patented the first steam engine, London and other English cities mainly used coal for domestic heating. Pithead steam engines used to pump water from coal mines greatly increased production capabilities. Not long afterward, a series of innovations in the textile industry set the stage for massive movement from cottage-based industries to factories relying on external power sources. Other key inventions included improvements in iron founding, mechanization of tool machining, gas lighting, efficient papermaking and printing, and Portland cement, as well as the birth of the chemical industry.

• Energy Consumption

Prior to about 1790, the mechanized textile industry in Britain relied upon water power. After 1790, coal-fired steam engines powered most factories. The use of coal to produce gas for illumination and cooking began in the first decade of the nineteenth century. Steamships started to replace sail for river and coastal traffic by 1820, while the first passenger railroad opened in 1828.

In the United States, consumption of fossil fuels was negligible before the Civil War. The textile industry used water power, and heating and transportation relied on wood from seemingly limitless forests.

The carbon dioxide (CO_2) content of the Earth's atmosphere remained nearly constant from 1700 to 1850, which correlates with a lack of observable greenhouse effect in temperature measurements from this period. Explanations for this stability in the face of greater fossil fuel use include sequestration in oceanic carbonates and an increased level of photosynthesis. In any event, although the rate of increase in fossil fuel consumption was impressive, the absolute numbers are low. The 45 million metric tons of coal consumed in 1850 are dwarfed by nearly 5.4 billion metric tons of coal consumed worldwide in 2006.

• Other Environmental Effects

Historically, industrialization stimulated population growth. In early eighteenth century Britain, improved food production and better control of epidemic disease reduced infant mortality. Employment in cities and the opportunity to emigrate to colonies meant that these children married early and produced large families. While the population of the world as a whole roughly doubled between 1750 and 1860, that of Great Britain went from 7,500,000 to 23,130,000, and that of the United States went from 1,500,000 to 31,400,000. While the effects of immigration dominate U.S. statistics, the bulk of it was from the British Isles. Industrialization played a significant part in creating the expanding resource base making such growth possible. Although per capita resource consumption among the working poor did not begin to rise significantly until after 1850, the rise in numbers meant it took more energy and raw materials to support the population.

Contemporary accounts of early industrial cities paint a vivid picture of belching smokestacks and sulfurous fumes. Pollution controls were nonexistent. This large volume of pollutants tended to offset any greenhouse effect due to CO_2. Pouring quantities of soot and sulfur dioxide into the atmosphere produces atmospheric cooling. Although sulfur dioxide (SO_2) is a greenhouse gas (GHG), it rapidly combines with water to form sulfuric acid, which reflects sunlight. Soot particles also reflect solar radiation. Both can serve as nuclei for cloud formation, increasing planetary albedo and producing additional cooling. Thus, a single pulse of sulfur and particulate matter, injected into the atmosphere, has the potential to set up a climatic feedback loop.

Particulate matter remains in the atmosphere less than a year, and sulfuric acid no more than three or four years, whereas CO_2 builds up over decades. Consequently, the dirtier and more polluting an industry, the less its energy consumption will contribute to global warming in the short term.

This helps explain why there is no global warming effect due to industrialization in the early nineteenth century.

The period 1750-1850 also saw at least two massive volcanic eruptions that contributed to global cooling: Laki in Iceland in 1783-1784 and Mount Tambora in the East Indies, which precipitated 1816's "year without a summer." Neither eruption set up a feedback loop which would account for the generally depressed temperature levels recorded in Europe and confirmed by Greenland ice cores and North American tree ring data for the entire period 1780-1850.

• Context

Comparison of industrialization rates, temperature profiles, and CO_2 levels in the period 1750-1850 with more recent trends suggests an insight into why global temperatures have not responded in a linear fashion to increases in atmospheric CO_2 levels, but instead show a marked acceleration in the 1980's, when acid rain became an environmental issue of grave concern, and western countries began aggressively curbing sulfur emissions from coal-fired electrical plants. Once the natural SO_2 pulse from Mount Pinatubo cleared the atmosphere, the Earth experienced the full effect of GHGs unmitigated by pollution. The importance of SO_2 pollution in counteracting greenhouse warming has also been recognized by British scientists studying drought cycles in the Amazon basin.

Martha A. Sherwood

• Further Reading

Alverson, Keith D., Raymond S. Bradley, and Thomas Pedersen, eds. *Paleoclimate, Global Change, and the Future.* Berlin: Springer Verlag, 2003. A collection of scholarly papers comparing past climate changes with present anthropogenic trends.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years.* Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008. Lack of a temperature response during the Industrial Revolution is used as evidence that global warming is primarily a natural phenomenon.

Stearns, Peter N. *The Industrial Revolution in World History.* Boulder, Colo.: Westview Press, 2007. A thorough, scholarly book with good information on the effect of population on industrialization.

See also: Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Climate feedback; Industrial emission controls; Industrial greenhouse emissions; Preindustrial society.

Information Council on the Environment

- **Category:** Organizations and agencies
- **Date:** Established 1991

• Mission

The Information Council on the Environment (ICE) was a skeptic organization created to promote the idea that there is no scientific consensus on global warming. ICE was a public information group funded by the Edison Electrical Institute, the National Coal Association, and the Western Fuels Association. Its mission, supported by a $500,000 advertising budget, was to "reposition global warming as theory rather than fact," according to internal documents of Cambridge Reports, the Council's polling firm. The group employed a scientific advisory panel comprising geography professor Robert Balling, research physicist Sherwood B. Idso, and climatologist Patrick J. Michaels, as well as environmental scientist S. Fred Singer, to promote skepticism in television and newspaper interviews, opinion columns, and advertisements. The polling firm advised the council to emphasize that "some members of the media scare the public about global warming to increase their audience and their influence."

• Significance for Climate Change

In addition to the messages carried by its spokespersons, ICE conducted polls about global climate change and greenhouse gas emissions, purporting to gauge public opinion about these issues. In fact, according to strategy documents, pollsters targeted "older, less-educated men from larger households who are not typically information seekers" and "young, low-income women" in areas whose electricity was generated by coal, in an attempt to skew the poll results in favor of less regulation of coal.

ICE also purchased magazine and newspaper ads in key sections of the country, including one that ran in Minnesota reading, "If the earth is getting warmer, why is Minneapolis getting colder?" Another ad showed a ship sailing off the edge of the Earth, with an open-mouthed dragon waiting to catch it. The caption read, "Some say the earth is warming. Some also said the earth was flat." The Arizona Public Service Company declined to join ICE, declaring that the ads over-simplified a complex issue.

ICE was disbanded after only a few months, after a packet of internal memos describing the organization's public relations strategies was leaked to the *Energy Daily*, a trade publication, and follow-up stories appeared in the *Arizona Daily Sun*, the *National Journal*, and *The New York Times*. After the press stories, Balling and Michaels broke with the council. In 1999, a former board member of ICE expressed regret that the campaign had not lasted longer, writing that ICE had resulted in a "dramatic turnaround in how people viewed the issue of global warming."

Cynthia A. Bily

See also: Media; Pseudoscience and junk science; Skeptics.

Institute for Trade, Standards, and Sustainable Development

- **Categories:** Organizations and agencies; economics, industries, and products
- **Date:** Established 2001
- **Web address:** http://www.itssd.org

• Mission

The Institute for Trade, Standards, and Sustainable Development (ITSSD) advocates sustainable development without absolute protection of natural resources and discounts anti-global warming measures as not scientifically or economically justified. Headquartered in Princeton, New Jersey, the ITSSD is a nonprofit organization dedicated to educating government, industry, and the public about science, technology and innovation policy, private property rights, and international trade. It is operated by its chief executive officer-president, vice president, and secretary and has a seventeen-member advisory board. The officers write white papers and articles, serve on a variety of discussion panels, administer an internship program for university students, and publish journals on economic freedom, intellectual property rights, trade barriers, the United Nations Convention on the Law of the Sea, "pathological communalism," and women's property rights.

The ITSSD's principal policy calls for positive sustainable development, which, it argues, has a general capacity to create well-being for present and future generations. This sustainable development is positive in that it eschews regulation "devoid of scientific and economic benchmarks" and "disguised trade barriers premised solely on cultural preferences" in favor of strongly protected property rights, free market (neoliberal) economics, decentralization, economic growth, and local, regional, or national (rather than supranational) institutions encouraging individual initiative. The ITSSD contends that regulations and standards must be developed "based on empirical science and economic cost-benefit analysis" under public scrutiny and free of the dominating influence of scientific fashion or sociopolitical ideology.

• Significance for Climate Change

Informing its stance on climate change, ITSSD relies on the arguments of global warming critics, including (according to ITSSD) "established scientists." Most prominently cited is British businessman, politician, and inventor Christopher Monckton, who argues that global warming derives from natural cycles and is misrepresented by the scientific community. In the white paper "Europe's

Warnings on Climate Change Belie More Nuanced Concerns" (2007), ITSSD president Lawrence A. Kogan accuses leaders of sidestepping what he portrays as the ongoing scientific debate. This debate concerns the extent to which certain human activities can be shown to cause measurable global warming or merely to correlate with a barely observable rise in global temperatures that may or may not prove to be cyclical in nature. The failure of European leaders to discuss this issue in the ITSSD's eyes suggests a nuanced effort to base intergovernmental regulatory policy on popularly fanned fears about largely hypothetical, unpredictable or unknowable future natural and anthropogenic hazards that have not yet been shown to pose direct ascertainable risks to human health or the environment.

Roger Smith

See also: American Enterprise Institute; Cato Institute; Competitive Enterprise Institute; Cooler Heads Coalition; Skeptics.

Intergenerational equity

- **Category:** Ethics, human rights, and social justice

- **Definition**

The principle of intergenerational equity is strongly embedded in the U.N. Framework Convention on Climate Change. Historically, it owes its recognition to the Brundtland Report, *Our Common Future* (1987), which popularized the principle of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The Declaration of Rio on Environment and Development (1992) adds a rights-based perspective to the principle, suggesting that "the right to development must be fulfilled so as to equitably meet development and environmental needs of present and future generations."

- **Significance for Climate Change**

The moral concerns over intergenerational equity have strong implications for climate-change-related policy making. The concept of intergenerational equity acknowledges the obligations of present generations in protecting the opportunities of future generations as well as the rights of future generations in enjoying the same level of opportunities and stocks of assets. This concept raises questions about how the interests of current generations are weighed against those of future generations and about the costs of inaction. Economists use discounting factors to address climate change by attempting to weigh the costs and benefits of alternative policies to different generations. The Stern Review, a report released by the British government in 2006, uses a similar approach to calculate optimal policy response and to highlight the consequences of inaction for future damage.

The concept of intergenerational equity is not without problems. It is hard to know the precise magnitude and distribution of the effects of climate change because of scientific uncertainty, as well as limited current knowledge about the future aspirations of particular societies. For instance, it is not clear how evenly the impact of climate change would be distributed over successive future generations. There is potential conflict between intragenerational and intergenerational needs. If current needs have not been met, this creates a dilemma about whether there is an obligation to meet future needs. Furthermore, countries have different capacities in meeting present and future needs. There are doubts about the reliability of discount rates. Research shows that unless the discount rate is very low, the benefits of climate change mitigation policies in future centuries are almost worthless in present value terms. There is also an implicit asymmetrical power in the concept. While current generations can influence how future generations live, future generations cannot exercise such an influence on presently living people.

Sam Wong

See also: Bioethics; Brundtland Commission and Report; United Nations Framework Convention on Climate Change.

Interglacials

• **Categories:** Climatic events and epochs; cryology and glaciology

The question of when the current interglacial period will end and a new glacial period will begin is of paramount importance when attempting to predict the future of Earth's climate.

• Key concepts

Holocene: the current interglacial, which began 11,700 years ago

isotopes: variants of an element that are chemically identical but have different atomic mass numbers and vary in radioactivity

marine isotope stage: half of a glacial cycle, as identified in the oxygen isotope data from ocean cores; advances are given even numbers, and retreats are given odd numbers

Milanković cycle: cyclical variance in Earth's orbital parameters, including axial inclination, climatic precession, and orbital eccentricity

MIS 11: an interglacial that may be the best analogue for the Holocene; also called the Holsteinian or Termination V

MIS 5e: the most recent interglacial before the Holocene, also known as the Eemian, LIG (Last InterGlacial), or Termination II

O^{18}/O^{16} ratio: ratio between two oxygen isotopes that is altered by the advance and retreat of continental glaciers

• Background

How does the present climate compare to the climate during other interglacials? Are current temperatures, sea levels, and carbon dioxide (CO_2) concentrations unprecedented, or should they be considered within the expected range? When, if ever, is the current interglacial going to end? These are among the important questions that climate science seeks to answer. Ice cores, loess deposits, pollen analysis, and other data and techniques provide information that comes together to form a detailed picture that will help answer them.

• Biological Data

Over the last three million years, there have been forty to fifty glacial/interglacial cycles. Scientists have sought to characterize conditions during these periods using a variety of approaches. Plant remains, particularly pollen, have been analyzed to estimate temperature and humidity. The carbonate shells of planktonic marine organisms, preserved as fossils in the sediments beneath the sea, have been analyzed to infer sea surface temperatures. It is difficult to separate regional effects from global ones, and often data from different time periods is only available in different locations, so acquiring a global picture is not easy.

In general, interglacial climate is seen as being quite similar to the current climate. In fact, the term is often restricted to periods during which temperatures were at least as high as they have been during the Holocene, the name given to the current interglacial.

• Ice Core Data

Cores have been drilled out of the ice in Greenland and Antarctica. Within the ice are bubbles of air that have been preserved since the ice was formed. The deepest core, from an area called Dome C in Antarctica, has samples of air from 800,000 years ago. These core samples provide detailed information on eight complete glacial cycles. Ratios of oxygen istopes O^{18} to O^{16} are used to infer how much of the Earth's water was tied up in glacial ice, since glaciers sequester O^{16} and thereby increase the proportion of O^{18} in the ocean. The concentration of deuterium (H^2) in a sample, moreover, can be used to infer the temperature of the air when the snow formed. Age is determined by combining depth, snow accumulation rates, ice flow rates, compaction rates, and so on, in a complex but reproducible way and calibrating the results by using radiometric dating techniques on volcanic dust incorporated in the ice. Dust is examined in detail, and often its place of origin can be determined. While no two cycles are identical, they all share a number of traits.

Each cycle has a saw-tooth shape. A glacial advance ends abruptly, with rapid melting of the ice and a rapid rise in air temperatures. For example, in MIS 9, the temperature rose 13° Celsius in eight thousand years. This warming can stop abruptly, with cooling starting almost immediately, or it can taper off, warming at a slower rate for perhaps a dozen millennia, before cooling begins. Of the eight previous terminations in the Dome C core, four started cooling immediately and four tapered off. Once cooling begins, it is far more gradual than is warming, continuing, with some reversals, for about 100,000 years. Ice is sequestered as cooling occurs, and CO_2 levels fall.

The air temperatures in Antarctica were higher than the average for the current millennium during each of the last four interglacials, but lower during those more than 500,000 years old. The Holocene (MIS 1) began 11,700 years ago. The three most recent interglacials before the Holocene (MIS 5, 7, and 9) had durations of about twelve thousand years or less, so simply by looking at the ice core data one might guess that the next glacial advance may be imminent. However, a theory proposed by Milutin Milanković suggests things may not be this simple.

Periodic variations in some of the orbital parameters of the Earth are known to control the timing of glacial cycles. One past interglacial during which those variations were similar to today's was MIS 11, which lasted for twenty-eight thousand years and had warming taper off after an early rapid rise. However, MIS 19, which also had similar orbital variations, saw cooling right after its initial warming and was of shorter duration. Perhaps the Milanković cycles are similar to lit matches thrown into the woods. When they are thrown will determine the timing of the fires produced, but the scale and intensity of the fires are dependent on how much fuel is available, how dry it is, the weather, relative humidity, and a host of other factors.

• Context

The Earth is currently in an interglacial state and has been in that state for nearly twelve thousand years. Geology and oceanography have shown that over the last three million years the Earth has switched between glacial and interglacial states some forty to fifty times. With no anthropogenic influence, one would conclude that continental glaciers will advance again, the only question being when. In the presence of anthropogenic influences, however, it is not clear that the Earth will return to another glacial state.

Although there is some discussion over whether the orbital conditions for triggering a glacial advance have already occurred or are yet to occur, it is still prudent to examine the conditions on the planet today to evaluate the risk posed by another glacial advance. Of particular interest is why, during times of elevated CO_2 and elevated temperatures, former interglacials succumbed to the minor fluctuations of solar energy produced by those orbital conditions.

Otto H. Muller

• Further Reading

Luthi, Dieter, et al. "High-Resolution Carbon Dioxide Concentration Record 650,000-800,000 Years Before Present." *Nature* 453, no. 7193 (2008): 379-82. Includes a plot of CO_2 concentrations and temperatures over eight glacial cycles. Charts, tables, bibliography.

Ruddiman, William F. *Earth's Climate Past and Future.* 2d ed. New York: W. H. Freeman, 2008. This elementary college textbook has a thorough discussion of how scientists have learned about the climate of interglacials. Illustrations, figures, tables, maps, bibliography, index.

_______. *Plows, Plagues, and Petroleum: How Humans Took Control of Climate.* Princeton, N.J.: Princeton University Press, 2005. Written for the lay public, this book provides the background and thinking behind the theory that humans have influenced the climate for the last nine thousand years, primarily through agriculture. Illustrations, figures, tables, maps, bibliography, index.

See also: Cryosphere; Deglaciation; Glaciations; Glaciers; Holocene climate; Ice cores; Last Glacial Maximum; Little Ice Age.

Intergovernmental Panel on Climate Change

- **Categories:** Organizations and agencies; meteorology and atmospheric sciences
- **Date:** Established 1988
- **Web address:** http://www.ipcc.ch

Since its creation in 1988, the IPCC has proven to be one of the most credible sources of information regarding the state of scientific knowledge about climate change, its impacts, and possible policy responses. Its input has been instrumental in the global effort to reduce GHG emissions.

• Key concepts

anthropogenic: caused by human activity

greenhouse gases (GHGs): gases that allow solar radiation to reach Earth's surface but trap heat, preventing it from escaping into space

International Council for Science: a global nongovernmental organization that fosters cooperation between national and international scientific unions and organizations in the advancement of science

Kyoto Protocol: an international treaty in which industrialized signatories made legally binding commitments to reduce their GHG emissions

United Nations Environment Programme (UNEP): a United Nations agency that promotes sensible environmental policies as the key to sustainable development in developing nations

United Nations Framework Convention on Climate Change (UNFCCC): an international agreement creating the overall context for future agreements designed to reduce GHG emissions

World Meteorological Organization (WMO): a United Nations agency charged with assessing the effects of atmospheric changes on weather, climate, and seas

• Mission

The first call for an international effort to study the effects of anthropogenic climate change on the global community was issued by the World Meteorological Organization (WMO) at its 1979 World Climate Conference. The statement urged world governments to use scientifically generated knowledge to direct policy initiatives designed to slow the progression of global warming. In 1985, the Advisory Group on Greenhouse Gases (AGGG) was established by the International Council of Scientific Unions (ICSU; later the International Council for Science), the WMO, and the United Nations Environment Programme (UNEP). The group was to periodically evaluate scientific data relating to climate change, following a joint conference. These events created the impetus for the establishment of the Intergovernmental Panel on Climate Change (IPCC).

In 1987, the WMO and UNEP agreed that an organization should be created to coordinate an ongoing international effort to evaluate the results of scientific research on the climatic and socioeconomic effects of greenhouse gas (GHG) emissions. This organization would both evaluate research findings and suggest appropriate and effective policy responses based on those findings. The WMO established the IPCC in 1988 and gave it its mission. The panel was to develop a strategy to increase scientific information on global warming, use that information to assess possible policy initiatives for addressing climate change, evaluate policies already in place or proposed, and report its findings to governments and international organizations. UNEP and the United Nations General Assembly endorsed the IPCC.

The IPCC convenes annually in meetings that include hundreds of government officials and researchers from government agencies and nongovernmental organizations (NGOs) from countries that are members of the WMO and UNEP. At these meetings, the IPCC's objectives and activities are determined, the election of its chair is held, and members of its bureau, Task Force Bureau, secretariat, working groups, and Task Force on National Greenhouse Gas Inventories are selected. The thirty-member bureau, with representatives from all regions of the world, oversees the three working groups, and the Task Force Bureau directs the work of the task force. Working Group I (WG I) analyzes the scientific evidence regarding the causes of climate change, Working Group II (WG II) deals with the effects of climate change, and Working Group III (WG III) examines possible ways to reduce the negative effects. The task force is charged with developing better ways of measuring and reporting countries' GHG emissions. In addition, temporary special topic groups may be formed as necessary. The secretariat oversees and organizes all IPCC functions.

• Activities of the IPCC

The main activities of the IPCC involve producing assessment reports (ARs) and methodology reports. The First Assessment Report (FAR) was requested by the U.N. General Assembly in 1989 to form the basis for the creation of the United Nations Framework Convention on Climate Change (UNFCCC). The FAR was completed in 1990. WG I concluded that anthropogenic GHG emissions, principally those of carbon dioxide (CO_2), would increase and would be responsible for global warming and sea-level rise during the twenty-first century. WG II asserted that this would have negative impacts on land and water ecosystems, coastal areas and cities, forestry and agriculture, and weather. WG III suggested short- and long-term policy responses. An IPCC supplementary report, prepared in 1992 to provide updated information for the newly created UNFCCC, supported the conclusions of the FAR.

Further IPCC ARs were published in 1995, 2001, and 2007. Each contained the three working group sections, with summaries for policy makers, as well as a synthesis report that summarizes the overall findings. These ARs reiterated and expanded the findings of the FAR and expressed greater confidence in the accuracy of the simulation models used to project future climate change, including the ability to better distinguish between natural and anthropogenic GHG emissions. The findings of these improved models indicated that human activity is the primary cause of past and future increases in global warming.

The Fourth Assessment Report, *Climate Change, 2007* (AR4), was the most strongly stated, asserting that mostly anthropogenic global warming will likely result in significant increases in global temperatures, ocean levels, hurricanes, droughts, heat waves, and other negative effects during the twenty-first century. It further stated that these effects will continue for hundreds of years under all simulated scenarios, even if GHG emissions could be limited to their current levels. All ARs undergo a rigorous review and revision process by the working groups, government officials, expert scientists, and the panel before receiving final approval.

In addition to the ARs produced by the working groups, the task force produced *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* to inform governments about the available methods for measuring GHG emissions. In 2006, an updated version was prepared that detailed improvements in software and methods for measuring emissions. The IPCC sponsors expert meetings and workshops to find more effective ways to do its work. It also creates special topic and function groups, such as the Task Group on Data and Scenario Support for Impacts and Climate Analysis, which provides the latest data from climate change studies that use different models for use by those who evaluate their impacts and develop response strategies.

• Controversies Involving the IPCC

The IPCC's activities and processes have not been without their critics. Some have said that the ARs are inaccurate, alarmist, and politically driven. For example, Christopher W. Landsea, science and operations officer at the National Hurricane Center, resigned from participation in AR4 in protest when a lead author of both the 1995 AR and AR4, Kevin E. Trenberth, director of the Climate Analysis Section at the National Center for Atmospheric Research, asserted that increased hurricane activity was caused by global warming, which Landsea strongly disputed. Landsea claimed that AR4's conclusions were a product of political pressure and scientific community consensus, and that they stated the research questions as though they had empirical support, which, in his opinion, they did not. In 2005, the British House of Lords expressed concerns that the IPCC was exaggerating the future magnitude and impacts of global warming. It commissioned a report to perform a more objective cost/benefit analysis regarding the IPCC's suggested responses and the expense of possible damage. Ironically, the resulting Stern Review concluded that IPCC ARs and reports from other sources had underestimated the future risks of global warming.

In fact, another general criticism of the IPCC has been that it is too conservative in its analytical approach and downplays the need for immediate aggressive action. Critics cite other analyses that forecast higher future increases in GHG emissions, global temperatures, and sea-level rise than do the IPCC. Some claim that political pressure from the United States resulted in Robert T. Watson being replaced by Rajendra K. Pachauri as IPCC chair in 2002, because the latter was seen as being more desirable by conservative politicians and large oil companies. At the heart of these concerns are the IPCC review, revision, and acceptance processes, which are viewed by some as being unnecessarily cumbersome, leading to more conservative, bureaucratically acceptable findings.

Critics have objected to line-by-line reviews and revisions of the summary sections of the ARs by the panel, with some saying that they downplayed and distorted findings that had been validated through the peer-review process. The heads of major atmospheric research and meteorological organizations have responded by saying that this was a media campaign attacking rigorously reviewed data compilations and summarizations because of the biases of the critics. The IPCC has stood by its position that the revisions make the ARs more understandable, rather than being politically motivated, and that the strength of the AR processes lies in its objective, cautious, analytical approach, following the ideals of the scientific method.

Critics have also asserted that the submission deadlines for AR material are too far in advance of their publication. As a result, in order to allow for the lengthy review processes, the latest research findings are excluded. On the eve of the release of AR4, Pachauri responded by acknowledging that important research that projected more pronounced future global warming had been completed since the submission deadlines, indicating that aggressive policy initiatives should be initiated sooner than recommended in the report.

• Context

The goal of the IPCC is to foster international cooperation between scientists working on climate

From left: Yvo de Boer, head of the United Nations Framework Convention on Climate Change, Rajendra Pachauri, chair of the Intergovernmental Panel on Climate Change, and Hungarian minister of environment and water management Gabor Fodor hold a press conference in April, 2008. A banner celebrating the IPCC's receipt of the 2007 Nobel Peace Prize hangs in the background. (AP/Wide World Photos) modeling, those assessing climate impacts, and policy advisers in order to determine the causes and dangers of climate change and develop sensible response strategies. This has proven to be a challenge because of the disagreements and debates among scientists and the frequent tension between political dynamics and research findings and conclusions. Nevertheless, the IPCC's work has had significant impacts.

Since 1988, multitudes of scientists have volunteered to participate in the panel's work without compensation, resulting in a dramatic increase in global warming research, and the IPCC has ensured that participants are from both developing and industrialized countries. Over 3,750 contributing and lead authors and expert reviewers from more than 130 countries contributed to AR4. The FAR brought about the creation of the UNFCCC and the Koyoto Protocol, which has been ratified by 183 nations.

Criticisms notwithstanding, a strong consensus of support for the IPCC has emerged within the global scientific establishment. A majority of scientific organizations from all parts of the world, including the United States' National Research Council, the Network of African Science Academies, the European Geosciences Union, and the Royal Meteorological Society have voiced strong support for the IPCC, calling it the foremost authority on the state of scientific knowledge relating to climate change. IPCC's ARs have become a primary source of information in climate change policy debates worldwide, and many conservative political factions that had denied the existence of anthropogenic global warming for decades have now conceded that it is real, in the face of the growing body of scientific evidence.

In 2007, the IPCC was awarded the Nobel Peace Prize for its efforts to compile, analyze, and disseminate scientific data about climate change as the basis for formulating strategies for mitigating against its negative global impacts. The co-winner of this award was former United States vice president Al Gore, who was also recognized for his work on global warming. The IPCC will undoubtedly continue to be an important force in the ongoing international efforts to understand and counteract the current and future effects of climate change. The Fifth Assessment Report (AR5) is scheduled for release in 2014.

Jack Carter

• Further Reading

Brolin, Bert. *A History of the Science and Politics of Climate Change: The Role of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press, 2008. The IPCC's first chairman discusses the mission and history of the organization and the tension between the science and politics of climate change that has undermined the implementation of decisive action. Notes, references, and index.

DiMento, Joseph F. C., and Pamela M. Doughman, eds. *Climate Change: What It Means for Us, Our Children, and Our Grandchildren*. Cambridge, Mass.: MIT Press, 2007. Collection of articles examining numerous interest- and activist groups' positions on climate change, emphasizing the role of the IPCC in these ongoing debates. Glossary and index.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry et al. New York: Cambridge University Press, 2007. Details the research on climate change that has led to the IPCC's calls for policy initiatives to combat global warming. Bibliographies, appendixes, index, and a CD-ROM with a summary for policy makers, technical summary, and regional and subject databases of references.

Skodvin, Tora. *Structure and Agent in the Scientific Diplomacy of Climate Change: An Empirical Case Study of Science-Policy Interaction in the Intergovernmental Panel on Climate Change*. Norwell, Mass.: Kluwer Academic, 2000. Comprehensive analysis of the IPCC's organization, assessment processes, and attempts to resolve conflicts between policy and science. References, appendix, and index.

See also: Greenhouse gases; International Council for Science; Kyoto Protocol; Skeptics; United Nations Environment Programme; United Nations Framework Convention on Climate Change; World Meteorological Organization.

Intergovernmental Panel on Forests

- **Category:** Organizations and agencies
- **Date:** 1995-1997; succeeded by the Intergovernmental Forum on Forests, 1997-2000
- **Web address:** http://www.un.org/esa/forests/ipf_iff.html

• Mission

As a U.N.-sponsored body on which all United Nations members were entitled to representation, the Intergovernmental Panel on Forests (IPF) strove to reach a consensus among all its members that could have provided the basis for a world forest convention. Discussions of the role played by forests in controlling climate change, specifically global warming, began in earnest at the United Nations Conference on Environment and Development (UNCED), which took place in Rio de Janeiro in June of 1992. This meeting highlighted the existence of two opposing groups in discussions of the role of forests in global warming. The object of U.N. climate discussions had already been defined as "sustainable development" by the Brundtland Commission of 1987, but the meeting in Rio brought the two opposing camps face to face, as developed nations advocated for a convention that would constrain deforestation while developing countries, notably Brazil and Malaysia, opposed the idea of a world forest convention. Their opposition rested on the fact that much of the deforestation then taking place was occurring in the developing world.

Following the meeting in Rio de Janeiro, a United Nations body was formed called the Commission on Sustainable Development (CSD), which authorized the establishment of the IPF to conduct research that could be used to provide a factual basis for a convention on forests. Such a convention could devise rules that would constrain further deforestation and thereby slow the addition of carbon dioxide to the atmosphere. The CSD began with fifty-three member states, but other U.N. members were free to join.

Meetings of the IPF, which continued to function as a subsidiary of the CSD, received input from a variety of other bodies, especially the Food and Agriculture Organization (FAO), which hoped to take the lead in defining the framework issues of a forest convention. Other bodies, including nongovernmental organizations (NGOs) representing various indigenous tribes, also sought to take part in the discussions. The result was a divisive set of meetings that was dominated by the fundamental division between the developed countries and the developing countries. Since the rules governing the CSD called for a consensus to be reached before a convention could be created, little if any progress was made.

In 1997, the CSD replaced the IPF with another body, the Intergovernmental Forum on Forests (IFF). Like its predecessor, the IFF was an "open-ended" body, which meant that any U.N. member could take part in its discussions. It met four times, in October, 1997, in New York; from August to September, 1998, in Geneva, Switzerland; in May of 1999 in Geneva; and from January to February of 2000 in New York. Discussions by the participants ranged over many issues, including the causes of deforestation, economic issues related to forests, and particularly how to value the services that forests provide. These services include not just possible climate stabilization but also biodiversity (especially in tropical forests) and preservation of indigenous cultures.

A consensus that could lead to a forest convention with terms that might be legally enforceable proved as elusive to the IFF as it had to the IPF. Meanwhile, deforestation of tropical forests continued, while at the same time the United States joined the developing nations in opposing any convention or binding agreement on the grounds that participation had to be "voluntary." Canada led the developed nations, including the European Union, in advocating for a binding convention. In 2001, the IFF was effectively replaced by the U.N. Forum on Forests, a subsidiary of the Economic and Social Council, where discussion of forest issues continued.

• Significance for Climate Change

The IPF and the IFF served to publicize the environmental impact of deforestation of tropical forests, and even though they did not develop a consensus that could lead to a convention on forests, they did bring to light a great deal of factual information about forests and their role in climate change. Forests cover about 30 percent of the world's land mass, but the percentage is declining. Between 15 and 30 percent of the carbon contributed to the atmosphere globally results from the reduction of the world's forests. Tropical forests contain almost as much carbon as do the temperate and boreal forests combined. Stopping deforestation could do much to stabilize Earth's climate.

Nancy M. Gordon

• Further Reading

Humphreys, David. *Logjam: Deforestation and the Crisis of Global Governance*. London: Earthscan, 2006. A comprehensive account of the various international efforts to control deforestation.

Ramakrishna, Kiloparti, and George M. Woodwell, eds. *World Forests for the Future: Their Use and Conservation*. New Haven, Conn.: Yale University Press, 1993. Various articles present much of the detail about forests and their role in climate change.

Ruddell, Steven, et al. "The Role for Sustainably Managed Forests in Climate Change Mitigation." *Journal of Forestry* 105, no. 6 (September, 2007). Surveys the state of the field.

See also: Amazon deforestation; Deforestation; Forestry and forest management; Forests; United Nations Conference on Environment and Development; United Nations Environment Programme; United Nations Framework Convention on Climate Change.

International agreements and cooperation

• Category: Laws, treaties, and protocols

• Definition

International law connects nation states in a framework of agreements that implement recognized principles, norms, rules, and procedures. Subjects of public international law include sovereign nation states, international organizations, and movements of national liberation. Sources of international law are customs, accepted standards of human behavior, and treaties. The design of international agreements is voluntary, but once concluded they are binding instruments to achieve collective benefits that states would not achieve unilaterally. To either open a new set of options that offer beneficial opportunities or to restrain options that are recognized as harmful, state governments abide by the terms of an international agreement, which in either case is a recognition of mutual interdependence. An ultimate goal of international law is to facilitate win-win solutions through cooperation.

The importance of international agreements is well demonstrated by the prisoner's dilemma in game theory. Here two actors are in a better situation if they both cooperate rather than do not cooperate. If either side individually gives up cooperation for individual benefits, the joint outcome is worse for both. To prevent actors from non-cooperation to maintain mutual benefits requires agreement based on communication, verification, and enforcement. To discourage violations of an agreement, they need to be detected and the expected benefits from violation to be denied. It is often efficient to transfer the tasks of verification and enforcement to institutions that are not bound by individual capabilities and interests.

• Significance for Climate Change

International agreements are essential in climate policy to address the tragedy of the commons regarding the atmosphere. They impose emission constraints for each member state and create opportunities for technology cooperation, capital flows, and trading markets.

The law of treaties defines the rules for legally binding agreements between states, which is codified in the 1969 Vienna Convention on the Law of Treaties. A treaty is a written agreement between two or more sovereign states in which the parties involved agree to abide by certain specified procedures and standards of conduct, which include the *signature* by an authorized State representative; the *ratification* process by parliamentarian bodies to enter a treaty into binding national legislation, independent of the political leadership; and the *entry into force* upon fulfillment of specified conditions, such as the number of ratifying states. During this process, the status of a member state changes from a negotiating state to a state signatory, ratifying state, and ultimately state party after entry into force. A state that has signed a treaty is bound to it and is obliged to refrain from acts that would defeat the object and purpose of a treaty even if it has not yet ratified it. A state can change agreements before ratification and announce that it is withdrawing its signature, after which it is no longer bound.

After ratification, a state is obligated to announce to the world in advance that it plans to withdraw from a treaty, following the advanced notice required. Usually treaties hold for a limited number of parties (bilateral, trilateral, multilateral) and for a given period (for example, the Kyoto Protocol, with obligations for industrialized countries by 2012). Rules of treaties are binding, regardless of the name (for example, protocol, accord, covenant, convention, memorandum of understanding, or exchange of letters or notes). A challenge for international agreements is to design mechanisms that strike a balance between the required commitments and the degree of support for an agreement.

GHG and CO_2 Emissions, by Nation

Nation	*Percent of Global CO_2 Emissions, 1850-2000*	*Percent of Global GHG Emissions, 2004*
United States	30	19
EU-25	27	13
Russia	8	5
China	7	17
Germany	7	3
United Kingdom	6	2
Japan	4	4
France	3	1
India	2	5
Canada	2	2
Italy	2	2
Ukraine	2	1
Poland	2	<1
Australia	1	1
South Africa	1	1
Brazil	<1	3
Mexico	<1	2
Indonesia	<1	2
South Korea	<1	1
Spain	<1	1

Source: Pew Center on Global Climate Change.

The threat of climate change cannot be resolved or prevented by a single nation, but requires an unprecedented degree of international cooperation to foster emission reductions and technological change in the energy sector. Instruments of international law define the rules of emissions, climate impacts, and policies to diminish the risks and enhance cooperation, providing mutual assurance that policies are pursued in an integrated, coordinated, and effective way. An adaptive regulatory framework would address the collective action problem in long-term climate policy, designing efficient legal mechanisms to improve the effectiveness of institutions, to reduce conflict and codify cooperation and compliance, including the international transfer of investments and technologies to shift the composition and learning rates of the energy system toward emission reductions. Coalitions are emerging where individual action is insufficient or inefficient—for example, in achieving a critical number of votes, a critical mass of investment to realize projects, or a threshold of emissions.

The legal framework of climate policy has been defined by the 1992 U.N. Framework Convention on Climate Change (UNFCCC). With the signing of the Kyoto Protocol in 1997 and its entry into force in 2005, the international community has established a first set of instruments through a combination of cooperative governance and market-based incentives. A lack of agreement on the underlying causes, expected risks, and required actions related to long-term climate change, as well as the expected costs and partial interests, has impeded progress during the past decade. To overcome the hurdles for post-Kyoto agreements, an evaluation and negotiation process across all levels is needed, involving citizens, firms, institutions, and states in a multi-stakeholder environment, which became visible during the Bali climate summit in December 2008. Moving beyond Kyoto is a challenge for the legal and policy process that is supposed to implement the longer-term objectives and manage the potentially severe implications in case of failure. It is also a challenge for the scientific community, which becomes involved in value judgments that require innovative integrated approaches.

Jurgen Scheffran

• **Further Reading**

Feaver, D., and N. Durrant. "A Regulatory Analysis of International Climate Change Regulation." *Law and Policy* 30, no. 4 (October, 2008): 394-422. Examines the regulatory architecture and coherence of global climate change regulations.

Scheffran, J. "Preventing Dangerous Climate Change." In *Global Warming and Climate Change*, edited by V. I. Grover. Enfield, N.H.: Science Publishers, 2008. Analyzes the implications of Article 2 of the UNFCCC.

Stein, J. von. "The International Law and Politics of Climate Change: Ratification of the United Nations Framework Convention and the Kyoto Protocol." *Journal of Conflict Resolution* 52 (2008): 243. Discusses the challenge to design mechanisms that deter defection without deterring participation; emphasizes international social networks and domestic nongovernmental organizations.

Verheyen, R. *Climate Change Damage and International Law: Prevention Duties and State Responsibility*. Boston: Martinus Nijhoff, 2005. Comprehensive assessment of the legal duties of states regarding damage from anthropogenic climate change. Analyzes the legal duties of states to prevent climate change damage and international liability to breaches of these duties. Advocates an internationally negotiated solution to the climate issue.

Yamin, F. *The International Climate Change Regime: A Guide to Rules, Institutions, and Procedures*. New York: Cambridge University Press, 2004. Provides a guide to the rapid developments in international law in climate change and explains the regime participants and commitments, adaptation, finance and capacity building, reporting and compliance, institutions and negotiation processes, and scientific and technical input.

See also: Antarctic Treaty; Basel Convention; Berlin Mandate; Convention on Biological Diversity; Convention on International Trade in Endangered Species; Convention on Long-Range Transboundary Air Pollution; Intergovernmental Panel on Climate Change; Kyoto Protocol; Montreal Protocol; United Nations Convention to Combat Desertification; United Nations Framework Convention on Climate Change; U.S. and European politics; World Trade Organization.

International Atomic Energy Agency

• **Categories:** Organizations and agencies; energy
• **Date:** Established July 29, 1957
• **Web address:** http://www.iaea.org

• **Mission**

The International Atomic Energy Agency (IAEA) promotes the peace, health, and prosperity of the people of the world through the use of atomic (nuclear) energy. The IAEA is independent of the United Nations but reports to the United Nations General Assembly, and if violations involving nuclear materials are detected, it reports to the U.N. Security Council. The agency, headquartered in Vienna, Austria, has over twenty-two hundred trained personnel and their support staff. Member nations pay a fee each year as part of their membership but there is also a voluntary fund, the Technical Cooperation Fund, that is used especially in developing countries. The mission of the IAEA is based on three work areas: safety and security, science and technology, and safeguards and verification.

In the safety and security area, the work is focused on helping countries develop standards and procedures for nuclear safety and security. That involves training sessions for untrained personnel, meetings for experts to share information, and planning sessions and training for emergencies. IAEA's budget is geared to the sharing of information with anyone needing nuclear information.

The science and technology area works toward the use of peaceful applications of nuclear science and technology to solve problems in health, poverty, pollution, and other areas of life. The work can be described in three components: technical cooperation, research and development, and energy and electricity. The technical cooperation includes expert advice, personnel, materials, and equipment to support projects that benefit people in developing countries socially or economically. The research and development includes not only the joint research done with IAEA, but also the support of research by different groups all over the world. Any area in which nuclear technology can be valuable is researched but issues in health, environment, poverty, and food are the main focus points. The energy and electricity area of work includes dealing with the energy needs of a country. If the needs can be met with nuclear power, IAEA provides support in equipment, personnel, training, and materials. Ideas that are innovative are especially encouraged in this work. In 2004 IAEA developed the Program of Action for Cancer Therapy (PACT) to aid developing countries in cancer detection and treatment using radioisotope and other nuclear techniques.

Safeguards and verification is the area of IAEA's mission that is most important for world peace. For over fifty years, IAEA has monitored the use of nuclear materials all over the world. The monitoring is not only to check that countries are not using nuclear materials to build weapons, but also that the nuclear materials used in a peaceful manner are used, stored, and secured in a manner that causes no chance of radiation exposure to humans. The United Nations Security Council has requested that IAEA keep a watch on Iran and its use of nuclear materials. The IAEA and its director were awarded the Nobel Peace Prize in 2005.

• Significance for Climate Change

The use of nuclear energy to generate electricity does not generate greenhouse gases to cause global warming. It does not generate smog-producing materials. The use of nuclear energy should not cause any change in the climate unless a disaster spreads radiation into the atmosphere. After the Chernobyl disaster in 1986, the IAEA increased its focus on nuclear safety.

C. Alton Hassell

• Further Reading

Fischer, David. *History of the International Atomic Energy Agency: The First Forty Years.* Vienna, Austria: International Atomic Energy Agency, 1997. This history of the IAEA covers the birth and growth of the agency and the history of nuclear energy during the same period of time. Illustrations, bibliography, index.

U.S. Congress. House. Committee on International Relations. Subcommittee on International Operations and Human Rights. *The Role of the International Atomic Energy Agency in Safeguarding Against Acts of Terrorism.* Washington, D.C.: Government Printing Office, 2001. In addition to discussing the role of the IAEA, this book contains reports on the safety measures necessary to prevent radioactive pollution in the use of nuclear energy.

U.S. Congress. Senate. Committee on Foreign Relations. *Safeguarding the Atom: Nuclear Energy and Nonproliferation Challenges.* Washington, D.C.: Government Printing Office, 2008. Reports the governmental hearings on the IAEA, international security, international cooperation in nuclear nonproliferation, and U.S. policies on nuclear arms control and nuclear nonproliferation. Illustrations.

_______. *The January 27 UNMOVIC and IAEA Reports to the U.N. Security Council on Inspections in Iraq.* Washington, D.C.: Government Printing Office, 2003. Contains the reports to the Senate Foreign Relations Committee of the U.N. Monitoring, Verification, and Inspection Commission and the IAEA on the on-site inspection of Iraq. Bibliography.

See also: International agreements and cooperation; Nuclear energy; United Nations Framework Convention on Climate Change.

International Council for Science

- **Category:** Organizations and agencies
- **Date:** Established 1931
- **Web address:** http://www.icsu.org/

• Mission

The International Council for Science (ICS) was formerly known as the International Council of Scientific Unions (ICSU). It is a nongovernmental organization of research councils or scientific academies, which are national, multidisciplinary bodies, and scientific unions, which are international, disciplinary organizations. These two complementary types of groups provide a wide range of scientific expertise. The mission of ICS includes research, information access, information exchange, and scientific freedom. The research area includes coordinating research by interdisciplinary groups in topics important to mankind's well-being. Climate change is one of those topics.

The ICS develops Internet Web sites to disseminate data and technology and publishes newsletters, books, journals, and proceedings. It supports over six hundred meetings of discipline-specific scientists, as well as multidisciplinary, topic-driven meetings. Support for science education and for exchange of ideas is also part of the group's mission, as is initiation of regional networks of scientists. Scientific freedom is supported by ICS, which defines it as the freedom to research scientific topics without gender, racial, economic, or geographical limitations. ICS cooperates closely with many other national, international, governmental, and nongovernmental groups, especially the agencies of the United Nations.

The funding for ICS comes from member contributions, grants, and contracts. The grants and contracts come from foundations, agencies, and other bodies that financially support scientific research and information sharing. Each member is part of the General Assembly, which elects an executive board and a slate of officers. The officers are members of the executive board and are responsible for the day-to-day operation of ICS. The officers are supported in the day-to-day operations by the Secretariat, the officers, advisors, and staff of ICS located in Paris, France. To expedite scientific research and education in developing countries, ICS is creating four regional offices for Africa, Latin America and the Caribbean, Asia, and the Arab region.

• Significance for Climate Change

With part of its mission to research areas that affect the well-being of the world's population, climate change is one of the major areas of study by the ICS. One of the major committees of ICS is the Scientific Committee on Problems of the Environment (SCOPE). SCOPE not only researches different factors concerning the environment but also publishes reports on the different factors. Other reports, such as *Invasive Alien Species*, *Sustaining Biodiversity and Ecosystem Services in Soils and Sediments*, and *Interactions of the Major Biogeochemical Cycles*, all deal with the environment; many deal with the climate and man's interaction with the climate, both how humans change the climate and how humans adapt to climate change.

In 2008, ICS initiated a major research program on natural disasters, including those caused by weather and climate. The study is designed to help countries plan for disasters, and to determine changes in lifestyle that will reduce loss of life and lessen economic impact of disasters. The study will also research how man may cause or increase the extent of disasters. Weather and climate disasters include events such as droughts, floods, hurricanes, tornados, cyclones, mudslides, and pollution. Another major study initiated in 2008 is to research the human impact on Earth's life-support systems. This study is to fill in the gaps in the knowledge about the global ecosystem, including the climate.

In each regional office, there are programs about climate or the ecosystem. In the Africa region, one of the four science plans is on global environmental change. The plan includes both climate change and adaptation to climate change. The plan is to develop projects in six areas: degradation of land and biodiversity and how it affects humans, the effect of climate change on rainfall, food system resilience, water resources, atmospheric change, and the effect of the ocean on Africa. The Latin

America and the Caribbean regional office held a conference on sustainable energy and another on the world's geosphere/biosphere. The Asia regional office held a meeting to form plans for the coastal cities to adapt to climate change. Other meetings were for sustainable energy and changes in the ecosystem. Training sessions were held for individuals to learn to study environmental problems.

C. Alton Hassell

• Further Reading

Committee on Data for Science and Technology. *Data Science Journal*. Paris, France: Author, 2002. Provides continuing coverage of the state of data science. Produced by the Committee on Data for Science and Technology (CODATA), a part of the International Council for Science.

Ernster, Lars. *ICSU: The First Sixty Years*. Paris, France: International Council of Scientific Unions, 1991. Details the establishment and growth of the International Council for Science.

Hak, Tomas, Bedrich Moldan, and Arthur Lyon Dahl. *Sustainability Indicators: A Scientific Assessment*. Scientific Committee on Problems of the Environment 67. Washington, D.C.: Island Press, 2007. Focuses on the evaluation of sustainable development, environmental monitoring, and environmental indicators. Illustrations, maps, bibliography, index.

Krupnik, Igor, Michael A. Lang, and Scott E. Miller, eds. *Smithsonian at the Poles: Contributions to International Polar Year Science*. Washington, D.C.: Smithsonian Institution Scholarly Press, 2009. Contains the record of the proceedings of a symposium organized as part of the International Polar Year (2007-2008) and sponsored by the International Council for Science and the World Meteorological Organization. Illustrations, maps, bibliography, index.

See also: International agreements and cooperation; Science and Public Policy Institute; Scientific Alliance; Union of Concerned Scientists.

International Geosphere-Biosphere Programme

- **Category:** Organizations and agencies
- **Date:** Established 1987
- **Web address:** http://www.igbp.kva.se

• Mission

The International Geosphere-Biosphere Programme (IGBP) is an international research program devoted to the study of global environmental change, with a focus on the interactions between the solid Earth and its living organisms. The IGBP's purpose is to work toward improving the sustainability of Earth's biosphere. A central secretariat, hosted by the Royal Swedish Academy of Sciences in Stockholm, Sweden, coordinates IGBP's scientific program. The organization has seventy-six member countries and international project offices in North America, Europe, and Australia.

The IGBP studies the interactions occurring among Earth's natural biological, chemical, and physical processes and the effects human activities have on these processes. Sponsored by the International Council for Science, the IGBP collaborates with other programs to gain and disseminate knowledge regarding global environmental change and to make recommendations regarding how best to respond to it. The IGBP, which emphasizes networking and integration, seeks to enhance scientific understanding by encouraging scientists to transcend disciplinary, institutional, and political boundaries in their research.

The International Council for Science established the IGBP in 1987. The international scientific community had recognized that the research efforts of a single country, region, or scientific discipline would not yield sufficient understanding of global environmental change; there was a clear need for international collaborative research. Key findings from the IGBP's initial studies (IGBP-I, 1990-1999) provided the foundations for a second phase of research (IGBP-II, 2004-2013). Phase II, like Phase I, concerns the Earth systems of land, ocean, and atmosphere and the interfaces among them.

• Significance for Climate Change

As of early 2009, IGBP research comprises nine projects: four focused on the major Earth system components of land, ocean, and atmosphere; three on the interfaces between those components (land-ocean, land-atmosphere, and ocean-atmosphere); and two on system-wide integration (Earth system modeling and paleoenvironmental research). The Global Land Project (GLP), cosponsored by the International Human Dimensions Programme on Global Environmental Change (IHDP), looks at how humans transform terrestrial ecosystems and landscapes. The Global Ocean Ecosystem Dynamics (GLOBEC) project studies the effects of global change on the abundance, diversity, and productivity of marine populations. Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) studies how marine ecosystems and biogeochemical cycles react to global change over time periods ranging from years to decades.

Both marine projects are cosponsored by the Scientific Committee on Oceanic Research (SCOR). International Global Atmospheric Chemistry (IGAC), a project cosponsored by the Commission on Atmospheric Chemistry and Global Pollution (CACGP), focuses on the atmospheric chemistry issues facing society. The project seeks to gain an understanding of the role of atmospheric chemistry in the Earth system while determining how changing regional emissions and depositions, long-range transport, and chemical transformations affect air quality.

Land-Ocean Interactions in the Coastal Zone (LOICZ) studies the coastal zone—an interface where land, atmosphere, and ocean interact—as a key player in the functioning of the Earth system. The project is cosponsored by IHDP. The Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) concerns the physical, chemical, and biological processes that transport and transform energy and matter at the land-atmosphere interface. These processes are tightly coupled and highly responsive to climate change. The Surface Ocean-Lower Atmosphere Study (SOLAS) looks at how the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere affect and are affected by climate and environmental change. Cosponsors are CACGP, SCOR, and the World Climate Research Programme (WCRP).

System-wide integration projects include Analysis, Integration, and Modelling of the Earth System (AIMES) and Past Global Changes (PAGES). AIMES focuses on the use of models and observations in reaching a better and more quantitative understanding of the role human action plays in biogeochemical cycles. PAGES supports study of the Earth's past environment as a means for making sound predictions regarding the future.

In addition to its project cosponsors, IGBP collaborates with a number of other international science organizations. IGBP participates in global assessments such as the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment (MEA), and it is part of the Earth System Science Partnership (ESSP).

In July, 2001, during the Global Change Open Science Conference in Amsterdam, the Netherlands, IGBP joined IHDP, WCRP, and the international biodiversity program DIVERSITAS (all ESSP members) to issue the Amsterdam Declaration on Global Change. The statement acknowledged the increasing effect of human activity on food, water, clean air, and the environment and likened some anthropogenic changes to great natural forces in terms of their extent and impact. Warning of the possibility of abrupt, irreversible, and inhospitable environmental changes in response to human actions, the declaration called for a new, multidisciplinary, multinational, and multicultural system of global environmental science to respond to the complex challenges of global change with good and ethical stewardship of the Earth. IGBP was one of the convening organizations of the Second Symposium on the Ocean in a High-CO_2 World, held in Monaco in October, 2008.

Karen N. Kähler

• Further Reading

Kabat, Pavel, et al., eds. *Vegetation, Water, Humans, and the Climate: A New Perspective on an Interactive System.* Berlin: Springer-Verlag, 2004. Part of IGBP's Global Change Series, this volume looks at how the land surface is related to weather and the climate—near-ground, regional, and global. Figures, references, index.

Steffen, Will, et al. *Global Change and the Earth System: A Planet Under Pressure.* Berlin: Springer-

Verlag, 2005. Considers the dynamics of the Earth system before it experienced significant human influence, as well as the changes humans have wrought since then. Part of IGBP's Global Change Series. Figures, references, appendix, index.

Steffen, Will, et al., eds. *Challenges of a Changing Earth*. Berlin: Springer-Verlag, 2002. Collection of papers presented at the Global Change Open Science Conference in Amsterdam in July, 2001. Includes the text of the Amsterdam Declaration on Global Change. Figures, references, index.

See also: Atmosphere; Climate and the climate system; Climatology; Earth structure and development; International agreements and cooperation; Ocean-atmosphere coupling.

International Human Dimensions Programme on Global Environmental Change

- **Category:** Organizations and agencies
- **Date:** Established 1996
- **Web address:** http://www.ihdp.unu.edu

• Mission

The International Human Dimensions Programme (IHDP) is an umbrella organization that funds and coordinates studies relating to the human impact on all biological, physical, and chemical systems and how those impacts relate to patterns of human social organization. An international, interdisciplinary science program specializing in a social science perspective on global change, it is a joint program of the International Council for Science (ICS), UNESCO's International Social Science Council (ISSC), and the United Nations University (UNU).

All IHDP projects address three major questions:

- How do human lifestyle choices and patterns of consumption contribute to global environmental change?
- How are humans affected by changes in the natural environment?
- How can humans reduce their negative effects on natural ecosystems necessary to support continued human existence?

• Significance for Climate Change

IHDP brings together scientific researchers as well as social scientists and political and economic policy makers in order to consider all aspects of human contributions to pressing environmental problems, probable consequences of continued anthropogenic stresses on a variety of ecosystems, and possible response to mitigate and even eliminate some anthropogenic environmental problems. All IHDP programs share a mission to help translate scientific research on environmental change into practical advice for policy makers. These programs and research projects may be local, regional, or global in scale.

IHDP administers six core scientific research projects. Earth System Governance (ESG) studies anthropogenic changes, local to global, in all physical and biological systems on the planet. The overarching goal of all research projects under ESG is to construct appropriate sustainable development responses that can actually be implemented. Some finds of sponsored research projects are published in the journal *Climate and Development*, as well as in the IHDP publication *Institutions and Environmental Change*.

Global Environmental Change and Human Security (GECHS) studies the impact of environmental changes on vulnerable human populations primarily located in the developing world. Flooding, drought, soil erosion, conflicts over access to natural resources, and human population issues are all research topics sponsored by GECHS, which publishes its research reports in the journal *AVISO*. GECHS encourages cooperation and communication between climate researchers and political leaders in the developing world.

The Global Land Project (GLP) sponsors projects on local and regional levels to study how human interact with both land and water-based systems. GLP projects also give direction on how humans might interact with those systems in more sustainable ways. The GLP projects also consider the negative impact global economic changes produce on local and regional environmental systems, primarily in the developing world.

Industrial transformation (IT) research initiatives look for ways to reduce the negative impact technology developments will continue to have on the natural environment, specifically in the developing world. IT-sponsored projects target energy production, distribution and usage, food production and consumption patterns, and urban development.

Land-Ocean Interactions in the Coastal Zone (LOICZ) is more narrowly focused than the other IHDP core projects. LOICZ research projects focus on coastal communities that are among the first to feel negative effects of environmental changes in the form of soil erosion, depletion of fishing stocks, increased water salinity, overdevelopment, decreased freshwater supplies, and increased vulnerability to catastrophic weather events.

Urbanization and Global Environmental Change (UGEC) projects study urban planning and lifestyle choices as well as patterns of consumption of energy, food, and goods and services. The research results are then used to suggest planning policies that would allow urban areas to become more environmentally sustainable and reduce the impact of environmental change on the urban poor.

In addition to the six core scientific research projects and their subprojects, IHDP shares joint responsibility with Earth System Science Partnership (ESSP) to promote research into climate change, agricultural responses and food security. IHDP also funds smaller pilot projects that allow younger researchers opportunities to secure funding and collaborate on an international scale. The goal of many of the pilot projects is to seek ways to reduce carbon production. IHDP also participates in a variety of research networks. The four primary research networks include the Mountain Research Initiative (MRI), Population and Environment Research Network (PERN), System for Analysis Research and Training (START), and Young Human Dimensions Researchers (YHDR) including students associated with research teams. The development of research networks allows researchers in developed countries to share funding, access to research information, and expertise with colleagues in the developing world. IHDP specifically funds research projects on issues of concern to societies in both the developed and developing world.

In its second decade, 2006-2016, IHDP looked forward to increased funding for pilot projects in order to increase the scale of the projects until some could become additional core scientific projects. As environmental concerns become more urgent and the capacity and economic feasibility of sustainable technologies more widely available, IHDP anticipates playing a wider, more public role in drafting policy positions related to environmental change and its impact on the human community.

Victoria Erhart

• Further Reading

Houghton, John. *Global Warming: The Complete Briefing*. 4th ed. New York: Cambridge University Press, 2009. A readily accessible, nontechnical introduction to the scientific research supporting theories of global warming and the impacts of climate change.

Weart, Spencer. *The Discovery of Global Warming*. Rev. and expanded ed. Cambridge, Mass.: Harvard University Press, 2008. Covers global warming from both a scientific as well as a political perspective. Includes a discussion on the history of global warming theory.

Young, Oran R. *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*. Cambridge, Mass.: MIT Press, 2002. Study conducted under the auspices of the IHDP that addresses both the contributions of human institutions to environmental changes and the ability of those institutions to respond to those changes.

See also: Climatology; Intergovernmental Panel on Climate Change; International agreements and cooperation; International Council for Science; International Geosphere-Biosphere Programme; International Institute for Applied Systems Analysis; Scientific credentials.

International Institute for Applied Systems Analysis

- **Category:** Organizations and agencies
- **Date:** Established 1972
- **Web address:** http://www.iiasa.ac.at

• Mission

The International Institute for Applied Systems Analysis (IIASA) is an interdisciplinary organization founded in 1972 with the aim of promoting East-West cooperation during the Cold War. It now devotes its efforts to complex systems problems of international or global scope. Through its various programs, IIASA conducts research into major economic, demographic, social, and environmental issues, including global climate change. The scope of IIASA research projects is huge, beyond the capabilities of any one country or national research institution to manage. IIASA research projects collect massive amounts of data on a variety of factors, such as the connection between climate change and air pollution, and then build computer simulations and statistical models based on various "what if" future scenarios. Since the days of its founding in the midst of the Cold War between the United States and the Soviet Union, IIASA has maintained a position of strict political neutrality in its research projects. At the same time, IIASA tries to build scientific consensus in order to present credible research findings to technical advisors for political policy makers.

IIASA is financially supported by contributions from fifteen member countries in both the developed and the developing world. In the past, IIASA conducted research projects of topics requested by member countries. Increasingly, however, IIASA is shifting its expertise in quantitative modeling and computational technologies to focus on problems of more urgency for the developing world. This allows IIASA to assist in the construction and implementation of policies relevant to global change. Most research projects focus on one or more problems and interconnections between climate policy, energy production and consumption, water management, agricultural policy, sustainable development, pollution studies, and the interplay between environmental and economic policies. IIASA devises models to reduce future uncertainties about the consequences of current policy options. IIASA divides its core research projects into three very broad categories: energy and technology, population and society, and environment and natural resources.

• Significance for Climate Change

Since the 1990's, IIASA has helped develop models of global energy production, consumption, and pollutant emissions. As developing economies become increasingly industrialized, IIASA provides information on the economic and environmental consequences of these changes, particularly how rising air pollution will affect the ability of boreal forests to function as carbon sinks to mitigate negative impacts of climate change. IIASA projects also provide models to forecast the environmental impact of changes in the global economy, particularly as previously centrally planned economies move in the direction of free-market economies.

IIASA projects under this heading study and analyze the very complex interdependence among population groups, economic development, and environmental impact. Computer simulations indicate the probable social, political, economic, and environmental consequences of probable population projections. Water management, long-term food security, biodiversity, and other environmental impacts related to population change are forecasted and analyzed. Research projects in this category also study age disparity among various national populations and what economic scenarios will be necessary to fund the social security, pension obligations, and health care costs of those populations.

IIASA research projects in this category study all aspects of the human impact on the natural environment, including climate change. Since its foundation, IIASA has been involved in forestry research and the impact of land use and land cover change research. IIASA continues its long-range studies on the global management of boreal forest areas and its impact on global carbon emissions. Recently IIASA projects have focused on cost-effective methods to reduce air pollution, particularly in the developing world. One of the larger projects is the Transboundary Air Pollution Project with India and China. Increasingly, IIASA addresses regional environmental problems in order to provide a scientific basis upon which countries can negotiate specific reductions in carbon dioxide, sulfur dioxide, and other greenhouse gas emissions that have a negative impact on the global climate.

All IIASA projects study global change, whether that change is demographic, political, economic, or environmental. Through increasingly sophisticated and comprehensive computer simulations, IIASA provides scientifically credible information on global greenhouse gas emissions, energy supply and demand, population increases and migration patterns, land use change, and transboundary air and water pollution. It then forecasts probable consequences of both current policies and various policy options to mitigate the harmful effects of anthropogenic impacts on all aspects of the natural environment.

Victoria Erhart

• Further Reading

Battarbee, Richard. *Natural Climate Variability and Global Warming: A Holocene Perspective.* New York: Wiley-Blackwell, 2008. Studies the Earth's naturally variable climate system and global warming on a variety of timescales, from the near future to a millennium away. Carefully lays out the paradigms and problems in Holocene climate research.

Schrattenholzer, Leo, et al. *Achieving a Sustainable Global Energy System: Identifying Possibilities Using Long-Term Energy Scenarios.* Northampton, Mass.: Edward Elgar, 2004. This study of responsible long-term energy policy was produced in association with the IIASA and exemplifies the group's contributions to such research.

Yoshimoto, Atsushi, ed. *Global Concerns for Forest Research Utilization: Sustainable Use and Management.* New York: Springer, 1998. Collects papers presented at a 1998 conference on global forest issues and climate change in Japan. Covers various modeling efforts to measure the impact of climate change and global warming on the global forest sector on a variety of timescales. Includes case studies of regional forest resources, as well as considerations of global forest resources as a whole.

See also: Climate models and modeling; Climate prediction and projection; Geographical information systems; International agreements and cooperation; Microwave sounding units; Nonlinear processes.

International Policy Network

- **Category:** Organizations and agencies
- **Date:** Established 2001
- **Web address:** http://www.policynetwork.net

• Mission

A nongovernmental, nonpartisan organization that is charity-based in the United Kingdom and a nonprofit in the United States, the International Policy Network (IPN) highlights the dangers of linking environmental regulations to trade rules. The IPN claims to achieve its vision by "promoting the role of market institutions in certain key international policy debates: sustainable development, health, and globalization and trade." In the area of sustainable development, the group takes the stand that, too often, sustainable development involves policies that may, in fact, perpetuate environmental problems and poverty. Although acknowledging a relationship between health, wealth, and a clean environment, IPN believes that sustainable development policies focus too much on sustainability at the expense of development.

To achieve its mission, IPN pursues a number of activities: It supports individuals and groups who profess similar beliefs with Web sites, advice, and small grants. It sponsors workshops, seminars, and conferences and cooperates with groups to produce books, monographs, and articles that express opinions on issues for the media. At international conferences, it helps coordinate the participation of experts in various fields that relate to the interests of IPN and promotes its partners among the news media.

In the area of health, IPN addresses issues such as access to medicine, barriers that reduce the spread of infectious diseases, and the impact of regulation on modern technologies related to nutrition and health. The group feels that the policies of governments and other agencies are often enthusiastic but not practical, thus wasting funds and labor hours on ill-conceived initiatives that ultimately cost lives. In the area of trade, IPN espouses the benefits of freedom to trade; trade is considered fundamental to eliminating poverty and gaining economic freedom. The organization also, however, sees as dangerous the linking of environmental and labor regulations with trade rules. IPN bases its vision of sustainable development on achieving both environmental and human well-being through eliminating poverty and promoting progress.

- **Significance for Climate Change**

IPN released a report in 2004 saying "climate change is 'a myth'" and that warnings of environmental disaster due to climate change are "fatally flawed." The activities of the organization are focused on resisting attempts to stave off global warming at the expense of economic interests.

Victoria Price

See also: American Enterprise Institute; Catastrophist-cornucopian debate; Cato Institute; Competitive Enterprise Institute; Heartland Institute; Heritage Foundation; Institute for Trade, Standards, and Sustainable Development; Nongovernmental organizations; Skeptics.

International Union for Conservation of Nature

- **Categories:** Organizations and agencies; environmentalism, conservation, and ecosystems
- **Date:** Established October, 1948, as International Union for the Protection of Nature; name changed to International Union for Conservation of Nature and Natural Resources in 1956
- **Web address:** http://www.iucn.org

- **Mission**

The International Union for Conservation of Nature (IUCN), formerly the World Conservation Union, is a hybrid organization of states, state agencies, and nongovernmental organizations that facilitates and encourages the conservation and equitable use of nature and natural resources. It was founded in 1948 and has gone by several names in its history (recently reverting from the World Conservation Union to its former title, the International Union for Conservation of Nature). Its Secretariat is headquartered in Gland, Switzerland, but it has a staff of one thousand experts in sixty nations which coordinates several theme-based programs that focus on issues such as forests, gender, and business and biodiversity. Under the IUCN are six Commissions, the most prominent being the Species Survival Commission, which updates the Red List of threatened species; the Commission on Environmental Law, which has facilitated negotiations on several conservation treaties; and the World Commission on Protected Areas. The IUCN is supported by over eleven thousand volunteer scientists in over 160 nations.

- **Significance for Climate Change**

The IUCN position on climate change is that nations should reduce greenhouse gas emissions by 50 percent below 1990 levels by 2050; use ecosystem-based management to mitigate and adapt to warming; and prioritize efforts on behalf of vulnerable peoples and ecosystems. Its research and communications emphasize linkages between conservation, energy use, globalization, and climate change. Internally, much of this work is coordinated by its Climate Change Initiative.

In its role as an expert adviser, the IUCN has advised members to the UN Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity, and other agreements on climate change mitigation, adaptation, and impacts, *inter alia*. It has alerted parties to the UNFCCC that if global average temperature were to rise 2° Celsius or more above preindustrial levels, massive extinctions and profound ecosystem changes would result. As a complement to its Red Lists, the IUCN has calculated the number of species that are currently of favorable conservation status that would be endangered by global warming (for example, 51 percent of currently unthreatened corals could be endangered by climate change).

The IUCN is one of the most prominent international organizations drawing attention to the linkages between warming, conservation, and human well-being. It assesses and promotes natural resource management practices that would aid mitigation and adaptation to global warming. For example, it advocates inclusion of REDD (Reduced Emissions from Deforestation and Degradation) in forthcoming climate agreements.

In conjunction with other organizations, the IUCN has worked to mainstream issues that have been sidelined by the dominant discussion, such as the role of indigenous peoples in climate policy and the relationship between gender and natural resource use.

Adam B. Smith

See also: Conservation and preservation; Environmental law; Environmental movement; International agreements and cooperation.

International waters

• **Category:** Laws, treaties, and protocols

International waters are less regulated than national waters, allowing environmentally damaging activities to occur. In addition, as global warming continues, changes in shorelines and the melting of the Arctic ice cap may create international complications.

• Key concepts

exclusive economic zone: a zone extending about 320 kilometers from a nation's shore in which all economic rights are granted to that nation

freedom of the seas: the principle that outside of water adjoining nations' shorelines, all nations have the right of free passage and use of the ocean's resources

territorial waters: areas within bodies of water that are within a nation's borders and subject to all laws and regulations of that nation

United Nations Convention on the Law of the Sea: an international agreement outlining the rights of nations regarding territorial waters, economic zones, and rights of passage

• Background

Nearly three-fourths of the world's surface is covered by water. Each terrestrial or oceanic ecosystem has developed depending upon the availability of a certain type and quantity of water. Major bodies of water and the atmosphere work together to form a circular system. The atmosphere affects glaciers, ice caps, rivers, lakes, seas, and oceans, while simultaneously these bodies of water affect the atmosphere. Changes in one directly result in changes in the other. Because international waters lie outside national boundaries, caring for them is often a low priority.

• Pre-Twentieth Century History

With the Portuguese and Spanish explorations of the fifteenth century, Europeans began to have aspirations for global dominance. New claims over the ocean were put forward, first by Portugal and Spain, which were quickly followed by the British and Dutch. In the early seventeenth century, to reduce conflict, Dutch jurist Hugo Grotius put forward the freedom of the seas theory, that all oceans and adjoining seas could be used by everyone for any purpose. By the beginning of the eighteenth century, this principle was accepted by all European nations, with the provision that each nation controlled the first 4.8 kilometers of water adjacent to its shoreline. In certain strategic straits, all vessels were allowed to travel. This was the norm for the next two hundred years. The assumption during this period was that the oceans were so vast that nothing people could do would cause any harm to them.

• Changes in the Twentieth Century

By the dawn of the twentieth century, it was becoming clear that not all the ocean's resources were inexhaustible. Not wanting to lose resources, in 1945 the United States claimed the entire continental shelf and all the water above it. Because of this, other countries extended their territorial claims to 19.3 kilometers off their coasts. The United Na-

A Chinese natural-gas drill begins operations in disputed territory of the East China Sea very near the border of Japan's exclusive economic zone in September, 2005. (AP/Wide World Photos)

tions organized the Conference on the Sea in 1958. Two more conferences were held, leading to the negotiation of the United Nations Convention on the Law of the Sea. This agreement recognized new economic realities, as well as assigning responsibility for preserving the ocean's resources to all nations. A 19-kilometer territorial limit from the shoreline was formally recognized, as well as the 320-kilometer exclusive economic zone. The country controlling a given economic zone was formally charged with protecting the oceanic environment within it. Free navigation by all countries was allowed in this zone, in international waters, and through strategic straits. It was formally agreed that in international waters, all nations would share both the right to use environmental resources and the responsibility to protect them.

• Effects of Climatic Changes on International Waters

The assumption that human actions can have little effect upon oceans has been discarded. The direct effect of Earth's oceans upon the climate has become well known, as the global effects of weather patterns such as the El Niño-Southern Oscillation and La Niña have become understood. In the Northern Hemisphere, most of the Atlantic Ocean and much of the western Pacific Ocean increased in temperature by at least 1° Celsius between 1990 and 2004. In some locations, water temperatures have increased by more than 2° Celsius. One of the most visible maritime biological changes is the bleaching of coral and the slow destruction of coral reefs caused by changes in both temperatures and currents.

The currents are a necessary part of the ocean's ecosystem. They help equalize the salinity and other aspects of seawater. Some parts of the ocean are becoming fresher, and some are becoming more acidic. Aquatic life is often more sensitive to subtle environmental changes than are land-based creatures, and changes in their habitats can be devastating both for sea creatures and for the humans that depend on them.

The melting of the polar ice caps also poses potential problems for island nations and for some continental nations that have large amounts of territory close to sea level. Many of the islands in the Pacific Ocean are not very high above sea level. With the projected sea-level rise during the twenty-first century, these islands face the prospect of losing much of their land. This loss will place great pressure on their inhabitants to take drastic steps to survive. It may become necessary for other nations to accept immigrants from these areas.

• Context

The oceans constitute an extremely complex system in themselves, and that system is merely a component in the larger and more complex global climate system. The full effect that climate change will have upon international waters remains unclear. Because historically much less study has been done in the world's oceans than on the land, scientists do not have the breadth of knowledge needed fully to understand physical and biological oceanic systems. Thus, it cannot be said with certainty when climatic changes will have catastrophic effects in maritime ecosystems. However, it is certain that those effects will not respect national boundaries. So much of the oceans lie outside of territorial waters that efforts to protect them must take place largely in international waters.

Climate change is already causing dramatic changes in places such as the Arctic Ocean. This not only affects the plants and animals in the region, but it is also stirring up new conflicts among the nations that border this ocean. Once again, the desire for economic supremacy is pushing nations to enforce their rights in the territorial and international waters of the Arctic. For example, in 2008, Norway detained Russian fishing trawlers that they claimed were in their territorial waters, while Russia claimed the area was open to all nations. Thus, climate change is causing not only physical changes but political changes as well. As changes in other international waters become more pronounced, similar conflicts might arise over resources in those areas that countries believe are vital to their well-being. The effect of climate change on international waters can directly touch people in all parts of the world.

Donald A. Watt

• Further Reading

Gore, Al. *An Inconvenient Truth: The Crisis of Global Warming*. Emmaus, Pa.: Rodale, 2006. This popular book contains chapters on the effects of global warming on the polar ice caps and how they will affect the oceans.

Grotius, Hugo. *The Free Sea*. Reprint. Indianapolis: Liberty Fund, 2004. Along with the classic work on the subject, this volume includes a contemporary critique and Grotius' response.

Strati, Anastasia, et al., eds. *Unresolved Issues and New Challenges to the Law of the Sea: Time Before and Time After*. Leiden, the Netherlands: Martinus Nijhoff, 2006. Focusing on areas of potential weakness in the treaty, this book examines how the document might apply to such issues as migrating fish populations.

United Nations. *United Nations Convention on Law of the Sea*. Hauppauge, N.Y.: Nova Science, 2008. The United Nations document that defines the international law of the sea.

See also: Arctic seafloor claims; El Niño-Southern Oscillation; La Niña; Marginal seas; Maritime climate; Ocean acidification; Ocean-atmosphere coupling; Ocean disposal; Ocean dynamics; Ocean life; Reefs; Sea-level change; United Nations Convention on the Law of the Sea.

Inter-Tropical Convergence Zone

• Category: Meteorology and atmospheric sciences

• Definition

The Inter-Tropical Convergence Zone (ITCZ) is a low-pressure belt located near and parallel to the Earth's equator, within a few degrees of latitude. Because it is a low-pressure belt and located in the vicinity of the equator, near-surface winds on both sides of this belt tend to converge into the belt. A band of clouds and accompanying precipitation is associated with the ITCZ, which can therefore be easily identified from satellite pictures.

The wind on the north side of the ITCZ comes from the northeast (blowing toward the southwest), and therefore, by meteorological convention, is called the "northeasterly." The obverse wind on the south side of the ITCZ is the "southeasterly." The northeasterly and southeasterly are also historically called "trade winds," because explorers, navigators, and merchant fleets once used these winds to sail to many tropical regions for trade and adventure. Thus, the ITCZ is the belt where the trade winds meet.

The ITCZ migrates slightly, oscillating across the equator with the change of seasons. It is primarily located north of the equator, although during winter in the Northern Hemisphere it sometimes moves to the south of the equator. The ITCZ can often be well organized, in the sense that the low pressure, clouds, and precipitation associated with the ITCZ form a solid band structure and make almost an entire circle around the globe. However, this well-organized structure can break down from time to time. When it breaks down, the ITCZ becomes separated into several blocks or a few segments.

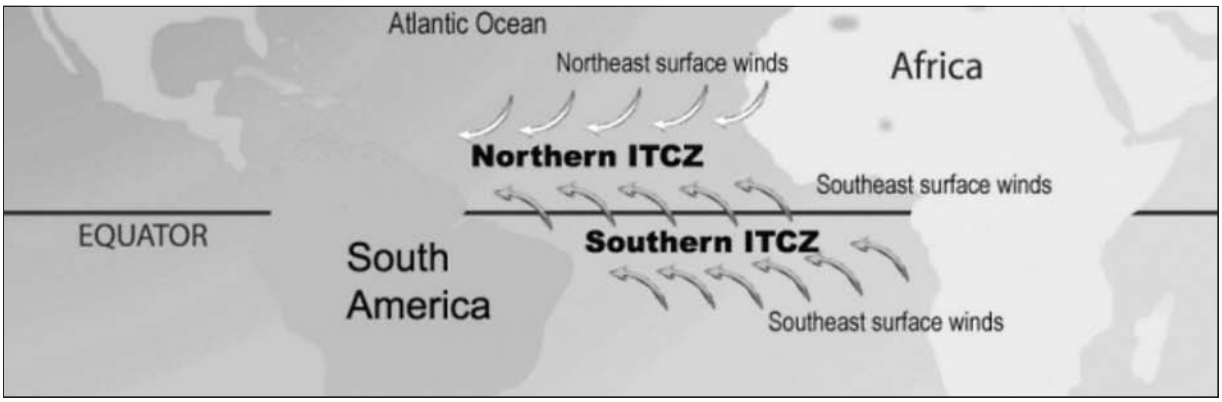
• Significance for Climate Change

The ITCZ is an important atmospheric phenomenon in tropical meteorology. In meteorology, a low-pressure center always draws air flows around it coming in, causes convection, and therefore generates a weather system. The ITCZ serves precisely this role. As the trade winds converge into the low-pressure belt, air starts to ascend to higher altitudes.

Because the ITCZ is typically formed over the tropical oceans, the air in the zone is very moist. The ascending of this moist air in the ITCZ typically leads to cloud formation as the air condenses at higher, colder altitudes. As the air continues to rise and condense, water will eventually precipitate back to the surface. In the ITCZ, this asending stream of tropical air forms the ascending branch of the Hadley cell. This air-circulation cell ascends in the tropics as a result of convection in the ITCZ, moves outward toward the poles, descends in the subtropical regions, and returns inward toward the equator at lower altitudes.

Hadley circulation thus typically transports warm, moist, tropical air to higher latitudes at upper levels. The air gradually cools and dries out as it travels poleward. In the subtropics, about 30° latitude north and south of the equator, the air begins to descend. This effect is believed to cause many of the large deserts in the subtropics, such as the Sahara Desert, because the descending air has lost most of its moisture to precipitation before it descends. Thus, the ITCZ plays an important role in global atmospheric circulation and global climate.

As a driving engine of global atmospheric circulation, the ITCZ plays a great enough role in Earth's climate that any change in the position and intensity of the ITCZ may have significant effects upon the climate. The ITCZ itself comprises the planet's deepest convective cloud systems with the



The northern Inter-Tropical Convergence Zone is created by the collision of the northern and southern trade winds, whereas the southern Inter-Tropical Convergence Zone results from two groups of southern winds squeezing together. (NASA-JPL) most frequent thunderstorm activities and produces the greatest rainfall on the Earth. The Hadley circulation, driven in party by the ITCZ, has a profound impact on a global scale. For example, the intensification of the ITCZ may cause more evaporation of water vapor from tropical oceans and enhance the transport of water vapor to high latitudes.

Many scientists believe that the ITCZ may intensify and produce even more precipitation with the increase of global surface temperature. The position, movement, and intensification of the ITCZ are also influenced by various climate regimes, such as the El Niño-Southern Oscillation and La Niña events. Scientists have also shown that when the ITCZ breaks down, some of its segments can form into tropical disturbances, the initial stage of tropical cyclones, hurricanes, and typhoons. However, it is still unclear whether global warming can cause more frequent breakdown of the ITCZ, thereby producing more tropical storms, although scientists do believe that hurricane intensity will increase as the climate warms.

Chungu Lu

• Further Reading

Ahrens, Donald C. *Essentials of Meteorology: An Invitation to the Atmosphere*. 4th ed. New York: Brooks/Cole, 2005. One of the most widely used introductory books on atmospheric science. The book covers a wide range of topics on weather and climate and places the ITCZ in the context of global weather patterns.

Henson, Robert. *The Rough Guide to Weather*. 2d ed. New York: Rough Guides, 2007. General, popular overview of meteorology that includes discussion of the ITCZ.

Levinson, D. H., et al. "State of the Climate in 2007." *Bulletin of the American Meteorological Society* 89, no. 7 (July, 2008): special supplement. Comprehensive overview of climatological issues and advances in the early twenty-first century. This annual assessment of global and regional climate status includes the status of the ITCZ.

Lu, J., G. A. Vecchi, and T. Reichler. "Expansion of the Hadley Cell Under Global Warming." *Geophysical Research Letters* 34 (2007). This paper examines the change in the Hadley circulation forced by the ITCZ in response to global warming, indicating that the Hadley cell experienced a northward expansion.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Textbook for students of atmospheric sciences; includes discussion of the ITCZ.

See also: Atmospheric dynamics; Atmospheric structure and evolution; Average weather; Climate and the climate system; Climate variability; Climate zones; El Niño-Southern Oscillation; Global climate; Hadley circulation; La Niña; North Atlantic Oscillation; Rainfall patterns; Tropical climate; Tropical storms.

Invasive exotic species

• **Categories:** Animals; plants and vegetation

With climate change come changes in species distributions. Invasive exotic species in particular can have significant effects upon other species and the structure and function of entire ecosystems.

• Key concepts

exotic species: a species found in an area where it is not native

habitat: an area normally inhabited by a particular species

invasive species: a species whose population grows out of control and negatively affects other species

niche: the role of a species within its ecosystem

preadaptation: the ability of a species to move into a new ecosystem or to assume a new niche as a result of adaptations it already possesses

• Background

An exotic species is a creature found in an area to which it is not native. Species that succeed after arriving in new areas, whose population growth is not limited by natural controls, and that negatively affect other species in their new ecosystems are considered invasive exotics. Such species often evince preadaptations for surviving differences in climate, so global climate change increases the threat they pose of rapidly invading new ecosystems.

Many exotic plants can only exist in new areas with special care and conditions, such as soil fortified with nutrients, a special watering regime, artificial lighting, or protection from cold. Many landscape plants, agricultural plants, domesticated livestock, and pets are exotic plants or animals that benefit humans when brought to new areas. Invasive exotic species spread uncontrollably and become problems for native species and humans. Often, their invasive potential is not apparent until long after they have become established in a new niche.

• Exotics and Global Warming

Global warming is one aspect of the more complex phenomenon of global climate change, and the bigger picture of climate change must be kept in mind relative to invasive exotics. Among other attributes, global climate change can include changes in temperature ranges; timing and amount of precipitation; wind patterns; frequency and intensity of storms; and frequency, intensity, and timing of lightning-started fires. Such changes can dramatically influence living creatures and favor invasive exotics.

Invasive exotic species are often adapted to be effective travelers and colonizers. Many plants can travel on animals, using hooked spines or sticky hairs that allow them or their seeds to adhere to clothes or fur. Lizards and insects may readily enter small openings in packing crates or suitcases and are inadvertently taken to new places. Other plants and animals can be dispersed over great distances by wind. Seeds often survive in the digestive tracts of animals that consume their fruit and are thus dispersed to distant locales. Wood pallets and goods, necklaces made with exotic seeds, and handicrafts made from palm leaves can contain insects and other plant pests or diseases that emerge after arrival at a new place.

Most creatures on the move do not survive the trip. Where they land is unpredictable, and most die, unable to cope with their new environment. They may be unable to reproduce for lack of a mate or appropriate breeding conditions. Those that survive are often adaptable and reproduce rapidly.

• Biodiversity and Interspecies Relationships

Biodiversity is a result of adaptations to local conditions that hone the survival potential of each species. An ecosystem includes a community of living organisms interacting with their physical environment. The species fill unique niches, together fitting into the ecosystem like a hand fits into a glove. Each finger represents a species, and each has a defined space and role within the ecosystem. In a stable ecosystem, species work together smoothly. When a new species is introduced, it is like trying to fit a sixth finger into a five-fingered glove. The exotic species may displace a native species and take its place within the glove, or it may constrict the population of native species so that it carves out a new space within the glove. It may alter the glove in such a way as to form a suitable place in which to exist. These habitat alterations may affect the survival of native species and the ability of the ecosystem to function appropriately. Adaptation to specific conditions is beneficial only so long as those conditions prevail. Changes in the physical environment or in the species composition of an ecosystem can cause minor to major disruptions.

Global climate change reshuffles the deck of biodiversity, and new winners and losers are likely to emerge. Some species hold better cards than others: They are preadapted to specific changes in their ecosystems. Exotic species are often among those; they have already overcome numerous obstacles to establish themselves in their new habitat. Native species, especially specialists with specific adaptations to an existing environment, are often unable to adapt to changed conditions.

• Why Exotics Become Invasive

When exotic plants and animals move or are moved from their native habitat to a new area, they often leave competitors, predators, and diseases behind, allowing their populations to grow unimpeded. If a species produces many offspring and has an easy means of dispersing, its population can grow rapidly, displacing, disrupting, or eliminating other species. In such circumstances, it has become invasive. Native species can become invasive also, but only if changing conditions or human impacts eliminate their natural controls. Invasive exotic species are found everywhere in the world.

• Prognosis

The melting pots of Florida, California, and Hawaii are experiencing severe problems from exotic invasives. They have subtropical climates that favor introduction of exotic plants and animals. Although often for local use, many such plants are also farmed for markets in more northern areas, where they might only survive indoors as pets, house plants, or outdoor perennial plants. Through the pet trade, many species of tropical fish, lizards, and parrots are breeding in Florida.

Interactions among exotics often exacerbate their effects upon an ecosystem, as introduced plants provide important food sources for introduced animals. In Florida, consumption of ornamental plants by exotic green iguanas (*Iguana iguana*), of plants and small animals by black spiny-tailed iguanas (*Ctenosaura similis*), and of animals as large as small dogs and cats by two-meter-long Nile monitors (*Varanus niloticus*) are regional problems that could spread northward with global warming. So, too, could the Burmese python (*Python molurus bivittatus*)—at up to six meters long and weighing ninety kilograms, one of the largest snakes in the world. It has been estimated that this snake could survive in the wild as far north as Washington, D.C. It presently breeds in the Everglades ecosystem, where more than two hundred have been captured. Sources for this population include pets lost or released by owners and some whose escapes were facilitated by hurricane-related damage.

Exotic plants once treasured for their blossoms or other attributes have invaded areas throughout North America and have the potential to spread farther north as the climate warms. Purple loosestrife (*Lythrum salicaria*), a native of Eurasia and widespread as an ornamental, replaces native plants and reduces habitat quality for wildlife as it forms dense stands in wetlands across North America. The Australian paperbark tree (*Melaleuca quinquefolia*) and Brazilian pepper (*Schinus terebinthefolius*), originally introduced as ornamentals, have formed dense monocultures in what had been habitats to a diversity of native plants and animals in south Florida. They are poised to spread northward as the climate warms. Kudzu (*Pueraria lobata*) vines, introduced from Asia to Gulf coast states in the 1800's to control erosion, often blanket ground, shrubs, and trees and are already expanding northward, following mild winters.

Major invasions of marine environments are also occurring around the world, as marine life is transported in the ballast water of ships. These invasions will alter natural ecosystems even further, as global climate change alters the temperature and salinity of the oceans, creating new opportunities for invaders.

Kudzu grows over abandoned vehicles in Tennessee. The invasive plant is extremely hearty and will grow over almost anything that is not moving. (©iStockphoto.com/Roel Smart)

• Context

As ecosystems are altered as a result of global climate change and enhanced invasions of exotic plants and animals, dramatic shifts in the populations of native species will result, causing the extinction of many species that are unable to compete favorably with their new neighbors. Shifts in ranges will vary from species to species, depending on their dispersal abilities, breeding success, and a diversity of habitat needs. A warmer climate might favor extinction of cold-adapted species and northward shifts for southern species, but if favored food plants do not shift at the same time or if a new range includes a predator or disease not previously encountered, the move could mean extinction.

Jerome A. Jackson

• **Further Reading**

Cox, George W. *Alien Species and Evolution: The Evolutionary Ecology of Exotic Plants, Animals, Microbes, and Interacting Native Species.* Washington, D.C.: Island Press, 2004. Considers the long-term ecosystem impacts of exotic, invasive species.

Occhipinti-Ambrogi, A. "Global Change and Marine Communities: Alien Species and Climate Change." *Marine Pollution Bulletin* 55 (2007): 342-352. Reviews linkages between exotic invasives in marine environments and climate change.

Willis, K. J., and H. J. B. Birks. "What Is Natural? The Need for a Long-Term Perspective in Biodiversity Conservation." *Science* 314 (November 24, 2006): 1261-1265. Focuses on recognition and understanding of long-term versus short-term changes within ecosystems; addresses the need to disentangle impacts of long-term climate change from short-term impacts of invasive species and wildfires in order better to address conservation challenges.

See also: Convention on International Trade in Endangered Species; Ecosystems; Endangered and threatened species; Extinctions and mass extinctions.

Iran

• **Category:** Nations and peoples

• **Key facts**

Population: 66,429,284 (July, 2009, estimate)

Area: 1,628,554 square kilometers

Gross domestic product (GDP): $842 billion (purchasing power parity, 2008 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 288 in 1990; 480 in 2000

Kyoto Protocol status: Ratified 2005

• **Historical and Geopolitical Context**

In 1979, millions of Iranians succeeded in ousting Muhammad Reza Shah Pahlavi (1941-1979), the Shah of Iran and son of Reza Khan, who came to power in 1921 via a coup. While the Shah was popular in the West, some believe he tried to modernize Iran too rapidly and did not adequately adapt his political institutions to the economic and social changes that ensued. Inspired by hopes for democracy, economic prosperity for all classes, gender equality, and a leadership that would not allow Iranian culture to be swallowed up by the West, many Iranian women joined the revolt that stunned the world. The Iranian Revolution was led by Ayatollah R. Khomeini, who had been living in exile in Paris, France.

Today, the Islamic Republic of Iran is a unitary Islamic republic with a sole legislative body, the Islamic Consultative Assembly. Since 1989, the spiritual leader of Iran or Rahbar has been Ayatollah Sayyed Ali Khamenei. The capital of Iran is Tehran, and Farsi (Persian) is the official language. In 2000, crude and refined petroleum composed 85.4 percent of the nation's exports, which totaled more than $28 billion. Trading partners included Japan, China, Italy, and Taiwan. Petroleum and natural gas accounted for 57 percent of $181 trillion in revenues. Since 2005, Mahmoud Ahmadinejad has served as president of the Republic of Iran. While relations with the United States have been shaky, newly elected U.S. president Barack Obama emphasized the importance of communicating with Iran, a country the George W. Bush administration had called "dangerous."

In 2006, the International Atomic Energy Agency (IAEA) demanded that Iran halt uranium enrichment for its nuclear program, which Iran claimed was to be used for peaceful purposes. While Obama eschewed Iran's pursuit of nuclear weapons, he said "it is important for us to be willing to talk to Iran, to express very clearly where our differences are, but where there are potential avenues for progress."

• Impact of Iranian Policies on Climate Change

Iran ratified the Kyoto Protocol in 2005. The decision was endorsed by the Guardian Council, which discussed Iran's plan to adhere to the U.N. Stockholm Declaration regarding sustainable development; the Stockholm Declaration put forth principles that might guide the world's nations to preserve and enhance the human environment. As such, the Office of Climate Change in Iran's Environmental Protection Agency released a report stating that since the Kyoto Protocol came into force in February, 2005, new activities designed to decrease greenhouse gas (GHG) emissions were occurring under the U.N. flexible mechanisms program of the protocol. In addition, it was thought that there was a need to immediately sign the protocol, because an upcoming summit in 2005 was to focus on technology transfer and financial aid to be given by developed, Annex I nations to developing, non-Annex I nations, and only parties to the Kyoto Protocol could participate.

• Iran as a GHG Emitter

Iran is ranked eighteenth of the highest GHG emitters. Developing nations, all of whose emissions rose during the first decade of the Kyoto Protocol, include China (now the top GHG emitter), India, Brazil, Mexico, South Korea, Indonesia, South Africa, and Iran. These eight nations accounted for 30.1 percent of global GHG emissions in 2000; the share of GHG emissions was 40 percent for the developing, non-Annex I countries. The developing countries have been increasing their shares; in 1990, the relative share was 32 percent. For the year 2000, twelve of the top twenty countries were Annex I countries, including seven of the top ten emitters. In 2000, the Annex I countries accounted for about 60 percent of the top-twenty GHG emissions. The number-one emitters of each group were the top two emitters overall: the leading developing, non-Annex I country, China, and the leading developed, Annex I country, the United States, now the second highest of the top-twenty GHG emitters. Together, China and the United States account for over one-third of total global GHG emissions.

While the Organization of Petroleum Exporting Countries (OPEC) Gulf States have the highest GHG emissions, data from 2000 show that—of the top twenty emitters—those with highest per capita emissions were the Annex I countries. Australia, the United States, and Canada ranked fifth, seventh, and ninth, respectively. Their per capita emissions (7.0, 6.6, and 6.1 metric tons per person) were approximately double the emissions of the highest-ranked developing country in the top twenty (South Korea, at 3.0 metric tons), and they were six times those of China (1.1 metric tons). Of note, the population density of Iran is 16 persons per square kilometer in a country that is relatively small.

• Summary and Foresight

It is indeed a paradox that OPEC countries concerned with manipulating the production of petroleum products so as to affect global financial markets have expressed concern with green energy. In January, 2009, Iran inaugurated its first solar energy power plant, adding a modest 250 kilowatts of solar energy to the country's energy grid. The power plant uses parabolic mirrored troughs to gather sunlight where it is used to produce steam and generate electricity. This solar thermal plant is part of 4,075 small-scale solar thermal installations throughout Iran, which comprise 3,781 solar water heaters for residential use, and 294 public baths that are heated with solar thermal energy. Putting an economic value on renewable resources makes Iran, with its abundance of sunlight, rich in "solar energy potential." Iran took its first step toward the large-scale realization of that potential with the inauguration of its first solar energy plant, which was constructed with domestic materials and labor in Shiraz.

Cynthia F. Racer

• **Further Reading**

Ardehali, M. M. "Rural Energy Development in Iran: Non-renewable and Renewable Resources." *Renewable Energy* 31, no. 5 (April, 2006): 655-662. Identifies problems and difficulties encountered in the socioeconomic infrastructure as related to rural energy development; presents the nonrenewable and renewable energy resources.

Axworthy, M. *A History of Iran: Empire of the Mind.* New York: Basic Books, 2008. Comprehensive history from Zoroaster and the Greeks to the Pahlavi dynasty.

Sagar, A. D. "Wealth, Responsibility, and Equity: Exploring an Allocation Framework for Global GHG Emissions." *Climatic Change* 45, nos. 3/4 (June, 2000): 511-527. Explores the framework derived from the climate convention regarding OPEC nations.

See also: Kyoto Protocol; Organization of Petroleum Exporting Countries; Saudi Arabia; United Nations Framework Convention on Climate Change.

Islands

• **Category:** Geology and geography

Global warming causes thermal expansion and ice melt, increasing seawater volume and provoking more frequent and more severe storms. As a result, small, low-lying islands are threatened with ecological degradation and submergence.

• **Key concepts**

brackish water: mixture of freshwater and seawater
calving: separation of a large portion of ice from a glacier or ice shelf, creating an iceberg
coral atoll: an island or islet composed of a lagoon encircled wholly or partly by a coral reef
methane: a gas whose greenhouse effect is considerably stronger than that of carbon dioxide
nissology: the study of islands
thermal expansion: a heat-induced increase in the volume of a liquid or gas

• **Background**

Global warming threatens the survival of low-lying islands, deltas, and beaches. Over two thousand scientists, in conjunction with the United Nations, have estimated that by the year 2100 sea levels will rise by between 9 and 88 centimeters. Rising sea levels threaten human, animal, and plant life, as arable land and potable water are compromised. Refugee migrations and species extinctions result.

• **Conditions**

For millennia before the nineteenth century, Earth's sea levels remained relatively stable. However, as the pace of industrialization and urbanization accelerated around the globe, sea levels began to rise by milliliters per year. Tide gauges and satellite monitoring indicate that this rise has increased in recent decades. Two factors contribute to increases in sea volume. One is thermal expansion, whereby warming waters increase in volume. The other is the melting of ice sheets and glaciers at the North and South Poles and in the mountains of the Andes, Alps, and Himalayas.

Retreating ice has been noted in all these regions. Ice melt in Greenland begins earlier each summer, leaving ever smaller areas to refreeze by winter. The runoff water from the melt penetrates glaciers, loosening their attachment to rock surfaces. Large chunks then break away, in a process known as "calving," launching masses of ice several square kilometers in area that float away, eventually melting in warmer waters. The snow and ice of ski fields in Switzerland have disappeared, as the snow line rises in altitude. Less snow and ice on the surface of the Earth reduces the deflection of sunlight, or albedo, thereby causing more warming in a

Millennium Island, Kiribati, as seen from the International Space Station. The island, no part of which is more than 6 meters above the ocean, has been identified by the United Nations as being at significant risk from rises in sea level. (AP/Wide World Photos)

postive feedback loop. Furthermore, thawing allows the escape of methane gases that have been locked in the frozen Earth, further strengthening the greenhouse effect.

- **Consequences**

Islands are bodies of land surrounded by water, ranging in size from continents to tiny atolls. They can be found on all continents, oceans, and seas. One type of island rises from an underwater, oceanic volcano, as the tip emerges above the water surface to form the island. The other type is an elevation of land on a continental shelf that rises above surrounding waters. Hawaii is an example of the former; the British Isles are instances of the latter. The smaller and lower in height an island is, the more vulnerable it is to rising seas. In addition to threats from rising sea levels, small islands are endangered by tropical storms, including hurricanes and cyclones. If the frequency and ferocity of these storms increase, the risk to islands does as well.

The consequences of this vulnerability are devastating in several respects. In addition to being submerged, small land bodies are being eaten away at their edges by erosion. Moreover, as salt water penetrates an island, salinity enters the water table below the island's surface. The more salinity that freshwater absorbs, the less potable it is for drinking. Moreover, brackish water stunts or kills crops, reducing the food supply. Not only is the sustenance of humans threatened but that of wildlife is as well.

Some islands are being abandoned by their inhabitants as the sea consumes the land. The two thousand inhabitants of the Carteret Islands of Papua New Guinea are refugees from their devastated habitat. Lohachara Island in the Bay of Bengal disappeared under water in 2006; its residents fled to the mainland. Tuvalu, with a population under ten thousand, is a country of nine narrow coral atolls in the South Pacific. New Zealand has agreed to accept thirty-five of its inhabitants per year as environmental refugees.

- **Prevention**

Small island countries produce negligible amounts of greenhouse gases (GHGs). However, they suffer most directly and critically the consequences of global warming that are due to the major emitters. Small island countries act cooperatively through a number of organizations. The Global Islands Network (GIN) is an information clearinghouse and resources cooperative for islands in all regions of the world. Complementing it is the Small Islands Development Network (SIDSnet), specializing in communications and information technology to support island maintenance and development. Members of the Alliance of Small Island States (AOSIS) coordinate their efforts through their respective U.N. diplomatic missions. The International Small Islands Studies Association (ISISA), which has held ten world conferences, is a professional organization that supports research about small islands. The International Scientific Council for Island Development (INSULA) supports the economic, technical, ecological, social, and cultural programs of the world's islands and publishes the journal *INSULA: The International Journal of Island Affairs*, which specializes in nissology. Another periodical is the *Island Studies Journal*.

• Context

Small, low-lying islands are both idyllic and fragile fragments of the Earth's surface. Somewhat like a canary in a coal mine, their extinction is an early warning sign of ecological danger. Before they submerge, erosion and saltwater intrusion render them uninhabitable. Larger, low-lying surfaces, such as delta regions and beaches, are also threatened. As more islands lose the means to sustain their populations, the number of environmental refugees in the world increases, putting further pressure on the planet's remaining resources.

The inhabitants of small islands have contributed the least to global warming, yet they suffer the worst of its initial consequences. They therefore unavoidably raise issues of social and environmental justice. Global warming admits of several feedback loops. The more the conditions for warming accumulate, the more such conditions are strengthened. For any inhabitant of a low-lying island or mainland surface, the question of the survival of one's physical environment is a daily concern.

Edward A. Riedinger

• Further Reading

Adamson, Joni, Mei Mei Evans, and Rachel Stein, eds. *The Environmental Justice Reader: Politics, Poetics, and Pedagogy*. Tucson: University of Arizona Press, 2002. Collection of texts that considers the legal and diplomatic issues and consequences of ecological damages.

Diamond, Jared M. *Collapse: How Societies Choose to Fail or Succeed*. New York: Viking, 2005. Noted author examines ecological and environmental causes of collapse of various societies, including several island civilizations, particularly that of Easter Island.

Gerdes, Louise I. *Endangered Oceans: Opposing Viewpoints*. San Diego, Calif.: Greenhaven Press, 2004. Collection of articles examining various ocean-related issues, including whether sea levels are rising.

Lisagor, Kimberly, and Heather Hansen. *Disappearing Destinations: Thirty-seven Places in Peril and What Can Be Done to Help Save Them*. New York: Vintage Departures, 2008. Places the threat of disappearing islands within the context of other endangered ecosystems such as retreating glaciers, thawing permafrost and peatland, and diminishing boreal forest.

Tompkins, Emma L., et al. *Surviving Climate Change in Small Islands: A Guidebook*. Norwich, Norfolk, England: Tyndale Centre for Climate Change Research, 2005. Describes climate change adaptation scenarios for small islands and offers plans and implementation strategies.

See also: Alliance of Small Island States; Barrier islands; Coastal impacts of global climate change; Easter Island; Human migration; Maldives; Saltwater intrusion; Sea-level change; Tuvalu.

Isostasy

• **Category:** Geology and geography

The theory of isostasy allows geologists and cryologists to understand the growth or retreat of ice sheets, based upon the movement of the land in response to its increasing or decreasing glacial load.

• Key concepts

continental crust: the uppermost layer of the Earth, granitic in composition, with a density of about 2,700 kilograms per cubic meter

flexure: the way in which an elastic plate bends

forebulge: an elevated area just beyond the area depressed by an ice sheet

glacial isostatic adjustments: vertical motions of the crust to restore it to preglacial elevations

mantle: the layer of the Earth beneath the crust, peridotite in composition, with a density of about 3,400 kilograms per cubic meter

viscosity: a measure of how easily a material flows

• Background

Earth's continental crust floats on a geological layer called the mantle. A continental ice sheet weighs a great deal, so an advancing ice sheet will cause the crust to subside beneath it. When the ice melts, the land it had depressed will rebound upward. These vertical motions of hundreds of meters control the growth and retreat of the glaciers, as well as the directions in which meltwater drainage flows. Models of mantle deformation based on data from the last glaciation can be applied to areas beneath contemporary ice sheets to better understand their dynamics.

• Theory of Isostasy

During the survey of Mount Everest, investigators found that their plumb bob was not attracted by the mass of the Himalayan mountain range as much as they had expected. They concluded that the mountain range was supported by some sort of mass deficiency beneath it. This led to the theory of isostasy, which holds that Earth's mantle is denser than its crust, which floats upon it; it is thicker or less dense beneath mountain ranges. This theory has been found to be generally true, except for some unusual circumstances such as the trenches near subduction zones. These exceptions have been explained by treating the surface of the Earth as an elastic plate that flexes and spreads out gravitational loads.

The continental ice sheets that developed in Canada and Northern Europe placed enormous loads on the crust of the Earth beneath them. Just as a boat rides lower in the water when fully loaded than when empty, the crust of the Earth sank further into the mantle to accommodate this additional load. The flexure produced by this motion on the elastic plate caused parts of it just beyond the loads to rise up as a forebulge. When the ice melted, the load disappeared, areas that had been depressed began to rise up, and the forebulge started to subside. These changes in elevation are often referred to as glacial isostatic adjustments. Although the ice disappeared thousands of years ago, the crust continues to move vertically today, because the mantle is incredibly viscous. Glacial rebound analysis suggests it has a viscosity between $10^{20.5}$ and 10^{22} Pascal seconds. (For comparison, the viscosity of water is 10^{-3} Pascal seconds, and the vicosity of molasses is 10^{4} Pascal seconds.)

• Application of the Theory

Waves coming ashore often cut terraces, erode cliffs, and produce beaches at elevations close to sea or lake level. If the land rises relative to these levels, a series of terraces may result. Organic remains can be used to date these terraces, and geologists have discovered that terraces of the same age at different locations are not at the same elevation. Those closest to where the glacial load was greatest are higher, as they have experienced greater isostatic rebound. Furthermore, terraces formed long ago will show a greater slope, presently, than those formed more recently. By studying such patterns of strandlines, a history of isostatic rebound can be reconstructed. For example, areas around Hudson Bay, in Canada, have already rebounded over 300 meters, continue to rise at rates on the order of 1 centimeter per year, and probably have another 100 meters of uplift to go before isostatic balance is obtained.

The history of isostatic rebound in a given area can be used to make estimates of mantle viscosity and of how this viscosity changes with depth. Computer models can help fill in the gaps where data are absent. Where there is a significant lack of data, suites of scenarios may be obtained, all of which fit the model equally well, and all of which are internally consistent. As additional data become available, some scenarios will be eliminated, and the preferred scenario can shift rather dramatically. For example, preferred scenarios in the mid-1990's envisioned 4 kilometers of ice in Greenland but only 2.5 kilometers of ice in central Canada during the last glacial maximum. A few new data points led to revisions in 2004 that reversed this distribution and placed parts of Greenland in the area of the glacial forebulge.

These scenarios are used by climate scientists to try to determine how rapidly the ice sheets on Greenland and Antarctica might be shrinking. The elevation of the top of the ice sheets and the gravitational attraction at points above the ice sheets can be determined from satellites. However, to calculate how much the volume of ice is changing, the elevation change of the bottom of the ice sheet must also be considered, and isostatic adjustment models are used to estimate this change.

Isostatic adjustments may also have influenced the growth and retreat of the continental glaciers. The accumulation of ice occurs much more rapidly than can be accommodated by isostatic subsidence. Just as the crust of the Earth is still rebounding thousands of years after the load was removed, it subsided over a period of thousands of years during and after the addition of the load. These changes in elevation, frequently called "bedrock lag," affect local climatic conditions and thus the growth or retreat of the continental ice sheets.

Another important consequence of isostatic adjustment concerns drainage of the large lakes at the southern margin of the continental glacier in North America. The route and ultimate destination of the drainage were likely important factors influencing global temperatures near the end of the last glaciation. These lakes consisted of freshwater, most at 4° Celsius, which would have floated on the more saline water in the North Atlantic. Such a freshwater cap would be unlikely to sink initially, and it would take a long time for the winds to mix it sufficiently to permit sinking. The cap may have slowed or turned off the thermohaline circulation, also called the global conveyor belt or the meridional overturning circulation (MOC). The North American lakes drained into the Atlantic Ocean through the Mississippi River Valley, the Hudson River Valley, and the St. Lawrence River Valley, as well as draining northwest to the Arctic Ocean.

- **Context**

Isostasy provides a theory to explain the vertical movements of Earth's crust as the load of continental ice sheets is added or removed from large areas. It permits us to estimate volume changes of contemporary ice sheets by providing estimates of the crustal movements taking place beneath them. By constraining drainage histories of the glacial lakes that formed near the end of the last glaciation, it makes it possible to determine where and when cold, freshwater pulses may have flooded out over the oceans, with their potential radically to modify Earth's climate.

Otto H. Muller

- **Further Reading**

Fowler, C. M. R. *The Solid Earth: An Introduction to Global Geophysics*. 2d ed. New York: Cambridge University Press, 2005. A somewhat technical text that thoroughly covers the flexure of elastic plates. Illustrations, figures, tables, map of the isostatic uplift of Fenno-Scandia, bibliography, index.

Peltier, W. R. "Chapter 4: Global Glacial Isostatic Adjustment and Modern Instrumental Records of Relative Sea Level History." In *Sea Level Rise: History and Consequences*, edited by B. C. Douglas, M. S. Kearney, and S. P. Leatherman. San Diego, Calif.: Academic Press, 2001. Explains how isostatic computations are done. Charts, figures.

Ruddiman, William F. *Earth's Climate Past and Future*. 2d ed. New York: W. H. Freeman and Company, 2008. Ruddiman's treatment of bedrock lag, which he calls "Delayed Bedrock Response Beneath Ice Sheets," explains this phenomenon with many excellent figures, making it easy to understand. Illustrations, figures, tables, maps, bibliography, index.

See also: Coastline changes; Deglaciation; Earth history; Earth structure and development; Freshwater; Glaciations; Glaciers; Ice shelves; Meridional overturning circulation; Plate tectonics; Thermocline; Thermohaline circulation.

Italy

- **Category:** Nations and peoples
- **Key facts**

Population: 58,126,212 (July, 2009, estimate)
Area: 301,230 square kilometers
Gross domestic product (GDP): $1.82 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 516.9 in 1990; 582.5 in 2004; 567.9 in 2006
Kyoto Protocol status: Ratified 2002

• Historical and Political Context

Italy has played a major role in the religious, philosophical, and artistic development of the world. For centuries, Italy served as the central point from which empire, religion, thought, and artistic creation emanated. The Roman Empire spread its political system and its culture throughout Europe and the Mediterranean. After its collapse, Rome became the center of Catholicism, and it was in Italy that the Renaissance began in the fourteenth and fifteenth centuries, eventually spreading across Europe and into the British Isles. It revived the thought and art of Antiquity with Humanism and rediscovered the human creative ability.

Politically, Italy has had many periods of political unrest. During the thirteenth century there were fierce battles between the imperial and religious powers. The eighteenth century saw regional factions competing for political power. And again in the twentieth century, Italy's government experienced serious instability. Under the republic established in 1946, some fifty different political groups have been in power. In contrast to its internal political volatibility, Italy is a consistent supporter of international organizations. Italy joined the United Nations in 1955 and is a member of five other international organizations, including the North Atlantic Treaty Organization (NATO), the organization of industrialized nations known as the G-8, and the World Trade Organization. Italy was a founding member of the European Union (formerly the European Community). Italy's main trading partners are in the European Union; the country trades mostly with Germany, France, and the United Kingdom. It also trades with the United States and ranked twelfth among the United States, trading partners in 2008.

• Impact of Italian Policies on Climate Change

Although Italy underwent some industrialization during the nineteenth century, it remained primarily an agricultural economy until after World War II. Agriculture is still important to the country. Italy produces a wide variety of products, including grapes, olives, rice, sugar beets, and soybeans. It is the largest producer of wine in the world. The agriculture sector employs a large portion of Italy's workforce. Approximately 1.4 million people are employed in farming. Tourism continues to be important in the Italian economy. The northern section of Italy where manufacturing is concentrated has one of the highest per capita incomes in the world, while the south remains poor by world standards. After the war, Italy became more and more involved in manufacturing and is now the sixth largest market economy in the world. While Italy possesses few natural resources other than natural gas, which is primarily in the Po Valley and in the Adriatic Sea, it imports a large quantity of raw materials for processing. In addition approximately 80 percent of its energy resources are also imported. Its major areas of manufacturing include precision machinery, motor vehicles, chemicals, and clothing. Italy also has a significant oil refining industry. This activity is one of the main sources of increased CO_2 emissions, amounting to a gain of 2.4 million metric tons. The other major source of increased greenhouse gas (GHG) emissions is road transport with a substantial increase in the consumption of diesel fuel. The increase in the use of fossil fuels to produce electricity has also greatly increased the GHG emissions. Production of the energy supply and energy use accounted for 60 percent of the GHG emissions in 2006. The transport sector was the source of another 23.5 percent.

• Italy as a GHG Emitter

According to data collected by the European Environment Agency (EEA), Italy ranked third among the members of the European Union in GHG emissions. In 1990, the base year for the Kyoto Protocol, Italy had GHG emissions totaling 516.9 million metric tons of carbon dioxide equivalent. Its emissions target under the Kyoto Protocol is 483 million metric tons. From 1990 to 1995, emissions remained more or less the same; the following years were then a period of substantial increase. From 2002 to 2006, Italy's average GHG emissions were 571.4 million metric tons, which was an average increase of 10.6 percent for the period. The amount of GHGs emitted by Italy in 2006 showed a small decrease to 567.9 million metric tons but was still an increase of 9.9 percent over its 1990 emissions and well in excess of its Kyoto Protocol target. Italy was responsible for 11 percent of the European Union's GHG emissions.

• Summary and Foresight

If Italy's amount of greenhouse emissions continues at its present rate, the country will not meet its burden-sharing target of 6.5 percent under the Kyoto Protocol by the 2008-2010 period. Italy expects the policies and measures it already has enacted to reduce its emission to a level 7 percent above the 1990 levels. This would be a reduction of 3 percent from the 2006 levels, which were 10 percent above the 1990 levels. Among the measures and policies already in place in Italy are the use of abatement technologies in the production of adipic acid and the replacement of fossil fuels with biomass for heating in the household sector. Italy plans to initiate additional measures, Kyoto mechanisms, and carbon sink activities to reduce emission further. However, the proposed measures will result in a level only 5 percent below the base year levels and will not meet the –6.5 percent target of the Kyoto Protocol.

Italy has been slow to regulate electrical consumption, and austerity is not a popular idea among the Italian citizens, but the European Union is proposing a program for changing the source of energy production to that of renewable resources. Other significant reductions in GHGs emitted by Italian industries should result from the restrictions that will be placed upon them under the European Union Emission Trading Scheme. Reduction of GHG emissions and control of global warming is important to Italy, which is already seeing the effects of global warming on its land area. The melting of Alpine glaciers is causing problems in regard to the Swiss/Italian border, which will probably need to be re-delineated.

Shawncey Webb

• Further Reading

Archer, David. *Global Warming: Understanding the Forecast.* Malden, Mass.: Blackwell, 2007. Targeted to undergraduates. Excellent discussion of global warming and its effects, combined with a concise scientific explanation of the phenomenon. Also looks at economic effects of global warming. Chapters on GHGs and fossil fuels.

Charnovitz, Steve, and Gary Clyde Hufbauer. *Global Warming and the World Trading System.* Washington, D.C.: Peterson Institute for International Economics, 2009. Discusses the reduction of GHGs and its relation to trade and trade organizations, especially the World Trade Organization. Suggests methods to reduce GHGs without harming carbon-intensive industries, both domestic and international. Appendix on biofuel.

Clapp, Jennifer, and Peter Dauvergne. *Paths to a Green World: The Political Economy of the Global Environment.* Cambridge, Mass.: MIT Press, 2005. Good discussion of environmental issues and global warming in respect to trade and the world economy.

Locke, Richard M. *Remaking the Italian Economy.* Ithaca, N.Y.: Cornell University Press, 1997. Good for understanding changes in the Italian economy that have increased Italy's GHG emissions. Pays special attention to the automobile and textile industries.

Shogren, Jason F. *The Benefits and Costs of the Kyoto Protocol.* Washington, D.C.: AEI Press, 1999. Excellent for understanding the Kyoto Protocol.

See also: Annex B of the Kyoto Protocol; Europe and the European Union; Kyoto Protocol; United Nations Framework Convention on Climate Change; Venice; World Trade Organization.

Japan

- **Category:** Nations and peoples
- **Key facts**

Population: 127,078,679 (July, 2009, estimate)
Area: 377,873 square kilometers
Gross domestic product (GDP): $4.348 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 1,154 in 1990; 1,223 in 2000; 1,216 in 2006
Kyoto Protocol status: Ratified 2002

• Historical and Political Context

A strong Asian island nation fiercely protective of its national identity and independence, Japan always sought to be at least on equal footing with the known leading nations of the ages. Thus, when industrialization with its attendant side effect of massive emission of carbon dioxide (CO_2) into the atmosphere gave Western nations a decisive military and economic edge by the middle of the nineteenth century, Japan chose to rapidly catch up and industrialize during the Meiji Restoration announced in 1868.

On the other hand, when concern for global warming led the leading nations of the world to seek for means to reduce the negative impact of their industry and consumers and traffic on the Earth's atmosphere by the end of the twentieth century, Japan took a leading role in researching and committing to less environmentally damaging alternatives. It certainly spoke to the Japanese self-understanding as a leading innovative nation that the decisive protocol to the United Nations Framework Convention on Climate Change was adopted in Kyoto, an ancient capital of Japan, on December 11, 1997. Known since as the Kyoto Protocol, the agreement represents a strong international commitment to combat global warming.

In a pattern still typical by the early twenty-first century, once Japan decided to industrialize, the government worked very closely with private enterprise and could draw on a well-educated, hard-working and frugal workforce. This public-private partnership contributed to Japan's fast industrial rise, albeit at the price of environmental damage.

Japan's first encounter with industrial pollution occurred in 1878. Runoff water contaminated with inorganic copper compounds from the privately owned Ashio Mine north of Tokyo caused copper poisoning among farmers and villagers living downstream. Tanaka Shozo, the local member of the lower house of Japan's new parliament, publicly raised the issue. As a result the company paid compensation, and the government erected runoff prevention, yet some problems remained. Well into the middle of the twentieth century, most Japanese pollution cases followed this pattern of privately caused pollution, public reaction, and increasingly vigorous financial, governmental, and legal redress.

An extremely negative side effect of Japan's drive to industrialization despite a surprising lack of natural resources such as coal, oil, iron, and nonferrous metals was its embarkation on imperialism and colonialism. Copying the West, Japan created a colonial empire that at its peak in 1932 encompassed Korea, Taiwan, and the puppet state of Manchukuo, carved out of Northeast China. Conflict with the United States over Japan's war in China after 1937 led to an American oil embargo of Japan in 1941 that persuaded Japanese militarists to attack the United States at Pearl Harbor on December 7, 1941, drawing the Americans into World War II. After surrendering unconditionally on August 15, 1945, Japan lost its colonies. To become an economic leader again was a major challenge.

• Impact of Japanese Policies on Climate Change

Japan's post-World War II political decision to promote Japanese economic recovery included a broad national consensus to rebuild and expand Japan's industry. This national aim was aided by the United States, who wanted a strong Japan as a free world counterpart to communist aggression in Europe and Asia during the Cold War. With virtually no natural fuel resources such as oil and coal, Japan had to import these from abroad, as well as almost all raw materials for industrial production of steel and industrial manufacturing. In this situation, Japanese policy promoted manufacturing of consumer goods, chemicals, and machines primarily for export to pay for its import of fuel and raw materials.

The strong pro-industry policies of Japan led to an initial postwar neglect of environmental protection and the outbreak of three major pollution incidents in 1956, 1961, and 1965. There was strong public reaction to these incidents. Two involved mercury poisoning, and the 1961 case resulted in poisonous smog created by unregulated burning of petroleum and crude oil waste by the Showa Yokkaichi Oil Corporation. As a result of public pressure and successful lawsuits based on irrevocable scientific evidence for the anthropogenic cause of the pollution incidents, Japan's public policy shifted toward more effective environmental protection.

In 1970, Japan passed six environmental laws and put much more teeth into eight existing ones. In 1971, the Environmental Agency was established and given a broad mandate to protect Japan's environment from air, soil, water, and other pollution. Exhaust by cars was also addressed aggressively and industrial polluters were held accountable by passage of the 1973 Pollution Health Damage Compensation Law. Ironically, the drastic oil price increases of the first oil crisis of 1973 forced Japanese companies, utilities, and consumers to find immediate means of conserving fuel to survive economically in the face of Japan's near total dependency on fuel imports. Its industry became more fuel efficient with lower emissions.

The first white paper of Japan's Environmental Agency in 1984 strengthened environmental awareness among Japanese corporations and citizens, as did further policy papers, campaigns, and surveys. The 1993 Basic Environment Law of Japan explicitly restricted industrial emissions considered harmful for the climate, as well as calling for improved energy conservation, recycling, and pollution control programs.

Indicative of Japan's serious commitment to environmental protection including addressing and combating climate change, in 2001, the Environmental Agency was upgraded to the Ministry of the Environment. In 2008, Tetsuo Saito became its Minister. He was chosen because of his scientific background, holding a Ph.D. in physics, and his knowledgeable commitment to clean energy technology.

• Japan as a GHG Emitter

According to Japan's emission statistics reported to the United Nations in 2008 for the years from 1990 to 2006, with 1.22 billion metric tons of greenhouse gases (GHGs) emitted in 2006, Japan was the world's fifth largest emitter of CO_2 and its equivalents. By comparison, the top two emitters were the United States with 6.37 billion metric tons in 2006, a figure closely matched or perhaps even surpassed by 8 percent by the People's Republic of China, according to a 2007 estimate by the Netherlands Environmental Assessment Agency. When Japan's emissions were compared to the size and output of its national economy, the Japanese economy proved remarkable emissions-effective. This was particularly in contrast to the number three and four GHG emitters, India and Russia. In 2008, Japan created with $4.84 trillion the world's second largest gross domestic product, just behind the United States, and remained in place five of the GHG-emitting countries.

Under the complex United Nations measuring system for GHGs, nations can earn some credit or debit to their overall emissions when they offset emissions through land use, land-use change, or forestry (abbreviated as LULUCF). This was an incentive for nations to promote reforestation and protect forests, as was done in Japan vigorously since the 1980's. As a result, Japan's overall 2006 emission was lowered by 82.6 million metric tons of GHGs. In addition, only anthropogenic emissions are considered, excluding, for example, CO_2 from volcanic eruptions.

In Japan, as elsewhere, CO_2 was the major GHG emitted, accounting for 1.156 billion metric tons in 2006 (without LULUCF credits). Under United Nations standards, other GHG emissions are added to those of CO_2 with a weighted formula. For example, each ton of methane is multiplied by 21, each ton of nitrous oxide by 310, and fluorocarbons each have specific values. In 2006, Japan emitted a CO_2 equivalent of 21.8 million metric tons of methane, a 23.6-million-metric-ton equivalent of nitrous oxide and just 15.4 million metric tons of CO_2 equivalents of the ozone-layer-damaging fluorocarbons and sulfur hexafluoride (all excluding LULUCF credits).

As an industrialized, Annex I country that signed and ratified the Kyoto Protocol, which became effective on February 16, 2005, Japan has committed to reduce its emissions to 6 percent below their 1990 level no later than 2012. This commitment is slightly higher than the 5.2 percent average for industrialized nations. However, Japan's 2006 data show an increase of 5.3 percent from the 1.154 billion metric tons of GHGs emitted in 1990. When the figures are used that account for possible LULUCF credits, Japan even increased its emissions by 5.8 percent as reforestation and other measures had reached their intended limits in the 1990's and had leveled off.

Japanese politicians and experts have pointed out that Japan had relatively low emission levels in 1990 already. Ever since the 1973 oil crisis, Japan had invested great resources in cleaner factories and power plants. Japan reduced emissions consid-

A man observes a factory smokestack in Kobe releasing pollutants into the atmosphere. (Yuriko Nakao/Reuters/Landov) erably earlier than other countries. Despite this relative disadvantage, Japan ratified the Kyoto Protocol in 2002 and remained committed to its targets.

• Summary and Foresight

As a leading industrial nation creating the world's second largest gross domestic product, behind the United States, and running the third largest economy, behind the United States and the People's Republic of China, if measured by purchasing power parity, in 2008, Japan would continue to emit a huge share of the world's GHGs. Japan has been particularly motivated to earn the money it needs to import its food and fuel, both of which it is lacking, through export of high-value goods that require considerable energy consumption and thus GHG emission in their manufacture. At the same time, Japanese politicians and the populace were seriously committed to combating global warming and willing to spend considerable resources to achieve this aim.

Far from the days of permitting rampant industrial pollution just after World War II, when economic recovery was on the top of the agenda, Japan has become a leader in environmental protection. By 2002, the second environmental performance review of Japan by the Organization for Economic Cooperation and Development (OECD) praised Japan for its highly effective implementation of positive environmental policies and its strict, well-enforced, and seriously monitored regulations. In 2006, Japan's Ministry of the Environment made prevention of global warming, ozone layer protection, and conservation of the air, water, and soil environments issues of top concern.

Japan has become strongly committed to an international approach to Earth-spanning challenges such as global warming. Japan is a founding member of the Asia-Pacific Partnership on Clean Development and Climate founded on January 12, 2006, in Sydney, Australia. In addition, Japan continues to stress environmental protection in the countries of its trade partners.

Japan has been actively involved on the cutting edge of meteorological research. A major scientific project concerns the Earth Simulator, a supercomputer used for developing and running global climate models since 2002 at the Earth Simulator Center in Yokohama. The Earth Simulator is projected to be replaced by an even more powerful model after 2009, indicating Japan's continuous commitment to climate research.

R. C. Lutz

• Further Reading

Bianchi, Adriana, et al., eds. *Local Approaches to Environmental Compliance: Japanese Case Studies and Lessons for Developing Countries.* Washington, D.C.: International Bank for Reconstruction and Development, 2005. Illustrated description and analysis of five successful cases of arresting pollution in Japan since the 1960's. Chapter 2, "Successful Air Pollution Control in Japan: History and Implications" by Ryo Fujikura, is of special relevance to combating causes of global warming.

Cruz, Wilfrido, et al., eds. *Protecting the Global Environment: Initiatives by Japanese Business.* Washington, D.C.: International Bank for Reconstruction and Development, 2002. Three case studies covering the steel industry, power plants, and forestry show how Japanese companies were successful in improving environmental protection while simultaneously increasing productivity.

Flath, David. *The Japanese Economy.* 2d ed. New York: Oxford University Press, 2005. Chapter 11 addresses Japanese environmental policy in the context of economic issues.

Ichikawa, Atsunobu, ed. *Global Warming—The Research Challenges: A Report of Japan's Global Warming Initiative.* New York: Springer Verlag, 2005. Presents the results of Japan's top scientific research. Covers climate monitoring, modeling, and projections; impact and risk assessment; and options for response policies. Japanese climate policy is presented and analyzed.

Kameyama, Yasuko. "Will Global Warming Affect Sino-Japanese Relations?" In *Japan and China,* edited by Hanns Gunther Hilpert. New York: Palgrave Macmillan, 2002. Analyzes the costs and benefits of regional environmental cooperation in northern Asia; considers the potential for Japanese-Chinese cooperation to reduce GHG emissions through successful bilateral treaties and agreements.

Oshitani, Shizuka. *Global Warming Policy in Japan* *and Britain: Interactions Between Institutions and Issue Characteristics*. Manchester, England: Manchester University Press, 2006. Comparative analysis of the relationship between government and industry in Japan and the United Kingdom. Contrasts national approaches to official decision making and implementation of new policies; explores how public institutions pursue climate policy in both nations.

See also: Carbon dioxide; Carbon dioxide equivalent; Greenhouse effect; Greenhouse gases; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change.

Jet stream

• **Category:** Meteorology and atmospheric sciences

• Definition

A jet stream is a band of high-velocity atmospheric current that encircles the Earth. This band of strong winds is typically found in the upper troposphere and lower stratosphere. In both the Northern and the Southern Hemisphere, there are two distinctive jet streams: one is located just outside the tropical latitudes, in the subtropics; the other is located at the boundary of the midlatitudes and the polar region. In these latitudes, the jet-stream winds are westerlies, blowing from west to east. The two jet streams are named, respectively, "the subtropical jet" and "the polar jet." These jets shift locations seasonally.

The rotation of the Earth around its own axis causes the air that surrounds the Earth to move as a result of the drag exerted by the Earth's solid surface. This movement of air is called "wind." Wind can blow in any direction, even though the Earth rotates from west to east. Two of the major forces in the atmosphere that determine wind direction are the pressure gradient force and the Coriolis effect. Because of differential solar heating between the tropics and a polar region, there is a strong tendency of the atmosphere to move outward from the warmer equator to the colder poles, distributing heat. This tendency would cause winds to blow in the north-south directions in the Northern and Southern Hemispheres at different altitudes.

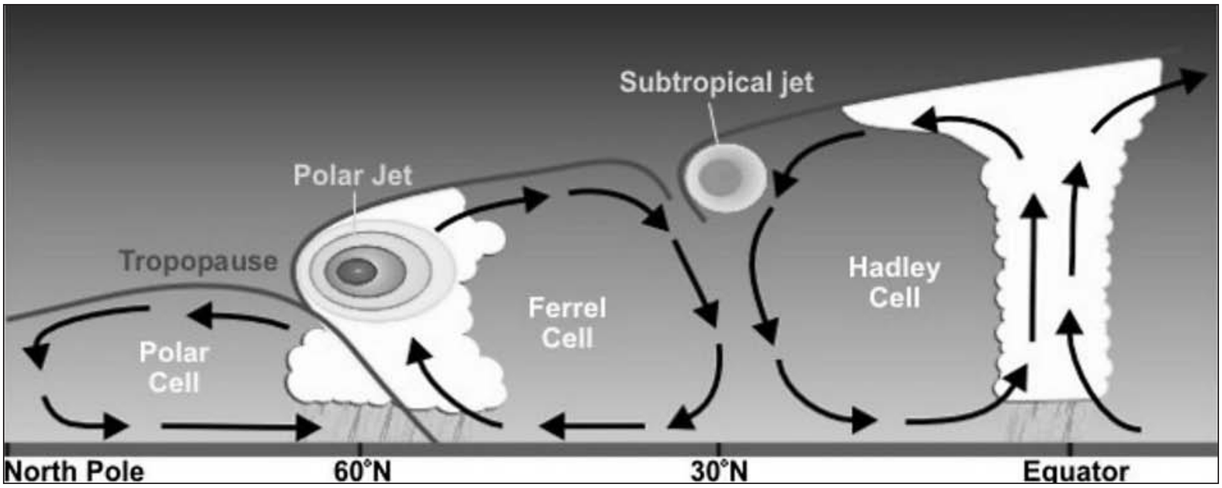
Owing to the Earth's rotation, these two major north-south circulations break up, forming several smaller cells of circulation. These smaller cells include the Hadley circulation, the Ferrel circulation, and the polar circulation, listing them from the equator to the poles in each hemisphere. At upper atmospheric levels, when air travels to the north in the Northern Hemisphere, the Coriolis effect turns this airstream to its right, turning a southerly wind into a westerly wind. Furthermore, because the Coriolis effect becomes stronger as air travels further north and the effect of Earth's surface drag is smaller at upper atmospheric levels, these westerly winds become very strong. As a result, jet streams form outside of the tropics, toward high latitudes, at upper atmospheric levels.

• Significance for Climate Change

Because it is a high-velocity wind current, a jet stream can be an important energy source for extratropical cyclones and storms. The position of a jet stream serves as an important indicator for the location of surface front and storm development. Both the subtropical and the polar jet are located at the boundaries of two different air masses. The boundaries of different air masses are the locations of surface fronts, at which extratropical cyclones develop. Therefore, a jet stream is an important component of a synoptic weather system.

Inside a jet stream, there is often a core region where winds become even stronger than they are in other parts of the jet. This core region is called the "jet streak." Because winds increase toward the jet streak, large horizontal and vertical wind shears exist at the boundaries of a jet stream. The sheared winds can cause a flow current to become curved and unstable. Therefore, in the vicinity of a jet stream, atmospheric waves and turbulence are often generated. Upper air turbulence may threaten aircraft.

Several studies have indicated that global warming tends to cause jet streams to move poleward.



This cross-section of the polar and subtropical jet streams illustrates their relationship to Earth's major atmospheric circulation cells. (NOAA)

The implication of this migration is that extratropical storms or "storm tracks" will extend poleward as well. Furthermore, the combined effects of global warming and the poleward movement of jet streams leave a larger spatial area in which tropical storms may develop. Therefore, the area of coastal land that is vulnerable to hurricanes may increase.

Some scientists have pointed out that, as a result of a continuous increase in Earth's average surface temperature and of the temperature throughout the troposphere, the temperature gradient from the equator to the poles may be decreased. This possibility seems to suggest that the jet stream's intensity may decrease as the climate warms. The weakening of jet streams may in turn decrease the activity of extratropical cyclones. However, other scientists have argued that global warming may not lead to a warming of the entire troposphere and a corresponding decrease in jet-stream intensity. Moreover, because global warming would also tend to increase atmospheric humidity, latent heat release may supply additional energy for extratropical cyclones despite a decreased global temperature gradient.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Widely used introductory textbook on atmospheric science; covers a wide range of topics on weather and climate.

Archer, Cristina L., and Ken Caldeira. "Historical Trends in the Jet Streams." *Geophysical Research Letters* 35, no. 24 (2008). Reports on an investigation of changes in the location of the jet stream in response to global warming.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Comprehensive overview of global climate change published by a network of the world's leading climate change scientists under the auspices of the World Meteorological Organization and the United Nations Environment Programme.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Introductory textbook that covers a wide range of atmospheric sciences.

Yin, Jeffrey H. "A Consistent Poleward Shift of the Storm Tracks in Simulation of Twenty-first Century Climate." *Geophysical Research Letters* 32,

(2005). Investigates poleward shifting of storm tracks in relation to the jet stream under global warming conditions.

See also: Adiabatic processes; Atmospheric dynamics; Gulf Stream; Hadley circulation; Walker circulation.

Journalism and journalistic ethics

• **Categories:** Popular culture and society; ethics, human rights, and social justice

The changing nature of journalism, including the competition between objective coverage and advocacy, has played a key role in the public perception of global warming.

• Key concepts

code of ethics: an unofficial standard for proper journalistic behavior

media bias: presentation of news or information that favors one side of a particular issue

Society of Environmental Journalists: a group of media professionals who focus wholly or in part on a wide range of environmental stories and issues

Society of Professional Journalists: a voluntary association of journalists who try to further the profession

• Background

American journalism is regarded as the Fourth Estate, or a final check and balance on government. Media professionals claim to have evolved a tradition of neutrality in news stories, but both the reality and the ideal of neutrality have been called into question. Journalists themselves are unsure of the role they should play in global warming debates. At the same time, the nature of journalism has blurred with the rise of the Internet and the focus on immediacy in news coverage.

• Traditional Media Approaches to Reporting

Over time, American journalists have evolved an unofficial code of ethics that calls for unbiased or neutral reporting. This concept is integral to ordinary reporters being seen as chroniclers rather than advocates. The ideal has gained widespread but not universal acceptance.

Journalists use several means to enforce neutrality in stories. The traditional approach would include editors removing any comments that are not objective from a given story. Journalists also seek the help of professional organizations to support unbiased reporting. The Society of Professional Journalists says reporters must distinguish between advocacy and news in their reporting. The Society of American Business Editors and Writers tells its members to simply avoid any action that might “appear” to harm objectivity. The Society of Environmental Journalists has been criticized for taking sides in the global warming debate.

Many newspapers also have their own codes of behavior for journalists. *The New York Times* urges staff to remain free of any bias, as do many other organizations. Some media outlets even employ ombudsmen to serve as reader representatives. Media outlets also have detailed correction policies.

There are flaws in all of these approaches. Editors do not catch every instance of bias. Organizations are voluntary and do not police a code. News outlets also use codes as guidelines, but public examples of enforcement are rare. Ombudsmen generally lack any real authority in a newsroom.

Every one of these strategies is at issue in the global warming debate. Scientists and other experts complain that biases are present in news stories. The other methods of controlling bias, from policies to ombudsmen, are unable to keep up with a sophisticated and scientific debate involving professionals who often know far more than reporters or editors.

• Other Strategies

The traditional approach is not the only approach. The term “news media” itself has become fluid. It encompasses alternative weeklies, freelance journalists, and opinion media that take an advocacy role. Even the mainstream media have a strong strain of advocacy. Many media outlets have long employed journalists who advocate for positions—from environmentalism to a higher minimum wage. There is a journalistic tradition that reporters should "afflict the comfortable and comfort the afflicted." That plays out in the climate change debate, as journalists try to show the potential harm of global warming—from species loss to climate disaster.

Several journalists have spoken out and complained about the neutrality requirements. Columbia Broadcasting System (CBS) reporter Scott Pelley famously compared global warming skeptics to Holocaust deniers. Other reporters and editors have taken an activist stand on the issue, claiming that too many lives are at risk because of global warming. *Time* magazine has repeatedly put global warming on its cover, warning that something must be done to stop it.

All major news outlets have found navigating the issue to be difficult. Fox News, whose motto is Fair and Balanced, was criticized by supporters of anthropogenic global warming theory for including too many skeptics. When Fox News ran a special that included their side, skeptics complained and Fox News then produced a second documentary highlighting flaws in the alleged global warming consensus.

• Context

The issue of media neutrality is central to how ordinary Americans see global warming. Do they view it as an imminent threat or as debated science? Journalists have been much criticized by readers, as well as by advocates on the Left and Right.

The issue of media bias about global warming has become almost as big a story as climate change itself. Scientist James E. Hansen complained that the George W. Bush administration censored his work, but he received a great deal of media attention as a result. Skeptical scientists have complained about being either ignored or undermined in stories. *Time* magazine modified the famous photo of the Iwo Jima flag raising to replace it with a tree in a push for global warming action. That decision resulted in thousands of reader complaints as well as criticism from photojournalists. Because global warming is such a controversial issue, it highlights the many flaws in journalistic neutrality. That, in turn, undermines the idea that reporters are objective in other areas of news coverage.

Dan Gainor

• Further Reading

Bowen, Mark. *Censoring Science: Inside the Political Attack on Dr. James Hansen and the Truth of Global Warming*. New York: Dutton Books, 2008. Explains how the Bush administration censored scientists who predicted global warming, effectively limiting their media access as well. Also lists facts that demonstrate the warming trend, primarily that recent years have reportedly been the warmest years on record.

Gelbspan, Ross. *Boiling Point: How Politicians, Big Oil and Coal, Journalists, and Activists Are Fueling the Climate Crisis—And What We Can Do to Avert Disaster*. New York: Basic Books, 2004. Describes climate change as a major crisis and refers to denial of it as "a crime against humanity." Gelbspan blames the media for delaying necessary action and calls for a global project to repair the planet. References, index.

Lomborg, Bjørn. *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. New York: Knopf, 2007. Director of the Copenhagen Consensus Centre, Lomborg discusses exaggerations of global warming in the media and how scaremongering tactics and misleading information are the media's primary tools. Rather than discount global warming theory, Lomborg suggests readers look at the costs of the suggested measures to stop it.

Michaels, Patrick J. *Meltdown: The Predictable Distortion of Global Warming by Scientists, Politicians, and the Media*. Washington, D.C.: Cato Institute, 2004. Covers the numerous and extreme exaggerations of climate change in the media. Argues that although there is warming occurring, it does not require panic from the public, and denies that humans can do much to affect the Earth's temperature.

See also: Carson, Rachel; *Collapse*; Gore, Al; *Inconvenient Truth, An*; *Limits to Growth, The*; Thoreau, Henry David.

Kilimanjaro

- **Category:** Geology and geography

During the political debates over global warming, Kilimanjaro's vanishing ice cap became an iconic image of the negative consequences of anthropogenic climate change, but climatologists and glaciologists have discovered that decreased snowfall, enhanced exposure to solar radiation, ice-sheet locations and shapes, and other factors are more important than climate change in explaining the disappearing ice.

• Key concepts

ice cap: semipermanent glacial crown of ice atop a mountain or other geologic formation

sublimation: the conversion of a solid directly into a gas, bypassing its liquid state

volcano: a usually mountainous rift in Earth's crust caused by magma erupting through fissures onto the planet's surface

• Background

Kilimanjaro—which, at 5,895 meters, is Africa's highest mountain—is of volcanic origin, based in its location alongside a rift zone created by the Earth's spreading crust. Its trio of volcanic peaks gradually became inactive, first Shira, then Mawenzi, and finally Kibo, the highest. Ice and snow gathered on Kilimanjaro's upper slopes during the late Pleistocene epoch, about eleven thousand years ago. Ice cores taken from the mountain's glaciers have revealed a history of expansions and contractions of the ice cap, with the contractions occurring during periods of drought eighty-three hundred, fifty-two hundred, and four thousand years ago. Periods of expansion resulted from climatic conditions that were warmer and wetter than those of today. Recently, Kilimanjaro's ice sheets have been confined to Kibo.

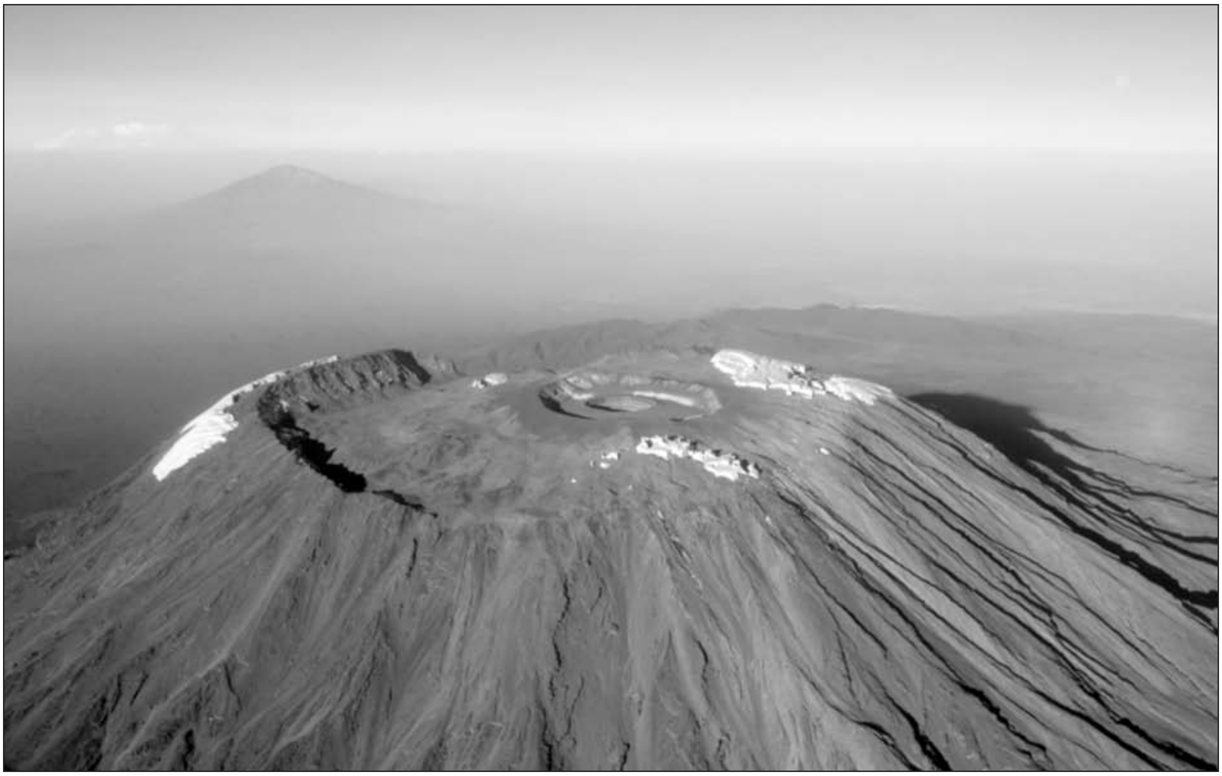
One-half million years ago, early human inhabitants of the Rift Valley first saw this majestic mountain, but its names derive from a much later period. African tribes called it the "white" or "shining" mountain, because of its ice cap. Its present name most likely comes from the Swahili, "Kilima Njaro," meaning "Mountain of Greatness" because of its massive height and bulk. The first European to see the mountain was a German missionary who published an account of his African explorations in 1849. This not only sparked interest in searches for the source of the Nile but also in the scientific study of Kilimanjaro and its ice sheets.

• Vanishing Ice Sheets

In the late nineteenth century, explorers created maps and drawings of the mountain and its environs. From these, scholars derived an estimate that, in 1880, ice covered about 20 square kilometers of Kilimanjaro's principal peak. In 1889, two Europeans were the first to reach Kilimanjaro's summit, and they brought back information about the extent and depth of the ice sheets. In the twentieth century, photographs from the mountain's base and, later, from airplanes, provided benchmarks by which the shrinkage of the ice cap could be measured. In 1912, a precise map was constructed based on photogrammetric evidence. At that time, the ice sheets had diminished to 12.1 square kilometers, though they still existed on all sides and descended to about 4,400 meters. From 1912 to the early twenty-first century, Kilimanjaro's icefields were periodically surveyed, and the data gathered indicated that the time of greatest contraction had been from about 1880 to 1950.

Ernest Hemingway, an American writer, made Kilimanjaro's ice cap world famous through his popular short story, "The Snows of Kilimanjaro," (1936) which was made into a successful Hollywood movie in 1952. By the early 1950's, the mountain's icefields had diminished to 6.7 square kilometers. Sufficient data had been collected to determine that the rarely observed trickles of meltwater were unable to account for the retreating glaciers. Some scientists began to attribute glacial contraction to the sublimation of summit ice into water vapor under the influence of the tropical sun in dry air at below-freezing temperatures. However, during the second half of the twentieth century, as evidence multiplied that midlatitude mountain glaciers were shrinking because of global warming, some scientists extended this explanation to such equatorial mountain glaciers as Kilimanjaro's.

Aerial photographs of Kibo's ice sheets had been supplemented by satellite pictures, and this



Kilimanjaro. (©iStockphoto.com/Alexei Zarubin)

new information showed that, although the ice cap's contraction had slowed since 1953, 75 to 80 percent of its area had vanished during the past century, along with deep reductions in the volume of its ice and snow. Some scientists predicted that the ice cap would be completely gone by 2015 or 2020. Since the "Snows of Kilimanjaro" were famous as well as photogenic, it was natural for advocates of greenhouse gas (GHG) reduction to use dramatic images of the mountain's disappearing ice cap to bolster their cause. Greenpeace advocates held a news conference from Kilimanjaro's summit, and, most significant, former vice president Al Gore argued in a very successful documentary film and companion book, both entitled *An Inconvenient Truth* (2006), that the vanishing ice cap was evidence of global warming. The movie's Academy Award and the book's best-seller status helped popularize the images of Kilimanjaro's vanishing ice, which Gore associated with carbon-dioxide-induced global warming.

• Significance for Climate Change

Although many scientists agreed that temperate-zone mountain glaciers were retreating because of global warming, an increasing number of climatologists and glaciologists believed that the specific case of Kilimanjaro's ice loss was caused by other factors. Data collected from balloons, satellites, and an automatic weather station on one of Kibo's icefields revealed that reduced precipitation of ice and snow in dessicated air, along with extensive exposure to solar radiation in below-freezing temperatures, led to the accelerated sublimation of ice and snow. Fluctuating weather systems in the Indian Ocean, which influenced humidity and cloud cover over Kilimanjaro, may also have played a role.

• Context

Most scientists familiar with the data held that global warming had little or no effect on the ice decline. These scientists chided global-warming enthusiasts for their misuse of Kilimanjaro's vanishing ice cap to support their views on climate change, but they also criticized global-warming deniers who overgeneralized the Kilimanjaro case to include midlatitude glaciers. Kilimanjaro can therefore serve as a cautionary tale of how politics and overheated rhetoric often lead passionate advocates to distort scientific data and images in unacceptable ways.

Robert J. Paradowski

• Further Reading

Bowen, Mark. *Thin Ice: Unlocking the Secrets of Climate in the World's Highest Mountains*. New York: Macmillan, 2005. This book has been called one of the best yet published on climate change. Part 6 is dedicated to Kilimanjaro. Notes, references, index.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. Emmaus, Pa.: Rodale Books, 2006. Written as a complement to a very successful film. The great popularity of the film and book helped create the image of Kilimanjaro as an "icon" of global warming advocacy.

Michaels, Patrick. *Meltdown: The Predictable Distortion of Global Warming by Scientists, Politicians, and the Media*. Washington, D.C.: Cato Institute, 2004. Although Michaels, a climatologist, accepts the reality of global warming, he argues that alarmists have exaggerated its future effects, and he uses the debate over Kilimanjaro's shrinking ice cap to show how science can be distorted for political ends.

Mote, Philip W., and Georg Kaser. "The Shrinking Glaciers of Kilimanjaro: Can Global Warming Be Blamed?" *American Scientist* 95 (July/August, 2007): 318-325. This article by a climatologist and glaciologist musters much scientific evidence to show that factors other than global warming are responsible for the retreat of Kibo's ice sheets. Illustrated with photographs, graphs, and a map. Bibliography.

See also: Greenland ice cap; Hockey stick graph; *Inconvenient Truth, An*; Mount Pinatubo; Sahara Desert; Volcanoes.

Kyoto lands

• **Category:** Laws, treaties, and protocols

Kyoto lands are lands within the territory of Kyoto Protocol party nations on which vegetation is planted that acts to sequester carbon. These lands enable protocol parties to earn carbon offset credits to balance their continuing GHG emissions.

• Key concepts

biomass: the organic substance of life-forms, especially plants

carbon fixation: incorporation of carbon atoms into organic compounds within biomass, making it unavailable for CO_2 production

carbon offset credits: credits earned by funding projects that remove GHGs from the atmosphere and that can be used to replace reductions in GHG emissions

carbon sequestration: isolation of carbon from the atmosphere, either by converting it into a form other than CO_2 or by capturing CO_2 and storing it outside of the atmosphere

greenhouse gases (GHGs): trace atmospheric gases that trap heat, preventing it from escaping into space

• Background

Forests and other types of vegetation that store or sequester carbons and are increasing in size are considered to be carbon sinks, or reservoirs. In the main, natural carbon sinks include trees, plants, and organisms that use photosynthesis to remove carbon dioxide (CO_2) from the atmosphere by incorporating, or fixing, carbon into biomass as carbohydrates $(CHOH)_n$ and releasing oxygen (O_2) into the air. Carbon sinks not only rid the atmosphere of greenhouse gases (GHGs) but also, by producing additional CO_2-consuming biomass, can scavenge even more CO_2 from the atmosphere.

The Kyoto Protocol, a United Nations treaty, aims to reduce anthropogenic GHG emissions. It allows member countries to use carbon sinks as a form of carbon offset, gaining credit for their sinks against their continued GHG emissions. These so-called Kyoto lands may then be used to comply with emission-reduction requirements of the treaty.

According to the Intergovernmental Panel on Climate Change (IPCC), if GHG emissions continue to rise at their current rate, global warming will accelerate to levels that will increase both floods and droughts, raise sea levels, and obliterate thousands of plant and animal species. The use of carbon sinks to mitigate the effects of global warming may be useful to countries with large areas of forest or other vegetation for compliance with the Kyoto Protocol. Specific, legally binding quotas for reduction of GHG emissions have been established for the developed nations; developing countries are not compelled to restrict their GHG emissions, which may come, in large part, from land use such as cultivation of lands and destruction of forests. For developed nations, land use would have little effect in meeting Kyoto quotas, since most of their land has already been cultivated. Developing countries may benefit from offsetting their GHG emissions with carbon sinks via land use or green projects, and can help developed countries meet their quotas by trading carbon credits. Usually, an industrialized country will purchase carbon credits from a developing country to meet its quota.

• Implementation

In implementing the Kyoto Protocol, parties to the treaty will most likely base their policy decisions on “defintions, accounting procedures . . . for carbon stocks, and changes in carbon stocks.” Per the protocol, each party “must devise its own method of verifying its carbon emission reductions (CER) to account for carbon sequestration.” In the clean development mechanism (CDM), only afforestation, “the establishment of forest on land that has been ‘unforested’ for a long period, decades to centuries,” and reforestation, the conversion of ‘nonforested’ lands to forest, are allowable methods of producing CERs for the first period of the protocol, 2008 to 2012. Forest conservation or avoidance of deforestation, “the conversion of forest to nonforest,” is ineligible.

The IPCC in its revised *Guidelines for National GHG Inventories* (1997) and the Kyoto Protocol itself call for a strict accounting of the carbon changes encompassing all carbon sinks within a given timeframe; they require that inclusion be limited to “land areas subject to direct human-induced activities.” GHG emissions and removals via land use, land-use change, and forestry (LULCF) may be designed to help parties to Annex B of the protocol meet their obligations. In this case, the *Guidelines* are to serve as the basis for “transparent and verifiable” reportage of changes in forestry and related GHG emissions.

• Significance for Climate Change

Changes in land use can appreciably change the GHG emission levels, with deforestation increasing them and afforestation reducing them. Anthropogenic emissions of CO_2 grew by 2.5 percent to record levels in 2006, as international efforts to fight global warming failed to curb the main gas blamed for rising temperatures. Burning fossil fuels and changing land use together produced 8.8 billion metric tons of CO_2 in 2006. The inclusion of land use as part of the calculations for GHG emissions tends to focus on certain developing nations, notably Indonesia and Brazil, which are significantly raising their GHG emission rankings. Between 1950 and 2000, when land use is taken into account these rankings rose from eighteenth to fifth and from twenty-seventh to fourth, respectively. Indonesia and Brazil have both cleared large parcels of forest, converting carbon sinks into timber and agricultural land and thereby emitting GHGs.

Cynthia F. Racer

• Further Reading

Bloomfield, J., M. Ratchford, and S. Brown. “Land-Use Change and Forestry in the Kyoto Protocol.” *Mitigation and Adaptation Strategies for Global Change* 5, no. 1 (March, 2000): 1381-2386. Rehearses the strategies employed to satisfy compliance with the Kyoto Protocol, emphasizing land use and forests.

Kindermann, G., et al. “Global Cost Estimates of Reducing Carbon Emissions Through Avoided Deforestation.” *PNAS* 105 (2008): 10302-10307. Explores the financial benefits accrued by using Kyoto lands to mitigate global warming through maintenance of forests.

Schulze, E.-D., et al. “Making Deforestation Pay Under the Kyoto Protocol?” *Science* 299 (March, 2003): 1669. Argues that changing regulations

governing the "reforestation time limit" may compromise basic principles of the protocol, including preservation of pristine forests.

See also: Amazon deforestation; Annex B of the Kyoto Protocol; Deforestation; Forestry and forest management; Forests; Kyoto mechanisms; Kyoto Protocol; Reservoirs, pools, and stocks; Sinks; United Nations Framework Convention on Climate Change.

Kyoto mechanisms

- **Category:** Laws, treaties, and protocols

The Kyoto Protocol established three mechanisms for GHG reduction: emissions trading, joint implementation, and the clean development mechanism. The aim of these mechanisms is to provide additional, cost-effective opportunities for industrialized countries to reduce their emissions of GHGs in order to mitigate climate change.

- **Key concepts**

Annex I parties: industrialized nations listed in Annex I of the UNFCCC

assigned amount units: greenhouse gas emission allowances of Annex I parties

certified emissions reductions (CERs): credits for contributing to reduced emissions in developing nations that Annex I nations can substitute for domestic reductions

emission reduction units (ERUs): measurement of the amount of GHG emissions reduced by a joint implementation project

removal units (RMUs): emission reduction units generated by land use, land-use change, and forestry projects

- **Background**

Article 3 of the Kyoto Protocol requires industrialized countries, identified in Annex I of the U.N. Framework Convention on Climate Change, to take on quantified emission limitation and reduction commitments (QELRCs). These QELRCs are set out in Annex B to the protocol and require parties listed in Annex I of the convention to reduce their emissions of six specified greenhouse gases (GHGs). Based on individual targets, Annex I parties are assigned the amount of carbon dioxide (CO_2) equivalent emission units, called assigned amount units (AAUs), they are allowed to emit during the protocol's first commitment period (2008-2012). These parties are obliged to meet their targets primarily through domestic measures. However, recognizing the need for flexibility, the protocol established three market-based mechanisms—emissions trading, joint implementation, and the clean development mechanism (CDM)—that are meant to provide additional, cost-effective ways for developed countries to meet their commitments.

- **Implementation and Participation Requirements**

The mechanisms are under the authority and guidance of the Conference of the Parties to the Convention serving as the meeting of the Parties to the Protocol (COP/MOP or CMP). The relevant articles in the protocol and decisions of the COP/MOP contain the rules and implementation modalities for the mechanisms. Decision 2/CMP.1 contains some general requirements and provides that use of the mechanisms must be supplemental to domestic actions taken by Annex I parties, with these domestic actions constituting a significant element in Annex I parties' efforts to meet their targets. The decision further provides that Annex I parties' eligibility to participate in the mechanisms depends on their compliance with their methodological and reporting obligations under Articles 5 and 7 of the protocol. Participation in the Kyoto mechanisms may involve private or public entities, which must be authorized by a party to the Kyoto Protocol to participate in any of the mechanisms.

- **Joint Implementation**

Under joint implementation, Article 6 of the protocol allows Annex I parties to earn or buy emission reduction units (ERUs) generated from emission reduction or removal projects implemented in other Annex I parties. These ERUs, each representing one metric ton of CO_2 equivalent emission reduction, can be used by Annex I parties to contribute to meeting their targets under the protocol. A joint implementation project could, for example, involve installing solar panels in homes in a developed country to replace power generation from fossil fuels. The use of these solar panels will result in reduced GHG emissions, and the investor can use the reductions achieved, issued in the form of ERUs, toward its own reduction target. The joint implementation mechanism is overseen by a supervisory committee.

The protocol sets out some of the eligibility criteria for participating in joint implementation. Article 6.1 provides that joint implementation projects must have the approval of the parties involved and must result in a reduction in emissions by sources, or removal by sinks, additional to what would have occurred in the absence of the project. The detailed participation requirements are set out in the Annex to Decision 9/CMP.1.

- **Clean Development Mechanism**

The CDM was established by Article 12 of the protocol. Under the CDM, Annex I parties can finance or invest in emission reduction or removal projects in developing countries. These projects generate certified emissions reductions (CERs), which Annex I parties can add to their assigned amounts and use toward meeting their targets under the protocol. Again, each CER represents one metric ton of CO_2 equivalent emission reduction. A CDM project could involve the same activities as a joint implementation. The only differences would be that the project would be implemented in a developing country, and the emission reductions would be issued as CERs. The CDM is overseen by an executive board.

Article 12 sets out some of the participation requirements for the CDM. It provides for the certification of emission reductions resulting from project activities by operational entities, on the basis of

A Madagascar nursery grows seedlings that will be used to plant new forests. The forests' carbon-fixing ability will be converted to credits and sold on the global market created by the Kyoto Protocol. (AP/Wide World Photos) voluntary participation of the parties involved; real, measurable, and long-term benefits related to the mitigation of climate change; and emission reductions additional to those that would have occurred in the absence of the project activity. The Annex to Decision 3/CMP.1 further provides that participants must be parties to the protocol and must designate a national authority. These requirements are additional to the general participation requirements described above.

• Emissions Trading

Article 17 of the protocol provides that parties with QELRCs may participate in emissions trading in order to fulfill their Article 3 commitments. Emissions trading involves Annex I parties trading in their AAUs. Here, Annex I parties who have not used up all their AAUs are allowed to sell them to other Annex I parties. These other Annex I parties are generally parties who either have exceeded or believe they will exceed their assigned amounts. Under the emissions trading scheme, Annex I parties can buy or sell any of the emission reduction units, including AAUs, CERs, ERUs, and removal units (RMUs). RMUs are ERUs generated under land use, land-use change, and forestry projects. This trade in emission reduction units or carbon credits has led to the creation of what is called the carbon market, where carbon emissions are traded like other commodities.

The rules governing emissions trading are contained in the Annex of Decision 11/CMP.1. In addition to the general participation requirements, Annex I parties are required to maintain a commitment period reserve of at least 90 percent of their assigned amounts. They are not allowed to make any transfer that would result in their holdings falling below this reserve.

• Context

The United Nations recognized that differing circumstances exist in different countries. Some countries may be relatively energy efficient, making it more difficult for them to reduce their GHG emissions sufficiently to meet their targets. In some countries, the potential cost of reducing their emissions may be very high. The need for flexibility was recognized, although the protocol provides that the use of the flexible mechanisms must be supplemental to domestic actions taken by Annex I parties. The Kyoto mechanisms were established to provide this flexibility, to enhance Annex I parties' ability to achieve their targets, and to provide them with cost-effective means of achieving these targets. In addition, other advantages of the mechanisms include contribution to the sustainable development of recipient countries through technology transfer and enhanced investment flows.

Tomi Akanle

• Further Reading

Freestone, David, and Charlotte Streck. *Legal Aspects of Implementing the Kyoto Protocol Mechanisms: Making Kyoto Work.* New York: Oxford University Press, 2005. Provides a broad overview of the Kyoto mechanisms, including the history of negotiations and provisions, and outstanding issues needing to be addressed.

Grubb, Michael, Christiaan Vrolijk, and Duncan Brack. *The Kyoto Protocol: A Guide and Assessment.* London: Earthscan, 1999. Part 2 of this book analyzes the commitments taken on by Annex I parties and the mechanisms established to assist them in achieving the commitments, assessing the pros and cons of the mechanisms.

Yamin, Farhana, ed. *Climate Change and Carbon Markets: A Handbook of Emissions Reductions Mechanisms.* London: Earthscan, 2005. Provides a comprehensive description of the carbon market, including the rules governing the three Kyoto mechanisms and related rules, such as those of the European Union Emission Trade Scheme.

See also: Annex B of the Kyoto Protocol; Carbon dioxide equivalent; Certified emissions reduction; Clean development mechanism; Kyoto lands; Kyoto Protocol; United Nations Framework Convention on Climate Change.

Kyoto Protocol

- **Category:** Laws, treaties, and protocols
- **Date:** Entered into force February 16, 2005

The Kyoto Protocol establishes clear targets for reducing GHG emissions, along with accounting mechanisms that encourage nations to undertake projects that reduce emissions. It balances national economic development plans with emissions reductions and sets up free market mechanisms to achieve the targets set by intergovernmental negotiations.

• Key concepts

Annex I nation: an industrialized nation listed under Annex I of the UNFCCC and committed to achieve a certain level of GHG emissions reduction within a specified period

certified emissions reduction (CER): a unit of GHG reduction, equal to 1 metric ton of carbon dioxide emissions, certified by the UNFCCC and tradeable on the carbon market

clean development mechanism (CDM): a system accounted by the UNFCCC, whereby an Annex I country sponsors a greenhouse gas reduction project in a developing country to earn CERs

joint implementation: a system in which Annex I countries can earn CERs by working on CDM projects in an economically transitional nation, generally one of the former Soviet or Balkan nations

United Nations Framework Convention on Climate Change (UNFCCC): an agreement between nations to participate in reducing anthropogenic effects on the climate

• Participating nations: *1998:* Antigua and Barbuda, El Salvador, Fiji, Maldives, Tuvalu; *1999:* Bahamas, Bolivia, Cyprus, Georgia, Guatemala, Jamaica, Mongolia, Nicaragua, Niue, Palau, Panama, Paraguay, Trinidad and Tobago, Turkmenistan, Uzbekistan; *2000:* Azerbaijan, Barbados, Ecuador, Equatorial Guinea, Guinea, Honduras, Kiribati, Lesotho, Mexico, Samoa; *2001:* Argentina, Bangladesh, Burundi, Colombia, Cook Islands, Czech Republic, Gambia, Malawi, Malta, Mauritius, Nauru, Romania, Senegal, Uruguay, Vanuatu; *2002:* Austria, Belgium, Benin, Bhutan, Brazil, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Costa Rica, Cuba, Denmark, Djibouti, Dominican Republic, Estonia, European Community, Finland, France, Germany, Greece, Grenada, Hungary, Iceland, India, Ireland, Italy, Japan, Latvia, Liberia, Luxembourg, Malaysia, Mali, Morocco, Netherlands, New Zealand, Norway, Papua New Guinea, Peru, Poland, Portugal, Republic of Korea, Seychelles, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Thailand, Uganda, United Kingdom, United Republic of Tanzania, Vietnam; *2003:* Armenia, Belize, Botswana, Ghana, Guyana, Jordan, Kyrgyzstan, Lao Democratic People's Republic, Lithuania, Madagascar, Marshall Islands, Myanmar, Namibia, Philippines, Republic of Moldova, Saint Lucia, Solomon Islands, Switzerland, Tunisia; *2004:* Indonesia, Israel, Liechtenstein, the former Yugoslav Republic of Macedonia, Niger, Nigeria, Russian Federation, Rwanda, Saint Vincent and the Grenadines, Sudan, Togo, Ukraine, Yemen; *2005:* Albania, Algeria, Belarus, Burkina Faso, Democratic People's Republic of Korea, Democratic Republic of Congo, Dominica, Egypt, Eritrea, Ethiopia, Guinea-Bissau, Haiti, Iran, Kenya, Kuwait, Mauritania, Mozambique, Nepal, Oman, Pakistan, Qatar, Saudi Arabia, United Arab Emirates, Venezuela; *2006:* Bahrain, Cape Verde, Gabon, Lebanon, Libyan Arab Jamahiriya, Monaco, Sierra Leone, Singapore, Suriname, Swaziland, Syrian Arab Republic, Zambia; *2007:* Angola, Australia, Bosnia and Herzegovina, Congo, Côte D'Ivoire, Croatia, Montenegro, Serbia; *2008:* Central African Republic, Comoros, Saint Kitts and Nevis, Sao Tomé and Principe, Timor-Leste, Tonga; *2009:* Kazakhstan, Tajikistan, Turkey

• Background

By the early 1990's, anthropogenic emissions had been identified as a significant contributor to the concentrations of greenhouse gases (GHGs) in the atmosphere and to climate changes. Such GHG emissions are generated by industrial activities, especially the burning of fossil fuels for energy, as well as agricultural processes in both developing and industrial nations. Thus, the United Nations sponsored the framing of the U.N. Framework Convention on Climate Change in 1992 and the

Gines Gonzalez Garcia, the president of the Tenth Conference of the Parties to the United Nations Framework Convention on Climate Change, declares the entry into force of the Kyoto Protocol on February 16, 2005. (Kimimasa Mayama/Reuters/Landov)

Kyoto Protocol to the UNFCCC in 1997 to address and mitigate the generation of GHGs by the signatories to those treaties.

On a per capita basis, the industrialized nations are by far the more intense of the world's emitters. The per capita carbon footprint, or the number of metric tons of carbon dioxide (CO_2) or other equivalent GHG emissions per year per person, is a useful metric for comparing national emissions. The per capita carbon footprint of the United States, for example, is around 18 metric tons, while Australia's is 25.5 metric tons. The world average is around 2.8 metric tons, China's is 2.4 metric tons and India's is 0.87 metric ton.

When the world's nations began negotiating a response to the perceived threat represented by anthropogenic GHG emissions, it was soon decided that the brunt of the effort would have to be borne by industrialized nations. This decision was not without controversy, but most parties to the negotiations believed that developing nations could not incur the costs of cutting emissions. It was argued that the industrialized nations, which were largely responsible for the rise in GHG concentrations, could not expect developing nations to curtail their attempts to improve their own people's standards of living by industrializing, nor could industrialized nations disavow their own primary responsibility for rising GHG levels and therefore their obligation to make amends. As a result of this decision, the United Nations Framework Convention on Climate Change (UNFCCC) divided its parties into Annex I (industrialized) nations and non-Annex I (developing) nations.

Annex I of the UNFCCC not only lists the industrialized parties to the convention but also commits them to reducing their GHG emissions by a specified date. It was left to the successor document, the Kyoto Protocol, to determine the details for each nation. That document spelled out the obligations of each party nation, as well as the specific accounting mechanisms that would be used both to measure a nation's progress toward reducing its emissions and to assign credits in lieu of actual reductions for certain complementary activities.

To meet the overall target of a 5.2 percent reduction in global GHG emissions from 1990 to 2012, the mandated reductions for individual nations are as large as an 8 percent reduction from the nation's 1990 emissions level. Some nations, including Australia, negotiated allowances for a rapid rate of growth and were allowed to increase their emissions by as much as 10 percent over their 1990 levels. They could also sell any unused portion of that quota as credits to other nations unable to meet their own reduction quotas. Countries set up national registries validated by the UNFCCC to monitor their emissions.

Each signatory to the Kyoto Protocol undertook to adopt policy measures to enhance energy efficiency; protect and enhance sinks and reservoirs of GHGs; and promote forest cover, sustainable forms of agriculture, and research on renewable energy and sequestration technologies. The signatories agreed progressively to remove policies and other incentives that support or encourage GHG emissions; to reduce emissions in the transport sector; and to reduce methane emissions through recovery and use in waste management. Emissions were also to be reduced in the production, transport, and distribution of energy.

Emissions Trading

Article 6 of the Kyoto Protocol, reproduced below, establishes the basic framework for parties to the treaty to trade pollution credits with one another, thereby employing market principles to drive international emission reductions.

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

(a) Any such project has the approval of the Parties involved;

(b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;

(c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and

(d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

- **Primary GHGs**

The specific gases covered by the Kyoto Protocol are listed in Annex A of the protocol. They are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The contribution of each gas to the greenhouse effect is converted to that of an equivalent amount of CO_2 for easy comparison. This standardized measure of a GHG's climatic effects is known as its global warming potential. Methane, for example, has a global warming potential of 20, meaning it is twenty times as potent per unit mass as CO_2 over a specific time horizon.

GHG emissions arise from fuel combustion, energy industries, manufacturing industries, construction, and transportation. High-value targets for reduction include fugitive emissions from stored fuels, such as oil and natural gas; industrial processes in the metal and chemical industry, such as solvent and other product use; and direct production of halocarbons and sulfur hexafluoride. In agriculture, enteric fermentation, manure management, rice cultivation, prescribed burning of savannas, field burning of agricultural residues, waste incineration, and wastewater handling are all targeted activities.

- **Parties in Annex I**

The parties included in Annex I of the UNFCCC are Australia, Austria, Belgium, Canada, Denmark, the European Community, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Liechtenstein, Luxembourg, Monaco, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Countries listed in Annex I as undergoing transitions to market economies are Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the Russian Federation, Slovakia, Slovenia, and Ukraine. Annex I nations have agreed to limit or reduce GHG emissions from aviation and marine bunker fuels and to ensure that their aggregate anthropogenic emissions of the GHGs listed in Annex A of the protocol do not exceed their assigned amounts. Each party included in Annex I was to have made demonstrable progress by 2005 in achieving its commitments under the protocol.

- **Credits Versus Taxes**

The Kyoto Protocol did not institute taxes on carbon emissions. Instead, it created a system of credits and trading as the favored mechanism to reduce GHG emissions. By turning emissions into tradeable market commodities, the protocol enabled businesses to better manage their emission reduction strategies. The carbon market sets pricing, and market growth is driven by investors. Using flexible mechanisms, the Kyoto Protocol ensures that investments contribute to genuine, sustainable carbon reduction schemes.

- **Certified Emissions Reductions and the Carbon Market**

One certified emissions reduction (CER) unit, also known as one carbon credit, is equivalent to 1 metric ton of equivalent reduction in CO_2 emissions. CERs can be sold privately or in the international market. Each international transfer is validated by the UNFCCC. The European Commission also validates each transfer of ownership within the European Union. Climate exchanges provide a spot market in allowances, as well as futures and options markets, to discover the market price and maintain liquidity.

Trading in CERs is done through at least four exchanges: the Chicago Climate Exchange, the European Climate Exchange, Nord Pool, and PowerNext. The carbon market has exceeded 60 billion euros and is projected to grow beyond 1 trillion euros within a decade. As the need to meet national quotas intensifies, the value of CERs may rise, encouraging more investment in generating new CERs. Speculation and derivatives trading in the value of CERs contributes to rising market activity.

- **Clean Development Mechanism, Joint Implementation, and International Emissions Trading**

Annex I countries earn CERs for financing projects in less developed countries, including projects started ahead of the Kyoto trading period. Under the clean development mechanism (CDM), a developed country can sponsor a GHG reduction project in a developing country, where the cost of GHG reduction activities is usually much lower than it is in the developed country itself. The CDM is administered through an executive board, based in Bonn, Germany.

Joint implementation refers to CDM projects implemented by Annex I countries with the transitional economies of Eastern Europe and the Balkans. Carbon projects can be created by a national government or by an operator within the country. Under international emissions trading, countries can trade in the international carbon credit market to cover their shortfall in allowances.

• Progress Since the Kyoto Protocol

A 4 percent reduction in GHG emissions had been achieved overall by 2004. Large reductions came from former Soviet states that were transitioning to market economies. As of May, 2008, 182 countries had ratified the Kyoto Protocol, representing 61.6 percent of global emissions of GHGs. The United States and Kazakhstan had signed but not yet ratified the treaty. Afghanistan, Andorra, Brunei, Chad, Iraq, the Palestinian Authority, the Sahrawi Arab Democratic Republic, San Marino, Somalia, Taiwan, Tajikistan, Vatican City, and Zimbabwe had not expressed any position.

• U.S. Approach to Kyoto

In 1997, the U.S. Senate voted 95-0 against ratifying the Kyoto Protocol unless several conditions were met. The vote reflected lawmakers' concerns that American manufacturing would be severely affected by the costs of compliance, at a time when strong economic growth was driving emissions up. There was, moreover, widespread skepticism about the claims regarding anthropogenic global warming. The government took the position that since China and India, whose overall emissions are large despite very low per capita emission levels, were not subject to reduction requirements, the United States should not participate in the agreement.

On March 29, 2001, President George W. Bush withdrew the United States from the Kyoto Protocol. By 2004, the country had showed a 15.8 percent rise in emissions, against the target of a 7 percent reduction. Early studies projected a 4.2 percent drop in U.S. gross domestic product (GDP) if Kyoto requirements were met. Subsequent studies have projected far lower effects.

The U.S. approach at the beginning of the twenty-first century focused on using federal tax credits to encourage reduction in GHG emissions, accompanied by a phase-out of the most harmful products such as chlorofluorocarbons. Several states adopted so-called Green Tags, or renewable energy certificates. A renewable energy certificate is earned for each 1,000 kilowatt-hours of electrical energy produced from renewable sources. Some large renewable energy projects, such as wind farms on Native American reservations, have been funded partially through the sale of long-term rights to Green Tags. Green Tags can be used by corporations to reduce their net emissions profile.

A sharp rise in fossil energy prices beginning in 2004 created new market realities in the United States. Nuclear energy, which despite its other problems is a clean source from the GHG perspective, seemed poised for a comeback, along with an increased push toward renewable energy. Coupled with the drive toward efficiency in using costlier fossil fuels, the United States was moving along the path needed to bring GHG emissions down.

• Context

The ambitious aspiration of the Kyoto Protocol is to hold anthropogenic emissions of GHGs at the levels of 1990, as the world economy grows. The technological and policy improvements required to achieve this goal imply dramatic changes in the way the world operates. Fundamentally, the emission of waste heat and hot gases implies thermodynamic inefficiency. The Kyoto Protocol provides the urgent motivation, means for accurate accounting, and substantial funding to improve efficiencies, which in turn reduces the need for energy.

Energy efficiency, as a cost-saving rather than a cost-inducing measure, is also more likely to gain favor among industrialized nations and businesses doubtful of their ability to compete globally while reducing GHG emissions. As the nations of the world begin to negotiate the successor treaty to the Kyoto Protocol, a new sense of urgency combined with a new belief that green technologies may become an economic growth sector may make the next treaty negotiated under the UNFCCC more successful than the Kyoto Protocol has been.

Narayanan M. Komerath

• **Further Reading**

Douma, W. Th., L. Massai, and M. Montini, eds. *The Kyoto Protocol and Beyond: Legal and Policy Challenges of Climate Change*. West Nyack, N.Y.: Cambridge University Press, 2007. Includes general discussion of the implementation of the protocol, as well as several detailed studies of the experiences of specific signatory nations.

Fletcher, S. R. *Global Climate Change: The Kyoto Protocol*. Washington, D.C.: Congressional Research Service, 2005. Provides an overview of and updates to the status of the Kyoto Protocol and specifically the U.S. role in its negotiation. Includes an interesting summary of negotiations subsequent to the signing of the protocol.

Holte, S. J., et al. "Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity." Washington, D.C.: U.S. Energy Information Administration, 1998. This 247-page report prepared by a team of scientists and policy makers analyzes six cases of varying amounts of emission reduction. Summarizes data from various sources and aspects of the economy.

Newell, P. *The Kyoto Protocol and Beyond: The World After 2012*. New York: Human Development Report Office, 2008. Summarizes the many implications of climate change and the Kyoto Protocol for various nations from the viewpoint of the World Bank as a lender to development projects.

See also: Annex B of the Kyoto Protocol; Certified emissions reduction; Clean development mechanism; Emissions standards; Greenhouse gases; International agreements and cooperation; Kyoto lands; Kyoto mechanisms; United Nations Framework Convention on Climate Change.

Lamb, Hubert Horace

English climatologist

Born: September 22, 1913; Bedford, England
Died: June 28, 1997; Holt, England

Lamb was a pioneer in examining climate change from a historical perspective.

• Life

Hubert Horace Lamb spent much of his life as a working climatologist engaged in long-range weather forecasting and examining climate change with the United Kingdom Meteorological Office. In this capacity, he spent time in Antarctica, North Africa, and Malta, as well as becoming a member of the World Health Organization Working Group on Climate Fluctuations. In 1971, he became the founding director of the Climatic Research Unit in the School of Environmental Sciences at the University of East Anglia. As the director of the Climatic Research unit, Lamb did a great deal to encourage historical research into climate change as well as research into recent climatic developments. Among other awards, he received the Royal Meteorological Society's Darton Prize in 1964.

• Climate Work

A prolific writer, Lamb authored or coauthored 145 publications in a career beginning in 1939 and lasting through the second edition of his *Climate, History, and the Modern World* (1982), which appeared in 1995. Although he wrote six books, *Climate, History, and the Modern World* is Lamb's most far-ranging and influential work. This book has served as a model of the interdisciplinary perspective necessary for historical climate research. Even though some of his conclusions may be disputed, his work along with E. LeRoy Ladurie's *Times of Feast, Times of Famine* introduced scholars and nonscholars alike to the importance that climate has played in human events.

Almost all of Lamb's written work has dealt with some aspect of climate change. Some of his publications are technical works written for scientists, while others are written for broader audiences. Gradually, Lamb turned to an examination of historical climate as a means to understanding climate change.

In 1982, the initial edition of *Climate, History, and the Modern World* laid out a research program for the historical study of climate that influenced many later works. In this book, Lamb first provided scientific background on how climate works and how it fluctuates. He then provided a useful discussion of the sources used by historical climatologists, such as meteorological records, chronicles, grain prices, archaeological material, pollen analysis, radiocarbon dating, tree ring data, and ocean bed deposits. By emphasizing the use of multiple sources, Lamb made it clear that reliance on one type of source could be misleading and that achieving a comprehensive record of past climate is often difficult. In carrying out his analysis of past climate change, Lamb often extrapolated from his sources, such as written records or tree ring data, to achieve a more complete picture.

The bulk of *Climate, History, and the Modern World* is devoted to an examination of climate from the time of early civilization to 1950 and beyond. Two highly influential chapters posited a medieval warm era that lasted until the end of the thirteenth century and a period encompassing the sixteenth and seventeenth centuries that he labeled the Little Ice Age. These chapters have spawned numerous other works dealing with topics such as the Medieval Warm Period or the Little Ice Age that have used Lamb's analysis as starting points for further work. Subsequent analysis has modified some of Lamb's conclusions, but his work remains the starting point for research.

As a practicing climatologist, not a historian, Lamb provided more of a discussion of the changing climate and how humans have affected climate than of the impact of climate on human affairs. In contrast to Le Roy Ladurie, Lamb argued that climatic changes have had an impact on humankind, a view that has come to be generally accepted. The final section of the book dealt with the human influences on climate change, forecasting future developments in the light of the past, and a chapter dealing with the lessons to be learned from the impact of humans on the climate and what can be done to lessen this impact. The second edition included a final chapter on more recent developments.

Lamb may be criticized for a narrowness of focus because he dealt primarily with Western Europe in his work. Although documentation is better for this region, there have been some interesting works that deal with other areas of the globe, such as China and North America. In addition he tended to paint with a broad brush, emphasizing climate change in general rather than dealing with climate change in a particular region that might even run counter to the overall trend that Lamb was describing.

Lamb deserves credit for helping to open up the historical study of climate change and human impact on climate and climatic impact on human endeavor. Although some of his interpretations have been superseded, he helped to pioneer a field and has helped enhance knowledge of the factors that have contributed to climate change.

John M. Theilmann

• Further Reading

Brown, Neville. *History and Climate Change*. London: Routledge, 2001. Updates, extends, and critiques some of Lamb's work.

Fagan, Brian. *The Great Warming*. New York: Bloomsbury Press, 2008. Extends Lamb's analysis of the medieval warm epoch along with providing some criticisms of his methodology.

Lamb, H. H. *Climate, History, and the Modern World*. 2d ed. London: Routledge: 1995. Lamb's most influential work, one that continues to generate debate among scholars of the historical climate.

_______. *Weather, Climate, and Human Affairs*. London: Routledge, 1988. Useful collection of several of Lamb's articles dealing with the history of climate and its impact on the human population.

See also: Climate reconstruction; Dating methods; Deglaciation; 8.2ka event; Little Ice Age; Medieval Warm Period; Pleistocene climate; Younger Dryas.

Land use and reclamation

• **Categories:** Economics, industries, and products; environmentalism, conservation, and ecosystems

Land use and reclamation affect and are affected by climate change in complex ways. The creation of new land from sea- or riverbeds or the restoration of an area to its previous natural state has the potential to shape the complex interaction between land cover and the atmosphere, an interaction that affects climate change as much as do GHG emissions.

• Key concepts

anthropogenic: due to human sources or activities

greenhouse gases (GHGs): trace atmospheric gases that trap heat, preventing it from escaping into space

land reclamation: modification of unsuitable land to allow for some form of human use or for a return to its original natural state

land rehabilitation: restoration of land that has suffered environmental degradation

• Background

The different types of land surface affect differently the interaction between the Earth and the atmosphere. Land cover and land-use patterns are affected by the distribution and density of human population, by its activities, and by natural causes. Land-use changes in urban and peri-urban areas, including land reclamation, often drive environmental change, reducing or increasing greenhouse gas (GHG) emissions. In turn, land use and land cover are affected by climate change through erosion, desertification, drought, heavy precipitation, ocean warming, sea-level rise, salinization, heat waves, increases in wind intensity, decline of glaciers and snow cover, and drying of wetlands, among other processes.

The role of land-use change in overall climate change is not well understood. However, if most of the observed increase in temperatures in recent decades can be attributed to GHG emissions, then urban and industrial land uses can be seen as coresponsible for global warming.

• Land Creation, Land Rehabilitation, and Soil Remediation

Land reclamation as a vehicle of land-use change can be one of two different processes. One consists in the creation of new land where there was once water, either in the sea or in a riverbed. Many cities


A section of jungle in southern Mexico lies scorched after being cleared by fire for agricultural use. (Jami Dwyer)

on all continents have used this process to create new residential or business areas, harbors, airports, and other infrastructure. Land reclamation also includes the construction of artificial islands for tourism-related activities or the creation or restoration of beaches in areas affected by beach erosion. Another form of land reclamation is the draining of seasonally submerged lands to convert them to agricultural uses and, in some places, also to control the agent of malaria.

The other form of land reclamation, also called land rehabilitation, consists in restoring an area after it has suffered physical degradation. Such degradation may be natural (for example, erosion) or anthropogenic (for example, pollution, soil contamination, or mining operations). Land can be rehabilitated to allow a new use, such as housing or commercial development, or it may be restored to its natural state in the interests of conservation. In the latter case, knowledge of the land's original soil, flora, and fauna characteristics will facilitate their restoration. Soil remediation, a soft form of land rehabilitation, is the removal of industrial contaminants in soil and water to reduce the risks for human health and for the ecosystem.

- **Land-Use and Climate Change**

GHG emissions and other anthropogenic and natural factors have the capacity to affect climate change. Urban and peri-urban areas have probably the greatest influence on climate change, being responsible for most GHG emissions. This influence is expected to increase, according to United Nations projections of urban population growth and urban sprawl. Outside urban areas, changes in land cover—including deforestation, reforestation, agriculture, and irrigation—affect temperatures, precipitation, and atmospheric circulation. Replacing a rain forest with agricultural lands reduces evaporation and consequently raises temperatures, while irrigation increases evaporation and, eventually, precipitation. Similar changes can be associated with reforestation of snow areas, with planting trees as carbon sinks, and with the creation of new areas for growing crops for fuel.

A changing climate can in turn affect land cover and land use. Climate change affects land cover by creating new risks associated with temperature rise, flooding of low areas, dike collapses, sea-level rise, storms and other natural disasters, erosion of coastal areas, salinization, droughts, the quantity and quality of groundwater resources, water scarcity, air quality, land subsidence, and deterioration of soils. These events can lead to habitat destruction, invasion by alien species, ecosystem fragmentation, and species loss, with profound and irreversible impacts on biodiversity. Climate change also directly affects many other economic and social activities that in turn affect land-use patterns. In some parts of the world, for example in small island states, the forecasted climate change and sea-level rise will make land one of the rarest and most vulnerable resources. In this context, cities will probably be the land-use type most affected by climate change, especially cities located on low coastal zones.

• Land-Use Planning in Adaptation and Mitigation Strategies

The interaction between climate changes and land-use calls for innovative adaptation and mitigation measures. Land-use planning can have an important role in climate change adaptation strategies at the local level, and can contribute to wider mitigation strategies as well. These measures include, for example, the coordination of public and private stakeholders involved in land-use and land reclamation processes, tax benefits, innovative financing mechanisms, and other incentives for the use of renewable energy.

Building codes can also be changed to incorporate norms for GHG emissions in public buildings, green roofs, energy efficiency within household dwellings, and energy conservation to prevent the production of carbon dioxide. Land-use planning strategies, including land zoning, must discourage automobile use, provide adequate incentives for mass transit, promote mixed land use and infill development in sites previously used by other urban functions (including land rehabilitated or areas subjected to soil remediation), and promote higher densities and compact urban layouts, stimulating walkability.

• Context

The interaction between landuse and land reclamation, on one side, and climate change, on the other, is exceptionally complex and is still insufficiently understood. However, the evidence available suggests that changes on each side of this relation affect the other, and, consequently, failure to consider these interactions and to act accordingly may have long-lasting negative consequences for the environment and for the economy and society. For that reason, measurable, verifiable, and reportable actions on adaptation and mitigation, in the field of land-use planning, must be taken sooner rather than later, in all countries, to reduce the environmental, economic, and social effects that would otherwise result from inaction. Special support for adaptation measures, including technology transfer and innovative finance, should be provided by the international community to the poorer and more vulnerable countries.

Carlos Nunes Silva

• Further Reading

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Suggests that climate change is already occurring, that it affects mainly the poorer and the more vulnerable, and that it is still possible to avoid cataclysms in the long term.

_______. *Emissions Scenarios.* Geneva, Switzerland: Author, 2000. Provides insights about the interlinkages between environmental quality and development choices. Demonstrates the impacts of different social, economic, and technological development on emission trends.

_______. *Land Use, Land-Use Change, and Forestry: A Special Report of the IPCC.* Edited by Robert T. Watson et al. New York: Cambridge University Press, 2000. Examines the scientific and technical state of understanding of carbon sequestration strategies related to land use, land-use change, and forestry activities.

Organization for Economic Cooperation and Development. *Literature Review on Climate Change Impacts on Urban City Centres: Initial Findings.* Paris: Author, 2007. Offers a review of the literature on climate change's impacts on cities, evaluates the methods used, and offers relevant policy guidance.

_______. *OECD Environmental Outlook to 2030.* Paris: Author, 2008. Based on projections of economic and environmental trends to 2030; presents simulations of policy actions to address key challenges.

See also: Agriculture and agricultural land; Kyoto lands; Soil erosion; Urban heat island.

La Niña

• **Category:** Meteorology and atmospheric sciences

• **Definition**

Two large weather anomalies alternate south of an equatorial band across the middle and eastern portions of the Pacific Ocean. One is El Niño, characterized by warmer-than-average surface waters; the other is La Niña, marked by cooler surface temperatures (the two are collectively designated as the El Niño-Southern Oscillation, or ENSO). La Niña is defined as Pacific surface temperatures of 0.5° Celsius or more below average for a period of at least five months. The cooling occurs as stronger-than-usual eastward trade winds blow across the Pacific, churning cold water from the ocean depths to the surface.

The Spanish names of these weather events originate from the appearance of El Niño off the coast of Peru at Christmastime; *niño* (boy child) refers to the birth of Jesus. The opposite pattern is termed *niña* (girl child), although at one time it was called El Viejo (the old man). ENSO does not occur on a scheduled basis but does happen regularly with vehement, widespread consequences.

• **Significance for Climate Change**

No definitive link has yet been made between global warming and ENSO, the causes of which are only incompletely known. A great number of ambiguous variables impede conclusive evidence of such a link. To obtain more data and understand long-term weather patterns, a monitoring system in the Pacific collects data from buoys, satellites, and computer models. Hotter or colder surface Pacific waters alter overhead trade winds, thereby shifting the North American jet stream. Altering the track and strength of the jet stream produces exceptional rain or drought. The cold, heavy air from La Niña pushes the jet stream to the upper part of the United States.

On average, a La Niña event may last from nine to twelve months, appearing at the end of one year and extending into the next. Consequently, in the southeastern portions of the United States, winter temperatures are warmer and dryer than normal. In northwestern regions, they are cooler and wetter. Hurricanes in the Atlantic and tornadoes in the United States tend to increase in number and force during La Niña events. In South America, dryer-than-usual conditions prevail in southern regions.

El Niño events occur more frequently than do La Niña events, in a ratio of approximately two to one. However, La Niña events last longer. One such event lasted, with a brief interlude, from mid-1998 to early 2001. Another occurred during the latter half of 2007 through the first half of 2008, provoking epic rainfall in Australia and record snowfalls in parts of China.

Edward A. Riedinger

See also: Average weather; Climate and the climate system; Ekman transport and pumping; El Niño-Southern Oscillation; Hadley circulation; Humidity; Inter-Tropical Convergence Zone; Maritime climate; Ocean-atmosphere coupling.

Last Glacial Maximum

• **Categories:** Cryology and glaciology; climatic events and epochs

• **Definition**

The Last Glacial Maximum, also called the Wisconsin Glacial Stage, commenced about 35,000 years ago and ended about 12,900 years ago. At that time, the Earth entered the current interglacial stage of warming. The Last Glacial Maximum reached its peak of cold about 20,000 years ago, when the continental glaciers reached their maximum extent of southern advance. In the Northern Hemisphere during the Last Glacial Maximum, continental glaciers flowed out over the land surface from three main centers, northern North America, Greenland, and Scandinavia. Much of the Northern Hemisphere was covered with ice, including the northern Atlantic Ocean. Similar effects occurred in the Southern Hemisphere.

During the maximum, global sea levels dropped by as much as 120 meters below present levels. This drop had profound effects on the locations of shorelines, the gradients of rivers, and the hydrologic cycle on Earth. Sea level was much lower than present as a result of the amount of water that was locked up in the world's ice sheets covering the land.

Continental ice sheets of the Last Glacial Maximum consisted of individual large lobes, which expanded and contracted at different rates. Action of the individual lobes resulted in deposition of vast layers and mounds of rock, sand, and fine sediment, as well as erosive scour of the land. The Great Lakes of the United States and Canada formed as a result of such scour during the Last Glacial Maximum. Glacial ice covering the northern latitudes reconfigured the land's surface and largely removed preexisting drainage patterns, which were reestablished after the ice melted away.

• Significance for Climate Change

The presence of so much ice on the land had a huge effect on global climate and local weather. As a result of the uptake of water by glaciers, many arid areas of the Earth became much more arid. An example of this occurred in the Sahara region of Africa, where deserts greatly expanded during the era. Rain forests, which were plentiful before the Wisconsin Stage, shrank considerably and were fragmented into small areas. One effect of this fragmentation of the rain forests was isolation of animal groups such as gorillas into separate geographic areas, where the various isolated populations diverged.

Reduced evaporation from cooler seas generally made the Last Glacial Maximum much dryer, but there were areas where this was not the case. For example, in parts of North America, heavy rains from moist winds flowing over continental glaciers caused much heavier precipitation to occur in areas not covered by ice. For this reason, vast continental lakes formed in areas where lakes are not found today, such as the Great Basin of the United States. The largest such lake, Lake Bonneville, was the forebear of the Great Salt Lake.

The onset of the Last Glacial Maximum may have been triggered by the development of the Isthmus of Panama. Prior to the uplift of rocks and volcanic activity that formed the isthmus, waters of the Atlantic and Pacific Oceans freely mixed, and the salinity of these waters was therefore kept nearly equal. After the Isthmus formed, dry winds from Africa evaporated Atlantic Ocean water and raised the Atlantic's salinity slightly. Mixing could no longer mitigate this effect, so Atlantic Ocean water that moved toward Earth's northern pole, which had helped warm that area in past, no longer reached the pole. Instead, the higher density resulting from the water's greater salinity caused that water to sink north of Iceland. The resulting cooling of the northern pole area is thought to have been enough to trigger the initial ice buildup that started the glacial development of the Last Glacial Maximum. Once the process of ice buildup began, increased reflectivity of the ice (known as albedo) sent increasing amounts of solar energy back into space, and the cycle of global cooling began to accelerate.

The history of the Last Glacial Maximum shows what happens when the Earth descends into a glacial episode of ice accumulation and cooling. All global systems, both living and nonliving, are affected by this climate change. In many ways, the contemporary Earth is the result of many vast changes that occurred during the Last Glacial Maximum, as well as the effects of the current interglacial episode of warming.

Sea-level rise since the end of the Last Glacial Maximum has caused nearly all of the world's coastlines to move and reestablish themselves. Most of the high-latitude rivers and streams have established new channels and drainage patterns since the continental ice sheets melted away. Temperature and rainfall patterns are now mostly different from those during the last glacial episode. Therefore, modern ecosystems have entirely shifted in most instances over the past 12,900 years. In many instances, populations of plants and animals have been dramatically affected by this climatic shift. As a result, mass extinctions have occurred in some groups of organisms, and changes have occurred in others. For example, the Ice Age fauna of North America, including the saber-toothed cats, mammoth and mastodon, giant ground sloths, and small native horses—all of which were once plentiful—are now entirely gone. The physical and biotic changes related to the onset, duration, and end of the Last Glacial Maximum serve as reminders that the world and its living systems can be profoundly changed by global climatic shifts such as the ones that occurred as recently as 12,900 years ago.

David T. King, Jr.

• **Further Reading**

Gillespie, A. R., S. C. Porter, and B. F. Atwater. *The Quaternary Period in the United States.* Developments in Quaternary Science 1. Amsterdam: Elsevier, 2004. Comprehensive guide to understanding the Last Glacial Maximum from the perspective of the United States. Discusses geology as well as the climatic implications of the profound changes of the last glacial episode.

Madsen, D. B., ed. *Entering America: Northeast Asia and Beringia Before the Last Glacial Maximum.* Salt Lake City: University of Utah Press, 2004. Provides a before-and-after examination of the Last Glacial Maximum and its relationship to Asian and North American demographics and migrations.

Stanley, Steven. *Earth Systems History.* 3d ed. New York: W. H. Freeman, 2009. Lays out the history of Earth, including the factors affecting global climates and climate change, over the vastness of geological time. Selected chapters focus on climate change in times of glaciers, including the Last Glacial Maximum.

See also: Alleroed oscillation; Climate reconstruction; Dating methods; Deglaciation; 8.2ka event; Holocene climate; Little Ice Age; Paleoclimates and paleoclimate change; Pleistocene climate; Younger Dryas.

Latent heat flux

• **Category:** Chemistry and geochemistry

• **Definition**

Water can exist as a liquid, solid, or vapor. The latent heat flux (expressed in joules per kilogram) is the rate at which energy is released or absorbed when water changes from one to another of these three states. It is latent by contrast with the sensible (or dry) heat flux caused by the movement of air. The energy involved in the various phase changes of water are known as the latent heat of vaporization (evaporation and condensation of gas and liquid), latent heat of fusion (melting of ice) and latent heat of sublimation (transition of ice directly to vapor). Evaporation of water, melting of ice, and sublimation of ice are heat-absorbing processes. The heat energy used is held in a latent or dormant (hidden) state until it is released back into the atmosphere when freezing, condensation, or the sublimation of vapor to ice occurs.

• **Significance for Climate Change**

A rise in the concentration of greenhouse gases (GHGs) in the atmosphere makes available more energy at the Earth's surface. This additional energy can be used either to heat the atmosphere by way of the sensible heat flux (increased warming) or evaporate water at the Earth's surface via the latent heat flux. If water is present, the latent heat flux will always be larger than the sensible heat flux, meaning that energy otherwise available to heat the atmosphere is used in evaporation. Given that over 70 percent of the Earth's surface is water, most of the additional energy at the surface due to GHG radiative forcing is used in an enhanced latent heat flux. The resulting warming of the atmosphere would be less in this case than if all the additional available energy was accounted for by the sensible heat flux alone.

The heating of air by the sensible heat flux at the Earth's surface causes the air to become buoyant and, as a result, to rise and mix with the cooler air above. Moisture is entrained in this rising air. As a result, the mean annual global climate impact of increased energy available due an enhanced greenhouse effect will manifest itself both as an increased sensible heat flux (warming) and increased evapotranspiration via the latent heat flux. The latter is dormant heat energy that can be transported great distances by wind and over time without loss. The impact on climate may occur in regions far from its source. This dormant heat energy does not radiate back to space until condensation occurs and returns the heat to the air.

C R de Freitas

See also: Aerosols; Alkalinity; Atmospheric chemistry; Dew point; Evapotranspiration; Greenhouse gases; Hydrologic cycle; Water vapor.

Lavoisier Group

- **Category:** Organizations and agencies
- **Date:** Established 2000
- **Web address:** http://www.lavoisier.com.au

- **Mission**

The Lavoisier Group is an independent, nonprofit organization that aims to promote debate within Australia on the science of global warming and climate change and the perceived need to reduce fossil fuel consumption through national and international regulation. The group's activities are motivated by the belief that some of the science on which national and international climate policy is based is not beyond reproach. In light of this belief, the organization encourages dialogue within Australia on the scientific merits of climate policies and agreements such as the Kyoto Protocol, as well as their economic consequences. The organization also seeks

> to explore the consequences which any international treaty relating to global decarbonisation targets, and the methods of policing such treaties, would have on Australian sovereignty and independence, and for the World Trade Organization rules which protect Australia from the use of trade sanctions as an instrument of extraterritorial power.

The group is run by volunteers comprising mainly active and retired earth and atmospheric scientists, engineers, and other professionals.

The Lavoisier Group is named after Antoine-Laurent Lavoisier, a French scientist, economist, and public servant. Although he is best known for his discovery of the role oxygen plays in combustion, Lavoisier was politically liberal and persuaded of the need for social reform in France during the years leading up to the French Revolution. At age fifty, during the Reign of Terror, he was found guilty of *incivisme* (avoiding civic responsibility) by the French revolutionists and put to death by guillotine. Eighteen months after his death, Lavoisier was exonerated by the French government when it was formally declared he had been falsely convicted.

- **Significance for Climate Change**

The Lavoisier Group highlights noteworthy developments in climatology, publishing information on its Web site and inviting speakers on the subject. The topics most frequently covered in the organization's site and seminars include greenhouse gas theory, solar and planetary influences on Earth's climate, predictions and projections of future climate, the history of climate change, the economics of energy and technology, energy security, the role of the Intergovernmental Panel on Climate Change in promoting global warming hysteria, and the response of Australia's governments to the decarbonization campaigns of the environmentalist movement and the media.

C R de Freitas

See also: Australia; Engineers Australia; Skeptics.

Levees

- **Category:** Economics, industries, and products

- **Definition**

Levees are embankments or engineered structures near bodies of water; they are designed to prevent flooding of the land behind them. Permanent levees are used along rivers, such as the Mississippi and Sacramento Rivers, and in coastal areas, such as New Orleans, Louisiana. Once constructed, lev-

A reinforced section of New Orleans's 17th Street levee, which was breached during the floods associated with Hurricane Katrina. (AP/Wide World Photos)

ees are protected from erosion by planting them with vegetation such as grass or willows on the river side. Concrete abutments may also be used on the river side of a levee to protect the structure from strong currents. A breech occurs when a section of levee is washed away, letting water onto the adjacent land. On large floodplains, levees are built in a series, stepping back from the river, to provide an extra measure of protection against a breech.

Levee systems along coasts and rivers are built and maintained by a variety of state and federal agencies, including the U.S. Army Corps of Engineers (USACE), state and tribal levee boards, and private groups. For example, in Missouri, a group of private landowners who own a majority of the land in a wetland or another region where flooding occurs may create their own levee district, obligating themselves to pay taxes to finance the building and maintenance of levees.

The National Levee Safety Act (NLSA) of 2007 includes several provisions related to the oversight of levee safety and maintenance—including of nonfederal (state and private) levees. One provision of the NLSA authorizes the USACE to develop a plan to create a national levee safety program and to inventory and inspect all federal levees. Nonfederal levees can be added to the USACE inspection and inventory program at the request of local levee boards, but the maintenance and safety of those levees remains the responsibility of the local board. The NLSA also created a National Committee on Levee Safety (NCLS), which consists of representatives from USACE; the Federal Emergency Management Administration (FEMA); and state, regional, and tribal levee boards and is charged with creating a national levee safety program.

• Significance for Climate Change

The U.S. levee system is a large, complex patchwork of many different structures that have been built by a variety of organizations over many years. Some of the oldest levees in the United States were built more than 150 years ago. Most levees are earthen structures, built with a tapered profile, at a width-to-height ratio of seven to one. Thus, a maximum height must be determined by the time construction begins, based on analysis of historical data regarding maximum local flood heights and storm surges and the recurrence interval of these events.

Results of climate models, notably those used by the Intergovernmental Panel on Climate Change (IPCC), predict that future increased global temperatures will lead to higher sea levels, increased precipitation rates, and a greater potential for large hurricanes. Also, a report released by Environment Texas in 2007 concluded that weather data from 1948 to 2006 demonstrated that extreme precipitation events had increased by 24 percent. Together, such weather events have the potential to lead to higher flood levels and storm surges. For example, during the Upper Mississippi Valley flood of June, 2008, peak flows were approximately 1.8 meters above those previously recorded. The storm surge from Hurricane Katrina on August 29, 2005, was 7.6 meters. A report by University of California, Berkeley, scientists concluded that flooding in New Orleans was a result of the levees not being built high enough; however, this conclusion has been disputed by the USACE and independent investigators.

Following Hurricane Katrina, the United States Congress passed the Water Resources Development Act of 2007, which authorized creation of the National Levee Safety Program. The law mandated the formation of the National Committee on Levee Safety. The direct effects of global warming on levee safety have not been considered in initial plans for levee safety standards. A further concern for levee safety in coastal Louisiana, and in other cities located on deltas, is the combined effects of ground subsidence and projected sea-level rise. One potential solution is to replace levees with other flood control technologies, such as the movable water gates employed in Japan, England, and the Netherlands.

Anna M. Cruse

• **Further Reading**

Cech, Thomas V. *Principles of Water Resources: History, Development, Management, and Policy*. Hoboken, N.J.: John Wiley & Sons, 2005. While levees are not given a separate chapter of their own, this book provides a comprehensive overview of water resources in the United States, including flood-control structures. Index, illustrations.

Fischetti, Mark. "Protecting New Orleans." *Scientific American* 294, no. 2 (February, 2006): 64-71. The levees in New Orleans were too small to prevent flooding from the Hurricane Katrina storm surge. This article discusses levee systems used in the Netherlands and Great Britain, plans for new systems, and the potential impacts for wetland restoration. Figures, maps.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Comprehensive treatment of the causes of climate change, written for a wide audience. Figures, illustrations, glossary, index, references.

O'Neill, Karen M. *Rivers by Design: State Power and the Origins of U.S. Flood Control*. Durham, N.C.: Duke University Press, 2006. Comprehensive historical treatment of the creation of the flood control system—including levees—in the United States. Bibliography, index.

See also: Flood barriers, movable; Floods and flooding; Louisiana coast; New Orleans; Storm surges.

Level of scientific understanding

• **Category:** Science and technology

• **Definition**

The Intergovernmental Panel on Climate Change (IPCC) is a scientific body that represents a hybrid of science and government. Its members strive for maximum reliability in their measurements, but they are keenly aware of the virtual impossibility of reaching that goal. Earth's climate is simply too vast a system to allow for carefully controlled experiments. Rather than ignore the problem, IPCC workers have designed a compromise system that specifies the degree to which workers in the field are confident of the validity of reported data. A level of scientific understanding (LOSU) designation is applied to assessments of each of the influences on the Earth's temperature. These radiative forcing factors include the greenhouse gases (GHGs), aerosols, mineral dust, and contrails.

Each of the radiative forcing factors is given an assessment of A to C depending on the evidence supporting it and an assessment of 1 to 3 for the degree of consensus among climate scientists. LOSU is assigned on the basis of these two evaluations. The terms used are high, medium, medium-low, low, and very low. This scale and its terminology were deliberately chosen to avoid confusion with the measures of confidence associated with statistics. IPCC reports clearly state that such statistical precision is not possible in the present state of climate science. The LOSU designation is designed to avoid the unwarranted impressions of understanding.

• **Significance for Climate Change**

Central to all scientific discussions is the reliability of the measurements that are used to support one's position. In the case of climate change or global warming, there are a number of extremely complex issues seldom encountered in scientific studies. These include the size of the system being studied; the constant changes undergone by that system; the large number of scientists conducting partial studies, each of whom has a particular objective; the lack of power to demand that specific procedures be followed; and so on. By contrast, scientists are accustomed to designing experiments with particular objectives and carrying them out under carefully controlled conditions. Added to these difficulties is the obvious necessity of collecting enormous amounts of data on a worldwide scale and attempting to draw from them meaningful leads for further investigation.

These problems pale in comparison to the realization that these scientific studies are conducted in a highly charged political arena. Imagine a range of scientists with little training and personal sympathies or antipathies toward policy makers presenting tentative conclusions to officials with little scientific background, and perhaps even a jaundiced view of civilians who never have to stand for reelection. Even assuming both groups earnestly desire to benefit humanity, it is clear that differences of viewpoint will often lead to discord over the appropriate strategies and tactics.

Those who disagree with a general position on global warming argue that science must not involve consensus and that the LOSU is therefore fatally flawed. This conclusion is based on a red herring and a profound lack of knowledge of the history of science. The most important reason for publication of the outcome of scientific experimentation is to allow other scientists to fulfill their obligation to question any new proposal. This is how new ideas are tested through peer review. The normal outcome of this process is debate over the validity and utility of that idea, and it inevitably leads to a mixture of acceptance, reservation, and rejection. It was long after John Dalton had proposed the atomic hypothesis that the majority of chemists accepted the existence of atoms. Even after an idea becomes textbook science and is accepted by nearly everyone, at least as a working hypothesis, it may still be modified or rejected when the consensus is broken. A consensus existed that the inert elements did not form compounds, until it was shown that they do. Science depends on consensus at every stage of its evolution.

With these technical and political problems in clear view, the IPCC has sought to bring common sense to bear on its mission. Nowhere is this effort clearer than in the LOSU approach. By considering both the strength of the evidence offered by scientists and the degree of acceptance it obtains from the scientific community, the group offers the public and the policy makers its best estimate of the real-world situation. It has been said that the only simple systems are those that have not yet been studied. It appears clear to informed people, scientists, and policy makers that the problems of climate change must be resolved using the best ideas and technology available. The level of scientific understanding represents a useful approach to evaluating and disseminating the current state of this aspect of climate science.

K. Thomas Finley

• Further Reading

Forster, P., et al. "Changes in Atmospheric Constituents and in Radiative Forcing." In *Climate Change, 2007: The Physical Basis*, edited by S. D. Solomon et al. New York: Cambridge University Press, 2008. A detailed analysis of the method of assigning the LOSU along with a complete set of current data. Technical in parts, but the main concepts are clear.

Haley, James, ed. *Global Warming: Opposing Viewpoints*. San Diego, Calif.: Greenhaven Press, 2002. An unusual approach, but perfect for this topic. Many questions are raised from both the positive and negative perspective. Experts in each area make their case for the particular viewpoint. Excellent bibliography.

Silver, Jerry. G*lobal Warming and Climate Change Demystified*. New York: McGraw-Hill, 2008. Comprehensible text filled with data that are all explained with a minimum of technical vocabulary. Good review quizzes for each chapter and a final exam with answers. A glossary, historical outline, and discussion of lingering doubts completes a worthwhile book.

See also: Falsifiability rule; Gaia hypothesis; Intergovernmental Panel on Climate Change; Peer review; Scientific credentials; Scientific proof.

Liberalism

- **Category:** Popular culture and society

Liberalism has an important impact on the modern mindset regarding the human relationship with nature. Liberal individualist viewpoints affect debates about global warming in diverse and sometimes contradictory ways. Examining liberalism is crucial in interpreting U.S. public policy regarding global warming.

• Key concepts

civil society: a voluntary community composed of individuals who share similar values and norms and who work to improve their collective welfare

complex interdependence: a situation in which intensive interconnections between transnational actors necessitate cooperation among those actors

faction: a group of individuals with common goals who work primarily to attain their interests within a larger political framework

liberty: the ability of individuals to act according to their own will without external coercion

natural law: the concept that some laws are given by nature and apply to everyone at all times in all places

neoliberalism: the liberal school of thought in economics that stresses the importance of free markets and minimal government intervention in economic matters

private property: the individual or group ownership and control over objects that have value and can be exchanged

reason: the use of logic and analysis to formulate and evaluate propositions and arguments

• Background

Liberalism is a political philosophy founded during the Enlightenment in Europe. Prominent liberal philosophers include John Locke, Adam Smith, Jean-Jacques Rousseau, Immanuel Kant, Jeremy Bentham, and John Stuart Mill. As a theory, liberalism represents a wide range of thought. At its core, liberalism is optimistic toward the ability of humans to use reason to achieve social progress. To pursue progress through reason, the individual must be autonomous, that is, free from unnecessary coercion and threat. The rise of liberalism coincides with the rise of the modern nation state. Liberalism justifies the authority of the nation state on the grounds that the nation state is a necessary social institution to protect individual rights and liberty. These rights are often defined as the right to enjoy one's property. Governments have a legitimate role in defending property rights and one's freedom to enjoy property according to one's will. Legitimate government to liberals is unbiased, representing no faction while equally protecting the rights of all citizens. Liberalism holds an optimistic view of human nature and enlightened self interest. Individual rights are central to the liberal outlook.

• Private Property

The liberal emphasis on the importance of private property has had a profound impact on modern society. Private property, according to John Locke, is the basis of self-preservation. Locke argues that the person who applies labor to nature to create value is the rightful owner of that value, or property. The industrious create value where there was previously none. In this view, nature is not valuable in itself, but only as a means toward providing for human ends. According to Locke, however, humans should take from nature only that which they can reasonably use. Humans should not allow value derived from nature to spoil. With the invention of money, however, this spoilage can be reduced. Money allows for the accumulation of wealth and enlargement of private property, because it does not spoil.

It should be noted, however, that classical liberalism also informed critics of private property. Many socialist, communist, and anarchist social theories operated under classical liberal principles of human freedom, liberty, and progress. This attests to the wide range of ideas and social movements inspired by liberalism.

• Civil Society

Liberalism emphasizes the importance of civil society. Civil society is achieved by the voluntary submission of each free individual to an objective power that can judge social conflicts arising between self-interested people. The primary force in civil society is the legislature. The legislature makes the laws that form the common bonds and rules among individuals. Civil society is necessary because prior to civil society people exist in the state of nature. The state of nature is one of mutual fear and danger. To enforce legislative bonds, an executive must possess the power to execute laws and punish those who fail to abide by the rules of civil society, or the social contract. Liberal democracies operate under social contracts, an example being the United States Constitution.

- **The Danger of Factions**

The end of civil society is to promote peace and to preserve private property. Sometimes however, legislative and executive power fall prey to the interests of factions. Factions view government as a means to pursue their own interests rather than the interests of the whole country. When factions become too powerful, civil society falls into despotism and possible dissolution. If powerful factions rule unjustly, those who are unjustly ruled are justified to resist. This liberal concept is explicitly stated in the reasoning of the Declaration of Independence of the United States written by Thomas Jefferson. Problems associated with factions are also a central concern in the *Federalist* papers, written by the early American statesmen Alexander Hamilton, James Madison, and John Jay.

- **Context**

Liberalism affects the economics and politics of global warming in diverse and contradictory ways. Much of this diversity and contradiction arises from the various ways in which principles of liberalism are interpreted. For example, liberals who accept the theory of climate change argue that rational people can work together to solve this collective problem. The enlightened self-interest of the individual enables one to cooperate with others to solve collective problems. Civil society would call upon government to address the problem of climate change through legislation and executive action. In the academic field of international relations, liberal theorists cite the importance of cooperation between nation states to achieve common goals. Liberals argue that common goals and interests promote peace between nation states. Liberal scholars in international relations recommend international agreements and institutions to address collective problems such as climate change. Climate change is a good example of a global problem that will require cooperative behavior among the nation states of the global system.

Locke on Property

John Locke's Two Treatises on Government *is one of the founding texts of liberalism. In the Second Treatise, excerpted below, he sets forth the liberal philosophy of property rights that continues to govern the understanding of most Western governments of the relationship between individual humans, society, and the environment. It is within the context of this ideology that most discussions of climate change and public policy take place.*

The earth, and all that is therein, is given to men for the support and comfort of their being. And tho' all the fruits it naturally produces, and beasts it feeds, belong to mankind in common, as they are produced by the spontaneous hand of nature; and no body has originally a private dominion, exclusive of the rest of mankind, in any of them, as they are thus in their natural state: yet being given for the use of men, there must of necessity be a means to appropriate them some way or other, before they can be of any use, or at all beneficial to any particular man. The fruit, or venison, which nourishes the wild Indian, who knows no enclosure, and is still a tenant in common, must be his, and so his, i.e. a part of him, that another can no longer have any right to it, before it can do him any good for the support of his life.

Though the earth, and all inferior creatures, be common to all men, yet every man has a property in his own person: this no body has any right to but himself. The labour of his body, and the work of his hands, we may say, are properly his. Whatsoever then he removes out of the state that nature hath provided, and left it in, he hath mixed his labour with, and joined to it something that is his own, and thereby makes it his property.

To global warming skeptics, however, liberalism is interpreted to defend the inviolability of private property. Skeptics argue that government intervention in the economic process should be kept to a minimum to protect the freedom to dispose of one's private property as one sees fit. Intrusion by governments to address climate change would diminish the liberty of individuals who possess property. The best way to address climate change, if it is a problem, is to allow individuals to create wealth that can then be applied to solve the problem.

Economic neoliberals, who are often political conservatives, are central to skeptical climate change discourse. Some neoliberals are openly hostile to environmentalists, arguing that they represent a new religious movement or reformation of socialism. The skeptical view contends climate change is not a real phenomenon, but a fabrication made by alarmists. These alarmists have a self-interest in promoting climate change theory for they profit from government intervention in the economy. Ironically, contending views of climate change theory allow differing schools of liberal thought to see each other as representing factions that endanger private property, civil society, and natural law.

Justin Ervin

- **Further Reading**

Clapp, Jennifer, and Peter Dauvergne. *Paths to a Green World: The Political Economy of the Global Environment.* Cambridge, Mass.: MIT Press, 2005. Explains four environmental worldviews of political economy: those of market liberals, institutionalists, bioenvironmentalists, and social greens.

Keohane, Robert O., and Joseph S. Nye. *Power and Interdependence: World Politics in Transition.* Boston: Little, Brown, 1977. Argues the self-interest of nation states is bound within "complex interdependence." Complex interdependence requires communication and cooperation to solve collective problems.

Locke, John. *The Second Treatise on Civil Government.* New York: Prometheus Books, 1986. A central exposition of liberal political theory. It has had an enormous impact on the political and economic culture in the United States.

Michaels, Patrick J. *Meltdown.* Washington, D.C.: Cato Institute, 2004. The author is a well-known climate change skeptic. Many of his arguments are based on interpretations of liberal concepts, including private property, limited government, freedom, and the dangers of tyranny.

See also: Conservatism; Libertarianism.

Libertarianism

- **Category:** Popular culture and society

Libertarianism is a political philosophy that champions individual rights and is suspicious of government restrictions on private property. Many libertarians are skeptical of the scientific basis of belief in anthropogenic climate change. Other libertarians endorse the scientific claims but favor voluntary private-sector efforts at mitigation and adaptation.

- **Key concepts**

geoengineering: the intentional production of large-scale changes to the Earth in order to promote human welfare

laissez-faire: an antiregulation policy that allows markets to operate free of government interference

private property: an institution through which legal rights to most or all tangible economic possessions are assigned to individual owners

revenue neutrality: an approach to fiscal policy in which new taxes (such as carbon taxes) are tied with dollar-for-dollar reductions in other taxes, in order to keep the total tax burden constant

tragedy of the commons: a term describing the perverse collective outcome of self-interested behavior in the absence of property rights

- **Background**

Libertarianism is a political philosophy rooted in individual liberty. It stands in contrast to other political philosophies that place the interests of the nation, state, or other collective group above the interests of the individuals composing the group. There is no list of beliefs shared by all libertarians, though they generally oppose the Drug War and military draft, while favoring large tax and spending cuts. The libertarian position is often described as conservative on economic issues and liberal on social issues, but its proponents believe that libertarianism represents a consistent defense of individual freedoms against government encroachment.

Major Libertarian Think Tanks and Climatological Organizations

- Cato Institute
- Fraser Institute
- Heartland Institute
- International Policy Network

• Strains of Libertarianism

Historically, many different political philosophies have embraced the term *libertarian.* Some libertarians do not have strict rules limiting state power but generally favor reducing the size of government in most areas. Economist Milton Friedman (1912-2006) falls into this camp. Another group of libertarians are principled minarchists, who believe that the only legitimate role for the government is to provide judicial, police, and military services for its citizens. The novelist Ayn Rand (1905-1982) was a famous minarchist libertarian.

Other self-described libertarians are more radical anarcho-capitalists, who call for the abolition of the modern state and the privatization of all legitimate government services, including defense from foreign invasion. Economists Murray Rothbard and David Friedman are anarcho-capitalist theorists. Finally, there are libertarians who reject the system of capitalism as it exists today and believe that private property rights can lead to unjust power relations among the capitalists and the common workers. Pierre Proudhon (1809-1865) and Emma Goldman (1869-1940) are examples. However, in modern American political debate, libertarianism is usually associated with support for private property and laissez-faire capitalism.

• Libertarianism and the Environment

In mainstream political debate, the libertarian position is often associated with the "pro-economy" forces and opposed to the "pro-environment" groups. For example, if there is a conflict between the livelihood of loggers and the natural habitat of the spotted owl, most libertarians would typically support the former. Despite this tendency, many libertarians embrace defense of the environment but believe that market solutions are more effective than government regulations. Such free market environmentalists argue that air and water pollution are not examples of market failure but rather government failure. Free market environmentalists argue that under the common law, a factory dumping chemicals into a river could be prosecuted by the homeowners living downstream. In the late nineteenth and early twentieth centuries, however, British and American courts often threw out lawsuits against big businesses, in order to promote industry.

Libertarians explain environmental abuses using the economics concept of the tragedy of the commons, defined in the essay "The Tragedy of the Commons" (1968) by Garrett Hardin. Historically, when pastureland was treated as common property, herders would routinely allow their animals to overgraze the land, because any individual's restraint would simply allow another herder's animals to eat more grass. Only the introduction of private property boundaries (and barbed wire in the United States) eliminated harmful overgrazing. Likewise, libertarians often recommend the introduction of well-defined property rights as solutions to overfishing, water shortages, air pollution, and other environmental problems typically blamed on capitalism.

• Libertarianism and Climate Change

In the political debate concerning anthropogenic climate change, most libertarians are skeptical of government solutions, which often involve new government powers and hundreds of billions of dollars. Many libertarians have embraced criticisms of the scientific evidence for anthropogenic climate change, especially as the consensus view is promulgated by a worldwide coalition of governments, the Intergovernmental Panel on Climate Change (IPCC). This group of libertarians does not believe continued carbon emissions pose any serious threat and therefore opposes new taxes or regulations because they would impose economic damages with no corresponding benefit.

A smaller but growing group of libertarians endorses the scientific evidence of anthropogenic global warming but supports voluntary, private-sector measures to address the problem. Many in this group rely on the public choice school of economic thought, which demonstrates that democratic systems often lead to unintended consequences. Even if climate change is a serious threat, these libertarians believe, politicians cannot be trusted to implement effective solutions. Instead, they argue that unfettered economic growth will allow mankind to adapt to rising sea levels, higher temperatures, and other possible changes. They also believe that if the situation requires it, the market can provide more extreme remedies such as geoengineering solutions (mirrors in space, aerosols released into the atmosphere, and so on).

Finally, there are some libertarians who believe the nature of global climate change requires a political remedy. Such libertarians usually favor a revenue-neutral approach, in which the revenues raised from a new carbon tax, or from auctioning carbon permits, are used to reduce preexisting taxes.

• Context

There has always been a strong emphasis on individual liberty and suspicion of bureaucratic government in American politics. Since Franklin Roosevelt's New Deal in the 1930's, Republican politicians have generally presented themselves as advocates of fewer taxes and regulations on business. Democrats, in contrast, have generally focused on protecting the rights of minority groups and others with little political power against abuses from employers, the police, and other powerful groups. In modern political debate, libertarians have combined both elements of this suspicion of government, emphasizing the freedom of the individual in both the marketplace and public arena. Because most of the proposed remedies for anthropogenic climate change involve more money and power for the federal government, many libertarians have been very skeptical of the growing calls for government-directed mitigation efforts.

Robert P. Murphy

• Further Reading

Adler, Jonathan H., ed. *Ecology, Liberty, and Property: A Free Market Environmental Reader*. Washington, D.C.: Competitive Enterprise Institute, 2000. Adler is a leader in this field and has assembled a collection of essays dealing with topics such as species preservation and conventional pollution, as well as climate change. The book emphasizes the reasons for government failure at these important tasks.

Anderson, Terry L., and Donald R. Leal, eds. *Free Market Environmentalism*. New York: Palgrave, 2001. Similar to Adler's collection, this book covers several different applications, including the assignment of property rights to the world's oceans. Tables, figures, index.

Boaz, David. *Libertarianism: A Primer*. New York: Free Press, 1997. Boaz, executive vice president of the Cato Institute, presents a very readable introduction to mainstream libertarian ideas. Further reading, index.

Dolan, Edwin. "Science, Public Policy, and Global Warming: Rethinking the Market-Liberal Position." *Cato Journal* 26, no. 3 (Fall, 2006): 445-468. In this provocative article, economist Dolan chides libertarians for parroting conservative Republican views in the global warming debate, and urges them to apply libertarian principles when formulating policy recommendations.

Rothbard, Murray. "Law, Property Rights, and Air Pollution." *Cato Journal* 2, no. 1 (Spring, 1982): 55-99. In this classic article, economist Rothbard summarizes the libertarian approach to legal remedies for violations of property rights, then applies the framework to the case of air pollution.

See also: Conservatism; Liberalism.

Lichens

• **Category:** Plants and vegetation

• **Definition**

Lichens are very common organisms found in widely diverse habitats, including rock surfaces, trees, and human-made structures. Lichens use structures on which they grow as hosts to support their growth. They are composites, composed of two different organisms, an alga and a fungus, resulting in a symbiotic organism that has a morphology very different from the two original organisms. In lichen symbiosis, the alga provides energy through photosynthesis and the fungus provides protection and support. Lichens come in three types: crustose, a crusty form that grows tightly on rocks or trees; foliose, which resembles foliage; and fruticose, which has the appearance of "fingers." Lichens provide food for animals, such as reindeer living in arctic regions, and habitat for invertebrates. Lichens absorb nutrients from air and rain and are an important part of nutrient recycling. They grow very slowly, with rates less than 5 millimeters per year. Some species even have growth rates of less than 0.5 millimeter per year. Lichens often live for long periods of time, with some species in the arctic estimated to be over five thousand years old.

• **Significance for Climate Change**

Because of their sensitivity to environmental factors, including temperature changes, lichens can serve as indicator species (or canaries in the coal mine) to predict environmental changes. Historically, lichens have been important indicators of pollution and climate changes. Many long-term climate change studies have used lichen growth to estimate changes in environmental temperature over time. Mapping the distribution of climate-sensitive species provides an indication of current climatic conditions, whereas monitoring over time reveals past climate change effects. Lichen growth studies have been an important part of the debate over greenhouse effects by providing data that support climate change and global warming. Because of global warming, arctic-alpine species have been diminishing, while more tropical species have flourished.

Lichens grow at very slow rates, increasing in diameter as they grow. The size of individual lichen patches on rocks can be used to estimate age, with measuring the diameter of the largest lichen on a rock surface a method to determine the time period during which that rock was exposed. The study of lichen growth to determine the age of, or to "date," surfaces is called "lichenometry." The slow growth and longevity of crustose lichens have made them especially useful in lichenometry. Measurement of lichens has been used to document effects of global warming, such as glacial deposits, former extent of persistent snow cover, and avalanche activity. Most climate change studies using lichens have been conducted using a group of crustose lichens of the genus *Rhizocarpon*, which is very abundant in many Arctic environments.

C. J. Walsh

See also: Canaries in the coal mine; Carbon 4 plants; Carbon 3 plants; Forests; Mangroves; Photosynthesis.

Lichens growing on rock. (©Alan Duffy/Dreamstime.com)

Liming

- **Category:** Economics, industries, and products

- **Definition**

Liming is the addition of calcium and magnesium to soil to neutralize acidity and increase the activity of soil bacteria. The amount of lime needed to reach the desired acidity depends on the pH and the buffering capacity of the soil. The pH is a measurement of acidity or alkalinity. Buffering capacity refers to the soil's ability to resist change to its pH. Additionally, liming improves nutrient efficiency by encouraging fertilizer uptake. However, there are important limits to liming, as oversupply may cause harm to plant life. The most common liming materials come from grinding natural limestone. Limestone is composed mostly of calcium carbonate ($CaCO_3$) and by most state laws must contain 6 percent magnesium for purposes of liming. In addition to buffering the soil, the main way to reverse acidification in freshwater is through liming the water body or its surrounding drainage basin.

- **Significance for Climate Change**

Carbon dioxide (CO_2) does not absorb the Sun's energy, but it does absorb the heat energy released from the Earth. Some of the released heat energy returns to Earth and some goes out into space. This describes the greenhouse effect of CO_2; that is, CO_2 lets light energy in, but not all of the heat energy can get out. Soil liming can act as either a source or a sink for CO_2. A heat sink absorbs and dissipates the heat energy.

Some studies indicate that rather than all of the carbon in lime becoming CO_2, the lime may sequester up to half of its carbon content, thus becoming an effective carbon sink. If this is so, liming might even be part of the strategy to moderate climate change. Streams draining agricultural watersheds generally show a net CO_2 uptake. However, as nitrate (a common fertilizer ingredient) concentrations increase, lime may switch from a net CO_2 sink to a CO_2 source.

Peat soil contains large amounts of carbon and therefore is a significant emission source of greenhouse gases—especially of methane. When farming acidic peat lands, adjustment of the acidity through liming is essential. However, when adding lime to these soils often rich in carbon and methane, CO_2 production increases. In addition, because of the enhanced decomposition of organic matter through liming, soluble organic carbon increases and may factor into climate change.

Finally, it is important to note that the amount of CO_2 emissions from liming is not completely clear. This is because the amount of carbonate lime applied to soils is unclear, as is the net amount of carbon from liming that is released as CO_2.

Richard S. Spira

See also: Agriculture and agricultural land; Composting; Land use and reclamation; Nitrogen fertilization; Ocean acidification; Pesticides and pest management; pH.

Limits to Growth, The

- **Category:** Popular culture and society
- **Date:** Published 1972; updated 2004
- **Authors:** Donella H. Meadows (1941-2001), Dennis L. Meadows (1942-), and Jørgen Randers (1945-)

- **Background**

In 1972, a team at the Massachusetts Institute of Technology led by Donella Meadows developed a computer model called World3 that consisted of a complex set of interrelated differential equations that modeled the global future in terms of human population growth, the global economy, and feedbacks to the environment. The book describing this model, *The Limits to Growth*, was prominent among many publications at the time that raised a clarion call regarding biological productivity, environmental degradation, increasing population growth, and economic activity. The five fundamental variables modeled in World3 were human population, industrialization, food production, pollution, and resource depletion. The model was criticized by many neoclassical economists and others for myriad reasons, including its aspatial formulation, failure to account for technological innovation, and exponential growth assumptions.

Other books were published in the decades leading up to the release of *The Limits of Growth*, including Rachel Carson's *Silent Spring* (1962), Aldo Leopold's *A Sand County Almanac* (1949), and Paul Ehrlich's *The Population Bomb* (1968). Indeed, debates about the sustainable limits of human society harkened all the way back to Thomas Robert Malthus' seminal *An Essay on the Principle of Population, As It Affects the Future Improvement of Society* (1798). The negative effects of humans on the environment seemed to rise in societal awareness in the late 1960's and early 1970's because of the polluted Cuyahoga River catching on fire (1969), oil spills in Santa Barbara (1969), and significant air quality problems in major cities such as Los Angeles. Many contemporary films also presented dystopic visions of the future based on problems associated with limits to growth, including *Soylent Green* (1973), *Silent Running* (1972), and *Logan's Run* (1976).

This heightened awareness of environmental degradation related to limits on sustainable growth contributed to the first Earth Day, which took place in 1970. Soon after, Republican president Richard Nixon signed a great deal of environmental legislation, including the Clean Air Act Extension of 1970 and the Clean Water Act (1972), as well as issuing an executive order establishing the Environmental Protection Agency (1970). The environmental movement laid the foundation for many subsequent considerations of limits to growth. Civilized and uncivilized discussions of the idea of a human population "carrying capacity" increased in frequency and vitriol. Many would argue that Gro Harlem Brundtland's subsequent coinage of the phrase "sustainable development" (meeting the needs of the present generation without sacrificing the needs of future generations) is intimately related to ideas of limits to growth. Nonetheless, discussions of limits to growth and related ideas of carrying capacity remain incredibly controversial today. Perhaps not surprisingly, the specter of present and looming climate change resulting from human activity seems to be rekindling these old and ongoing debates.

Ecological Footprint

In the following excerpt from Donella Meadows, Dennis Meadows, and Jørgen Randers's The Limits to Growth: The Thirty-Year Update, *the authors introduce the concept of an ecological footprint and explain its importance to their argument.*

The term [ecological footprint] was popularized by a study Mathis Wackernagel and his colleagues conducted for the Earth Council in 1997. Wackernagel calculated the amount of land that would be required to provide the natural resources consumed by the population of various nations and to absorb their wastes. Wackernagel's term and mathematical approach were later adopted by the World Wide Fund for Nature (WWF), which provides semiannual data on the ecological footprint of more than 150 nations in its *Living Planet Report*. According to these data, since the late 1980's the earth's peoples have been using more of the planet's resource production each year than could be regenerated in that year. In other words, the ecological footprint of global society has overshot the earth's capacity to provide. There is much information to support this conclusion.

• Significance for Climate Change

Discussions of limits to growth are often centered around the limits represented by the interrelated resources of food, water, and energy. The causes and consequences of climate change are also intimately related to those resources. Most policy proposals regarding climate change involve adaptation to the impacts of climate change or reduction or elimination of its causes. Primary among these causes is the anthropogenic emission of greenhouse gases (GHGs), particularly carbon dioxide (CO_2). Perhaps fortunately, global oil supplies seem to be dwindling. Increasing use of biofuels as a substitute for oil, however, demonstrates the problematic and interconnected nature of limits to growth.

When corn is used to produce ethanol as a substitute for gasoline, food supplies are affected, and the combustion of ethanol still produces CO_2 emissions. When densely populated coastal communities resort to the desalination of ocean water to obtain freshwater, they often burn fossil fuels to generate the energy needed to do so. Global warming also has the potential significantly to alter climate patterns in ways that will negatively affect both food and water supplies. The concepts of carbon footprints and carbon neutrality have gained currency in discussions of climate change. The idea of a carbon footprint borrows from a broader and older idea, than of an ecological footprint, which is itself essentially an analysis of limits.

Typical ecological-footprint analyses compare human demands on Earth's ecosystems and natural resources and contrast them with Earth's ability to provide for those demands through time. Many scholars and researchers are convinced that the present demands of the human population on Earth's resources exceed Earth's ability to provide them and that the human population is therefore in a state of ecological deficit. Increasingly, scholars are conducting various kinds of economic-ecological accounting studies that raise once again some very contentious and controversial questions about the limits to growth. The prospects of climate change, global warming, and their consequences have reignited the interest in and perhaps the urgency of resolving these important questions regarding the limits to growth.

Paul C. Sutton

- **Further Reading**

Cohen, Joel E. *How Many People Can the Earth Support?* New York: W. W. Norton, 1995. Useful, objective discussion of sustainable populations and practices that seeks to avoid taking for granted the validity of points of view on either side of the issue (cornucopians or catastrophists).

Ehrlich, Paul. *The Population Bomb.* Rev ed. New York: Ballantine Books, 1978. Seminal work in both the environmental movement and population studies.

Hardin, G. "The Tragedy of the Commons." *Science* 162, no. 3859 (December 13, 1968): 1243-1248. Extremely influential essay, arguing that solutions to Earth's population problem can only be moral, rather than technological.

McKibben, Bill. *Deep Economy: The Wealth of Communities and the Durable Future.* New York: Times Books, 2007. Forceful argument against economic models based on growth, arguing that they should be replaced with economic models that seek to strengthen communities and increase happiness rather than wealth.

Meadows, Donella, Jørgen Randers, and Dennis Meadows. *Limits to Growth: The Thirty-Year Update.* White River Junction, Vt.: Chelsea Green, 2004. Updated version of the original book that looks at changes in the environmental movement, politics, and economics over the three decades since the initial publication, as well as the changes in technology, modeling, and theory deployed and experienced by the authors themselves.

See also: Biodiversity; Biofuels; Desalination of seawater; Energy resources; Ethanol; Freshwater; Hubbert's peak; Population growth; Renewable energy; Sustainable development; Water resources, global.

Lithosphere

- **Category:** Geology and geography

- **Definition**

Besides compositional classification, the Earth is separated into layers based on mechanical properties. The topmost layer is called the lithosphere, composed of tectonic plates that float on top of another layer known as the asthenosphere. The term lithosphere is derived from the Greek words *lithos*, meaning rock, and *sfaira*, or sphere. The rigid, brittle lithosphere extends about 70 kilometers and is made up of Earth's crust and the upper part of the mantle underneath. It is broken into a mosaic of rigid plates that move parallel across the Earth's surface relative to each other.

The lithosphere rests on a relatively ductile, partially molten layer known as the asthenosphere, which derives its name from the Greek word *asthenes*, meaning "without strength." The asthenosphere extends to a depth of about 400 kilometers in the mantle, over which the lithospheric plates slide along. Slow convection currents within the mantle, generated by radioactive decay of minerals, are the fundamental heat energy source that causes the lateral movements of the plates on top of the asthenosphere. According to the plate tectonic theory, there are approximately twenty lithospheric plates, each composed of a layer of continental crust or oceanic crust. These plates are separated by three types of plate boundaries. At divergent boundaries, tensional forces dominate the interaction between the lithospheric plates, and they move apart and new crust is created. At convergent boundaries, compression of lithospheric plate material dominates, and the plates move toward each other where crust is either destroyed by subduction or uplifted to form mountain chains. Lateral movements due to shearing forces between two lithospheric plates create transform fault boundaries. Earthquakes and volcanic activities are mostly the result of lithospheric plate movement and are concentrated at the plate boundaries.

• Significance for Climate Change

Volcanic eruptions have severe effects on global climate. The greenhouse effect, icehouse effect, and ozone depletion by far have gained the most attention in climate research and planning. In addition to lava and pyroclastic materials (fragments of hot and molten rocks), volcanoes emit a variety of gases such as water vapor, carbon dioxide (CO_2), carbon monoxide (CO), chlorine, fluorine, and sulfur dioxide (SO_2). Both CO_2 and CO are greenhouse gases (GHGs) that contribute to global warming by creating a shield over the Earth that prevents heat from escaping into the atmosphere.

In contrast, SO_2 gas causes short-term cooling resulting from what is known as the icehouse effect. In the lower atmosphere, SO_2 gas is converted to sulfuric acid (H_2SO4), which condenses to form a thick layer of sulfate aerosol. The suspended aerosols increase Earth's albedo by reflecting the Sun's rays back to space and cause cooling of the Earth's surface. An anomalous increase in SO_2 layers in the atmosphere and decrease in average temperature correlates significantly with several volcanic eruptions. The 1991 eruptions of Mount Pinatubo in the Philippines were responsible for about a 0.5° Celsius decrease in global temperature and an unusually cold summer in 1992 in the intermediate latitude of the Northern Hemisphere.

Although volcanic activity increases the global temperature by adding CO_2 to the atmosphere, a much greater amount of CO_2 is added to the atmosphere by anthropogenic activities each year. Research by Terrence M. Gerlach indicates that anthropogenic CO_2 emissions are about 150 times greater than volcanic CO_2 emissions. A small amount of global warming caused by the GHGs from volcanic eruption can considerably supersede the greater amount of global cooling caused by volcano-generated aerosol particles in the atmosphere. Without such cooling effect, global warming due to GHGs would have been more pronounced.

The lithosphere's plates move at a rate of about 3 centimeters per year. The distribution and relative movement of the oceanic and continental plates across the latitude also have profoundly affected the global climate. The major contributing factors are differences in surface albedo, land area at high latitudes, the transfer of latent heat, restrictions on ocean currents, and the thermal inertia of continents and oceans. According to the present configuration of oceans and continents, the low latitudes have a greater influence on surface albedo because the lower latitudes receive a greater amount of solar radiation than the higher latitudes.

Whereas the continents in higher latitudes receive lesser solar radiation and accumulate snow that consecutively increases the albedo and decreases the Earth's surface temperature, the latent heat of evaporation influences the surface temperature at lower latitudes, where there is greater oceanic surface. The evaporation of water from the oceanic surface, a dominant mode of heat transfer, results in greater heat loss in lower latitudes. Oceanic circulation is a primary mechanism by which the heat due to solar radiation is spread from equatorial to polar latitudes. The continents in between work as barriers that restrict the oceanic heat transport toward the poles, and can influence the area and thickness of polar snow cover. The thermal inertias of continents and oceans are different. The continents respond quickly if there is a change in solar input, whereas oceans have high heat capacity and act slowly. In addition to the present positions of the continents and oceans, the higher elevations due to mountain orogeny also control the global climate.

Arpita Nandi

• Further Reading

Gerlach, Terrence M., et al. "Carbon Dioxide Emission Rate of Kilauea Volcano: Implications for Primary Magma and the Summit Reservoir." *Journal of Geophysical Research* 107 (2002). Comparative study of anthropogenic and volcanic CO_2 emissions.

Schuiling, Roelof D. "Thermal Effects of Massive CO_2 Emissions Associated with Subduction Volcanism." *Comptes Rendus Geosciences* 336 (2004). Study of CO_2 emitted during volcanic activity that is not concentrated in volcanic centers. Such CO_2 derives from the decarbonization of subducted limestones and carbonated metabasalts.

Zielinski, Gregory A. "Use of Paleo-Records in Determining Variability Within the Volcanism-Climate System." *Quaternary Science Reviews* 19 (2000). Focuses on the volcanic eruptions that inject SO_2 into the stratosphere, resulting in global climate cooling. Examines variations in cooling by latitude.

See also: Atmosphere; Cryosphere; Hydrosphere; Plate tectonics; Sulfur cycle.

Little Ice Age

• **Categories:** Climatic events and epochs; cryology and glaciology

A brief cold period may have occurred during the seventeenth and eighteenth centuries. Some researchers think that the lower temperatures resulted from a reduced solar energy output related to the Maunder Minimum in sunspot activity. The possibility that climate variations may be induced by solar activity complicates the conventional theory that human activity is causing global warming.

• Key concepts

luminosity of Sun: the total energy output of the Sun every second, measured in watts

Maunder Minimum: a period from about 1645 to about 1715 when very few sunspots were observed

sunspot cycle: also known as the solar activity cycle, an eleven-year cycle in the number of sunspots and amount of other solar magnetic activity

sunspot minimum/maximum: the time when there is the minimum/maximum number of sunspots during the eleven-year sunspot cycle

sunspots: dark spots on the surface of the Sun caused by solar magnetic activity

• Background

Indirect and anecdotal evidence indicates that it was colder than normal during the seventeenth century in Europe, and possibly worldwide as well. Without accurate weather records for this time period, the exact dates of the Little Ice Age are not known. The coldest period was the seventeenth century, but date estimates range from as early as about 1350 or 1400 to as late as 1850. Indeed, some writers use the term "Little Ice Age" to refer only to that coldest period, while others designate the entire period from 1350 to 1850 with the term. The coldest portion of the Little Ice Age occurred during the time of the Maunder Minimum, a period of virtually no sunspot activity. If the Sun's luminosity is slightly lower during periods of reduced sunspot activity, the Little Ice Age may have been caused by a temporary decrease in the Sun's luminosity.

• Little Ice Age

The Little Ice Age was not an ice age. During the various ice ages, which occurred many millennia ago, glaciers invaded temperate midlatitude regions. The evidence for these ice ages is geologic, because they occurred before recorded history. The Little Ice Age occurred only a few centuries ago. It was colder that normal, but not nearly as cold as the ice ages. Historians know about the Little Ice Age from various anecdotal documents and indirect proxies. There are, however, no accurate weather records for this period, because the instrumentation needed to produce such records had for the most part not yet been invented. Therefore, scientific knowledge of the extent and severity of the Little Ice Age is not precise.

The exact dates of the start and end of the Little Ice Age are somewhat controversial. Authors generally agree that the Little Ice Age encompassed the seventeenth century, but there is some disagreement as to both how long afterward it lasted and how much sooner it started. This disagreement can be understood by examining reconstructed temperatures for the past millennium. The seventeenth century, which was about 0.5° Celsius cooler than the 1961-1990 average temperature, was both the longest-lasting cool period and the coldest period of the past one thousand years. Thus, nearly all researchers agree that this century was part of the Little Ice Age.

The entire period from about 1300 to the late nineteenth century was cooler than normal for the millennium. However, most of this time was not as cold as the seventeenth century, and there were some relatively warm periods during these centuries. The first half of the nineteenth century was colder than normal, but the eighteenth century was about as warm as the average for the millennium. Thus, the Little Ice Age may have lasted as late as 1850, but it may have ended in the early 1700's.

The period from 1000 to shortly after 1200, the Medieval Warm Period, was nearly as warm as the end of the twentieth century. Average temperatures then dropped fairly quickly during the late thirteenth century, making it possible to date the beginning of the Little Ice Age as early as about 1350 to 1400. The middle of the fourteenth and fifteenth centuries were nearly as cold as the seventeenth century, but there were warmer periods about 1400 and during the first portion of the sixteenth century. Thus, the Little Ice Age may not have started until the seventeenth century.

The uncertainty of dating the beginning and end of the Little Ice Age results from the facts that the cool climate from approximately 1350 to 1850 was interspersed with relatively warm periods and that the longest-lasting and coolest period was the seventeenth century. The exact time period of the Little Ice Age is therefore fairly loosely defined.

• Evidence for the Little Ice Age

Thermometers were not invented until the end of the sixteenth century, and widespread, systematic use of accurate thermometers did not occur until much later. There are therefore no accurate weather records to verify the Little Ice Age. Climate researchers must use other lines of evidence, including both various proxies and anecdotal evidence.

The most common proxy studies for climate involve tree rings. The thickness and density of the rings varies with various climatic conditions, including temperature and rainfall. In polar regions, studies of various properties of ice cores provide climate information. The properties include the rate at which ice accumulates, layers that have melted, and isotope ratios. Growth thicknesses and other properties of corals can also provide climate information.

For all of these proxy studies, climate researchers statistically analyze the relationship between the proxy and climate conditions during recent periods for which accurate weather records exist. The researchers then extrapolate the climate conditions back to the dates before accurate weather records. The further back researchers extrapolate, the less accurate the proxy is in reconstructing climate conditions. Hence, climate estimates for the first half of the millennium are less accurate than are more recent estimates. Proxy studies are further complicated by the fact that multiple variables can affect the proxy. For example, tree rings are affected by both temperature and rainfall conditions.

In addition to proxy studies, there is anecdotal evidence for the Little Ice Age. Examples of this type of evidence include such things as diary entries and paintings. Diary entries might include reports of unusual freezings of various bodies of water, extreme snowfalls, and so forth. Paintings in eras when artists strove for realism can also depict frozen landscapes and bodies of water. If the paintings made during a particular time period show a large number of frozen landscapes of locations that seldom freeze now, researchers can conclude that the time period was cooler than normal. These lines of evidence are not scientific, but many reports of a particular time period being colder than normal strongly suggest that it actually was colder, even in the absence of scientifically reliable weather records. These lines of evidence apply primarily to Europe, so the Little Ice Age could have been either a strictly European phenomenon or a global phenomenon.

• The Maunder Minimum and the Little Ice Age

There is fairly strong evidence that variations in the Sun's luminosity related to sunspot activity caused the Little Ice Age.

Sunspots are dark regions on the surface of the Sun caused by solar magnetic activity. Solar magnetic activity also causes bright areas, or faculae, on the Sun's surface. The Sun undergoes an eleven-year cycle regulating the amount of sunspots, faculae, and related solar magnetic activity it experiences. Satellite measurements over the most recent solar cycles show that the Sun's luminosity is a very small amount higher during sunspot maximum than during sunspot minimum. The net effect of the bright areas on the Sun is slightly larger than the net effect of the dark areas, so the Sun is brighter during sunspot maximum.

There are also less well established longer cycles in solar activity. Notably, the Maunder Minimum was a period from about 1645 (possibly as early as 1620) to 1715 when there were very few sunspots. This period corresponds to the coldest portion of the Little Ice Age. If the observation that the Sun emits less energy during periods of minimal sunspot activity holds, then the Sun's lower luminosity during the Maunder Minimum may have caused the coldest portions of the Little Ice Age.

Closer comparison of the sunspot activity and global temperatures over the past thousand years supports this hypothesis. The warm period from 1000 to 1200 corresponds to the Medieval Grand Maximum in sunspot activity: During sunspot maxima, there were many more sunspots than is usual during sunspot maxima. There were also other extended periods of very few sunspots similar to the Maunder Minimum, including the Spörer, Wolf, and Dalton minima. Like the Maunder Minimum, these other minima correspond to the cooler periods of the extended Little Ice Age. It is not proven that variations in the Sun's luminosity caused the Little Ice Age, but it seems to be the most likely explanation.

• Context

Global warming, especially since the later half of the twentieth century, has become a serious worldwide concern. Most climate researchers attribute this global warming to anthropogenic causes, particularly increased emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs). The extremely hot surface temperatures on Venus clearly demonstrate that CO_2 can warm a planet.

If, however, the Little Ice Age resulted from solar luminosity variations related to long-term solar activity cycles, then there is the possibility that similar solar variations are contributing to current global warming. Some, but not all, late twentieth century sunspot maxima are higher than normal, suggesting the possibility that Earth is entering another sunspot grand maximum similar to the Medieval Grand Maximum. If this is the case, then global warming may have solar variations as well as increased GHGs as a component cause.

Paul A. Heckert

• Further Reading

Eddy, J. A. "The Maunder Minimum." *Science* 192 (1976): 1189-1192. In this seminal article, Eddy demonstrates that the Maunder Minimum is real and argues both that the Sun's energy output varies with long-term cycles in the amount of sunspot activity and that this variation caused the Little Ice Age.

Foukal, P., C. Fröhlich, H. Spruit, and T. M. L. Wigley. "Variations in Solar Luminosity and Their Effect on Earth's Climate." *Nature* 443 (2006): 161-166. Reviews the state of knowledge of solar variability and its role in climate changes such as the Little Ice Age.

Golub, Leon, and Jay M. Pasachoff. *Nearest Star: The Surprising Science of Our Sun.* Cambridge, Mass.: Harvard University Press, 2001. This well-written book gives a detailed summary of scientists' knowledge of the Sun. Includes sections on climate variations and their relation to solar variability.

Hoyt, Douglas V., and Kenneth H. Schatten. *The Role of the Sun in Climate Change.* New York: Oxford University Press, 1997. Well-written, extensively documented, comprehensive account of solar variability and possible associated climate changes, including the Little Ice Age. The line of evidence for the reality of the Little Ice Age is well presented. Presents both sides of controversial issues and tries realistically to appraise therole that solar variability plays in climate changes.

Jones, P. D., T. J. Osborn, and K. R. Briffa. "The Evolution of Climate Over the Last Millennium." *Science* 292 (2001): 662-667. This review paper nicely summarizes the state of knowledge of Earth's temperature and climate changes from the years 1000 to 2000. Graphs show a temperature minimum during the seventeenth century.

Maunder, E. Walter. "A Prolonged Sunspot Minimum." *Knowledge* 17 (1894): 173-176.

_______. "The Prolonged Sunspot Minimum, 1645-1715." *Journal of the British Astronomical Society* 32 (1922): 140. These two papers are Maunder's original publications arguing that there was a prolonged minimum in sunspot activity in the late seventeenth century. Argues that the minimum is real and not an effect of few people observing the Sun. Hints at the possibility that this dearth of sunspot activity may have had some effect on Earth.

Soon, Willie Wei-Hock, and Steven H. Yaskell. *The Maunder Minimum and the Variable Sun-Earth Connection*. River Edge, N.J.: World Scientific, 2003. This well-documented book explores the Maunder Minimum and other long-term solar variability as well as the role this variability plays in Earth's climate changes, including the Little Ice Age.

See also: Faculae; Medieval Warm Period; Solar cycle; Sun; Sunspots.

Louisiana coast

- **Category:** Geology and geography

The southern third of Louisiana lies no more than 7.6 meters above sea level, and the extensive salt marshes on the central and western coast average less than 1 meter above sea level. Much of the city of New Orleans is below sea level. This land is highly susceptible to the consequences of rising sea levels and increased storm intensity associated with global warming.

• Key concepts

barrier island: an offshore island running parallel to a coastline that protects the coastline from storm surges

bayou: a small, often intermittent, distributary

delta: a network of distributaries through deposited sediments at the mouth of a river

distributary: a branch of a river that removes water from the main river, especially near or in a delta

levee: a natural or human-made raised bank along a river

saltwater intrusion: inland movement of seawater

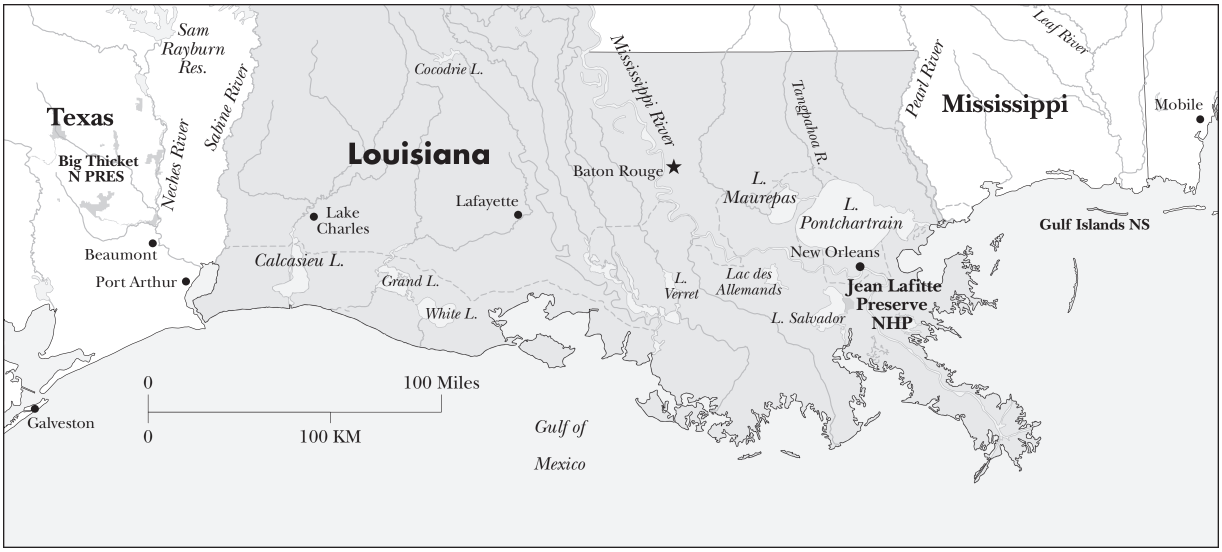
subsidence: land sinkage due to compaction of underlying material

• Background

New Orleans was founded in 1718 on a crescent of land on the east bank of the Mississippi River that was considered high enough to be safe from tidal surges and hurricanes. This high ground, about 5 meters above sea level, was a natural levee produced by sediment deposited during annual floods. Although New Orleans remains the highest land along the entire coast of Louisiana, the extensive salt marshes and river delta that once protected the city have eroded during the past century as a result of "improvements" to the river and development associated with the oil and gas industry.

• Natural Mississippi River

Much of the coast of Louisiana was formed by alluvial deposits of the Mississippi River, and even today the Mississippi and its primary distributary, the Atchafalaya River, have a tremendous impact on the Louisiana coast, carrying 1-2 million metric tons of sediment per day to the Gulf of Mexico. During the past five thousand years, six different outlets formed deltas whose remnants can be identified. The earliest followed roughly the course of the present-day Atchafalaya River and emptied into what is now Cote Blanche Bay. Much of the sediment was carried by the westward gulf current toward the Texas border. The next outlet was further



east, near present-day Terrebonne Bay. The third moved to its westernmost outlet along the general course of today's Bayou Teche. Once again, sediments moved westward, stranding the earlier beaches, called cheniers, behind extensive mudflats.

The fourth delta, far to the east, formed present-day St. Bernard Parish, most of which was underwater during the flooding caused by Hurricane Katrina. The river again moved west along the present course of Bayou Lafourche, and finally, about six hundred years ago, the river moved to its current course and began to form the bird's-foot delta at its mouth. As each delta was abandoned, sediments began to compact, resulting in local land subsidence. The interaction of sediment deposition and wave action formed a series of barrier islands, from the Chandeleur Islands on the east to Marsh Island on the west.

• Managed Mississippi River

Since the time of French settlement, landowners along the Mississippi were required to build and maintain levees, but it was not until major floods in 1849 and 1850 that national concern was raised for controlling the Mississippi River. In 1882, the U.S. Army Corps of Engineers began levee construction. Following the 1927 flood, the federal government committed to a comprehensive flood-control and navigation program that included levees, floodways, channel improvements, and stabilization.

The entire lengths of the Mississippi River and Atchafalaya Basin in Louisiana are confined by levees. Two breaches are designed into the levee system to provide controlled floodways for diverting high flow. The Old River Control Structure, near the natural confluence of the Red River, diverts up to half the flow of the Mississippi during high flood into the Atchafalaya basin. There, it is divided between the Morganza and West Atchafalaya floodways straddling the Atchafalaya River channel. About 24 kilometers above New Orleans, a second floodway, the Bonnet Carre' Spillway, can divert more than 7,000 cubic meters per second from the Mississippi River into Lake Pontchartrain to relieve pressure on the New Orleans levees.

The Atchafalaya River formed from the lower Red River in the 1500's, when a new bend in the Mississippi River captured the Red River and most of its flow. Over the years, the Atchafalaya gradually broadened and deepened until it began to capture Mississippi River water even during normal flow. By 1953, 30 percent of the flow moved down the Atchafalaya, and there was concern that the Mississippi would shift course and strand Baton Rouge and New Orleans. The Old River Control Structures, completed in 1963, regulate flow from the Mississippi. In 1973, part of the structure nearly failed during a major flood. It is likely the Mississippi will change course if and when such a failure occurs.

• Marshes

The broad alluvial plain of the Louisiana coast supports a sequence of four marsh types categorized primarily based on elevation above sea level. They range from 24-32 kilometers wide on the west side of the state to more than 80 kilometers wide south of New Orleans. The first 1 to 24 kilometers from the shore, a total of 3,640 square kilometers, is saline marsh dominated by salt-tolerant species. The salt marsh merges gradually into brackish marsh covering 4,850 square kilometers. Another 2,830 square kilometers are intermediate marshes, which grade into nearly 4,850 square kilometers of freshwater marsh. Because of the levees, annual floods no longer cover the marshes with fresh sediments, and erosion and subsidence exceeds land building along the entire coast, except for the mouth of the Atchafalaya River, which has a growing delta.

• Oil and Gas

Although most of Louisiana's oil and gas production is now offshore in the Gulf of Mexico, the first productive well was about 40 kilometers north of the coast, near the town of Jennings. The easiest way to access well sites was to dredge canals and float equipment to the site. Virtually all of the state's marshland is laced with service canals running from the coast, rivers, bayous, or the commercial Intracoastal Waterway. South of the Intracoastal Waterway, there are more than 7,240 kilometers of canals and 11,590 kilometers of bayous. These waterways permit saltwater intrusion into the heart of freshwater marshes, killing intolerant plant species. They also provide water courses through which storm surges can move far inland, eroding the fragile marshes.

• Context

As a result of human "improvements" in south Louisiana, approximately 155 square kilometers of coastline is lost every year, and what remains is even more susceptible to storm surges that are expected to increase as a result of global warming. New floodways have been opened through the Mississippi River levees south of New Orleans in an effort to flood the marshes with new sediments so they will grow again. However, the region remains increasingly vulnerable to warming-related weather patterns, and if the sea level rises, it will only become more vulnerable still.

Marshall D. Sundberg

• Further Reading

Dunne, Mike. *America's Wetland: Louisiana's Vanishing Coast*. Photographs by Bevil Knapp. Baton Rouge: Louisiana State University Press, 2005. Heavily illustrated study of land loss on the Louisiana coast.

Kelley, Joseph T., Orrin H. Pilkey, and Alica Kelley. *Living with the Louisiana Shore*. Durham, N.C.: Duke University Press, 1983. Describes the geologic history of the shoreline, particularly the influence of the Mississippi River, and provides a variety of contemporary perspectives from the barrier islands on the east to Holly Beach (destroyed in 2005 by Hurricane Rita) on the west.

Mathur, Anuradha, and Dilip da Cunha. *Mississippi Floods: Designing a Shifting Landscape*. New Haven, Conn.: Yale University Press, 2001. Combines environmental history and engineering to look at human attempts to control the river and the river's drive to control itself.

See also: Barrier islands; Coastal impacts of global climate change; Coastline changes; Flood barriers, movable; Floods and flooding; Levees; New Orleans; Sea-level change; Soil erosion; Tropical storms; Wetlands.

Maldives

- **Category:** Nations and peoples
- **Key facts**

Population: 379,174 (July, 2008, estimate)
Area: 298 square kilometers
Gross domestic product (GDP): $1.738 billion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 0.6 in 2004
Kyoto Protocol status: Ratified December, 1998

• Historical and Political Context

Maldives is an archipelago grouped into nineteen atolls located on the Indian Ocean, south-southwest of India. It is an Islamic republic and became independent from England on July 26, 1965. The majority of its people are Sunni Muslims who were originally Buddhists. The official language is Dhivehi, an Indo-European language related to Sinhala, the major language of Sri Lanka.

Maldives became a republic under the 1968 constitution, which established executive, legislative, and judicial branches of government. The Majilis (legislature) is composed of fifty members who serve five-year terms. The judicial system is derived mainly from traditional Islamic law and administered by secular officials, a chief justice and judges on each of the ninteteen atolls. Ibrahim Nasir became the president in 1968 and was succeeded in 1978 by Maumoon Abdul Gayoom.

Maldives has faced no external threat since independence, but has witnessed two internal threats. President Gayoom disclosed in 1980 details of an abortive coup involving Ibrahim Nasir, the first president. The other threat occurred in 1988, when Abdullah Luthufi, a Maldivian businessman, led a group of Tamil militants who invaded the nation in an effort to overthrow the government. Gayoom asked for help from the Indian government, which sent troops to put down the invasion. By 1990, the government had embarked on a democratization program, and the country's security improved.

In 2005, members of the Majilis voted unanimously to legally recognize political parties, and a year later the government introduced a roadmap for reform. A first-ever presidential election under a multiparty system was held in October, 2008. The Maldivian Democratic Party led by Mohamed Nasheed and his running mate, Mohammed Waheed Hassan, defeated incumbent president Abdul Gayoom. On November 11, 2008, Mohamed Nasheed was sworn in as president and Dr. Waheed Hassan as vice president of Maldives.

• Impact of Maldivian Policies on Climate Change

Climate change and rising sea levels are a great concern to Maldives, which is less than 2.5 meters above sea level at its highest point. The country's entire existence is in jeopardy, as global warming causes the polar ice caps to melt and sea levels to rise. Scientists predict that Maldives could sink beneath the ocean surface by 2100 if global warming continues. As a result, the government of Maldives is doing all it can to fight global warming.

The nation was among the first to raise climate change as a serious issue at the United Nations. President Gayoom raised the alarm in 1987, when most nations had not recognized the problem. In 1989, Maldives played a major role in calling and hosting the first small states conference on sea levels. The conference issued the Male' Declaration on global warming and sea-level rise and urged intergovernmental action on the issue. Maldives was also one of the first countries to sign the Kyoto Protocol, written in Japan in 1997. The protocol aimed at tackling the issue of global warming and reducing greenhouse gas (GHG) emissions.

Apart from the county's involvement in several international conferences on climate change, it has also implemented several projects aimed at resisting the rising sea by raising the elevation of some islands. For example, it has completed the construction of a flood-resistant island named Hulhumale, made possible by a $60 million Japanese grant.

• Maldives as a GHG Emitter

According to a United Nations development report, Maldives accounts for 0.0 percent of global emissions, with an emission rate of 2.5 metric tons of carbon dioxide (CO_2) per person in 2004. Maldives' economy is based mostly on tourism and fishing and hence it has little or no industries that pollute. However, that rate was only 0.7 metric ton per person in 1990. As a result, Maldives is not bound by a specific target for GHG emissions. The developed countries, led by the United States, are the greatest emitters of GHGs. With 15 percent of the world's population, they account for almost half of all emissions.

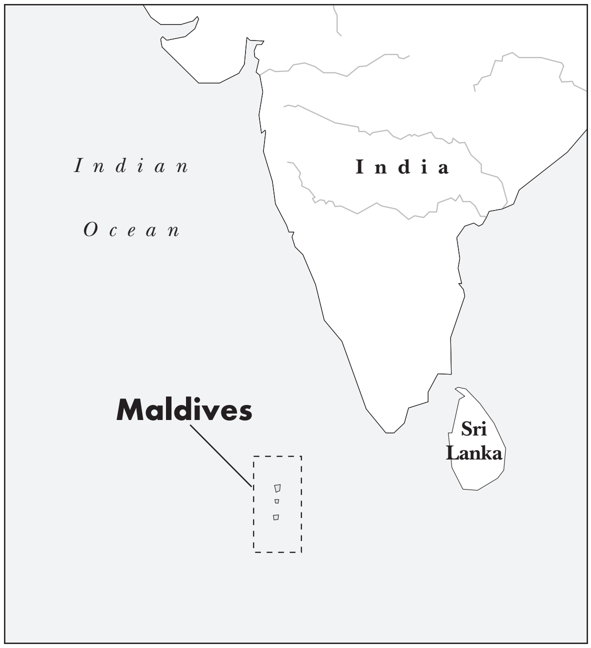
• Summary and Foresight

Tourism is the largest industry in Maldives, taking advantage of the islands' beautiful resorts and beaches. Government revenues from import duties and tourism-related taxes may be threatened by rising sea levels. For example, the 2004 Asian tsunami battered Maldives, forcing the evacuation of thirteen of its two hundred inhabited islands and causing millions of dollars in damage to its resorts and beaches.

Corals are the major ecological component of coral reefs, and elevated sea temperature causes corals to bleach. In 1998, temperature-induced bleaching killed over 95 percent of shallow-water corals in Maldives. The elimination of coral reefs is beginning to affect Maldives, since reefs protect coastlines from storm damage, erosion, and flooding by reducing wave action.

The beaches and shorelines of Maldives are vanishing. They are being washed into the sea, a consequence of global warming. These tiny islands cannot combat this threat alone. They need support from the world community, especially the developed nations that are the major contributors to global warming.

Femi Ferreira



• Further Reading

Gayoom, Maumoon Abdul. *The Maldives—a Nation in Peril: Speeches by Maumoon Abdul Gayoom, President of the Maldives, on the Challenge of Environmental Instability to the Maldives and the Global Community*. Maldives: Ministry of Planning Human Resources and Environment, 1998. Maldives president Gayoom discusses tourism, sustainable development, and the environment in relation to his island nation.

Goreau, Thomas, Wolf Hilbertz, and Azeez A. Hakeem. "Maldives Shorelines: Growing a Beach." New York: Global Coral Reef Alliances, 2004. Addresses the death of corals around the world caused by global warming by focusing on countries such as Maldives, Tuvalu, Bangladesh, and others.

Naseer, Abdulla. *Coral Reefs and Impacts of Climate Change in the Maldives*. Bangkok, Thailand: Workshop on Climate Science and Policy, 2008. Discusses the importance of coral reefs on the formation of beaches. Argues that the destruction of coral reefs in Maldives is responsible for the continued destruction of its beaches.

United Nations Environment Programme. *Maldives: Post-tsunami Environmental Assessment*. Geneva, Switzerland: Author, [2005?]. Examines the environmental impact of the 2004 Indian Ocean tsunami on the Maldives.

See also: Alliance of Small Island States; Coastal impacts of global climate change; Islands; Reefs; Sea-level change.

Malthus, Thomas Robert
English demographer and economist

Born: February 13, 1766; The Rookery, near Dorking, Surrey, England

Died: December 23, 1834; St. Catherine, near Bath, Somerset, England

Malthus hypothesized that, while food supplies increase only in an arithmetical progression, populations increase in a geometric progression. Thus, as both entities increase, the food supply would become insufficient for the population, resulting in famines and increased poverty. Malthus's predictions failed to materialize but may become relevant in the context of global warming.

• Life
The British demographer and political economist Thomas Robert Malthus was born in 1766. Malthus was homeschooled until he entered Jesus College, Cambridge, in 1784. He studied English, Latin, and Greek, but his main interest was math. Receiving a master's degree in 1791, he was elected a fellow of Jesus College and ordained an Anglican minister in 1797. Malthus's training as a church leader served him well in describing his ideas about poverty, disease, and famine. These issues and his schooling led Malthus to develop a unique philosophy about God's rule and how populations could be controlled.

Malthus formulated his theory of population growth in the pamphlet *An Essay on the Principle of Population, As It Affects the Future Improvement of Society* (1798), creating a public flurry. Malthus researched many methods of containing catastrophic population growth. He understood that humankind had natural devices, such as crime, disease, and war, for controlling population. The heart of Malthus's doctrine is that an increasing population puts an ever-increasing pressure on natural resources. He was searching for an answer that would allow a balance between population growth and the increase in the world's supply of food.

• Climate Work
Malthus's *An Essay on the Principle of Population* caused immediate debate in intellectual circles. It proposed that population growth would outpace food production, with devastating consequences. The technologies that have allowed food growth to increase in step with population growth may only be an intermediate solution to the problems posed by Malthus. The concept of climate change did not exist in Malthus's world or in his theories, but the effects of climate change today may be more than technology can deal with. Malthus also recognized that human activities could reduce the fertility of natural resources and further impair people's abilities to supply the essential goods needed to survive.

Notable intellectuals have called Malthus's principles of population growth a theory of doom and gloom, yet his work may reveal the need for equal and just allocation and use of resources. Malthus's theory ignited scholarly debate about the balanced use of natural resources

The Premature Death of the Human Race

In An Essay on the Principle of Population *(1798), Thomas Robert Malthus expressed his belief that Earth's limited resources would place a limit on the potential of human societies to thrive or even subsist on the planet.*

The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation. They are the precursors in the great army of destruction, and often finish the dreadful work themselves. But should they fail in this war of extermination, sickly seasons, epidemics, pestilence, and plague advance in terrific array, and sweep off their thousands and tens of thousands. Should success be still incomplete, gigantic inevitable famine stalks in the rear, and with one mighty blow levels the population with the food of the world.

in order to keep the climate in harmony with the universe. A new factor in the race between population growth and increasing food supplies is the effect of climate change on food production. Climate change is attributed to many causes, primarily human related, including increasing carbon dioxide (CO_2) levels and increasing ozone levels. Malthus's principles of population growth are an important factor in understanding the effects of change and how these changes affect human beings and their climate. The very process of providing the basics of human existence alters the environment that provided these basics, positively or negatively, and may affect Earth's climate.

In spite of living with the ideas and advances of the Enlightenment, Malthus overlooked the technological innovations that were being developed. These innovations were changing lives, altering the environment, and allowing people to survive longer. The science of agriculture made many advances in the 1800's that allowed farmers to make more productive use of their lands. The development of effective contraception also had the potential to check population growth. These events illustrated the flaws in Malthus's theory.

Many developing nations have not adopted improved farming techniques or methods of contraception, however. In the case of these nations, Malthus's theory seems to be coming true. Overpopulation, famine, and war continue to devastate these nations, yet the economic successes of industrializing nations tend to counter Malthus's theory. Economists of the nineteenth and twentieth centuries have criticized Malthus's theory on the grounds that technological advances, the expansion of the market economy, the division of labor, and capital goods have offset large population increases. These developments have made possible the competition between nations for wealth, power, glory, and prestige. This competition, while increasing food and resource supplies, has also resulted in environmental degradation. This environmental abuse has led many environmentalists to claim that continuing resource depletion and waste will lead to a Malthusian end to the recognizable world.

It is sometimes asserted that Malthus was incorrect, because the population grew more slowly than he predicted, while resources have grown at a much faster rate. What is important to his argument is that the population always expands to the limits imposed upon the society. He points out that a growth in population forces an increase in productivity, which causes a larger growth in the population. The same increase in productivity fuels changes to the environment that may cause changes in climate as well.

Loralee Davenport

• Further Reading

Ehrlich, Paul, and Anne Ehrlich. *The Population Explosion.* New York: Simon and Schuster, 1990. Explains how economists and biologists can work together to understand human beings and how they survive. Illustrates Malthus's role in recognizing that human behavior and money are major factors in population growth.

Eiseley, Loren. *Darwin's Century: Evolution and the Men Who Discovered It.* New York: Doubleday, 1961. Eiseley describes Darwin's study of Malthus's theory of the "struggle for existence." Darwin also gives credit to Malthus for stimulating his work on the theory of natural selection.

Eldredge, Niles. *Time Frames: The Rethinking of Darwinian Evolution and the Theory of Punctuated Equilibria.* New York: Simon and Schuster, 1982. Addresses the concepts of Darwinian natural selection. Explains that Malthusian populations naturally increase geometrically and that there are natural factors controlling population growth.

Fulford, Tim. *Apocalyptic Economics and Prophetic Politics: Radical and Romantic Responses to Malthus and Burke.* Boston: Boston University, 2001. Describes the Romantic and radical views of Malthus's theory of population growth. Explores the impact of rising prices and falling wages during the 1700's on Malthus's views of the impact of population growth.

Hardin, Garrett. *Population Evolution and Birth Control.* San Francisco, Calif.: W. H. Freeman, 1964. Examines Malthus's theory and his understanding of the human elements of love, sex, and contraception. Explains that Malthus believed that humans would not use contraceptives until they were forced to and that overpopulation would therefore occur rapidly.

Hasian, Marouf. *Legal Argumentation in the Godwin-*

Malthus Debates. Farmington Hills, Mich.: American Forensic Association, 2001. Details the relationship between Malthus and his contemporary interlocutors, including his father, William Godwin, and Jean-Jacques Rousseau.

Heer, David M. *Society and Population.* Englewood Cliffs, N.J.: Prentice-Hall, 1968. Discusses Malthus's ideas concerning hunger, epidemic, and war as methods of population control.

Malthus, Thomas. *Population: The First Essay.* Foreword by Kenneth E. Boulding. Ann Arbor: University of Michigan Press, 1959. In this volume, Malthus contends that people have a duty to remove evil from themselves and that without the evils of society they could control population growth.

________. *Principles of Political Economy Considered with a View to Their Practical Application.* London: William Pickering, 1836. This work can aid a researcher in understanding Malthus's views on population growth and his application of mathematical principles.

Pingle, Mark. *Introducing Dynamic Analysis Using Malthus' Principles of Population.* Farmington Hills, Mich.: Heldref, 2003. Illustrates the roots of Malthus's principle of population theory in economics and static models.

See also: Anthropogenic climate change; Energy resources; Industrial Revolution; Human behavior change; Population growth; Sustainable development.

Manabe, Syukuro

Japanese meteorologist

Born: September 21, 1931; Shingu-Mura, Uma-Gun, Ehim e-Ken, Japan

Award-winning meteorologist Manabe pioneered the use of computer models to simulate the impact of GHGs on climate change.

• Life

Syukuro Manabe was born in Japan, earning a doctorate in meteorology from Tokyo University. After moving to the United States in 1958, he worked as a research meteorologist at the U.S. Weather Bureau's General Circulation Research Section, eventually becoming a senior scientist in the Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration (NOAA). At NOAA, Manabe contributed his expertise to both national and international panels exploring the global climate. He also held an appointment as professor in the Program in Atmospheric and Oceanic Sciences at Princeton University. In 1997, Manabe returned to Tokyo as the director of the Global Warming Research Program of the Frontier Research System for Global Change. In 2002, he returned to Princeton.

• Climate Work

Manabe concentrates on modeling the atmosphere in order to predict global climate change. He has summarized his work on his Princeton University Web page:

> In the early 1960's, we developed a radiative-convective model of the atmosphere, and explored the role of greenhouse gases such as water vapor, carbon dioxide and ozone in maintaining and changing the thermal structure of the atmosphere. This was the beginning of the long-term research on global warming. . . .

Manabe pioneered the use of atmosphere-ocean circulation models in the analysis of climate disturbances involving greenhouse gases (GHGs). With the aid of a computer, modelers construct a system of mathematical equations that mimics a particular segment of nature. Manabe's equations center on the heat balance of Earth's atmosphere in order to mimic Earth's climate. The goal is to use data from previous years to predict global weather patterns. Even an approximate model allows its users to find the long-term effects of short-term environmental atmospheric inputs.

In 1967, Manabe and Richard Wetherald demonstrated that increased carbon dioxide (CO_2) in the atmosphere would increase the altitude at which the atmosphere reradiated heat into space, thereby lending supporting evidence for the greenhouse theory. In 1969, he and Kirk Bryan issued the first climate models that combined atmospheric and oceanic models. Using these models, Manabe demonstrated how Earth's climate might respond to increasing GHGs in the atmosphere, and his work has formed the basis for many of the assessments issued by the Intergovernmental Panel on Climate Change.

Kenneth H. Brown, updated by Christina J. Moose

See also: Climate models and modeling; Climate prediction and projection; General circulation models; Intergovernmental Panel on Climate Change.

Mangroves

- **Category:** Plants and vegetation

- **Definition**

Mangroves are both a genus of tropical and subtropical trees, the *Rhizophora*, and the family of plants to which the genus belongs, the Rhizophoracae. The term most commonly refers to an assemblage of mangrove trees and other associated trees and shrubs that includes more than one hundred species. Such an assemblage may also be called a mangrove swamp, a mangrove forest, or a mangal.

Mangroves occur in shallow, protected coastal waters, such as flats in intertidal zones, bays, and estuaries in the tropics and subtropics. They cannot survive freezing or even consistently cold water. They are usually canopied forests up to about 10 meters tall, although in rare cases old-growth mangroves can reach 40 meters in height.

Mangroves survive in a difficult niche. They must be salt-tolerant plants (halophytes), and some can thrive in water of twice the salinity of seawater. Mangrove roots can filter salt from water intake, and those growing in the most saline areas excrete salt from their leaves. Mangrove forests shade from the most salt-tolerant species on their seaward side, to the least salt-tolerant species on their landward side, and they shade to conventional forests or freshwater plants.

Mangrove mudflats tend to be oxygen poor (hypoxic), to contain toxic levels of sulfides, to be subject to periodic flooding, and to be very weak for holding trees. Consequently, mangroves have a maze of roots, some of which (pneumataphores) reach up out of the water to get oxygen, while some function as stilts to help brace the trees.

The mangrove niche between freshwater, dry land, and ocean is very small, perhaps only 0.1 percent of the Earth's surface. However, it is very important for three reasons: The maze of roots catches nutrient flows from the land and holds them for gradual release to the sea rather than short, polluting surges. Conversely, the roots protect the land from ordinary erosion and disasters such as hurricanes and tsunamis. Finally, the maze of roots holding leaves and nutrients from shore provides habitat and food for sea life. Young from as many as

Brown pelicans sit in a group of mangrove trees on the Florida coast. (U.S. Fish and Wildlife Service) three-quarters of tropical deepwater fish species live in mangroves.

• Significance for Climate Change

Theoretically, mangroves would benefit from global warming, because their tropical climate area would extend farther toward the poles. More mangroves would increase the capture (sequestration) of carbon from atmospheric carbon dioxide (CO_2) and help reduce the greenhouse effect. Moreover, increased mangrove buffering of nutrient surges washing off the land would release a steadier gentle flow of dissolved organic compounds, allowing plankton and other marine plants to capture more CO_2 from the air and to increase the oceans' reflectivity. Thus, mangroves would create a significant negative feedback retarding global warming.

In practice, however, the decline of mangroves due to human development may be a significant positive driver of global warming. The percentage of Earth's surface covered by mangroves has been cut in half (from 0.2 percent to 0.1 percent) in the last century, mostly as a result of human development. For instance, sand dredged from Biscayne Bay, Florida, buried a mangrove swamp and built a city—Miami. Recent increases in shrimp aquaculture have also caused major destruction of mangroves.

Major warming would also raise sea levels, causing mangroves to retreat from the deeper water and attempt to colonize new inland swampy areas. However, people would likely erect dikes to protect existing structures and agricultural land. Hence, the effective surface area available for mangroves would be constricted even further. This reduction in surface area would decrease the area of ocean fertility, the corresponding amount of carbon sequestration, and the buffering of the land against ocean disasters. Indeed, the damage to New Orleans caused by Hurricane Katrina in 2005 can be partly attributed to reduced swamplands around the city, which left the dikes more vulnerable (although the major causes of bayou losses in New Orleans were subsidence and navigation channels).

A number of groups have tried to replenish mangroves and even establish them in new areas. The best-known of these is the Manzanar Mangrove Initiative, which is backed by the Eritrean government on the East African coast. (It was largely sparked by Gordon Sato, who was interned during World War II at Manzanar, California.) The Manzanar Mangrove Initiative uses small amounts of fertilizer in bags for slow release to vastly increase the area of mangroves and resulting silage for livestock.

An extension of the Manzanar Mangrove Initiative would pump seawater into desert areas to vastly increase mangrove areas, food production, and capture of CO_2 from the atmosphere. However, the required pumping would require major investments in either some form of alternate energy or fossil-fuel-fired power for the pumping. Moreover, skeptics of the Manzanar Mangrove Initiative worry that overzealous fertilization of the mangroves might damage coral reefs further out to sea.

Roger V. Carlson

• Further Reading

Hogarth, Peter J. *The Biology of Mangroves and Seagrasses.* 2d ed. New York: Oxford University Press, 2007. University of York Lecturer Peter Hogarth provides an excellent introduction to mangroves.

Lieth, Helmut, Maximo Garcia Sucre, and Brigitte Herzog, eds. *Mangroves and Halophytes: Restoration and Utilisation.* New York: Springer, 2008. This collection of articles is focused on restoration and use of mangroves and other halophytes in the Caribbean area, especially Venezuela.

Saenger, P. *Mangrove Ecology, Silviculture, and Conservation.* New York: Springer, 2003. Summarizes pertinent mangrove issues, from global biological patterns to threats to methods for restoration.

Sato, Gordon, et al. "A Novel Approach to Growing Mangroves on the Coastal Mud Flats of Eritrea with the Potential for Relieving Regional Poverty and Hunger." *Wetlands* 25, no. 3 (September, 2005): 776-779. Briefly summarizes the Manzanar Mangrove Initiative, which seeks to develop methods of culturing mangroves along virtually any tropical coast and of developing agricultural products from mangroves.

See also: Coastal impacts of global climate change; Coastline changes; New Orleans; Plankton; Sequestration; Soil erosion.

Marginal seas

- **Category:** Oceanography

• Definition

Marginal seas are ocean regions that connect coastal zones to the open ocean. Marginal seas are found as indentations in the continental landmasses and are often separated from the open ocean by an archipelago or peninsula. They vary considerably in size, depth, the nature of their connection to the ocean, and the circulation of water within them.

The Mediterranean Sea is connected to the Atlantic Ocean through the Strait of Gibraltar, which is only 14 kilometers wide. In contrast, the Gulf of Mexico is connected to the Atlantic Ocean via the Caribbean Sea through the Yucatan Channel (271 kilometers wide) and the Florida Straits (180 kilometers wide). The largest of the marginal seas is the South China Sea, with an area of 2.97 million square kilometers, while the Irish Sea is one of the smallest, with an area of approximately 90,000 square kilometers. The Caribbean Sea has the greatest average depth, at 2,400 meters, and the shallowest marginal sea is the Persian Gulf, at 24 meters deep.

Water circulation in marginal seas varies depending on bathymetry, the nature of the connection with the open ocean, riverine input, and local climate. In seas such as the Black Sea, where riverine input exceeds evaporation, surface waters are less saline than is average ocean water. In other seas, such as the Mediterranean Sea, where evaporation exceeds riverine inflow and precipitation, salinity can exceed that of average ocean water. These salinity variations have important implications for the vertical circulation of water in the sea and therefore the chemistry of the bottom waters. Because marginal seas are relatively shallow and small in area compared to the open ocean, they are strongly affected by variations in river runoff, local climate, and direct human impacts, such as nutrient runoff. For example, the sediments of the Arabian Sea are characterized by a regular banding that reflects the annual development of monsoons.

• Significance for Climate Change

Marginal seas represent the buffer between land and the ocean system. They have a major economic impact on those nations that adjoin them as a result of their effects upon tourism, fishing, and the transport of goods. Marginal seas in many regions of the world suffer negative impacts from direct human activities. For example, runoff of fertilizers from agriculture triggers algal blooms in the surface water of many marginal seas. When the algae die and settle to the bottom of the sea, decay of the organic matter consumes almost all of the sea's dissolved oxygen, creating regions devoid of sea life known as "dead zones." A dead zone up to 18,000 square kilometers in area develops every summer in the Gulf of Mexico at the mouth of the Mississippi River. The development of dead zones could be exacerbated, assuming societal activities remain unchanged, in a warmer climate. Increased river runoff and warmer temperatures would lead to a situation in which greater amounts of nutrients are delivered to marginal seas, which generally have lower amounts of dissolved oxygen than does the open ocean.

Marginal seas are also sensitive to rises in sea level, such as those that may accompany global warming. Such a sea-level rise could inundate land that is currently populated. Rises in sea level coupled with changes in runoff to the ocean will affect the hydrologic balance of many marginal seas, with potentially negative ecosystem consequences. For example, decreased freshwater flow into the Black Sea could cause upwelling of the oxygen-depleted, sulfidic bottom waters onto the shelf, causing widespread loss of marine life.

Marginal seas in the Arctic and Antarctic are sites of concern because melting sea ice could contribute to sea-level rise and perhaps also to the shutdown of thermohaline circulation in the Atlantic Ocean. The collapse of the Larsen B ice shelf, in the northwestern Weddell Sea, in 2002, remains a dramatic example of the effects of global warming. The loss of sea ice in marginal seas will have major impacts on many aspects of the Earth system, including ocean circulation, sea level, radiative forcing, biological productivity, and community structure.

Anna M. Cruse

• **Further Reading**

Black, Kenneth D., and Graham B. Shimmield. *Biogeochemistry of Marine Systems*. Oxford, England: Blackwell/CRC Press, 2003. Discusses the impacts of a wide range of changes—including climate change—on various ocean systems. Each chapter discusses biogeochemical reactions to changes in specific oceanic environments. Individual chapters are devoted to the Mediterranean, Arctic, and Arabian Seas. Figures, tables, index, references.

Mee, Laurence. "Reviving Dead Zones." *Scientific American* 295, no. 5 (November, 2006): 78-85. The formation of dead zones could become more widespread with a warmer climate, if current societal practices continue. This article, written by a leader in marine conservation issues, discusses the formation of dead zones and steps that can be taken to reverse and restore dead zones once they exist. Figures.

Pew Oceans Commission. *America's Living Oceans—Charting a Course for Sea Change: A Report to the Nation*. Arlington, Va.: Pew Oceans Commission, 2003. Provides a review of the state of U.S. coastal waters and marginal seas, including the potential direct and indirect consequences of climate change. Figures, illustrations, maps, tables, index.

Yanko-Hombach, Valentina, et al. *The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement*. Dordrecht: Springer, 2007. Provides views of expert scientists on the effects of climate change upon the Black Sea, a major marginal sea, and the consequences of those changes for early human societies. Figures, graphs, tables, references, bibliography.

See also: Arctic; Atlantic heat conveyor; Freshwater; Hydrologic cycle; Maritime climate; Mediterranean Sea; Ocean-atmosphere coupling; Ocean dynamics; Ocean life; Sea ice; Sea-level change; Sea surface temperatures; Thermohaline circulation.

Maritime climate

• **Categories:** Oceanography; meteorology and atmospheric sciences

• **Definition**

Maritime climates are generally considered to be those that are moderated by the sea. However, a true maritime climate is in most cases a climate in which it is neither very warm nor very cold, with adequate rainfall throughout most of the year. A typical maritime climate occurs on the coast of Oregon and Washington in the United States, in many parts of New Zealand, in Tasmania, and in much of western Europe. Although surrounded by the sea, tropical islands are not normally considered to have a maritime climate but rather a tropical climate. True maritime climates usually have winter daytime temperatures of about 15° Celsius and winter nighttime temperatures of about 5° Celsius. In the summer, daytime temperatures average about 25° Celsius and nighttime temperatures average about 15° Celsius. Rainfall in a true maritime climate occurs throughout the year, with no pronounced wet or dry season, and averages 10 centimeters per month.

Despite the moderate nature of the true maritime climate, extremes do occur. In many maritime climates, daytime temperatures can reach above 35° Celsius, and occasionally even above 40° Celsius, while nighttime temperatures may reach 0° Celsius, and occasionally as low as –10° Celsius. Sunshine is generally more than adequate for plant growth, and annual bright sunshine hours of two thousand to twenty-five hundred hours are the norm. Rainfall, although generally adequate for plant growth, can vary: Maritime climates can have periods of up to six weeks without any appreciable rainfall, and there is at least one known instance of no rain at all falling during almost every month on the calendar. In contrast, monthly rainfalls of over 20 centimeters in a month are reasonably common, but monthly rainfalls of over 50 centimeters are not impossible. Although a daily rainfall of more than 0.3 centimeter is uncommon, at times, the rainfall in a twenty-four-hour period may exceed 20 centimeters. In summary, a true maritime climate is generally an easy climate to live in for people, plants, and animals, but relatively extreme events do occur.

• Significance for Climate Change

Although the true maritime climate has milder winters, generally cooler summers, and greater temperature ranges from nighttime to daytime than do continental climates, there are many variations from place to place. For example, the climate of New York City, although situated on a coast, has a climate quite different from that of Vancouver, on the coast of British Columbia. Alterations in the true maritime climate brought about by global climate change are likely to be relatively small, and in most places plants and animals should be able to adapt to the change. However, if there is an overall increase in temperatures in the middle latitudes of both hemispheres, where most of the true maritime climates occur, summers are likely to become warmer, albeit not as warm as current continental climates, and winters are likely to have fewer days below freezing. Sunshine hours are unlikely to change, but rainfall extremes, especially on a daily basis, are likely to increase somewhat.

New Zealand is considered to have a typical maritime climate, although there are some areas in New Zealand that are quite dry, with an average annual rainfall of only 30 centimeters. Nevertheless, most of New Zealand, as well as much of western Europe, has a typical maritime climate. Questions arise as to the effects of global warming on the temperature and agricultural production of such a climate. Considering New Zealand as an example, vineyards over the past one hundred years have flourished in many parts of the country, but as yet, in the far south of New Zealand in the Southland district, there are no commercial vineyards. Instead, the district is dairy country, covered with very green pastures and grazing cattle. The Southland District Council and the Southland Regional Council might consider the probable effects on the region of changes predicted in the Intergovernmental Panel on Climate Change's 2007 report. If they did, they might advertise the prospects of the Southland district to become a major grape-growing region in the twenty-first century.

W. J. Maunder

See also: Continental climate; Mediterranean climate; Polar climate; Tropical climate.

Marsh, George Perkins

American statesman

Born: March 15, 1801; Woodstock, Vermont
Died: July 23, 1882; Vallombrosa, Italy

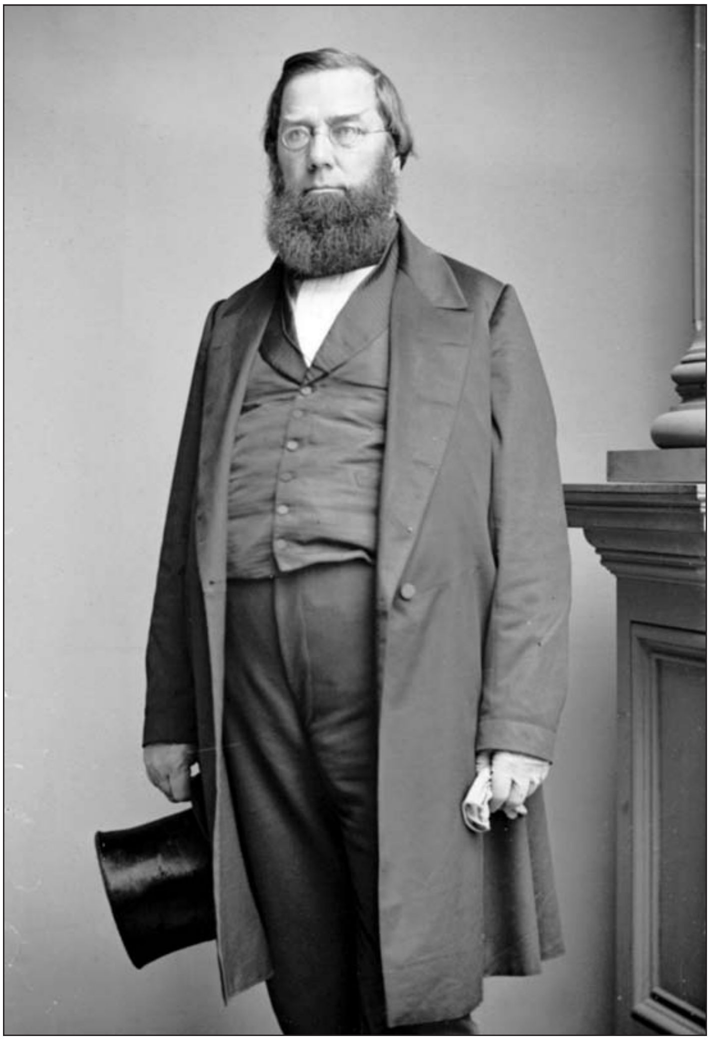
In his seminal work, Man and Nature*, Marsh argued that humans, from their very beginning, have been active agents of environmental change.*

• Life

George Perkins Marsh was born in Woodstock, Vermont, in 1801. In his boyhood years, he took careful note of how this forested region was changing before his eyes as a result of extensive settlement. These early impressions of his cultural geography and his firsthand experiences with the mountains and valleys of Vermont, he would later write, set the tone for his perspective on the impact that humans can have on their environment.

Marsh had a keen sense for the environment and enjoyed the outdoors. His academic interests drew him to Dartmouth College, where he studied languages and law. After moving back to Burlington, Vermont, he set up a law practice, ultimately finding his way into politics and serving as a U.S. representative from Vermont between 1843 and 1849. His interests in science and learning in general provided him with the skills to help organize the establishment of the Smithsonian Institution. His fondness for languages served him well, as he later became a U.S. diplomat to Turkey in 1849 and to Italy in 1861.

Marsh was an avid traveler and, as a nineteenth century naturalist, was well versed in the process of collecting specimens and observing his surroundings. These skills helped hone his understanding of the relationship between humans and their environment. Although he was a prolific writer on a wide range of subjects, it was while he was in Italy that he began his most popular literary work, *Man* *and Nature*, published in 1864. Emerging from an eclectic scientific mix of geography, statesmanship, and common sense, the text, through an exhaustive collection of local case studies, attempted to increase public consciousness of the impact that humans have on their environment. A later edition included the subtitle *Or, Physical Geography as Modified by Human Action*. The book acquired international acclaim, and Marsh would come to be considered the founder of the American conservation movement. He is credited with establishing the first scientific approaches to forest management in the United States.



George Perkins Marsh. (Library of Congress)

• Climate Work

Marsh suggests in *Man and Nature* that the destruction of Earth's forests could have an influence on climate change. Citing scientists from both sides of the question, he puts forth the notion that deforestation, by virtue of its potential to raise soil temperatures and lower humidity, could generate a change in at least regional climate. Extensive historical evidence for the connection of forests and precipitation is presented. He cites some writers who suggest more precipitation is evident over forested lands. Marsh concludes that forests, within their regional setting, influence the humidity of the atmosphere around them.

Marsh goes on to say that forests influence the climates of continental interiors just as the sea influences coastal climates. He cites sources that argue not only that tropical rain forests and other forests increase rainfall and moderate climate but also that their destruction can be linked to the development of hotter regions. Marsh's linking of forests and precipitation may lead readers to conclude that no place on Earth is free of the potential impact of human actions.

Marsh alludes to the impact of humans on climate by introducing a common nineteenth century forestry management practice, now known as clear-cutting. He suggests that regions and countries that clear their forests subject their soils to drying and could see that effect go on indefinitely. Additionally, fallen trees can dam up water courses, creating an environment conducive to higher humidity. These impacts, he concludes, could lead to seasonal temperature changes in both the atmosphere and the soil.

As a naturalist, Marsh had interests in the whole of the environment, not just a singular component of it. His unique consideration of humans as agents of environmental change suggests that they can affect their environment in positive or negative ways. For his time, Marsh's work embraced an unusual environmental paradigm. It represented a drastic departure from the homesteading Romanticists of the 1860's and the notion that humans had a right of dominion over the land such that the rain and the blessings of God would follow the ploughs of settlement. *Man and Nature* is considered to be one of the earliest influential writings on conservation and the environment. Its insights and advocacy of restraint in the use of resources is a clarion call to any society concerned for the future of its natural landscape.

M. Marian Mustoe

- **Further Reading**

Marsh, G. P. *Man and Nature*. 1864. Reprint. Edited by David Lowenthal. Foreword by William Cronon. Seattle: University of Washington Press, 2003. The complete text, including extensive case studies on the impact of human actions on the landscape. This publication also includes notes from Marsh's biographer, David Lowenthal.

Sauer, C. O., ed. *Land and Life: A Selection from the Writings of Carl Ortwin Sauer*. Edited by J. Leighly. Berkeley: University of California Press, 1969. Outlines some of Marsh's themes in the context of historical geography.

Trombulak, Stephen C., ed. *So Great a Vision: The Conservation Writings of George Perkins Marsh*. Hanover, N.H.: Middlebury College Press, 2001. An introduction to the conservationist philosophy of George Perkins Marsh.

See also: Axelrod, Daniel; Bennett, Hugh Hammond; Carson, Rachel; Conservation and preservation; Deforestation; Desertification; Ecosystems; Elton, Charles Sutherland; Environmental movement; Forestry and forest management; Thoreau, Henry David.

Mass balance

- **Category:** Cryology and glaciology

- **Definition**

Generally, mass balance refers to the net sum between the input and loss of mass to a reservoir. In glaciology, the term refers to the balance between the loss and gain of ice from a glacier, ice cap, or ice sheet. When more ice is gained than lost, the result is a positive mass balance and the overall growth of the ice body. A negative mass balance occurs when more ice is lost than is gained and the ice body shrinks.

Several other terms are used to specify the gain or loss of glacial ice. "Total mass balance" refers to the total net gain or loss of ice from an entire glacier over a single hydrologic cycle. "Specific mass balance," by contrast, refers to such loss or gain at a particular point on the surface of a glacier. Total and specific mass balances can diverge in extremely large ice bodies, such as the Antarctic ice sheets, whose mass balances vary in different geographic locations. The average mass balance per unit area of an ice body is called the "mean specific mass balance." It can be used to compare the amount of ice gained or lost by ice bodies of different sizes.

- **Significance for Climate Change**

Glaciers and other ice bodies are highly sensitive to climate change and are viewed by many scientists as early warning detectors for global warming or global cooling. Ice bodies do not form in a single year or in response to a single snow event. Instead, they form over a sustained period of time, as temperatures remain cool enough that not all of the snow that falls in a given winter melts in the subsequent summer. It is this long-term accumulation of snow that leads to the development of ice and, eventually, a glacier or other ice body. Ice bodies are dynamic, much like rivers. Ice can accumulate at the head of a glacier at the same time that it is being lost from the toe of the same glacier through ablation or iceberg calving. Also, ice bodies can change in size and shape throughout the course of a hydrologic cycle. Thus, to determine whether a glacier is growing or shrinking in size, it is necessary to consider the mass balance, or net sum, of ice that accumulates and is lost throughout an entire hydrologic cycle, rather than simply examining the size of a glacier at two points in time.

Anna M. Cruse

See also: Antarctica: threats and responses; Arctic; Deglaciation; Glaciations; Glaciers; Greenland ice cap; Ice shelves.

Mauna Loa Record

• **Category:** Meteorology and atmospheric sciences

• **Definition**

The Mauna Loa Record (or Mauna Loa Carbon Dioxide Record) is the longest continuous record of atmospheric carbon dioxide (CO_2) concentrations. The level of CO_2 in the Earth's atmosphere is one of the primary determinants of global temperature, and higher levels of CO_2 correspond with warmer global temperatures. The CO_2 data collected at the Mauna Loa Observatory in Hawaii since 1958 has been called the most important geophysical record on Earth.

A carbon dioxide monitoring station at Mauna Loa, Hawaii. (NOAA)

• **Significance for Climate Change**

In the 1950's, continuous monitoring of CO_2 levels represented a break from the conventional view that occasional measurements in selected places would provide enough data. Despite this, scientists at the Mauna Loa Observatory, founded by the U.S. Weather Bureau, decided to maintain continuous records of the CO_2 levels at its location. The observatory is located at an elevation of 3,353 meters on the island of Hawaii, and its CO_2 measurements have been supported by the Weather Bureau and the National Oceanic and Atmospheric Administration (NOAA) ever since. Within only a few years of the project's founding, an annual increase in atmospheric CO_2 concentration was measured.

In 1974, NOAA installed a new CO_2 analyzer that operated parallel to the original analyzer installed by the Scripps Institution of Oceanography. The Scripps analyzer was replaced with a newer model in 2006. The two-analyzer system provides redundancy to ensure the quality of the Mauna Loa Record and the integrity of the global CO_2 measurement network. In the 1960's and 1970's, Scripps added several measurement stations ranging from the Arctic to Antarctica. However, these stations collect flask samples that are analyzed in a lab rather than collecting on-the-spot data via an analyzer, as the Mauna Loa Observatory does.

Despite the project's importance, it has faced numerous budget and staff cuts over its existence, as well as questions of whether it constituted basic research or routine monitoring. Even today, such long-term studies are rare and often poorly supported. Despite the obstacles it has faced, the Mauna Loa project has continued, producing large amounts of valuable data that have led to several breakthroughs in climate science.

A simple graph of the Mauna Loa Record data (called the Keeling Curve after Scripps scientist Charles Keeling, who cofounded the project) shows a steady increase of 2 parts per million (0.53 percent) per year in atmospheric CO_2 since the observatory began collecting data in 1958. According to NOAA's Earth System Research Lab, 63 percent of global warming due to greenhouse gases is due to CO_2.

The record has provided crucial evidence that human activity has changed and is changing the composition of the atmosphere. Climate scientists have used the Mauna Loa data to model the state of the Earth's future climate, affecting political actions such as the drafting of the Kyoto Protocol, a multinational agreement to limit carbon emissions.

The Mauna Loa data also demonstrated for the first time the annual fluctuation in atmospheric CO_2 attributable to biological activity. CO_2 levels reach their maximum in May and their minimum in October. Both of these averages, however, have increased every year since the project began. While the curve is small, it indicates an exponential increase rather than a linear one—the average CO_2 level increases by slightly more each year than the previous year. Atmospheric CO_2 has increased by more than 35 percent over amounts recorded before the Industrial Revolution, and over 6 percent between 1990 and 2009. Comparison with ice-core records suggests that current CO_2 concentrations are unprecedented in the past 650,000 years.

In 1983, Keeling and other scientists began addressing how El Niño weather events affected atmospheric temperature and CO_2 concentration, using the data from Mauna Loa. They were able to identify approximately ten-year fluctuations in temperature correlated with CO_2 fluctuations, leading to a better understanding of long-term global temperature variance.

Skeptics have put forth critiques of the Mauna Loa data, citing the Mauna Loa Observatory's location on an active volcano and increasing traffic near the observatory. However, the project has attempted to minimize contamination through careful sampling and by normalizing to negate local contamination. Atmospheric CO_2 samples from other stations worldwide corroborate the Mauna Loa data, and the Mauna Loa Record continues to form a base data set for crucial research into climate change.

Melissa A. Barton

• Further Reading

Field, Christopher B., and Michael R. Raupach, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Washington, D.C.: Island Press, 2004. Explores scientific knowledge of the global carbon cycle from a multidisciplinary viewpoint, including coverage of carbon-climate-human interactions. Discusses research into the history of atmospheric CO_2 and the factors that have influenced past changes, as well as the gas's role in the modern carbon cycle. Includes discussion of the Mauna Loa Record within a global context. Tables, figures, color photographs, index.

Keeling, Charles D. "Rewards and Penalties of Monitoring the Earth." *Annual Review of Energy and the Environment* 23 (November, 1998): 25-82. A review of the Mauna Loa Record project and its implications for science by one of its founders; autobiographical. Also discusses the history and challenges of the project. Figures, references.

Keeling, C. D., et al. "Atmospheric CO_2 and CO_2 exchange with the Terrestrial Biosphere and Oceans, from 1978 to 2000: Observations and Carbon Cycle Implications." In *A History of Atmospheric CO_2 and Its Effects on Plants, Animals, and Ecosystems,* edited by J. R. Ehleringer, T. E. Cerling, and M. D. Dearing. New York: Springer Verlag, 2005. Report on atmospheric carbon research, including the Mauna Loa Record. Figures, references.

See also: Carbon dioxide; Climate reconstruction; Greenhouse effect; Greenhouse gases.

Mean sea level

• **Category:** Oceanography

• Definition

Sea level is the height of the surface of the ocean at any given location. Sea level is highly variable and can undergo very rapid changes due to such events as tides, tsunamis, changes in barometric pressure, wind-generated waves, and even freshwater floods. While these events can produce changes in sea level of several meters, they are local in scale and of a very short duration, generally lasting only for hours. Mean sea level is the average, global height of the sea surface, independent of these local, short-term changes. Changes in mean sea level are on the order of a few millimeters per year.

Mean sea level at specific locations can be calculated using tide gauge records and subtracting the effects of annual changes in atmospheric pressure and long-term changes in tidal ranges, which are driven by astronomical factors. Changes in global mean sea level can be calculated using satellite-based radar altimetry, such as with the TOPEX/Poseidon satellite. The radar altimeter measures the height of the satellite above the ocean, based on the time it takes for a radio signal to travel from the satellite to the sea surface and back. Since the actual altitude of the satellite is known, any changes in the altimeter measurement reflect changes in the height of the sea surface itself.

• Significance for Climate Change

On short timescales (decades to centuries), mean sea level is a function of the amount of water stored as ice in glaciers and ice sheets. As global temperature rises, less water is stored as ice, contributing to a rise in mean sea level. A rise in mean sea level in response to global warming has important societal consequences. First, such a rise contributes to a loss of land, as coastal areas are slowly inundated by water. This is a concern for certain low-lying island nations such as the Maldives or Tuvalu. The Maldives is a nation made up of twelve hundred islands in the Indian Ocean, which has a maximum elevation of only 2.5 meters above current sea level. Thus, the Maldivian population of approximately 380,000 people is highly vulnerable to even a slow rise in mean sea level. For other nations, a rise in mean sea level is also a concern because of increased hazards from flooding during high tides—especially spring tides—and storms. A rise in mean sea level provides a higher baseline upon which tidal fluctuations build. According to the Fourth Assessment Report released by the Intergovernmental Panel on Climate Change, from 1993 to 2003, mean sea level rose approximately 3.1 millimeters per year.

Anna M. Cruse

See also: Coastal impacts of global climate change; Floods and flooding; Glaciers; Islands; Maldives; Sea ice; Tuvalu.

Media

• **Category:** Popular culture and society

The battle over climate change has played out publicly in the media. Conservatives have charged the media with bias against questioning anthropogenic climate change. Liberals have argued that there is a scientific consensus and the media are irresponsible to portray the issue as subject to debate.

• Key concepts

bloggers: people who publish information or commentary known as blogs on Web sites

mainstream media (MSM): an often derogatory term for major journalistic media outlets, including major television networks and newspapers

media bias: valuations made or endorsed by information sources that are supposed to strive for objectivity

• Background

Modern media climate coverage dates to the 1890's. In the late nineteenth century, *The New York Times* warned of a possible return to an ice age. That coverage continued until the 1920's and 1930's, when media outlets cautioned about a warming trend. The coverage again shifted in the 1950's to global cooling, which lasted in some form into the 1990's. The global warming focus, though, began in the 1960's and escalated with publication of Al Gore's book *Earth in the Balance* (1992). Since the release of Gore's movie *An Inconvenient Truth* (2006), the warming debate has become a politicized argument, in which media coverage is scrutinized as much as climate science.

• Media Coverage History

As far back as February 24, 1895, *The New York Times* was warning of the return of an ice age. The paper pointed to scientific concerns about a second glacial period following increases in northern glaciers. Fear spread through the print media over the next three decades. On October 7, 1912, both *The New York Times* and *The Los Angeles Times* cited the worries of Cornell University professor Nathaniel Schmidt about a new ice age. Arctic expeditions added to

California governor and film star Arnold Schwarzenegger addresses the media in June, 2005, exhorting President George W. Bush to accept the reality of global warming. (AP/Wide World Photos)

media coverage and public concern about a cooling climate, but by the time *The Atlantic* was reporting on cooling in 1932, many other outlets had started reporting a warming trend.

The Post discussed a warming Earth in 1930. *The New York Times* told readers in 1933 that America was experiencing the longest warming spell since 1776. Both the *Quarterly Journal of the Royal Meteorological Society* and *Monthly Weather Review* printed articles about humankind having a role in making the planet warmer. Major news media continued coverage of warming into the 1950's, when the trend shifted again.

In 1954, *Fortune* magazine reported that the Earth was growing colder. *Science News* described cooling as a major threat in 1969 and again six years later. The 1975 magazine cover depicted a city in a snow globe, as the magazine ranked the threat of a new ice age as high as nuclear war for potentially harming human life.

The New York Times wrote about global warming in 1969, but there was still little coverage of the topic in the 1970's in major news media. Toward the end of the decade, global warming and the greenhouse effect began appearing in print more than a dozen times in the top newspapers. In the 1980's, that number increased to more than one thousand stories on global warming. *The Post, The New York Times, The Los Angeles Times, The Wall Street Journal*, and *USA Today* all told readers of a looming threat from a warming Earth.

That trend continued through the 1990's. By the end of 1999, *The New York Times* alone had published more than sixteen hundred stories on global warming and *The Post* had published more than thirteen hundred. Throughout the decade, other outlets also devoted broadcast time or pages to the issue. The Public Broadcasting System (PBS), *Newsweek*, and others depicted global warming as an issue of national concern.

Climate reporting continued to gain momentum into the new millennium, but the coverage began to change significantly. More and more, the news stories were criticized for either including or excluding scientists who disputed some aspect of anthropogenic climate change. Reporting on the issue increased in virtually all major news outlets.

Gore and warming appeared everywhere from *People* magazine to *Saturday Night Live* when *An Inconvenient Truth* opened in theaters in 2006. The added attention focused the debate not just on the science but on whether a debate even existed. That trend continued, as television networks from the Cable News Network (CNN) to Fox News to the American Broadcasting Company (ABC) focused their efforts on daily coverage as well as news specials about climate. More than two hundred stories on the issue appeared on the Big Three broadcast networks in just the second half of 2007.

• Spinning the Debate

The two primary sides of the global warming debate agree that the issue is spun by the media, but they do not agree in what way. Environmental groups and liberal media critics claim that the traditional view of journalist as neutral observer has muddled the debate. They embrace a position often repeated by Gore that the debate is over. Conservatives point to numerous examples of activist journalism ignoring scientific disagreement. They complain that reporters hype weather stories as climate change and call for expensive global warming solutions without giving any time to the opposition.

• Mainstream Media

News outlets are the primary source of information about climate. Newspapers have lost their dominance as the primary news source, but newspaper Web sites have gained in popularity at the same time. Thus, newspapers have joined television news and the Internet as the major news media in the early twenty-first century.

Discussion of climate change became easy to find in major news outlets. It was featured repeatedly on the cover of *Time* magazine, on the front page of newspapers, and as the lead story of national network news broadcasts. In most cases, it was reported as an imminent crisis with potentially devastating results. Hurricanes, floods, drought, and a host of minor threats were linked in the press to global warming.

Skeptical scientists and public policy groups roundly criticized what they perceived as media bias in these stories. Journalists who covered the topic, from ABC's Bill Blakemore to *The New York Times*' Andrew Revkin, were often criticized for bias in their reporting. Prominent media watchdog groups and individual bloggers analyzed reporting, while scientists would dissect scientific claims in major news stories.

Other critics attacked any journalist who disseminated stories about climate change skeptics. A conference organized by the Heartland Institute brought together numerous scientists and public policy experts who raised questions about climate consensus in 2008. The event was a metaphor for the debate. The skeptical view received little coverage, and what coverage it did receive was often critical. CNN, for example, compared those who were skeptical to flat-earthers after the world was discovered to be round.

• Alternative Media

The alternative media—including talk radio and nonmainstream Web sites—have had a field day with climate change. Bloggers focus much of their effort on monitoring the news media coverage of the climate. Numerous individuals and groups on the Left and the Right maintain media blogs, and much of their focus has been on environmental coverage. The most famous of these, the Drudge Report, regularly links to climate stories. Whether the topic is snowfall during a global warming hearing in Washington or Gore's own carbon footprint, Drudge and others have driven a significant news agenda. The biggest of such stories can cross over into the mainstream media.

Think tanks, environmental groups, and politicians have all participated in the news media debate on climate change. The ability to link from one to another helped further blur the lines of traditional journalism, as advocacy organizations left and right targeted the other side's positions. The diverse voices also allowed readers and viewers to self-select the information they received. That caused ordinary information consumers to harden positions along ideological lines.

Talk radio also has a significant hand in the global warming debate. In 2008, much of private talk radio remained conservative. Criticism of Gore or climate science was commonplace. Often, talk radio would highlight a story made popular by bloggers such as Matt Drudge or would address a topic that, in turn, would drive the blogosphere. Liberal talk radio, including National Public Radio and Air America, took an opposite approach. Environment and climate stories were prime topics of concern for hosts and listeners alike.

• Entertainment Media

Film and television played a big role in the climate debate. With the rise of global warming as an issue in the 1980's, Turner Broadcasting responded with a cartoon called *Captain Planet*. The cartoon's superheroes protected the Earth from evils such as pollution and global warming.

Several popular movies featuring global warming themes followed. The made-for-television movie *The Fire Next Time* aired in 1993. Kevin Costner's 1995 disaster picture *Waterworld* depicted a world awash in a flood caused by warming. *The Day After Tomorrow* (2004) was one of the most controversial of these films. When it opened, the climate debate was in full force. The movie's title was reminiscent of that of the antinuclear made-for-television film *The Day After* (1983), and it depicted a climate apocalypse brought on by global warming. In the film, the changing climate results in a rapid cooling of the Earth and the onset of a new ice age. The movie was criticized by conservatives for characterizations of a president and vice president similar to George W. Bush and Dick Cheney. It also showed Americans fleeing the freeze being stopped at the Mexican border as illegal immigrants.

Also in 2004, science-fiction thriller author Michael Crichton released a novel critical of the environmental movement. *State of Fear* portrayed murderous environmentalists altering the Earth's climate to force humans into eco-friendly behavior. The novel also included extensive footnotes to raise objections to the idea of anthropogenic global warming. Crichton's book was criticized by scientists such as the National Aeronautics and Space Administration's James E. Hansen and praised in Congress by Republican Senator James Inhofe of Oklahoma.

Film and television portrayals of climate change escalated in 2006. Gore's *An Inconvenient Truth* became one of the top-grossing documentaries of all time. The movie version of his PowerPoint presentation was lauded by environmentalists and widely criticized by conservatives. Either way, it prompted widespread discussion of the topic. The film is shown widely in school systems, but a British court ruled that it contained nine significant errors.

A string of climate documentaries followed Gore's film in 2007 and 2008. They included actor Leonardo DiCaprio's *Eleventh Hour*, *Arctic Tale*, *The Great Global Warming Swindle*, and *Everything's Cool*. Each drew predictable criticism from opponents. Even the SciFi network included global warming as one of ten potentially lethal threats to humankind in its *Countdown to Doomsday* in 2007.

• Context

Despite almost countless news stories, the climate debate remains a major issue in the mainstream media. Polls show a significant number of Americans remain skeptical both about media coverage and about climate science. Because of this, media coverage has become a major topic of concern. Environmentalists continue to criticize skeptics and challenge the media to disregard such voices. Conservatives are joined by a growing and vocal group of scientists who publicly challenge what eco-groups call a climate consensus. Each side tends to complain about the tenor of media coverage of both themselves and their interlocutors.

Dan Gainor

• Further Reading

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. Emmaus, Pa.: Rodale, 2006. Discusses the dangers of global warming and links it to human production of carbon dioxide emissions. An appropriate companion to the movie of the same name. Illustrations, graphs.

Horner, Chris. *The Politically Incorrect Guide to Global Warming (and Environmentalism)*. Washington, D.C.: Regnery, 2007. Chris Horner, attorney and counselor of Cooler Heads Coalition, exposes the misconceptions surrounding the global warming hype. Explains that possible climate remedies may actually be worse than the effects of any theoretical warming. References, graphs, index.

McKibben, Bill. *Fight Global Warming Now: The Handbook for Taking Action in Your Community*. New York: Henry Holt, 2007. McKibben, a one-time writer for *The New Yorker*, describes the use of grassroots campaigns to fight for global warming legislation. The book teaches an activist approach, including ways to maximize use of the media.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years*. Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008. Avery, director of the Center for Global Food Issues, and Singer, an atmospheric physicist, explain that global warming is a part of Earth's natural cycle. They elaborate on the reasons for warming and why it is not as perilous as the media suggest. References, glossary, index.

See also: Catastrophist-cornucopian debate; Conservatism; *Day After Tomorrow, The*; Environmental movement; Gore, Al; Heartland Institute; *Inconvenient Truth, An*; Journalism and journalistic ethics; Liberalism; Popular culture; Pseudoscience and junk science; Skeptics.

Medieval Warm Period

- **Category:** Climatic events and epochs

- **Definition**

The Medieval Warm Period (MWP) is a term used to describe a period of several centuries that preceded the Little Ice Age (LIA). The MWP (also the Medieval Warm Epoch or the Little Climatic Optimum) was proposed in 1965 by Hubert Horace Lamb, a British meteorologist and groundbreaking climate historian, who believed it lasted from roughly 900 to 1300 C.E. During the MWP, Lamb believed, the North Atlantic and northern and western Europe experienced warmer conditions on average. He presented evidence drawn primarily from historical documentary data such as the expansion of agriculture to higher-altitude fields in mountainous regions, shifts in the cultivation of certain crops (such as wine production in the British Isles), changes in tree lines, and reports of weather and weather-related events (such as floods and droughts) in historical writings. This period also coincided with the Viking settlement of Greenland and excursions to Labrador, as well as a population boom in Europe, which grew from roughly 35 million to 80 million people between 1000 and 1347 C.E. All of these events seemed consistent with a milder climate and improved agricultural production.

In the decades following Lamb's assertion, temperature proxies were examined to better define the MWP, the transition to the LIA, and the extent to which they were regional or global phenomena. For example, measurements of oxygen isotope ratios in marine sediments from a Sargasso Sea core indicated an ocean temperature around 1100 that was about 1° Celsius warmer than present levels. This was followed by a nearly 2° Celsius decrease between 1100 and 1700.

Dendroclimatology, or the study of climate through tree-ring growth, conducted in the Sierra Nevada and the Great Basin of the western United States suggests periods of increased warmth and later periods of severe drought during the MWP. Similar tree-ring studies in northern Sweden and the Polar Ural Mountains provide evidence of increased temperatures from 971 to 1100 and from 1110 to 1350, respectively. Ice core and borehole studies in Greenland indicate a warm period peaking around 1000, followed by a 3° Celsius decrease into the LIA. Studies of glaciers and their moraines suggest that the MWP generally coincided with glacial retreat and the shift to the LIA with glacial advance. Other types of proxy studies include examining lake sediments, speleotherm (stalactite/stalagmite) growth, and coral growth. Many, but not all, proxy studies of sufficient length do indicate a temperature peak during the MWP and a decrease into the LIA, but with considerable variability in the details.

• Significance for Climate Change

The MWP is a central issue in the debate over climate change, as it is the most recent period of climatic warmth assumed to be free of anthropogenic factors. Likewise, the transition to the LIA is the most recent significant temperature shift before the warming of the twentieth century. The initial estimates by Lamb suggest MWP temperatures were about 0.5° Celsius warmer than those of the late twentieth century. This peak subsequently decreased, as more Northern Hemisphere data sets were combined. While many proxy data sets showed a temperature peak in the MWP, the heterogeneity of the peak locations, magnitudes, and durations meant that averaged temperature changes were reduced from those seen at individual sites.

Even with multidecadal filtering to extract long-term trends during the MWP from year-to-year fluctuations, interludes of cold have appeared in periods of relative warmth. The 2001 report of the Intergovernmental Panel on Climate Change (IPCC) largely dismissed the existence of a distinct, global MWP and LIA, epitomized by the famous hockey stick graph that showed a small, nearly linear decrease in average temperature from 1000 to the late nineteenth century with no distinct MWP to LIA transition. After some controversy, the next IPCC report in 2007 revived the MWP and LIA, using eight proxy-based temperature reconstructions to define a mild Northern Hemisphere temperature peak between 950 and 1100 that was 0.1°-0.2° Celsius cooler than the mean global temperature between 1961 and 1990 and 0.3°-0.4° Celsius warmer than the coolest LIA period.

Attempts to measure the MWP illustrate the challenges of using temperature proxies rather than instrumental temperature readings. Proxies are influenced by effects other than temperature—for example, growth patterns in tree-ring studies can reflect precipitation, diseases, and atmospheric carbon dioxide concentration. Studies that combine multiple proxy data sets must accurately calibrate their results against a common temperature standard, but different researchers use different approaches. Only a limited number of proxy sites extend back to the MWP, with few in the Southern Hemisphere and unbalanced coverage in the Northern. Overall, there is considerable potential error in each reconstruction, such that current views of the MWP are tentative and will likely change with future data.

Interest in the cause of the MWP has been muted by the debate over its nature. If the event was only regional, then changes in regional meteorological features such as the North Atlantic Oscillation might provide a sufficient explanation. If the MWP was more global, solar activity may account for it. Sunspot records do not exist for the MWP, but concentrations of the cosmogenic isotopes carbon 14 and beryllium 10 in tree rings and ice cores suggest that there was stronger than normal solar radiation around 1000 and again between 1100 and 1250. These isotope concentrations are also consistent with evidence of weaker radiation during much of the LIA.

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• Further Reading

Fagan, Brian. *The Great Warming: Climatic Change and the Rise and Fall of Civilizations.* New York: Bloomsbury Press, 2008. An anthropological view of the MWP and its impact on society. Illustrations, maps, references, index.

Hughes, Malcolm, and Henry F. Diaz, eds. *The Medieval Warm Period.* Berlin: Springer-Verlag, 1994. A frequently cited compilation of articles published in the journal *Climatic Change* from a workshop in 1991. Figures, references.

Lamb, Hubert H. *Climate, History, and the Modern World.* 2d ed. London: Routledge, 1995. Text by the pioneering climatic historian who proposed the concept of the Medieval Warm Period. Illustrations, references, index.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years.* Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008. Argumentative in tone, this book contends that the MWP and the current warming are peaks of a long-term climatic cycle. Figures, references.

See also: Dating methods; Hockey stick graph; Intergovernmental Panel on Climate Change; Lamb, Hubert Horace; Little Ice Age; Sunspots.

Mediterranean climate

• **Category:** Meteorology and atmospheric sciences

• Definition

Climate is the long-term average weather of a particular location. A Mediterranean climate is characterized by wet winters and dry summers, with mild winter and hot summer temperatures. This type of climate covers just under 2 percent of Earth's land area. It is found only in the middle latitudes (around 35° to 45° north or south latitude) and near an ocean or the Mediterranean Sea. Most of the area included in this climatic zone is the Mediterranean Sea basin, for which it was named. Other Mediterranean climate regions include the coastal regions of central and southern California, central Chile, the west side of the tip of South Africa, and parts of southern Australia, particularly the southwest.

The summer dryness in Mediterranean climates is caused by stable atmospheric high-pressure systems preventing storm systems from entering the area. These semipermanent high-pressure systems move away from the area and toward the equator during the fall, allowing rain-producing low-pressure systems to move in. When high pressure is reestablished in the spring, low-pressure areas can no longer move through the area, and rain-free conditions are reestablished for a number of months.

Because this climatic zone is always near a large body of water and such water bodies moderate temperatures (water heats and cools more slowly than does land), Mediterranean winter temperatures rarely reach the freezing point. Summer temperatures are greatly affected by the relative warmth or coolness of the body of water adjoining the area. The Mediterranean Sea is a warm body of water, causing the Mediterranean basin to be relatively warm in the summer. Other areas, such as California, have relatively cool summer temperatures near the coast, because the Pacific Ocean, for example, is cooler than the Mediterranean Sea. The dryness of summer allows large temperature fluctuations during the day/night cycle. It also contributes to Mediterranean areas experiencing a relatively large number of wildfires, both because the air contains less moisture to resist fire and because the vegetation native to dry areas is itself drier and more prone to burn than that of wetter climates.

• Significance for Climate Change

Mediterranean climates depend for their stability upon a combination of specific atmospheric conditions and the presence of a large body of water. Thus, if the atmospheric conditions are altered by climate change, or if they cease to exist near large bodies of water, Mediterranean climates will disappear. On the other hand, new Mediterranean climates could be established near different water bodies under the right circumstances.

Areas such as California or Chile are on north-south coastlines, and it is possible that climate change could move the climatic zone farther north or south. If the change is not overly abrupt, Mediterranean flora and fauna could migrate along with the climate zone. However, in the Mediterranean basin, a substantial increase in global warming or another climatic change could destroy the ecosystem altogether, because there is no large body of water to the north to which the climate, flora, and fauna could shift. Within Europe, there could be some movement north, as seems to be taking place in the British Isles. The little egret, commonly found in the Mediterranean Sea area, was unknown in England prior to 1996. As southern England has begun to develop a more Mediterranean climate, as of 2008 it was the second most populous heron in the United Kingdom. While birds have the ability to move from the European mainland to Great Britain, however, plants and land animals do not.

Climatic changes have been documented in several Mediterranean and nearby regions. These changes raise particular concerns regarding biodiversity, which is more affected by climate than by other environmental factors. The Iberian Peninsula, for example, has the greatest animal diversity of any region in Europe, and many Iberian species are endangered by global warming. Average summer temperatures in the region are generally rising, which is putting a substantial heat stress upon both plants and animals. Humans are not immune to such factors, and a study documenting a 200 percent increase in the number of extremely hot days on the peninsula concluded that frail people's lives were at risk from the increase.

Desertification is also taking place in the Mediterranean, as rainfall decreases and higher temperatures increase the rate of evaporation. A large number of droughts in the early twenty-first century have contributed to the encroachment of the desert from the south. Although during the past fifty years there has generally been a decrease in the amount of rainfall, in some specific locations there has been an increase in precipitation.

It is estimated that up to 20 percent of plant species live in Mediterranean regions. In some areas, such as California, population growth has played a major factor in decreasing the number and diversity of plants, but changes in the precipitation patterns have also been a contributing factor, as has the resulting increase in wildfires. Even in areas where climate change has not substantially altered the total rainfall, the number of days on which it rains has changed. Many areas have fewer but harder rains than normal, resulting in less moisture being absorbed by the soil. An Intergovernmental Panel on Climate Change study has indicated that Mediterranean climates will very probably experience an increase in severe droughts, heat waves, and wildfires as a result of the changing climate.

Donald A. Watt

• Further Reading

Bolle, Hans-Jurgen, ed. *Mediterranean Climate: Variability and Trends.* Berlin: Springer, 2003. Examines past climatic information for the region around the Mediterranean Sea, as well as contemporary climatic trends and projections for the future. Many charts and illustrations.

Giupponi, Carlo, and Mordechai Shechter, eds. *Climate Change and the Mediterranean: Socio-economic Perspectives of Impacts, Vulnerability, and Adaptation.* Cheltenham, Gloucestershire, England: Edward Elgar, 2003. Collection of papers summarizing the human experience of climate change in the Mediterranean region.

Moreno, José, and Walter C. Oechel, eds. *Anticipated Effects of a Changing Global Environment in Mediterranean-Type Ecosystems.* New York: Springer-Verlag, 1995. Outlines changes that are likely to occur at a variety of systemic levels, both in the Mediterranean and in other, similar ecosystems.

See also: Continental climate; Fire; Maritime climate; Polar climate; Rainfall patterns; Tropical climate.

Mediterranean Sea

• **Categories:** Oceanography; geology and geography

• Definition

Bounded by Africa to the south, Asia to the east, and Europe to the north and west, the Mediterranean Sea is virtually landlocked. It is approximately 2,510,000 square kilometers in area, has an average depth of 1,501 meters, and reaches a maximum depth of 5,092 meters. It is believed that the Mediterranean was created as a result of interactions over millions of years between the Eurasian and African continental plates.

The major source of the Mediterranean's water is a surface current flowing inward from the Atlantic Ocean at the Strait of Gibraltar in the west. This current increases in salinity as it progresses, eventually sinking in the eastern Mediterranean and reversing course to flow outward along the seabed through the strait. Other important sources of water are the Black Sea (considered by some to be an arm of the Mediterranean) to the northeast, several large rivers (including the Nile), and rainfall. Because of its semilandlocked nature, the Mediterranean has limited tides, and its high rate of evaporation makes it saltier than the Atlantic. The narrow, human-made Suez Canal links the Mediterranean to the even saltier Red Sea in the southeast.

In general, the Mediterranean region is dry and hot during the summer and wet and cool during the winter. It is positioned between rainy, temperate Central Europe and arid North Africa and is sensitive to variations in these regions' normal weather patterns.

• Significance for Climate Change

Climatologists and meteorologists predict that global warming will have a marked negative effect on the Mediterranean Sea and the countries lying on its shores. Existing problems such as flooding, heat extremes, water shortages, and desertification are likely to grow worse.

Global warming may raise the level of the Mediterranean Sea as much as 1 meter by the end of the twenty-first century, covering beaches and inundating coastal communities that are home to millions. The World Bank has warned that the Nile delta, in which one-tenth of Egypt's population lives and in which nearly half of the country's crops are grown, is in particular danger. Some have suggested that the Mediterranean could grow stagnant and that the flow of surface water through the Strait of Gibraltar might even reverse. The sea's resources are already threatened by overfishing, and warmer, saltier water threatens other native species such as corals and sponges, while favoring invasive species that have entered the Mediterranean from the Red Sea by way of the Suez Canal.

According to the United Nations' Intergovernmental Panel on Climate Change (IPCC), annual mean temperatures will probably increase throughout Europe, and the Mediterranean region is expected to experience hotter summers. This increase could have particularly serious consequences along the coast of North Africa. Heat waves are likely to increase in number and intensity, as they did throughout the second half of the twentieth century. The region may suffer from three to six times as many dangerously hot days in the twenty-first century, with France at greatest vulnerability. Rising temperatures will probably also result in increasingly intense storms, and although hurricanes rarely touch Europe, a 2007 study suggests that heat-induced atmospheric instability coupled with warmer sea temperatures could lead to tropical storms forming in the Mediterranean.

Overall, annual precipitation is likely to decrease in all but the northernmost parts of the Mediterranean region. Summers in particular are expected to be drier, with some studies suggesting that summer precipitation over southern Europe may decline by as much as 80 percent. Only in the areas dominated by mountain ranges such as the Alps is precipitation likely to rise, and those areas may lose a greater proportion of moisture due to higher temperatures. Droughts are likely to increase in frequency and severity, especially in the western Mediterranean.

Urban development along the Mediterranean coast of Spain. Significant climate change would pose a threat to such coastal developments. (Heino Kalis/Reuters/Landov)

Water usage in the Mediterranean region doubled in the second half of the twentieth century, and lack of water, already a serious problem in many parts of North Africa and the Middle East because of growing populations, will intensify. Rising sea levels will result in the salinization of freshwater needed for agriculture and human consumption.

Historically, the lands of the Mediterranean region have suffered from anthropogenic deforestation, and the resulting desertification is likely to spread in many areas. The increase in the number of forest fires forecast by the European Spatial Planning Observation Network in 2006 will add to the severity of the problem and will contribute to a loss of biodiversity.

Under conditions of global warming, death rates in the Mediterranean region from storms, heat stroke, air pollution, lack of water, and even malaria can be expected to rise. Many Mediterranean destinations will become too hot for tourists, undermining one of the region's major sources of revenue.

Grove Koger

• Further Reading

Giorgi, Filippo, and Piero Lionello. "Climate Change Projections for the Mediterranean Region." *Global and Planetary Change* 63 (2008): 90-104. Review of projections suggesting that the region is particularly vulnerable to global warming and is likely to experience decreased precipitation, pronounced warming, and increasingly frequent heat waves.

Hughes, J. Donald. *The Mediterranean: An Environmental History*. Santa Barbara, Calif.: ABC-CLIO, 2005. Chronological survey of the sea's environmental development, including considerations of the possible effects of global warming. Maps, photographs, glossary, annotated bibliography.

Marquina Barrio, Antonio, ed. *Environmental Challenges in the Mediterranean, 2000-2050.* Boston: Kluwer, 2004. Papers presented at a North Atlantic Treaty Organization (NATO) research workshop addressing climate change along with other problems such as population growth, desertification, and pollution. Maps, graphs, bibliographies.

Ulbrich, U., et al. "The Mediterranean Climate Change Under Global Warming." In *Mediterranean Climate Variability*, edited by Piero Lionello, Paola Malanotte-Rizzoli, and R. Boscolo. Oxford, England: Elsevier, 2006. Overview of contemporary research, including studies based on regional climate models and atmospheric general circulation models. Maps and graphs.

See also: Coastal impacts of global climate change; Desertification; Floods and flooding; Health impacts of global warming; Marginal seas; Ocean dynamics; Ocean life; Rainfall patterns; Sea-level change.

Megacities

• **Category:** Economics, industries, and products

Megacities are vast population centers with equally great effects upon local climate. They both concentrate and require significant amounts of resources, posing unique challenges for sustainability and environmentalism generally.

• Key concepts

megalopolis: a megacity that sprawls over a large area, rather than being concentrated spatially in the manner of traditional cities

urban heat island: an urban region that is significantly warmer than the surrounding rural areas

urbanization: the process of concentration of the human population in cities

• Background

A megacity is a city with a population greater than 10 million. When cities such as Mexico City, Los Angeles, or Hong Kong get this large, it becomes difficult to determine their precise boundaries or true population. The U.S. Census Bureau and the United Nations often disagree in nonsystematic ways about the population of some of the

Construction workers build a new apartment building in Jakarta, Indonesia, one of Asia's fastest-growing megacities. (Supri/Reuters/Landov)

world's largest cities, and the discrepancies between their estimates can represent several million people.

The bureaucracy and infrastructure of megacities can be as complex as those of small nations, and resource allocation within them is particularly difficult. In 1950, New York City was arguably Earth's only megacity. In less than one human lifetime there were at least twenty megacities on the planet. One of the most challenging aspects of this dramatic increase in the number of megacities is that they are increasingly appearing in some of the poorest nations of the world. In 1950, only three of the world's most populous cities were in the developing world. In 2005, about 75 percent of the world's largest cities were in the developing world. The rise of these megacities represents a profound development in the history of humanity, and the challenges they present with respect to climate change may also be among the greatest opportunities to address that change.

• Reality on the Ground

A megacity is a complex structure consisting of a sophisticated built environment that shelters and sustains millions of human agents. These agents, living in close proximity to one another, often represent extremes of human experience, as megacities juxtapose great wealth and poverty, as well as the diversity of human cultures. In their vast urban landscapes, millions of people live and die in sad and tragic conditions of poverty and low life expectancy. At the same time, others live lives of almost unfathomable wealth and freedom to travel about the globe. These urban environments simultaneously represent both a pinnacle of human achievement and a shameful failure to realize human potential.

• Change Challenges and Opportunities

Cities almost always depend on a hinterland beyond their spatial extent to provide food, water, energy, and raw materials to sustain the lives of their citizens. They also increasingly depend on this hinterland to absorb their sewage, solid waste, and greenhouse gas (GHG) emissions. Historically this hinterland was predominantly nearby. Increasingly, however, hinterlands are farther and farther away from megacities, and, in regard to GHG emissions, the global atmosphere itself may be considered part of the hinterland. The hinterland of Los Angeles is global, as the city receives oil from the Middle East, water from the eastern Sierra, and food from Mexico, Europe, and Asia. Mexico City has built vast tunnels to divert sewage to distant hinterlands. Denver, Colorado, uses a network of tunnels to divert water from the western slope of the Rocky Mountains that would normally flow into Mexico's Sea of Cortez.

Almost all of these processes relate to climate change forcing factors in direct or indirect ways. Nonetheless, a fundamental and primary impact of megacites with respect to climate change is the energy used by these cities to provide electricity (often provided by coal-fired power plants) and the energy used to provide transportation (predominantly generated by fossil-fuel combustion). These urban areas are the most densely populated areas of the world. This density is an opportunity for numerous efficiencies with respect to energy consumption for electricity, transportation, and the myriad other related needs of urban residents that require electricity and transportation. Leveraging the energy efficiency opportunities that these densely populated areas represent will be of paramount importance with respect to humanity's collective response to the challenges of climate change.

Paul C. Sutton

• **Further Reading**

Burdett, Ricky, and Deyan Sudjic. *The Endless City: The Urban Age Project by the London School of Economics and Deutsche Bank's Alfred Herrhausen Society*. New York: Phaidon, 2007. This brilliantly illustrated text provides detailed case studies of the realities, prospects, and challenges facing six major cities of the world (New York City, Shanghai, London, Mexico City, Johannesburg, and Berlin).

"Cities." *Science* 319 (February 8, 2008). This special journal section includes numerous articles on various urban issues such as poverty, sewage treatment, population growth, and transportation challenges.

Hardoy, Jorge E., Diana Mitlin, and David Satterthwaite. *Environmental Problems in an Urbanizing World*. Sterling, Va.: Earthscan, 2001. Focuses on human health issues related to environmental problems in the urban areas of the developing world. Relates the political and economic realities and challenges of urban environments to the growing social and environmental justice issues of the developing world.

National Geographic, November, 2002. Edited by Erla Zwingle. This special issue titled "Cities: Challenges for Humanity" includes a pull-out map of megacities that illustrates their increase through time and projections into the future. Features many photographs and a good general discussion of contemporary urbanization trends around the world.

See also: Energy efficiency; Energy resources; Population growth; Urban heat island; Water resources, global.

Meridional overturning circulation

• **Category:** Oceanography

• **Definition**

Meridional overturning circulation (MOC) is an oceanographic term for water flows in the plane defined by the vertical and meridional (or north-south) axes. It is calculated by averaging those north-south, up-down flows from east to west across the width of an ocean basin.

Most discussions of the MOC focus on the deep, overturning circulations that connect the ocean abyss to the surface. Deepwater formation (the "sinking branches" of the deep MOC) occurs in two broad regions of the global ocean: the high-latitude North Atlantic, predominantly in the Labrador Sea and the Nordic Sea, and the southern ocean, near Antarctica. Water's density increases when it is cold and salty. Thus, the densest surface waters occur in the polar regions. Temperatures there are low, and brine-rejection during ice-formation increases the salinity of surface ocean water.

Dense polar water sinks to form deepwater masses that spread out horizontally along the meridional axis to fill most of the global deep oceans. The return branch of this deep MOC is more diffusely distributed. Deep water becomes more buoyant, and it will return back toward the surface if it is heated or made less saline. Vertical mixing with less dense water higher in the water column will decrease the density of deep water, producing a return flow toward the surface. The deep MOC is sometimes referred to as the "thermohaline circulation," a term that is meant to evoke the idea that vertical motions are caused by changes in the temperature and salinity of seawater.

Shallow, wind-driven overturning circulations exist closer to the ocean's surface, the most prominent such feature being the subtropical cells in the Atlantic and Pacific Oceans. The winds blowing over the subtropical oceans force a convergence of surface waters, which pushes surface water downward in a process known as "Ekman pumping." This water travels at depth toward the equator, where the pattern of winds forces surface waters to diverge, bringing the water that was pumped downward in the subtropics back to the surface. Surface winds then force the surface waters back toward the subtropics, completing the subtropical cell.

• Significance for Climate Change

The MOC plays a crucial role in maintaining Earth's climate. The Earth is heated primarily in the tropics. Warm ocean currents move a large amount of tropical heat to higher latitudes in the subtropical cell and the deep MOC. This transfer of heat helps keep the high latitudes warm. The poleward heat flux is particularly strong in the North Atlantic Ocean. Heat brought poleward in the North Atlantic is then advected by large-scale winds eastward, where it warms Europe. Scientists have suggested that the North Atlantic MOC may slow down or shut down completely as a result of global warming; if this happens, the heat flux associated with the MOC would decrease, and Europe would become colder.

A climatic change that warms the high latitudes will introduce freshwater into the high-latitude North Atlantic Ocean as ice sheets melt and precipitation increases. This added freshwater would decrease the salinity of surface waters, reducing their tendency to sink. If polar water stops sinking, the warm surface current that brings lighter water to replace the sinking water would be disrupted, so the flow of heat to the North Atlantic and Europe would diminish or cease entirely.

Geologic evidence supports the argument that the introduction of freshwater into the North Atlantic can weaken heat transport by the Atlantic MOC. During the last ice age, ice sheets several kilometers thick covered a large portion of North America and northern Europe. Around 14,000 years ago, Northern Hemisphere glaciers retreated as a result of astronomically forced changes in Earth's orbit. Temperatures rose, and the ice sheets began to melt. Then, approximately 12,800 years ago, temperatures dropped rapidly back into the glacial range and ice sheets returned for another 1,300 years. This rapid drop in temperatures, known as the Younger Dryas, is believed to have been caused by the rapid input of freshwater into the North Atlantic from the melting North American ice sheet, which dramatically decreased the Atlantic MOC. While there is no large ice sheet on North America today, scientists are concerned that global warming could cause freshwater melt from Greenland to trigger analogous processes.

Alexander R. Stine

• Further Reading

Kuhlbrodt, T., et al. "On the Driving Processes of the Atlantic Meridional Overturning Circulation." *Reviews in Geophysics* 45 (April 24, 2007). Review article that discusses the current state of understanding of the energetics of the Atlantic MOC; explicates the implications of existing data for attempts to evaluate which mechanisms drive the overturning flow.

Richardson, P. L. "On the History of Meridional Overturning Circulation Schematic Diagrams." *Progress In Oceanography* 76 (2008): 466-486. Reviews the history of oceanographers' visualizations of the MOC. Includes many schematic diagrams useful for picturing the MOC.

Schmittner, A., John C. H. Chiang, and Sidney R. Hemming, eds. *Ocean Circulation: Mechanisms and Impacts.* Geophysical Monograph 173. Washington, D.C.: American Geophysical Union, 2007. Collection of articles on the general circulation of the oceans, with a focus on the deep MOC. The introductory chapters provide a historical overview of the evolving scientific understanding of the MOC.

Siedler, Gerold, John Church, and John Gould, eds. *Ocean Circulation and Climate.* London: Academic Press, 2001. Collects articles on the ocean circulation, focusing on the results of the World Ocean Circulation Experiment (WOCE).

See also: Freshwater; Glaciers; Ice shelves; Ocean dynamics; Polar climate; Thermohaline circulation; Younger Dryas.

Mesosphere

• **Category:** Meteorology and atmospheric sciences

• **Definition**

The mesosphere is the region of the atmosphere extending from the top of the stratopause (about 50 kilometers high) to the bottom of the mesopause-lower thermosphere boundary (MLT), about 100 kilometers high. It is the coldest region of the atmosphere. The warmest temperatures in the mesosphere are found just above the stratopause, where air temperatures may be as high as –5° Celsius. Mesospheric temperatures decrease with increasing altitude, with the lowest temperatures, around –125° Celsius, occurring during summer at the mesopause.

• **Significance for Climate Change**

The natural source of water in the mesosphere is oxidation of methane. Atmospheric concentrations of the greenhouse gas (GHG) methane have increased dramatically since the beginning of the Industrial Revolution and may have influenced the appearance of noctilucent clouds. Water vapor emitted by rockets and the Space Shuttle has been observed to form noctilucent clouds. Exhaust from one shuttle mission may increase the appearance of noctilucent clouds by as much as 20 percent. Carbon dioxide (CO_2) in the mesosphere releases heat to space. Solar proton events have been observed to cool the lower mesosphere by causing photochemical reactions leading to ozone depletion, causing an estimated temperature drop of up to 3° Celsius.

Gravity waves are the dominant form of motion in the mesosphere, with wavelengths of around 10 kilometers. Wind speeds on the order of 100 meters per second may occur in the MLT. Gravity wave flux is lowest at solar maximum. Direction of atmospheric transport is from the summer hemisphere to the winter hemisphere.

In the mesosphere, clouds can form only at the coldest temperatures, within about thirty days of the summer solstice at latitudes above 50° north and below 50° south. Because they form at 82 kilometers altitude, the thin filamentous noctilucent clouds (sometimes called polar mesospheric clouds, or PMCs) are illuminated only when the Sun is between 6° and 16° below the horizon.

There has been speculation that noctilucent clouds are a recent phenomenon resulting from anthropogenic activity, as they were not reported prior to 1885, when scientists began studying the colorful twilight displays that followed the eruption of Krakatoa. Soon after the discovery of noctilucent clouds, speculations began that the particles composing the clouds were of extraterrestrial origin. In 1962, rockets launched to investigate noctilucent clouds determined that the cloud particles had nuclei of iron or nickel dust of extraterrestrial origin, which were coated by water ice. One of the most surprising aspects of noctilucent clouds is their strong radar reflectivity. After some study, an explanation was advanced in 2008 that molecules of sodium and molecules of iron form a thin metallic film over the tiny ice crystals. This film reflects radar waves in a special, amplified way that makes the clouds more prominent on radar than if they were a cloud of disordered metal dust. Noctilucent clouds are postulated to remove about 80 percent of the sodium and iron from their environment in the mesosphere.

Water is formed in the mesosphere as a result of the oxidation of methane gas, rather than arising from the Earth's surface. Because methane is released as a by-product of incomplete combustion, as well as through coal-mining activity and anaerobic production from animals, swamps, and rice paddies, its concentration has been rising steadily as a result of anthropogenic activity. The concentration of methane in the atmosphere has increased 150 percent since the industrial age began, around 1750.

After rockets are launched through the mesosphere, their exhaust trails may form artificial noctilucent clouds. These noctilucent trails can form in the mesosphere in temperate latitudes, but ground observations of them are made only when the Sun is between 6° and 16° below the horizon.

After the launch of the STS-107 shuttle mission in January, 2003, it was determined that vaporized iron and water from its exhaust traveled to Antarctica at 110 kilometers altitude in about two days. This exhaust plume went on to form noctilucent clouds in the southern polar summer. Data from this event indicate that a single Space Shuttle's exhaust might cause a 10 percent to 20 percent increase in the appearance of seasonal noctilucent clouds.

Anita Baker-Blocker

• Further Reading

Arnold, Neil. "Solar Variability, Coupling Between Atmospheric Layers, and Climate Change." *Philosophical Transactions of the Royal Society of London A* 360, no. 1801 (December, 2002): 2787-2804. Reprinted in *Advances in Astronomy*, edited by J. M. T. Thompson. Vol. 1. London: Imperial College Press, 2005. Excellent technical survey of the relationship between solar activity and the atmosphere, including the mesosphere, suggesting a mechanism for solar influences in the mesosphere to influence the climate in the troposphere.

Bellan, Paul M. "Ice Iron/Sodium Film as Cause for High Noctilucent Cloud Radar Reflectivity." *Journal of Geophysical Research D* 113 (2008): 16,215-16,218. Advances a hypothesis as to why noctilucent clouds show up on radar.

Glickman, Todd S., ed. *Glossary of Meteorology*. 2d ed. Boston: American Meteorological Society, 2000. This standard reference book contains definitions of meteorological terms, such as the mesosphere.

Schroeder, Wilfried, and Karl-Heinrich Wiederkehr. "Johann Kiessling, the Krakatoa Event, and the Development of Atmospheric Optics After 1883." *Notes and Records of the Royal Society of London* 54, no. 2 (May, 2000): 249-258. Briefly discusses the discovery of noctilucent clouds following the eruption of Krakatoa.

See also: Atmosphere; Atmospheric boundary layer; Atmospheric dynamics; Atmospheric structure and evolution; Stratosphere; Thermosphere; Troposphere.

Meteorology

• **Category:** Meteorology and atmospheric sciences

Arguably the most important aspect of climate change is its effects on the physical and chemical properties of Earth's atmosphere. Meteorologists can assess those effects and their consequences, informing climate policy decisions.

• Key concepts

climate: long-term average weather conditions

mesoscale: the atmospheric scale between microscale and synoptic scale, ranging from a few kilometers to hundreds of kilometers

microscale: the smallest scale of atmospheric motion, ranging from meters to kilometers

planetary scale: the largest scale of atmospheric motion, covering the entire globe

synoptic scale: the typical scale of weather maps, showing such features as high- and low-pressure systems, fronts, and jet streams over an area spanning a continent

weather: a particular atmospheric state at a given time and place

• Background

Meteorology is the scientific study of the atmosphere, weather, and climate. It combines most of the basic scientific disciplines, such as mathematics, physics, chemistry, statistics, and computer science, and applies them to Earth's atmosphere and its phenomena. Thus, meteorology is a branch of Earth science and of physical science.

Meteorology provides the core knowledge about climate change and global warming. It can be used to analyze planetary climate patterns as well as continental, regional, and local patterns. Meteorologists measure weather and other specific atmospheric phenomena and abstract from those measurements to determine the climate, the long-term average conditions in a given location.

• Dynamic Meteorology

Dynamic meteorology is the core discipline of the atmospheric sciences. It employs dynamics, fluid mechanics, and classical mechanics, coupled with rigorous mathematics, to study atmospheric motion and evolution. Dynamic meteorology treats the atmosphere as a fluid continuum, applying Newtonian principles to atmospheric systems. Modern numerical weather prediction is a result of this approach. Many methods in dynamic meteorology are also extended to study climate systems in the closely related discipline of climate dynamics. Climate dynamics may provide a good tool for studying climate change. Various global circulation models (GCMs) are examples of this application.

- **Physical Meteorology**

In addition to its kinetic properties and dynamic evolution, the atmosphere possesses many other physical properties, such as its thermal content, its humidity, its electrical and optical properties, and so forth. To study these physical properties of the atmosphere, meteorologists incorporate the principles and approaches of physics. A wide range of subjects is helpful in studying such atmospheric phenomena, including cloud physics, thermodynamics, precipitation physics, boundary-layer meteorology, thermal convection, atmospheric electricity, and atmospheric optics.

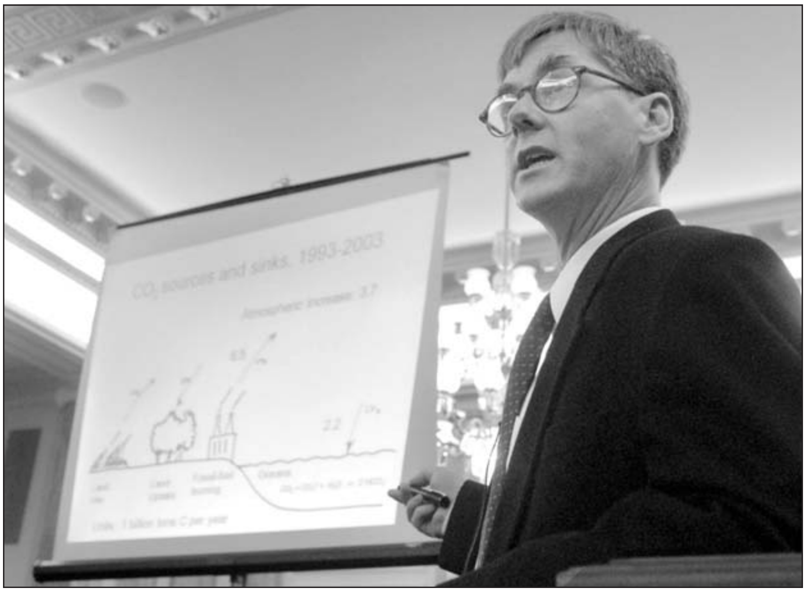
Many atmospheric physical properties are directly related to global climate change. For example, clouds are an important factor in global warming. Clouds play a dual role in the global climate system. On one hand, they contribute significantly to Earth's albedo, reflecting a large amount of solar energy back into space and producing a global cooling effect. On the other hand, they absorb long-wave radiation from the Earth's surface and re-emit it, thereby heating the atmosphere and surface. Increased atmospheric humidity due to global warming will increase cloud cover and influence severe weather patterns as well. Physical meteorology can provide a detailed understanding of these aspects of climate change.

- **Applied Meteorology**

As meteorologists' understanding of the complexity of Earth's climate system has increased, new applied meteorological specializations have emerged. Thus, the field now includes satellite meteorology, radar meteorology, statistical meteorology, agricultural micrometeorology, and climatology. These new subdisciplines are fundamentally interdisciplinary. They not only help translate meteorological concepts and research methods to other scientific disciplines but also strengthen meteorology by incorporating the technologies and methods of its sister sciences. For example, modern technologies, such as radar and satellites, add fresh content to meteorology and provide new observational tools for studying the atmosphere. These new areas are also important for global climate studies. For example, satellites can provide a global view of the global warming effect.

- **Atmospheric Chemistry**

Traditional meteorology is mostly concerned with the physical aspects of the atmosphere. Climate researchers, however, have found that atmospheric chemistry is just as important for understanding



Professor Ralph Keeling addresses members of the American Meteorological Society about the policy implications of natural carbon sinks. (Kevin Dietsch/UPI/Landov) climate change. Greenhouse gases are central to global climate change, and other aspects of atmospheric composition may play similarly important roles. Ozone depletion in the stratosphere is both an atmospheric dynamics and atmospheric chemistry problem that concerns climate change. In addition, Earth's carbon cycle is an important area for climate study.

With an increasing level of global industrialization and urbanization, environmental conservation and protection become more concerned issues. Air pollution and air quality are central to these environmental problems. Acid rain and environmental acidification are also concerns for environment protection and conservation. For all these problems, atmospheric chemistry can provide fundamental understanding.

• Context

Meteorology is one of the primary sciences employed in the study of Earth's climate system. Earth's climate is a complex system, however, that includes five components: atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere. It is the interaction of all five of these components that determines Earth's climatic environment. Therefore, meteorology, although providing a core understanding of global climate and climate change, must be combined with knowledge from other scientific disciplines, such as oceanography, geology, hydrology, chemistry, biology, ecology, astronomy, and glaciology, to address global climate change.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere.* 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. One of the most widely used introductory books on atmospheric science; covers a wide range of topics on weather and climate.

Geer, Ira W., ed. *Glossary of Weather and Climate.* Boston: American Meteorological Society, 1996. Collection of terms, concepts, and definitions related to weather and climate.

Glickman, Todd S., ed. *Glossary of Meteorology.* 2d ed. Boston: American Meteorological Society, 2000. Collection of most meteorological terms, concepts, and definitions, and is useful for a quick lookup.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere.* 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Elementary textbook covering a wide range of atmospheric sciences.

See also: Atmosphere; Atmospheric chemistry; Atmospheric dynamics; Atmospheric structure and evolution; Average weather; Climate and the climate system; Climate change; Climatology; Weather vs. climate.

Methane

• **Category:** Chemistry and geochemistry

Methane is among the six GHGs restricted under the Kyoto Protocol. Its global warming potential is more than twenty times that of CO_2.

• Key concepts

alternative fuel: clean or renewable fuel that can replace traditional fossil fuels

archaea: a taxonomic group of prokaryotic, single-celled microorganisms similar to bacteria, but evolved differently

energy from waste: technologies that are designed to produce energy and reduce or eliminate waste at the same time

fuel: an energy source that is burned to release energy

fuel alternative: replacement energy source that can be used instead of fuel

greenhouse gas (GHG): a gas in the atmosphere that traps heat on Earth that would otherwise radiate into space

• Background

Methane is a colorless, odorless gas with the molecular formula CH_4. It is the main chemical component of natural gas (accounting for 70-90 percent of such gas). Natural gas makes up up to 20 percent of the U.S. energy supply. Methane was discovered by the Italian scientist Alessandro Volta, who collected it from marsh sediments and demonstrated that it was flammable. He called it "combustible air."

• Methane as a Greenhouse Gas

As with all greenhouse gases (GHGs), methane in the atmosphere acts similarly to glass in a greenhouse. It allows light energy from the Sun to reach Earth's surface, but it traps heat energy radiated back from the surface in the form of infrared radiation. Since the beginning of the Industrial Revolution in the mid-eighteenth century, methane concentrations have more than doubled in the atmosphere, causing nearly one-quarter of the planet's anthropogenic global warming. Continuous release of methane into the atmosphere causes rapid warming, because methane's contribution to the greenhouse effect is much more powerful than that of carbon dioxide (CO_2).

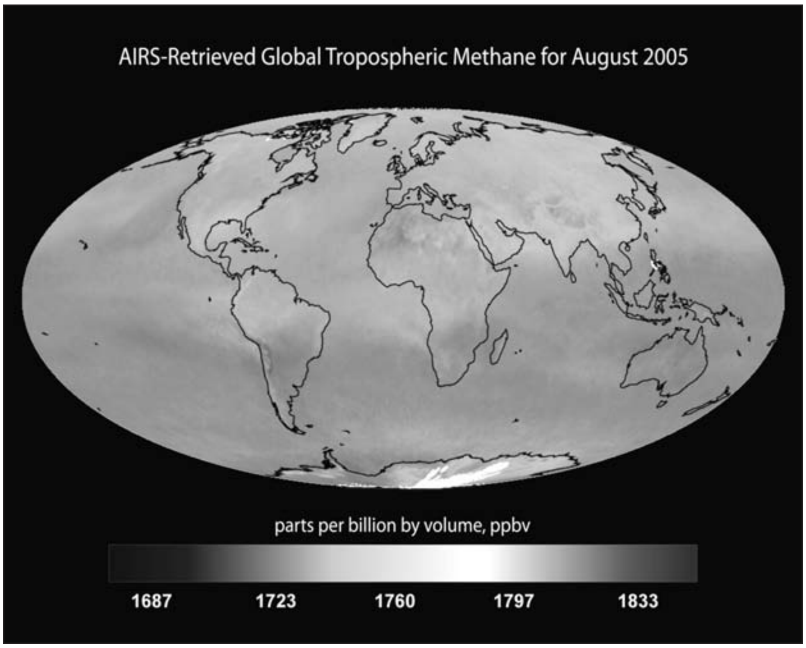
Global warming itself may trigger the release of methane trapped in tundra permafrost or ocean deposits, thereby accelerating climate change in a positive feedback loop. The release of large volumes of methane from such geological formations into the atmosphere has been suggested as a possible cause for global warming events in the past. Methane oxidizes to CO_2 and therefore remains in the atmosphere for a shorter time-period of nine to fifteen years, compared to CO_2, which may remain in the atmosphere for one hundred years.

• Sources of Methane

According to the U.S. Environmental Protection Agency (EPA), about 60 percent of global methane emissions are a direct result of human-related activities. These activities include creating landfills, treating wastewater, animal husbandry (through enteric fermentation and manure production), cultivating rice fields, mining coal, and producing and processing natural gas. For instance, the livestock sector (including cattle, chickens, and pigs) generates 37 percent of all anthropogenic methane. Landfills are the second largest anthropogenic source of methane in the United States.

Natural sources of methane include wetlands, lake sediments, natural gas fields, termites, oceans, permafrost, and methane hydrates. Wetlands are responsible for up to 76 percent of global natural methane emissions. Surprisingly, according to EPA data, termites contribute about 11 percent of global natural methane emissions. In most of these processes, methane is produced by microorganisms called archaea as the integral part of their metabolism. Such microbes are called methanogens, and the route of methane generation is called methanogenesis.

Archaea live in oxygen-depleted habitats, because the presence of oxygen would kill them instantly. For their food source, methanoges use products of bacterial fermentation such as CO_2 and molecular hydrogen (H_2); different acids such as acetate, pyruvate, or formate; or even carbon monoxide. That is why methanogenic archaea usually



A satellite image of the global distribution of methane in Earth's troposphere. (NASA-JPL)

Global Methane Emissions by Sector, 2000

Economic Sector	*Percent of Total Emissions*
Agricultural by-products	40.0
Fossil fuel retrieval, processing, and distribution	29.6
Waste disposal and treatment	18.1
Land use and biomass burning	6.6
Residential, commercial, and other sources	4.8
Power stations	0.9

Data from the Netherlands Environmental Assessment Agency.

exist in consortium with other microorganisms (bacteria). They also live in symbiotic relationships with other life forms, such as termites, cattle, sheep, deer, camels, and rice crops.

• Methane as a Fuel

In the 1985 science-fiction film *Mad Max Beyond Thunderdome* starring Mel Gibson, a futuristic city was run on methane generated by pig manure. In reality, methane can be a very good alternative fuel. It has a number of advantages over other fuels produced by microorganisms. It is easy to make and can be generated locally, obviating the need for long-distance distribution. Extensive natural gas infrastructure is already in place to be utilized. Utilization of methane as a fuel is a very attractive way to reduce wastes such as manure, wastewater, or municipal and industrial wastes. In local farms, manure is fed into digesters (bioreactors), where microorganisms metabolize it into methane. Methane can be used to fuel electrical generators to produce electricity.

In China, millions of small farmers maintain simple, small, underground digesters near their houses. There are several landfill gas facilities in the United States that generate electricity using methane. San Francisco has extended its recycling program to include conversion of dog waste into methane to produce electricity and to heat homes. With a city dog population of 120,000, this initiative promises to generate significant amounts of fuel with a huge reduction of waste at the same time.

Methane was used as a fuel for vehicles for a number of years. Several Volvo car models with bi-fuel engines were made to run on methane, with gasoline as a back up. Methane is more environmentally friendly than are fossil fuels. Burning methane results in production of CO_2 and contributes to global warming, but with less impact on Earth's climate than methane itself would have in the atmosphere, for a net benefit. Even though the use of methane as an energy source releases CO_2, the process as a whole can be considered CO_2 neutral, in that the released CO_2 can be assimilated by archaea.

• Methane Removal Processes

The natural mechanism of methane removal from the atmosphere involves its destruction by the hydroxyl radical (OH). Significant amounts of methane are also consumed by microorganisms called methanotrophs, which use the methane for energy and biosynthesis. These bacteria are prevalent in nature and potentially could be used for methane mitigation.

• Context

Since methane is a powerful contributor to global warming, any efforts to reduce methane emissions will have a rapid impact on Earth's climate. One way to avoid methane release into the atmosphere is to turn it into a fuel. Supply of fossil fuels, particularly oil, is limited and does not satisfy world energy demands, which consistently increase. The extensive use of fossil fuels causes global warming. Methane utilization in place of fossil fuels as an energy source can provide significant environmental and economic benefits. In the future, landfills and wastewater treatment facilities can possibly be redesigned to optimize methane production. However, further research is needed to better understand archaean-bacterial methanogenic communities in landfills and wastewater treatment facilities in order to improve methane generation.

Some technical obstacles exist to efficiently converting landfill wastes that primarily contain plant lignocellulosic material. Lignocellulose is a combination of lignin, cellulose, and hemicellulose that strengthens plant cell walls. Microbial communities in landfills cannot utilize lignin. Creating efficient methane-producing facilities that are also capable of reducing waste is a feasible option for sustainable development to provide fuel to heat homes, run cars, generate electricity, and eliminate powerful GHG and health hazards.

Sergei Arlenovich Markov

• **Further Reading**

Archer, David. *Global Warming: Understanding Forecast*. Malden, Mass.: Blackwell, 2007. Devotes a chapter to discussion of methane and its greenhouse effects.

Madigan, Michael T., et al. *Brock Biology of Microorganisms*. 12th ed. San Francisco, Calif.: Pearson/Benjamin Cummings, 2009. Introductory microbiology textbook. Chapter 17 describes methane production by archaea.

National Academy of Sciences. *Methane Generation from Human, Animal, and Agricultural Wastes*. Washington, D.C.: Author, 2001. Describes the role of disparate sources in methane production.

Nebel, Bernard J., and Richard T. Wright. *Environmental Science: Towards a Sustainable Future*. Englewood Cliffs, N.J.: Prentice Hall, 2008. Several chapters describe methane as a GHG and an alternative fuel.

See also: Biofuels; Carbon dioxide; Clean energy; Energy from waste; Fossil fuel emissions; Fossil fuels; Greenhouse effect; Greenhouse gases.

Mexico

• **Category:** Nations and peoples

• **Key facts**

Population: 109,955,400 (January, 2009, estimate)
Area: 1,922,550 square kilometers
Gross domestic product (GDP): \$1.559 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 686 in 2000
Kyoto Protocol status: Ratified 2000

• **Historical and Political Context**

Mexico has experienced political strife throughout its history, including major wars and executions of leaders. The Spaniards invaded the region in 1519, conquering the Aztec and Mayan native cultures. Mexico attempted to declare independence from Spain in 1810, resulting in war and the execution of a number of leaders from Mexico. This war of independence lasted until 1821, when Spain finally granted Mexico its autonomy. The Mexico of 1821 included most of present-day Central America and the southwestern United States.

There was constant strife in Mexico until 1867, especially between a group supporting the centralized federal government required by the 1824 constitution and a group that supported a more localized government. During this time, the constitution was suspended, which resulted in civil war. The Republic of Texas, among others, declared independence from Mexico and was able to defeat the Mexican forces. Later, Mexico lost a war with the United States for control of Texas.

In 1867, Benito Juárez restored the republic of Mexico as a democracy, and he began to modernize the country. His acts reduced the power of the Catholic Church over Mexican politics, required equal rights for all people, and brought the army under civilian control. Porfirio Díaz was the ruler of Mexico from 1876 to 1911. He helped invest in the arts and sciences, and he improved Mexico's economy, reducing economic inequality and political repression. Diaz resigned in 1911 after an election fraud was found, and this event caused another Mexican revolution.

The government entered a chaotic period. A number of elected leaders were overthrown and assassinated. Finally, in 1929, Plutarco Calles founded the Institutional Revolutionary Party, which became the dominant party in Mexican politics until the end of the twentieth century. Mexico became more stable under the party. The economy grew significantly from 1940 to 1980. The government took over mineral rights, including nationalizing the petroleum industry into the organization called PEMEX. The Institutional Revolutionary Party, however, gradually became oppressive and authoritarian. For example, the government in 1968 killed many protestors.

The Institutional Revolutionary Party began to lose its control over Mexican politics in the 1970's, as some non-Institutional Revolutionary Party politicians were elected. In 1989, the first non-Institutional Revolutionary Party governor of a state was elected. It was suspected, however, that the Institutional Revolutionary Party changed the election results in the 1988 presidential elections so that its candidate, Carlos Salinas, won. This infuriated many people. Salinas signed the North American Free Trade Agreement and helped control inflation. By 1994, however, the economy in Mexico collapsed. The United States helped spur the Mexican economy, so that it had rebounded by 1999. In 2000, Vincente Fox became the first non-Institutional Revolutionary Party candidate to be elected president.

• Impact of Mexican Policies on Climate Change

Mexico has a free-market economy with the eleventh highest gross domestic product (GDP) in the world. Mexico has improved railroads, the distribution of natural gas, airports, and the generation of electricity. It has also become the largest producer of cars and trucks in North America. The economy of Mexico tends to be linked to that of the United States, as economic downturns and upturns in the United States have been reflected in Mexico. The country has a large middle class, although there are still significant income disparities among the Mexican people. Many persons live in poverty, especially in rural areas.

Mexico has made a definite commitment to energy conservation to reduce pollutants and greenhouse gases (GHGs) in the atmosphere and to promote energy efficiency. The nation has seven major metropolitans areas with populations over one million. The Mexico City metropolitan area is the largest, with over twenty-two million inhabitants.

The use of refining fuels such as gasoline and diesel, the two most used liquid fuels, has been growing steadily in Mexico. For instance, the use of refining fuels in Mexico grew from 141,000 kiloliters per day in 1988 to 206,000 kiloliters per day in 2000. Lead was eliminated from gasoline, and sulfur in gasoline and diesel fuels was drastically decreased in the 1990's. Fuel oil (4 percent sulfur) and national diesel (2 percent sulfur) have been replaced by gas oil (2 percent sulfur), industrial fuel (1 percent sulfur), and Pemex Diesel Industrial (0.05 percent sulfur).

These improvements in fuel have helped greatly to reduce air pollution, especially from lead and sulfur, in the Mexico City metropolitan area. The metropolitan area lies in a valley, with mountains surrounding much of the region. Pollution settles in this valley for much of the year because of an atmospheric inversion layer that forms over the valley trapping them. This results in a multitude of health effects on the city's inhabitants. The adoption of catalytic converters has also improved air quality. Mexico City's carbon monoxide emissions decreased by 454,000 metric tons per year from 1989 to 1994, reducing the amount of carbon monoxide in the atmosphere by 67 percent. In addition, ozone concentrations decreased by 36 percent from 1991 to 2003.

The use of fossil fuels will likely continue to increase with time in Mexico. Thus, other means need to be found to further re-

duce fossil fuel emissions. For example, public transport needs to be increased so fewer persons drive their own vehicles, and all vehicles need to burn fuel more efficiently.

• Mexico as a GHG Emitter

The GHG emissions of Mexico have grown steadily since 1990. For instance, carbon dioxide (CO_2) emissions were estimated to be 385 million metric tons in 2000 and 438 million metric tons in 2007. During this period, Mexico produced about 1.6 percent of the world's CO_2 emissions. The largest CO_2 emissions are from burning of fuels from industry and in the home (about 32 percent) and from transportation (about 15 percent). Mexico's CO_2 emissions will likely continue to increase as the country remains dependent on fossil fuels and its population grows, unless a more effective means to reduce emissions can be found.

Mexico signed the Kyoto Protocol in 2000. The goal of the protocol was to stabilize GHG emissions (especially those of CO_2, methane, nitrous oxide, and sulfur hexafluoride) to prevent climate change. The industrialized countries agreed to reduce their GHG emissions by 5.2 percent compared to those of 1990. The Kyoto Protocol was put into effect in February, 2005. The treaty divided countries into Annex I (industrialized) countries and non-Annex I (developing) countries. Under the treaty, an Annex I country can invest in projects to help reduce GHG emissions in a non-Annex I country. The Annex I country will earn credit for reducing the other country's GHG emissions that it can use to offset its own emissions in excess of its treaty obligations. For instance, Japan could invest in developing solar energy in Mexico to be used for electrical generation. Japan would then be given credits that it could either use to gain permission to emit more GHGs or sell to a third party.

The major commitment of Mexico as a non-Annex I country is to examine its GHG emissions with time to help limit their emissions. One approach to limiting its GHG emissions might be to add a tax on fossil fuels to increase the costs of the fuels and to reduce the Mexican government's subsidies on fossil fuels. The higher cost of the fossil fuels would reduce the use of the fuels and reduce GHG emissions. For example, it was predicted that if a tax of $10 per ton (in U.S. dollars) had been levied on Mexican fossil fuels starting in 1987, this tax would have resulted in a reduction of about 943 kilograms per person in CO_2 emissions. It would also have increased the Mexican government's revenues by $772 million, or about 3.2 percent. The petroleum, mining, chemical, and construction industries of Mexico would likely stand to lose the most from such a tax. Also, a tax on fossil fuels would encourage the development of more energy-efficient motors in vehicles and the use of more energy-efficient fuels.

Bioenergy sources, such as wood fuels, grain ethanol and other farming fuels, and cattle residues, have been suggested to replace some fossil fuels and reduce GHG emissions. For instance, if Mexico used biofuels (especially ethanol, biodiesel, and electricity generated from biological materials) to replace 16 percent of fossil fuels, then CO_2 emissions could be reduced by 79 million metric tons of CO_2 by 2030.

• Summary and Foresight

The economy of Mexico in the latter half of the twentieth century went from an agrarian economy to a more industrialized economy, increasing national consumption of fossil fuels and production of hard goods such as cars and trucks. Correspondingly, GHG emissions spiraled upward as well. The Mexican government has become more stable in the early twenty-first century than it was for much of its past, as political and police corruption have decreased. Nevertheless, there still appears to be a number of corrupt government officials, including police officers, who are ready to take bribes.

Traffic in illegal drugs appears to be a steadily increasing problem in Mexico. The so-called drug lords have been killing the police, army officials, one another, and many innocent civilians. Some civilians appear to have been held for ransom to obtain more money for the drug lords and some persons appear to have been killed to provoke fear in the general population. Also, some local areas in Mexico have been taken over by those involved with drugs. There may be an imminent danger that much of Mexico could be destabilized if these actions continue, and an unstable society will be much less equipped to institute climate policy initiatives to respond to global warming. Thus, Mexico must curtail these problems to be able to progress as a stable, democratic society. The efforts of Mexico to reduce the GHG emissions could fail if money is channeled elsewhere to stop the activity in drugs.

Robert L. Cullers

- **Further Reading**

Boyd, Roy, and Maria E. Ibarraran. "Costs of Compliance with the Kyoto Protocol: A Developing Country Prospective." *Energy Economics* 24 (2002): 21-39. Describes a potential method for Mexico to limit GHG emissions by imposing an energy tax on the burning of fossil fuels.

Islas, Jorge, Fabio Manzini, and Omar Masera. "A Prospective Study of Bioenergy Use in Mexico." *Energy* 32 (2007): 2306-2320. Describes the use of wood, farming fuels (such as alcohol produced to run cars), and municipal waste as alternative fuels to reduce CO_2 emissions. Numerous tables and figures.

McKinley, Galen, et al. "Quantification of Local and Global Benefits from Air Pollution Control in Mexico City." *Environmental Science and Technology* 39 (2005): 1954-1961. Summarizes information about air pollution in Mexico City and potential means for improving air quality. Includes seven data tables.

Mexico Air Quality Management Team. "Improving Air Quality in Metropolitan Mexico City: An Economic Evaluation." Washington, D.C.: World Bank Latin America and the Caribbean Region, 2002. Evaluates air pollution in Mexico City and argues that reducing air pollution by certain amounts could affect the health of the residents. Tables and graphs.

Nova, M., J. Gasca, and U. Gonzalez. "The Energy Demand and the Impact by Fossil Fuels Use in the Mexico City Metropolitan Area from 1988 to 2000." *Energy* 31 (2006): 3381-3390. Compares contemporary and predicted future use of fossil fuels in Mexico generally to that of the Mexico City Metropolitan Area. Discusses the city's influence on the air quality in Mexico. Numerous tables and figures.

See also: Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. energy policy.

Microwave sounding units

- **Categories:** Science and technology; meteorology and atmospheric sciences

- **Definition**

A microwave sounding unit sounds (produces a profile of) the temperature and the moisture levels in the atmosphere. The first microwave sounding units were placed on National Oceanic and Atmospheric Administration (NOAA) satellites in 1978. In 1998, the Advanced Microwave Sounding Units replaced the older units. The satellites are polar-orbiting and synchronous with the sun. The satellites will make about sixteen orbits in twenty-four hours. The instruments make a scan every eight seconds, during which time the point on the surface below the satellite will have moved by 45 kilometers. During six of the eight seconds, the AMSU-A instrument is making thirty observations about 3° apart from 48° on one side to 48° on the other. The next scan will be 45 kilometers farther along its orbit. After the thirty observations, the instrument makes an observation of a warm calibration target and an observation of cold space before returning to its original starting position. The AMSU-A instrument is determining temperature of the different layers of the atmosphere. Another instrument, AMSU-B, is scanning in a similar mode but makes three times as many observations and determines water vapor concentration. In 2005, the AMSU-B instrument was replaced by a Microwave Humidity Sounder (MHS). In 2009 or 2010, the Advanced Technology Microwave Sounder (ATMS) is slated to replace the AMSU-A.

The AMSU-A is detecting thermal emissions from atmospheric oxygen. Those emissions are in the microwave region of 23 to 89 gigahertz. The microwave radiation is low-energy and high-frequency. The AMSU-A instrument has several channels. Different channels record different wavelengths of radiation. Groups of channels emphasize different layers of the atmosphere. Combined together a profile of the temperature of the different layers of the atmosphere is produced. Channels 2 through 4 emphasize the surface, channels 5 through 8 emphasize the mid-troposphere, and channels 9 through 14 emphasize the lower stratosphere.

• Significance for Climate Change

The data obtained from AMSU-A includes temperature and water vapor profiles of the atmosphere, snow and ice coverage, cloud water content, and rain rate. With data from other instruments, scientists can produce not only the temperature and water vapor profiles but also a measurement of the ozone, properties of clouds, and the amount of infrared radiation emitted by the Earth in areas not covered by clouds. The AMSU data are used in weather prediction. The more quickly the data get to weather prediction centers, the better the accuracy of the predictions.

It would appear that the data on temperature profiles that have been acquired since 1958 by balloons and since 1978 by MSU would allow for a determination of the increase or decrease of the temperature of the atmosphere. It has not proven to be so simple. Because of a change in equipment, the balloon data have a discontinuity that makes it much less valuable in determining temperature change. The data from MSU are not temperatures but thermal radiation from oxygen molecules. Different scientists use different methods to calculate the temperatures from the MSU data and consequently obtain different temperatures. Two of the groups doing calculations of this type are the Remote Sensing System (RSS) and the University of Alabama in Huntsville (UAH). The lower troposphere temperatures, in which stratospheric cooling has been eliminated, has been measured by RSS with an increase of 0.156° Celsius per decade and by UAH with an increase of 0.13° Celsius per decade. Other scientists have used the RSS data and the UAH data and have derived increases from 0.050° Celsius per decade to 0.20° Celsius per decade. Climate models indicate that the troposphere should warm about 20 percent more than the surface over the entire world and 50 percent more in the tropics. The surface temperature has increased by 0.17° Celsius per decade since 1979. Reconsideration of the data from UAH and RSS has led to corrections that have brought the data into fair agreement and into a not inconsistent agreement with the surface data. Probably the best statement about the data was made in a report by the National Research Council. The report states that whether the two sets of data agree with each other or with surface data, the fact is that there is a warming trend. The amount of warming may be less important than the fact that it exists.

C. Alton Hassell

• Further Reading

Chahine, Moustafa T. *AIRS/AMSU/HSB—The Atmospheric Infrared Sounder, with Its Companion Advanced Microwave Sounding Unit and Humidity Sounder for Brazil: Providing New Insights into Earth's Weather and Climate.* Greenbelt, Md.: National Aeronautics and Space Administration, Goddard Space Flight Center, 2001. Describes the infrared equipment used to determine the temperature and humidity of the atmosphere. Illustrations.

Kegawa, Seiichiro, and Tsan Mo. *An Algorithm for Correction of Lunar Contamination in AMSU-A Data.* Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 2002. Technical report that covers microwave remote sensing and radiometers, in addition to the errors caused by the Moon in the AMSU data. Illustrations, biography.

Kegawa, Seiichiro, and Michael P. Weinreb. *An Algorithm for Correction of Navigation Errors in AMSU-A Data.* Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 2002. Technical report detailing radiometry that demonstrates the change of radiant energy into mechanical work. Illustrations, biography.

Mo, Tsan. *NOAA-L and NOAA-M AMSU-A Antenna Pattern Corrections.* Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 2000. Technical report that also covers microwave remote sensing, radio meteorology, microwave antennas, and satellite meteorology. Illustrations, biography.

See also: Geographical information systems; Meteorology; Weather forecasting; Weather vs. climate.

Middle East

- **Category:** Nations and peoples

The Middle East is largely desert, with limited annual precipitation and limited usable freshwater sources. Increased consumption of Middle Eastern petroleum and related fossil fuels appears to be increasing atmospheric CO_2 concentrations, and reliance upon those resources causes the relative political instability of the region to have disproportionate effects on global socioeconomic stability.

• Key concepts:

desalination: removal of soluble salts from water, usually to make it potable or suitable for irrigation

dew point: the temperature at which airborne water vapor condenses

Fresnel lenses: small plastic sheets with very small, patterned, concentric circles stamped or milled into them that concentrate sunlight

orographic precipitation: rainfall caused by rising topography that cools moisture-laden marine air

paleoclimatology: the scientific study of ancient climates

palynology: the study of relict pollen from ancient pollen traps

water rights: the rights of sovereign states or other legal entities to contested water supplies

• Background

The Middle East comprises the sovereign states of the Eastern Mediterranean and North Africa, as well as those states along the Persian Gulf north of the Indian Ocean. Political definitions of the Middle East normally include the states of Syria, Lebanon, Israel, Egypt, Jordan, Saudi Arabia, Iraq, Yemen, Kuwait, Qatar, Bahrain, the United Arab Emirates, and Iran and the quasi-state territories of Palestine. These nations often act as a geopolitical bloc, because many of them are unified by their interests in the global oil market and their largely Muslim populations. The region is more than 92 percent Muslim, and it contains over 60 percent of known global oil reserves, as well as over 40 percent of natural gas reserves.

• Petroleum Production

Middle Eastern oil reserves from both conventional and unconventional sources combined are estimated at over 750 billion barrels. In 2008, the Middle East supplied over 60 percent of all global oil production. Middle Eastern oil reserves may be divided into three categories, in a formula known as 3P: what is provable, what is probable, and what is possible. These are all based on measurable analytic estimates and hypotheses or directly known from instruments used in petroleum exploration.

Saudi Arabia is arguably the most progressive state in the Middle East in the sense that it has declared a long-term goal of preparing for a future without oil. This plan requires Saudi Arabian society to be restructured to find alternative sources of economic wealth and diversification to replace lost oil revenues. The Saudis seek to become self-sufficient in their ability to provide themselves with food and water, among other resources. Nonetheless, Saudi Arabia remains the largest oil producer in the world, producing over 10 million barrels per day, 12 percent of global output.

Climate change represents a significant threat to the peoples and nations of the Middle East. Warming in the region would be likely to spread desertification, and the already marginal vegetation cover would become even more threatened. Ironically, much of the regional Middle Eastern economy is overwhelmingly dependent on oil production, which is seen as one of the major contributors to greenhouse gas (GHG) emissions and global warming, because burning oil releases carbon dioxide (CO_2) into the atmosphere.

• Water Desalination

The peoples of the arid Middle East have been working for decades on increasing freshwater supplies by developing desalination technology. The Middle East accounts for 75 percent of global water desalination. Saudi Arabia—the world's largest producer of desalinated water—has thirty desalination plants that supply 70 percent of national drinking water needs for a 2009 population of 29 million people, although this population is increasing. The Red Sea facility at Shoaiba, for example, a multiflash distillation operation, uses intense hot steam from a local power plant to boil out the salts from water. Its esti-

Anticipating an Israeli raid on Gaza, Palestinians wait in line for water in June, 2006. Water is an even more precious resource in the Middle East than it is in much of the rest of the world. (AP/Wide World Photos)

mated freshwater production is 150 million cubic meters for 2009 and 3 billion cubic meters by 2012.

Israel is also a high-tech leader in desalination, with a volume of 100 million cubic meters of freshwater produced in 2006 at the Israeli Ashkelon desalination facility alone, which uses seawater reverse osmosis (SWRO) technology. This facility, the world's largest SWRO operation, provides 13 percent of Israel's domestic water needs. Overall, the world's largest multiflash distillation operation is at Jebel Ali in the United Arab Emirates, which produces 300 million cubic meters of freshwater per year from the Persian Gulf.

If the Middle East could increase its collective water desalination efforts by 1,000 percent, it could theoretically produce enough freshwater to alter the region's climate. Such a quantity of freshwater would make it possible to sustain significant vegetation and forestation programs that could cause increased humidity and give rise to a sustainable regional hydrologic cycle. If this cycle were achieved, it could transform the desert into a sustainable agricultural region.

Major obstacles stand in the way of such a program, however. The necessary desalination technologies would be extremely energy intensive, practically requiring that they be powered by renewable energy sources such as solar and wind power to avoid depleting even the Middle East's energy reserves. Because the Middle East enjoys high levels of insolution, solar-powered desalination is not beyond the realm of theoretical possibility, and many global pioneering efforts in solar energy technologies are funded by Middle Eastern venture capital.

• Water Rights

Gudea of Lagash, ruler of Neo-Sumeria circa 2100 B.C.E., made a statement four millennia ago that may resonate during the twenty-first century: "He who controls water controls life." This statement is increasingly true in the Middle East, where marginal water sources are increasingly sources of conflict and the United Nations is encountering increasing difficulties in mediating disputes.

Sovereign Middle Eastern states involved in water rights disputes include Israel, Lebanon, Syria, and Jordan, where mountain ranges of the Amana and Hermon Mountains and the Golan Heights lie in the territories of multiple countries. The Amana Mountains are primarily in Lebanon, but their Mediterranean coastal rain shadow extends to Syria. The Hermon Mountain massif is shared between Syria and Israel. The contested Golan Heights are shared between Israel and Syria.

The Jordan River watershed, issuing from the Sea of Galilee, has become a highly charged geopolitical battleground: Jordan has long claimed that the technologically adept Israel supports its agricultural needs by siphoning off at least 70 percent of the watershed above the Jordanian border, leaving little water for Jordan's own agriculture and reducing its potential self-sustenance while increasing its need to import food. If climate change renders the Middle East increasingly arid, water rights will become an even more acrimonious issue, potentially further destabilizing an already tense region where the Jewish state of Israel and its predominantly Muslim neighbors coexist uneasily, and where tensions between Sunni and Shiite Islam and between secular and religious factions and states also cause unrest.

Increasing desertification as a result of climate change is likely, unless growth in regional desalination can compensate for lowering water tables combined with higher demand for rainwater. Overconsumption of water resources (for example, by denizens of the Jordan Valley in the Levant) results in smaller bodies of water (for example, the Sea of Galilee and the Dead Sea), which increases desertification by reducing the available watershed and increases evaporation by increasing the overall land temperature.

• Potential Reforestation

Portions of the eastern Mediterranean landscapes of the Levant now composing Israel were covered in antiquity by dense forests that were lost over time. Palynological studies of remnant pollen verify that this ancient hill forest comprised oak and other hardwoods, among other species. Photographs from the late nineteenth and early twentieth centuries show, however, that the coastal hills were completely denuded of trees in an arid landscape. Systematic, extensive planting of thousands of hardy pine trees, mostly fast-growing Aleppo pines acclimated to aridity, began in Israel in the 1950's.

Meteorological records kept since 1948 show that the annual average Israeli rainfall in the 1950's was around 25 to 30 centimeters. As the new pine forests matured, they cooled the surrounding air and mitigated surface temperatures, drastically altering rainfall. Moisture-laden air off the Mediterranean had previously risen over these hot hills and kept going, since the dew point was too high to cause precipitation. With cooler temperatures from forest cover, there was marked increase in orographic precipitation at lower elevations, as the dew point lowered significantly. Thus, rainfall in Israel increased dramatically over the fifty years between 1950 and 2000, reaching around 1 meter annually. This reforestation practice is thus now known to be effective and could potentially change microclimates all over the Middle East, especially where moisture-laden winds from bodies of water could be "harvested" to produce rainfall for agriculture.

• Solar Energy

Middle Eastern states such as Saudi Arabia and Israel are pioneering solar energy research and experimental projects. The amount of sunlight in the Middle East exceeds that of most other global regions, so solar energy has an extremely high potential there. Near Ashdod and in the Negev area, for example, where 330 sunny days per year are normal, Israel has planned or is building some of the world's most progressive solar energy facilities, with many hectares of solar collectors placed on solar "farms," some using rotating dishes made from mirrors. One Negev site alone is expected to cover 400 hectares when completed in 2012.

Rotating-mirror solar collection can harness 75 percent of incoming sunlight, which is about five times the proportion harvestable using traditional solar panels. The technology also reduces the quantity of photovoltaic cells needed by a factor of about one thousand. Israel is planning to produce about 65 percent of its energy by such means within twenty years. Saudi Arabia also has comparable technology and goals, embodied in its Saudi Solar Village Project, where model solar villages have solar units that use Fresnel lenses to concentrate sunlight. This renewable solar energy source has great potential to reduce dependence on carbon-emitting fossil fuels and also to power desalination for agricultural needs.

• Context

The Middle East is not only a geographic but also a geopolitical bloc that often operates on ideological commonalities reinforced by shared language, culture, and religion. It is predominantly Arabic in language and Islamic in culture. Additionally, its shared climate zone is overwhelmingly arid, bordering on desert, with overall annual precipitation under 20.8 centimeters. Only Lebanon and parts of Syria exceed this annual precipitation average and usually by only a small margin.

The arid Middle East as a geographic and geopolitical unit will be highly influenced by any increased global warming, because it is already under climatic stress. That the region contains a majority of the world's known petroleum reserves only complicates this economic and climatic problem, because its economic health is likely to diminish as a result of decreased global reliance on fossil fuels.

Although models by which one can infer climatic relationships are becoming increasingly sophisticated, one of the most difficult tasks ahead may be to differentiate between correlation and causation in global warming, especially given the increasing fossil fuel carbon footprint. The Middle East, with its enormous but nonrenewable energy reserves, is vital to the future of anthropogenic climate change.

Patrick Norman Hunt

• Further Reading

Atlas of Israel: Cartography, Physical and Human Geography. New York: Macmillan, 1985. Documents and maps all geophysical data available in Israel from over forty years of quantitative measurements from meteorology, oceanography, demography, and other parameters.

BP [British Petroleum]. *Statistical Review of World Energy, June, 2008*. London: Author, 2008. Reveals that regional and global oil production fell during 2008 for the first time since 2002, mostly as a result of changing crude oil costs tied to economically driven conservation.

Hyne, Norman J. *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*. 2d ed. Tulsa, Okla.: PennWell, 2001. Explains key concepts of geology and applied engineering relevant to the petroleum industry globally; provides useful statistics on Middle Eastern oil production.

"Middle Eastern Oil Consumption Shows Strong Growth." *Bahrain Tribune*, April 9, 2009. Reports that global consumption of Middle Eastern oil rose to 6.2 million barrels per day in 2007, representing a 4.4 percent increase over 2006 consumption. Examines this growth from the perspectives of both GHG emissions and Middle Eastern economic health.

"Saudi Arabia's Prince Nayef: A Rising but Enigmatic Prince." *The Economist* 391, no. 8625 (April 4-10, 2009): 53. Suggests potential trends in current Saudi Arabian succession for the royal Saudi family, acknowledging that Saudi Arabia contains 25 percent of the known global oil reserves; discusses how political succession might impact those reserves.

See also: Desertification; Iran; Kyoto Protocol; Saudi Arabia; Security; United Nations Framework Convention on Climate Change.

Milanković, Milutin

Serbian mathematician

Born: May 28, 1879; Dalj, Slavonia (now in Croatia)
Died: December 12, 1958; Belgrade, Serbia

Milanković produced a curve demonstrating the variation in intensity of summer sunlight over the past 600,000 years. Once established, the curve enabled scientific explo-

ration of past and future relationships between solar radiation, eccentricity, and climate.

• Life

Milutin Milanković is credited with developing the concept of astronomical cycles that affect global climate and the timing of ice ages. In December, 1904, he received a doctorate of technical science from the Vienna University of Technology. Late in 1909, he was offered a professorship at the University of Belgrade, where for almost a half century, he would lecture on rational mechanics, theoretical physics, and celestial mechanics. Around 1915, he began to study the astronomical explanation for the Pleistocene epoch ice age. This work examined long-term solar radiation at various latitudes and seasons to determine the influence of the astronomical input to Earth's climate. The research was completed in the 1930's, culminating in the 1941 publication of *Kanon der Erdbestrahlung* (*Canon of Insolation and the Ice Age Problem*).

• Climate Work

Milanković proposed that if incoming solar radiation cyclically varies, then those variations of solar energy may be correlative with glacial and interglacial ages, which may arise from the orbital geometries between the Sun and Earth. About every 100,000 years, Earth's orbit around the Sun changes from a near-circular orbit to a slightly elliptical orbit, a variable known as eccentricity. Circular orbits are said to exhibit low eccentricity (around 0); more elliptical orbits have a high eccentricity (around 0.07).

An additional orbital cycle is the tilt (obliquity) of Earth's rotational axis relative to the ecliptic. The tilt varies from 22° to 25° over a period of forty-one thousand years and increases seasonal cycles at high latitudes, whereas lower latitudes undergo a reduced seasonal effect. The greater the obliquity, the more warmth high latitudes receive in summer, and the less they receive in winter. Only the eccentricity cycle affects the amount of solar radiation reaching Earth, so when Earth's eccentricity is at a maxim (causing less solar input) and its obliquity is at a minimum (resulting in less warmth in high latitudes), Milanković proposed that the onset of glacial conditions would occur.

An additional cyclic variation is the precession of the equinoxes, which has two components that regulate the seasonal change of the distance between Earth and the Sun. One component is elliptical precession, which relates to Earth's rotation around one of the foci of the orbit, having a periodicity of twenty-six thousand years; the other component is the "wobble" of the Earth on its rotational axis. Recall the slowing motion of a stationary top: It spins around its rotational axis, but the top of the top also wobbles (orbits). The effects of combining these two components of precession are present at the low latitudes (with periodicities of nineteen thousand and twenty-three thousand years).

With these three major variations in operation, the essence of Milanković's theory is demonstrated: Cooler summers would retard the melting of winter snow and ice; in turn, the relative mildness of winter at low latitudes would lead to sizable evaporation, which would produce abundant snowfall at middle and high latitudes. As snow and ice accumulate on land and remains, the icy surface reflects more energy back into space; over time, this snow and glacial ice can develop into continental ice sheets and mountain glaciers. Also, due to reduced insolation in the cooler, middle- and higher-latitude oceans, less greenhouse gas (GHGs) is available. Less GHG allows more long-wave radiation to leave the Earth, further cooling the planet.

Until the 1960's, Milanković's astronomical explanation for the presence or absence of glaciers was disputed because of a lack of geologic evidence. However, a complex study using climate-sensitive microorganisms in deep-sea sediments was undertaken to establish a chronology of temperature changes over the past one-half million years. The microorganisms used were foraminifera ("forams"), a protozoa that secretes a shell and whose shell, upon death, is deposited on the ocean floor, mixing with other sediments. The foram shell contains specific percentages of oxygen 18 (O^{18}) and oxygen 16 (O^{16}). Since ordinary oxygen (O^{16}) is atomically lighter than heavy O^{18}, during evaporation of ocean water O^{16} would go into ice formation in ice sheets and O^{18} would remain in ocean waters. Thus, when forams with shells rich in O^{18} were plentiful in ocean sediments, Earth was in a phase of glaciation.

Using isotope analysis, temperature variations over time can be compared. The established climate-time scale was then compared to the astronomical calculations of eccentricity, obliquity, and precession to determine whether there was a correlation. The conclusion of Milanković's mathematically complex research is that major variations in climate are closely linked to periods of obliquity, precession, and orbital eccentricity.

Research into future climate regimes investigates the relationship between solar radiation and eccentricity. Studies have demonstrated that for the next twenty-five thousand years, insolation will increase only 25 watts per square meter as received at 65° north latitude in June. Eccentricity will approach 0 for the same period, which will subdue the variations of precession. With these values (which do not consider anthropogenic changes to climate), the present interglacial cycle may continue into the future for twenty-five thousand years. Climate modeling that considers CO_2 input from anthropogenic sources and insolation variation over the next 100,000 years suggests that CO_2 concentrations over 220 parts per million volume will lead to protracted interglacial periods—about fifty thousand years into the future. An overview of most climate models confirms that future global climates will be similar to the warmest portions of the last few tens of millions of years. If the models are correct in predicting long, warm interglacial periods, the additional heat of global warming may strongly modify Earth processes and severely stress living organisms.

Mariana L. Rhoades

• Further Reading

Berger, A., and M. F. Loutre. "An Exceptionally Long Interglacial Ahead?" *Science* 297 (August 23, 2002): 1287-1288. Summarizes Milanković cycles as they relate to climate. Describes the current status of those cycles and projects future glaciations.

Eyles, Nick, and Andrew Miall. *Canada Rocks: The Geologic Journey*. Markham, Ont.: Fitzhenry & Whiteside, 2007. Provides textual accounts and useful charts of Milanković variables, sea-level change, the oxygen isotope record and its correlation to the geomagnetic polarity timescale, Pleistocene glaciation, and sediments.

Hays, J. D., J. Imbrie, and N. J. Shackleton. "Variations in the Earth's Orbit: Pacemaker of the Ice Ages." *Science* 194 (December 10, 1976): 1121-1132. Geologic investigation of Milanković cycles using deep-sea foraminifera to document variations in obliquity and precession.

See also: Earth motions; Solar cycle; Sun.

Military implications of global warming

• **Category:** Nations and peoples

Climate change is an emerging global threat that may aggravate conflicts and undermine security in many regions of the world. Climate-related impacts and shocks could trigger military responses and absorb resources for risk reduction, disaster mitigation, and conflict resolution.

• Key concepts

conflict: discord between opposing or incompatible values, interests, or actions of individual or collective actors

crisis: a potential turning point to the worse in a difficult situation

disaster: a drastic disruption in the functioning of a system with severe implications

instability: a state in which one or more normally constant, essential features of a system are in flux

risk: an indicator used to evaluate possible dangers that combines possible damages and the likelihood of their occurrence

vulnerability: susceptibility of a social system or group to pressures and stresses

• Background

Global warming not only affects the lives of individual human beings but may also have larger societal consequences. By triggering a cycle of environmental degradation, economic decline, social unrest, and political instability, climate change may become a crucial issue of geopolitical security and conflict. In some parts of the world (notably in Africa, Asia, and Latin America), the erosion of social

In eastern Chad, a dried up river filled with sand sits in the midst of a land already troubled by warfare related to competition for scant resources. (Finbarr O'Reilly/Reuters/Landov)

order, state failure, and violence have traditionally gone hand in hand. In the most susceptible regions, conflicts that begin within one state or between two states may spread to other neighboring states—for example, through refugee flows, ethnic links, environmental resource flows, or arms exports. Such spillover effects can destabilize entire regions and expand the geographical extent of a crisis, overstretching global and regional governance structures.

• Policy Debate on Climate Security

In 2007, the United Nations Security Council held its first discussion on the security risks of climate change, and the U.N. secretary general warned that climate change may pose as much of a danger as war. With its 2007 joint award of the Nobel Peace Prize to Al Gore and the Intergovernmental Panel on Climate Change (IPCC), the Nobel Prize Committee emphasized that extensive climate change could result in "increased danger of violent conflicts and wars, within and between states." A panel of experts that included, among others, former U.S. director of central intelligence James Woolsey and Nobel laureate Thomas Schelling asserted that climate change "has the potential to be one of the greatest national security challenges that this or any other generation of policy makers is likely to confront."

The German Advisory Council on Global Change (WBGU) concluded in its 2007 comprehensive analysis that, without resolute counteraction, climate change will overwhelm many societies' adaptive capacities in the near future, resulting in a level of instability that could jeopardize national and international security. In a 2008 report, the Office of the European Union High Representative and the European Commission suggested that "climate change acts as a threat multiplier, worsening existing tensions in countries and regions which are already fragile and conflict-prone." In particular, the warming of the Arctic region opens up new avenues for potential cooperation, but also for possible territorial disputes.

• Water Stress and Conflict

Climate change will likely exacerbate water scarcity for hundreds of millions of people. Uneven water distribution may induce migration or the quest for resources from neighboring regions. Individual case studies suggest that water scarcity undermines human security and heightens competition for water and land resources. According to Peter Gleick's chronology, water has been a factor in at least forty-two violent conflicts since the beginning of the twentieth century, but only in a few cases was the exchange of fire involved. By contrast, the Basins at Risk project at Oregon State University has concluded that water scarcity does not increase the likelihood of interstate conflicts but rather strengthens cooperation through transboundary water agreements and institutions.

In the Middle East, water scarcity is intertwined with the region's general conflicts. The arid climate, the imbalance between water demand and supply, and the ongoing confrontation between key political actors exacerbate the water crisis of the Nile, Euphrates, and Jordan Rivers. Global warming—together with population growth, overexploitation, and pollution—is projected to increase the likelihood and intensity of droughts in the region, undermining the conditions for peace and human security. However, statements on "Water Wars" in the Middle East have been questioned. The region's conflicts are largely determined by political differences, where hydrological matters represent an additional dimension of conflict as well as cooperation. Further progress of the water talks is connected to the fate of the Middle East peace process.

Central Asia is another region vulnerable to water conflicts, and the IPCC projects a sharp temperature rise in that region. Agriculture largely relies on irrigation and accounts for 20 to 40 percent of the gross domestic product (GDP) of most central Asian nations. Electricity in the region is based almost completely on hydroelectric power, which depends on glacier meltwater from mountain ranges. Some of the glaciers in the region have already declined in the past decades, and by 2050 about 20 percent of the glaciers in some mountains may disappear. The states of central Asia are characterized by largely closed markets, extreme social disparities, and weak state structures, making them unable to cope with these changes. Struggles over land and water resources have already played a major role in this region, and they have been aggravated by ethnic disputes, separatist movements, and religious-fundamentalist groups.

• Land-Use Conflicts and Food Insecurity

Reduction of arable land, water shortages, diminishing food and fish stocks, increased flooding, and prolonged droughts already threaten food security in many parts of the world, and climate change will aggravate this trend. With global warming, a drop in agricultural productivity is anticipated that will be reinforced by desertification, soil salinization, and water scarcity. More frequent extreme weather events may trigger regional food crises and further undermine the economic performance of weak and unstable states, thereby exacerbating destabilization, the collapse of social systems, and violent conflicts.

Particularly vulnerable will be Africa's food production, which has been in decline per capita for more than twenty years. Around 34 percent of the African population lives in arid regions, and about one-third of the population in sub-Saharan Africa is malnourished or undernourished. By 2020, in some African countries, yields from rain-fed agriculture could decline by as much as 50 percent, severely compromising agricultural production and access to food. Food crises impair the livelihoods of subsistence farmers and increase unemployment and migration for millions of people. As a result of migration from rural to urban areas, slums in African cities grow and become breeding grounds for crime and violence. Growing numbers of marginalized people could join riots and armed rebel groups, possibly culminating in civil war and ethnic conflict.

An example of ethnic conflict aggravated by resource scarcity is the 1994 genocide in Rwanda. In Rwanda, soil degradation, population growth, and unequal land distribution gave radical forces an opportunity to escalate ethnic rivalries into a political power struggle. Elsewhere in Northern Africa, a seried of droughts caused Arabic herders to move into the more fertile areas of Darfur, where grazing cattle trampled farmers' fields, contributing to existing clashes and tensions. The Sudan Post-Conflict Environmental Assessment of the U.N. Environmental Programme in 2007 concluded that Darfur is a "tragic example of the social breakdown that can result from ecological collapse."

• Natural Disasters

The IPCC projects that many areas of the globe will experience more frequent and intense extreme weather events and natural disasters, including droughts, heat waves, wildfires, flash floods, and storms. Disasters have dramatic impacts on human lives, generate rising economic and social costs, cause large numbers of fatalities, and temporarily impair or collapse state functions. Regions at high risk from storm and flood disasters generally have weak economic and political capacities, making adaptation and crisis management more difficult. Storm and flood disasters along the densely populated east coasts of India and China could cause major damage and trigger large migration processes. Developed countries are also vulnerable to natural disasters, as was seen during the 2003 heatwave in Europe, when more than thirty-five thousand people died and agricultural losses reached $15 billion.

The record hurricane season of 2005 demonstrated that even the world's most powerful nation is vulnerable and unable to cope with natural disasters. When Hurricane Katrina hit the U.S. Gulf Coast with wind speeds of up to 230 kilometers per hour, it left a trail of destruction over an area as large as the British Isles. In the Gulf of Mexico, 90 percent of oil refinery capacity had to be shut down. When New Orleans was flooded, over fifteen hundred people lost their lives, and hundreds of thousands fled their homes. The Earth Policy Institute in Washington, D.C., called this outflux "the first documented mass movement of climate refugees." The city's entire infrastructure was devastated, including water, food, energy, transportation, communications, and sanitation. Public order broke down. Most vulnerable were those living in poor-quality housing in high-risk areas and having few financial resources and no insurance to cope with disasters.

• Environmental Migration

In response to environmental degradation and weather extremes, or their indirect consequences such as economic decline and conflict, people will be forced to leave their homelands for other regions. Most vulnerable are high-risk climate hot spots, especially coastal and riverine areas and areas whose economies depend on climate-sensitive resources. Although most of the affected people in the Southern Hemisphere will remain within their national borders, industrialized regions face substantially increased migratory pressure—Europe from sub-Saharan Africa and the Arab world, and North America from the Caribbean and Central and South America.

The potential pressure on China to resettle large populations from flooded coastal regions or dry areas may put migration pressure on neighboring countries, including Russia. Migration of people can increase the likelihood of conflict in transit and target regions where migrants have to compete with the resident population for scarce resources such as land, accommodation, water, employment, and basic social services. Immigrants are perceived as competitors who change the "ethnic balance" in the region.

Populated mega-deltas in southern and eastern Asia will be at greatest risk due to increased flooding from the sea and, in some mega-deltas, from rivers as well. Climate change would significantly aggravate human insecurity in Bangladesh, one of the poorest and most densely populated countries of the world. Since 1960, about 600,000 persons have died as a result of cyclones, storm surges, and floods. Improved warning systems and shelters have drastically lowered the number of such deaths in recent years. The impacts of projected sea-level rise could be disastrous, threatening the Bangladeshi economy and exacerbating insecurity.

A 1-meter increase in the sea level could inundate about 17 percent of Bangladesh and displace some 40 million people, according to the World Bank. On several occasions, the migration of impoverished people has already caused violent clashes within Bangladesh and between emigrating Bangladeshi and tribal people in northern India, where several thousand people have died. The complex interaction of both anthropogenic and natural trends and their socioeconomic and political implications may further lead to situations of political instability and violent clashes, undermining young democratic institutions.

• Context

The security risks of climate change are determined by the causal links among climate stress factors, human impacts and responses, and societal instabilities. Whether societies are able to cope with the impacts and restrain the risks depends on their responses to change and their ability to solve and moderate associated instabilities and conflicts. While a gradual temperature rise of several degrees will already severely affect national and international security, abrupt and large-scale climate change beyond critical tipping points (for example, the collapse of the North Atlantic thermohaline circulation, the loss of the Amazon rain forest or of the South Asian monsoon, and the melting of the Greenland or the western Antarctic ice sheets with several meters of consequent sea-level rise) will likely have catastrophic consequences that could be comparable to major wars. Addressing the problem will require integrated approaches that combine climate and security policy in a mutually enforcing way. Adaptive strategies for mitigation and adaptation are needed that minimize security risks and mitigate conflicts by strengthening institutions, economic well-being, energy systems, and other critical infrastructures.

Jürgen Scheffran

• **Further Reading**

Campbell, K. M. *The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change*. Washington, D.C.: Center for Strategic and International Studies, 2007. Provides a U.S. perspective on emerging national security threats, which are evaluated in the framework of three scenarios of global temperature change.

Scheffran, J. "Climate Change and Security." *Bulletin of the Atomic Scientists*, May/June, 2008, 19-25. Provides an overview of contemporary and historical perspectives on the climate-security link.

U.N. Development Programme. *Human Development Report, 2007: Fighting Climate Change*. New York: Author, 2007. Covers the link between climate shocks and human development and discusses cooperative strategies to avoid dangerous climate change.

See also: Agriculture and agricultural land; Displaced persons and refugees; Drought; Extreme weather events; Famine; Floods and flooding; Human migration; Tropical storms; Water resources, global; Water resources, North American; Water rights.

Minerals and mining

• **Category:** Economics, industries, and products

• **Definition**

Minerals are naturally occurring inorganic substances with definite chemical compositions and characteristic physical properties. A rock is an aggregate of minerals. Minerals range in composition from native elements and metals, sulfides, halides, and carbonates to complex silicates, which are the most common rock-forming substances. Contemporary society depends on the availability of mineral resources: Metallic minerals such as iron, copper, aluminum, lead, and zinc; nonmetallic minerals such as salt, clay, gypsum, soil, and water; and energy resources such as coal, petroleum, natural gas, uranium, and palladium have all become necessary to the functioning of human civilizations.

With few exceptions, minerals are generally nonrenewable (exhaustible), since mineral resources generally have required long expanses of geologic time to develop and thus are present in effectively fixed amounts in the Earth. Minerals are extracted from the Earth by a variety of mining methods when the resource is economically viable. As world population increases exponentially and that population aspires to and achieves middle-class socioeconomic status, an escalating resource crisis has begun to develop that propels the mining of nonrenewable mineral resources. This industrial mining is coupled with many environmental concerns.

It is believed that Earth may have reached its maximum capacity to absorb environmental degradation related to mining. Potential environmental impacts of mineral mining depend on factors such as mine waste management, mining procedures, local hydrology, climate, rock types, size of operation, and related factors. Mining disrupts the landscape and can instigate mine subsidence, disrupting biological and water resources. Underground mining is generally more hazardous as a result of poorer ventilation and visibility and slope instability along mine walls. Moreover, the dust and toxic gases in mines lead to severe respiratory problems, and the possibility of exposure to radiation poses serious health threats.

Through mining processes, large amounts of material accumulate as waste that needs to be disposed of. Many copper mines, for example, extract ore that contains less than 1 percent copper. For many nonferrous metals, almost all of the mined ore becomes waste. Artisanal mining, such as alluvial mining for gold and diamonds, often has impacts on landscape, which is disrupted by trenches.

These activities can lead to erosion and localized destruction of river banks. The waste also contains dangerous substances, such as heavy metals, which leach into the soil and result in the generation of acid or alkaline mine drainage.

The sulfide-containing minerals in metal mining get oxidized in the presence of air and react with water to form sulfuric acid. The acid mine drainage water contaminates surface and underground water. With the proliferation of the petroleum industry, numerous large-scale oil spills are becoming usual industrial accidents, and oil percolates through the soil and pollutes groundwater. The fuels and chemicals used in the mining industry are potential pollutants too. These chemicals left behind by explosives are usually toxic, and they increase the salinity of water. Small-scale artisanal mining may also affect water where mercury is used to process gold. Excavation and removal of raw ore are only the initial stage in the mining process. The ores are processed at refineries, and the valuable portion is extracted by flotation, gravity, or chemical methods. The by-products of mineral refining are sulfur, arsenic, and radioactive substances that are dangerous if they are released into the environment.

• Significance for Climate Change

The mineral mining industries contribute to the global climate. Fossil fuels are used to generate the energy required for moving mining equipment, mining procedures, ore processing and drying, transportation, and building operations. Burning them generates greenhouse gases (GHGs). The mining industry consumes large amounts of electricity to transport material by huge vehicles or extensive hoisting systems for underground mines. The underground mines become very warm with time, and cooling of deep underground mines is energy intensive. Refining metal ores by smelting also requires large amounts of energy. Surface mines pollute the air through blasting operations. Coal mines release methane, which is a primary GHG. However, methane can be captured through expensive processes to reduce the enhanced greenhouse effect.

Some members of the mining industry use ozone-depleting gases such as chlorofluorocarbons, hydrochlorofluorocarbons, and hydrofluoro-compounds for cooling. Similar to coal mining, the petroleum industry also has severe impacts on climate. The production and use of oil and natural gas makes a significant contribution to global warming by increasing atmospheric carbon dioxide (CO_2) concentrations. Additionally, mining operations cause extensive deforestation, one of the major changes in landscape that lead to increased CO_2 concentration in the atmosphere and promotes warming.

All these impacts can have long-term environmental and socioeconomic consequences and will be extremely difficult and expensive to address through remedial actions. Therefore, the mining industries are moving toward meeting standards of air and water quality set by Environmental Protection Agency (EPA) and other government agencies. At present, wastes from the extractive industries are properly managed in order to ensure the long-term stability of disposal facilities and to minimize water and soil contamination arising from acid or alkaline drainage and leaching of heavy metals.

The coal industries are participating in the Clean Air Acts (1963-1990) and controlling methane emissions, although this is not economically feasible in many locations. Methane is removed from coal mines through degasification systems or mine ventilation systems during mining activities, or after mining has occurred. Over the 1990-2000 time period, the EPA reports that recovery of coal mine methane resulted in a reduction of methane emissions by 30 percent or by the equivalent of approximately 25 million metric tons of CO_2 per year. The terrestrial and geological sequestration of carbon and improvement of carbon uptake of soils are areas of research in mining industries that can reduce anthropogenic CO_2 significantly. Moreover, the mining industries are promoting clean coal technologies to refine emissions reduction. The final goal is the development and implementation of zero-emissions mining industries. This requires both time and research dollars, and several organizations are participating and investing in this cutting-edge research endeavor, along with the potential for emissions savings.

Arpita Nandi

• **Further Reading**

Caldeira, Ken, et al. "A Portfolio of Carbon Management Options." *Journal of Geophysical Research* 110 (2005). Discusses the options available to help stabilize the radiative forcing from GHGs and other atmospheric constituents.

Hoffert, Martin I., et al. "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet." *Science* 298, no. 5595 (November, 2002): 981-987. Report of a group of researchers that surveyed possible future energy sources, evaluating them for their capability to supply massive amounts of carbon-emission-free energy and for their potential for large-scale commercialization.

Raupach, Michael R., et al. "Global and Regional Drivers of Accelerating CO_2 Emissions." *Proceedings of National Academy of Science* 104 (2007). Focuses on trends in emissions and their demographic, economic, and technological drivers, using annual time-series data on national emissions, population, energy consumption, and gross domestic product. Understanding the magnitudes and patterns of CO_2 emissions will help scientists predict future climate changes.

See also: Arctic seafloor claims; Coal; Energy resources; Fossil fuels; Lithosphere.

Modes of climate variability

• **Categories:** Climatic events and epochs; meteorology and atmospheric sciences

Modern technologies, particularly satellites and supercomputers, have allowed scientists to view climate from a global perspective, revealing recurrent patterns of climate parameters that affect large areas of the planet over varying periods of time, often years or decades.

• **Key concepts**

El Niño-Southern Oscillation (ENSO): a coupled oceanic/atmospheric seesaw that occurs in the equatorial Pacific but often has global climatic consequences

modes: phases of a climatic seesaw; for example, El Niño is the warm mode of the ENSO seesaw, whereas La Niña is the cold mode

North Atlantic Oscillation (NAO): a seesaw in pressure between the Azores and southwestern Iceland, thought by some scientists to be an expression of the Northern Annular Mode

Northern Annular Mode (NAM) and Southern Annular Mode (SAM): also called, respectively, the Arctic and Antarctic Oscillations, seesaws in pressure between the latitudes near 45° northern (or southern) latitude and the North (or South) Pole

Pacific Decadal Oscillation (PDO): a temperature, pressure, and wind seesaw in the Pacific Ocean

Pacific-North American (PNA) pattern: a seesaw between northern Pacific and North American pressures

regimes: another word for "modes," fitting in with meteorological metaphors such as "fronts"

seesaw: a change in opposite directions, such as high pressure in one region and low pressure in the other

teleconnection: a connection between two widely separated regions of the planet that have highly correlated changes in some climatic parameter, usually resulting from a seesaw

• **Background**

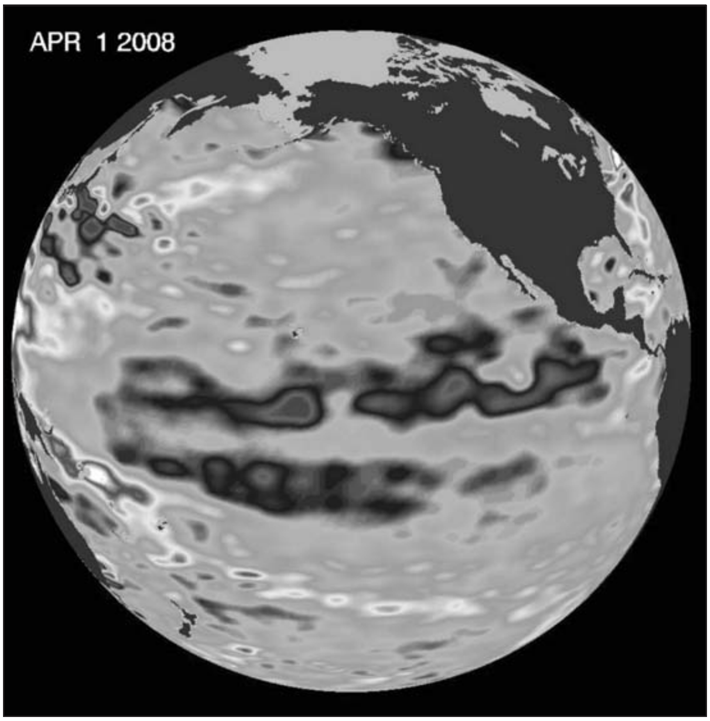
A college town with 2,000 residents that hosts 10,000 students for eight months every year has an average population of 8,666, but it will almost never have that number present. In "academic year" mode, it has a population of 12,000, and in "vacation" mode, it has 2,000. The climate also has modes, and its behavior varies dramatically between them. Temperatures, rainfall, winds, and other climatic phenomena during El Niño are very different from those during La Niña. Recognizing these modes is essential to understanding how the climate operates.

• **Seesaws**

Modes of climate variability are often referred to as "seesaws" because what is missing from one region (such as warmth, atmospheric pressure, or precipitation) is found in excess in the other region. Such seesaws result from the fact that the atmosphere is a finite body of gas that obeys the laws of physics.

By 1924, a number of seesaws had been identified by Sir Gilbert Walker. The data set he presented in 1932 had 183 stations widely spaced across the globe, with multiyear records that permitted statistical analysis. He put his North Atlantic Oscillation (NAO) and North Pacific Oscillation (NPO) on a statistical footing, detailing the strength of correlations between what he called "action centers." He also established the existence of the Southern Oscillation, which he defined in terms of a pressure seesaw. By the 1960's others had shown that this coincided with a pattern of sea surface temperature fluctuations called El Niño, and so it is now known as the El Niño-Southern Oscillation (ENSO).

Additional workers found more seesaws, and often an index was determined by combining the values of some climatological variable at two or more locations in a simple algebraic way: The Southern Oscillation Index was obtained by subtracting the sea-level barometric pressure at Darwin, Australia, from that at Tahiti; the North Atlantic Oscillation Index was obtained by subtracting the sea-level pressure at Iceland from that at the Azores.



The dark area above reveals a cooling trend corresponding to La Niña and the cool phase of the Pacific Decadal Oscillation. (NASA-JPL)

• Statistical Identification of Seesaws

Since Walker's work, the data series from many of his stations have been extended by more than seventy years, hundreds of new stations have been established, and satellite and other remote-sensing techniques have contributed immense amounts of climate information. New statistical techniques involving eigenvector analysis have been developed to analyze these data, particularly Principal Component (PC)/Empirical Orthogonal Function (EOF) analysis.

These techniques take data sets, which can be enormous, and rearrange them into separate, independent components that reveal how the data points are linked. As an example, consider the pressure data for points in the Northern Hemisphere, but outside the tropics (that is, at latitudes greater than 20° north). Eigenvector analysis finds that much of the variability in these data can be explained by two regional seesaws, EOF1, and EOF2. A map of which regions are controlled by each EOF shows that EOF1 corresponds to the NAM, and EOF2 corresponds to the PNA. Because this representation of PNA uses criteria that differ from its original index-based definition, it is often referred to as PNA.

• Context

Teleconnections show that Earth's climate is not entirely random. Spatial patterns exist, and the polarity of the seesaws within these patterns alternates, often with far-reaching consequences. What is less well known is the temporal behavior of these patterns, what causes them to switch polarity, and how they interact.

ENSO is the shortest and best-known seesaw, having an average period of four years, but this period can vary from two to seven years. Efforts to explain why its period should change, or to predict how long a particular El Niño or La Niña will last, have so far been unsuccessful.

The PDO has effects that are geographically similar to those of the ENSO but has a period of twenty to fifty years. Cool before 1924, then warm until 1947, cool again until 1976, and warm again until at least 1998, it has had ambiguous behavior since then. In addition to not knowing why it reverses or when it might reverse again, climatologists do not know whether the PDO causes increased ENSO fluctuations or is caused by them.

Scientists' understanding of the modes of climate variability is incomplete, but most climate scientists agree that they play an important role over periods of years to decades. Our ability to interpret climate data correctly depends on being able to place them in context with respect to these modes. Predictions of climate change would improve if it were possible to predict when these modes will reverse and how strong they would be.

Otto H. Muller

- **Further Reading**

Alley, R. B., et al. *Abrupt Climate Change: Inevitable Surprises*. Washington, D.C.: National Academy Press, 2002. In the section on modes of climate variability (pages 48-69), this book presents an excellent overview of what is known, and what remains to be learned, about teleconnections and their influence on twentieth century climate.

Collier, Michael, and Robert H. Webb. *Floods, Droughts, and Climate Change*. Tucson: University of Arizona Press, 2002. Written for the layperson, this book provides a very accessible explanation of many teleconnections, with an emphasis on how they affect people.

Rohli, Robert V., and Anthony J. Vega. *Climatology*. Sudbury, Mass.: Jones & Bartlett, 2008. With excellent images and clear descriptions, this textbook offers an outstanding examination of the various modes of climate variability. The treatment of statistical methods, particularly those involving eigenvalues and principal components, provides a good feel for how they work without requiring the reader to become enmeshed in equations and linear algebra.

See also: Atlantic multidecadal oscillation; Climate and the climate system; Ekman transport and pumping; El Niño-Southern Oscillation; La Niña; North Atlantic Oscillation; Ocean-atmosphere coupling; Rainfall patterns; Thermohaline circulation.

Mold spores

- **Category:** Plants and vegetation

- **Definition**

Mold spores are reproductive structures of filamentous fungi (molds). A single microscopic mold filament, called a hypha, forms a mat that is called a mycelium. Mycelia are visible without a microscope. Molds are very common organisms and can be found where there is moisture, oxygen, and food they need. Molds can be seen on bread, cheese, or fruit. Hot spots of mold growth can be found in basements and bathrooms (especially shower stalls), house plants, and even air conditioners. Molds grow on fallen leaves, rotting logs, certain grasses, and weeds. They also can be found in barns, dairies, bakeries, and greenhouses.

The mold mycelium produces reproductive branches above the surface of the mold. These branches carry spores called conidia that function in distribution of mold by air, water, and animals. Among different molds, spores—employed in asexual reproduction—vary in size, shape, and color. Each spore can germinate to start a new mold, which in turn produces million of spores. Spores are very tough structures: they are resistant to drying, freezing, heating, and some chemicals.

The majority of the mold spores are disseminated by air. A sample of air may contain up to 2 million spores per cubic meter, but on average, about 10,000 spores inhabit one cubic meter of air. The amount of mold spores in the air in some areas is greater than the amount of pollen. Certain types of mold spores can cause various allergic reactions in humans, such as irritations of the eyes, nose, and throat. About 20 to 30 percent of the population develops allergic responses after exposure to these mold spores. The most common allergenic spores in the United States are *Alternaria cladosporium*, *Aspergillus*, *Fusarium*, *Mucor*, *Rhizopus*, and *Penicillium*.

In some people, exposure to mold spores leads to asthma. Some mold spores, if they reach lungs, can cause infections called mycoses. Systemic mycoses are the most serious category of mold infection. The host becomes infected by inhaling spores that germinate in the lungs. In the United States, two of the most common mold infections of that type are coccidioidomycosis, caused by *Coccidioides immitis*, and histoplasmosis, caused by *Histoplasma capsulatum*. Mild coccidioidomycosis may go unnoticed or produce symptoms similar to those of pneumonia or tuberculosis. The human immune system normally destroys mold spores and neutralizes mold infections. In a small number of cases, however, more serious coccidioidomycosis develops and lesions of the skin, bones, joints, internal organs, and brain (meningitis) occur. Progressive histoplasmosis symptoms include lung cavities, sputum production, night sweats, and weight loss.

• Significance for Climate Change

The weather and mold-spore distribution are closely related. Spore count is usually higher in temperate and tropical regions than in the polar and northern regions. In colder climates, molds are present in the air during the period between late winter and late fall. In warmer climates, mold spores are found throughout the year. It is likely that warmer temperatures due to global warming will result in an increase and even abundance of mold spores and, therefore, in considerable increase of allergic reactions. Repeated exposure to a massive amount of mold spores (100 million per cubic meter) can cause serious allergy-related health problems, including chills, fever, dry cough, breathlessness, weight loss, and even permanent lung damage.

Global warming is believed to be a major factor in the explosion of mold-related asthma and mold infections. For instance, the causative agent of coccidioidomycosis can be found in geographical areas with high summer temperatures and mild winters. In the southwestern regions of the United States, where this climate prevails, an estimated 80 percent of inhabitants are currently infected. Infectious disease specialists suggest that global warming will cause the further expansion of the geographic ranges of coccidioidomycosis infection.

Scientists predict that climate change could also increase the spread of histoplasmosis, which at present afflicts about 500,000 people annually. Another example of mold-spore infection spreading as a result of climate change is the infection caused by *Cryptococcus gattii*. Though previously it was only seen in Australia and other subtropical regions, this mold is spreading in Canada's Vancouver Island and the Pacific Northwest. It can cause serious human infection of the lungs and brain.

In addition, molds are the cause of numerous plant diseases. The increase of plant fungal diseases due to global warming may have a negative impact on plants' ability to take up carbon dioxide (CO_2), a greenhouse gas, thereby increasing the CO_2 concentration of the atmosphere and contributing to further warming. Managing mold plant infections may also require pesticides whose production consumes fossil fuels and generates even more CO_2 emissions.

There is another indirect relationship between mold spores and climate change. In nature, many molds are capable of decomposing woody plants such as trees. Cellulose and lignin in these trees are the biological molecules most resistant to decomposition. Molds, however, use cellulose and lignin from woody plants as their source of energy and carbon, and they release CO_2 in the process. Trees function as carbon sinks, retaining carbon for the duration of their lives and sequestering it from the atmosphere. As global climate change increases the amount of mold spores and, eventually, molds, the CO_2 released by decomposition of woody plants by those molds will also increase. Eliminating mold spores is impractical. Therefore, the only solution to keep molds under control is to control global warming.

Sergei Arlenovich Markov

• Further Reading

Beggs, Paul J. "Impacts of Climate Change on Aeroallergens: Past and Future." *Clinical and Experimental Allergy* 34, no. 10 (October, 2004): 1507-1513. Describes the link between mold spores, climate change, and asthma.

Madigan, Michael T., et al. *Brock Biology of Microorganisms*. 12th ed. San Francisco, Calif.: Pearson/Benjamin Cummings, 2009. Introductory microbiology textbook. Chapter 18 describes molds.

Moore-Landecker, Elizabeth. *Fundamentals of the Fungi*. 4th ed. Upper Saddle River, N.J.: Prentice Hall, 1996. Comprehensive textbook about fungi and molds.

See also: Carbon 4 plants; Carbon 3 plants; Composting; Mangroves; Sequestration.

Monsoons

• **Category:** Meteorology and atmospheric sciences

• Definition

Monsoons are seasonal changes in surface wind and precipitation patterns over the tropical and subtropical continents and surrounding oceans. These changes are due to the differences in thermal properties between land and ocean that give rise to different responses to seasonal changes in insolation.

The specific heat of land is typically less than that of ocean. That is, it requires less thermal energy to raise the temperature of a given amount of land by a given amount than it does to raise the temperature of the same amount of ocean by the same amount. As a result, the summer Sun warms the land more quickly and to a greater extent than it warms the oceans, which remain relatively cool. Typically, low-pressure weather systems form over warm surfaces and high-pressure systems form over cool surfaces. Thus, in the summertime, landmasses often become centers of low pressure, whereas the adjacent oceans become centers of high pressure. Wind blows from high-pressure centers to low-pressure centers, so in summer winds typically blow from the ocean to the land. This phenomenon is called "wind convergence" over land.

When wind converges over land, convection causes clouds to form. Precipitation typically follows the development of these clouds. Therefore, summer monsoons are characterized by winds blowing from the ocean to the land, over which clouds then form and rain falls.

In the winter, the entire process reverses. The lower specific heat of land, which caused it to heat more quickly than the oceans in the summer, causes it to cool more quickly than the oceans in the winter. As insolation decreases, the land quickly loses heat, becoming cold relative to the oceans, which retain much of their heat. As a result, the oceans become centers of low pressure, landmasses become centers of high pressure, and winds begin to blow from the land to the oceans. Clouds and precipitation also move from land to the oceans.

The contrast between the thermal properties of land and seawater is the basic cause of monsoons, but certain topographic features can enhance this effect. Larger landmasses and higher-altitude land surfaces increase the thermal and pressure differentials between land and water. As a result, the world's strongest monsoons are all related to the world's largest mountain ranges: The East Asian and South Asian monsoons are related to the Tibetan Plateau, the North American monsoon is related to the Rocky Mountains, and the South American monsoon is related to the Andes Mountains.

While monsoons are thus caused by contrasts between land and ocean, the atmosphere plays a crucial role in the system as well. The atmosphere couples with both land and sea to mediate and react to the thermal differences between them. It forms different pressure systems over the two bodies based on their temperature differential, reversing the direction of the winds. It also transports large amounts of water from sea to land, first by absorbing evaporated water vapor and then by precipitating the water onto the land.

• Significance for Climate Change

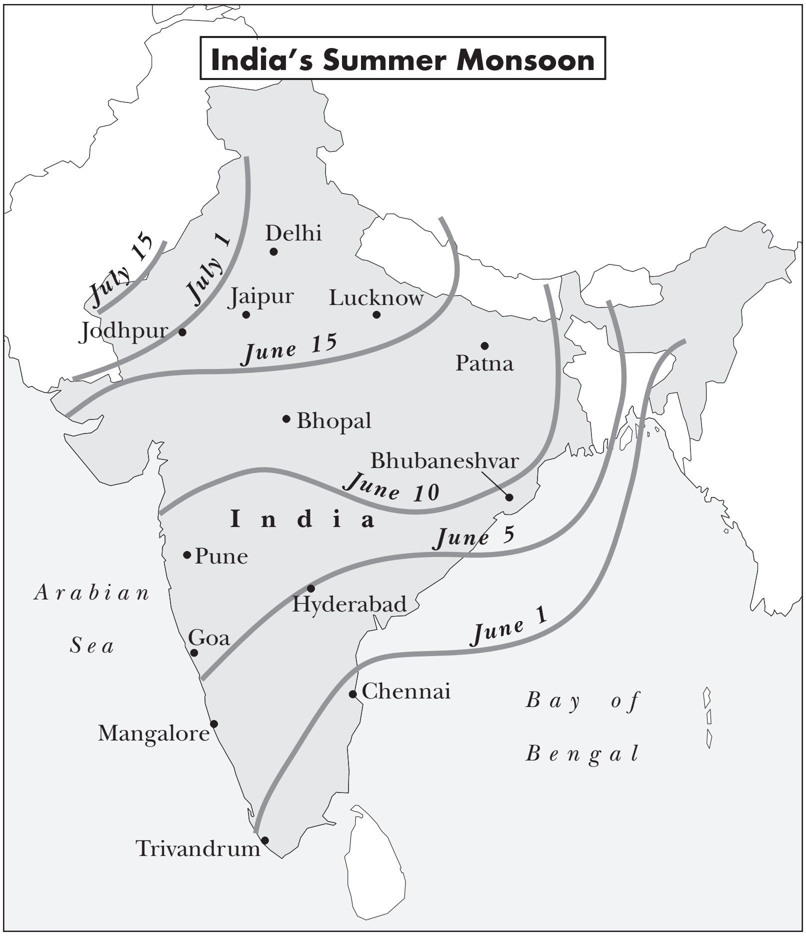
Monsoons form a central part of many regional climate systems. In many parts of the world, monsoonal precipitation constitutes a major rainfall system, providing water resources for regional ecosystems. Many tropical and subtropical climates are dependent upon the monsoonal rains.

Any significant climate change will inevitably affect global monsoon circulations, causing changes in the patterns and intensity of monsoonal rainfall. However, it is a matter of debate among climatologists as to whether global warming will intensify or weaken the monsoons. On one hand, generally warmer climates may reduce the temperature contrast between land and ocean, resulting in weaker monsoons. Evidence to support this hypothesis exists in studies of Himalayan ice cores. Data for the last three hundred years indicate that for every 0.1° Celsius increase in temperature in the Himalayas, there was a decrease of about 100 millimeters in monsoonal rainfall.

On the other hand, global warming may enhance evaporation from the ocean's surface, because warmer air holds more water vapor than does cooler air. An increase in the amount of atmospheric water vapor would likely lead to greater monsoonal rainfall and stronger monsoons. Data from the Tibetan Plateau—where Earth's strongest monsoon is located—indicate that over the last fifty years, total atmospheric water vapor content and total surface rainfall both increased.

Some scientists argue that, rather than strengthen or weaken monsoons, global warming might simply redistribute rainfall without significantly altering average amounts. Such redistribution would entail more severe events at both extremes, as heavy precipitation and flooding would occur in some areas and drought would occur in others. Thus, life in monsoonal areas is likely to change signficantly if global warming continues, but the nature of those changes remains uncertain.

Chungu Lu



The monsoons determine the beginning and end of rainy seasons in many parts of the world, but particularly in the Indian subcontinent. The map above illustrates the progression of rains northward during a typical year, as the summer monsoon moves onto the subcontinent, bringing moist air from the south.

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Widely used introductory textbook on atmospheric science; covers a wide range of topics on weather and climate.

Duan, Keqing, Tandong Yao, and Lonnie G. Thompson. "Response of Monsoon Precipitation in the Himalayas to Global Warming." *Journal of Geophysical Research* 111 (2006). Examines historical ice core data and finds that Indian monsoon precipitation decreased in response to an increase in surface temperature.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Comprehensive overview of global climate change published by a network of the world's leading climate change scientists under the auspices of the World Meteorological Organization and the United Nations Environment Programme.

Kripalani, R. H., A. Kulkarni, and S. S. Sabade. "Indian Monsoon Variability in a Global Warming Scenario." *Natural Hazards* 29 (2003): 189-206. Examines Indian monsoon variability under global warming conditions and suggests that there is no clear evidence of changes in Indian monsoon rainfall.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Introductory textbook that covers a wide range of atmospheric sciences.

Xu, Xiangde, Chungu Lu, Xiaohui Shi, and Shouting Gao. "World Water Tower: An Atmospheric Perspective." *Geophysical Research Letters* 35 (2008). Discusses trends in Tibetan Plateau precipitation and atmospheric water vapor content in response to global warming. The plateau is the world's largest monsoon region.

See also: Average weather; El Niño-Southern Oscillation; Meteorology; Rainfall patterns; Weather vs. climate.

Montreal Protocol

- **Category:** Laws, treaties, and protocols
- **Date:** September, 1987

The Montreal Protocol initiated a process to restore Earth's ozone layer, which protects the planet's inhabitants from dangerous ultraviolet rays. It has been ratified by most of the world's nations.

- **Participating nations:** *1988:* Belarus, Belgium, Canada, Denmark, Egypt, European Community, Finland, France, Germany, Greece, Ireland, Italy, Japan, Kenya, Luxembourg, Malta, Mexico, Netherlands, New Zealand, Nigeria, Norway, Portugal, Russian Federation, Spain, Sweden, Switzerland, Uganda, Ukraine, United Kingdom, United States; *1989:* Australia, Austria, Burkina Faso, Cameroon, Fiji, Ghana, Guatemala, Hungary, Iceland, Jordan, Liechtenstein, Malaysia, Maldives, Panama, Singapore, Sri Lanka, Syrian Arab Republic, Thailand, Trinidad and Tobago, Tunisia, United Arab Emirates, Venezuela; *1990:* Argentina, Bahrain, Bangladesh, Brazil, Bulgaria, Chile, Ecuador, Gambia, Iran, Libyan Arab Jamahiriya, Poland, South Africa, Zambia; *1991:* Botswana, China, Costa Rica, Malawi, Philippines, Togo, Turkey, Uruguay; *1992:* Algeria, Antigua and Barbuda, Barbados, Croatia, Cuba, Cyprus, El Salvador, Guinea, India, Indonesia, Israel, Republic of Korea, Kuwait, Mauritius, Niger, Pakistan, Papua New Guinea, Paraguay, Saint Kitts and Nevis, Samoa, Slovenia, Swaziland, Zimbabwe; *1993:* Bahamas, Benin, Bosnia and Herzegovina, Brunei Darussalam, Central African Republic, Colombia, Côte d'Ivoire, Czech Republic, Dominica, Dominican Republic, Grenada, Guyana, Honduras, Jamaica, Kiribati, Lebanon, Marshall Islands, Monaco, Myanmar, Namibia, Nicaragua, Peru, Romania, Saint Lucia, Saudi Arabia, Senegal, Seychelles, Slovakia, Solomon Islands, Sudan, Tanzania, Turkmenistan, Tuvalu, Uzbekistan; *1994:* Bolivia, Chad, Comoros, Congo, Democratic Republic of the Congo, Ethiopia, Gabon, Lesotho, Macedonia, Mali, Mauritania, Mozambique, Nepal, Vanuatu, Viet Nam; *1995:* Democratic People's Republic of Korea, Latvia, Lithuania, Micronesia, Morocco; *1996:* Azerbaijan, Estonia, Georgia, Liberia, Madagascar, Republic of Moldova, Mongolia, Qatar, Saint Vincent and the Grenadines, Yemen; *1997:* Burundi, Suriname; *1998:* Belize, Kazakhstan, Lao People's Democratic Republic, Tajikistan, Tonga; *1999:* Albania, Armenia, Djibouti, Oman; *2000:* Angola, Haiti, Kyrgyzstan; *2001:* Cambodia, Cape Verde, Nauru, Palau, Rwanda, Sao Tome and Principe, Serbia, Sierra Leone, Somalia; *2002:* Guinea-Bissau; *2003:* Cook Islands, Niue; *2004:* Afghanistan, Bhutan; *2005:* Eritrea; *2006:* Equatorial Guinea, Montenegro; *2008:* Holy See, Iraq; *2009:* Andorra, San Marino

- **Background**

In September, 1987, representatives of most of the world's nations met in Montreal, Quebec, to draft a protocol that called for a cessation in the production of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). By July, 1996, this protocol had been subscribed to by representatives of 158 nations. The Montreal Protocol grew out of a concern among most of the world's nations about the depletion of the ozone layer, a thin invisible band in the stratosphere ranging from 10 to 40 kilometers above the Earth's surface. The ozone layer is crucial to the survival of life on Earth, because it filters out most of the deadly ultraviolet rays the Sun produces, permitting moderate temperatures and allowing visible light to get through. Without this natural filtration system, Earth would not be habitable.

Scientists have studied closely the four levels of the atmosphere—the troposphere, the stratosphere, the mesosphere, and the thermosphere—since the 1960's, using weather balloons and satellites to determine what gases are present. The ozone in the atmosphere was first measured in 1956 by scientists working out of Halley Bay in Antarctica.

The earliest weather satellites were launched in the 1970's. In 1978, the United States launched Nimbus 7, the first satellite designed to measure the ozone in the stratosphere in order to ascertain how profusely distributed the ozone atoms are and to determine the extent of the ultraviolet rays the ozone is filtering out. Using scientific data from these experiments, Joseph Farman, a British scientist, concluded in 1985 that the ozone layer had become extremely thin. People began to refer to an ozone "hole," a somewhat inaccurate designation. By this time, earlier researchers had discovered that CFCs, widely used as propellants in aerosol cans, were causing substantial damage to the ozone layer. The presence of CFCs and HCFCs in the atmosphere tripled between 1976 and 1987.

Halons, which contain bromine rather than chlorine, are produced in smaller quantities than CFCs and HCFCs, but they are extremely threatening to the atmosphere, because they destroy ozone at ten times the rate that these other pollutants do. Halons are widely used for extinguishing vehicular fires.

By 1985, after scientists had determined categorically that the depletion of the ozone layer was much more advanced than they had originally feared, many nations banned the continued manufacture and use of CFCs and other such substances. Reexamining information gathered by Nimbus 7, researchers were startled to find that a serious depletion of the ozone layer began in the 1970's and had continued apace since then with a steady thinning in the ozone layer.

Another source of pollution came from the refrigerants used in refrigerators and in air conditioning systems. The improper disposal of refrigerators released dangerous toxins into the air, so an effort was launched to make sure that refrigerators were disposed of safely. The refrigerants in them began to be reused in new refrigerators, employing a process developed by scientists in Germany. By far the greatest offender in pollution from refrigerants is the automobile, because many air conditioned vehicles have leaking rubber tubes from which refrigerants can escape.

By 1985, the hazards the ozone layer was experiencing from various sorts of pollution were considered so critical that immediate action was essential. This pollution compromised the safety of the entire planet, although it was most pronounced over the Northern Hemisphere. There, the ozone layer was shrinking above industrialized regions, where harmful chemicals were regularly released into the atmosphere as by-products of manufacturing. By the end of the decade that began in 1970, ozone in the stratosphere was found to be disappearing at twice the rate it previously had.

• Summary of Provisions

One of the earliest efforts to control the depletion of the ozone layer occurred in March, 1985, when a group of concerned scientists met in Vienna and drafted the Framework for the Protection of the Ozone Layer. The provisions of this document, signed by representatives of twenty-one countries, set a deadline of August 1, 1988, for the signatory countries to cease manufacturing CFCs and called for bans on the use of these chemicals as propellants in aerosol and spray cans, which were major factors in compromising the ozone layer.

This meeting in Vienna marked an important beginning but did not accomplish the sort of widespread action that the urgency of the situation demanded. In May, 1985, reliable scientific journals published findings clearly pointing to the existence of a substantial depletion of the ozone layer over Antarctica. Because of the speed at which this depletion was taking place, it was argued that the future of life on Earth was endangered.

By July, 1996, representatives of 158 countries had signed the protocol that grew out of the Vienna meeting. Although this meeting was not initially a notable success, it was significant for highlighting a critical problem and bringing it to the attention of the world's governments, which, despite their marked political and ethnic differences, realized that no time could be wasted in moving toward a tenable solution.

The Montreal Protocol on Substances That Deplete the Ozone Layer called for a 50 percent reduction in the production of CFCs by the year 2000. It spelled out how the gradual reduction in the production and use of chemicals that threaten the ozone layer must occur.

The protocol defines procedures for controlling the production of CFCs and specifies limits on their export and import. Many serious, seemingly unresolvable disagreements arose among the many nations participating in the drafting of the agreement. Representatives from industrialized nations were pressured by industrial lobbyists to resist approving any actions that might harm industry. In the United States, the Ronald Reagan administration, which was fiercely probusiness, viewed the protocol as a dangerous infringement on free enterprise. Most of Europe's industrial nations had vested interests that ran counter to the provisions of the protocol.

Representatives from countries in the Southern Hemisphere had other concerns, with many representatives of developing countries that teetered on the brink of insolvency resisting measures that might disturb the delicate equilibrium that characterized their economies. Special provisions and alterations in deadlines as they pertained to developing countries were enacted. Provision was made in the protocol to establish the Ozone Fund, which was subsidized by the industrialized nations for the benefit of developing nations. By 1996, this fund exceeded $500 million.

Despite the numerous quibbles that the organizers of the Montreal meeting had to address, the development of the Montreal Protocol moved forward. Annual meetings of those who participated in the Montreal Protocol were held in various venues, including Helsinki, Copenhagen, Beijing, Nairobi, Bangkok, and Vienna. The Montreal Protocol, signed in September, 1987, went into effect in 1989. It created mechanisms to regularly review parties' adherence to the protocol, taking into

Preamble to the Montreal Protocol

The Parties to this Protocol,

Being Parties to the Vienna Convention for the Protection of the Ozone Layer,

Mindful of their obligation under that Convention to take appropriate measures to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer,

Recognizing that world-wide emissions of certain substances can significantly deplete and otherwise modify the ozone layer in a manner that is likely to result in adverse effects on human health and the environment,

Conscious of the potential climatic effects of emissions of these substances,

Aware that measures taken to protect the ozone layer from depletion should be based on relevant scientific knowledge, taking into account technical and economic considerations,

Determined to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination on the basis of developments in scientific knowledge, taking into account technical and economic considerations and bearing in mind the developmental needs of developing countries,

Acknowledging that special provision is required to meet the needs of developing countries, including the provision of additional financial resources and access to relevant technologies, bearing in mind that the magnitude of funds necessary is predictable, and the funds can be expected to make a substantial difference in the world's ability to address the scientifically established problem of ozone depletion and its harmful effects,

Noting the precautionary measures for controlling emissions of certain chlorofluorocarbons that have already been taken at national and regional levels,

Considering the importance of promoting international co-operation in the research, development and transfer of alternative technologies relating to the control and reduction of emissions of substances that deplete the ozone layer, bearing in mind in particular the needs of developing countries,

HAVE AGREED [to adopt this protocol.]

consideration the changes that scientific, environmental, technical, and financial factors might dictate in the future.

In 1990, at a meeting in London, the parties to the protocol voted to eliminate controlled substances that endanger the world's atmosphere gradually. At a meeting of the group in Copenhagen in 1992, the schedule for phasing out ozone-depleting elements was accelerated. Specified substances included CFCs, halons, carbon tetracholoride, methyl chloroform, HCFCs, hydrobromofluorocarbons (HBFCs), and methyl bromide.

Parties to the Montreal Protocol organized panels to discuss scientific issues relating to the depletion of the ozone layer, to consider the effects this depletion had on the environment worldwide, and to deal with technical and economic problems that provisions of the Montreal Protocol created. Some of these meetings resulted in amendments to the original protocol aimed at strengthening earlier provisions. As information about new substances dangerous to the ozone layer—such as CFCs, methyl chloroform, and carbon tetrachloride—came to be known, such substances were added to the list of those already banned or controlled.

• Significance for Climate Change

Because of the danger of ultraviolet rays emitted by the Sun, Earth's earliest inhabitants lived under water. Over billions of years, the oxygen released by aquatic plants rose and over eons created the ozone layer. With such a layer to protect Earth from ultraviolet rays, life eventually was able to emerge from the oceans and, over considerable time, to establish itself on Earth. Ozone absorbs all ultraviolet rays with wavelengths less than 290 nanometers and some with wavelengths between 290 and 320 nanometers, but it absorbs almost none with wavelengths above 320 nanometers. It is the latter rays, known as UV-C rays, that are deadly.

Ozone is made continuously in nature, originating mostly above the tropics and then carried by winds toward the Arctic and Antarctic, where ozone concentrations are greatest. Thus, once the phenomenon of the depletion of the ozone layer was recognized, scientists sought to explain this depletion. They determined that such substances as bromine, chlorine, the hydroxyl radical, and nitric acid threaten the ozone layer. It thus became clear that industrial pollutants were the culprits and that the depletion of the ozone layer could cause ultraviolet irradiation of Earth's surface, endangering human and nonhuman life. The actions demanded by the Montreal Protocol offer humankind's most effective hope of averting this irradiation and preserving Earth's ozone layer.

R. Baird Shuman

• Further Reading

Calhoun, Yael, ed. *Climate Change*. New York: Chelsea House, 2005. Section B of this study, "Greenhouse Gases and the Ozone Layer," addresses the depletion of the ozone layer and details attempts being made to reverse this depletion. The introduction to this volume discusses the Montreal Protocol.

DiMento, F. C., and Pamela Doughman, eds. *Climate Change: What It Means for Us, Our Children, and Our Grandchildren*. Cambridge, Mass.: MIT Press, 2007. Chapter 5, "Climate Change: How the World Is Responding," written by the editors, is particularly relevant. Richard A. Matthew's contribution, "Climate Change and Human Security," focuses productively on dealing with the problem.

Grundmann, Reiner. *Transnational Environmental Policy: Reconstructing Ozone*. New York: Routledge, 2001. Chapters 5 and 6, "The Road to Montreal" and "The Montreal Protocol and After," are valuable for their clear overviews of the Montreal Protocol.

Hillman, Mayer, with Tina Fawcett and Sudhir Chella Rajan. *The Suicidal Planet: How to Prevent Global Climate Catastrophe*. New York: St. Martin's Press, 2007. Chapter 7, "The Blueprint for Survival," deals directly with means of replenishing the ozone layer.

Labitzke, Karin G., and Harry van Loon. *The Stratosphere: Phenomena, History, and Relevance*. Berlin: Springer, 1999. The material presented in chapter 5, "The Ozone Layer," is valuable for its discussion of measures directed at reducing the emissions of chlorine atoms that attach themselves to ozone atoms and destroy them.

Parson, Edward A. *Protecting the Ozone Layer: Science and Strategy*. New York: Oxford University Press,

2003. A thorough account of the Montreal Protocol. Especially valuable for its discussion of the protocol's provisions for developing countries.

See also: Aerosols; International agreements and cooperation; Kyoto Protocol; Ozone; Ultraviolet radiation; United Nations Framework Convention on Climate Change.

Motor vehicles

• **Categories:** Economics, industries, and products; energy

Passenger vehicles in the United States by 2007 accounted for 40 percent of the country's oil consumption and 10 percent of the world's consumption. Cars and trucks used in the United States burned 15 percent of the world's annual oil production.

• Key concepts

congestion charge: a tax levied for driving in the urban core of a large city

Golden Quadrilateral: India's first superhighway system, linking the country's east and west coasts with Delhi

miles per gallon (MPGs): a fuel efficiency standard for motor vehicles, measuring the average distance traveled on one gallon of fuel

Target Neutral: a carbon-offset plan for drivers in Great Britain

• Background

Motor vehicles consume one-third of the world's oil production. The number of automobiles has been increasing more quickly than population, especially in countries that have just begun to experience widespread industrial development, such as India and China. The tailpipes of motorized vehicles also emit 47 percent of North America's nitrous oxide, a primary component of ozone in the lower atmosphere that also retains heat as a greenhouse gas (GHG).

• U.S. Cities

Cities in the United States and elsewhere have been remade to accommodate automobiles. The U.S. cities that reached maturity after the 1930's—the last decade in which the average person did not own a car—have become energy-intensive, sprawling regions of suburbs and freeways, in which most residents are required to use automobiles for transportation. Outside of a few major eastern cities (New York and Boston being prominent examples), the automobile has become an everyday necessity for nearly everyone in the United States. After the year 2000, urban planners began to deemphasize the automobile in order to reduce GHG emissions. Even General Motors (GM) during 2007 entered a partnership to develop residences in once-abandoned buildings along the Detroit waterfront. One of the selling points for these lofts was the fact that people who live in them will be able to walk to work at GM's headquarters.

In New York City, Mayor Michael Bloomberg proposed a congestion charge for the crowded southern half of Manhattan Island, roughly from 86th Street southward. Under Bloomberg's plan, on weekdays between 6:00 A.M. to 6:00 P.M., trucks would be charged $21 per day and cars would be charged $8 per day to drive in the city. This tax would be in addition to the premium parking fees charged by city-owned and private lots. In 2008, only 5 percent of the people who worked on Manhattan Island and lived outside the island commuted by car. According to Bloomberg's proposal, drivers traveling only within the congestion zone would pay half price; taxis and livery cabs would be exempt, with uncontrolled, free access to the area.

Studies have shown that vehicle speeds on southern Manhattan Island average from 4 to 6 kilometers per hour. Many times, walking is almost as fast as driving. Subways are generally much faster means of transportation in the city. The value of the time lost to congestion delays in New York City has been estimated at $5 billion per year. When the cost is adjusted to include wasted fuel, lost revenue, and increasing costs of doing business, the total rises to $13 billion per year. Bloomberg's plan was defeated by the New York State Assembly in July of 2007.

- **Existing Congestion Charges**

Singapore was the first city to introduce a congestion charge. London introduced such a charge in 2003, followed by Milan, Italy. In London, vehicle speeds have since risen by 37 percent and carbon dioxide (CO_2) emissions have fallen by 15 percent. London's mayor, Ken Livingstone, a major proponent of the charge, was easily reelected in 2004, and in 2006 two-thirds of London residents supported the charge. During January, 2007, London's congestion zone was expanded westward to include most of Kensington, Chelsea, and Westminster. By early 2007, London's congestion charge had reduced private automobile use 38 percent and CO_2 emissions 20 percent in the congestion charge zone.

London also improved its public transport system to offer its residents easier alternatives; many commuters had complained that the buses were slow and expensive. By the time the London bus fleet was upgraded, more than six million people used it daily. The number of people commuting by bicycle in London soared by 80 percent after the congestion charge was implemented.

In the meantime, BP proposed that every motorist in Great Britain sign up for a plan called Target Neutral. Drivers can fund ventures that offset the amount of CO_2 that their driving adds to the atmosphere. Drivers register at a Target Neutral Web site, which calculates the estimated amount of CO_2 that may be produced by their driving over the coming year. Drivers then pay offsets based on the estimate. The typical family car, traveling 16,100 kilometers per year, is likely to cost about £20 ($39) to offset.

- **Stockholm**

Congestion charging in downtown Stockholm was a controversial issue in the Swedish general election during the late summer of 2006. A congestion charge of up to $7 per day was narrowly approved

Traffic grinds to a halt in New York City in May of 2007. Mayor Michael Bloomberg has proposed a congestion charge to help relieve traffic problems in Manhattan. (Xinhua/Landov) by 52 percent in a referendum September 17, 2006. The Stockholm congestion charge reduced auto traffic by 20 to 25 percent, while the use of trains, buses, and Stockholm's subway system increased. Emissions of CO_2 declined 10 to 14 percent in the inner city and 2 to 3 percent in Stockholm County. The project also increased the use of environmentally friendly cars (such as hybrids), which are exempt from congestion taxes. As in London, commuting by bicycle also increased. Following a trial period, the Stockholm congestion tax became permanent during August of 2007.

• **Context**

While some cities restrict automobile use, developing countries' fleets are increasing quickly. In China, by 2008, there were 20 personal vehicles per 1,000 people of driving age; in India, there were 18 per 1,000. In the United States, the same figure stood at 1,148 per 1,000. Between 2000 and 2006, sales of heavy trucks in China increased 800 percent. Sales of passenger cars increased 600 percent. Sales of new passenger vehicles in India tripled (from 500,000 per year to 1.5 million) between 1998 and 2008, a period during which the country built its first interstate highway system, the Golden Quadrilateral, which links Mumbai (Bombay), Delhi, Kolkata (Calcutta), and Bangalore.

If people in India and China drove at half the rate of those in the United States, world oil consumption, 86 million barrels per day in 2006, would balloon to more than 200 million. If drivers in India and China used cars as Americans do, world oil consumption would more than triple, with attendant impacts on its price, as well as GHG emissions.

Bruce E. Johansen

• **Further Reading**

Brown, Lester R. *Plan B 3.0: Mobilizing to Save Civilization.* 3d ed. New York: W. W. Norton, 2008. Provides a detailed analysis of motor vehicles' role in global warming.

Cline, William R. *The Economics of Global Warming.* Washington, D.C.: Institute for International Economics, 1992. An early attempt to sketch the costs and benefits of global warming, including the role of motorized transportation.

Steinman, David. *Safe Trip to Eden: Ten Steps to Save Planet Earth from Global Warming Meltdown.* New York: Thunder's Mouth Press, 2007. A solutions-oriented work that includes alternatives to motor vehicles.

See also: Automobile technology; Carbon dioxide; Carbon footprint; Catalytic converters; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Hubbert's peak; Transportation.

Mount Pinatubo

• **Category:** Geology and geography

• **Definition**

Mount Pinatubo is an explosive volcano located near the tropics at latitude 15.1° north and longitude 120.4° east, in the Philippine Islands in the western Pacific Ocean. The volcano erupted on June 15, 1991, producing the second largest eruption of volcanic material in the twentieth century. About 10 billion metric tons of magma (molten rock plus suspended crystals) were brought to the surface, along with abundant volcanic gases, including about 20 million metric tons of sulfur dioxide. This was the largest amount of sulfur dioxide injected into the atmosphere since the eruption of the Krakatoa (Krakatau) volcano near Java in 1883.

Part of the hot gas, volcanic ash, and larger rock fragments spewed by the eruption tore down the valleys of Mount Pinatubo as pyroclastic flows. Great quantities of volcanic ash and gases rose soon after the eruption to heights of over 34 kilometers into the atmosphere. Much of the island of Luzon was completely dark during the day, as the dense ash cloud covered around 125,000 square kilometers around the volcano. Volcanic ash covered everything, and many people died when their roofs collapsed under the weight of the ash. Much of the ash became saturated with water from a nearby typhoon that produced large volcanic mudflows. Many previously abundant organisms such as foraminifera were greatly depleted in the nearby oceans after the eruption.

Mount Pinatubo, as it spews volcanic ash and steam during its 1991 eruption. (USGS/USAF/R. Batalon)

• Significance for Climate Change

The eruption of Mount Pinatubo gives some evidence as to how a big volcanic eruption at equatorial latitudes can change the climate. Larger volcanic eruptions that occurred through geologic time should have had an even more drastic effect on climate than did the eruption of Mount Pinatubo. Based on this eruption, volcanic ash quickly settles to the ground, so its effect on climate is short-lived. Only large eruptions such as that of Mount Pinatubo can eject volcanic gases (mostly water vapor, carbon dioxide, and sulfur dioxide) into the stratosphere to affect climate for more than a few days. The sulfur dioxide gas ejected from Mount Pinatubo circled the globe in twenty-two days. Sulfur dioxide gas ejected from erupting volcanoes at higher latitudes generally takes less time to circle the Earth.

Sulfur dioxide injected into the atmosphere by the eruption was rapidly oxidized to sulfuric acid and mixed with water vapor. This reduced the amount of heat absorbed by the atmosphere from the Sun by about 10 percent. Much of the sulfuric acid stayed in the atmosphere for over a year. This appears to have reduced the average temperature close to the Earth's surface by about 0.5° Celsius.

This cooling reversed the trend of global warming for several years after the eruption of Mount Pinatubo. For example, the ice sheet in Greenland did not melt as much as usual during this time. This cooling was not uniform, however, as parts of North America, Siberia, and Europe experienced higher-than-normal temperatures during this time. The warming trend in those regions was due to circulation changes in the atmosphere that are not completely understood, although several climate models to explain these changes were successful.

The generally cooling temperature of the lower atmosphere reduced the temperature of the ocean at the surface by about 0.4° Celsius for several years after the eruption, especially at midlatitudes. This cooling slightly reduced the evaporation rate of the ocean, so there was on the average less precipitation on the land's surface. The slow rise in sea level that occurred before the eruption was somewhat reduced as well, presumably because there was less evaporation from the oceans and less melting of the glaciers.

Various species of chlorine (such as Cl, ClO, HCl, HOCl, and $ClONO_2$), bromine, and iodine catalyze the removal of ozone in the stratosphere. The eruption of Mount Pinatubo liberated a large amount of chlorine species. Thus, the amount of ozone in the atmosphere dropped significantly after the eruption. For instance, ozone in the atmosphere of the tropics was reduced by about 15 percent after the eruption. The ozone hole in the Antarctic became much larger after the eruption.

Robert L. Cullers

• Further Reading

Church, John A., Neil J. White, and Julie M. Arblaster. "Significant Decadal-Scale Impact of Volcanic Eruptions on Sea Level and Ocean Heat Content." *Nature* 438 (November 3, 2005): 74-77. Estimates the drop in ocean heat content due to aerosols being injected into the atmosphere after the Mount Pinatubo eruption.

Grainger, R. G., and E. J. Highwood. "Changes in Stratospheric Composition, Chemistry, Radiation, and Climate Caused by Volcanic Eruptions." In *Volcanic Degassing*, edited by C. Oppenheimer, D. M. Pyle, and J. Barclay. Geological Society Special Publication 213. Bath, Somerset, England: Geological Society, 2003. Provides an overview of the effects of volcanic ejecta and gases upon the composition of the atmosphere and the climate. Some of the discussion is moderately technical.

Kump, Lee R., James F. Kasting, and Robert G. Crane. *The Earth System.* Upper Saddle River, N.J.: Prentice Hall, 2003. Describes global environmental changes. Includes global warming, atmospheric shifts, and the relation of volcanic activity to climate. Appendixes, tables, figures, glossary.

Robock, Alan. "The Climatic Aftermath." *Science* 295 (February 15, 2002): 1242-1244. Describes the climate variations over the Earth for several years after the Mount Pinatubo eruptions and some of the reasons why this occurred.

See also: Chlorofluorocarbons and related compounds; Global dimming; Ozone; Sulfur cycle; Volcanoes.

National Center for Policy Analysis

- **Category:** Organizations and agencies
- **Date:** Established 1983
- **Web address:** http://www.ncpa.org

- **Mission**

An American nonprofit conservative think tank, the National Center for Policy Analysis (NCPA) promotes an environmental regulation program that seeks to solve problems by relying on a competitive private sector rather than on government control and regulation. The NCPA maintains offices in Dallas, Texas, and Washington, D.C. Well over half of its funding comes from foundations, with the rest from corporations and individuals. Acting as an organizer for other conservative groups, the NCPA also conducts its own free-market-oriented analysis of various issues.

- **Significance for Climate Change**

The NCPA's E-Team focuses on environmental policy. The individuals who form the E-Team are climate-change skeptics who opposed the Kyoto Protocol and also oppose any greenhouse gas (GHG) regulation. NCPA scholars hold that the causes and consequences of the current global warming are unknown. Since it would be very expensive to reduce carbon dioxide (CO_2) emissions substantially, they believe doing so would result in economic decline and increased environmental destruction with little or nothing accomplished to prevent global warming, whatever its cause.

A typical project of the group was an analysis of the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Citing the purpose of the IPCC as being to provide a

> comprehensive, objective, scientific, technical and socio-economic assessment of the current understanding of human-induced climate change, its potential impacts and options for adaptation and mitigation,

the NCPA concludes that, despite dire predictions of world temperature changes that could result in a global sea level rise, tropical disease spread, accelerated rate of loss of glaciers and ice caps, and increased severity of drought and flooding, forecasts in Chapter 8 of the report violate basic forecasting principles and are therefore invalid.

Because the NCPA is principally concerned with opposing government regulation in favor of promoting private alternatives, the group has concluded, for example, that global warming regulation is a key portfolio risk for state and local pension funds and has recommended that pension fund administrators not promote global warming legislation unless they can demonstrate how such regulation will benefit their portfolios.

The 2007 NCPA publication *A Global Warming Primer* maintains that predictions by some scientists that global warming will cause such things as droughts, floods, and hurricanes of greater intensity are not valid. Given its stance, the group recommends "focused adaptation," taking steps to adapt to warmer conditions, rather than implementing measures that it feels would have more negative economic impact than is justified given the facts that the group accepts as valid regarding global warming.

Victoria Price

See also: Cato Institute; Conservatism; Cooler Heads Coalition; Heartland Institute; Intergovernmental Panel on Climate Change; Nongovernmental International Panel on Climate Change; Skeptics.

National Climate Program Act

- **Category:** Laws, treaties, and protocols
- **Date:** Signed into law September 17, 1978

The National Climate Program Act created an interagency program that conducts climate research, provides climate information, and supports policy decisions in the United States.

• Background

Following a period of reduced global average temperatures in the early 1970's, and growing out of years of effort by groups of climatologists, several bills were introduced in the U.S. Congress to coordinate climate research, prediction, and planning. One such bill, the National Climate Program Bill of 1975, failed to pass. Two years later, U.S. representative George Brown of California introduced the National Climate Program Bill of 1977, but it also failed, largely because of disagreements between the American Association of State Climatologists and the National Oceanic and Atmospheric Administration (NOAA) over funding priorities. Finally, in 1978, Congress passed the National Climate Program Act, and it was signed by President Jimmy Carter on September 17, 1978.

• Summary of Provisions

The National Climate Program Act (Public Law 367 of the Ninety-Fifth Congress), called for the establishment of the National Climate Program (NCP), as well as the Climate Program Advisory Committee and the Climate Program Policy Board. These entities are to issue periodic reports and plans to "assist the Nation and the world to understand and respond to natural and human-induced climate processes and their implications." The act required the secretary of commerce to establish a National Climate Program Office that would coordinate efforts and develop a series of research and climate services, drawing together the strengths of NOAA and other governmental agencies. These responsibilities were delegated to NOAA. The Department of the Interior and its U.S. Geological Survey are among the other agencies assigned specific roles under the NCP.

• Significance for Climate Change

The NOAA Climate Program conducts research and monitoring related to climate, climate change, and climate impact. It gathers and manages data from surface, marine, upper-air, and satellite observations; issues monthly and seasonal predictions of temperature, precipitation, and other weather indicators; predicts the impact of climate fluctuations on water resources, including fisheries, crop irrigation, and energy demands; and conducts new research. Five divisions of NOAA contribute to these efforts: the National Environmental Satellite, Data, and Information Service; the National Marine Fisheries Service; the National Ocean Service; the National Weather Service; and the Office of Oceanic and Atmospheric Research.

Several climate projects under NOAA have yielded important results. Under the direction of the NOAA administration, the United States is part of the Group on Earth Observations, an international organization developing the Global Earth Observation System of Systems (GEOSS), which will collect and manage data around the world. NCP awards grants and fellowships for outside research on the Arctic, on atmospheric composition and climate, on the global climate cycle, and other topics. It also operates the Regional Integrated Sciences and Assessments program, a partnership with American universities to connect with local and regional researchers and policy makers. The Climate Program Office operates separate divisions for climate observations, research, climate assessments and services, planning, and communications and education.

Although the 1978 act established the National Climate Program Office, the office received only a few million dollars of funding, so for its first five years the program accomplished little. No climate-related bills were introduced in the year after passage of the act, and in 1980 most of the funding for climate research was canceled as a result of a budget crisis. By 1984, pilot programs and new structures, including a strongly linked network of regional monitoring centers, enabled the NCP to produce and disseminate useful climate data. These data were essential in the growing national and international understanding of the causes and the effects of global warming.

As policy makers became more interested in global warming, they were unable to make use of much of the pure science that NCP was conducting, and they pressed for more information in forms that would help them draft policy. In response, in 1990 Congress created the United States Global Change Research Program to increase understanding of and response to global warming through research presented by NCP. Several amendments to the National Climate Program Act have been proposed since the 1980's to provide more funding, to solidify the various roles of the various agencies involved, or to require specific actions based on the data. In 2007, the Climate Change Adaptation Bill was introduced in Congress to amend the National Climate Program Act. It would require the president to draw up a strategic plan to address the impacts of global warming in the United States, and to establish a national climate service within NOAA. The bill was reported out of comittee in June, 2008, but no further action was taken by the 110th Congress.

Cynthia A. Bily

• Further Reading

Dessler, Andrew Emory, and Edward Parson. *The Science and Politics of Global Climate Change: A Guide to the Debate*. New York: Cambridge University Press, 2006. An introductory overview explaining the science and the politics of global warming.

Gerrard, Michael. *Global Climate Change and U.S. Law*. Washington, D.C.: American Bar Association, 2007. An examination of existing U.S. law related to global warming, including a historical overview of governmental involvement in the scientific research.

Harris, Paul G. *Climate Change and American Foreign Policy*. New York: Macmillan, 2000. Analyzes U.S. climate change policy, including important federal agencies and legislation, from the Jimmy Carter administration to Kyoto.

Mooney, Chris. *Storm World: Hurricanes, Politics, and the Battle Over Global Warming*. Orlando, Fla.: Harcourt Trade, 2008. Examines scientific disagreements over the ties between hurricanes and global warming; illuminates differing views within NOAA.

See also: Clean Air Acts, U.S.; Energy Policy Act of 1992; U.S. energy policy; U.S. legislation.

National Research Council

- **Category:** Organizations and agencies
- **Date:** Established 1991
- **Web address:** http://www.gefweb.org

• Mission

The National Research Council (NRC) is the operating arm of the United States National Academies of Science. It was established in 1916 and made permanent by President Woodrow Wilson in 1918. The National Academies of Science include the National Academy of Sciences (NAS), the National Academy of Engineering (NAE), and the Institute of Medicine (IOM). These are private, nonprofit organizations chartered to provide policy advice to the federal government on science, technology, and medicine. They provide this policy guidance through the six divisions of the NRC. For global warming questions, most of these activities are carried out through the Division of Earth and Life Studies.

The NRC initiates studies at the request of the White House, a department of the federal government, or the Congress by calling together a committee of experts from the academies and from the nation. The committee studies the issue and publishes a public report on its findings, including policy recommendations. The NRC publishes more than two hundred reports and other documents each year.

• Significance for Climate Change

The NRC has been studying climate change since 1992. In 2002, it was charged with providing strategic advice to the U.S. Climate Change Science Program (CCSP), which coordinates the climate change activities of thirteen federal agencies. In addition to the annual advisory reports for CCSP, twenty-five other reports regarding global warming have been issued. The highlights of these reports have been compiled and published as *Understanding and Responding to Climate Change, 2008 Edition.*

The report indicates that available scientific data clearly show that the Earth is warming, and most of this temperature increase is likely due to human causes. Temperatures reconstructed by several different methods indicate that the planet's surface temperatures since the middle of the twentieth century have been higher than in any comparable period since about 1500 and have increased at the same rate as has the emission of greenhouse gases (GHGs). The report states, "Climate change will affect ecosystems and human systems—such as agriculture, transportation, and health infrastructure—in ways we are only beginning to understand." It concludes, "The increasing need for energy is the single greatest challenge to slowing climate change." As a result, the main action that should be taken is to reduce the amount of carbon dioxide and other GHGs that are released into the atmosphere: The world must work together to make use of alternative energy sources and prepare its populations for the effects of higher temperatures during the next decades.

Raymond D. Cooper

See also: Clean Air Acts, U.S.; Climate Change Science Program, U.S.; Energy Policy Act of 1992; United States; U.S. energy policy; U.S. legislation.

Natural Resources Stewardship Project

- **Category:** Organizations and agencies
- **Date:** Established October 12, 2006
- **Web address:** http://www.nrsp.com

• Mission

As a skeptic organization, the Natural Resources Stewardship Project (NRSP) casts doubt on groups that view global warming as an issue that demands immediate attention, calling this stance a "hypothesis" and arguing that "current climate change is within natural variations." The NRSP is a Canadian, federally incorporated, nonprofit, nonpartisan organization that claims to promote responsible environmental stewardship through media and public relations; consumer education; promotion of private property rights; market-based approaches; and efficient and sensible regulatory and legislative frameworks, particularly at the federal level.

• Significance for Climate Change

The NRSP was established when there was a perception that caring for the natural environment had changed from being about individual responsibility to being about nonaccountable actions of transnational and nongovernmental organizations (NGOs), with negative economic consequences. This perceived change resulted in lessening citizens' initiatives and undermining private property rights. Members felt that many governmental and NGO initiatives followed an agenda not based on science or on rational economics. Overall, they felt that the situation was damaging the economy more than it was helping the environment.

The NRSP defines "responsible environmental stewardship" as prudent use of all resources, minimizing unnecessary pollution, transforming waste into resources, and improving material conditions; formulating practical environmental policies based on logic, scientific objectivity, and an understanding of risk; individual rather than governmental action as the preferred means to achieve goals; an understanding that private property encourages private responsibility; a recognition that regulation of resources is best at the most local level possible; and an understanding that more economic freedom allows more responsible individual action.

A top-priority initiative of the NRSP entitled "Understand Climate Change" used proactive grassroots groups to campaign against the Kyoto Protocol and other greenhouse gas emission reduction schemes and to promote sensible climate change policy. Another project, "The Science Centre," will establish a credible independent auditing mechanism to review scientific studies before they are used as a basis for widespread environmental decisions.

The NRSP addresses climate issues differently from less skeptical groups. They applaud the Canadian government's moving toward reducing greenhouse intensities over the short term rather than in terms of absolute emission caps. Believing that carbon dioxide is "almost certainly not a significant driver of global climate change," they will devote time and effort to studying natural factors, such as changes in the Sun's output. Funds will be used to find ways to adapt to the natural phenomenon of climate change rather to reduce carbon dioxide, and the group will oppose establishing further emission standards except at the most local level possible.

Victoria Price

See also: Canada; Skeptics.

Netherlands

- **Category:** Nations and peoples
- **Key facts**

Population: 16,715,999 (July, 2009, estimate)
Area: 41,526 square kilometers
Gross domestic product (GDP): $670.2 billion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 213 in 1990; 174 in 1999; 217 in 2004
Kyoto Protocol status: Ratified 2002

• Historical and Political Context

By the seventeenth century, the Netherlands was playing a major role in the world's economy. The creation of the Dutch East India Company established the country as one of the major seafaring and trading powers. The mercantile class became extremely influential in all aspects of the country's life. The Netherlands' major trade rival was England and the competition between the countries led to the Dutch Wars, which were resolved in 1667 by the Treaty of Breda. England recognized the Netherlands' right to the Dutch East Indies. During this period, the Netherlands' capital city of Amsterdam became the site of the first stock exchange and was recognized as the wealthiest trading city at the time. In 1652, the Netherlands had become a republic under Jan de Witt. In 1672, the French invaded the country and killed de Witt. This marked the beginning of a decline in the economic prosperity of the country, which lasted throughout the eighteenth century. From 1795 to 1815, the Netherlands was under French control as part of Napoleon's Empire.

The Industrial Revolution of the nineteenth century did not bring about rapid changes in the Netherlands, because the country relied heavily on waterways for transportation and on wind power for energy. Up to the time of World War II, the Netherlands maintained a neutrality and independence from its neighboring countries that adversely affected its economic prosperity. After the war, the country made a dramatic change in policy and began interacting with its neighbors; this new policy brought about renewed economic prosperity. The Netherlands became an important founding member of major international organizations including the Benelux, the North Atlantic Treaty Organization (NATO), and the European Coal and Steel Community. As one of the fifteen founding members of the European Union, the Netherlands plays an important role in Europe's economy and welfare.

• Impact of Dutch Policies on Climate Change

Sea level, rising tides, and the potential of flooding have always been of major concern to the Netherlands since approximately 27 percent of its land lies below sea level. Throughout its history, the country has intervened to protect its land and inhabitants from encroachment by the sea and from flooding caused by overflowing rivers and rising sea levels. The industrialization of the Netherlands has adversely affected the country's situation. With the exception of the natural gas fields near Sloctern, the country has few natural resources and the economy depends on manufacturing and processing for a considerable amount of its wealth. Petroleum refining, food processing, and chemical processing, along with the manufacture of electrical machinery, all increase greenhouse gas (GHG) emissions. This adds to global warming, which may raise sea levels and increase erratic weather patterns that may contribute to the overflow of rivers and flooding. This situation is worsened by the Netherlands' use of intensive agriculture and horticulture, which produce more GHGs.

The coastline of the Netherlands has undergone considerable changes over the centuries. In 1134, a severe storm created the archipelago of Zeeland. In 1421, the Saint Elizabeth flood caused serious damage to the Netherlands. To combat these problems, the Dutch built polders and dikes to control the water levels and prevent disasters. There are three different kinds of polders, which are tracts of lowlands enclosed by dikes. The first is land reclaimed from a lake or the sea, the second is an area prone to flooding that is protected from the sea by dikes, and the third is a drained marsh separated from the surrounding water by dikes. Windmills are used to pump the excess water. Water bodies or home councils, which are groups independent of any government control, supervise the maintenance of the flood prevention systems.

In 1953, the Netherlands experienced one of its worst floods. The country put into effect the Delta Works, which raised 3,000 kilometers of outer sea dikes and 10,000 kilometers of canal and river dikes to a flood-prevention level and closed off the Zeeland sea estuaries.

• Netherlands as a GHG Emitter

As a member of the European Union, the Netherlands ratified the Kyoto Protocol in 2002. According to the data gathered by the European Environment Agency, the Netherlands emitted 213 million metric tons of GHGs in the base year of 1990. In 2006, the Netherlands had reduced its emissions to 207.5 million metric tons, ranking seventh among the EU27 and sixth among the EU15 as an emitter of GHGs. The burden-sharing target of the Netherlands under the Kyoto Protocol is –6 percent, to an annual average of 200.3 million metric tons of emissions between 2008 and 2012. From 2002 to 2006, the Netherlands produced an average of 213.6 million metric tons of GHG emissions, representing an increase of 0.3 percent. The country's 2006 emissions, at 207.5 million metric tons, were 3 percent below its base year emissions but were still above its treaty target. The Netherlands has projected an increase in its emissions to a level just 2 percent below the 1990 levels, as present policies continue in energy supply and use, as well as in transport and agriculture.

• Summary and Foresight

The Netherlands believes that it will exceed its target of 6 percent below 1990 levels by 2012. By implementing carbon sink activities and using Kyoto mechanisms, specifically that of providing funds for projects reducing GHG emissions in other countries under the clean development mechanism, the Netherlands projects a level of GHG emissions 8 percent below those of 1990.

In view of the prospects of continued global warming, the Netherlands is embarking upon a major flood-control project. Projected to continue to the year 2100, the project is estimated to cost about one billion Euros per year. At the core of the project is the planned raising of dikes and reinforcing of storm barriers. Many different approaches are being considered, from amelioration of the protection from the sea at major ports, especially Rotterdam, to extending the coastline of the North Sea as much as 1 kilometer by dumping millions of metric tons of sand into the ocean. The Netherlands is also working to use technology to protect the country from floods. A system of sensors to determine the stability of the dikes is being developed to replace the human volunteers who carry out the inspection. The Netherlands is also working with International Business Machines (IBM) to create software that can analyze weather, provide early warning of flood threats, and help coordinate plans for evacuation. The law approving funding for the massive and costly project and maintaining its funding over the century-long period has yet to be passed, but the Netherlands is convinced that the sea level will rise and significant preventive measures must be in place before 2100.

Shawncey Webb

• Further Reading

Abboud, Leila. "Before the Deluge." *The Wall Street Journal*, March 9, 2009, p. R10. Good account of

the Netherlands' plans for future flood control.

Clapp, Jennifer, and Peter Dauvergne. *Paths to a Green World: The Political Economy of the Global Environment.* Cambridge, Mass.: MIT Press, 2005. Good discussion of environmental issues and global warming with respect to trade and the world economy.

Delta Project. *The Delta Project: Preserving the Environment and Securing Zeeland Against Flooding.* Goes, Netherlands: Florad Marketing Group, 2002. Provides details of Netherlands' flood protection projects.

Hoeksema, Robert J. *Designed for Dry Feet: Flood Protection and Land Reclamation in the Netherlands.* Reston, Va.: American Society of Civil Engineers, 2006. Excellent study of flood threats and water control covering the reclamation of the Zuiderzee and the coasts, sea defenses, and the Delta Project.

Shogren, Jason F. *The Benefits and Costs of the Kyoto Protocol.* Washington, D.C.: AEI Press, 1999. Excellent overview of the environmental and economic effects of the Kyoto Protocol.

See also: Europe and the European Union; Floods and flooding; Kyoto Protocol; Levees; Sea-level change; United Nations Framework Convention on Climate Change.

New Orleans

• **Category:** Nations and peoples

After Hurricane Katrina devastated New Orleans in 2005, the city's experience became a pivotal point for increasing interest in understanding and mitigating the contribution of global warming to future coastal disasters.

• Key concepts

Atlantic Multidecadal Oscillation: cyclical increases and decreases in sea temperatures that last for decades

Power Dissipation Index: a measure of the total annual energy output of all hurricanes in a region

Saffir-Simpson scale: a scale that ranks hurricanes from category 1 through category 5, based on their sustained wind velocity

storm surge: rising water that is caused when a hurricane's winds push the ocean's surface inland

U.S. Army Corps of Engineers: a government agency whose duties include flood control

• Background

New Orleans, the only major American city below sea level (2.4 to 3 meters below in some places), depends on a system of levees and natural buffers, such as coastal wetlands and barrier islands, for flood protection. When Hurricane Katrina's storm surge breached and topped the city's levees in the summer of 2005, 80 percent of New Orleans was flooded. Post-storm queries have sought to determine how to assess and reduce the probability of future New Orleans disasters by better understanding the conditions that caused Katrina's devastation.

• Rising Sea Levels and Hurricane Strength

Whether New Orleans will suffer future catastrophes that are similar or worse in magnitude than the one caused by Katrina depends on a number of factors, including the current and projected effects of climate change. There is a fairly strong consensus among scientists that sea levels have increased because of global warming and will rise another 0.3 to 1 meter over the next one hundred years. Additionally, some scientists have hypothesized that, since hurricanes' high winds, rain, and tornados are created as they push water vapor up into the atmosphere, more sea surface heat should increase the storms' power.

A study conducted at the Massachusetts Institute of Technology combined hurricanes' duration and wind speed to create the Power Dissipation Index to measure their intensity. The research report, which was published a month before Katrina, concluded that an examination of 1,557 Pacific and 558 Atlantic hurricanes over a thirty-year period showed a doubling of storm power, with a strong correlation between rising water temperatures and increasing hurricane strength. Research conducted at the Georgia Institute of Technology similarly showed that, since the mid-1990's, the number of Category 4 or 5 hurricanes on the Saffir-Simpson scale had doubled. A report issued in 2007 by the United Nations Intergovernmental Panel on Climate Change (IPCC) asserts that climate change has created the potential for more intense hurricanes that could threaten the Gulf Coast for the next one hundred years or more.

These and similar studies' conclusions are not accepted by all scientists. Some meteorologists, including National Oceanic and Atmospheric Administration researchers, take the position that the Atlantic Multidecadal Oscillation (AMO) has created decades-long increases and decreases in sea temperatures, and the AMO is more responsible for the recent upsurge in hurricane strength than is global warming. These critics concede, however, that the AMO will cause decades of more powerful hurricanes.

- **Loss of Natural Protections**

Historically, Southeast Louisiana's coastal wetlands and barrier islands have served as natural buffers that reduced hurricane damage to New Orleans (the U.S. Army Corps of Engineers asserts that 4.3 kilometers of wetlands dissipates 0.3 meter of storm surge). Soil subsidence, meanwhile, was counteracted by continuous silt deposits from the Mississippi River. Both human development and climate change have created the potential for extensive damage from future storms. Flood control and navigation projects stopped the land buildup from the Mississippi River in both the wetlands and the New Orleans area, while the channels created by the oil industry sped up the pace of coastal erosion.

The combined effects of sea level rise, land subsidence, and erosion have resulted in the loss of thousands of square kilometers of Louisiana's coastal land, a 1-meter increase in "relative sea level" for New Orleans over the past one hundred years (one-third due to sea rise and two-thirds due to soil compaction), and concerns that New Orleans may be on the coast in another one hundred years. The destruction of barrier islands has also increased (Ka-

A U.S. Coast Guard rescue boat moves through a flooded section of New Orleans during the aftermath of Hurricane Katrina in September, 2005. (Getty Images) trina destroyed half of the Chandeleur Islands located east of New Orleans). Many experts claim that current and proposed coastal restoration efforts would only minimally reduce annual losses.

• Government Responses and Calls for Action

Whether New Orleans can avoid future disasters of Katrina's magnitude will depend on the effectiveness of measures that have been taken and the implementation of additional proposals for better protecting the city. The federal government began increasing the height and strength of the levees shortly after Katrina, and millions of dollars have been spent on coastal restoration programs. Critics argue that these measures cannot begin to counteract the ongoing effects of global warming. They propose that a comprehensive approach that includes billions of dollars in coastal restoration projects and local, national, and global efforts to significantly reduce greenhouse gas (GHG) emissions will be necessary to ensure New Orleans's future survival. Private organizations have rebuilt neighborhoods in New Orleans using green construction to serve as pilot projects to promote energy-efficient housing everywhere and have joined with scientists and legislators in calling for the federal government to end its resistence to both increasing investment in renewable clean energy and participating in international agreements to reduce carbon dioxide emissions.

• Context

Within the debate over the best ways to secure New Orleans's future, there are those who assert that concerns about that city's fate should be viewed as a wake-up call that draws attention to a much broader threat. They posit that, if the future effects of global warming occur as currently projected, all of America's coastal areas, where half of the nation's population resides, would be in danger from catastrophes caused by coastal erosion, higher sea levels, and strong storms. This could result in cities like New York and Miami being below sea level and dependent on levees for protection, as New Orleans's improved levee system becomes obsolete and ineffective. The IPCC report asserts that, during the next century, coastal communities all over the world will be at risk of disasters like Katrina's destruction of New Orleans. This report also states that, beyond the hundred-year projections, current rates of ocean temperature increases could cause much higher sea levels as huge Antarctic and Greenland ice sheets melt.

Jack Carter

• Further Reading

Mooney, Chris C. *Storm World: Hurricanes, Politics, and the Battle Over Global Warming.* Orlando, Fla.: Harcourt, 2007. A New Orleanian examines the debate regarding the effect of global warming on increased hurricane threats, including the impact of leading authorities, interest groups, politics, and the media. Appendixes, bibliography, and recommended reading.

Sargent, William. *Just Seconds from the Ocean: Coastal Living in the Wake of Katrina.* Hanover, N.H.: University Press of New England, 2007. Uses analyses of historical and recent coastal disasters to posit that shortsighted development has increased the effects of global warming and undermined natural safeguards such as barrier islands and wetlands. Argues for more effective environmental and coastal regulatory policy initiatives.

Tidwell, Mike. *The Ravaging Tide: Strange Weather, Future Katrinas, and the Coming Death of America's Coastal Cities.* New York: Free Press, 2006. The author, who predicted Hurricane Katrina in a 2003 publication, asserts that cities everywhere will experience similar catastrophes absent a concerted, comprehensive effort to address the causes of global warming, which will otherwise continue to raise sea levels and produce stronger hurricanes.

See also: Atlantic multidecadal oscillation; Coastal impacts of global climate change; Louisiana coast; Tropical storms.

Nitrogen cycle

• **Categories:** Chemistry and geochemistry; environmentalism, conservation, and ecosystems

• **Definition**

The nitrogen cycle is a natural process by which nitrogen in the air moves into the soil, is utilized by living organisms, and returns to the air. Organisms need nitrogen to make macromolecules, including amino acids and nucleic acids. Air is 79 percent nitrogen gas (N_2). N_2 has a triple bond, making it relatively inert and unable to be used by most organisms. Nitrogen fixation, converting N_2 to NH_4+ (an ammonium ion), is carried out by *Rhizobium* bacteria, which live in root nodules of host plants of the legume family such as peas, beans, and clover. Bacteria get carbohydrates from the plant, and the plant uses some of the ammonium the bacteria fix.

Free-living cyanobacteria also fix nitrogen. Lightning fixes smaller amounts of nitrogen. Plants absorb nitrate or ammonium ions from the soil through root hairs. Ammonium is converted into organic nitrogen compounds by bacteria and by plants. Other organisms get organic nitrogen from what they eat. Organic nitrogen is converted to ammonia as microorganisms decompose dead matter. Soil bacteria, *Nitrosomona*, perform nitrification where NH_4 is converted to NO_2^- (nitrite). NO_2^- is converted to NO_3^- (nitrate) by *Nitrobacter*. Completing the nitrogen cycle, nitrites are converted to N_2 and N_2O (nitrous oxide) in anaerobic conditions by bacteria *Pseudomonas* and *Clostridium*.

• **Significance for Climate Change**

Humans have more than doubled the annual transfer of nitrogen gas into biologically available forms of nitrogen. This has occurred through burning of fossil fuels, manufacture of synthetic nitrogen fertilizers, and widespread cultivation of legumes (soy, alfalfa, and clover). Burning fossil fuels causes formation of oxides of carbon (carbon monoxide, carbon dioxide). The burning of such fuels occurs at elevated temperatures that cause nitrogen and oxygen molecules in air to react to form oxides of nitrogen (NO, N_2O, and NO_2). NO_2 forms smog and mixed with water forms nitric acid (HNO_3), contributing to acid rain.

The Haber-Bosch process fixes N_2 using hydrogen, high temperature, and pressure to form ammonia. Synthetic nitrogen fertilizers (ammonia, ammonium nitrate, and urea), applied directly to the soil, have led to a huge increase in agricultural productivity. The applied fertilizer not utilized by plants leaches out of soil and accumulates in water. N_2O and CO_2 are greenhouse gases (GHGs) that contribute to global warming by absorbing energy from the Earth's surface, stopping the loss of this energy, and raising the Earth's temperature. NO_2 is not as abundant as CO_2, yet it is an important, stable GHG that absorbs infrared energy about 270 times more strongly than does CO_2. Nitrogen cycle influence on global warming is complex, as an increase in biologically active nitrogen stimulates plant growth, which increases uptake of CO_2.

Susan J. Karcher

See also: Carbon cycle; Hydrologic cycle; Nitrogen fertilization; Nitrous oxide; Phosphorus cycle; Sulfur cycle.

Nitrogen fertilization

• **Categories:** Plants and vegetation; economics, industries, and products; chemistry and geochemistry

• **Definition**

Nitrogen fertilization is a phenomenon in which plant growth is unusually stimulated by the addition of reactive nitrogen compounds, such as ammonia and nitrate. Nitrogen compounds are usually applied as fertilizers to soil for uptake by plant roots. They are also often applied through air deposition from the atmosphere to foliage for uptake through leaves and to surface soil for plant-root uptake. Nitrogen fertilizers are usually manufactured through chemical processes, such as the Haber-Bosch process, to produce ammonia. This ammonia is applied directly to the soil or used to produce other compounds, including ammonium nitrate and urea. Reactive nitrogen compounds in the atmosphere are side-products of fossil fuel combustion.

Nitrogen is an essential element of all proteins, enzymes, and metabolic processes for the synthesis and transfer of energy. Nitrogen is also an element

The Cherepovets nitrogen fertilizer plant in Cherepovets, Russia. (Smirnov Vladimir/ITAR-TASS/Landov)

in chlorophyll, the green pigment of plants that facilitates light harvest and photosynthesis. Thus, nitrogen is essential for plant survival, growth, and reproduction. Many experiments have shown that photosynthesis is linearly correlated with nitrogen concentration in leaves. Increased nitrogen availability via fertilization or deposition generally increases photosynthetic carbon fixation and stimulates plant growth.

• Significance for Climate Change

Nitrogen is very abundant in the Earth's atmosphere but mostly not active for plants to use. Most plants take up only reactive nitrogen compounds, mostly from soil, for photosynthesis and growth. In natural ecosystems, inactive nitrogen in the atmosphere is converted to biologically useful forms mainly via nitrogen fixation by lightning or by a limited number of plant and microbial species. Anthropogenic activities, such as manufacture of nitrogen fertilizer, cultivation-induced nitrogen fixation, and combustion of fossile fuels, have accelerated the addition of reactive nitrogen to ecosystems, roughly doubling the rate of introduction. It is expected that conversion of inactive nitrogen in the atmosphere and in fossils to reactive nitrogen will increase another two- to threefold in the future.

Nitrogen addition, particularly through fertilization and deposition, has profound implications for climate change and global warming. Nitrogen deposition has been suggested to be a major mechanism underlying terrestrial ecosystem carbon sequestration. Extensive experimental evidence supports the theory that plant growth is limited by nitrogen in almost all ecosystems, and nitrogen addition to ecosystems often stimulates plant biomass growth and increases carbon storage in plant pools. The nitrogen limitation is usually persistent in ecosystems, largely because of the transient nature of biologically available forms of nitrogen. Biologically available nitrogen enters natural ecosystems primarily by biological fixation, but it is highly susceptible to loss by leaching and volatilization.

Although nitrogen stimulates biomass growth and carbon storage in plant pools, the effects of nitrogen fertilization on soil carbon storage are controversial. In several studies, nitrogen addition did not significantly affect soil carbon storage. It caused significant increases in soil carbon content in European and North American forests, and it stimulated substantial carbon loss from soil in other ecosystems. Nitrogen addition not only stimulates plant biomass growth and carbon input to the soil systems but also potentially stimulates microbial decomposition of litter and soil organic matter. Particularly in forests, most litter and soil organic matter have high carbon contents and low nitrogen contents.

Microbial activities are strongly limited by nitrogen availability. Nitrogen deposition can relieve nitrogen stress and stimulate microbial activities. As a consequence, soil carbon content can decrease with additional nitrogen input from deposition. In an ecosystem with low carbon content and high nitrogen content in litter and soil organic matter, nitrogen-induced increases in plant biomass growth and carbon input can result in increases in soil carbon sequestration. Since carbon in terrestrial ecosystems is mostly stored in soil, the inconsistent, often opposite responses of soil carbon storage to nitrogen addition suggest that stimulation of carbon sequestration in terrestrial ecosystems by nitrogen deposition may be minor.

Nitrogen fertilization and deposition may indirectly affect land-surface energy balance and then feedback to climate change. Nitrogen addition usually results in increases in leaf chlorophyll content and greenness of plant canopy and land surface. Green land surface has low albedo, so it readily absorbs solar radiation, and its high transpiration levels influence local and regional water vapor dynamics and air circulation.

Nitrogen fertilization and deposition can cause emissions of nitrous oxide (N_2O), ammonia gas (NH_3), and nitrogen oxides to the atmosphere, leading to greenhouse effects. The production and application of nitrogen fertilizers also consume energy and emit carbon dioxide (CO_2) into the atmosphere. Reactive nitrogen in the atmosphere can influence tropospheric aerosols and stratospheric ozone, resulting in cooling effects. Moreover, nitrogen-induced increases in tropospheric aerosols can reduce plant carbon uptake and ecosystem carbon storage.

Nitrogen fertilization and deposition can result in degradation of ecosystems. Runoff with nitrogen-rich compounds from high-deposition regions and fertilized fields causes eutrophication in rivers and lakes and hypoxia in coastal zones.

Yiqi Luo

• Further Reading

Galloway, J. N., et al. "Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions." *Science* 320 (2008): 889-892. Comprehensive overview of the nitrogen cycle, including its impacts on climate change and global warming.

Hungate, B. A., et al. "Nitrogen and Climate Change." *Science* 302 (2003): 1512-1513. Critically examines nitrogen's effects on carbon processes and climate change. Concludes that projections of the global carbon cycle and its influence on climate change must consider nitrogen regulation.

LeBauer, D. S., and K. K. Treseder. "Nitrogen Limitation of Net Primary Productivity in Terrestrial Ecosystems Is Globally Distributed." *Ecology* 89 (2008): 371-379. Synthesizes experimental results from many studies and concludes that nitrogen addition increases plant production in all types of ecosystems except deserts. Illustrates that nitrogen limits plant growth even in tropical regions, where it is traditionally thought to be limited by phosphorus.

Reay, D. S., et al. "Global Nitrogen Deposition and Carbon Sinks." *Nature Geoscience* 1 (2008): 430-437. Focuses on impacts of nitrogen deposition on carbon sequestration. Demonstrates that nitrogen deposition likely increases carbon sequestration in plant pools. Nitrogen's effects on soil carbon pools are controversial.

See also: Carbon dioxide fertilization; Carbon 4 plants; Carbon 3 plants; Composting; Forests; Nitrogen cycle; Photosynthesis.

Nitrous oxide

• **Category:** Chemistry and geochemistry

• Definition

A colorless gas with a sweet odor, nitrous oxide is one of the many oxides of nitrogen. Sometimes called laughing gas, funny gas, nitrogen suboxide, or dinitrogen monoxide, it was first manufactured by Joseph Priestley, an English chemist, in 1775. It can be used to render a person insensible to pain in short surgical procedures; if inhaled for too long a period, it will cause death. It is also used as a propellant in aerosals and as an oxidizer to increase a racing-car engine's power output.

• Significance for Climate Change

Nitrous oxide is a trace gas produced by human industrial activity that affects the environment as do the other greenhouse gases (GHGs) and, as such, is limited by the Kyoto Protocol. (The other nitrogen oxides are not considered to be GHGs.) Another source of nitrous oxide is nitrogen fertilizers. Nitrous oxide also occurs naturally as a by-product of the bacteria in soil and water, particularly in tropi-

Global Nitrous Oxide Emissions by Sector, 2000

Economic Sector	*Percent of Total Emissions*
Agricultural by-products	62.0
Land use and biomass burning	26.0
Industrial processes	5.9
Waste disposal and treatment	2.3
Residential, commercial, and other sources	1.5
Transportation fuels	1.1
Power stations	1.1

Data from the Netherlands Environmental Assessment Agency.

cal forest areas, and in animal waste products. Nitrous oxide may have slightly less effect than the halocarbons, as nitrous oxide reacts naturally with soil and water, so is less likely to make its way into the atmosphere. However, one molecule of N_2O in the atmosphere has two to three hundred times the warming effect of one molecule of CO_2.

As light from the Sun enters the atmosphere, some of that light gets scattered by molecules in the air or gets reflected from clouds back into space. Some of the light that reaches Earth is reflected back into space, such as light that bounces off snow or ice. Much of the light that reaches Earth is absorbed into the Earth and retained as heat. The Earth's surface warms and emits infrared photons, which make several passes between the Earth and the atmosphere, warming the atmosphere and the Earth as they go back and forth. Eventually, these infrared photons return to space.

The GHGs, including nitrous oxide, all have three or more atoms. They are able to absorb infrared photons as they pass, transferring the energy from the photon to the molecule and affecting the way these infrared photons are able to warm the Earth by trapping them. Eventually, this absorption of energy affects the net change in the Earth's energy balance. The effect caused depends on the radiative force associated with the gas.

This balance is also affected by the global warming potential (GWP) of the gas. Some gases stay in the atmosphere much longer than others before any natural process is able to remove them. Some gases can stay in the atmosphere for hundreds or thousands of years. Gases with long lifetimes continue to affect the warming of the Earth and its atmosphere. This warming, in turn, affects changes in weather, sea levels, and land.

These gases can be removed from the atmosphere through condensation and precipitation or by chemical reactions in the atmosphere. However, due to their long lives in the atmosphere, they are, generally speaking, accumulating more quickly than they can be dispersed.

Because of their effects on the global climate, the retention of these gases in the atmosphere could lead to melting of glaciers and polar ice caps, flooding and droughts becoming more severe, rising sea levels, increases in the salinity of freshwater, more devastating tropical cyclones and tidal waves, and erosion of beaches on the coasts.

These effects on the global climate could also help increase food production. As the Earth becomes warmer, growing cycles lengthen, more land becomes available for food production, and more and different varieties of food are able to be grown.

Climate change from the greenhouse gases, including nitrous oxide, could also lead to more insect-borne disease spreading further throughout the world. As mosquitoes and other pests are able to survive in more and different areas, malaria, dengue fever, and cholera could spread further.

Marianne M. Madsen

• Further Reading

Cowie, J. *Climate Change: Biological and Human Aspects.* New York: Cambridge University Press, 2007. Reviews past and projects future climate changes due to GHG release.

Emanuel, Kerry. *What We Know About Climate Change.* Cambridge, Mass.: MIT Press, 2007. Discusses how GHGs, including nitrous oxide, have increased in the atmosphere and the climate changes they may cause.

Fagan, B. M. *The Little Ice Age: How Climate Made History, 1300-1850.* New York: Basic Books, 2001. Reviews the history of climate change over time, discussing whether the current changes are part of a natural cycle.

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming*. Rev. ed. London: Penguin, 2007. Argues that global warming is real, providing definitions and models.

Hoffman, Jennifer, Tina Tin, and George Ochoa. *Climate: The Force That Shapes Our World and the Future of Life on Earth*. London: Rodale Books, 2005. Explains how human actions have caused a shift in the climate; includes photos, graphs, diagrams, and maps.

Marshall, John, and R. Alan Plumb. *Atmosphere, Ocean, and Climate Dynamics*. Boston: Elsevier Academic Press, 2008. Discusses changes in the atmosphere and how those changes affect the oceans.

See also: Enhanced greenhouse effect; Greenhouse effect; Greenhouse gases; Nitrogen cycle; Nitrogen fertilization.

Noctilucent clouds

- **Category:** Meteorology and atmospheric sciences

- **Definition**

At very high latitudes, usually farther than 50° from the equator, very thin, extremely high-altitude clouds sometimes form during the summer. These clouds are very difficult to observe directly from Earth. They are easiest to see at the end of twilight, when darkness has settled on the surface of the Earth but sunlight is still shining at very high altitudes: The ultra-high-altitude clouds appear to shine after dusk, so they are called noctilucent clouds (German for "night-shining" clouds).

Noctilucent clouds form in the mesosphere, an upper layer of Earth's atmosphere, at an altitude of about 85 kilometers. At that altitude, the air is exceedingly thin and cold. Dust and tiny ice crystals form the clouds, but the ice crystals require exceedingly cold temperatures, typically colder than –120° Celsius, which occur during the summer months in the polar regions (when surface temperatures are warmest). As a result, the technical name for noctilucent clouds is polar mesospheric clouds.

The first known reports of noctilucent clouds followed the 1883 explosive eruption of Krakatoa, when the clouds were extensively studied by Jesse Otto. Initially, it was believed that the clouds were simply a by-product of the volcanic eruption. However, the clouds persisted long after the ash from the eruption had dissipated. Otto and subsequent researchers were able to determine very little about the clouds. They are too high for balloon studies and have prompted satellite missions to study them, including the Aeronomy of Ice in the Mesosphere (AIM) mission.

Though little is known about nocticlucent clouds, scientists have observed that they are somewhat more frequent after meteor showers. Some

An artist's rendering of the satellite Glory, *which measures the effects of noctilucent and other clouds, as well as those of particles and solar energy, upon climate change.* (MCT/Landov) rocket exhausts, such as those of the Space Shuttle main engines, have also been implicated in the formation of nocticlucent clouds. Despite over a century of research, the nature and actual cause of noctilucent clouds is still not known.

• Significance for Climate Change

Because noctilucent clouds were not reported until 1883, some have speculated that they did not exist before then, but that claim is unsubstantiated. Many subtle phenomena were first studied scientifically in the nineteenth century, but that does not mean that they did not exist beforehand. Noctilucent clouds have also been more commonly reported over the course of the twentieth century, leading to claims that these clouds are becoming more common. That claim, too, is disputed. Noctilucent clouds have been more widely publicized over the course of the last century, so there may have simply been more people looking for them or recognizing and reporting them when they saw them. Concerted and in-depth scientific investigations of noctilucent clouds have been fairly recent, so there is little long-term data.

Not only have noctilucent clouds been observed more frequently in high latitudes, but they have also been observed at lower latitudes than before, with reports of noctilucent clouds from as far south as Colorado. The apparent increase in noctilucent cloud reports appears to correlate with the reported increases in global temperatures over the last century. Since noctilucent clouds require extremely cold mesospheric temperatures, sighting these clouds at lower latitudes may suggest a cooling of the mesosphere. This has led to claims that noctilucent clouds are in some manner related to global warming, which may also relate to cooling of the upper atmosphere. However, these claims are difficult to substantiate, because the nature of the noctilucent clouds is still not understood, nor is the mechanism by which these clouds form.

Some theoretical models indicate that certain greenhouse gases, such as methane, may provide hydrogen to the mesosphere that can oxidize to form water from which the clouds can form. One of the mysteries about noctilucent clouds is the source of the water in the mesosphere, one of the driest parts of Earth's atmosphere. An increase in methane could be one explanation. However, other sources for the water in the mesosphere could also result in noctilucent clouds. Major volcanic eruptions or impacts from icy bodies from space could also impart water to the mesosphere, but impacts should occur at fairly consistent rates, and there have been no major volcanic eruptions of the order of Krakatoa in the last century.

In recent years, it has been discovered that noctilucent clouds could be monitored from the ground by radar even when they were not visible. The ice crystals forming the clouds seem to act as attractors for iron and sodium ions in Earth's thermosphere. These metal ions are believed to come from meteoroids burning up in Earth's upper atmosphere. Satellite detection of noctilucent clouds is also now possible. These new methods of study may answer questions about the origins of the clouds and any possible link between them and global climate change.

Raymond D. Benge, Jr.

• Further Reading

Dalin, P., et al. "Ground-Based Observations of Noctilucent Clouds with a Northern Hemisphere Network of Automatic Digital Cameras." *Journal of Atmospheric and Solar-Terrestrial Physics* 70, nos. 11/12 (August, 2008): 1460-1472. Extensive technical report of scientific investigations of noctilucent clouds.

Petersen, Carolyn Collins. "Noctilucent Clouds from Rocket Exhaust." *Sky and Telescope* 106, no. 3 (September, 2003): 26. Illustrated summary of research linking noctilucent clouds to rocket exhaust.

Schroder, Wilfried. "Otto Jesse and the Investigation of Noctilucent Clouds 115 Years Ago." *Bulletin of the American Meteorological Society* 82, no. 11 (November, 2001): 2457-2468. Details the early history of noctilucent cloud studies.

Stevens, Michael H. "Heavenly Harbingers." *Smithsonian* 32, no. 2 (November, 2001): 20. A brief first-hand account of studies of noctilucent clouds, with illustrations.

Witze, Alexandra. "Enigmatic Clouds Illuminated." *Nature* 927, no. 7172 (2007): 927. Some of the early findings of the AIM mission are summarized.

See also: Atmospheric structure and evolution; Clouds and cloud feedback; Mesosphere; Polar stratospheric clouds.

Nongovernmental International Panel on Climate Change

- **Category:** Organizations and agencies
- **Date:** Established 2007
- **Web address:** http://www.sepp.org

- **Mission**

The Nongovernmental International Panel on Climate Change (NIPCC) is an international panel of nongovernmental scientists and scholars assembled to address the causes and consequences of global climate change. The NIPCC was established by the Science and Environmental Policy Project (SEPP). The SEPP was founded in 1990 by eminent atmospheric physicist (and former director of the United States Weather Satellite Service) S. Fred Singer,

> on the premise that sound, credible science must form the basis for health and environmental decisions that affect millions of people and cost tens of billions of dollars every year.

NIPCC set out to produce an independent evaluation of the available scientific evidence on the causes of climate change. Motivation for this grew out of widespread dissatisfaction with the global climate assessment reports of the United Nation's Intergovernmental Panel on Climate Change (IPCC), in particular the Fourth Assessment Report (2007).

SEPP brought together an international panel of nongovernmental scientists and scholars who were not predisposed to believe that climate change is caused mostly by human greenhouse gas emissions. The organization's report, *Nature, Not Human Activity, Rules the Climate* (2008), focused on evidence that the NIPCC felt that the IPCC had ignored. The report stems from an international climate workshop in Vienna in April, 2007, organized by the NIPCC.

- **Significance for Climate Change**

The NIPCC's 2008 report aims to provide an independent, nongovernmental second opinion on the global warming issue. NIPCC claims

> the central problems for policymakers in the debate over global warming are (a) is the reported warming trend real and how significant is it? (b) how much of the warming trend is due to natural causes and how much is due to human-generated greenhouse gases? and (c) would the effects of continued warming be harmful or beneficial to plant and wildlife and to human civilization?

The report presents evidence that helps provide answers to all three questions.

The NIPCC could find no convincing evidence or observations of significant global climate change from other than natural causes. The authors sum up their findings as follows:

> This NIPCC report falsifies the principal IPCC conclusion that most of the reported warming (since 1979) is "very likely" (that is, 90-99 percent certain) caused by the human emission of greenhouse gases. In other words, increasing carbon dioxide is not responsible for current warming. Policies adopted and called for in the name of "fighting global warming" are unnecessary.

C R de Freitas

See also: Intergovernmental Panel on Climate Change.

Nongovernmental organizations

- **Categories:** Environmentalism, conservation, and ecosystems; ethics, human rights, and social justice

• **Definition**

Nongovernmental organizations (NGOs) are broadly defined as private, philanthropic, and nonprofit organizations that aim to provide services for needy people and to challenge sociopolitical inequalities at local, national, or international levels. Oxfam, Greenpeace, the Red Cross, Save the Children, and Doctors Without Borders are a few high-profile NGOs that have been active in shaping climate change policies.

• **Significance for Climate Change**

An increasing number of NGOs have showed their growing interest and influence in putting the environment on the global agenda and pressuring governments, business, and international organizations to take climate change seriously. Climate change affects both developed and developing countries, but many NGOs pay extra attention to the needs of vulnerable groups in developing countries since the climate-change-induced destruction falls disproportionately on them. These impoverished people rely heavily on natural resources, such as land and sea, for survival, but climate change would cause more floods, droughts, and extreme weather, and that will destroy their livelihoods and worsen poverty. However, the adaptive capacity of developing countries is low, and their governments are not strong enough to respond effectively to the challenges posed by climate change. Some NGOs, such as Oxfam, take an environmental justice perspective, arguing that rich countries control access to carbon and are capable of protecting themselves from the ravages of climate change. In contrast, poor countries are least responsible for greenhouse gas (GHG) emissions, but they pay the price for industrial growth in rich countries. They highlight the implicit power imbalance between rich and poor countries and between carbon haves and have-nots.

NGOs have comparative advantages in global environmental politics. First, global warming is a crisis on a global scale and requires global coordination to provide a solution. Most international NGOs have dense networks, and they often work together in coalitions and coordinate their lobbying efforts in order to maximize the impact. Second, donors do not always trust governments in the developing countries. They prefer offering development aid through NGOs, which are seen as transparent, accountable, and trustworthy. Third, NGOs can respond more quickly than many governments to the needs of local communities. They are also sensitive to gender and power dynamics.

Maarten van Aalst, the International Red Cross's leading climate expert, discusses the consequences of climate change for people and property during a press conference in April, 2007. (AP/Wide World Photos)

Therefore, NGOs try to build bridges for local people, governments, and international communities. Apart from raising public awareness and engaging affected communities in the decision-making process, NGOs are keen to advocate mitigation and adaptation policies. They launch campaigns to cut GHG emissions in order to reduce global average temperature. They also help poor countries to develop alternative livelihoods, to improve global humanitarian systems, to increase emergency aid, and to reduce risks of disaster by building long-term social protection. They build local capacity by focusing on disaster preparedness and recovery plans. They also help identify new funding sources for the Adaptation Fund, the largest potential source of funds for climate adaptation in poor countries. Furthermore, they build partnerships with other organizations to provide essential services, such as water and sanitation, to local people.

It needs to be noted that NGOs are a diverse group with varied goals, structures, and motivations. These differences mark heterogeneous policy design, priority, and response to climate change. Different targets, priorities, and strategies show the disparities in history, resources, leadership, expertise, networks, and visions. While some focus more on targets for national CO_2 emissions, financial mechanisms, and technology transfer, others are more concerned with humanitarian work and disaster preparedness. For example, Doctors Without Borders focuses on the health implications of higher temperature on disease patterns, while the International Red Cross, in contrast, emphasizes community-based self-reliance, early-warning operation, risk-mapping, and vulnerability assessment. Oxfam takes a rights-based perspective, arguing that the excessive GHG emission of rich countries has violated the human rights of poor people in developing countries.

NGOs have faced a number of challenges. First, NGO relationships with local governments in developing countries can be rough. Some NGOs suffer from excessive government interference. Second, NGOs rely on financial support from donors. Donors can make unreasonable demands and put their own agendas above the needs of recipient communities. Third, the legitimacy and governance of NGOs are sometimes questioned because the public wants to know how funds are allocated. Finally, local NGOs feel cash-rich international NGOs imposing their agendas on them, without building their capacity for dealing with local issues. Local NGOs are concerned that overreliance on foreign NGOs will create a culture of dependence, and that is not conducive to the healthy development of NGOs in developing countries.

Sam Wong

• Further Reading

Magrath, John, with Andrew Simms. *Africa: Up in Smoke 2*. London: New Economics Foundation, 2006. Offers a critical examination of the impact of climate change on Africa.

Revi, Aromar. "Climate Change Risk: An Adaptation and Mitigation Agenda for Indian Cities." *Environment and Urbanisation* 20, no. 1 (2007): 207-229. Recommends interventions into India's climate change agenda to be undertaken by NGOs. Highlights the mitigation and adaptation policies available to developing nations.

World Bank. *Not If but When: Adapting to Natural Hazards in the Pacific*. Washington, D.C.: Author, 2006. Gives examples of public-private partnerships in promoting mitigation and adaptation policies. Emphasizes the constraints in promoting mitigation-adaptation strategies.

See also: Climate Project; Consultative Group on International Agricultural Research; Food and Agriculture Organization; Greenpeace; International Union for Conservation of Nature.

Nonlinear processes

• **Category:** Science and technology

• Definition

In science, a process is a series of changes of one or more variables that represent properties or states of an object or a system. Examples of physical, chemical, and biological processes include evaporation, land erosion, oxidation, cell division, germination, dispersion, growth, accumulation, and global warming. In addition to the processes themselves, the study of the relationship between causes and effects of changes accounts for a major portion of scientific research. There are many ways to classify a process, based on properties of the process itself or the cause-effect relationship behind it. For example, a process can be continuous or discrete, stable or unstable, convergent or divergent, and linear or nonlinear.

A process is nonlinear when its effect is not simply proportional to its cause. For example, water evaporation is a nonlinear process, because water being boiled will not vaporize until the temperature reaches the critical threshold of 100° Celsius, causing a change in water's state from liquid to gas.

- **Significance for Climate Change**

The global climate system includes a variety of nonlinear processes that are subject to positive feedbacks, as well as complex interrelations between numerous factors affecting the climate. Such complexity exposes the Earth to a high risk of abrupt climate changes.

A positive feedback loop worth noting is the Arctic permafrost melt, which can speed up the cycle between the accumulation of GHGs in the atmosphere and temperature growth. The greenhouse effect contributes to global warming and higher temperature leads to melting frozen soils in the Artic region. The ice melting can release vast amounts of carbon dioxide (CO_2) and methane trapped in the permafrost soils. Estimates show that billions of metric tons of methane—a greenhouse gas twenty-one times more potent than is CO_2—can be emitted into the atmosphere and amplify the greenhouse effect.

Another important positive feedback loop is the Arctic albedo change. The albedo of a surface is the percentage of incident light that it reflects back into space. Since ice masses have high albedos, the ice covering the Arctic Ocean and land surfaces can help the Earth absorb only a small fraction of solar energy. As the Arctic ice melts due to global warming, the uncovered surface assimilates more solar energy and as a consequence intensifies the warming effect.

Besides permafrost melt and the Arctic albedo change, rain-forest decline, water scarcity, land degradation, ocean decline, and persistent toxins have the potential to cause abrupt climate change. Studies of the effects of the nonlinear processes, as well as their interactions with other elements of the climate system, are in progress to resolve uncertainty about abrupt and irreversible climate changes.

To N. Nguyen

See also: Albedo feedback; Climate feedback; Clouds and cloud feedback.

North Atlantic Oscillation

- **Category:** Oceanography

- **Definition**

The North Atlantic Oscillation (NAO) is the dominant pattern of atmospheric circulation in the North Atlantic region ranging from central North America to Europe and northern Asia. The NAO is usually developed in the winter and is caused by fluctuations in atmospheric pressure between a subpolar, low-pressure center near Iceland and a subtropical, high-pressure center near the Azores-Gibraltar region. The NAO is generally described by the North Atlantic Oscillation index, which is a weighted measurement of the difference between the subpolar low-pressure zone and the subtropical high-pressure center during the winter season of the North Atlantic region.

The positive NAO index phase corresponds with time periods when a stronger subtropical high-pressure center and a deeper-than-normal subpolar low-pressure zone exist in the North Atlantic region, increasing the atmospheric pressure gradient in this region. During positive-NAO-index years, the western subtropical North Atlantic Ocean is warm. Strengthened westerly winds blow warmth and moisture into north-central Europe. The warm, moisture-bearing winds arriving from the subtropical Atlantic Ocean make Europe warmer and wetter. In the meantime, northern Canada and Greenland experience cold and dry winters. Cooler temperatures occur off the west coast of Africa. Strong trade winds send more dust out across the ocean toward the Caribbean Sea. The eastern United States undergoes a mild and wet winter season.

The negative NAO index phase corresponds with time periods when both the subtropical high-pressure center and the subpolar low-pressure zone are weakened, which would reduce the atmospheric pressure gradient in the North Atlantic region. As a result, fewer and weaker winter storms occur in this region. More moist air is brought to the Mediterranean, and cold air is brought to northern Europe. Northeastern Canada and Greenland experience mild and wet winters and the eastern United States undergoes a cold and dry winter season.

• Significance for Climate Change

The NAO index varies from year to year and has evidenced a cyclicity of decadal scales over the past 150 years. The NAO index was persistently positive in the early 1900's, negative in the 1960's and 1970's, and considerably more positive during the 1980's and early 1990's. Since the heat capacity of the ocean is much greater than that of a continent, the NAO accounts for approximately one-third of the changes in average winter surface temperatures in the northern hemisphere. Variations in the NAO have significant impacts on many aspects of North Atlantic societies and the environment, such as agricultural harvests, water resources, fishery yields, industrial energy production, and ecosystems. Significant changes in the NAO may in turn influence climatic changes, including changes in sea surface temperature (SST), ocean circulation patterns, and Arctic sea-ice coverage.

Many mechanisms have been proposed to account for NAO index variability, including atmospheric response to changes in SST, variability of atmospheric convection in the tropics, internal and nonlinear dynamics of the extratropical atmosphere, and anthropogenic forcing caused by greenhouse gas (GHG) emissions and ozone depletion. Tropical heating has been proved to influence the atmospheric circulation over the North Atlantic region. Since tropical convection is sensitive to the underlying SST distribution, recent warming of the tropical oceans may lead to persistently positive values for the NAO index.

Some scientists think that changes in atmospheric circulation associated with the NAO index have contributed to the winter warming of the Northern Hemisphere in recent decades. Recent statistical evidence has demonstrated that the forcing of increased GHG concentration in the atmosphere may have affected the long-term variability of the NAO. Recent comparisons of NAO index records between the 1800's and the late twentieth century demonstrate that global warming may cause the increased variability of the NAO. Even though studies have linked climate change to the NAO, however, the mechanism of the NAO is still not fully understood. The NAO needs to be further investigated to advance understanding of the linkages between anthropogenic forcing and NAO variability.

Yongli Gao

• Further Reading

Appenzeller, C., T. F. Stocker, and M. Anklin. "North Atlantic Oscillation Dynamics Recorded in Greenland Ice Cores." *Science* 282 (1998): 446-449. Reconstructs the NAO index for the past 350 years using ice core data from Greenland.

Goodkin, N. F., K. A. Hughen, S. C. Doney, and W. B. Curry. "Increased Multidecadal Variability of the North Atlantic Oscillation Since 1781." *Nature Geoscience* 1 (2008): 844-848. Study by scientists from the Woods Hole Oceanographic Institution of NAO index variability based a record of stronium-to-calcium ratios in a Bermuda coral dated between 1781 and 1999. Concludes that global warming increased the variability of NAO in the late twentieth century.

Holland, D. M., et al. "Acceleration of Jakobshavn Isbrae Triggered by Warm Subsurface Ocean Waters." *Nature Geoscience* 1 (2008): 659-664. Demonstrates that a major change in the behavior of the NAO after the mid-1990's weakened the subpolar gyre. This weakening caused warm subpolar waters to spread westward and accelerate the thinning of Greenland's glacier.

Hurrell, J. W., et al., eds. *The North Atlantic Oscillation: Climate Significance and Environmental Impact.* Washington, D.C.: American Geophysical Union, 2003. Includes twelve papers written by atmospheric scientists, oceanographers, paleoclimatologists, and biologists to present a state-of-the-art assessment of the contemporary understandings of the NAO and its environmental and societal impact.

Paeth, H., et al. "The North Atlantic Oscillation as an Indicator for Greenhouse-Gas Induced Regional Climate Change." *Climate Dynamics* 15, no. 12 (1999): 953-960. Studies the forcing of increased GHG concentration in the atmosphere and its effect on the long-term variability of the NAO.

See also: Atmosphere; Atmospheric dynamics; Hadley circulation; Inter-Tropical Convergence Zone; Walker circulation.

North Korea

- **Category:** Nations and peoples
- **Key facts**

Population: 23.5 million (2008 estimate)
Area: 122,762 square kilometers
Gross domestic product (GDP): $40 billion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 71.8 in 2004
Kyoto Protocol status: Ratified 2005

• Historical and Political Context

In the aftermath of World War II in 1945, Korea was divided into two countries in accordance with a United Nations arrangement. North of the 38th parallel, the North Korean government, or the Democratic People's Republic of Korea (DPRK), was formally established in 1948. The Korean Workers Party, supported by the Soviet Union, became a ruling party. The government established a centralizing system and nationalized all properties. Economic activities were conducted under state control. In June, 1950, North Korea entered the Korean War against South Korea, and the war lasted until July, 1953. After the war, the government emphasized heavy industry, along with a centralized, planned economy.

North Korea developed a political ideology, *Juche* (self-reliance), whose goal was to strengthen the country economically and militarily and finally to make North Korea immune to foreign invasion and capitalist intervention. This ideology has prevented the nation from keeping technological pace with other industrialized countries and has made North Korea one of the poorest nations in the world.

In 1994, Kim Jung-il succeeded his father, Kim Il-sung, as general secretary of the Korean Workers Party. In July, 2002, North Korea started to open its border and to adopt capitalism. The government set up a free-trade zone near its border with China. However, the government still maintained a firm political control of the economy and denied access to foreign media. North Korea declared that it had developed nuclear weapons, and six-party talks began that were aimed at finding a peaceful means to curb the North Korean nuclear program.

• Impact of North Korean Policies on Climate Change

After the Korean War, the government moved toward a command economy and nationalized all assets. Since then, all economic activities have been conducted under state control. The centralized, planned economy grew significantly in industrial production and made significant progress in social infrastructure. The government has consistently promoted economic development policies that place top priority on heavy industry, including electricity production, steel production, and machine building. In turn, unreasonably one-sided promotion of heavy industry has deepened structural imbalances between North Korean industries. This "heavy industry first" policy has made North Korea unable to catch up to new technological developments or to phase out its coal-and-steel-based economy. The government also pursues military strength while striving to develop its economy.

In the 1970's, environmental pollution became a serious issue after two decades of industrialization emphasizing heavy industry and reckless development of natural resources. However, the government did not regulate this pollution until the Environmental Protection Law, established to prevent pollution and promote environmental preservation in 1986. Other environmental policies have also been implemented to establish air and water pollution standards. In 1996, the government established the State Environmental Protection Bureau to implement the Environmental Protection Law. North Korea has also participated in the United Nations Environment Programme (UNEP) since 1992.

In spite of North Korea's efforts to restore its environment, environmental degradation in the country is getting worse. This is primarily because of the government's policies emphasizing development in areas of heavy industries and an increase in food production, rather than environmental protection, as well as the lack of investment in the environment due to the weak economy.

• North Korea as a GHG Emitter

The Carbon Dioxide Information Analysis Center (CDIAC) reported that North Korea emitted almost 72 million metric tons of greenhouse gas

(GHG), in carbon dioxide (CO_2) equivalent, in 2004. The CO_2 emission as a percent of global CO_2 production is about 0.3 percent. CO_2 emissions of North Korea had been significantly increased by the early 1990's. Then, the emission sharply decreased; it stabilized in the early twenty-first century. CO_2 emission is primarily from the manufacturing industries and construction sector (78.6 percent), as well as the electricity and heat-production sector (15.9 percent). Less than 5 percent of CO_2 emission is from transportation and residential use.

Because of its self-reliance policy, North Korea avoids dependency on foreign energy sources, but it heavily relies on its own coal as a primary source of energy. North Korea uses coal with high sulfur content to produce heat and to generate electricity. Therefore, besides CO_2, other air pollutant emissions such as SO_x are also significant. North Korea's use of coal is projected to increase fivefold from 2005 to 2020. However, the use of obsolete industrial technology with poor energy efficiency, lack of exhaust gas purification technology, and lack of renewable energy alternatives induces a great deal of GHG emission. North Korea's inability to deal with this GHG emission, even from its power plants and refineries, has led to accelerated air and water pollution.

To cooperate in international efforts to protect the global environment, North Korea ratified the Kyoto Protocol in 2005. The government has also signed several international environmental agreements, such as the Convention of Biological Diversity. The government established the State Environmental Protection Bureau to implement environmental laws and regulations.

• Summary and Foresight

North Korean environmental degradation results from enforcement of misguided economic policies such as putting heavy industry first and engaging in the parallel development of military strength and the economy. Furthermore, North Korea's self-reliance ideology rendered the government unable to carry out reforms of its closed economy. However, North Korea has recognized the serious environmental degradation that has taken place over the past several decades. By adjusting its legal and administrative framework, the government has designated environmental protection as a priority over all other productive practices. The government established environmental laws and regulations and improved environment management systems.

North Korea has demonstrated its willingness to engage with the global community through organs such as UNEP to protect its environment. The government also attempts to strengthen cooperation with international societies such as the United Nations Development Programme (UNDP) in order to overcome economic hardship, to acquire economic support, and to lift the economy. The nation has adopted a pragmatic strategy. The government also emphasizes the need for foreign trade and economic cooperation with other nations. Proclamation of a Free Economic Zone and enactment of the Law on Attraction of Foreign Investment are good examples of the recent changes in North Korea. The country, however, continues its self-reliance policy and confronts contradictions between protection of national security and economic development, although diplomatic relations are ac-

tive. Thus, the government needs to make internal changes to facilitate and acquire international support.

Because of a lack of energy, economic growth in North Korea may need to scarify its environment like other developing countries, developing abundant but poor-quality coals to meet energy demands. International organizations also need to respond to North Korea's effort to protect its environment by supporting the improvement of North Korea's economic condition and by establishing environmental cooperation to promote environmental infrastructure, such as clean coal combustion, purification technologies, and renewable energy alternatives.

Jongnam Choi

• Further Reading

Hong, Soon-jick. "Environmental Pollution in North Korea: Another South Korean Burden." *Asian-Pacific Economic Literature* 13, no. 2 (November, 1999): 199-214. Describes the causes of pollution in North Korea and discusses approaches that South Korea should take to prevent pollution on the Korean Peninsula.

Park, Song-dong. "The Situation Regarding the North Korean Environment and the Long-Term and Short-Term Tasks." In *Unified Economy*. Seoul, South Korea: Hyundai Research Institute, 1997. Discusses South Korea's long-term and short-term strategies to preserve the environment in North Korea and promote good relations between the two Koreas.

United Nations Environment Programme. *DPRK: State of the Environment, 2003*. Nairobi, Kenya: Author, 2003. The first comprehensive survey of North Korean environmental issues, including water resources, air and soil pollution, deforestation, and biodiversity.

See also: Industrial greenhouse emissions; Kyoto lands; Kyoto mechanisms; Kyoto Protocol; United Nations Environment Programme; United Nations Framework Convention on Climate Change.

Northwest Passage

• Categories: Geology and geography; oceanography

• Definition

In the 1400's and early 1500's, Portuguese and Spanish navigators developed routes to the rich oriental spice trade going south of Africa and South America, respectively. Their rivals, England and France, hoped to find another, shorter route. They sought a way west at the north end of North America—the Northwest Passage. Many expeditions failed, often tragically, to find an ice-free northwest passage through the maze of islands west of Greenland in the Canadian north. Their attempts pitted them against the polar cold and floating pack ice of the Arctic Ocean.

Finally, in 1903, Roald Amundsen allowed his small ship, *Gjoa*, to be locked in ice and drift westward for three years, until it melted free on the Alaska side. That was an exploring feat, but it had no commercial potential. Likewise, the 1969 passage of the supertanker *Manhattan* was a nautical triumph but a commercial failure, because it required assistance from two icebreakers and repairs afterwards.

Since then, two things have changed: The climate has warmed, and the Arctic's energy resources have become better known and more sorely desired. The Little Ice Age reached its coldest point in the early 1800's, and world temperatures have moved generally higher ever since (with cooling retreats such as the 1880's to through about 1910 and the early 1940's through the mid-1970's). Beginning in the mid-1970's, temperature increases resumed and increased more steeply. This increase has been ascribed to the greenhouse effect of global warming caused by higher levels of carbon dioxide (CO_2), which slows the escape of heat through the Earth's atmosphere.

By the mid-1980's, cruise ships began making summer cruises through many Northwest Passage waters. In 2007, the summer melt reduced the extent of Arctic ice to its smallest area since comprehensive satellite data were collected beginning about 1970. The Northwest Passage was largely ice


Satellite imagery of the Northwest Passage, free of ice and navigable by ships, taken in August of 2008. (ESA/dpa/Landov)

free for several weeks before the cold returned. Moreover, those open summer waters replace the near total solar reflectivity of polar ice with the near total solar absorption of dark, open water. Several climate models suggest that all of the Arctic pack ice may melt in summers by 2100, or even much sooner.

Beside climate change, development is coming to the entire Arctic region, because world demand for petroleum and natural gas may soon exceed production both because of continued economic growth and exhaustion of a number of existing deposits. Meanwhile, about a quarter of the world's hydrocarbon deposits ring the Arctic from the Norwegian Sea through Siberia, Alaska, and northern Canada.

• Significance for Climate Change

The fabled Northwest Passage may soon become a functional reality because of the confluence of climate warming, the resource wealth of the Arctic, and the Arctic's central position between Europe and East Asia. These factors could make a navigable Arctic Ocean "the Mediterranean of the north." However, there is still doubt about a functioning Northwest Passage. A minority group of climatologists suggests that most of the warming in the Arctic since the early 1800's is due to natural cycles. They posit that the mechanisms of global change are still only dimly understood and that computer modelers are applying mere decades of firm data against processes that operate over millennia. Consequently, the recent melting could be replaced by cold and increased pack ice comparable to the 1800's or beyond any in recorded history.

Still, the general pattern of two centuries has been of warming climate and decreased ice. This suggests that offshore drilling and even coal mining will progress northward into the various seas of the Arctic Ocean. It suggests that thousands of ships will ply that waterway, either through Canadian waters or through a longer but serviceable route north of Russia (the Northeast Passage). Once in place, it may be a factor for increased global warming for four reasons.

First, incidental pollution and accidental spills are inevitable. Pollution tends to melt ice. Soot on ice or snow increases melting by increasing absorption. Any major petroleum spills would result in black, absorbing areas on, in, and beneath the ice for decades, because petroleum-digesting bacteria function slowly at near freezing temperatures.

Second, major industrial development also brings thermal pollution that could significantly increase melting of the pack ice. Moreover, there is a major limitation to cooling waters compared to temperate regions. The Arctic Ocean has an unusual thermal structure, with warm salty Gulf Stream water reaching the Arctic Ocean but diving under a major layer of less-dense freshwater. The deeper waters are often a degree above freezing, and they are more saline, which hinders them from freezing. Thus, bringing cooler waters from the depths is not an option.

Third, industries and governments making sizeable investments in ports, icebreaking ships, and mining facilities would not gladly surrender those treasures to returning ice. The first two mechanisms could be applied deliberately to melt ice. Fourth, activities to enforce sovereignty claims, such as building bases, would also contribute to warming.

The sheer volume of Arctic ice makes it difficult to predict the full climatological consequences of its melting. One climate theory has held that an ice-free Arctic in winter would provide sufficient water vapor for vastly increased snowfall on surrounding lands, perhaps enough to generate a new ice age.

Roger V. Carlson

• Further Reading

Easterbrook, Gregg. "Global Warming: Who Loses—and Who Wins?" *The Atlantic* 299 (April, 2007): 52-64. Science journalist Easterbrook focuses on the politics of who owns the Arctic, especially the Northwest Passage.

Hall, Sam. *The Fourth World: The Heritage of the Arctic and Its Destruction.* New York: Alfred A. Knopf, 1987. Journalist Sam Hall describes the interrelated Arctic issues of climate, resources, people, and sovereignty.

Moss, Sarah. *The Frozen Ship: The Histories and Tales of Polar Expeditions.* New York: Blue Bridge, 2006. Historian Sarah Moss provides not just historical accounts but also a survey of the literature and beliefs surrounding polar expeditions.

Open University Course Team. *Case Studies in Oceanography and Marine Affairs.* New York: Pergamon Press, 1991. Although dated, this book has an extensive chapter on the key Northwest Passage issues of resources, pollution, sovereignty, trade, and climate change.

See also: Albedo feedback; Arctic; Arctic peoples; Arctic seafloor claims; Greenhouse effect; Oil industry.

Nuclear energy

• Category: Energy

Nuclear energy may offer a partial alternative to fossil fuels. Nuclear power generates no GHGs, but adequate measures to dispose of nuclear waste have yet to be developed, and the long lead time required to construct a nuclear power plant precludes using nuclear energy as a global replacement for GHG-emitting energy sources in the short term.

• Key concepts

fission: the splitting of a heavy nucleus (such as in a uranium atom) into two, with a release of a relatively large amount of energy

fossil fuels: fuels, including coal, gas, and oil, based on compressed, ancient organic materials

fusion: the combination of two light nuclei to produce a heavier nucleus; if accomplished in a contained setting, this is infinitely sustainable

greenhouse gases (GHGs): gases emitted by burning fossil fuels that trap heat in Earth's atmosphere

high-level waste: extremely radioactive fission products and transuranic elements such as plutonium, often produced by fission processes

A crane operator stands in front of the containers used to transport nuclear waste from the reactor site at La Hague, France, to a storage site in Gorleben, Germany. (Kay Nietfeld/dpa/Landov)

• Background

Since the 1950's, countries such as the United States, the Soviet Union (now Russia), and France have relied on nuclear power as an energy source. Electric power is generated in nuclear power plants by fission reactors that heat water to turn turbines. Nuclear fission produces no greenhouse gases (GHGs). Mining uranium to power the reactors causes some environmental degradation, but the most significant drawbacks of nuclear energy are the high cost of reactor construction, the long lag time required to build reactors, and the difficulty of safely disposing of the nuclear waste generated by the reactors.

• Nuclear Energy as a Power Source

When several countries began to build nuclear reactors to generate electric power in the 1950's, nuclear energy was haled as the energy of the future. Uranium was and still is in plentiful supply, and supporters of nuclear power indicated it would provide inexhaustible electric power in the future. A few countries, most notably France, engaged in extensive reactor construction, and approximately 80 percent of France's electric power now comes from nuclear power. Other countries, such as the United States, initially built several reactors. Support for nuclear power declined in the United States, however. No new power reactors were ordered after 1978. Approximately 20 percent of the electric power produced in the United States in the first decade of the twenty-first century came from nuclear energy.

Worldwide, approximately 16 percent of all electric power is generated by nuclear energy. In the first decade of the twenty-first century, some 440 nuclear power reactors were in operation in thirty countries. Six different types of power reactor were in operation, with research underway to expand this number. The most common reactor was the pressurized water reactor (268 reactors), followed by the boiling water reactor (94 reactors).

In spite of its initial problems, nuclear power may offer some advantages in dealing with climate change generated by burning fossil fuels. The operation of fission reactors does not generate any GHGs. Uranium is in plentiful supply, both from mines throughout the world and as material reprocessed from old nuclear weapons. Nuclear reactors can be constructed to fit existing needs, with electric power capacities ranging from nearly 2 gigawatts per reactor to much smaller capacities to serve small communities. Once in operation, a power reactor may be expected to operate for forty to sixty years.

Although challenging, it may be possible to generate as much as 1 terawatt of electric power per year with nuclear energy by 2050. If this goal is accomplished, it will be possible to achieve a substantial reduction in carbon emissions by mid-century. The technology to build nuclear reactors already exists and does not have to be invented; new advances, however, can lead to increased reactor efficiency. The construction of nuclear power reactors is a feasible alternative to fossil fuel power plants.

One criticism that has sometimes been levied against nuclear power is that it is not safe. Some critics indicate that reactors may leak radioactive matter. Power reactors in Western countries such as the United States, the United Kingdom, and France have had minimal leakages with no health risks. Other critics indicate that power reactors may have major accidents, including core meltdowns, pointing to accidents at the Three Mile Island Nuclear Power Plant in the United States in 1979 and the Soviet reactor at Chernobyl in 1986. The Three Mile Island accident led to a radiation leak of less than 50 curies of radiation, and no health issues have been traced to this incident. The Chernobyl accident was far more severe, with a release of 100 million curies of radiation, numerous deaths, and continuing health problems resulting from the accident, as well as lingering health problems in the region. Western countries do not use reactors of the Soviet design, which had limited containment around the reactors. The safety claims regarding most Western power reactors are generally overstated. In many ways, nuclear power produces fewer health problems than do coal-fired power plants.

All existing nuclear power reactors are fission reactors. The potential exists, however, eventually to construct fusion reactors. Such reactors would produce much less radioactive waste and operate more efficiently than fission reactors. Although advocates over the last thirty years have repeatedly indicated that fusion would become the energy source of the future, the technology remains relegated to the laboratory for the near term. No means of sustaining the temperatures required for fusion (about 100 million° Celsius) has yet been found. In addition, questions involving the high costs of construction and the production of the tritium gas necessary for a fusion reaction must be addressed.

Several environmentalists and other advocates of nuclear energy argue that the United States and other Western countries should reconsider its use. They point to the negative impacts of coal and oil plants, such as acid rain and GHG emissions. In addition, some economists predict that oil will become increasingly expensive, making nuclear energy more cost-effective.

• Drawbacks and Liabilities of Nuclear Energy

Most of the twentieth century problems with nuclear energy remain, and some new issues have been raised as well. As fears of terrorism and so-called suitcase devices have increased, the need to control even relatively small amounts of nuclear material has become more urgent, and even well-protected nuclear power plants pose security risks. Although terrorists might prefer more high profile targets than reactors and upgrading nuclear fuel is difficult, the security threat may sway public opinion against expanding nuclear energy.

Moreover, there are no ideal methods of nuclear waste disposal. Wastes with low levels of radioactivity are currently being stored underground in the United States and elsewhere. The greatest source of concern is high-level radioactive waste, such as spent fuel rods, piping, and the like. France has long followed a policy of reprocessing and reusing spent fuel rods. This is an attractive solution, but the process produces weapons-grade plutonium as a by-product. The United States and most other countries have not adopted this practice, in part out of fear that some plutonium might fall into the wrong hands.

The United States and most other countries that use nuclear energy have not solved the problem of spent nuclear fuel as yet. The United States is developing an underground storage facility at Yucca Mountain in Nevada, but it is controversial and is unlikely to be operational until 2015 at best. Until the Yucca Mountain site becomes operational, American nuclear power facilities are storing spent fuel on site. This approach is also being followed by most of the other countries that operate nuclear power reactors. The Russian Federation stores spent fuel on site but also engages in a limited amount of reprocessing at Chelyabinsk-65, and another facility at Krasnoyarsk is scheduled to start operation in 2015. The former Soviet government also engaged in extensive injection into the ground of a good deal of its lower-level waste such as cesium 137 and strontium 90. This injection occurred at three Soviet sites, producing several environmental problems.

Nuclear waste storage on site remains an option for nuclear power facilities, but the waste issue will need to be resolved if extensive use is to be made of nuclear energy in the future. The French and possibly the Russians seem to be comfortable with reprocessing. France and the United Kingdom are engaged in a joint project to develop a means to recycle spent nuclear fuel without producing weapons-grade plutonium. Most other countries are trying to develop underground sites, as Finland is doing at Olkiluoto, or shipping their nuclear waste to countries such as the United States for storage. Because of the long period of radioactive decay of some of this waste (several million years in some cases), developing safe, permanent storage facilities remains a challenging issue.

• Timetables for Nuclear Deployment

Nuclear energy may provide some help in mitigating global warming, but its impact is unlikely to be felt in the short run. In the United States, for example, the time required to obtain a permit to build a power reactor had increased to three and one-half years by the time the last reactor was permitted in 1978. Once a permit was issued, construction required around ten additional years. Although reactors have been constructed in other countries such as France or Russia in much shorter periods of time, they are complex facilities that cannot be constructed in short order. In some nations—such as Germany or the Scandinavian countries, where power reactors have been shut down—the largely antinuclear public will have to be convinced to allow new nuclear facilities to be contructed before any such project can be considered.

A large-scale expansion of nuclear energy is not likely until the 2020's, if then. In the United States, sixteen utilities had announced plans for potential reactor construction by 2007, but it would be several years before any of these facilities could go online. Elsewhere, the situation was much the same.

• Context

Nuclear energy has much to offer as an alternative to fossil fuels. Utilization of nuclear energy can help to provide a middle-term solution to the need for clean energy until ways can be found to enable cleaner, renewable sources such as solar energy to satisfy humanity's energy needs. In addition to environmental factors, the increasing cost of oil will help make nuclear energy more attractive. Fears of terrorism, radiation leaks, and the difficulties surrounding nuclear waste disposal are obstacles to a resurgence of nuclear energy. The length of time required to build an operational reactor negates any advantages of nuclear energy as a short-term solution to energy-related GHG emissions. Public opinion appears to be becoming more favorably inclined toward nuclear energy, but a good deal of opposition remains. As with many issues concerning global warming, the longer the wait before construction of power reactors begins, the more costly the process will be, and the less help the reactors will provide in combating the increasing emission of GHGs.

John M. Theilmann

• Further Reading

Caldicott, Helen. *Nuclear Power Is Not the Answer.* New York: New Press, 2006. Argues that the various issues facing nuclear energy are so great as to outweigh the advantages of nuclear power.

Deutch, John M., and Ernest J. Moniz. "The Nuclear Option," *Scientific American*, September, 2006, 75-83. Indicates that a significant expansion of nuclear power could reduce GHG emissions in a cost-effective fashion.

Herbst, Alan M., and George W. Hopley. *Nuclear Energy Now*. New York: John Wiley, 2007. Primarily economic analysis of nuclear energy that advocates its adoption.

Lake, James A., Ralph G. Bennett, and John F. Kotek. "Next Generation Nuclear Power." In *Oil and the Future of Energy*. Guilford, Conn.: Lyons Press, 2007. Examines the evolving technology of nuclear reactor construction.

Macfarlane, Allison M., and Rodney C. Ewing, eds. *Uncertainty Underground*. Cambridge, Mass.: MIT Press, 2006. Useful collection of essays about the technology of dealing with high-level nuclear waste at Yucca Mountain, as well as public policy issues.

Morris, Robert C. *The Environmental Case for Nuclear Power*. St. Paul, Minn.: Paragon House, 2000. Contrasts nuclear energy favorably with fossil fuels in terms of their environmental and medical effects.

Nuttall, W. J. *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power*. New York: Taylor and Francis, 2004. Good treatment of the technical, political, and economic issues surrounding nuclear power.

See also: Clean energy; Coal; Energy resources; Fossil fuels; Fuels, alternative; Hubbert's peak; International Atomic Energy Agency; Nuclear winter; U.S. energy policy.

Nuclear winter

- **Category:** Climatic events and epochs

• Definition

"Nuclear winter" was the term coined in the 1980's to describe the global climatic effects of a major nuclear weapons exchange between the United States and the Soviet Union. The concept arose from scientific theories attempting to explain the extinction of the dinosaurs. Evidence to suggest an unusual geological event was found at the boundary between the Cretaceous and Tertiary periods (65-70 million years ago). An iridium-rich layer of sediment separated the dinosaur-fossil-bearing layers below from the dinosaur-fossil-lacking layers above. It was theorized that this amount of iridium could only have come from a collision with an asteroid-sized object, at least 10 to 16 kilometers in diameter.

If such an object had hit the Earth, the impact would have had a global effect on the planet's environment. Rock and ash debris would have been thrown high into the atmosphere, and the impact would have ignited huge forest fires. Ash from these fires, combined with the fine dust from the impact, could have remained in the atmosphere for several years and altered the Earth's albedo. Less sunlight would reach the surface, as the dust-laden atmosphere reflected it back into space. Those life forms surviving the initial impact would have to adapt to a rapidly changing environment. Less sunlight would affect photosynthesis, and the food chain would be disrupted as the Earth entered into a long global winter.

Some scientists saw a correlation between this scenario and the possible aftermath of a massive nuclear weapons exchange. The smoke and ash coming from the hundreds of burning cities and forests would pollute the atmosphere and alter weather patterns. Scientists envisioned an Earth enshrouded by dust-laden clouds that would block out sunlight and lower surface temperatures. The summer days would be cloudy, cooler, and wetter, with a short growing season. Winters would be cold and brutal. It was estimated that within three years of the nuclear conflagration, over one-half of the Earth's population would face starvation.

• Significance for Climate Change

The end of World War II in 1945 saw the beginning of the Cold War between the United States and the Soviet Union. During the war, the United States and the Soviet Union had been allies fighting against a common enemy in Nazi Germany. Although the two countries had different political ideals and agendas, they put aside their differences to win the war.

Once the war was over, each side began to mistrust the other. What made matters worse was the development and use of the atomic bomb.

The United States was the first country to develop a nuclear bomb, which it used twice to end the war with Japan, bombing the cities of Hiroshima and Nagasaki. Conventional bombing raids over Germany and Japan killed more people and damaged more property than a single atomic bomb. However, the psychological effect of one bomb doing the same amount of damage as thousands of conventional weapons made a difference and motivated Japan to end the war. The bomb blasts had unanticipated, lingering effects on the area, however, in the form of radioactive fallout. Tens of thousands of people may have died from the nuclear blast, while perhaps hundreds of thousands more would later die from radiation poisoning.

The nuclear attacks on Hiroshima and Nagasaki demonstrated to the world the horrors of nuclear war. It was hoped that they would serve as a reason for avoiding any further nuclear conflicts. Throughout the 1950's, 1960's, and 1970's, the United States and the Soviet Union each developed sufficient nuclear capability to deter the other from attacking, following a doctrine of mutual assured destruction. It was understood that in the event of a nuclear exchange, the fallout would affect the global community. In an attempt to persuade political leaders to cut back their stockpiles of nuclear weapons, scientists began to study the global environmental effects of a massive nuclear weapons exchange.

Throughout the 1980's and 1990's, scientists and political activists publicized the effects of a nuclear weapons exchange and the threat it would pose to the survival of humankind. Perhaps their efforts played an important role in reducing the stockpiles of nuclear weapons and bringing an end to the Cold War. In the wake of the Cold War, however, nuclear weapons remain. The threat of an all-out nuclear exchange involving thousands of warheads may be a thing of the past, but several nations have the ability to wage a limited nuclear war and are apparently willing to do so.

The possibility also exists of nuclear weapons falling into the hands of terrorists. Even a relatively small conventional engagement such as the 1991 Gulf War has environmental effects. When Saddam Hussein set fire to hundreds of Kuwaiti oil wells, the intense smoke from these fires polluted the environment. While full-scale nuclear war—and thus full-scale nuclear winter—appears unlikely, even a limited exchange would have severe environmental consequences and could affect the global climate in an unforeseeable manner.

Paul P. Sipiera

• Further Reading

Fisher, David E. *Fire and Ice: The Greenhouse Effect, Ozone Depletion, and Nuclear Winter.* New York: Harper and Row, 1990. A good introduction to the concept of global climatic change and humankind's effects upon the environment.

Greene, Owen, Ian Percival, and Irene Ridge. *Nuclear Winter: The Evidence and Risks.* New York: Polity Press, 1985. One of the first books written to capture the public's attention to the dangers of climatic change induced by nuclear weapons or natural disasters.

Sagan, Carl, and Richard P. Turco. *A Path Where No Man Thought: Nuclear Winter and the End of the Arms Race.* New York: Random House, 1990. Coauthor Sagan, a popular scientist, was probably the best-known proponent of the nuclear winter concept.

See also: Mount Pinatubo; Nuclear energy; Volcanoes.

Ocean acidification

• **Categories:** Pollution and waste; oceanography

• Definition

Ocean acidification describes the decrease in pH of the oceans due to increased concentration of dissolved carbon dioxide (CO_2). CO_2 is a trace gas found in the atmosphere. The concentration of dissolved oceanic CO_2 is in equilibrium with the gas's atmospheric concentration, such that an increase in the atmospheric concentration leads to an increase in the dissolved concentration, and vice versa. Throughout geologic time, atmospheric CO_2 reflected a balance between various sources and sinks found on land and in the oceans—such as photosynthesis, respiration, chemical weathering of rocks and burial of organic and inorganic carbon. Since the onset of the industrial age, human activities, such as fossil fuel combustion and intensification of agriculture, represent a new source of atmospheric CO_2.

These activities are thought to cause the observed increases in atmospheric CO_2, which in turn lead to increased dissolved CO_2 concentrations in the oceans. Dissolved CO_2 combines with water to form carbonic acid (H_2CO_3), which subsequently dissociates to produce bicarbonate (HCO_3^-) and carbonate ions (CO_3^{2-}) and protons (H^+). The balance among these different reactions is such that increased concentrations of dissolved CO_2 lead to increased proton concentrations (acidity). Since pH is an inverse scale of the concentration of dissolved H^+, the higher the proton concentrations, the lower the pH and the greater the acidity. Modeling experiments using different scenarios to project future atmospheric CO_2 concentrations indicate that by 2100, the ocean's pH will drop by up to 0.45 unit.

Effects of Ocean Acidification on Coral Reef Calcification Rate

Atmospheric CO_2 Level[a]	*Coral Calcification Rate*[b]
280 (preindustrial)	70
380 (current)	55
560	20
840	5

Data from National Oceanographic and Atmospheric Administration.
a. parts per million.
b. millimoles per square meter per day.

• Significance for Climate Change

The reactions by which CO_2 and water form H_2CO_3, HCO_3^- and CO_3^{2-} control the pH of the world's oceans. Oceanic pH has important ecological consequences, because many plankton (including the *Coccolithophoridae*, which are marine algae, and the *Foraminiferida*, which are planktic protists) and macrofauna (corals, mollusks, brachiopods, and so on) precipitate the minerals calcite or aragonite (which both have the chemical formula $CaCO_3$) to make exoskeletons, shells, and tests in a process called calcification. Under normal conditions, calcite and aragonite are stable minerals in surface waters, because CO_3^{2-} concentrations are naturally maintained at levels that prevent their dissolution. However, increasing atmospheric CO_2 concentrations lead to decreased oceanic pH values and a concomitant decrease in carbonate ion concentration.

This effect is currently observed in a vertical profile of the oceans, where carbonate ion concentrations decrease with increasing depth. At a depth known as the lysocline, the rate of carbonate mineral dissolution increases rapidly with decreasing carbonate ion concentrations. Thus, in surface and intermediate waters, carbonate minerals are not dissolved. Below the lysocline, carbonate minerals are readily dissolved. Many laboratory experiments seem to indicate that ocean acidification will prove detrimental to many marine ecosystems. This finding has been recently validated by a study of a benthic ecosystem located near a naturally occurring volcanic vent that delivers CO_2 to the surrounding waters. The full-scale consequences of acidification of the global ocean are likely to be numerous, and could include extinctions as food webs collapse due to a loss of calcareous planktonic primary producers and consequences for the strength of the biological pump.

The biological pump is the process by which CO_2 is actively removed from the atmosphere by primary producing phytoplankton who convert the CO_2 to organic matter via photosynthesis. When these organisms die, their hard parts act as ballast to help the organic matter sink to the ocean floor, where it is buried in sediments. Ultimately, this sequesters the CO_2 in rocks for geologic time scales. However, if ocean acidification leads to dissolution of calcareous tests, organic matter will not be effectively buried because it is not dense enough to settle to the ocean floor. Not all scientists agree with the negative predicted consequences of ocean acidification. They argue that carbonate minerals present in sedimentary rocks on the ocean floor should, over time, consume the excess H^+ produced from increased atmospheric CO_2 concentrations, causing ocean acidification to slow or even stop.

The increase in atmospheric CO_2 concentrations appears to be linked to an increase in global temperatures. Temperature is a strong control on the conversion of atmospheric CO_2 to dissolved CO_2 in the ocean. Henry's Law states that the dissolved concentration of a gas is proportional to the partial pressure of that gas in the atmosphere in contact with that liquid. Gases are characterized by different Henry's Law constants that give the proportionality of dissolved gas that will be in equilibrium with the overlying atmosphere. For most gases, including CO_2, the value of the Henry's Law constant decreases with increasing temperature—that is, at higher temperatures, the amount of CO_2 that can be dissolved in the ocean will decrease. This temperature dependence provides a negative feedback on the amount of ocean acidification that could occur. However, this also means that a greater proportion of anthropogenic CO_2 would remain in the atmosphere as global temperature rises.

Anna M. Cruse

• Further Reading

Doney, Scott C. "The Dangers of Ocean Acidification." *Scientific American* 294, no. 3 (March, 2006): 58-65. Discusses the impact of fossil fuel combustion on the world's oceans. Examines the ecosystem effects of increased ocean acidity.

Hall-Spencer, Jason M., et al. "Volcanic Carbon Dioxide Vents Show Ecosystem Effects of Ocean Acidification." *Nature* 454, no. 7200 (July 3, 2008): 96-99. Presents data from an ecosystem-scale study that used a naturally occurring volcanic CO_2 vent as an analogue for the effects of ocean acidification caused by increased anthropogenic CO_2 concentrations.

Loáiciga, Hugo. "Modern-Age Buildup of CO_2 and Its Effects on Seawater Acidity and Salinity." *Geophysical Research Letters* 33, no. 10 (May 26, 2006). Uses an equilibrium model of carbonate speciation to conclude that increased atmospheric CO_2 concentrations will not cause ocean acidification on time scales of hundreds of years.

Royal Society. *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide.* London: Author, 2005. This policy document provides a comprehensive overview of ocean acidification and its possible consequences. Illustrations, figures, maps, references, glossary.

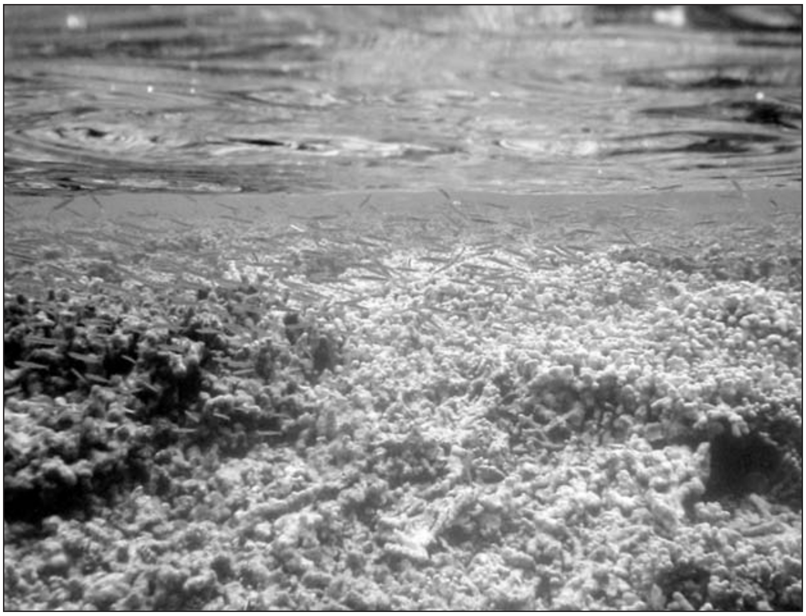
See also: Ekman transport and pumping; Freshwater; Groundwater; Hydrologic cycle; Ocean-atmosphere coupling; Ocean dynamics; Ocean life; Petroleum hydrocarbons in the ocean; pH; Plankton.

Ocean-atmosphere coupling

• **Categories:** Meteorology and atmospheric sciences; oceanography

• Definition

Ocean-atmosphere coupling describes the interdependency between the temperatures and circulation of water in the ocean and those of air in the atmosphere. Changes in the surface temperature of ocean water produce changes in the atmosphere above the water, which alters wind patterns and leads to further changes in surface ocean temperature. If these changes are significantly large or long-lived, changes in atmospheric patterns capable of producing changes in global weather patterns can result. The most prominent example of this is the El Niño/La Niña weather cycle, which



An image of the point of interface between atmosphere and ocean. (NOAA)

gained notoriety as the cause of numerous climate disruptions in North America during the late twentieth and early twenty-first centuries.

• Significance for Climate Change

The specific heat of water—that is, the amount of energy required to alter water's temperature—is extremely high. As a result, Earth's water systems are a significant stabilizing influence on global surface temperatures. The ocean-atmosphere coupling is among the most significant points of distribution of water in the global hydrologic cycle. Water evaporates from the oceans into the atmosphere, which carries water vapor over land, where it precipitates, providing freshwater to terrestrial ecosystems. This cycle, and particularly the interface between air and sea, both directly affect and are affected by global climate patterns, particularly those involving temperature.

The significance of ocean-atmosphere coupling to global warming increased as cyclical meteorological phenomena, such as the El Niño/La Niña cycle in the southern Pacific and the North Atlantic Oscillation patterns affecting weather in northern Europe and North America, began accelerating in the early 1980's. Of particular concern was the alteration of cyclical El Niño periods, triggered by higher sea surface temperatures in the southern Pacific, and La Niña periods, caused by lower sea surface temperatures in this region. Seven El Niño periods took place during the 1980's and 1990's, while only three La Niña periods occurred. Many scientists regarded this phenomenon as possible evidence of the escalation of global warming.

The study of ocean-atmosphere coupling thus intensified during the late twentieth and early twenty-first century, as scientists sought to determine the causes and extent of global warming, as well as its future duration and potential for escalation. Many of these studies sought to determine whether global warming patterns have human causes, while others attempted to forecast changes in global weather patterns to determine the potential for future extreme weather events such as severe droughts, flooding, and drastic changes in temperature. Long-term studies of patterns of climate variability involving ocean-atmosphere coupling have failed to yield definitive answers to these inquiries, leading many scientists to conclude that these patterns must be examined for longer periods in order to determine their implications for global warming and its causes.

Michael H. Burchett

See also: Atmosphere; Atmospheric dynamics; El Niño-Southern Oscillation; Hadley circulation; Inter-Tropical Convergence Zone; La Niña; Ocean dynamics.

Ocean disposal

- **Category:** Pollution and waste

- **Definition**

Ocean disposal ranges from dumping toxic chemicals, sewage, dredge spoils (material removed during dredging), and bilge water to accidental spills from oil tankers. Dumping of waste and dredge spoils has long been a part of the United States' waste process, as it provides an economically viable option for disposing millions of metric tons of waste. Dumping waste into the oceans has increasingly been shown to adversely affect aquatic ecosystems and contribute to global warming. There are strict ocean disposal regulations in the United States, including the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972 and the Clean Water Act (CWA) of 1972; nevertheless, illegal ocean disposal still occurs frequently.

- **Significance for Climate Change**

Toxins from pesticides, as well as heavy metals, phosphorus, and nitrogen from dredge spoils, are a few of the harmful wastes dumped into the ocean. The effects of ocean disposal are not fully understood, but ocean disposal has been shown to cause substantial loss of marine life and indirectly enhance global warming. When plants and animals die, the dead organisms decay and release carbon dioxide (CO_2). CO_2 collects in the atmosphere and traps the Sun's heat, increasing the Earth's temperature. Recent consequences attributed to this climate change include the melting of glaciers, rising sea levels, disruption of coral reef habitats, and more extreme hurricanes.

In addition to the evidence of climate change caused by ocean disposal, hazardous waste disposal, such as nuclear refuse, can cause genetic defects, leading to cancer or death in both humans and marine life. Because of this danger, long-term burial of hazardous waste at sea is controversial. From the 1940's through the 1960's, the United States discarded barrels of radioactive waste in the ocean. The Environmental Protection Agency (EPA) then prohibited all dumping as a result of many of the barrels leaking.

Most of the material being dumped into the ocean is dredged waste. One approach to long-term storage of dredge spoils entails drilling holes into the ocean's floor and saturating the holes with the dredged waste. San Francisco, California, houses one such site approximately 91 kilometers offshore. This site is the deepest ocean disposal site in the United States, covering 22 square kilometers at a depth of 2,500-3,000 meters. The consequences of drilling deep into the ocean floor are not well known, raising questions of the short- and long-term effects of dredge spoils deposited in deepwater sediment on deep-sea biodiversity.

Sandie Zlotorzynski and Kathryn Rowberg

See also: Ocean acidification; Ocean life; Petroleum hydrocarbons in the ocean; Water resources, global; Water resources, North American.

Ocean dynamics

- **Categories:** Meteorology and atmospheric sciences; oceanography

The movement of water in the Earth's oceans is the primary process that transports heat from the tropics to the polar regions, keeps the oceans uniform in chemistry, and transports heat between the ocean's surface and its floor.

- **Key concepts**

gyres: large, rotating loops of ocean current found in all major oceans; they are driven westward by the trade winds near the equator and eastward by the westerlies at high latitudes

meridional: referring to the motion of air or water in a generally north-south direction, that is, along meridians

thermohaline circulation: a vertical circulation in the oceans that is mostly driven by water-density differences, which in turn are governed by temperature and salinity

trade winds: twin wind belts on either side of the equator that generally blow westward

westerlies: belts of wind in midlatitudes that generally blow from west to east

• Background

Motions in the Earth's oceans include tides, which are caused by the gravity of the Sun and Moon; surface currents, which are driven by wind; and thermohaline circulation, which is driven by density differences in seawater. All of these motions move large amounts of water from place to place. In so doing, they also transport heat from equator to pole and from the surface to the deep ocean, and they also transport dissolved chemicals, including greenhouse gases. Although the saltiness of ocean water varies from place to place, the relative proportions of dissolved materials—say, the ratio of sodium to chlorine—are extremely uniform. Ocean dynamics keep the oceans thoroughly mixed and profoundly affect Earth's temperature; hence, they are important in climate modeling. Although waves are the most obvious water motion to most people, the water in waves merely oscillates back and forth; that is, waves do not transport water long distances and thus are not discussed in this article.

• Tides

Tides are the result of the gravitational attraction of the Moon and Sun. Although the Sun is far more massive than the Moon, its much greater distance means that its tidal effect is only about half that of the Moon. Nevertheless, if the Earth lacked a Moon, it would still have appreciable tides.

The continents prevent water from moving freely, so the actual movement of the tides is very complex. In most ocean basins the high and low tides revolve like the spokes of a wheel or the wave in a drinking glass oscillating in a circle. Tides move water through the connections between oceans and are important in keeping ocean water uniformly mixed. In small bodies of water it can take hours for the tides to progress from one end to the other, so tide predictions have to be based on local observations as well as the positions of the Sun and Moon.

Solar and lunar tides affect each other appreciably. Solar and lunar high and low tides can reinforce each other or partially cancel each other out. When the Earth, Sun, and Moon are in a straight line, at new or full moon, solar and lunar tides reinforce each other. The range between low and high tide is large, a condition called spring tide. When the Sun and Moon are 90° apart, as at first or last quarter moon, solar and lunar tides partially cancel each other out. The range between low and high tide is unusually small, a condition called neap tide.

• Ocean Currents

Surface ocean currents are driven by the winds. Generally, water near the equator is pushed west by the trade winds until it strikes a continent. Most of it then is diverted poleward, where it encounters the prevailing westerlies and is pushed east. Once it reaches the eastern side of the ocean, most of the water is diverted toward the equator. Thus, in all the ocean basins there is a large loop, or gyre, rotating clockwise in the Northern Hemisphere and counterclockwise in the Southern.

Around the Antarctic is a unique geography, a belt of latitude consisting entirely of ocean. With no topography to hinder them, the westerly winds in the Southern Hemisphere, called the Roaring Forties, create some of the roughest seas in the world. They also create a globe-girdling current, the Circum-Antarctic Current, that continuously circles Antarctica and is the principal mechanism for transferring water from one ocean to another.

• Thermohaline Circulation

The densest seawater on Earth is found around the Antarctic. The water is dense because it is both cold and salty. The water is salty because freezing of sea ice leaves dissolved salt concentrated in the remaining liquid. This cold, dense water sinks to the bottom and flows northward as a dense layer called Antarctic bottom water. The largest amount of Antarctic bottom water flows beneath the Pacific until it reaches Alaska, where it rises and merges into the surface circulation. It then flows around the North Pacific gyre until it reaches the southwest Pacific, where it has warmed to over 30° Celsius. Some warm water circulates through Indonesia to the Indian Ocean, and even though the amount of water involved is fairly small, the amount of heat transferred is large. Warm Indian Ocean water rounds Africa, cooling somewhat, then warms again in the South Atlantic. Some warm water crosses into the North Atlantic, travels up the eastern coast of North America as the Gulf Stream, then crosses to Europe. Finally, in the Arctic, the water cools and sinks. It then begins traveling south as North Atlantic deep water. Antarctic bottom water is also creeping northward in the Atlantic, colder and denser than North Atlantic deep water. Thus, in the North Atlantic, Gulf Stream water is moving northward on the surface, Antarctic bottom water is moving north along the bottom, and North Atlantic deep water is moving south just above the Antarctic bottom water. Because much of the water movement is northward or southward, thermohaline circulation is sometimes called meridional overturning circulation.

Scientists in the Argo program deploy a float to monitor ocean temperature and salinity. More than three thousand such floats are deployed worldwide. (NOAA)

• Context

Large-scale movements of ocean water affect local and global climate by transporting heat. They also affect climate change by transporting dissolved greenhouse gases into the deep ocean for storage and back to the surface for release. One aspect of thermohaline circulation has received particular attention. Many scientists are convinced that a sudden release of freshwater from glacial lakes in North America covered the North Atlantic with a layer of freshwater that prevented the exchange of heat between the ocean and the atmosphere and caused a sharp cooling event, called the Younger Dryas, about twelve thousand years ago. Some have suggested that melting of the Greenland ice cap might have a similar effect, so that warming of the climate might, paradoxically, produce a cooling episode.

Steven I. Dutch

• Further Reading

Denny, Mark. *How the Ocean Works: An Introduction to Oceanography*. Princeton, N.J.: Princeton University Press, 2008. Summary of oceanography for introductory college students.

Garrison, Tom S. *Essentials of Oceanography*. 4th ed. Belmont, Calif.: Brooks/Cole, 2006. Summary of oceanography for introductory college students.

Pinet, Paul R. *Invitation to Oceanography*. Sudbury, Mass.: Jones & Bartlett, 2009. Discusses geology, biology, chemistry, and physics of the oceans at an introductory college level. Includes a chapter on climate change.

Stewart, Robert H. *Introduction to Physical Oceanography*. College Station: Texas A&M University, 2004. Available at http://oceanworld.tamu.edu/home/course_book.htm. This treatment of oceanography offers extensive discussion of the physics of water movement in the oceans. Intended for upper-level college students.

See also: Atlantic heat conveyor; Atlantic multidecadal oscillation; Climate and the climate system; Ekman transport and pumping; El Niño-Southern Oscillation; General circulation models; Gulf Stream; Gyres; La Niña; Marginal seas; Mean sea level; Mediterranean Sea; Meridional overturning circulation; North Atlantic Oscillation; Ocean acidification; Ocean-atmosphere coupling; Ocean life; Rainfall patterns; Sea-level change; Sea sediments; Sea surface temperatures; Slab-ocean model; Thermocline; Thermohaline circulation; Younger Dryas.

Ocean life

• **Categories:** Oceanography; animals; plants and vegetation

Oceans, which cover 71 percent of the Earth's surface, respond more slowly than land to global warming. This warming, however, may cause damage to Arctic and Antarctic ecosystems due to melting sea ice, bleaching and die-off of reef corals, disruption of ocean currents, and shifting predator-prey relationships favoring reduced biodiversity. Long-term effects could include massive extinctions due to changes in seawater chemistry.

• Key concepts

dead zones: areas of deepwater oxygen depletion due to surface algal blooms or disruption of thermohaline circulation

El Niño-Southern Oscillation (ENSO) events: periodic fluctuation of temperatures and currents in the Pacific Ocean on a four-, ten-, and ninety-year cycle

primary productivity: production of fixed carbon through photosynthesis

thermohaline circulation: the rising and sinking of water caused by differences in water density due to differences in temperature and salinity

• Background

Until quite recently, scientists and the general public considered the Earth's oceans to be impervious to anthropogenic degradation. Oceans cover 71 percent of the Earth's surface and account for a little less than half of its primary productivity, that is, the photosynthetic conversion of carbon dioxide (CO_2) into the organic compounds that make up the bodies of living organisms.

The ocean is far from being a uniform habitat; however, with the exception of some near-shore environments, ecological niches cover wide areas and intergrade, meaning that species can readily adapt by shifting their ranges. In consequence, environmental pressures producing elevated extinction rates on land have a less dramatic effect in the open ocean.

Nonetheless, human activity has had an adverse effect on marine life, from phytoplankton to top marine predators such as sharks. While overfishing, pollution, and damming of rivers that serve as spawning grounds for marine fish have all taken their toll, these are only indirectly related to global warming.

Present effects attributable to elevated land temperatures include displacement of currents and upwelling zones and increased runoff in major river systems. Effects attributable to elevated sea surface temperatures include melting sea ice in the Arctic and Antarctic, reducing habitat for polar bears, penguins, and the many humbler species of plants and animals that thrive at the margins of the polar ice caps. In the tropics, higher sea surface temperatures alter coral metabolism, causing corals to bleach when they lose symbiotic algae (zooxanthellae) critical to their growth. Degradation of coral reefs profoundly affects the many organisms restricted to this habitat.

If atmospheric CO_2 continues to increase, altered seawater chemistry will become a concern. An increase in dissolved CO_2 increases acidity, which in turn inhibits production of shells. Coelenterates such as corals, whose skeletons are made up of aragonite, are more susceptible than are mollusks that have calcite shells. Present-day stunting effects attributable to this cause have not yet been observed in nature, but such stunting is suspected in the geologic record, so coelenterates are being closely monitored.

• Climate Change and Marine Life in the Geologic Record

Scientists recognize at least five major global mass-extinction events, of which the one at the Permian-Triassic boundary, 251 million years ago, was the most devastating. At that time, 95 percent of marine genera and 70 percent of land genera became extinct in three distinct pulses over a period of about eighty thousand years. At least two respected theories suggest that climate change caused these extinctions.

According to these theories, massive volcanic eruptions in Siberia started the catastrophe in motion. Each eruption caused cooling due to atmospheric volcanic dust and sulfur dioxide, followed by warming due to the longer-lived carbon-dioxide, augmented by heightened decomposition. Over the course of a million years, repeated eruptions, dwarfing anything humans have experienced in their brief tenure on Earth, eventually overwhelmed the Earth's capacity to self-correct.

One theory postulates that the ocean depths became increasingly oxygen-depleted, favoring the growth of bacteria that produce hydrogen sulfide. High pressures and cold temperatures in the abyss allowed that gas to build up, only to be released in a gigantic "burp" of highly toxic fumes. Another theory points to the storage of large quantities of methane in the form of clathrates in deep-sea sediments. It suggests that this methane was abruptly released when warming raised the temperature of the deeper regions of the ocean by 5° Celsius. In addition to being toxic and a powerful greenhouse gas (GHG), methane is explosive at concentrations as low as 5 percent.

Whatever the cause, the extinction, which devastated every group of plants and animals, was extremely abrupt by geological standards. Following the cataclysm, sedimentary rocks are nearly bare of fossils for the first ten million years of the Triassic period.

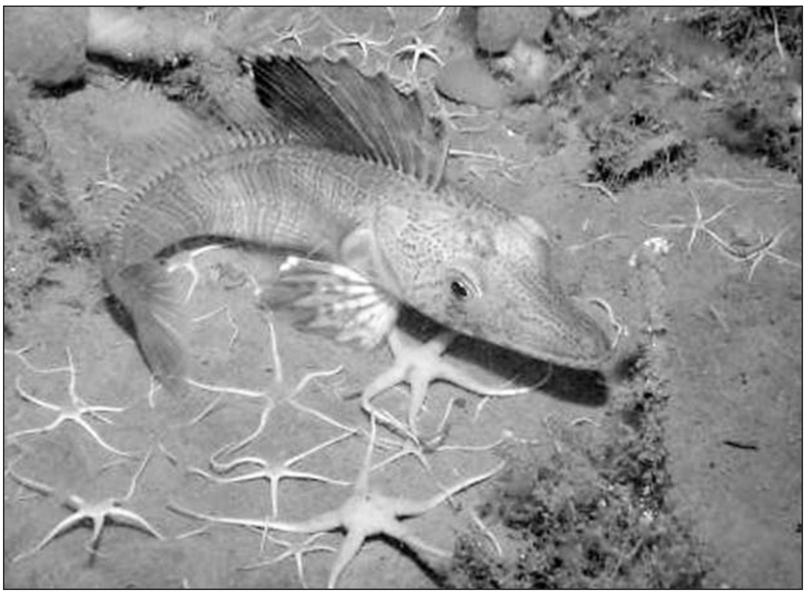
• The Present and Near Future

Unless the most carefully researched models are far off the mark, nothing resembling the devastating geochemical upheavals of the Permian-Triassic period looms in the foreseeable future, even if present levels of fossil fuel consumption persist. These models presuppose that volcanic activity will continue at levels typical of the Holocene and that no asteroids are headed in Earth's direction.

Possible changes due to increasing acidity are being closely monitored, but so far no notable effects on organisms have been observed in nature. Scientists working with a tiny marine snail that is crucial to Antarctic food chains have demonstrated, however, that there is ample cause for concern, because both higher temperatures and increasing acidity inhibit growth and shell production and can be expected to act synergistically. Acidity alone is not expected to reach lethal levels for another fifty years, but temperatures are rising rapidly, and marine organisms in the Antarctic cannot adjust their ranges southward. A wide variety of fish and birds depend on this snail for continued survival.

• Polar Regions

In both the Arctic and the Antarctic, chilled surface seawater sinks, allowing nutrient-rich waters to well up from below and support high phytoplankton productivity. The polar seas teem with life. The lower surfaces of ice sheets also support dense growth of attached algae. Global warming near the North Pole causes the most productive zone to retreat northward and contract in extent. This restricts the number of herbivores and carnivores the system can support. Most polar animals are unable to extend their ranges into temperate seas, because their unique adaptations to frigid temperatures make them poor competitors and susceptible to disease in warmer climates. The situation in the Southern Hemisphere is even more acute, as spe-



A species of fish evolved to thrive in the freezing waters of the Antarctic. (Dr. Julian Gutt/PA Photos/Landov) cies migrating southward encounter the continental margin.

The plight of polar bears has received considerable attention. These huge carnivores prey almost entirely on seals that they hunt on sea ice; they hibernate on land. The seals are declining in numbers and retreating farther from shore as the ice cap shrinks. Bears are starving and failing to reproduce. Whale populations that had begun to recover from overexploitation by the whaling industry are also declining again as a result of low food supplies. Antarctic penguins also face declining food supplies and an influx of predators, including sharks, which are extending their ranges southward.

• Coral Reefs

Reef-building corals, and the numerous species that depend upon them, have a narrow temperature range for optimum growth. They are also vulnerable to changes in sea level due to either global warming or global cooling. During the last Pleistocene glaciation, the resulting drop in sea level exposed much of Australia's Great Barrier reef, restricting this unique ecosystem to isolated pockets. A rapid rise in sea level would damage existing reefs by reducing light levels below those needed by symbiotic algae.

A 2° Celsius rise in surface temperature is sufficient to cause bleaching in corals as the individual polyps eject symbiotic algae. Bleaching initially causes growth to cease and eventually kills the coral colony. In recent years, there have been massive die-offs of corals—80 percent in the Caribbean and 50 percent in the South Pacific—but it is uncertain how much of this is due directly to global warming. The die-off in the South Pacific was associated with a severe El Niño-Southern Oscillation (ENSO) event to which global warming may have contributed. Near-shore pollution also devastates coral reefs in populated areas.

• Dead Zones

In a number of parts of the world, extensive areas of ocean have become depleted in oxygen, turning once productive fisheries into wastelands. Most of these dead zones are associated with rivers draining populated areas; one of the largest lies offshore of the mouth of the Mississippi River. This dead zone owes its existence to influxes of nutrient-laden freshwater to the Gulf of Mexico. These nutrients stimulate massive algal blooms. There is an indirect connection to global warming, in that warming generally causes increased precipitation and therefore increased runoff. Dead zones off the west coasts of the United States and South Africa result from disruption of cold currents and associated upwelling zones and thus may be directly related to global warming.

• Productivity

While global warming due to elevated CO_2 levels can cause local drops in productivity due to drought on land and disruption of thermohaline cycles in the ocean, the long-term predicted effect, on a global scale, of such warming is a net increase in photosynthesis, with an upper limit that far exceeds any projections based on realistic economic indicators. In the long term, this is good news. If the Earth is producing more food, both the numbers and the diversity of herbivores and predators can be expected to increase.

In the short term, however, such changes lead to the proliferation of weedy species with high reproductive rates and broad ecological ranges, loss of diversity, and generally unstable conditions. Species with specialized ecological requirements become extinct, and natural ecosystems increasingly resemble intentional agriculture or aquaculture. A glimpse of the future may be gleaned from the formerly rich fisheries off the West Coast of North America. These have been in decline for several decades, mainly because of pollution and over-fishing. Warmer waters coupled with a persistent dead zone off the coast of California and Oregon have further reduced stocks of commercial and sport fishes, but they have favored proliferation of the Humboldt giant squid, an aggressive predator adapted to warm temperatures and low oxygen levels. Sport fishermen are now being lured with the prospect of landing a 34-kilogram squid that puts up a mean fight.

Rising temperatures can be expected to reduce areas of high planktonic productivity near the poles while expanding them near the equator and at continental margins, threatening polar species with starvation and extinction while increasing numbers in warmer climates without a corresponding increase in diversity.

There are undoubtedly reef-building organisms ready to replace corals should the seas become inhospitable. During the very warm late Cretaceous, rudists, a group of bivalve mollusks related to clams, were the main reef builders. Several types of algae also have limestone skeletons. If any of these groups were to replace corals, the structural integrity of reefs would be preserved, but the beauty and diversity of the ecosystem would be sadly compromised on any conceivable human time scale.

• Context

The main threats to the abundance and diversity of marine life derive from Earth's human population explosion with its concomitant overexploitation and pollution of coastal waters. The exploding population is also a major factor in global warming. In terms of direct threats posed to marine life from rising temperatures, dwindling sea ice in the Arctic and especially the Antarctic is probably the most clear-cut. While anthropogenic warming is undoubtedly a factor in coral reef destruction and the decline of fisheries, it may well not be the principal cause. As scientists learn more about long-term cycles involving ENSO and analogous oscillating pressure and current systems in other oceans, a better understanding of the relationship of current extreme events to long-term trends should emerge.

Martha A. Sherwood

• Further Reading

Benton, Michael J., and Richard Twitchett. "How to Kill (Almost) All Life: The End-Permian Extinction Event." *Trends in Ecology and Evolution* 18, no. 7 (July, 2003): 358-365. Attributes this mass extinction to massive methane release producing a catastrophic breakdown in normal temperature feedback mechanisms.

Peters, Robert L., and Thomas Lovejoy, eds. *Global Warming and Biological Diversity*. New Haven, Conn.: Yale University Press, 1992. Includes a chapter on marine biodiversity that emphasizes coral reefs.

Reynolds, Colin S. *Ecology of Phytoplankton*. New York: Cambridge University Press, 2006. Technical discussion of dead zones and their relationship to global warming and of theories of the Permian extinctions.

Saltzman, Barry. *Dynamical Paleoclimatology: Generalized Theory of Global Climate Change*. New York: Academic Press, 2002. Treats interactions between abiotic, biotic, and anthropogenic variables; discusses controversies about the magnitude of human climatological impact.

See also: Dolphins and porpoises; Endangered and threatened species; Extinctions and mass extinctions; Fishing industry, fisheries, and fish farming; Invasive exotic species; Ocean acidification; Ocean disposal; Penguins; Plankton; Polar bears; Reefs; Whales.

Offsetting

• **Categories:** Pollution and waste; economics, industries, and products

• Definition

Offsetting is the practice of compensating for pollution from one source or location by reducing or mitigating pollution from another—for example, planting trees to offset carbon dioxide (CO_2) emissions from vehicle use. Individuals have become more conscious of their possible impact on global climate (referred to as their "carbon footprint"), as well as of the difficulties of reducing GHG emissions. Thus, an idea has emerged that increases in greenhouse gas (GHG) emissions from a given source can be mitigated—or "offset"—by parallel activities to decrease emissions from another source or to remove carbon from the atmosphere and store it in sinks.

• Significance for Climate Change

Using vegetation to remove carbon from the atmosphere was proposed as early as 1976 by physicist Freeman Dyson. A decade later, in 1988, one of the first projects to provide an offset for carbon emissions—the planting of 52 million trees in Guatemala—was undertaken at the instigation of the Arlington, Virginia, energy company Applied Energy Services to justify a proposed power station. By the late 1990's, celebrity participation began to popularize the idea of individuals offsetting their carbon-emitting activities by paying companies to engage in tree planting and other green activities.

For example, the Rolling Stones in 2003 highlighted "carbon neutral touring," paying the company Future Forests to plant trees to neutralize the environmental impact of their British concerts: The Edinburgh Center for Carbon Management calculated that one tree for every 60 of the band's anticipated 160,000 fans should suffice. (The following year, questions were raised about how Future Forests was spending its money, and the company subsequently renamed itself the Carbon Neutral Company.) In 2006, former vice president and later Nobel laureate Al Gore applied the idea to his influential book, *An Inconvenient Truth*: "By supporting a new Native American wind farm and a new family farm methane energy project through NativeEnergy, this publication is carbon neutral."

The emphasis on newness reflects the so-called additionality requirement—that any carbon decrease produced by an offset be additional to what would otherwise occur. Such counterfactual claims are notoriously uncertain. Though such offsetting does focus attention on the environmental impact of people's lifestyle choices, critics view it as either confused (because of insurmountable problems in definition and measurement) or self-deceptive (because people are questionably encouraged to believe their environmental impact has really been neutralized).

On a larger scale, analogous issues arise about carbon emissions trading among, or within, nations. In agreements such as the Kyoto Protocol's clean development mechanism, many countries have committed to reduce GHGs by certain future dates, but such agreements sometimes permit targets to be reached through credits for activities that remove CO_2 from the atmosphere (carbon sequestration) or that reduce the amount of CO_2 added to the atmosphere (alternative energy), even if emissions are otherwise increasing. Critics of carbon trading question whether pollution is really offset, pointing to scams, misjudgments, and counterproductive efforts. They also challenge the fairness of offsets, criticizing in the name of environmental justice what has been labeled "CO_2lonialism." (See, for example, the 2004 Durban Declaration against carbon trading.)

"Carbon forestry," Larry Lohmann complained in 1999,

> proposes to lessen the atmospheric effects of the mining of fossil fuels by colonizing still other resources and exerting new pressures on local land and water rights; the community evicted by oil drillers today may find itself displaced by carbon-"offset" plantations tomorrow.

Nearly a decade later, Dyson remarked: "The humanist ethic accepts an increase of CO_2 in the atmosphere as a small price to pay, if worldwide industrial development can alleviate the miseries of the poor half of humanity." The empirical and ethical complexities of the offsetting issue are highlighted by the fact that Dyson and his critics both claim the moral high ground.

Edward Johnson

• Further Reading

Dyson, Freeman J. "Can We Control the Carbon Dioxide in the Atmosphere?" *Energy* 2 (1977): 287-291. Originally a 1976 Institute for Energy Analysis occasional paper. Dyson proposes removing CO_2 from the atmosphere through tree cultivation.

_______. *A Many-Colored Glass: Reflections on the Place of Life in the Universe*. Charlottesville: University of Virginia, 2007. Predicts and lauds the power of genetic engineering to provide for the world's food and energy needs while controlling GHG emissions.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. Emmaus, Pa.: Rodale, 2006. The print version of Gore's call to action represents itself as "the first book produced to offset 100 percent of the CO_2 emissions generated from production activities with renewable energy."

Lohmann, Larry. *The Dyson Effect: Carbon "Offset" Forestry and the Privatisation of the Atmosphere*. Sturminster Newton, Dorset, England: Corner House, 1999. Briefing paper critiquing "the privatization of carbon sinks" inspired by Dyson's proposal.

_______, ed. *Carbon Trading: A Critical Conversation on Climate Change, Privatisation, and Power*. Development Dialogue 48. Sturminster Newton, Dorset, England: Corner House, 2006. Study published by the Dag Hammarskjold Foundation, the Durban Group for Climate Justice, and the Corner House. Detailed, 362-page critical analysis of carbon trading and offsets.

Smith, Kevin, ed. *The Carbon Neutral Myth: Offset Indulgences for Your Climate Sins*. Amsterdam, the Netherlands: Transnational Institute/Carbon Trade Watch, 2007. A critique of the idea that carbon offsets could neutralize environmental impact; Jamie Hartzell's essay, "Offsets and 'Future Value Accounting,'" is particularly useful.

Willey, Zach, and Bill Chameides, eds. *Harnessing Farms and Forests in the Low-Carbon Economy: How to Create, Measure, and Verify Greenhouse Gas Offsets*. Durham, N.C.: Duke University Press, 2007. Collects a dozen essays and twenty-seven appendixes that discuss the practical specifics of establishing offsets.

See also: Baseline emissions; Carbon footprint; Certified emissions reduction; Clean development mechanism; Gore, Al; *Inconvenient Truth, An*; Kyoto Protocol.

Oil industry

• **Categories:** Fossil fuels; economics, industries, and products

The history, globalization, exploration, and geographic distribution of oil reserves, along with their eventual depletion, will affect not only the future of oil markets but also the way humans react to climate change.

• Key concepts

alternative energy: fuels and other energy resources that are renewable, nonpolluting, or both and have the potential to replace fossil fuels and other traditional energy resources

fossil fuels: energy resources formed from decayed organic matter under geological pressures over millions of years

greenhouse gases (GHGs): trace atmospheric gases that trap heat, preventing it from escaping into space

peak oil: the point at which oil availability and production reaches its zenith, before the Earth's oil resources begin either to dwindle or to become prohibitively expensive to exploit

• Background

The oil industry is a capital-intensive industry, and, therefore, its story generally is one of enormous wealth and, through wealth, one of political power and influence. The modern form of oil industry began when John D. Rockefeller's Standard Oil monopoly was vertically integrated, spanning production, refining, transporting, and retailing operations. The industry's fruits were initially spread abroad by Rockefeller's fleet of kerosene tankers. At the same time, Standard Oil was also securing a tight hold on the U.S. oil market. At the beginning of the twentieth century, it already controlled 87 percent of production, 82 percent of refining, and 85 percent of all petroleum marketing operations in the United States.

In short order, however, a brace of developments turned both the U.S. oil market and the petroleum industry into a competitive, global operation. The application of the Sherman Antitrust Act (1890) and subsequent breakup of Standard Oil into its regional components in 1911 forced some of its newly independent, "oil-short" units (notably Standard Oil of New York and later Mobil Oil) to look abroad for the oil that its gas stations had previously acquired from other parts of the Standard Oil trust. At approximately the same time, the conversion of navy ships to oil prompted Britain and the United States to urge their nascent oil companies to explore abroad for secure sources of oil to service their fleets in remote parts of the world. Soon the ancestor of British Petroleum and Standard Oil of New Jersey (originally Jersey Oil and later Exxon in the United States and Esso in Canada), Rockefeller's core unit, were competing with one another for the status of the world's largest petroleum corporation. That competition would endure throughout the twentieth century.

World War I introduced aircraft, tanks, and ambulances to the battlefield, further underscoring the relationship between national security and a healthy oil industry. Taking advantage of that fact, by the time that Henry Ford introduced the assembly-line

A Petro-Canada oil refinery and distribution center in Edmonton, Alberta. (Dan Riedlhuber/Reuters/Landov)

technique for making automobiles an affordable part of the average American's life, the U.S. oil industry had already used the war to turn the government in Washington from a trust-busting foe of big oil into one of its biggest supporters. Except for a few minor disruptions, that relationship lasted throughout the twentieth century, manifested in favorable tax laws, support of oil company efforts to stabilize the markets, and—following the rise of the Organization of Petroleum Exporting Countries (OPEC)—a willingness to allow the major oil corporations to undertake mergers akin to those that the Sherman Antitrust Act had been enacted to prevent. However, even before the rise of OPEC and those mergers, U.S. petroleum corporations had remained major players in the U.S. and global economies. On the eve of the 1973 oil crisis, the American petroleum industry was generating 30 percent of all domestic investment and 40 percent of all American investment in the developing world.

The benefits that the U.S. government offered to its smaller oil companies to go abroad and find new sources of oil to meet the growing demand for oil after World War II ultimately undermined the cartel of private oil companies that had stabilized the international price of oil for two generations. Known as "the Seven Sisters," this cartel—composed of Exxon, Mobil, Standard Oil of California (SoCal, later Chevron), British Petroleum, Royal Dutch Shell, Texaco, and Gulf—accounted for 90 percent of all global production outside the United States and Russia, 80 percent of all refining operations, and 70 percent of all marketing operations in the early post-World War II years. Oil-producing states either sold their oil to these companies at the proffered price or did not sell their oil at all.

Encouraged by government incentives, in the aftermath of World War II, several smaller U.S. oil companies began to explore for oil abroad. More joined the pack when one of the first, Getty Oil, struck it rich by finding oil in Kuwait. Unlike the Sisters, these individual companies had little bargaining power. Gradually they cut into the share of the market controlled by the Sisters (whose control over production outside the United States and the Soviet Union dropped to 70 percent by 1970). More important, their individual operations were usually in one country only, and they either bought their oil from that state on its terms or did not acquire foreign oil at all. As the international oil market grew ever tighter during the 1968-1973 era of Western economic expansion, their host governments demanded—and received from these companies—much better financial payoffs than those offered by the Sisters to their producing states. Given the increasingly tight energy market, the Sisters had to extend the same deals to their host governments. Consequently, even before the October, 1973, Yom Kippur War led to the Arab oil embargo and OPEC's rise to prominence, the Seven Sisters' hold on the global industry was already eroding rapidly.

• OPEC and the Global Economy

The 1973 Arab oil embargo on countries friendly to Israel created panic in the marketplace, as Western states bid against one another for oil that, in some instances, they did not have the storage facilities to accommodate. The price of oil on the spot market jumped from under three dollars per barrel (the Sisters' last posted price on the eve of the Yom

Kippur War) to the twenty-dollar-per-barrel range. In turn, this hysteria allowed OPEC to buy out the Seven Sisters and other Western oil companies and establish itself as the new international cartel in charge of setting the price of oil. Subsequently, both the fortunes of the international petroleum industry and those of the international economy fluctuated with OPEC's fortunes and its ability to keep the price of oil stable and in a price range affordable enough to allow for overall economic growth and the economic development of Third World countries.

In general, OPEC's record has been spotty. The OPEC-endorsed price hikes in the 1970's—to twelve dollars per barrel in 1973 and to more than thirty dollars per barrel in 1979 (following the fall of the shah of Iran and resultant drop in the availability of Iranian oil in the market)—led to a prolonged recession in the oil-importing, economically advanced Western world throughout much of the 1980's, which depressed the price of OPEC oil significantly. As a result, oil was relatively cheap in the 1990's, which not only led to a renewed expansion of the global economy but also enabled both India and China to mount significant development plans fueled by low-cost, imported petroleum. With the tightening of the market at the turn of the twenty-first century and the uncertain market conditions during the first decade thereof, OPEC again allowed the price of oil to soar to recession-inducing levels, slowing the base of globalization and, in many instances, encouraging countries to adopt protectionist policies antithetical to the ideals of a globalized economy.

Meanwhile, partly in order to survive the eras of depressed oil prices, the global petroleum industry reshaped itself, from the dominant Seven Sisters cartel of private oil companies into a complex mixture of private and state oil companies, complicated by the fact that not all of the state-owned oil companies in the world were the economic creatures of OPEC members.

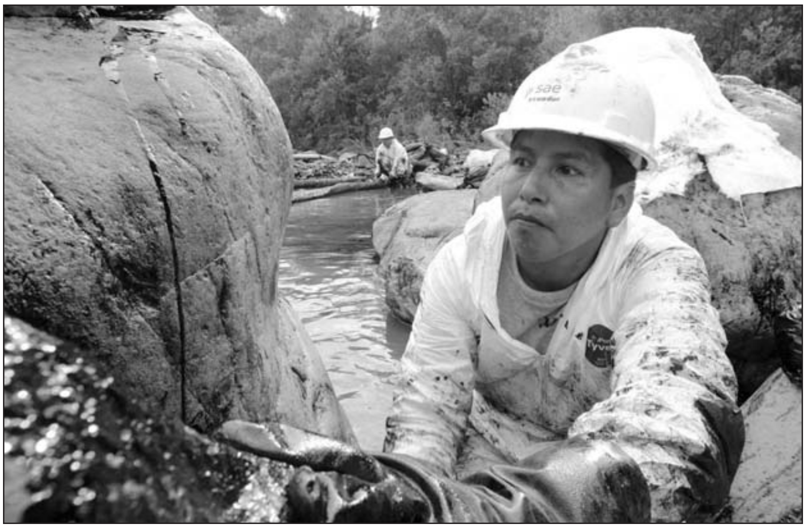
• Diversification, Mergers, and the Western Oil Corporations

When OPEC took over the international oil market in 1973, the possibility remained of discussing Western oil companies in the terminology that had been used for half a century. There were the "majors," the Seven Sisters, and then there were the "independents," that is, the comparatively small producers that included enterprises from family operations like Krumme Oil in Oklahoma to large, multinational oil companies like Getty Oil and Atlantic Richfield Company (ARCO). During the high-price energy era of the 1970's and early years of the following decade, all these companies reaped large profits, and the majors and many of the larger independents reinvested those profits in the pursuit of alternative energy schemes (Exxon, for example, invested five billion dollars in its oil-from-shale project in Colony, Colorado) and the acquisition of holdings in such other energy sectors as coal and uranium. These companies would do much the same vis-à-vis biofuels in the high-cost petroleum era that followed the U.S. invasion of Iraq in 2003.

The downturn in the price of oil in the 1980's caused the majors to shut down most of their alternative energy projects and to seek means for surviving in the lean years of the global recession. As these companies would do in even more publicized ventures during the 1990's, when the price of oil remained in the twenty-five-dollar-per-barrel range, many turned to mergers in order to economize, beginning with the 1984 merger between SoCal and Gulf Oil that enabled Gulf to sell off many of its subsidiaries and service stations and led SoCal to change its name to Chevron. A decade later, what had been exceptional in 1984 became, momentarily, almost commonplace. The process began in December, 1998, when British Petroleum (BP) acquired Amoca (formerly the American Oil Company or Standard Oil of Indiana) for more than fifty billion dollars. The following year the combined corporation purchased ARCO (one of the major players in the discovery of Alaskan oil). Combined with its subsequent acquisition of Burmah Castrol, a lubricant manufacturing company, BP was able to pare approximately twenty thousand jobs worldwide and become temporarily the world's largest oil company.

BP held that distinction for only a few months until Exxon and Mobil merged in November, 1999, into the largest corporation in the world. The transaction enabled the combined corporation to sell off more than seventeen hundred service stations (to Tosco) and trim its payroll by nearly ten thousand employees. The merger mania did not end there, or on the U.S. side of the Atlantic Ocean. In 1999, two giant European petroleum firms, France's Total and Belgium's Petrofina, merged into TotalFina and then acquired France's other major petroleum company, Elf, to make TotalFina the fourth largest petroleum company in the world. Then, in 2001, another Sister-Sister marriage occurred, this time involving Chevron and Texaco.

In short, by the time oil prices began to rise appreciably shortly after the terrorist attacks on New York and Washington, D.C., on September 11, 2001, and especially following the U.S. invasion of Iraq in 2003, a new set of six "supermajors" had emerged in the world of private oil companies: Exxon-Mobil, BP-Amoco, Chevron-Texaco, TotalFina, Royal Dutch Shell, and Conoco-Phillips (whose two units completed their merger in August, 2002). All are vertically integrated and, compared to the "independents," have a commanding share of the market. Unlike that of the Seven Sisters, though, their power is rooted in sales, not in the production of oil: They accounted for only about 10 percent of the oil produced in the early years of the twenty-first century and their combined ownership of oil and gas accounts for less than 5 percent of the world's know oil and gas reserves.



Ecuadoran workers clean up an oil spill on the Santa Rosa River in February, 2009. (Guillermo Granja/Reuters/Landov)

• State-Owned Petroleum Industries

Comparatively speaking, the real "supermajors" are not these private oil companies but the seven largest state-owned petroleum companies in the contemporary world, led by those of Saudi Arabia, Iran, Russia, and Venezuela, but also including the state-owned companies of China, Brazil, and Malaysia. Collectively, these seven account for nearly one-third of the world's gas and oil production and the majority of its know oil reserves. More important, when combined with the production capacity and reserve holdings of other state-owned oil companies, these actors account for the overwhelming majority of the world's oil and gas production and reserves. In that sense they are more analogous to the Seven Sisters than today's "supermajor" private oil corporations. However, unlike the Seven Sisters, they do not collaborate with one another. Quite to the contrary, they sometimes compete with one another for influence inside OPEC (where only Saudi Arabia, Iran, and Venezuela are represented) and for profits in the world's petroleum marketplace.

• Oil Depletion and "Peak Oil"

Because petroleum is a nonrenewable natural resource, the industry will someday face the inevitable depletion of the world's oil supply. In 2007, the BP *Statistical Review of World Energy* predicted that the reserves in the Middle East would last 79.5 more years; those in Latin America, 41.2 years; and those in North America, 12 years. At 2008 production levels, the world's oil reserves would be depleted in 40.5 years.

A theory developed by geologists Marion King Hubbert in the 1940's, known as the Hubbert's peak theory (also known as "peak oil") or the "Hubbert curve," identified patterns of resource use that let Hubbert to predict that U.S. oil production would peak in the early 1970's. The extension of this analysis to world energy production to the prediction that a worldwide energy crisis would occur after production of oil and gas peaked. Research conducted by IBISWorld suggested that biofuels such as ethanol and biodiesel would continue to supplement petroleum but that, because output levels were low, these fuels would not replace local oil production and would play only a minor role in reducing dependence on imported crude oil.

• Peak Oil and Climate Change

Perhaps the most damaging effect of petrochemicals is global warming. The use of fossil fuels releases carbon dioxide (CO_2) and methane, two greenhouse gases (GHGs) that trap the Earth's heat within the atmosphere and lead to warmer oceans, warmer climates, unstable weather, rising sea levels, and concomitant phenomena such as floods, drought, shifts in water flow, forest fires, famines, and extinctions. Such changes have already been noted but do not take place simultaneously or immediately; still they can occur over as short a time as decades, and their ecological and climate impacts are extremely complex and difficult to predict.

There is some consensus, however, that such changes, and their climate impacts, will increase in occurrence and severity, requiring ongoing mitigation and response. The projected effects of climate change are sufficient reason by themselves to seek to reduce fossil fuel dependency and replace energy needs with more sustainable resources. Peak oil will challenge humankind's ability to deal with and adapt to global warming: a decline in global oil supply, paired with an increase in the cost of goods and services, reduces the ability to make the investments in infrastructure that are required in order to respond to global warming in a proactive and coordinated fashion. Therefore, it is imperative that policy makers consider proposed responses to peak oil and global warming in tandem.

Joseph R. Rudolph, Jr.

• Further Reading

Deffeyes, Kenneth S. *Hubbert's Peak: The Impending World Oil Shortage.* Rev. ed. Princeton, N.J.: Princeton University Press, 2003. Argues that oil production is peaking and will soon enter a terminal decline as existing oil fields run dry and large new finds become increasingly scarce.

Falola, Toyin, and Ann Genova. *The Politics of the Global Oil Industry: An Introduction.* Westport, Conn.: Praeger, 2005. Details connections throughout the world between business and political interests in the production and distribution of oil.

Heinberg, Richard. *The Party's Over: Oil, War, and the Fate of Industrial Societies.* 2d ed. Gabriola Island, B.C.: New Society, 2003. Argues that cheap energy sources, such as oil, are about to become more expensive, bringing about the end of the industrial era, which depends upon cheap energy. Recommends actions that Western nations and local communities can undertake to manage this transition.

International Energy Agency. *Oil Crises and Climate Challenges: Thirty Years of Energy Use in IEA Countries.* Paris: Author, 2004. Study of energy use during the last three decades of the twentieth century, detailing national and international responses to energy shortages and climatic shifts.

Paul, Bill. *Future Energy: How the New Oil Industry Will Change People, Politics, and Portfolios.* Hoboken, N.J.: John Wiley and Sons, 2007. Argues that a coming revolution in energy technology will transform the global economy, as well as sociopolitical structures. Recommends steps to benefit from the change.

Raymond, Martin S., and William L. Leffler. *Oil and Gas Production in Nontechnical Language.* Tulsa, Okla.: PennWell, 2006. Good overview of the oil and gas industries. Contains illustrative graphs, charts, and drawings that make the complex processes involved in oil and gas production understandable.

Sampson, Anthony. *The Seven Sisters: The Great Oil Companies and the World They Shaped.* New York: Bantam Books, 1976. History of the oil industry, its development into a major force, and its effects on the world.

Simmons, Matthew R. *Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy.* Hoboken, N.J.: John Wiley and Sons, 2005. Focuses on Middle Eastern peak oil production and its threat to global economic stability.

Skeet, Ian. *OPEC: Twenty-five Years of Prices and Politics.* New York: Cambridge University Press, 1988. Focused study of the Organization of Petroleum Exporting Countries and the political motives and consequences of its decisions to raise and lower oil prices.

Solberg, Carl. *Oil Power: The Rise and Imminent Fall of an American Empire.* New York: Mason/Charter, 1976. Explication of the role of petroleum (both domestic and imported) in driving the United States' rise as a global superpower and the implications of peak oil for its future geopolitical status.

Yergin, Daniel. *The Prize: The Epic Quest for Oil, Money, and Power.* 1991. New ed. New York: The Free Press, 2008. Comprehensive, Pulitzer Prize-winning history of oil as a commodity and of the oil industry.

See also: Fossil fuel reserves; Fossil fuels; Fuels, alternative; Gasoline prices; Hubbert's peak; Organization of Petroleum Exporting Countries.

Oregon Institute of Science and Medicine

- **Category:** Organizations and agencies
- **Date:** Established 1980
- **Web address:** http://www.oism.org

• Mission

The Oregon Institute of Science and Medicine (OISM) figures in the debate on global climate change mostly because of controversial mailings sent out in 1998 and 2007, and its sponsorship of the Petition Project or Oregon Petition, a petition by scientists opposed to the idea of global warming that as of January, 2009, had more than thirty-one thousand signers. OISM is a small, nonprofit private institution in Cave Junction, Oregon, a small community of about fourteen hundred residents in southwestern Oregon. The Institute was founded in 1980 and as of 2009 had six faculty (though it does not teach classes) as well as a number of volunteers. Most of its stated research efforts involve research on medical subjects, but it also lists as research interests "improvement in precollege education curricula, especially in the sciences; and improved civilian emergency preparedness." In the climate debate it is prominent as sponsor of the Oregon Petition and distributor of papers rejecting the idea of global warming. The late, eminent scientist Frederick Seitz served as spokesperson for some of these efforts.

• Significance for Climate Change

In 1998, the OISM first attracted widespread attention among climate researchers by distributing a mass mailing of a paper casting doubt on global warming. The paper was accompanied by a letter signed by Seitz, who had an illustrious career in solid state physics at the University of Illinois and Rockefeller University that included chairing the United States National Academy of Sciences from 1962 to 1969 and receiving the National Medal of Science in 1973. In 1979, Seitz became a paid consultant to the tobacco industry and led its scientific research program to discredit the evidence linking smoking to cancer and other illnesses. After his connections with the tobacco industry ended, Seitz became a critic of various environmental causes, including climate change.

The article mailed by the OISM looked like a genuine article reprinted by a scientific journal. In fact, the article almost exactly duplicated the format of the *Journal of the National Academy of Sciences.* The academy took the unusual step of issuing a public statement disclaiming any connection between itself and the paper, and many scientists expressed anger that Seitz had used his former connections to the academy to promote a paper that seemed purposely designed to resemble an academy publication. Seitz later claimed to have urged the authors of the paper to submit it for peer review.

In 2007, the OISM sent out another mass-mailed paper, "Environmental Effects of Increased Atmospheric Carbon Dioxide," by Arthur B. Robinson, Noah E. Robinson, and Willie Soon, which had been published in the *Journal of American Physicians and Surgeons.* The *Journal of American Physicians and Surgeons* is published online by a politically conservative medical organization, the Association of American Physicians and Surgeons. The journal specializes in articles critical of government health care regulations, but it also frequently publishes nonmedical articles appealing to political conservatives. The paper by Robinson, Robinson, and

Soon included much of the material from the 1998 paper and was also accompanied by a letter from Seitz.

The other major effort by the OISM to influence the climate debate is the Petition Project or Oregon Petition. The petition reads in part:

> We urge the United States government to reject the global warming agreement that was written in Kyoto, Japan in December, 1997, and any other similar proposals. The proposed limits on greenhouse gases would harm the environment, hinder the advance of science and technology, and damage the health and welfare of mankind.

The Petition Project provides lists of signatories and data on their academic credentials. As of January 23, 2009, the Petition Project claimed:

> The current list of 31,072 petition signers includes 9,021 PhD; 6,961 MS; 2,240 MD [medical] and DVM [veterinary]; and 12,850 BS or equivalent academic degrees. Most of the MD and DVM signers also have underlying degrees in basic science.

One significant problem with the Oregon Petition is that it does not list the institutional affiliations of signers. It also does not verify the credentials of signers. The words "credential" and "credibility" both come from the same Latin word meaning "believe." Credentials are evidence that someone is credible when talking about a subject. A patient may not have the technical training to understand or identify a medical problem, but a doctor's credentials are a strong indication that the doctor's opinion is credible. The doctor may also be well informed about many other nonmedical subjects (like climate change), but without credentials in those areas, there is no evidence one way or the other to judge his or her credibility.

Only 29 percent of the signers of the Oregon Petition have doctoral degrees in science, whereas 41 percent have only a bachelor's degree. A breakdown by specialty claimed 3,697 signers were scientists in the Earth, atmospheric, and environmental sciences, including 578 atmospheric scientists. Only 12 percent of the signers have degrees in Earth, atmospheric, and environmental science, and fewer than 2 percent are atmospheric scientists. The Oregon Petition Web site claims:

> All of the listed signers have formal educations in fields of specialization that suitably qualify them to evaluate the research data related to the petition statement.

Most of the signers, however, are in fields that have no real bearing on climate change, and most do not have the level of training needed to evaluate the research on climate change. They may be perfectly qualified in their own specialties, but they do not have credentials, or credibility, in climate research.

Although there are many uncertainties in predicting future climate changes and in formulating policy on climate change, campaigns such as the Oregon Petition and the Seitz mailings damage, rather than advance, the skeptic cause. Real experts on climate change are not persuaded by the Oregon Petition or the OISM mailings. The use of deceptive mailings and irrelevant credentials may persuade people without expertise in science, but those tactics serve only to erode the credibility of skeptics in the eyes of scientists.

Steven I. Dutch

• Further Reading

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Climate Change: A Guide to the Debate*. New York: Cambridge University Press, 2006. Overview of the controversy over global warming that includes analysis of the philosophical and practical issues raised in general by the intersection of politics and science.

Michaels, David. *Doubt Is Their Product: How Industry's Assault on Science Threatens Your Health*. New York: Oxford University Press, 2008. Examination of tactics used to exaggerate doubt in environmental health controversies. Many of these techniques were first used in the campaign to downplay the health risks of tobacco and are being applied to climate change.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change*. Boston: Beacon Press, 2007. The chapter "Turning Up the Heat: A Skeptic's Guide to Climate Change" lays out a careful response to global warming skeptics that addresses their concerns.

Pittock, A. Barrie. *Climate Change: Turning Up the Heat*. Sterling, Va.: Earthscan, 2005. Includes a chapter on the function of skeptics and uncertainty in the global warming debate.

Robinson, Arthur B., Noah E. Robinson, and Willie Soon. "Environmental Effects of Increased Atmospheric Carbon Dioxide." *Journal of American Physicians and Surgeons* 12, no. 3 (Fall, 2007). The 2007 paper of the OISM. Contains much of the information published in the 1998 paper but with some further discussion, figures, and references.

See also: Pseudoscience and junk science; Scientific credentials; Scientific proof; Skeptics.

Organization of Petroleum Exporting Countries

- **Categories:** Organizations and agencies; fossil fuels; energy
- **Date:** Established 1960
- **Web address:** http://www.opec.org/

OPEC promotes the use of petroleum and attempts to make oil production profitable for its member countries. Petroleum is one of the three fossil fuels contributing to an increase in atmospheric CO_2, which is a key factor in global warming.

• Key concepts

Arab oil embargo: a 1973 action by Arab members of OPEC to stop exporting petroleum to the United States and other supporters of Israel

Arab states: countries in the Middle East in which Arabs are the primary ethnic group, often incorrectly assumed to include Iran

cartel: an organization that limits competition in a particular industry to increase profitability for its members

fossil fuels: carbon-based fuels derived from decayed plants and animals under geologic pressure over millions of years

founding members: an official designation given to the five countries that formed OPEC

OPEC Conference: the chief authority within OPEC; composed of representatives of all the member states

secretariat: the administrative section of OPEC, which carries out the day-to-day functions of the organization

• Mission

Meeting in Baghdad, Iraq, September 10-14, 1960, Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela formed the Organization of Petroleum Exporting Countries (OPEC). The organization is often referred to as a cartel, with the aim of coordinating petroleum production and policies. Through these actions, the members hope to achieve maximum economic return, without causing a decrease in demand for petroleum. There are seven other active members (Algeria, Angola, Ecuador, Libya, Nigeria, Qatar, and the United Arab Emirates).

• OPEC Organization

OPEC is an intergovernmental organization with its headquarters in Vienna, Austria. Any oil-exporting country may apply for membership, which is granted if the application is accepted by three-fourths of the current members, including all five of the founding members. At the OPEC Conference all members have one vote, and the conference alone has the power to make decisions on all policy issues of substance, by unanimous vote. At its semiannual sessions, the conference also appoints a secretary general who oversees the daily operation of the organization. All sections of the organization are charged with developing an acceptable policy that will match supply and demand for petroleum, allowing for stable prices and supplies. OPEC must take into consideration the effect these policies will have on other oil exporting countries and upon the nations that consume petroleum.

For the first decade of its existence, OPEC had limited opportunities. Large American and European petroleum companies dominated all aspects of oil production and marketing. Around the end of the decade, most members nationalized oil production, giving themselves greater power. This also gave the countries a greater stake in having a stable mar-

OPEC president Chakib Khelil of Algeria prepares to take questions from the press in September, 2008. (Heinz-Peter Bader/Reuters/Landov)

ketplace for trading petroleum. OPEC set production quotas for each country that insured relative stability, since slightly more than half the traded oil originates in OPEC. OPEC prices all of its oil in U.S. dollars.

• The 1973 Arab Oil Embargo

In 1973, American economic problems had caused a decrease in the value of the dollar. Thus, OPEC leaders desired to increase the price of oil. On October 6, the Yom Kippur War was launched by Egypt and Syria against Israel, giving OPEC an excuse to raise prices and make a political statement. Led by the Persian Gulf oil producers, other Middle Eastern states sought to weaken the ties between the United States and Israel. On October 17, OPEC decided to end oil exports to those countries supporting Israel. OPEC cannot force its members to follow its decisions. However, within two days all the Arab states that were OPEC members joined in this action, as did Iran. In just over two weeks, OPEC cut production by one fourth. The actual military conflict was only twenty days in length, but the oil embargo lasted five months. The rising oil prices were a strong incentive for other oil producing countries to increase their production. This caused the resolve of some participating in the embargo to weaken, so with the military conflict ended and the price of oil greatly increased, OPEC could declare victory and stop boycotting the American market.

Even though the Arab oil embargo only affected 7 percent of the oil available to the United States, it sent tremors throughout the United States. The psychological impact of people worrying about the gasoline supply resulted in long lines forming at gas stations across the country. Many areas of the country suffered gasoline shortages. By the end of the embargo, the price of gasoline had increased by about 45 percent nationwide. The threat of another oil embargo led to support for more domestic oil production and exploration and for non-OPEC suppliers. In the United States, the long term effect of the embargo was energy conservation, including mandated automobile efficiency standards. By decreasing dependence upon OPEC oil, the United States was able to decrease OPEC's economic and political power.

• The Post-Embargo Era

The focus of OPEC's work since the mid-1970's has been to stabilize oil prices in a range that is advantageous for its members. About twice a decade an unexpected political or economic situation has affected the oil markets, causing rapid price increases or decreases. OPEC desires stability or orderly petroleum price increases. Since the 1990's a new challenge has arisen: the strong international movement to reduce dependence upon fossil fuels to combat global warming. OPEC fears this could significantly reduce the world's demand for oil. During the 2000's, OPEC produces about 45 percent of the world's petroleum and anticipates this increasing to over 50 percent in the next decade. While it has passed resolutions in favor of environmental responsibility and efficient automobiles, it also lobbies hard against any special taxation of oil, or petroleum products. OPEC believes that in the foreseeable future there is a continuing major role for oil. To offset any contribution oil makes to global warming, it advocates carbon capture and storage technologies, which captures carbon dioxide pollution and stores it underground. It is an advocate for investment in exploration for new oil fields and development of current fields.

• Context

The balancing act that OPEC must undertake between optimal profitability and continued demand for oil products means that the secretariat is very active. The secretariat is constantly trying to forecast the global economic future, while at the same time watching for political activity that might be seen as a threat to the stability of the oil supply. OPEC was formed because there was a strong desire for the governments and citizens of the countries with the oil resources to get a larger share of the profits, rather than having them go to foreign firms. As such, it is only to be expected that OPEC will push hard to retain its markets for oil. With its central focus on economic interests, it should be expected that OPEC will fight hard to stop any movement to greatly reduce the use of oil, even if these changes are part of a process toward ending global warming. To get OPEC support on climate change issues, any proposals must allow continued use of petroleum products.

Donald A. Watt

• Further Reading

Leggett, Jeremy. *Carbon War: Global Warming and the End of the Oil Era*. London: Routledge, 2001. Advocate of alternative forms of energy argues that lobbyists for OPEC and the major oil companies have caused continuing climate change by blocking the development of nonfossil fuel resources.

Mills, Robin. *The Myth of the Oil Crisis: Overcoming the Challenges of Depletion, Geopolitics, and Global Warming*. Santa Barbara, Calif.: Praeger, 2008. Asserts that oil resources will continue to be available; discusses the need to develop policies that will ensure political stability and keep climate change to a minimum.

Parra, Francisco. *Oil Politics: A Modern History of Petroleum*. London: I. B. Tauris, 2004. A former Secretary General of OPEC, the author focuses on the interactions between the producers and consumers of oil since the middle of the twentieth century.

See also: Fossil fuel reserves; Fossil fuels; Gasoline prices; Hubbert's peak; Iran; Motor vehicles; Oil industry; Saudi Arabia; World Trade Organization.

ENCYCLOPEDIA OF
GLOBAL WARMING

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Volume 3

Oxygen, atmospheric-Younger Dryas
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Abbreviations and Acronyms

AMO: Atlantic multidecadal oscillation
AQI: Air Quality Index
C^{14}: carbon 14
CCS: carbon capture and storage
CDM: clean development mechanism
CER: certified emissions reduction
CFCs: chlorofluorocarbons
CH_4: methane
CITES: Convention on International Trade in Endangered Species
CMP: Conference of the Parties to the United Nations Framework Convention on Climate Change, functioning as the meeting of the Parties to the Kyoto Protocol
CO: carbon monoxide
CO_2: carbon dioxide
CO_2e: carbon dioxide equivalent
COP: Conference of the Parties [to a treaty, such as the Framework Convention on Climate Change or the Convention on Biological Diversity]
COP/MOP: Conference of the Parties to the United Nations Framework Convention on Climate Change, functioning as the meeting of the Parties to the Kyoto Protocol
COP-1: First Conference of the Parties
CSD: Commission on Sustainable Development
DNA: deoxyribonucleic acid
EEZ: exclusive economic zone
ENSO: El Niño-Southern Oscillation
EPA: Environmental Protection Agency
ERU: emission reduction unit
FAO: Food and Agriculture Organization
GCM: general circulation model
GDP: gross domestic product
GHG: greenhouse gas
GWP: global warming potential
H_2: hydrogen (molecular)
HCFCs: hydroclorofluorocarbons
HFCs: hydrofluorocarbons
IAEA: International Atomic Energy Agency
IGY: International Geophysical Year
IMF: International Monetary Fund
INQUA: International Union for Quaternary Research
IPCC: Intergovernmental Panel on Climate Change
ITCZ: Inter-Tropical Convergence Zone
IUCN: International Union for Conservation of Nature
LOICZ: Land-Ocean Interactions in the Coastal Zone
MOC: meridional overturning circulation
MOP: meeting of the Parties [to a treaty, such as the Kyoto Protocol]
MOP-1: first meeting of the Parties
N_2O: nitrous oxide
NAAQS: National Ambient Air Quality Standards
NAM: Northern annular mode
NAO: North Atlantic Oscillation
NASA: National Aeronautics and Space Administration
NATO: North Atlantic Treaty Organization
NGO: nongovernmental organization
NOAA: National Oceanic and Atmospheric Administration
NO_x: nitrogen oxides
NRC: National Research Council
O^{16}: oxygen 16
O^{18}: oxygen 18
O_2: oxygen (molecular)
O_3: ozone
OECD: Organization for Economic Cooperation and Development
OPEC: Organization of Petroleum Exporting Countries
PFCs: perfluorocarbons
QELRCs: quantified emission limitation and reduction commitments
RuBisCO: Ribulose-1,5-bisphosphate carboxylase/oxygenase
SAM: Southern annular mode
SCOPE: Scientific Committee on Problems of the Environment
SF_6: sulfur hexafluoride
SO_2: sulfur dioxide

SSTs: sea surface temperatures
SUV: sports utility vehicle
THC: Thermohaline circulation
UNCED: United Nations Conference on Environment and Development
UNDP: United Nations Development Programme
UNEP: United Nations Economic Programme
UNESCO: United Nations Educational, Scientific, and Cultural Organization
UNFCCC: United Nations Framework Convention on Climate Change
UV: ultraviolet
VOCs: volatile organic compounds
WHO: World Health Organization
WMO: World Meteorological Organization

Common Units of Measure

Common prefixes for metric units—which may apply in more cases than shown below—include *giga-* (1 billion times the unit), *mega-* (one million times), *kilo-* (1,000 times), *hecto-* (100 times), *deka-* (10 times), *deci-* (0.1 times, or one tenth), *centi-* (0.01, or one hundredth), *milli-* (0.001, or one thousandth), and *micro-* (0.0001, or one millionth).

Unit	***Quantity***	***Symbol***	***Equivalents***
Acre	Area	ac	43,560 square feet 4,840 square yards 0.405 hectare
Ampere	Electric current	A *or* amp	1.00016502722949 international ampere 0.1 biot *or* abampere
Angstrom	Length	Å	0.1 nanometer 0.0000001 millimeter 0.000000004 inch
Astronomical unit	Length	AU	92,955,807 miles 149,597,871 kilometers (mean Earth-Sun distance)
Barn	Area	b	10^{-28} meters squared (approx. cross-sectional area of 1 uranium nucleus)
Barrel (dry, for most produce)	Volume/capacity	bbl	7,056 cubic inches; 105 dry quarts; 3.281 bushels, struck measure
Barrel (liquid)	Volume/capacity	bbl	31 to 42 gallons
British thermal unit	Energy	Btu	1055.05585262 joule
Bushel (U.S., heaped)	Volume/capacity	bsh *or* bu	2,747.715 cubic inches 1.278 bushels, struck measure
Bushel (U.S., struck measure)	Volume/capacity	bsh *or* bu	2,150.42 cubic inches 35.238 liters
Candela	Luminous intensity	cd	1.09 hefner candle
Celsius	Temperature	C	1° centigrade
Centigram	Mass/weight	cg	0.15 grain
Centimeter	Length	cm	0.3937 inch
Centimeter, cubic	Volume/capacity	cm^3	0.061 cubic inch
Centimeter, square	Area	cm^2	0.155 square inch

Unit	*Quantity*	*Symbol*	*Equivalents*
Coulomb	Electric charge	C	1 ampere second
Cup	Volume/capacity	C	250 milliliters 8 fluid ounces 0.5 liquid pint
Deciliter	Volume/capacity	dl	0.21 pint
Decimeter	Length	dm	3.937 inches
Decimeter, cubic	Volume/capacity	dm^3	61.024 cubic inches
Decimeter, square	Area	dm^2	15.5 square inches
Dekaliter	Volume/capacity	dal	2.642 gallons 1.135 pecks
Dekameter	Length	dam	32.808 feet
Dram	Mass/weight	dr *or* dr avdp	0.0625 ounce 27.344 grains 1.772 grams
Electron volt	Energy	eV	$1.5185847232839 \times 10^{-22}$ Btus $1.6021917 \times 10^{-19}$ joules
Fermi	Length	fm	1 femtometer 1.0×10^{-15} meters
Foot	Length	ft *or* ′	12 inches 0.3048 meter 30.48 centimeters
Foot, cubic	Volume/capacity	ft^3	0.028 cubic meter 0.0370 cubic yard 1,728 cubic inches
Foot, square	Area	ft^2	929.030 square centimeters
Gallon (British Imperial)	Volume/capacity	gal	277.42 cubic inches 1.201 U.S. gallons 4.546 liters 160 British fluid ounces
Gallon (U.S.)	Volume/capacity	gal	231 cubic inches 3.785 liters 0.833 British gallon 128 U.S. fluid ounces
Giga-electron volt	Energy	GeV	$1.6021917 \times 10^{-10}$ joule
Gigahertz	Frequency	GHz	—
Gill	Volume/capacity	gi	7.219 cubic inches 4 fluid ounces 0.118 liter

Unit	*Quantity*	*Symbol*	*Equivalents*
Grain	Mass/weight	gr	0.037 dram 0.002083 ounce 0.0648 gram
Gram	Mass/weight	g	15.432 grains 0.035 avoirdupois ounce
Hectare	Area	ha	2.471 acres
Hectoliter	Volume/capacity	hl	26.418 gallons 2.838 bushels
Hertz	Frequency	Hz	$1.08782775707767 \times 10^{-10}$ cesium atom frequency
Hour	Time	h	60 minutes 3,600 seconds
Inch	Length	in *or* ″	2.54 centimeters
Inch, cubic	Volume/capacity	in^3	0.554 fluid ounce 4.433 fluid drams 16.387 cubic centimeters
Inch, square	Area	in^2	6.4516 square centimeters
Joule	Energy	J	$6.2414503832469 \times 10^{18}$ electron volt
Joule per kelvin	Heat capacity	J/K	$7.24311216248908 \times 10^{22}$ Boltzmann constant
Joule per second	Power	J/s	1 watt
Kelvin	Temperature	K	–272.15 Celsius
Kilo-electron volt	Energy	keV	$1.5185847232839 \times 10^{-19}$ joule
Kilogram	Mass/weight	kg	2.205 pounds
Kilogram per cubic meter	Mass/weight density	kg/m^3	$5.78036672001339 \times 10^{-4}$ ounces per cubic inch
Kilohertz	Frequency	kHz	—
Kiloliter	Volume/capacity	kl	—
Kilometer	Length	km	0.621 mile
Kilometer, square	Area	km^2	0.386 square mile 247.105 acres
Light-year (distance traveled by light in one Earth year)	Length/distance	lt-yr	5,878,499,814,275.88 miles 9.46×10^{12} kilometers

Unit	*Quantity*	*Symbol*	*Equivalents*
Liter	Volume/capacity	L	1.057 liquid quarts 0.908 dry quart 61.024 cubic inches
Mega-electron volt	Energy	MeV	—
Megahertz	Frequency	MHz	—
Meter	Length	m	39.37 inches
Meter, cubic	Volume/capacity	m^3	1.308 cubic yards
Meter per second	Velocity	m/s	2.24 miles per hour 3.60 kilometers per hour
Meter per second per second	Acceleration	m/s^2	12,960.00 kilometers per hour per hour 8,052.97 miles per hour per hour
Meter, square	Area	m^2	1.196 square yards 10.764 square feet
Metric. *See* unit name			
Microgram	Mass/weight	mcg *or* µg	0.000001 gram
Microliter	Volume/capacity	µl	0.00027 fluid ounce
Micrometer	Length	µm	0.001 millimeter 0.00003937 inch
Mile (nautical international)	Length	mi	1.852 kilometers 1.151 statute miles 0.999 U.S. nautical miles
Mile (statute or land)	Length	mi	5,280 feet 1.609 kilometers
Mile, square	Area	mi^2	258.999 hectares
Milligram	Mass/weight	mg	0.015 grain
Milliliter	Volume/capacity	ml	0.271 fluid dram 16.231 minims 0.061 cubic inch
Millimeter	Length	mm	0.03937 inch
Millimeter, square	Area	mm^2	0.002 square inch
Minute	Time	m	60 seconds
Mole	Amount of substance	mol	6.02×10^{23} atoms or molecules of a given substance

Unit	*Quantity*	*Symbol*	*Equivalents*
Nanometer	Length	nm	1,000,000 fermis 10 angstroms 0.001 micrometer 0.00000003937 inch
Newton	Force	N	x 0.224808943099711 pound force 0.101971621297793 kilogram force 100,000 dynes
Newton meter	Torque	N·m	0.7375621 foot-pound
Ounce (avoirdupois)	Mass/weight	oz	28.350 grams 437.5 grains 0.911 troy or apothecaries' ounce
Ounce (troy)	Mass/weight	oz	31.103 grams 480 grains 1.097 avoirdupois ounces
Ounce (U.S., fluid or liquid)	Mass/weight	oz	1.805 cubic inch 29.574 milliliters 1.041 British fluid ounces
Parsec	Length	pc	30,856,775,876,793 kilometers 19,173,511,615,163 miles
Peck	Volume/capacity	pk	8.810 liters
Pint (dry)	Volume/capacity	pt	33.600 cubic inches 0.551 liter
Pint (liquid)	Volume/capacity	pt	28.875 cubic inches 0.473 liter
Pound (avoirdupois)	Mass/weight	lb	7,000 grains 1.215 troy or apothecaries' pounds 453.59237 grams
Pound (troy)	Mass/weight	lb	5,760 grains 0.823 avoirdupois pound 373.242 grams
Quart (British)	Volume/capacity	qt	69.354 cubic inches 1.032 U.S. dry quarts 1.201 U.S. liquid quarts
Quart (U.S., dry)	Volume/capacity	qt	67.201 cubic inches 1.101 liters 0.969 British quart
Quart (U.S., liquid)	Volume/capacity	qt	57.75 cubic inches 0.946 liter 0.833 British quart
Rod	Length	rd	5.029 meters 5.50 yards

Unit	*Quantity*	*Symbol*	*Equivalents*
Rod, square	Area	rd^2	25.293 square meters 30.25 square yards 0.00625 acre
Second	Time	s *or* sec	$\frac{1}{60}$ minute $\frac{1}{3600}$ hour
Tablespoon	Volume/capacity	T *or* tb	3 teaspoons 4 fluid drams
Teaspoon	Volume/capacity	t *or* tsp	0.33 tablespoon 1.33 fluid drams
Ton (gross or long)	Mass/weight	t	2,240 pounds 1.12 net tons 1.016 metric tons
Ton (metric)	Mass/weight	t	1,000 kilograms 2,204.62 pounds 0.984 gross ton 1.102 net tons
Ton (net or short)	Mass/weight	t	2,000 pounds 0.893 gross ton 0.907 metric ton
Volt	Electric potential	V	1 joule per coulomb
Watt	Power	W	1 joule per second 0.001 kilowatt $2.84345136093995 \times 10^{-4}$ ton of refrigeration
Yard	Length	yd	0.9144 meter
Yard, cubic	Volume/capacity	yd^3	0.765 cubic meter
Yard, square	Area	yd^2	0.836 square meter

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ENCYCLOPEDIA OF GLOBAL WARMING

Oxygen, atmospheric

• **Categories:** Chemistry and geochemistry; meteorology and atmospheric sciences

The amount of oxygen in Earth's atmosphere is linked to the biological cycling of carbon via photosynthesis and respiration, as well as to the geological cycling of carbon through the planet's crust, oceans, and atmosphere. As a result, periods of high atmospheric oxygen concentration tend to be periods of low concentration for CO_2, an important GHG.

• Key concepts

aerobic: in the presence of oxygen
anaerobic: in the absence of oxygen
endosymbiont: an organism living inside a cell or body of another organism
eukaryote: an advanced cell, containing a nucleus and other membrane-bound organelles
fermentation: the biochemical generation of energy from organic compounds in the absence of oxygen
organic matter: carbon-containing compounds produced by life processes
photosynthesis: the production of food from light energy, carbon dioxide, and water
prokaryote: a primitive cell (bacterium), lacking a nucleus and other membrane-bound organelles
respiration: the biological generation of energy, using oxygen

• Background

Oxygen exists in Earth's atmosphere mainly as dioxygen gas (O_2). It is a by-product of photosynthesis and accumulated in the primordial atmosphere primarily as a result of the photosynthetic activities of cyanobacteria in the oceans. Algae and plants are also important contributors of atmospheric oxygen.

In photosynthesis, organisms take up carbon dioxide (CO_2) from the air and water and minerals from the soil, and, using the energy of sunlight, they convert these substances into chemical compounds from which they build their cellular constituents. The oxygen released in the process is used in respiration by animals, including humans, as well as by plants and many other organisms, to retrieve the energy stored in chemical bonds. CO_2 is given off as a respiratory by-product. In cyanobacteria, algae, and plants, photosynthesis outpaces respiration, yielding a net gain of oxygen by the atmosphere.

• The Early Atmosphere and Photosynthesis

When the Earth formed, some 4.5 billion years ago, the atmosphere contained almost no free oxygen. This early atmosphere probably consisted of CO_2, water vapor, nitrogen, hydrogen, and trace gases. Earth's first living things, bacteria, appeared around 3.8 billion years ago, in the oceans. These early prokaryotes were unable to photosynthesize. They probably derived their nutrients from chemical compounds in seawater, and their energy through fermentation. Some prokaryotes developed the ability to photosynthesize, and, about 2.8 billion years ago, one group of these, the cyanobacteria, began to produce oxygen as a by-product. These microbes still exist today.

• Effects of Atmospheric Oxygen on Life

Oxygen reached appreciable levels in the atmosphere by about 2.3 billion years ago. It changed the course of evolution. Because it is a highly reactive gas, oxygen was a deadly poison to many of the earliest bacteria, but some bacteria harnessed it to break the chemical bonds in their food, yielding energy. Thus, they developed respiration, an aerobic pathway for energy production. Respiration is more efficient than fermentation. It became life's predominant energy-producing pathway.

The build-up of oxygen in the atmosphere aided life in another way: It led to the formation of the planet's ozone layer. Ozone (O_3) is produced by the interaction of the Sun's ultraviolet radiation with O_2 gas. The ozone layer shields terrestrial life from ultraviolet radiation.

About 1.5 billion years ago, the accumulation of abundant free oxygen was accompanied by the evolution of a new, more complex cell type, the eukaryote. Those eukaryotes that acquired photosynthetic endosymbionts became algae. By 600 million years ago, multicellular eukaryotic forms had arisen, and the organismal groups that dominate the globe today—animals, plants, and fungi—became established.

Atmospheric Oxygen and the Geological Carbon Cycle

The countervailing processes of photosynthesis and respiration help stabilize the atmospheric concentrations of oxygen and CO_2 on timescales of single years to tens of thousands of years. Over longer timescales—millions of years—recycling of the Earth's crust regulates carbon exchange between rocks, oceans, and the atmosphere and affects the balance of atmospheric gases. As plant matter and sulfur in rocks and sediments are alternately buried and oxidized, oxygen is added to the atmosphere or removed from it. CO_2's abundance is generally inversely related to oxygen's abundance in these processes.

The concentration of oxygen in Earth's atmosphere is about 20.95 percent. The remainder of the atmosphere consists mainly of the relatively unreactive gas nitrogen, at 78.09 percent. The other atmospheric components are trace gases, which include CO_2, at about 0.035 percent, and water vapor, which fluctuates in concentration. Although a slight decrease in atmospheric oxygen has been recorded during recent decades, attributable to the burning of fossil fuels, the reservoir of atmospheric oxygen is so large that significant change cannot readily occur. Conversely, atmospheric CO_2 is present in such small concentrations that minor changes make a large proportional difference.

There is evidence that, in the distant past, the atmospheric oxygen concentration was not completely stable. About 540 million years ago, oxygen composed about 15 percent of the atmosphere. Then, around 300 million years ago, it reached about 35 percent, as a result of the conquest of the land by plants and the attendant increase in global photosynthesis. Oxygen concentration also increased by the burial of forests in coal swamps, which sequestered vast amounts of organic carbon from the atmosphere. Under normal circumstances, the trees would decay, and their carbon would be oxidized to CO_2 and water, but the swamps prevented this from happening. By around 200 million years ago, the atmospheric oxygen concentration had plummeted back to about 15 percent, accompanied by a major extinction event at the Permian-Triassic boundary.

Context

Oxygen's existence has been known only since 1774, when Englishman Joseph Priestley isolated the gas and noted its special properties, including its ability to make a flame burn particularly brightly. In Priestley's day, the atmosphere was just beginning to be understood as a collection of individual gases, rather than the single, uniform "air" it had been supposed to be. Priestley was also the first to note that plants and animals exist in a reciprocal relationship, mediated by the gases of photosynthesis and respiration.

It took nearly two centuries following Priestley's discovery of oxygen for the origin of this gas to be understood: Only in the 1960's did the idea that photosynthesis was responsible for the build-up of atmospheric oxygen over the eons become widely accepted by scientists.

Jane F. Hill

Further Reading

Beerling, David J. *The Emerald Planet: How Plants Changed Earth's History*. New York: Oxford University Press, 2007. Paleoclimatologist Beerling presents a detailed, illuminating account of how plant life has driven changes in the Earth's atmosphere. Endnotes, index.

Berkner, Lloyd V., and Lauriston C. Marshall. "On the Origin and Rise of Oxygen Concentration in the Earth's Atmosphere." *Journal of the Atmospheric Sciences* 22, no. 3 (1965): 225-261. Physicists Berkner and Marshall provide important support for the idea that plants are the source of the build-up of atmospheric oxygen.

Johnson, Steven. *The Invention of Air: A Story of Science, Faith, Revolution, and the Birth of America*. New York: Riverhead Books, 2008. Account of Joseph Priestley's discovery of oxygen and other achievements. Bibliography, index, endnotes.

Lane, Nick. *Oxygen: The Molecule That Made the World*. New York: Oxford University Press, 2002. Detailed account of the science of oxygen. Explores mechanisms that could explain oxygen's build-up in the primordial atmosphere and addresses oxygen's probable role in human aging and disease. Further reading, glossary, index.

Morton, Oliver. *Eating the Sun: How Plants Power the Planet*. New York: HarperCollins, 2008. Morton, a journalist, brings together powerful evidence that plants have had a major influence on Earth's climate over geological time. Glossary, bibliography, further reading, index.

Walker, Gabrielle. *An Ocean of Air: Why the Wind Blows, and Other Mysteries of the Atmosphere.* Orlando, Fla.: Harcourt, 2007. Series of essays on the discoveries, and discoverers, of important facts about the atmosphere. Further reading, endnotes, index.

See also: Atmospheric chemistry; Atmospheric structure and evolution; Carbon dioxide; Ozone; Photosynthesis; Sequestration.

Oxygen isotopes

- **Category:** Chemistry and geochemistry

- **Definition**

All atoms of a chemical element contain the same number of protons, but they may contain different numbers of neutrons and thus have different masses. Forms of elements with differing masses are called isotopes. Oxygen in nature always has eight protons, but it may have eight, nine, or ten neutrons for a total mass of 16, 17, or 18. Out of every 100,000 oxygen atoms, almost all are oxygen 16 (O^{16}). Only 205 are oxygen 18 (O^{18}), and only 38 are oxygen 17 (O^{17}). Isotopes of an element are chemically identical, but since they differ in mass, atoms of lighter isotopes move more readily than heavier ones. Chemical and physical processes can partially sort isotopes of differing weights, a process called fractionation. Since O^{16} atoms are 11 percent lighter than O^{18} atoms, water molecules with O^{16} evaporate more readily, so that variations in the ratio of O^{16} to O^{18} can be used to trace movements of water in the environment.

- **Significance for Climate Change**

Oxygen isotope analysis is among the most important and most accurate tools available for the study of ancient climates. During ice ages, the evaporation of O^{16}-rich water from the oceans to form ice caps leaves the oceans depleted of O^{16} and enriched in O^{18}, so that shells formed by marine organisms during ice ages are enriched in O^{18}. During warm periods, much less water is locked up in ice, so the oceans are richer in O^{16} and poorer in O^{18}.

Oxygen isotope abundances are described in terms of the Vienna Standard Mean Ocean Water (VSMOW), which is actually an average of ocean water composition adopted by the International Atomic Energy Agency. An older term, Standard Mean Ocean Water (SMOW) is still sometimes used. Scientists measure the abundance of isotopes using an instrument called a mass spectrometer. Atoms or molecules are vaporized, electrically charged (ionized), then accelerated by an electric field. They can be sorted either by measuring their speed (heavier atoms or molecules accelerate more slowly) or by deflecting them with a magnetic field (heavier atoms or molecules are deflected less).

During warm periods (when there is less ice on Earth than now), marine shells are up to 0.3 percent poorer in O^{18} than VSMOW, and during ice ages they are up to 0.3 percent richer. For example, researchers at Woods Hole Oceanographic Institute have used oxygen isotope data on the shells of marine microorganisms to infer that one thousand years ago, during the Medieval Warm Period, the surface temperature of the Sargasso Sea was about 1° Celsius higher than it is at present; it was 1° Celsius lower than present during the Little Ice Age, four hundred years ago.

Steven I. Dutch

See also: Carbon isotopes; Climate reconstruction; Dating methods; Little Ice Age; Medieval Warm Period; Oxygen, atmospheric.

Ozone

- **Categories:** Chemistry and geochemistry; meteorology and atmospheric sciences

Earth's atmosphere is divided into layers, of which the stratosphere and troposphere are significant to climate change. Ozone is present in both layers. In the strato-

sphere, ozone protects life by absorbing dangerous solar ultraviolet radiation. In the troposphere, ozone is a pollutant that creates smog, affecting air temperature, evaporation, moisture, and precipitation.

• Key concepts

greenhouse gases (GHGs): gases that trap heat in the atmosphere
ozone hole: an area of diminished ozone in the ozone layer
ozone layer: an atmospheric layer that contains a high (over 91 percent) concentration of ozone
stratosphere: the layer of Earth's atmosphere above the troposphere, situated between 10 and 50 kilometers above the planet's surface
troposphere: an atmospheric layer closer to Earth, where weather phenomena occur
volatile organic compounds: substances with carbon backbones that evaporate or vaporize easily at room temperature

• Background

Ozone in the stratosphere absorbs ultraviolet solar radiation; in the troposphere, it creates pollution with other greenhouse gases (GHGs). Stratospheric ozone absorbs the Sun's rays and protects life from harmful wavelengths. It is produced naturally through photochemical reactions and electrical discharges. High-energy, ultraviolet light splits oxygen atoms, which in effect form ozone molecules. Ozone-depleting substances, chlorofluorocarbons (CFCs) destroy the gas and create "ozone holes." Ozone holes transmit ultraviolet solar radiation and increase temperature at the Earth's surface. Tropospheric ozone is produced by the reaction between volatile organic compounds and nitrogen oxide. It creates smog, limiting the ability of solar energy reflected from the surface to escape to the atmosphere.

• "Good" vs. "Bad" Ozone

Ozone in the stratosphere protects Earth's surface from ultraviolet solar radiation. High-energy, ultraviolet rays are absorbed by oxygen and ozone for atmospheric reactions. Oxygen molecules, which are of greater stability than ozone, require energy corresponding to a wavelength of 242 nanometers in the electromagnetic radiation spectrum to split their atoms. Triatomic ozone, which is less stable than is biatomic molecular oxygen, requires energy corresponding to a wavelength of 200-320 nanometers.

"Good" ozone can be depleted by the ozone-depleting substances, which do not undergo chemical reaction in the troposphere, but can be destroyed by ultraviolet radiation in the stratosphere. Ozone-depleting substances derive from Earth's surface, and they are recognized in the Montreal Protocol. They degrade slowly and remain in the troposphere for years, until they reach the stratosphere, where they are broken down by intense solar radiation and release chlorine and bromine molecules, which destroy the good ozone. One chlorine atom can destroy 100,000 ozone molecules.

"Bad" ozone is not emitted directly into the air, but produced in the troposphere through chemical reactions of nitrogen oxide and volatile organic compounds in the presence of sunlight. These compounds are primary air pollutants, emitted from sources that include industrial facilities, electric utilities, motor vehicles exhaust, gasoline vapors and chemical solvents, coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants. Ozone, dangerous to vegetation and ecosystems, reduces agricultural crops and tree growth and creates harsh weather.

The Industrial Revolution affected the composition of the atmosphere. The burning of fuels released large amounts of smoke and gases directly into the atmosphere. Among the most important emissions are carbon dioxide (CO_2), nitrogen oxides, sulfur dioxide, and CFCs. Ozone in the stratosphere blocks ultraviolet light from reaching the surface of the Earth, but chlorine and bromine from halogenated compounds are very effective at destroying ozone. The concentrations of these chemicals already present in the atmosphere will continue to affect ozone for a long time.

• Healing the Ozone Layer

Ozone concentration in the lower and higher atmosphere is a result of the temperature and climate change. The pollutants producing bad ozone create a cooling affect on the Earth's surface; at the same time, ozone-depleting substances create ozone holes in the higher atmosphere. A major concern of today's scientists is balance calculations regarding ozone sinks and sources. A few countries, such as the United States, China, India, Malaysia, and Indonesia, are the major polluters. Their amount of pollution significantly affects bad ozone production and good ozone depletion. The discovery of the thinning of the ozone layer led to the 1987 Montreal Protocol, which regulates these harmful substances. The protocol was signed by almost all developed and developing counties.

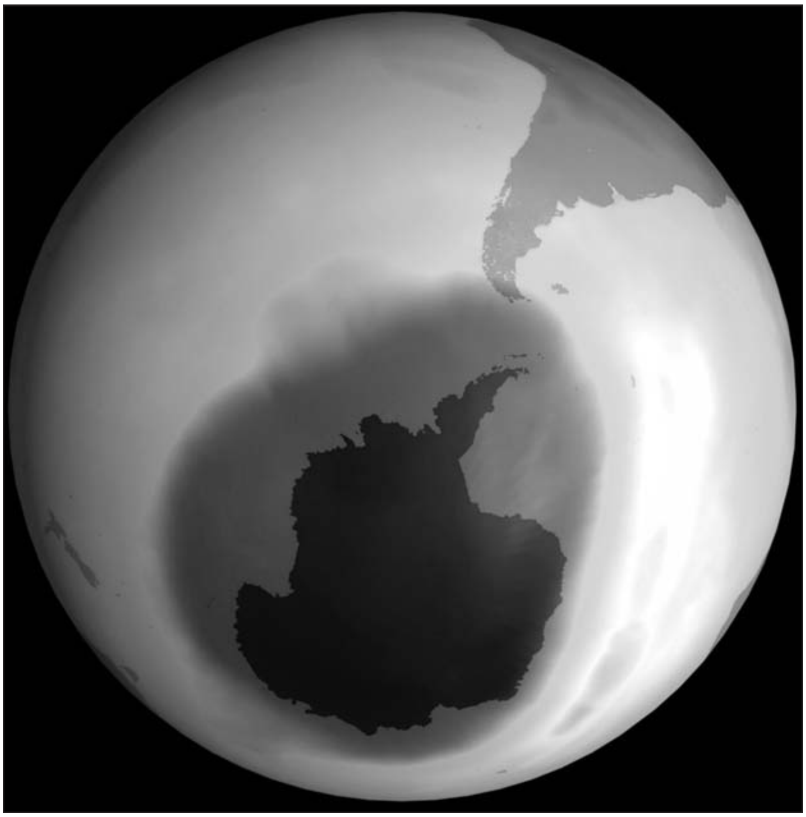
Joseph Farman, a British scientist who discovered the ozone hole over Antarctica, has stated that China, India, and other developing counties such as Malaysia and Indonesia fail to comply with new regulations and are damaging the progress made in healing the Earth's protective ozone layer. Since 1985, governments have stopped or controlled some harmful emissions, such those from aerosol sprays. Progress on the release of ozone-depleting substances has improved, and the ozone hole over Antarctica is not worsening. However, when the harmful substances are in the air, it takes a long time before they are removed. The reduction of the ozone layer is observed above the Arctic and Europe, and it is projected to worsen, according to Nora Schultz.

Ozone, along with methane, is being sucked out of the atmosphere over the tropical Atlantic Ocean, based on the data collected in Cape Verde at the west coast of Africa. The atmospheric observatory there records that 13 percent of ozone is lost each day. This discovery suggests that 50 percent more ozone is being destroyed above the tropical Atlantic Ocean by halogens released by the seawater. More ozone and methane is being destroyed than was thought previously, says Alastar Lewis of the National Atmospheric Science center in Leeds, England. The ozone in the troposphere is the third most important anthropogenic gas, after CO_2 and methane.

• Context

Neil Harris of the European Ozone Research Coordinating Unit at Cambridge University says that it is important to include halogens in climate models to understand their effects on climate change, such as changes in winds, in water temperature, and in ocean productivity. Winds affect how much bromine is released in sea spray. Harris's research indicates that GHG sinks are threatened by nitric oxides released by cars and factories, which increase the production of ozone. Wind affects the fate and transport of compounds in the atmosphere.

In 2007, the ozone hole shrank, but in 2008, it grew again. Thinning of the ozone layer contributes to global warming. The increase of ozone concentration is an effect of the increase of pollution



Graphic of the Antarctic hole in Earth's ozone layer based on data from the Total Ozone Mapping Spectrometer. (UPI/Landov) in the air. This increase has occurred particularly since the Industrial Revolution, which took place in Europe and the United States in the late eighteenth and early nineteenth centuries. The major changes in agriculture, manufacturing, and transportation had important effects on the socioeconomic and cultural conditions, leading to industrialization. The Kyoto Protocol was issued to set the standards for the emission of GHGs. It is still uncertain if the proceeding climate changes can be stopped. The air, water, soil, and the whole Earth environment are already affected by these changes.

Ewa M. Burchard

• Further Reading

Meier, Gerald M., and James E. Rauch. *Leading Issues in Economic Development.* New York: Oxford University Press, 2000. Provides an overview of the Industrial Revolution and the history of economic development.

Seinfeld, J. H., and S. N. Pandis. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change.* 2d ed. Hoboken, N.J.: Wiley, 2006. Good source of information on the composition, physics, and chemistry of the atmosphere.

World Meteorological Organization. *Global Atmosphere Watch: Antarctic Ozone Bulletin* 1 (August 28, 2008). Contains illustrations, graphs, and tables based on precise measurements of atmospheric ozone concentrations.

See also: Aerosols; Chlorofluorocarbons and related compounds; Halocarbons; Hydrofluorocarbons; Perfluorocarbons.

Paleoclimates and paleoclimate change

• **Category:** Climatic events and epochs

Reconstructing climates from the Earth's geologic past and human prehistory provides a context for evaluating the extent to which the present global warming trend is an anthropogenic phenomenon. Paleoclimatic records also allow projections of the impacts of global warming on natural ecosystems and human society.

• Key concepts

astronomical forcing: climatic change triggered by changes in solar luminosity, variation in the Earth's orbit, and bolide impact

Milanković cycles: variations in the eccentricity of the Earth's orbit, the tilt of the Earth's axis, and the precession of equinoxes, resulting in climatic variation on a scale of tens of thousands of years

positive climate feedback loops: self-reinforcing climatic processes, such as increased snow cover increasing planetary albedo, promoting additional cooling and therefore more snow cover

proxies: measurable parameters, correlated with climate, that are preserved in the geologic record

• Background

The Earth's climate has not been uniform in geologic or even historic time. Climatic changes form the backdrop for much of human prehistory and are viewed by some as a driving force in the rise and fall of civilizations. Looking further back into the geologic record, the abrupt transitions between eras indicate periods of rapid climatic change. Despite decades of intensive research, there remain many uncertainties and unanswered questions about the causes and impact of climatic change, particularly in remote geologic time.

Paleoclimatology as a science owes its beginnings to the work of Louis Agassiz (1807-1873), who in 1840 tuned his attention from the study of fossilized fish to observations on glaciers in Switzerland and concluded that the presence of characteristic glacial geologic formations in widely separated localities indicated that an ice sheet had once covered northern Europe. At about the same time, systematic study of fossilized plants in Britain, Germany, and Pennsylvania suggested that the climate at a more remote period had been tropical. Paleoclimatology as a scientific discipline remained largely a tool to study ancient ecosystems until the last quarter of the twentieth century, when the focus turned to understanding mass extinctions in the remote past and historical climatic extremes in order to predict and manage global warming in the present.

• Research Techniques

Systematic instrumental records of temperature, precipitation, and wind speed in parts of Europe and North America exist for the last 150 years, with spotty records for the eighteenth century. Data such as timing of the grape harvest in Southern Europe and the maximum extent of the annual flooding of the Nile extend the range of human observations several centuries backward in time, and historic and even legendary sources chronicle catastrophic events throughout human history.

Most paleoclimatology relies on the study of proxies, of which tree rings (dendrochronology) are a good example. If a variation in ring width in historic times correlates with fluctuations in temperature or precipitation, a similar pattern in the more remote past indicates similar fluctuations. Within the roughly four-thousand-year lifespan of the oldest living trees, dendrochronology provides very high resolution of climatic fluctuations. It has helped establish that the El Niño-Southern Oscillation (ENSO) cycle of wet and dry years has occurred for many centuries in coastal Peru and the American Southwest. Some corals and mollusks also develop annual rings that are indicative of fluctuation in water temperature at a given locality.

The type of vegetation and species present in a region are both good climatic indicators. Leaves, woody material, and particularly pollen occur in abundance in bogs, lake sediments, and sedimentary rocks. Plant species and genera have changed very little over the last few million years, making it a safe assumption that the environment in which a fossil was deposited closely resembled the environment where the same species occurs today. The genus *Metasequoia* (dawn redwood) today thrives in wet temperate climates. Its occurrence in a fifty-million-year-old fossil assemblage of the Eocene Age on Ellesmere Island in the Canadian Arctic is one of many pieces of evidence for an unusually warm period in geologic time.

Pollen analysis is a powerful tool, because pollen is extraordinarily resistant to decay, many pollen grains can be identified to genus, and analysis of relative abundance provides a fairly complete picture of the vegetation that produced it. Pollen in bog cores provided the first evidence for the Younger Dryas, an episode of drastic cooling in Europe between 12,900 and 11,500 years ago. The prevalence of pollen of an arctic plant, *Dryas octopetala*, indicated an abrupt return to arctic-tundra conditions within a ten-year period.

Further back in the geologic record, general morphology of plant fossils can be used as a climate proxy. Forest vegetation indicates relatively high precipitation; broad-leaved evergreens, a tropical or subtropical climate; and slow-growing woody plants with small vessel elements, a semiarid ecosystem.

The abundance and species composition of oceanic plankton are highly sensitive to water temperatures. Foraminifera (protozoa) and diatoms (algae) produce distinctive resistant outer coatings. The ratio of stable isotopes of carbon and oxygen in carbonate-containing marine sediments reflects their concentration in seawater. Plants selectively use carbon 12 in photosynthesis, so oceanic sediments become enriched in carbon 13 during warm, moist periods. Evaporated water is enriched in oxygen 16 relative to oxygen 18, leaving seawater with a higher proportion of oxygen 18 during periods of glaciation.

There are many geologic indicators of past climatic conditions. Cool, arid conditions produce deposits of loess (windblown dust). Volcanic ash distributed over a wide area may signal the onset of a cooling period. Low sea levels indicate glaciation, and high sea levels indicate warming episodes. Organic matter accumulates on land during cool wet periods. Continental glaciers produce characteristic scouring of rocks and glacial moraines. Ice-rafted debris found far from the continental margin, especially at low latitudes, indicates extensive glaciation.

The effects of geological and astronomic forcing mechanisms can be modeled based on a knowledge of plate tectonics and changes in the Earth's orbit and solar luminosity, and the results can be compared with proxy measurements. The relative proportions of sea and land mass and the latitudinal distribution of continents have changed substantially over nearly four billion years of life on Earth, but continental drift occurs too slowly to account for dramatic climate changes in the Phanerozoic. Plate tectonics do, however, spawn massive episodes of volcanism, such as those associated with the Permian-Triassic and Miocene-Pliocene transitions. Milanković cycles, which predict changes in the absolute amount of solar radiation reaching the Earth, show some positive correlation with Pleistocene glaciation pulses. Cores taken from glaciers in Greenland and Antarctica provide evidence of climate over the last 400,000 years in the form of rates of precipitation, amounts of atmospheric dust, and concentrations of carbon dioxide (CO_2) in trapped air.

• Climatic Change in the Geologic Record

Scientists who developed the geologic timescale used today based their division into eras and periods on marked discontinuities in both the inorganic constituents and fossils in sedimentary rocks. The discovery of radiometric dating based on decay of uranium isotopes at the end of the nineteenth century allowed an absolute time scale to be superimposed on the stratigraphic sequence. From a climatic perspective, the periods represent spans of millions of years, during which global climate was relatively uniform, divided by much briefer spans that were characterized by climatic extremes, elevated extinction rates, and the subsequent emergence of numerous new taxa.

The geologic record is punctuated by five recognized episodes of catastrophic extinction, when 60-80 percent of the then extant species disappeared in less than a million years. The best-known of these is the end-Cretaceous event marking the end of the dinosaurs 65 million years ago. Most biologists accept that the precipitating factor was an asteroid collision. The end-Ordovician extinctions, 440 million years ago, coincided with a drastic lowering of the sea level, possibly representing extensive glaciation. The causes of the late Devonian and Triassic-

Jurassic extinctions are uncertain. From the point of view of present policy makers attempting to learn from the lessons of geologic history, the Permian-Triassic extinctions, 250 million years ago, are probably the most instructive, both because they were the most profound and because the postulated causes most closely mirror global anthropogenic changes that are rapidly creating what Richard Leakey and others have termed "the sixth extinction."

A somewhat controversial interpretation of late Precambrian geologic formations postulates a "snowball Earth" between 790 and 630 million years ago. This period encompassed three or possibly four major glacial episodes, during which the Earth's oceans may have completely frozen, halting the evolution of multicellular life. At the time, most of the Earth's land mass centered over the South Pole. There is also evidence of major glaciation during the Huronian, 2 billion years ago. The postulated cause is depletion of methane due to release of oxygen by photosynthesis.

For most of the Phanerozoic, temperatures on Earth, as inferred from sea levels, isotope ratios, and vegetation at high latitudes have been significantly higher than they are at present. The late Cretaceous and the Eocene were particularly warm periods, characterized by temperate deciduous forests in Antarctica and the Canadian Arctic, and tropical jungles in Central Europe and the Pacific Northwest. The past 50 million years have witnessed gradual cooling and increasing aridity. Pronounced aridity and a drop in sea level in the Pliocene caused both the Mediterranean and Black Seas to become landlocked and shrink to a fraction of their present size.

• Climatic Change in Human Prehistory

The tenure of modern humans on Earth encompasses the last Pleistocene glaciation and the ten thousand years of the Holocene, during which the Earth's climate has fluctuated, with a temperature maximum roughly six thousand years ago and a temperature minimum, the Little Ice Age, from the fourteenth to early nineteenth centuries. There are many studies correlating prehistoric cultural changes with climatic changes. For agricultural societies, the droughts associated with colder periods are more devastating than lower temperatures themselves. The historic and geologic records contain no compelling evidence of rapid rises in temperature such as the Earth is currently experiencing—global warming in geologic time appears to be a gradual process to which life adapts itself. Cooling, on the other hand, can be extremely rapid and catastrophic. Massive volcanic eruptions cause global cooling by ejecting fine ash and sulfates into the atmosphere. Historic cold episodes beginning in 1470 B.C.E., 535 C.E., 1315, and 1815 are dwarfed by the eruption of Mount Toba on the island of Sumatra seventy-four thousand years ago, which is believed by some to have nearly wiped out the human race.

• Context

Probably the most important lesson to be learned from paleoclimatology in respect to global warming is that of the disruption of North Atlantic currents and resulting deep freeze in Europe in the 8.2ka event. Very rapid melting of the Greenland ice cap and release of freshwater into the Atlantic could well mimic the effects of the rapid draining of glacial Lake Agassiz through the St. Lawrence at the end of the Wisconsin Glaciation. The other lesson to be learned, although it does not so readily translate into international policy making, is that a massive volcanic eruption could, within a period of a few months, cause a substantial drop in global temperatures and global agricultural productivity, a much grimmer scenario in today's overpopulated and environmentally degraded world than in 1315 or 1815.

Martha A. Sherwood

• Further Reading

Alverson, Keith D., Raymond S. Bradley, and Thomas Pedersen, eds. *Paleoclimate, Global Change, and the Future*. Berlin: Springer Verlag, 2003. Collection of scholarly papers comparing natural paleoclimate changes with modern anthropogenic trends; discusses ancient civilizations.

Cronin, Thomas M. *Principles of Paleoclimatology*. New York: Columbia University Press, 1999. A standard textbook explaining in detail the methodology of paleoclimatological research. Includes an extensive discussion of the implications of late twentieth century discoveries for global energy policies.

Pap, Judit M., and Peter Fox, eds. *Solar Variability* *and Its Effects on Climate*. Washington, D.C.: American Geophysical Union, 2004. In addition to Milanković cycles, discusses sunspots and changes in solar output in geologic time.

Saltzman, Barry. *Dynamical Paleoclimatology: Generalized Theory of Global Climate Change*. New York: Academic Press, 2002. Treats interactions between abiotic, biotic, and anthropogenic variables; discusses controversies about the magnitude of human climatological impacts.

See also: Alleroed oscillation; Climate reconstruction; Dating methods; Earth history; 8.2ka event; Holocene climate; Little Ice Age; Pleistocene climate; Younger Dryas.

Parameterization

- **Category:** Science and technology

- **Definition**

In climate models, parameterization is the technique of representing processes that are too complex or otherwise cannot be effectively simulated in the model. Climate models are based on a series of mathematical equations that represent different chemical and physical processes—such as the evaporation of water from the ocean, the condensation of water vapor in the atmosphere to form clouds, and the direction of cloud transport based on wind directions and strengths. While processes such as these can be exactly solved within the climate model, other processes are too complex to treat in this manner. An example of this is local weather patterns such as the development of small-scale rainstorms. In this case, some other variable or data set must be chosen to represent the effects of the rainstorms. Long-term data on the regional average rainfall could be chosen as the parameterization for rainstorms. Thus, rather than a model solving a series of equations to predict when or where future rainstorms will occur, the average regional data is used to predict variations in the total average amount of rain under different climate change models.

- **Significance for Climate Change**

Global climate models are mathematical representations of a large series of complex chemical and physical phenomena. These mathematical models are the basis for future predictions of the potential effects of global warming. Global climate models are created by dividing the whole atmosphere into a horizontal and vertical series of grid boxes. These boxes can vary in size from 2°-10°, latitudinally and longitudally (approximately 200-1,000 kilometers), and tens of kilometers in height.

Certain processes—such as large-scale atmospheric circulation patterns—can be represented by relatively simple mathematical equations that can be solved for every time point and within every grid cell of the model. Other processes, such as small rainstorms or variations in local wind speed, are too complex, are not well understood, or occur on a geographic scale that is much smaller than the grid size of the model. Thus, these processes must be parameterized—or represented by some other type of data in order to let the model run. In effect, parameterization is a type of approximation, but is important in decreasing the complexity of the global climate models, so that climate models can be run using existing computing technology. However, an important part of developing and using a climate model is determining the amount of error that parameterizations introduce to predicted model results.

Anna M. Cruse

See also: Bayesian method; Climate models and modeling; Climate prediction and projection; Downscaling; General circulation models.

Particulates

- **Category:** Chemistry and geochemistry

- **Definition**

Particulates, also known as particulate matter, are fine particles of solid or liquid matter suspended in a gaseous medium. The particulates and the gas medium are collectively referred to as an aerosol. Particulates can be of natural or anthropogenic origin. Natural sources of particulates include volcanoes, dust storms, and fires, while anthropogenic sources include by-products of industrial processes, such as the burning of fossil fuels.

- **Significance for Climate Change**

Particulates are known contributory factors of climate change. Anthropogenic aerosols affect the climate by altering the atmospheric radiation field through scattering and absorption mechanisms. Aerosols can both absorb and scatter radiation. Whether a given aerosol is classified as radiation-absorbing or -scattering depends on its net effect and can be expressed by a single scattering albedo (SSA) value. Higher values indicate radiation scattering, whereas lower values indicate radiation absorption. For example, sea salt, a natural aerosol, has an SSA value of 1, whereas soot has an SSA value of 0.23, characterizing its immense atmospheric absorbing potential.

The manner and degree to which solar radiation is affected by atmospheric particulates depends on the chemical composition of both the particulates and the gaseous medium in which they are suspended. Sulfate aerosols, for example, have a cooling effect due to their tendency to scatter light. It appears that the slight decrease in global temperature observed in the middle of the twentieth century can be attributed to sulfate aerosols. By contrast, soot, also known as black carbon or carbonaceous aerosol, has absorbing properties that contribute to a warming effect. According to the Intergovernmental Panel on Climate Change (IPCC), black carbon contributes a global mean radiative forcing (the difference between the incoming and outgoing radiation energy in a given climate system) of +0.2 watts per square meter.

Globally, approximately 10 percent of aerosols are generated as a result of human activity. The health effects associated with particulates and aerosols are well documented. The inhalation of particulates and aerosols has been positively correlated to the development of asthma, lung cancer, and cardiovascular disease. The size of a particle is the key determinant as to which area of the respiratory system it will first contact and primarily affect. Large particles tend to become trapped in the nose and throat and are generally eliminated before harm is caused. However, smaller particles (around 10 micrometers) settle lower in the airway in the bronchi and lungs and can result in adverse health conditions. Particles smaller than 2.5 micrometers, can penetrate the gas-exchanging tissues of the lung, and those smaller than 100 nanometers can enter cardiovascular organs such as arteries, causing vascular disease.

Rena Christina Tabata

See also: Aerosols; Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Carbonaceous aerosols; Dust storms; Sulfate aerosols.

Peer review

- **Category:** Science and technology

- **Definition**

When a scholar completes a research project, he or she is expected to publish the original findings. Before such publication takes place, however, the research undergoes a process known as peer review: Scholars with expertise in the relevant field read prospective articles to evaluate their conformity to the professional standards and conventions of the field. Peer review is employed in all scholarly fields, from the humanities to the sciences, so criteria of evaluation can vary significantly from field to field. For example, scientific papers are expected to present objective, scientifically verifiable data, whereas humanities research is expected to support arguments with evidence but it need not and cannot be purely objective or conform to scientific principles. In some fields, reviewers are strongly encouraged to help authors whose work is deemed acceptable but open to improvement.

While the procedure varies in different journals and fields of study, a journal's central office generally maintains a file of people willing to review articles and their areas of expertise. An editor selects scholars who are most likely to be knowledgeable in the general area of the proposed publication (peers) and requests their assistance (review). The identity of the article's author is often known to the reviewer, but the author rarely knows the reviewer's name. In as short a time as is reasonable (which varies from a few weeks to a year), the editor receives the recommendation concerning publication. The article is designated as acceptable for publication, needing revisions, or recommended for rejection. It is not unusual for an editor to receive conflicting reviews of a manuscript.

• Significance for Climate Change

Scientists working strictly in the area of climate change are relatively few, but there is a large number whose work contributes to the debate concerning the reality, magnitude, and causes of global warming. Furthermore, these men and women come from virtually every field of science and engineering. It follows that they read and publish in a wide variety of learned journals. While the public image of science may not emphasize it, each of these groups has somewhat different expectations and procedures with respect to peer review.

The peer review process is of central importance in all scientific work, but it is more sharply focused in studies associated with global warming, because the relationship between science and politics is more apparent in such studies. Generally scientists and politicians function in separate arenas. The chemist, for example, may submit a research proposal to the National Science Foundation, where it is subjected to peer review and funded or rejected. When the research is completed, an article may be written and submitted to the *Journal of the American Chemical Society*, where it is again subjected to peer review and published or rejected. The new addition to the chemical literature is built upon, modified, or negated by future studies, each of which is peer reviewed.

The politician stands for election on the basis of his or her total record and personality. The review is not by peers, but by constituents. The new legislator works to persuade peers not only that an action is right but also that it is possible and preferable to a number of alternatives. In the debate, the proposal is reviewed by peers; their conclusions and actions are reviewed by constituents in the next election. The legislator may make written arguments in the *Congressional Record* or the *Wall Street Journal*, neither of which is peer reviewed.

These activities possess many similarities along with important differences. In the context of global warming, both frames of reference are crucial. Elegant scientific studies are meaningless without effective policies. International agreements based on mediocre science can do more harm than good. It is useful for discussions about the importance of climate change to refer to both the *Journal of Climatic Studies* and the *New York Times*, but it is vital that interlocutors distinguish between factual studies and policy debates. It is crucial that both what is probably true and what is possible are addressed, but they must be addressed in different ways using different sources.

K. Thomas Finley

• Further Reading

Bauer, Henry H. *Scientific Literacy and the Myth of the Scientific Method*. Urbana: University of Illinois Press, 1994. While showing that the normal view of scientific research is seriously flawed, the author discusses from a variety of perspectives the importance and inadequacies of peer review as it is actually practiced.

Booth, Barbara A. "Peer Review." In *The ACS Style Guide*, edited by Anne M. Coghill and Lorrin R. Garson. 3d ed. Washington, D.C.: Oxford University Press, 2006. A detailed discussion of the purpose and process of peer review. Treats the responsibilities of both the reviewer and the author.

Perrin, William F. "In Search of Peer Reviewers." *Science* 319 (January 4, 2008): 32. A plea for scientists to accept responsibility to their profession and to be willing to undertake peer review assignments. In an accompanying letter to the editor, Robert S. Zucker presents "A Peer Review How-To." An excellent, concise description.

See also: Falsifiability rule; Level of scientific understanding; Scientific credentials; Scientific proof.

Penguins

- **Category:** Animals

- **Definition**

Penguins are aquatic, flightless birds that strictly inhabit the Southern Hemisphere. Though popularly associated with Antarctica, penguins inhabit all southern continents, extending as far north as the Galapagos Islands off the coast of Ecuador. In fact, only a few penguin species live in the southernmost regions, and at least ten species live in the temperate zone. Most penguins spend half of their lives on land and half in the oceans. They feed on small marine creatures such as krill, fish, and squid while swimming underwater.

- **Significance for Climate Change**

Cold-species penguins are dependent on Antarctic ice, so temperature increases that thin ice shelves, which are important breeding and feeding sites for penguins, can adversely affect penguin populations. Antarctic warming led to the collapse of portions of the Antarctic Larsen Ice Shelf in 2002, reducing important penguin breeding and feeding areas and drowning thousands of emperor penguin chicks, who were forced to take to the water before they learned to swim. Some scientists believe that cold-species penguins are indicators of the health of Antarctic ecosystems and the consequences of Antarctic climate change.

Global climate changes can perturb the distribution of penguin food sources and harm the health of cold-species penguin populations. During the winter, marine algae freeze into the ice pack. Ice melts during the spring release algae, which are eaten by krill. This increased food source expands the krill population in time for the penguin's spring breeding time. Warming decreases winter ice, which in turn decreases the release of algae and, consequently, the surge in krill population. Less food available for breeding penguins reduces penguin fertility.

A group of penguins gather on a small ice floe in the Antarctic. (©Vladimir Seliverstov/Dreamstime.com)

Not all penguin populations are equally affected by global climate change. Populations of Adélie penguins—the most southerly distributed penguin species, which inhabits the area from South Africa's Prince Edward Islands to the Antarctic Peninsula—are declining. Penguin populations in the Indian Ocean and more southerly regions of Antarctica are thriving. In some cases, penguin populations thrive because they have access to their primary food source earlier in the breeding season. In other cases, shifts in the location of the primary food source forces penguins to forage further to feed, reducing their fertility.

These changes in food availability are due to the Antarctic Circumpolar Current (ACC), which mixes 140 million cubic meters of water from the Indian, Pacific, and Atlantic Oceans and flows from west to east around Antarctica. The ACC is filled with krill and other penguin food sources. Climate change can alter wind patterns and drive the ACC away from or closer to penguin nesting sites, affecting their populations both directly (by increasing or decreasing food supply) and indirectly (because food supply affects fertility).

Michael A. Buratovich

See also: Antarctic Treaty; Antarctica: threats and responses; Dolphins and porpoises; Endangered and threatened species; Polar bears; Whales.

Perfluorocarbons

• **Category:** Chemistry and geochemistry

• **Definition**

Perfluorocarbons are chemical compounds that are formed when some hydrogen atoms in hydrocarbons are replaced by fluorine atoms. True perfluorocarbons (PFCs) contain only carbon and fluorine atoms and generally include only CF_4 and C_2F_6; PFC derivatives may have other chemical groups attached to them. PFCs are chemically inert. They exist in a clear and colorless liquid form that has two times the density of water because of its high molecular weight. There are also five PFC gases: tetrafluoromethane, hexafluoroethane, octafluoropropane, perfluoro-n-butane, and perfluoro-iso-butane. These gases are formed synthetically and are by-products of aluminum smelting, uranium enrichment, and semiconductor manufacturing, as well as refrigerant blends. They have also been used as substitutes for CFCs in manufacturing.

PFCs are used in medical procedures, such as eye surgery and certain types of imaging procedures. They are being investigated for use as artificial blood, though this application is not yet feasible. However, PFCs are also suspected as agents in human disease and damage, such as breast, liver, prostate, and testicular cancer; hypothyroidism; and other developmental damage associated with toxic chemicals.

• **Significance for Climate Change**

PFCs affect the warming and cooling cycle of the Earth, as do the other greenhouse gases (GHGs) addressed by the Kyoto Protocol. PFCs are part of the class of fluorinated gases, which—along with carbon dioxide (CO_2), methane, and nitrous oxide—are considered to be the major GHGs listed in the Kyoto Protocol. However, they do not affect the atmosphere to the extent that other gases, such as water vapor, CO_2, or methane, do. PFCs also do not affect the ozone layer as some other gases do, and they were introduced as an alternative to ozone-depleting substances.

As light from the Sun enters the atmosphere, some of that light is scattered by molecules in the air or reflected from clouds back into space. Some of the light that reaches the Earth is also reflected back into space by surfaces such as snow or ice. Much of the light that reaches the Earth is absorbed and retained as heat. The Earth's surface warms and emits infrared photons, which make several passes between the Earth and the atmosphere, warming the atmosphere and the Earth as they go back and forth. Eventually, these infrared photons return to space.

The GHGs, whose molecules are all composed of three or more atoms, are able to absorb infrared photons as they pass, transferring the energy from the photons to the gases' molecules and trapping the thermal energy associated with them. Eventually, this absorption of energy effects a net change in the Earth's energy balance. The extent of the net change depends on the radiative force associated with the gas, as well as the lifetime of the gas. These two factors are expressed together by the gas's global warming potential. PFCs can stay in the atmosphere for hundreds or thousands of years. Thus, they continue to affect Earth's atmosphere and climate far longer than other GHGs.

Many GHGs are emitted as a result of human energy use, such as when fuel is used to generate electricity. Though human-made gases, such as PFCs, only account for approximately 2 percent of total GHG emissions, some scientists believe these emissions are enough to tip the delicate balance of the Earth's warming and cooling patterns. PFCs can be removed from the atmosphere through condensation and precipitation or by chemical reactions. However, because of their long lifetimes, they tend to accumulate more quickly than they can be dispersed.

Because of PFCs' effects on the global climate, the retention of these gases in the atmosphere could lead to melting of glaciers and polar ice caps, increased severity of flooding and droughts, rising sea levels, increases in the salinity of freshwater, more devastating tropical cyclones and tidal waves, and coastal erosion. These effects on the global climate could also help increase food production. As the Earth becomes warmer, growing cycles lengthen, more land becomes available for food production, and more and different varieties of food are able to be grown. Climate change from the GHGs, including PFCs, could also lead to more insect-borne disease spreading further throughout the world. As mosquitos and other pests are able to survive in more and different areas, malaria, dengue fever, and cholera could spread further.

Marianne M. Madsen

- **Further Reading**

Fabian, P., and O. N. Singh, eds. *Reactive Halogen Compounds in the Atmosphere: Handbook of Environmental Chemistry*. New York: Springer, 1999. Discusses how releases of chemicals into the atmosphere affect seasonal ozone depletions.

Manahan, Stanley E. *Environmental Chemistry*. 8th ed. Boca Raton, Fla.: CRC Press, 2005. Discusses major concepts in environmental science and how chemicals affect the environment, including their contribution to the greenhouse effect.

Silverstein, Robert M., Francis X. Webster, and David J. Kiemle. 7th ed. *Spectrometric Identification of Organic Compounds*. Hoboken, N.J.: John Wiley & Sons, 2005. Classic text discussing organic compounds. Includes charts, tables, and problems.

See also: Aerosols; Chemical industry; Chlorofluorocarbons and related compounds; Greenhouse gases; Halocarbons; Halons; Hydrofluorocarbons; Kyoto Protocol.

Permafrost

- **Category:** Cryology and glaciology

- **Definition**

Permafrost is permanently frozen ground, including soil, sediment, or rock. In order to be considered permafrost, the ground must remain below freezing for at least two consecutive years. Permafrost can persist for tens of thousands of years or more. Depending on the ground temperature, permafrost can be either continuous or sporadic. Permafrost is composed of different layers. Seasonal frost, which thaws during warmer times of the year, is generally present on top of permafrost and is called the "active layer." In the Arctic zone, permafrost may extend more than 100 meters below an active layer. Sometimes, a layer of unfrozen ground, called a "talik," is sandwiched between the active layer and the permafrost.

Permafrost is most commonly found in high latitudes near the North and South Poles. About half of the world's permafrost is found in Russia and Siberia. Permafrost is found in the Arctic, Alaska, and northern Canada, as well as further south in the Rocky Mountains. In the Southern Hemisphere, permafrost is found in Antarctica and the Andes Mountains.

• Significance for Climate Change

Although permafrost can persist for thousands of years, it's temperature is often near its melting point. Therefore, slight changes in ground temperature can quickly affect the distribution and thickness of permafrost. Recent warming trends have caused large sections of permafrost to thaw, decreasing the amount and depth of permafrost observed in many areas. Situations in which the ground thaws deeper than the next winter's freeze can result in a talik forming. This allows heat to accumulate within the ground, accelerating permafrost thaw.

Thawing permafrost can have significant impacts on ecosystems and human infrastructure, as well as potentially contributing to the release of greenhouse gases (GHGs). Roughly one-third of the world's total soil carbon is estimated to be stored in permafrost. GHGs, such as carbon dioxide (CO_2) and methane, are often trapped within frozen ground. As permafrost thaws, these gases may potentially be released into the atmosphere. Permafrost-related GHG emissions can contribute to a positive feedback loop as well: As more permafrost thaws, more GHGs are released, increasing the greenhouse effect and warming the climate. Consequently, permafrost thaw increases, releasing more GHGs.

Significant impacts on infrastructure and ecosystems can result from permafrost loss, as pockets of soil that contain large amounts of ice melt, buckling highways and destabilizing building foundations. Ground underneath forests can also cave in, causing what is referred to as "drunken forests," with trees leaning inward at an angle. Permafrost degradation can also result in erosion and landslides. Ecosystem diversity, composition, and productivity are also impacted by declining permafrost.

C. J. Walsh

See also: Cryosphere; Glaciers; Greenland ice cap; Ground ice; Ice shelves; Sea ice.

Pesticides and pest management

• Category: Economics, industries, and products

• Definition

Pesticides are generally defined as substances intended to prevent, or interfere with, the growth of a given pest (normally an insect, its larval form, or a noxious plant). In the ideal case, the pest is killed, so its descendents can cause no further damage. Most pesticides target more than a single species of pest, and they can be very toxic to animals and humans. Pesticides differ in their chemical structures, and some are difficult or impossible to biodegrade because they are human made and not naturally occurring. Their toxicity and resistance to biodegradation leads to environmental problems, such as runoff and stream contamination, that can endanger livestock, humans, and wildlife.

These challenges have led to growing interest in other approaches to pest management, such as developing alternative physical and biological procedures (called integrated pest management, or IPM); using purely organic techniques, employing no synthetic pesticides or fertilizers; or genetically engineering plants to be pest resistant. For example, the bacterium *Bacillus thuriengensis* is a popular biopesticide. It is found in the soil and produces a protein crystal that is deadly to the larval forms of some insects when consumed. The biodegradable crystal kills only certain insects and does not affect animals, humans, or plants.

Genetic engineers have inserted the gene that codes for protein crystal production in *Bacillus thuriengensis* into the chromosomes of different crop species, such as corn. The resulting plant produces its own toxic crystal that kills insects that seek to consume the plant. This approach to pest control has potential dangers, however, as it has killed not only pests but also beneficial insects such as butterflies. This was documented in a California field test, when pollen from a genetically engineered strain of corn landed on milkweed plants. When Monarch butterfly larvae consumed the infected leaves, they were killed. Another IPM ap-

Nicaraguan banana plantation workers suffering the effects of exposure to the insecticide Nemagon await medical treatment. (Oswaldo Rivas/Reuters/Landov)

proach, biofumigation, involves planting crops such as *Brassica* (cabbage) species that, when plowed, release biocidal substances that kill soil-borne insects and nematodes. When other crops are then planted in the field, the pests are deterred without the use of additional pesticides.

• Significance for Climate Change

Photosynthetic organisms (plants, bacteria, algae, phytoplankton, and so on) capture carbon dioxide (CO_2) and remove, or sequester, it from the atmosphere. Other types of bacteria absorb methane and other substances and further metabolize them. When used properly, pesticides contribute to the survival of photosynthetic plants, making them important devices for combating greenhouse gas (GHG) emission and climate change. However, excessive use of toxic chemical pesticides can prevent natural processes from controlling GHGs. For example, synthetic pesticides and fertilizers inhibit soil fungi (mycorrhizae) that promote carbon sequestration in the soil.

The changes in temperature, wind patterns, and rainfall that accompany global warming facilitate the transfer of pests from one territory to another. They also affect the ability of certain types of native plants to survive changes in their new environment and promote competition between native and exotic plants.

Plant-growth-chamber and greenhouse studies have shown that carbon 3 plants (such as wheat and soybeans) grow more efficiently than carbon 4 plants (such as corn) when the CO_2 concentration is increased, a process known as CO_2 fertilization.

In addition, most weeds (both carbon 3 and carbon 4) grow more efficiently than crops because of their greater genetic diversity and the larger number of weed species. Changes in crop species also lend themselves to potentially new plant and insect pests that may require increased pesticide usage, as well as use of additional types of pesticides.

Rises in global temperatures have also been hypothesized to increase the numbers and efficiency of insect pests, thereby leading to the necessity of increased pesticide use. Warmer climates allow earlier arrival of migrating insects and the appearance of exotic invasive species previously unable to survive in a given area. Many such new species are able to survive longer in altered climates because winters remain warmer. As a result, more generations of a given insect species can develop during a given season, leading to increased pest populations.

Observations made in the northeastern United States demonstrate this trend. Summer temperatures between 1970 and 2000 rose by approximately 0.5° Celsius, and winter temperatures rose by about 2° Celsius. Spring also arrived sooner, and winters became warmer and produced less snowfall. A larger number and variety of insect pests were recorded. These included species not previously seen, such as mosquitoes carrying both West Nile virus and viruses capable of causing Japanese and St. Louis encephalitis. Tree-eating insects that previously would not have survived the winter, such as the hemlock wooly agelid, have also been seen in the region.

Finally, it has been shown that herbicides are not as effective against weeds grown under increasing CO_2 concentrations. Certain insecticides (pyrethroids and spinosad) have also been shown to be less effective at higher temperatures. According to most sources, the GHGs (mostly CO_2) produced during the manufacture of pesticides make only a minor contribution to global warming. The benefits of well-balanced pest management programs can offset that potential harm.

Steven A. Kuhl

• Further Reading

Johansen, Bruce Elliot. *The Global Warming Desk Reference.* Westport, Conn.: Greenwood, 2002. Summarizes pertinent theories and evidence relating to global warming. Discusses future scenarios pertaining to human health, animals, and plants. Illustrations and a very complete bibliography.

Pritchard, Seth G., and Jeffrey S. Amthor. *Crops and Environmental Change: An Introduction to Effects of Global Warming, Increasing Atmospheric CO_2 and O_3 Concentrations, and Soil Salinization on Crop Physiology and Yield.* New York: Food Products Press, 2005. Examines the effects of climate change on all aspects of agriculture. Charts, tables, figures.

Vincent, Charles, Mark Stanislw Goettel, and George Lazarovits. *Biological Control: A Global Perspective.* Cambridge, Mass.: CABI, 2007. Explores all aspects of integrated pest management involving bacteria, fungi, and insects, including both historical perspectives and contemporary questions.

See also: Agriculture and agricultural land; Chemical industry; Invasive exotic species; Nitrogen fertilization.

Petroleum hydrocarbons in the ocean

• Categories: Chemistry and geochemistry; oceanography; environmentalism, conservation, and ecosystems

• Definition

Hydrocarbons are organic compounds formed exclusively from the elements hydrogen and carbon and are straight-chain, branched, or cyclic molecules. The types of carbon-to-carbon bonds in hydrocarbons range from single to triple. Very low mass hydrocarbons are gases. Liquid and solid hydrocarbons spread out as a floating layer, if less dense than ocean water, or sink below the ocean's surface, if more dense.

Hydrocarbons in the ocean originate from point and nonpoint sources. Point sources include oil spills from vessels, facilities, pipelines, and rivers. In 2007, 10.6 million liters of oil were released near South Korea in a barge accident. In 2005, more than 26.5 million liters were released from petroleum refining facilities in the aftermath of Hurricane Katrina. Nonpoint sources include vents in the ocean floor and marine transport operations. The National Research Council reported in *Oil in the Sea III*, that 46 percent of oil released in the ocean comes from natural leaks from fissures in the ocean floor. It is a matter of debate whether these hydrocarbons come from biotic or, less likely, abiotic processes.

- **Significance for Climate Change**

Methane, or natural gas, is the most volatile of the hydrocarbons. Over 85 percent of methane released from deep ocean vents dissolves in the water column as a result of the high pressure and low temperature of the deep ocean. In shallow waters, methane bubbles rapidly rise to the surface. Methane is also released from landfills, oil production, and ocean oil spills. Methane is a greenhouse gas (GHG) with twenty-five times the global warming potential of carbon dioxide (CO_2).

Nonvolatile hydrocarbons forming ocean spills may undergo chemical, biological, or physical alteration. Chemical breakdown of surface hydrocarbons in the ocean occurs as a natural photooxidative process in which hydrocarbons, catalyzed by sunlight, react with oxygen. Because hydrocarbons do not absorb light efficiently, the reaction requires other organic matter to absorb and transfer energy to oxygen, which becomes the highly energetic and reactive species, singlet oxygen. Singlet oxygen reacts with hydrocarbons to produce alcohols, aldehydes, ketones, and carboxylic acids in a series of complex reactions. These oxidized products are more water soluble than the parent hydrocarbon.

Less subtle is in-situ burning of oil spills. When immediate removal is important or other oil removal methods are infeasible, an oil spill can be burned to form the products CO_2 and water. However, tremendous amounts of toxic carbonaceous particulate matter are released to the air as a dark cloud of smoke that eventually settles on the ocean surface. Although the combustion product CO_2 is a GHG and causes global warming, the smoky particulate matter deflects radiation and cools the atmosphere.

Biological breakdown of hydrocarbons occurs with bacteria, fungi, and some phytoplankton. The two pathways to breakdown hydrocarbons are oxidative phosphorylation, or respiration, and a detoxification mechanism that oxidizes the hydrocarbons to water-soluble oxygen-containing compounds that are easily excreted. Respiration of simple hydrocarbons results in the production of CO_2, a GHG. Bacteria that have acclimated to environs containing hydrocarbons are faster to initiate biodegradation.

Several physical methods are used to contain and remediate oil spills, including floating boom barriers to surround an oil spill, skimming boats to remove oil, sorbent materials that transfer oil away from water, and chemical dispersants to finely divide and dilute oil spills. The method used depends on the type, amount, and location of spill and also weather conditions.

Some ocean flora and fauna have adapted to live

Oil leaks from the merchant ship Syros *off the Uruguayan coast in June, 2008.* (Reuters/Landov) near sea vents of crude oil and natural gas. However, high hydrocarbon concentration in the ocean is a stressor to other ocean flora and fauna. For example, coral appears bleached after hydrocarbon exposure destroys the pigmented zooxanthellae of coral polyps. Bleached coral, if they survive, evince decreased exoskeleton maintenance, growth, and reproduction. In general, coral bleaching may be due to any number of stressors. Another likely stressor is elevated sea surface temperature associated with climate change. Attributing coral bleaching to specific stressors is complicated.

Although hydrocarbons are present in the marine environment, marine organisms are exposed only to the hydrocarbon that is bioavailable. The amount of hydrocarbon that is bioavailable depends on the partitioning of the hydrocarbon between ocean and tissues such as gills and cell membranes. Hydrocarbons can also be bioavailable when ingested (adsorbed to foods). Bioaccumulation of hydrocarbons in organisms requires desorption of hydrocarbons from foods in the gut and transport of hydrocarbons among cells. Birds and waterfowl are exposed to hydrocarbons that adsorb to feathers, skin, bills, and beaks. Even with sublethal exposure, the fitness of waterfowl may be compromised. For example, waterfowl with oily feathers cannot maneuver well enough to obtain sufficient food to survive.

The long-term effects of hydrocarbons in the ocean on populations, communities, and ecosystems are difficult to determine due to the magnitude of the studies and multiple variables. The effect of climate change must be factored into studies. Changes in CO_2 concentration affect ocean pH while global warming affects ocean currents and ocean temperature. These factors must be included in studies of marine populations and ecosystems.

Kathryn Rowberg

• **Further Reading**

National Research Council. *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, D.C.: National Academy Press, 2003. Summarizes previous research and reports on risk issues, the fate of oil, and biological effects of oil.

_______. *Oil Spill Dispersants: Efficacy and Effects*. Washington, D.C.: National Academy Press, 2005. Addresses the controversial method of oil dispersants. Helpful for oil spill mitigation decision-makers.

Proskurowski, Giora, et al. "Abiogenic Hydrocarbon Production at Lost City Hydrothermal Field." *Science* 319, no. 5863 (February 1, 2008): 604-607. Resurrects the theory of abiotic origins of hydrocarbons with carbon 13 methane collected in benthic vents.

See also: Chlorofluorocarbons and related compounds; Halocarbons; Hydrofluorocarbons; Ocean acidification; Ocean disposal; Ocean life; Oil industry.

pH

• **Category:** Chemistry and geochemistry

• **Definition**

pH is a quantitative measure of the acidity or basicity of a solution. The pH scale assigns a value between 0 and 14 based on the concentration of the hydrogen atoms in the solution. The more hydrogen present, the more acidic the solution and the lower the pH value. The fewer hydrogen ions present, the less acidic the solution and the higher the pH value. Pure water, which is neutral (neither acidic nor alkaline) has a pH of 7, which means that the concentration of the hydrogen ion is 10^{-7} gram-equivalent per liter. This mathematical system of stating pH was developed by a Danish chemist, Soren Peter Lauritz Sorenson, around 1909. "pH" is thought to be an abbreviation for the "potential of hydrogen" in English. The same abbreviation makes sense in several other languages, as it could stand for *pondus hydrogenii* or *potentia hydrogenii* in Latin or *potentiel hydrogene* in French.

• **Significance for Climate Change**

Soil pH. Arguably the single most important property of the moisture that is provided to soil is its pH. Soil's acidity determines which kinds of plants are able to grow in that soil. It is possible to adjust the pH of soil or of the water provided to it; acidic soil can be treated with lime to "sweeten" or neutralize it.

Acidic soil is usually considered to be infertile, as most conventional crops will not grow in it. Soil acidity also causes certain metals, such as aluminum and manganese, to become more soluble in the soil; many plants will not tolerate more than tiny quantities of these metals. Of the seventeen essential nutrients a plant needs to grow, it gets fourteen of them from the surrounding soil. The soil's pH is an important factor in the solubility and availability of these nutrients.

Soil acidity can be increased by aspects of the global climate. For example, acid rain (rain with a pH of 5.6 or lower) acidifies the soil upon which it falls. Other contributors to soil acidity include the oxidation of sulfur compounds that occurs when salt marshes are drained to be used as farmland, as well as the addition of fertilizer salts that hydrolyze or the addition of microbes that decompose organic materials. The pH of soil can be determined using a pH meter, a device that uses electrodes in the soil to generate a weak charge that can measure the concentration of hydrogen ions. Indicator dyes are also used in determining soil pH; these dyes are mixed into soil suspensions and matched against a color chart.

Water pH. Acidity is also important in bodies of water. When water becomes polluted, the temperature of the water increases and excess nutrients are formed. This causes greater algal and plant growth in the water, which may increase acid levels. These increased levels can greatly change the solubility of all the chemicals in the water, affecting the entire ecosystem. For example, if changes in pH increase the solubility of phosphorus, that increase may in turn increase plant growth, eventually generating a greater demand for the dissolved oxygen in the water and decreasing the availability of the oxygen to fish. pH is also important in seawater simply because different types of marine plants and animals are able to survive in acidic or alkaline environments, so the pH of an ocean region helps determine the inhabitants of that region.

Bodies of water have a natural ability to buffer changes in the pH, so adding acids or bases to the water does not generally change the pH value as much as one might expect. (The pH values throughout a body of water may vary naturally. At the bottom of a lake, for example, the pH may be lower than at the top, perhaps between 6.5 and 7.5. At the top of a lake during the summer, pH may range from 7.5 to 8.5.) However, the ability of a body of water to buffer changes in pH is greatly affected by acid rain. When the water absorbs great quantities of acid from rain, it loses its buffering ability, and even a slight addition to the water, such as from more rain or from snow melt, will then alter its pH.

Some microorganisms are able to affect the pH of their environment. For example, when a food is pickled, microbes are used to acidify and preserve it. However, microbes used in farming and agriculture can also affect soil and water quality when they acidify the soil or, through runoff, the water.

Marianne M. Madsen

The pH Scale

	pH	*Typical of*
Acidic	0	
	1	Battery acid
	2	Lemon juice
	3	Vinegar
	4	
	5	
	6	
	6.5	Milk
Neutral	7	
Basic	8	Baking soda, seawater
	9	
	10	Milk of magnesia
	11	
	12	Ammonia
	13	Lye
	14	

• Further Reading

Date, R. A., et al., eds. *Plant-Soil Interactions at Low pH: Principles and Management.* Boston: Kluwer Academic, 1995. Discusses the chemistry and physics of acid soils and how they affect crop production, particularly in developing countries.

Rengel, Z., ed. *Handbook of Plant Growth: pH as the*

Master Variable. Boca Raton, Fla.: CRC Press, 2002. Explores the role of pH in all parts of a plant. Includes an overview of all plant mechanisms and how they are affected by pH.

_______. *Handbook of Soil Acidity*. Boca Raton, Fla.: CRC Press, 2003. Discusses how soil acidity affects crop production and effective strategies for balancing soil pH.

See also: Alkalinity; Ocean acidification.

Phosphorus cycle

- **Category:** Chemistry and geochemistry

• Definition

The chemical element phosphorus is essential for terrestrial life. Plants, animals, fungi, and microorganisms use phosphorus for intercellular signaling. They also use it to make membrane lipids that compose the cell membrane; molecules such as adenosine triphosphate (ATP) that store usable chemical energy and transfer it from one reaction to another; and deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which store genetic information. Some animals also use phosphorus to make bones and teeth.

The phosphorus cycle is a biogeochemical cycle that describes the movement of phosphorus through rocks, living organisms, and water. Because phosphorus and phosphorus-based compounds are typically solids at terrestrial ranges of temperature and pressure, the atmosphere does not play a significant role in the movements of phosphorus. Phosphorus, therefore, is usually found on land, in rock and soil minerals, and in salts that form oceanic sediments. Since phosphorus-containing compounds are poorly soluble, phosphorus is a limiting factor for plant growth in marine environments.

In rocks, phosphorus is found primarily in marine sedimentary rocks (in the mineral apatite), guano deposits (bird and bat droppings) in tropical caves, and in some calcium-rich volcanic rocks. Erosion of phosphorus-containing rocks redistributes it throughout the soil and water. Plants take up this phosphorus, herbivores eat the plants, carnivores eat the herbivores, and phosphates absorbed by animals eventually return to the soil by excretion of urine and feces and by decomposition after death. Phosphorus enters aquatic ecosystems by means of rainwater runoff, sewage seepage, natural mineral deposits, and industrial wastes. The poor solubility of phosphorus-containing compounds causes them to settle on lake bottoms and the ocean floor. Tectonic uplifting of such sediments and their subsequent erosion returns them to the phosphorus cycle.

• Significance for Climate Change

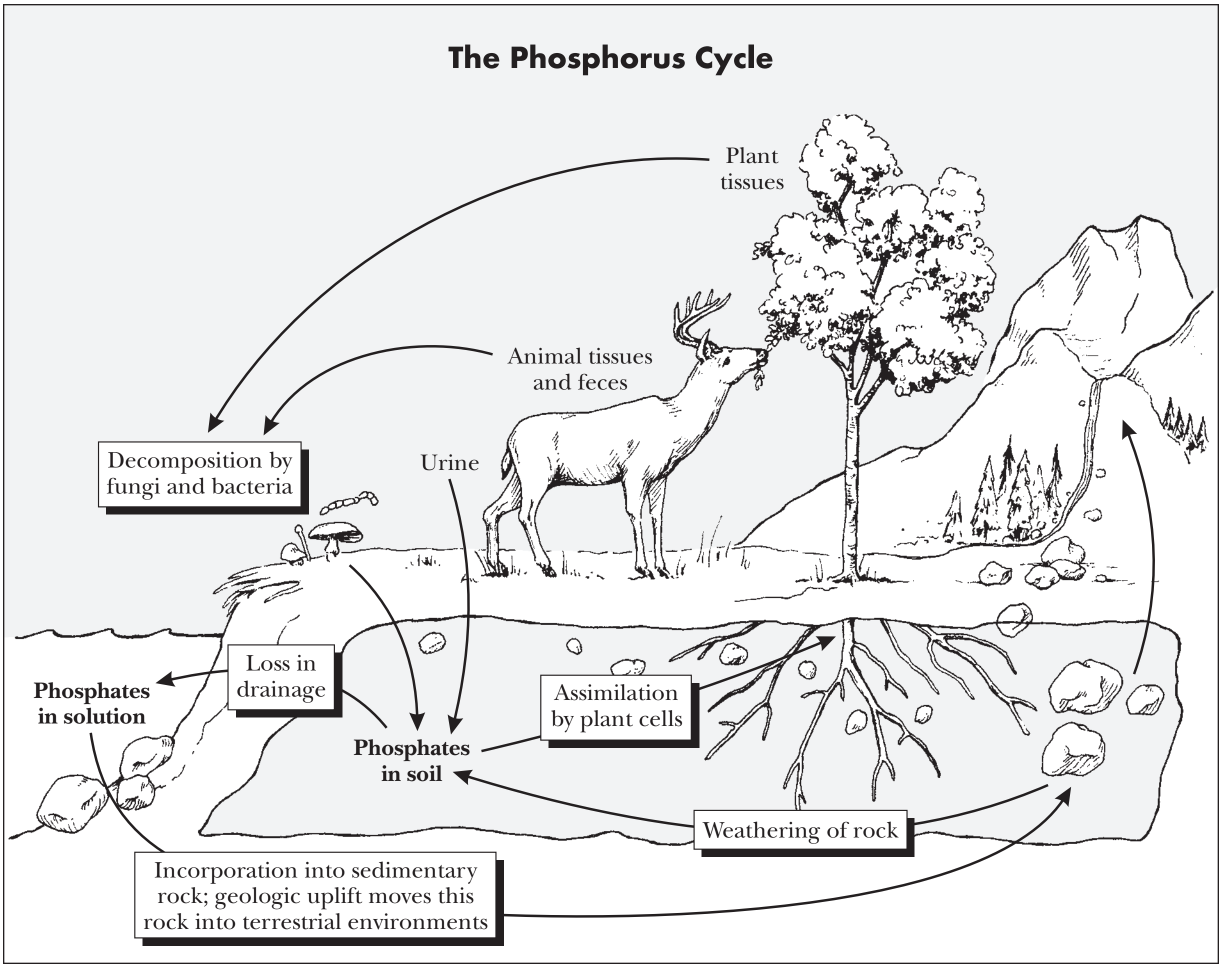
In the environment, phosphorus is found in combination with oxygen, and it forms ions such as phosphate (PO_4^{-3}), hydrogen phosphate (HPO_4^{-2}), dihydrogen phosphate ($H_2PO_4^{-1}$), and phosphoric acid (H_3PO_4). In rocks, phosphorus can also exist as metaphosphate (PO_3^{-1}), which is also known as phosphite.

Phosphorus is mined, largely, for the production of fertilizers. The use of phosphate minerals and their products as fertilizers has increased tremendously global food production. However, fertilizers have also increased phosphates in runoff waters.

Phosphorus moves quickly through plants and animals, but slowly through soils or oceans. Thus, the phosphorus cycle is one of the slowest of all biogeochemical cycles. Consequently, phosphorus is usually the limiting nutrient that controls biological productivity in many terrestrial and marine environments. Excess dissolved phosphorus leads to uncontrollable aquatic biological growth and water-quality problems. This process, called eutrophication, causes explosive algal growth or "algal blooms." Algal blooms rapidly utilize all the available nutrients, and after the algae die, thick pads of dead organisms fall to the bottom and oxidize. This reduces dissolved oxygen and creates an inhospitable environment for fish. Animals that depend upon fish as a food source or the water for reproduction are adversely affected by such events. Consequently, sharp increases in phosphorus influx tend to reduce animal populations.

Serious disruption of the phosphorus cycle occurs during cutting of tropical rain forests. Rainforest ecosystems are supported by highly efficient mineral recycling. Heavy rainfall leaches nutrients like phosphorus from the soil, but warm, moist conditions favor high decomposition rates. Fungi called mycorrhizae form special relationships with the roots of rain-forest trees, and this symbiotic association between the tree and the fungus allows the trees to absorb phosphorus before it enters the soil. This prevents phosphorus loss by leaching. Cutting down rain-forest trees leaves phosphorus in the soils and copious rain waters drive it into the lakes or oceans. Excess phosphorus kills sea creatures and also affects the predators that depend on these creatures for their survival. With the death of the large trees, there is not enough plant life to hold the soil in place and accelerated erosion ensues. Thus tree loss initiates a vicious cycle of erosion, nutrient loss, plant death, further erosion, more nutrient loss, and so on.

Rain forests play a major role in the regulation



The biogeochemical phosphorus cycle is the movement of the essential element phosphorus through the earth's ecosystems. Released largely from eroding rocks, as well as from dead plant and animal tissues by decomposers such as bacteria and fungi, phosphorus migrates into the soil, where it is picked up by plant cells and is assimilated into plant tissues. The plant tissues are then eaten by animals and released back into the soil via urination, defecation, and decomposition of dead animals. In marine and freshwater aquatic environments, phosphorus is a large component of shells, from which it sediments back into rock and can return to the land environment as a result of seismic uplift.

of global weather patterns and the balance of carbon dioxide (CO_2) in the atmosphere. Tropical rain-forest destruction puts large amounts of CO_2 into the air and concomitantly removes the trees that are responsible for removing CO_2, thus exacerbating atmospheric warming on a global scale.

Increased atmospheric CO_2 levels also increase ocean acidity. Acidification of the ocean decreases the ability of plankton to use dissolved phosphates. This would effectively starve plankton for phosphorus, and subsequently starve any organism that eats plankton and all organisms that depend on plankton eaters, thus causing a cascade of extinctions.

Michael A. Buratovich

• Further Reading

Filippelli, Gabriel M. "The Global Phosphorus Cycle: Past, Present, and Future." *Elements* 4 (2008): 89-95. Interesting summary of the results of increased phosphorus input throughout geologic history and the likely consequences of increased phosphorus input in modern times.

Föllmi, K. B. "The Phosphorus Cycle, Phosphogenesis, and Marine Phosphate-Rich Deposits." *Earth-Science Reviews* 40 (1996): 55-124. Excellent explanation of the phosphorus cycle, its importance to the history of life of Earth, and the implications of human intervention in it.

Oelkers, E. H., and E. Valsami-Jones. "Phosphate Mineral Reactivity and Global Sustainability." *Elements* 4 (2008): 83-87. Explains how the need for agricultural phosphorus must be balanced with the admission that global phosphorus resources are limited and may not last the next one hundred years.

Oelkers, E. H., E. Valsami-Jones, and T. Roncal-Herrero. "Phosphate Mineral Reactivity: From Global Cycles to Sustainable Development." *Mineralogical Magazine* 72 (2008): 337-340. A remarkable study that examines the differential solubility of different phosphorus minerals and argues that recognition of these data might provide clues for future sustainable phosphorus use.

See also: Carbon cycle; Hydrologic cycle; Nitrogen cycle; Sulfur cycle.

Photosynthesis

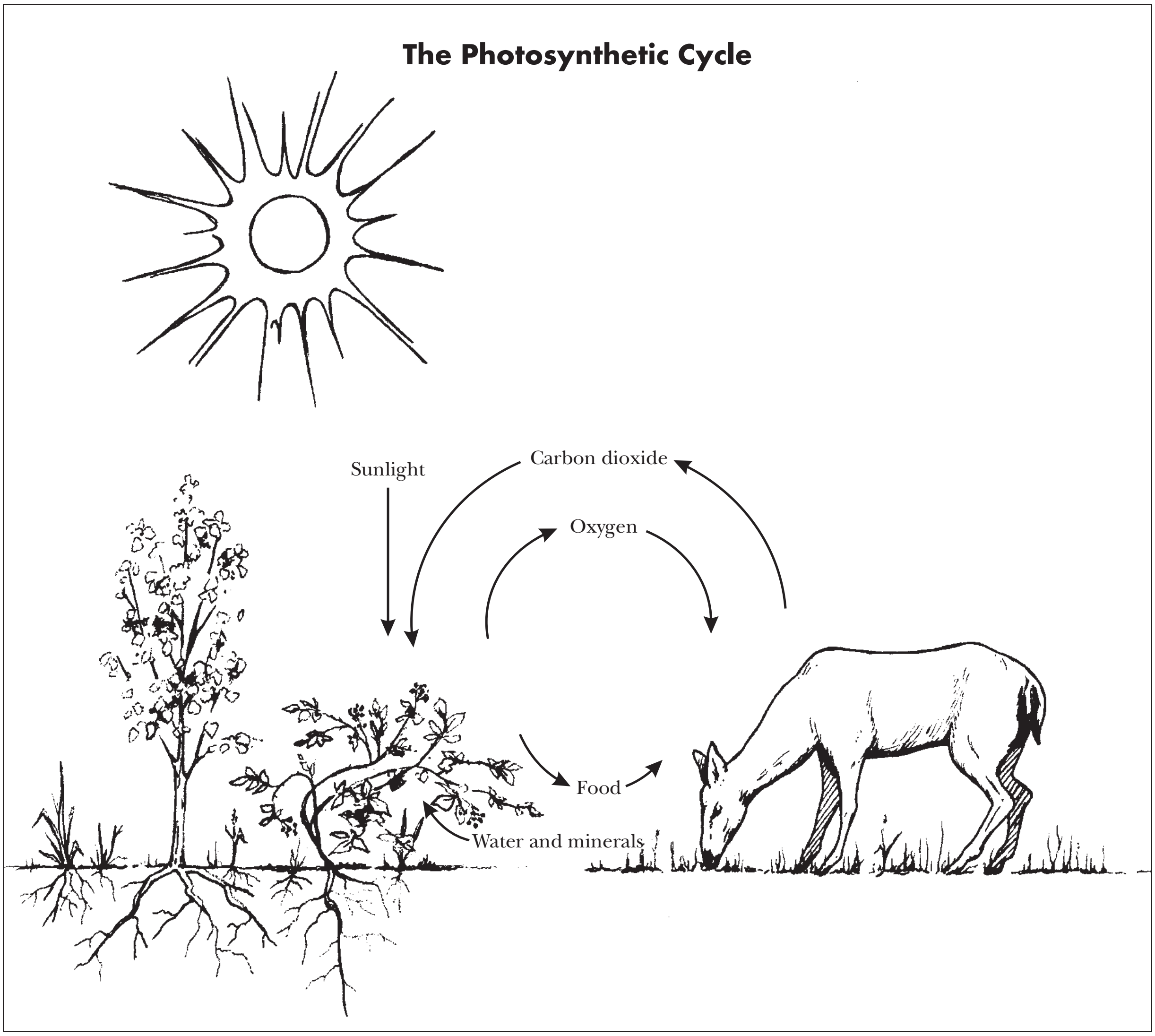
• **Categories:** Plants and vegetation; chemistry and geochemistry

• Definition

Photosynthesis is the process by which plants convert light energy from the Sun into chemical energy in the form of carbohydrates. The name carbohydrate literally means "carbon plus water," a vivid descriptive term for the sugar formed from combining carbon dioxide (CO_2) with water. The process of photosynthesis begins with the absorption of photons by plant pigments. As photons reach a reaction center made up of chlorophylls, light energy excites electrons from the splitting of water molecules. A portion of the energy released by the energized electrons is used to produce adenosine triphosphate (ATP). ATP is then used to produce carbohydrates from CO_2 and water. In the process, water acts as the source of both electrons and oxygen gas. Photosynthesis produces food for all living organisms, directly or indirectly, in all ecosystems. In addition, it releases oxygen and utilizes CO_2 and thus becomes an indispensable link in the carbon cycle.

Several pathways of photosynthesis are employed by different plants as a response to different climatic conditions, primarily temperature and water availability. In order to survive terrestrial environments, all land plants must cope with water deficits from time to time. When plants open their numerous microscopic pores, called stomata, to admit CO_2 for photosynthesis, they risk losing water through these openings by evaporation. Plants will thus at times close stomata in order to conserve water for survival. The delicate balance between conserving water and admitting CO_2 has led to the evolution of three major types of photosynthesis. The plants that employ each of these three different pathways not only display different anatomies but are adapted to different climates as well.

Some plants convert CO_2 into a three-carbon sugar and are thus called carbon 3 plants. Carbon 3 plants are typically well suited to temperate regions, where the weather is not very dry or hot and water is generally not a limiting factor. Examples of



The processes of photosynthesis and cellular respiration are complementary: Oxygen released into the atmosphere, a by-product of photosynthesis, is breathed in by animals, which in turn breathe out carbon dioxide, the gas that is essential for photosynthesis. (Kimberly L. Dawson Kurnizki)

carbon 3 plants include such crops as wheat, barley, and peas.

Other plants convert CO_2 into a four-carbon sugar and are thus called carbon 4 plants. Carbon 4 plants are equipped with a CO_2 pump that can concentrate CO_2 inside their leaves. This enables these plants to perform photosynthesis even when their stomata have to partially or temporarily close in order to conserve water on a hot and sunny day. Thus, carbon 4 plants are well adapted to high daytime temperatures and intense sunlight with periodic water deficits. This is the reason the carbon 4 crabgrass often outcompetes carbon 3 lawn grass when water becomes a limiting factor in the summertime. Other examples of carbon 4 plants include corn, sugarcane, and sorghum.

Carbon 4 plants generally do better than carbon 3 plants in hot and sunny habitats. Because operating their CO_2 pumps requires energy, however, in a cooler and moist habitat where water is not a limiting factor, carbon 3 plants possess an advantage over carbon 4 plants. When water is plentiful, there is no need to close the stomata to conserve water. Thus, the energy expenditure of pumping CO_2 by carbon 4 plants becomes a wasteful process.

Plants employing the third type of photosynthesis are uniquely adapted to desert habitats. Because of the scarcity of water, these plants cannot afford to open their stomata during the day at all lest they dehydrate. Desert plants thus engage in what is called crassulacean acid metabolism (CAM), in which they open their stomata to admit CO_2 at night, convert it into acids, and store them inside their vacuoles. They release the CO_2 stored inside the acids during the day for use in photosynthesis. CAM plants are well adapted to the high daytime temperatures, intense sunlight, and very low soil moisture of the desert biome. Some familiar CAM plants include cacti, pineapple, and sedums.

• Significance for Climate Change

Both water and CO_2 serve as essential raw materials in photosynthesis. Therefore, any climate change that affects the availability of either substance will affect photosynthesis. Given the various pathways different plants employ for photosynthesis, the same climate change will have different effects on different plants. Rising CO_2 concentrations in the atmosphere would in theory increase the photosynthetic rates of all plants. This phenomenon is described as CO_2 fertilization. However, the increase in photosynthesis from rising atmospheric CO_2 concentrations is short-lived: The response decreases under long-term exposure, because plants acclimate to elevated CO_2 concentrations through a process known as down regulation.

Plants' response to rising temperatures is complex, may be positive or negative, and is often compounded by other climatic factors. Moisture in the environment is particularly influential, as changes in temperature may correlate to changes in dew point and evaporation rate, significantly affecting the availability of water. Depending upon the degree of increase, warming temperatures may drive some plants out of their natural habitats, causing biodiversity declines or species extinction.

Carbon 3 plants tend to increase their photosynthetic rate as a result of CO_2 fertilization to a point where the associated temperature increase may offset the positive effect of rising CO_2. If the temperature increases above the level at which carbon 3 plants need to shut their stomata to conserve water, the positive effect of CO_2 fertilization diminishes or disappears entirely. In fact, facing the prospect of dehydration and drought as a result of climate change, some carbon 3 plants may no longer be able to even survive in their natural habitat.

On the other hand, carbon 4 plants may benefit from a warmer climate simply because they reach their maximum photosynthetic rate at a much higher temperature. Within certain range, the increases in both daily temperature and CO_2 concentration may have short-term benefits for carbon 4 plants. The increases in atmospheric CO_2 may have very little effect on CAM plants, because the leading constraints for their photosynthesis lies with the capacity to store acids inside their vacuoles. Since CAM plants are already adapted to the desert biome, however, an appreciable temperature rise that renders deserts even more hostile could be detrimental to the survival of CAM plants in general.

Ming Y. Zheng

• Further Reading

Margaris, N. S., and H. A. Mooney, eds. *Components of Productivity of Mediterranean-Climate Regions: Basic and Applied Aspects.* Boston: W. Junk, 1981. Compendium of papers from a conference on photosynthesis, primary production, and biomass utilization. Details the effects of Mediterranean climate on photosynthesis and thus gives insight into the general relationship between photosynthesis and climate.

Morison, James I. L., and Michael D. Morecroft, eds. *Plant Growth and Climate Change.* Ames, Iowa: Blackwell, 2006. Includes extensive discussion of the relationship between global and regional climate change and photosynthesis.

Morton, Oliver. *Eating the Sun: How Plants Power the Planet.* New York: HarperCollins, 2008. Extensive scientific analysis of photosynthesis from the points of view of both geologic time and human history. Emphasizes the role of the process in hu-

man societies and its particular relation to contemporary environmental challenges.

See also: Carbon dioxide; Carbon dioxide fertilization; Carbon 4 plants; Carbon 3 plants; Forestry and forest management; Forests; Mangroves.

Pinchot, Gifford
American forester

Born: August 11, 1865; Simsbury, Connecticut
Died: October 4, 1946; Milford, Pennsylvania

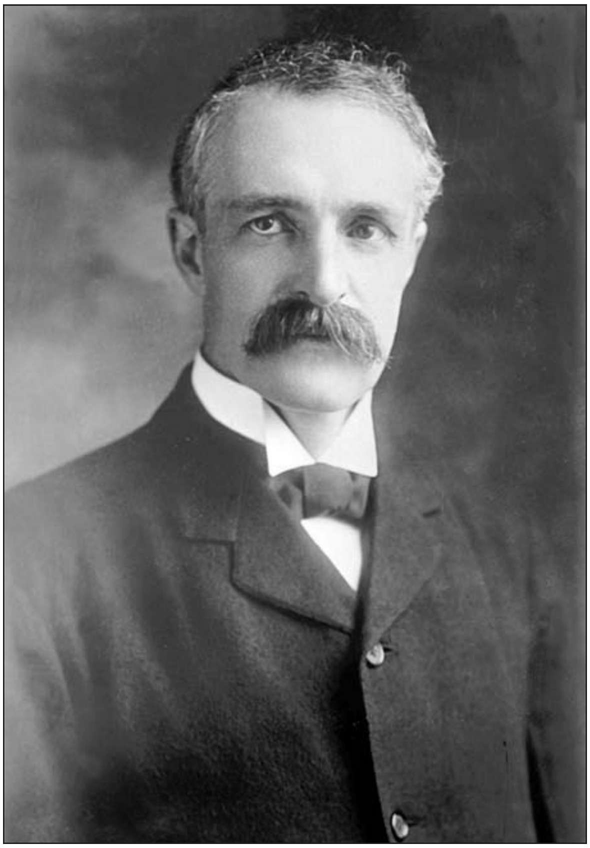
As first chief of the United States Forest Service, Pinchot set the example for modern forestry in general and U.S. forestry and forest management policy in particular.

• Life
Gifford Pinchot was the eldest child of James Pinchot, who obtained vast wealth from lumbering and land speculation. Disturbed by the damage that had been done to the land, James suggested that Gifford become a forester. Gifford graduated from Yale in 1889 and spent a year at the French National Forestry School. He was the resident forester for the Biltmore Estates for three years.

In 1896, Pinchot was appointed to the National Forest Commission by the National Academy of Sciences. In 1898, he was named head of the Division of Forestry. Later the Division of Forestry became the United States Forest Service, with Pinchot as its first chief. Fired by President William Howard Taft in 1910, Pinchot ran for the Senate in 1914 but was not elected. In 1920, he was appointed Pennsylvania state commissioner of forestry. He was elected governor of Pennsylvania in 1922 and in 1930, with unsuccessful Senate bids in between and again afterward. As a young man, Pinchot had fallen in love with a young lady who died after a long illness. Pinchot was so heartbroken that he did not marry until 1914, when he married Cornelia Bryce. They had one son, Gifford Bryce Pinchot. Pinchot died of leukemia at age eighty-one.

• Climate Work
Pinchot first saw how forests could be maintained by selective cutting while touring forests in Great Britain, France, Switzerland, and Germany during his year of study at the French National Forestry School. He had seen the devastation caused by clear-cutting of timber. Clear-cut forests do not quickly grow back, soil erodes, streams fill with silt, and animals cannot survive. Pinchot wanted to devise a way to maintain the forests of the United States. Thus, he adapted the European methods so that they would be useful in the United States.

Pinchot devised three tenets of a conservation ethic that proved successful for the National Forests of the United States. First, people should protect and preserve natural resources but also put those resources to use wisely and in a way that allows the resources to be renewed. He advocated selective cutting of forests and replanting after cut-



Gifford Pinchot. (Library of Congress) ting. He had seen that forests that were never cut at all gradually filled with dead trees. Second, natural resources were to be used for the good of all people and at a fair cost. Pinchot believed that only the government could keep large companies from monopolizing natural resources. He also thought that monopolies would drive up costs for the people. Third, conservationists should be willing to fight politically to protect the rights of the people against large companies.

Pinchot firmly believed that the Forest Service should not be politically based. He wanted a Forest Service of committed people, not political appointees. Political appointees, who owe someone else, may have to make decisions based on their appointment that are not in the best interests of the forests. Pinchot had to fight a two-front war during his time in the Forest Service. Some of the strict conservationists wanted the forests preserved as they were and wanted no cutting at all. Pinchot knew that no forest survives as is. Forests must be maintained, and Pinchot believed that selective cutting with replanting was the best way to do that.

On the other front, lumber companies had been clear-cutting and moving on for years. The forests seemed endless to them, so they saw no need to spend money replanting the cleared ground. Pinchot had seen the results of clear-cutting many times before. His idea to require a promise to replant before permission to cut was put into practice, angering many lumber companies.

Pinchot organized a Forest Service that was based on his conservation ethic. He arranged for the Forest Service to have authority and control of the National Forests and helped increase the National Forests from 22.7 million hectares to 69.7 million hectares. He contributed to the formation of the Society of American Foresters. He also was instrumental in establishing the Yale Forest School and served as a faculty member for many years. Pinchot's work for the Forest Service thus contributed directly to one of the United States' most important climatic resources, its forests.

C. Alton Hassell

• Further Reading

McGeary, M. Nelson. *Gifford Pinchot: Forester-Politician.* Princeton, N.J.: Princeton University Press, 1960. This book was planned as a discussion of Pinchot as a politician, but McGeary soon decided that the forester aspect of his life was too intertwined to be left out. Illustrations, bibliography, index.

Miller, Char. *Gifford Pinchot and the Making of Modern Environmentalism.* Washington, D.C.: Island Press/Shearwater Books, 2001. Discusses Pinchot's development of his distinctive concept of forest conservation. Illustrations, bibliography, index.

Pinchot, Gifford. *The Conservation Diaries of Gifford Pinchot.* Edited by Harold Steen. Durham, N.C.: Forest History Society, 2001. Important primary source for understanding Pinchot's life and work. Illustrations, maps, index.

_______. *The Fight for Conservation.* Reprint. New York: Doubleday, Page, 2004. More polemic than the diaries; presents Pinchot's arguments in favor of conservationism.

See also: Conservation and preservation; Deforestation; Forestry and forest management; Forests.

Planetary atmospheres and evolution

• **Categories:** Astronomy; meteorology and atmospheric sciences

Comparisons of Earth's atmosphere with similar atmospheres such as those of Venus, Mars, and Titan provide insight into atmospheric evolution and physics.

• Key concepts

comparative planetology: scientific approach that tests theories by comparing data and observations of multiple planets

terrestrial atmosphere: a globally significant atmosphere covering a rocky planetary body

volatile: an element or compound with a low melting or boiling point

weathering: a chemical process in which atmospheric carbon dioxide is converted to carbonates through reactions with water and silicate minerals

• Background

The atmosphere of Earth defines the category of terrestrial atmospheres. Similar atmospheres are those of Venus, Mars, and Titan—the largest moon of Saturn. These atmospheres share the basic qualities of terrestrial atmospheres, yet they are quite different from one another. Using comparative planetology, the causes for these differences can be investigated, in turn providing further understanding of the atmosphere of Earth.

• The Current Atmospheres of Venus, Earth, and Mars

Earth and its two nearest planetary neighbors, Venus and Mars, possess atmospheres with different qualities. Earth's atmosphere has an average atmospheric pressure of 1.013 bars and an average surface temperature of around 15° Celsius. The chemical composition of the atmosphere is primarily nitrogen (N_2; 78.1 percent by volume) and oxygen (O_2; 21.0 percent). It also contains water vapor (H_2O; less than 3 percent) and a small amount of carbon dioxide (CO_2; about 380 parts per million). The atmosphere of Venus is thicker at 92 bars and has a surface temperature of 500° Celsius. Its composition is almost entirely CO_2 (96.5 percent), with a little N_2 (3.5 percent) and only trace amounts of H_2O (about 50 parts per million).

Mars has a much thinner atmosphere than Earth or Venus. Its atmospheric pressure is 0.006 bar and its surface temperature is –58° Celsius. As with the Venusian atmosphere, the Martian atmosphere is mostly CO_2 (95.3 percent) and N_2 (2.7 percent) with a trace amount of H_2O (less than 100 parts per million). Mars and Venus have no liquid water on the surface, although Mars possesses polar water ice caps. All three atmospheres experience greenhouse warming, about 500° Celsius for Venus, 35° Celsius for Earth, and 6° Celsius for Mars.

The differences between the three planets cannot be explained by current conditions alone. Rather, these differences arose as the planets evolved over the history of the solar system.

• Evolution of the Atmospheres of Venus, Earth, and Mars

The solar system formed 4.6 billion years ago; the planets' atmospheres formed in the first few hundred thousand years. Volcanic activity released CO_2, N_2, H_2O, and other volatiles previously trapped in molten mantles, with additional gases supplied by collisions with icy, volatile-rich small bodies. Some atmospheric gases were lost at the top of the atmospheres to space and at the planetary surfaces to liquid, ice, and incorporation into solids. All three planets probably had roughly comparable early reservoirs of volatiles in roughly the same proportions, meaning all three planets had the same materials to draw on, and each could have developed an atmosphere resembling that of either of the other two. Each atmosphere, however, evolved along a different path.

On Earth, early conditions allowed water in the atmosphere to condense into rain and create liquid water oceans. The rain, the oceans, and exposed regions of crust created conditions in which CO_2 could be trapped in solid carbonates through weathering. Weathering kept atmospheric temperatures within a range in which water remains liquid. As the solid Earth cooled further, volcanic activity decreased but weathering continued, removing CO_2 and leaving behind an atmosphere largely of N_2. The development of biological life also converted some CO_2 to O_2, with significant oxygen content appearing in the atmosphere around two billion years ago.

Being closer to the Sun, the early Venusian atmosphere was warmer than was Earth's. This warmth was enhanced by the greenhouse effect of an increasingly thick atmosphere of CO_2 and H_2O. As it grew warmer, virtually all the water on the planet vaporized, preventing weathering. This caused a runaway greenhouse effect, in which atmospheric CO_2 and greenhouse warming steadily increased while H_2 was preferentially lost at the top of the atmosphere, gradually reducing the water supply. This process created the thick, nearly waterless CO_2 atmosphere seen today. The runaway greenhouse effect may date from the origin of Venus's atmosphere, but another possibility is that a moist greenhouse phase preceded the later phase. The moist phase would have involved condensation, liquid

Planetary Atmospheres: Comparative Data

	Mercury	*Venus*	*Earth*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
Surface pressure (bars)	~10^{-15}	92	1.014	6.1-9 millibars	>100	>100	>100	>100
Surface density (kg/m^3)	—	~65	1.217	~0.020	~0.16	~0.19	~0.42	~0.45
Avg. temperature (Kelvin)	440	737	288	~210	~129	~97	~58	~58
Scale height (kilometers)	—	15.9	8.5	11.1	27	59.5	27.7	~20
Wind speeds (meters/second)	—	0.3-1.0	up to 100	2-30	up to 150	up to 400	up to 200	up to 200
Composition[a]								
Ammonia	—	—	—	—	260 ppm	125 ppm	—	—
Argon	tr?	70 ppm	9430 ppm	1.6%	—	—	—	—
Carbon dioxide	tr?	96.5%	350 ppm	95.32%	—	—	—	—
Carbon monoxide	—	17 ppm	—	—	—	—	—	—
Ethane	—	—	—	—	5.8 ppm	7 ppm	—	1.5 ppm
Helium	6%	12 ppm	5.24 ppm	—	10.2%	3.25%	15.2%	19%
Hydrogen	22%	—	0.55 ppm	—	89.8%	96.3%	82.5%	80%
Hydrogen chloride	—	tr	—	—	—	—	—	—
Hydrogen deuteride	—	—	—	0.85 ppm	28 ppm	110 ppm	~148 ppm	192 ppm
Hydrogen fluoride	—	tr	—	—	—	—	—	—
Krypton	tr?	—	1.14 ppm	0.3 ppm	—	—	—	—
Methane	—	—	—	1.7 ppm	3000 ppm	4500 ppm	~2.3%	1.5%
Neon	tr?	7 ppm	18.18 ppm	2.5 ppm	—	—	—	—
Nitrogen	tr?	3.5%	78.084%	2.7%	—	—	—	—
Nitrogen oxide	—	—	—	100 ppm	—	—	—	—
Oxygen	42%	—	20.946	0.13%	—	—	—	—
Potassium	0.5%	—	—	—	—	—	—	—
Sodium	29%	—	—	—	—	—	—	—
Sulfur dioxide	—	150 ppm	—	—	—	—	—	—
Water	tr?	20 ppm	1%	210 ppm	—	~4 ppm	—	—
Xenon	tr?	—	0.08 ppm	—	—	—	—	—

Notes:
a. Composition: % = percentages; ppm = parts per million; tr = trace amounts.
Source: Data are from the National Space Science Data Center, NASA/Goddard Space Flight Center. URL: http://nssdc.gsfc.nasa.gov/planetary/factsheet.

water, and weathering similar to those experienced on Earth at warmer temperatures. This period of moist greenhouse may have lasted for up to two billion years.

Evidence also exists for an earlier, moist or wet phase on Mars. This evidence is apparent in large fluvial erosion features, the detection of substantial subsurface ice, and similar observations. The early atmosphere was probably thicker and wetter than the contemporary Martian atmosphere, with significant rainfall. Debate is ongoing as to whether this rainfall resulted in large oceans or transient floods, relatively short-lived lakes, and more ice and glacial features.

Mars's wet period probably lasted for less than a billion years, with a substantial amount of liquid water lost to subsurface permafrost and the polar ice caps. Only one-half the radial size of Earth, solid Mars cooled more rapidly, so its volcanic activity ended earlier, ending the supply of volatiles. Volatiles continued to escape to space from a planet with a gravitational field 2.6 times weaker than that of Earth. Increasing this loss was a period of heightened asteroid bombardment around 3.9 billion years ago and solar-wind stripping after the disappearance of the Martian magnetic field around 4.0 billion years ago. These losses reduced the Martian atmosphere to its current thin veneer. Still, the variable obliquity and orbital eccentricity of Mars over geological time scales may have permitted occasional bursts of subsurface water to surface, creating more recent erosion features.

• Observations of Mars and Titan

The program of Mars exploration starting with Mars Pathfinder in 1996-1997 has been critical to reconstructing the past and current states of the Martian climate. These observations are also studied to determine if changes in solar output influence the climate on Mars (where human influences are nonexistent), contributing to the scientific understanding of Earth's climate and solar output as well. The Martian atmosphere also provides an additional testing ground for general circulation models, potentially improving models of Earth's atmosphere.

The Cassini-Huygens mission to Saturn and Titan explored another earthlike atmosphere in the solar system. Titan's atmospheric pressure is about 1.5 times that of Earth, and the moon has a surface temperature of around −179° Celsius with a largely N_2 atmosphere (more than 96 percent). Titan has a phase-change cycle, including rain and surface liquid lakes—but of methane (CH_4) rather than water. These similarities to Earth make Titan an inviting target for comparative planetology.

• Context

Comparative planetology has clarified the evolution of the terrestrial atmospheres. Venus is a planet where greenhouse warming occurred unabated; Mars was too small and too cold to maintain a thick, warm atmosphere. Both resulted in dry climates, likely inhospitable to life. The evolution of Earth struck a more hospitable balance, resulting in abundant liquid water and abundant life. Continuing to compare Earth's atmosphere and atmospheric history with those of Venus, Mars, and Titan will promote further understanding of the physics and chemistry that govern climate change.

Raymond P. LeBeau, Jr.

• Further Reading

Atreya, S. K., J. B. Pollack, and M. S. Matthews, eds. *Origin and Evolution of Planetary and Satellite Atmospheres.* Tucson: University of Arizona Press, 1989. Collection of work by leading scientists covering planetary atmosphere formation and evolution. Figures, tables, bibliography, index.

De Pater, Imke, and Jack J. Lissauer. *Planetary Sciences.* New York: Cambridge University Press, 2001. College textbook that provides an equation-based introduction to planetary atmospheres. Figures, tables, references, index.

Grinspoon, David H. *Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet.* New York: Basic Books, 1998. Sometimes-quirky review of Venus post-Magellan. Illustrations, index.

Lorenz, Ralph, and Jacqueline Mitton. *Titan Unveiled: Saturn's Mysterious Moon Explored.* Princeton, N.J.: Princeton University Press, 2008. Review of Titan and the Cassini-Huygens mission. Illustrations, tables, index.

Read, Peter L., and Stephen R. Lewis. *The Martian Climate Revisted: Atmosphere and Environment of a Desert Planet.* Berlin: Springer-Verlag, 2004. Includes a discussion of Mars general circulation

models and other details of the planetary climate system. Figures, table, references, index.

See also: Atmosphere; Atmospheric chemistry; Atmospheric structure and evolution; Earth structure and development; Global energy balance; Sun.

Plankton

• **Categories:** Plants and vegetation; animals

• **Definition**

Plankton (from the Greek *planktos*, or wanderer) comprise a vast assortment of life-forms with limited or no swimming power that largely drift in the ocean. They are divided into the plantlike phytoplankton and the animal-like zooplankton.

Phytoplankton comprise at least four thousand species of plants that, as on land, use sunlight in the process of photosynthesis to generate sugars and other high-energy organic compounds. They live in the ocean's euphotic zone, the sunlit upper layer, which is only tens of meters deep. Phytoplankton range in size from microscopic to a millimeter in length and include single-celled organisms and tiny clumps of algae.

Because the ocean covers 71 percent of the Earth's surface, phytoplankton are a major driver of Earth's carbon cycle. Their photosynthesis extracts carbon dioxide (CO_2) from surrounding water and replaces it with oxygen. The resulting changes in oceanic gas levels change atmospheric gas levels as well. Some phytoplankton (such as coccolithophores) accrete calcium carbonate ($CaCO_3$) for shielding. If the carbon contained in their bodies reaches the ocean depths, it may be sequestered there for years, or even for millions of years.

Oceanic nutrient levels are major determinants of phytoplankton productivity. The most fertile areas are river estuaries, shallow waters, and upwelling areas in the deep ocean. Phytoplankton are eaten by zooplankton. Zooplankton range mostly from microscopic to the size of small snails, although jellyfish, some more than 2 meters in diameter, also swim weakly and can be classed as zooplankton.

Zooplankton slow the carbon cycle, because they consume phytoplankton and emit CO_2. Phytoplankton "blooms" of increased productivity are quickly followed by surging zooplankton populations. Conversely, zooplankton contribute to carbon cycling by accreting carbonate shells, dropping fecal pellets, and falling to the sea bottom upon death.

Together, phytoplankton and zooplankton directly or indirectly feed all the rest of the animals in the ocean, including human fisheries. Oceanic acidification may affect both planktonic food production and planktonic capture of CO_2. Increasing CO_2 levels in the atmosphere translate into higher levels in oceanic surface waters and favor increased photosynthesis. However, increased CO_2 levels also cause greater ocean acidity. Increased acidity in the waters may strongly hinder carbonate shell-building among plankton and other marine life-forms. If so, it would slow the marine carbon-capture process and contribute to even greater atmospheric CO_2 levels.

• **Significance for Climate Change**

In 1988, oceanographer John Martin declared, "Give me half a tanker of iron, and I can start a new ice age." Martin was referring to phytoplankton growth in the "bluewater desert" areas of the deep ocean. The creatures' growth rate is often limited by the availability of trace amounts of iron. It has been hypothesized that ice ages may result from large amounts of wind-blown dust enriching the oceans with iron. Such enrichment could have caused phytoplankton blooms that reduced atmospheric CO_2 levels, thus reducing the greenhouse effect and cooling the planet.

Similarly, Martin suggested that artificial iron fertilization in the oceans might reduce global warming. (A major campaign of oceanic fertilization would be a species of geoengineering.) Several limited experiments of a few hundred square kilometers and a few days duration have confirmed major iron fertilization in the Pacific Ocean and in the southern ocean around Antarctica.

Phytoplankton emit the sulfur-bearing gases dimethyl sulfide (DMS, CH_3SCH_3) and carbonyl sulfide (COS). Their breakdown product, sulfur dioxide (SO_2), produces airborne particles (aerosols) that reflect visible light but allow infrared light (heat waves) to pass through, thus causing more cooling. Ocean fertilization could be self-funding, because a part of the increased planktonic production could be harvested via increased fisheries production.

The major objections to oceanic fertilization are as follows: First, as noted, zooplankton populations grow to feed on phytoplankton blooms, and they quickly return much CO_2 to the atmosphere. Second, even if it is not eaten, much planktonic biomass decays and gives up captured carbon before it can sink to the bottom, so it is not an efficient carbon sink. Third, if fertilization were widely implemented, organic material reaching the deep ocean would vastly increase. In decaying, it could harm marine life by lowering oxygen levels in the deep waters. Fourth, plankton emit some greenhouse gases (GHGs), such as oxides of nitrogen, that might cancel some aerosol cooling. Finally, aerosols released by fertilization in sufficient amounts to cause noticeable cooling would also significantly decrease the sunlight available for photosynthesis. For these reasons, opponents of oceanic fertilization argue that it might result in some mitigation of global warming, but it could never represent a comprehensive solution to the problem.

Roger V. Carlson

• Further Reading

Adhiya, Jagat, and Sallie W. Chisholm. "Is Ocean Fertilization a Good Carbon Sequestration Option?" Cambridge, Mass.: MIT Press, 2001. This white paper presents the case against oceanic fertilization.

Field, Christopher B., and Michael R. Rapauch, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Washington, D.C.: Island Press, 2004. This compendium of articles from the Scientific Committee on Problems of the Environment (SCOPE) discusses the major atmospheric sources and sinks. The final chapter details possible advantages and limitations of ocean fertilization.

Mitra, Abhijit, Kakoli Bannerjee, and Avijit Gangopadhyay. *Introduction to Marine Plankton.* Delhi, India: Daya, 2008. Although the authors emphasize plankton in the waters near India, they provide an excellent overall description of plankton, its role in the carbon cycle, fertilization effects, identification, and even culturing. However, the book does not comment directly on oceanic fertilization or acidification.

"The Ocean in a High-CO_2 World." Special Section in *Journal of Geophysical Research* 110, no. C9 (2005). Includes papers on the carbon cycle, as well as articles making arguments for and against oceanic fertilization.

Royal Society. *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide.* London: Author, 2005. The Royal Society in the United Kingdom assembled a group of distinguished scientists to summarize the issues of oceanic acidification in this study.

See also: Carbon cycle; Estuaries; Fishing industry, fisheries, and fish farming; Maritime climate; Ocean acidification; Ocean-atmosphere coupling; Ocean life; Reefs; Sea sediments; Sulfate aerosols.

Plate tectonics

• Category: Geology and geography

The Earth's lithosphere moves laterally, from regions in which it is being formed by igneous activity to regions where lithospheric plates are being subducted below other plates, forming more explosive volcanism. The volcanism can produce GHGs, and movement of the lithosphere can slowly move continents, affecting climate over time.

• Key concepts

crust: the upper part of the Earth's surface—about 7 to 10 kilometers thick in the oceans and about 25 to 70 kilometers thick on the continents

greenhouse gases (GHGs): atmospheric trace gases that trap heat rather than allowing it to escape into space

igneous rocks: rocks formed by the crystallization of magma or lava

lithosphere: the rigid part of the Earth, comprising Earth's crust and the rigid part of its upper mantle—about 100 kilometers thick in the ocean basins and about 150 kilometers thick on the continents

magma: molten rock and suspended crystals below the Earth's surface
mantle: the dense layer of the Earth below the crust
oceanic rise: linear mountain chains on the ocean floors in which lithosphere is formed by crystallization of magma or volcanism
subduction: the movement of one lithospheric plate below another

• Background

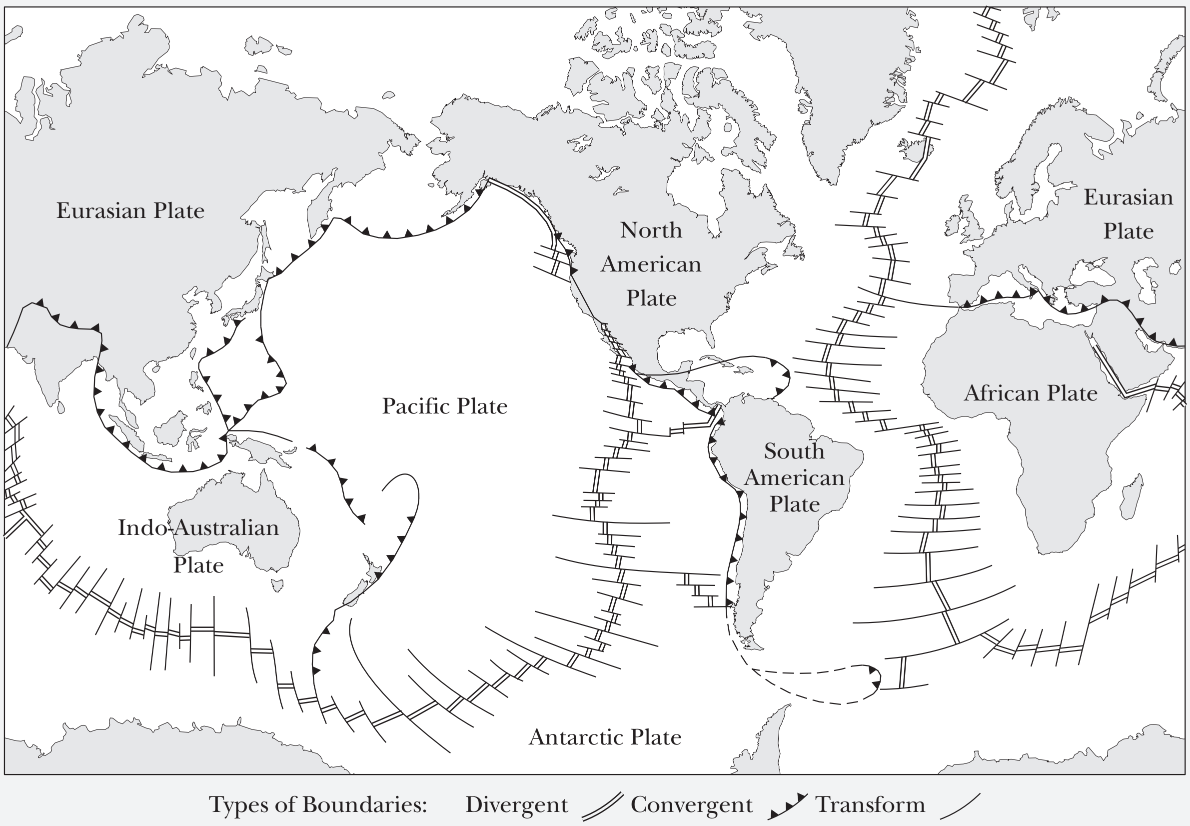
The atmosphere of the Earth has varied through geologic time, from times of global warming with no glaciers to times with abundant glaciers. For instance, there was significant cooling and glaciation from about 1 billion to 550 million years ago, from 300 to 260 million years ago, and from 35 million years ago to nearly the present. At other times, significant global warming occurred, especially in the interval from about 145 to 55 million years ago. Thus, global warming has occurred in the past and is not just a recent event. Reasons for these large global changes in temperature must be explained by natural processes such as plate tectonics.

• Earth's Tectonic Activity

The lithosphere of the Earth is composed of about twenty plates of varied sizes in which igneous rocks are being formed by volcanism or crystallization of magma along oceanic rises. In addition, volcanic gases are continually being evolved along the oceanic rises.

The oceanic lithosphere moves laterally away from oceanic rises, usually at a rate of less than 10 centimeters per year. A portion of the oceanic litho-

Earth's Tectonic Plates and Mid-Ocean Ridges



sphere eventually moves below another oceanic lithospheric plate or below continental lithosphere at a subduction zone. For instance, the portion of the lithosphere beneath the Pacific Ocean continuously moves below the portion of the lithosphere on which South America occurs. In addition, abundant volcanic activity, evolution of volcanic gases, and earthquakes occur above the subducted plate in South America. Also, continents resting on these lithospheric plates move laterally and vertically through geologic time.

• Greenhouse Gases

The amount of greenhouse gases (GHGs) in the atmosphere can affect the amount of energy given off from the Earth into space. Carbon dioxide (CO_2) is believed to be one of the most important of these gases that affect the atmospheric temperature. Most notable is the direct correlation of the amount of CO_2 in atmosphere trapped in ice cores in Antarctica over the last 400,000 years to that of the inferred temperature of the atmosphere.

Thus, understanding how and why the CO_2 content of the atmosphere changes is critical to understanding why the temperature of the atmosphere changes with time. Increased volcanic activity, for instance, will increase the rate of CO_2 production into the atmosphere, thus favoring temperature rise. Weathering of rocks uses up CO_2 and moves it as dissolved bicarbonate into the oceans, where it is used by organisms to create shells and skeletons of calcium carbonate, thereby sequestering the carbon from the atmosphere and favoring a decrease in atmospheric temperature. Movement of continents that allows for increased plant growth should also remove CO_2 from the atmosphere and favor a decrease in atmospheric temperature.

• Warming Climate

Global temperatures from about 250 million years to 55 million years ago were much warmer than those today. During this time, the temperatures at the equator are estimated to have been 2° to 6° Celsius warmer and those at the north and south poles on the order of 20° to 40° Celsius warmer than those today. Thus, there were no ice fields at the poles and many plants and animals could live further north and south than they can today. For example, dinosaurs could live at high latitudes until they disappeared about 65 million years ago.

The continents formed a supercontinent called Pangaea from 250 to 180 million years ago that extended from the north to the south poles. Then, the continental landmass began to rupture along an oceanic rise, so that what is now North and South America moved to the west and what is now Europe, Asia, and Africa moved to the east. Pangaea was likely dry in the interior, since rain near the coast would have dried the air before it reached the interior. This could have resulted in significant temperature variation in the interior of Pangaea from hot, moist summers to cold, dry winters. The lack of moisture could have kept glaciers from forming in the winter, and the hot summers could have melted most ice at the poles.

Spreading rates from the oceanic rift around 100 million years ago could have moved the continents at more rapid rates than do current plate tectonics. The rapid spreading could have generated much more magma at oceanic rises and subduction zones, producing large amounts of CO_2 and further warming the atmosphere. This process could explain the very high average temperature during this time. In addition, the ocean may have been more able to transport heat to warm the poles and cool the tropics.

• Cooling Climate

The climate began to cool about 55 million years ago. Large continental glaciers formed during some of this time that covered, for instance, what is now Canada and the northern United States. The reasons for this drastic cooling are a matter of debate, but there are several possibilities. Ocean spreading rates may have decreased slowly to the current spreading rates, reducing the amount of CO_2 emitted into the atmosphere and favoring cooling. Another possibility is that the continents may have been uplifted, making more moisture available to produce more rapid chemical weathering of the rocks. This increased weathering would have used more CO_2, as would the consequent increase in carbonate organisms in the oceans, sequestering carbon from the atmosphere and decreasing the greenhouse effect.

• **Context**

Plate tectonics are a function of geological and geothermal processes that bring heat to Earth's surface and that directly and indirectly influence the level of GHGs in the atmosphere. As such, they contribute to increases and decreases in global temperature, although they are not generally thought to be determining factors in climate change, either recent or on geologic timescales.

Robert L. Cullers

• **Further Reading**

Kump, Lee R., James F. Kasting, and Robert G. Crane. *The Earth System.* Upper Saddle River, N.J.: Prentice Hall, 2003. Describes the changes in the Earth as they affect the environment. Includes global warming, the atmosphere, and plate tectonics, among other topics. Appendixes, tables, figures, glossary.

Marshak, Stephen. *Earth: Portrait of a Planet.* New York: W. W. Norton, 2005. Gives a reasonably detailed description of plate tectonics and geology and touches on the evolution of climates over time. Figures, glossary, index.

Ruddiman, William F. *Earth's Climate: Past and Future.* 2d ed. New York: W. H. Freeman, 2008. Describes the Earth's climate changes through geologic time and the possible reasons for these changes. Figures and tables, glossary, index.

See also: Carbon dioxide; Coastline changes; Cryosphere; Deglaciation; Earth history; Earth structure and development; Earthquakes; Greenhouse effect; Lithosphere; Plankton.

Pleistocene climate

• **Category:** Climatic events and epochs

During the Pleistocene epoch, major climatic fluctuations, including the advance and retreat of continental glaciers, were influenced by small variations in the amount of solar energy reaching high latitudes in the summer. Determining the details of this influence has major implications for scientists' ability to predict future climate change.

• **Key concepts**

climatic precession: cycle of variations in the Earth-Sun distance at summer solstice

loess: deposits of very fine grained, wind-blown material often associated with glacial deposits

marine isotope stage: half of a glacial cycle, as identified in the oxygen isotope data from ocean cores

orbital eccentricity: cyclically variant deformities in Earth's orbit

Pleistocene epoch: an epoch within the geologic timescale, ending at 11,700 years ago

Pliocene epoch: the epoch preceding the Pleistocene and beginning around 5.332 million years ago

• **Background**

Characterized by repeated cycles of glacial cold and interglacial warmth, Pleistocene climate was always changing. Scientists believe that the timing of these changes was controlled by periodic variations in the orbit of the Earth. They are still trying to figure out how the small changes produced by these variations were amplified into dramatic climatic shifts. Of particular interest is the question of if and when another glacial advance will occur.

• **Climate During the Pleistocene**

Geologists divide up the 4.6 billion years of Earth's history, usually based on the planet's fossil record. The planet's history is divided into eras, which are divided into periods, which are divided into epochs, which are divided into ages. Eras are neatly separated by major mass extinctions, and most of the other divisions are also reasonably clear. However, the division between two period/epoch pairs has proven to be more difficult: The base of the Quaternary period and the base of the Pleistocene epoch are either at the top or the bottom of the Gelasian age.

The ages within both the Pliocene and the Pleistocene epochs are determined by the marine fossils from those epochs, which are not difficult to date. A problem arises, however, from an attempt to put the beginning of the ice ages at the right age boundary. In 1948, at a meeting of the International Union of Geological Sciences, the top of the Gelasian age (1.81 milion years ago) was chosen as the advent of the ice ages. Since then, a tremendous amount of climate-related research has sug-

The unearthed tusks of a Pleistocene-epoch woolly mammoth—approximately twenty-three thousand years old—are tied to a reindeer sled for transport to Khatanga, Siberia. (AP/Wide World Photos)

gested that the bottom of the Gelasian, 2.59 million years ago, might have been a better choice. As often happens, both dates are used. The discrepancy is not signfiicant in the context of climate issues. Because the climate began to behave differently a little before 2.59 million years ago and it did not change much 1.81 million years ago, a description of Pleistocene climate will also apply to Gelasian climate, whether one considers the Gelasian age to be part of the Pleistocene or part of the Pliocene epoch.

Around 2.6 million years ago, the climate began to oscillate between glacial and interglacial states. When only land-based data on glacial advances were available, only a few advances were described, but as the ability to interpret isotope data from ocean cores developed, it was determined that there have been at least fifty advance/retreat cycles in the last 2.6 million years. The shift from continental rocks to ocean sediment cores as the source of definitive data was important in providing this additional data.

The surfaces of the continents, particularly when being scraped repeatedly by large glaciers, do not keep very good archives. In some places, glacial deposits lie on top of other glacial deposits, and those earlier deposits often have complete soil profiles. Geologists thus knew that there had been more than one glacial period, but they had little detailed knowledge about the succession of such periods. Each new advance usually removed any former glacial deposits, obscuring the record. In the deep oceans, however, remains of dead organisms accumulate, and there is little to remove them. As isotope geochemistry developed, it became apparent that the ratio of oxygen 18 (O^{18}) to oxygen 16 (O^{16}) preserved in these remains changed systematically in all of the world's oceans during the last three million years or so. Evaporation removes more O^{16}, and during glaciations will sequester much of this isotope in the ice sheets, thereby enriching the oceans in O^{18}. Fluctuations in the isotope ratio can indicate whether the Earth was in a glacial (high O^{18}/O^{16} level) or interglacial (low O^{18}/O^{16} level) state.

As cores of sediments were retrieved from the ocean floor, changes in the O^{18}/O^{16} ratio as a function of time were observed and analyzed. Shifts were numbered, starting with 1 for the present interglacial and using odd numbers for interglacials and even numbers for glacials. The time period represented by each number is called a marine isotope stage (MIS). Glacial cycles already known from continental evidence correlated with some of the MIS cycles, but there were many more MIS cycles, they were global in nature, and their dates were known more accurately. Terms such as "Illinoian" and "Moscovian Dnieper" were replaced by designations such as "MIS 6."

Using Fourier analysis and other methods, scientists found that some periods of time were very strongly represented in the marine isotope record. These peaks in information seemed to correspond to natural cycles. (Imagine recording the sounds from a neighborhood continuously for a decade and then analyzing them. One might expect to see information peaks at intervals corresponding to the cycles governing human activity: every twenty-four hours, every week, and possibly every year.) The peaks in the sediment cores occurred every forty-one thousand years, about every twenty-two thousand years, and every hundred thousand years.

• Causes

A glacier will grow if snow accumulates over periods of years, as snow that fell during the previous winter does not melt completely during the summer. Thus, summer temperatures are the limiting factor in glaciation. If summers are not warm enough to melt all of winter's ice accumulation, the glaciers will advance. Winter temperatures do not matter to this process, so long as they remain below freezing.

Temperatures on Earth are determined primarily by the Sun, and its influence is modulated by periodic changes in the tilt of the planet's rotational axis, the precession of that axis, and the eccentricity of Earth's orbit. These changes were known by the middle of the nineteenth century, and James Croll suggested in 1864 that they might be responsible for the advance and retreat of continental glaciers. Data, computations, and dating techniques were not yet sufficient to support the theory, however, and interest in it waned until Milutin Milanković resurrected the idea in 1913. He worked on the problem for decades, publishing his completed book in 1941; it was translated into English in 1969.

Milanković was able to calculate how much solar energy would reach a latitude of 65° north during the summer. He obtained this result by combining the effects of a 100,000-year cycle in the eccentricity of the Earth's orbit, a 41,000-year cycle in the inclination of the Earth's axis, and a roughly 22,000-year cycle in climatic precession. Thus, the peaks evident in ocean sediment cores matched precisely Milanković's cycles.

When the ocean core analyses were complete, there was no question that glacial advances and retreats followed the timing of the Milanković cycles. As a result, serious concerns were raised for a time about a coming glacial advance. Some papers written in the 1970's—as well as meetings, symposia, and water cooler discussions—concerned the global cooling that Milanković's work seemed to predict. In part, this was due to a decade-long cooling period in the Northern Hemisphere, but it also stemmed from the recognition that, according to Milanković, the current interglacial should end soon.

Trying to guess when it will end, scientists examined the record. Between 3 million and 0.8 million years ago, the cycles were dominated by the 41,000-year cycle. Afterward, however, a period began that is often called the Mid-Pleistocene Transition, and the cycles became dominated by the 100,000-year cycle. Although many theories have been put forward to explain this transition, it is still not well understood. In addition, it is unknown whether the current interglacial period has been extended by the effects of agriculture and other human activities over the last eight thousand years or whether it would have been longer than average regardless of human behavior.

• Pleistocene Weather

Estimates made from isostatic rebound studies suggest that the continental glaciers at their height during Pleistocene glaciations were 1-2 kilometers thick. The ice moved from north to south, reaching a latitude of 40° north, near the northern boundary of the state of Pennsylvania. Even when the glacier stopped advancing, the ice within it continued to move from north to south, grinding away at the material beneath it. At its southern edge, melting converted the ice to liquid water.

Where the glaciers terminated, the ice rose steeply, with large accumulations of ice adjacent to large lakes and hills. In the summer, this ice must have caused wind and precipitation patterns quite different from those experienced during interglacial periods. All year long, the presence of the glacier is likely to have altered global wind patterns. It was white, cold, and added considerably to the elevation. With so much water tied up in ice, sea level fell by about 100 meters, exposing huge expanses of the continental shelves to weathering and erosion.

• Context

If Earth's climate continues to behave cyclically, as it has for the past 2.6 million years, then another glacial advance will occur in the future, perhaps within a millenium or two. Alternatively, anthropogenic inputs of greenhouse gases may have warmed the planet so much that another glacial advance will only occur after humans stop burning fossil fuels and the resulting emissions have left the atmosphere. A third possibility is that anthropogenic outputs have altered the land so much that continental glaciations are no longer possible.

Clearly, these alternatives represent very different climate change scenarios. Although scientists are confident that Milanković cycles were the pacemakers for Pleistocene climate change, there is little agreement on the mechanisms connecting these pacemakers to the various drivers and amplifiers of the climate system. Nor is there agreement as to why the dominant cycle shifted from one of 41,000 years to one of 100,000 years in the middle of the Pleistocene epoch. As these and other issues become better understood, it may become possible to predict the future with greater confidence.

Otto H. Muller

• Further Reading

Imbrie, J., and K. P. Imbrie. *Ice Ages: Solving the Mystery*. Short Hills, N.J.: Enslow, 1979. Excellent history of the efforts to understand what caused the ice ages. Full of personal anecdotes, it gives a sense of the excitement and the frustrations experienced.

Macdougall, J. D. *Frozen Earth: The Once and Future Story of Ice Ages*. Berkeley: University of California Press, 2004. Compelling tale for the general reader about how the Pleistocene ice ages were discovered, studied, and understood. Provides biographical sketches of many of the major contributors. Photos, diagrams, maps, annotated bibliography.

Nilsson, T. *The Pleistocene: Geology and Life in the Quaternary Age*. Dordrecht, Holland: D. Ridel, 1982. Somewhat technical, this book includes material on the anthropology and biology of the Pleistocene. Organized by geographical area; contains many maps and diagrams.

Ruddiman, W. F. *Plows, Plagues, and Petroleum: How Humans Took Control of Climate*. Princeton, N.J.: Princeton University Press, 2005. Written for the lay public, this book provides the background and thinking behind the theory that humans have influenced the climate for the last nine thousand years, primarily through agriculture. Illustrations, figures, tables, maps, bibliography, index.

See also: Alleroed oscillation; Climate reconstruction; Dating methods; Deglaciation; 8.2ka event; Holocene climate; Milanković, Milutin; Paleoclimates and paleoclimate change; Younger Dryas.

Poland

- **Category:** Nations and peoples
- **Key facts**

Population: 38,500,696 (July, 2008, estimate)
Area: 312,679 square kilometers
Gross domestic product (GDP): $667.4 billion (purchasing power parity, 2008 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 586.9 in 1992; 399.0 in 2005
Kyoto Protocol status: Ratified, December, 2002

• Historical and Political Context

Poland is a central European country located south of the Baltic Sea, between Germany and Ukraine. It has historically been the site of conflict among its neighbors, and has at times ceased to exist, when the entire area of the nation was annexed by other states. In 966, during the kingdom of Mieszko I, Poland accepted Christianity. In 1386, under the Jagiellon dynasty, Poland became an economic power, and that power increased in 1410. The decline of the Polish economy began in 1795 and resulted in the partition of Poland by Prussia, Russia, and Austria.

It took one hundred years for Poland to regain its independence, in 1918. On August 23, 1939, Germany and the Soviet Union signed the Ribbentrop-Molotov nonaggression pact; in this pact, Poland was secretly divided into Nazi- and Soviet-controlled zones. Germany invaded Poland on September 1, 1939, and the Soviets invaded on September 17. Poland became occupied by German troops after June, 1941, when Germany invaded the Soviet Union. The nation regained its independence in 1945, following the Yalta Conference; thereafter, the Polish Provisional Government of National Unity was formed. In January, 1947, elections were held that were controlled by the Communist Party, which established a communist regime.

Poland had became a Soviet satellite state; however, the Polish government was tolerant. In 1980, the independent trade union called Solidarity was formed. Solidarity became a political force, and in 1990 the country transformed its economy into one of the fastest growing in central Europe. Poland, however, was still underdeveloped and had high unemployment rates and poor infrastructure. Poland underwent significant political reorganization, becoming a democratic nation; it joined the North Atlantic Treaty Organization (NATO) in 1999 and the European Union in 2004.

• Impact of Polish Policies on Climate Change

International concerns for the environment and over greenhouse gas (GHG) emissions led environmental scientists—miners, coal processors, electrical and other engineers, economists, and others—to seek ways to save energy and decrease emissions during future development. This work, conducted under the auspices of the United Nations, gave rise to the Kyoto Protocol and new directions in the emission standards. The Kyoto Protocol to the U.N. Framework Convention on Climate Change (UNFCCC), adopted in December, 1997, entered into force in February, 2005. The objective of the protocol was to stabilize the GHG concentration in the atmosphere at a level that would minimize dangerous anthropogenic influence on the climate system. Poland ratified the Kyoto Protocol on December 2, 2002. The target reduction level of Polish GHG emissions is 6 percent in the period from 1988 to 2012.

Directive 2003/87/EC of the European Parliament and Council, issued October 13, 2003, established a scheme for GHG emission allowance trading within the European Community, amending Council Directive 96/61/EC. The directive was transposed into Polish law by the Act on Greenhouse Gas and Other Substances Emission Allowance Trading and eleven other regulations. Under this legislation, Poland is required to perform carbon dioxide (CO_2) monitoring for all installations that are covered by the European Union Emission Trading Scheme. The goal is for all countries to cut

GHG emissions and to find new energy sources to ensure clean, secure energy supplies.

In March, 2005, the European Commission issued a decision regarding Poland's national action plan for CO_2 emission allowances under the E.U. emissions trading scheme. The plan sought to reduce the nation's total CO_2 output by 141.3 million metric tons (16.5 percent) between 2005 and 2007. It was one of the four largest plans devised by European Union nations, covering more than eleven hundred installations.

Concerned to protect the environment, Poland became a member of the Party of Air Pollution, the Antarctic-Environmental Protocol, Antarctic-Marine Living Resources, the Antarctic Seals, and the Antarctic Treaty, as well as international agreements on biodiversity, climate change, desertification, endangered species, environmental modification, hazardous wastes, the United Nations Convention on the Law of the Sea, marine dumping, ozone-layer protection, ship pollution, and wetlands. Poland signed, but as of 2009 had not yet ratified, air pollution treaties governing nitrogen oxides, persistent organic pollutants, and sulfur.

• Poland as a GHG Emitter

Coal-powered plants are major GHG polluters in Poland. In the early twenty-first century, Poland has experienced significant economic growth, and electricity consumption is expected to rise by 80-93 percent by 2025. Therefore, GHG emissions are also expected to increase.

Poland's base-year emissions in 1992 were 586.9 million metric tons of CO_2 equivalent. In 2005, the nation emitted 399.0 million metric tons, and it is projected to emit 420.0 million metric tons in 2010. Under the Kyoto Protocol, Poland's target emissions are 551.7 million metric tons, or 6 percent below the base-year emissions. Poland's emissions were 32 percent below its base-year levels in 1988 and only 0.6 percent above that amount in 2004 and 2005. This decrease was a function of the decline of energy-inefficient heavy industry and of restructuring the economy in the late 1980's and early 1990's. Between 2004 and 2005, emissions from metal production and energy-related emissions from manufacturing and industrial processes decreased. However, the emissions from transportation, household energy use, and services increased.

Emission models predict that Poland will meet its Kyoto targets in almost all sectors, which will stabilize around their 2005 levels. The only major exception is in the transportation sector, where emissions are expected to increase beyond their target before 2012. After 2012, however, Polish GHG emissions will continue to increase. GDP growth in 2008-2012 is expected to be over 6 percent, and emissions between 2010 and 2020 will also increase. By 2020, Poland should emit about 81.6 percent of its base-year emissions.

Based on a United Nations 2004 report, Poland is the twentieth-largest GHG emitter on the world. Poland has reduced its GHG emissions by almost 18 percent since 1990. According to the European Commission, the March, 2007, requirements will cause Polish firms to reduce their emissions from 239 million metric tons to 208.5 million metric tons per year between 2008 and 2012. The cement industry, powered by coal, is one of the largest emitters of GHGs in Poland, accounting for 3 percent of total emissions (1.4 million metric tons of CO_2 equivalent). Poland attempts to trap some of these emissions in underground CO_2 depositional structures.

• Summary and Foresight

During World War II, Poland's economy lost 40 percent of its potential, and 66 percent of its industries were destroyed. Between 1949 and 1955, the People's Republic of Poland was able to begin realizing a six-year recovery plan. The plan changed the socioeconomic structure of Poland, transforming it from an agrarian-industrial country into an industrial-agrarian country. Under the Soviet Union, an economic transformation led to a planning-based economy, with an important focus on industries. Beginning in 1948, Poland started developing heavy industry, following the ideas of Joseph Stalin. Stalinist industrialization brought the acid-making plant Polchem to Torun, the Nowa Huta steelworks near Krakow, and the symbol of Soviet influence, the Palace of Culture, to Warsaw. Environmental protection was not of concern during postwar industrialization.

In 1980, the Ecology Club was established in Krakow, following the green movement in Western

Europe. The Ecology Club responded to environmental problems and abuses, blaming the Soviet Union for the state of Poland's rivers and its poor air quality. New industries emerged; the industrial basis of agriculture was changed, and the nation became increasingly urbanized. The six-year plan created a stable economy that formed the basis for further socialist transformation.

After the fall of communism, the government of Poland became concerned about the environment and sought to develop a responsible environmental policy. In the late 1990's, however, this attitude changed as a result of the relationship between central Europe and the European Union. After the Soviet Union's collapse, Poland found it needed to modernize and increase production to survive, while at the same time holding emissions below the Kyoto limits. After the breakdown of the Eastern Bloc, the country rapidly transformed to a market-based economy with strong growth rates, growing by 44.6 percent between 1990 and 2001. The transition to a well-developed, industrialized country was fostered by Poland's accession to the European Union. The country's main industries became machine building, iron and steel, coal mining, chemicals, shipbuilding, food processing, glass, beverages, and textiles.

Increasing production creates a higher demand for energy and causes an increase in GHG emissions. In 2007, GDP grew by an estimated 6.5 percent, driven by rising private consumption, increasing corporate investment, and the inflow of E.U. funds. Poland has ratified the Kyoto Protocol and must comply with its E.U. National Action Plan commitments. Poland has no nuclear power plants and relies mostly on coal to meet its energy needs. Many of the country's coal-fired power plants have been operated for over thirty years and need to be modernized or decommissioned.

In January, 2005, Poland's Council of Ministers approved a policy document entitled *Energy Policy to 2025*, which included a plan to build a nuclear power plant, to begin operation in 2021 or 2022. Since 1989, the Polish government has restructured the coal industry to make it more efficient, applying improved pollution prevention policies and technologies. In March, 2005, the European Union provisionally accepted Poland's National Allocation Plan, in which Poland reduced annual CO_2 emissions by 47 million metric tons. Poland has already met its Kyoto Protocol targets and reduced CO_2 emissions by 30 percent of their 1988 level.

Ewa M. Burchard

• **Further Reading**

Agh, Attila. "Europeanization of Policy-Making in East Central Europe: The Hungarian Approach to EU Accession." *Journal of European Public Policy* 6, no. 5 (1999): 839-854. Discusses the relation between Polish and Hungarian attitudes toward the European Union.

Damtoft, J. S., et al. "Sustainable Development and Climate Change Initiatives." *Cement and Concrete Research* 38, no. 2 (February, 2008): 115-127. Discusses climate change and the cement industry as a CO_2 emitter, as well as mitigation methods.

Jehlicka, Peter, and Andrew Tickle. "Poland: The Environmental Implications of Eastern Enlargement—The End of Progressive EU Environmental Policy?" *The Geographical Journal* 165, no. 2 (July, 1999): 209-221. Discusses Poland's environmental problems and national transition to sustainable development.

Slocock, Brian. "The Paradoxes of Environmental Policy in Eastern Europe: The Dynamics of Policy-Making in the Czech Republic." *Environmental Politics* 5, no. 3 (1996). Describes the development of environmental policies in new EU member countries.

See also: Eastern Europe; Europe and the European Union; Kyoto Protocol; Russian Federation.

Polar bears

• **Category:** Animals

• **Definition**

The polar bear has become an icon of global warming. In 1973, the five "polar bear nations" (the United States, Canada, Denmark, Norway, and the former Soviet Union) agreed to limit polar bear hunting to the Inuit and other native peoples. The bear population recovered, only to face a new threat: global climate change.

Changes in sea ice, permafrost, and prey species in the Arctic and subarctic are linked to reduced body condition and smaller litter size in polar bears. In western Hudson Bay, long-term studies conducted by wildlife biologist Ian Stirling of the Canadian Wildlife Service and his colleagues document climate warming and a significant reduction in the amount, location, and persistence of sea ice adjacent to the shore. The polar bear is heavily dependent on the ringed seal as a food source. Its usual hunting technique requires sea ice. A bear will locate the breathing hole of a seal and then ambush the animal when it comes up for air or will prey upon young seals in their dens. As sea ice diminishes, bears are less able to catch their prey.

A polar bear emerges from the Arctic sea among a group of ice floes. (©Dreamstime.com/Outdoorsman)

Hungry polar bears waiting on shore for sea ice to form have become a problem, invading northern villages and encountering native hunters. At one time, this increase in sightings was interpreted as evidence of increasing numbers and used to justify higher quotas for the taking of polar bears.

• Significance for Climate Change

A series of studies requested by U.S. secretary of the interior Dirk Kempthorne, coordinated by the United States Geological Survey, and released on September 7, 2007, predicted that two-thirds of polar bears would perish by the year 2050. All polar bears in Alaska would be gone. The studies—conducted by American and Canadian scientists—used conservative assumptions to project loss of sea ice due to global warming. At the time of the studies, there were an estimated twenty thousand to twenty-five thousand polar bears worldwide.

Because the polar bear, *Ursus maritimus,* is thought to have evolved from the brown bear, *Ursus arctos,* 200,000 years ago, some have suggested that the polar bear might reverse course and adapt to and live in the terrestrial ecological niche now occupied by the brown bear. Brown bears are primarily vegetarian, whereas polar bears are primarily carnivorous. Brown bear claws are adapted for digging, polar bear claws for grabbing and holding prey. Polar bears are slow to reproduce, and it is unlikely that they could change both their behavior and their physical characteristics quickly enough to cope with disappearing sea ice. Sea ice is central to the life of a polar bear. It provides habitat to prey animals and hunting, mating, and denning sites for the bears themselves. In western Hudson Bay, polar bears gather on the shore each year to wait for sea ice to form.

While polar bears and their response to global warming have been studied longer and in greater depth than has any other Arctic species, they are far from the only animal affected by a changing climate. Gray whales migrating south to their breeding grounds off the coast of Mexico have recently appeared to be emaciated, suggesting a shortage of their normal diet of tube worms and amphipods in their summer feeding grounds of the Bering and Chukchi Seas.

Other marine animals that are affected by the loss of sea ice and climate warming in the Arctic include ringed seals, bearded seals, ribbon seals, sea lions, walruses, narwhals, fish, and many sea birds. Biologists have only begun to study how these creatures will respond to the profound changes in their habitat. Polar bears—known to eat dead whales washed up on the shore as well as other carrion—might benefit temporarily from the die-off of marine animals, but will suffer eventually as their prey species are reduced.

On May 14, 2008, Secretary Kempthorne announced the listing of the polar bear as threatened under the provisions of the Endangered Species Act. This designation is one step down from that of endangered species and offers less protection from human activities. Kempthorne made clear that the Department of the Interior would not allow the polar bear's plight to be used to justify limits on greenhouse gases (GHGs) saying: "When the Endangered Species Act was adopted in 1973, I don't think terms like 'climate change' were part of our vernacular." The act, he said, "is not the instrument that's going to be effective" to deal with climate change.

Images of polar bears have been used by conservation groups to advocate reductions in GHGs in hopes of slowing and perhaps reversing global warming and also in fund-raising by these groups. Global warming skeptics complain that such images appeal to emotion and not to reason and demand further proof that a warming climate will result in great reduction and even extinction of polar bear populations by mid-century.

Thomas Coffield

- **Further Reading**

Kazlowski, Steve. *The Last Polar Bear: Facing the Truth of a Warming World.* Seattle, Wash.: Mountaineers Books, 2008. The author has spent thousands of hours observing and photographing polar bears in the wild.

Stirling, Ian. *Polar Bears.* Ann Arbor: University of Michigan Press, 1999. Written for the general reader by the world's most experienced polar bear researcher. Richly illustrated with photographs by Dan Guravich.

Stirling, Ian, and Claire L. Parkinson. "Possible Effects of Climate Warming on Selected Populations of Polar Bears (*Ursus Maritimus*) in the Canadian Arctic." *Arctic* 59, no.3 (2006): 261-275. Research paper postulating that climate warming is responsible for Canadian polar bears' declining populations, reduced body condition, and reduced survival among young.

See also: Amphibians; Arctic; Arctic peoples; Convention on International Trade in Endangered Species; Dolphins and porpoises; Endangered and threatened species; Fishing industry, fisheries, and fish farming; Invasive exotic species; Penguins; Polar climate; Whales.

Polar climate

- **Category:** Arctic and Antarctic

- **Definition**

Polar climate is characterized by year-round cold conditions, tundra or ice cap, and permafrost. At Earth's south pole is Antarctica, 95 percent of which is covered in ice. Temperatures on the continent range from 0° Celsius to −70° Celsius. At Earth's north pole is the Arctic tundra, as well as treeless vegetation zones. The tundra is bordered on the south by forests and on the north by the Arctic lands and has a layer of permafrost. The Arctic is characterized by short, cool summers and long, cold winters. Arctic high temperatures range from 0° Celsius in Russia to 12.2° Celsius in Alaska; lows range from −16.3° Celsius in Canada to −28.1° Celsius at the highest point of Greenland's ice sheet.

Permafrost is a permanently frozen soil layer under the topsoil. The top layer, or active layer, melts and refreezes each year, while the lower level stays frozen year-round. The active layer provides water and a place for plants to grow. The temperature in the lower levels is at or below 0° Celsius, and usually ranges from −6° to −9° Celsius. One-fourth of the land in the Northern Hemisphere is in permafrost zones, and almost all of the permafrost areas in the Southern Hemisphere are in Antarctica.

At Law Dome Camp, in Antarctica, scientists study the polar climate and monitor any changes in it. (AFP/Getty Images)

• **Significance for Climate Change**

Although the ice sheet is not expected to melt completely in the near future, the Antarctic is warming ten times faster than the average anywhere else in the world. Since the mid-1940's, the average temperature is −16° Celsius warmer year-round and −13° to −14° Celsius warmer in early winter. The far western edges and ground are becoming warmer, and the ice sheet edge is rapidly eroding. The amount of sea ice was stable from 1840 to 1950, but has decreased since then by roughly 20 percent.

The icebergs are shrinking, glaciers are receding, and the immense Larsen Ice Shelf began disintegrating in 1995. Nearly 2,590 square kilometers of the ice shelf collapsed between 1998 and 2000. The breakups of ice chunks lead to the faster flow of ice from the glaciers upstream, which in turn can increase the sea level over time. With the edges of the ice sheet melting, the wildlife populations are fluctuating. Adelie penguins are dying off, because they cannot adjust to the changes in their environment. Meanwhile, other species are migrating south and establishing colonies. Scientists have observed the southern migration of elephant and fur seals, as well as other species of penguins. Additionally, low grasses, mosses, and tiny shrubs are thickening in several areas.

Climate changes are more dramatic in the Arctic. The Arctic is ringed by the lands of Canada, Denmark (through Greenland), Finland, Iceland, Norway, Russia, Sweden, and the United States. Sea ice remains over the entire Arctic Ocean and parts of nearby waters every winter. This sea ice provides a home for polar bears and transportation routes for people, and shields coastal towns and underwater creatures. Normally, the ice melts on land in the summer and breaks up some in the Arctic Ocean, but there was 80 percent less ice in 2005 than in the 1970's, with more rapid melting since 2003. Scientific data suggest that the Arctic Ocean may be ice-free in the summer as early as the 2030's, which has not happened in at least 800,000 years. A rise in ice sheet melting raises the sea level, and even a 1-2 millimeter rise increases flooding at the coastlines.

Summertime temperatures in parts of the Arctic are warmer than those recorded in the last four hundred years, and winter temperatures have increased by 2° to 4° Celsius since 1976. The Arctic cools the Earth, because it reflects more solar radiation than it absorbs, with ice and snow the most reflective, followed by tundra vegetation. The warmer temperatures have led to unpredictable weather patterns that threaten the delicate natural balance of the environment and endangered the plants and animals, as well as the humans who depend on them. The ice sheets near the coastline are smaller or nonexistent, which greatly affects subsistence whalers and seal hunters and subjects the coastline to damaging waves. Several coastal Alaskan villages have had to relocate inland and others are threatened because of coastal erosion.

When the lower layers of permafrost thaw, they can create an underground lake which may drain off, leaving a cavity. The surface will then slump inward, causing trees, roads, and buildings to slowly fall in. This melting has already happened in Siberia and Fairbanks, Alaska, where the permafrost is at the warmest levels since the last ice age. The sinkholes are patchy so far and usually occur where digging and construction opened up the landscape. Thawing permafrost can also cause the sea levels to rise slowly and, because it traps large amounts of carbon, melting permafrost releases the carbon back into the atmosphere as methane, a greenhouse gas.

Virginia L. Salmon

• Further Reading

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming.* Rev. ed. London: Penguin, 2007. The author, a world-renowned scientist and conservationist, presents the history of climate change and its effect on the planet. Includes illustrations, notes, and index.

Henson, Robert. *The Rough Guide to Climate Change: The Symptoms, the Science, the Solutions.* New York: Penguin Putnam, 2006. Presents well-balanced, organized, and easy-to-follow information on climate change. Includes illustrations, charts, side articles, and bibliography.

Wohlforth, Charles. *The Whale and the Supercomputer: On the Northern Front of Climate Change.* New York: North Point Press, 2004. A more person-oriented narrative about the realities of climate change in the north, its effects on native peoples, and the scientists who study the changes. Includes notes and index.

See also: Antarctica: threats and responses; Arctic; Arctic peoples; Greenland ice cap; Ice shelves; Permafrost; Tundra.

Polar stratospheric clouds

• **Category:** Meteorology and atmospheric sciences

• Definition

Polar stratospheric clouds (referred to as "PSCs" by scientists and called nacreous clouds by the general public) form in the lower stratosphere between heights of 15 kilometers and 25 kilometers in the lee of high-latitude mountain ranges in winter. Ice crystals and particles composing the visible cloud are of uniform size, about 10 micrometers in diameter. After sunset, light from the Sun below the horizon continues to illuminate particles within PSCs, producing iridescent bright red and blue coloration zones in the clouds. Colorful PSC displays are most frequently photographed before dawn and after sunset when they appear in Oslo, Norway, but photographs and videotapes have also been taken in Scotland, England, Scandinavia, Iceland, Alaska, and Antarctica.

Atmospheric scientists have divided PSCs into two "Types" as defined by chemical and thermal differences. Type I PSCs have temperatures of about −78° Celsius. Type I(a) PSCs contain crystalline compounds of water and nitric acid; Type I(b) PSCs contain droplets of nitric (HNO_3) and sulfuric (H_2SO_4) acids; Type I(c) PSCs contain nonspherical particles of metastable nitric acid in water; and Type II PSCs are composed of water ice crystals at temperatures of −85° Celsius.

• Significance for Climate Change

Discovery of the formation of the ozone hole in the stratosphere above the Antarctic continent each spring focused scientific attention on chemical reactions depleting ozone. Scientists deduced that ultraviolet light from the rising Sun promoted chemical reactions leading to ozone destruction, and investigations linked chemical reactions going on within the PSCs to regional ozone depletion above the Antarctic.

Particles within Antarctic PSCs act as catalytic surfaces for reactions involving the destruction of relatively stable atmospheric chlorine compounds (including artificial chlorofluorocarbons sometimes called Freons). Through a series of reactions, these chlorine compounds are transformed into highly reactive molecular chlorine gas ($C1_2$) and hypochlorous acid (HCl) molecules, which rapidly form chlorine radicals, which in turn destroy ozone molecules. During winter and early spring, there is a strong easterly flow of air in the Antarctic stratosphere, the Antarctic Polar Vortex. Little air from lower latitudes mixes with the ozone-depleted air within the vortex, allowing greater depletion of ozone to occur, creating the ozone hole.

PSCs also catalyze other important chemical reactions, including denoxification, the conversion of oxides of nitrogen to nitric acid, which is found in all three Type I PSCs. Because decreasing the level of nitric oxide (NO_2) allows high levels of ozone-removing hypochlorite (ClO) to remain in the stratosphere, this denoxification promotes development of the ozone hole. Denoxification leaves the waste product nitric acid behind in the cloud particles, which eventually exits the stratosphere, a process called denitrification.

Anita Baker-Blocker

See also: Albedo feedback; Clouds and cloud feedback; Noctilucent clouds; Polar climate; Polar vortex.

Polar vortex

- **Category:** Meteorology and atmospheric sciences

- **Definition**

When circulating, or spinning, liquids or gases occupy a region of space, scientists call that pattern of motion a vortex. A vortex can occur in a bathtub, in a kitchen sink, or in the atmosphere. When it takes place near the poles, it is called a polar vortex.

Polar vortices are so large that they surround the polar heights and often straddle the troposphere and the stratosphere. Their strength varies with the seasons; they are strongest in winter, reaching speeds of 100 meters per second, and they are weakest, or even nonexistent, in summer. Polar vortices have been observed on Jupiter, Mars, Saturn, and Venus.

pgas) that is inside them and prevent it from escaping through the sides. When the temperature drops below a certain critical value (about –80° Celsius), special clouds called polar stratospheric clouds (PSCs) form inside the vortex. Unlike ordinary clouds near the surface of the Earth, PSCs contain water-ice droplets mixed with a variety of other particles, and the chemical interactions among them are extremely sensitive to changes in temperature.

- **Significance for Climate Change**

Factories and homes produce chemicals known collectively as chlorofluorocarbons (CFCs). When CFCs are released into the atmosphere, they interact with sunlight and form chlorine compounds such as hydrochloric acid (HCl) and chlorine nitrate ($ClONO_2$). Ozone, which absorbs harmful ultraviolet radiation from the Sun, is found in a thin layer of the upper atmosphere called the ozone layer. Chlorine compounds in the atmosphere combine with each other, with water, and with other chemicals to create products that attack ozone. Scientists now know that the key chemical reactions that create these products only occur on the surface of PSCs. There is evidence that they cannot take place elsewhere in Earth's atmosphere.

Greenhouse gases (GHGs), which include CFCs, enhance the depletion of the ozone layer. While they cause atmospheric warming near the Earth's surface, GHGs actually cool the stratosphere, where ozone resides; since the chemistry of the ozone layer is very sensitive to temperature, even very small decreases in the temperature of the stratosphere increase the loss of ozone.

Scientists have observed a statistical correlation between the cycles of the polar vortex and the weather: Severe cold weather in the Northern Hemisphere correlates well with a weak polar vortex. Similarly, when that vortex is strong, weather in the Northern Hemisphere turns warm.

Josué Njock Libii

See also: Atmospheric dynamics; Chlorofluorocarbons and related compounds; Clouds and cloud feedback; Ozone; Polar climate; Polar stratospheric clouds.

Pollen analysis

• **Categories:** Science and technology; plants and vegetation

• **Definition**

Pollen grains are produced by seed plants (gymnosperms and angiosperms), and they range in size from 10 to 100 microns. They contain undeveloped male gametophytes that are surrounded by a complex protective wall. Depending on the species that produces it, the pollen may or may not yet contain sperm. Most insect-pollinated plants produce small quantities of pollen because insects are efficient dispersers of pollen, so relatively little is wasted or released into the air. On the other hand, wind-pollinated plants produce large quantities of pollen because of the low probability that any given grain will land on another flower.

Many forest trees (including pines, oaks, and maples) and prairie plants (including grasses, ragweed, and sage) are wind pollinated, so most of their pollen is dispersed over some distances. In fact, much wind-blown pollen ends up in oceans, lakes, swamps, mangroves, or peat lands, and it accumulates with other deposits, layer by layer, year after year. As a result, the profile of pollen in sediments represents the types of vegetation in the surrounding areas at a given point in time and the proportion of each type of pollen is directly related to the relative abundance of its associated species.

• **Significance for Climate Change**

Pollen preserves best if its sedimentary environment lacks oxygen or is acidic, conditions that are unfavorable for decomposing organisms. If the sediments remain moist, pollen can be preserved for thousands or even millions of years. Using fossilized pollen, scientists can reconstruct changes in vegetation over thousands of years and determine when and how rapidly these changes occurred. Since vegetation is sensitive to climate change, a comparison of fossil pollen profiles with modern climate patterns has allowed scientists to reconstruct past climates. The term "pollen analysis" also includes the study of spores. Spores are produced by non-seed plants such as bryophytes and pteridophytes, but they have been included in the discipline of pollen analysis for the sake of convenience.

Pollen analysts concentrate on pollen walls, which are made up of two major layers. The outer layer, or exine, is subdivided into the ectexine and endexine, while the inner layer is referred to as the intine. The ectexine is composed primarily of sporopollenin, which is the most decay- and chemical-resistant biopolymer in nature. The endexine and intine are composed of proteins, callose, pectins, and cellulose and are easily degraded by microorganisms and chemicals. Since the structures of ectexines have not changed for thousands of years and they usually appear consistent within a genus or family, they are most useful in the identification of the plants that produced them. Some criteria used in identifying pollen include the presence or absence of apertures, type of apertures (pores or furrows), number of apertures, and surface ornamentations (spines, ridges, bumps, or striations).

To identify and analyze the sequences of fossilized pollen from lake sediments, most scientists obtain cores of sediments using a square-rod piston corer, a device that consists of a meter-long tube fitted with a piston. Several cores from various spots are obtained from a study area, and subsamples are taken at regular intervals along a core. The sediments of virtually any substrate will contain abundant fossil pollen. In fact, a cubic centimeter of lake sediment will typically contain tens or hundreds of thousands of pollen grains. However, since pollen is a very small portion of the sediments, these grains must be concentrated prior to analysis.

Pollen from peats and other substrates presents a particular problem, because contaminating organic materials from other sedementary materials are likely to be present. Therefore, core samples are passed through a series of sieves and washes designed to isolate the pollen. Humic materials are removed with potassium hydroxide. Carbonates are removed with hydrochloric acid. Silicates are dissolved with hydrofluoric acid. Cellulose is removed with a mixture of sulfuric acid and acetic anhydride. After this series of treatments, most of what remains is pollen. The ability of the pollen wall, specifically the ectexine, to resist strong organic acids and alkaline substances makes this concentration process possible.

The purified and concentrated pollen is mixed with immersion oil and mounted on a glass slide for microscopic analysis. Hundreds of pollen grains are counted from each subsample from a core. The variety of pollen types and quantity of each type are determined. Surface ornamentations and other pollen wall features are used to identify the associated plants. Fossilized pollen grains are also subjected to relative dating techniques to estimate their age. Radiocarbon dating is one such technique. It uses the naturally occurring radioisotope carbon 14 (C^{14}) to establish the age of organic remains up to about fifty thousand years. Plants and animals incorporate a quantity of C^{14} into their tissues in about the same proportion as that in the atmosphere. When these organisms die, the C^{14} decays at a fixed exponential rate. A comparison of the remaining C^{14} from a sample to that expected from atmospheric C^{14} allows scientists to determine the age of the sample.

Pollen analysis is used in Quaternary studies, such as paleoecology, paleoclimatology, paleogeography, and archaeology. By analyzing fossilized pollen from a broad geographic region, scientists can document changing patterns of vegetation over time and migration of individual taxa. At the largest spatial scale, pollen analysis has been used to reconstruct past climatic and environmental changes, as well as changes in biomes. These data have strengthened predictions of how vegetation is likely to respond to future climatic and environmental conditions. When taken together, all this information provides an indication of the future of agriculture and silviculture.

Danilo D. Fernando

• Further Reading

Davis, Margaret B. "On the Theory of Pollen Analysis." *American Journal of Science* 261 (1963): 897-912. Overview of the theoretical basis for practical applications of pollen analysis.

Erdtman, Gunnar. *Handbook of Palynology: An Introduction to the Study of Pollen Grains and Spores.* New York: Hafner, 1969. General text on pollen and spores that includes information relevant to their use in climatological research.

Faegri, Knut, and Johs Iversen. *Textbook of Pollen Analysis.* New York: John Wiley & Sons, 1989. Comprehensive textbook explaining how to analyze pollen and spores to determine the paleoclimate of a given region.

Pearman, Peter B., et al. "Predictions of Plant Species Distributions Across Six Millennia." *Ecology Letters* 11 (2008): 357-369. Brief overview of six thousand years of ecological history.

Peteet, Dorothy. "Sensitivity and Rapidity of Vegetational Response to Abrupt Climate Change." *Proceedings of the National Academy of Sciences* 97 (2000): 1359-1361. Analysis of the effects upon vegetation of abrupt climate change—and therefore of the nature of the pollen-based evidence that such change would leave behind.

Pickett, Elizabeth J., et al. "Pollen-Based Reconstructions of Biome Distributions for Australia, Southeast Asia, and the Pacific (SEAPAC Region) at Zero, Six Thousand, and Eighteen Thousand C^{14} Years Before the Present." *Journal of Biogeography* 31 (2004): 1381-1444. Extensive summary of the information gleaned from pollen analysis about changes in vegetation over the past eighteen thousand years.

Wright, H. E., Jr. "A Square-Rod Piston Sampler for Lake Sediments." *Journal of Sedimentary Research* 37, no. 3 (September, 1967): 957-976. Describes a device used to take sedimentary core samples from lake beds.

See also: Climate reconstruction; Dating methods; Holocene climate; Paleoclimates and paleoclimate change.

Polluter pays principle

• **Categories:** Pollution and waste; ethics, human rights, and social justice; laws, treaties, and protocols

• Definition

The polluter pays principle is a moral and sometimes legal principle in which the cost of curtailing and remediating environmental damages is assessed against those who have (knowingly or not) engaged in environmentally destructive actions. Legally, the polluter pays principle is an application of the doctrine of strict liability. This stands in contrast with remediation approaches in which a governmental entity remediates, or subsidizes remediation of, an environmental harm using tax revenues.

The polluter pays principle likely has ancient roots, as it is simply an aspect of personal responsibility applied to damages done to the environment and to others affected by environmental damage. Plato constructed one version of the principle involving water pollution in his *Nomoi* (*Laws*, 1804) codified from 428 to 348 B.C.E.:

> And let this be the law—if any one intentionally pollutes the water of another, whether the water of a spring, or collected in reservoirs, either by poisonous substances, or by digging or by theft, let the injured party bring the cause before the wardens of the city, and claim in writing the value of the loss; if the accused be found guilty of injuring the water by deleterious substances, let him not only pay damages, but purify the stream or the cistern which contains the water, in such manner as the laws of the interpreters order the purification to be made by the offender in each case.

Somewhat more recently, the Organization of Economic Cooperation and Development (OECD) enshrined the polluter pays principle in its 1972 Guiding Principles Concerning International Economic Aspects of Environmental Policies. In its original form, the modern polluter pays principle called only for polluters to bear the cost of instituting control measures, not of remediating existing damages. The principle gradually expanded after 1972 to place on polluters not only the costs of pollution controls but also the costs of remediating past pollution and of compensating those damaged by previous polluting behavior. This has led some to describe the current version as the "extended polluter pays principle."

• Significance for Climate Change

The polluter pays principle is either explicitly endorsed or referenced in a broad swath of international agreements, including the Convention on the Protection of the Marine Environment of the Baltic Sea Area; the International Convention on Oil Pollution Preparedness, Response, and Cooperation; the Agreement on the European Economic Area; the Protocol on Water and Health; the Declaration on Environment and Development (the Rio Declaration); and others. It is also considered an element of sustainable development, as that concept has evolved from its beginnings in the Brundtland Report. The polluter pays principle is also recognized in the preamble of the Canadian Environmental Protection Act.

The polluter pays principle is applied haphazardly in U.S. environmental regulations, and the principle is a far less widely recognized element of U.S. policy. The most prominent application of the polluter pays principle in the United States is as part of Superfund, a massive governmental effort to clean up hazardous waste sites. But even when, as in Superfund, the underlying law is strict, the polluter pays principle is more jargon than reality: Costs are not assessed based on a polluter's contribution to the problem, but on the ability of any polluter to pay, regardless of the damages they caused.

Several challenges have been raised with regard to the polluter pays principle. For example, it has been argued that those in lower economic brackets cannot always afford to remedy harms done in the course of fulfilling their basic needs. In places where older vehicle emissions contribute the majority of an air pollutant to a given region, applying the polluter pays principle would place the cost of avoidance and mitigation on those who cannot afford to pay. A related challenge is assessing the costs of pollution control and remediation on economically marginal (but socially beneficial) businesses that cannot pass on costs without losing economic competitiveness.

Still another challenge to the polluter pays principle is ensuring economic efficiency: Determinations of harm are often the result of judgments by juries, rather than hard forensic evidence. Subjective social values are also a part of this process that has often led to settlements in which the polluter pays substantially more than the true cost of damages inflicted by a polluting activity.

The involvement of the polluter pays principle in climate change policy debate is complex and inconsistent. At the global level, many governmental and nongovernmental organizations assert that the principle dictates that developed countries should pay to reduce their greenhouse gas (GHG) emissions and mitigate harms to developing countries before those countries should have to essay GHG controls of their own. Some governments, such as that of the United States, reject this application of the principle, asserting that the economic costs would be unsustainable. They argue from a long-term perspective that the principle would lead to an undue burden of controls falling on the countries that became significant polluters first, rather than on the countries that are the most significant polluters in the present.

Kenneth P. Green

• Further Reading

Beder, Sharon. "The Polluter Pays Principle." Chapter 2 in *Environmental Principles and Policies: An Interdisciplinary Introduction.* Sterling, Va.: Earthscan, 2006. Provides a thorough summary of the polluter pays principle in its development and application.

Buchner, Barbara, and Janna Lehmann. "The Polluter Pays Principle and Its Relationship to the Concept of Common but Differentiated Responsibility." Section 2.3 in *Climate Change Policy*, edited by Michael Bothe and Eckard Rehbinder. Netherlands: Eleven, 2005. Explores gradations of industrial responsibility established by law and public policy.

Sands, Phillipe. *Principles of International Environmental Law.* New York: Cambridge University Press, 2002. The section on the polluter pays principle in this legal reference book contains a concise description of both the principle and its legal history.

See also: Air pollution and pollutants: anthropogenic; Basel Convention; Convention on Long-Range Transboundary Air Pollution; Environmental law; Industrial emission controls.

Popular culture

• **Category:** Popular culture and society

Popular and scientific conceptions of global warming have often diverged. Popular portrayals of global warming have been shaped by political agendas, commercial interests of both fiction and nonfiction content producers (including the news media), and incomplete understandings based on fragmentary data. These popular potrayals and viewpoints have influenced political rhetoric and action, including some legislative initiatives.

• Key concepts

greenwashing: the exploitation and appropriation of environmental concerns and issues by corporations, government agencies, and political operatives to advance self-interested agendas

masscult: the dominant, mainstream culture as disseminated by the mass media

noble savage: an idea popularized during the eighteenth century Enlightenment that stressed the purity of early human beings and nature untainted by modern technology

• Background

A popular ecological mind-set was put into place by such pioneering 1960's best sellers as Rachel Carson's *Silent Spring* (1962), although the mind-set's ideological roots could be said to go back much further, to the Enlightenment and Romantic movements of the eighteenth and early nineteenth centuries. A tradition developed out of these movements that portrayed a split between nature and culture in which nature was seen as pure and benevolent, while human intervention was corrupting and destructive. This tradition was refined by the environmental movements of the late 1960's, blossoming into the green movements of the late twentieth century.

These movements entailed, among other things, alterations in attitudes toward and definitions of progress that called for people significantly to alter their lifestyles. The new valuations developed by the green movement were reminiscent of Enlightenment ideals relating to the figure of the noble savage and natural law. This image of an unsullied natural world jeopardized by misguided human intrusion proved to be a seductive vehicle, one with tremendous potential for commercial exploitation, not the least by the film industry. One avenue for its exploitation has been anxieties about global warming and climate change.

• Nightmare Scenarios

The popular concept that links global warming and climate change to potential worldwide disaster has played out most strongly in the film medium. In *Waterworld* (1995), a future Earth is depicted as covered almost entirely by ocean after a catastrophic melting of the polar ice caps. The film's protagonist struggles violently in his drearily boring aquatic environment to find a mythical thing called "land." The film ends with his success, as a colony is established on a piece of dry land (indicated, in some of the more complete versions of the film, to be the tip of Mount Everest), to begin civilization afresh.

Waterworld illustrates the nearly universal popular conception of global warming as a potentially disastrous problem, holding dire consequences for future generations. The scenario's likelihood is seriously questioned from scientific quarters. A total ice cap meltdown to the extent that all land is inundated except for part of Mount Everest surpasses all but the direst of environmental claims. Fiction films tend to modify fact based on their genre conventions and on the requirements of a visual medium. Narrative and spectacle are more important to film makers than is verifiable science.

It was the blockbuster film *The Day After Tomorrow* (2004) that fully defined the masscult image of the possible consequences of anthropogenic climate change. That film depicts a sudden worldwide disaster, brought on by abrupt melting of polar ice. Floods strike much of the world, as tidal waves are portrayed sweeping over downtown Manhattan. In addition, massive hurricanes and tornados are generated, and an ice age rapidly develops across the Northern Hemisphere. Here again, the film's scenario is extremely improbable, as it is generated by the requirements of blockbuster disaster films rather than scientific meteorological knowledge.

Kevin Costner waves to the German press while standing in front of a poster for his film Waterworld. *The film portrays an Earth completely covered in water after the melting of the polar ice caps.* (AP/Wide World Photos)

• Noncinematic Popular Culture

Commercials and advertisements have played upon environmental themes by advertising their products as being environmentally friendly. This is particularly true of automobile producers and dealers who market their motor vehicles as being fuel efficient and therefore ecologically responsible. Consumers are encouraged by marketing campaigns to "buy green," thereby limiting their impacts on the environment. Consumers who value environmentalism thus pay not only for the product but also for the feeling of socially constructive engagement that accompanies their purchases. So prevalent did commercial exploitation of conservationism become that in 1986 conservationist Jay Westerveld introduced the term "greenwashing" to denote this phenomenon.

Global warming is just one of many issues that the mass media has been accused of sensationalistically manipulating for profit. The media are too diverse to be encompassed by simple blanket statements, but one general assumption appears to be that scientific facts are sometimes moderated or overlooked for the sake of headlines. Media content is often driven by a cycle of crises, because such cycles have proven commercially desirable. As a result, newpapers and television news tend to convert stories into disaster stories whenever possible.

Popular interest is always maintained by a good, keen rivalry, especially when high-profile individuals pit themselves against one another over emotionally charged topics. Thus, when notables such as former vice president Al Gore—author of *An Inconvenient Truth* (2006) and *The Assault on Reason* (2007)—and celebrity author Michael Crichton—author of *State of Fear* (2004)—added their literary polemics to the debates on global warming, they increased the market for such polemics, causing many lesser-known authors to take sides as well.

• Myth and Half-Truths

Though most scientists accept the likelihood of some anthropogenic global warming associated with greenhouse gas emissions, they differ widely on both its extent and its probable results. The most glaring discrepancy between popular representations and the scientific consensus centers on the notion of sudden, cataclysmic change. The ecological armageddon exemplified in *The Day After Tomorrow* and other disaster films and novels is a lucrative scenario but one with very slight basis in scientific fact. Rapid global deterioration resulting from melting polar ice caps and sudden climatic shifts are considered unlikely. Theories of gradual climate change are far more widely embraced, as even "abrupt" changes in the context of Earth's climate usually take decades to occur. Such gradual changes, however, do not fit the conventions of disaster films.

Three popular suppositions have most frequently come under challenge. First, polar melting is unlikely to occasion a sudden and extreme rise in sea level causing massive inundation and loss of life. Far more likely is a rise in sea level of around 40 centimeters, impacting coastal areas and possibly forcing gradual relocation and resettlement. Second, temperature change is often portrayed as far more abrupt than it is likely to be. The most widely accepted scientific scenario views vast areas encompassing most of Africa, South America, the continental United States, southern Canada, southern Europe, and Asia from Siberia to the Himalayas becoming drier. At the same time, the Caribbean, Mexico, the southeastern United States, northern Europe, India, southern China, Japan, and Southeast Asia would become wetter. Neither change would result in the nearly instantaneous transformation of savanna to desert portrayed in some works of science fiction.

• Context

It remains to be seen how popular representations of global warming might meet and mesh with scientific consensus or whether the divide between the two will narrow. Looked upon from a more positive perspective, one might foresee that the differing views could continue to generate greater debate, maintain heightened interest, and in time lead to genuine efforts aimed at addressing real problems, while avoiding the extremes of either position.

Raymond Pierre Hylton

• Further Reading

Anderson, Alison. *Media, Culture, and the Environment.* New Brunswick, N.J.: Rutgers University Press, 1997. Argues that a pro-environmentalist media bias influences popular perceptions and political decisions.

Gore, Al. *The Assault on Reason: How the Politics of Fear, Secrecy, and Blind Faith Subvert Wise Decision Making, Degrade Our Democracy, and Put Our Country and Our World in Peril.* New York: Penguin Press, 2007. Asserts that conservative, anti-environmental forces manipulate popular culture to prevent real action being taken to fight global warming.

Horner, Christopher C. *The Politically Incorrect Guide to Global Warming and the Environment.* Washington, D.C.: Regnery, 2007. A very opinionated, popularized refutation of the activist pro-environmental movement, which is virtually labeled as a subversive tendency. Al Gore especially is heavily criticized.

Kempton, Willet, James S. Boster, and Jennifer A. Hartley. *Environmental Values in American Culture.* Cambridge, Mass.: MIT Press, 1995. Detailed analysis of the representation of the environment and environmentalism in American culture. Details and refutes popular myths and misconceptions.

Meister, Mark, and Phyllis Japp, eds. *Enviropop: Studies in Environmental Rhetoric and Popular Culture.* Westport, Conn.: Praeger, 2002. Collection of essays examining topics as far ranging as environmental allusions in *The Simpsons* and the climate politics surrounding national parks and the Hollywood film industry. Invaluable reference on the broader subject of popular culture and global warming.

Myers, Norman, ed. *Gaia: An Atlas of Planet Management.* New York: Anchor Books, 1993. Well-conceived and clearly illustrated geography of ecological issues, including global warming. Paints a disturbing scenario in a reasoned manner, avoiding the sensationalism of more extreme proponents.

Ray, Dixy Lee, with Lou Guzzo. *Environmental Overkill: Whatever Happened to Common Sense?* Washington, D.C.: Regnery Gateway, 1993. Seeks to rebut many environmental suppositions as being unfounded or unproven.

Rushkoff, Douglas. *Media Virus: Hidden Agendas in Popular Culture.* New York: Ballantine Books, 1994. Indispensible work for understanding the rationale behind allegations that the masscult and popular opinion are being shaped by special interests.

See also: Carson, Rachel; *Collapse*; Conspiracy theories; *Day After Tomorrow, The*; Gore, Al; *Inconvenient Truth, An*; Journalism and journalistic ethics; *Limits to Growth, The*; Media; Speculative fiction.

Population growth

• **Category:** Environmentalism, conservation, and ecosystems

The world's human population is rapidly approaching seven billion. Human beings have increased the concentration of GHGs in Earth's atmosphere via many processes, including agricultural practices and the burning of fossil fuels. The sheer size and growth rate of the human population is a fundamental driver of global change, including global warming.

• Key concepts

agricultural revolution: the advent of human domestication and cultivation of plants and animals about ten thousand years ago

Green Revolution: a dramatic increase in global food production brought about by the development of new strains of wheat, rice, and corn around 1960

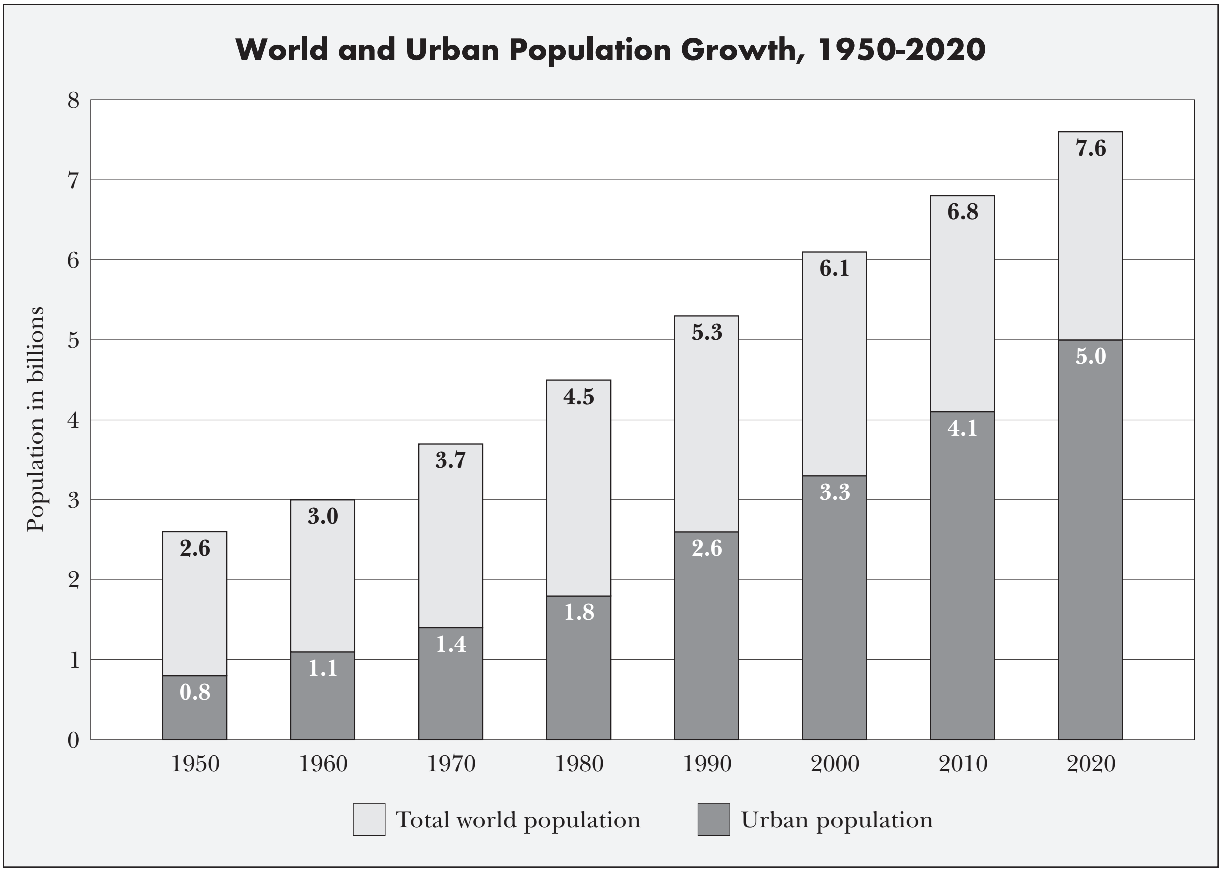
human population growth rate: the percentage by which a given population increases annually

Industrial Revolution: the eighteenth and nineteenth century mechanization of mining, manufacturing, and agriculture that transformed national economies

urbanization: the process of spatial concentration of the human population in cities

• Background

The human population is a fundamental driving force of climate change. Human activities ranging from agricultural practices to the burning of fossil fuels contribute greenhouse gases (GHGs) to the atmosphere. Both the number and the behavior of human beings are basic drivers of climate change.



In terms of numbers only, in the early twenty-first century, the global human population increased by about 200,000 people per day.

• History of Population Growth

Hominids that painted cave walls (*Homo erectus*) appeared almost one million years ago. By 8000 B.C.E., modern humans (*Homo sapiens*) numbered around 8 million. The first 990,000 years of human existence were characterized by a very low population growth rate (15 persons per million per year). The pro-natal fertility beliefs of early humans (whether conscious, unconscious, or instinctive) were undoubtedly necessary to maintain the tenuous presence of humanity on the face of the Earth. Pro-natal fertility beliefs served humanity well for 990,000 years, which perhaps explains why they continue.

Historical estimates of the Earth's total population are problematic. Nonetheless, there is little argument that human numbers have increased dramatically in the past three hundred years. The conventional wisdom regarding the dramatic changes in the growth rate of the human population typically attributes them to three significant epochs of human cultural evolution: the agricultural, industrial, and green revolutions.

• Agricultural, Industrial, and Green Revolutions

Prior to the agricultural revolution, the human population was probably less than ten million individuals, who survived primarily by hunting and gathering. With the domestication of plant and animal species about ten thousand years ago, the human population experienced an increase in its growth rate. Jared Diamond's book *Guns, Germs, and Steel* (1997) suggests that the geographic endowments of domesticable plants and animals, climate, and other environmental variables have had a profound influence on the fate of human societies, including their ability to engage in agricultural innovation. By about 5000 B.C.E., food production gains caused by the agricultural revolution enabled the planet to support about 50 million individuals.

For the next several thousand years, population continued to grow at a rate of about 0.03 percent per year. By the year 0, the population numbered about 300 million. Through the Roman Empire and the Middle Ages (0-1300 C.E.), the rate of population growth began to increase slightly because of colonization and agricultural expansion. However, there is evidence from this period to suggest that the size of the population was actively controlled by factors such as disease, famine, and war for short periods of time.

At the end of the Middle Ages, the human population numbered about 400 million. As people became more concentrated in denser urban environments, the effects of disease increased. Starting in 1348 and continuing to 1650, the human population was subjected to massive declines caused by the effects of the bubonic plague. At its peak in about 1400, the Black Death may have killed 25 percent of Europe's population in just over fifty years. However, by the end of the last great plague in 1650, the human population numbered 600 million, and this expansion may have been the outcome of the introduction of new species for agricultural cultivation. Agricultural cultivation expands with human population and produces climate change both by increasing GHG emissions and by deforesting and desertifying the surface of the Earth.

The Industrial Revolution began sometime between 1650 and 1750. In the period following 1700, the human population expanded at an accelerating rate. In just under three hundred years, the population of the Earth went from 500 million to well over 5 billion individuals, and the annual rate of increase went from 0.1 percent to 1.8 percent. It is believed the global population growth rate peaked at around 2.1 percent in the early 1970's.

A third revolution occurred sometime in the 1960's. The development of various vaccines and antibiotics in the twentieth century and the spread of their use to most of the world after World War II caused dramatic reductions in the crude death rate. This resulted in increased population growth rates. The third revolution is often called the Green Revolution because of the technology used to increase crop yields. The Green Revolution was really a combination of improvements in health care, medicine, and sanitation, in addition to an increase in the production of food.

• Context

The last few hundred years of human history was also a time of change in the human demographics. During this period, the concentration of industry in urban areas and the efficiency gains of modern agricultural machinery caused large numbers of individuals to move from rural areas to cities to find jobs. From 1900 to the present, the percentage of people living in cities went from 14 percent to about 50 percent. Demographers estimate that by the year 2025 more than 60 percent of the Earth's human population will be living in cities. Scientists estimate that the human population will continue to increase until the year 2050, at which time it will level out at between 8 and 15 billion. In this projection, it is assumed that 90 percent of this growth will take place in the developing world.

Every human being contributes GHGs to the atmosphere because of their food, shelter, and transportation needs. Increasing human numbers means increasing GHGs in the atmosphere. As the world's inhabitants have increased in wealth, GHG emissions have also increased. Increasing wealth historically has been related with increasing energy consumption per capita for housing, transportation, and agriculture. The significance of myriad environmental impacts associated with the size, growth, and spatial distribution of the human population should not be underestimated.

Paul C. Sutton

• Further Reading

Diamond, Jared. *Guns, Germs, and Steel: The Fate of Human Societies.* New York: W. W. Norton, 1997. This Pulitzer Prize-winning book synthesizes a broad range of findings from many disciplines to paint a picture of how and why certain civilizations manifested in certain areas based on natural climatic and environmental factors.

Harrison, Paul, and Fred Pearce. *AAAS Atlas of Population and Environment*. Berkeley: University of California Press, 2001. Very useful for understanding the linkages between population and environment. Provides a history of human impact on the environment and discusses many of the policy responses to environmental degradation related to population and consumption.

Livi-Bacci, Massimo. *A Concise History of World Population*. 3d ed. Malden, Mass.: Blackwell, 2001. Excellent history of the growth of the human population in both space and time.

Weeks, John. *Population: An Introduction to Concepts and Issues*. Belmont, Calif.: Wadsworth Press, 1999. Introductory textbook in demography with linkages to related ideas in sociology and geography.

See also: Agriculture and agricultural land; Anthropogenic climate change; Displaced persons and refugees; Human migration; Industrial Revolution; Human behavior change; Megacities; Poverty; United Nations Conference on the Human Environment; Urban heat island.

Portfolio analysis

• **Category:** Economics, industries, and products

• **Definition**

Around 2001, reports and publications about climate change began referring to a broad or diverse portfolio of policies, approaches, or technologies for coping with climate change. Working Group III of the Intergovernmental Panel on Climate Change (IPCC) issued a 2001 report listing portfolio theory as a potential tool of analysis. This report's description of portfolio theory highlighted the weighing of options by their risks and expected returns, consideration of budget, and arrival at a portfolio of options providing the highest anticipated returns for the lowest level of risk.

In the early 1970's, when large companies were acquiring unrelated businesses and becoming conglomerates, Barry Hedley and the Boston Consulting Group (BCG) developed the business portfolio concept as a planning framework. A parent company's managers could examine their various businesses, which might vary widely in performance and market share, in light of the company's overall resources. In portfolio analysis, managers view the company as a portfolio of businesses and select strategies for each business that fit the business's position in the growth-share matrix, as well as the overall needs of the company.

• **Significance for Climate Change**

The 2007 IPCC Working Group III report, "Mitigation of Climate Change," includes numerous references to both portfolio analysis and portfolios of policies. Gary Yohe, an economics professor at Wesleyan University and a lead author of the 2007 report, has written that his research strongly supports a portfolio approach. The portfolio's components should include adaptation measures (whose benefits would be immediate but would gradually decline); mitigation techniques (which would grow in importance as climate change has greater impact); and research and development (to create green technologies that will increase mitigation's efficiency).

This decision-making approach, unlike some others, takes market risk into consideration, weighing actions that will help businesses diversify their investments against risk. For example, it considers the interrelationships of the costs of different energy sources. This allows a diverse portfolio that contains large amounts of wind, solar, geothermal, and other nonfossil fuels. Though they cost more to generate than do fossil fuels, these alternative fuels do not fluctuate as much in cost. They decrease risk by increasing energy security and thus ultimately reduce costs.

The 2007 report recommends a broad portfolio for both mitigation and adaptation technologies—as well as a broad portfolio of research into such technologies—because it is doubtful that any single technology will solve the climate change problem. It also notes that many research studies show that certain adaptation measures affect mitigation, while other mitigation measures affect adaptation.

Glenn Ellen Starr Stilling

See also: Carbon footprint; Conservation and preservation; Damages: market and nonmarket; Economics of global climate change; Emission scenario; Environmental economics; Offsetting; Sustainable development.

Poverty

• **Categories:** Ethics, human rights, and social justice; economics, industries, and products

Extreme or prolonged climate changes affect poor people's ability to secure a basic standard of living, reducing access to drinking water, threatening food security, and exacerbating health problems. Low crop yields, famines, and landmass erosion are expected to force millions of Earth's poorest people to leave their homes and seek better conditions elsewhere.

• Key concepts

developing countries: poor, primarily agricultural or island nations, many of which are located in the Southern Hemisphere

millennium development goals (MDGs): a set of objectives for economic development adopted by the United Nations in 2000

vulnerability to climate change: the risk that climate variability and extremes will cause a decline in the well-being of a given group or entity

• Background

Rises in average global temperatures will most adversely affect the world's poor and place at risk international efforts to eradicate poverty. Developing countries will bear the brunt of climate-related adversities that have already affected millions of people. The $6 billion spent annually on humanitarian responses to disasters would face sharp increases if global warming continues.

• What Is Known

Estimated deaths due to climate change are concentrated in the poorer regions of the globe. In 2000, mortality per million persons ranged from lows of 0-2 throughout countries in the more affluent Northern Hemisphere to highs of 70-100 in the poorest regions of the world such as sub-Saharan Africa. The area of the world stricken by drought doubled between 1970 and the early 2000's, turning even fertile land in Africa to desert.

Between 1900 and 2004, 73 percent of disasters were climate related; 94 percent of disasters and 97 percent of disaster-related deaths occurred in developing countries. In 1998, Hurricane Mitch affected more than 25 percent of households in Honduras, led to a 7 percent drop in agricultural output, and increased the nation's poverty rate significantly. The loss of livestock to Rift Valley disease from the 1997-1998 El Niño resulted in a billion-dollar ban by the Gulf States on trade from East Africa. Following the 2000 floods in Mozambique, the country's real annual growth rate fell by 7 percent. In 2002, flooding in Bangladesh damaged 20 percent of crops and left 1.4 million people food insecure.

Climate change brings the risk of increases in serious diseases. Subsequent Hurricane Mitch flooding increased the incidence of cholera fourfold in Guatemala and sixfold in Nicaragua. Since 1940, El Niño-related floods increased the severity of cholera in Bangladesh. Longer rainy seasons increased malaria in parts of Rwanda and Tanzania and diarrhea in young children in Gambia.

• Anticipated Consequences

By 2020, drought is expected to reduce African farming harvests by 50 percent. Between 75 and 250 million people in Africa may face water shortages, as may 3 billion people in the Middle East and on the Indian subcontinent.

By 2035, glaciers in the Himalayas are likely to melt to such an extent that the water supply of three-quarters of a billion people in Asia would be severely compromised. By 2050, rising sea levels, floods, and drought could render more than 200 million people homeless. The number of people at risk of annual flooding alone is expected to increase from 75 million to 206 million, with 90 percent of those at risk within Africa and Asia.

By 2070, rainfall in the wet season in Pakistan could increase by 5 to 50 percent, which would have significant impacts on the annual yield of cotton, the country's main cash crop, and thereby affect Pakistani prospects for economic growth, trade, and foreign investment. The world's percentage of people at risk from malaria is expected to increase from 40 percent to 80 percent by 2080, severely taxing many countries' and the international community's health care systems.

• Who Is Doing What to Help

The 1992 U.N. Conference on Environment and Development adopted the Framework Convention on Climate Change (UNFCCC). At the third conference of the UNFCCC in 1997, the Kyoto Protocol was adopted. Fearing that stabilizing its greenhouse gas (GHG) emissions would adversely affect its economy, the United States did not ratify the Kyoto Protocol.

In addition to the UNFCCC, over twenty-five other organizations constitute the United Nations Systems Work on Climate Change, including the Intergovernmental Panel on Climate Change (IPCC), the United Nations Environment Programme (UNEP), the United Nations Commission on Sustainable Development (CSD), the World Bank, the International Monetary Fund, and the World Health Organization (WHO).

Under United Nations auspices, the September 8, 2000, Millennium Declaration, signed by 189 countries, identified poverty eradication and environmental stability as two of eight interrelated millennium development goals (MDGs). The World Bank's *World Development Report, 2000/2001: Attacking Poverty* and the United Nations-commissioned *Human Development Report, 2007/2008* also linked poverty reduction goals to sustainable environmental strategies. International figures such as former U.S. vice president and 2007 Nobel Peace laureate Al Gore and rock singer Bono have taken up the cause of linking poverty reduction with sustainable development at world forum events.

This charcoal maker's child is one of hundreds of people who live and work in a garbage dump in Manila, Philippines, surrounded by the waste that they recycle to make their living. (Darren Whiteside/Reuters/Landov)

Linking poverty reduction with environmentally sustainable initiatives may work at cross purposes. Reducing trade barriers and promoting tourism to enhance economic growth increase the use of the transport sector, which accounts for about 20 percent of global carbon dioxide (CO_2) emissions. Neither international aviation nor shipping was included in the national emission-control targets set under the Kyoto Protocol.

The United Nations encourages nations to prepare themselves for extreme variations in climate. Many developing countries such as Bangladesh and Malawi, as well as more affluent countries such as Australia, use the U.N. National Adaptation Programmes of Action (NAPA) framework. About seventy low-income countries participate in the Poverty Reduction Strategy Papers (PRSP) process, which incorporates climate adaption strategies, as required for receiving debt relief under the Heavily Indebted Poor Countries (HIPC) Initiative and concessional assistance from the World Bank and International Monetary Fund (IMF).

• Context

Climate change may be the definitive human development issue of the twenty-first century, as Great Britain's 2006 Stern Review suggested and the *Human Development Report, 2007/2008* contended. Increased exposure to drought, more intense storms, floods, and environmental stress will dilute efforts of the world's poor to build a better life. Failure to meet climate-related challenges would consign the poorest 40 percent of the world's population, some 2.6 billion people, to a future of increased socioeconomic destitution and diminished opportunity. It would exacerbate socioeconomic disparities within countries, increasing the likelihood of civil conflicts and undermining efforts to build a more inclusive pattern of globalization, and it would raise the prospects of geopolitical confrontations between developed nations such as the United States and developing ones such as China as they compete for scare resources.

Richard K. Caputo

• Further Reading

Ravindranath, N. H., and Jayanta A. Sathaye. *Climate Change and Developing Countries.* New York: Kluwer Academic, 2008. Provides a balanced presentation of varying perspectives on climate change as it affects the future role of developing countries. Rich in detail; discusses global mechanisms for capacity building, technology transfer, and investment flow from developed to underdeveloped countries. Figures, index, references.

Roberts, J. Timmons, and Bradley C. Parks. *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy.* Cambridge, Mass.: MIT Press, 2007. Argues that north-south inequality sustains diametrically opposed conceptions of "climate justice," precludes cooperative efforts, and poses a serious threat to political resolutions to bearing costs to enable developing countries to prepare themselves for climate-related adversities. Appendixes, notes, references, index.

Van Drunen, M. A., R. Lasage, and C. Dorland, eds. *Climate Change in Developing Countries: Results from the Netherlands Climate Change Studies Assistance Programme.* Oxford, England: CAB International, 2006. Presents select studies from thirteen least developed countries about the interdependence of climate change, GHG emissions, vulnerability and adaption, and policy responses. Appendix with questionnaire results, figures, index.

See also: Displaced persons and refugees; Intergenerational equity; Stockholm Declaration.

Precautionary approach

• **Categories:** Environmentalism, conservation, and ecosystems; laws, treaties, and protocols

• Definition

The precautionary approach, or precautionary principle, is a major principle of environmental policy in the presence of fundamental uncertainties. It can be traced to the early 1950's, when economist Sigfried von Ciriacy-Wantrup advocated a "safe minimum standard of conservation" as a policy goal. It can now be found in many international and national policy documents and conventions.

Uncertainties are the result of a lack of scientific knowledge or final proof of the consequences of human activities. Many of the effects of human consumption and production on both human and environmental health, including Earth's climate, are not yet known with certainty. Traditionally, science policy experts have argued that a final scientific proof should be reached prior to taking political actions such as mandating a reduction of greenhouse gas (GHG) emissions or banning chemicals. Some experts, however, have advocated taking action to protect the environment even if final proofs cannot be delivered or if scientists differ in their assessment of environmental risk.

The precautionary principle is a principle that tries to retain future development options and avoid irreversible effects. It is also a major element in policies pursuing sustainable development. Policy fields engaging with the precautionary approach include not only climate change policy but also policies regarding the release and admission of chemicals and genetically modified organisms.

• Significance for Climate Change

Referring to climate change, political decision makers have two alternatives. They can await final scientific proof that anthropogenic GHG emissions cause irreversible changes to the Earth's climate, or they can take immediate action. In the former case, no costs would be borne by today's generation, but there is a risk of tremendous cost to future generations if scientists are right and the Earth's mean temperature rises significantly. In the latter case, costs may be substantial to today's generation but future generations could be saved from bearing the enormous costs of climate change.

The United Nations Framework Convention on Climate Change (UNFCCC) has acknowledged the importance of the precautionary principle in climate change policies by aiming at a stabilization of "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system." The convention does not specify the target level of GHG concentrations in the absence of a final scientific proof determining that level. However, the precautionary principle realizes that decisions have to be made under conditions of uncertainty and that they may have irreversible effects. Therefore, the parties to the convention agreed to take

> precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures. . . .

Scientific evidence suggests that costs of a precautionary policy today may be much less than future costs of climate change in the case that no action were taken today.

Michael Getzner

See also: Benefits of climate policy; Catastrophist-cornucopian debate; Economics of global climate change; Environmental economics; Level of scientific understanding; Polluter pays principle; Portfolio analysis; Scientific proof; United Nations Framework Convention on Climate Change.

Preindustrial society

• Category: Economics, industries, and products

• Definition

Beginning about the second half of the eighteenth century, the Industrial Revolution ushered in the age of machine technology, driven by engines powered through steam and the combustion of wood, coal, and eventually oil. Social life, initially in Europe and ultimately throughout the world, was radically transformed. All aspects of human culture became increasingly mechanized and rationalized. The era of the factory, urban congestion, rapid transportation, and agricultural modification had begun. Patterns of employment and housing fell into line. It was no longer necessary to live so close to the source of food, and a gradual abandonment

Tribal leader Ashonko Alalaparoe of Kwamalasamutu, Suriname, has agreed to help American environmentalists protect the Amazon rain forest. Earth's remaining preindustrial societies are important allies in attempts to preserve natural resources from increasing industrialization. (Antonio Perez/MCT/Landov)

of agrarian customs for the higher energy consumption lifestyle of city and suburb began.

Preindustrial society came to be defined in retrospect in terms of its differences from industrialized society. In particular, it came to be seen as characterized by a slower lifestyle and one less rigorously rationalized by time clocks and assembly lines and cities planned to maximize traffic circulation. From a conservationist standpoint, the environmental footprint of preindustrial societies was radically smaller than that of a fully industrialized twenty-first century (or even nineteenth century) nation.

• Significance for Climate Change

Estimates indicate that the atmospheric concentration of carbon dioxide (CO_2) has roughly doubled since the last ice age, with half of that increase occurring in the two centuries since the Industrial Revolution. Many scientists would relate that change (and the global warming it arguably promotes) to the burning of wood, coal, and oil as fuels. Industrialization has meant a vast increase in the release of greenhouse gases (GHGs) into the atmosphere, as well as environmental pollution of soil and stream.

Some critics feel nostalgia for the world they see as having been lost to industrialization, and some foresee an inevitable recurrence of preindustrial circumstances in a "postindustrial" future. Still other critics emphasize that preindustrial societies did not necessarily engage in environmentally friendly practices, but were small enough, in terms of human population, that their impact on the environment was insignificant.

Preindustrial societies were nonetheless affected by sometimes abrupt climate change. They were extremely vulnerable in the event of sudden, extreme, or prolonged shifts in climatic conditions, which could affect the success of established agricultural practices, alter vectors of disease transmission, and encourage or obstruct population movement (with ensuing cultural and biological effects). As climate historian Hubert Horace Lamb soberly notes, for example, the

> drying up of the north African, Arabian, northwest Indian and central Asian deserts ended the human activities and cultures there and must have caused at first famines and ultimately . . . shift of populations.

The environmental habits of preindustrial societies may have been virtuous, or they may have been noxious but inconsequential in practice. In either case, their small scale guaranteed limited impact. The primary change in recent centuries has been increasingly rapid growth of human population. Whatever the initiating causes of that growth—improvements in nutrition and health are often mentioned, but the issue is complicated—there is little doubt that the lapse of key features of preindustrial life has helped produce high, expanding, and perhaps unsustainable levels of human population.

It may be difficult to address climate change effectively as long as human population continues to expand exponentially. On the other hand, if population in traditional societies was kept in check by high mortality because of disease, famine, and war, it would be hard to argue for the reinstatement of such factors.

Edward Johnson

• Further Reading

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It.* New York: Hill and Wang, 2008. Presents lessons from Broecker's career as an eminent paleoclimatologist and suggestions for addressing global warming.

Cohen, Joel E. *How Many People Can the Earth Support?* New York: W. W. Norton, 1995. A key work on many issues related to the history and the future of human population growth.

Fagan, Brian. *The Great Warming: Climate Change and the Rise and Fall of Civilizations.* New York: Bloomsbury, 2008. Analysis of the social effects of the "great warming" that occurred after Europe's Little Ice Age.

Krech, Shepard, III. *The Ecological Indian: Myth and History.* New York: W. W. Norton, 1999. Argues that Native Americans probably had a negative impact on their environment.

Kunstler, James Howard. *The Long Emergency: Surviving the Converging Catastrophes of the Twenty-first Century.* New York: Atlantic Monthly Press, 2005. Bleak forecast of the collapse of the world's "cheap-oil fiesta" and ensuing postindustrial disasters.

Lamb, H. H. *Climate, History, and the Modern World.* 2d ed. New York: Routledge, 1995. Historical account of climatic fluctuations, with discussion of their impact on both preindustrial and industrial societies.

Laslett, Peter. *The World We Have Lost, Further Explored: England Before the Industrial Age.* 3d ed. New York: Charles Scribner's Sons, 1984. The third edition of Laslett's celebrated examination of preindustrial English society.

Mann, Charles C. *1491: New Revelations of the Americas Before Columbus.* New York: Alfred A. Knopf, 2005. Reassesses the state of knowledge about life in the American hemisphere before the modern era.

Ponting, Clive. *A New Green History of the World: The Environment and the Collapse of Great Civilizations.* New York: Penguin, 2007. Provides a long view of human history that sees agriculture as the original mistake.

Zerzan, John. *Twilight of the Machines.* Port Townsend, Wash.: Feral House, 2008. Compares "productionism" and the "primitive future" as fates for the human species and argues for voluntary abandonment of the industrial mode of existence.

See also: Agriculture and agricultural land; Industrial ecology; Industrial emission controls; Industrial greenhouse emissions; Industrial Revolution.

Pseudoscience and junk science

• Categories: Popular culture and society; science and technology

Many ideas that are presented in popular media as science are actually false or very poorly supported by evidence. These pseudoscientific ideas can be used both as general disinformation and for specific practical purposes, such as winning a court case or influencing legislation.

• Key concepts

anecdotal evidence: isolated instances illegitimately used to establish a logical principle or general rule

conspiratorial outlook: a belief that others' behavior is caused by bias or ulterior motives

junk science: faulty science that attacks established scientific findings or advances poorly supported theories for a practical goal

pseudoscience: scientific-sounding claims that are either scientifically false or so poorly supported by evidence that they should not be taken seriously

• Background

Many people assume that any idea that claims to be science actually is science; they find the very existence of pseudoscience surprising. Pseudoscience is more than merely wrong or unsupported science. Merely being wrong or speculative does not make an idea pseudoscience. Speculation is a legitimate part of science, and many ideas in science that initially look promising turn out to be wrong (and vice versa). When ideas in legitimate science turn out to be wrong, supporters eventually admit it and abandon the ideas.

One example of such self-correction is cold fusion, the idea that nuclear fusion was possible using simple apparatus. After an initial flurry of interest in the 1980's, it turned out that the initial observations that seemed to support cold fusion were faulty. Most scientist supporters of cold fusion abandoned the idea. A few scientists continue to believe there was some basis for believing in cold fusion, but they also realize that they must supply adequate proof in order to convince other scientists.

In contrast, pseudoscience is not merely wrong, but its supporters also refuse to accept contrary evidence, often invent complex alternative explanations to support their ideas, and openly defy the consensus of the scientific community, often militantly. Frequently, they accuse the scientific community of bias or ulterior motives for refusing to accept unorthodox ideas.

There is no sharp boundary between science and pseudoscience. One useful simple classification is that of physicist James Trefil, who grouped scientific ideas into a center, where ideas are firmly supported and unlikely to be disproven, a frontier, where ideas are debatable, and a fringe, where ideas are very unlikely to be valid. Generally, frontier ideas move either into the center or out toward the fringe fairly quickly. For example, the idea that a meteor impact triggered the extinction of the dinosaurs was a frontier idea when it was first proposed but has moved toward the center. Cold fusion was also a frontier idea when it was first proposed but moved fairly rapidly to the fringe.

Rarely, even larger shifts occur. For example, continental drift was considered a fringe idea for decades before new evidence was discovered that caused it to move rapidly to the center in a modified form called plate tectonics. Not all fringe ideas necessarily deserve the label "pseudoscience." For example, although medical studies have not confirmed the idea that vitamin C in large doses helps prevent colds, the theory itself is harmless and does not violate any well-established scientific findings. Bigfoot and UFOs are fringe ideas that do not necessarily violate known scientific findings, but they count as pseudoscience because the evidence for these ideas is very poor. Finally, some ideas, such as the Earth being only a few thousand years old, are pseudoscience because they contradict well-demonstrated scientific findings.

Although some advocates of pseudoscience engage in deliberate deception, most sincerely believe the ideas they publish. They are often motivated by a desire for fame or to have their beliefs accepted as science, or for psychological reasons such as a need for mental or spiritual satisfaction. Usually, their ideas are supported by a combination of wishful thinking, faulty data, and logical fallacies.

• Identifying Pseudoscience

For scientists well trained in their fields, the distinction between science and pseudoscience is generally obvious. For nonscientists without specialized training, the distinction can be difficult. However, there are a number of clues that often are revealing and do not require much specialized training. If a new theory directly conflicts with established science, explicitly claims that existing science is wrong, or makes sweeping claims that most scientists reject, it is less likely to be legitimate science. If it merely reports a new discovery that seems improbable but does not contradict core scientific principles, it is more likely to follow accepted scientific practice, although it may still be incorrect.

The more strongly a theory opposes accepted science, the more likely it is to be pseudoscience—although almost all revolutionary scientific breakthroughs would also appear to be pseudoscience from the point of view of the prerevolutionary scientist. If a theory does radically oppose established science, one question to consider is whether its author makes obvious mistakes about simple matters. If so, the author is very unlikely to be correct in more complex matters that require more technical knowledge.

There are certain kinds of faulty data that crop up repeatedly in pseudoscience. Anecdotal data, for example, is data gathered from isolated cases and used to support a general conclusion. In order to be useful, anecdotal data must be both true and representative. If the anecdote is false, of course, then it cannot be used to prove anything, but even if it is true, it must still be representative and not just an isolated case. For example, it may be true that someone became ill after a vaccination, but if the event is just a rare case, it does not necessarily prove the vaccination is unsafe. To count as scientific evidence, the anecdote must be reproducible—that it, scientists must be able to reconstruct the situation described and obtain the same result.

Pseudoscience often also makes use of obsolete data. Often, the alleged facts were reported in newspapers or popular media or were early scientific findings that later either were found to be erroneous or were superseded by more accurate results. If a theory is based heavily on old data, especially from popular sources that are hard to check, it should be considered suspect.

Pseudoscientists often cite other authorities in support of their ideas. Important questions to ask about alleged supporting authorities include how well respected they are in their own fields, how well informed they are about the subject they are supposedly supporting, and whether they really do support the theory in question or whether they are being quoted out of context and without their consent.

• Logical Fallacies

One of the most widespread and conspicuous features of pseudoscience is a conspiratorial outlook. Pseudoscientists commonly claim that their theories are not being taken seriously by the scientific establishment because of ulterior motives, such as protecting research funding, refusal to admit that an outsider might have made an important discovery, pride, or ideology. Even if these claims are true, they have nothing at all to do with whether the scientific claims of the author are true.

A common tactic in pseudoscience, often termed the "Galileo fallacy," is to point to examples of scientists who were persecuted in the past only to be vindicated later on. Often, as in the case of Galileo, the examples are based on oversimplified stereotypes that are not historically valid. Even when it is true that an idea met opposition from other scientists only to be found true later, that does not mean that opposition makes an idea true. The vast majority of ideas that encounter opposition turn out to be false.

Disproving an idea does not prove its opposite. For example, in 2008 the method of lead analysis used to analyze the bullets that killed President John F. Kennedy was found to be faulty. The method could not be used to prove that all the bullets came from the same gun, as had been claimed. However, that does not prove that the bullets came from more than one gun; it only proves that the method was inconclusive. It is very common in pseudoscience for the author to attack some finding in science and then assert that his own idea must be correct. Even if the scientific concept really is incorrect, that does not prove that some contrary idea is true. Unanswered questions are merely unanswered; they are never proof for an idea. For example, although there are many unanswered questions about evolution, those unanswered questions do not disprove evolution.

• Junk Science

The term "junk science" came into widespread use in the 1980's. Perhaps the first significant example was the attempt by the tobacco industry to discredit the scientific evidence linking tobacco and lung cancer. Scientists and others working for the industry attacked minor and generally irrelevant flaws in the medical research, offered alternative explanations for the data, and questioned the validity of applying animal studies to humans. The intent of this strategy was to justify doubt in the minds of customers, legislators, judges, and juries. In fact, a common strategy in both pseudoscience and junk science is to exaggerate the degree of uncertainty about some scientific idea, and then assert that, since "the experts do not agree," people should decide for themselves whether or not an idea is valid.

• Context

Pseudoscience is a significant concept for many reasons. First, many people are unaware of its existence, and merely knowing that pseudoscience exists can help them understand that some claims that sound revolutionary are not worth serious consideration. Pseudoscience has often been used in support of extremist movements, and a historical understanding of its function will help to contextualize future pseudoscientific claims. Widespread popular acceptance of pseudoscience is an indication that public understanding of science and logic are poor. Considering that many public policy issues involve science and that scientific evidence is so widely used in court, poor public understanding of science and of the proper use of evidence are matters of grave concern. Finally, pseudoscience can illuminate the workings of science by contrasting real science with counterfeit science.

Both sides in the climate change controversy have accused the opposition of practicing pseudoscience and junk science. The most reliable way to determine which side is more correct is to become well informed about climatology. However, clues such as allegations of conspiracy or ulterior motive, strength and relevance of professional credentials, use of logical fallacies and questionable data, attempts to exaggerate doubt, and the weight of scientific opinion are all revealing.

Steven I. Dutch

• Further Reading

Feder, Kenneth L. *Frauds, Myths, and Mysteries: Science and Pseudoscience in Archaeology*. Boston: McGraw-Hill, 2008. Every legitimate scholarly field has a pseudoscience counterpart. This book discusses topics such as ancient astronauts, Atlantis, Noah's Ark, and the Shroud of Turin.

Gardner, Martin. *Did Adam and Eve Have Navels? Debunking Pseudoscience*. New York: W. W. Norton, 2001. Gardner has been observing and writing about pseudoscience for over half a century, and his collected works cover almost every pseudoscientific theory of modern times. This book deals with issues as varied as opposition to evolutionary theory and alternative medicine fads.

Randi, James, and Arthur C. Clarke. *An Encyclopedia of Claims, Frauds, and Hoaxes of the Occult and Supernatural*. New York: St. Martin's Griffin, 1997. A former professional magician whose expertise in magic enabled him to spot the tricks used by alleged psychics, Randi has become one of the most prolific authors on pseudoscience. He joins forces with celebrated science-fiction author Arthur C. Clarke in a comprehensive survey of pseudoscience.

Schadewald, Robert J. *Worlds of Their Own*. Philadelphia, Pa.: Xlibris, 2008. Collects major essays previously published in numerous periodicals. Uses enduring themes in pseudoscience to explore the workings of science and shows that pseudoscience movements all have features in common.

Shermer, Michael, and Stephen Jay Gould. *Why People Believe Weird Things: Pseudoscience, Superstition, and Other Confusions of Our Time*. New York: Holt, 2002. Shermer, who writes the "Skeptic" column in *Scientific American*, and Gould, a biologist and popularizer of science, explore numerous popular delusions. They argue that a desire for mental and spiritual comfort plus a tendency to see nonexistent patterns account for much of the widespread belief in false ideas.

See also: Catastrophist-cornucopian debate; Conspiracy theories; Scientific credentials; Scientific proof; Skeptics.

Radiative damping

• **Categories:** Meteorology and atmospheric sciences; physics and geophysics

• **Definition**

When the temperatures of the lower atmosphere and surface of the Earth increase as a result of radiation-producing agents, such as the increase of greenhouse gas (GHG) emissions, the amount of infrared radiation emitted into space increases, producing a new energy balance for the Earth. The amount by which emissions of infrared radiation into space increases for a given increase of temperature is termed the radiative damping. The radiative damping coefficient equals the change in incoming radiation and outgoing radiation as a function of time (the radiative forcing) per change in global temperature.

• **Significance for Climate Change**

The radiation balance of the Earth is altered by the exchange of incoming solar radiation and the outgoing radiation emitted by the Earth or reflected by the Earth's surface, clouds, and aerosols. Changes in this balance produce changes in the Earth's temperature and climate. If the radiative damping coefficient, also referred to as the climate sensitivity coefficient, is large, the climate will change slowly. Radiative damping acts as a negative feedback mechanism to stabilize the Earth's climate against any major changes. If the atmospheric temperature rises, the amount of infrared energy radiated back into space increases, which in turn reduces the temperature rise. The sensitivity of global climate is essentially determined by the radiative damping of the global mean surface temperature anomaly through the outgoing radiation at the top of the atmosphere.

Predictions of values for radiative damping are based on computer algorithms known as general circulation models (GCMs). During the early twenty-first century, models have been improved to include not only radiative effects of the atmosphere but also simulations of the radiative effects of clouds, oceans, ice, and vegetation. Upwelling and diffusion within the oceans are included to account for their radiative damping effect. According to the Intergovernmental Panel on Climate Change (IPCC), GCMs indicate evidence for discernible human influence on the global climate via increased GHG emissions. Warmer temperatures cause ice to melt, which exposes more land and water, reducing radiative damping because more sunlight is absorbed than is reflected.

Controlling radiative damping is critical for reducing climate change. To maintain radiative damping at a level that negates global warming, radiative forcing needs to be stabilized, reduced to zero, and then sustained at or very near this newly established equilibrium level. Based on recent GCMs, achieving this would most likely involve reducing GHG emissions, stabilizing GHG concentrations, and reducing any of the agents that drive radiative forcing away from equilibrium. Adjusting radiative damping will help stabilize the Earth's climate and maintain an equitable habitat for life that depends on water.

Alvin K. Benson

See also: Climate feedback; General circulation models; Global energy balance; Greenhouse gases; Radiative forcing.

Radiative forcing

• **Categories:** Meteorology and atmospheric sciences; physics and geophysics

• **Definition**

Earth's radiative forcing is the change over time of the net difference between the amount of the planet's incoming radiation energy and the amount of its outgoing radiation energy (the net irradiance). This differential is measured at the tropopause, the boundary in the atmosphere between the troposphere and the stratosphere. When there is more incoming than outgoing radiation energy, corresponding to positive radiative forcing, the average temperature of the Earth rises. When there is more outgoing than incoming radiation energy (negative radiative forcing), the average temperature decreases. Changes in radiation forcing can be produced by a variety of agents, most notably varying radiation outputs from the Sun or variations in the concentrations of greenhouse gases (GHGs) in the atmosphere.

• Significance for Climate Change

The Intergovernmental Panel on Climate Change (IPCC) requires that values of radiative forcing be reported relative to the year 1750, which is taken as the beginning of the industrial era. When the Earth's radiative balance strays away from its equilibrium state, global temperatures change. A linear relationship has been established between the amount of radiative forcing and the average global equilibrium surface temperature. The change in radiative forcing is equal to the change in global temperature multiplied by the climate sensitivity, or radiative damping, coefficient. Values of radiative forcing are reported in watts per square meter.

The Earth's radiation balance is directly influenced by changes in atmospheric composition, cloud properties, and surface and atmospheric temperatures. Since radiative forcing is rather easy to calculate, it provides a general estimate of climate changes due to variations in the radiation output of the Sun, changes in GHG concentrations, changes produced by emission of heat by various materials, and other agents that change the net amount of radiation energy. Since the majority of energy that affects the Earth's climate comes from the Sun, if radiative forcing were close to zero, the solar radiation energy coming to the Earth would be approximately equal to the infrared radiation emitted from the Earth.

Radiative forcing values are estimated by inputting available weather data into computer algorithms that are based on general circulation models (GCMs). Values are generated for contributions due to natural influences, particularly varying solar radiation, volcanic eruptions, and seasonal effects that alter cloud and ground cover, and for human contributions, particularly GHG emissions and aerosols. Some calculations indicate that the radiative forcing caused by human activities is more influential on climate change than is the radiative forcing caused by natural means. Other calculations indicate the opposite. In either scenario, reduction of GHG emissions is an important goal in regulating the Earth's climate.

Alvin K. Benson

See also: Climate feedback; General circulation models; Global energy balance; Greenhouse gases; Radiative damping.

Rainfall patterns

• **Categories:** Meteorology and atmospheric sciences; water resources

• Definition

Global rainfall patterns are produced by global scale atmospheric motions. In the tropics, warm air at the surface holds considerable moisture. As it is heated and rises, it cools, and the moisture condenses and falls out as rain. High in the atmosphere this air moves away from the equator to descend at latitudes near 30° north or south. As this dry, descending air approaches the surface, it warms, increasing its capacity to evaporate water. These latitudes contain many of the Earth's major deserts: the Sahara, Kalahari, Australian, and Saudi Arabian, for example. Air high in the atmosphere that reaches either pole also cools and descends. Most of Antarctica is a desert, and the dry valleys there are among the driest places on Earth.

Each of these convective systems has a return flow directed toward the equator, across the surface of the Earth. Between them is a third convective system, complicated by the jet stream and other factors. In this system the upper atmosphere moves toward the equator, and the return flow across the surface moves away from the equator.

The Coriolis effect, a result of the Earth's rotation, causes things in motion in the Northern Hemisphere to be deflected to the right and those moving in the Southern Hemisphere to be deflected to the left. Therefore, the return flows in the three cells described above, responsible for Earth's surface winds, come from the east between the equator and 30° latitude, from the west between 30° and 45° latitude, and again from the east at latitudes greater than 45°. As these winds move across the oceans, they evaporate water. If they are brought onto a continent and then are forced up over a mountain range, the air they are moving will cool and rain will fall out. Moving down the far side of the mountain range, the now dry air will warm and evaporate moisture again. In this way, mountain ranges typically have an excess of rain (orographic rainfall) on their windward sides and a deficiency of rain (rain shadows) on their leeward sides.

Other winds are produced by the variation in temperature between continents and oceans. In the summer, continents are warmer and air rises above them, bringing moisture-laden air in from the oceans, and monsoon rains occur. In the winter, this pattern reverses, and little rain falls.

• Significance for Climate Change

Humankind depends on patterns of rainfall—but not the total amount (most of which falls on the oceans) and not the amount that falls at a given location during a year (if it all comes in one torrential downpour, rain does more harm than good). What is important is the pattern, in both space and time, of the right amount of rainfall.

As climate changes, the geographically determined patterns of rainfall will probably change very little. The atmospheric convective cells will continue to operate, resulting in the variations in rainfall with latitude that are seen today and producing winds that will continue to blow in generally the same directions. On human timescales, mountains will stay the same, and hence orographic rainfall and rain shadows will persist.

Rainfall patterns, however, are also affected by the strength and locations of persistent high and low pressure regions, which control the particular paths taken by various air masses. In the temperate zone (between 30° and 45°), the generally west-to-east flow of air produced by the large-scale convective systems is actually rather wavy, wandering north and south as it interacts with topography and with the persistent pressure systems set up by the various modes, or pressure seesaws, that exist in the atmosphere. The degree of waviness and where the waves occur change with the seasons (the excursions of the jet stream are larger in the winter) and with these modes.

Some of these modes are the El Niño-Southern Oscillation cycle, the Pacific-North American (PNA) cycle, the Pacific Decadal Oscillation (PDO), and the Northern Annular Mode (NAM), which may include the North Atlantic Oscillation (NAO). Although what controls these oscillations is not well understood, their timing and intensity are probably more likely to change as the climate evolves than the larger, geographically determined, patterns.

Studies of proxies for rainfall and temperature have attributed variations in the monsoons to fluctuations in the strength of the ENSO. The Medieval Warm Period (MWP), from roughly 900 to 1300 C.E. when the North Atlantic and northern and western Europe experienced warmer conditions on average, is thought by some to have resulted from a very persistent phase of the NAO, causing the winds that blow from the west over much of Europe to be deflected far to the south prior to reaching that continent. In terms of human suffering, changing rainfall patterns may well turn out to be more significant than temperature changes or sea-level rise.

Otto H. Muller

• Further Reading

Collier, Michael, and Robert H. Webb. *Floods, Droughts, and Climate Change.* Tucson: University of Arizona Press, 2002. Written for a general audience, this book presents a very readable account of the many factors affecting rainfall patterns and does a fine job of describing the various climate modes.

Gautier, C. *Oil, Water, and Climate: An Introduction.* New York: Cambridge University Press, 2008. Somewhat slanted toward policy issues, this book describes how societies are likely to cope with changes to rainfall patterns as the climate changes.

Kandel, Robert. *Water from Heaven.* New York: Columbia University Press, 2003. A grand overview of water on the planet, this book describes shifts in rainfall patterns due to ENSO and NAO.

Rohli, Robert V., and Anthony J. Vega. *Climatology.* Sudbury, Mass.: Jones & Bartlett, 2008. An excel-

lent textbook with clear discussions of why rain falls where it does, what climate modes are, and some of the likely outcomes of climate change.

See also: Abrupt climate change; Agriculture and agricultural land; Atlantic heat conveyor; Climate zones; Drought; El Niño-Southern Oscillation; Global climate; Hydrologic cycle; Hydrosphere; La Niña; Mediterranean climate; Monsoons; Seasonal changes; Thermohaline circulation; Tropical climate; Water resources, global; Water resources, North American; Water rights; Weather forecasting.

Ramsar Convention

- **Category:** Laws, treaties, and protocols
- **Date:** Adopted February 2, 1971; entered into force December 21, 1975

Signed by eighteen nations in 1971, the Ramsar Convention was the first international treaty on environmental conservation. Although its original mission was to conserve wetlands "as a contribution toward achieving sustainable development throughout the world," its efforts have expanded to consider the importance of wetlands in global climate change.

- **Participating nations:** *1971:* Belgium, Denmark, Finland, France, Germany (Federal Republic), India, Iran, Ireland, Jordan, Netherlands, Pakistan, South Africa, Soviet Union, Spain, Sweden, Switzerland, Turkey, and the United Kingdom. *Additional Parties as of December, 2008:* Albania, Algeria, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, The Bahamas, Bahrain, Bangladesh, Belarus, Belize, Benin, Bermuda, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Republic of the Congo, Costa Rica, Côte d'Ivoire, Croatia, Cuba, Cyprus, Czech Republic, Democratic Republic of the Congo, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Estonia, Gabon, The Gambia, Georgia, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Honduras, Hungary, Hong Kong, Iceland, Indonesia, Iraq, Israel, Italy, Jamaica, Japan, Kazakhstan, Kenya, Kyrgyz Republic, Latvia, Lebanon, Lesotho, Liberia, Libya, Liechtenstein, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Moldova, Monaco, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, New Zealand, Nicaragua, Niger, Nigeria, Norway, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Republic of Macedonia, Romania, Russia, Rwanda, Saint Lucia, Samoa, Senegal, Serbia, Seychelles, Sierra Leone, Slovakia, Slovenia, South Korea, Sri Lanka, Sudan, Suriname, Syria, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Uganda, Ukraine, United Arab Emirates, United States of America, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia

- **Background**

International organizations, including the International Union for Conservation of Nature, have worked to protect waterfowl since the beginning of the twentieth century. In 1962, Luc Hoffman and several international conservation groups called for an international convention on wetlands. The group later known as Wetlands International spent the next eight years conducting meetings and drafting treaty language, guided by G. V. T. Matthews. The agreement formally titled the Convention on Wetlands of International Importance, Especially as Waterfowl Habitat was signed in the town of Ramsar, Iran, in 1971, and came to be known informally as the Ramsar Convention.

- **Summary of Provisions**

The Ramsar Convention was the first environmental treaty to consider both conservation and the "wise use" of natural resources. Contracting nations have agreed to employ national land-use planning, law, management and public education to work toward the wise use of all their wetlands; to identify and manage appropriate wetland areas for inclusion on the Ramsar List, an official List of Wetlands of International Importance; and to cooperate internationally to protect wetlands and inhabit-

The List of Wetlands of International Importance

Article 2 of the Ramsar Convention, reproduced below, forms the heart of the convention. It establishes the List of Wetlands of International Importance, wherein the wetlands designated for conservation by the signatories are enumerated.

1. Each Contracting Party shall designate suitable wetlands within its territory for inclusion in a List of Wetlands of International Importance, hereinafter referred to as "the List" which is maintained by the bureau established under Article 8. The boundaries of each wetland shall be precisely described and also delimited on a map and they may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands, especially where these have importance as waterfowl habitat.

2. Wetlands should be selected for the List on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology. In the first instance wetlands of international importance to waterfowl at any season should be included.

3. The inclusion of a wetland in the List does not prejudice the exclusive sovereign rights of the Contracting Party in whose territory the wetland is situated.

4. Each Contracting Party shall designate at least one wetland to be included in the List when signing this Convention or when depositing its instrument of ratification or accession, as provided in Article 9.

5. Any Contracting Party shall have the right to add to the List further wetlands situated within its territory, to extend the boundaries of those wetlands already included by it in the List, or, because of its urgent national interests, to delete or restrict the boundaries of wetlands already included by it in the List and shall, at the earliest possible time, inform the organization or government responsible for the continuing bureau duties specified in Article 8 of any such changes.

6. Each Contracting Party shall consider its international responsibilities for the conservation, management and wise use of migratory stocks of waterfowl, both when designating entries for the List and when exercising its right to change entries in the List relating to wetlands within its territory.

ing species that cross national boundaries. The Conference of the Contracting Parties (COP) meets every three years, and a smaller standing committee meets every year, to guide conservation efforts and measure progress. Contracting parties can make use of convention consultants, grant funds, and other assistance.

• Significance for Climate Change

The Convention on Wetlands and the United Nations Framework Convention on Climate Change (UNFCCC) are linked in several ways. The UNFCCC's Kyoto Protocol article on land use, land-use change, and forestry, as well as the article on development and transfer of technology, directly affects the conservation of wetlands. The convention has passed a series of resolutions calling for cooperation with the UNFCCC, especially in sharing information. Kyoto Protocol contracting parties invited advice from Ramsar scientists in drafting policies on peatland and carbon sequestration. Further, the convention has endorsed the development of a memorandum of cooperation between the Ramsar Convention Bureau and the UNFCCC to protect the interests of small island states, threatened by climate change and encroaching wetlands.

During the tenth meeting of the Ramsar Convention on Wetlands' COP, held in October, 2008, in the Republic of Korea, the Ramsar Convention entered into a new partnership with the International Union for Conservation of Nature (IUCN) and the Danon Group, producers of Evian bottled water. The initiative will attempt to control global warming through wetlands protection and restoration.

The convention has achieved great success in educating the general public about the importance of wetlands. By January, 2008, more than seventeen hundred wetland areas, covering more than 153 million hectares, had been included on the Ramsar List, ranging in size from less than one hectare to more than 6 million hectares.

Cynthia A. Bily

- **Further Reading**

DiMento, Joseph F. C., and Pamela Doughman, eds. *Climate Change: What It Means for Us, Our Children, and Our Grandchildren.* Cambridge, Mass.: MIT Press, 2007. An accessible overview of the science and politics on global warming, with clear discussion of the role of international cooperation.

Hunt, Constance Elizabeth. *Thirsty Planet: Strategies for Sustainable Water Management.* London: Zed Books, 2004. Analysis of the need to preserve freshwater ecosystems and the challenges presented by irrigation, water companies, and population growth.

Matthews, Geoffrey Vernon Townsend. *The Ramsar Convention on Wetlands: Its History and Development.* Ramsar, Iran: Ramsar Convention Bureau, 1993. This volume, by one of the founders of the convention, traces the water conservation movement's history through the decade leading up to the Ramsar Convention.

Ramsar Convention Secretariat. *The Ramsar Convention Manual: A Guide to the Convention on Wetlands.* 4th ed. Gland, Switzerland: Author, 2006. Overview of the Ramsar Convention, its history and present structures, the services it provides, the workings of the Conference of the Parties, the standing committee, the scientific and technical review panel, and the secretariat.

Yamin, Farhana, and Joanna Depledge. *The International Climate Change Regime: A Guide to Rules, Institutions, and Procedures.* New York: Cambridge University Press, 2004. Comprehensive legal analysis of the procedures, agreements, organizations, and policies of the United Nations Framework Convention on Climate Change.

See also: Kyoto Protocol; United Nations Framework Convention on Climate Change; Wetlands.

Reason Public Policy Institute

- **Category:** Organizations and agencies
- **Date:** Established 1976
- **Web address:** http://www.reason.org

- **Mission**

The Reason Public Policy Institute works to apply marketplace principles to the issue of global warming, arguing against environmental regulations that might harm business. Many Web sites identify the Reason Public Policy Institute (RPPI) as a global warming skeptic organization funded by ExxonMobil, but it is much more than that. RPPI, the research division of the Reason Foundation, generates original research on issues including the environment, education, infrastructure, transportation, urban land use, local economic development, social services, privatization, and government reform.

According to a description in several RPPI reports, the Institute

> brings a political philosophy that supports rule of law, marketplace competition, economic and civil liberty, personal responsibility in social and economic interactions, and institutional arrangements that foster dynamism and innovation.

The Reason Foundation has been funded largely by corporations affected by these issues, including ExxonMobil, the Western States Petroleum Association, Shell Oil, the Edison Electric Institute, DaimlerChrysler, the Ford Motor Company, and other energy and transportation companies, as well as Microsoft, Bayer, Bank of America, and others.

RPPI research supports the views that anthropogenic causes are minimally responsible for global warming and argues against regulations proposed to combat global warming—especially those aimed at reducing greenhouse gas emissions. The 2001 report *Q and A About Forests and Global Climate Change* summarizes the organization's positions:

> Despite many remaining uncertainties in scientific understanding of climate change, most initiatives propose to slow or stop the buildup of greenhouse

gases by reducing fossil fuel use. Such policy options are likely to have little positive impact on climate, but could result in negative impacts on energy production, national economies, and personal autonomy.

• Significance for Climate Change

While the Reason Foundation continues to operate and to publish *Reason* magazine and research reports, documents issued after about 2005 have not carried the RPPI logo, and inquiries to the RPPI Web site are automatically redirected to the Reason Foundation's site. The Reason Foundation continues to work on climate and environmental issues and runs the Web site www.newenvironmentalism.org. For some years, Kenneth Green was director of the environmental program. Among his peer-reviewed studies published by RPPI are *A Plain English Guide to the Science of Climate Change*, *Climate Change Policy Options and Impacts*, *Evaluating the Kyoto Approach to Climate Change*, and *A Baker's Dozen: Thirteen Questions People Ask About the Science of Climate Change*. In 2004, RPPI published reports and op-eds challenging the Arctic Climate Impact Assessment report from the Arctic Council. Some time after 2005, ExxonMobil stopped supporting RPPI and other public policy think tanks, stating that these organizations had become a "distraction" from the real work of finding solutions.

Cynthia A. Bily

See also: American Enterprise Institute; Cato Institute; Economics of global climate change; Environmental economics; Libertarianism.

Reefs

• **Categories:** Environmentalism, conservation, and ecosystems; oceanography

Reefs are sensitive, extremely biodiverse ecosystems that are strongly affected by climate change and play a vital role in ocean health. As global temperatures rise, the fragility and importance of the world's reefs simultaneously makes them a source of serious concern for environmentalists and provides early indications of the severity of climate change's future effects.

• Key concepts

ahermatypic corals: non-reef-forming corals

coral bleaching: loss of color in a coral colony due to stress-induced expulsion of zooxanthellae; often followed by death

corals: colonial cnidarians that excrete calcium carbonate exoskeletons

El Niño: weather phenomenon that sends an influx of nutrient-poor warm water into the normally cold, nutrient-rich surface waters off the coast of Ecuador and Peru

hermatypic corals: tropical corals that form reefs

reef: a marine feature lying below the water's surface; often formed by biological activity, as by corals

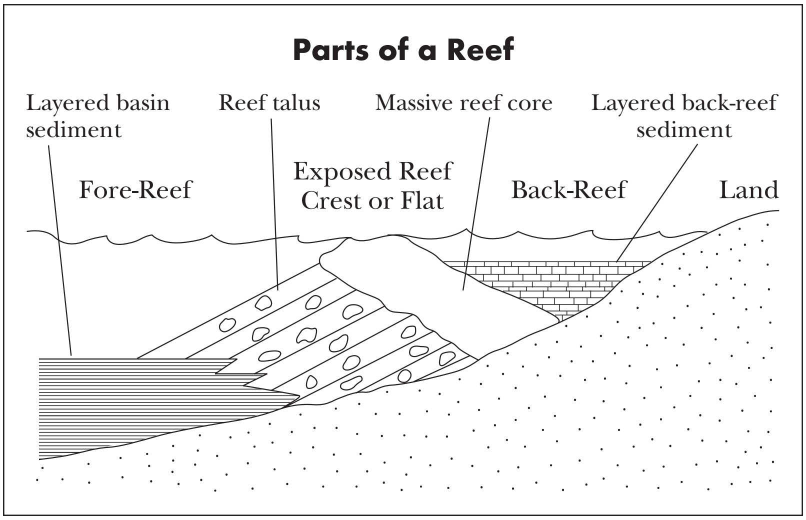
zooxanthellae: photosynthetic organisms that live in symbiosis with corals and other organisms, providing up to 90 percent of a coral's energy requirements

• Background

Coral reefs occupy thousands of square kilometers of shallow inshore waters in the tropics over a region of millions of square kilometers and are often used to define the tropical marine environment. Unlike other marine communities, reefs are built entirely by biological activity. They are composed of calcium carbonate produced by corals (phylum Cnidaria, class Anthozoa), with some contributions from calcareous algae and other organisms. Corals and the organisms that live with them are extremely sensitive to climate and are important indicators of ocean health.

• Reefs in Geological History

Reefs have a long history—reef-building organisms were some of the first marine life to develop hard skeletons. Reefs reached their periods of maximum development during the Middle Cambrian (513-501 million years ago), Devonian (416-359 million years ago), and Carboniferous (354-290 million years ago) periods, when they were dominated by a now extinct order, the rugose corals. During the Late Cretaceous (100-65 million years ago) and Neogene (23 million years ago to present) periods they have been dominated by scleractinian corals.



The fossil record shows that some reefs were formed by other organisms in the past. Calcareous algae and archaeocyathids (small, cone-shaped animals probably related to sponges) formed reefs in the Early Cambrian period (542-513 million years ago), as did rudist bivalves in the Late Cretaceous period (100-65 million years ago). However, corals have generally been the dominant reef formers through geologic history.

• Modern Reef Ecosystems

Although corals live throughout the world, even in polar and temperate regions, only tropical (hermatypic) corals form reefs. Most hermatypic corals have symbiotic unicellular organisms called zooxanthellae living in their tissues. Zooxanthellae are vital to coral reef health, providing up to 90 percent of a coral's energy requirements by photosynthesis. Reef distribution is also limited by temperature, water depth, light, salinity, sedimentation, and emergence into air.

Coral reefs are limited to shallow waters, typically less than 25 meters deep, which is why they are restricted to island and continent margins (with the exception of atolls). This limitation dervies from the symbiotic zooxanthellae, which require light for photosynthesis. Below 25 meters, there is insufficient sunlight to support photosynthesis. When the photosynthesis rate is reduced, corals produce calcium carbonate at a slower rate and are unable to form reefs. Hermatypic corals also require water with salinity close to normal seawater, or, in some cases, higher. Excessive sediment from runoff can smother corals and make it difficult for zooxanthellae to photosynthesize. Coral reefs thrive in areas with strong wave action, but are limited by low tide levels, as exposure to air can kill them relatively rapidly.

Reefs are typically divided into three categories: atolls, barrier reefs, and fringing reefs. Atolls are ring-shaped reefs that rise from very deep offshore waters and enclose a lagoon. They are found primarily in the Indo-Pacific area. Barrier and fringing reefs occur near a landmass, with a barrier reef being separated from land by a greater distance and deeper water. These two categories grade into each other and are sometimes considered one.

Although hard corals are the dominant organisms of reefs today, they are one of the most diverse, species-rich marine ecosystems as a result of efficient nutrient recycling. Some of the other important groups of organisms found in reefs are gorgonians or sea fans (order Gorgonacea), soft corals (order Alcyonacea), the fire coral *Millepora* (order Hydrocorallina), coralline algae such as Halimeda, mollusks, echinoderms, crustaceans, polychaete worms, sponges, and fish. Coral reefs may have hundreds or thousands of fish species, making them one of the richest environments for fish, which in turn contribute to the biological structure of the reefs. Finally, bacteria play a key role in decomposition and recycling of organic matter, as well as the biological productivity of reefs. Tropical marine waters are nutrient poor, while coral reefs are nutrient rich and extremely biodiverse. They provide crucial environments for many marine species.

• Reefs and Global Warming

Severe tropical storms, which may be increasing in frequency and severity due to global warming, are a major cause of reef mortality. Although hard corals are extremely sturdy and stand up to strong wave action, hurricanes and typhoons can destroy large areas of reef by uprooting coral colonies and carrying them off the reef. Storm deposits of broken coral are common in Caribbean fossil reefs.

The El Niño weather phenomenon, which sends an influx of nutrient-poor warm water into the normally cold, nutrient-rich surface waters off the coast of Ecuador and Peru, is also a periodic cause of catastrophic reef mortality. These changes in ocean patterns and climate can raise surface water temperatures for long periods of time, resulting in increased coral mortality rates, ranging from 50-98 percent overall.

The most puzzling cause of coral die-off is coral bleaching, which occurs when corals expel their zooxanthellae. If zooxanthellae do not recolonize quickly, the corals can die. Coral bleaching has been reported since the 1980's, sometimes associated with El Niño events. The causes are unclear, but it is likely associated with stress, particularly in warm water. Coral bleaching events have become more common, which some attribute to global warming. Reefs develop best in areas where the mean annual temperatures are between 23° and 25° Celsius, and only some can tolerate temperatures above 36° to 40° Celsius.

Coral reefs weakened by bleaching and storms are less resistant to diseases such as black band and white band disease, the latter of which has decimated Caribbean corals on a regional scale. Reefs can take over a hundred years to recover from some types of catastrophic mortality events.

• Context

Coral reefs are in increasing danger from the effects of global warming, from warmer waters to increasingly severe storms. Throughout history, reefs have completely disappeared for millions of years following mass extinction events, and there is evidence that reefs may soon disappear for the re-

A coral reef off the coast of Florida. (U.S. Fish and Wildlife Service) mainder of human history. Reefs act as an indicator of global warming and are crucial to marine biodiversity. It is also important to protect the health of coral reefs because they provide an important habitat for many food species, as well as protective barriers against storms for tropical islands.

Melissa A. Barton

• Further Reading

Spalding, Mark D., Edmund P. Green, and Corinna Ravilious. *World Atlas of Coral Reefs.* Berkeley: University of California Press, 2001. Comprehensive book about coral reef history and ecology, as well as environmental concerns, aimed at high schoolers but suitable for adults as well. Photographs, maps, illustrations.

Tackett, Denise Neilsen, and Larry Tackett. *Reef Life: Natural History and Behaviors of Marine Fishes and Invertebrates.* Neptune, N.J.: TFH, 2002. Guide to reef organisms and their behavior and environment, with some discussion of environmental concerns. Photographs.

Veron, J. E. N. *A Reef in Time: The Great Barrier Reef from Beginning to End.* Cambridge, Mass.: Harvard University Press, 2008. The former chief scientist with the Australian Institute of Marine Science uses the Great Barrier Reef as an example of how reefs are indicators of climate change's effects on marine and other ecosystems; argues that reefs may soon disappear. Illustrated.

See also: Barrier islands; Coastline changes; Conservation and preservation; Environmental movement; Ocean life.

Regional, local, and microclimates

• **Category:** Meteorology and atmospheric sciences

Climate change is not uniform across the world. Regional, local, and microscale processes often determine how the climate of a particular location will change in response to increasing concentrations of GHGs or other factors.

• Key concepts

aspect: the direction of slope, such as south-facing or north-facing

Gulf Stream: the warm current originating in the Gulf of Mexico that travels along the U.S. east coast before turning east to cross the Atlantic Ocean

monsoon: a seasonal shift in prevailing wind, often associated with significant rainfall

orographic process: any process triggered by topographic features

sea breeze: a sea-to-land wind developed as a result of land-water temperature gradients

trade winds: easterly surface winds in the tropics

urban heat island: an urban region that is significantly warmer than the surrounding rural areas

• Background

Climate is the long-term average of weather patterns. Due to the spherical shape of the Earth, the climate at any location is primarily determined by its latitude. However, the climates of certain regions can be significantly different from those at similar latitudes. Depending upon the spatial scale of interest, these climates are categorized as regional (covering hundreds or thousands of kilometers), local (covering tens of kilometers), and micro (covering few kilometers or even meters). Often, the climate in each of these cases is dominated by atmospheric processes operating only at those spatial scales.

• Regional Climates

Regional climates refer to climates of significantly large geographical area covering hundreds to thousands of kilometers with distinctive features distinguishing them from neighboring regions. The uniqueness of regional climates is driven by factors involving their locations, including distance from oceans and the proximity of large topographic features. Additionally, they are often characterized by specific large-scale atmospheric and oceanic processes such as the Atlantic and Pacific hurricanes, and the Asian and African monsoons that dominate other weather processes operating at smaller scales.

The oceanic influence is strongly evident in various regional climates of the United States. The cold water of the vast Pacific Ocean keeps the climate

Monsoon clouds pass over a beach in southern India. The Indian Ocean and the Asian monsoon are integral parts of the regional climate of South Asia. (Sivaram V/Reuters/Landov)

mild year-round in the western United States However, the relatively warm Atlantic helps generate massive hurricanes leading to hot and humid summers with lots of rain in the Southeast. The Atlantic Ocean strongly influences the regional climate of western Europe. In particular, the Gulf Stream, carrying warm tropical waters northward, keeps the western coast of Europe, especially the British Isles, unseasonably mild. Southern European and northern African climate is mild as a result of proximity to the Mediterranean Sea.

The Asian monsoon and the Indian Ocean play an important role in determining the distinctive climate of South Asia. The typical dry northeasterly trade winds reverse direction in the summer, bringing months of heavy and continuous rain to India and Southeast Asia. The influence of the Indian Ocean and the monsoon decreases, leading to drier climates, in the northern part of the Indian subcontinent.

Continental effects are evident in the climates of the midwestern United States, central and eastern Europe, midlatitudes of central Asia, and subtropical Africa. These regions experience hot summers, cold winters, and dryness throughout the year. As a consequence of this extreme climate, semiarid grasslands such as the prairie, savanna, and steppes are one of the most common vegetation in these regions.

• Local Climates

Local climates are climates of limited geographical areas covering only a few kilometers or tens of kilometers. Examples of local climates include land, sea, and lake breezes, orographic effects, and urban heat islands.

Sea/lake/land breezes are forced by the difference in thermal properties between land and water. Due to its high specific heat capacity, water heats up slower than land. Hence, on a warm summer day, the air over land gets warmer than the air over water. Since warm air is lighter, it rises, and cooler offshore air is drawn in to replace the rising air over land. Thus a cool sea/lake breeze develops. At night, the land cools down quickly, radiating heat to the atmosphere, but the sea remains relatively warm. Under these conditions the sea/lake breeze may reverse to form a land breeze.

Topographic features such as mountains/valleys can significantly influence the local climate. When moist air hits a mountain, it rises and cools, leading to orographic clouds and precipitation. Consequently, the windward side of a mountain is much cooler and wetter than the leeward side. Another important local climate process is mountain/valley winds. As the morning sun heats up the south- and east-facing slopes, air above the slopes warms and starts to rise, causing an upslope (anabatic) breeze. If the air is humid, it may lead to clouds and rain on mountain ridges. At night, the slopes cool radiatively and the cold air sinks back into the valley as downslope (katabatic) breeze. If there is a source of moisture in the valley, it may lead to extensive fog.

Another example of local climate is urban heat islands. They form in large developed metropolitan areas due to multiple reasons: increased heat absorption by concrete and asphalt structures, reduced evaporative cooling, trapping of outgoing radiation by buildings and waste heat from cars, air-conditioning, and industries. Consequently, cities tend to be several degrees hotter than surrounding regions.

• Microclimates

Microclimates are climates of very small areas with spatial scales ranging from a few meters to a few kilometers. The major factor behind the existence of a microclimate is the proximity to a heat sink or source. Microclimates exist near ponds, lakes, and wooded areas that generate a cooling effect or near factories and construction sites where the waste heat warms the ambient air.

Topographic aspect (direction of slope) has a profound effect on microclimate. South-facing slopes in the Northern Hemisphere and north-facing slopes in the Southern Hemisphere are exposed to more direct sunlight. Hence, they warm up quickly, reach higher temperatures, and stay warm for longer. Due to this effect the vegetation cover in opposing slopes of the same hill may be dramatically different. A similar effect is seen in areas that are shaded by natural or anthropogenic structures such as fences or tall buildings.

The city of San Francisco is a textbook example of microclimates. The city lies between the Pacific Ocean and the San Francisco Bay and the topography is complex, with 44 named hills. Due to these natural and anthropogenic reasons the city contains about 30 well-defined microclimate regions. The temperature within the city can vary by 5-10° Celsius, with similar range of variability in precipitation, wind speed, and incoming solar radiation.

• Context

It is well established that global warming is going to affect different regions differently. Local impacts will depend on how regional, local, and microscale processes respond to greenhouse gas forcing. Extracting regional climate information from global data sets or general circulation model simulations is very difficult. Simulations with regional climate models can provide this information but are computationally very expensive. Statistical methods can also be used to downscale information from global scales, but these are based on the assumption that the fundamental nature of interactions between different meteorological parameters remain the same across various climate regimes. Hence, regional climate change is one of the major challenges in climate change science.

Somnath Baidya Roy

• Further Reading

Intergovernmental Panel on Climate Change. *Climate Change, 2001—The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by J. T. Houghton et al. New York: Cambridge University Press, 2001. Provides a scientific assessment of past, present, and future climate change. Chapter 10 contains a thorough discussion on regional climate, regional climate modeling, and how to derive regional climate information from general circulation models. Illustrations, references, index.

———. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Chapter 11 discuses how regional climates will change in response to changes in greenhouse gas concentrations. Illustrations, references, index.

Oke, T. R. *Boundary Layer Climates.* New York: Routledge, 1988. Provides a lucid description of various micrometeorological processes that shape local and microclimates. Geared toward a nonmeteorologist audience.

See also: Climate and the climate system; Climate zones; Climatology; El Niño-Southern Oscillation; Monsoons; Rainfall patterns.

Religious Right

- **Category:** Popular culture and society

The Religious Right is a loose, informal group of Christians and Jews who base political conservatism in religious doctrine. Americans classified as members of the Religious Right have split in their responses to reports of global warming, with some emphasizing the divine command to tend the Earth and others, while acknowledging their duty as caretakers, emphasizing the dominion God granted humans over other creatures.

• Key concepts

eschatological: pertaining to the end of this world

evangelical: pertaining to proselytizing Protestants who emphasize individual salvation through faith and place what they consider scriptural authority above church tradition

King James Bible: an English translation of the Bible authorized by King James I of England and originally published in 1611

prelapsarian: occurring before the fall of humanity into sin through the eating of the forbidden fruit in the Garden of Eden

• Background

Jews and Christians recognize Genesis as the first book of Scripture. It contains, according to many scholars, two consecutive accounts of Creation. In the older, a verse gives the prelapsarian intent of God for human beings: "And the LORD God took the man, and put him into the garden of Eden to dress it and to keep it." The other account of Creation provides for many readers a different picture of the place of men and women in what God has made, as the following verse indicates:

> And God blessed them, and God said unto them, Be fruitful, and multiply, and replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth.

• Difficulty in Classifying Religious Americans

Classifying religious Americans according to whether they are members of the Religious Right is hard in some instances. American Catholics, for example, vary in their political beliefs and the importance they place on particular issues. Catholic opponents of abortion noted that, upon meeting Pope Benedict XVI on February 18, 2009, House Speaker Nancy Pelosi, a liberal Catholic, praised the Vatican's campaign against global warming but did not mention abortion, while the Vatican stressed that dignified human life begins at conception.

Southern Baptists, for their part, have disagreed about not only primarily theological issues but also superficially secular issues with religious implications, such as global warming. In response to prevailing Southern Baptist positions, the Nobel Laureate and climate activist Al Gore ended his long membership in the Southern Baptist Convention. Furthermore, among evangelicals in general there has been disagreement about public topics, with some evangelicals, such as Ron Sider, being far from right-wing and others, such as Joel Hunter, registering as Republicans but working closely with Democrats. With respect to global warming, at least one prominent, politically conservative evangelical, Pat Robertson, has shifted from skepticism to cautious support of Gore.

• Emphasis on Caretaking

Seeing human beings as caretakers of the Earth even after humanity's first sin, the National Religious Partnership for the Environment, founded in 1993, comprises the Coalition on the Environment and Jewish Life, the United States Conference of Catholic Bishops, the National Council of Churches USA, and the Evangelical Environmental Network. Among the founders of the Jewish group in 1992 was Sheldon Rudoff, the president of the Union of Orthodox Jewish Congregations of America. Among the members of the National Council of Churches, besides such left-leaning denominations as the United Church of Christ, are various Orthodox communions.

As for the Evangelical Environmental Network, in 1994 it issued its Evangelical Declaration on the Care of Creation, the signers of which included David Neff, the editor of *Christianity Today*, usually thought of as a conservative magazine. Led by Jim Ball, the network explicitly opposes nature worship but applauded the Evangelical Climate Initiative, which became public with a statement released in February, 2006, and signed by many prominent evangelicals, including Joel Hunter and Rick Warren. Ironically, Richard Cizik, who was instrumental in obtaining signatures, had to withdraw his own because he worked for the National Association of Evangelicals, which declined to support the initiative. The statement spoke of the great harm that global warming would bring, especially to the poor, and advocated laws to reduce emissions of carbon dioxide (CO_2).

• Emphasis on Ruling

An environmental document differing notably from the 2006 statement of the Evangelical Climate Initiative was the Cornwall Declaration on Environmental Stewardship, issued in 2000, which eventually included as signatories Jacob Neusner, an eminent scholar of Judaism; Richard John Neuhaus, the Catholic priest who edited *First Things*; and the famous evangelicals R. C. Sproul, D. James Kennedy, James Dobson, and Charles Colson. The declaration recognizes the moral obligations that humans have to care for their natural environment, but it claims that they serve as stewards and producers (as well as polluters and consumers), that untouched nature does not mean paradise, and that some environmental matters receive so much concern in rich countries that serious environmental problems in poor countries receive little concern.

In the same vein, the Interfaith Stewardship Alliance was formed in late 2005 and included among its members not only Dobson and Colson but also the global warming skeptic E. Calvin Beisner of Knox Theological Seminary and Richard Land of the Ethics and Religious Liberty Commission of the Southern Baptist Convention. In "A Call to Truth, Prudence, and Protection of the Poor: An Evangelical Response to Global Warming," the Alliance advocated efforts to lessen poverty and help all peoples adjust to whatever climates may come instead of efforts to try to stop global warming at the cost of big increases in energy prices. The Cornwall Alliance, the successor in 2007 to the Interfaith Stewardship Alliance, continued the previous program to respect individual productivity and freedom while following God's law for His Creation.

• Context

Despite differences, all members of the vaguely defined Religious Right believe that God owns the Earth, whether they consider humans as gardeners or viceroys. Neither group rejects the idea of caretaking, however much they disagree about how that care is to be taken. Furthermore, neither group totally rejects the idea of human dominion, because to be ruled by nonhuman creatures and never to harm any of them at all is to die. A charitable examination of each side should reveal good intentions, whether or not they are misdirected. The examination should also reveal that those persons who reject extensive governmental intervention to reduce global warming are, in that respect, to the political right of those who otherwise may be members in good standing of the Religious Right.

Victor Lindsey

• Further Reading

Gustafson, David I. *Reaping the Real Whirlwind: A Biblical Response to the Theory of Man-Made Global Warming*. Sisters, Oreg.: VMI, 2008. Environmental scientist argues that anthropogenic global warming is a prophesied eschatological reality and that Christians should use less fuel and spread Christ's gospel. Graphs, annotated bibliography.

Murray, Iain. *The Really Inconvenient Truths: Seven Environmental Catastrophes Liberals Don't Want You to Know About—Because They Helped Cause Them.* Washington, D.C.: Regnery, 2008. Senior fellow at the Competitive Enterprise Institute attacks what he considers the leftist ecological church and advocates private property and free market stewardship to protect the environment. Cartoons, graphs, chart, notes, index.

White, Lynn, Jr. "The Historical Roots of Our Ecological Crisis." *Science* 155 (1967): 1203-1207. Reprinted in *Earth Ethics: Introductory Readings on Animal Rights and Environmental Ethics*, edited by James P. Sterba. 2d ed. Upper Saddle River, N.J.: Prentice Hall, 2000. Historian claims that environmental catastrophe comes from the Western Christian idea that humans should rule the Earth and endorses the idea of Saint Francis of Assisi that all God's creatures are equal.

See also: Conservatism; Liberalism; Libertarianism; Skeptics.

Renewable energy

• **Categories:** Energy; environmentalism, conservation, and ecosystems

• Definition

Renewable energy is derived from inexhaustible sources, such as solar energy, wind, biomass, geothermal energy, and the ocean's tides. Solar energy is captured through passive or active means and can be used as heat or electricity. Passive solar energy can be captured by constructing buildings and houses, so heat radiating from the Sun can be used to heat interiors through the strategic placement of windows. Active solar energy comes from the use of photovoltaic (PV) technology, concentrating systems, solar water heaters, and solar cookers.

Only PV technology and concentrating systems can produce electricity from the Sun's heat. PV technology consists of solar cells made of silicon or thin films made from semiconductor materials. Concentrating systems, also known as central solar power (CSP), use mirrors to concentrate sunlight onto a liquid to produce steam, which can then be used to power a turbine and generate electricity.

Wind power is created through the use of wind turbines, which create electricity when the blades are turned by blowing wind. Biomass includes all living or dead plant material and organic waste from humans. Biomass, such as wood and other plants, can be burned in heat and electricity operations, or it can be converted into biofuel to be used in an internal combustion engine. Geothermal energy is the internal heat energy of the Earth. It can be taken directly from vents in the Earth's crust, where it can be used to heat homes or greenhouses. It can also be used to create electricity by injecting water into hot spots so that steam is produced, which can then be used to run a turbine.

Ocean energy includes the energy from waves, tides, and changes in water temperatures. Waves and tides can produce electricity by turning turbines, similar to wind. Changes in sea temperatures at various depths can create energy through a process called ocean thermal energy conversion (OTEC). OTEC can be used in certain areas of the ocean where the water is warm enough to create steam from a special low-boiling-point fluid, which is then used to power a turbine and produce electricity.

• Significance for Climate Change

Many experts and world leaders view renewable energy as a major solution for mitigating climate change. The use of fossil fuels to satisfy human energy needs is one of the major contributors to greenhouse gas (GHG) accumulation in the atmosphere. Renewable energy, with the exception of biomass, does not create GHGs in the process of creating heat or electricity as fossil fuels do, because nothing has to be burned. Although biomass must be combusted, it has the potential to emit less GHGs than do fossil fuels, though how much less is heavily debated.

If renewable energy sources are used as substitutes for fossil fuels, the amount of GHG emissions would be reduced and presumably so would climate change. Renewable energy is also seen as a solution to the worldwide growth in energy demand that has the potential to contribute even more GHG emissions. As more developing countries seek electrification for household and industrial uses and find needs for motorized transportation, their demand for energy will increase their use of fossil fuels and their GHG emissions. Renewable energy is thus a potential solution to allow for development to continue while reducing its impact on the climate.

A geothermal drilling rig in Paris, France, participates in an initiative to provide clean heat for the entire nineteenth arondissement. (Benoit Tessier/Reuters/Landov)

Although political agreements such as the Kyoto Protocol do not require that renewable energy be used to reduce GHG emissions, it is expected that renewable sources will have to become part of the energy mix to achieve the goals of such agreements. From transnational organizations like the European Union to the cities that are a party to the U.S. Conference of Mayors Climate Protection Agreement, governments are passing laws that require utilities to produce electricity from renewable energy. Renewable energy has had difficulty competing in an open market with fossil fuels, a seemingly inexpensive energy source, creating a need for government intervention. It is expected that once renewable energy is economically competitive with fossil fuels, demand for it will soar. Energy experts such as Jeremy Leggett and U.S. representative Jay Inslee argue that efforts similar to those that put humans into space, developed nuclear energy, and won World War II will be needed to make renewable energy a viable solution for global warming.

Katrina Darlene Taylor

• Further Reading

Boyle, Godfrey. *Renewable Energy*. New York: Oxford University Press, 2004. Provides a comprehensive explanation of the different kinds of renewable energy and the concepts behind them. Colorful graphics contribute to enhanced understanding of the topic.

Inslee, Jay, and Braken Hendricks. *Apollo's Fire: Igniting America's Clean Energy Economy*. Washington, D.C.: Island Press, 2007. Emphasizes the bold leadership and commitment that will be required to move the United States toward a more sustainable energy economy.

Leggett, Jeremy. *The Empty Tank: Oil, Gas, Hot Air, and the Coming Global Financial Catastrophe*. New York: Random House, 2005. Thoroughly explains the oil topping point, the financial and

environmental risks of global warming, the role of government and business in promoting continued fossil fuel use, and the solutions to the problem.

Sweet, William. "Going All Out for Renewables, Conservation and Green Design." In *Kicking the Carbon Habit*. New York: Columbia University Press, 2006. This chapter provides a thorough examination of the successes of the wind industry and the disappointing development of the photovoltaic market.

See also: Biofuels; Clean energy; Energy from waste; Energy resources; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Geothermal energy; Hydroelectricity; Solar energy; Tidal power; Wind power.

Reservoirs, pools, and stocks

• **Categories:** Meteorology and atmospheric sciences; environmentalism, conservation, and ecosystems

• Definition

Reservoirs, pools, and stocks are designations used in box models. A box model is a simplified version of a complex system, in which various parts of that system are reduced to boxes that are linked by fluxes. A reservoir is any box within that system that can accumulate, store, or release the substance of interest. In box models of the global carbon system, the oceans, terrestrial plants, soil, and rocks are examples of reservoirs. The atmosphere is typically not considered to be a reservoir. "Pool" is a term that is synonymous with "reservoir" but can include the atmosphere.

Stocks are the actual accumulations of the substance of interest. Thus, in a box model of the global carbon cycle, the stock is the mass or amount of carbon in various forms—including carbon dioxide (CO_2) gas and dissolved species or solids, such as organic matter or inorganic minerals—in each reservoir. The stock in each reservoir is assumed to be well mixed, so that regardless of the size of the reservoir, the concentration of stock throughout the reservoir is uniform. The stock present in each reservoir can change over time, as the rate of input or output from each reservoir varies. In simple box models, reservoirs or pools are held to constant volumes. In more complicated models, the size of a reservoir can change. Numerical methods and computer programs are utilized with box models to solve equations to determine parameters such as the amount of stock in a given reservoir over time or the time needed for the amount of stock in a reservoir to change.

• Significance for Climate Change

Box models, as simplified conceptual models of complex systems and processes, are of fundamental importance for predicting future climate conditions. Results from such models underlie the predictions that are published by the Intergovernmental Panel on Climate Change and other scientific and policy-making bodies. Such models can be applied to any complex system, regardless of scale, such as the global carbon cycle or the biochemical processes in a single cell. With regard to future global warming scenarios, variations in the global carbon cycle are among the fundamental drivers of climate change. Other topics of interest include the global cycles of water, nitrogen, oxygen, and sulfur.

In the development of a box model, the reservoirs and stocks of the species of interest are fundamental properties that must be defined in order to perform the necessary calculations. One of the largest sources of error in box models involves defining the size of reservoirs and pools and determining the amount of stock in each. For example, within the global carbon cycle, the stock of carbon present as gas hydrates in the seafloor is presently not well known. This value must be estimated from a relatively low number of measurements in specific regions and extrapolated to all other places on Earth where these compounds might be present. Gas hydrates have been a source of discussion in the scientific community as a trigger for rapid warming in the recent geologic past (as in the clathrate gun hypothesis of James Kennett).

A key question that is often addressed using box models is how the stock within a given reservoir might change in response to certain events. For example, to estimate the amount of global warming that has been caused by anthropogenic production of CO_2, scientists must use box models to determine how the stock of CO_2 in various pools (such as the atmosphere and oceans) has changed in response to the increased input of CO_2 to the environment. Predictions of the length of time needed for atmospheric CO_2 stocks to decline in response to future CO_2 emissions are also based upon box models of the global carbon cycle.

Anna M. Cruse

- **Further Reading**

Berner, Robert A. *The Phanerozoic Carbon Cycle: CO_2 and O_2*. New York: Oxford University Press, 2004. Berner is a pioneer in the field of biogeochemistry and is one of the creators of the BLAG numerical model, which was used to simulate the carbon cycle over geological timescales. In this book, he discusses that model, assuming a minimal background in mathematics and geochemistry. Illustrations, figures, tables, references, index.

Denman, Kenneth L., et al. "Couplings Between Changes in the Climate System and Biogeochemistry." In *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Provides an overview of the global carbon cycle and how variations in this cycle are used in climate change models. Illustrations, figures, tables, maps, references.

Kennett, James P., ed. *Methane Hydrates in Quaternary Climate Change: The Clathrate Gun Hypothesis.* Washington, D.C.: American Geophysical Union, 2003. Presents Kennett's clathrate gun hypothesis, whereby rapid climate change is driven by the release of large amounts of methane from gas hydrates in a geological instant. Gas hydrates are one example of a reservoir in the global carbon cycle. Illustrations, figures, tables, references.

Roston, Eric. *The Carbon Age: How Life's Core Element Has Become Civilization's Greatest Threat.* New York: Walker, 2008. Focuses on the irony of carbon's dual—foundational and antithetical—roles in Earth's life cycles. Illustrations, figures, tables, references, index.

See also: Climate models and modeling; Climate prediction and projection; General circulation models; Parameterization; Sinks.

Residence time

- **Category:** Chemistry and geochemistry

- **Definition**

Residence time measures how long an individual atom or molecule spends in a system from entrance to exit. For example, the residence time of a carbon dioxide (CO_2) molecule in the atmosphere is the duration spent by the molecule from its entrance via emission from fossil fuel combustion to its exit via uptake by ocean or land ecosystems. The residence time of a carbon atom in a land ecosystem is the length of time spent by the atom from photosynthetic fixation to the respiratory release of the carbon.

An average residence time of an element (molecule or atom) in a system can be calculated from division of pool size by flux of the element when the system is in equilibrium. For example, residence time of CO_2 in the atmosphere is approximately equal to

$$750 \text{ Gigatons} \div 200 \text{ Gigaton years}^{-1} = 3.75 \text{ years}$$

The residence time of the carbon atom in the land ecosystem is approximately

$$2{,}000 \text{ Gigatons} \div 120 \text{ Gigaton years}^{-1} = 16.67 \text{ years}$$

However, when a system is not in equilibrium, the influx of an element into a system is no longer equal to the efflux. For example, CO_2 concentration is building up in the atmosphere. Thus, influx of CO_2 into the atmopshere is larger than the efflux. In this case, the residence time calculated by pool/influx is smaller than pool/efflux.

• **Significance for Climate Change**

Residence time is a critical parameter to characterize element cycling in a system. In studies of carbon sequestration in terrestrial ecosystems, residence time is a key parameter to quantify the potential capacity of an ecosystem to sequester carbon. All carbon atoms that enter an ecosystem from the atmosphere via photosynthesis will eventually be released back to the atmosphere via respiration. Carbon sequestration occurs in a land ecosystem when a fraction of influxing carbon stays in the ecosystem for a long time. Thus, the longer the residence time, the larger the carbon sequestration capacity. Carbon incorporated into the wood of trees has a longer residence time than that in leaves or fine roots. Carbon incorporated into soil organic matter in general has an even longer residence time than that in wood. That is the reason why stimulating carbon sequestration in forests and soils is potentially effective at mitigating greenhouse emissions.

The residence time can describe the average time for a molecule to stay in the atmosphere before being removed by mixing into the ocean and land ecosystems. To evaluate the impacts of greenhouse gases (GHGs) on enhanced greenhouse effects, a concept, atmospheric lifetime, has been introduced to represent the net concentration changes of the various GHGs by all sources and sinks instead of just the removal processes as described by residence time. Although the residence time of CO_2 in the atmosphere is only a few years, its atmospheric lifetime to indicate recovery from a large input of atmospheric CO_2 from burning fossil fuels is tens of thousands of years. The atmospheric lifetime is estimated to be 12 ± 3 years for methane, 120 years for nitrous oxide, and 3,200 years for sulfur hexafluoride. The longer the atmospheric lifetime is, the greater the total impact of a GHG on global warming. That means the impacts of these GHGs on global warming will last long after emission is cut back.

Yiqi Luo

See also: Atmospheric chemistry; Atmospheric dynamics; Carbon cycle; Carbon dioxide; Greenhouse gases; Sequestration; Sinks.

Response time

• **Categories:** Chemistry and geochemistry; meteorology and atmospheric sciences

• **Definition**

The response time of a natural system is the amount of time it takes for the system to respond to a change in the forcing mechanisms. In the case of the climate system, the forcing mechanism of most importance is radiative forcing, which is defined as the net irradiance at the top of the tropopause (boundary between the troposphere and the stratosphere). There are many processes that can affect radiative forcing, including natural phenomena such as variations in the Earth's orbit or in the output of solar radiation, or anthropogenic (human-induced) effects such as the addition of greenhouse gases to the atmosphere. Different components of the Earth system, such as the troposphere, stratosphere, or ocean, have different response times. These differences are largely controlled by heat capacity, which is the amount of heat required to change the temperature of a specific mass of the substance by 1° Celsius.

Heat capacity acts like a shock absorber, slowing the response rate of a system to a temperature change. The heat capacity of the ocean is approximately four times greater than that of the atmosphere, so that the response time of the ocean is much slower than that of the atmosphere. Response times of the atmosphere are typically on the scale of days to weeks, while that of the deepest parts of the ocean can exceed one thousand years. Variations in response time are also observed within each reservoir. For example, because the troposphere is coupled to the ocean—which acts as a brake for changes in the troposphere—its response time is typically on the order of weeks to a few months. In contrast, the response time of the stratosphere is shorter, ranging from a few days to weeks.

• Significance for Climate Change

The response time of different reservoirs is a critical aspect in attempts to predict future climate change. For example, the Intergovernmental Panel on Climate Change (IPCC) uses coupled ocean-atmosphere models to determine the effects of anthropogenic carbon dioxide (CO_2) emissions on climate change. Even in a scenario where CO_2 emissions would be fixed at a level equal to that of the year 2000, global temperature in 2100 is predicted to be 0.6° Celsius higher than today. This continued rise in temperature is due to the slow response time of the oceans. Regional variations in global temperature changes are also observed in models, because the response time of the individual ocean basins vary. The National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory has shown that the response time of the ocean varies with the direction of the change in radiative forcing. If the change was cooling (for example, decreased amounts of atmospheric CO_2), the ocean responded approximately twice as fast as if the change was in a warming direction.

Because the slow response time of the oceans means that global temperatures are predicted to rise even if CO_2 emissions were instantly held at year 2000 levels, many scientists and policy makers are calling for research into geoengineering solutions to global warming. Geoengineering refers to any attempt by humans to control global climate. A variety of possible mechanisms have been proposed, which are designed to achieve one of two outcomes: decrease the amount of incoming solar radiation or reduce the amount of CO_2 in the atmosphere. Proposed projects include chemical approaches such as adding iron to the ocean to reduce atmospheric concentrations of CO_2 ("iron fertilization") and pumping sulfur dioxide into the stratosphere to cause a higher rate of cloud formation.

Other proposals include the installation of a "sunshade" made from stacks of very thin silicon nitride ceramic in space to block incoming solar radiation. Currently, most climate scientists and geoengineering advocates are in agreement that not enough is known about the negative consequences of any of the proposed geoengineering projects. Therefore, these scientists advocate conducting research to determine the potential consequences, such as regional variations in drought cycles or a decrease in atmospheric ozone. Finally, projects aimed at reducing the amount of incoming solar radiation may eventually lead to a decrease in global temperature, but may not directly affect other effects of increased concentrations of atmospheric CO_2 that will remain a concern, such as ocean acidification.

Anna M. Cruse

• Further Reading

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Comprehensive treatment of the causes of climate change; written for a wide audience. Figures, illustrations, glossary, index, references.

Kunzig, Robert. "A Sunshade for Planet Earth." *Scientific American* 299, no. 5 (November, 2008): 46-55. Explains the basic premise of geoengineering and discusses the potential pros and cons of geoengineering approaches, as well as several geoengineering projects discussed at a workshop convened in 2007 between leading climate change scientists and geoengineering advocates.

Oldfield, Frank. *Environmental Change: Key Issues and Alternative Perspectives.* New York: Cambridge University Press, 2005. Written for a general audience; seeks to provide the conceptual framework to understand environmental change, especially climate change. Issues related to the Earth system and response time are outlined in the first two chapters, especially. Figures, illustrations, index, references.

Schellnhuber, Hans, et al., eds. *Avoiding Dangerous Climate Change.* New York: Cambridge University Press, 2006. Collection of papers presented by leading climate change scientists at the 2005 Avoiding Dangerous Climate Change conference. Chapters 5 and 6 discuss THC in the Atlantic Ocean. Figures, tables, references.

See also: Climate and the climate system; Climate change; Climate feedback; Climate lag; Climate sensitivity; Forcing mechanisms.

Revelle, Roger
American oceanographer

Born: March 7, 1909; Seattle, Washington
Died: July 15, 1991; San Diego, California

In an article coauthored with Hans Seuss in 1957, Revelle proposed the idea of the greenhouse effect, indicating that this phenomenon would lead eventually to global warming. Later in his career, Revelle served on the faculty of Harvard University, where he taught Al Gore, among others.

• Life
Roger Revelle was born in Seattle, Washington, on March 7, 1909. He received a bachelor's degree in geology in 1929 from Pomona College and then attended the University of California at Berkeley, receiving a Ph.D. in oceanography in 1936. After completing his studies, Revelle went to work at the Scripps Institution of Oceanography in San Diego, leaving briefly to serve as an oceanographer for the U.S. Navy during World War II. During this time, he was quite influential in the Navy's oceanographic research program. He returned to Scripps, remaining there until 1964 and serving as director of the institution from 1950 until 1964. Thus, Revelle was a major contributor to the field of oceanography in both the public and the private sector. He also served as a science adviser to the John F. Kennedy administration.

Upon leaving Scripps, Revelle went to Harvard University, where he founded the Center for Population Studies and served as a professor for Al Gore, sparking his interest in climate change and global warming. Gore later cited Revelle as his mentor in his crusade against global warming, for which Gore won the Nobel Peace Prize. While at Harvard University, Revelle focused his interest and his research on the problems of world hunger. Revelle was hopeful that by increasing knowledge of biology and of the environment, science could improve agricultural production. In 1976, he returned to California as a professor of science, technology, and public affairs at the University of California in San Diego. In 1974, he served as president of the American Association for the Advancement of Science. Shortly before his death in 1991, he was awarded the National Medal of Science for his work on the greenhouse effect.

• Climate Work
Revelle and Hans Seuss wrote the seminal paper in the field of global warming. In this paper, Revelle and Seuss suggested that the burning of fossil fuels was dramatically increasing the amount of carbon dioxide (CO_2) in the atmosphere. They then went on to indicate that this CO_2 was very slowly absorbed by the surface of the ocean. They attributed the slowness of this process to the buffer effect, which has become known as the Revelle effect. Revelle and Seuss also believed that the CO_2 unleashed by the burning of fossil fuels would result in a greenhouse effect, with the CO_2 absorbing infrared radiation and trapping heat over the Earth's surface. This process in the long run would lead to global warming.

Revelle hoped that the International Geophysical Year (July, 1957-December, 1958), which he helped create, would provide an opportunity to investigate the impact of increasing CO_2 levels on the temperature of the planet. In 1984, Revelle became the first chair of the Committee on Climate Change and the Ocean under the auspices of the Scientific Committee on Ocean Research. Since that time, this organization has been concerned with the ocean's role in global warming. Work that Revelle pioneered in the mid-twentieth century served as the precursor to the concern over global warming and climate change as it existed in the early twenty-first century.

Robin Kamienny Montvilo

• Further Reading
Dorfman, R., and P. P. Rogers, eds. *Science with a Human Face: In Honor of Roger Randall Revelle.* Cambridge, Mass.: Harvard School of Public Health Press, 1997. Compendium of papers based on a 1992 conference held at Harvard University in honor of Roger Revelle. Includes a paper on oceanic global warming.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It.* New York: Rodale Press, 2006. Attempts to explain the impact of global warming on the Earth, demonstrating how several species are moving toward extinction as a result of this process. Gore attributes his work on global warming to his time as a student of Roger Revelle at Harvard.

Munk, W. H., and E. A. Frieman. "Let Roger Revelle Speak for Himself." *Oceanography* 5, no. 125 (1992). Discusses Revelle's presentation at a AAAS meeting in 1990, in which he made suggestions as to things that might be done to forestall global warming.

Revelle, R., and H. E. Suess. "Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 During the Past Decades." *Tellus* 9 (1957): 18-27. The original paper in which Revelle and Seuss pointed out that CO_2 is absorbed from the environment by the ocean's water much more slowly than had previously been thought, resulting in a greenhouse effect and eventual global warming.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years.* Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008. Argues against the premise of the greenhouse effect and global warming and against the ideas of Revelle and Gore.

See also: Carbon dioxide; Gore, Al; Greenhouse effect; *Inconvenient Truth, An.*

Rowland, F. Sherwood

American chemist

Born: June 28, 1927; Delaware, Ohio

The award of the 1995 Nobel Prize in Chemistry to Rowland, his coworker Mario J. Molina, and Paul J. Crutzen "for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone" was considered a vindication of environmental science, thitherto belittled by the mainstream scientific community.

• Life

F. Sherwood Rowland was the second of three sons born to Sidney Rowland and Margaret Lois Rowland (née Drake). His father was a professor of mathematics and chair of the Department of Mathematics at Ohio Wesleyan University in Delaware. Frank received his elementary and high school education in the Delaware public school system. Accelerated promotion policy allowed him to enter first grade at age five, skip fourth grade, enter high school at age twelve, and graduate at age fifteen. During summers in high school, he operated the local volunteer weather station, his first exposure to experimentation and data collection. He also played varsity tennis and basketball.

After graduating in 1943, Rowland attended Ohio Wesleyan University and enlisted in a U.S. Navy program, attaining the rank of specialist (athletics) third class. After his discharge, he returned to Ohio Wesleyan, receiving a bachelor's degree in 1948. He enrolled in his parents' alma mater, the University of Chicago, where he continued to participate in basketball and baseball and worked on radiochemistry under future (1960) Nobel chemistry laureate Willard Frank Libby, receiving a master's degree in 1951 and a Ph.D. in 1952. On June 7, 1952, he married Joan Evelyn Lundberg, with whom he had two children, Ingrid Drake (b. 1953) and Jeffrey Sherwood (b. 1955).

Rowland became an instructor in chemistry at Princeton University (1952-1956), spending summers (1953-1955) at the Brookhaven National Laboratory. In 1956, he became assistant professor of chemistry at the University of Kansas, where he headed a research group studying the chemistry of energetic tritium atoms and rising to the rank of full professor. In 1964, he became professor of chemistry and department chair (1964-1970) at the newly established University of California, Irvine, where he was later named Donald Bren Research Professsor of Chemistry.

• Climate Work

Rowland has deliberately changed his research subject every few years, turning to the environment, a significant topic to the general public and his family. He learned that in 1971 British atmospheric scientist James E. Lovelock used his new electron capture detector to demonstrate that the inert synthetic chlorofluorocarbon (CFC or Freon) trichlorofluoromethane ($CC1_3F$) had spread throughout the troposphere (the 10-kilometer layer of the atmosphere below the stratosphere) over the north and south Atlantic Ocean. As a photochemist and kineticist, Rowland was aware that the molecule could not remain inert in the troposphere indefinitely.

In 1973, together with postdoctoral research associate Mario J. Molina, who had just received a Ph.D. from the University of California, Berkeley, Rowland began to search for a sink—a source of reactions by which CFCs are decomposed. The researchers concluded that the CFCs would rise into the stratosphere, where ultraviolet rays would break them down into chlorine atoms, which would react with the ozone layer by catalytic chain reactions. Based on their measurements of the relevant reaction rates, Molina and Rowland calculated within three months that continued usage of CFCs for several decades would deplete the ozone layer by several percentage points.

Among the deleterious environmental consequences of the depletion of the ozone layer is the increase in the number of cases of skin cancer. Molina and Rowland predicted an additional forty thousand cases in the United States alone by 2050. Also, the increased ultraviolet radiation could kill the phytoplankton that form the bottom of the ocean's food chain, as well as affecting global climate. The Environmental Protection Agency (EPA) banned the use of CFCs in aerosols in 1974. The United Nations' 1987 Montreal Protocol and later provisions further restricted their release into the atmosphere. Although there has been an anti-environmental backlash because of political considerations, additional work by Rowland, Molina, and numerous other scientists have confirmed the reality of the anthropogenic depletion of the ozone layer.

George B. Kauffman

• **Further Reading**

Kauffman, George B., and Laurie M. Kauffman. "Atmospheric Chemistry Comes of Age." *Today's Chemistry at Work* 5, no. 6 (November, 1996): 52-58. Account of the award of the 1995 Nobel Prize in Chemistry to Paul J. Crutzen, Molina, and Rowland with details of their lives and work.

Molina, M. J., and F. S. Rowland. "Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom-Catalysed Destruction of Ozone." *Nature* 249 (June 28, 1974): 810-812. This often-cited article was the pair's first disclosure of the action of CFCs on the ozone layer, an effect described as a "planetary time bomb" and "invisible menace."

Read, Katie, et al. "Extensive Halogen-Mediated Ozone Destruction over the Tropical Atlantic Ocean." *Nature* 453 (June 26, 2008): 1232-1235. Presents data from the Cape Verde Observatory in the tropical North Atlantic showing the photochemical destruction of ozone caused by halogens to be 50 percent greater than previously predicted.

Rowland, F. Sherwood. "Stratospheric Ozone Depletion." *Philosophical Transactions of the Royal Society B* 361 (May 29, 2006): 769-790. Account of the complex chemical chain mechanisms that operate to deplete the ozone layer based on its reactions with atomic chlorine and chlorine monoxide.

_______. "Stratospheric Ozone Depletion by Chlorofluorocarbons." *Angewandte Chemie* 35 (1996): 1786-1798. Nobel lecture describes Rowland and Molina's research and their results.

Von Glasow, Roland. "Atmospheric Chemistry: Sun, Sea and Ozone Destruction." *Nature* 453 (June 26, 2008): 1195-1196. New measurements show that halogens decrease levels of ozone not only in the stratosphere but also in the lower atmosphere.

See also: Aerosols; Chlorofluorocarbons and related compounds; Montreal Protocol; Ozone.

Rural air quality

• **Category:** Pollution and waste

• **Definition**

Pollutants affecting the quality of rural air include particulate matter, ozone, and emissions from industries, power plants, and vehicles. Air in rural areas is also polluted with dust from unpaved roads, livestock gases, and agricultural products containing ammonia, nitrogen oxide, sulfur dioxide, and other toxic chemicals. Urban emissions transported by wind currents also pollute rural air.

Medical professionals identify health risks associated with rural residents' contact with harmful pollutants in air they breathe. Local, state, and national governments worldwide consider strategies to control rural air pollution and restrict emissions. The U.S. Environmental Protection Agency (EPA) developed the National Ambient Air Quality Standards (NAAQS), which is frequently used to measure pollution levels in rural areas.

• Significance for Climate Change

During the 1990's, temperature increases associated with global warming exacerbated pollution in rural locations, resulting in the EPA issuing stricter emission standards. This federal regulation alerted the public that rural areas experienced severe air pollution, contrary to many people's perception of the countryside as having cleaner air than do urban sites. Many agricultural organizations, including the American Farm Bureau Federation, stated that emission standards would impede farming and resisted compliance. At that time, most pollution control agencies did not enforce attainment, and rural air quality declined.

By the early twenty-first century, ozone, particulate matter, and smog represented significant pollution hazards to rural residents. Vehicle exhaust and other emissions chemically react with sunlight to produce ozone. Officials recognized that ozone pollution was created both by rural emissions and by urban industries releasing greenhouse gases (GHGs) that drifted into rural areas and contributed to raising temperatures conducive to generating ozone. As smog accumulated in rural areas, the EPA adjusted prior NAAQSs, considering air safe if 1 cubic meter did not exceed a maximum of 15 micrograms of particulates and 75 parts per billion of ozone.

The San Joaquin Valley, an agricultural region in central California, suffers poor rural air quality. Mountains in that area restrict pollutants' movement. Smog fills the valley. In 1999, a coalition consisting of such groups as Medical Advocates for Healthy Air had focused on poor air quality, as global warming conditions heated the San Joaquin Valley. That alliance estimated that particulates caused thirteen hundred deaths annually in the valley. Citing provisions of the Clean Air Acts (1963-1990), the coalition legally pressured officials in the San Joaquin Valley Unified Air Pollution Control District to devise programs to protect rural air quality and seek attainment of federal standards.

The San Joaquin Valley Unified Air Pollution Control District monitors wineries' boilers, verifying that they do not discharge excess carbon and other pollutants while burning. Approximately 2.5 million dairy cattle in the valley contribute to smog by expelling gas containing volatile organic compounds created by microorganisms during digestion. These compounds convert into ozone in the atmosphere. The San Joaquin Valley Unified Air Pollution Control District's Rule 4570 requires dairies stocking one thousand or more cattle to comply with air quality regulations in order to secure permits.

Costs of Rural and Urban Air Quality Degradation by Motor Vehicles, 2000

Pollutant	*Impact*	*Rural Emissions ($)*	*Urban Emissions ($)*
Particulate matter	Mortality	12,695	21,558
Particulate matter	Nonfatal illness	3,683	6,232
Sulfur dioxide, nitrogen dioxide, carbon monoxide	Nonfatal illness	0	51
Ozone	Nonfatal illness	28	16
Total		16,406	27,857

Source: Federal Highway Administration, United States Department of Transportation.
*Costs of human illnesses, in millions of 1990 dollars. Costs of crop damage, reduced visibility, and other physical effects on the environment are not included.

Increased ozone associated with climate change harms tomato cultivation in the San Joaquin and Sacramento Valleys; tomatoes generate several hundred million dollars yearly for the region. Rural air pollution affects crop yields globally. Despite these damages, nonattainment of EPA standards often prevails. Exemptions allow commercial agriculturists to use machinery and diesel fuels that emit pollutants that are harmful to air quality and also intensify global warming. Livestock confinements produce methane, hydrogen sulfide, and other pollutants that contribute to climate change while lowering air quality.

Industries often select sparsely populated rural locations for their factories. Many rural residents represent lower socioeconomic classes and lack the influence and resources to prevent industrial intrusion. Factories generate heat that traps GHGs and smog above rural areas. Industrial particulates damage fields and forests. Commuters' vehicles, moving between rural and urban areas, worsen air quality in the countryside. The San Joaquin Valley Unified Air Pollution Control District utilizes the Indirect Source Rule to reduce rural development pollutants, charging fees for construction of subdivisions and buildings with substantial square footage. Officials invest those funds in alternative fuels and air quality and climate control projects.

Wildfires and domestic fires for cooking or waste removal add smoke and ozone to rural air. Fires set to clear rural land destroy carbon-absorbing plants. In 2007, as temperatures warmed, a combination of GHGs and air pollution referred to as the Asian Brown Cloud contributed to melting approximately forty-six thousand glaciers, causing flooding and depleting long-term water sources in rural areas. This pollution traveled to other continents. The California Air Resources Board and the National Aeronautics and Space Administration (NASA) deployed aircraft in 2008 for scientists to evaluate air pollution movement and how it affects the atmosphere and climate changes.

Elizabeth D. Schafer

- **Further Reading**

Chameides, William L., R. D. Saylor, and Ellis B. Cowling. "Ozone Pollution in the Rural United States and the New NAAQS." *Science* 276, no. 5314 (May 9, 1997): 916. Rural air pollution experts discuss the role federal regulations serve in shaping local efforts to improve rural air quality.

"Seeking Relief Where the Air Is Deemed the Dirtiest." *The New York Times*, August 12, 2007, A-17. Profiles Arvin, California, located in the San Joaquin Valley, which the EPA says is the most polluted U.S. town, explaining why pollution occurs and providing related health statistics.

Shrestha, Anil, and D. A. Grantz. "Ozone Impacts on Competition Between Tomato and Yellow Nutsedge: Above- and Below-Ground Effects." *Crop Science* 45, no. 4 (July/August, 2005): 1587-1595. Technical article that examines how rural air pollution detrimentally alters agricultural conditions, specifically in the San Joaquin Valley; discusses economic repercussions.

Tevis, Cheryl. "Rural Health: Health Ordinance Is Controversial Rx for Rural Counties." *Successful Farming* 100, no. 11 (November, 2002): 67. Describes legislation to protect rural air quality from agricultural pollutants and farmers' resistance to those regulations.

Wilson, Janet. "More Deaths in State Are Linked to Air Pollution." *Los Angeles Times*, May 22, 2008, p. B-3. States that approximately twenty-four thousand deaths related to particulates occur in California annually, noting efforts to control agricultural contaminants and other pollution sources.

See also: Agriculture and agricultural land; Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Air quality standards and measurement; California; Clean Air Acts, U.S.; Convention on Long-Range Transboundary Air Pollution.

Russian Federation

- **Category:** Nations and peoples
- **Key facts**

Population: 141,377,752 (July, 2007, estimate); population of former Soviet Union: 293,047,571 (July, 1991)

Area: 17,075,200 square kilometers; area of former Soviet Union: 22,402,200 square kilometers

Gross domestic product (GDP): $2.225 trillion (purchasing power parity, 2008 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 2,763 in 1990; 1,699 in 1999; 1,932 in 2005

Kyoto Protocol status: Ratified, 2004

• Historical and Political Context

Several major themes in Russia's history influence the nation's political, military, and economic actions to the present day. Among them are its geographic and cultural isolation from the rest of Europe and repeated invasions from both Europe and Asia. The hardships endured by Russians throughout their history have created a deep sense of tragedy that is readily apparent in Russian literature and music and that has led to a pervasive political culture of suspicion against external and internal threats.

During the nineteenth century, Russia alternated between periods of reform and repression, as some rulers (czars) attempted to enact long-overdue reforms and others resorted to repression to control the mounting pressures for change. Following Russia's catastrophic losses during World War I (1914-1918), a revolution deposed the last czar, only to be followed by the overthrow of the new government during the Bolshevik Revolution of October, 1917. The Bolsheviks (from the Russian word *bolshe*, meaning "more") were so called because they became the majority faction of the Marxist Russian Social Democratic Labor Party. The system of government imposed by the Bolsheviks, called communism, was an attempt to implement the economic theories of Karl Marx. Under communism, the state owned and ran all businesses. The former Russian Empire was renamed the Union of Soviet Socialist Republics (or Soviet Union).

In theory, communism was supposed to act on behalf of the people. In practice, it was inefficient and repressive. The worst repression came under the rule of Joseph Stalin, from 1922 to 1953. Stalin's attempt rapidly to industrialize the Soviet Union resulted in famines in which millions died, and in the 1930's he launched a vast campaign of terror, called the Great Purge, during which millions of alleged enemies of the state were killed or exiled to prison camps. During World War II (1939-1945), the armies of Nazi Germany drove deep into Russia before being driven out, and more than 20 million Russians died.

After World War II, the Soviet Union succeeded in imposing communist governments in much of Eastern Europe and emerged as the main geopolitical rival of the United States and its allies. The rivalry was expressed in a long period of tension called the Cold War (1947-1991), which saw no direct warfare but many "proxy wars" in which the United States and Soviet Union supported opposing sides. After Stalin's death in 1953, the Soviet Union moderated its internal repression somewhat, although it remained highly authoritarian, and it advanced rapidly in military and space technology. Having acquired nuclear weapons by 1949, the Soviets launched the first artificial satellite in 1957 and the first human in space in 1961. By the late 1980's, Soviet leaders, aware of growing problems in the Soviet system, began inaugurating reforms, but the reforms failed to prevent the dissolution of the Soviet Union in 1991. Roughly one-quarter of the area of the Soviet Union and half of its population—former satellite states, or soviets—seceded from Russia to form fourteen independent countries.

• Impact of Russian Policies on Climate Change

Under communism, many of the important themes of Russian history reasserted themselves. The cult of suspicion that long pervaded Russian thinking produced a vast secret police and prison camp system, tight controls on dissent and access to information, and tight controls on outside access. The Soviet Union vigorously disseminated propaganda, displaying its greatest successes in an effort to persuade others of the superiority of its system, while simultaneously making it difficult or impossible to learn about failures. Furthermore, the Soviet Union focused its efforts on heavy industry, military power, and spectacular achievements in technology, to the detriment of the consumer sector and the environment.

In one respect, the Soviet Union was a victim of its own success. It succeeded in portraying itself as far more militarily powerful than it actually was,

and the resulting arms race with the United States was a principal factor in finally bankrupting the Soviet Union. The Soviet Union also succeeded in portraying itself as having far better social services and concern for the environment than it really did, and the limited access to much of the Soviet Union made it difficult for outsiders to learn the real extent of the nation's environmental disasters. The secret police system stifled even constructive dissent, so foreigners and Russians alike remained uninformed about even grave environmental problems. The reality was that in remote industrial areas of the Soviet Union there were appalling toxic chemical accidents, oil spills, and pollution.

Two environmental disasters are emblematic of the environmental problems Russia has inherited from the former Soviet Union. The 1986 disaster at the Chernobyl Nuclear Power Plant (located in the present Ukraine) was the worst nuclear reactor accident in history. The cause of the Chernobyl disaster has been attributed both to operator errors and to poor reactor design, but it is clear from all accounts that the accident was the result of conducting a crucial test when only a skeleton crew was on duty, that many of the workers were inexperienced and familiar only with conventional power plants, that monitoring devices did not adequately reflect the developing crisis, and that neither the reactor crew nor first responders were aware of the radiation danger (and many died as a result). The meltdown of the Chernobyl nuclear reactor released radioactive fallout into the atmosphere that eventually extended across the western Soviet Union, Europe, and eastern North America; more than 300,000 people had to be evacuated and resettled, and parts of Ukraine, Belarus, and Russia were severely contaminated.

The drying up of the Aral Sea (actually a large lake shared by present Kazakhstan and Uzbekistan) has been called the greatest environmental disaster of modern times. Because of water diversion for agriculture, the lake shrank in area by three quarters between 1960 and 2008. A plan to divert water from Siberia to the Aral Sea was abandoned in the 1980's but may be revived in the future.

Both the Chernobyl and the Aral Sea disasters typify the Soviet-era tendency to ignore future risks and environmental dangers in favor of immediate practical results, coupled with poor planning and lack of accountability to the society. Although Russia reformed many features of its government and economy after the dissolution of the Soviet Union, many of its regulatory agencies remained inefficient or corrupt. In such an environment, there are many opportunities to ignore greenhouse gas (GHG) emissions standards or divert funds meant for modernization.

• Russia as a GHG Emitter

According to the United Nations Environment Programme, in 1990 Russia emitted 2.763 billion metric tons of GHGs measured in carbon dioxide (CO_2) equivalent, the amount of CO_2 that would have the same effect as the gas in question. (For example, 1 metric ton of methane is measured as about 20 metric tons of CO_2 equivalent.) These 1990 emissions account for about one-sixth of total global GHG emissions for 1990, the year before the Soviet Union dissolved. By 1999, thanks to Russia's economic collapse and the shutdown of many industries, emissions fell to 1.699 billion metric tons of CO_2 equivalent. By 2005, Russia's emissions had risen to 1.932 billion metric tons of CO_2 equivalent, still 28.7 percent below their 1990 levels.

In 2004, Russia ratified the Kyoto Protocol. Thanks to its economic decline, Russia was already below its Kyoto emissions target. The Kyoto Protocol called for a 5 percent reduction in GHG emissions from 1990 levels by 2008, but Russia's emissions in 2005 were 28.7 percent below 1990 levels. As analyst John Carey pointed out, Russia's low emissions were a "valuable commodity" that it could trade under emissions-trading rules. The trading is advantageous to other European nations, because it is cheaper for them to buy emissions credits from Russia than to remodel their own industries. Russia's ratification pushed the protocol over the threshold for entry into legal force. The ratification was opposed by the United States, which was left as the only leading industrial nation not to have ratified the protocol.

Russia is also one of the world's largest petroleum producers, fourth in the world after Saudi Arabia, Kuwait, and Iraq, with an estimated 70 to 130 billion barrels of proven oil reserves and 47 trillion cubic meters of natural gas. Sale of petroleum and natural gas can furnish Russia with much-needed funds for modernization. More than half of Russia's own energy comes from natural gas. By selling its petroleum and natural gas abroad, Russia effectively exports its emissions while receiving additional money for emissions credits. As Russia recovers economically, its own domestic emissions are certain to increase.

Russia is among the world's largest producers of oil. This pumping station is one of many driving the nation's Eastern Siberia-Pacific Ocean oil pipeline. (Kolbasov Alexander/ITAR-TASS/Landov)

• Summary and Foresight

For more than a decade following the collapse of the Soviet Union, Russia struggled to maintain its stability and economic survival. By 2008, Russia had begun to recover and began rebuilding militarily and asserting its interests more vigorously. For example, it resumed its practice of long-range flights over neutral waters and held joint military exercises with other nations, including China. In 2005, Russian president Vladimir Putin said, "the demise of the Soviet Union was the greatest geopolitical catastrophe of the century," a clear sign of Russia's hope to regain its global influence.

Despite its problems, Russia in the early twenty-first century was a far more open and free society than the Soviet Union. However, Russia continued to suffer the Soviet legacy of inefficient production, widespread corruption, and poorly designed and outdated equipment. Although Russia's economic decline made it easy to meet its Kyoto obligations, in order to improve the quality of life of its people, Russia will have to increase its industrial output, and to do that it will need to modernize its antiquated industries. In turn, the nation's GHG emissions will inevitably increase. The challenge facing Russia in the first half of the twenty-first century is to modernize and increase output while simultaneously holding emissions below the Kyoto limits.

A major obstacle facing Russia in rebuilding its economy is widespread corruption and organized crime. According to many accounts, a substantial amount of the cost of any business venture is bribes to the bureaucrats responsible for approving the project. Organized crime existed under communism as a widespread black market, and, after the collapse of the Soviet Union, organized crime quickly gained control of many sectors of the Russian economy. Numerous journalists and business leaders who threatened to expose corruption or refused to pay bribes to organized crime gangs have been assassinated. Russian organized crime has also emerged as a world leader in cybercrime, such as online identity theft and distribution of computer malware.

Steven I. Dutch

• Further Reading

Bernstein, Jonas. "Researchers Study the 'Nature and Structure' of Russian Corruption." *Eurasia Daily Monitor* 5, no. 26 (February 11, 2008). The ability of Russians to speak bluntly about corruption stands in sharp contrast to the secrecy of Soviet days, but this article makes it clear how serious the problem is. Russia's ability to modernize its industry and improve its quality of life will be hobbled until corruption is controlled.

Carey, John. "Russia's Path to Kyoto." *BusinessWeek*, October 1, 2004. Discusses why Russia signed the Kyoto Protocol despite internal opposition. Its reasons were only partially environmental and included economic concessions from Europe.

Korppoo, Anna, Jacqueline Karas, and Michael Grubb, eds. *Russia and the Kyoto Protocol: Opportunities and Challenges*. London: Chatham House, 2006. Discusses Russia's supply of surplus emissions credits to assist other countries' compliance in the light of Russia's economic ambitions and developments in the energy sector.

Lecocq, Franck, and Zmarak Shalizi. *Will the Kyoto Protocol Affect Growth in Russia?* Washington, D.C.: World Bank, 2004. Addresses the costs and benefits of ratification of the Kyoto Protocol by Russia, concluding that even if Russia experiences very high economic growth, the country will still benefit from a net surplus of emissions allowances and thus will not see its growth adversely affected by its Kyoto target.

Moe, Arild, and Kristian Tangen. *The Kyoto Mechanisms and Russian Climate Politics*. London: Royal Institute of International Affairs, Energy and Environment Programme, 2000. Discusses Russian climate policy, particularly the natural gas sector and its potentially powerful combination with the Kyoto mechanisms.

Pearce, Fred. "Russia Reviving Massive River Diversion Plan." *New Scientist*, February 9, 2004. An account of the dependence of central Asian countries on cotton, a crop requiring huge amounts of water, and a history of the Siberian diversion proposal, with map.

See also: Kyoto Protocol; Nuclear winter; Siberian river diversion proposal; United Nations Framework Convention on Climate Change.

Sahara Desert

• **Categories:** Environmentalism, conservation, and ecosystems; geology and geography

• **Definition**

The Sahara Desert is the world's largest warm desert region and covers an area of approximately 9 million square kilometers, from the Atlantic coast of Africa to the Red Sea and from the Mediterranean Sea to the Niger River and the margins of the Ethiopian highlands. Most of the Sahara Desert experiences an arid or hyperarid climate, with scant precipitation. Rainfall is mainly from winter cyclonic storms on its northern margins, whereas the southern Sahara receives summer monsoonal rainfall.

• **Significance for Climate Change**

The history of climate change and variability in the Sahara is a clear indication of the sensitivity of a major desert region to climate change on all timescales. Changes in Saharan climates also affected global biophysical systems via variations in the flux of windblown dust, for which the Sahara is the major global source. The major past climate changes in the Sahara Desert were the result of cyclic changes in the Earth's orbit and are therefore not good analogues for future climates in the region, although some authors have suggested that the early-to-mid Holocene humid period may be an appropriate model for the response of the Sahara region to future climate change and global warming.

Information on the history of climate in the Sahara comes from deposits of lake basins, fossil rivers, springs, and sand dunes, supplemented by the record of marine sediments offshore of the western Sahara. Desert conditions appear to have prevailed in the Sahara for at least 7 million years, evidenced by pollen in ocean cores and sand dune deposits in Mali dating back that far, but these conditions were interrupted on many occasions by periods of increased rainfall.

The present extent of the Sahara Desert dates to a period lasting from six thousand to four thousand years ago, when the region was desiccated following an interval of much increased rainfall that lasted for several thousand years—the African Humid Period. Reconstructions of past environments from the region show that savanna vegetation covered most of the region in the early-to-mid Holocene, with perennial or intermittent streams occupying now dry wadis and large lakes in topographic basins, such as the Bodelé Depression. Human and animal populations greatly increased at this time. These lakes gradually dried out starting about six thousand years ago, resulting in increased dust flux. Increased rainfall throughout the Sahara was the result of the insolation maximum in Northern Hemisphere low latitudes caused by cyclical changes in Earth's orbit. This phenomenon promoted a much stronger West African monsoon circulation. The African Humid Period in the Sahara was, however, not uniformly wetter: A significant dry spell occurred around eight thousand years ago.

A nomad and his camel survey the Sahara Desert. (©iStockphoto/Graeme Purdy)

Prior to the Last Glacial Maximum (LGM), the northern Sahara experienced increased and more effective precipitation from winter storms, giving rise to groundwater recharge in the period from 45,000 to 23,500 years ago. Studies of noble gases in groundwater indicate temperatures were 2°-3° Celsius lower at that time than they are today in the northern parts of Sahara. They were at least 5°-6° Celsius lower in the southern Sahara. Other periods of wetter climate in the Sahara are poorly dated but appear to have occurred during several interglacial periods.

At the time of the LGM, the Sahara experienced intense aridity and sand dune formation that extended to areas far to the south of the modern limits of the Sahara, including Mauritania, Mali, and Niger, where linear dunes formed between twenty-five thousand and twelve thousand years ago. Dust flux to ocean sediments also increased at this time. Glacial age aridity in the Sahara was accompanied by an intensified trade wind circulation and the virtual absence of monsoon circulations.

Analysis of climatic data and historical records show the sensitivity of the southern Sahara and its margins to climate variability, with major droughts occurring at regular intervals. In recent decades, such climate variability has been linked to Atlantic Ocean surface temperatures. Warmer waters off Africa result in convection over the ocean rather than the land and reduced monsoon rainfall in a wide area from Senegal to Ethiopia.

Global climate models differ in their predictions of the direction and magnitude of future change in the Sahara, as in many other arid regions, in large part because prediction of precipitation in global climate models is less reliable than are estimates of future temperatures. In the Sahara, there is support in many climate model predictions for increased rainfall in southern and southeastern areas (including the Sahel) but strong drying in the northern and western areas. Some models, however, suggest that strong drying will occur throughout the region. The differences between model predictions for the Sahara show the complexity of forcing factors for this region, as well as the possible influence of feedbacks between land surface conditions and the atmosphere, which may affect rainfall total, effectiveness, and spatial distribution.

Nicholas Lancaster

- **Further Reading**

Brooks, N., et al. "The Climate-Environment-Society Nexus in the Sahara from Prehistoric Times to the Present Day." *Journal of North African Studies* 10, nos. 3/4 (2005): 253-292. Reviews the climatic history of the Sahara, with an emphasis on its effects on human populations.

Hoelzmann, P., et al. "Palaeoenvironmental Changes in the Arid and Sub Arid Belt (Sahara-Sahel-Arabian Peninsula), from 150 Kyr to Present." In *Past Climate Variability through Europe and Africa*, edited by R. W. Battarbee, F. Gasse, and C. E. Stickley. Dordrecht, the Netherlands: Springer, 2004. Thorough review of the evidence for late Quaternary climate change in the region.

Kröpelin, S., et al. "Climate-Driven Ecosystem Succession in the Sahara: The Past Six Thousand Years." *Science* 320, no. 5877 (May 9, 2008): 765-768. Reexamination of the desiccation of the Sahara, with many new ideas.

See also: Climate models and modeling; Climate prediction and projection; Climate reconstruction; Desertification; Deserts; Last Glacial Maximum; Sahel drought; United Nations Convention to Combat Desertification.

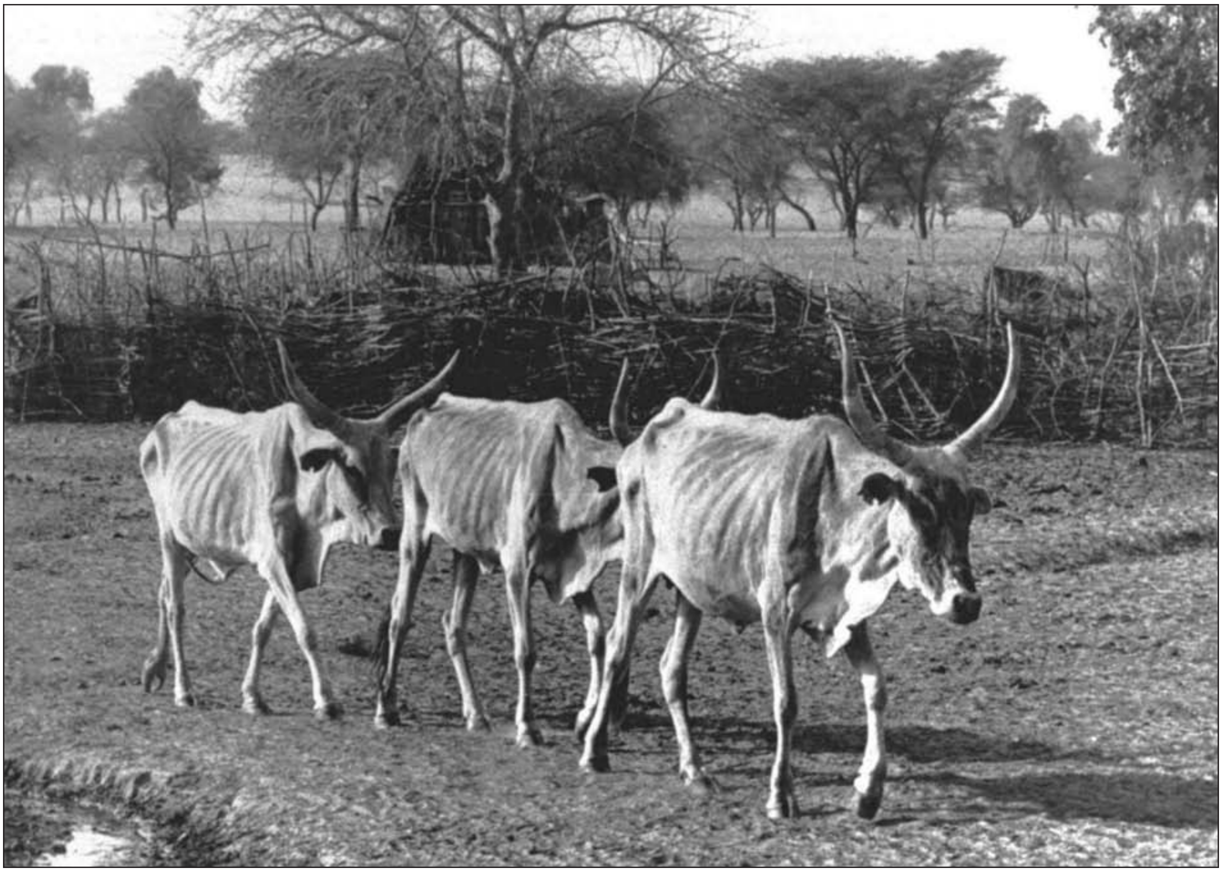
Sahel drought

- **Category:** Meteorology and atmospheric sciences

- **Definition**

The Sahel (meaning "shore" or "edge" in Arabic) is the region in Africa between the Sahara Desert and the savanna and stretches from the Atlantic Ocean to the Red Sea and Indian Ocean. The area covers all or part of twenty-three countries, the majority of which are in West Africa. Sahel in West Africa is also a geopolitical group made up of nine countries.

The Sahel experienced droughts in 1968, 1973, 1983, 1985, and the late 1980's and 1990's that brought untold hardships to several millions inhab-



Emaciated cattle wander through the drought-ridden Sahel district of Senegal. (AP/Wide World Photos)

iting the region. The memory of these droughts still commands the world's attention, as their effects contribute to human suffering and ecological degradation in the region. During this period, more than one million people died of starvation because of crop failures resulting from low rainfall. Goats and other livestock ate everything in sight, including clothes spread outside to dry.

Initially, the droughts of the 1970's and 1980's were blamed on anthropogenic sources, but these do not appear to have been the cause, as the sharp decline in annual precipitation in the Sahel correlates with the difference in temperatures between northern and southern Atlantic Oceans and the Indian Ocean. The slight warming of these oceans may have led to the formation of a deep convective current that is believed to weaken the convergence of the air mass systems that produce precipitation in the Sahel region. The warming of the Indian Ocean is thought to have minimal effect on the Sahel droughts.

On a geologic timescale, the Sahel has experienced wet seasons, as evidenced by buried river valleys seen in radar images of the region and by animal drawings (petroglyphs) on the desert rocks. In addition, geologic records show that the region does experience droughts from time to time. The presence of sand dunes in Lake Chad suggests that the lake was once dry. Multidecadel- to centennial-scale droughts have occurred in the Sahel, and the region's climate has changed over several millennia as it has experienced desertification.

• Significance for Climate Change

Desertification is the process by which marginal lands, such as in semiarid regions, lose natural vegetation cover; it can be anthropogenic or natural. Desertification in turn affects climate. Desertification is widespread in the Sahel, and it appears to be moving southward.

Few surface waters exist in the Sahel; the Niger River and Lake Chad are the two dominant surface-water bodies in the region. The vast majority of inhabitants are pastoral farmers. Overgrazing occurs in the region, especially during drought. Overgrazing leads to the decimation of vegetation, and this leads to decrease of the land surface albedo—that is, the surface absorbs more incident radiation from the Sun, increasing the temperature at the land surface. This is one of the reasons semiarid and arid regions are hot. In addition, because of the felling of trees for fuel and overgrazing, the land surface becomes exposed to severe wind and water erosion. The wind removes the topsoil as dust, typical of the Sahara Desert to the north. Most African dust comes from the semiarid Sahel region south of the Sahara. As rainfall decreases, more dust is produced. The presence of the dust may reduce daytime temperature by 3° Celsius and increase nighttime temperature by the same amount. Currently, there is an upswing in rainfall.

Drought and conflict are of concern in the Sahel. The increase in population of both humans and animals places a greater demand on resources that may further exacerbate the drought conditions in the region. There is no consensus as to whether the Sahel will experience increased rainfall due to global warming. Although conflicting models make it difficult to predict the outcome of climate change in the area, a higher temperature would lead to higher rates of water evaporation and a greater demand for water.

The pastoral system, land tenure, politics, and climate change would lead to change in land use and land cover (LU/LC). Animals move southward during drought, denuding the land of vegetation. Lack of vegetation would result in severe soil erosion from flash floods and wind erosion, as observed around Lake Chad. The change in LU/LC affects the climate of the region, including the production of dust, and contributes to a positive feedback loop leading to greater desertification and climate change. Although human activities adversely affect the Sahel, the people of the region plant trees and drought-tolerant crops, and they collaborate internationally to minimize adverse effects and to adapt to climate-related changes in the Sahel.

Solomon A. Isiorho

• **Further Reading**

Benjaminsen, Tor A., and Christian Lund, eds. *Politics, Properties, and Production in the West African Sahel: Understanding Natural Resources Management.* Uppsala, Sweden: Nordic Institute of African Studies, 2001. Uses case studies to examine the relationship between natural resources management with land tenure and the politics of the region.

Dietz, A. J., Ruben Ruerd, and A. Verhagen, eds. *The Impact of Climate Change on Drylands: With a Focus on West Africa.* Boston: Kluwer Academic, 2004. Examines the preparedness and adaptation of the people to global warming and the lessons learned during the last thirty years of the twentieth century.

Nicholson, Sharon. "Land Surface Processes and Sahel Climate." *Reviews of Geophysics* 38, no. 1 (February, 2000): 117-139. Good technical review of work done on the Sahel climate.

Salgado, Sebastiao. *Sahel: The End of the Road.* Berkeley: University of California Press, 2004. Illustrated with black-and-white pictures of suffering peoples of the Sahel region.

See also: Climate models and modeling; Climate prediction and projection; Climate reconstruction; Desertification; Deserts; Drought; Dust storms; Last Glacial Maximum; Sahara Desert; United Nations Convention to Combat Desertification.

Saltwater intrusion

• **Category:** Water resources

• **Definition**

Under normal conditions, freshwater prevents salt water from encroaching on coastal aquifers. Along coastlines, freshwater and salt water are in equilibrium, such that less dense freshwater floats on more dense salt water. The interface between freshwater and salt water is maintained near the coast and below land surface. Saltwater intrusion happens when seawater flows into coastal freshwater as a result of changes in the elevation of groundwater near the coasts. Hydraulically connected groundwater and seawater may change their elevation gradient direction as a result of changes in water storage due to pumping and droughts or due to sea-level rise caused by melting ice. These changes create a diffusive zone, or a zone of dispersion—a brackish region of transition between freshwater and salt water. A hydrostatic equilibrium is achieved by the weight of a unit column of freshwater extending from the water table to the saltwater-freshwater interface stabilized by a unit column of salt water extending from sea level to the same point on the interface, which is roughly 40 meters of freshwater below sea level for every meter of groundwater.

Freshwater resources in coastal regions are threatened by salinization. Salinization is the increase of chloride ion concentrations in freshwater aquifers along coastlines and in some instances inland. Saltwater intrusion, caused by both natural and human activities, occurs by lateral inflow from coastal waters and vertical influx to discharging wells. Groundwater pumping can reduce freshwater flow toward coastal discharge areas, causing salt water to be drawn toward the freshwater zones of the aquifer. Saltwater intrusion decreases freshwater storage in the aquifers, which can result in the abandonment of supply wells.

Once saltwater intrusion has occurred, it is almost impossible to reverse, making it a significant threat to freshwater resources. Many coastal areas are arid, increasing the magnitude of the threat. Indeed, in many such areas, including California, the Middle East, and the Mediterranean, the future sustainability of groundwater resources is at risk from overuse and from contamination, increasing the urgency of managing and protecting water resources in a sustainable manner.

A numerical ranking system known as the GALDIT index exists to assess the potential for saltwater intrusion. Developed by the EU-India INCO-DEV COASTIN project, this index rates coastal aquifers' vulnerability to saltwater intrusion based on a combination of factors, including aquifer hydraulic conductivity, depth to groundwater, level above the sea, distance from the shore, impact of existing seawater intrusions in the area, and thickness of the aquifer. The index also considers the stability of groundwater in the vicinity, categorizing it as unconfined, confined, or leaky.

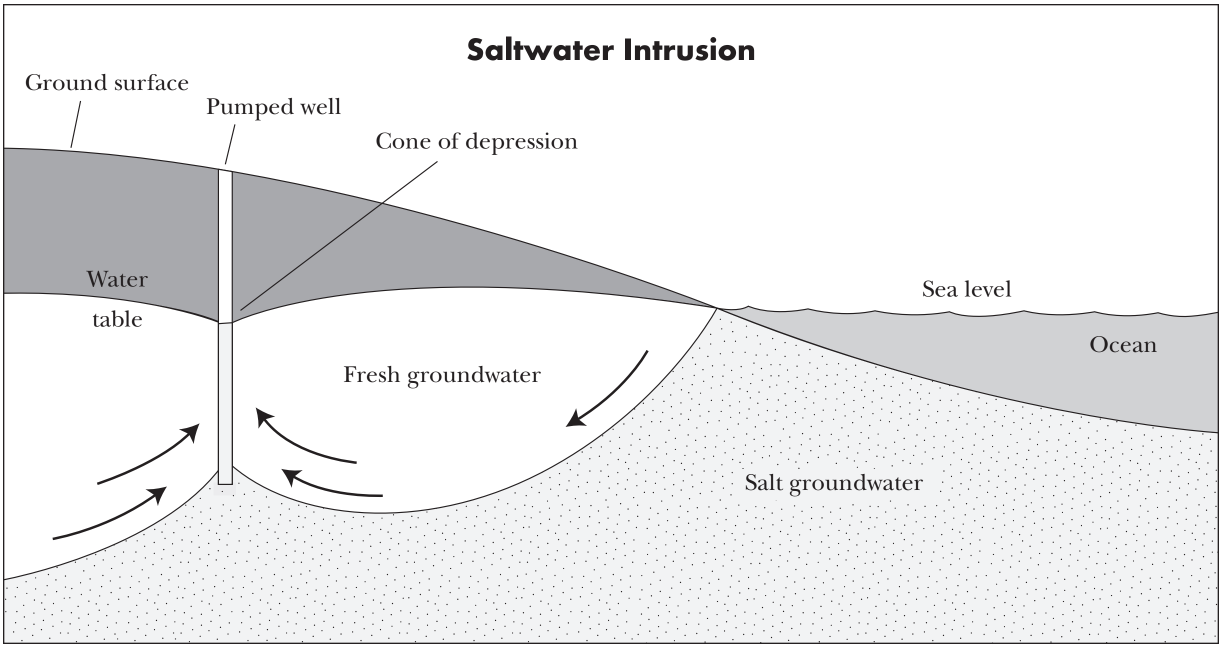
• Significance for Climate Change

Saltwater intrusion can be related to climate change and global warming. Increasing temperatures at the Earth's surface cause droughts, higher evaporation, increases in surface runoff, decreases in precipitation and infiltration, and ice melt. These changes affect groundwater storage and therefore groundwater elevation and gradient. Natural causes of saltwater intrusion include storm surges caused by hurricanes and other tropical systems and rises in sea level. The rise of sea levels pushes seawater further inland, threatening freshwater aquifers.

Anthropogenic saltwater intrusion can result from dredging canals in coastal zones that allow salt water to migrate farther inland. Louisiana, moreover, has experienced this type of saltwater intrusion as a result of overpumping the freshwater aquifer for potable water and irrigation needs, which reduces the head difference at the saltwater-freshwater interface and induces the flow of salt water into the freshwater system when that system is not capable of recharging completely, such as during drought conditions.

Freshwater systems benefit from mechanisms capable of restoring equilibrium after potentially damaging events. After Hurricanes Katrina and Rita, for example, salinity that had been introduced into the freshwater marshes was naturally removed by tidal flushing before substantial damage was done. Damage to freshwater systems was observed in areas not affected by tidal and precipitation flushing of salt water from the water table.

Coastal communities are taking into account the impact of rising sea level on water resources. The Florida Aquifer is endangered by saltwater intrusion, motivating Floridians to reduce groundwater pumping and find alternative water resources. This saltwater intrusion cannot be stopped, but the rate of its progression can be slowed down.



In southwest Florida, the Southwest Florida Water Management District established the Southern Water Use Caution Area to mitigate saltwater intrusion, among other hazards due to overpumping the Florida Aquifer. Another form of mitigation used in California is to use treated wastewater to recharge the aquifer.

Since 1850, the Los Angeles area has used an injection-well barrier to push freshwater into the aquifer near the coast. The State of New Jersey constructed sea walls, bulkheads, and jetties to protect the freshwater aquifer from the rising sea level. Overall, in coastal communities exposed to storm surge, a sustainability plan for saltwater intrusion proposes to construct coastal barriers slowing storm surge to prevent the loss of wetland habitat. This project requires coordination by state and federal agencies, such as the United States Geological Survey, the Environmental Protection Agency, and the Army Corps of Engineers.

The sustainability of freshwater resources is associated with the sustainability of life in coastal communities. Sustainability plans to protect these resources are costly, but if such plans are not executed, freshwater may become unavailable in many heavily populated coastal areas. The threat of global and coastal climate change simply increases the vulnerability of these freshwater resources.

Ewa M. Burchard

• Further Reading

Chachadi, A. G., and J. P. Lobo-Ferreira. "Assessing Aquifer Vulnerability to Seawater Intrusion Using GALDIT Method: Part 1—Application to the Portuguese Aquifer of Monte Gordo." *Coastal Policy Research Newsletter* 4 (March, 2001): 7-9.

_______. "Assessing Aquifer Vulnerability to Seawater Intrusion Using GALDIT Method: Part 2." In *Proceedings of the Fourth Inter-Celtic Colloquium on Hydrology and Management of Water Resources.* Guimarães, Portugal: Universidade do Minho, 2005. These two documents evaluate the vulnerability of coastal aquifers to saltwater intrusion, the most important parameters controlling saltwater intrusion, and the major methods for assessing risk.

Le Treut, H., et al. "Historical Overview of Climate Change." In *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Susan Solomon et al. New York: Cambridge University Press,

2007. Presents long-term research on climate change and summarizes scientific discoveries revealing the complexities of Earth's climate.

McNew, Elizabeth R., and Sara Arav. "Surface Geophysical Surveys of the Freshwater-Saltwater Interface in a Coastal Area of Long Island, New York." *Ground Water* 33, no. 4 (1995): 615-626. Describes geophysical techniques used to assess freshwater-saltwater interfaces and the thickness of freshwater lenses.

Yuqun Xue, et al. "A Study on Sea-Water Intrusion in the Coastal Area of Laizhou Bay, China: Distribution of Sea-Water Intrusion and Its Hydrochemical Characteristics." *Ground Water* 31, no. 4 (1993): 532-537. Discusses saltwater intrusion in Chinese coastal aquifers; includes an extensive compilation of data regarding groundwater elevation and chemical analyses.

See also: Desalination of seawater; Freshwater; Groundwater; Water quality; Water resources, global; Water resources, North American.

Saudi Arabia

- **Category:** Nations and peoples
- **Key facts**

Population: 28,146,656 (July, 2008; includes 5,576,076 non-nationals)

Area: 2,149,690 square kilometers

Gross domestic product (GDP): $582.8 billion (purchasing power parity, 2008 estimate)

Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 341 in 2000

Kyoto Protocol status: Ratified, 2005

• Historical and Political Context

Saudi Arabia is located in the Middle East and borders the Persian Gulf, the Red Sea, Yemen, the United Arab Emirates, Iraq, Qatar, Oman, Jordan, and Kuwait. Riyadh is its capital city, with a population of 4,193,000. Saudi Arabia is a monarchy led by King Abdullah, who has been head of state since 2005, and an appointed 150-member consultative council. Saudi Arabia is the historical home of Islam, its official religion, and Arabic is its official language. Like most of its Gulf State neighbors, Saudi Arabia is a founding member of the Organization of Petroleum Exporting Countries (OPEC) and is the world's largest producer and exporter of total petroleum liquids. It was the world's largest producer of crude oil in 2008, producing 3.9 million barrels per day.

As of 2009, Saudi Arabia held the world's greatest proven oil reserves—264.2 billion barrel—and the fourth greatest proven natural gas reserves—7,306 cubic kilometers. With approximately one-fifth of the global proven oil reserves and minimal production costs, Saudi Arabia is expected to remain the world's largest oil exporter over the short and long term. As a result of its role in energy production, Saudi Arabia, with 0.4 percent of the world's population, accounts for 1.1 percent of global greenhouse gas (GHG) emissions, the highest level of GHGs on average among the oil-producing Gulf States. Since World War II, Saudi Arabia has been closely aligned with the United States as a major trading partner. It is the second-largest exporter of oil to the United States after Canada.

• Impact of Saudi Policies on Climate Change

On January 31, 2005, Saudi Arabia ratified the Kyoto Protocol and was classified as a developing, non-Annex I nation, meaning that it was not required by the protocol to reduce its GHG emissions. Because of its relatively high GHG emissions, however, Saudi Arabia expressed interest in the protocol's clean development mechanism (CDM), which allows industrialized, Annex I countries to satisfy their Kyoto commitments in part by funding environmentally friendly development projects in non-Annex I countries.

In 2006, Saudi Oil Minister Ali al-Nuaimi hosted an international CDM conference in Riyadh, where attendees reviewed investment opportunities in Saudi Arabia and other oil-rich Gulf States for new CDM projects, including some that employed high-technology carbon capture-and-storage technology. In such technology, carbon dioxide (CO_2) is removed from petroleum processing plants and sequestered in mature oil fields. CDM programs have assumed greater significance for the Gulf States that fear their oil exports might be restricted should the United Nations raise environmental standards in 2012, when the Kyoto Protocol is to be replaced. Industrial diversification is an alternative to CDM programs.

The World Trade Organization (WTO) has encouraged Saudi Arabia to lessen its economic dependence on its oil and petroleum industries by diversifying its industrial sector so as to include more environmentally friendly endeavors. Paradoxically, since 2000, the wealth garnered from the GHG-emitting energy industry has driven such diversification, enabling Saudi Arabia and other Gulf States to achieve significant economic development both with their own domestic capital and through some 750 American business ventures. This activity has resulted in a diverse range of new business opportunities for the Saudi government and employment opportunities for the country's workforce. As part of an effort to attract foreign investment and diversify the economy, Saudi Arabia has substantially increased spending on job training and education, infrastructure development, and salaries for government employees. Saudi Arabia acceded to the wishes of the WTO in 2005 and announced plans to establish six "economic cities" in different regions of the country to promote development and diversification.

• Saudi Arabia as a GHG Emitter

According to the United Nations Development Programme (UNDP), if all the countries in the world were to emit CO_2 at levels comparable to that of Saudi Arabia, the world would exceed its sustainable carbon budget by approximately 511 percent. Reuters in 2008 ranked Saudi Arabia twenty-third out of the twenty-five highest GHG emitters in the world. The top-twenty-five GHG emitters are a diverse group comprising thirteen Annex I nations, eleven non-Annex I nations, and one regional party, the European Union.

One unifying metric among the top GHG emitters is the significant association between GHG emissions, population size, and gross domestic product (GDP) ranking; most of the top GHG emitters have either large populations, large GDPs, or both: Seventeen of the top twenty-five emitters are among the twenty-five most populated countries, and twenty-two of the top twenty-five emitters have the largest economies, some because of large populations and others because of high wealth per capita. For example, from 1990-2002, the growth rate of CO_2 emissions for affluent oil exporters Indonesia, Iran, and Saudi Arabia was 97 percent, 93 percent, and 91 percent, respectively.

Saudi Arabia's non-CO_2 emissions grew by 50 percent from 1990-2000, the highest percentage among the top-twenty-five GHG emitters. Population growth in Saudi Arabia was 46 percent from 1990-2002, the highest percentage of the top-twenty-five GHG emitters, three times greater than that of China, and almost twice that of Iran. Energy intensity (energy consumption per unit of GDP) increased in Saudi Arabia by 52 percent from 1990-2002, the highest percentage among the top-twenty-five GHG emitters.

As regards per capita ranking, while the OPEC Gulf States have high per capita GHG emissions, data show that of the top-twenty GHG emitters, generally, the highest emitters per capita were the Annex I countries (Australia, the United States, and Canada, ranked fifth, seventh, and eighth, respectively, with per capita GHG emissions of 25.6 metric tons, 24.3 metric tons, and 22.2 metric tons, respectively). Annex I countries' per capita emissions are approximately double those of the highest-

ranked developing country in the top twenty (South Korea, at 11.0 metric tons per capita), and they are six times that of China (3.9 metric tons per capita). Saudi Arabia was ranked fifteenth in per capita GHG emissions, producing 16.5 metric tons per person.

The population density of Saudi Arabia in 2007 was 11.3 persons per square kilometer, in a country a little more than one-fifth the size of the United States. Economic growth in the top GHG emitters is sometimes measured in terms of GDP per capita, and this measurement has been shown to bear a significant relationship to a country's GHG emissions. Usually, significant GDP growth per capita results from energy-intensive activities, which significantly increase GHG emissions. In 2008, the Saudi GDP was ranked twenty-third in the world by the International Monetary Fund (IMF); the Saudi petroleum sector accounted for roughly 45 percent of the nation's GDP, 80 percent of its budget revenues, and 90 percent of its export earnings. Some 40 percent of the GDP came from the private sector.

High oil prices through mid-2008 enhanced economic growth, government revenues, and Saudi ownership of foreign assets, enabling Saudi Arabia to pay down its domestic debt. In March, 2009, Saudi Arabia, along with other OPEC member nations, cut production of oil to support falling oil prices on the world market, and crude oil futures rose to $51.55 per barrel in New York. OPEC lowered Saudi Arabia's production quota for oil, although it was reported that the Saudi government privately promised to satisfy the energy needs of their export partners. However, liquid fuel demands in the United States are expected to increase by only one million barrels per day from 2007 to 2030, as domestic biofuels and other renewable energy sources, along with increasing domestic oil production, reduce U.S. dependence on the foreign oil market. As a result, the United States is projected to import less than 40 percent of liquid fuels it consumes in 2025. This decrease will likely decrease Saudi oil revenues, either directly by lowering volume of sales or indirectly by lowering prices.

• Summary and Foresight

At the April, 2009, Group of 20 (G-20) summit in London, French President Nicholas Sarkozy declared that global leaders were moving to create a new world order, less centered on U.S. and Anglo-Saxon models, with increased regulation of the global financial sector and a greater role for international institutions and emerging markets. In addition, the G-20 pledged to triple the resources of the IMF, enabling developing countries to more fully participate in the global economy; the United States and the European Community need the monetary and energy resources of rising powers such as Brazil, China, and Saudi Arabia to help restore the global economy and tackle the ongoing challenge of climate change.

While the United States remains the preeminent military and economic power in the world, its ability to manage its financial markets and banking system will be significant factors in overcoming the global economic and climate crises. Also important is how emerging nations such as Saudi Arabia, the only Arab country and OPEC member invited to the G-20 summit, present themselves to the world. Saudi Arabia's handling of its currency reserves, trade policies, and energy exports will influence global climate policy and affect the efficacy of that policy. Saudi energy policy and development will also affect the rights of indigenous populations, farmers, youth, and women, who, according to the U.N. Stockholm Declaration of 1972, enjoy a human right to a healthy environment.

When the U.N. Conference of the Parties to the Framework Convention on Climate Change (COP) meets in Copenhagen, Denmark, in December of 2009 to address climate change and to plan the treaty that will replace the Kyoto Protocol in 2012, Saudi Arabia will provide input as both a developing, non-Annex I country and a wealthy, OPEC-member oil exporter and a significant emitter of GHGs. At a pre-COP meeting in March, 2009, U.S. president Barack Obama called for an increase in the amount of corn-based ethanol for use in U.S. gasoline. An advisor to the Saudi oil minister, Mohammad al-Sabban, indicated that while his country does not support subsidies for biofuels, citing environmental and economical concerns, it would cooperate, demonstrating a willingness to consider alternative energy sources.

Al-Sabban also declared that Saudi Arabia would invest heavily in renewable, especially solar, energy and build a carbon-neutral city, stating that Saudi Arabia has abundant sunshine and land and is able to export solar power to its neighbors on a large scale. Saudi Arabia's aim is to diversify its economy and become environmentally friendly at the same time, but it needs the assistance of the industrialized countries, in the form of direct investment and transfer of technologies, to ease the burden of the new climate regimen likely to be set forth by the successor treaty to the Kyoto Protocol. Thus, the Saudi government, which controls the petroleum and crude oil sector, is encouraging increased growth of the private sector—especially in power generation, telecommunications, alternative energy, natural gas exploration, and production of petrochemicals—in order to lessen the domestic economy's dependence on oil exports and to increase employment and educational opportunities for the burgeoning Saudi population. Saudi unemployment is rampant, and the large youth population generally lacks the education and technical skills required by private-sector employers.

Cultural and economic change go hand in hand in Saudi Arabia. In 2009, Saudi king Abdullah appointed Nour Fayez as the first female cabinet minister of the country as part of major cabinet reorganization, producing a cabinet with a more liberal bent. Nour Fayez became the deputy minister for women's education, a milestone for a country where women gained the right to vote in 2004. In Saudi Arabia, women are 5 percent of the country's workforce, the lowest percentage worldwide. The appointment of Nour Fayez will not only empower Saudi women but will also enhance the recognition of the importance of women's contribution to the workforce and their role in Saudi development.

King Abdullah also appointed a moderate, Prince Faisal bin Abdullah bin Muhammad, to be minister of education. These recent events reflect some of the aspirations of the Green Party of Saudi Arabia (GPSA), a political organization established in 2001 in a semi-clandestine fashion, because political parties are officially banned in Saudi Arabia. Both Saudi citizens and expatriates are known members of GPSA, which fosters the values of the worldwide green movement and its aims to protect the evironment by supporting biodiversity, sustainability, and personal and global responsibility, while opposing the use of nuclear energy as harmful to the environment. In addition, the GSPA supports the creation of a constitutional monarchy that balances economic development with sustainability, along with promotion of environmentally friendly education, industry, and public policy, as well as gender equality in the political sector. The GPSA supports the Saudi government's efforts gradually to reform political and social life, but it does not advocate the violent overthrow of the kingdom's current institutions.

Cynthia F. Racer

• Further Reading

Agrawaler, S., and S. Frankhauser, eds. *Economic Aspects of Adapting to Climate Change: Costs and Policy Instruments.* Paris: Organization for Economic Cooperation and Development, 2008. Explains why efforts to reduce GHG emissions must parallel policies on adapting to the impacts of climate change.

Louer, L. *Transnational Shia Politics: Religious and Political Networks in the Gulf.* New York: Columbia University Press, 2008. Examines the Shiite populations of the Middle Eastern Gulf states, including Saudi Arabia, Iran, and Bahrain.

Ottaway, D. B. *The King's Messenger: Prince Bandar bin Sultan and America's Tangled Relationship with Saudi Arabia.* New York: Walker, 2008. Recounts Prince Bandar's tenure as the Saudi ambassador to the United States for over three decades.

Sagar, A. D. "Wealth, Responsibility, and Equity: Exploring an Allocation Framework for Global GHG Emissions." *Climatic Change* 45, nos. 3/4 (June, 2000): 511-527. Explores the framework derived from climate conventions and applied to OPEC nations.

See also: Desertification; Iran; Kyoto Protocol; Middle East; Security; United Nations Framework Convention on Climate Change.

Sauer, Carl
American geographer

Born: December 24, 1889; Warrenton, Missouri
Died: July 18, 1975; Berkeley, California

Sauer's "The Morphology of Landscape" was a seminal work in geography, establishing the idea of cultural landscapes. For this work, he is known as the founder of American cultural geography.

• Life
Carl Sauer was born in Warrenton, Missouri, on December 24, 1889. He received a bachelor's degree in 1908 from Central Wesleyan College, where his father was on the faculty. He then attended Northwestern University and in 1915 received a Ph.D. in geography from the University of Chicago. While he was attending graduate school, he served as a map editor for Rand McNally Publishers (1912-1913). Upon his graduation from the University of Chicago, he was hired by the University of Michigan as an instructor in the Geography Department.

By 1922, Sauer had become a full professor at the University of Michigan, but he chose to leave in 1923. At that time, he moved to the University of California, Berkeley, as a full professor and chair of the Department of Geography. In large part as a result of Sauer's efforts, the graduate program in geography at the University of California, Berkeley, came into being and became world renowned. Sauer remained at Berkeley until 1957, when he retired and was appointed professor emeritus. He worked closely with the Department of Geography at Berkeley as an emeritus professor until his death in 1975.

• Climate Work
The notion of a cultural landscape was developed by Sauer in 1925 in his paper "The Morphology of Landscape," which appeared in the *University of California Publications in Geography*. Cultural landscape quickly became a central concept in the field of geography. Today, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) defines cultural landscapes as specific geographical locations that in some unique ways represent the interactions of people and nature. When Sauer developed this concept in his 1925 article, he indicated that culture is a major force in determining the visible features of the planet within specific areas. He therefore was the first person who indicated that humankind (culture) and the environment have a mutual impact on each other.

Sauer indicated that the natural landscape is a medium upon which culture can act, resulting in the notion of cultural landscape. He indicated that while both culture and society develop

"Foreword to Historical Geography"

In an address given to the Association of American Geographers in 1940, excerpted below, Carl Sauer set out his ideas about the nature and function of a discipline of historical geography.

Every human landscape, every habitation, at any moment is an accumulation of practical experience and of what Pareto was pleased to call residues. The geographer cannot study houses and towns, fields and factories, as to their where and why without asking himself about their origins. He cannot treat the localization of activities without knowing the functioning of the culture, the process of living together of the group, and he cannot do this except by historical reconstruction. If the object is to define and understand human associations as areal growths, we must find out how they and their distributions (settlements) and their activities (land use) came to be what they are. Modes of living and winning a livelihood from their land involve knowing both the ways (culture traits) they discovered for themselves, and those they acquired from other groups. Such study of culture areas is historical geography. The quality of understanding sought is that of analysis of origins and processes. The all-inclusive objective is spatial differentiation of culture. Dealing with man and being genetic in its analysis, the subject is of necessity concerned with sequences in time.

out of their landscape, they also work together to shape that landscape. This notion of the cultural landscape forms the basis for the field of cultural geography. It is often discussed in relation to global warming. Over the past century, human interaction with the landscape (environment) of the planet has involved many changes in agricultural practices, as society has emerged from the family-run farm to much more technologically advanced farming communities. Old land-use practices have been pushed aside to make way for technology.

These changes in culture result in changes in the landscape. Technology, along with the demands and challenges of the modern world, may gradually cause loss of biodiversity. This use of technology along with a lack of concern for the land may be at least partly responsible for major changes in the climate, including the warming of ocean temperatures and the melting of glacial and polar ice. If people continue to expose their natural resources to the demands of advancing technology, they may accelerate the changes occurring within the environment, which in turn may produce potentially harmful situations for humankind. Should this continue to occur, climatic events such as tsunamis and increased global warming will become ever more problematic for human societies. While Sauer did not highlight these specific ways in which culture and the environment might mutually affect one another, his notion of the cultural landscape did indirectly predict and does account for these climate-related changes today.

Robin Kamienny Montvilo

• Further Reading

Harris, D. R. "The Farther Reaches of Human Time: Retrospect on Carl Sauer as Prehistorian." *The Geographical Review* 92, no. 4 (October, 2002): 526-544. Reviews Sauer's work in cultural geography, with a focus on the pros and cons of that work. Attempts to evaluate Sauer's contribution to planetary studies, as well as fallacies he may have perpetuated.

Rubinstein, J. M. *The Cultural Landscape: An Introduction to Human Geography*. Saddle River, N.J.: Prentice Hall, 2005. This college-level textbook looks at the relevance of the cultural landscape in terms of today's world. One of the important areas of focus is the impact of society on global warming, as well as the impact of global warming on society.

Sauer, Carl. "The Morphology of Landscape." *University of California Publications in Geography* 2, no. 2 (1925): 19-53. The landmark article in which Sauer introduced the idea of the cultural landscape, decisively shaping the field of geography and the social sciences generally.

Solot, M. "Carl Sauer and Cultural Evolution." *Annals of the Association of American Geographers* 76 (1986): 508-520. Explores Sauer's notion of cultural geography, emphasizing his model of cultural landscapes, while highlighting his rejection of environmental determinism. Focuses on the impact of cultural geography on the planet over a sixty-year period.

See also: Anthropogenic climate change; Environmental economics; Glacken, Clarence J.; Industrial ecology; Human behavior change; Malthus, Thomas Robert; Marsh, George Perkins; Schumacher, E. F.

Schumacher, E. F.

German English economist

Born: August 16, 1911; Bonn, Germany
Died: September 4, 1977; On a train en route to Zurich, Switzerland

Schumacher foresaw the problems that would be caused by societies that embraced the exploitation of resources for immediate gain without considering the long-term effects of such exploitation.

• Life

E. F. Schumacher was the third of five children born to Edith Zitelmann and Hermann Albert Schumacher, a professor of economics at Bonn and Berlin Universities. Schumacher matriculated from Ardnt Gymnasium and moved to New College, Oxford, and then to Columbia University, New York, to study economics and politics as a Rhodes Scholar

Solving the Problem of Production

In Small Is Beautiful, *his seminal work, Ernst Friedrich Schumacher begins by declaring that modern people have made a fundamental error: They believe that the "problem of production" has been solved and that any current micro problems are easily overcome coincidences. Schumacher argues that production is still an inherent problem for humanity, and he examines the consequences of overlooking this problem by erroneously declaring it solved.*

Modern man does not experience himself as a part of nature but as an outside force destined to dominate and conquer it. He even talks of a battle with nature, forgetting that, if he won the battle, he would find himself on the losing side. Until quite recently, the battle seemed to go well enough to give him the illusion of unlimited powers, but not so well as to bring the possibility of total victory into view. This has now come into view, and many people, albeit only a minority, are beginning to realise what this means for the continued existence of humanity.

The illusion of unlimited powers, nourished by astonishing scientific and technological achievements, has produced the concurrent illusion of having solved the problem of production. The latter illusion is based on the failure to distinguish between income and capital where this distinction matters most. Every economist and businessman is familiar with the distinction, and applies it conscientiously and with considerable subtlety to all economic affairs—except where it really matters; namely, the irreplaceable capital which man has not made, but simply found, and without which he can do nothing.

from 1930 to 1933. He was not comfortable with the Nazi government, and, after marrying Anna Maria (Muschi) Petersen on October 10, 1936, he and Muschi moved to London, where Schumacher took a job in a financial firm. The couple would have four children.

During World War II, Schumacher was interned as an enemy alien. An article that he wrote attracted the notice of John Maynard Keynes, who arranged for his release from internment. Soon afterward, Schumacher took a job at Oxford's Institute of Statistics. Toward the end of the war, the institute's work changed from war economics to planning a reconstruction and recovery program. Schumacher's advice greatly aided Great Britain's recovery after the war.

In 1946, Schumacher became a British citizen in order to become economic adviser to the Allied Control Commission in the British zone of western Germany. By 1950, he felt that his influence was declining. He returned to England to be the economic adviser to the National Coal Board. This position entailed less travel, so he and Muschi bought a home in Caterham, Surrey, where he lived until his death. He worked for the coal board for twenty years, although he did take some leaves of absence to travel to Burma and India. Muschi developed cancer and died at her family's home in Germany in 1960.

On January 29, 1962, Schumacher married Verena (Vreni) Rosenberger, a Swiss woman who had been hired originally as an au pair. She and Schumacher would have four children together. In 1971, Schumacher began to work full time in intermediate technology and resigned from the coal board. He also became a Roman Catholic. In 1973, he published his ground-breaking book, *Small Is Beautiful: Economics as if People Mattered.* It was a great success and led him to publish *A Guide for the Perplexed* (1977). He was in much demand as a speaker. While on a train in Switzerland, during a speaking tour, he had a fatal heart attack; he was buried at Caterham.

• Climate Work

Schumacher believed that if one accepts that there is a god who made humanity, then one's responsibility is to work toward the good of humankind. He saw the scientific, technological materialism of the Western world as a problem for the future of the world. While in Burma, Schumacher developed the principles that he called "Buddhist economics." He made the claim that he could have called it "Christian economics" but no one would have listened.

The four principles were based on the idea that doing good work was essential for people and that using local labor and resources for a locale was the logical ideal.

Schumacher's four principles were as follows: first, that work to an employer is the cost of an item and needs to be as small as possible. Work to the worker is made in place of leisure and wages are the compensation for the discomfort. Second, it is wrong to consider products as more important than people from a Buddhist (or Christian) view. Third, work has three values to a person: it provides a chance to grow in ability, to give of one's person to a common cause, and to produce products that are needed to exist. Fourth, work should not be designed to be so mundane that the worker is bored. That is valuing the product more than the person.

Along with his Buddhist economics, Schumacher proposed the principles of intermediate size and intermediate technology. He believed that a large concentration of industry using the maximum in technology would put people out of work. If an industry's size were controlled, its technology would be simpler and it would employ more workers. In this way, more people would work and the standard of living would stay high for everyone, not just the privileged who had jobs. Schumacher was also a strong proponent of renewable resources and protecting the environment.

C. Alton Hassell

• Further Reading

De Steiguer, Joseph Edward. *The Origins of Modern Environmental Thought.* Tucson: University of Arizona Press, 2006. Places Schumacher as one of the intellectual founders of modern environmentalism. Bibliography, index.

Schumacher, E. F. *Small Is Beautiful: Economics as if People Mattered.* New York: Harper & Row, 1975. Schumacher's founding, seminal work arguing against growth-driven economic models.

Schumacher, E. F., and Joseph Pearce. *Small Is Still Beautiful: Economics as if Families Mattered.* Wilmington, Del.: ISI Books, 2006. An updated continuation of the work begun in *Small Is Beautiful.*

Wood, Barbara. *E. F. Schumacher: His Life and Thought.* New York: Harper & Row, 1984. Written by Schumacher's daughter, this critical biography was first published in England as *Alias Papa: A Life of Fritz Schumacher.* Bibliography, index.

See also: Economics of global climate change; Employment; Environmental economics; Global economy; Intergenerational equity; Sustainable development.

Science and Public Policy Institute

- **Category:** Organizations and agencies
- **Date:** Established February, 1995
- **Web address:** http://scienceand publicpolicy.org

• Mission

The Science and Public Policy Institute (SPPI) is a global warming skeptic organization that focuses its efforts on research and education surrounding advancement of public policies for energy and the environment. The SPPI was formerly known as the Center for Science and Public Policy for the Frontiers of Freedom, which was founded by former Republican senator and directing member of the El Paso Natural Gas Company Malcolm Wallop in February of 1995.

As of 2008, the organization's executive director was Robert Ferguson, former chief of staff to several Republican members of Congress. The SPPI's membership includes prominent climate change skeptics. Its chief policy advisor is Christopher Monckton, a former advisor to British prime minister Margaret Thatcher. Its chief scientific advisor is Willie Soon, who is an astrophysicist and geoscientist by training and a proponent of the theory that climate change is caused by solar variation and not by human activities. The activities of the SPPI are supported by money from tobacco and oil companies, including Philip Morris, RJ Reynolds Tobacco, and ExxonMobil. Since 1998, the SPPI has received $467,000 from ExxonMobil.

• **Significance for Climate Change**

The SPPI funded a film titled *Apocalypse? No!* (2008), created to refute the theories highlighted in the Al Gore film *An Inconvenient Truth* (2006) The SPPI's other projects and publications also center on environmentalist skeptism. In July, 2008, SPPI policy advisor Monckton published in the journal *Physics and Society* an article arguing that computer models used by the United Nations Intergovernmental Panel on Climate Change were preprogrammed with erroneous values. These values, according to Monckton, effectively resulted in a 500 to 2000 percent overestimate of carbon-dioxide-induced effects on temperature that was reported in the 2007 U.N. climate assessment report. The SPPI is closely affiliated with other notable global warming skeptic organizations such as the Heartland Institute and the Center for the Study of Carbon Dioxide and Global Change.

The SPPI has programs to continually monitor and review publications and projects centered on climate change. For example, SPPI's ScareWatch program provides annotated bibliographies of publications that cover the negative implications of global warming and attempts to rebut and discredit organizations and individuals affiliated with such publications.

Rena Christina Tabata

See also: Advancement of Sound Science Center; Catastrophist-cornucopian debate; Cooler Heads Coalition; Heartland Institute; Intergovernmental Panel on Climate Change; Pseudoscience and junk science; Skeptics.

Scientific Alliance

• **Category:** Organizations and agencies
• **Date:** Established 2001
• **Web address:** http://www.scientific-alliance.org/

• **Mission**

The Scientific Alliance is a nonprofit organization that was formed in 2001 in the United Kingdom in order to deal with issues facing the environment. Businessman Robert Durward started it in conjunction with political consultant Mark Adams. The organization's membership consists of individuals interested in the field of biotechnology and environmental change; some are scientists and others are nonscientists. Its present director is Martin Livermore, the author of *Climate Change: A Guide to the Scientific Uncertainties* (2007), published by the Centre for Policy Studies. The Scientific Alliance tries to foster discussion about issues dealing with the environment, but it is generally felt to be pro-business.

• **Significance for Climate Change**

The Scientific Alliance is an activist group that contends that it deals logically with issues of the environment, trying to calm the panic caused by extremist groups who use scare tactics to frighten the public. The organization currently consists of many individuals in the field of biotechnology and people skeptical about the issues of climate change. It maintains an active Web site that it contends is dedicated to discussion of present-day environmental challenges. It has sponsored several conferences dedicated to exploration of environmental challenges. Its first conference was held in November, 2002, and was entitled Fields of the Future. This conference highlighted the importance of genetically modified foods for the future of the world while indicating that organic farming would lead to ecological collapse and mass starvation.

A second conference held in November of 2004 was entitled Cautionary Tales: Rethinking Environmental Decision Making and Risk Assessment. This conference warned of the risks of organic farming as well as the risks that would be associated with wind power. In 2005, the organization's conference was titled "Apocalypse No: Assessing Catastrophic Climate Change." This conference featured many speakers who indicated that individuals such as Al Gore (author of *An Inconvenient Truth*) and other pro-environmentalists were attempting to determine the direction of the future of the world by falsely creating a panic based on environmental change.

In December of 2004, the Scientific Alliance published a paper criticizing the Kyoto Protocol and minimizing the risks of global warming. The Kyoto Protocol was adopted in the late 1990's in an attempt to reduce greenhouse gases and minimize global warming. The Scientific Alliance as an organization has worked and continues to work to convince society that climate change is unlikely to occur, unimportant, and proposed by radicals trying to influence the course of society.

Robin Kamienny Montvilo

See also: Advancement of Sound Science Center; Catastrophist-cornucopian debate; Cooler Heads Coalition; Heartland Institute; Intergovernmental Panel on Climate Change; Pseudoscience and junk science; Skeptics.

Scientific credentials

- **Category:** Science and technology

- **Definition**

Scientific credentials include academic degrees, institutional affiliations, scholarly publications, grants, and awards. They are used to establish expertise, entitling one's opinions on scientific issues to special attention from professional colleagues, policy makers, and the public.

- **Significance for Climate Change**

In light of disagreements about the existence, causes, and importance of global warming, there has been debate over whose opinions should be taken seriously. Scientists are frequently invited to speak outside their field, especially by journalists who may see little difference (for their purposes) between one expert and another. As citizens, scientists of course have views about various subjects on which they are not experts, but they (or others) may exaggerate the weight of these opinions.

The only earned degree of Freeman Dyson, known by some as the best physicist never to have received a Nobel prize, was an undergraduate bachelor's degree in mathematics (he has been awarded numerous honorary degrees). Despite his many accomplishments, including early recognition of the possibilities for offsetting carbon emissions through forest management, Dyson has complained that

> they say, I have no degree in meteorology and I am therefore not qualified to speak. But I have studied the climate models and I know what they can do. The models . . . do a very good job of describing the fluid motions of the atmosphere and the oceans. They do a very poor job of describing the clouds, the dust, the chemistry and the biology of fields and farms and forests.

Danish political scientist Bjørn Lomborg complained that when he wrote *Verdens sande tilstand* (1998; *The Skeptical Environmentalist,* 2001) his book was reviewed in *Scientific American* by four scientists

The 2009 appointment of Nobel laureate Stephen Chu, foreground, as U.S. secretary of energy was hailed by some as a sign that the Obama administration would take seriously the scientific credentials of those whose advice it sought on climate policy. (AP/Wide World Photos) without his having an opportunity to reply. He responded online. In April, 2002, the journal's editor, John Rennie, replied to the critique, emphasizing that

> Lomborg's lack of credentials as an environmental scientist does not disqualify him from making an environmental argument, but it does legitimately bear on whether his knowledge of the field and his paraphrasing of its findings can be trusted.

To his critics, Lomborg was a scientific neophyte who drew misleading conclusions because he failed to consider the full range of facts a professionally qualified environmental scientist would know. In Rennie's view, Lomborg's book was "not really a scientific work so much as a polemic." Lomborg's supporters saw *Scientific American*'s dismissal of his work as motivated by rejection of his "politically incorrect" views. The controversy made Lomborg famous, and in 2004 *Time* magazine named him one of the world's hundred most influential people.

Prominence in the media—including radio, television, movies, publishing, journalism, and the Internet—can create the appearance of scientific authority. Popularity, influenced by criteria such as plausibility and likableness, supports political influence. Popular misconceptions about scientific credentials have been exploited by all sides of the culture wars. Scientists such as Lomborg and Dyson are alternately seen as experts or interlopers. Former NASA climatologist Roy Spencer, also out of sympathy with the Kyoto consensus, wrote,

> Contrary to popular accounts, very few scientists in the world—possibly none—have a sufficiently thorough, "big picture" understanding of the climate system to be relied upon for a prediction of the magnitude of global warming. To the public, we all might seem like experts, but the vast majority of us work on only a small portion of the problem.

Some experts believe people must radically change their lives to deal with global warming, while others think little change is required. Some advocate adopting a precautionary principle and acting in light of worst-case scenarios, while others say an excess of caution is unfair to the disadvantaged. Those who dislike business as usual, for independent reasons, may find a lower level of confidence (about the probability and results of global warming) a satisfactory basis for change. Those who support business as usual will demand more justification before abandoning accustomed ways. With global warming, as with other large issues, it is easy to see the glass as now half full, now half empty—when, in fact, it is both.

Edward Johnson

• Further Reading

Bowen, Mark. *Censoring Science: Inside the Political Attack on Dr. James Hansen and the Surprising Truth About Global Warming*. New York: Penguin, 2007. Discusses pressures on NASA's Hansen, whose 1988 congressional testimony sounded an alarm about global warming.

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Climate Change: A Guide to the Debate*. New York: Cambridge University Press, 2006. Covers the interaction of scientific and political considerations in the debate.

Dyson, Freeman. *A Many-Colored Glass: Reflections on the Place of Life in the Universe*. Charlottesville: University of Virginia Press, 2007. Dyson defends his "heresy" about what he calls "the misleading phrase 'global warming.'"

Lomborg, Bjørn. *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. New York: Knopf, 2007. Conceding that global warming is real and is caused (in part) by the burning of fossil fuels, Lomborg insists there are better ways to address the issue than the Kyoto Protocol approach of drastic short-term curtailment of GHG emissions.

_______. *The Skeptical Environmentalist: Measuring the Real State of the World*. Cambridge, Mass.: Cambridge University Press, 2001. Arguing that the world is better off than environmentalists suggest, this book raised a firestorm of controversy over its use of facts and statistics.

Mooney, Chris. *Storm World: Hurricanes, Politics, and the Battle over Global Warming*. New York: Harcourt, 2007. A critic of the politicization of science brings his critique to bear on climate change.

Rennie, John. "A Response to Lomborg's Rebut-tal." *Scientific American*, April 15, 2002. The *Scientific American* editor responds to Lomborg's attack on his reviewers.

Spencer, Roy W. *Climate Confusion: How Global Warming Hysteria Leads to Bad Science, Pandering Politicians, and Misguided Policies That Hurt the Poor.* New York: Encounter Books, 2008. Spencer defends his skeptical approach to global warming.

See also: Falsifiability rule; Level of scientific understanding; Peer review; Scientific proof.

Scientific proof

- **Category:** Science and technology

- **Definition**

Scientific proof is the means by which a question comes to be considered sufficiently settled, on the basis of scientific argument and evidence. What makes a theory, method, or result count as scientific has been controversial, both among philosophers of science and as a practical issue in courts of law. The term "proof" is also problematic. To prove originally meant to test (the word stems from the same Latin root as "probe"): Thus, something successfully tested has been "proven," but such proof is, contrary to popular expectation, no guarantee of truth.

Scientific theories create confidence by their ability to explain and predict events. In an experiment, investigators test their theory about how the world works: If certain forces are in play, then specific results should be observed. Hard sciences (such as physics and chemistry) often allow for such simple testing. Social sciences (such as economics and sociology) do not permit this, though there is dispute as to whether this is because they cannot offer good theories or because they deal with more complicated aspects of the world. Confidence in claims is increased if they are supported by evidence from distinct and various sources. Confidence is diminished if those who discover, test, or report facts seem to lack objectivity.

- **Significance for Climate Change**

While climates cannot as yet be created in a test tube, it is possible to compare the theoretical expectations of a given theory or model with what is known about the past. When the available climatological evidence consists, for example, of tree rings or ice cores, scientists hypothesize earlier events that would explain that evidence. When a climate model correctly "predicts" facts (such as temperature) known to be correct for the data available from the past, there is some reason to take its future predictions seriously. On the other hand, if a theory gets the past wrong, that is reason for suspicion (though, in some cases, it might be reason for a correction of the historical record).

Climate systems are so complex that there is room for much disagreement about what constitutes the facts of Earth's climate, about the history of those facts, and about the causal relationships determining them. Consider, for instance, the gradual disappearance of the snows of Kilimanjaro. Coastal protection activist Mike Tidwell reported in 2006 that Kilimanjaro would be free of ice within a decade as a result of warming climate. Skeptical environmentalist Bjørn Lomborg, on the other hand, claimed in 2007 that Kilimanjaro's ice loss is attributable not to temperature changes but rather to a drying climate.

Both arguments relied on the reports of others, and with regard to such reports there is controversy about what is, or is not, scientific proof. Tidwell has characterized the leading climatological reporting agency, the Intergovernmental Panel on Climate Change (IPCC), as "the largest scientific collaboration in human history," but skeptic Roy Spencer claims that "most of those 2,000 'scientists' are actually bureaucrats and governmental representatives; very few of them are climate scientists." He believes that these representatives promote policy for ulterior reasons and find the science after the fact to justify their positions.

There is an important asymmetry between alarmists and deniers. For those who believe climate change to be occurring through processes over which human beings may be able to exert some control, waiting until all the evidence is in risks fatal delay in reversing causes and mitigating effects. They think it prudent to emphasize the scope of the risks, while avoiding the endless qualifications that are part of normal scientific practice. Those who minimize the idea of anthropogenic global warming, on the other hand, see no need for a rush to judgment. They view alarmists as overstating troubling results and understating qualifications and uncertainties, using oversimplified science to achieve policy objectives.

Edward Johnson

- **Further Reading**

Curd, Martin, and J. A. Cover, eds. *Philosophy of Science: The Central Issues.* New York: W. W. Norton, 1998. A massive anthology (nearly fourteen hundred pages) that places issues about evidence and proof in the context of influential ideas in the twentieth century philosophy of science.

Doherty, Peter. *The Beginner's Guide to Winning the Nobel Prize: A Life in Science.* New York: Columbia University Press, 2006. A Nobel-laureate immunologist combines reflections on scientific practice as he has experienced it with discussion of global warming and other questions of public policy.

Haack, Susan. *Defending Science—Within Reason: Between Scientism and Cynicism.* Amherst, N.Y.: Prometheus Books, 2003. A lucid interpretation, by a "passionate moderate," of science's strengths and limitations.

Lomborg, Bjørn. *Cool It: The Skeptical Environmentalist's Guide to Global Warming.* New York: Knopf, 2007. Conceding that global warming partly derives from GHGs, Lomborg disagrees about policy implications of that fact and remains skeptical about particular pieces of evidence.

Maslin, Mark. *Global Warming: A Very Short Introduction.* New York: Oxford University Press, 2004. A concise introduction to the evidence for climate change.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change.* Boston: Beacon Press, 2007. A leading science journalist's account of why the story about climate change may be even worse than feared.

Spencer, Roy W. *Climate Confusion: How Global Warming Hysteria Leads to Bad Science, Pandering Politicians, and Misguided Policies That Hurt the Poor.* New York: Encounter Books, 2008. A former NASA scientist argues that the situation regarding climate change may be much better than feared.

Tidwell, Mike. *The Ravaging Tide: Strange Weather, Future Katrinas, and the Coming Death of America's Coastal Cities.* New York: Free Press, 2006. An activist's survey of evidence for global warming and a forecast of its likely dire consequences.

See also: Falsifiability rule; Level of scientific understanding; Peer review; Scientific credentials.

Sea ice

- **Categories:** Cryology and glaciology; oceanography

- **Definition**

Sea ice is formed when the surface layer of the ocean reaches the freezing point. For salt water, this occurs at a temperature of –1.8 Celsius, slightly colder than the freezing point of freshwater. Because water is more buoyant in its solid state, the newly formed ice floats on top of the ocean, forming a barrier between the cool air and the warm water.

There are two types of sea ice. Fast ice (also known as land fast ice) is seawater that has frozen along the shore line, or, in shallow areas, has frozen to the ocean floor. These formations are, by their very nature, stationary. Drift ice is frozen salt water that floats and is affected by winds and currents. First-year ice sheets, or floes, are typically thin and subject to shattering and refreezing, forming rafts and ridges.

A cluster of drift ice is called pack ice, and this is what covers both the Arctic and the Antarctic regions of the planet. The amount of pack ice in the polar regions varies with the season. During winter, sea ice usually covers between 14 and 16 million square kilometers in the Arctic and between 17 and 20 million square kilometers in the Antarctic. In the Antarctic, the sea ice melts during the summer and is therefore considered seasonal ice, but in the Arctic it remains year around.

The German vessel Polarstern *makes its way through sea ice.* (AFP/Getty Images)

Sea ice poses a hazard for shipping and has been noted in sailors' logs going back to the fourth century B.C.E. Sea ice is commonly confused with icebergs. Although both represent significant shipping hazards, icebergs are made of freshwater, usually from precipitation or snow melt, and break off from glaciers.

• Significance for Climate Change

Sea ice, especially Arctic sea ice, plays a significant role in the overall global climate by regulating the exchange of heat, moisture, and salinity in the ocean. As seawater freezes, its salt content is reduced in a process called brine rejection. The salt rejected from the frozen water increases the salinity of the surrounding ocean and can affect ocean currents. Sea ice insulates the warm ocean water and keeps it from losing heat to the much colder arctic or subarctic air. It also, however, reflects more sunlight than the surrounding ocean, preventing the sunlight from warming the ocean. When more sunlight reaches the water, the heat is absorbed, raising the temperature. Fissures or cracks in the ice release the trapped heat from the warmer ocean water, which can affect precipitation and cloud cover.

Greenhouse gases (GHGs) emitted through human activities and the resulting increase in global mean temperatures are the most likely underlying cause of sea ice decline, but the direct cause is a complicated combination of factors resulting from the warming and from climate variability.

Passive microwave satellite data show that, as of 2006, the Arctic sea ice decreased by 3.6 percent during each of the previous three decades. In 2007, Arctic sea ice was at a record low. Despite a recovery to near average levels during the following winter, 2008 summer sea ice coverage was nearly as low as the previous year. As a result, the remaining ice pack is thinner than in previous years and is less able to withstand the varying temperatures brought about by global warming.

As the global climate changes, the quantity of polar sea ice is diminishing, affecting regional ecosystems. Animals such as polar bears, walruses, and seals rely on ice floes for breeding, shelter, and especially hunting. As the summer ice diminishes, the summer hunting season—crucial for animals that hibernate—grows shorter. The large mammals have to travel farther to find food, and more time passes between kills. A 1980 study found that the average female polar bear in the Hudson Bay region of Canada weighed 300 kilograms. By 2004, that average weight had dropped to 230 kilograms. This decline has led to an overall 15 percent drop in polar bear birth rate. Scientists at the United States National Snow and Ice Data Center have predicted that, if current trends persist, by the year 2030, the Arctic Ocean will be without ice for the first time in over one million years.

P. S. Ramsey

• Further Reading

Gosnell, Mariana. *Ice: The Nature, the History, and the Uses of an Astonishing Substance.* Chicago: University of Chicago Press, 2007. Provides an overview of the various types of ice found all over the planet.

Melnikov, I. A. *The Arctic Sea Ice Ecosystem.* Amsterdam, the Netherlands: Gordon and Breach, 1997. Examines in detail ice and its impact on Earth and its inhabitants.

Mulvaney, Kieran. *At the Ends of the Earth: A History of the Polar Regions.* Washington, D.C.: Island Press/ Shearwater Books, 2001. A history of human interaction with the polar regions and how those regions are affected by the changing climate.

Thomas, David N. *Frozen Oceans: The Floating World of Pack Ice.* London: Natural History Museum, 2004. Accessible, illustrated overview of pack ice.

Thomas, David N., and Gerhard S. Dieckmann, eds. *Sea Ice: An Introduction to its Physics, Chemistry, Biology, and Geology.* Malden, Mass.: Blackwell Science, 2003. Collection of research papers covering all aspects of sea ice.

See also: Antarctica: threats and responses; Arctic; Arctic peoples; Deglaciation; Ground ice; Northwest Passage; Ocean life; Polar bears; Sea surface temperatures.

Sea-level change

• Category: Oceanography

Rising sea levels associated with global warming pose a threat to beaches and coastlines, coastal communities, and aquifers, directly or indirectly affecting the lives of hundreds of millions of people.

• Key concepts

aquifer: a layer of sand, gravel, or permeable rock containing water

glacier: a flowing body of land ice

ice cap: a domed body of ice covering a highland; smaller than an ice sheet

ice sheet: a deep body of ice covering and dominating a land mass

ice shelf: a floating body of ice extending from a coast and often attached to an ice sheet

post-glacial rebound: a rise in elevation of a land mass after a glacier on top of it melts

sea level: the theoretical level of the surface of the ocean, halfway between high and low tide

sea-level equivalent (SLE): the change in global average sea level that would occur if a given amount of water or ice were added to or removed from the oceans

thermosteric sea-level change: variability in sea level due to changes in water temperature

water table: the upper level of groundwater

• Background

Sea level can change, both globally and locally, as a result of changes in the shape and size of the ocean basins, changes in the total mass of seawater, and variations in water temperature and salinity. It is estimated that the global sea level rose by 10 to 25 centimeters in the twentieth century, and forecasts made in 2007 predicted an increase of 20 to 60 centimeters during the twenty-first century. However, these forecasts were subsequently revised upward.

• Dynamics of Sea-Level Change and Rise

The forecasts made by the Intergovernmental Panel on Climate Change (IPCC) in 2007 took some account of runoff from melting mountain glaciers and melting ice sheets in Antarctica and Greenland. For the most part, however, they were estimates of thermosteric sea-level change. Water increases in volume as it grows warmer, although it is difficult to establish a timescale for such expansion, delayed as it is by the thermal inertia of oceans (especially at their greatest depths). Thus, at least some of the observed changes in sea level in the recent past are undoubtedly due to earlier changes in air and sea temperature, while sea levels will probably rise over a period of several hundred years even if temperatures are brought under control. Regional and local sea levels are and will continue to be affected by such factors as salinity, atmospheric pressure, river runoff, currents, storms, tides, and wave patterns.

• Consequences of Sea-Level Rise

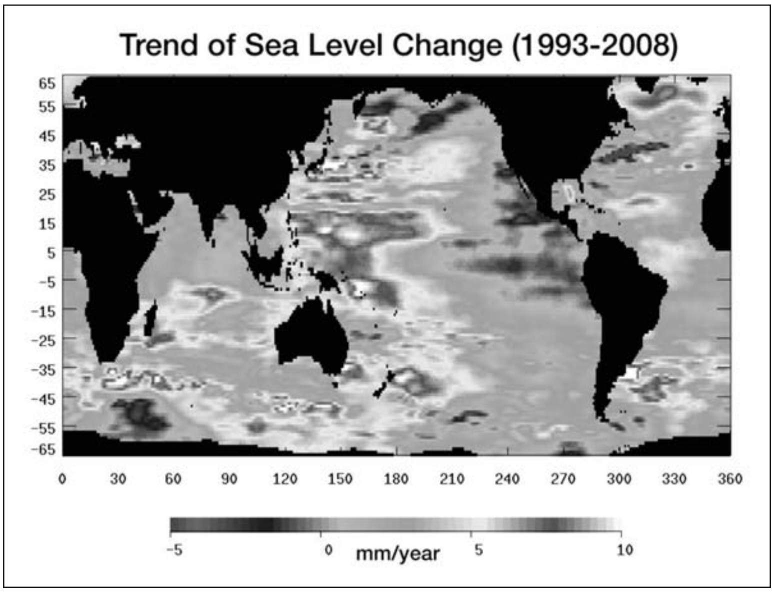
Although the dynamics of sea-level change are complex and not completely understood, there is less uncertainty about the consequences of sea-level rise, which poses severe dangers to coastlines by eroding beaches and flooding adjacent low-lying areas. There is no indication that rising sea levels (as opposed to warmer seas) contribute to the intensity of storms, but they do leave coastal areas more vulnerable to their effects by overwhelming estuaries and covering barrier islands. In particular, rising sea levels threaten the developing countries of Asia and Africa, where major population centers are often situated in or near low-lying deltas. Island nations such as Maldives and Kiribati will in time disappear below the sea, necessitating the mass relocation of their entire populations. Rising sea levels also pose the danger of saline pollution to aquifers, which in turn will lead to shortages of freshwater needed for agriculture and human consumption. Because of growing populations, such shortages are already a serious problem in many parts of the world.

• Increased Danger

The IPCC acknowledged that limited understanding of the processes involved in melting ice sheets meant that their effects were underestimated in its 2007 report. Soon afterward, however, more thorough studies of the Greenland and Antarctic ice sheets revealed that they were melting more rapidly than expected. This melting was due not only to increases in temperature but also to disintegration caused by water seepage in crevasses. Coupled with other findings, this evidence suggested that sea levels would increase by 50 to 100 centimeters in the twenty-first century. A rise of the latter dimension would flood over 33,670 square kilometers in the United States alone and create over 100 million refugees worldwide.

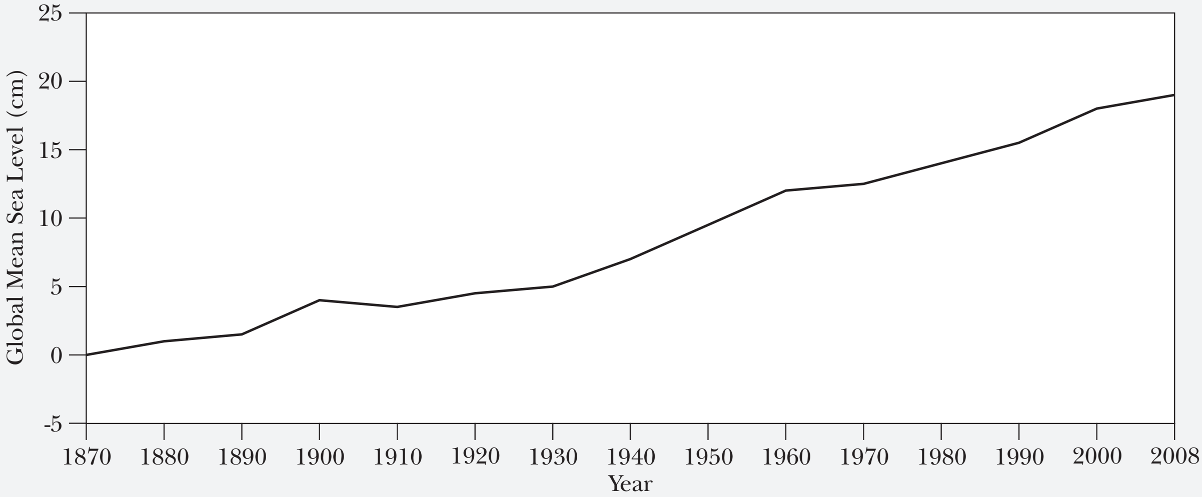
Concerns about rising sea levels heightened in April, 2009, with the collapse of an ice bridge linking the Wilkins Ice Shelf, which once covered some 16,000 square kilometers of the Antarctic Ocean, to Charcot Island. It was one of nearly a dozen such formations in the region to have collapsed in the preceding fifty years. Because ice shelves float, their disintegration does not raise water levels, but in their absence, the glacier ice accumulated behind them enters the sea more readily—a process that does raise water levels.

Forecasts of sea-level rise created by melting ice



This chart of sea-level changes from 1993 to 2008 shows that such changes are very different in different regions of the globe. (NASA/JPL)

Estimated Global Mean Sea-Level Rise, 1870-2008



Data from World Climate Research Programme.

sheets are complicated by two other factors. Postglacial rebound would decrease the size of the ocean basins, while small but significant changes in the Earth's rotation are also likely to follow the disappearance of the enormously heavy ice sheets in Antarctica, resulting in higher sea levels in the Indian Ocean.

• Context

Fragmentary evidence suggests that sea level began to rise in the middle of the nineteenth century, while more compelling evidence shows that this rate began to increase toward the end of the twentieth century. A number of factors enter into this increase, but because so many people live in coastal areas around the world, the immediate consequences of what appears to be an increasingly rapid rate of sea-level rise are grave.

The long-term consequences of melting ice sheets are even more profound. For instance, the West Antarctic Ice Sheet, a formation that scientists believe is particularly vulnerable to disintegration as world temperatures increase, contains the sea-level equivalent of 5 meters. The Earth's glaciers, ice caps, and ice sheets combined contain an extraordinary sea-level equivalent of 68.5 meters. While no one predicts that the ice sheets are in immediate danger of wholesale melting, the momentum of such a change, should it begin, would be virtually impossible to counter by any technology currently available to humankind.

Grove Koger

• Further Reading

Douglas, Bruce C., Michael S. Kearney, and Stephen P. Leatherman, eds. *Sea Level Rise: History and Consequences*. San Diego: Academic Press, 2001. Scholarly discussion of the evidence for historical sea-level change, including observations based on tide gauges and satellite altimetry. Illustrations, maps, bibliographic references, CD-ROM.

Johansen, Bruce E. "Sea-Level Rise." In *Melting Ice and Warming Seas*. Vol. 2 in *Global Warming in the Twenty-first Century*. Analyzes the impact of global warming on the Earth's water resources. Illustrations, maps, charts, bibliographical references.

King, Michael D., ed. *Our Changing Planet: The View from Space*. New York: Cambridge University Press, 2007. Satellite images accompanied by interpretive essays detail the effects of climate change, including sea-level change. Illustrations, maps.

MacCracken, Michael C., Frances Moore, and John C. Topping, Jr., eds. *Sudden and Disruptive Climate Change: Exploring the Real Risks and How We Can Avoid Them.* Sterling, Va.: Earthscan, 2008. Includes several essays dealing with aspects of sea-level change, including the implications of rapidly melting ice sheets and glaciers. Illustrations, bibliographical references.

See also: Coastal impacts of global climate change; Deglaciation; Glaciers; Ice shelves; Islands; Ocean dynamics; Sea surface temperatures.

Sea sediments

• **Categories:** Oceanography; geology and geography

• Definition

Sea sediments collect on the sea bottom, constituting the upper layer of the ocean floor. They consist of materials weathered from the continents, the remains of planktonic organisms, and minerals that are deposited by hydrothermal vents. Marine sediments are generally classified according to their source as terrigenous, metalliferous, or biogenic.

Terrigenous sediments are derived from the weathering of continental material, and are transported to the oceans by rivers, wind, and even glaciers. Terrigenous sediments are found most often near the continental margins, where rivers deposit much of their load. Very fine grained terrigenous sediments (clays) are transported to the central abyssal plains by wind and are the dominant sediment type under surface waters characterized by low levels of plankton productivity. Local accumulations of terrigenous sediments deposited by calved icebergs after they melt are known as "ice-rafted debris." These terrigenous sediments are typically larger than are sediments transported by rivers or winds and accumulate near the polar regions.

Biogenic sediments, which dominate most regions of the seafloor, are the skeletal remains of microscopic plankton. Biogenic sediments are classified as either calcareous or siliceous depending on their chemical composition. Coccolithophores, foramaniferans, and pteropods produce calcareous skeletons composed of carbonate minerals, while diatoms and radiolarians produce siliceous skeletons composed of opaline silica.

Metalliferous sediments are found near the crests of mid-ocean ridges, where mixing of hot hydrothermal vent fluids with deep ocean waters causes the precipitation of metal (iron, zinc, copper) sulfide and oxide minerals. Sea sediments accumulate on the seafloor at very different rates. Accumulation of sediments near the continental margins can be as rapid as 1-10 centimeters every thousand years, while wind-blown terrigenous dust accumulates on the abyssal plains at rates of 1-2 millimeters per thousand years.

• Significance for Climate Change

The distribution of marine sediments is a function of the location of the sediment source, the chemical reactions that occur in the water column and on the seafloor as the sediments accumulate, and the input rate of terrigenous sediments. Biogenic sediments are produced in surface waters in regions that contain sufficient concentrations of nutrients such as nitrogen, phosphorus, and silica. Production of siliceous plankton dominates in surface waters of the southern ocean, the Arctic Ocean, along continental margins where upwelling occurs, and along the Equatorial Divergence. Production of calcareous plankton dominates in the remaining regions.

When both calcareous and siliceous plankton settle through the water column, they are subject to chemical dissolution. Calcareous sediments are preserved where the ocean floor is generally less than approximately 4,000 meters deep and large inputs of terrigenous material are absent. Below 4,000 meters, the carbonate minerals that make up calcareous sediments are dissolved before they can be preserved, because there are low concentrations of dissolved carbonate ions in deep waters.

While the ocean is everywhere undersaturated with respect to silica, the rate of dissolution decreases with temperature, and thus with depth, in the ocean. Siliceous sediments are therefore preserved in deep regions of the ocean, under areas of high radiolarian or diatom productivity. The preservation of large amounts of terrigenous sediments in the deep abyssal plains, far removed from the continents, reflects the low levels of productivity found in the central gyres: There are no biogenic sediments produced in these waters to dilute the amount of terrigenous sediments delivered by the wind.

Changes in sea sediments preserved over geologic time reflect climate change in a variety of ways. For example, along a transect from a mid-ocean ridge toward a continental margin, the expected distribution of sediments will be as follows: metalferous sediments near the ridge crest, calcareous sediments, siliceous sediments as the ocean floor deepens below 4,000 meters, and then terrigenous clay. During times of colder climate, when sea level drops in response to glacier formation, a larger region of the ocean floor will be shallow enough to preserve calcareous sediments. When the climate is colder, the atmospheric concentration of carbon dioxide (CO_2) decreases. This, in turn, leads to an increase in the concentration of carbonate ions in the deep ocean and a deepening of the depth at which calcareous sediments can be preserved. Thus, a wider swath of seafloor on either side of a mid-ocean ridge will preserve calcareous sediments.

Because siliceous oozes accumulate under highly productive surface waters in generally cool regions, colder climates can favor the expansion of areas on the seafloor where these sediments are found. Generally drier conditions during glacial times, moreover, contribute to an increase in the flux of terrigenous sediments to the deep abyssal plains. Warmer, wetter climates can be recorded in sea sediments by an increase in the deposition of terrigenous sediments near the continental margins. Finally, global temperature changes are recorded in the isotopic composition of oxygen preserved in calcareous or siliceous sediments, and of carbon found in calcareous sediments. Changes in the pH of the ocean—which reflect atmospheric concentrations of CO_2 and temperature—are recorded in the isotopic composition of boron that is preserved in some biogenic sediments.

Anna M. Cruse

- **Further Reading**

Burroughs, William James. *Climate Change in Prehistory: The End of the Reign of Chaos.* New York: Cambridge University Press, 2005. Covers a broad spectrum of data concerning human adaptation to climate change in prehistory, but has chapters specific to the evidence for climate change that is found in ocean sediments.

Open University. *Marine Biogeochemical Cycles.* 2d ed. Boston: Elsevier Butterworth-Heinemann, 2005. Introductory oceanography textbook that covers the processes by which marine sediments are formed, the chemical reactions by which they are modified, and the use of marine sediments in paleoceanographic studies to reconstruct past environments and climates.

Schulz, Horst D., and Mattias Zabel, eds. *Marine Geochemistry.* New York: Springer, 2006. Collection of papers discussing the physical and chemical properties of marine sediments and the chemical reactions that occur to those sediments as they undergo diagenesis and are converted into sedimentary rocks.

See also: Arctic seafloor claims; Gyres; Maritime climate; Ocean acidification; Ocean-atmosphere coupling; Ocean dynamics; Ocean life; Plankton; Sea-level change.

Sea surface temperatures

- **Category:** Oceanography

- **Definition**

Sea surface temperature (SST) is a bulk measurement of the temperature of the surface of the ocean. Average SST ranges from approximately –3° Celsius in the Arctic Ocean to 28° Celsius in equatorial waters. SST is one of the parameters recorded by ships as part of their standard atmospheric and oceanic observation practices, which are governed by international codes first established in the late nineteenth century.

The earliest sea surface temperature measurements were taken using a simple bucket and thermometer. Such measurements reported the average value for the upper 1-2 meters of the ocean. Since the 1940's, it has been standard practice to record the temperature of water coming through a ship's intake ports. This measurement, however, can record a temperature of any depth up to 20 meters, depending on the ship's buoyancy, and can be affected by heat from the ship's engines. Today, temperature data are still recorded in this manner on research vessels, weather ships, and many commercial and military vessels, with the result that many of the data are concentrated along shipping routes.

SST data are transmitted to the World Meteorological Commission and then transferred to weather services around the globe. SST readings are also recorded using moored and drifting buoys. With buoy readings, temperature probes are placed at a standard depth of 1 meter below the surface. Data from buoys are often transmitted by satellite to a data center, such as the National Data Buoy Center. As part of the World Ocean Circulation Experiment (WOCE), over forty-eight hundred drifting buoys were released to record SST among other data. Since the 1980's, SSTs have increasingly been obtained using satellite-borne radiometers. These instruments indirectly measure the temperature of the ocean's "skin" (the top 10 microns) based on the radiation intensity of select wavelengths, typically in the infrared spectrum.

• Significance for Climate Change

Sea surface temperature is a critical parameter used in general circulation models (GCMs), as well as meteorological models, to predict future climate and weather, respectively. While air surface temperatures have increased since the 1900's, global SST records are more complicated. In fact, an examination of historical records of SSTs showed a warming in the Atlantic Ocean by up to 0.4° Celsius, while equatorial Pacific SSTs cooled by approximately 0.2° Celsius.

Because of the slow response time of the oceans, as compared to the atmosphere, most scientists consider that, in most cases, observed seasonal changes in SST reflect changes in atmospheric conditions. However, there are exceptions to this assumption, most notably El Niño-Southern Oscillation (ENSO) events. ENSO events are coupled atmosphere-ocean phenomena that occur when warmer SSTs feed back into changes in atmospheric circulation patterns. El Niño phenomena are marked by warmer SSTs in the eastern equatorial Pacific Ocean, centered near the coasts of Peru and Ecuador, and they lead to a shift in the strength and direction of atmospheric circulation across the equatorial Pacific. This shift is known as the Southern Oscillation. ENSO events appear to have a periodicity of approximately three to eight years, in a highly irregular pattern.

On seasonal timescales, SSTs are important factors in the development of storms and hurricanes (tropical cyclones). A threshold SST of approximately 27°-29° Celsius is required for a hurricane to develop. The reasons for this threshold remain unknown, but, generally, higher SSTs appear to be correlated with the development of stronger hurricanes. According to observations correlated by the Intergovernmental Panel on Climate Change (IPCC), there has been an increase in intense hur-

Deviations in Mean Global Sea Surface Temperature

The following table lists deviations in average global sea surface temperature from the baseline temperature average set during the period between 1951 and 1980.

Year	*Deviation (in 0.1° Celsius)*
1880	–2
1890	–2
1900	–1
1910	–3
1920	–2
1930	–1
1940	+1
1950	0
1960	+1
1970	0
1980	+1
1990	+3
2000	+4

Data from Goddard Institute for Space Studies, National Aeronautics and Space Administration.

ricane activity in the North Atlantic since 1970. The available data do not show a clear trend in the annual number of tropical cyclones, however, and data integrity prior to 1970 remains questionable. Climate models used by the IPCC, which are based on projections of global temperature to the year 2100, indicate that an increase in hurricane activity is likely.

SST measurements are crucial to the coupled atmosphere-ocean models used to predict weather and climate, but obtaining long-term and reliable data sets that cover a wide geographic region remains a challenge. Because satellite-based SST measurements and ship- or buoy-based measurements are taken at different depths in the water, these data sets cannot be directly compared. This complication arises because satellite-based measurements are strongly affected by daytime heating of the thin layer they are able to measure, as well as by surface evaporation and reflected radiation. Also, because radiometers often cannot obtain readings through cloud cover, satellite SST data contain a fair-weather bias: SST readings are not obtained from these instruments on cloudy days, so short-term variations related to these meteorological conditions are not recorded. Ships, meanwhile, retain their own problems, because any craft powered by a motor will necessarily alter the temperature of the water through which it travels.

Anna M. Cruse

• Further Reading

Burroughs, William James. *Climate Change: A Multidisciplinary Approach.* 2d ed. New York: Cambridge University Press, 2007. Describes the climate system and the physical behavior of the various parts of the system. Considers ocean circulation and SST variations in the context of atmospheric circulation and presents information on how this knowledge is used in the predictive models that inform policy makers and political leaders. Figures, references, index.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Comprehensive treatment of the causes of climate change, written for a wide audience. Figures, illustrations, glossary, index, references.

Open University. *Ocean Circulation.* 2d ed. Boston: Elsevier Butterworth-Heinemann, 2005. This introductory oceanography textbook covers atmospheric and oceanic circulation, with references to sea surface temperature throughout. Also of note is the discussion of ENSO. Knowledge of algebra and trigonometry is assumed. Illustrations, figures, tables, maps, references, index.

See also: Antarctica: threats and responses; Arctic; Ocean dynamics; Ocean life; Sea ice; Sea-level change.

Seasonal changes

• Category: Meteorology and atmospheric sciences

• Definition

Weather and climate are variable phenomena in all regions of the world. Thus, irrespective of whether climate is undergoing a linear change to a new climate regime, climate is in some sense always changing. For example, an arid region in Peru may well have several years without any appreciable rain, followed by one or two weeks of relatively wet conditions. This might in turn be followed by another long period with no appreciable rain. Such climatic changes are quite normal. To determine whether climate change is of the type generally referred to by such phrases as “global warming,” one would look at a relatively significant change in the overall weather pattern. For example, long periods of dry years may become less lengthy or more lengthy, and periods of appreciable rain may also become more or less lengthy.

Another example would be snowfalls in the winter in much of northeastern North America, where snowfall varies considerably from one year to the next, and one decade to the next. Thus, the 1940’s was a period of relatively low snowfalls in some places, while the 1950's was a period of relatively high snowfalls in the same places. Such variations are quite common and are simply part of the total climate package of any particular area.

- **Significance for Climate Change**

Seasonal climates in all regions of the world have varied over all timescales, and the last one hundred to two hundred years is, in most cases and most areas, not significantly different than any other period of similar length. During the last millennium, for example, there have been long periods with warm and dry conditions (especially during the Viking explorations of northern Europe in the eleventh century), as well as long periods of cold conditions (especially during the Maunder Minimum from 1645 to 1715, which was a period when very low sunspot activity coincided closely with the coldest part of the Little Ice Age).

Global warming may cause the seasons to become generally warmer in most cases, but they may become cooler in some places. There may also be greater variation or greater change in daytime or nighttime temperatures than in overall average temperatures. In addition, the average temperatures during winter months may change in a given area in a direction opposite that of the change in the average temperatures of the summer months. Rainfall patterns and frequencies of heavy rainfalls and droughts may be affected, as well as the frequency, path, and intensities of tropical storms such as hurricanes, tropical cyclones, and typhoons.

The climate predictions from the 2008 report of the Intergovernmental Panel on Climate Change (IPCC) suggest an overall warming in the winter in North America by 2°-3° Celsius by the year 2050 and drier conditions during the summer in the Mediterranean. However, given the complexities of global, regional, and local climate systems, it is not at all easy to translate such broad-scale predictions into more focused predictions. Thus, even if the report is accurate, it is extremely difficult to know how those changes will affect winters in the American Midwest or tourism and agricultural water supplies in southern Europe, for example.

Thus, in the 2040's, Chicago could experience fewer days with snow but a greater intensity of snowfall. A 3°-4° Celsius increase in summertime temperatures may well translate into a nighttime temperature increase of 1°-2° Celsius, a daytime increase of 4° Celsius, and an overall increase of 10 percent in the number of days with a maximum temperature of 38° Celsius or more. While the climate models from the IPCC reports appear on the surface to be relatively specific for an area such as the western United States, the specific translation of such forecasts into, say, the Rocky Mountain area poses considerable difficulties, especially if one is interested in what will happen in the wintertime or the summertime in a place such as Denver during a specific decade.

W. J. Maunder

See also: Average weather; Climate change; Climate variability; Weather vs. climate.

Rainfall Patterns in Tauranga, New Zealand, 1898-2008

Weather averages may hide relatively intense variation in seasonal precipitation from year to year. For example, Tauranga, New Zealand, experienced rainfalls between 1898 and 2008 that were as much as 56 percent above or 43 percent below the average for that time period.

Year	*Deviation from Average Rainfall (%)*
1906	–28
1915	–41
1916	+47
1917	+43
1919	–27
1920	+36
1935	+27
1938	+38
1956	+35
1962	+56
1971	+33
1973	–25
1979	+31
1982	–36
1986	–25
1993	–33
1997	–26
1999	–24
2002	–43
2005	+28

Second Assessment Report

- **Category:** Laws, treaties, and protocols
- **Date:** Published 1995

- **Definition**

The United Nations Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme

> . . . to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation.

The IPCC publishes a set of assessment reports at approximately five-year intervals. The IPCC's Second Assessment Report (SAR), published in 1995, consisted of three volumes, each assembled by a separate "working group." The three volumes of the SAR were:

- *WG I: The Science of Climate Change*
- *WG II: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses*
- *WG III: Economic and Social Dimensions of Climate Change*

Together, the technical volumes were nearly two thousand pages long. Each of the volumes was summarized in a short "summary for policy makers." The SAR was accompanied by a synthesis report that summarized information specifically relevant to Article 2 of the United Nations Framework Convention on Climate Change.

The SAR is a highly technical document that few, if any, individuals are qualified to understand in its entirety. Most discussion of the SAR is actually based on the summaries for policy makers, which were published considerably earlier than the underlying technical materials. Unlike the technical reports, the summaries for policy makers are drafted by governmental representatives to the IPCC and are formally approved by a panel comprising only a small selection of lead authors.

The SAR itself was written by a team of approximately 1,200 authors, with approximately 476 lead authors and 748 contributing authors. Authors and contributors could contribute to more than one section, so this tally is not of "unique" authors. The SAR lists 1,417 expert reviewers.

- **Significance for Climate Change**

Publication of the SAR marked a sharp turning point in the understanding of and public debate regarding climate change, as well as the need to reduce greenhouse gas emissions. While the First Assessment Report (FAR) of the IPCC (1990) had concluded only that "[t]he unequivocal detection of the enhanced greenhouse effect is not likely for a decade or more," the SAR concluded that "[t]he balance of evidence suggests a discernible human influence on global climate." This attribution marked a shift in the debate from a speculative linkage to human activity to an authoritative one.

The conclusions of the SAR in the Summary for Policymakers were:

(1) Greenhouse gas concentrations have continued to increase.
(2) Anthropogenic aerosols tend to produce negative radiative forcings.
(3) Climate has changed over the past century.
(4) The balance of evidence suggests a discernible human influence on global climate.
(5) Climate is expected to continue to change in the future.
(6) There are still many uncertainties.

The conclusions of the SAR were accepted as definitive by world governments and served as the knowledge base used in negotiation of the Kyoto Protocol in 1997.

Perhaps because of its import in public policy development, the SAR was a source of more controversy than earlier reports. Several contributing authors to the SAR, physicists Frederick Seitz, William Nirenberg, and S. Fred Singer, accused physicist Benjamin D. Santer (lead author of a key chapter on the attribution of climate change to human activity) of making unauthorized changes to the text of the chapter after peer reviews had been concluded and final wording agreed upon by contributing authors. Santer asserted that his changes were made as a normal part of the peer review process.

Santer's claim was supported by the chairman of the IPCC as well as the other authors of the chapter, but the claims against Santer were never retracted and continue to circulate on the Internet and in publications critical of the IPCC assessment report process.

In a separate controversy, the economic analysis conducted in volume 3 of the SAR was attacked for improperly using statistical values of human life that assigned more or less value to human life based on country of origin. This was the only assessment report that conducted such economic assessments of climate damage that included valuation of human mortality.

Kenneth P. Green

• **Further Reading**

Houghton, John. *Global Warming: The Complete Briefing*. New York: Cambridge University Press, 2009. A leading textbook on climate change, updated to reflect findings of the IPCC's latest assessment reports.

Singer, S. Fred. *Hot Talk, Cold Science: Global Warming's Unfinished Debate*. Oakland, Calif.: Independent Institute, 1998. A slim volume, published by a nongovernmental organization, in which Singer presents his case against the definitive claims of human causation of climate change, along with the reasons for his opposition to the Kyoto Protocol.

United Nations Intergovernmental Panel on Climate Change. *WG I: The Science of Climate Change*. Edited by J. T. Houghton et al. New York: Cambridge University Press, 1995. The first volume of the Second Assessment Report, focusing on the quantification of climate change, atmospheric greenhouse gas concentrations, and the fundamental science underlying the theory of climate change.

_______. *WG II: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses*. Edited by R. T. Watson, M. C. Zinyowera, and R. H. Moss. New York: Cambridge University Press, 1995. The second volume of the Second Assessment Report, focused on estimating what impacts climate change might have on societies and ecosystems, as well as evaluating what types of policy responses might be employed to ameliorate damages stemming from climate change.

_______. *WG III: Economic and Social Dimensions of Climate Change*. Edited by J. P. Bruce, H. Lee, and E. F. Haites. New York: Cambridge University Press, 1995. The third volume of the Second Assessment Report, focusing on the economic dimensions of climate change.

See also: Intergovernmental Panel on Climate Change; WGII LESS scenarios.

Security

• **Category:** Nations and peoples

• **Definition**

Security refers to the general stability of a nation; it includes military defense against other nations and threats, as well as defenses against lower-level threats to stability, including civil unrest, political instability, disruptions of resources, and terrorism. Climate change has the potential to affect many of the resources that industrialized nations take for granted. Those resources are necessary to protect the land, air, and sea, as well as nations' military capabilities. Provisions for food, shelter, health, longevity, space, and transportation may suffer, as may the general level of emotional security that helps maintain civil order in any nation where the populace vastly outnumbers the military and civil peacekeepers.

Governments must adapt to altering climates to maintain their security, so they must search for preventive and collaborative ways to pursue both military and health security that respond both to actual threats and to potential future threats. All societies need to conserve vital resources, while maintaining the ability to protect themselves. Even within the realm of military defense alone, competing interests must be taken into account. For example, testing nuclear weapons may make nuclear powers better able to defend themselves from other nuclear powers, but it could just as easily prove significantly counterproductive by destabilizing the relations among such powers. On a broader level, the military-industrial complex of the United States and other developed nations accounts for extremely high greenhouse gas (GHG) emissions, as it is an energy-intensive manufacturing sector. Thus, traditional military security activities may contribute significantly to the decrease in national and international climate security.

- **Significance for Climate Change**

Food availability is just one immediate example of a security concern raised by climate change. Such change can affect land fertility, and traditional methods of increasing fertility depend heavily on fossil fuels and GHG emissions, which may increase global warming and exacerbate the problem. Global warming may also lead to an increase in the number and spread of infectious diseases: Malnutrition and other disruptions in food quality can contribute to disease, as can changes in temperature and humidity that increase such disease vectors as mosquitoes and water contamination.

As food quality suffers, this in turn can lead to a decline in labor productivity, both for those who own and run farms and for those who cannot obtain the necessary nutrition to function effectively at work. The decline in productivity could specifically hinder military workers. New diseases can also weaken military capabilities, making nations more vulnerable and placing them at higher risk of security threats. Microbial changes in the environment can affect the very young and the very old, potentially increasing mortality rates. In nature, bees and other pollinators could become extinct, further endangering food supplies.

Firefighters battle a blaze set by members of the ecoterrorist Earth Liberation Front in Woodinville, Washington. Ecoterrorism is one climate-change-related threat to security. (Marcus R. Donner/Reuters/Landov)

The most vulnerable nations, like the most vulnerable individuals, are those with the least power and resources. Thus, climate change is widely expected to have the greatest immediate security impacts on the nations that are already the least secure. In Darfur, for example, a scarcity of natural resources has led to conflict among the local populations. There has been competition for water between groups that, in the past, were able to coexist. In the Palestinian territories, Israeli settlers receive more water per capita than do Palestinians, greatly exacerbating political and social tensions between the two groups. These conflicts may serve as canaries in the coal mine, revealing to more stable nations the dangers of severe climate change. However, they are also of immediate concern, because the world's major economic powers depend upon the availability of the world's markets, so any significant global instability, even in the developing world, represents a threat to the industrialized nations' economic security.

Global transportation could be significantly affected by the need to reduce GHG emissions, as it is a major source of such emissions. Business travel in particular could be significantly curtailed, as telecommuting and teleconferencing technologies replace in-person meetings. At the same time, the potential collapse of some national resource chains and infrastructure increases the likelihood of significant international migration, as climate refugees seek new homes in which to support themselves. Such large potential influxes of immigrants threaten the social and economic stability of their new homes, especially if resources in those new homes are already under pressure from climate change.

At the extreme end of climate-related security concerns lies the threat of significant and sustained violence in the service of resource competition, both within and among nations. Such violence could escalate to warfare. This danger makes it all the more necessary for nations to collaborate and succeed at finding a solution to projected climate changes. In order for national governments and their people to be protected from the risk of political unrest and terrorism, this goal is key.

Gina M. Robertiello

• Further Reading

Demeritt, David. "The Construction of Global Warming and the Politics of Science." *Annals of the American Association of Geographers* 91, no. 2 (June, 2001): 307-337. Reviews global warming from a political perspective and examines possible impacts of politics upon science and of science on politics.

Hess, Pamela. "Warming, National Security Linked: Trouble in Political Hot Spots Will Strain Resources, Officials Say." *The Grand Rapids Press*, June 26, 2008, p. A9. Covers how U.S. intelligence agencies have assessed the ways global warming will affect illegal immigration, governments, and national security.

O'Brien, Karen L., and Robin M. Leichenko. "Winners and Losers in the Context of Global Change." *Annals of the Association of American Geographers* 93, no. 1 (March, 2003): 89-103. Explores economic globalization and climate change, specifying who stands to gain and who stands to lose from global warming.

Schmidhuber, Josef, and Francesco N. Tubiello. "Global Food Security Under Climate Change." *Proceedings of the National Academy of Sciences* 104, no. 50 (December 11, 2007): 19,703-19,708. Reviews the potential effects of climate change on food security, as well as possible negative future scenarios.

Soroos, Marvin K. *The Endangered Atmosphere: Preserving a Global Commons*. Columbia: University of South Carolina Press, 1997. Describes the deterioration of Earth's atmosphere and the steps being taken to help preserve it from future degradation.

Tubiello, Francesco, and G. Fischer. "Reducing Climate Change Impacts on Agriculture." *Technological Forecasting and Social Change* 74, no. 7 (2007): 1030-1056. Evaluates the impact of climate change on crop yields, food demand, production, and trade.

See also: Displaced persons and refugees; Drought; Floods and flooding; International agreements and cooperation; Military implications of global warming; U.S. energy policy.

Sequestration

• **Categories:** Pollution and waste; meteorology and atmospheric sciences

Sequestering CO_2 and other GHGs from the atmosphere by geological, biological, or chemical processes and storing them in forms that will not affect Earth's climate is a primary mechanism for reducing atmospheric GHG concentrations and limiting global warming.

• Key concepts

carbon neutral: the quality of neither subtracting nor adding a net amount of carbon to the atmosphere

photosynthesis: process whereby carbon is taken from the atmosphere and incorporated into organic compounds by plants in order to store solar energy by converting it into chemical energy

sink: a source of storage of a substance that removes it from environmental circulation

• Background

Since the Industrial Revolution began, atmospheric levels of carbon dioxide (CO_2) have risen from 275 parts per million to the present level of 380 parts per million. Evidence suggests that this observed rise in atmospheric CO_2 levels is due primarily to the use of fossil fuels. There is a worldwide awareness that global warming is a result of the rising levels of CO_2 and other greenhouse gases (GHGs). Earth's atmospheric CO_2 level could easily exceed 550 parts per million by the middle of the twenty-first century if no corrective actions are taken. A variety of methods of CO_2 sequestration has been suggested, including the use of oceans, underground caves, chemical reactions, or living organisms for CO_2 removal. Several pilot projects for CO_2 sequestration are under way in different countries.

• Ocean Sequestration

Oceans serve as Earth's largest CO_2 sink—and a natural one as well. CO_2 simply dissolves in the ocean or is taken up by resident microscopic algae (phytoplankton). Based on these ocean features, scientists are considering two approaches for CO_2 sequestration. One option envisions direct injection of a stream of CO_2 waste into the ocean depths. An immediate problem with this approach is that direct injection may create acidic water that would kill a majority of oceanic life forms.

A second idea is to enhance photosynthesis by algae. Algae are the most important carbon sink on Earth, consuming CO_2 as they photosynthesize and converting it into organic matter, a process known as carbon fixation. For instance, oceanic algae annually sequester 2 gigatons of CO_2, compared to the 1.5 gigatons sequestered by all terrestrial ecosystems together. Some of this CO_2 permanently remains in the ocean in the form of calcium carbonate or silicates. One proposal for algal sequestration suggests fertilizing the ocean with iron in order to stimulate photosynthesis by algae. However, because water circulates very slowly throughout the oceans, this method might require hundreds of years before significant amounts of CO_2 are sequestered.

• Underground Sequestration

CO_2 can also be pumped into depleted underground oil and gas reservoirs. There is enough underground capacity to store the gigatons of excess atmospheric CO_2 accumulated over hundreds years. These reservoirs would be sealed and capped to avoid the escape of CO_2. Safety is a concern for CO_2 underground storage, as the CO_2 may escape, suffocating people and animals in its path. This happened in Cameroon in 1986, when 1 million cubic meters of CO_2 erupted from the Lake Nyos crater, killing eighteen hundred people. This CO_2, however, was not placed underground by humans. Another possibility is to inject CO_2 into saline aquifers, geological formations that contain salt water in their pore spaces. These aquifers have the capacity to store up to 10,000 gigatons of CO_2.

• Microalgal Sequestration

One proposed solution for carbon sequestration would be to use microalgae (microscopic algae) to capture CO_2 that is discharged into the atmosphere by power stations and other industrial plants. Several U.S. start-up companies (GreenFuel Technologies, GreenShift, Solix, and Valcent Products) are pursuing this idea by using pilot-scale algal photobioreactors to remove CO_2 from power plant waste gases. Microalgae are photosynthetic microorganisms similar to plants, but they grow quickly and can greatly increase their total biomass within hours. Photobioreactors are various types of closed systems made of an array of transparent tubes in which microalgae are cultivated and monitored.

The design of a photobioreactor is an important factor governing algal productivity for CO_2 sequestration. Photobioreactors should be simple, inexpensive, and energy efficient and should allow a high-cell density of algal growth. For the efficient removal of CO_2 from power plant effluent gases, it would also be advantageous to use algal species that can tolerate and assimilate high concentrations of CO_2 (more than one hundred times atmospheric levels).

Large-scale cultivation of microalgae in photobioreactors as a technology for CO_2 sequestration will have an impact on global climate only if the algal biomass is used to substitute for fossil fuel. Algae in photobioreactors, for example, can be used to generate environmentally friendly biofuels such as biodiesel and hydrogen. Although the use of algal biomass as an energy source releases CO_2, the process as a whole can be considered carbon neutral in that the CO_2 released during conversion to fuel or through the use of fuels had been assimilated during the original growth of microalgae and can be recycled again through uptake by microalgae.

U.S. GHG Sequestration, 1990-2007 (in millions of metric tons of CO_2 equivalent)

Year	*U.S. GHG Emissions*	*Reduction by Sinks*	*Net Emissions*
1990	6,098.7	841.4	5,257.3
1995	6,463.3	851.0	5,612.3
2000	7,008.2	717.5	6,290.7
2005	7,108.6	1,122.7	5,985.9
2006	7,051.1	1,050.5	6,000.6
2007	7,150.1	1,062.6	6,087.5

Data from U.S. Environmental Protection Agency.

• Other Biological Sequestration

Other biological methods of CO_2 sequestration have also been investigated. One is the conversion of CO_2 into methane by microbes called archaea. The resulting methane could be used as fuel. Another biological method of carbon sequestration would be to enhance natural terrestrial ecosystems. Terrestrial ecosystems absorb CO_2 mainly through plant photosynthesis. These ecosystems can help remove CO_2 from the atmosphere by storing it in plant biomass and soils. Certain woody plants, such as poplars, are being considered for CO_2 sequestration. These plants consume CO_2 during vegetative growth and convert it into lignin, a biological compound that is very resistant to decomposition. However, even when woody plants are used, the CO_2 will ultimately return to the atmosphere by fermentation or through respiration by microbes and animals. A potential solution would be similar to microalgal sequestration technologies, involving the use of plant biomass to generate biofuels.

• Chemical Sequestration

In addition to the geological and biological methods mentioned above, there are also chemical methods for CO_2 sequestration. These methods use chemicals such as magnesium silicate, amines, or ammonia to capture CO_2. All known CO_2 sequestration technologies are very expensive. It may therefore be more cost effective to adopt alternative fuels and avoid CO_2 emissions to the extent possible, rather than continuing to emit CO_2 and relying on sequestration to mitigate its greenhouse effect.

Sergei Arlenovich Markov

• Further Reading

Archer, David. *Global Warming: Understanding Forecast.* Malden, Mass.: Blackwell, 2007. One chapter describes how CO_2 functions as a greenhouse gas.

Hall, David O., Sergei A. Markov, Watanabe Yoshitomo, and Krishna K. Rao. "The Potential Application of Cyanobacterial Photosynthesis for Clean Technologies." *Photosynthesis Research* 46 (1995): 159-167. Describes the application of algae for CO_2 sequestration and other clean technologies.

Hawkins, David G., Daniel A. Lashof, and Robert

H. Williams. "What to Do About Coal." *Scientific American*, September, 2006, 68-73. Explains technologies for extracting CO_2 from coal-fired power plants and sequestering it from the atmosphere.

See also: Carbon cycle; Carbon dioxide; Carbon footprint; Fossil fuel emissions; Ocean acidification; Plankton; Reservoirs, pools, and stocks; Sinks.

Siberian river diversion proposal

- **Category:** Water resources

- **Definition**

Until the 1960's, the Aral Sea in Central Asia was the fifth-largest freshwater sea in the world. At 66,900 square kilometers, it was roughly the size of Belgium and the Netherlands combined. It had a major fishery, and seaside resorts were located on its shores in the Soviet Union. Irrigation from the sea's main tributaries, the Amu Dar'ya and the smaller Syra Dar'ya, supported varied agriculture, including some cotton.

Then, the Soviets massively expanded cotton production. The desert of the Aral Sea Basin was the only Soviet region warm enough to grow cotton. The nation increased cotton production and suppressed other crops. It became the world's greatest cotton producer for a number of years.

Cotton is a water-intensive crop, and the necessary irrigation infrastructure installed by the Soviets caused much water to evaporate away rather than flowing to the Aral Sea. Furthermore, inefficient irrigation methods leached salts from the soil to the surface. Farmers fought this salinization by annually "washing" their fields with more water. Finally, the Karakum Canal sent water to an area outside the Aral Sea Basin.

The result of all these factors in combination has been possibly the world's worst ecological disaster. The Aral Sea shrank to three saline lakes with one-tenth the water it once held. Most of its dry seabed became a salty, pesticide-laced desert. Meanwhile, the breakup of the Soviet Union in the early 1990's left five independent countries in the basin: Kazakhstan, Krgystan, Uzbekistan, Tajikistan, and Turkmenistan. Coordinating water policy became an international endeavor and was therefore much more difficult. The five countries have been too poor to be able to switch from cotton, and their decaying irrigation systems are even less efficient than they were in the Soviet days. One initiative has brought increased freshwater to a portion of the original Aral Sea, and this area is diked off from the saline areas. However, this program is only regenerating a small part of the original sea.

One desperate response to this disaster would be massive water diversion from major rivers that flow north into the Arctic Ocean. The Soviets designed such a project and began construction on it from 1976 until 1986, when cost and environmental concerns killed the project. However, the project was revived as a possibility in the early twenty-first century.

- **Significance for Climate Change**

Critics of the Siberian rivers diversion scheme called it fixing one disaster with another. Dams would back up reservoirs, and pumps would take headwaters from these reservoirs into other basins. The Arctic river diversions would actually have started in European Russia, involving 19 cubic kilometers per year, mostly from the Pechora and Sakona Rivers. These waters would have been diverted to the Volga River for drainage to the Caspian. (The small gradient eastward from the Volga would have allowed easy diversion to the Aral Basin.)

Diversion from the Ob and Irtysh Rivers, discharging roughly 385 cubic kilometers of water to the Arctic Ocean each year, might yield as much as 60 cubic kilometers. However, those waters would come at the cost of 3 gigawatts of pumping power to get over the 113-meter Turgay Divide from Western Siberia to the Aral Basin. Then, a 2,200-kilometer Siberal canal would need to be constructed to reach the Aral Sea.

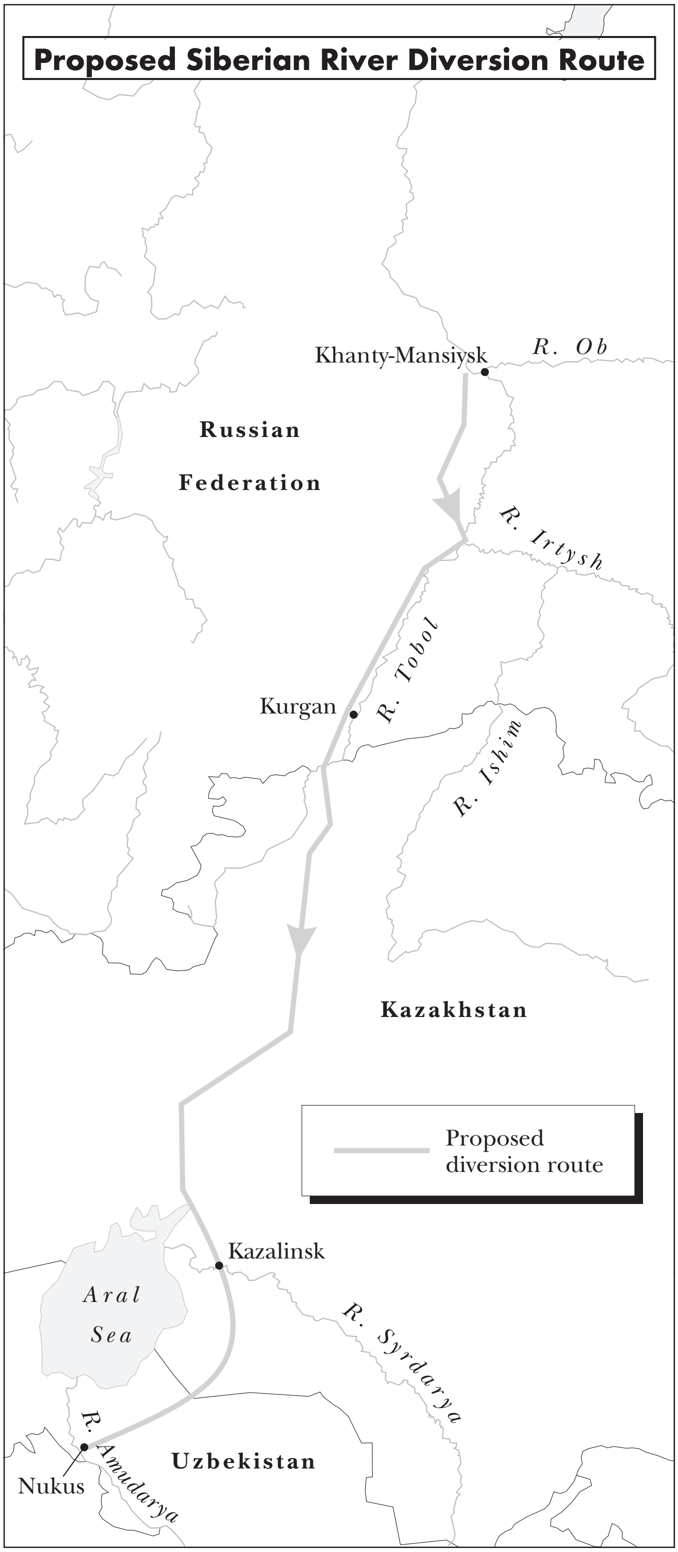
The greatest complaint about these potential diversions has been that better irrigation practices would be more cost effective. Water leakage from the Siberal canal would vastly increase the water demand from the rivers and the cost of the project.

Most important for world climate, these diversions would decrease freshwater flow to the Arctic Ocean. This decrease would be important, because the Arctic is not temperature stratified as tropical and temperate ocean waters are. The Arctic Ocean is salinity stratified. Warmer, saltier water flows northward from the Gulf Stream in the Atlantic (which has become the Norwegian Current) and flows under the frozen freshwater at the surface. These salty waters are as much as 1° Celsius above freezing, while the surface waters are at freezing or below during winter. Moreover, saline water freezes at lower temperatures than does freshwater.

The Siberian river diversions could radically change the Arctic and, consequently, the world's climate. If freshwater inflow were significantly decreased, as from the Aral Sea diversions, the Arctic pack ice might melt in the summer. This would probably contribute to global warming. However, open water could provide more evaporated water to generate snow that could cause global cooling. It would be a global experiment.

That experiment could happen for two reasons. First, the countries around the Aral Sea may go from poverty to oil and gas riches. Second, Russia's government may continue "the Great Game" of the last two centuries by trading water for the allegiance of the countries around the Aral Sea. Third, Russia could also use water moving toward the Aral Basin for its own irrigation.

Roger V. Carlson



• Further Reading

Ferguson, Rob. *The Devil and the Disappearing Sea: Or, How I Tried to Stop the World's Worst Ecological Catastrophe*. Vancouver, B.C.: Raincoast Books, 2003. Canadian public relations expert interweaves analysis with his grim personal account of trying to develop water-savings publicity campaigns in a joint program attempting to unite efforts of the five countries involved with the Aral Sea.

Glantz, Michael J., ed. *Creeping Environmen-*

tal Problems and Sustainable Development in the Aral Sea Basin. New York: Cambridge University Press, 1999. Glantz and his contributors provide a scientific analysis of both causes and results on the ongoing tragedy around the former Aral Sea.

Pearce, Fred. *When the Rivers Run Dry.* Boston: Beacon Press, 2006. Journalist Pearce surveys the Aral Sea disaster as one of the primary instigators of desperate ventures such as the Siberian rivers diversion.

Salay, Jürgen. *The Soviet Union River Diversion Project from Plan to Cancellation, 1976-1986.* Uppsala Papers in Economic History, Research Report 17. Uppsala, Sweden: Uppsala Universitat Press, 1988. This academic report details the diversion project, its history, its advantages, and its problems.

See also: Agriculture and agricultural land; Colorado River transformation; Desalination of seawater; Freshwater; Groundwater; Water resources, global; Water rights.

Sierra Club

- **Category:** Organizations and agencies
- **Date:** Established 1892
- **Web address:** http://www.sierraclub.com

• Mission

The Sierra Club was one of the first major environmental organizations to address climate change. In 2005, the organization took its efforts even further by making climate change the centerpiece of its campaign for environmental protection for the next several years.

Founded in California by renowned environmentalist John Muir, the Sierra Club has grown from a club that promoted outdoor excursions to foster an appreciation for the natural environment, to a grassroots political organization under David Brower, to a political powerhouse with state chapters and national offices in Washington, D.C. Historically, state chapters have focused on issues pertinent to their areas, while the national chapter campaigns for federal solutions to more widespread problems. With the national chapter's commitment to the issue of global climate change, all chapters have converged on the issue, promoting local, regional, and national solutions. The club's mission, while promoting the enjoyment of nature through outings, also includes educating and involving people in the protection of natural resources through all lawful means possible. Their efforts to combat global warming directly relate to their mission.

• Significance for Climate Change

The Sierra Club first put global warming on its agenda in the late 1980's, after scientific reports indicated that humans may be responsible for warming and that the effects could be detrimental. During the 1990's, the Sierra Club focused on pressuring the federal government to take action. In 1992, the group funded a television advertising campaign aimed at President George H. W. Bush and his lack of attention to global warming at the 1992 Earth Summit. The club collaborated with other groups and held the unofficial Global Forum concurrently with the Rio Earth Summit. At the forum, strategies for influencing government that focused on influencing policies at the national level were discussed.

With Democrats in Congress, the Sierra Club maintained a dominant strategy of campaigning for federal action on global warming. This strategy was perpetuated by the election of President Bill Clinton and Vice President Al Gore, who was seen as a sympathizer to the group's cause. Under President Clinton and Vice President Gore, representatives of the Sierra Club and other members of the environmental movement were allowed to the table during policy formulations on global warming. Having open access to this level of policy making facilitated a continuing strategy to focus their efforts on encouraging federal action on the issue. However, the club's efforts did not result in passage of federal legislation, and although Gore signed the Kyoto Protocol, it was seen as a largely symbolic gesture, as the Clinton administration failed to send the document to the Senate for ratification. The federal government had basically refused to make a commitment to greenhouse gas emissions reductions.

The Sierra Club's strategy broadened, and it began a campaign to target automobile manufacturers in the mid-1990's. This campaign initially critiqued the use of cars and sports utility vehicles (SUVs) that have low gas mileage and thus contribute more carbon emissions to the atmosphere. It expanded to target companies making SUVs, and the club launched a full-scale attack on Ford's Excursion in late 1998. In 2000, the Sierra Club presented Toyota with an environmental excellence award for the release of the Prius hybrid. It was the first time in the club's 108-year history that it had honored a product. It continued its disparagement of SUVs into the new millennium.

In 2003, the Sierra Club joined forces with other environmental groups in lobbying the Environmental Protection Agency (EPA) to regulate carbon emissions under the Clean Air Acts (1963-1990), but the agency refused. As a result, the Sierra Club joined other groups, states, cities, and petitioners in a suit against the EPA for not properly enforcing the Clean Air Acts. In 2007, the Supreme Court sided with the Sierra Club in *Massachusetts v. EPA*, agreeing that greenhouse gases (GHGs) could be regulated under the Clean Air Acts.

In 2005, the Sierra Club changed the focus of its conservation efforts. The main goal of its efforts became to move the United States beyond fossil fuel reliance as a solution for reducing carbon emissions. As part of this focus, the organization encourages states and cities to adopt legislation to move beyond fossil fuels. This strategy represented a direct response to a lack of federal action on global warming, although the club continued its traditional efforts to lobby for federal legislation on global warming as well. A cornerstone of this effort was the Sierra Club's Smart Energy Solutions initiative. Within this initiative is the Clean Car Campaign, a continuing effort by the Sierra Club to encourage the federal government and automakers to raise the CAFE standards and allow states to do the same. The club sees improved fuel economy as the most important solution for reducing GHG emissions in the United States.

Another campaign within the Smart Energy Solutions initiative is Cool Cities Campaign. Cool Cities encourages and supports local communities that sign on to the U.S. Conference of Mayors Climate Protection Agreement, an effort started by Seattle mayor Greg Nickels to adopt the Kyoto Protocol at the local level. The campaign encourages new cities to join and provides a network of support for participating cities to share their success stories and learn from the efforts of other cities throughout the country. The campaign also provides support for grassroots organizers wishing to convince their home cities to sign the agreement. The club also encourages legislation at the state level to improve

David Brower stands in his office at the Sierra Club in 1968. (Joe Munroe/Landov) energy efficiency and investment in renewable energy. Furthermore, the club opposes every new coal power plant through litigation and lobbying in an effort to move the country away from fossil fuel dependency.

The Sierra Club educates and encourages individuals to join its campaigns through a variety of outreach methods, including the Two Percent Solution campaign to reduce people's carbon footprints through changes in lifestyle and personal consumption choices. The Two Percent Solution campaign is an effort to reduce carbon emissions by 2 percent per year, the amount needed to reduce emissions by 80 percent by 2050. The club has utilized the Internet to promote the Smart Energy Solutions initiative through the use of mass e-mailings and the Hotline E-newsletter, a bimonthly publication that consolidates news and information about global warming.

Katrina Darlene Taylor

• Further Reading

Bosso, Christopher. *Environment, Inc.: From Grassroots to Beltway.* Lawrence: University of Kansas Press, 2005. Traces changes in environmental organizations, including the Sierra Club, as they evolved over the decades from grassroots to professionalized organizations modeled after businesses. Discussion of the Sierra Club provides insight into the strategies the organization uses to combat global warming.

Hjelmar, Ulf. *The Political Practice of Environmental Organizations.* Brookfield, Vt.: Avebury, 1996. Uses the Sierra Club as a case study to highlight the strategies of environmental organizations in affecting politics. Provides a comprehensive overview of the club's history as a political advocacy organization.

McCloskey, J. Michael. *In the Thick of It: My Life in the Sierra Club.* Washington, D.C.: Island Press, 2005. Insider's perspective on the history and functioning of the organization.

See also: Conservation and preservation; Deforestation; Earth Summits; Ecological impact of global climate change; Environmental economics; Environmental law; Environmental movement; Gore, Al; Kyoto lands; Sustainable development.

Sinks

• **Categories:** Meteorology and atmospheric sciences; pollution and waste

• Definition

A sink is a process or mechanism that removes or absorbs carbon dioxide (CO_2) and other greenhouse gases (GHGs) from the atmosphere. The 1992 U.N. Framework Convention on Climate Change (UNFCCC) defines a sink as any process, activity, or mechanism that removes or absorbs a GHG, aerosol, or precursor of a GHG from the atmosphere.

Sinks, to be so called, must be net sinks—that is, if they also release GHGs into the atmosphere, they must remove more GHGs than they emit. Otherwise, they would count as sources of GHG emissions. The most common sinks are carbon sinks, which include oceans and terrestrial ecosystems such as forestry and soil. Carbon sinks remove carbon from the atmosphere and store them; in the latter respect, they are also referred to as reservoirs.

Forests act as carbon sinks through the process of photosynthesis. Oceans act as sinks when atmospheric CO_2 dissolves in ocean surface waters and is stored there. This continues until the surface waters are saturated, at which point the rate of CO_2 uptake declines. The CO_2 remains in the surface until the oceans turn over, which happens in cycles of about one thousand years. During this overturning, the surface waters move downward, carrying with them the dissolved carbon. This enables the oceans to continue to absorb carbon from the atmosphere.

• Significance for Climate Change

CO_2 is the most important anthropogenic GHG, and the amount of CO_2 in the atmosphere has increased by about 35 percent in the industrial era, mainly by human activities. However, the increase in CO_2 in the atmosphere is less than the increase in CO_2 emissions. This is because, of approximately 400 billion metric tons of carbon released into the atmosphere by human activity in the past two hundred years, only about 40 percent has remained in the atmosphere. The rest has been absorbed by carbon sinks, especially land and oceans. Without these carbon sinks, the amount of CO_2 in the atmosphere, one of the major causes of anthropogenic climate change, would be considerably higher than it currently is.

Terrestrial ecosystems—land and vegetation—currently act as a net global sink for carbon. They are, however, also potentially major sources of GHG emissions. Over the years, deforestation has contributed an estimated 30 percent to GHG concentration. When trees are cut down, the atmosphere is affected in two ways: The trees, which also act as reservoirs of CO_2, release carbon into the atmosphere, and the CO_2 that would otherwise have been removed from the atmosphere by these trees remains in the atmosphere. These two effects of deforestation on the whole make the warming of the climate worse.

Modifying carbon sinks to enhance their carbon uptake would have the effect of slowing the rate of climate change. By reducing the rate of deforestation or by planting more trees (afforestation or reforestation), Earth's carbon sinks can be expanded. Under the Kyoto Protocol's clean development mechanism (CDM), afforestation and reforestation projects are eligible to earn carbon credits. This provides an incentive to increase the planting of trees and hence to enhance Earth's reserve of carbon sinks.

Tomi Akanle

• **Further Reading**

Binkley, C. S., et al. "Carbon Sink by the Forest Sector: Options and Needs for Implementation." *Forest Policy and Economics* 4 (2002): 65-77. Assesses the mitigation potential of forest carbon sinks and identifies some of the outstanding issues that need to be addressed in order to maximize this potential.

Field, Christopher B., and Michael R. Raupach, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Washington, D.C.: Island Press, 2004. Chapters 12-16 contain a description of the carbon cycle as it relates to the uptake of carbon by oceans and land.

Missfeldt, Fanny, and Erik Haites. "The Potential Contribution of Sinks to Meeting Kyoto Protocol Commitments." *Environmental Science and Policy* 4 (2001): 269-292. Analyzes the potential of sinks to help industrialized countries meet their emission-reduction targets under the Kyoto Protocol, the costs of using sinks, and the potential impact the use of sinks could have on industrialized and developing countries.

Nabuurs, G. J., et al. "Forestry." In *Climate Change, 2007—Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by Beth Metz et al. New York: Cambridge University Press, 2007. Assesses the climate change mitigation potential of the forestry sector, analyzing various forest mitigation options.

Prentice, I. C., et al. "The Carbon Cycle and Atmospheric Carbon Dioxide." In *Climate Change, 2001: The Scientific Basis,* edited by J. T. Houghton et al. New York: Cambridge University Press, 2001. In this chapter, the IPCC summarizes the global carbon cycle and the factors influencing removal or release of CO_2 into the atmosphere by carbon sinks.

See also: Carbon dioxide; Carbon footprint; Certified emissions reduction; Clean development mechanism; Greenhouse effect; Greenhouse gases; Reservoirs, pools, and stocks; Sequestration.

Skeptics

• **Category:** Meteorology and atmospheric sciences

• **Definition**

In the climate change controversy, the term "skeptic" is a generic term widely used to denote people who question some or all notions of anthropogenic climate change. The term "denier" was used earlier in the controversy but is unsatisfactory for several reasons. First, many skeptics accept some aspects of anthropogenic climate change. Also, the term "denier" implies arbitrary or unreasonable doubt about anthropogenic climate change, whereas many doubters believe they have sound reason for being skeptical. The term "skeptic" has emerged as a general label used by both sides in the debate, because it is reasonably neutral. There remain people on both sides who use more polemic and less neutral terms to describe the opposition.

The range of skeptical opinion on anthropogenic climate change spans a spectrum from relatively mild and reasonable concerns about data gathering or interpretation, on one hand, to outright denial that climate is changing at all on the other hand. In roughly increasing order of dissent, skeptical positions include:

(1) Concerns about features not adequately modeled by climate studies, such as cloud cover
(2) Concerns about the need to program many assumptions into climate models
(3) Doubts about the validity of computer modeling of climate in general
(4) Doubts about how data are measured
(5) Doubts about how to link recent quantitative measurements with older historical and prehistoric climate indicators
(6) Doubts about whether present climate changes are anthropogenic or are merely part of long-term natural climate changes
(7) Claims that warming of the climate might actually be beneficial
(8) Claims that climate change is too far along to reverse or mitigate
(9) Claims that attempts to halt or reverse climate change would impose unacceptable economic or political costs
(10) Claims that human activities have no effect
(11) Claims that no long-term climate changes are occurring at all
(12) Claims that the Earth is actually cooling, or has begun to cool after a warming period

The first five of these positions are not skeptical per se. All scientists engaged in climate studies are well aware of the problems and uncertainties in climate modeling, and in many cases, scientists who are described in the media as skeptics are merely describing problems that are common knowledge in the scientific community. The polarity of the debate and the desire of the media to maintain that polarity leads many scientists to be described as skeptics who are not skeptics at all: They may be fully convinced of the reality of anthropogenic climate change in general but critical of a particular study or hypothesis regarding that change.

Defenders of the sixth position argue that long-term climate cycles and solar variability are more important than anthropogenic changes. They are not necessarily skeptical of the existence of minor anthropogenic factors, but they doubt that such factors are the primary cause or that changes to those factors are capable of preventing global warming.

The seventh through ninth positions are policy positions rather than scientific ideas. Some people who take those positions agree that humans have modified the climate but believe the costs of trying to reverse the effects outweigh the benefits. They are not necessarily skeptics, but strong advocates of these policy positions very often either are skeptics or are categorized as such within the context of climate policy debates. The last three positions amount to outright denial of anthropogenic climate change.

• Significance for Climate Change

Confirming anthropogenic climate change involves collecting and interpreting vast amounts of data on a global scale and correctly understanding the physical mechanisms that store heat on the Earth. Also, attempting to predict what climate will do in the future requires the use of extremely complex computer models that are still imperfect. Climate change is not merely a scientific question but also one that has enormous implications for economics, public policy, and national security. If governments act to reduce climate change and the predictions of danger are wrong, trillions of dollars may be wasted and enormous harm done to freedom and the economy. If governments do not act and climate change does occur, then the consequences may include coastal flooding, droughts, famine, and vast refugee movements. Anthropogenic climate change presents the frightening prospect of unavoidable risk where every course of action, including doing nothing at all, poses danger.

Some aspects of anthropogenic climate change are settled beyond debate. There is virtually no argument that carbon dioxide (CO_2) has increased in the atmosphere since the start of the Industrial Revolution (roughly since 1750), there is little debate over whether the increase is due to human activity, and it is well established that CO_2 absorbs infrared radiation. Although there are dissenters, more and more people on both sides of the debate agree that Earth's climate is getting warmer. The debate over anthropogenic climate change revolves mostly around how much of the warming is due to human activity, how certain scientists can be of a human role, and whether it is possible or desirable to intervene.

Unfortunately, in addition to people who question anthropogenic climate change for responsible scientific reasons or who debate whether attempts to affect climate change will be useful, there are people in the skeptic camp who exploit legitimate questions as a pretext for outright denial of climate change. For example, many prominent skeptics have ties to front organizations run by business and political interests opposed to attempts to reduce greenhouse gas emissions. Some skeptics distort or misinterpret credentials. A common example is for media weather reporters to comment on climate change, even though many do not have scientific credentials relevant to climate research. In another example, U.S. senator James Inhofe of Oklahoma published a Web page in 2007 claiming that 650 prominent scientists rejected climate change, but detailed examination of the list shows that over half of those listed have no qualifications at all to comment on climate change.

Steven I. Dutch

• Further Reading

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Climate Change: A Guide to the Debate*. New York: Cambridge University Press, 2006. Overview of the controversy over global warming that includes analysis of the philosophical and practical issues raised in general by the intersection of politics and science.

Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change*. Boston: Beacon Press, 2007. The chapter "Turning Up the Heat: A Skeptic's Guide to Climate Change" lays out a careful response to global warming skeptics that addresses their concerns.

Pittock, A. Barrie. *Climate Change: Turning Up the Heat*. Sterling, Va.: Earthscan, 2005. Includes a chapter on the function of skeptics and uncertainty in the global warming debate.

See also: Scientific credentials; Scientific proof.

Skin cancer

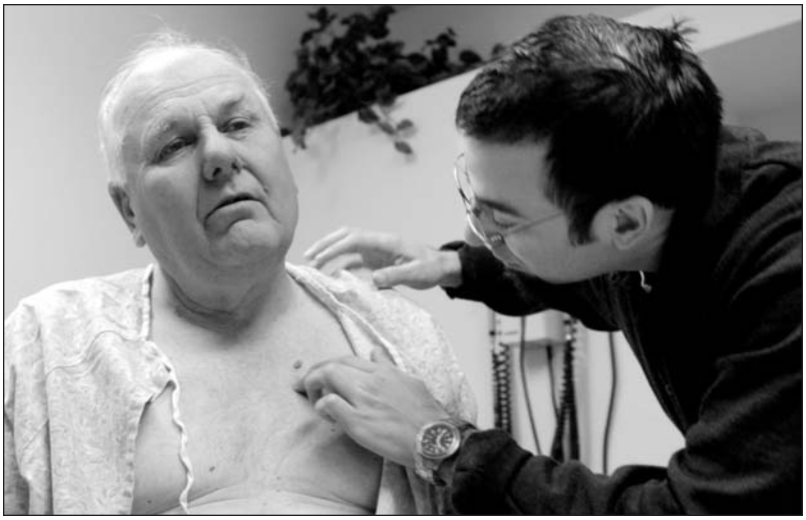
• **Category:** Diseases and health effects

• Definition

Skin cancer is the most common type of cancer in the United States, with about one million Americans developing skin cancer each year. The two most common types of skin cancer are basal cell and squamous cell cancers. These nonmelanoma skin cancers are less serious than melanoma. Most basal cell and squamous cell skin cancers can be cured if found and treated early. Left untreated, however, they can spread and cause more serious health problems.

Although skin cancer can occur anywhere, these cancers usually occur on parts of the skin frequently exposed to the Sun, such as the face, head, neck, hands, and arms. Basal cell carcinoma, the most common type of skin cancer, grows slowly and rarely spreads to other parts of the body. Squamous cell carcinomas are more aggressive, sometimes spreading to lymph nodes and body organs. Another skin disorder related to Sun exposure is actinic keratoses, premalignant skin growths that develop on body areas exposed to the Sun and are considered a risk factor for developing squamous cell carcinoma. Although much less prevalent than other types, melanoma is the most serious type of skin cancer and is also one of the fastest-growing cancers. Melanoma occurs in skin pigment cells called melanocytes, which produce melanin and give skin its natural color. Melanoma can occur on any skin surface and can become invasive and spread to other parts of the body.

Most skin cancers are caused by exposure to sunlight or ultraviolet (UV) radiation. Although the chance of developing skin cancer increases with



A dermatologist examines cherry orchard owner Gary Honald for possible skin cancer. (Benjamin Brink/The Oregonian/Landov)

age, especially after age fifty, skin damage from the Sun can occur at an early age, and skin cancer can affect people of all ages. Skin cancer risk is associated with exposure to UV radiation over a person's lifetime. Skin cancers are more common in individuals with fair skin that burns or freckles easily and in people who have red or blond hair and light-colored eyes. Although it is less common in darker-skinned individuals, they also are susceptible to skin cancer.

• Significance for Climate Change

The incidence of skin cancers is likely to increase with global warming. Ultraviolet radiation comes from the Sun; two types of rays, UVA and UVB, reach the Earth's surface. Although UVB rays are more likely than UVA rays to cause sunburn, UVA rays penetrate further into the skin. Many studies have demonstrated that exposure to UV radiation has contributed to the worldwide increase in skin cancers, including malignant melanoma. People who live in areas that get large amounts of UV radiation have a higher risk of skin cancer.

In the United States, areas in the south, such as Texas and Florida, receive more UV radiation than areas in the north, such as Minnesota. Skin cancers occur more commonly per capita in Australia and in other parts of the Southern Hemisphere. People who live in the mountains are also exposed to higher levels of UV radiation. In Santiago, Chile, the incidence of melanoma increased by 105 percent between 1992 and 1998. In some parts of the world, especially Western countries, melanoma is becoming more common every year, with the percentage of people developing melanoma more than doubling in a thirty-year period; this increase is expected to continue.

One of the major environmental changes associated with global warming is depletion of the ozone layer. The ozone layer forms a physical barrier in the stratosphere and protects living organisms from harmful UV radiation coming from the Sun. Scientists have documented a decrease in the ozone layer during the latter part of the twentieth century, and this decrease is expected to continue into the twenty-first century. The decrease in ozone levels permits more UV radiation to pass through the atmosphere and reach Earth's surface. Although the amount of UV radiation produced by the Sun does not change, the ozone layer provides less protection as it gets smaller. The amount of UVB radiation measured at the Earth's surface doubles during the annual formation of an ozone hole over the Antarctic. A relationship between reduced ozone and increased UVB levels was also confirmed in a study conducted in Canada.

Ozone depletion and the resulting increase in UV radiation have significant human health effects. Since more UV radiation reaches the Earth, human exposure to these harmful rays is increasing. Among other potential effects on human health, this situation may entail increases in the incidence of skin cancers, including melanoma. People having lightly pigmented skin will be most susceptible. Changes in the immune system may also occur, and although such alterations do not directly cause skin cancer, they may impair the body's ability to defend against cancer.

C. J. Walsh

- **Further Reading**

Barrow, Mary Mills, and John F. Barrow. *Sun Protection for Life: Your Guide to a Lifetime of Healthy and Beautiful Skin*. Oakland, Calif.: New Harbinger, 2005. Explains sun protection and discusses changing environmental factors that influence solar exposure.

Hanslmeier, Arnold. *The Sun and Space Weather*. 2d ed. Dordrecht, the Netherlands: Springer, 2007. Provides a general introduction to the physics of the Sun, including possible influence of the Sun on Earth's atmosphere and climate.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry et al. New York: Cambridge University Press, 2007. Written by the world's leading experts on climate change, this volume provides a comprehensive and balanced assessment of the subject with up-to-date information on climate change issues.

Nilsson, Annika. *Ultraviolet Reflections: Life Under a Thinning Ozone Layer*. New York: John Wiley and Sons, 1996. Examines effects on living organisms of increasing ultraviolet radiation that is due to ozone-layer depletion.

Urbach, Frederick. "Potential Health Effects of Climatic Change: Effects of Increased Ultraviolet Radiation of Man." *Environmental Health Perspectives* 96 (1991): 175-176. Reviews potential human health impacts of increased ultraviolet radiation.

See also: Ozone; Sun; Sun protection; Ultraviolet radiation.

Slab-ocean model

- **Category:** Oceanography

- **Definition**

A slab-ocean model is a simple, nondynamic, computer-generated ocean model used in coupled simulations between ocean and atmosphere where the ocean is represented as a motionless layer of water with a depth of 50-100 meters. "Slab" refers to the layer of nominal thickness of water chosen to represent simple upper-ocean seasonal heat capacity. In slab models, sea surface temperatures (SSTs) are computed from surface energy balance and heat storage, appearing as a fixed-depth, homogeneous, mixed layer of water with no ocean currents. Because of their general nature, slab-ocean models are also referred to as "simple mixed-layer models" or "bulk models." Standardized equations are used to define the momentum, temperature, and salinity of the model's mixed layer, implying that these parameters are constant over the depth of the model's mixed layer.

When run coupled with atmospheric data, a slab-ocean model can simulate seasonal cycles of upper-ocean heat storage, permitting a simplified understanding of the seasonal cycle and its effects on climate sensitivity: Shifts in climate are reflected as changes to the seasonal heat capacity of the upper ocean. Changing input values can cause the defined slab-ocean layer to act as a heat source or sink for a larger model, and to some extent it can simulate the effect of moving currents. However, there is no true current or upwelling (vertical motion) in a slab-ocean model, so it can only simulate the climate effects of a steady ocean current. As a result, a slab-ocean model cannot simulate a dynamic change in an ocean current, upwelling, or overturning of circulation due to atmospheric climatic changes. Since ocean currents are a major portion of real ocean morphology and they are not represented in slab-ocean models, the models cannot simulate all aspects of SST distributions.

Ocean currents work to move heat horizontally from the tropics poleward, and excluding currents from slab models tends to produce simulations in which SSTs are higher in modeled tropical environments and colder in modeled high latitudes than they are in actuality. Slab models also exclude the contributions of upwelling, which produces temperature changes in upper ocean layers. As a result, areas rich in upwelling regimes require input corrections.

In an effort to correct such temperature errors in slab-ocean models, simulations often include a heat flux value called the *Q*-flux. The heat flux correction simulates a source of heat transport producing effects similar to those generated by real ocean currents, but, when running slab-ocean models, the same *Q*-flux corrections must be run in both the control and forced simulations to maintain experimental integrity. Changes to upper-ocean temperatures due to increased atmospheric temperatures, melting ice, or increased radiation can be simulated simplistically and run to equilibrium with *Q*-flux corrections.

Equilibrium for a slab-ocean model is the point at which the atmosphere and the ocean reach a balanced state, such that the climate variables being measured do not drift toward another state. Taken as a representation of thermodynamic equilibrium, slab models may reflect changes to the climate system, assuming the observed ocean heat transport is the same in both controlled and forced experiments. Forcing parameters in slab-ocean models include energetic effects of surface fluxes, such as solar radiation; work from waves; buoyancy dissipation; and frictional effects of wind.

• Significance for Climate Change

In climate studies, slab-ocean models are used to estimate the equilibrium response of climate to a given forcing, not the transient evolution of climate. Also, as the model's layer is considered motionless, the model cannot reflect ocean circulation changes resulting from environmental changes. In spite of their simplistic nature and problems with SST errors due to known ocean currents and upwelling, slab-ocean models are useful in researching global climate sensitivity and have helped establish data for the assessment of global response to such forcing mechanisms as increased atmospheric carbon dioxide and melting ice. In practice, their sensitivity to upper-ocean-layer temperature changes causes slab-ocean models to be affected by data reflecting changes in sea ice and glacial melt waters.

The Earth's oceans and atmosphere have different response times to changes: ocean depths may take centuries to react to a change in forcing, whereas the atmosphere may respond in days. Because of their limited thickness parameters, slab models do not take a long time to adjust to forcings applied to the model. Where complex models reflecting the slow response time of deep-ocean circulation may require changes to develop over hundreds or thousands of model years to reach equilibrium, slab models reach equilibrium in twenty to thirty model years for a 50-meter-thick slab. As a result of a slab model's simplified parameters, researchers can get reasonable results for the overall effect of a forcing as a percent increase or decrease using less computing time than would be consumed by a more complex model.

Coupling slab-ocean models with atmospheric models allows for a quick comparison of differences in the timescales over which ocean and atmospheric phenomena form and react to changes. When coupled ocean and atmospheric models are further coupled with additional models, such as carbon or nitrogen models, they produce increasingly accurate simulations of the Earth's climate. These coupled models, however, retain all errors introduced in each individual simulation, and this fact imposes an important constraint on the models' collective findings.

Randall L. Milstein

• Further Reading

Griffies, S. *Fundamentals of Ocean Climate Models*. Princeton, N.J.: Princeton University Press, 2004. Describes the physical, mathematical, and numerical basis of computer climate models.

Kiehl, J. T., and V. Ramanathan, eds. *Frontiers of Climate Modeling*. New York: Cambridge University Press, 2006. Addresses key aspects of coupled ocean-atmosphere models and the history of their development.

Siedler, G., J. Church, and J. Gould, eds. *Ocean Circulation and Climate: Observing and Modeling the Global Ocean*. New York: Academic Press, 2001. Provides the basis of ocean-atmosphere circulation models used for projecting climate change.

Toba, Y., ed. *Ocean-Atmosphere Interactions*. Tokyo: Terra Scientific, 2003. Describes basic dynamics, data analysis techniques, remote sensing, and numerical modeling of ocean-atmosphere interactions.

See also: Climate models and modeling; Climate prediction and projection; General circulation models; Ocean-atmosphere coupling; Ocean dynamics.

Soil erosion

• **Category:** Environmentalism, conservation, and ecosystems

Soil is one of Earth's most vital natural resources. Erosion removes topsoil, reduces soil fertility, lowers the primary productivity of plants, and thus diminishes the land's capacity to hold CO_2 and other GHGs. Climate change, especially in precipitation and temperature, can exacerbate soil erosion, which in turn may help drive climate change.

• Key concepts

conservation tillage: practices designed to leave stubble and other crop residues on the land surface to reduce soil erosion and surface runoff

cover crops: plants grown to cover the land surface for the purpose of managing soil fertility, soil quality, water, weeds, pests, diseases, diversity, or wildlife

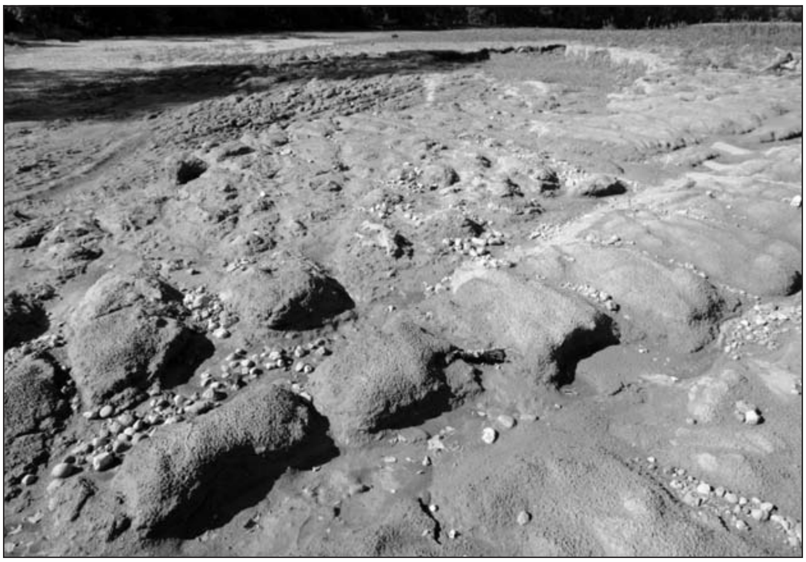
intercropping: the cultivation of two or more crops simultaneously on the same field

land management: the oversight and planning of land use and development

runoff: precipitated water flowing over land toward water bodies, including the land surface material dislodged and carried by it

• Background

Soil is the material formed from weathering rocks and decaying plants and animals. It is considered a nonrenewable resource on a human timescale, because it takes thousands of years to form fertile soil. The degradation of soil quality is thus considered permanent and irreversible. President Franklin D. Roosevelt once wrote, "A nation that destroys its soils, destroys itself." Soil is the foundation on which agriculture produces all goods that sustain human society. Thus, it is paramount to preserve this resource in order to maintain agricultural productivity and environmental quality. A changing climate, especially in terms of temperature and precipitation, affects soil quality through heightened erosion and accelerated runoff.



The soil of this Indiana cornfield was badly eroded by flooding in July, 2008. (AP/Wide World Photos)

• Agricultural Practices

About 80 percent of the world's agricultural land is affected by soil erosion. Intensive agriculture practices have resulted in changes in soil structure and its microbial community and made the land more prone to erosion and surface runoff. Because topsoil supplies plant roots with much of the nutrients required for growth, the loss of topsoil necessitates the application of chemical fertilizers to replenish the lost nutrients. The short-term solution of using fertilizers and other chemicals, however, has led to several long-term detrimental effects. First, the resulting structural changes reduce the porosity and infiltration rate of soil and lower the land's capacity to hold water. These in turn increase surface runoff and soil erosion. Second, both topsoil loss and applied chemicals act to reduce microbial diversity and population levels in the soil. As a result, even a very limited amount of organic residue cannot be readily converted to useful soil ingredients.

The overuse of chemical fertilizers also creates other environmental problems. For example, there exists a progressively diminished return from fertilizer applications. As a result, higher doses of fertilizers are needed to maintain the same level of crop yields. The hiked application of agro-chemicals further damages the soil structure and microbial community, creating a vicious cycle of soil erosion. Historically, natural erosion rates varied from 38 to 161 grams per square meter per year. Erosion from present-day farmland reaches an average of 577 to 966 grams per square meter per year. In addition, excess fertilizers are washed off to streams and lakes, causing eutrophication. The most potent greenhouse gas (GHG), nitrous oxide, is also released from excess fertilizers. Other agricultural practices that are known to intensify soil erosions include row-cropping, tillage, and monocropping.

• Impact of Climate Change

Several major climate factors contribute significantly to soil erosion, including temperature, precipitation, carbon dioxide (CO_2) concentration, and wind. Increasing temperatures contribute to soil erosion indirectly in several ways. First, warmer temperatures can increase biomass production rates as a result of a faster accumulation of the required growing degree-days for crop maturity. Second, temperature affects microbial activity levels and subsequently the decomposition rates of plant residues in the soil. Higher temperatures mean faster decomposition, which may lead to more soil erosion due to a low level of ground cover by residues. Third, temperature has major impacts on evapotranspiration rates, which affect soil moisture, which in turn influences water infiltration rates and runoff amounts. Finally, extended periods of high temperatures may lead to drought and make soil prone to wind erosion or water erosion when storms do fall.

Soil erosion and runoff patterns often follow those of annual precipitation. Predictions from various modeling systems all seem to suggest that, where precipitation increases significantly, erosion also increases significantly. A 7 percent increase in precipitation in Great Britain could lead to a 26 percent increase in erosion. A 10 percent rainfall increase in South Africa could lead to a 20-40 percent increase in runoff. For the U.S. Corn Belt, a 20 percent precipitation hike was predicted to result in a 37 percent increase in erosion and a 40 percent increase in runoff. Wetter soil from precipitation entails lower infiltration rates and increased surface sealing, both of which may increase runoff rates. Increased runoff leads to heightened shear stress, which in turn increases the detachment force of the flow and thus increases erosion.

Atmospheric CO_2 concentrations affect soil erosion directly through the amount of biomass accumulation and transpiration by plants and indirectly as a GHG. Higher CO_2 levels may increase photosynthetic rates, which lead to higher biomass accumulation, which in turn affects ground residue cover. Increased plant residue results in reduced soil erosion and runoff. At the same time, increased CO_2 may suppress transpiration through stomatal resistance, which leads to wetter soil, conducive to higher runoff-induced erosion. Increased air CO_2 levels may warm the climate and exert their effects through higher temperatures as well. Increased wind erosion is often associated with rising air temperatures, excessively dry soil due to drought, lack of ground cover or wind breaker, and high wind speed.

• Context

Despite the known damaging effects of soil erosion, there is little reliable information regarding its global impacts, nor is there a comprehensive monitoring system to gather data. There is little doubt, however, that soil erosion has been accelerated during the past century. Studies using various modeling systems have all demonstrated that climate changes contribute to soil erosion. Up to 68 billion metric tons of topsoil are eroded annually, an equivalent of 90,000 square kilometers of productive land lost.

Erosion results directly in the loss of topsoil and reduction of soil fertility, both of which lead to lower crop yields and higher production costs. Indirectly, erosion causes sediment movement and deposits that create problems downstream, including the clogging of water ways, increased potential for floods, decreased reservoir capacity, and poorer water quality resulting from agro-chemical contamination. Minimizing erosion is important not only for the present but also for generations to come. Soil erosion should be monitored through a comprehensive network that is fully equipped and standardized across the globe. Sustainable agricultural practices will make significant differences in erosion control: Conservation tillage, crop rotations, intercropping, and cover crops will all help reduce soil erosion.

Ming Y. Zheng

- **Further Reading**

Hillel, D. J. *Out of the Earth.* New York: Free Press, 1991. Provides convincing evidence of humanity's mistreatment of soil in the past and the present. Paints a clear and grave picture regarding the consequences humanity must face as a result of soil degradation.

Lindert, Peter H. *The Shifting Ground: The Changing Agricultural Soils of China and Indonesia.* Cambridge, Mass.: MIT Press, 2000. Insightful and thought-provoking discussion of events in China and Indonesia, where soil erosion has not created extensive loss of topsoil, and what the world can learn from these agricultural systems.

Roose, Eric J., et al., eds. *Soil Erosion and Carbon Dynamics.* Boca Raton, Fla.: CRC Press, 2006. Comprehensive review of soil erosion and its role in the carbon cycle. Drives home the message that global climate change is the most serious environmental problem in the twenty-first century.

Soil and Water Conservation Society. *Climate Change: Soil Erosion and Runoff from Cropland.* Ankeny, Iowa: Author, 2003. Assesses the state of soil erosion and projects the impacts of climate change on soil loss from cropland.

See also: Agriculture and agricultural land; Carbon dioxide; Conservation and preservation; Nitrogen fertilization.

Solar cycle

- **Category:** Astronomy

- **Definition**

Temporary dark markings on the surface of the Sun, known as sunspots, have been observed since ancient times. As seen from Earth, though, most sunspots are too small to be observed with the naked eye. It was not until the invention of the telescope that sunspots could be observed with regularity. Sunspots were a regular feature on the face of the Sun in the early seventeenth century; however, sunspots all but disappeared later in that century for a period of time lasting into the eighteenth century. This period with almost no sunspots is called the Maunder Minimum.

By the beginning of the nineteenth century, astronomers had recognized that the number of sunspots increased and decreased according to a pattern. A peak number of sunspots, called the solar maximum, occurs about every eleven years. The cycle of sunspot activity does not have an exact period, however, with some cycles lasting closer to ten years and others lasting close to twelve years. Furthermore, each sunspot cycle does not result in the same average number of sunspots at its maximum. Every sunspot cycle is a little different from the other cycles.

Sunspots are visible signs of magnetic activity on the Sun. Sunspots form in regions of intense magnetic field activity. These active regions are also the locations of huge explosive releases of magnetic energy called solar flares. The more active the Sun's magnetic field becomes, the more sunspots will appear on its surface. Astronomers have also found that, during each sunspot cycle, the Sun's magnetic field is reversed from that of the cycle before. Thus, the magnetic field follows a twenty-two-year cycle, composed of two eleven-year sunspot cycles.

- **Significance for Climate Change**

Since the advent of space-based observations of the Sun, astronomers have found that the Sun's energy output varies slightly with the sunspot cycle. The more active the Sun is, the more active the sunspot cycle, and the greater the solar irradiance. Since solar energy is the driving force behind Earth's climate, variations in the Sun's energy output could potentially result in climate change. The variation in solar energy is very small, typically less than 0.1 percent. Small changes of that magnitude, averaged out over a solar cycle, should not have a long-term effect on the climate. However, not all sunspot cycles are equal in activity. Some are more active than average and some are less active than average. Historical data indicate that sunspot cycles sometimes exhibit trends in activity over long periods of time. An extended period of unusually active or unusually inactive sunspot cycles could have a cumulative effect on the climate.

During the Maunder Minimum in the seventeenth century, a significant shift toward a cooler climate was observed in many locations. This period of cooling is called the Little Ice Age. (The term "Little Ice Age" is used differently by different writers. Many use it to refer to the climate cooling from about 1300 to 1850, while others use it for the latter half of that interval, when cooling was greatest, beginning around 1550 or 1600.) There is no proof that there was a causal relationship between the two events, but most solar astronomers believe that the Maunder Minimum and the Little Ice Age are connected. Furthermore, there has been a general trend of increasing activity since the Maunder Minimum. Detailed measurements of solar irradiation go back only about a half century. During that time, there has been an observed correlation between solar energy output and the average number of sunspots. Thus, it makes sense that during the Maunder Minimum, the Sun was less active and was providing less solar energy to Earth than normal, resulting in a general cooling of the climate.

If the correlation between sunspot numbers and solar irradiation is consistent, the general increase in average solar activity since the Maunder Minimum would be expected to correspond with a period of increased solar heating of the Earth. Some researchers believe that much of the global warming observed during this time period may be the result of natural solar energy increases. Other researchers, though, dispute the degree of change in solar energy output, suggesting instead that the increase in solar energy reaching Earth may only partially explain the observed temperature increases on Earth during the same period of time. If it is true that current global warming trends are the result of increased solar activity rather than human activity, it is unclear whether any human actions could reverse those trends, since they may not be a function of greenhouse gas (GHG) levels. On the other hand, a correlation between solar activity and global warming does not in and of itself establish that atmospheric GHG concentrations are unrelated to warming. Both factors could be contributors to climate change.

The Sun emits more charged particles when it is more active. These charged particles interfere with galactic cosmic rays, changing the amount of carbon 14 produced on Earth. Increased activity results in less carbon 14. These changes can be monitored by measuring the carbon 14 content of artifacts of known age. Such studies seem to support the hypothesis that increases in solar activity correlate with warmer periods in Earth's climate history and periods of reduced solar activity correlate with cooler periods in history.

Raymond D. Benge, Jr.

• Further Reading

Hoyt, Douglas V., and Kenneth H. Schatten. *The Role of the Sun in Climate Change.* New York: Oxford, 1997. Provides an extremely well written and easy-to-follow explanation of how solar variations can affect climate. Extensive bibliography.

Leroux, Marcel. *Global Warming: Myth or Reality? The Erring Ways of Climatology.* Chichester, West Sussex, England: Praxis, 2005. Describes both natural and anthropogenic climate change, with many references. Some discussion is given to the role of solar variations in producing climate change.

Odenwald, Sten F. *The Twenty-Third Cycle: Learning to Live with a Stormy Star.* New York: Columbia University Press, 2001. Well-referenced layperson's guide to solar activity over a sunspot cycle and the geomagnetic effects of solar storms that occur during high sunspot activity.

Soon, Willie Wei-Hock, and Steven H. Yaskell. *The Maunder Minimum and the Variable Sun-Earth Connection.* River Edge, N.J.: World Scientific, 2003. The bulk of the book is about the Sun's Maunder Minimum, with discussions of climatic changes occurring at that time. Good bibliography.

See also: Faculae; Little Ice Age; Medieval Warm Period; Sun; Sunspots.

Solar energy

- **Category:** Energy

- **Definition**

Solar energy includes all human-derived means of collecting and utilizing energy from the Sun, for such applications as heat, air conditioning, or electric power generation. Two primary classes of solar energy are photovoltaics, converting radiant energy into electricity, and thermal solar, using radiant energy for heat or directly to power air-conditioning units. Thermal solar energy may be subdivided into active systems and passive systems.

Active systems require another source of energy, typically electricity, to power pumps or fans. These systems may be used to provide domestic hot water, to heat the interior of a building, or in some cases to provide steam. Active systems include flat-panel, exterior, stationary collectors and systems that concentrate solar rays in order to produce higher temperatures. Arrays of mirrors have also been used to concentrate diffuse sunlight in a small region, where extremely high temperatures may be achieved. Other focusing systems use troughs of parabolic mirrors to reflect light to a central axis, where a contained moving fluid transports the heat.

Passive systems require no input energy beyond that of the Sun itself; they convert sunlight directly into space heat for buildings. Three types of passive systems are direct gain, indirect gain, and attached gain. Direct gain systems utilize large expanses of glass facing toward the equator to admit sunlight, as well as substantial amounts of interior mass to avoid overheating. Indirect gain systems place a dark-colored, massive wall close to sunward-facing glass. The wall converts sunlight into heat, which then radiates into the room. The third passive system, attached gain, is essentially a greenhouse attached to the sunward wall of a building and accessible through insulated doors. When the greenhouse is warm, the doors are opened to provide heat to the rest of the building; when the greenhouse is cold, the doors remain closed.

A fourth type of passive system, used for domestic hot-water production, is the thermo-siphon. It utilizes flat-plate collectors, with a water storage tank placed at a higher elevation than the top of the collectors. When water in a collector is heated by the Sun, it naturally rises and enters the storage tank, where a heat exchanger transfers the heat to a hot-water line. The rising collector fluid creates a siphon effect, which maintains the circulation.

- **Significance for Climate Change**

Global warming is likely caused in part by the anthropogenic release of carbon dioxide (CO_2) from the combustion of fossil fuels. Moreover, fossil fuels, as a nonrenewable resource, are being depleted by energy-intensive nations such as the United States. Enough solar energy reaches Earth to provide virtually all of humanity's energy needs if it can be collected and used efficiently. Solar technology is not yet capable of exploiting solar energy to such an extent, but research is ongoing. Meanwhile, fossil fuels still provide the vast majority of the energy

A bank of photovoltaic cells in Spain collects solar energy and converts it to electricity. (©Milacroft/Dreamstime.com) consumed in the production, delivery, and utilization of consumer goods.

Crude oil is the most important raw material for industrial manufacturing, but it is a nonrenewable resource that may reach peak production in the near future. Ecological destruction is also associated with resource recovery and manufacturing. Thus, it is in the best interests of contemporary industrialized societies to engage in a concerted effort to transition to renewable energy and environmentally sustainable resource use by terminating the dependence on fossil fuels.

Solar energy is a dilute source of energy that lends itself to small-scale applications. In almost any location in the United States, homeowners can reduce their dependence on fossil-fuel-derived energy by passive solar design or retrofitting an existing structure for passive solar gain. Although even a good solar design will not usually eliminate the need for a backup system in locations where winters tend to be overcast, it can substantially reduce energy consumption. Active systems for domestic water heating can provide 100 percent of a family's needs, since, unlike space-heating systems, they can be used throughout the summer.

Passive solar energy uses few nonrenewable resources and creates no pollution; active systems require collectors that necessitate using nonrenewable resources, such as copper and aluminum, but these are recyclable. Furthermore, well-constructed collectors will function for decades. Photovoltaic systems are still relatively expensive, but the price is expected to decline in the near future. Although it may not yet be cost effective to derive all of one's electrical energy needs from photovoltaics, the systems will reduce dependence on the electrical grid, and if more energy is generated than is required, the excess can be sold back to the utility company.

George R. Plitnik

• Further Reading

Anderson, Bruce, and Malcolm Wells. *Passive Solar Energy*. 2d ed. Amherst, N.H.: Brick House, 1994. Authoritative work containing succinct but inclusive information sufficient to guide both amateurs and professionals in constructing a passively heated solar dwelling.

Chiras, Daniel D. *The Solar House: Passive Heating and Cooling*. White River Junction, N.H.: Chelsea Green, 2002. Provides all the detailed information and diagnostic aids necessary to design and build a solar home incorporating solar power for both heating and electricity.

Michaels, Tim. *Solar Energy Utilization*. New York: Van Nostrand Reinhold, 1979. Presents comprehensive information on active systems, including sizing, collectors, and storage.

Ramsey, Dan. *Solar Power for Your Home*. New York: Alpha Books, 2003. Covers virtually all aspects of solar power, including photovoltaic systems and wind energy. Includes ideas for improving energy efficiency, calculations for sizing systems, and the practical means to achieve an energy-efficient lifestyle.

Scheer, Hermann. *The Solar Economy: Renewable Energy for a Sustainable Global Future*. London: Earthscan, 2004. Explores how and why humans must transition from fossil fuel economies to an alternative-energy-based supply. Provides the economic analysis to show how this can be achieved with minimal disruption to society.

Solar Energy International. *Photovoltaics Design and Installation Manual*. Carbondale, Colo.: New Society, 2004. Includes all the detailed information necessary to design, size, install, and maintain photovoltaic systems.

See also: Clean energy; Energy efficiency; Energy resources; Renewable energy; Sun.

SourceWatch

- **Category:** Organizations and agencies
- **Date:** Established 2003
- **Web address:** http://www.sourcewatch.org

• Mission

SourceWatch has a general mission of monitoring and reporting on efforts by propagandists and public relations organizations to shape public opinion. Although climate change is not its sole mission, the large number of front organizations active in the controversy make climate change a major area of concern, and SourceWatch has a portal dedicated to climate change.

SourceWatch is a Web site run by the Center for Media and Democracy. It began as Disinfopedia in March, 2003. The name was a conscious play on Wikipedia, and, like Wikipedia, Disinfopedia was a wiki-based (user-written and -edited) reference site. The name was changed to the present SourceWatch in January, 2005. The site has a strong resemblance in format and appearance to Wikipedia, but it uses different logos and color schemes to distinguish itself. Also, in an effort to regulate editing, the site adopted a policy in 2006 of requiring users to register before being allowed to edit content. In addition to SourceWatch, the Center for Media and Democracy hosts numerous sites such as Congresspedia, which reports on Congress, and wikis devoted to the tobacco industry, nuclear issues, election protection, and climate change. All of these sites are cross-linked.

SourceWatch

SourceWatch describes itself in these terms:

SourceWatch is a collaborative project of the Center for Media and Democracy to produce a directory of the people, organizations and issues shaping the public agenda. A primary purpose of SourceWatch is documenting the PR and propaganda activities of public relations firms and public relations professionals engaged in managing and manipulating public perception, opinion and policy. SourceWatch also includes profiles on think tanks, industry-funded organizations and industry-friendly experts that work to influence public opinion and public policy on behalf of corporations, governments and special interests. Over time, SourceWatch has broadened to include others involved in public debates including media outlets, journalists, government agencies, activists and nongovernmental organizations. Unlike some other wikis, SourceWatch has a policy of strict referencing, and is overseen by a paid editor. SourceWatch has 43,353 articles [as of April 8, 2009].

• Significance for Climate Change

It is important to realize that being funded by industry, being supportive of industry, and working to influence public opinion do not automatically make someone's ideas wrong. Knowing that an organization has a secret purpose or source of funding can be useful, because it demonstrates the need to beware of distorted facts and arguments and the need to cross-check information against other sources. However, the simple fact that someone has connections to industry does not prove anything about the truth or falsity of that person's statements.

Although SourceWatch has a political stance that can be described as liberal, environmentalist, and critical of corporations, it generally avoids a polemic tone, although a somewhat sarcastic tone is evident on some of its portal pages and lead articles. Most of the articles are quite short, with longer commentary and analysis found on the other sites linked to SourceWatch. The political orientation of SourceWatch is evident not so much in the content of its articles as in the selection of topics it chooses to include, as well as the other sites it links to.

SourceWatch's portal on front groups includes many references to organizations secretly working on behalf of industry, but none to groups opposed to tort reform and secretly supported by the legal profession or to groups with hidden ties to radical leftist movements. SourceWatch does have the virtue that its articles have extensive references. SourceWatch can provide a quick overview of an author's stance on political or environmental issues, as well as information about groups that sponsor the author's work. It is also a useful starting point for finding links to additional information on people, organizations, and issues related to politics and the environment.

Steven I. Dutch

• Further Reading

Herman, Edward S., and Noam Chomsky. *Manufacturing Consent: The Political Economy of the Mass Media.* New York: Pantheon, 2002. Analyzes ways that media coverage is influenced by government and corporate interests. Written by acclaimed experts on media and its use in shaping opinion, both unabashedly strongly liberal in their political beliefs.

Union of Concerned Scientists. *Smoke, Mirrors, and Hot Air: How ExxonMobil Uses Big Tobacco's Tactics to Manufacture Uncertainty on Climate Science.* Cambridge, Mass.: Author, 2007. Details the role of front organizations in creating doubts about the dangers of tobacco and describes how the same methods, and even some of the same organizations and spokespersons, have been used to attack the credibility of climate change.

See also: Conservatism; Journalism and journalistic ethics; Liberalism; Libertarianism; Media; Scientific credentials; Scientific proof.

South Africa

- **Category:** Nations and peoples
- **Key facts**

Population: 48,687,000 (July, 2008, estimate)
Area: 1,219,912 square kilometers
Gross domestic product (GDP): $489.7 billion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 303.2 in 1990; 348.0 in 2000; 383.6 in 2005
Kyoto Protocol status: Accessed 2002

• Historical and Political Context

Native South Africans were immigrants from other parts of Africa. Since 1652, South Africa was occupied by Europeans for over 300 years. The power shifted between the Dutch and the British through all these years and sometime was shared by the two parties. In 1652, the Dutch East India Company founded Cape Town. In 1806, the British took over Cape Town. The Boers, descendants of the Dutch settlers, founded their own republics in the South African interior. In 1899-1902, the Boers and the British fought the Anglo-Boer War for the control of South Africa's diamonds and gold. The British won the war. In 1910, South Africa became a British dominion. The Boers later negotiated with the British and gained hegemony.

Under Europeans' control, racial discrimination and racial segregation were generally practiced. The infamous policies of apartheid were officially made into laws in 1948 and were enforced for nearly forty years. Laws divided South African residents into racial groups including black, colored, Asian, and white. The whites lived in the white area, which covered more than 80 percent of South African land. Nonwhites had to carry permits when entering white areas. Laws also segregated educational standards, job categories, and public facilities. Through the "homeland" system established in 1959, blacks were deprived of their citizenship and forced to live in the so-called tribal homelands, which occupied small and economically unproductive areas of the country. Uprisings and protests against apartheid were ruthlessly repressed. The anti-apartheid leader Nelson Mandela was arrested and jailed. He was released from the jail in 1990 after serving 28 years. In 1994, South Africa held the first election in which blacks had the right to vote. Nelson Mandela, representing the African National Congress (ANC), won the election and became the first black president of South Africa. Since then, the ANC has become the governing party of South Africa.

• Impact of South African Policies on Climate Change

In the last four decades, South Africa has lost a large area of natural habitat mainly due to extensive economic development and deforestation during the nineteenth century. The early European settlers exploited South Africa's forest brutally. Nowadays forest only covers approximately 1 percent of South Africa. Coal is the major energy resource in South Africa. In the past, South Africa had limited access to foreign oil due to anti-apartheid sanctions. Sasol Ltd., a partly state-owned company, built several coal-to-liquids (CTL) plants. These CTL plants became big greenhouse (GHG) emitters. Sasol's Secunda CTL plant is one of the largest single emitters of CO_2 on Earth.

After 1994's democratic election, the South African government implemented the Reconstruction and Development Programme (RDP). RDP intended to meet people's basic needs and create jobs

through public works. In 1996, a new economic policy called Growth, Employment and Redistribution (GEAR) was adopted. At the beginning of the twenty-first century, the South African government started to promote independent power producers (IPPs) in the South African electricity market. However, the government did not make much progress on these policies due to the lack of investment in infrastructure.

• South Africa as a GHG Emitter

According to the Climate Analysis Indicators Tool (CAIT), in 1990, South Africa emitted 303.2 million metric tons of carbon dioxide (CO_2) equivalent in GHGs. Annual GHG emission increased to 348.0 million metric tons CO_2 equivalent and 383.6 million metric tons CO_2 equivalent in 2000 and 2005, respectively. GHG emissions ranked 17, 19, and 20 among the twenty top GHG emitters worldwide in 1990, 2000, and 2005, respectively. In the past two decades, South Africa's annual GHG emission contributed about 1.1-1.2 percent of total GHG emissions worldwide. In the past decade, GHG emission has increased nearly 2 percent annually. Mining and the energy industry contributed most of the GHG emissions in South Africa. The state-owned utility, Eskom, contributed to about 50 percent of the nation's GHG emissions. Eskom provides 95 percent of the country's electricity.

The international community agreed to address global climate change and drafted the United Nations Framework Convention on Climate Change (UNFCC) and the subsequent Kyoto Protocol. South Africa ratified the Convention in 1997. In 2001, the Seventh Conference of the Parties (COP-7) to the UNFCCC reached agreement to facilitate the accession of the Kyoto Protocol, and South Africa acceded to the Kyoto Protocol in 2002. South Africa is classified as a non-Annex I (or developing) country and is not obliged to adhere to a commitment to reduce GHG emissions.

• Summary and Foresight

South Africa is the most economically advanced country in Africa. Its economy has heavily depended on energy-intensive industries. Although its government has often been commended for taking active roles in controlling climate change, GHG emissions still increased significantly in the past decade. The government made many ambitious plans to reduce GHG emissions, such as generating 15 percent of electricity from renewable resources by 2020; conducting a National Greening Strategy through forestry development; promoting energy-efficient lighting; and reducing the use of coal for energy. For example, South Africa is committed to "greening" the 2010 World Cup by conserving water and energy and reducing GHG emissions.

Although apartheid has been replaced by multiracial democracy, consequences of apartheid still influence South Africa's politics and society. Recent elections still show a major racial divide in the country. The income imparity between white and black remains significant. The governing party has stressed its commitment to economic development and environmental protection. However, the nation is still facing serious challenges such as poverty, unemployment, environmental degradation, and the HIV/AIDS epidemic.

Yongli Gao

• Further Reading

McKinley, James C. "Global Warming: Around the Globe, Big Worries and Small Signs of Progress." *The New York Times*, December 1, 1997. Discusses South Africa as the most economically advanced country in Africa and a major contributor to the continent's GHG emissions. Africa's least developed nations contribute very few GHGs but suffer the most from climate change.

Scholes, R. J., and M. R. Van der Merwe. "Greenhouse Gas Emissions from South Africa." *South African Journal of Science* 92, no. 5 (1996): 220-222. Provides an overview of historical trends in South Africa's GHG emissions.

South Africa. Department of Environmental Affairs and Tourism. *South Africa's Review Report for the Sixteenth Session of the United Nations Commission on Sustainable Development.* New York: United Nations, 2008. Reflects the views and opinions of an inclusive group of South African stakeholders who represent economic, social, and environmental perspectives on sustainable development.

Winkler, Harald, ed. "Energy Policies for Sustainable Development in South Africa." Cape Town, South Africa: Energy Research Centre, University of Cape Town, 2006. Profile of energy and sustainable development in South Africa that uses modeling tools and indicators to assess future policy options for the country.

Winkler, Harald, et al. "Multi-project Baselines for Potential Clean Development Mechanism Projects in the Electricity Sector in South Africa." *Journal of Energy in Southern Africa* 12, no. 4 (2001): 449-457. Contributes to a larger research effort coordinated by the Lawrence Berkeley National Laboratory (LBNL). Discusses options for a single baseline or different baselines for clean development mechanism investment in South Africa.

See also: International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change.

South Korea

- **Category:** Nations and peoples
- **Key facts**

Population: 48,508,972 (July, 2009 estimate)
Area: 98,477 square kilometers
Gross domestic product (GDP): $1.278 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 410 in 1995; 532.5 in 2004; 536 in 2005
Kyoto Protocol status: Ratified 2002

• Historical and Political Context

Korea's history dates from 2333 B.C.E. In its earlier dynasties, Buddhism greatly influenced the nation's politics and culture. The last regime, the Joseon Dynasty, formed in the fourteenth century, and Confucianism exerted a massive influence over the whole of the society. From the seventeenth century on, practical and liberal ideologies began to be adopted, leading to agricultural improvements and social reforms.

Korea has suffered many foreign invasions. In 1910, Japan colonized the peninsula. Korea was librated from Japanese colonial rule at the end of World War II, when Japan surrendered unconditionally to Allied forces in August, 1945. After the war, the new global geopolitics and ideology of the Cold War led to the division of the peninsula into two nations, South Korea and North Korea, with utterly opposed political and economic systems.

In August, 1948, the legitimate, democratic South Korean government was formally established. South Korea developed full democracy and a market economy. In June, 1950, the Korean War broke out, as North Korea invaded South Korea. The war lasted until July, 1953. Since the 1960's, South Korea's growth-oriented, export-led economic development has seen remarkable growth. In 2006, South Korea's economy was the twelfth largest in the world, and the nation became a global economic leader. Meanwhile, South Korea successfully hosted the twenty-fourth Olympic Games in 1988 and cohosted the 2002 FIFA World Cup with Japan. Since the 1990's, Korean popular culture has become popular throughout Asia, in a phenomenon known as the

Korean wave. Through these occasions, Korea has demonstrated to the world not only its advanced economy and modern technologies but also its rich cultural heritage.

• Impact of South Korean Policies on Climate Change

South Korea's development strategy since 1960 achieved extraordinary economic growth rates. The unprecedented growth was achieved by massive production and an energy-concentrated industrial structure, focusing on the steel, petrochemical, and cement industries. After thirty years of rapid economic development, Korea transformed itself from an agricultural economy into a highly industrialized economy. This development strategy required a seemingly infinite supply of energy and natural resources and entailed considerable consumption of fossil fuels and emission of greenhouse gases (GHGs). Furthermore, low oil prices for industrial use and very low investment in energy-saving equipment were responsible for inefficient energy consumption that contributed to rapid increases in carbon dioxide (CO_2) emissions.

Since the late 1990's, South Korea has changed its traditional energy paradigm of mass production and mass consumption in response to international climate change agreements. This effort has resulted in significant decreases in GHG emissions per capita. The skyrocketing price of oil and increasing dependence on imported energy, moreover, forced the government to adapt sustainable economic growth strategies. In 2008, South Korea launched a green energy development strategy, Green Korea, focused on changing the national energy structure to fight global climate change by cutting GHG emissions and to reduce energy dependency. This strategy includes devising various initiatives to develop new and renewable energy resources, promoting energy conservation, and improving energy efficiency. To accomplish these goals, the government will emphasize investment in solar and wind energies, hydrogen fuel cells, carbon capture and storage, and energy storage technologies. By 2030, fossil fuel and renewable energy are projected to account for 61 percent and 11 percent of energy consumption, down from 82.7 percent and 2.4 percent, respectively, in 2008.

• South Korea as a GHG Emitter

As a result of South Korea's rapid economic growth from the 1960's to the late 1990's, energy consumption and CO_2 emissions also grew rapidly. Energy consumption, however, grew much more rapidly than did economic growth. This was primarily because of the poor energy efficiency of each sector of industry and governmental heavy-industry-oriented development strategies. During the period of economic development, CO_2 emissions increased significantly. The average annual growth rate of CO_2 emissions was 7.4 percent between 1981 and 1997. Over this period, total CO_2 emissions increased 3.3 times. In addition, the growth rate of the transportation sector was greater than that of other sectors because of significant increases in the number of automobiles in the nation. This trend slowed after the late 1990's.

CO_2 emissions doubled again between 1990 and 2004. These emissions grew faster than those of any other member nation of the Organization for Economic Cooperation and Development (OECD) over the same period. South Korea's total emissions continue to increase, although the ratio of GHG emission to gross domestic product (GDP) has de-

creased. In 2004, South Korea was the world's thirteenth-largest economy but ranked as the ninth-greatest GHG emitter, and it contributed about 1.7 percent of global CO_2 emissions. It was on track to become the sixth-greatest GHG emitter by 2010.

- **Summary and Foresight**

South Korean GHG emissions have grown significantly along with rapid economic growth. Because Korea's industrial structure is biased to the resource- and energy-intensive industries, South Korea consumes more energy than do other leading industrial countries to make the same products. This energy-intensivity results from South Korea's heavy and chemical industry drives in the 1970's and 1980's and the poor energy efficiency of those industries. In the early twenty-first century, South Korea undertook rapid restructuring of its industrial sector, transitioning from conventional heavy industry to new high-technology industries.

In 2008, South Korea adapted a new energy plan for sustainable development, focusing on clean energy industrial initiatives, introducing highly energy efficient technologies and products, and promoting the use of non-polluting, alternative, renewable energy sources. Particular emphasis was placed on the government's initiatives to restructure the electricity industry, which contributes one-third of South Korea's total CO_2 emissions, and to significantly increase the share of renewable energy sources from 2.4 percent in 2008 to 11 percent in 2030. According to this plan, the government seeks to maintain the level of CO_2 emissions of 2005 (536 million metric tons) until 2012 and then reduce the emission by an average 2.2 percent annually.

South Korea also takes responsibility for matching global efforts for global climate change. South Korea was the first developing country to express its intent to reduce GHGs voluntarily from 2018. Developed countries that are party to the Kyoto Protocol are required to reduce GHG emissions by an average of 5.2 percent from their 1990 levels between 2008 and 2012.

Jongnam Choi

- **Further Reading**

Choi, Yearn Hong. *South Korea's Environmental Policy and Management*. Seoul, South Korea: Shinkwang, 2008. Describes environmental policy and management from a comparative perspective and surveys a wide range of environmental issues facing the people and politicians of South Korea.

Korea Environment Institute. "Policies on Promoting Environmental Industries and International Cooperation." *Korea Environmental Policy Bulletin* 5 (2007): 1-11. Provides an overview of South Korea's policies promoting environmental industries as future growth engines and increasing international cooperation by participating in global environmental efforts.

Oberdorfer, Don. *The Two Koreas: A Contemporary History*. New York: Basic Books, 2002. Surveys contemporary Korean history, narrating the history of Korea's travails and triumphs over the last three decades of the twentieth century.

Yoon, Esook. "South Korean Environmental Foreign Policy." *Asia-Pacific Review* 13 (2006): 74-96. Examines two different stances of South Korea's environmental foreign policy: prioritizing its own economic interests in global negotiations and promoting regional environmental cooperation in Northeast Asia.

See also: Greenhouse effect; Greenhouse Gas Protocol; Greenhouse gases; Industrial emission controls; Industrial greenhouse emissions; International agreements and cooperation; Kyoto Protocol; North Korea.

Speculative fiction

- **Category:** Popular culture and society

Speculative fiction portrays alternate realities, often in order to comment on present-day reality. Either through analogy or through literal use of contemporary science, speculative-fiction authors have commented upon issues involving climate change and have introduced some readers to the central concepts used in its scientific study and policy discussion.

- **Key concepts**

dystopia: a fictional world in which living conditions are extremely bad; the opposite of a utopia *science fiction:* the branch of speculative fiction that attempts to be scientifically plausible

speculative fiction: the branch of fiction that deals with unproven entities and occurrences, including science fiction, fantasy, alternative history, and supernatural horror

• Background

Climate change has been used by the science-fiction branch of speculative fiction since the late nineteenth century. In *The War of the Worlds* (1898) by H. G. Wells, Mars has undergone climate change to the point where it is dying. The Martians then invade the Earth so that they can live here instead. Science fiction involving climate change is usually dystopian. In Philip K. Dick's *The Three Stigmata of Palmer Eldritch* (1965), global warming is one of several background details that inform the reader that the setting is a future much worse than the present.

• Natural Climate Change

Traditionally, science-fiction novels have assumed that climate change happens naturally. One example is J. G. Ballard's 1962 novel *The Drowned World*, whose premise is that solar flares destroy the ionosphere. This raises global temperatures, causing the polar ice caps to melt. Even at the time, the premise was considered dubious. Subsequent research has shown that the relationship between the Sun's output and the Earth's climate is more complicated than Ballard assumed. Critics generally approach this and Ballard's other ecological disaster novels as metaphorical rather than as possible futures.

In Larry Niven and Jerry Pournelle's *Lucifer's Hammer* (1977), a comet strikes the Earth, initially causing an outbreak of volcanoes, tsunamis, and earthquakes, then widespread flooding, and eventually a new ice age. This premise has become more plausible in the twenty-first century than at the time the book was written, because the theory that a similar event caused the demise of the dinosaurs has gained widespread acceptance.

• Anthropogenic Climate Change

Beginning in the late twentieth century, speculative fiction that used climate change as a premise usually also assumed that the change had human origins. One challenge of writing fiction involving climate change is that the science behind the stories can become obsolete after only a few years. Examples are David Brin's *Earth* (1990) and Bruce Sterling's *Heavy Weather* (1994), which were current with climate science at the time they were written but are now somewhat dated.

One example, Kim Stanley Robinson's *Science in the Capital* trilogy (*Forty Signs of Rain*, 2004; *Fifty Degrees Below*, 2005; and *Sixty Days and Counting*, 2007), received critical acclaim both for the quality of the writing and for the author's knowledge of climate science. The action takes place mostly in Washington, D.C., and most of the main characters are scientists. A rise in the average global temperature caused by human emission of greenhouse gases (GHGs) generates an unfortunate chain of events. The Arctic ice cap melts, and the infusion of freshwater into the North Atlantic causes the Gulf Stream to stall, in turn causing winters in North America and Europe to become much colder, longer, and drier. The characters undergo food scarcities, housing shortages, power outages, and reduced medical services.

Other examples include *Global Warming Aftermaths* (2008), edited by Eric Reynolds, an original short story anthology in which all the stories are set in a future after global warming has occurred, *Hotter than Hell* (2005) by Canadian environmental scientist Mark Tushingham, in which war breaks out between the United States and Canada over freshwater, and Tushingham's sequel *Hell on Earth* (2008).

• Denial of Climate Change

There are also works of speculative fiction that assume that climate change is not taking place. The premise of Michael Crichton's novel *State of Fear* (2004), for instance, is that the theory of global warming caused by the human emission of GHGs is not only false, but a deliberate hoax. Most global warming advocates are mistaken, according to the book, but some intentionally misrepresent the data in their quest for power. Crichton inserts graphs, charts, and footnotes into the text and provides twenty pages of references at the end of the book. At the time the book was published, Crichton was criticized in scientific circles for citing only the books and papers that supported his premise and for misrepresenting the ones he did cite.

• Context

In literature, there is a type of story known as the cautionary tale. This kind of story has a message along the lines of "if you do x (or fail to do x), then y will happen." "Y" is always an avoidable negative consequence. (Robert Heinlein used the prototypical title "If This Goes On—" for a 1940 science-fiction cautionary tale, although it was about religious fundamentalism rather than climate change.) The very best cautionary tales are the ones for which the readers do not realize there is a message until after they have finished reading and think about what they have just read. The ones that are too overt in their message either alienate or bore the reader. If they are published at all, they usually do not stay in print for long. Speculative fiction is full of such stories, good, bad, and indifferent, and many of the recent ones concern climate change.

Thomas R. Feller

• Further Reading

Grazier, Kevin R., ed. *Michael Crichton: An Unauthorized Exploration into the Real Science Behind the Fiction Worlds of Michael Crichton*. Dallas, Tex.: BenBella Books, 2008. Collection of essays analyzing the science behind Crichton's fiction, including one devoted to *State of Fear*.

Herreid, Clyde Freeman. "Using Novels as Bases for Case Studies: Michael Crichton's *State of Fear* and Global Warming." *Journal of College Science Teaching* 35, no. 7 (July/August, 2005). Essay by a college professor on using Crichton's *State of Fear* as a textbook.

Hultman, Nathan E. "Novel Takes on Climate Change." *Geotimes* 50, no. 6 (June, 2005). Review comparing Robinson's *Forty Signs of Rain* and Crichton's *State of Fear*.

Luckhurst, Roger. *The Angle Between Two Walls: The Fiction of J. G. Ballard*. New York: St. Martin's Press, 1997. Critical study of Ballard's fiction with a section devoted to *The Drowned World* and his other ecological disaster novels.

Robinson, Kim Stanley. Interview by Cassandra Willyard. *Earth* 53, no. 9 (September, 2008): 65. Robinson discusses her work and its basis in environmental science.

See also: Conspiracy theories; *Day After Tomorrow, The*; Popular culture.

Stockholm Declaration

- **Category:** Conferences and meetings
- **Date:** Issued June 16, 1972

Presented by the U.N. Conference on the Human Environment, the Stockholm Declaration put forth principles that might guide the world's nations to preserve and enhance the human environment, while recognizing that a healthy environment is a human right.

• Definition

In 1968, the notion of holding an international conference on the environment was brought to the fore by the United Nations Economic and Social Council at its forty-fifth session. A council resolution underscored the immediate need for intensified action at the national and the international levels to contain and, if possible, halt the continuous deterioration of the human environment. The U.N. General Assembly, at its twenty-third session, endorsed the council's recommendations. As a result, the Stockholm Conference on the Human Environment was convened on June 5-16, 1972, in Stockholm, Sweden. The importance of the Stockholm conference was threefold: It was the first global conference on the human environment; it was the predecessor of the first U.N. Conference on Environment and Development (UNCED) in 1992; and it acknowledged the need to articulate "third generation human rights," those that go beyond the merely civil and social. Such rights are legally difficult to enact, but the conference endorsed them in the Stockholm Declaration, which recognized a human right to a "healthy environment."

• Summary of Provisions

The framers of the Stockholm Declararios considered the need for a common outlook and shared principles for various international environmental issues, including human rights as proclaimed in the first article, "[b]oth aspects of man's environment, the natural and the man-made, are essential to his well-being and to the enjoyment of basic human rights, the right to life itself." The first Principle of the Declaration echoes this sentiment:

> Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment that permits a life of dignity and well-being, and he bears a solemn responsibility to protect and improve the environment for present and future generations.

Principle 8 focuses on economic and social development as being "essential for a favorable working environment . . . necessary for the improvement of the quality of life." Principle 9 declares

> Environmental deficiencies generated by the conditions of underdevelopment and natural disasters . . . can best be remedied by accelerated development through the transfer of financial and technical assistance as a supplement to the . . . developing countries and such timely assistance as may be required.

The twenty-first of the Declaration Principles is the best known, and it is believed by many international legal scholars to be the foundation for much of the environmental diplomacy that has occurred since Stockholm because it acknowledges that states have,

> . . . in accordance with the Charter of the UN and the principles of international law . . . the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their own jurisdiction or control do not cause damage to the environment of other States . . . .

Other principles stress the need for scientific research and technology, education for youth and adults alike, rational planning, and international cooperation to protect the global environment.

The Stockholm Delcaration

The Stockholm Declaration, excerpted below, begins with a statement regarding the fundamental nature of humanity and of the human-nature relationship. This ontological statement forms the philosophical underpinning for the declaration.

The United Nations Conference on the Human Environment, having met at Stockholm from 5 to 16 June 1972, having considered the need for a common outlook and for common principles to inspire and guide the peoples of the world in the preservation and enhancement of the human environment,

Proclaims that:

1. Man is both creature and moulder of his environment, which gives him physical sustenance and affords him the opportunity for intellectual, moral, social and spiritual growth. In the long and tortuous evolution of the human race on this planet a stage has been reached when, through the rapid acceleration of science and technology, man has acquired the power to transform his environment in countless ways and on an unprecedented scale. Both aspects of man's environment, the natural and the man-made, are essential to his well-being and to the enjoyment of basic human rights the right to life itself. . . .

3. Man has constantly to sum up experience and go on discovering, inventing, creating and advancing. In our time, man's capability to transform his surroundings, if used wisely, can bring to all peoples the benefits of development and the opportunity to enhance the quality of life. Wrongly or heedlessly applied, the same power can do incalculable harm to human beings and the human environment. We see around us growing evidence of man-made harm in many regions of the earth: dangerous levels of pollution in water, air, earth and living beings; major and undesirable disturbances to the ecological balance of the biosphere; destruction and depletion of irreplaceable resources; and gross deficiencies, harmful to the physical, mental and social health of man, in the man-made environment, particularly in the living and working environment.

In addition to the declaration, an action plan comprising 109 recommendations was put forth at Stockholm. The plan encompassed six general topics, including educational, informational, and sociocultural aspects of the environment. For example, recommendation 95 called for

> providing countries with . . . technical and financial assistance in preparing national reports on the environment, in setting up machinery for monitoring environmental development . . . and drawing up national social, educational and cultural programmes.

Recommendation 96 called for the secretary-general and the U.N. Educational, Scientific, and Cultural Organization (UNESCO) "to establish an international programme in environmental education . . . directed toward the general public." Other recommendations addressed the need for financial support, as well as management of "global pollution, natural resources, and human settlements." However, while development was included as a Stockholm conference agenda issue, it was not dealt with until UNCED in 1992.

• Significance for Climate Change

The first international conference of its kind, the U.N. Conference on the Human Environment focused attention on the need for global collaboration to decrease general and marine pollution, and created environmental monitoring networks both regional and global, providing the framework for future environmental collaboration that led to the establishment of the U.N. Environment Programme (UNEP) for which Canadian Maurice F. Strong served as the first executive director. UNEP continues to coordinate U.N. environmental activities, helping developing countries implement environmentally sound policies by encouraging sustainable environmental practices. Importantly, the Stockholm Conference and the scientific conferences on the environment that it preceded significantly influenced the environmental policies of the European Community, later the European Union.

As an example, in 1973, the European Union established the Environmental and Consumer Protection Directorate and the first Environmental Action Program. The Stockholm Conference was the predecessor of the first U.N. Earth Summit, which specifically focused on the environment alongside development, and put forth the notion of sustainability as a necessary component of climate change. Importantly, UNCED produced the U.N. Framework Convention on Climate Change (UNFCCC), a most significant treaty with a mission of stabilizing greenhouse gas (GHG) emissions at a level that might prevent anthropogenic disruption of the Earth's climate, such as global warming. Originally a legally nonbinding document, the treaty included provisions for updates called "protocols," the best known being the legally binding Kyoto Protocol, which established specific limitations for GHG emissions for developed nations.

Cynthia F. Racer

• Further Reading

Bhatt, S. *The UN Stockholm Declaration of 1972 on the Human Environment: A Global and Federal View of Environmental Protection.* New Delhi: Hamdard University, 1999. Covers such topics as conservation of the environment, global environmental politics, and the need to educate the public on the environment.

Nordquist, M., J. N. Moore, and S. Mahmoudi, eds. *The Stockholm Declaration and Law of the Marine Environment.* Amsterdam: Martinus Nijhoff, 2003. Collection of essays commemorating the thirtieth anniversary of the Stockholm Declaration of 1972, including a presentation by Dr. Hans Blix, primary author of the Declaration.

Van Ginkel, H., B. Barrett, J. Court, and J. Velasquez. *Challenges for the United Nations in the New Millennium.* New York: New York University Press, 2002. Topics include congresses on human ecology, social problems, and the United Nations.

See also: International agreements and cooperation; Kyoto Protocol; Nongovernmental International Panel on Climate Change; United Nations Conference on the Human Environment; United Nations Environment Programme; United Nations Framework Convention on Climate Change.

Storm surges

- **Category:** Meteorology and atmospheric sciences

- **Definition**

A storm surge, or tidal surge, is water pushed toward the shore by the winds of a storm. The combination of high winds, low pressure, and wave action is what makes a storm surge. The rush of water, combined with the regular action of the tide, causes water to rise significantly higher. This influx of water can cause significant flooding, especially in low-lying coastal areas.

Storm surges occur when a tropical storm or hurricane makes landfall. The pressure in the center, or eye, of a storm is low enough that surface water is drawn upward in a dome, just as beverages may be drawn up through a drinking straw. As the storm reaches land, this dome of water piles up against the shoreline, and the area within the right front quadrant of the storm's forward motion is in particular danger.

Storm surges are sometimes confused with tsunamis. A tsunami (from the Japanese word for "harbor wave") is generated by an undersea earthquake or volcanic eruption that creates a set of waves that can grow in intensity as they reach shallow coastal regions. Storm surges only occur in the presence of tropical storms, hurricanes, or cyclones.

The amount of surge is related to the size of the storm, as well as the slope of the Continental Shelf. A shallow slope allows more water to travel inland, while a steeper slope limits the surge but poses a greater danger of generating a breaking wave. The effects of a storm surge are multiplied in confined areas such as harbors and can also be felt in inland rivers and lakes.

The National Hurricane Center (NHC) uses the

A storm surge slams into the beach in central Bombay, India, in May, 2001, destroying the stalls in its path. (AP/Wide World Photos) sea, lake, and overland surges from hurricanes (SLOSH) model to determine which areas should be evacuated in the event of a storm surge. Storm factors taken into consideration by this model include forward speed, pressure, size, track, and wind speed. These factors are weighed against the timing of the tide and the topological configuration of the projected landfall.

• Significance for Climate Change

The inland reach of a storm surge is dependent on the slope of the Continental Shelf and the height of the land above sea level. In the United States, most of the population on the Gulf of Mexico and the Atlantic coastline is a little more than 3 meters above sea level, making those areas particularly vulnerable. If the sea level were to rise as a result of climate change, the population's vulnerability would increase significantly.

Waves and the action of the current during a storm surge can cause additional damage. Water weighs 1,000 kilograms per cubic meter, and the erosion of beaches and coastal highways is a particular problem. Moreover, the influx of salt water on freshwater bodies disrupts local ecosystems. Salt water that travels far inland may not dissipate for weeks.

The storm surge associated with Hurricane Katrina in August, 2005, was one of the most massive in U.S. history, spanning an area between Grand Isle, Louisiana, and Mobile Bay, Alabama. The storm surge drove water from the Gulf of Mexico up into Lake Pontchartrain and the Mississippi River, which in turn breached the levees in the city of New Orleans and the surrounding areas. Lake Pontchartrain, normally about 0.3 meter above sea level, peaked at 2.62 meters above sea level. According to the U.S. Geological Survey, more than 560 square kilometers of land were eroded into the ocean. The Chandeleur Islands, which formed the easternmost point of Louisiana, were completely destroyed.

The human and financial impact of the Katrina storm surge on the northern Gulf Coast is well documented, but there was a significant ecological price as well. Retreating flood waters carried raw sewage, pesticides, toxic chemicals, and other waste products into the surrounding wetlands. Overall, sixty national wildlife refuges were damaged as a result of Hurricanes Rita and Katrina. A contributing factor to the damage from the 2005 storm season was the ongoing loss of wetlands and barrier islands, which had previously protected the low-lying areas from the worst of the earlier hurricanes.

P. S. Ramsey

• Further Reading

Boon, John D. *Secrets of the Tide: Tide and Tidal Current Analysis and Applications, Storm Surges, and Sea Level Trends.* Chichester, West Sussex, England: Horwood, 2004. Comprehensive reference book about the effects of the tides on coastal regions.

Larson, Eric. *Isaac's Storm: A Man, a Time, and the Deadliest Hurricane in History.* New York: Vintage Books, 2000. Detailed account of the hurricane that struck Galveston, Texas, in September, 1900—considered the deadliest hurricane ever to strike the United States.

Mooney, Chris. *Storm World: Hurricanes, Politics, and the Battle over Global Warming.* Orlando, Fla.: Harcourt, 2007. A look at the manner in which science and politics collide over the predications and preparations for hurricane season and global warming in general.

Pugh, David. *Changing Sea Levels: Effects of Tides, Weather, and Climate.* New York: Cambridge University Press, 2004. Overview of the effects of tides and changing sea levels on coastal regions.

Sargent, William. *Storm Surge: A Coastal Village Battles the Rising Atlantic.* Lebanon, N.H.: University Press of New England, 1995. Site-specific account of the effects of storm-related coastal erosion near the town of Chatham, Massachusetts, including conflicts between residents and environmentalists.

See also: Barrier islands; Coastal impacts of global climate change; Coastline changes; Islands; Louisiana coast; New Orleans; Sea-level change; Tropical storms; Wetlands.

Stratigraphy Commission of the Geological Society of London

- **Category:** Organizations and agencies
- **Date:** Geological Society established 1807
- **Web address:** http://www.geolsoc.org.uk

- **Mission**

The Stratigraphy Commission of the Geological Society of London is a body within the society that operates independently from any industrial or academic organization and apart from the Geological Survey of Britain. The Stratigraphy Commission represents the interests of geological scientists in all aspects of stratigraphic studies (mainly the study of sediments and sedimentary rocks) and helps provide a forum for discussion of issues related to stratigraphy. The commission contributes to selected topical debates within the geological community, one of which is global warming.

- **Significance for Climate Change**

The commission has prepared a global warming essay, or position paper, that lays out the consensus of scientific opinion on this matter for the public and political leaders. The essay commences its discussion by delving into a review of climate change as rooted in geological history, which entails discussing the stratigraphic record of climate change.

The global warming essay of the Stratigraphy Commission minces no words in saying at the outset that global climate change is recognized as a key threat to the continued development and even the continued survival of human society. The essay goes on to say that the commission finds the evidence compelling that anthropogenic climate change is now pervasive and that the need for immediate action is compelling.

Drawing on the stratigraphic record, the commission noted that ice age climate change has historically been pervasive, rapid, and frequent. The essay notes that during the last 2.6 million years, there have been at least 104 major fluctuations from global cold to global warmth. Each fluctuation, the report notes, was complex within itself and typically involved global temperature changes spanning 5° Celsius and sea-level changes averaging 130 meters. The report notes that animal populations of the past avoided mass death by migration; however, human populations do not have the available space to which to migrate. The essay says that human population growth and development have coincided with one of the few and infrequent episodes of climate stability (over about ten thousand years) in recent Earth history.

The essay discusses ice core records, global greenhouse gases, and the geological record of climate change in calling for a plan of action on anthropogenic climate change. The essay goes so far as to suggest a program of massive human sequestration of carbon dioxide in human-made reservoirs and a switch to alternative fuel sources, including conversion to nuclear power generation as much as possible.

David T. King, Jr.

See also: American Association of Petroleum Geologists; American Geophysical Union; Earth history; Geological Society of America.

Stratosphere

- **Category:** Meteorology and atmospheric sciences

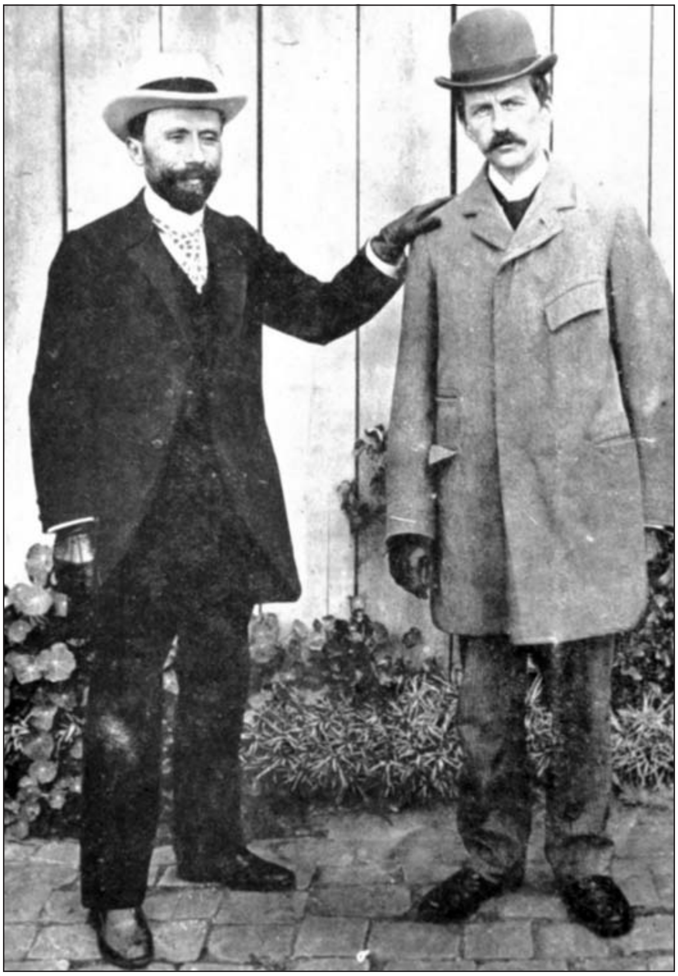
- **Definition**

The stratosphere is a highly stratified region of the atmosphere that is bounded below by the troposphere and above by the mesosphere. The stratosphere ranges from about 15 kilometers above the Earth's surface at its lower boundary to about 50 kilometers at its upper boundary. The stratosphere contains about 90 percent of the ozone in the atmosphere. Because of the ozone layer in the stratosphere, which absorbs much of the ultraviolet radiation reaching Earth from the Sun, the temperature increases with increasing height throughout the stratosphere. This ozone-induced increase in temperature with height corresponds to stable stratification, which has a strong impact on the stratospheric circulation.

• Significance for Climate Change

Since scientists Richard Assmann (1845-1918) and Léon Philippe Teisserenc de Bort (1855-1913) independently launched balloons and discovered the stratosphere more than a century ago, the stratosphere continues to be probed and measured by a wide variety of scientific instruments, including radiosondes, lidars, rocketsondes, and satellite sensors. These measurements have revealed a region containing a number of prominent circulation features. These features include the midlatitude westerlies in the wintertime hemisphere, the corresponding easterlies in the summertime hemisphere, the Brewer-Dobson circulation, and the equatorial quasi-biennial oscillation (QBO).

The midlatitude westerlies and easterlies affect the planetary wave energy that propagates vertically from the troposphere into the stratosphere, while the Brewer-Dobson circulation, which is characterized by ascent in the equatorial region of the stratosphere and descent in the polar regions, transports ozone from its production region in the tropics to the polar regions. The QBO, which is characterized by an oscillation in zonal winds in the equatorial lower stratosphere, can extend its influence far beyond its seat of origin to affect, for example, Northern Hemisphere surface temperatures. These features, as well as the space-time evolution of the stratosphere, depend vitally on the interactions between radiation, chemistry, and dynamics. Perturbations to these interactions are caused by both anthropogenic and natural forcing and occur over a wide range of timescales.



Léon Philippe Teisserenc de Bort, who helped discover the stratosphere, places his hand on the shoulder of Abbott Lawrence Rotch, who founded the Blue Hill Meteorological Observatory. (NOAA)

Changes in stratospheric temperature, which are intimately connected to the radiative, chemical, and dynamical interactions in the stratosphere, have undergone episodic, quasi-periodic, and secular changes over the past several decades. These changes have been attributed to volcanic events, the eleven-year solar cycle, and anthropogenic forcing. Studies have shown that volcanic events can eject aerosols into the lower stratosphere that alter the radiation balance there, resulting in elevated temperatures that can last for a couple of years.

The eleven-year solar cycle has been shown to modulate the temperature and ozone in the stratosphere, which modulate the stratospheric westerlies. The modulation of the westerlies in turn affects the energy propagation of the planetary waves, which through refraction and reflection can impart a downward influence on the troposphere. Anthropogenic forcing has caused ozone depletion and increases in well-mixed greenhouse gases (WMGGs) such as carbon dioxide (CO_2), which together have produced a cooling trend in the stratosphere that began most noticeably in the early to mid-1980's. Stratospheric ozone is expected to recover in the coming decades, but not enough to offset the cooling due to the projected increases in WMGGs.

The significance of the stratosphere to climate change hinges on the fact that as the composition of the stratosphere changes, so too will the dynamical circulation. Climate models show, for example, that anthropogenic forcing agents such as WMGGs cause the Brewer-Dobson circulation to strengthen. A strengthening of the Brewer-Dobson circulation will cause the westerly winds to weaken and the temperatures to increase in the extratropical stratosphere. The changes in the winds and temperature in the stratosphere are expected to couple downward to affect the weather and climate of the troposphere.

Terrence R. Nathan

- **Further Reading**

Baldwin, M. P., M. Dameris, and T. G. Shepherd. "How Will the Stratosphere Affect Climate Change?" *Science* 316 (June 15, 2007): 1576-1577. Addresses changes in both the composition and circulation of the stratosphere and their potential impact on troposphere climate.

Cordero, E. C., and T. R. Nathan. "The Influence of Wave- and Zonal Mean-Ozone Feedbacks on the Quasi-Biennial Oscillation." *Journal of the Atmospheric Sciences* 57 (2000): 3426-3442. Provides an overview of the role of the QBO in the stratosphere and examines the effects of ozone on its space-time evolution.

_______. "A New Pathway for Communicating the Eleven-Year Solar Cycle Signal to the QBO." *Geophysical Research Letters* 32 (2005). Demonstrates how the interactions between equatorial motions and ozone can amplify and communicate the eleven-year solar cycle signal to the equatorial quasi-biennial oscillation.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. The IPCC report provides the latest scientific consensus on the physical basis for observed changes in Earth's climate.

Labitzke, Karin G., and Harry Van Loon. *The Stratosphere: Phenomena, History, and Relevance*. Berlin: Springer, 1999. Provides a history of the stratosphere, from the announcement of its discovery in the early twentieth century to the understanding of its structure and evolution prevalent at century's end.

Nathan, T. R., and E. C. Cordero. "An Ozone-Modified Refractive Index for Vertically Propagating Planetary Waves." *Journal of Geophysical Research* 112 (2007). Demonstrates that longitudinal variations in stratospheric ozone can alter the propagation of stratospherically forced planetary waves and produce changes in the zonal-mean circulation.

Schwarzkoph, M. Daniel, and V. Ramaswamy. "Evolution of Stratospheric Temperature in the Twentieth Century." *Geophysical Research Letters* 35 (2008). Uses a coupled atmosphere-ocean climate model to examine how known anthropogenic and natural radiative forcing agents have affected the evolution of stratospheric temperature during the twentieth century.

See also: Atmosphere; Atmospheric boundary layer; Atmospheric chemistry; Atmospheric dynamics; Atmospheric structure and evolution; Ozone.

Subsidiary Body for Scientific and Technological Advice

- **Category:** Organizations and agencies
- **Date:** Established 1994
- **Web address:** http://unfccc.int

- **Mission**

Established by Article 9 of the United Nations Framework Convention on Climate Change (UNFCCC), the Subsidiary Body for Scientific and Technological Advice (SBSTA) provides the UNFCCC Conference of the Parties (COP) with information and advice on scientific and technological issues relating to the convention.

The SBSTA serves as the link between the scientific, technical, and technological assessments and the information provided by competent international bodies, and the policy-oriented needs of the COP. The SBSTA is open to participation to all parties to the UNFCCC and comprises government representatives competent in the relevant fields of expertise. With the entry into force of the Kyoto Protocol to the UNFCCC in 2005 the SBSTA also began to serve as the Subsidiary Body for Scientific and Technological Advice to the Protocol. As in the COP, parties to the convention who are not parties to the protocol may participate as observers when the SBSTA serves as a subsidiary body to the Protocol. The SBSTA generally meets twice per year and reports to the COP and the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) on all aspects of its work.

- **Significance for Climate Change**

The SBSTA responds to scientific, technological and methodological questions asked by the COP/CMP and their subsidiary bodies, and assesses both the scientific knowledge relating to climate change and the effects of measures taken in the implementation of the Convention. It also works to identify technologies and promote technology development and transfer, to provide advice on scientific programs and international cooperation in research and development related to climate change, and to support capacity-building in developing countries.

The SBSTA considers a wide variety of issues. As of 2008, specific examples include consideration of the reports of the Intergovernmental Panel on Climate Change (IPCC); provision of information and advice on the scientific, technical and socioeconomic aspects of impacts, vulnerability, and adaptation to climate change; consideration of scientific, technical and socioeconomic aspects of mitigation of climate change; consideration of methodological issues, including reporting and accounting procedures, under the Convention and the Protocol; and consideration of methodological issues related to reducing emissions from deforestation in developing countries.

Douglas Bushey

See also: Kyoto Protocol; United Nations Framework Convention on Climate Change.

Sulfate aerosols

- **Category:** Chemistry and geochemistry

- **Definition**

Sulfate aerosols are tiny (submicron) liquid or solid particles suspended in the atmosphere. Anthropogenic emissions are probably the leading source of sulfate aerosols in the atmosphere. The global dimming from sulfates and certain other aerosols may partly counterbalance global warming, masking the greenhouse effect. The most important anthropogenic sources of sulfate aerosols are sulfur impurities in coal, petroleum products, and natural gas. Health and environmental concerns have caused Western countries to sharply curtail these emissions, but rapidly industrializing developing nations are more than compensating for this reduction in the developed world.

In addition to anthropogenic emissions of sulfur into the environment, the world has a natural sulfur cycle analogous to the carbon cycle. Sulfur compounds, especially, hydrogen sulfide (H_2S) and sulfur dioxide (SO_2), escape from volcanoes and eroding rocks. These and other sulfur compounds eventually redeposit. However, some of this sulfur flux passes through the atmosphere, with significant climatic effects. Non-SO_2 sulfur compounds entering the atmosphere are oxidized into SO_2. The SO_2 combines with hydrogen in water to form sulfuric acid (H_2SO_4) or with ammonium ions to form ammonium sulfate $(NH_3)_2SO_4$. These form liquid or gas aerosols that eventually fall to the ground or are washed down in rain.

Before returning to the ground, sulfate aerosols influence climate by reflecting visible light back up into space while allowing infrared light (heat waves) to pass through and by providing nucleation sites for water condensation into clouds. The clouds also reflect visible light and allow infrared to pass. The resulting cooling is the opposite of the warming greenhouse effect.

Sulfur is also a small but significant fraction of the mass in organic matter. The most significant terrestrial source of sulfur-compound emissions is organic decay, particularly in marshlands, but all organisms emit some by-product sulfur compounds. At sea, plankton metabolism dominates sulfur emissions, with dimethyl sulfide (DMS or CH_3SCH_3) and carbonyl sulfide (COS) being the most common.

Volcanic sulfur emissions average significantly less than anthropogenic emissions. However, major explosive volcanic eruptions insert large pulses of sulfate aerosols into the stratosphere. Reaching the greater altitude and drier air of the stratosphere allows these aerosols to remain aloft longer. These pulses have been associated with significant cooling, including the 1816 "year without a summer" after the 1815 eruption of Mount Tambora and the milder cooling after the smaller 1883 Krakatoa eruption. The much smaller (but better documented) 1991 eruption of Mount Pinatubo put roughly 18 million metric tons of sulfates into the stratosphere and caused cooling for several months.

• Significance for Climate Change

Although aerosol analyses are even hazier than are most climate science, humanity may be balancing a significant fraction of greenhouse-gas-related warming with sulfate-aerosol-related cooling. Increased industrialization in areas without pollution controls could tip the balance into cooling. Conversely, humanity may opt to attempt planetary climate change or geoengineering if global warming is seen as a major threat. Two methods have been seriously proposed, direct sulfate injection into the stratosphere and ocean fertilization. The arguments for both are that they could be stopped at any time. The arguments against them are that they might have only limited effects and might have unexpected side effects.

In 1974, Russian geologist Mikhail I. Budyko suggested that, if global warming became a problem, humanity could burn sulfur in the stratosphere to create a haze similar to that arising from volcanic eruptions. Recent calculations suggest that such an "artificial volcano" could offset the warming of twofold or even threefold increased atmospheric carbon dioxide (CO_2), and the price might be as low as one billion dollars annually. The sulfates would also stop some ultraviolet radiation. This ability might prove important, because sulfates attack ozone, and the need to preserve the ozone layer may be a limitation. Continued sulfate injections might be needed to compensate for the lost ozone.

In 1988, California oceanographer John Martin said "Give me a half tanker of iron, and I will give you an ice age." Less ambitious fertilization of nutrient-limited areas in the ocean would cause plankton blooms emitting sulfate aerosols for greater albedo and capturing CO_2 from the atmosphere. The plan could even be self-funding through increased fishery yields.

However, ocean fertilization has potential limitations. The effects may be less efficient because of predator activity on the plankton, and some plankton emissions may be greenhouse agents rather than cooling agents. Most worrisome, an attempt to compensate for a major fraction of yearly greenhouse warming might cause so much organic material to rain into deeper waters that they could become toxic from excess CO_2.

Roger V. Carlson

• Further Reading

Field, Christopher B., and Michael R. Rapauch, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Washington, D.C.: Island Press, 2004. This compendium of articles from the Scientific Committee on Problems of the Environment (SCOPE) discusses the major atmospheric carbon sources and sinks. The final chapter details possible advantages and limitations of ocean fertilization.

Kondratyev, Kirill Y., et al. *Atmospheric Aerosol Properties: Formation, Processes, and Impacts.* Chichester, West Sussex, England: Praxis, 2006. Provides an overall summary of atmospheric aerosols with a particularly good analysis of sulfate aerosols.

"The Ocean in a High-CO_2 World." Special section in *Journal of Geophysical Research* 110, no. C9 (2005). Includes papers on the carbon cycle as well as arguments for and against oceanic fertilization.

Warneck, Peter. *Chemistry of the Natural Atmosphere*. 2d ed. Edited by Renata Dmowska, James R. Holton, and H. Thomas Rossby. San Diego, Calif.: Academic Press, 2000. Max-Planck-Institut für Chemie Emeritus Professor Warneck provides a detailed chapter, "Sulfur Compounds in the Atmosphere," including sources, sinks, and processes within the atmosphere.

See also: Aerosols; Carbonaceous aerosols; Greenhouse effect; Ozone; Sulfur cycle.

Sulfur cycle

- **Category:** Chemistry and geochemistry

- **Definition**

The ancients referred to hell as a place of fire and burning brimstone. Brimstone was their term for the rotten-egg-smelling gas of sulfur dioxide (SO_2). Sulfur is also present in other, less odious forms owing to a series of transforming oxidation-reduction reactions, and in one form or another it is in constant flux between Earth and sky and back again to Earth. This is the sulfur cycle. Technically, the sulfur cycle describes the mineralization of organic sulfur to sulfide, its oxidation to sulfate, and the reduction of sulfate to sulfide, followed by microbial conversion into organic compounds.

Oxidation is most simply defined as the addition of oxygen, while reduction is the removal of oxygen from a compound. However, chemists more narrowly define oxidation-reduction reactions as the transfer of electrons between compounds. The term organic refers to chemical compounds having a carbon basis, which implies having come from living organisms. During its cycle, electrons recombine to move sulfur in and out of organic and inorganic compounds.

From the Earth's crust, sulfur finds its way into the atmosphere in the form of hydrogen sulfide (H_2S). It does this in a variety of ways: It comes from volcanic eruptions, decomposition of organic material, fossil fuel combustion, and gas exchange from the ocean. Once it is in the atmosphere, H_2S is oxidized to SO_2. SO_2 then combines with water vapor to become sulfuric acid, allowing sulfur to return to Earth in drops of rain. Because living things require low levels of sulfur, plants then take up the sulfur and incorporate it into protein, and it becomes part of the food chain. These organic sulfur compounds are returned to the land or water after the plants die or are consumed by animals. Ultimately, decomposition returns sulfur to its H_2S form, and the cycle begins again. The source of sulfur is the Earth's crust. Rocks and salts contain most of the planet's sulfur, but it is also found in ocean sediments and in an organic form in protein.

- **Significance for Climate Change**

SO_2 when dissolved in the moisture of clouds transforms into weak sulfuric acid. These acid-laden clouds reflect more of the Sun's radiant energy than do uncontaminated clouds, in a process called cloud brightening. The result is climate cooling.

Another form of sulfur of environmental concern is dimethyl sulfide (DMS). Marine life in the form of phytoplankton produces DMS in great quantities. When DMS escapes into the troposphere, it oxidizes into sulfate particles. Scientists have found that these particles play a role in forming condensation nuclei, which promote cloud growth and increased rainfall. This suggests that elevated ultraviolet radiation from large-scale climate change might damage phytoplankton to the extent that DMS levels are reduced, thereby lowering rainfall amounts.

Highly populated and industrial areas of the United States, Eastern Europe, and—increasingly—Asia have the highest levels of sulfur emissions. The associated problems are likely to increase, as areas such as industrialized China continue to grow. One specific problem is that of acid rain. These rain droplets containing sulfuric acid have caused great damage to freshwater ecosystems.

The issue of climate impact from sulfur is not in doubt, but authorities debate whether carbon dioxide (CO_2) discharged from burning fossil fuels raises climate temperatures beyond the cooling effects of the sulfur dioxide that is also discharged. Millions of metric tons of SO_2 gas can reach the stratosphere from a major volcanic eruption. The year 1816 witnessed the great Mount Tambora eruption. Because of the lingering ash cloud that had spewed into the atmosphere, thereby lowering temperatures around the world, the following year became known as the year without a summer. Crops failed in the United States, and food shortages became commonplace around the globe. More recently, environmentalists think it likely that greenhouse warming was delayed for a few years by the eruption of Mount Pinatubo in 1991. Research reveals that volcanic ash clouds together with sulfur dioxide emissions can force dramatic temperature changes.

A certain type of bacteria known as *Thiobacillus ferroxidans* is capable of harvesting energy for its growth and reproduction through the oxidation of sulfides into sulfates, leaving large amounts of caustic acid in its wake. In heavy metal or coal mining, large amounts of acid are produced in this way that are often referred to as acid mine drainage. Many treatment systems are coming on line to treat coal-mine drainage in order to raise the pH of contaminated water and control the precipitation of dissolved metals.

Richard S. Spira

• Further Reading

Bianchi, Thomas S. *Biogeochemistry of Estuaries.* New York: Oxford University Press, 2007. Includes a chapter on the sulfur cycle in relation to estuary ecosystems.

Cunningham, William, and Barbara Woodworth Saigo. *Environmental Science: A Global Concern.* 6th ed. New York: McGraw-Hill, 2001. Gives an overview of environmental science with an excellent chapter on the effects of the sulfur cycle on climate.

Mitchell, Stephen C. *Biological Interactions of Sulfur Compounds.* New York: Routledge, 2006. Introduces readers to the chemistry and biology of sulfur; gives an excellent description of the biological interactions of sulfur compounds resulting from the presence of sulfur within the molecule.

See also: Mount Pinatubo; Nitrogen cycle; Plankton; Sulfate aerosols; Sulfur hexafluoride; Volcanoes.

Sulfur hexafluoride

• **Category:** Chemistry and geochemistry

• Definition

Sulfur hexafluoride, also called sulfur (VI) fluoride, is a gas that is about five times as dense as air, tasteless, odorless, nonflammable, nontoxic, and with very little chemical reactivity. Thus, it will not corrode metals with which it is in contact at ordinary temperatures. In 1937, it was discovered to have a higher dielectric strength than air and was suggested for use as an insulating material in electrical equipment—a use that continues to the present. About 80 percent of the sulfur hexafluoride used is in the electric power industry. Other than its electrical uses, sulfur hexafluoride has found application in etching silicon films for liquid crystal display panels, as a filling in double-paned windows, and as an inert atmosphere in magnesium metal casting.

• Significance for Climate Change

Sulfur hexafluoride strongly absorbs infrared radiation in the wavelength region 8-12 microns. The solar heating of the Earth causes the planet to emit infrared radiation. In the absence of an atmosphere, the Earth would stay relatively cool. Greenhouse gases (GHGs) in the atmosphere, such as water vapor, carbon dioxide (CO_2), and methane, absorb infrared radiation, ultimately raising the temperature of the Earth.

The Intergovernmental Panel on Climate Change (IPCC) has evaluated various gases for their global warming potential (GWP) and found that sulfur hexafluoride is the most potent greenhouse gas tested. Sulfur hexafluoride is 22,200 times as potent a greenhouse gas as is CO_2 under comparable conditions. In addition, the compound has an estimated atmospheric lifetime of thirty-two hundred years, guaranteeing that any emissions will accumulate over time. Emissions are estimated at 1,000-1,500 metric tons per year, leading to an atmospheric concentration in 1990 of 4 parts per trillion. This is a considerably lower level than CO_2 (around 380 parts per million), but because of the great GWP of sulfur hexafluoride, it is still a serious consideration.

Sulfur hexafluoride has been named in the Kyoto Protocol (1997) as a GHG that must be phased out as much as possible. The electric power industry has responded by putting better seals on circuit breakers to prevent leaking and by reducing the amount of the gas in each unit. Substitutes have been found for the inert atmosphere in magnesium casting, but in electrical applications, substitutes such as perfluorocarbons are not as effective in the application and are also serious GHGs.

John R. Phillips

See also: Global warming potential; Greenhouse effect; Greenhouse gases; Kyoto Protocol; Perfluorocarbons.

Sun

- **Category:** Astronomy

Solar radiation is the fuel that drives Earth's climate engine. Global average temperatures respond to variations in both the amount of energy emitted by the Sun and the amount of that energy absorbed and retained by the Earth.

• Key concepts

albedo: the fraction of incident light reflected from a body such as Earth

greenhouse effect: the tendency of Earth's atmosphere to transmit visible radiation from the Sun to the ground, where it is absorbed and reemitted as infrared radiation that cannot readily escape to space

insolation: the amount of radiant energy per square meter per second received by the Earth from the Sun

• Background

The Sun is a typical yellow dwarf star. It is a mixture of incandescent gases, primarily hydrogen (80 percent by mass) and helium (20 percent by mass) with trace amounts of heavier elements. The Sun has a total mass of 1.99×10^{30} kilograms and a radius of 6.96×10^{8} meters. The Earth orbits the Sun at an average distance of 1.5×10^{11} meters.

The surface of the Sun has a temperature of 5,800 Kelvins, the temperature at which thermal radiation peaks at yellow in the visible section of the electromagnetic spectrum. Radiation emitted by the Sun totals 3.93×10^{26} watts. This tremendous amount of energy emitted each second is replenished by nuclear reactions occurring in the core of the Sun. Hydrogen is converted into helium (four atoms of hydrogen fuse to form one atom of helium), with the excess mass converted to energy.

• Structure

At the center of the Sun, the pressure is approximately 3.16 quadrillion kilograms per square meter, 300 billion times Earth's atmospheric pressure. The temperature is 15 billion Kelvins. These conditions permit the fusion of four hydrogen nuclei (protons) into one helium nucleus with the net loss of 7 percent of the original mass. This mass is converted into energy in accordance with Albert Einstein's special theory of relativity. The Sun converts 4.5 million metric tons of matter into energy each second.

The core of the Sun is the region where nuclear fusion takes place. It contains 40 percent of the mass of the Sun and produces 90 percent of the energy radiated by the Sun. The core extends outward to one-quarter of the distance to the surface. At this radius, the temperature falls to 13 million Kelvins, which is too cool to sustain the fusion reaction.

The energy escaping the core is predominantly in the form of X rays, an extremely energetic type of electromagnetic radiation. The material of the Sun from the top of the core out to three-quarters of the distance to the surface is a hot, dense plasma that is opaque to X-ray radiation. This layer slows the transport of energy from the core outward to such an extent that it may take millions of years for the energy from the core to reach the Sun's surface and escape into interplanetary space.

At the three-quarters mark, the temperature of the Sun is about 1.5 million Kelvins. The X-radiation has been replaced by ultraviolet radiation. The plasma in this region undergoes convection, in which hot, buoyant plasma rises to be replaced by cooler and denser plasma from above. This drastically increases the rate at which energy moves outward toward the surface, with the result that the temperature begins to drop precipitously. Three tiers of ever-smaller convection cells fill the Sun from the three-quarters mark out to the surface. The temperature drops steeply in this region to the relatively cool 5,800 Kelvins at the surface.

The outermost shell of the Sun is called the photosphere. The appearance that the Sun has a definite physical surface is an illusion. The density, pressure, and temperature of the photosphere drop continuously and smoothly with increasing distance from the center, but at a certain point the gas composing the photosphere abruptly changes from opaque to visible to transparent and becomes invisible from that point outward.

The region outside the photosphere is regarded as the atmosphere of the Sun. It is divided into two layers. The chromosphere reaches out to 10,000 kilometers above the photosphere, where the temperature rises abruptly to 1 million Kelvins. This new region of the solar atmosphere is called the corona.

The photosphere is an intensely active region. The tops of the third-tier convection cells are visible and give the surface a granular appearance. Sunspots are large, relatively cool regions that appear dark in contrast to the surrounding hotter material. They are associated with intense localized magnetic fields. About 1 percent of the solar surface is covered by spicules, jets of superheated plasma visually resembling flames. Prominences are loops of plasma trapped by the magnetic field lines associated with sunspots. Prominences may extend thousands of kilometers out into the chromosphere and occasionally erupt, flinging solar material out into interplanetary space.

Facts About the Sun

	Sun	*Earth*
Mass (10^{24} kg)	1,989,100	5.9736
Volume (10^{12} km^3)	1,412,000	1.083
Volumetric mean radius (km)	696,000	6,371
Mean density (kg/m^3)	1,408	5,520
Surface gravity at equator (m/s^2)	274.0	9.78
Escape velocity (km/s)	617.7	11.2
Ellipticity	0.00005	0.0034
Absolute magnitude	+4.83	—
Luminosity (10^{24} J/s)	384.6	—
Mean distance from Earth (10^6 km)	149.6	—

The Sun's Atmosphere

Surface gas pressure (top of photosphere)	0.868 millibar
Effective temperature	5,778 Kelvins
Temperature at bottom of photosphere	6,600 Kelvins
Temperature at top of photosphere	4,400 Kelvins
Temperature at top of chromosphere	~30,000 Kelvins
Photosphere thickness	~400 km
Chromosphere thickness	~2,500 km
Sunspot cycle	11.4 yrs.
Photosphere composition:	
Hydrogen	90.965%
Helium	8.889%
Oxygen	774 ppm
Carbon	330 ppm
Neon	112 ppm
Nitrogen	102 ppm
Iron	43 ppm
Magnesium	35 ppm
Silicon	32 ppm
Sulfur	15 ppm

Source: Data are from the National Aeronautics and Space Administration/Goddard Space Flight Center, National Space Science Data Center. URL: http://nssdc.gsfc.nasa.gov/planetary.

• Capacity to Effect Climate Change

The Earth receives 1,350 watts per square meter of radiation from the Sun at the top of the atmosphere. This is referred to as the average insolation. The insolation varies over the course of the year due to the eccentricity of the Earth's orbit. The insolation also varies as the number of sunspots waxes and wanes over an eleven-year cycle. Long period variations in insolation associated with recurrent ice ages are due to minute variations in the shape of the Earth's orbit traceable to interplanetary gravitational influences.

Approximately 36 percent of the radiation received from the Sun is reflected back into space, with most of this reflection coming from clouds and ocean water. The ratio of radiation reflected to radiation received is called albedo.

The ultraviolet portion of the solar spectrum ionizes virtually all of the atoms at altitudes above 160 kilometers to form the ionosphere; more is absorbed in the stratosphere. Only a small fraction of solar ultraviolet radiation reaches the surface of the Earth. Virtually all of the visible and near-visible infrared radiation reaches the surface. With limited exceptions, all of the rest of the solar radiation, in the form of infrared radiation and radio waves, is absorbed in the atmosphere. The portion of solar radiation absorbed by the ground is reemitted as infrared radiation to which the atmosphere is opaque. The atmosphere thus acts as a gate that lets the energy of the visible radiation in but does not permit the reemitted infrared radiation to escape. This phenomenon is called the greenhouse effect; it keeps the Earth warmer than it would otherwise be.

Billy R. Smith, Jr.

• Further Reading

Friedman, Herbert. *Sun and Earth.* New York: Scientific American Library, 1986. Engaging, informative work by a pioneer of Sun observation from high-altitude rockets and satellites. Copiously illustrated with photos, diagrams, and graphs. Also includes a chapter-by-chapter list of further reading and an index.

Prialnik, Dina. *An Introduction to the Theory of Stellar Structure and Evolution.* New York: Cambridge University Press, 2000. Undergraduate text suitable for students of physics, astronomy, or the space sciences. Assumes a mastery of basic physics and calculus. Index.

Tribble, Alan. *The Space Environment: Implications for Spacecraft Design.* Rev. and expanded ed. Princeton, N.J.: Princeton University Press, 2003. Requires a knowledge of physics and mathematics at the advanced undergraduate level. Illustrations, data tables, end-of-chapter references, index.

See also: Atmosphere; Greenhouse effect; Ozone; Solar cycle; Solar energy; Sunspots.

Sun protection

- **Category:** Diseases and health effects

• Definition

Sun protection refers to methods of preventing damage or injury to the skin from ultraviolet radiation (UVR) emitted by the Sun. Such methods often involve physical or chemical barriers, Sun exposure reduction, or both. Physical barriers act to physically block UVR and include sunscreens, fabrics, and glass. Chemical barriers act by absorbing UVR and primarily include the chemicals incorporated in some sunscreens and in certain fabrics.

Sunscreens, usually applied as creams, lotions, or sprays, are composed of chemical substances that prevent UVR penetration of the skin. Sunscreens that act as a physical barrier to UVR include zinc oxide and titanium dioxide. Sunscreens that act as a chemical barrier to UVR include para-aminobenzoic acid (PABA), cinnamates, camphor derivatives, oxybenzone, avobenzone, octocrylene, and salicylates. The effectiveness of sunscreens in protecting skin against UVR is measured by a number called the Sun protection factor (SPF); a higher number indicates a greater degree of protection.

Fabrics act as physical barriers to UVR and include those that make up clothing, umbrellas, and hats (especially wide-brimmed hats to protect the face, eyes, and neck). The effectiveness of fabrics to block out UVR is indicated with a number called the ultraviolet protection factor (UPF); the higher the number, the greater the ability to protect against UVR. Fabrics that have a greater ability to block UVR are darker in color, heavy-weight, and tightly woven. Fabrics may also act as chemical barriers when they are made from fibers having such an ability or when the fabric is impregnated with a chemical sunscreen.

Limiting Sun exposure, especially between 10:00 A.M. and 4:00 P.M., when the Sun's ultraviolet rays are the strongest, and seeking shade when appropriate are effective in protecting against UVR. These precautions must be observed even on cloudy days, because UVR can penetrate clouds. Although a certain amount of protection is afforded by a hat or umbrella, the ground can reflect UVR. Therefore, sunscreens should also be applied.

Glass also acts as a physical barrier to block the three main types of UVR (UVA, UVB, and UVC). Some glass (such as the side and rear windows of many automobiles) block only UVB and transmit a considerable amount of UVA. Other types of glass used in automobile windshields, such as laminated glass (two pieces of glass bonded together with a plastic), are much more effective in blocking UVA and UVB. The effectiveness of glass to block UVR can also be increased by the application of UVR-blocking substances to the glass. Sunglasses, which may be made of glass, polycarbonate, or other materials, are particularly effective in protecting the eyes from UVR. Sunglasses designed with side panels or that wrap around afford better protection against UVR reaching the eyes from the sides.

Sun protection is particularly important for beach visitors. (©iStockphoto.com/Sieto Verver)

• Significance for Climate Change

The ozone layer is a layer of gas present in the stratosphere (the middle portion of the Earth's atmosphere) that plays a significant role in the regulation of UVR transmission to the Earth. Of the three main types of UV radiation that reach the Earth from the Sun, UVC is extremely hazardous, but it is completely absorbed by the ozone layer, as is most of UVB; UVA is completely transmitted through the ozone layer.

Substances that contribute to global warming can deplete the ozone layer, thereby allowing increased amounts of dangerous UVR to reach the Earth. Ozone-depleting substances include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, methyl bromide, carbon tetrachloride, and methyl chloroform. These chemical compounds are unstable in the stratosphere when subjected to UVR. As these compounds undergo reactions in the stratosphere, they are broken down into halogens such as chlorine, fluorine, or bromine. These halogens play a role in converting ozone into oxygen and other related by-products, thereby depleting the ozone layer. The continued depletion of the ozone layer leads to higher levels of UVB transmitted to the Earth, which in turn can lead to an increase in various medical problems.

All forms of UVR are harmful to biological organisms. UVA is responsible for damaging the deeper layers of the skin and producing harmful skin effects, including accelerated skin aging, tanning, and other conditions, such as drug-induced sunlight sensitivities. UVB affects the top layer of the skin and can produce skin cancers, especially basal cell carcinoma and melanoma. Skin cancer is the most common form of cancer in the United States, and more than 90 percent of the cases are due to Sun exposure. Significantly, Australia has the highest incidence of skin cancer in the world; associated risk factors are the great number of fair-skinned individuals in the country and the amount of Sun exposure.

UVB also causes tanning, sunburns, actinic keratosis (benign skin lesions that may develop into invasive squamous cell cancer), and formation of senile cataracts. UVB has been associated with other effects on the eyes, including the development of pterygium (benign tissue growth of the conjunctiva) and acute inflammation of the eyes, specifically the inside lining of the eyelids, cornea, and iris.

UVB has also been linked with decreased ability of the immune system to elicit a protective response.

This immunosuppression has been observed in a number of rodent and human studies; in fact, rodents exposed to UVB have shown increased susceptibility to certain infectious diseases. Solar UVR and exposure to sunlamps and sunbeds were classified by the United States Department of Health and Human Services in 2000 as known human carcinogens. Therefore, as the continued depletion of the ozone layer will lead to higher levels of UVR and a concomitant increase in the various medical conditions discussed above, Sun protection is essential for everyone exposed to UVR and should begin even in infancy.

Johanna C. Estanislao and Miriam E. Schwartz

- **Further Reading**

Bellenir, Karen, ed. *Health Reference Series Cancer Sourcebook*. 5th ed. Detroit, Mich.: Omnigraphics, 2007. Good source for basic information on skin cancers, sunscreens, and tanning products.

Kroschwitz, Jacqueline I., and Arza Seidel, eds. *Kirk-Othmer Encyclopedia of Chemical Technology*. 5th ed. Hoboken, N.J.: Wiley-Interscience, 2004-2007. Extensive resource to research various chemicals, their properties, and other related matters.

Skin Cancer Foundation. *2007 Skin Cancer Facts*. New York: Author, 2007. Provides most salient information on skin cancer.

World Health Organization. *Global Solar UV Index: An Educational Tool to Reduce Risks of Skin Cancer and Cataract*. Geneva, Switzerland: Author, 2004. Provides facts to the general public about UVR and its consequences.

See also: Chlorofluorocarbons and related compounds; Halocarbons; Halons; Hydrofluorocarbons; Ozone; Skin cancer; Solar energy; Sun.

Sunspots

- **Category:** Astronomy

- **Definition**

Sunspots are concentrated areas of magnetic activity on the surface of the Sun. They are both cooler and darker than the areas that surround them. The difference in temperature is caused by the fluctuation of the Sun's intense magnetic field, which in turn affects the convection zone on the surface. The convection zone is the outer 20 to 30 percent of the Sun, in which hot gases rise from the star's core and cool gases sink toward that core. Sunspots appear as dark blotches on the surface of the Sun and can have a diameter as great as 80,000 kilometers. The surface area varies as they travel over the Sun's surface, but the average sunspot is the same size as the planet Earth.

Sunspots are divided into two areas: the darker umbra and the lighter penumbra. Plasma on the surface of the Sun reacts with a sunspot's magnetic field, exploding from the surface in what is called a solar flare. Similar spots have been identified on other stars and are known as starspots. Sunspots vary in intensity over recurring cycles of roughly eleven years. These cycles form part of a longer, twenty-two-year cycle, in which sunspots appear in the northern hemisphere of the Sun for the first eleven years and the southern hemisphere for the second eleven years.

The ancient Aztecs had a myth of a Sun god with a pockmarked face, which may indicate that they were aware of sunspots. The first recorded observation of sunspots was made by ancient Chinese astronomers. The first Western reference occurs in Greece during the fourth century B.C.E.

While it is possible, albeit very dangerous, to observe sunspots with the naked eye, the invention of the telescope in 1608 changed the way astronomers looked at the Sun. It is unknown who was the first European to measure and record information about sunspots; the discovery is variously attributed to the Italian Galileo, Johannes Fabricius of Holland, Englishman Thomas Herriot, and Christopher Scheiner of Germany. While these men all noted the appearance and activity of sunspots, however, they lacked the detailed instruments needed to identify the nature of the phenomenon correctly. Scheiner, a priest who believed that the heavens were perfect, identified them as small moons and planets orbiting the Sun. It was Galileo who correctly observed that the appearance of the sunspots changed as reached the edge of the Sun's surface, which meant they had to be a feature of the

Sun, not something orbiting the Sun. He posited that they might be clouds.

• Significance for Climate Change

Throughout history, sunspots have been blamed for everything from earthquakes to economic fluctuations, but their effect on the Earth is far subtler. Early astronomers noted the correlation between heavy sunspot activity and Earth's magnetic activity. European astronomers noted a long-term decrease in sunspot activity from 1645 to 1715, called the Maunder Minimum for E. W. Maunder, who did much of the research. This era of low sunspot activity corresponds with what is called the Little Ice Age, a particularly cold era for much of the Earth.

Using historic records of sunspots and the aurora borealis (also known as the northern lights), as well as geological evidence of atmospheric deposits, scientists have determined that the Sun was very active prior to the Little Ice Age. Similar occurrences have been noted during the Oort Minimum (1010-1050), the Wolf Minimum (1280-1340), and the Spoerer Minimum (1420-1530). The pattern seems to be a cycle of seventy years of abnormal cold, followed by two hundred to three hundred years of warming.

Modern telescopes operate in many different wavelengths, and modern sunspot measurements include ultraviolet and infrared light, as well as gamma rays and X rays. The problem with identifying a definitive connection between solar activity and climate change on Earth is that scientists have only been able to accurately measure solar radiation since the satellite age. Measurements taken since the late 1970's have confirmed the existence of an eleven-year cycle, but also found that solar radiation only fluctuated by 0.1 percent.

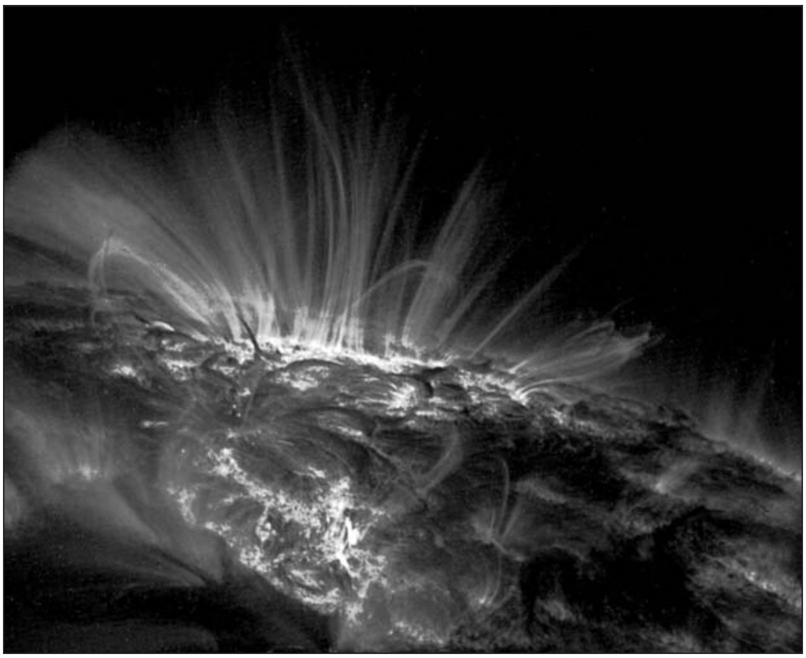
When solar radiation output is at its peak, the level of high-energy radiation in Earth's upper atmosphere increases. This increase causes an increase of ozone, which can double the temperature in the thin upper atmosphere. This in turn affects the stratosphere, specifically the wind patterns, and has an impact on climate around the world. Increased solar radiation is also tied to increased cloud cover.

Scientists base their findings on total solar irradiance (TSI), a measurement of all wavelengths of solar energy outside the Earth's atmosphere. This measurement confirms the 0.1 percent fluctuation over time, but it also reveals that solar radiation can vary by 0.2 percent over the course of just a few days and that such variation is tied to sunspot activity. While this appears to be an insignificant figure and plays only one small part in the overall climate picture, it is equivalent to the total energy used by the human race over the course of one year.

P. S. Ramsey

• Further Reading

Brody, Judit. *The Enigma of Sunspots: A Story of Discovery and Scientific Revolution.* Edinburgh, Scotland: Floris Books, 2003. Overview of the science of



A close-up of a sunspot group taken by NASA's TRACE spacecraft in September, 2000. (NASA/TRACE)

sunspots, from their ancient discovery to their current implications for the Earth's climate.

Shindell, D., et al. "Solar Cycle Variability, Ozone, and Climate." *Science* 284 (1999): 305-308. Details how interactions of solar output and ozone affect climate.

Thomas, John H., and Nigel O. Weiss. *Sunspots and Starspots.* New York: Cambridge University Press, 2008. Comprehensive scientific look at sunspot and starspot activity geared toward the advanced reader or college student.

See also: Faculae; Little Ice Age; Solar cycle; Solar energy; Sun; Ultraviolet radiation.

Sustainable development

• **Categories:** Economics, industries, and products; environmentalism, conservation, and ecosystems

In the face of climate change and dwindling environmental resources, sustainable development is key to maintaining the ways of life and standards of living to which industrialized nations have become accustomed, while protecting Earth's environment and the interests of future generations.

• Key concepts

biofuels: energy sources derived from recently dead organisms, most commonly plants

carrying capacity: the maximum population that can be supported indefinitely with the available resources and services of a given ecosystem

community: a group of people who live and interact within a specific geographic or social sphere

ecosystem services: all the interdependent organisms and nonbiological factors that combine to provide the conditions necessary to the sustainable existence of life within a given ecosystem

sustainability: the ability of an environmental or environmentally dependent system to continue indefinitely without exhausting the means of its reproduction

• Background

Sustainable development aims to address a number of interrelated global issues, such as poverty, inequality, hunger, and environmental degradation. The concept emerged out of numerous environmental movements begun in the 1970's and 1980's. The 1992 Earth Summit in Rio de Janeiro, Brazil, was one of the major international events to bring sustainable development into the mainstream. However, the progress in sustainable development has been quite slow across the globe. Many challenges and a lack of political will are responsible for this less-than-satisfactory progress.

• Progress and History

The term "sustainability" was first officially defined by the World Commission on Environment and Development as entailing "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Although it means many different things to different people, sustainable development generally refers to sustainability in terms of environmental, economic, and social progress and equity, all interconnected and operating within the limits of natural resources. At the heart of such development is the goal of a healthy and harmonious relationship between humans and natural resources, such that the latter can continue to provide for future generations of the former.

Sustainable development has been an urgent global issue for many years, although the record on moving toward achieving the goal has been quite poor. For instance, the world has failed not only to protect the interests of future generations but also to meet the needs of present generations. Currently, 1.3 billion people live without access to clean water, and nearly 50 percent of Earth's population survives on less than two dollars a day and lacks access to basic sanitation. A further 2 billion people are without electricity. These alarming statistics come in an age of immense wealth that is increasingly concentrated in fewer hands.

In the years since the Rio Earth Summit, sustainable development has ranked very low on international agendas. As a result, poverty has deepened, global inequality has widened, and environmental degradation has heightened. According to the

United Nations Human Development Report, 20 percent of the world's population in the richest countries accounts for 86 percent of total consumption expenditures, while the poorest 20 percent accounts for a minuscule 1.3 percent of expenditures. Given the tremendous inequality of wealth and resource partitioning in the world, it is no wonder the term "sustainability" bears quite different meanings to different people.

• Sustainable Agriculture and Forestry

Beginning in the second half of the twentieth century, agricultural productivity increased dramatically. This increase has helped improve the lives of billions, but at the same time it has weakened nature's ability to deliver other key services. These range from clean air and water to protection from disasters to preservation of biodiversity to prevention of soil erosion. Environmentally damaging industrial agriculture threatens future sustainability. Sustainable development seems to be the best option to halt or even reverse environmental degradation and grow food now without jeopardizing key services later.

Sustainable development must begin with a transformation of fundamental philosophies on agriculture. Many current agricultural systems are operated on business models that are geared solely to make money and profit. In other words, crops are not grown for people to eat but are produced for consumers to buy. This practice leads to a major diversion of land use from food production to profit generation. It also makes food less nutritious and less tasty, as crops are bred for shelf life and uniform appearance (qualities that are evident to shoppers in supermarkets and that facilitate lucrative high-volume models of production) rather than nutritional content or taste (qualities that are invisible until after one makes a purchase).

Much of the best agricultural land in the world is used to grow cash crops such as cocoa, cotton, tea, tobacco, and sugarcane or is converted to rangelands for high-demand livestock. Profit-driven operations have also led to overexploitation of natural resources. Mathematical ecologist Dick Levins comments about the necessity of changing attitudes on farming, saying,

> . . . farmers in sustainable agriculture are concerned about feeding their families and paying their bills, but those are not their only goals in life. They set out to protect the land, improve their quality of life, and enhance the communities in which they live. Their day-to-day decisions are not guided by a single minded search for profit, but by a delicate balancing act among many goals.

Because people rely upon trees and plants to build houses, produce paper, make furniture, and provide medicines, pressures on forests are staggering. Sustainable forest management is the only way to maintain the long-term health of the world's forests. According to the United Nations Food and Agriculture Organization (FAO), sustainable forest management is

> the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.

Without preserving any of these vital components, forests will eventually cease to provide society's members with the goods and benefits to which they have grown accustomed, including many valuable species that provide medicines. This loss of these species will be irreversible and permanent.

• Sustainable Energy Sources

Among the most important resources that must be sustained are energy resources. Alternative and renewable energy sources, particularly clean energy sources, are necessary components of any plan of sustainable development. Such sources include biofuels, geothermal power, solar power, wind power, and wave power. In the short term, any technology that improves energy efficiency may be considered a component of the transition to sustainable energy practices.

Biofuels in particular can be produced from almost any organic carbon source. However, most biofuels are produced using plants and plant-derived materials. The first generation of biofuels includes vegetable oils, biodiesel, bioalcohols, and solid biofuels such as wood, grass cuttings, domestic refuse, and dried manure. The most common use of these substances is as liquid fuel for transportation. Two common strategies are employed to produce biofuels: Sugar and starchy crops are used to produce ethanol through yeast fermentation, while natural plant oils, such as canola, soybean, and palm oils, are extracted and processed for use as biodiesel.

Production of first-generation biofuels is highly controversial, because it requires direct use of grains and takes away land from growing food crops, exacerbating world hunger. Moreover, biofuel crops, particularly corn, are extremely hard on soil, making them among the least sustainable crops in the world. The low energy efficiency of such crops is also cause for concern. As a result of these factors and related debates, technologies are being developed for second- and third-generation biofuels. Second-generation biofuels will be produced using cellulosic biomass, which is theoretically capable of much greater energy efficiency than is corn, as well as a variety of nonfood crops. Third-generation biofuel is also called algae fuel or oilgae, and it will be derived from low input/high yield algae (which produces thirty times more energy per unit of area than do land crops).

In general, sustainable economic development improves the economy without undermining society or the environment. There are various definitions of sustainable business or economic development from different sources, most of which share many common characteristics. According to the Lowell Center for Sustainable Development,

> Sustainable Production is the creation of goods and services using processes and systems that are: nonpolluting; conserving of energy and natural resources; economically efficient; safe and healthful for workers, communities, and consumers; and, socially and creatively rewarding for all working people.

• Context

By and large, current societies and socioeconomic practices are unsustainable. As a result, future generations will have a poorer, more polluted world to live in. Everyone depends on nature and ecosystem services for the resources necessary to live decent, healthy, and sustainable lives, including clean air, drinkable water, nutritious food, clothing, shelter, and so forth. Human activities in recent decades have pushed the Earth to the brink of massive species extinctions, threatening humanity's well-being. While the Industrial Revolution and technological advancement have served to improve the living standards of millions, the associated environmental degradation remains a heavy price.

Anthropogenic scourges of the planet have become significant barriers to sustainable development. Better protection and more efficient uses of various natural assets are vital if humans expect to inhabit the Earth in harmony with the planet's many other species and their ecosystems. Real sustainable development must recognize the interconnectedness between human beings and the environment if true environmental and social justice is to be obtained. Measures must be taken and technology must be developed to conserve natural resources, to secure alternative forms of energy, to develop an economy friendly to the environment, and to preserve cultural diversity and heritages. These goals can be achieved only through coordinated global efforts, across all sections of government, business, and local communities.

Ming Y. Zheng

Global GHG Emissions by Sector, 2000

Economic Sector	*Percent of Total Emissions*
Power stations	21.3
Industrial processes	16.8
Transportation fuels	14.0
Agricultural by-products	12.5
Fossil fuel retrieval, processing, and distribution	11.3
Residential, commerical, and other sources	10.3
Land use and biomass burning	10.0
Waste disposal and treatment	3.4

Data from the Netherlands Environmental Assessment Agency.

• Further Reading

Adkin, Laurie E. *The Politics of Sustainable Development: Citizens, Unions, and the Corporations.* Buffalo, N.Y.: Black Rose Books, 1998. Explores the attitudes of different entities in society as they reflect on not only their stake in protecting particular interests but also the limits of their abilities to envision alternatives regarding economic development. Argues for the convergence of both in pursuing sustainable development.

Buck, Louise, J. P. Lassoie, and Erick C. M. Fernandes. *Agroforestry in Sustainable Agricultural Systems.* Boca Raton, Fla.: CRC Press, 1998. Examines the environmental and social conditions that affect the roles and performance of trees in field- and forest-based agricultural production systems; presents case studies from around the world that offer innovative strategies that have been used successfully in raising forests and tree products on a sustainable basis.

Hawken, Paul. *The Ecology of Commerce: A Declaration of Sustainability.* New York: Collins Business, 2005. Provides a visionary blueprint for a marketplace in which businesses and environmentalists collaborate to redesign and manufacture products in innovative ways that move toward a profitable, productive, and ecologically sound future.

Mason, John. *Sustainable Agriculture.* 2d ed. Collingwood, Vic.: Landlinks Press, 2003. A must-read book for anyone who wants to know the fundamentals regarding sustainability and sustainable agriculture; clearly written and very informative.

Quaschning, Volker. *Understanding Renewable Energy Systems.* Sterling, Va.: Earthscan, 2005. This small book provides useful information on different renewable energy systems and climate change; deals consciously with problems of the energy industry.

Sandalow, David. *Freedom from Oil: How the Next President Can End the United States' Oil Addiction.* New York: McGraw-Hill, 2008. This well-researched, nonpartisan book offers a fair and realistic assessment of the U.S. addiction to oil, the adverse consequences of that addiction, and various policy options regarding liquid fuel substitutions that should be vigorously pursued.

See also: Agriculture and agricultural land; Biodiversity; Civilization and the environment; Conservation and preservation; Deforestation; Desertification; Ecological impact of global climate change; Ecosystems; Environmental movement; Forestry and forest management; Industrial ecology; Soil erosion; United Nations Division for Sustainable Development.

Technological change

- **Category:** Science and technology

The growth and continued evolution of technological systems and artifacts pose significant challenges and opportunities relating to global climate change. New technologies may damage the environment, but technologies may also be created to protect or restore that environment. In either case, technology is the driving force behind anthropogenic climate change.

• Key concepts

product life cycle: the complete history of a product, from the process of its creation to its ultimate disposal or reconstitution

tradeoffs: the balanced benefits and harms attributable to a given action or entity

unanticipated consequences: effects not foreseen

• Background

Human beings have an inherent capacity to create and re-create their environments. Human technological prowess far outstrips that of any other species. The ability of human beings to reshape landscapes, for example, can be easily observed from orbit. With the advent of industrialization and mass production and distribution, the pace and intensity of technological change accelerated.

Humans have created more devices and achieved more wholesale reshaping of the Earth during the past few hundred years than the previous several millennia. Perhaps the most outstanding exemplar of this reshaping has been the widespread creation and growth of cities, many of which contain populations of over ten million persons. Over one-half of the world's population lives in these densely packed urban environments, and collectively their inhabitants or those who service their needs from afar generate the bulk of the pollutants that affect the soils, water, other species, and air of the Earth.

• Measuring Technological Change

The extent of technological change is difficult to characterize precisely. One could catalog the patents granted in a certain time frame, but that information is just a small part of the overall picture. Many patents, which globally number in the millions, are never commercialized. Many patents that do result in actual products, goods, or services do not achieve large-scale success or dissemination. A significant number of patents, however, achieve extraordinary levels of influence, affecting human beings and the entire planet in profound ways. For example, the automobile and the many patents associated with it over time have arguably transformed both the human-made and the natural world.

Technological change itself can be thought of as a set of interrelated processes whereby a particular new artifact, system, or innovation is introduced on a scale sufficient to alter in some measurable manner the various environments in which that artifact, system, or innovation functions. All technological change involves a complex interaction among a host of actors, including inventors, government officials, sponsors, producers or manufacturers, distributors, users, and beneficiaries.

Each technology or technological system embodies within itself a set of implicit or explicit values, constraints, limitations, and problems that either are readily discernible or become discernible over time. For example, automobiles are designed to transport human beings and cargo from one location to another, but they also embody a set of values involving comfort, speed, agility, safety, efficiency, aesthetics, and so forth. They are designed and built within a set of constraints that minimally includes statutes and regulations that govern the sector, cost, marketability, and life cycle of each product, as well as the condition of the larger environment within which it will be embedded. For example, a nation that has few roads in good condition may require a significantly different type of automobile from one in which there are many paved highways.

• Technological Change and Global Climate

Modern technological systems have forever altered the relationship between users of technology and the natural world. Many technological devices exhibit a "black box" character for their users, who cannot discern or understand the fundamental principles upon which the devices operate or the ways in which they interact with larger technological systems to achieve their intended results. Because they do not understand the technologies they use, few people reflect on the consequences associated with personal technological choices. Human beings are thus separated from the natural world in ways that they were not in earlier centuries, when individuals could easily trace a set of relationships between, say, the food on their table or the artifacts in their local environments and the sources from which those foodstuffs and artifacts were derived. This disconnection from the natural world and the technology underlying everyday objects makes it difficult for consumers to think of their daily choices as affecting the environment.

Rampant consumerism is a second feature of the contemporary technological world, in which the average person accumulates multitudes of devices and technological systems over the course of his or her lifetime. The sheer amount of consumer products found within the home of an average American family would elicit envy from a wealthy ancient Roman nobleman. Average American families have traveled and personally experienced more of the sights and sounds of the world than ancient counterparts who were kings, queens, or emperors. All of these accumulated devices and the larger technological systems within which they are embedded directly or indirectly contribute to pollution and global climate change. The sheer weight of these devices is thus more important to climate change than any particular technology. Because virtually all industrial technologies are energy intensive and because so many aspects of life in a highly technological society contribute to environmental degradation, consumers may feel that calls to act environmentally responsible represent direct attacks upon their way of life.

• Technological Solutions to Global Climate Issues

Just as humans have created technologies to meet their needs and serve their desires across millennia, there is emerging evidence that this same capability is increasingly being employed by the private and public sectors to address problems related to global climate change. The state of California, which is home to 10 percent of the U.S. population, is just one encouraging example among many around the globe. During the early twenty-first century, it has decreased its ratio of carbon dioxide (CO_2) emissions to each dollar of gross domestic product (GDP), reaching a level that is 20 percent less than that of Germany. California generates 24 percent of its electrical power from renewable fuels and has the world's largest solar-power plant, largest wind farm, and most powerful geothermal facility. The Energy Efficiency Center at the University of California at Davis is pioneering new ways to take the best ideas from research and rapidly commercialize them.

Actions undertaken by President Barack Obama and the U.S. Congress to provide billions of dollars in economic stimulus monies for green technologies represent another encouraging sign that change is possible. However, technological change is an unpredictable process, and there is no clear relationship between monetary investments and productive outcomes. Most experts believe that it will take decades to provide adequate technological solutions to the challenges presented by global climate change. The history of technology cautions that such solutions will themselves embody tradeoffs and spawn unanticipated consequences that will require further solutions.

• Context

Accelerated technological change has both created many of the dilemmas of the modern world and presented opportunities for some of these challenges to be addressed. The debates over whether technology is inherently good or bad and the related debates over the proper relationship of human beings to nature are as old as philosophy itself. Climate change is perhaps the single greatest contemporary instance of those debates, and the practical responses to such abstract questions may well determine the course of both technological and societal change during the coming century. Whether a sustainable balance between the technological activities of human beings and Earth's ecosystems can be achieved remains a fundamental question of the human condition.

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• Further Reading

Grübler, Arnulf, Nebojsa Nakicenoric, and William D. Nordhaus, eds. *Technological Change and the*

Environment. Washington, D.C.: RFF Press, 2002. Experts from various fields argue that technological innovation remains poorly understood and that the forecasting of environmental impacts is still in its infancy.

Hughes, Thomas P. *Human-Built World: How to Think About Technology and Culture*. Chicago: University of Chicago Press, 2004. A noted historian of technology chronicles the American fascination with technologies of all kinds and the inherent dilemmas and benefits of living in a human-designed world.

Pernick, Ron, and Clint Wilder. *The Clean Tech Revolution: Discover the Top Trends, Technologies, and Companies to Watch*. New York: Collins Business, 2008. Survey of key developments from the perspective of two venture capitalists who invest in green technologies.

Volti, Rudi. *Society and Technological Change*. 6th ed. New York: Worth, 2009. Technology sociologist provides short, incisive commentary regarding a huge breadth of technologies found within modern societies.

See also: Air conditioning and air-cooling technology; Automobile technology; Biotechnology; Climate engineering; Industrial Revolution.

Thermocline

• **Category:** Oceanography

• Definition

The global ocean consists of three layers of varying density. The density of ocean water is a function of changes in salinity and temperature. A shallow, mixed layer extends from the surface to a depth of approximately 30 meters. At the bottom of the ocean is a cold layer that extends from approximately 500 meters deep to the ocean floor. The thermocline is the middle layer between these two. Within the thermocline, the temperature of the ocean changes rapidly from approximately 20° Celsius in the mixed layer to 2° Celsius in deep waters.

The thermocline is found only in waters between 60° north and 60° south latitude; it is replaced by a halocline (a layer of rapidly changing salinity) in the polar regions. The precise depth of the thermocline varies with seasonal changes in solar heating and wind strength. It is shallowest in the summer, deepest in the early spring or late fall, and sometimes absent during the winter.

• Significance for Climate Change

The influence of global warming on the thermocline can affect ocean biomes. The thermocline is shallowest and strongest (that is, it has the greatest temperature change over the shortest depth) when surface waters are warmest and they experience relatively weak winds and wave action—typically during the summer. The density of water decreases with increasing temperature, so a column of water is stable when a zone of warm, low-density water (the mixed layer) exists over a layer of cold, high-density water. The thermocline, when it is present, prevents water from the mixed layer from mixing down into the deep ocean.

The surface mixed layer is the region of the ocean where phytoplankton live and produce biomass that forms the base of the food chain. As phytoplankton grow and produce biomass, they take up carbon and nutrients that are dissolved in surface waters. These nutrients are returned to surface waters during the winter, when the thermocline breaks down and disappears. Mixing of surface and deep waters can also return dissolved oxygen to the deep waters.

Thus, when the thermocline is present and prevents mixing between the mixed layer and deep waters, surface nutrients cannot be renewed, and biomass production by phytoplankton eventually stops. Also, since oxygen is not returned to deep waters, they can become uninhabitable by organisms that require dissolved oxygen, such as fish and corals. A warmer climate could cause the development of a permanent, stable thermocline, which, in turn, could lead to decreased biomass production in the surface waters and to the development of large areas in the deep ocean that are uninhabitable by marine life because of extremely low dissolved oxygen concentrations.

Anna M. Cruse

See also: Fishing industry, fisheries, and fish farming; Ocean-atmosphere coupling; Ocean dynamics; Ocean life; Plankton; Polar climate; Reefs; Sea surface temperatures; Seasonal changes; Thermohaline circulation.

Thermohaline circulation

- **Category:** Oceanography

- **Definition**

Thermohaline circulation (THC) is the large-scale circulation of water in the ocean basins, driven by the dense deep water of the polar regions. The density of ocean water is a function of both temperature and salinity. Water increases in density in the polar regions, as surface water cools and its salinity is increased through sea-ice formation. (Salt excluded from sea ice increases the salt content of polar liquid water.) A column of water becomes unstable when surface water has a higher density than deeper water, causing the high-density surface water to sink until it reaches a depth at which it is neutrally buoyant. At that depth, the water will flow horizontally throughout the oceans.

High-density surface water that forms in the Labrador and Greenland Seas sinks to become North Atlantic deep water (NADW), while the high-density water that forms in the Weddell and Ross Seas sinks to become Antarctic bottom water (AABW). Other water masses that sink to intermediate depths form in the Mediterranean Sea (Mediterranean intermediate water) and along the edges of the Antarctic Circumpolar Current (Antarctic intermediate water); yet other water masses downwell in the centers of the subtropical gyres. NADW flows southward in the Atlantic Ocean, until it mixes with north-flowing AABW in the extreme southern Atlantic Ocean. Once mixed, these two masses form Pacific-Indian common water (PICO).

AABW flows north through the South Atlantic Ocean and can be detected as far north as the equator. After forming in the southern polar regions, deep water circulates around Antarctica and then flows northward into the Indian and Pacific Oceans. Although the mechanisms are not yet fully explained, it is thought that deep water ultimately returns to the surface as diffuse flow over a large area of the North Pacific Ocean. The net transport of warm surface water to the polar regions to replace surface water that sinks to become deep water is brought about by wind-driven surface currents.

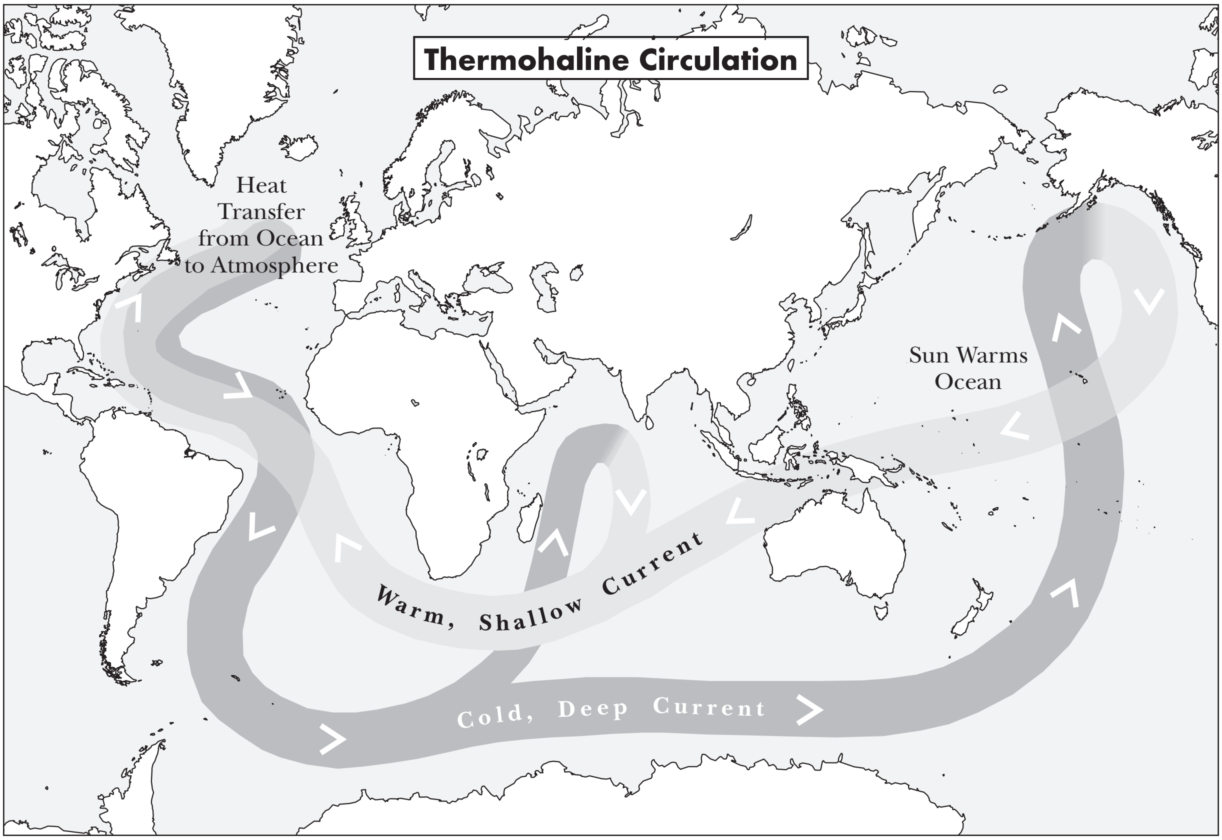
Thermohaline circulation is sometimes used synonymously with meridional overturning circulation (MOC), although this is not technically correct. THC refers to a global circulation pattern linking surface- and deep-ocean circulation, while MOC refers to deep circulation in the Atlantic Ocean.

- **Significance for Climate Change**

THC can be thought of as a large conveyer belt that transports surface water and heat from the equator to the North and South Poles, with a return flow of cold, deep water to the equator along the ocean bottom. THC is driven by water sinking to the ocean depths in a few distinct locations. After sinking, this water returns to the surface via diffuse flow over a broad geographic region in the North Pacific Ocean. THC is relatively slow: A single cycle takes approximately one thousand years.

Because THC redistributes large amounts of heat on the Earth, it is an important facet of global climate and climate change. In particular, global warming could lead to an increase in the freshwater flux into the North Atlantic by melting glaciers or increasing precipitation and river flow. An increase in freshwater flux to the polar regions would lower the density of polar surface water, stabilizing water columns and preventing the surface water from sinking into the ocean depths. An influx of surface freshwater in the Greenland Sea would also serve to block the northward flow of the Gulf Stream, a surface current that brings heat and ocean water to the polar regions.

It has been hypothesized that a shutdown of THC would lead to localized cooling of the Northern Hemisphere. In 2005, scientists from Britain's National Oceanography Centre presented data to suggest that THC in the Atlantic had slowed during the late twentieth century. These data were subsequently challenged by other scientists, who presented other data sets that showed no such slowing.



Despite the controversy regarding whether slowing is occurring, computer models consistently indicate that a shutdown of THC could lead to decreased warming or even cooling in the Northern Hemisphere. Geologic evidence suggests that the Younger Dryas, a time of global cooling that lasted from 12,800 to 11,500 years ago, may have been caused by THC collapse due to a large flux of freshwater from the emptying Glacial Lake Agassiz into the North Atlantic. In addition to climate changes, a shutdown of THC would have other important consequences, including the formation of anoxic conditions in large portions of the world oceans, reduction or collapse of phytoplankton productivity, and more frequent and severe El Niño events.

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• Further Reading

Alley, Richard B. "Abrupt Climate Change." *Scientific American* 291, no. 5 (November, 2004): 62-69. One of the pioneers of ice-core records explains the science behind theories of abrupt climate change and thermohaline circulation.

Open University. *Ocean Circulation.* 2d ed. Boston: Elsevier Butterworth-Heinemann, 2005. This introductory oceanography textbook covers atmospheric circulation, surface currents, and thermohaline circulation. The theory of fluid flow throughout the ocean is developed with a minimum of mathematics (knowledge of algebra and trigonometry is assumed). Illustrations, figures, tables, maps, references, index.

Schellnhuber, Hans, et al., eds. *Avoiding Dangerous Climate Change.* New York: Cambridge University Press, 2006. Collection of papers presented by leading climate-change scientists at the Avoiding Dangerous Climate Change conference, hosted by the British government in 2005. Chapters 5 and 6 discuss THC in the Atlantic Ocean. Figures, tables, references.

Vellinga, Michael, and Richard A Wood. "Global Climatic Impacts of a Collapse of the Atlantic Thermohaline Circulation." *Climatic Change* 54, no. 3 (August, 2002): 251-267. Presents data from a computer model to determine the rate of climate response if thermohaline circulation in the Atlantic were to collapse. Among the variables investigated are air temperature, rainfall patterns, the location of the ITCZ, and variations in oceanic primary productivity.

See also: Fishing industry, fisheries, and fish farming; Meridional overturning circulation; Ocean-atmosphere coupling; Ocean dynamics; Ocean life; Plankton; Polar climate; Reefs; Sea surface temperatures; Seasonal changes; Thermocline.

Thermosphere

- **Category:** Meteorology and atmospheric sciences

High levels of solar activity, including increases in extreme ultraviolet radiation and soft solar X rays, influence the atmospheric chemistry of the thermosphere. Increasing concentrations of CO_2 in the atmosphere have decreased the density of the thermosphere by about 10 percent over thirty-five years, lessening drag and extending satellite lifetimes.

• Key concepts

drag: friction caused by air as an object passes through it

extreme ultraviolet radiation (EUV): electromagnetic radiation with wavelengths between 10 nanometers and 120 nanometers

galactic cosmic rays: protons, electrons, and nuclei of light elements that originate outside the solar system and penetrate Earth's atmosphere

geomagnetic storm: magnetic activity caused when charged particles from solar flares strike Earth's magnetic field

low Earth orbit (LEO): an orbit situated between 160 kilometers and 1,600 kilometers above Earth's surface

soft solar X rays: solar radiation with wavelengths between 0.1 nanometer and 10 nanometers

space weather: conditions in outer space resulting from solar activity

• Background

The lower thermosphere is the region of the atmosphere above the mesopause-lower thermosphere boundary (MLT, about 90 kilometers above the Earth's surface). It extends to an altitude of about 550 kilometers. Atmospheric density decreases with altitude, as the numbers of atoms and molecules decrease and temperatures rise. The lower thermosphere is sometimes called the ionosphere, because the atmosphere there is highly charged by energetic solar photons.

Solar radiation drives photochemical reactions and motions in Earth's atmosphere. Careful monitoring of total solar output has revealed that it can vary by as much as 0.1 percent. This magnitude of variability would have little direct effect on Earth's surface temperatures. However, bursts of activity on the Sun, such as flares and coronal mass ejections, release large amounts of extreme ultraviolet radiation (EUV), soft solar X rays, and radio waves that cause ionization to strengthen in Earth's thermosphere, creating visible auroras over the polar regions. Above altitudes of 100 kilometers, ambient temperatures may be 1,000° Celsius higher at solar maximum than at solar minimum.

The supposition that variations in solar activity could influence Earth's weather and climate began several centuries ago. More than a millennium of solar observations have demonstrated that the appearance of sunspots follows irregular eleven-year and twenty-two-year cycles and that the appearance of auroras in the thermosphere closely follows the appearance of sunspots. Scientific attempts to link auroral appearance to weather patterns at Earth's surface have proved negative. Conclusive scientific evidence that variations in solar activity have caused recent changes in Earth's climate has been elusive.

Auroras occur when geomagnetic storms cause energetic particles to travel toward Earth along magnetic field lines. The high-altitude (300 kilometers) red aurora and middle green aurora result from the excitation of oxygen atoms, and the lower-altitude (75 kilometers) blue aurora is caused by the excitation of nitrogen atoms and molecules. The greater the number of molecules and atoms that are excited, the stronger the coloration of the aurora.

In the late twentieth century, scientific proponents of solar influences on climate began to claim that, when the Sun is very active over a long period of time, global warming occurs. During the period from about 1750 to the early twenty-first century, the Sun experienced more sunspots than it did during the period from 1645 to 1715, a time period referred to as the Maunder Minimum because few sunspots were observed then. The Maunder Minimum corresponds to the coldest portion of the Little Ice Age, which was observed in Europe and North America between the mid-thirteenth century and the mid-nineteenth century. Solar activity has increased since the Industrial Revolution, when anthropogenic greenhouse gas (GHG) emissions began to increase dramatically. Some scientists contend that up to half of the warming observed since the end of the Little Ice Age might be attributable to increased solar activity. This view has been met with skepticism by the international scientific community.

• Space Weather and the Thermosphere

When the Sun is active, the Earth's magnetic field (which extends beyond the thermosphere to the magnetosphere) is strengthened, lessening the number of galactic cosmic rays entering Earth's atmosphere. The solar magnetic flux affecting Earth has doubled in the last one hundred years. Protons in the inner Van Allen belt (700 kilometers to 10,000 kilometers above Earth) having energy above 50 million electron volts are assumed to arise from the decay of neutrons produced by galactic cosmic-ray collisions in the high atmosphere.

• Indirect Human Modifications of the Thermosphere

Carbon dioxide (CO_2) concentration continues to increase in Earth's atmosphere, and increased CO_2 reaching the lower thermosphere has caused cooling. As the thermosphere cools, atmospheric gases settle, causing the air density at an altitude of 400 kilometers to decrease by about 2 percent. This lowered density has decreased drag on satellites, extending their useful lifetimes. Atmospheric drag causes unpowered objects below altitudes of 480 kilometers to fall back to Earth within months. Because drag above this altitude is lower, more debris remains in orbit at that height for extended periods of time.

Most satellites orbit Earth in the lower thermosphere, from communications satellites to the Space Shuttle and International Space Station (ISS) to weather surveillance satellites. They circle the globe in low Earth orbit (LEO), from about 160 kilometers to 1,600 kilometers above the Earth's surface.

• Pollution of the Thermosphere

Low Earth orbit altitudes are monitored for space junk by ground-based radar systems that track objects larger than 5 centimeters. The lower thermosphere is occupied by hundreds of thousands of old satellite parts; on March 11, 2009, the Space Station was temporarily evacuated because of a near miss with a piece of junk about 12 centimeters in diameter.

On February 10, 2009, two LEO satellites (one defunct and one operational) collided over Siberia at an altitude of 750 kilometers, producing over 160,000 pieces of debris. Proliferation of debris by collisions of orbiting space junk is referred to as the Kessler syndrome: As more objects occupy the lower thermosphere, the chance of collision increases, and each collision creates even more debris, further increasing the chance of collisions.

Detonation of a nuclear weapon at an altitude of 420 kilometers above Johnson Island on July 8, 1962, generated an electromagnetic pulse (EMP) that disrupted electrical systems in Hawaii, 1,290 kilometers away. It also damaged most orbiting satellites. Detonation of a few nuclear weapons in the thermosphere at the start of a major war might cripple ground-based retaliation capabilities by destroying conventional communications that use integrated circuits, leaving intact only "hardened," or specially shielded, communications systems. (This was the reason for proposed construction of the extremely low frequency grid in North America.) Speculation has been raised about weapons in space that could be used against selected ground targets, but this option would be very costly and dangerous, leading to another arms race.

Because spy satellites play an important role in information-gathering by major countries including the United States, Russia, and China, eliminating enemy satellites at the start of any major conflict would be advantageous. There is a consensus that this type of satellite warfare would render the lower thermosphere unusable to satellites for many years because of the Kessler syndrome.

• Context

The thermosphere has undergone great change because of anthropogenic activity in the last fifty years. Increased anthropogenic CO_2 emissions have decreased drag at LEO, extending satellite lifetimes. Debris from satellites has rendered LEO more dangerous to piloted space missions and poses a steadily increasing hazard to functioning satellites. During the last century, the Sun has been more active, which may have caused solar influences on the Earth's atmosphere to increase. During active solar periods in the past, Earth's climate has apparently warmed, and when the Sun was less active, global cooling occurred. The mechanisms by which the small increases in total solar output might cause climate change on Earth are not known.

Anita Baker-Blocker

• Further Reading

Arnold, Neil. "Solar Variability, Coupling Between Atmospheric Layers and Climate Change." *Philosophical Transactions of the Royal Society of London Annual* 360 (2002): 2787-2804. Excellent technical survey of the relationship between solar activity and the atmosphere, including mechanisms that cause solar activity to influence Earth's climate.

Barth, Charles A., Scott M. Bailey, and Stanley Soloman. "Solar-Terrestrial Coupling: Soft Solar X-Rays and Thermospheric Nitric Oxide." *Geophysical Research Letters* 26, no. 9 (1999): 1251-1254. Report on satellite observations that soft solar X rays determine nitric oxide concentrations at an altitude of 110 kilometers over Earth's tropics during periods of low solar activity.

Glickman, Todd S., ed. *Glossary of Meteorology*. 2d ed. Boston: American Meteorological Society, 2000. This standard reference book contains definitions of meteorological terms.

Hitchens, Theresa. "Space Wars: Coming to the Sky Near You?" *Scientific American* 238, no. 3 (March, 2008): 78-85. Describes the consequences of militarizing the thermosphere and proliferating space junk.

Meinel, Aden, and Marjorie Meinel. *Sunsets, Twilights, and Evening Skies*. New York: Cambridge University Press, 1983. Discusses the consequences of detonating nuclear weapons in the thermosphere.

See also: Atmosphere; Atmospheric structure and evolution; Mesosphere; Stratosphere; Troposphere.

Thoreau, Henry David

American philosopher and writer

Born: July 12, 1817; Concord, Massachusetts
Died: May 6, 1862; Concord, Massachusetts

In Walden, *Thoreau presented an autobiographical account of his two solitary years living on Walden Pond. The work became a seminal statement of conservationism and environmentalism and may be seen as an early guide to global warming solutions from a personal point of view.*

• Life

Henry David Thoreau was born in Concord, Massachusetts, on July 12, 1817. At the age of eleven, he was sent to Concord Academy. Upon graduation, he entered Harvard University and received a bachelor's degree in 1837. After completing his degree, Thoreau had a very brief career in teaching (at Concord Academy). He was fired from the academy, because he refused to use corporal punishment in dealing with the students. He opened a school with his brother, showing his interest in nature by introducing the concept of nature walks to the students.

After four years and the death of his brother, Thoreau closed the school and returned home to join his family's pencil-making business. While at home, he became friends with a community of writers, including Ralph Waldo Emerson and Nathaniel Hawthorne. They encouraged his writing and urged him to publish his works. After a canoe trip, he came to realize that his true interests were nature and poetry. His first published work was entitled "Natural History of Massachusetts" (1842). From 1841 to 1844, Thoreau lived with the Emerson family, as a tutor for the children. In July of 1845, he moved to a small cabin that he had built on the shores of Walden Pond, on land owned by his friend Emerson. He remained there until September of 1847 and spent the subsequent seven years writing and revising his description of his twenty-six months there. This book, *Walden: Or, Life in the Woods* (1854), became his best-known work. He continued to explore nature and write throughout his life, dying in 1862 at age forty-four of sequelae of tuberculosis.

• Climate Work

In the journal he kept during his twenty-six months in solitude, Thoreau recorded information about what he saw in the landscape around Walden Pond during the 1840's. He recorded the migration patterns of birds, the flowering cycles of plants, and observations about wildlife and temperature. Modern-day researchers in Walden are replicating the work of Thoreau, using field notebooks and carefully recording the dates and times when flowers bloom and when birds return each migrating season. By comparing these current data with those obtained by Thoreau, one can determine whether global warming is influencing the behavior of plants and wildlife in this area of New England.

Following his time at Walden Pond, Thoreau remained extremely interested in travel and nature. He became a surveyor and kept very detailed notes on his natural history observations. These notes served as the basis for several of Thoreau's essays dealing with nature. In these essays, Thoreau argued for the necessity of conserving natural resources and preserving wilderness for the good of the planet. For instance, in his essay "Wild Fruits" (pb. 1999), he strongly argued for preserving the wilderness for the good of humankind.

In other essays, Thoreau discussed the destruction of various species (such as wild apples) caused by interference from humankind. He explained how forests were being destroyed through the acts of people or accidentally by fire, and

Generosity at the Roots

In A Week on the Concord and Merrimac Rivers *(1895), Henry David Thoreau described the superiority of nature to human art, locating a great part of it in the sense of boundless abundance in even a sparse wilderness—a sense that would come to seem ever more fragile and endangered in the next century.*

Art can never match the luxury and superfluity of Nature. In the former all is seen; it cannot afford concealed wealth, and is niggardly in comparison; but Nature, even when she is scant and thin outwardly, satisfies us still by the assurance of a certain generosity at the roots. In swamps, where there is only here and there an evergreen tree amid the quaking moss and cranberry beds, the bareness does not suggest poverty. The single-spruce, which I had hardly noticed in gardens, attracts me in such places, and now first I understand why men try to make them grow about their houses. But though there may be very perfect specimens in front-yard plots, their beauty is for the most part ineffectual there, for there is no such assurance of kindred wealth beneath and around them to make them show to advantage. As we have said, Nature is a greater and more perfect art, the art of God ; though, referred to herself, she is genius; and there is a similarity between her operations and man's art even in the details and trifles. When the overhanging pine drops into the water, by the sun and water, and the wind rubbing it against the shore, its boughs are worn into fantastic shapes, and white and smooth, as if turned in a lathe.

how they regenerated afterward when winds or animals spread seeds. In *The Maine Woods* (1864), Thoreau pointed out the important need for forest conservation. Through his work as a naturalist and a prolific author, he helped make the world aware of the need for conservation of resources in order to preserve the planet and avoid inadvertent changes in the environment. Many such changes have since led to global warming. Researchers replicating Thoreau's work at Walden Pond are investigating these changes. By comparing the dates when seasonal changes occurred in the 1840's to the dates of the same changes in the present, scientists are gathering data relevant to understanding global warming.

Robin Kamienny Montvilo

• Further Reading

Cain, W. E. *A Historical Guide to Henry David Thoreau.* New York: Oxford University Press, 2000. This biography of Thoreau offers historical insights into his impact on views of the natural world, as well as his philosophy of life.

Myerson, J. *The Cambridge Companion to Henry David Thoreau.* New York: Cambridge University Press, 1995. This collection of essays serves as a guide to the written works of Thoreau, while providing insight into his life in New England.

Olson, S. P. *Henry David Thoreau: American Naturalist, Writer, and Transcendentalist.* New York: Rosen, 2006. Describes Thoreau's early life, leading up to his time at Walden Pond. Culminates with his writings, his views on life, and their impact on the world.

Thoreau, H. D. *Walden.* New York: Thomas Crowell, 1910. Thoreau's best-known work describes his time at Walden Pond, and provides insights on the natural world. This book is the most direct link between Thoreau and global warming.

See also: Axelrod, Daniel; Bennett, Hugh Hammond; Carson, Rachel; Civilization and the environment; Conservation and preservation; Deforestation; Ecological impact of global climate change; Environmental movement; Forestry and forest management; Marsh, George Perkins; Tree-planting programs.

Thunderstorms

• Category: Meteorology and atmospheric sciences

• Definition

Thunderstorms can be both beneficial and detrimental. Normally formed under warm summertime conditions, they can bring needed rainfall to dry, parched soils. They can also, however, deliver rain with such force that it can cause severe soil erosion and property damage by flooding. Additionally, hail from these storms can wipe out crops and kill people and livestock. Each year, thunderstorms cause over a billion dollars' worth of damage to property, livestock, and crops in the United States. Tornadoes and other high wind events can also be spawned by these storms. However, lightning associated with thunderstorms is the major severe-weather-related cause of death in the United States. More deaths occur from lightning each year than from severe winter storms, hurricanes, and tornadoes combined. Thunderstorms are also associated with flash flooding, another major cause of U.S. weather-related deaths. Over one hundred U.S. deaths occur each year as a result of flash flooding due to thunderstorms, more than the average annual death count associated with tornadoes.

Worldwide, over two thousand thunderstorms are active at any given time. The basic preconditions for a thunderstorm are heat, instability, and moisture. Insolation from the Sun (heat) warms the land but does so inconsistently within the target zone of the storm. Some land surfaces may warm faster than others, creating pockets of warm and cool air. Where this differential heating warms the atmosphere, the air begins to rise, expand, and cool adiabatically. This rising, unstable air releases heat, which in turn generates greater atmospheric instability, more adiabatic cooling, and additional condensation. As this cycle continues, the storm builds.

Thunderstorms develop through a series of stages. The first stage is the cumulus or towering cumulus stage. Cumulus clouds are "cotton ball" type clouds, usually associated with fair weather.

Lightning strikes during a thunderstorm in Budapest, Hungary, in June of 2009. (Reuters/Landov)

However, these clouds develop as a result of atmospheric instability and differential heating. During the cumulus stage, updrafts lift the air to levels at which condensation occurs, sometimes accompanied by precipitation. As precipitation begins to fall from the upper portions of the cloud, the mature stage emerges. This stage is characterized by both an updraft and a downdraft component within the storm. From its beginnings to the mature stage, the storm may reach as high as 6,096 meters.

As the storm develops, more precipitation falls. This precipitation cools the lower levels of the storm and cuts off its updraft component. This dissipating phase is the final stage in storm development. Thunderstorms can spawn other storms around themselves as their gust fronts—cold air flowing out of the main tower of the storm—mechanically lift warm air in the vicinity of the main storm. Thunderstorms at their full development can reach upward to over 12,200 meters. Winds from these storms can range from mild to severe. Downbursts and straight-line winds emerging from the gust front can reach over 97 kilometers per hour. Tornadoes from these storms can produce winds from 64 kilometers per hour to in excess of 312 kilometers per hour.

Thunderstorms can be classified into four general types: single cell storms; multicell, or cluster, storms; multicell lines; and supercell storms. These classifications relate to the characteristic structure of the storm, its duration, and its severity. Single cell storms are rare but can produce 20- to 30-minute storms. Multicell storms contain more than one storm in a cluster. Each storm is in different stages of development. Line storms are multicell clusters associated with squall lines and are notorious for producing heavy rain, large hail, and sometimes tornadoes. The supercell is a single cell multiple kilometers across. The energy of these storms can rotate the storm, producing a mesocyclone. Although rare, supercells pose the greatest threat of damage.

High downburst winds in excess of 128 kilometers per hour are possible, along with baseball-sized hail and violent tornadoes.

• Significance for Climate Change

Additional heat added to the lower atmosphere through general warming of the climate might contribute to an increase in atmospheric instability; however, moisture must be present to generate a thunderstorm. Some studies suggest that precipitation in the tropics, a region known for thunderstorms and atmospheric instability, has increased as a result of warming temperatures. However, the increase in precipitation tends to be over oceanic areas rather than continental regions. In contrast, some climate models suggest that although fewer storms may occur over continental areas, their intensity may be increased by global warming—albeit without accompanying precipitation.

With some areas of the world expected to become drier as the climate changes, so-called dry storms could develop, producing more wind and more lightning. If warming is accompanied by drought, the potential for wildfires fueled by lightning could increase. Additionally, some models suggest that wind shear, the lateral movement of the wind, would give way to more violent updraft conditions. It is generally understood that the combination of wind shear and updraft has the potential to produce tornadic conditions in these kinds of storms. Some climatologists suggest that given the complexity of the physical geography and atmospheric environment, predicting the potential for increased tornadoes in these kinds of storms is not possible.

M. Marian Mustoe

• Further Reading

Aguado, Edward, and James E. Burt. *Understanding Weather and Climate*. 4th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Discusses storm structure, cloud development, severe storms, hail, rain, and flooding.

Ahrens, C. Donald. *Meteorology Today*. 9th ed. Pacific Grove, Calif.: Thomson/Brooks/Cole, 2009. Explains how lightning forms and is discharged, the structure of thunderstorms, updrafts, and micro bursts.

Battan, Louis J. *The Nature of Violent Storms*. Garden City, N.Y.: Doubleday, 1961. Provides a narrative following the formation of severe storms, as well as explications of their structure and propagation of lightning.

See also: Average weather; Drought; Dust storms; Extreme weather events; Monsoons; Rainfall patterns; Storm surges; Tornadoes; Tropical storms.

Tidal power

• **Category:** Energy

• Definition

Of all the ways that humans have sought to obtain power from the sea, harnessing tidal movements has proved the most effective. A traditional tidal power installation requires a dam or barrage placed across a natural bay or river, behind which a large amount of water can be stored. The vertical distance between low tide and high tide must be at least 5 meters, and it is helpful to have a major population center nearby in order to minimize transmission requirements.

At high tide, seawater is impounded behind the dam, producing a hydrostatic head. Then, as sea level falls, electric power is generated as the impounded water moves seaward through the dam's turbines. The world's largest tidal installation of this type is the La Rance power plant on the Rance River in France, which produces 240 megawatts of power. It also has turbines that can be reversed by 180°, so it can generate power on a rising tide as well as when the tide falls. Power can be generated only sixteen to eighteen hours per day, however, as power generation is impossible at slack water. A second major tidal power plant is on the Annapolis River in Nova Scotia. It produces 20 megawatts of power. Smaller plants are located in Russia and China, but their power generation is believed to be 5 megawatts or less.

Because few locations meet the requirements to

La Rance tidal power station, in Brittany, France. (Philippe Cherel/Maxppp/Landov)

harness tidal power using a dam or barrage, offshore turbines have begun to be introduced. They look exactly like the well-known wind farms on land but are anchored underwater in narrow channels that experience strong current flows during the tidal cycle. An early installation consisted of six turbines anchored in 9 meters of water offshore from New York City in the East River. The power generated was added to the city's power grid, but so far the amount has been small. Other installations have either been built as prototypes or are in the planning stages in Canada, Ireland, Scotland, and Norway.

- **Significance for Climate Change**

Environmental concerns are one of the reasons that more traditional tidal power plants have not been built. The Bay of Fundy, for example, which lies between Nova Scotia and New Brunswick in eastern Canada, has the greatest tide differential in the world, averaging more than 15 meters between low tide and high tide, yet no tidal power plant has ever been built here. Some of the environmental concerns preventing such a plant's construction are the potential impact on fisheries and shellfish, the potential damage to bird populations that feed on the tidal mud flats at low tide, and potential changes in the tidal basin behind the dam, such as reductions in water quality due to less flushing, altered tidal cycles, or damaging high-speed currents.

Environmental changes have already been reported from the Rance River, where tidal patterns have been disrupted, high-speed currents have developed around the barrage, and fish stocks have been affected. Construction of the Annapolis River plant has also caused problems. Shellfish beds upstream from the dam have been destroyed, there is increased erosion and flooding due to higher river levels, and lawsuits have resulted from damage to private property. Even offshore turbine installations may have environmental consequences, such as damage to boats and marine life, as well as harmful changes in a channel's currents or the tidal cycle.

Future climate changes will cause even more problems. Because land-based tidal power plants are located at sea level, warming temperatures will flood them as sea levels rise, while falling temperatures will leave them stranded inland as sea levels fall. In addition, higher sea levels will bring damaging waves, especially during storm surges and hurricanes. Underwater installations will be less affected, but locations that are favorable for power generation today may become useless as the shoreline configuration changes. On the other hand, new locations favorable for power generation may appear.

Damage to tidal basins upstream from established tidal power plants will also occur, especially with a rise in sea level. River banks may be eroded, and land may be lost as a result of permanent inundation. Destruction of personal property and loss of life may result as well. In addition, some scientists anticipate damaging saltwater intrusion into wetlands, agricultural soils, and coastal well fields. Tidal patterns may even change upstream and downstream from the tidal power plant, resulting in higher tidal levels; flooded coastal lands; and threatened roads, bridges, structures, wells, sewage systems, salt marshes, and harbors, all of which would result in higher operating costs.

Donald W. Lovejoy

- **Further Reading**

Boon, John D. *Secrets of the Tide: Tide and Tidal Current Analysis and Applications—Storm Surges and Sea Level Trends*. Chichester, West Sussex, England: Horwood, 2004. Summarizes tidal behavior along coastlines, with special attention to the effects of storm surges and sea-level rise.

Sverdrup, Keith A., and E. Virginia Armbrust. *An Introduction to the World's Oceans*. 9th ed. New York: McGraw-Hill, 2008. Reviews the origin and the characteristics of the tides, with an extended discussion of how tidal power plants work and their limitations.

Warrick, R. A., E. M. Barrow, and T. M. L. Wigley, eds. *Climate and Sea Level Change: Observations, Projections, and Implications*. New York: Cambridge University Press, 1993. An exhaustive treatment of the observed and predicted results for coastal areas of sea-level change.

See also: Clean energy; Mean sea level; Renewable energy; Sea-level change; Wave power.

Tornadoes

- **Category:** Meteorology and atmospheric sciences

- **Definition**

A tornado is a violently rotating column of air that is in contact with both the surface of the Earth and, usually pendant (held from above) to a cumulonimbus cloud, or, in very rare cases, the base of a cumulus cloud. It nearly always starts as a funnel cloud and may be accompanied by a loud roaring sound, most often compared to that of a speeding freight train. The funnel, initially filled with visible condensation (due to water vapor becoming visible due to cyclostrophic balance) and later with dirt and debris picked up along its path, has a narrow end that touches the ground.

The funnel cloud often is seen as it forms in the sky, it can stay on a continuous path or take on the effect of a bouncing motion, the latter can be seen from news reports that show several houses on either side of a fairly intact building demolished to their foundations. On a local scale, according to the National Oceanic and Atmospheric Administration (NOAA), a tornado is the most destructive of all atmospheric phenomena.

The majority of tornadoes have wind speeds ranging from 64 to 177 kilometers per hour, are approximately 75 meters across, and travel a few kilometers before breaking up and dispersing. Some tornadoes can achieve wind speeds greater than 480 kilometers per hour and stretch in excess of 1.5 kilometers across. Massive tornadoes such as these can stay on the ground for dozens of kilometers; a particularly devastating tornado in Illinois stayed on the ground for over 60 kilometers, killing almost two dozen people and destroying the then newly built subdivision of Plainfield, within 48 kilometers of the Chicago city limits.

Tornadoes occur primarily in the United States, although they have been spotted on every continent excluding Antarctica. Other global sites of common occurrence are in southern Canada, southern Africa near Johannesburg, central Asia, east-central South America, as well as in several areas of Europe, southeastern Australia, and New Zealand.

Enhanced Fujita Tornado Intensity Scale

EF Number	*Wind Speed**
0	105-137
1	138-177
2	178-217
3	218-266
4	267-322
5	over 322

Source: Storm Prediction Center, National Oceanic and Atmospheric Administration.

*Three-second gust, in kilometers per hour, estimated at the point of damage.

Types of tornadoes include the multiple vortex tornado (which has two or more funnel clouds), the satellite tornado (as the name suggests, a smaller vortex of wind which circles the main tornado), waterspouts, and land spouts (the last being extremely rare).

The most extreme tornado in recorded history was the Tristate Tornado, which left a path through Missouri, Illinois, and Indiana on March 18, 1925. The Fujita scale, ranging from F1 to F5 and based on the amount of damage caused, is considered to be an F5, although the Fujita scale was not a measurement at that time. This tornado was officially on the ground for 352 kilometers and produced a death toll of nearly seven hundred.

The most extensive outbreak on record (in almost every category) has been labeled the Super Outbreak, affecting the central United States in 1974. For eighteen hours, between April 3 and 4, 148 tornadoes touched ground, 6 were considered F5, and 24 were F4. At the peak of the outbreak, 16 tornadoes were on the ground simultaneously; over three hundred people were killed.

• Significance for Climate Change

Tornadoes are most common in cool seasons, such as early spring and early autumn. An increase in the surface temperatures of the sea (regions of origin such as the Mediterranean Sea and the Gulf of Mexico) increases moisture content, fueling an increase in tornado activity.

Climatic shifts affect tornadoes via teleconnections and shift the jet stream and, therefore, any larger weather patterns. Also, although insufficient support exists to make conclusions, evidence does suggest that El Niño and La Niña can have atmospheric effects ideal for tornado formation.

Possible effects from global warming: there are opposing views towards climatic changes, ranging from global warming being the cause for tornado droughts to an upsurge in more violent storms, as well as funnel clouds forming with more frequency over major metropolitan areas.

In the thirty-county warning area of southeastern Nebraska and north-central Kansas, a prime "tornado alley" in the midwestern United States, there was not a single confirmed tornado for the first six months of 2008. As global warming continues, certain areas will receive more storms, while others will experience less. The National Weather Service could be adversely affected by the absence of twisters, as the area mentioned above may consider discontinuing the NEXRAD radar service, while still utilizing Doppler radar from scattered locations.

In 2007, NASA scientists developed a new climate model that indicates more tornadoes because there will be more rainstorms in a warmer climate. The model was applied to a hypothetical future climate with double the current carbon dioxide level with a surface 2.5° Celsius warmer than the current climate. The central and eastern United States are more prone to severe storms based on this model.

The tornado outbreak—91 in total—of February 5, 2008, in the southeastern United States occurred when record highs were recorded in dozens of cities, 24° Celsius in Memphis as an example, while the Great Lakes area still suffered under winter storm watches with temperatures near freezing. In June of 2008, seven funnel clouds were recorded over Tinley Park, Illinois, a highly populated suburb just 16 kilometers south of Chicago. This is in comparison to the 1989 tornado that destroyed Plainfield, Illinois, the storm breaking up as it went from a primarily rural to a well-populated, urban area. Other tornadoes of record over major population centers include one near downtown Salt Lake City, Utah, in 2004, and one near Dallas, Texas, in 2007.

Wayne Allen Sallee

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere.* 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Comprehensive textbook that includes sections on tornadoes, global climate, and climate change. Bibliographic references and index.

Burt, Christopher C. *Extreme Weather: A Guide and Record Book.* Cartography by Mark Stroud. New York: W. W. Norton, 2004. Includes a section on tornadoes that addresses typical tornadoes, major historic events, and water spouts.

Ross, Tom, and Neal Lott. *A Climatology of Recent Extreme Weather and Climate Events.* Asheville, N.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National

Environmental Satellite Data and Information Service, National Climatic Data Center, 2000. Brief pamphlet that provides an overview of forty-six extreme weather events occurring between 1980 and 1999, each of which caused at least $1 billion in damage. Discusses the relationship of the storms and damages to both climate change and shifting population centers.

See also: Dust storms; Extreme weather events; Tropical storms; Tsunamis.

Trace gases

• **Categories:** Chemistry and geochemistry; meteorology and atmospheric sciences

• **Definition**

Trace gases are gases that exist at low concentrations in an atmosphere, generally less than one part per thousand. The bulk of Earth's atmosphere is made up of "permanent" gases—molecular oxygen and nitrogen—and argon, as well as the "variable" gas water vapor. In addition to these gases, thousands of trace gases are present, including many compounds of such common elements as carbon, sulfur, nitrogen, oxygen, and hydrogen. The atmosphere also contains small amounts of the halogens (fluorine, chlorine, bromine, and iodine) and the noble gases (helium, neon, krypton, and radon), as well as very small quantities of some metallic species such as mercury.

Each of the elements carbon, nitrogen, sulfur, and the halogens exists in numerous forms, ranging from fully reduced (that is, bound to the maximum possible number of hydrogen atoms) to completely oxidized (that is, bound to the maximum possible number of oxygen atoms). Carbon, for example, may exist within methane (CH_4, its fully reduced form) or carbon dioxide (CO_2, its fully oxidized form). Between these two extremes, the element is found in such other species as formaldehyde (H_2CO) and methanol (CH_3OH). Carbon can also be found within larger species containing two or more carbon atoms, including volatile organic compounds.

Hydrogen sulfide (H_2S, the gas associated with the smell of rotten eggs) is the fully reduced form of sulfur, and sulfuric acid (H_2SO_4) is the most oxidized form that is stable in the atmosphere. Nitrogen can be found as ammonia (NH_3, the most reduced form), nitric oxide (NO), nitrogen dioxide (NO_2), the nitrate radical (NO_3, the most oxidized) or other species such as nitric acid (HNO_3). Likewise, the halogens can be found bound to hydrogen or oxygen, as in hydrochloric acid (HCl), chlorine dioxide (ClO_2), and chlorine monoxide (ClO), which play a key role in destruction of the stratospheric ozone layer. (While molecular oxygen, O_2, is a permanent gas, ozone, O_3, is a highly variable and important trace gas.)

Most metals are present in gaseous form only very briefly if at all. Because they have very low volatility, if metals are released in their gas phase (usually in a hot combustion plume), they very quickly enter the aerosol phase. A notable exception is mercury, which has a sufficiently high volatility that its gas phase concentration typically exceeds its aerosol concentration. Most trace gases have both natural and human sources.

• **Significance for Climate Change**

Numerous trace gases have impacts on the Earth's changing climate, some large and others small. All of the major greenhouse gases (GHGs) released by human activities—including CO_2, methane, ozone,

Major GHGs

Gas	*Pre-1750 Concentration (ppb)**	*2008 Concentration (ppb)*	*Global Warming Potential*	*Lifetime (years)*
CO_2	280,000	383,900	1	~100
CH_4	700	1,735-1,857	25	12
N_2O	270	320-321	298	114
O_3	25	34	n/a	days

Data from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

*ppb = parts per billion.

and the chlorofluorocarbons—are trace gases. Trace gases make up a tiny fraction of the gases in the atmosphere, currently less than 0.05 percent combined, although this value is creeping up as CO_2 levels rise. However, they have large and disproportionate impacts on several properties of the atmosphere. Trace gases contribute significantly to the strength of the greenhouse effect, the degree to which the atmosphere traps heat received from the Sun. They also influence the rate at which pollutants emitted from the Earth's surface react and are removed from the atmosphere, the thermal structure of the atmosphere, and the healthfulness of the air.

Although present only at very low concentrations, trace species can have such significant effects because the permanent gases behave as though they are not there. Because molecular nitrogen and oxygen are both pairs of identical atoms and argon is a single atom, the permanent gases cannot absorb heat (far infrared light). As a result, all of the energy released by the Earth is available to be absorbed by the trace gases, as well as water vapor. The permanent gases also do not absorb visible light, although most of the trace gases do not either, so this distinction has limited climate importance. However, more than half of the incoming sunlight falls in the region of the electromagnetic spectrum just beyond red (near infrared), which the permanent gases absorb only slightly but CO_2, ozone, and water vapor all absorb strongly.

Nitrogen and argon are unreactive, and oxygen is only mildly reactive, so the chemical reactions of the trace gases are free to dominate the chemistry of the atmosphere. This situation has many climate implications, because it controls the concentrations and lifetimes of most of the anthropogenic pollutants released into the atmosphere.

Throughout most of the lower 90 kilometers of the atmosphere, the average temperature is controlled by atmospheric pressure. At higher altitudes, the pressure decreases. As it does, the air becomes markedly colder by an average of 9.6° Celsius per kilometer increase in altitude. This trend reverses briefly in the stratosphere, however. In this region, the atmosphere becomes warmer with altitude as a result of the stratospheric ozone layer. There is sufficient ozone in this layer to trap a large fraction of the incoming sunlight, heating the air with the Sun's energy. Above the stratospheric ozone layer is the mesosphere, where the atmosphere again cools with rising altitude.

Toxic air contaminants impact climate indirectly, but in some instances significantly. Urban ozone, acid rain, dry acid deposition, and other toxic pollutants can affect forest health for hundreds of kilometers downwind of their sources. Forest ecosystems may die off as a direct result of airborne pollutants. They may also be weakened by pollution, decreasing their ability to resist pests, which in turn may result in loss of forest biomass, either directly or by increasing susceptabilty to fires. Further, the transport and eventual deposition of nitrogen from combustion sources can change substantially the quantity of available nitrogen in soils, which in turn can cause changes in species distributions, net biomass, and fire frequency—again, for hundreds of kilometers downwind of major sources.

Suzanne E. Paulson

• Further Reading

Finlayson-Pitts, Barbara J., and James N. Pitts, Jr. *Chemistry of the Upper and Lower Atmosphere: Theory, Experiments, and Applications*. San Diego, Calif.: Academic Press, 2000. Provides a comprehensive look at the composition of the atmosphere and the many impacts of trace gases; many figures and data.

Lutgens, Frederick K., Edward J. Tarbuck, and Dennis Tasa. *The Atmosphere: An Introduction to Meteorology*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. General text that introduces very basic facts about atmospheric composition and the impacts of trace gases. The main focus of the text is on movements of the atmosphere.

Turco, Richard P. *Earth Under Siege: From Air Pollution to Global Change*. 2d ed. New York: Oxford University Press, 2002. Accessible text that covers all the major impacts of trace gases on the atmosphere and discusses atmospheric composition.

See also: Aerosols; Air pollution and pollutants: anthropogenic; Air pollution and pollutants: natural; Air pollution history; Atmospheric chemistry;

Carbon dioxide; Chlorofluorocarbons and related compounds; Greenhouse gases; Halocarbons; Methane; Nitrous oxide; Oxygen, atmospheric; Ozone; Volatile organic compounds; Water vapor.

Transportation

• **Category:** Economics, industries, and products

• **Definition**

Transportation is a means to facilitate spatially separated activities: for example, individuals travel to work or for leisure purposes; firms ship raw goods or finished products to clients or distribution centers, and employees travel for business. A small percentage of travel occurs for its own sake, such as walks in parks. The most common modes of personal urban transportation are the automobile, public transportation (buses, rail modes, ferries), motorcycles, bicycles, and walking. Personal intercity travel is commonly associated with intercity rail and buses, airplanes, ships, and the automobile. Freight transportation generally distinguishes between trucks, rail, pipelines, airplanes, ships, and barges.

Individual and freight transportation are the backbone of national and international economic activity and can provide benefits to businesses, individuals, and the nation. Transportation can positively impact employment, product prices, and economic growth. Population growth, increasing incomes, more spread-out land uses, and longer distances between activities have contributed to more than a quadrupling of global car ownership and use since 1950.

In 2006, the United States had the highest motor vehicle ownership rate in the world: 776 cars and light trucks per 1,000 population, compared to 97 cars per 1,000 population globally. In 2001, almost 90 percent of all personal trips in the United States were made by automobile, and Americans traveled roughly 24,000 kilometers by car annually. Wealthy European and Asian countries also had high levels of automobile ownership, but public transportation, walking, and cycling accounted for up to 50 percent of personal trips in those countries. Automobile ownership is predicted to increase rapidly in developing countries such as China and India. Transportation and spatial development patterns are closely connected. Faster motorized modes of transportation allow more spread-out human settlements. Low-density settlements in turn necessitate motorized modes of transportation.

• **Significance for Climate Change**

According to the Oak Ridge National Laboratories (ORNL) and the United States Department of Transportation (USDOT), in 2006, transportation was a principal source of greenhouse gas (GHG) emissions, accounting for about 20 percent of all GHG emissions globally and roughly 30 percent of U.S. emissions. Transportation contributes to climate change mainly through the burning of fossil fuels.

Compared to the residential, industrial, and commercial sectors, transportation is uniquely dependent on petroleum. ORNL reports that, in 2006, over 98 percent of all energy used in the transportation sector in the United States was petroleum based. CO_2 emissions accounted for almost 99 percent of all transportation-related GHG emissions. According to the International Energy Agency (IEA), transportation accounted for 23 percent of CO_2 emissions from fuel combustion worldwide, compared to 30 percent in the United States. Within the transportation sector, road transportation accounted for roughly 70 percent of CO_2 emissions from fuel combustion worldwide and 80 percent in the United States. Even among developed nations, the United States is uniquely dependent on the automobile and petroleum-based fuels.

ORNL and USDOT estimate that over 60 percent of all U.S. transportation-related GHG emissions come from automobiles, sports utility vehicles (SUVs), and light passenger trucks; only 20 percent of such emissions are attributable to medium and heavy trucks. Airplanes account for 8 percent and rail, water transportation, and pipelines for another 7 percent of transportation-related GHG emissions.

According to the IEA, global CO_2 emissions from transportation increased by 37 percent from 1990 to 2004, compared to an increase of 26 percent in the United States. In 2004, CO_2 emissions from transportation sources per capita in the United States were three times higher than those of European countries and six times higher than the global average. Even adjusting for economic activity, CO_2 emissions from transportation per unit of gross domestic product (GDP) were 60 percent higher in the United States than in Europe. USDOT predicts a doubling of energy-related CO_2 emissions in China and India from 2004 to 2030, partly fueled by increasing motorization there.

Transportation-related GHG emissions depend on the level of transportation activity (including number of trips and distance traveled), the mode of transportation (motorized or nonmotorized), and the fuel type and its carbon intensity. Reductions in transportation-related GHG emissions can be achieved through technological and behavioral changes. Technological innovation can improve vehicle efficiency and increase the viability of low-carbon or noncarbon fuels. Changes in behavior can reduce the total amount of travel and increase the share of trips on foot, by bike, or by public transportation.

Ralph Buehler

• Further Reading

Banister, David. *Unsustainable Transport: City Transport in the New Century*. New York: Routeldge, 2005. Global overview and city-level analysis of the connections between the transportation sector and sustainable development.

Ewing, Reid, et al. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Washington, D.C.: Urban Land Institute, 2008. Presents original research as well as a literature review linking spatial development patterns to personal travel behavior, transportation energy use, and climate change.

Greene, David. "Transportation and Energy." In *The Geography of Urban Transportation*, edited by Susan Hanson and Genevieve Giuliano. New York: Guilford, 2004. Provides a basic introduction to transportation and energy use and an overview of U.S. policies and regulation of energy use in the transportation sector.

International Energy Agency. "CO_2 Emissions from Fuel Combustion, 1971-2004." Paris: International Energy Agency, 2006. Extensive overview of global statistics and trends in CO_2 emissions from transportation-related fuel combustion.

Oak Ridge National Laboratories. "Transportation Energy Data Book." Oak Ridge, Tenn.: Author, 2008. Annual publication of energy use and GHG emissions data from transportation sources in the United States.

Sperling, Daniel, and James Cannon, eds. "Reducing Climate Impacts in the Transportation Sector." New York: Springer, 2008. Collection of proceedings from the 2008 Conference on Transportation and Energy Policy, focusing on transportation's potential role in reducing GHG emissions.

U.S. Department of Transportation. "Transportation and Climate Change Clearinghouse." Washington, D.C.: U.S. Department of Transportation, 2009. Extensive national and global inventory and forecasts of transportation-related GHG emissions.

See also: Contrails; Fossil fuel emissions; Fossil fuel reserves; Fossil fuels; Fuels, alternative; Gasoline prices; Hubbert's peak; Hybrid automobiles; Motor vehicles.

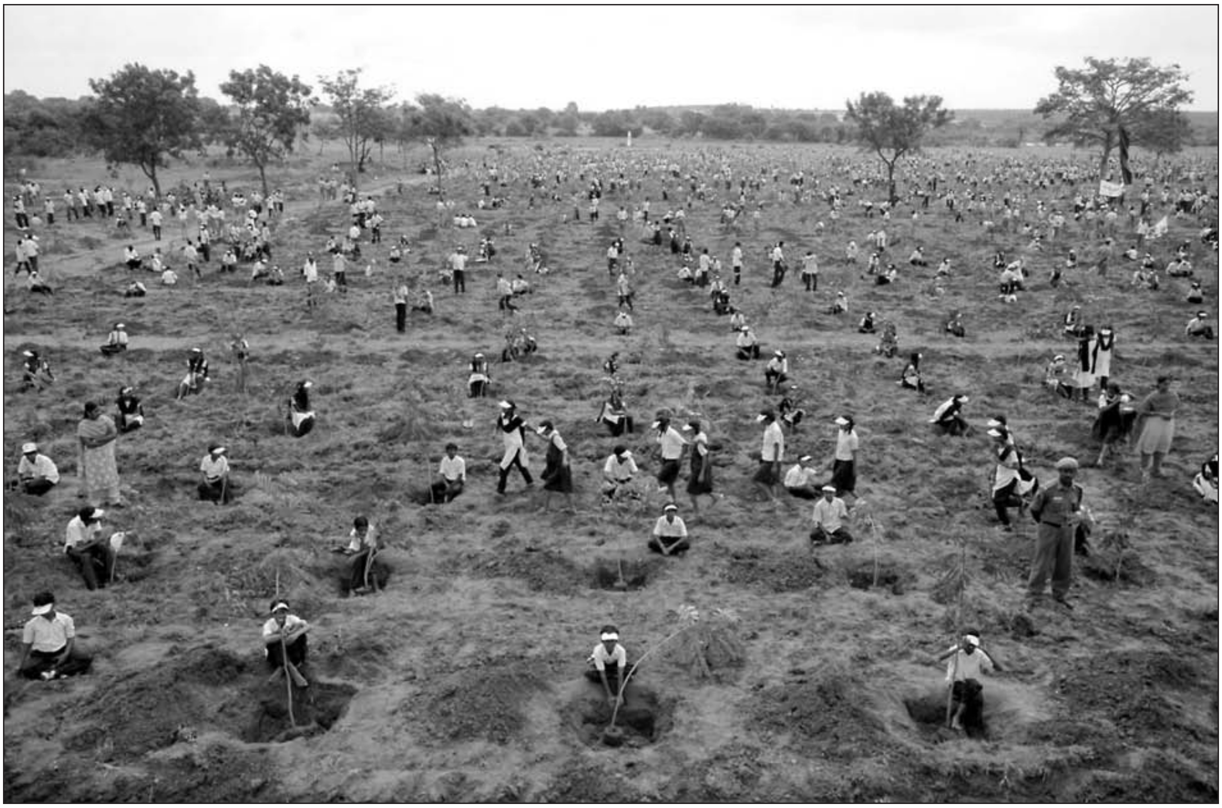
Tree-planting programs

• Categories: Environmentalism, conservation, and ecosystems; Plants and vegetation

• Definition

One of the environmental and economic benefits of trees is their potential to mitigate climate change by absorbing carbon as they grow. Many tree-planting programs exist worldwide, from village-scale community efforts to massive undertakings by the United Nations, national governments, and corporations. These programs vary widely in their approach and their goals. Rarely is climate mitigation the sole motive for tree-planting programs, but it is becoming increasingly important.

Tree-planting falls into several different catego-



Children from Hyderabad, India, participate in a day of tree planting coordinated by the Hyderabad Urban Development Authority. (Krishnendu Halder/Reuters/Landov)

ries defined by prior land use of the planted area. Reforestation is the planting of trees to replace those that have been destroyed by logging, agriculture, fire, or other disturbances. (Without human intervention, the regeneration of a forest is usually termed "forest regrowth.") Afforestation is the planting of a trees on land that was not historically forested. Agroforestry is the integration of trees and agricultural crops on the same land. These definitions may blur or overlap, such as when regrowth is promoted by management practices. Tree-planting often occurs without the need for special programs or incentives; for example, commercial timber operations reforest cleared land to ensure a steady timber supply.

• Significance for Climate Change

Reforestation, afforestation, and agroforestry programs can play a major role in combating climate change, sequestering 10 to 20 percent of global greenhouse gas (GHG) emissions by 2050, according to a 2001 estimate by the Intergovernmental Panel on Climate Change (IPCC). However, estimating the climate benefit of a given project is a technically complex undertaking. The impact depends not only on the number of trees planted, but also their survival and growth rates, their average lifespan, their contribution to soil carbon, their effects on evapotranspiration and surface albedo, and other factors. These factors can be difficult to measure, especially when the tree-planting is implemented on a community scale by many participants. Some standard metrics have been developed, but assumptions and reporting vary greatly.

Under current rules, tree-planting schemes rarely qualify for international funding through the clean development mechanism (CDM) of the Kyoto Protocol. Thus, tree-planting programs that focus on carbon sequestration seek to fund their work through voluntary "carbon offset" payments from individuals and organizations. Such programs include Fondo Bioclimatico in Mexico and the International Small Group and Tree Planting Program (TIST) in East Africa.

Climate mitigation is not the only or even the foremost motivation for tree-planting. Many programs (such as Trees for Life and Trees for the Future) predate widespread concern about global warming. Even programs focused on climate usually acknowledge and pursue other benefits, such as food security, income generation, and wildlife habitat.

Tree-planting campaigns are often run by national governments. The United States was the first country to declare a national tree-planting day, Arbor Day, created in 1872 to promote soil and water conservation. Similar holidays are now observed in dozens of countries as diverse as the Philippines, Venezuela, Belgium, and Algeria. Some countries have year-round initiatives, such as Costa Rica, which in 1996 created a national forestry fund to compensate farmers for protecting and replanting the "cloud forests" upon which the country's hydrology and biodiversity depend.

Nongovernmental organizations (NGOs) also play a major role in tree-planting efforts. A notable example is the Green Belt Movement (GBM), founded by Wangari Maathai, who won the 2004 Nobel Peace Prize for her work. GBM began in Kenya, training women to grow and distribute tree seedlings in their communities, and later expanded to reforestation of public land. Maathai went on to inspire the Billion Tree Campaign, an initiative by the United Nations Environment Programme to coordinate tree-planting efforts worldwide. As of early 2009, nearly 3 billion trees had been planted by 155 participating countries.

Although tree-planting is sometimes perceived as a universal good—for the climate and for other reasons—it is subject to many social and ecological pitfalls. Inappropriately planted trees can disrupt water flows, invade ecosystems, and disempower communities. Furthermore, tree-planting cannot fully substitute for the preservation of mature natural forests, which usually contain not only greater carbon stocks but also unique biological and cultural value.

Amber C. Kerr

• Further Reading

Bala, G., et al. "Combined Climate and Carbon-Cycle Effects of Large-Scale Deforestation." *Proceedings of the National Academy of Sciences of the United States of America* 104, no. 16 (April 17, 2007): 6550-6555. This controversial paper argues that trees at high latitudes have a net warming effect and that only in the tropics can trees mitigate global warming.

Freer-Smith, P. H. , M. S. J. Broadmeadow, and J. M. Lynch, eds. *Forestry and Climate Change*. Oxfordshire, England: CAB International, 2007. Based on a 2006 conference, this book reviews technical and policy aspects of climate-forest interactions; includes a chapter on reforestation programs. Figures, tables, index.

Hayward, Becky. *From the Mountain to the Tap: How Land Use and Water Management Can Work for the Rural Poor*. Hayle, Cornwall, England: Rowe the Printers, 2005. This review of research in developing countries seeks to dispel the myth that tree-planting benefits water supplies; sometimes the reverse is true.

Intergovernmental Panel on Climate Change. *Land Use, Land-Use Change, and Forestry: A Special Report of the IPCC*. Edited by Robert T. Watson et al. New York: Cambridge University Press, 2000. Definitive volume on conceptual, technical, and legal aspects of forestry for climate mitigation. Includes details of carbon accounting methods. Figures, tables, glossary.

Polgreen, Lydia. "In Niger, Trees and Crops Turn Back the Desert." *The New York Times*, February 11, 2007, p. A1. Describes the recent increase of tree cover in southern Niger and its beneficial effects on food security and income generation. Photos, maps.

See also: Agroforestry; Albedo feedback; Deforestation; Forestry and forest management; Forests; Offsetting; Sequestration.

Tree rings

- **Category:** Plants and vegetation

- **Definition**

Tree rings, also known as growth rings or annual rings, are visible in the woody stems of trees. A woody stem is composed of cells collectively known as secondary xylem. These cells are responsible for moving water and nutrients upward in the plant and provide support for the aboveground portion of the tree.

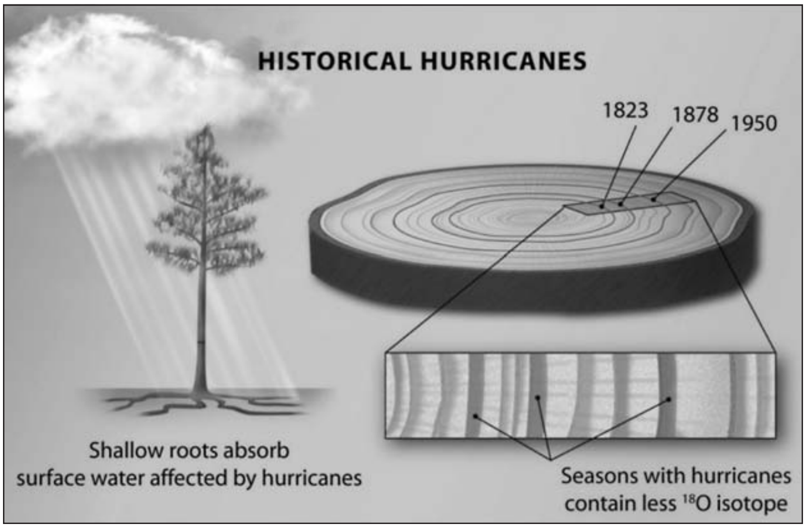
Tree rings are formed by the production of cells of different widths. When growing conditions are more optimal, as is typical in the earlier part of the temperate growing season, the diameters or width of the cells are large and the cells appear light to the naked eye. This growth is typically called early wood. During less optimal growing conditions or later in the season, the diameters of the conducting cells are smaller and more fibers for support are produced. Both fibers and the conducting cells produced in the later portion of the growing season (or under less desirable environmental conditions) are smaller in size and have thicker walls than do the cells in the early wood. Because the cells are smaller and the walls are thicker, the wood appears darker to the eye. This darker, denser wood is often called late wood. Bands of lighter, early wood alternating with bands of darker, denser wood creates the appearance of rings in a cross-section of a tree.

In temperate areas with distinctive seasons, trees typically produce one ring for each growing season. Scientists are able to determine the age of a tree by examining the number of rings in the trunk of the tree. Since the width of the ring correlates to the quality of the growing season, one can infer past climatological information by measuring the width of the growth rings. The information gathered represents localized conditions for that species in that particular environment. In tropical areas, the growth in trees is more continuous and the use of rings to determine age and climatic conditions is less reliable.

Numerous factors contribute to the overall quality of a growing season. Environmental factors include moisture, temperature, nutrient availability, sunlight, carbon dioxide (CO_2) availability, wind, and pollution. Researchers have shown that the width of a ring in most trees is most closely associated with temperature and moisture availability. The age of the tree, competition with other organisms, herbivory, and disease can also influence the growth of a tree.

- **Significance for Climate Change**

Changes in climate affect tree growth. Increasing levels of CO_2 have been shown to enhance the rates of photosynthesis and improve water efficiency in some tree species. This enhancement, however, has been observed in laboratory and modified field environments, for relatively short periods of time (up to three years), on seedlings, under weed-free and insect-free conditions. It is uncertain whether the same result would occur under field conditions with older trees. Enhanced growth would poten-



Because hurricane precipitation contains less oxygen 18 than does most other precipitation, tree rings low in this isotope can be used to construct a record of hurricanes in a given area. (National Science Foundation/Zina Deretsky) tially result in the accumulation of more wood through the production of wider rings.

With increasing CO_2 concentrations and global warming, temperatures are increasing. It is likely that this temperature increase will affect the composition of tree species in some ecosystems. Ranges for many tree species are likely to be extended and will decrease for those species adapted to cooler environments. Temperature is likely to affect conditions such as fire, drought, wind, and ice, thus influencing the growth of trees.

In addition to atmospheric warming, warming of the soil will affect the growth of trees. Research has shown that root growth and root turnover is enhanced with elevated CO_2 and temperatures. Much of the carbon in a tree is stored within its roots. Enhanced root growth might provide additional nutrients for the plant. In addition, as temperature increases, leaf litter decomposition also increases, which in turn increases the cycling of nutrients to the organisms growing in the soil.

Besides increases in CO_2 and temperature, other climatic factors are increasing that could have a significant impact on tree growth. Two such factors are ozone and sulfur. Both have been studied extensively, with seemingly conflicting results. Trees have been shown to be susceptible to increasing levels of ozone and acid rain (the latter produced from sulfur in the atmosphere). This has been well documented in the laboratory, in modified field experiments, in individual field observations, and in highly polluted localized areas. A difference in susceptibility among tree species has also been documented. In mixed forests, some tree species are damaged by acid rain, ozone, and other pollutants, while other species in the forest remain seemingly unaffected.

It has been more difficult for researchers to link pollutants with the decline of entire forests. The most dramatic and best-documented example of the impact of acid rain on a forest is the devastation of the Black Forest in Germany. Clearly the potential for damage by pollutants exists and is a reality in some areas, but additional field research and careful monitoring are needed to understand forest ecosystems and the levels at which pollutants are significantly impacting the ecosystem.

Joyce M. Hardin

- **Further Reading**

Bell, J. N. B., and M. Treshow. *Air Pollution and Plant Life.* 2d ed. New York: John Wiley & Sons, 2002. Details the impact of a wide variety of pollutants on plant life. Illustrations, figures, tables, bibliography, index, maps.

Karnosky, D. F., et al., eds. *Air Pollution, Global Change, and Forests in the New Millennium.* Oxford, England: Elsevier, 2003. Overview of the effects of climatic factors that emphasizes the impact of ozone, acid rain, and CO_2 on the growth and health of forests. Illustrations, figures, tables, bibliography, index, maps.

Raven, Peter H., Ray F. Evert, and Susan E. Eichorn. *Biology of Plants.* 7th ed. New York: W. H. Freeman, 2005. Text includes general information on plant growth, tree rings, and the impact of climate change. Illustrations, figures, tables, bibliography, index, maps.

See also: Budongo Forest Project; Carbon dioxide fertilization; Climate reconstruction; Dating methods; Fire; Forestry and forest management; Forests; Photosynthesis; Pollen analysis.

Tropical climate

- **Category:** Meteorology and atmospheric sciences

- **Definition**

The tropics are the equatorial region between the Tropic of Cancer (23.5° north latitude) and the Tropic of Capricorn (23.5° south latitude). Because of an atmospheric circulation pattern known as the Hadley circulation, the tropics tend to be warm and wet. This region contains a variety of ecosystems, including deserts, rain forests, savannas, and several islands. Although each of these ecosystems resembles the others in having hot weather (with the exception of a few mountains, such as Kilimanjaro in Tanzania, which lies only a few degrees south of the equator), they differ widely in average annual rainfall. In parts of Asia, Latin America, and Africa, rain forests are common, with average rainfall of more than 250 centimeters per year. The Sahara Desert also falls within the tropics, and it has some of the driest climate in the world. Some savanna regions, such as those in Kenya, have moderate amounts of rainfall. Indeed, some savannas are at a high enough altitude that they have a fairly wide daily temperature range during some parts of the year. The tropics also include several important coral reefs, such as those off the northern coast of Australia.

• Significance for Climate Change

One aspect of concern related to global climate change is that many of the tropical nations are among the poorest on Earth. These developing nations will be less able to adapt to climate change than the industrial nations of Europe and North America. All of the scenarios generated by the researchers connected with the Intergovernmental Panel on Climate Change (IPCC) indicate that global warming will have less of an impact on the temperature of the tropics than on the temperatures of regions at higher latitudes. Nonetheless, even minor temperature changes coupled with other factors can produce dramatic results.

In 1912, the average snow cover on Mount Kilimanjaro was 12 kilometers thick, yet by 2007 the snow cover had decreased to an average of only 1.5 kilometers thick. If the climate warms, in some places rainfall is expected to increase a great deal, while in other regions, such as northern Australia, drought conditions will intensify. In tropical rain forests in parts of Africa and South America, the intensity of rainstorms is predicted to increase, causing further erosion in cleared regions of the forests. Because many tropical ecosystems are quite fragile, even small changes in temperature, precipitation, and wind patterns will produce large adverse impacts on the affected nations. The major impacts in the tropics will come less from direct increases in temperature and more from changes in precipitation patterns, wind currents, and indirect impacts combining these two with temperature increases.

The impact of climate change on the tropics will differ from region to region, but it will become increasingly severe as global warming increases. For example, the IPCC projects that a 3° Celsius increase in global temperature will lead to a major loss of tropical rain forests, and, with this increase, as many as one-third of all species will become extinct. A 4° Celsius increase in temperature could lead to as many as 70 percent of all species worldwide, many in the tropics, becoming extinct. A temperature increase of this magnitude is also likely to lead increased acidification of the oceans and the bleaching and ultimate death of most coral reefs, many of which are found in the tropics.

Increased rainfall and the resulting runoff in countries such as Bangladesh would lead to extensive flooding, a problem exacerbated in Bangladesh by coastal flooding. Coastal flooding in southern India is projected to threaten the water supplies of many communities by the latter part of the twenty-first century. Because most hurricanes are found in the tropics, tropical peoples have long been concerned by the number and magnitude of hurricanes. Several scientists predict that increasingly warmer oceans would be likely to spawn more hurricanes and cyclones of greater magnitude than in the past.

A combination of climate change and concomitant socioeconomic changes is likely to produce several negative social and economic effects for societies in the tropics. In Nigeria, for example, many people may be forced to migrate from the interior to already-crowded coastal cities. Increasing temperature combined with precipitation changes (either too little or too much) are likely to have a negative impact on the food supplies of tropical regions. In some cases, diseases such as malaria are likely to become more common because of increased standing water.

The various scenarios for climate change accepted by most scientists project an average increase in temperature of between 3° and 7° Celsius by the end of the twenty-first century. Although the temperature is projected to increase less in the tropics than in the temperate zones, the impact is likely to be severe. Many tropical nations lack the resources to adapt to climate change, so there is likely to be widespread suffering, in addition to extensive ecosystem damage.

John M. Theilmann

- **Further Reading**

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry et al. New York: Cambridge University Press, 2007. The product of extensive research by a large team of leading scientists, this text is generally accepted as the authoritative statement on climate change.

Lomborg, Bjørn. *Cool It*. New York: Random House, 2007. Noted climate change skeptic argues against taking action to reduce GHG emissions or otherwise modify human behavior in the name of climate policy.

Mann, Michael E., and Lee R. Kump. *Dire Predictions*. New York: D.K., 2008. Accessible summary of the IPCC reports, explaining their projections of future climate trends.

See also: Continental climate; Inter-Tropical Convergence Zone; Mediterranean climate; Polar climate; Tropical storms.

Tropical storms

- **Category:** Meteorology and atmospheric sciences

Hurricanes thrive in warm water, weakening if sea surface temperatures fall below 27° Celsius. Partly for this reason, the possible effects of global warming upon hurricanes—particularly their frequency and intensity—is a subject of intense debate.

- **Key concepts**

El Niño-Southern Oscillation (ENSO): an ocean-circulation pattern that warms the Pacific Ocean west of Peru, affecting world weather

hurricane: a severe oceanic cyclonic storm in the Atlantic Ocean—called a typhoon in the Pacific Ocean and a cyclone in the Indian Ocean

La Niña: an ocean-circulation pattern that cools the Pacific Ocean west of Peru, affecting world weather

thermodynamic disequilibrium: a state of instability in the energy distribution of a system; indicative of tropical storm intensity

West African monsoon: a seasonal climatic variation that can affect hurricane intensity and frequency in the Atlantic Ocean

- **Background**

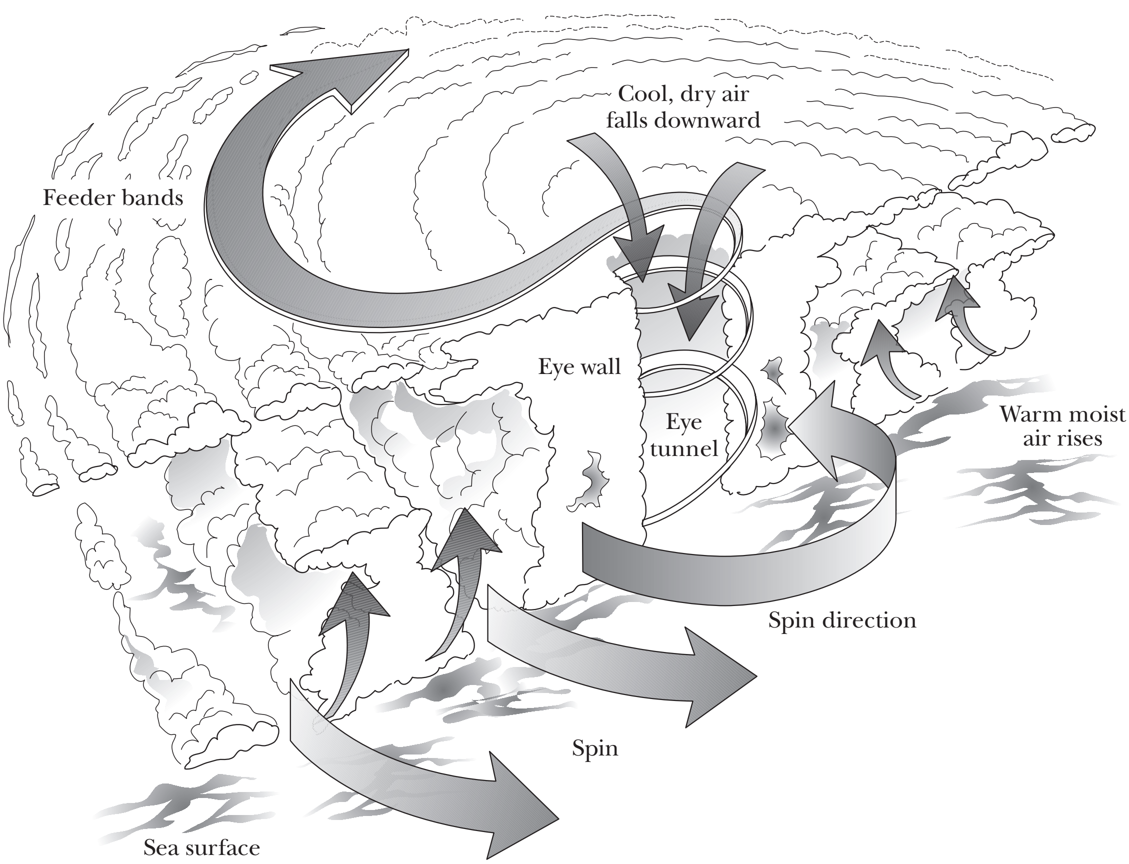
A tropical storm is a cyclonic storm pattern originating in the tropics that has the potential to develop into a hurricane. Sea surface temperatures (SSTs) are believed to play a role in hurricane frequency and intensity, since hurricanes usually require SSTs of at least 27° Celsius to form and sustain themselves. Many other factors contribute to hurricane development, however, making a simple linear association of hurricane intensity with SST, or with global warming generally, difficult to prove.

As is the case with other phenomena, global warming's effect on hurricanes plays out in a broader climatic context. The relationship (or lack thereof) between hurricane intensity and warming atmospheric and oceanic temperatures is complicated by the fact that water temperatures (like air temperatures) sometimes vary over periods of several decades. The long-term effect of rising greenhouse gas (GHG) levels upon climate is only part of the total picture.

Cyclonic oceanic storms that generate over the oceans are known by different names around the world. "Tropical storms" contain winds of less than hurricane strength (under 119 kilometers per hour). Storms that are called "hurricanes" in the Atlantic Ocean are known as "typhoons" in the Pacific Ocean and "cyclones" in the Indian Ocean. These storms also are rated numerically on the Saffir-Simpson scale, from 1, a minimal hurricane, to 5, a storm with winds of more than 251 kilometers per hour that can produce catastrophic damage.

Most research on tropical storms and climate change has been performed on hurricanes. The debate in the United States also has been parsed mainly regarding hurricanes, since these are the

Anatomy of a Hurricane



storms that affect that country. Since tropical storms are similar worldwide, however, this research may be generalized to other regions.

• Hurricane Intensity and Frequency

SSTs in the Atlantic Ocean, which produces nearly all the hurricanes that have an impact on the United States, have been rising slowly but steadily since the 1970's, paralleling a general global rise in air temperatures. Frequency and intensity of hurricanes (as well as the number hitting U.S. coastlines and inflicting major damage) also have been rising during the same period. While heat is important to hurricanes, they are very sensitive to other influences as well. After the devastating hurricane seasons of 2004 and 2005, the next year was very quiet. A major reason for the drastic decrease in hurricane activity in 2006 appears to have been an increase in the level of dust from the Sahara Desert present in the air over the Atlantic Ocean. During the 2006 hurricane season, SSTs also remained relatively cool, and only five hurricanes formed, one-third the number that formed in 2005.

Still other factors influence hurricane number and intensity, including El Niño conditions in the tropical eastern Pacific Ocean and the strength of the West African monsoon. If other conditions are right, a hurricane season can be intense even if SSTs are cooler than usual, and vice versa.

Any study of tropical storms that begins in the 1970's will indicate a very close relationship between ocean warming, hurricane intensity, and air temperatures. However, during the 1950's and 1960's, air temperatures were generally cooler than during the 1970's, but average hurricane intensity was higher. By 2005, this divergence was fueling a debate between some hurricane experts regarding whether, and to what degree, hurricane intensity and frequency is related to an overall warming trend.

• The Temperature-Intensity Argument

In 1988, Kerry Emanuel, a hurricane specialist at the Massachusetts Institute of Technology, published an article in the *Journal of the Atmospheric Sciences* in which he argued that hurricane intensity is governed, in part, by the degree of thermodynamic disequilibrium between the atmosphere and the underlying ocean. Therefore, Emanuel reasoned, warmer ocean waters should breed more intense tropical cyclones. While tracing any specific storm to warming is a tenuous exercise, hurricanes may intensify generally as oceans warm. Hurricanes are essentially heat engines, so storms that approach their upper limits of intensity are expected to be slightly stronger—and produce more rainfall—in warmer climates as a result of higher SSTs.

According to a simulation study by a group of scientists at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), a 5 to 12 percent increase in wind speeds for the strongest typhoons in the northwest tropical Pacific is projected if tropical SSTs increase by a little over 2° Celsius. Thomas R. Knutson and Robert E. Tuleya's models indicate that given SST increases of 0.8° to 2.4° Celsius, hurricanes would become 14 percent more intense (based on central pressure), with a 6 percent increase in maximum wind speeds and an 18 percent rise in average precipitation rates within 100 kilometers of storm centers.

• Criticism of the Climate-Hurricane Link

A report by Christopher W. Landsea of the National Oceanic and Atmospheric Administration's Miami, Florida, office asserts that an increase in carbon dioxide (CO_2) levels may raise the threshold temperature at which hurricanes thrive (presently 27° Celsius). This change might nullify the increase in strength that is implied by warmer SSTs, because it would increase the amount of thermal energy required to drive a hurricane.

Landsea also speculates that increased frequency of El Niño weather patterns in the Pacific tend to dampen hurricane development in the Atlantic, although storm frequency and intensity often rises in the eastern Pacific under the same conditions. Landsea contends that intensity of Atlantic hurricanes has decreased since the middle of the twentieth century. He believes that any warming-induced change in hurricane frequency and intensity will probably be lost in the noise of year-to-year hurricane variability.

William M. Gray, a professor emeritus of atmospheric sciences at Colorado State University, is a longstanding opponent of the idea that warming temperatures have anything to do with hurricanes. According to his tally, between 1957 and 2006, 83 hurricanes hit the United States, 34 of them major (with wind speeds above 177 kilometers per hour). Between 1900 and 1949, 101 hurricanes hit the same area, 39 of which were major. From 1966 to 2006, according to Gray, only 22 major hurricanes hit the United States, whereas between 1925 and 1965, 39 such storms

Storm Classifications

Tropical Classification	
Gale-force winds	>15 meters/second
Tropical depression	20-34 knots and a closed circulation
Tropical storm (named)	35-64 knots
Hurricane	65+ knots (74+ mph)
Saffir-Simpson Scale for Hurricanes	
Category 1	63-83 knots (74-95 mph)
Category 2	83-95 knots (96-110 mph)
Category 3	96-113 knots (111-130 mph)
Category 4	114-135 knots (131-155 mph)
Category 5	>135 knots (>155 mph)

Notes: 1 knot = 1 nautical mile/hour = 1.152 miles/hour = 1.85 kilometers/hour.
Source: National Aeronautics and Space Administration, Office of Space Science, Planetary Data System. URL: http://atmos.nmsu.edu/jsdap/encyclopediawork.html

hit the same area. Gray's evidence is not universally accepted as conclusive, but it calls into question the hypothesis that global warming will increase the frequency of storms. It has somewhat less bearing on the question of increased intensity among those storms that do reach the level of a major hurricane.

Bruce E. Johansen

• Further Reading

Donnelly, Jeffrey P., and Jonathan D. Woodruff. "Intense Hurricane Activity over the Past Five Thousand Years Controlled by El Niño and the West African Monsoon." *Nature* 447 (May 24, 2007): 465-468. Explains the relationship of hurricane activity to El Niño conditions.

Emanuel, Kerry A. "The Maximum Intensity of Hurricanes." *Journal of the Atmospheric Sciences* 45 (1988): 1143-1156. Examines potential hurricane strength under a warmer climate.

Gray, William M. "Hurricanes and Hot Air." *Wall Street Journal*, July 26, 2006, p. A-12. An example of the contrarian opinion that holds that global warming will not make tropical storms more severe.

Knutson, T. R., R. E. Tuleya, and Y. Kurihara. "Simulated Increase in Hurricane Intensities in a CO_2-Warmed Climate." *Science* 279 (February 13, 1998): 1018-1020. Presents the case for storm intensity increasing as climates warm.

Landsea, C. W., N. Nicholls, W. M. Gray, and L. A. Avila. "Downward Trends of Atlantic Hurricanes During the Past Five Decades." *Geophysical Research Letters* 23 (1996): 1697-1700. Argues that warming oceans affect hurricanes only minimally.

See also: Average weather; Drought; Dust storms; Extreme weather events; Meteorology; Rainfall patterns; Sahel drought; Storm surges; Thunderstorms; Tornadoes; Tsunamis.

Troposphere

• Category: Meteorology and atmospheric sciences

• Definition

The troposphere is the lowest layer of the Earth's atmosphere. It typically extends from the Earth's surface to an altitude of about 10-16 kilometers high, varying by latitude. In the tropics, the troposphere extends relatively high, whereas in the polar region, its upper boundary is significantly lower.

Because gravity weakens as the distance from a body increases, the atmosphere's density and pressure decrease exponentially with altitude. Most of the air molecules in the atmosphere are located in the atmospheric layers closest to Earth's surface. As altitude increases, the number of atmospheric molecules per unit of volume decreases, so the air becomes thinner.

By contrast, air-temperature changes as a function of altitude are much more complex. The temperature of Earth's atmosphere decreases with altitude to the tropospheric boundary, 10-16 kilometers high. From that point to about 20 kilometers high, there is a "pause" in the temperature change, as temperature remains relatively constant. Above 20 kilometers, the temperature begins to increase. From about 45 to 50 kilometers up and from about 80 to 90 kilometers up, there exist two other zones of relatively constant temperature. Between them, from 50 to 80 kilometers up, the temperature decreases with height. Above 90 kilometers, the temperature increases with height throughout the rest of Earth's atmosphere. These zones of different types of temperature change define the structural layers of Earth's atmosphere: the troposphere, tropopause, stratosphere, stratopause, mesosphere, mesopause, and thermosphere.

Because more than 90 percent of atmospheric molecules are located in the troposphere, most weather and convection happen within this layer of the atmosphere. During the daytime, the Earth's surface warms relatively quickly. This radiative heating is necessary for convection to be generated. Warm, moist air rises, condensing when the air temperature drops at mid-to-high levels of the troposphere. This pattern of convection and condensation is the core process generating weather and storms.

During the nighttime, the air near the Earth's surface cools faster than that above it. Very low in the troposphere, radiative cooling can cause a tem-

The Troposphere at a Glance

- Maximum Height: 20 kilometers
- Minimum Height: 7 kilometers
- Average Height: 17 kilometers
- Percentage of Atmospheric Mass: 75 percent
- Percentage of Atmospheric Water Vapor: 99 percent

perature inversion, in which a warm layer of air is situated above the cool air near the surface and below the cold air of the upper troposphere. This temperature structure acts as a lid in the mid-troposphere, limiting convection. This phenomenon is the reason storms do not typically occur in the late night or early morning.

• Significance for Climate Change

The importance of the troposphere to global warming and climate change is twofold. First, most greenhouse gas (GHG) emissions, both natural and anthropogenic, are released into the troposphere, close to Earth's surface. Since gravity keeps more than 90 percent of air molecules within the troposphere, most of the emitted GHGs will stay there as well. Second, because the troposphere is in direct contact with Earth's surface, tropospheric reflections of global warming will be the most sensible and evident atmospheric reflections.

Many scientists predict that global warming will result in a significant increase of tropospheric temperatures. However, some studies based on the analyses of satellite measurements and radiosonde (weather balloon) data have shown no evidence of tropospheric warming. These studies have been critiqued in other studies, which have argued that results indicating no warming or even cooling in the troposphere were based on incomplete analyses, because they failed to take into account the cooling effect exerted by the stratosphere on the troposphere. However, some scientists believe that the overall temperature of the troposphere could remain unchanged or even decrease even while the Earth's surface temperature rises. They argue that an increase in atmospheric GHG concentrations may result in an increase in cloud cover. These clouds would increase Earth's albedo, reflecting solar radiation back into space and acting as a cooling influence.

Most weather occurs inside the troposphere. Thus, any changes affecting the troposphere will inevitably affect Earth's weather patterns. As the example of tropospheric temperature studies illustrates, however, it is difficult to predict the precise nature of these changes and their effects. If the troposphere does warm, it will extend higher than it does currently. If this happens, scientists predict that there will be much stronger convective storms, because an extended troposphere will allow deeper convection and thicker clouds. This is perhaps one reason that the Intergovernmental Panel on Climate Change (IPCC) predicted more severe storms would accompany future climate warming. Another possible effect of tropospheric warmth is an extension of tropical regions poleward. Such an extension would fundamentally alter the environment of many regions on Earth, with significant socioeconomic consequences.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Widely used introductory textbook on atmospheric science; covers a wide range of topics on weather and climate.

Fu, Qiang, Celeste M. Johnson, Stephen G. Warren, and Dian J. Seidel. "Contribution of Stratospheric Cooling to Satellite-Inferred Tropospheric Temperature Trends." *Nature* 429 (2004): 55-58. Analyzes processes involving warming in the troposphere and cooling in the stratosphere.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Comprehensive overview of global climate change published by a network of the world's leading climate change scientists under the auspices of the

World Meteorological Organization and the United Nations Environment Programme.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Introductory textbook that covers a wide range of atmospheric sciences.

Santer, B. D., et al. "Contributions of Anthropogenic and Natural Forcing to Recent Tropopause Height Change." *Science* 301 (2003): 479-483. Examines the extent to which GHGs have contributed to a rise in the tropopause.

See also: Atmosphere; Atmospheric dynamics; Atmospheric structure and evolution; Mesosphere; Stratosphere; Thermosphere.

Tsunamis

• **Category:** Meteorology and atmospheric sciences

• Definition

A tsunami (Japanese for "harbor wave") is a train of waves that heaves mountains of water from the ocean onto the shore. Just as dropping a pebble into a pond sends out a series of ripples, the oceanic impact of a mountain-sized asteroid would send out tsunamis, but most tsunamis are caused by explosive volcanic eruptions, earthquakes, or landslides near, or more commonly beneath, the ocean.

Ocean waves resemble wind-driven waves in a wheatfield, where the wave form moves across the field, but the wheat stalks remain rooted to one spot. A given portion of water in an ocean wave makes little forward progress; instead, it moves forward, downward, backward, and then upward, tracing out an orbit of centimeters or tens of centimeters. In normal waves, stacks of these circulation cells begin at the surface and extend downward by meters or tens of meters. Each circulation cell grows smaller than the one above it, until the motion dissipates altogether. In a tsunami, the cells extend all the way to the ocean floor, so vastly more water is in motion than in a normal wave. In deep water, tsunamis can travel at the speed of a jet plane, but they slow considerably as they reach shallow water near shore.

On December 26, 2004, a magnitude 9.2 earthquake struck near Sumatra. Perhaps 1 percent of the quake's energy went into lifting the surface of the ocean by 5 meters over an area nearly the size of Florida. As the lifted water slab sank back into the ocean, it created a series of tsunami waves, both crests and troughs, that struck fourteen countries and killed over 250,000 people.

There is about a 50 percent chance that the trough of a tsunami will arrive onshore before the crest. If this happens, water will retreat rapidly from the shore, emulating an unusally fast and strong lowtide. Such a retreat is a sure sign of an impending tsunami. Many lives were saved in 2004, when people observed the warning retreat and raced for higher ground. Tragically, however, others ran to explore the freshly exposed ocean bottom with its stranded fish; they were drowned when the tsunami arrived.

In the open ocean, tsunami crests are less than a meter high, but as they approach the shore, they can grow significantly. If the water becomes shallow, two factors can build the wave upward and push it onto shore. First, the wave energy near the ocean floor has no way to discharge itself except to hurl the wave upward and onto the shore. Second, the front of the wave slows first, since it reaches shallow water first. This uneven slowing causes the trailing parts of the wave to pile onto the slower front part, building the wave's height. The Aceh region of northern Sumatra experienced such an increase in wave height in the 2004 tsunami. There, the wave reached 24 meters high as it crashed ashore, causing massive damage and numerous deaths. Sri Lanka's experience of the tsunami was different: Because the land rises steeply from the deep ocean at Sri Lanka, the front, middle, and back of the tsunami waves all had the same speed, so they did not pile up. As a result, the tsunamis reaching Sri Lanka resembled especially high tides, rather than violently impacting waves.

• Significance for Climate Change

More than seven times as many people died in the 2004 tsunami than had in the previous worst tsunami on record. In trying to explain this dramatic increase, scientists looked to global warming as a possible factor. Global warming has slowly accumulating affects, but tsunamis are caused by catastrophic events, so there can be no direct link. For example, the idea that the few centimeters of sea-level rise attributed to global warming over the past century made the 12- to 24-meter-high tsunami waves significantly more destructive is simply not credible.

Perhaps there is an indirect link in which warming triggers a catastrophic event. Large amounts of methane ice lie on the ocean floor in some areas. Warming might melt some of the methane ice, and the released methane might cause waves or landslides. Such events do happen, but they are on far too small a scale to cause a tsunami. Similarly, gradually increasing the ocean's depth by melting glaciers may gradually increase the pressure on undersea magma chambers, but that pressure increase would be small compared with pressures in the main magma chamber. It is more likely that the water would cool and strengthen the overlying rock than it is that the increased pressure would trigger an eruption.

Since earthquakes cause tsunamis, whenever a sufficiently large earthquake occurs in a tsunami-prone region, a warning may be given. A much faster and more accurate warning can be given if deep ocean buoys are used. The National Oceanic and Atmospheric Administration (NOAA) developed the deep-ocean assessment and reporting of tsunamis (DART) system, and the Envirtech company developed its tsunami warning system (TWS). Both systems use sensors placed on the ocean bottom that communicate with buoys at the surface, which then communicate with satellites.

A lone mosque stands in a coastal village near Aceh, Indonesia, amid the devastation of the 2004 Sumatra tsunami. (AP/Wide World Photos)

Tsunamis have periods (time between crests) of ten minutes to an hour or more. These periods are far longer than the periods of normal ocean waves, and this is a key to identifying tsunamis. Very sensitive pressure sensors placed on the ocean floor can measure the periods of surface waves so that timely warnings can be given. By contrast, the global positioning system (GPS) displacement method uses GPS radio signals to judge the distances between ground stations. Within fifteen minutes, this method can detect if the distances between stations have changed and determine if tsunamis are likely.

Charles W. Rogers

- **Further Reading**

Blackhall, Susan. *Tsunami*. Cobham, Surrey, England: Taj Books, 2005. Describes tsunamis and their history, as well as detailing the 2004 tsunami, survivor stories, and the extensive ensuing relief efforts.

Spencer, Roy. *Climate Confusion: How Global Warming Hysteria Leads to Bad Science, Pandering Politicians, and Misguided Policies That Hurt the Poor*. New York: Encounter Books, 2008. Contests the idea that global warming makes tsunamis worse and argues that natural processes such as precipitation will act to limit warming. Controversial, but well-written and easily understood.

Tibballs, Geoff. *Tsunami: The Most Terrifying Disaster*. London: Carlton Books, 2005. Describes the 2004 tsunami, some history, and other tsunamis. Profusely illustrated.

See also: Earthquakes; Extreme weather events; Floods and flooding; Storm surges; Volcanoes.

Tundra

- **Category:** Environmentalism, conservation, and ecosystems

- **Definition**

Tundra ecosystems are treeless regions found in the Arctic and on mountaintops. The word "tundra" is derived from the Finnish word *tunturi*, which refers to treeless areas of hills and mountains. There are two types of tundra: those in the north, called Arctic tundra, and those in high mountains, called alpine tundra. Antarctica has some tundra as well. Tundra climate is very harsh, involving extremely cold and snowy winters and short, cool summers with very little precipitation. In the Arctic tundra, the average temperature is between −12° and −7° Celsius. Most Arctic tundra regions have permafrost, a layer of ground below the surface soil that remains permanently frozen. The tundra landscape is shaped by periodic freezing and thawing of soil, which forms cracks and alters drainage.

On the tundra, tree growth is hindered by low temperatures and short growing seasons. The boundary between tundra and forest is known as the tree line, or timberline. The plant species on the tundra are few, and most are low-growing. Tundra vegetation consists mainly of sedges, grasses, dwarf shrubs, wildflowers, mosses, and lichens. During summer months, scattered wildflowers, such as purple mountain saxifrage and Arctic poppies, are also present. The summer growing season is short, only fifty to sixty days, during which the Sun shines twenty-four hours a day. Hardy plants, such as cushion plants, survive by growing in rock depressions, where it is warmer and sheltered from the wind. Plant communities in the tundra have adapted to gusty winds and soil disturbances and are able to photosynthesize at low temperatures and with fluctuating light intensities.

Animal life on the tundra is somewhat limited by the challenging environment. Most Arctic wildlife consists of species that are the same or similar to those found worldwide. Tundra ecosystems also support a variety of animal species that do not live in other areas, such as the Arctic hare, musk oxen, lemming, Arctic ground squirrel, and a grouselike bird called a ptarmigan. Other animals, such as caribou and many species of bird, migrate annually to the Arctic. Arctic foxes, polar bears, some brown bears, gray wolves, and snow geese are also seen on the tundra. Large grazing animals such as caribou and reindeer feed on tundra vegetation. Mountain goats, big-horned sheep, rabbits, and birds inhabit alpine tundra. During summer months, many birds nest in shrubs on the tundra, migrating to warmer climates as winter approaches. Insects such as black

Permafrost thaws in a region of the Siberian tundra, forming thermokarst lakes and releasing sequestered gases and organic materials into the environment. (Reuters/Landov)

flies, mosquitoes, butterflies, and grasshoppers are abundant. Tundra predators include the wolf, arctic fox, and snowy owl.

• Significance for Climate Change

Although it remains one of the least exploited regions on Earth, the Arctic tundra is changing dramatically as a result of warmer temperatures. The tundra ecosystem is extremely sensitive to disturbance, and global warming is consequently likely to have some of its greatest effects in the tundra. Some major impacts associated with rising temperatures in the tundra are thawing of permafrost and advancing tree lines, both of which decrease tundra area and contribute further to global warming.

Permafrost is the foundation for most of the Arctic's unique ecosystem. Thawing permafrost disrupts the tundra landscape by forming bogs and shallow lakes. Shrubs and spruce that previously were not able to grow in the tundra because of permafrost are able to thrive in thawed tundra soil. Permafrost is also believed to contain large amounts of carbon sequestered in frozen soil. As it thaws, greenhouse gases (GHGs), such as carbon dioxide (CO_2), are released into the atmosphere.

As the Earth warms, tundra in northern Canada and Siberia is rapidly being replaced by northern, or boreal, forests. Over the last century, the tree line has advanced into the area, with trees currently living where no tree had previously grown during the last one thousand years. With continued warming, treelines may continue to advance, and tundra landscapes may be transformed into woodland areas. In addition to being a consequence of global warming, the encroaching tree line also contributes to global warming by absorbing larger amounts of sunlight.

Tundra, particularly when it is snow- or ice-covered, has a high albedo, or reflectivity, that helps maintain the region's cooler temperatures by reflecting sunlight rather than absorbing it. Compared to tundra, trees have low reflectivity; consequently, more heat is retained in areas with greater tree growth. The shift in tundra vegetation from grasses to shrubs and trees also increases the risk of wildfire in the tundra by creating more biomass available to burn. Fires in the tundra may potentially release more carbon into the atmosphere, adding to GHGs already contributing to global warming.

As the tundra shrinks, the few plant and animal species that thrive in the harsh environment will be affected. These species are highly vulnerable to environmental stresses such as reduced snow cover and warmer temperatures brought on by global warming. Animal species are affected by changes in the vegetation and in their habitats. Animals that generally live in warmer climates, such as the red fox, have moved onto the tundra and begun competing with Arctic species for territory and food.

C. J. Walsh

• Further Reading

Archer, David. *Global Warming: Understanding the Forecast.* Malden, Mass.: Blackwell, 2007. Explores global warming and the processes of climate change in a format that is readily understandable to the nonspecialist.

Houghton, John. *Global Warming: The Complete Brief-*

ing. 4th ed. New York: Cambridge University Press, 2009. Provides a comprehensive overview of the scientific basis of global warming for the interested general reader and motivated student.

Weart, Spencer R. *The Discovery of Global Warming*. Rev. and expanded ed. Cambridge, Mass.: Harvard University Press, 2008. A history of global warming that also includes a balanced assessment of current issues related to climate change.

Winner, Cherie. *Life in the Tundra*. Minneapolis, Minn.: Lerner, 2003. One in a ten-volume series entitled Ecosystems in Action; examines the many plants and animals as well as the ecosystem of the tundra.

See also: Arctic; Ecosystems; Endangered and threatened species; Penguins; Polar bears; Polar climate.

Tuvalu

- **Category:** Nations and peoples

• Background

A tiny low-lying archipelago nation in Oceania made up of three reef islands and six coral atolls, Tuvalu began attracting international attention as early as 1995, as rising Pacific Ocean levels, largely from global warming, began to threaten to submerge the nation, likely making its roughly twelve thousand residents the world's first climate-refugees. Located in the South Pacific just below the equator, roughly 3,200 kilometers northeast of Australia, Tuvalu's nine islands are in area roughly 26 square kilometers, 90 percent of which is coastline, making it the world's fourth-smallest country. None of Tuvalu's nine islands rises more than 5 meters above sea level.

• Significance for Climate Change

The island nation became a kind of bellwether—or as the grimmer prognostications began to emerge in the 1990's, a kind of canary in the coal mine—alerting the global community to the reality of the impact of the greenhouse effect, specifically rising sea levels as polar ice reserves gradually melt and ocean temperatures rise, causing thermal expansion. The government of Tuvalu was quick to address the world community, largely through the United Nations and most vigorously during the international debate over the Kyoto Protocol in the late 1990's. Reliable data that extrapolated from the measured rise in sea levels from 1978 to 1995 projected that by the close of the twenty-first century sea levels could rise more than a one-half meter, significant enough to make Tuvalu uninhabitable.

Long-term threats are not the only troubles facing the island nation. In addition to fears over the incremental rise of the ocean, Tuvalu is particularly susceptible to the weather changes that have resulted from rising sea temperatures. More frequent and more intense cyclones ravage the limited farming done on the islands, disrupt the water supply, and spread disease. The gradual rise in tides—particularly the so-called king tides that have become commonplace in the last decades—also threatens Tuvalu, specifically its root crops. Given the reluctance of the government to curb the clearance of the island's forest undergrowth for fuel, the island has stripped itself of its natural protection from the force of windstorms and heavy rains.

The response to the threat of rising sea levels has been two pronged, short-term and long-term. The rhetoric from successive administrations of the Tuvalu government blamed global warming for their country's dire situation. Initially, the Tuvalu government sought the financial resources of Australia and the United States, the two industrial nations most directly responsible for their plight and both of which had refused to ratify the Kyoto Protocol calling for a curb in greenhouse gas (GHG) emissions.

In 2002, litigation was filed on behalf of the Tuvalu government in the World Court against both nations, a move seen less as a likely way to receive significant reparations and more as a way to draw international attention to the plight of the island and its implications for the greater global community. Tuvalu, its representatives tirelessly pointed out, is only the first nation to be affected. Given the reluctance of industrial nations to meet the Kyoto standards and given that the real impact of the current environmental damage will not be felt in rising sea levels for some time, climatologists estimate that by the close of the twenty-first century more than 100 million coastal residents may have to be evacuated on all six inhabited continents.

As tide damage proliferated, eccentric weather patterns expanded, and salt water slowly seeped into the groundwater and ruined the rooted plants of the islands, the Tuvalu government, as early as 2000, began making plans for long-term permanent evacuation of the island's residents. The government steadfastly refused to concede the inevitability of the island's disappearance and claimed that should the islands be entirely submerged the nation itself would continue to exist, its sovereignty intact despite being under the sea. Realistically, the island would be lost long before it was actually submerged. It would be lost when its cash crops, such as breadfruit, bananas, and coconuts, were rendered inedible and the islands' meager water supplies were flooded with seawater.

Plans to create an artificial retaining wall around the capital city of Funafuti were proposed but rejected. To secure the safety of the residents, the government sought the agreement of New Zealand and Australia and Fiji, the nearest countries able to accept a significant number of immigrants, to a long-term (thirty-year) gradual immigration protocol. Only New Zealand agreed. The Australian government claimed any agreement premised upon suspect data they dismissed as speculation would not be in the best interests of its government. Nevertheless, by 2007 nearly one-fourth of the island population had been evacuated, the world's first climate refugees.

Joseph Dewey

• Further Reading

Archer, David. *Global Warming: Understanding the Forecast.* Malden, Mass.: Blackwell, 2007. Accessible and concise introduction to the basic concept of global warming, the phenomena global warming encompasses, and the prognostication process itself.

Bennetts, Peter, and Tony Wheeler. *Time and Tide: The Islands of Tuvalu.* London: Lonely Planet Press, 2001. Powerfully written, beautifully illustrated account of the island as a threatened environment. Argues that the end of the island nation is inevitable.

Michaels, Patrick J. *Climate of Extremes: Global Warming Science They Don't Want You to Know.* Washington, D.C.: Cato, 2009. Conservative reassessment of global warming data that provides an important counter-reading of climatological data, puts the threat to Tuvalu in a far less dramatic context, and argues that poor land management and agricultural policy are as much to blame for the island's distress as is global warming.

Northcott, Michael S. *A Moral Climate: The Ethics of Global Warming.* Maryknoll, N.Y.: Orbis, 2007. Fascinating look at the moral responsibilities involved in addressing global warming; uses Tuvalu as an example of developing nations that suffer for the greed and arrogance of industrial nations.

See also: Coastal impacts of global climate change; Easter Island; Islands; Maldives.

A Tuvalu man cuts coconuts to feed to his pigs outside his house, which has been flooded by rising tides. (AP/Wide World Photos)

Ukraine

- **Category:** Nations and peoples
- **Key facts**

Population: 45,700,395 (July, 2009, estimate)
Area: 603,700 square kilometers
Gross domestic product (GDP): $337 billion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 922 in 1990; 482 in 2000; 443 in 2006
Kyoto Protocol status: Ratified February 4, 2004

• Historical and Geopolitical Context

Only three years after an independent Ukrainian republic was established in 1918, the country was occupied by its Russian neighbors and shortly thereafter, during World War II, became a constituent of the Soviet Union. Following that war, the Soviet Union imposed its repressive communist regime on most of Eastern Europe, including Ukraine. Later, the Soviet Union attenuated its internal repression, but it could not quell the growing political unrest that led to its dissolution in 1991. Peoples in one-fourth of the area of the former Soviet Union, including satellite states such as Ukraine, seceded, forming fourteen independent countries.

Five years before Ukrainian independence was restored, the worst accidental nuclear disaster in history occurred in Ukraine. On April 26, 1986, at 1:23 A.M., a massive explosion tore through the Chernobyl Nuclear Power Plant, destroying the reactor block and igniting nearby buildings with fiery graphite projectiles. The disaster followed a poorly executed experiment conducted at low power under unsuitable cooling conditions. Even though thousands of metric tons of neutralizing agents were poured over the core reactor, the fire continued to burn; the core melted down, solidifying and sealing the entrance to the nuclear plant.

This process took approximately ten days, during which time 71 percent of the radioactive, fuel-containing reactor core remained uncovered. As a result, approximately 135,000 individuals had to be evacuated from the 30-kilometer so-called forbidden zone, which took 800,000 persons called "liquidators" to clean up. It is estimated that the radioactivity released by the Chernobyl explosions was at least two hundred times that of the atomic bombings of Hiroshima and Nagasaki during World War II. Millions of people were put at risk, as deadly radioactive particles raced across the globe from western Russia, through Europe, and across the Northern Hemisphere, where death rates from childhood leukemia increased in Canada and the United States.

The Chernobyl disaster typified the environmental problems the independent Ukraine would inherit from the Soviet Union. These problems had their root in a decaying industrial infrastructure whose decay was exacerbated by substandard workmanship and planning. Adverse health and environmental consequences of the Chernobyl disaster continued to plague survivors, many of whom immigrated to countries both within and outside the former Soviet Union, including the United States. It is in this context that Ukraine's approach to climate change and global warming must be understood.

• Impact of Ukrainian Policies on Climate Change

The United Nations has been instrumental in forming and advancing Ukrainian policies on greenhouse gas (GHG) emissions. Ukraine is an active participant in international initiatives related to improving the global environment and a party to nineteen conventions, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The protocol introduced so-called flexible mechanisms, such as emissions trading and joint implementation, to help Eastern European Annex I countries achieve their commitments to limit and reduce GHG emissions by trading carbon offsets with wealthier countries such as Japan.

The commitments of Annex I countries include monitoring and reporting GHG emissions. By 2000, the Annex I nations were to have reduced their emissions to the 1990 baseline listed in Annex I of the UNFCCC. Per the Kyoto Protocol, Annex I countries must control their annual GHG emissions, limiting them to specific percentages of their baseline emissions when averaged over the period from 2008 to 2012. The U.N. Development Programme

(UNDP) focuses on legislative documents for procedures and compliance with UNFCCC, as well as creation of infrastructure required for the Kyoto Protocol's flexible mechanisms. Joint implementation allows nations to attain cost-effective reductions in GHG emissions, which may help promote development of new, low-GHG-emission technologies.

In March of 2005, Ukraine presented its policy on climate change and its plan for implementing the UNFCCC and the Kyoto Protocol to a group of Japanese investors. Eighteen projects were submitted to the Commission on Climate Change for a variety of carbon funds, including those directed at energy conservation, renewable energy sources, biogas, and mine methane utilization. Emission reduction units (ERUs) would be transferred to the partner country, Japan.

• Ukraine as a GHG Emitter

Paradoxically, though Ukraine has some of the richest environmental and natural assets in Eastern Europe, it is one of the most heavily polluted and least energy efficient countries. According to the UNDP, Ukraine has a history of substandard environmental management, which has increased its incidence of natural and anthropogenic disasters. As of 2008, 40 percent of Ukraine comprised eroded land, and the area of eroded land within the country was increasing at a rate of 80,000 hectares per year. In addition, most of Ukraine's power plants, installed in the 1930's and 1940's, are considered obsolete and are operating at 28-30 percent of capacity. Not surprisingly, therefore, Ukraine is the seventeenth highest GHG emitter. The top twenty GHG-emitting nations were responsible for 75 percent of all GHG emissions in the year 2000, worldwide.

• Summary and Foresight

Despite these problems, as well as ongoing political unrest in Ukraine and its neighboring former Soviet states, Ukraine wishes to be involved with protecting the environment of planet Earth. A relative newcomer to this cause, Ukraine requires assistance in implementing treaties such as the UNFCCC and Kyoto Protocol, relying on the United Nations. The UNDP, for example, has agreed to help Ukraine in the preservation of bio systems via effective management of natural resources. UNDP is addressing these issues with initiatives that limit GHG emissions by promoting energy efficiency, such as a pilot project in Rivne, Ukraine, that aims to reduce GHGs through improvements in the communal heat supply.

In addition, Ukraine uses carbon trading and is transitioning to sustainable energy development while adhering to the flexible mechanisms set forth by the Kyoto Protocol. However, mitigating the effects of GHG emissions through the practice of carbon offsets is not without its critics; some believe it allows countries, organizations, and even individuals to continue polluting the environment by simply paying a fee, the premise being that if one country can reduce emissions more efficiently than another country, the second country can pay the first one to reduce emissions for both. In addition, loopholes allow poorer countries to sell inexpensive offset credits to heavily polluting countries, which can then sell them for profit.

Ukraine, like other Eastern European and former Soviet Union countries, is an industrialized, developed Annex I nation, but a poor one that has suffered from many wars fought on its land and Soviet-era repression. A top-twenty emitter of GHGs, Ukraine possesses an outdated industrial infrastructure inherited from the Soviet Union. Joint implementation may be a positive solution to Ukraine's environmental problems, allowing carbon trading with wealthy countries. Ukraine could use the resulting funds to improve its environment and transition to a sustainable development model, fostering environmentally responsible economic growth.

Cynthia F. Racer

• Further Reading

Kostin, I. *Chernobyl: Confessions of a Reporter.* London: Umbrage Editions, 2006. Kostin worked for the Ukrainian News Agency and took the first photo of the Chernobyl nuclear accident; he followed the story for the next twenty years, covering the disaster's effects on humans and the environment.

Lohmann, Larry, ed. *Carbon Trading: A Critical Conversation on Climate Change, Privatisation, and Power.* Uppsala, Sweden: Dag Hammarskjöld Foundation, 2006. Tackles the controversial aspects of carbon trading; argues that the poorest countries suffer most from increased pollution.

Subtelny, O. *Ukraine: A History.* 3d ed. Toronto: University of Toronto Press, 2000. Describes the years of Soviet repression and their influence on all aspects of Ukrainian society; covers Ukrainian independence from the former Soviet Union, international affairs, internal politics, and economic and social development.

See also: Industrial emission controls; Industrial greenhouse emissions; Kyoto Protocol; Nuclear energy; Russian Federation; United Nations Framework Convention on Climate Change.

Ultraviolet radiation

• Category: Physics and geophysics

• Definition

The Sun produces ultraviolet (UV) light. UV light is a portion of the electromagnetic spectrum with wavelengths shorter than those of visible light but longer than those of X rays. UV light wavelengths—shorter than the shortest wavelength of visible light, violet—are too short to be seen by the human eye (ultraviolet literally means "beyond violet"). UV radiation produced by the Sun is commonly split into three bands: UV-A, with wavelengths of 320-400 nanometers; UV-B, with wavelengths of 320-280 nanometers; and UV-C, with wavelengths of 200-280 nanometers. Most people are familiar with UV light through the painful effects of sunburn. A small amount of UV radiation is necessary for the well-being of humans and other organisms, because it promotes vitamin D synthesis in humans and acts as a germicide, controlling microbial growth. Too much UV radiation, however, is associated with many harmful effects.

Ozone is a very important part of the upper atmosphere, or stratosphere. It absorbs UV rays, forming a physical barrier that protects living organisms from harmful solar UV radiation. Although some of this radiation passes through the ozone layer and reaches the surface, most of the UV-B radiation entering Earth's atmosphere is absorbed by the ozone layer. UV-A radiation is not. Consequently, more than 98 percent of the UV radiation currently reaching Earth's surface is UV-A radiation. When UV-B radiation encounters an ozone (O_3) molecule, it can split O_3 into molecular oxygen (O_2) and atomic oxygen (O), which can then recombine with O_2 to form O_3 in a dynamic equilibrium.

The ozone layer, however, is being destroyed by a variety of environmental factors disrupting this equilibirum. Certain industrial chemicals, such as refrigerants, halons, and methyl bromide (a deadly pesticide used on crops), destroy Earth's ozone layer. Chlorofluorocarbons, chemicals used in many refrigerant systems and aerosols, are broken down by UV light into components that deplete ozone. As atmospheric ozone decreases, UV radiation infiltrates both marine and terrestrial ecosystems with potentially harmful effects. The intensity of UV-B radiation that reaches the Earth increases by 2 percent for every 1 percent decrease in the ozone layer.

• Significance for Climate Change

As the ozone layer decreases in size, it provides less protection from UV light. Consequently, more UV radiation passes through the atmosphere and reaches Earth's surface. Changes in the amount of UV radiation reaching the planetary surface have many potential consequences for climate change, most of which are interrelated. Heat is generated in the stratosphere as the ozone layer absorbs UV radiation. The resultant warming of the stratosphere creates a temperature inversion at the boundary between the stratosphere and the troposphere, helping stabilize climatic conditions. The stratosphere becomes cooler as the ozone layer declines, which could ultimately result in cooling of Earth's surface, despite more UV light reaching the ground.

An ozone monitoring station in Lhasa, Tibet, tracks changes in atmospheric ozone and ultraviolet radiation over the Tibetan Plateau. (Xinhua/Landov)

An increase in greenhouse gases (GHGs), however, may offset such surface cooling. In many cases, the same gases are responsible for both ozone destruction and climate change due to the greenhouse effect. For example, chlorofluorocarbons not only play a major role in ozone layer destruction but also are potent GHGs. As the ozone layer becomes more depleted by GHGs and other chemical contaminants, the amount of UV radiation that reaches Earth's surface will increase.

An increase in UV light reaching Earth's surface impacts human health and the well-being of other organisms and can also degrade nonliving materials. Changes in UV radiation have significant effects on both terrestrial and aquatic ecosystems, with important implications for the cycling of carbon, nitrogen, and other elements. Increased UV light induces carbon release from decaying plant material and nitrogen release from Arctic snow. Changes in UV radiation affect carbon cycling, including its capture through photosynthesis, and net ecosystem CO_2 exchange through storage and release. UV exposure can also affect cycling of the mineral nutrients, such as nitrogen, that plants depend on for growth. In aquatic ecosystems, UV radiation impacts cycling of carbon, nitrogen, sulfur, and metals, affecting numerous life processes.

Many studies have demonstrated that exposure to UV radiation has contributed to a worldwide increase in skin cancers, including malignant melanoma. UV radiation may cause changes in the body's immune system, which may impair its ability to defend against cancer and facilitate the spread of infectious disease. Increased UV-B exposure has also been linked to increased incidence of cataracts, the leading cause of blindness worldwide. Many amphibian population declines have been associated with UV exposure. Increased UV radiation also disrupts insect activity and, consequently, affects organisms that depend on insects.

Plants and animals living in freshwater and marine ecosystems are sensitive to UV radiation. UV-B can penetrate several meters of water and affect the survival and growth of marine invertebrates and algae. High levels of UV radiation can inhibit photosynthesis and growth in some plants, including many food crops, and can also result in declines in forest productivity. UV radiation also damages nonliving material and accelerates the breakdown of many paints and plastics used to construct products and structures regularly exposed to sunlight.

C. J. Walsh

- **Further Reading**

Cockell, Charles, and Andrew R. Blaustein, eds. *Ecosystems, Evolution, and Ultraviolet Radiation.* New York: Springer-Verlag, 2001. Discusses the ecological effects of UV radiation, including the evolutionary consequences of a changed UV environment.

Hanslmeir, Arnold. *The Sun and Space Weather.* 2d ed. Dordrecht, the Netherlands: Springer, 2008. Provides a general introduction to the physics of the Sun, including possible influence of the Sun on Earth's atmosphere and climate.

McKinney, Michael L., Robert M. Schoch, and Logan Yonavjak. *Environmental Science: Systems and Solutions.* Sudbury, Mass.: Jones and Bartlett, 2007. Introduction to environmental science for nonmajors. Covers basic principles necessary to understand complex environmental concerns and includes a chapter on ozone layer destruction.

Nilsson, Annika. *Ultraviolet Reflections: Life Under a Thinning Ozone Layer.* New York: John Wiley and Sons, 1996. Examines the effects of the increasing UV radiation levels experienced by living organisms as a result of ozone layer depletion.

See also: Carbon cycle; Nitrogen cycle; Ozone; Skin cancer; Stratosphere; Sulfur cycle; Sun.

Union of Concerned Scientists

- **Category:** Organizations and agencies
- **Date:** Established 1969
- **Web address:** http://www.ucsusa.org

- **Mission**

The Union of Concerned Scientists, a science-based nonprofit advocacy group based in the United States, combines independent scientific research with citizen action to publicize and address issues pertaining to the environment and international security, including global climate change. Headquartered in Cambridge, Massachusetts, UCS works to influence government policies, corporate practices, and consumer choices through scientific research and citizen advocacy.

UCS was founded by faculty and students at the Massachusetts Institute of Technology on March 4, 1969, a few months after forty-eight senior faculty members signed a statement voicing concern over the militarization of science and technology. The fledgling organization called for research to be diverted away from military efforts and toward solving environmental and societal problems. From its initial focus on nuclear weapons and the military funding of academic research, UCS has since become active in the areas of global climate change, clean vehicles and energy, safety in the nuclear power industry, nuclear weapons reduction, global security, food and agriculture, invasive species, and scientific integrity.

UCS is an alliance of scientists and citizens. The organization's staff includes scientists, engineers, researchers, economists, analysts, advisors, and policy experts. UCS experts are frequently called to testify before state and federal government committees. In addition to issuing reports, videos, position papers, and fact sheets for policy makers, the media, and the general public, UCS coordinates citizen advocacy efforts such as petitioning and letter-writing campaigns. UCS also offers tips for consumers seeking to make environmentally sound choices in their daily lives. At the end of fiscal year 2007, UCS membership numbered over seventy-nine thousand individuals.

• Significance for Climate Change

In November, 1992, in the wake of that summer's United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, UCS issued the "World Scientists' Warning to Humanity." This declaration, signed by more than 1,700 scientists (including 104 Nobel laureates) from seventy-one countries, warned that human activities were putting the living world in peril; it called for fundamental change.

Among the environmental stressors enumerated in the "World Scientists' Warning to Humanity" was the atmospheric accumulation of carbon dioxide released by deforestation and by combustion of fossil fuels—a buildup that had the potential to induce global climate change. The declaration called for scientists in all disciplines; the world's governmental, business, industrial, and religious leaders; and all peoples to work together to effect needed changes. Proposed improvements in humanity's stewardship of the Earth included moving toward clean and sustainable fuels, ending widespread deforestation, and providing developing nations with financial and technological aid to enable them to develop in an environmentally responsible manner.

In 1997, UCS presented a follow-up petition to President Bill Clinton's administration a few months before the Kyoto Climate Summit. "World Scientists' Call for Action" was signed by more than 1,500 scientists from sixty-three countries. Among the signers were 110 Nobel laureates and 60 winners of the United States National Medal of Science. The petition urged government leaders to strengthen the 1992 United Nations Framework Convention on Climate Change (UNFCCC) by completing an effective climate treaty at Kyoto. It called for legally binding commitments and near-term timetables from industrial and developing nations to augment the UNFCCC's voluntary measures regarding greenhouse gas (GHG) emissions. The petition also encouraged the world's scientists and citizens to hold their leaders accountable for mitigating anthropogenic influences on global climate.

In 2004, UCS published "Scientific Integrity in Policy Making," a report criticizing President George W. Bush's administration for its politicization of science. The report included the allegation that climate change research findings at federal agencies had been suppressed and distorted. The White House Office of Science and Technology Policy dismissed the report as biased, but UCS stood by its findings. An associated statement calling for the restoration of scientific integrity in policy making was signed by 62 prominent scientists. After Barack Obama won the presidential election in November, 2008, UCS members met with the president-elect's transition team to discuss scientific integrity in federal policy making.

UCS has published several reports on global warming. *How to Avoid Dangerous Climate Change: A Target for U.S. Emissions Reductions* (2007) sets a long-term target for U.S. reductions in GHG emissions and assesses then-pending federal climate bills in light of the proposed target. *Smoke, Mirrors, and Hot Air* (2007) maintains that ExxonMobil conducted a deliberate campaign of disinformation to delay action, influence legislation, and cloud public opinion regarding global climate change. *Atmosphere of Pressure: Political Interference in Federal Climate Science* (2007), copublished with the Government Accountability Project, documents the suppression and manipulation of findings that many federal climate researchers claim to have experienced under the Bush administration. Other UCS publications include a series of state and regional reports that assess possible climate-change impacts in the United States and available means for mitigation. UCS is one of the national governing-board organizations of the Sustainable Energy Coalition and is an institutional endorser of the 2007 Forests Now Declaration.

Karen N. Kähler

- **Further Reading**

Haley, James, ed. *Global Warming: Opposing Viewpoints*. San Diego: Greenhaven Press, 2002. The first chapter includes UCS's arguments supporting global warming as a scientifically credible theory. UCS and other organizations involved in the global warming debate are described in an appendix. Bibliographies, index.

Moore, Kelly. *Disrupting Science: Social Movements, American Scientists, and the Politics of the Military, 1945-1975*. Princeton, N.J.: Princeton University Press, 2008. Chapter 5 includes a detailed description of UCS's origins at the Massachusetts Institute of Technology, its antiwar roots, and its early days. Notes, bibliography, index.

Newbold, Heather, ed. *Life Stories: World-Renowned Scientists Reflect on Their Lives and the Future of Life on Earth*. Berkeley: University of California Press, 2000. The final chapter, contributed by Nobel Prize-winning physicist and UCS cofounder Henry Kendall, includes the texts of the UCS-sponsored "World Scientists' Call for Action" and "World Scientists' Warning to Humanity."

See also: Peer review; Scientific credentials; Scientific proof.

United Kingdom

- **Category:** Nations and peoples
- **Key facts**

Population: 61,113,205 (July, 2009, estimate)
Area: 244,820 square kilometers
Gross domestic product (GDP): $2.231 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 776.3 in 1990; approximately 725 in 1995; 659.3 in 2004; 652.3 in 2006
Kyoto Protocol status: Ratified 2002

- **Historical and Political Context**

The United Kingdom is composed of England, Scotland, Wales, and Northern Ireland. England and Wales were united in 1536. Scotland was joined to its two neighboring countries, England and Wales, in 1707. Ireland became part of the nation in 1801 but many Irish were in rebellion against the union. The Anglo-Irish Treaty created the Irish Free State, and in 1922 six northern counties recognized as Northern Ireland became part of the United Kingdom. Each of the countries has maintained a certain amount of political autonomy, especially in the area of legislative control.

In the thirteenth century, Great Britain evolved its parliamentary form of government. This system, composed of the monarch, a House of Lords, and a House of Commons, has become the model for the governments of many nations throughout the world. In the fifteenth century, Great Britain began exploring the world and claiming new lands. The United Kingdom has played a major role globally throughout its history. During the sixteenth and seventeenth centuries, the United Kingdom was an important seafaring power and one of the major colonizing countries in the world. The United Kingdom's preeminence as a colonial power continued into the following centuries, as did its power on the seas.

The eighteenth century was the period in which two world-significant revolutions began in the United Kingdom: the agricultural revolution and the Industrial Revolution. Both were made possible by scientific discoveries and inventions and each transformed its specific economic sector. The agricultural revolution changed methods of farming as crop rotation, improved machinery, and scientific breeding, as well as other innovations, were introduced.

The Industrial Revolution changed manufacturing of goods and created a new lifestyle for workers. New machines improved production, first of textiles and then of all types of products, and led to the building of factories and mass production. This increase in the amount of goods produced required more and better means of transport and provided the impetus for the building of railroads and more roads and canals in the country. Britain's revolutionized economic system soon began to spread to and industrialize the European continent.

By the early nineteenth century, the United Kingdom was the strongest and most influential European power. With industrial development in the United States and Germany, the nation lost some of its position but remained economically important. The world wars of the twentieth century and the damage suffered by the United Kingdom placed it in a position of rebuilding during the late 1940's.

The United Kingdom, like the rest of the war-torn European countries, regained its economic and political importance during the 1950's and 1960's. In 1949, the United Kingdom joined the North Atlantic Treaty Organization (NATO). The United Kingdom has close economic and political ties with both the United States and the continental European countries. It was one of the founding members of the European Free Trade Association (EFTA), which was formed in 1959. In 1973, the United Kingdom became a member of the European Economic Community (EEC) and a founding member of the G-8 in 1977. The United Kingdom is a member of the European Union. It ranks as the second-largest economy among EU members. Worldwide, the United Kingdom is the fifth-largest economy and plays a major role in global trade.

• Impact of British Policies on Climate Change

The United Kingdom has implemented a number of policies to positively affect the world's climate and to reduce the amount of detrimental climate change. One of its main concerns is the increase in temperature, which threatens to result in erratic weather patterns producing severe storms and a significant rise in sea level. This could result in disastrous ice melting in the Arctic and reduction of fish populations due to increased water temperature. The government is particularly targeting the areas of energy production and consumption, transport, and agriculture with incentives and regulations to improve energy efficiency and reduce greenhouse gas (GHG) emissions.

One of the major programs is the Renewables Obligation, introduced in April of 2002. This program requires energy suppliers who supply electricity to end-consumers to use renewable resources, not fossil fuels, to generate a certain set amount of the electricity. The projected requirement incorporates a yearly increase in the amount of electricity to be generated from renewable resources through 2015. The starting percentage in 2002 of 2 percent will increase to 15.4 percent by 2015. The program also requires the coal-firing of biomass to be eliminated by 2016. Through various programs, the United Kingdom is providing money for the installation of renewable energy sources in private homes and community buildings.

The United Kingdom is also hoping to enact a law putting in place a renewable transport fuel obligation. The obligation would require that 2 to 5.75 percent of road fuel be either bioethanol or biodiesel. To implement this program, the country would need to produce the biomass from which the bioethanol and biodiesel fuel were made. Experts and analysts in the field believe that this is possible if the country were to use all of its net wheat exports to produce the biomass.

Concern over climate change and commitment to work actively to stop detrimental climate change has not been limited to the national level of government in the United Kingdom. As early as 2000 with the creation of documents such as the Nottingham Declaration, local governmental units and private citizens were becoming involved in programs and activities related to climate change. The Nottingham Declaration, when signed by a local council, commits them to support the national programs and to work locally to reduce GHG emissions and factors producing negative effects on climate.

• The United Kingdom as a GHG Emitter

According to data collected by the European Environment Agency (EEA), the United Kingdom ranked second in GHG emissions in both the EU15 and the EU27 in 2006. Ranked by GHG emissions per capita, the nation ranked tenth among the EU15 and thirteenth among the EU27. However, the United Kingdom reduced its GHG emissions by 16 percent, while the European Union achieved an average of 2.7 percent reduction in GHG emissions. The United Kingdom's 2006 emissions of 652.3 million metric tons were 18 percent below those of its base year (1990) which were 776.3 million metric tons and also a greater reduction than its burden-sharing target of −12.5 percent. The United Kingdom projects that it can reduce its GHG emissions to 16 percent below those of the base year by 2010. The United Kingdom believes that it not only will reach its burden-sharing target but will surpass the reductions it committed to achive in the Kyoto Protocol agreement.

• Summary and Foresight

The United Kingdom is one of the world's largest consumers of energy and the only EU country exporting any significant amount of energy. In 2007, according to the United Nations Framework Convention on Climate Change, the country ranked eighth in the world for GHG emissions from the burning of fossil fuels with some 587,261 metric tons. The country is working to replace fossil fuels with renewable energy resources. The United Kingdom has significantly reduced its GHG emissions. It has made significant reductions in emissions from household use and from petroleum refining. However, the production of electricity and heat has shown a rise in emissions. The Renewables Obligation program, enacted in 2002, is addressing this issue. In addition, the use of natural gas rather than coal as an energy source is helping to reduce emissions. GHG emissions from transport have continued to increase at a steady rate. The United Kingdom is taking steps to stop this rate of increase by implementing a program requiring the use of fuel that contains a percentage of either bioethanol or biodiesel.

The United Kingdom continues to play a committed role in the efforts to reduce GHG emissions and positively affect climate change by minimizing temperature increase. The United Kingdom signed the Kyoto Protocol and accepted the commitment to reduction of GHG emissions to 12.5 percent below the levels of the base year (1990). In view of the amount of GHGs being produced within its borders, the United Kingdom, fearing it would not meet its target, began considering an emissions regulatory system to apply to itself.

In 2000, the Royal Commission on Environmental Pollution presented its conclusion that if the United Kingdom, and other countries as well, would accept a target of a reduction of 60 percent by 2050 holding emissions to 550 parts per million, the rise in temperature could be held to 2° Celsius. Then in 2005, an assessment of GHG emissions presented at the international conference Avoiding Dangerous Climate Change proposed that a greater reduction was necessary to limit the rise in temperature to 2° Celsius. The report stated that the emissions had to be held to less than 400 parts per million. An 80 percent reduction rather than a 60 percent reduction would be necessary.

In response to this evidence, the United Kingdom turned its attention to enacting a law that would target a significant reduction in GHG emissions, set in place mechanisms of regulation, and enable the country to become a low-carbon economy. Political conservatives and liberals, the Confederation of British Industry, and the Trade Unions Congress all supported the bill. On November 26, 2008, the Climate Change Act became law. It set the reduction target for the United Kingdom at 80 percent below the base year level by 2050. It also gave the ministers authority to enact various measures to ensure that the target is met. The United Kingdom was the first nation to pass a law regulating carbon emissions reduction and providing the means to achieve the target set.

Shawncey Webb

• Further Reading

Archer, David. *Global Warming: Understanding the Forecast.* Malden, Mass.: Blackwell, 2007. Excellent discussion of global warming and its effects, including economic consequences, combined with concise scientific explanation of the phenomena. Chapters on GHGs and fossil fuels. Targeted to undergraduates.

Charnovitz, Steve, and Gary Clyde Hufbauer. *Global Warming and the World Trading System.* Washington, D.C.: Peterson Institute for International Economics, 2009. Discusses reductions in GHG emissions and their relation to trade and to trade organizations, especially the World Trade Organization. Describes domestic and global methods of reducing GHGs without hurting carbon-intensive industries. Appendix.

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Change: A Guide to the Debate.* New York: Cambridge University Press, 2006. Excellent scientific introduction to climate change that also clearly reviews global politics and their effects on decision making. Written for the general reader. Graphs, tables, suggestions for further reading.

Faure, Michael, and Marjean Peeters, eds. *Climate Change and European Emissions Trading.* Northampton, Mass.: Edward Elgar, 2009. Discusses legal aspects of emissions trading, as well as economic effects. Includes a chapter on the United Kingdom and its Climate Change Act. Treats aviation emissions trading.

Glover, Leigh. *Postmodern Climate Change.* New York: Routledge, 2006. Good analysis of problems encountered in trying to implement climate change initiatives. Discusses the political and economic interests affecting climate policy.

Maslin, Mark. *Global Warming: A Very Short Introduction.* 2d ed. New York: Oxford University Press, 2009. Good, easy-to-understand discussion of global warming and related political controversies. Treats the British climate change bill and the Kyoto Protocol.

Pettenger, Mary A., ed. *The Social Construction of Climate Change.* Burlington, Vt.: Ashgate, 2007. Views the problems surrounding climate change and regulatory efforts from the perspective of social settings. Examines disputes and opposition encountered by programs such as the Kyoto Protocol.

Shogren, Jason F. *The Benefits and Costs of the Kyoto Protocol.* Washington, D.C.: AEI Press, 1999. Excellent explication of the Kyoto Protocol as a driver of national action.

See also: Carbon dioxide; Carbon dioxide equivalent; Environmental law; Europe and the European Union; Greenhouse gases; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. and European politics.

United Nations Climate Change Conference

- **Category:** Conferences and meetings
- **Date:** December 3-14, 2007

• Background

In 1994, the United Nations Framework Convention on Climate Change (UNFCCC) entered into force, and the nations, or parties, that ratified it have met annually in different cities in what are called the Conferences of the Parties to the Framework Convention on Climate Change (COP). It was during the third annual meeting in 1997, or COP-3, that the Kyoto Protocol was adopted. COP-11, held in Montreal, Canada, included the first official meeting of the parties (MOP) of the Kyoto Protocol since the protocol was adopted, and the group agreed to continue to meet annually. The United Nations Climate Change Conference (also known as the Bali Conference) was hosted December 3-14, 2007, by the Indonesian government and held in the Bali International Convention Center.

The conference was attended by over ten thousand governmental representatives, members of nongovernmental organizations, and journalists, from more than 180 countries. It comprised several separate but related events, including COP-13 and MOP-3, as well as an annual meeting of the Subsidiary Body for Scientific and Technological Advice, the Subsidiary Body for Implementation, and the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol.

Going into the Bali Conference, serious tensions and conflicts existed between several major parties. The United States was at odds with most of the rest of the European and the developing nations, because it did not believe that any nation should be bound by internationally determined targets. The United States hoped to persuade other nations that global warming could be addressed by each nation voluntarily setting its own targets and procedures for reaching them.

• Summary of Provisions

The focus of the Bali Conference was preparing for what will happen after 2012, the last year covered by the Kyoto Protocol. Most experts agree that, however difficult it has been for the world to reach Kyoto Protocol targets for emissions reductions, even greater reductions will be necessary after 2012 if global warming is to be effectively addressed. At the end of the conference, representatives from both developed and developing nations adopted the Bali Roadmap, a series of future steps to reduce global warming. One part of the roadmap, the Bali Action Plan, outlines a two-year process for a series of negotiations that would determine how countries would reduce their greenhouse gas (GHG) emissions after 2012. The negotiations were scheduled to occur four times in 2008, with a major meeting at COP-14, in Poznan, Poland, and to conclude with a binding agreement at COP-15, in Copenhagen, Denmark, in 2009.

The roadmap included the launching of the Adaptation Fund, which will finance projects for developing clean energy technologies in developing countries. The fund had been devised in 1997 at the Kyoto Conference, to be paid for through proceeds from the clean development mechanism, but it had not actually been created. As established at Bali, the fund is administered by a board of sixteen members that will meet twice each year to consider projects. Also included in the roadmap were clarifications and agreements on the scope of Article 9 of the Kyoto Protocol, which calls for periodic scientific review of global warming and its effects. The roadmap also included agreements about how developed nations can effectively transfer clean energy technology to developing nations and how deforestation, which increases the harmful effects of GHG emissions, can be reduced.

Former U.S. vice president Al Gore addresses the United Nations Climate Change Conference in Bali, Indonesia, on December 13, 2007. (SUPRI/Reuters/Landov)

• Significance for Climate Change

The Bali Conference had the potential to draw more participants into concrete plans to reduce emissions than had been involved previously. The roadmap, while it does not specify reduction targets overall or for any individual country, leaves open the likelihood that the two-year negotiation process will result in reduction commitments from additional nations. China, India, and Brazil, countries whose economies have grown quickly in the twenty-first century and that are among the largest emitters of GHGs, will likely be called upon to reduce their emissions after 2012.

Cynthia A. Bily

• Further Reading

Burleson, Elizabeth. "The Bali Climate Change Conference." *ASIL Insight* 12, no. 4 (March 18, 2008). Optimistic analysis of the Bali roadmap by a law professor who attended the Bali Conference with the United Nations Children's Fund (UNICEF) Delegation.

Fletcher, Susan R., Larry Parker, and Jane A. Leggett. *Climate Change: Issues Underlying Negotiations at the Bali Conference of Parties.* Washington, D.C.: Congressional Research Service, 2007. This report, prepared for the United States Congress before the Bali Conference, includes background information about the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), a review of the science and economics of emissions reduction, and expectations for future negotiations.

International Debates: The Pro and Con Monthly. "Controlling Global Warming, the Bali Roadmap and Beyond." 6, no. 1 (January, 2008). This special issue includes background information about Kyoto and Bali, remarks by the Bali Conference president, and articles arguing opposing sides by U.N. Secretary-General Ban Ki-moon, former U.S. vice president Al Gore, President George W. Bush, and others.

See also: International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; United States.

United Nations Conference on Environment and Development

• **Categories:** Conferences and meetings; environmentalism, conservation, and ecosystems
• **Date:** June 3-14, 1992, Rio de Janeiro, Brazil

• Background

During the twenty years following the 1972 U.N. Conference on the Human Environment, the deterioration of the global environment continued to accelerate with depletion of the ozone layer and natural resources, while global warming and pollution increased. Little had been accomplished over these years to integrate environmental issues with national economics and development. However, in 1983, Gro Harlem Brundtland of Norway, head of the World Commission on Environment and Development, put forth the notion of sustainable development. Based on the Brundtland Report, the U.N. General Assembly requested that a conference be convened that specifically focused on the environment and development. As a result, UNCED, or the Earth Summit, was held in Rio de Janeiro from June 3 to June 14, 1992.

• Summary of the Conference

The aim of UNCED was to arrive at an understanding of development that would provide a basis for global collaboration between the developed and the developing nations so as to bolster socioeconomic development and halt the deterioration of the Earth's environment. Governments of 108 countries adopted five significant agreements with the goals of improving the environment and redefining the traditional concept of development.

Agenda 21 was the only product of UNCED that encompassed the whole environment and development agenda. It entailed a comprehensive program of global action that covered all aspects of sustainable development with the aim of readying the world for the twenty-first century. Proposals called for social and economic action, including fighting poverty, considering global demographics, and balancing patterns of production with those of consumption. It was agreed that protecting the oceans, freshwater, the atmosphere, forests, and other natural resources, while promoting biodiversity and integrating environmental and developmental concerns, would improve conditions for all states, ensuring a prosperous and healthy future for planet Earth.

The Rio Declaration on Environment and Development was a series of principles that supported Agenda 21 by elucidating the rights and responsibilities of states. For example, people are entitled to live in harmony with nature via sustainable development; states have the right to use their own resources, but must not damage the environment of other states; reducing global disparities and eradicating poverty are necessary for sustainable development, which can be aided by strengthening the role of women, youth, farmers, indigenous peoples, and local authorities in the process.

The Statement of Forest Principles describes the legally nonbinding set of principles that underlie the sustainable management of forests. This was the first global consensus on forests that called for all nations, particularly the developed countries, to engage in forest conservation and reforestation. Moreover, it proclaimed that all states have the right to develop forests compatible with their socioeconomic needs and sustainable development policies.

The United Nations Framework Convention on Climate Change (UNFCCC), an environmental, nonbinding treaty, was ratified in March, 1994, with the intent to stabilize their greenhouse gas (GHG) emissions at 1990 levels by 2000. The principle of "common but differentiated responsibilities" was agreed upon, with the developed coun-

U.N. secretary-general Boutros Boutros-Ghali stands flanked by the conference organizers during the opening ceremonies of the United Nations Conference on Environment and Development. (AP/Wide World Photos) tries bearing the greater burden of accountability. The Convention on Biodiversity had several aims: sustaining and conserving biodiversity, sharing gene stocks, and commercial access to biotechnology with acceptance of associated liabilities.

• Significance for Climate Change

From June 23 to 27, 1997, more than fifty-three heads of state or government attended a special session of the U.N. General Assembly in New York City to review and appraise the implementation of Agenda 21. Called Earth Summit +5, its participants determined that the global environment had deteriorated since UNCED convened in 1992; the final document adopted by delegates from 165 nations agreed that while some headway had been made in forestalling climate change and loss of forest and freshwater, there were few commitments to reduce GHGs and help fund sustainable development, mainly because of North-South differences. Minister Msuya Waldi Mangachi of Tanzania, who represented 133 developing countries, stated that disagreements arose because financial pledges made by the developed countries had not been kept. In 1995, a U.N. panel of scientists found a discernible human influence on global climate. While the UNFCCC was ratified by more than 190 countries, few developed countries met the goal of reducing GHG emissions to 1990 levels by 2000. Parties to the UNFCCC were asked to adopt legally binding targets for developed countries by signing the Kyoto Protocol. On the positive side, one of the first accomplishments of the UNFCCC was creation of a national GHG inventory to keep track of gases and their removal from the atmosphere. Signers of the UNFCCC must update their accounts on a regular basis and release them to the UNFCCC. U.S. president George H. W. Bush presented the UNFCCC to the U.S. Senate, which ratified it in October, 1992. The Earth Summit also catalyzed many new institutional arrangements, such as the Commission on Sustainable Development (CSD), which became a central forum to review implementation of Agenda 21, and the U.N. Interagency Committee on Sustainable Development.

Cynthia F. Racer

• Further Reading

Annan, Kofi. "U.N. Development Programme: Choices." Interview by D. Diallo. *International Journal of Humanities and Peace* 16 (2000). Interview with the then-secretary general of the United Nations. Annan discusses the role of U.N. conferences on the environment and development in addressing concerns about the status of developing nations.

Caldwell, L. K. *International Environmental Policy: From the Twentieth to the Twenty-first Century*. 3d ed. Durham, N.C.: Duke University Press, 1996. Provides an update on the global international movement to protect the environment; covers the Rio conference and Agenda 21, as well as providing a post-Stockholm assessment.

Seufert-Barr, N. "Special General Assembly Review of Agenda 21 Should 'Revitalize' International Commitment to Sustainable Development." *UN Chronicle* 33 (Summer, 1996). Topics addressed include international aspects of economic and sustainable development; planning the United Nations Conference on Environment and Development, 1992; and the integration of the environment and development in decision-making processes.

Singer, S. Fred. "Dirty Climate: The Clinton Administration Is Determined to Save the Environment Whether It Needs Saving or Not." *National Review* 48 (November 25, 1996). Covers the scientific and political aspects of the 1992 United Nations Conference on Environment and Development, the political aspects of the Intergovernmental Panel on Climate Change, and global warming, as well as the environmental and international aspects of energy conservation.

See also: Agenda 21; Earth Summits; Kyoto Protocol; United Nations Climate Change Conference; United Nations Conference on the Human Environment; United Nations Environment Programme; United Nations Framework Convention on Climate Change.

United Nations Conference on the Human Environment

- **Categories:** Conferences and meetings; environmentalism, conservation, and ecosystems
- **Date:** June 5-16, 1972

• Background

In 1968, at the forty-fifth session of the United Nations Economic and Social Council, a resolution was passed underscoring the immediate need for intensified action at the national and the international levels to halt the continuing deterioration of the "human environment." The council reasoned that proper attention to the problems of the human environment was necessary for sound global economic and social development, and it recommended that the U.N. General Assembly convene the United Nations Conference on the Human Environment (also known as the Stockholm Conference). In response, the General Assembly, at its twenty-third session, endorsed the council's recommendations and issued U.N. Resolution 2398, resolving to hold the conference in order to explore the problems associated with the human environment, focusing on challenges that could be properly addressed only by international collaboration and agreement.

Accepting an invitation from the Swedish government to hold the event in Sweden, Secretary-General U Thant appointed the head of the Canadian Foreign Aid Agency, Maurice F. Strong, to oversee a conference preparatory committee that met from 1970 to 1972. At the urgent request of developing nations, matters concerning development were added to the conference agenda. While 114 nations and over 400 inter- and nongovernmental agencies sent representatives to the meeting, the entire Eastern Bloc boycotted the conference because of conflicts over the political division of postwar Germany. In addition, eighteen thousand persons attended simultaneous events that were sponsored by a trio of nongovernmental organizations (NGOs)—the People's Forum, the Environment Forum, and Dai Dong—and held outside the grounds of the conference. These events and their participants produced their own set of environmental principles.

• Summary of the Conference

Having considered the need for a common outlook and shared principles that might inspire and guide the world's nations to preserve and enhance the human environment, the conference put forth a declaration composed of twenty-six principles on the environment and development. The first principle broadly stated,

> Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment that permits a life of dignity and well-being, and he bears a solemn responsibility to protect and improve the environment for present and future generations.

The twenty-first of these principles is the best known and is believed by many international legal scholars to be the foundation for much of the environmental diplomacy that has occurred since the Stockholm meeting, because it acknowledges that states have,

> in accordance with the UN Charter and international law . . . the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their own jurisdiction do not cause damage to the environment of other States.

Other principles stress the need for scientific research and technology, education for youth and adults alike, rational planning, and international cooperation to protect the global environment. In addition to the declaration, an action plan was put forth comprising 109 recommendations encompassing six general topics, including educational, informational, social, and cultural aspects of the environment. For example, recommendation 95 called for

> providing countries with . . . technical and financial assistance in preparing national reports on the environment, in setting up machinery for monitoring environmental development . . . and drawing up national social, educational and cultural programmes.

Recommendation 96 called for the secretary general and the U.N. organizational system, particularly the U.N. Educational, Scientific, and Cultural Organization, ". . . to establish an international programme in environmental education, interdisciplinary in approach, [and] encompassing all levels of education and directed toward the general public."

Other recommendations addressed financial support for these endeavors, as well as "managing global pollution, natural resources, and human settlements." Importantly, the Stockholm conference acknowledged the need to articulate "third generation human rights," those that exceed the merely civil and social but are legally difficult to enact. Broadly based, these rights include the right to a healthy environment; to preservation of natural resources through sustainable practices, and to economic and social development. However, while development was included as a Stockholm Conference agenda issue, it was not dealt with in later follow-ups.

• Significance for Climate Change

The first international conference of its kind, the U.N. Conference on the Human Environment focused attention on the need for global collaboration to decrease general and marine pollution and created environmental monitoring networks, both regional and global. It provided the framework for future environmental collaboration, leading to the establishment of the U.N. Environment Programme (UNEP). UNEP coordinates U.N. environmental activities, helping developing countries implement environmentally sound policies by encouraging sustainable environmental practices. Importantly, the Stockholm Conference and the scientific conferences on the environment that it preceded significantly influenced the environmental policies of the European Union. As an example, in 1973, the union established the Environmental and Consumer Protection Directorate and the first Environmental Action Program. Increased awareness and interest in the global environment have stimulated research on climate change and led to further understanding of global warming and agreements such as the Kyoto Protocol.

Cynthia F. Racer

• Further Reading

Annan, Kofi. "U.N. Development Programme: Choices." Interview by D. Diallo. *International Journal of Humanities and Peace* 16 (2000). Interview with the then-secretary general of the United Nations. Annan discusses the role of U.N. conferences on the environment and development in addressing concerns about the status of developing nations.

Gagain, J. R., Jr. "The United Nations and Civil Society: A New Step in the Right Direction." *UN Chronicle* 40 (June, 2003). Report on the United Nations Conference on Environment and Development (UNCED), which demonstrated the need for countries to interact with the United Nations, particularly on "borderless" issues such as the environment and development.

Van Ginkel, H., B. Barrett, J. Court, and J. Velasquez. *Challenges for the United Nations in the New Millennium.* New York: University Press, 2002. Topics include congresses on human ecology, social problems, and the United Nations.

See also: Earth Summits; Kyoto Protocol; United Nations Climate Change Conference; United Nations Conference on Environment and Development; United Nations Environment Programme.

United Nations Convention on the Law of the Sea

• **Category:** Laws, treaties, and protocols

Among the goals set forward in the U.N. Convention on the Law of the Sea is that of establishing parameters for sovereignty among the nations of the world, and the international community as a whole, over coastal and oceanic waters. This sovereignty includes responsibility for and administration over the use and abuse of the maritime environment and its resources.

• Key concepts

contiguous zone: area between 22.2 and 44.4 kilometers from a nation's coastline within which the nation enjoys partial but not full sovereignty *exclusive economic zone (EEZ):* a zone extending from a nation's coast up to 370, or even 650, kilometers that is considered that nation's sole legal preserve to regulate and exploit economically

International Seabed Authority: an independent international organization set up to regulate and authorize the exploitation of seabed resources within international waters

international waters: all areas lying beyond EEZs and considered open to all nations for all legitimate, nonbelligerent purposes; also known as the high seas

territorial waters: the seas within 22 kilometers of a national coast that are considered a nation's exclusive jurisdiction and through which foreign vessels are allowed "innocent passage"

• **Participating nations:** *1982:* Fiji; *1983:* Bahamas, Belize, Egypt, Ghana, Jamaica, Mexico, Namibia, Zambia; *1984:* Côte d'Ivoire, Cuba, Gambia, Philippines, Senegal; *1985:* Bahrain, Cameroon, Guinea, Iceland, Iraq, Mali, Saint Lucia, Sudan, Togo, Tunisia, United Republic of Tanzania; *1986:* Guinea-Bissau, Indonesia, Kuwait, Nigeria, Paraguay, Trinidad and Tobago; *1987:* Cape Verde, São Tomé and Príncipe, Yemen; *1988:* Brazil, Cyprus; *1989:* Antigua and Barbuda, Democratic Republic of the Congo, Kenya, Oman, Somalia; *1990:* Angola, Botswana, Uganda; *1991:* Djibouti, Dominica, Grenada, Marshall Islands, Micronesia, Seychelles; *1992:* Costa Rica, Uruguay; *1993:* Barbados, Guyana, Honduras, Malta, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Zimbabwe; *1994:* Australia, Bosnia and Herzegovina, Comoros, Germany, Mauritius, Sierra Leone, Singapore, Sri Lanka, the former Yugoslav Republic of Macedonia, Vietnam; *1995:* Argentina, Austria, Bolivia, Cook Islands, Croatia, Greece, India, Italy, Jordan, Lebanon, Samoa, Slovenia, Tonga; *1996:* Algeria, Brunei Darussalam, Bulgaria, China, Czech Republic, Finland, France, Georgia, Haiti, Ireland, Japan, Malaysia, Mauritania, Monaco, Mongolia, Myanmar, Nauru, Netherlands, New Zealand, Norway, Palau, Panama, Republic of Korea, Romania, Saudi Arabia, Slovakia, Sweden; *1997:* Benin, Chile, Equatorial Guinea, Guatemala, Mozambique, Pakistan, Papua New Guinea, Portugal, Russian Federation, Solomon Islands, South Africa, Spain, United Kingdom; *1998:* Belgium, European Community, Gabon, Lao People's Democratic Republic, Nepal, Poland, Suriname; *1999:* Ukraine, Vanuatu; *2000:* Luxembourg, Maldives, Nicaragua; *2001:* Bangladesh, Madagascar, Serbia; *2002:* Armenia, Hungary, Qatar, Tuvalu; *2003:* Albania, Canada, Kiribati, Lithuania; *2004:* Denmark, Latvia; *2005:* Burkina Faso, Estonia; *2006:* Belarus, Montenegro, Niue; *2007:* Lesotho, Morocco, Republic of Moldova; *2008:* Congo, Liberia; *2009:* Switzerland

• Background

In the strictest sense, the Law of the Sea may refer to the United Nations Convention on the Law of the Sea (UNCLOS), which has been in official operation only since November 16, 1994. The process that brought this law about, however, dates back to quite a few years prior to that date, and the concept of a law of the sea within international law and relations is much older still. Control over the coastline and over the sea and seabed resources has been a bone of contention that figured in disputes and even wars from the ancient through the medieval eras of history. It was, however, the rise of the western European nation-states and the opening of the Atlantic and Indian Ocean seaways for trade and transportation that led to the first attempts to formulate a definitive maritime law regarding sovereignty over coastal waters.

The Dutch legal philosopher Hugo Grotius (1583-1645)—his country alarmed at the prospect of being forced out of both the East and the West Indies trade by England, Spain, France, and Portugal—wrote in *Mare Liberum* (1609; *Freedom of the Seas*, 1916) that the seas should be a free area, where ships of all nations should be able to travel unfettered and unmolested. Grotius's concept was further solidified by Cornelius van Bynkershoek (1673-1743), who set the boundary between a country's territorial waters, over which it had legal jurisdiction, and Grotius' "high seas," which were free to be used by all nations. Territorial waters were seen as falling within "cannon shot" range (at that time, 5.5 kilometers).

• Role of the United Nations

From its inception, however, Grotius's concept was not universally accepted: The British philosopher-spokesman John Selden (1584-1654) argued as early as 1635 that sovereign states had the right to allot and subdivide the oceans in the same way as was done with land. Ambiguity over this question on the occasion of wartime naval blockades could sometimes lead to armed conflict. Cases in point include the British naval impressment of American sailors, which served as a partial cause for the War of 1812, and Germany's "unrestricted submarine warfare" policy, which contributed to the United States' decision to enter World War I on the Allied side in 1917.

In order to arrive at a universal agreement on maritime jurisdiction and to forestall future sources of conflict, the first United Nations Conference on the Law of the Sea convened at Geneva, Switzerland, in 1958. This was followed by the second conference in 1960 at Geneva, and a third in New York in 1973. The third conference deliberated over the course of more than nine years until, on December 10, 1982, the final UNCLOS document was signed at Montego Bay, Jamaica. It needed, however, to be separately ratified by sixty countries before it could take effect, and this did not happen until November 16, 1994, with ratification by Guyana.

• Provisions and Organization

UNCLOS spells out the legal definitions of territorial waters (which had largely been expanded from 5.5 to 22.2 kilometers long prior to 1982); a 22.2- to 44.4-kilometer offshore contiguous zone of quasi sovereignty; an exclusive economic zone (EEZ) of 370 to 650 kilometers of resource jurisdiction; and the international "high seas." The International Tribunal for the Law of the Sea (ITLOS) was inaugurated as a special court of twenty-one judges to convene in Hamburg, Germany, to arbitrate disputes among UNCLOS members. The court is composed of four chambers: Summary Procedure; Fisheries Disputes; Marine Environmental Disputes; and Conservation and Sustainable Exploitation of Swordfish Stocks in the South-Eastern Pacific Ocean. Part 11 of UNCLOS, one of the more controversial provisions, set into motion the International Seabed Authority, which operates apart from the United Nations as an international consortium to license and administer scientific research and exploration, as well as potential exploitation of all ocean floor (mainly mineral) resources outside the EEZs.

• Context

Some 156 countries ratified UNCLOS, though the United States has not, chiefly due to objections over Part 11 as being potentially detrimental to U.S. defense policies and discriminatory against U.S. business enterprises. On the issues of environment and climate change, opinions seem to be divided over the effects of UNCLOS. On one hand, there is the assertion that a regulatory agency such as the International Seabed Authority could exert control to prevent possible drastic anthropogenic climate changes resulting from overexploitation of oceanic resources. On the other hand, it is argued the greater likelihood exists that the authority may open the seabed to misdirected or excessive exploitation—such as overfishing, over-mining, or drilling—and thus trigger global climatic shifts that might have unforeseen results.

Raymond Pierre Hylton

• Further Reading

Kiss, Alexandre, and Dinah Shelton. *Guide to International Environmental Law.* Boston: Martinus Nijhoff, 2007. This account is very evenhanded in that, while citing UNCLOS as a worthy foundational concept, it also criticizes its shortcomings.

Kunich, John Lynch. *Killing Our Oceans: Dealing with the Mass Extinction of Marine Life.* Westport, Conn.: Praeger, 2006. Singles UNCLOS out as being a crucial step, and really the only one thus far taken, to resolve international maritime issues; highly critical of the U.S. reluctance to endorse all its provisions.

Rao, P. Sreenivasa. *The Public Order of Ocean Resources: A Critique of the Contemporary Law of the Sea.* Cambridge, Mass.: MIT Press, 1975. Goes into a multiplicity of detail and may at times be hard to follow for the layperson, but does give a thoroughly informative description of UNCLOS and the challenges it faces.

Van Dyke, Jon M., Durwood Zaelke, and Grant Hewison. *Freedom of the Seas in the Twenty-first Century: Global Governance and Environmental Harmony.* Washington, D.C.: Island Press, 1993. A se-

ries of essays that go into some detail in describing the modern conflict between the ideals of individual freedom of entrepreneurship, as opposed to collective environmental protection.

See also: Antarctic Treaty; Arctic seafloor claims; Basel Convention; Convention on Long-Range Transboundary Air Pollution; Earth Summits; International agreements and cooperation; International waters; United Nations Climate Change Conference; United Nations Conference on the Human Environment; United Nations Convention to Combat Desertification.

United Nations Convention to Combat Desertification

- **Category:** Laws, treaties, and protocols
- **Date:** Adopted by the United Nations June 17, 1994; entered into force December 26, 1996
- **Participating nations:** *1995:* Afghanistan, Canada, Cape Verde, Denmark, Ecuador, Egypt, Finland, Guinea-Bissau, Lesotho, Mali, Mexico, Netherlands, Peru, Senegal, Sudan, Sweden, Togo, Tunisia, Uzbekistan; *1996:* Algeria, Bangladesh, Benin, Bolivia, Botswana, Burkina Faso, Central African Republic, Chad, Eritrea, Gabon, Gambia, Germany, Ghana, Haiti, India, Israel, Jordan, Lao People's Democratic Republic, Lebanon, Libyan Arab Jamahiriya, Malawi, Mauritania, Mauritius, Micronesia, Mongolia, Morocco, Nepal, Niger, Norway, Oman, Panama, Portugal, Spain, Swaziland, Switzerland, Turkmenistan, United Kingdom, Zambia; *1997:* Angola, Antigua and Barbuda, Argentina, Armenia, Austria, Bahrain, Barbados, Belgium, Brazil, Burundi, Cambodia, Cameroon, Chile, China, Côte d'Ivoire, Cuba, Democratic Republic of Congo, Djibouti, Dominica, Dominican Republic, El Salvador, Equatorial Guinea, Ethiopia, France, Greece, Grenada, Guinea, Guyana, Honduras, Iceland, Iran, Ireland, Italy, Jamaica, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Luxembourg, Madagascar, Malaysia, Mozambique, Myanmar, Namibia, Nigeria, Pakistan, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saudi Arabia, Seychelles, Sierra Leone, South Africa, Syrian Arab Republic, Tajikistan, Tanzania, Uganda, Yemen, Zimbabwe; *1998:* Costa Rica, Malta, Nicaragua, Liberia, Comoros, Saint Vincent and the Grenadines, European Community, Turkey, Marshall Islands, Venezuela, São Tomé and Príncipe, Belize, Azerbaijan, Niue, Romania, Cook Islands, Samoa, Vietnam, Fiji, Indonesia, Kiribati, Guatemala, Japan, Tuvalu, Nauru, Tonga, United Arab Emirates, Rwanda, Sri Lanka; *1999:* Colombia, Republic of the Congo, Georgia, Hungary, Republic of Korea, Liechtenstein, Republic of Moldova, Monaco, Palau, Qatar, San Marino, Singapore, Solomon Islands, Uruguay, Vanuatu; *2000:* Albania, Australia, Bahamas, Croatia, Cyprus, Czech Republic, New Zealand, Papua New Guinea, Philippines, Suriname, Trinidad and Tobago, United States; *2001:* Belarus, Bulgaria, Poland, Slovenia, Thailand; *2002:* Andorra, Bosnia and Herzegovina, Brunei Darussalam, Latvia, Macedonia, Maldives, Slovak Republic, Somalia, Ukraine; *2003:* Bhutan, Democratic People's Republic of Korea, Lithuania, Russian Federation, Timor Leste; *2007:* Montenegro, Serbia

• Background

The United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (UNCCD; also known as the Desertification Convention) was developed following concerns expressed in 1991 by the United Nations Environment Programme (UNEP). UNEP indicated that the Plan of Action to Combat Desertification (PACD), which had been developed as a result of the 1977 United Nations Conference on Desertification (UNCOD), was ineffective. Since the plan's implementation, the problem of land degradation in arid, semiarid, and dry sub-humid areas had intensified rather than diminished. The PACD's ineffectiveness was seen as due in part to the "top down" approach it had adopted and to the low priority given to desertification by many governments.

As a result of pressure from African states, the participants in the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro supported a new approach to de-

Participants in a 2008 international conference on desertification in Beijing, China. Chinese vice premier Hui Liangyu addressed the conference, calling upon all parties to the Convention to Combat Desertification to honor their commitments. (Xinhua/Landov)

sertification, emphasizing integrated action and sustainable development at the community level. They proposed a new international treaty addressing the issue of desertification. Despite a lukewarm reception from many developed nations, the U.N. General Assembly established an international committee to negotiate a desertification convention, and the convention was adopted on June 17, 1994, after intensive debate. The UNCCD frames desertification at both an environmental and a political level and emphasizes local action and the involvement of communities and nongovernmental organizations (NGOs) in providing solutions and developing national action programs.

• Summary of Provisions

The UNCCD aims to combat desertification and mitigate the effects of drought in affected areas, especially in Africa, via action at all levels of society and government, with support from international cooperation and partnerships. The convention promotes an integrated approach to arid and semiarid environmental problems in order to achieve sustainable development in these areas. It recognizes the fragile nature of dryland environments and their vulnerability to climate change and variability, including prolonged episodes of regional drought.

• Significance for Climate Change

Global warming has been associated with expanding deserts in several parts of the world, especially Saharan Africa. Warmer air holds more moisture, allowing greater evaporation and removing freshwater and groundwater from the land. Moreover, climate change is associated with alterations in global wind and weather patterns that have brought drought and desertification to several areas in the past few decades. It was the need to respond to this growing desertification that created the pressing need for an international agreement on the subject. The Desertification Convention is unlikely to reverse desertification, but it may minimize the human suffering and ecological damage caused by this process.

Nicholas Lancaster

See also: Climate change; Climate zones; Desertification; Deserts; Displaced persons and refugees; International agreements and cooperation; United Nations Framework Convention on Climate Change.

United Nations Division for Sustainable Development

- **Categories:** Organizations and agencies; economics, industries, and products
- **Date:** Established 1992
- **Web address:** http://www.un.org/esa/dsd/index.shtml

• Mission

An agency of the United Nations, the Division for Sustainable Development supports and helps implement programs of the Commission on Sustainable Development. The commission and division were created by the General Assembly of the United Nations to carry out the Rio Declaration on Environment and Development, which was adopted at the Earth Summit held in June, 1992. Climate change is one of the areas specifically assigned to this organization as part of its responsibilities in natural resources management.

The Division for Sustainable Development (DSD) has the mission of enabling economic development in such a manner that it not only works in the present but also will be viable in the foreseeable future. The DSD is to provide assistance and information to all organizations seeking to implement sustainable development. This includes research to define what are central factors preventing sustainable development as well as seeking solutions to overcome these factors. It seeks to work with other groups within the United Nations, as well as encouraging regional and global cooperation to implement successful patterns of sustainable development.

The DSD does not have the power to mandate actions by the members of the United Nations, nongovernmental organizations (NGOs), or citizens of any country. However, it does work to facilitate changes in the way economic development is implemented. It does this through securing funding for pilot projects, research, and educational efforts. The basic document defining the mission of the DSD, as the staff for the Commission on Sustainable Development (CSD), is Agenda 21. Agenda 21 was adopted at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil.

The 1992 document is composed of the Rio Declaration and the Statement of Principles for the Sustainable Management of Forests. The main section focusing on climatic issues is chapter 9, "Protection of the Atmosphere." In 2002, a meeting was held in Johannesburg, South Africa, to evaluate what progress had been made toward reaching the goals of Agenda 21 and what obstacles were preventing positive movement on the issues. This meeting adopted the Johannesburg Plan of Implementation, which contains specific steps to be taken toward the goals.

As the portion of the U.N. secretariat charged with fulfilling the implementation plan, the DSD works with a wide variety of organizations to move toward the goal of sustainable development. Climate change, including global warming and desertification, is an area of special focus. The DSD also works with the Small Island Developing States network, a special work group established in 1997 because of the special vulnerability of small islands to any rise in ocean levels. Such a sea-level rise could occur if global warming causes the melting of the polar ice caps.

• Significance for Climate Change

Development is not sustainable if it creates climatic or other environmental changes that interfere with the continuation of proposed economic enterprises. It is for this reason that diligent research is undertaken on all development proposals to discern if any factor of a proposal might increase any type of pollution. The DSD has accepted a finding by the Intergovernmental Panel on Climate Change that it is more than 90 percent likely that the current fossil-fuel-based energy system emits greenhouse gases (GHGs) that cause global warming.

While recognizing that fossil fuels will remain part of the energy system in the short run, the DSD seeks the means to move to alternative sources of energy as rapidly as possible. An example of this program is the electrification of rural areas of Kiribati. These areas are not connected to the urban electrical grid, which relies mainly on imported fossil fuels. Instead, a DSD-sponsored pilot project installed solar panels and batteries on private houses to power electric lights. The project proved the practicality and reliability of such systems in relatively isolated areas, as well as investigating the minimum number of panels and batteries needed in an area to allow an economically feasible support structure to operate. Providing the support structure also made it possible for individuals to consider adding more solar panels to power refrigeration and other applications.

In addition to providing numerous publications and online forums, the CSD holds annual conferences that generally focus on selected issues. In 2002, the World Summit on Sustainable Development was held. This meeting encouraged all nations to develop sustainable development plans. In 2007, the DSD sponsored an experts' meeting on the topic of "Integrating Climate Change into National Sustainable Development Strategies." The philosophy behind this meeting is summarized in this statement from the "Concept Note" regarding the rationale for the conference: "Its objective is to strengthen sustainable development as the most effective framework within which to tackle climate change." Thus, while the DSD has a broad charge, going well beyond just climate change and global warming, it does envision sustainable development as the key to solving anthropogenic climatic problems.

Donald A. Watt

• Further Reading

Boyle, Alan E., and David Freestone, eds. *International Law and Sustainable Development: Past Achievements and Future Challenges*. New York: Oxford University Press, 2001. Collection of essays that examine how the issues raised at the Earth Summit have been incorporated into international law.

Robinson, Nicholas A. *Strategies Toward Sustainable Development: Implementing Agenda 21*. New York: Oceana, 2005. With Agenda 21 as the foundation for international negotiations on sustainable development, this book examines the major agreements and efforts to implement Agenda 21's ideals.

World Bank. Office of the Publisher, ed. *Five Years After Rio: Innovations in Environmental Policy*. Washington, D.C.: Author, 1997. Assuming that sustainable development policies must work within a market economy, this publication examines how they fit into contemporary markets and what new market systems might be needed to accommodate them.

See also: Sustainable development; United Nations Conference on Environment and Development; United Nations Environment Programme; World Bank.

United Nations Environment Programme

- **Categories:** Organizations and agencies; environmentalism, conservation, and ecosystems
- **Date:** Established 1972
- **Web address:** http://www.unep.org/

• Mission

The United Nations Environment Programme (UNEP) is a designated agency of the United Nations system on environment that develops international agreements; assesses global, regional, and national environmental events; and fosters international partnerships. UNEP has a mission to provide leadership and develop partnerships in caring for the environment by working with countries and their people to improve the quality of life of present and future generations. The program provides environmental data and information that governments around the world use in planning and executing sustainable development projects. It develops policy guidelines to address salient environmental issues, such as lack of freshwater, degradation of the marine environment, and atmospheric pollution. UNEP assists governments in anticipating, responding to, and managing disasters caused by environmental factors. It also helps assess the environmental effects of wars and provides postwar cleanup and mitigation advice. It builds national environmental capacity and helps develop international environmental law.

UNEP's headquarters are in Nairobi, Kenya. The program has additional regional offices in Bangkok, Thailand; Geneva, Switzerland; Mexico City; Washington, D.C.; and Manama, Bahrain. UNEP

Achim Steiner, executive director of the United Nations Environment Programme, addresses the eighth Conference of the Parties to the Basel Convention in November, 2006. (Xinhua/Landov)

also supports several centers of excellence, such as the UNEP Collaborating Center on Energy and Environment (UCCEE), the UNEP World Conservation Monitoring Centre (UNEP-WCMC), and the Global Resource Information Database (GRID).

UNEP is organized into eight divisions that work toward promoting and facilitating effective environmental management for sustainable development. These include the divisions for Early Warning and Assessment; Policy Development and Law; Environmental Policy Implementation; Technology, Industry and Economics; Regional Cooperation; Environmental Conventions; Communications and Public Information; and Global Environment Facility Coordination. UNEP focuses on five priority areas: environmental assessment and early warning; development of policy instruments; enhanced coordination with environmental conventions; technology transfer; and providing particular support to African nations.

UNEP is the host for several environmental convention secretariats. Some of these include the Secretariat of the Vienna Convention for the Protection of the Ozone Layer, in Nairobi; the Multilateral Fund of the Montreal Protocol, in Montreal, Canada; the Convention on International Trade in Endangered Species (CITES), in Geneva; the Convention on Biological Diversity, in Montreal; the Convention on Migratory Species of Wild Animals, in Bonn, Germany; the Basel Convention on the Transboundary Movement of Hazardous and Other Wastes, in Geneva; the Stockholm Convention on Persistent Organic Pollutants (POPs), in Geneva; and the Rotterdam Convention on Prior Informed Consent, also in Geneva.

• Significance for Climate Change

UNEP makes periodic assessments and forecasts of environmental threats. It has obtained support for effective national and international responses to such threats and has developed effective coordination of environmental issues within the United Nations. Since 2000, on the directions of the U.N. General Assembly, UNEP has started an annual Global Ministerial Environment Forum (GMEF). This forum's participants review policy issues in the field of environment and try to build consensus. Based on the work of the forum in 2000, environmental sustainability was listed in the Millennium Declaration as one of eight millennium development goals.

Several international environmental agreements have been established with the help of UNEP. Examples of such agreements include the Montreal Protocol to restore the ozone layer in 1987, the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, and the Kyoto Protocol to the UNFCCC in 1997. The program has also aided in the framing of several treaties that govern the production, transportation, use, release, and disposal of chemicals, as well as several treaties that protect global biodiversity.

UNEP has been involved in the development of environmental programs that affect climate. An example of such a project is the OzonAction program, which implements the Montreal Protocol and helps restore Earth's ozone layer by phasing out ozone-depleting substances. Another project is the Global Programme of Action, which protects the marine environment from common land-based sources of pollution by promoting integrated management of river basins and coastal zones. The International Coral Reef Action Network fosters the conservation and sustainable management of the world's coral reefs, while the Great Apes Survival Project (GRASP) mobilizes political will toward preserving apes and their forest habitats.

Manoj Sharma

• **Further Reading**

Molle, Willem. *Global Economic Institutions.* New York: Routledge, 2003. Discusses several international economic institutions, including the World Trade Organization and the International Monetary Fund. Several pages are devoted to the United Nations Environment Programme.

Tolba, Mostafa Kamal. *Sustainable Development: Constraints and Opportunities.* London: Butterworths, 1987. Collection of thirty-five speeches made between 1982 and 1986 by the then executive director of the United Nations Environment Programme. The work of the program and how environment and development are interdependent are nicely brought out in this text.

United Nations Environment Programme. *One Planet, Many People: Atlas of Our Changing Environment.* Nairobi, Kenya: Author, 2005. This atlas contains photographs, satellite images, maps, and narratives related to the environment. Intended for environmental policy makers, nongovernmental organizations, people from the private sector, those in academia, and lay people.

_______. *The UNEP Year Book 2008.* Nairobi, Kenya: Author, 2008. Formerly called the *GEO Year Book*, this is the fifth annual report on the changing environment developed by the United Nations Environment Programme in collaboration with many world environmental experts. Rich with graphs, charts, and photos and discusses key environmental issues.

See also: Basel Convention; Convention on Biological Diversity; Convention on International Trade in Endangered Species; International agreements and cooperation; Kyoto Protocol; Montreal Protocol; Ramsar Convention; Stockholm Declaration; United Nations Framework Convention on Climate Change.

United Nations Framework Convention on Climate Change

• **Category:** Laws, treaties, and protocols
• **Date:** Entered into force March 21, 1994

The UNFCCC was the first comprehensive global agreement seeking to control the atmospheric factors contributing to global warming. Although the initial agreement did not identify specific environmental changes, it established a process through which pollution-control agreements could be made. The Kyoto Protocol is the most well known of these subsequent agreements.

• **Participating nations:** *1992:* Australia, Canada, Maldives, Marshall Islands, Mauritius, Monaco, Seychelles, United States, Zimbabwe; *1993:* Algeria, Antigua and Barbuda, Armenia, Burkina Faso, China, Cook Islands, Czech Republic, Denmark, Dominica, Ecuador, Fiji, Germany, Guinea, Iceland, India, Japan, Jordan, Mexico, Micronesia, Mongolia, Nauru, Netherlands, New Zealand, Norway, Papua New Guinea, Peru, Portugal, Republic of Korea, Saint Kitts and Nevis, Saint Lucia, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Tunisia, Tuvalu, Uganda, United Kingdom, Uzbekistan, Vanuatu, Zambia; *1994:* Albania, Argentina, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bolivia, Botswana, Brazil, Cameroon, Chad, Chile, Comoros, Costa Rica, Côte d'Ivoire, Cuba, Democratic People's Republic of Korea, Egypt, Estonia, Ethiopia, Finland, France, Gambia, Georgia, Greece, Grenada, Guyana, Hungary, Indonesia, Ireland, Italy, Kenya, Kuwait, Lebanon, Liechtenstein, Luxembourg, Malawi, Malaysia, Mali, Malta, Mauritania, Myanmar, Nepal, Nigeria, Pakistan, Paraguay, Philippines, Poland, Romania, Russian Federation, Samoa, San Marino, Saudi Arabia, Senegal, Slovakia, Solomon Islands, Thailand, Trinidad and Tobago, Uruguay, Venezuela, Vietnam; *1995:* Azerbaijan, Bhutan, Bulgaria, Cambodia, Cape Verde, Central African Republic, Colombia, Democratic Republic of the Congo, Djibouti, El Salvador, Eritrea, Ghana, Guatemala, Guinea-Bissau, Honduras, Jamaica, Kazakhstan, Kiribati, Lao People's Democratic Republic, Latvia, Lesotho, Lithuania, Morocco, Mozambique, Namibia, Nicaragua, Niger, Oman, Panama, Republic of Moldova, Sierra Leone, Slovenia, Togo, Turkmenistan, United Arab Emirates; *1996:* Belgium, Congo, Croatia, Haiti, Iran, Israel, Niue, Qatar, Saint Vincent and the Grenadines, Swaziland, Syrian Arab Republic, United Republic of Tanzania, Yemen; *1997:* Burundi, Cyprus, Singapore, South Africa, Suriname, Ukraine; *1998:* Dominican Republic, Gabon, Rwanda, Tajikistan, Tonga, the former Yugoslav Republic of Macedonia; *1999:* Libyan Arab Jamahiriya, Madagascar, Palau, São Tomé and Príncipe; *2000:* Angola, Belarus, Bosnia and Herzegovina, Equatorial Guinea, Kyrgyzstan; *2001:* Serbia; *2002:* Afghanistan, Liberia; *2004:* Turkey; *2006:* Montenegro, Timor-Leste; *2007:* Brunei Darussalam

• Background

Although the environmental movement had been around for decades, it initially dealt with localized problems or changes that could be easily seen. Some individuals considered the broader picture, but the size of the Earth made many assume that people could not make significant changes on a global scale. In the late 1960's, partially as a result of the moon landings, people saw how small the Earth is within the universe. More people became concerned about the environment, as seen in movements such as Earth Day.

Funding for the scientific collection of environmental data grew, and the understanding of what was happening to the global system, especially the atmosphere, increased. Some scientists began to issue warnings about anthropogenic damage to the global system. In the United States, two examples helped people accept these warnings: acid rain and the depletion of the ozone layer. While acid rain was a problem only for specific locations and treated at that level, depletion of the ozone was seen as a global problem. Scientists could demonstrate how chlorofluorocarbons and related compounds were causing the expansion of holes in the ozone layer. A result was the Montreal Protocol of 1987, which limited the production and use of ozone-depleting chemicals. Within the agreement, countries were divided into developed and developing categories, with different regulations applying to each group. This proved to be an important precedent for future environmental treaties.

In June, 1992, the United Nations hosted the Conference on Environment and Development in Rio de Janeiro, Brazil (the Earth Summit). Among the items passed by the conference was the United Nations Framework Convention on Climate Change (UNFCCC). After enough countries ratified the agreement, it went into effect in March, 1994. The UNFCCC recognizes that greenhouse gases (GHGs) created by human activities are a major factor in global warming and mandates that member nations reduce their GHG emissions to a level that will not cause environmental harm.

• Summary of Provisions

Scientific study of the role that GHGs play in regulating the temperature of the Earth has indicated that they contribute to an increase in the atmosphere's average temperature. Leading up to the Earth Summit, a major point of contention was whether or not the agreement to be negotiated there should contain specific limits on GHG emissions, with the United States arguing against setting such limits. The UNFCCC accepted the premise that anthropogenic GHGs are a major factor causing global warming, said that GHG emissions would be monitored, and established a system for future discussions for specific steps to be taken. Since the UNFCCC did not contain specific limits, the United States agreed and was the first industrialized country to ratify this agreement.

The UNFCCC established three steps toward reducing GHG emissions, in addition to establishing the framework for future negotiations. These included an agreement in principle to reduce GHG emissions to below their 1990 levels, the establishment of a market for trading emission credits, and the creation of a mechanism for industrialized countries to help developing countries acquire low-polluting systems. In addition, Annex I of the convention listed the parties that were industrialized nations, and it committed only those nations to make significant, albeit unspecified, GHG reductions. Developing, non-Annex I parties were given no such commitments. A secretariat was established in Bonn, Germany, to facilitate the implementation of these measures.

• The Kyoto Protocol and Implementation

Beginning in 1995, there has been an annual Conference of the Parties (COP) to the UNFCCC. Meeting in Kyoto in 1997, the conference adopted the Kyoto Protocol. It stated that the developed countries must reduce their GHG emissions during the period from 2008 to 2012. The base year for measuring these reductions was 1990. The goals set varied for the developed countries, but the 7 percent reduction assigned to the United States was relatively typical.

The United States signed the protocol, but President George W. Bush never sent it to the Senate for ratification, so it is not binding on the United States. Using the system already established to record the amount of GHGs emitted, plans were to be developed in each country to reduce those emissions.

Principles of the U.N. Framework Convention on Climate Change

Article 3 of the UNFCCC sets out the five principles that should guide all parties to the convention in all actions relating to the convention.

1. The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.

2. The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.

3. The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.

4. The Parties have a right to, and should, promote sustainable development. Policies and measures to protect the climate system against human-induced change should be appropriate for the specific conditions of each Party and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change.

5. The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

The Kyoto Protocol also set the standards for reporting this information to the Climate Change Secretariat. A compliance committee was established to ensure that the goals were met. At each annual COP meeting, issues regarding the implementation of current agreements or proposals for new ones are discussed.

• Context

In 1994 not all governments were convinced that human activities were a major factor in global warming. That is no longer the case. The gradual acceptance of this proposition has pushed forward the agenda of controlling GHG emissions. However, this situation falls into the category of being a political problem of the commons: No one country is the cause, nor can any country's response be a full solution. The more countries act, the better for everyone, so some nations see their ideal response as being to let everyone else work toward the solution, sharing in the benefits without experiencing any costs. This is the mind-set that the Earth Summit and the UNFCCC had to overcome.

With more than 190 nations as parties, the UNFCCC has overcome the problem of nonparticipation, at least on paper. By this measure, it is one of the most successful venues of international cooperation, with virtually every country in the world as a member. The division of the membership into different categories, with differing responsibilities, has made possible progress toward the goal of reducing global warming. The UNFCCC institutes a system that philosophically resembles a progressive tax system, in which the nations with the greatest economic resources are asked to make the greatest contributions toward reducing GHG emissions.

This division between industrialized and developing nations enables developing nations to continue developing, whereas requiring equal concessions from all nations would reinforce the status quo of economic relations, ensuring that the poor nations would remain poor. This provision has proven crucial to obtaining widespread cooperation. On the other hand, the UNFCCC gives economically developed countries the incentive to develop and use new technologies, which some believe will allow them to continue their economic dominance. Thus, while climate change is a physical change, how it is dealt with has many political and economic consequences.

Donald A. Watt

• Further Reading

Jackson, T. *Mitigating Climate Change: Flexibility Mechanisms.* Amsterdam: Elsevier Science, 2002. Collection of papers explicating UNFCCC influence on the development and implementation of plans for reducing climate change.

Mintzer, Irving M., and Michael J. Chadwick. *Negotiating Climate Change: The Inside Story of the Rio Convention.* New York: Cambridge University Press, 1994. Describes the negotiations leading up to the Earth Summit—a landmark in environmental cooperation—as well as the adoption of the UNFCCC.

Luterbacher, Urs, and Detlef F. Sprinz, eds. *International Relations and Global Climate Change.* Cambridge, Mass.: MIT Press, 2001. Considers both state and nonstate entities; discusses the substantial obstacles to successfully and equitably implementing the UNFCCC and Kyoto Protocol.

See also: Greenhouse gases; Intergovernmental Panel on Climate Change; International agreements and cooperation; Kyoto Protocol; United Nations Conference on Environment and Development; United Nations Conference on the Human Environment; United Nations Division for Sustainable Development; United Nations Environment Programme.

United States

- **Category:** Nations and peoples
- **Key facts**

Population: 307,212,123 (July, 2009, estimate)
Area: 9,552,058 square kilometers
Gross domestic product (GDP): $14.29 trillion (purchasing power parity, 2008 estimate)
Greenhouse gas (GHG) emissions in millions of metric tons of carbon dioxide equivalent (CO_2e): 6,135 in 1990; 6,928 in 2000; 7,017 in 2006
Kyoto Protocol status: Not ratified

• Historical and Geopolitical Context

The United States is bordered by Canada on the north, Mexico on the south, the Atlantic Ocean on the east, and the Pacific Ocean to the the west. It includes the island state of Hawaii, and the state of Alaska is located northwest of Canada. Despite its relatively self-contained and geographically isolated situation, the country has eschewed isolationism and assumed a leadership role in the free world. The United States is a relatively young nation but a rich one, though the U.S. national debt may climb to between $10 and $15 trillion. On January 20, 2009, the forty-fourth president of the United States, Barack Obama, was inaugurated in Washington, D.C., the nation's capital. Upon seeing the first man of color sworn into the office, Americans and people across the globe anticipated changes in U.S. policy that might help alleviate the world's problems, such as starvation and disease in developing countries, as well as climate change.

The Obama administration faced wars in Iraq and Afghanistan, a slumping economy, and an unsustainable dependence on foreign oil. Many compare the plight of President Obama to that of President Franklin D. Roosevelt, elected in 1932 during the Great Depression. The U.S. economy began to recover from that depression when the United States entered World War II in 1941. The war ended when the atomic bomb was used in Nagasaki and Hiroshima, Japan. With the end of the Cold War and collapse of the Soviet Union in 1991, the United States became the world's sole superpower.

U.S. GHG Emissions by Sector, 2004

Sector	*GHG Emissions (%)*
Industry	30
Transportation	28
Commercial	17
Residential	17
Agriculture	8
Total	100

Data from the U.S. Environmental Protection Agency.

• Impact of American Policies on Climate Change

From 2000 to 2007, U.S. greenhouse gas (GHG) emissions increased by 3 percent, air pollution (fine particles) decreased by 12 percent, and renewable energy increased as a share of total energy consumption from 5.4 to 6.7 percent. The first large and highly successful "cap-and-trade" program in the United States followed the Clean Air Act Amendments of 1990, which mandated a 50 percent decrease over ten years in sulfur dioxide (SO_2) emissions produced by the coal and petroleum industries. This led to anticipated savings in health care costs. In 2007, the 110th U.S. Congress passed the Energy and Security Act of 2007, which aimed to increase production of clean, renewable fuels and the energy performance of the federal government.

Individual states, academic institutions, and business enterprises have begun enacting their own initiatives to address global warming: In 2008, California governor Arnold Schwarzenegger signed a state law to integrate GHG emissions reduction into California's transportation planning decisions. President Obama asked federal regulators to act on applications by California and ten other states to set stricter fuel efficiency standards for vehicles. Nine governors signed on to the Midwestern GHG Reduction Accord in 2007, and New York City won an international award for sustainable transport.

In January, 2009, outgoing president George W. Bush designated 505,770 square kilometers of Pacific Ocean reefs, islands, surface waters, and sea floor as marine national monuments, thereby restricting fishing, oil exploration, and mining in those areas. Also in 2009, the U.S. Senate advanced legislation to preserve over 809,000 hectares of land in nine states as wilderness. On the downside, a sludge spill in Tennessee of almost 1 million kilograms of toxic materials brought into question the notion of clean coal. The outgoing Bush administration announced a plan to make 3.64 million hectares in Utah available for energy exploration.

• The United States as a GHG Emitter

According to Reuters, China may have replaced the United States as the top GHG emitter in the world in 2007; China has reported that its GHG emissions have caught up with those of the United States and that China's dependence on coal would make curbing GHG emissions difficult. Of note, total U.S. GHG emissions in 2007 were 1.4 percent above the 2006 total. This increase was largely the result of an increase in CO_2 emissions attributable to poor weather conditions, which led to greater demand for heating or cooling in buildings, and to a decrease in accessible hydropower resulting in a greater demand for fossil fuels such as coal and natural gas.

The Kyoto Protocol established carbon quotas for member countries, which may use carbon sinks (reservoirs of foliage or forests) as a form of "carbon offset." This ability may be useful to countries with large areas of forest or vegetation. However, for industrial, developed nations such as the United States, land use would have little effect in meeting Kyoto Protocol quotas, since most of the lands have already been cultivated. In addition, developing countries such as Brazil and Indonesia are not compelled to restrict their GHG emissions, which may come from land-use choices such as cultivating crops and destroying forests. As a result, the United States has refused to ratify the Kyoto Protocol.

While the Gulf states who are members of the Organization of Petroleum Exporting Countries (OPEC) have the highest GHG emissions, data from 2000 shows that—of the top twenty emitters—those with highest per capita emissions were the industrialized, or Annex I, countries. Australia, the United States, and Canada ranked fifth, seventh, and ninth, respectively. Their per capita emissions (7.0, 6.6, and 6.1 metric tons per person) were approximately double the emissions of the highest-ranked developing country in the top twenty (South Korea, at 3.0 metric tons), and they were six times those of China (1.1 metric tons). The reasons the United States has such high per capita GHG emissions include its dependence on fossil fuels to transport people and goods over large distances and its relatively low population density, fifty persons per square kilometer as of 2006.

• Summary and Foresight

The European Union has pledged to cut GHG emissions 20-30 percent by 2020, below 1990 levels, if other large GHG emitters such as the United States would follow suit. Sir Nicholas Stern, an adviser to the British government, has testified before the U.S. Congress: Stern had authored a report asking the global community to either take "urgent action" on global warming or face severe economic consequences that would "rival the Depression of 1929." The Americans responded that Stern's study was "50 years ahead of its time." Sir Stern may have been prophetic; the economic downturn of 2008 and following has focused on the plight of the U.S. automobile industry with its high-GHG-emitting vehicles, which appear to be losing out to their more energy-efficient foreign counterparts.

The Obama administration has linked the rescue and restructuring of the U.S. auto industry to a redesign of its products to be more fuel efficient and has

U.S. GHG Emissions, 1990-2007

	Emissions in Millions of Metric Tons of CO_2 Equivalent					
Gas	*1990*	*1995*	*2000*	*2005*	*2006*	*2007*
Carbon dioxide	5,076.7	5,407.9	5,955.2	6,090.8	6,014.9	6,103.4
Methane	616.6	615.8	591.1	561.7	582.0	585.3
Nitrous oxide	315.0	334.1	329.2	315.9	312.1	311.9
HFCs	36.9	61.8	100.1	116.1	119.1	125.5
PFCs	20.8	15.6	13.5	6.2	6.0	7.5
Sulfur hexafluoride	32.8	28.1	19.2	17.9	17.0	16.5
Total	6,098.8	6,463.3	7,008.3	7,108.6	7,051.1	7,150.1
Net total*	5,257.3	5,612.3	6,290.7	5,985.9	6,000.6	6,087.5

Data from U.S. Environmental Protection Agency.
*Total emissions, less reductions by sinks.

asked the Department of Transportation to enforce a 2007 law that would increase fuel efficiency standards that would affect vehicles sold in 2011. During the Great Depression, President Roosevelt blamed the bankers and drafted the New Deal, which focused on the U.S. farmer. Today, many believe the United States needs a "Green New Deal," which would turn environmentally friendly products and techniques into the nation's major growth sector, driving recovery. Indeed, fostering green energy may be key to rebuilding the U.S. economy.

Cynthia F. Racer

- **Further Reading**

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry et al. New York: Cambridge University Press, 2007. Summary by the United Nations' central climate change body of ways in which global warming has affected the planet.

Victor, D. G., J. C. House, and S. Joy. "A Madisonian Approach to Climate Change." *Science* 309, no. 5742 (2005): 1820-1821. Compares James Madison's vision with "global federalism."

Weitzman, M. L. "A Review of the *Stern Review* on the Economics of Climate Change." *Journal of Economic Literature* 45, no. 3 (2007): 703-724. Recognizes the ethical foundations of cost-benefit economics.

See also: Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. and European politics; U.S. energy policy.

Urban heat island

- **Category:** Economics, industries, and products

- **Definition**

An urban heat island is a metropolitan area that is significantly warmer in surface and air temperature than its suburban and rural surroundings. English amateur meteorologist Luke Howard, in his book *The Climate of London* (1818), described temperature differences between London and its surrounding countryside. He noted that it was warmer at night in London than in the country and speculated that the cause might be the burning of fuels. Research over the subsequent two centuries has charted a variety of differences between cities and their surroundings, as distinctive urban landscapes, domestic and industrial structures, and the behavior of urban dwellers affect the ways in which solar and other heat enters and exits the area. Urbanization causes changes to the preexisting natural landscape, as original materials (soil, vegetation, rock, water, and so on) are gradually replaced or modified with materials (concrete, tile, and many others) that, in conjunction with the activities and life patterns of a city's inhabitants, result in greater heat retention. This heat retention can in turn affect weather patterns.

- **Significance for Climate Change**

Scientists have identified many interconnected causes for the urban heat island effect. During the day, the Sun warms buildings and roadways. Pollution from automotive traffic and industrial processes contributes to the formation of clouds and smog, which help trap heat, and tall buildings limit the ability of winds to disperse such formations (the "canyon effect"). The predominance of land structures and the paucity of bodies of water lessen the influence of evaporation, which would use some of the heat energy for the formation of water vapor. Instead, that energy raises the ambient temperature. The concentration of human bodies in cities also contributes to their heat level. The increase in city heat in turn encourages activities, such as the use of air conditioning, that further contribute to localized heat increases, since air conditioners make interiors cooler by making the exterior city warmer. Moreover, increased power plant emissions resulting from the additional consumption of electricity will contribute to global warming.

To the extent that urban areas encourage structures or behaviors that stimulate additional activities, increasing emission of greenhouse gases (GHGs), urban heat islands may be viewed as contributing indirectly to global warming. (If cities are hotter than rural areas, then those who move to cities will be more likely to use energy to cool themselves than they otherwise would be.) As large metropolitan areas fuse into megalopolises, or megacities, the problems only become exacerbated. Accordingly, students of the urban heat island effect have seen the need for various degrees of urban redesign as a key element in attempts to mitigate the noxious consequences of the effect. Chief among these is increase in, and optimal distribution of, urban vegetation and green space, including the planting and sustaining of suitable trees.

The urban heat island effect must be taken into account in any attempt to read the historical record of Earth's temperature. To compare today's temperature with that of a century ago requires comparability, and that can be affected by urban growth. Places where temperatures were measured in the past often have since experienced significant urban growth, with the associated increased temperature measurements. This growth makes direct comparisons of present and past measurements difficult. In light of this problem, climatologists must adjust the data on the basis of their best guess about distorting factors.

Rebecca S. Carrasco

• Further Reading

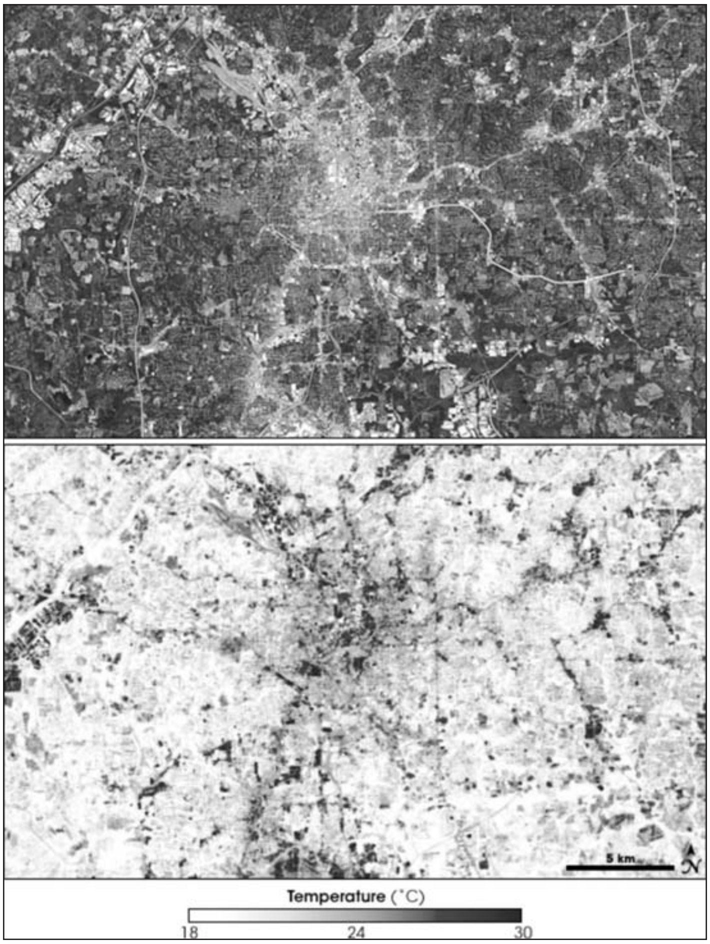
Gartland, Lisa. *Heat Islands: Understanding and Mitigating Heat in Urban Areas.* Basingstoke, Hampshire, England: Earthscan/James and James, 2008. Focuses on the urban heat island problem with regard to construction practices, lack of vegetation and shade, and roofing and paving materials; offers some smart solutions for communities.

Lee, Derek O. "Urban Climates." *Progress in Physical Geography* 8, no. 1 (1984): 1-31. Focuses on research in three areas: radiation and energy balance, the influence of the warm, rough city surface on mesoscale airflow, and the urban effect on precipitation over or downwind of the city.

McKendry, Ian G. "Progress Reports: Applied Climatology." *Progress in Physical Geography* 27, no. 4 (2003): 597-606. Reviews research on the observational/process-based studies of the urban heat island; flex measurements or exchanges of radiation, heat, moisture, and momentum within the urban context; and numerical mesocale modeling studies.

Maslin, Mark. *Global Warming: A Very Short Introduction.* New York: Oxford University Press, 2004. A survey of global warming issues, including urban heat islands.

Parker, David E. "A Demonstration That Large-



Satellite images of Atlanta, Georgia, in the visible and infrared spectra demonstrate the urban heat island effect of the city. (NASA)

Scale Warming Is Not Urban." *Journal of Climate* 19 (2005): 2882-2895. Discusses the lack of relationship between urban heat islands and global warming.

Peterson, Thomas C. "Assessment of Urban Versus Rural In Situ Surface Temperatures in the Contiguous United States: No Difference Found." *Journal of Climate* 16, no. 18 (2003): 2941-2959. Argues data from urban heat islands must be removed from in situ temperature observations in order to ensure comparability of data.

Souch, Catherine, and Sue Grimmond. "Applied Climatology: Urban Climates." *Progress in Physical Geography* 30, no. 2 (2006): 270-279. Reviews the research on spatial patterns of urban climate elements, energetics and dynamics of urban climates, and modeling of urban climates and their effects.

Spencer, Roy W. *Climate Confusion: How Global Warming Hysteria Leads to Bad Science, Pandering Politicians, and Misguided Policies That Hurt the Poor.* New York: Encounter Books, 2008. Spencer, a skeptic about certain aspects of the global warming debate and also an expert of satellite measurement of surface temperatures, includes a useful discussion of the urban heat island effect.

Sturman, Andrew P. "Applied Climatology." *Progress in Physical Geography* 22, no. 4 (1998): 558-565. Focuses on research with regard to urban climate processes, mitigation of urban climate effects, and implications for urban design.

See also: Air pollution and pollutants: anthropogenic; Air pollution history; Cities for Climate Protection; Human migration; Megacities; Population growth.

U.S. and European politics

• **Category:** Nations and peoples

The United States accounts for about 25 percent of the world's GHG emissions, while the countries of Europe account for about 14 percent. The technological capabilities and innovative potential of these nations create an opportunity for major reductions in GHG emissions, but such reductions would almost certainly need to be mandated by the American and European governments, subjecting them to the vagaries of democratic political practices.

• Key concepts

European Union: a supra-governmental organization to which many European countries belong and that has been given many powers traditionally associated with national governments

green politics: a political orientation founded upon environmental concerns

greenhouse gases (GHGs): gases, such as carbon dioxide, that tend to keep heat in the atmosphere rather than allowing it to dissipate into space

parliamentary system: the system in most European countries, where the chief executive of the government (the prime minister) is elected by the members of the legislative body

presidential system: the system in the United States, where the chief executive of the government (the president) is elected by the people

• Background

Politics is a social choice mechanism established to create an orderly society. Democratic theory assumes that people will vote for candidates who will best serve the interests of the people. Most European countries and the United States are well established democracies in which the choice mechanisms of politics and economics freely interact. Environmental concerns, including climate change, are a part of both the political and economic arena. In Europe the environment tends to be seen as social/political, while in the United States it is economic.

• European Politics and Policy

Most European countries use some form of the parliamentary system. In a parliamentary system the majority party can usually pass its desired laws and implement its desired policies because the same person leads the legislative and executive branches. When the citizens of a country push for policies to limit climate change, it happens much more quickly. Having had a relatively high population density for centuries, the human effect on the environment seems to be more easily understood by Europeans. When evidence that human activity caused climate change became clear, Europeans generally responded to it much more quickly than Americans.

At the end of his first week in office, President Barack Obama signs an executive order dealing with climate change and energy independence. Behind him are Environmental Protection Agency administrator Lisa Jackson and Transportation Secretary Ray LaHood. (Chuck Kennedy/MCT/Landov)

As a whole, the fifteen members (in 1997 when the Kyoto Protocol was signed) of the European Union are expected to reduce their GHG emissions by eight percent from 1990 levels. The European Union allocated this among its members, as it understood that not all countries could reduce their emissions the same amount. The two most industrialized countries in Europe, Germany and the United Kingdom, create about fifty percent of the GHG emissions. However, they volunteered to accept more than their share of GHG emission reductions to lead the community. Throughout Europe, whether conservative or liberal parties govern, they accept much tougher antipollution standards than does the United States. The United Kingdom had already met its 2012 goals prior to 2008, as was the case for Finland, France, and Sweden. The only two European Union countries that might not reach their 2012 goals are Spain and Portugal. The European Parliament passed the necessary legislation to set up an emissions trading network to add market pressures for GHG emission reductions. Overall, Europe has come to the understanding that the rights of the community outweigh the rights of individuals when it comes to GHG emissions and climate change.

- **United States Politics and Policy**

In the United States, the dominant economic view is that the individual has most of the rights in determining how to make use of the environment. This does not mean that there are no regulations, but when in doubt, the individual's rights are generally seen as stronger than the community's. This is the case with pollution controls and GHG emissions. While leading European countries were reducing their GHG emissions, the United States' emissions increased by sixteen percent from 1990 to 2004. Some states, such as California, have enacted laws to try to contain pollution; others continue with few regulations. Texas has more GHG emissions than any European country except Germany. The basic stance of many politicians is that the free market economy can take care of any problem, including GHG emissions. If consumers do not want products made by polluting factories, they will buy other products. When it becomes more economical to use nonpolluting technologies, then businesses will use nonpolluting technology. This does not lead to a strong anti-GHG emission policy.

A second problem in creating change in the United States is the fact that the American political system has more checks and balances than do most European systems of government. Thus the separate executive and legislative branches are often in conflict, even when controlled by the same political party. No major piece of environmental legislation was passed during the presidencies of Bill Clinton or George W. Bush. The year the Kyoto Protocol was negotiated, the U.S. Senate passed a resolution stating it would not ratify it. President Clinton signed it and said the United States would strive to reach its goals under the agreement; however, President Bush rescinded this effort. In 2003, the Senate for first time actually allowed GHG limit legislation to reach the floor for a vote. In 2005, Congress passed a resolution calling for GHG limits consistent with a free market economy.

- **Context**

While the collective effect of actions by individuals can make a significant difference in global warming, national policies can make changes much more rapidly. With scientific predictions of increased global warming affecting all forms of life, a rapid response to the situation is needed. If the major nations of the world take the initiative to combat global warming, the possibility to avert catastrophic consequences increases greatly. However, democracies only respond to the will of the people. When political parties believe that support of policies combating climate change will help them win elections, these policies become incorporated into a party's platform. It has been several decades since all political parties have accepted the need to unsure clean water for the citizens and proper sewage treatment. More recently, lower atmospheric air quality became a common concern and laws were passed regarding many types of air pollution. With the developing concern regarding GHG pollution, stronger citizen expressions of that concern are being made. As these expressions become more widespread, it is logical to assume that most political parties will incorporate GHG reduction into their stated goals. When this happens, decisions on global warming policy will no longer be seen as a political action. Combating climate change will be seen as a nonpartisan action, like unsuring a safe water supply, which is a proper area of governmental involvement.

Donald A. Watt

- **Further Reading**

Compston, Hugh, and Ian Bailey, eds. *Turning Down the Heat: The Politics and Climate Policy in Affluent Democracies.* New York: Palgrave Macmillan, 2009. Collection of writings on all the major Western European countries, the United States, Canada, and Australia. Outlines the political dimensions of climate policy in each country.

Gerrard, Michael B., ed. *Global Change and U.S. Law.* Chicago: American Bar Association, 2007. Compilation of analyses of U.S. state and federal environmental laws and the incorporation by those laws of international agreements and environmental policy.

Jaggard, Lyn. *Climate Change Politics in Europe: Germany and the International Relations of the Environment.* New York: Tauris Academic Studies, 2007. Environmental politics has been more successful in Germany than in most countries. This book examines the role this success has played in Germany's international relations.

Klyza, Christopher McGregory, and David Sousa. *American Environmental Policy, 1990-2006: Beyond Gridlock.* Cambridge, Mass.: MIT Press, 2008. Portrays the 1990's and early twenty-first century as bogged down by legislative inertia. Examines the advancement of green policies despite that inertia.

See also: Europe and the European Union; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; United States; U.S. energy policy; U.S. legislation.

U.S. Climate Action Report, 2002

- **Category:** Laws, treaties, and protocols
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With the U.S. Climate Action Report, 2002*, the Bush administration acknowledged for the first time that global warming has anthropogenic causes and that if warming remains unchecked it will seriously harm the environment of the United States.*

- **Background**

The United Nations Framework Convention on Climate Change (UNFCCC) was signed by President George H. W. Bush in June, 1992. Under the terms of the convention and of later agreements of the UNFCCC Conference of the Parties (COP), signatory nations were to report their progress toward reducing global warming. The United States submitted its first two climate action reports in 1994 and 1997 under President Bill Clinton and its third and fourth reports in 2002 and 2007 under President George W. Bush.

From the time Bush took office, his administration denied the scientific validity of the theories that human action was causing global warming and that global warming posed a serious threat. Instead, the administration's official position was that there was no scientific consensus on the subject and that more research was needed to determine whether or not global warming should be taken seriously. Although in 2000 the *National Assessment of the Potential Consequences of Climate Variability and Change,* a report commissioned by the U.S. Congress, had warned of serious consequences if global warming was not addressed, the Bush administration rejected these findings.

• Summary of Provisions

The findings of the *U.S. Climate Action Report, 2002,* which was prepared by the Environmental Protection Agency (EPA), are strikingly similar to those of the 2000 *National Assessment.* The report states that the Earth's air and ocean temperatures are increasing, primarily as a result of the accumulation of anthropogenic greenhouse gas (GHG) emissions, although natural fluctuations in temperature are also mentioned. If GHG emissions continue to increase and temperatures continue to rise, the report says, serious damage will occur.

If global warming continues, according to the report, some of the Barrier Islands of the Atlantic Coast and alpine meadows in the Rocky Mountains will likely disappear. Forests in the Southeast and the habitats of several migratory species will be disrupted, heat waves will become more severe and more common, and roads and other elements of infrastructure will suffer damage because of rising water levels or melting permafrost.

The report also describes potential environmental and economic benefits of global warming. Warmer temperatures will lead to longer growing seasons in parts of the country, increasing agricultural output and forest growth. In addition, the report states, increased rainfall will aid crops, as will higher concentrations of carbon dioxide (CO_2) in the atmosphere.

The report emphasizes the idea that no matter what is done in the future to slow GHG emissions, there is no way to stop the damage from the GHGs that are already in the atmosphere. Because environmental harm is irreversible, the report calls only for voluntary measures to reduce GHG emissions, but it encourages businesses and policy makers to begin to adapt to the inevitable changes. It notes that while total U.S. GHG emissions have continued to increase, the amount of emissions per capita—which the report refers to as "greenhouse gas intensity"—decreased between 1990 and 2002.

• Significance for Climate Change

While the *U.S. Climate Action Report, 2002* acknowledged the role that the burning of fossil fuels plays in causing global warming, it did not recommend any major changes in government policy to reduce GHG emissions. Rather, it called on the United States to make broad changes to accommodate or accept inevitable environmental destruction.

The report was sent quietly to the United Nations Secretariat without a press conference or press release from the White House. It nevertheless attracted a great deal of media attention. It put the Bush administration at odds with business and industry interests with which it was usually allied. Those interests disagreed with the position that theories about global warming were based in science. Environmental groups, meanwhile, complained that the report did not call for any substantive action. The administration itself acknowledged that the report was of little significance, as it represented no change in American policy or in American interpretation of international treaties.

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• Further Reading

"Bush's Global Warming Flip-Flop." *The New American* 18, no. 13 (July 1, 2002): 6. Discusses the immediate reaction to the *U.S. Climate Action Report, 2002* by supporters of President Bush, who considered the report a betrayal of conservative principles.

Hertsgaard, Mark. "The Truth on Warming." *The Nation* 275, no. 2 (July 8, 2002): 6-7. Agrees with the findings of the climate action report that it may be too late to counter the effects of GHGs already in the atmosphere; describes the report's reception.

Mooney, Chris. *The Republican War on Science*. New York: Basic Books, 2006. Documents efforts by the George W. Bush administration to influence governmental reports about controversial scientific issues, including the administration's editing of the climate action report.

Schreurs, Miranda A. "The Climate Change Divide: The European Union, the United States, and the Future of the Kyoto Protocol." In *Green Giants? Environmental Policies of the United States and the European Union*, edited by Norman J. Vig and Michael G. Faure. Cambridge, Mass.: MIT Press, 2004. Explores the ways that the European Union and the United States have taken opposing approaches to addressing climate change and notes that the European Union ratified the Kyoto Protocol while the United States countered with the *U.S. Climate Action Report, 2002*.

See also: Carbon dioxide; Carbon dioxide fertilization; Greenhouse gases; United Nations Framework Convention on Climate Change; U.S. energy policy.

U.S. energy policy

• **Categories:** Nations and peoples; laws, treaties, and protocols

The energy policy of the United States is set by the president and guides both the recommendations of the executive to Congress and the instructions issued by the executive to the cabinet. Twenty-first century energy policy has dealt largely with the question of the best ways to transition from an economy dependent on foreign and polluting sources of energy to an economy that produces its own, cleaner energy.

• Key concepts

alternative energy: fuels and other energy resources that are renewable, nonpolluting, or both and have the potential to replace fossil fuels and other traditional energy resources

energy independence: the ability of a nation to generate energy sufficient for its needs domestically, without relying on foreign imports

fossil fuels: energy resources formed from decayed organic matter under geological pressures over millions of years

greenhouse gases (GHGs): atmospheric trace gases that trap heat, preventing it from escaping into space

policy: the broad set of principles guiding governmental actions and legislation in a specific arena, such as energy or foreign affairs

• Background

U.S. energy policy addresses issues of energy production, consumption, and economic and environmental impact. The direction of the policy is established by the president, but it is also defined by legislation, acts, treaties, tax codes, subsidies, and other government actions. The earliest policies of the late eighteenth century dealt with timber for heating and industry and were directly tied to land management at the federal level. In the nineteenth century, natural gas, coal, and oil dominated energy concerns. Around 1950, oil overtook coal as the most consumed energy source and continued to gain in importance, especially when highways made the automobile the preferred mode of transportation. In the second half of the twentieth century, nuclear power was added to the nation's energy concerns.

• Natural Gas

In the nineteenth century, natural gas was widely used as lighting fuel until the advent of electricity in the 1890's. Later on, the development of steel pipelines allowed for large quantities of natural gas to be safely transported over great distances, resulting in the modern natural gas industry. The first natural gas pipeline, which was more than 320 kilometers in length, was built in 1925, connecting Louisiana to Texas. Thereafter, U.S. demand for natural gas increased with rapidity, especially at the conclusion of World War II. Between 1906 and 1970, residential demand for natural gas grew fifty-fold. The United States was self-sufficient in natural gas until the late 1980's, when consumption began to significantly outpace production and the need for imports increased.

The U.S. economic slump of 2009 contributed to a decrease in domestic natural gas consumption, especially in the industrial sector, resulting in lower prices. In June, 2009, estimations of U.S. reserves of natural gas were revised upward by 35 percent, to 58.736 trillion cubic meters in 2008. The Energy Information Administration (EIA) estimates that U.S. domestic consumption and production of natural gas will increase as a result of greater demand for electricity; net imports are projected to decrease from 16 percent in 2007 to less than 3 percent in 2030 because of the increasing use of onshore resources in Alaska and offshore reserves in the Gulf of Mexico.

• Coal

Prior to 1800, the amount of coal consumed in the United States was an estimated 98,000 metric tons, much of it imported. The demand for coal expanded slowly, and it was not until 1885 that the United States burned more coal than wood. However, the advent of the Industrial Revolution—and the expansion of the railroad system in the mid-1800's—initiated a period of increasing production and use of coal that continued. In 2007, U.S. production of coal reached a record 1.06 billion metric tons (1.16 billion tons), second only to China.

Producing 27 percent of the global coal supply, the United States has the world's largest reserves of coal, totaling 444 billion metric tons at the beginning of 2008. Plentiful and inexpensive, coal generates 50 percent of the electricity in the United States. Because the cost of constructing and operating coal-fired plants is rising as a result of clean air standards, current U.S. policy on coal focuses on research and development of clean, efficient, and price-competitive technology both for domestic use and for export. In the long term, coal-generated electricity is predicted to decrease by 4 percent from 2007 to 2025 but increase once more as new plants are constructed in 2030.

• Oil

The modern petroleum age began in Pennsylvania, in 1859, when "Colonel" Edwin L. Drake's homemade drilling rig struck oil. The rapid acceptance and use of the internal combustion engine in the late 1800's increased demand for oil in the United States and globally. Up until the 1950's, the United States was self-sufficient in petroleum with 22,268 billion barrels (bl) of proven reserves. U.S. oil reserves peaked at 35,300 billion bl in 1973; in 1994, the United States imported more petroleum than it produced for the first time.

In 2008, total petroleum consumption in the United States decreased by 1.2 million barrels per day (bl/d), the steepest drop since 1980. This drop paralleled a decrease in the price of crude oil, which fell steeply. As a result, the Organization of Petroleum Exporting Countries (OPEC) agreed to production cutbacks. With demand for liquid fuel expected to rise by just one million bl/d from 2007 to 2030, in addition to the greater use of domestic biofuels, as well as increasing domestic oil production, the net import of total liquid fuels is predicted to decrease by 40 percent by 2025.

• U.S. Energy Policy in the Twentieth Century

At the beginning of the twentieth century, conservationist Theodore Roosevelt, the twenty-sixth president of the United States (1901-1909) preserved U.S. national forests and parks, as well as oil, mineral, and coal lands. His cousin, Franklin Delano Roosevelt (FDR), was elected in 1932, during the Great Depression. In 1941, during FDR's presidency, the United States joined forces with the Soviet Union and Great Britain and entered World War II. Franklin Delano Roosevelt's successor, Harry S. Truman, ordered the atomic bombing of Hiroshima and Nagasaki in Japan, thus ending the Pacific campaign and World War II. However, the use of nuclear weapons resulted in one of the worst human-made environmental disasters and long-term radioactive contamination. Twenty years later, John F. Kennedy, the thirty-fifth president of the United States (1961-1963), facilitated the limited Nuclear Test-Ban Treaty, and in September, 1996, the United Nations adopted the Comprehensive Nuclear Test-Ban Treaty. Kennedy was succeeded by Lyndon B. Johnson, who was lauded for his civil rights programs but criticized for escalating the Vietnam War and using the environmentally harmful herbicide Agent Orange in Vietnam.

In the early 1950's, both the United States and Western Europe had become net importers of Middle Eastern crude oil. It was thought that nuclear power would provide a less expensive alternative to oil. In 1959, President Dwight D. Eisenhower (1953-1961) attempted to dampen the country's reliance on foreign oil with the Oil Import Program, which limited imports of crude oil east of the Rocky Mountains. However, the American appetite for costly fossil fuels was unabated, culminating in the oil crisis of 1973. Richard M. Nixon, the thirty-seventh president (1969-1974), imposed mandatory price controls on twenty-three of the largest oil companies and later instituted a sixty-day country-wide price freeze. Following the Arab-Israeli war of October 6, 1973, OPEC raised the price of oil by 70 percent and embargoed oil shipments to the United States and other countries friendly to Israel. Gasoline prices dramatically increased in the United States thereby reducing demand for large, American-made, gas-guzzling automobiles and increasing the popularity of foreign and U.S. compact cars.

In 1979, the overthrow of the Shah of Iran by Islamic revolutionaries led to yet another Middle East crisis. Five hundred Iranian students seized the American embassy in Tehran, detaining fifty-two hostages for more than two years. President Jimmy Carter (1977-1981) halted oil imports from Iran and froze Iranian assets in the United States. Diplomatic efforts to rescue the detainees and an attempted U.S. military rescue mission failed. Even though President Carter brokered a peace treaty between Egypt and Israel, he lost the 1980 presidential election to Ronald Reagan. President Reagan facilitated the Intermediate Nuclear Forces (INF) treaty with the Soviet Union. However, in 1987 during the Iran-Iraq war (1980-1988), U.S. officials in the Reagan administration brokered a sale of arms to Iran in exchange for hostages, the so-called Iran-Contra scandal.

President Reagan's successor, George H. W. Bush, later engaged the United States in a war in the oil-rich Middle East involving Kuwait and its attacker, Iraq. Under his watch, the Clean Air Act of 1990 was passed. In 1997, the Kyoto Protocol was set forth by the United Nations to address climate change. Although Bill Clinton, the forty-first U.S. president (1993-2001), approved of the Kyoto Protocol, the United States did not ratify the treaty. President Clinton promoted globalism and increased U.S. trade via the North American Free Trade Agreement (NAFTA). In 2008, President Clinton's vice president, Al Gore, was awarded the Nobel Prize for his work on climate change.

• U.S. Energy Policy in the Twenty-first Century

George W. Bush, the son of President George H. W. Bush, was elected the forty-third U.S. president (2001-2009), and, once more, the United States focused on the Middle East following terrorist attacks on the United States by al-Qaeda on September 11, 2001. In retaliation, the first U.S. president of the twenty-first century invaded oil-rich Iraq on the premise of destroying its weapons of mass destruction, which were never recovered. At the end of the first decade of the twenty-first century, the United States was dealing with ending the war in Iraq, while confronting the U.S. dependence on fossil fuels and its environmental consequences. President Bush embraced federalism and advocated state's rights; he believed that individual states, cities, and industries could facilitate their own measures to combat global warming. His policy of laissez-faire translated into attenuation of federal regulation of industries regarding air and water pollution. Globally, the Bush administration chose not to ratify the Kyoto Protocol because it differentiated responsibilities between industrialized Annex I nations, such as the United States, and developing, non-Annex I nations, such as India and China.

During Bush's presidency, the United States became the largest purveyor of biofuels. His policies aimed at increasing the use of renewable energy included the Renewable Electricity Production Tax Credit, the Renewable Portfolio Standards (RPS), and the Renewable Energy Certificates/Credits (RECs). President Bush signed into law the Energy Policy Act of 2005, which encouraged energy conservation and efficiency through modernization of the energy infrastructure and through diversification of the U.S. energy supply, including nuclear energy development.

Two years later, the 110th U.S. Congress passed the Energy and Security Act of 2007 with the aim of increasing production of clean, renewable fuels and enhancing the "energy performance" of the federal government. In early 2009, President Bush designated 505,736 square kilomters of U.S. Pacific Ocean reefs, islands, surface waters, and seafloor as "marine national monuments," thereby restricting fishing, oil exploration, and mining in the region. On the other hand, the outgoing Bush administration supported a plan to make available 3.6 million hectares in Utah for energy exploration, such as prospecting for minerals. At the end of President Bush's term, the Environmental Protection Agency (EPA) began an "aggressive review" of mountaintop coal mining permits, while expressing concern about strip mining procedures that blast the tops off mountains, spewing rocks and waste into surface water in violation of the Clean Water Act of 1972.

President Barack Obama became the forty-fourth U.S. president in 2009, the first man of color to hold the office. President Obama came into office with promises to change U.S. energy policy in ways that would better address problems such as climate change. President Obama also entered the office confronting wars in Iraq and Afghanistan, a slumping economy, and an unsustainable dependence on oil imports. In February, 2009, Congress agreed to a $787 billion package of tax breaks and funding called the American Recovery and Reinvestment Act of 2009 (ARRA). President Obama's energy agenda allotted more than $20 billion for tax incentives for renewable energy providers and activities that encourage the use of renewable energy sources. About $1 billion would go to the National Aeronautics and Space Administration (NASA), and $1.6 billion to the Department of Energy for research and development in climate science.

President Obama called on Congress to put forth legislation that places a market-driven cap on carbon and increases the production of renewable energy. Of note, the Clean Air Act of 1990 preceded the first highly successful "cap and trade" program in the United States, which mandated a 50 percent decrease over ten years in sulfur dioxide emissions produced by the coal and petroleum industries. In addition, President Obama's $800 billion economic stimulus proposal included $50.8 billion for energy and water development, $20 billion of which was allocated for building a smart-grid power network and a high-tech infrastructure to draw upon renewable energy sources—such as wind turbines and solar panels—which could handle uneven energy production.

On February 24, 2009, a federal appeals court ordered the EPA to reconsider the standards regulated by the Clean Air Act it had adopted in 2006 for the pollutants and fine particles associated with heart and lung diseases. In 2006, EPA scientists had recommended that allowable levels for fine particles be adjusted downward, though action was not taken. In April, 2009, the EPA officially proposed that GHGs be considered a danger to public health and welfare in response to a Supreme Court decision in 2007 that found GHG emissions to be subject to federal Clean Air Act standards.

• Context

The famous English poet Sir Geoffrey Chaucer said that the "past is prologue," and nowhere is this more apparent than the U.S. government's energy policies of the twentieth and twenty-first centuries; over and again, three themes are repeated: first, the U.S. addiction to fossil fuels; second, the country's dependence on foreign countries (mainly in the Middle East) to fulfill its energy needs; and third, the inadequate response of the United States to address climate change. Though president George W. Bush acknowledged the need for renewable energy sources, he advocated state's rights and attenuated federal regulations on pollution.

Upon his election, President Obama called on Americans and U.S. policymakers to move forward with investments in clean, efficient renewable energy, and he submitted a federal budget that included $150 billion for creating "green" jobs, reducing dependence on foreign fossil fuels, and preventing the dire consequences of global warming. However, the pundits warn that while renewable energy is gaining momentum, it is not a panacea. For it to be truly effective, renewable energy has to have zero-carbon output such as that obtained by recycling heat. Eco-friendly and water-sparing renewable energy should not require an inordinate amount of energy for production, or it defeats its own purpose.

Will conversion to clean, efficient renewable energies happen in time to forestall the consequences of global warming? Sharon Begley of *Newsweek* magazine is pessimistic about the ability to reduce GHG emissions using current methods, "even if we scale up existing technologies to mind-bending levels . . . we'll still fall short of how much low-carbon energy will be needed to keep atmospheric levels of carbon dioxide below the 'point of no return' in order to prevent a climate crisis in 2050."

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• Further Reading

Chick, Martin. *Electricity and Energy Policy in Britain, France, and the United States Since 1945*. Northampton, Mass.: Edward Elgar, 2007. Compares U.S. energy policy to those of two other Western industrial democracies.

Clark, John G. *The Political Economy of World Energy: A Twentieth Century Perspective*. Chapel Hill: University of North Carolina Press, 1991. A thorough, global overview of the economics and politics around energy issues in the twentieth century. It covers coal, oil, gas, electricity, and nuclear power. Includes maps, references, and an index.

Gallagher, Kelly Sims, ed. *Acting in Time on Energy Policy*. Washington, D.C.: Brookings Institution Press, 2009. A collection of papers presented at a conference of the same name, hosted by the Energy Technology Innovation Policy research group at Harvard Kennedy School's Belfer Center for Science and International Affairs, under the auspices of the Consortium for Energy Policy Research at Harvard and in collaboration with the Harvard University Center for Environment.

Kelley, Ingrid. "Clean Energy Policy and the Government Role." In *Energy in America: A Tour of Our Fossil Fuel Culture and Beyond*. Hanover, N.H.: University Press of New England, 2008. Explores the ability of community energy planning to drive the transition to clean energy—and the role of governmental sustainable energy policy in fostering such planning.

Raupach, M. R., et al. "Global and Regional Drivers of Accelerating CO_2 Emissions." *Proceedings of the National Academy of the Sciences* 104, no. 24 (2007): 10,288-10,293. Details reasons for continuing increases in carbon emissions.

Sabin, Paul. *Crude Politics: The California Oil Market, 1900-1940*. Berkeley: University of California Press, 2005. Delves into the role of the West Coast oil industry in shaping U.S. energy policy in the early twentieth century.

See also: Byrd-Hagel Resolution; Clean Air Acts, U.S.; Emissions standards; Energy Policy Act of 1992; Environmental law; Industrial emission controls; International agreements and cooperation; Kyoto Protocol; United Nations Framework Convention on Climate Change; U.S. legislation.

U.S. legislation

• Category: Laws, treaties, and protocols

U.S. climate-related legislation has attempted to reverse or reduce some of the damage done to the environment, to minimize resource depletion, and to prevent or mitigate GHG emissions and other climate-related pollution.

• Key concepts

carbon dioxide: a colorless, odorless greenhouse gas that is emitted by burning fossil fuels

climate action plan: a plan that identifies cost-effective ways to reduce GHG emissions

climate change: changes in long-term trends in the average weather of a given region

emissions cap: a mandatory limit on the amount of GHG emissions that can be released into the atmosphere by a given nation, business, or other specific entity

greenhouse effect: the process whereby certain gases in a planet's atmosphere prevent heat from escaping into space

greenhouse gases (GHGs): gases that contribute to the greenhouse effect

• Background

Climate change is the result of a complex of changes in atmospheric and oceanic composition and dynamics, and it has been suspected that Earth's climate is warming. Many scientists believe that available data indicate that human activity—particularly increased emissions of greenhouse gases (GHGs)—is contributing to this warming. Global warming, in turn, is expected to affect supplies of food and water, air quality, energy resources, biodiversity, and human and nonhuman migration patterns. Over the past several decades, therefore, legislation has been proposed and passed in the United States in an attempt to ameliorate the effects of global warming.

• Air Pollution Control Act

The first federal legislation regarding air pollution was the 1955 Air Pollution Control Act. This law established funding requirements for federal research on air pollution but did nothing to control that pollution. It was not until the Clean Air Act of 1963 that an attempt was made to place controls on emissions of air pollutants, mostly through monitoring manufacturing techniques. On the international scene, the following year saw the establishment of a new international organization. Originally called the Group of 77 and China (because it consisted of seventy-seven developing countries and China), this group met periodically to discuss and negotiate policy related to climate-change issues.

• Clean Air Act and Its Amendments

The Clean Air Act of 1963 was amended in 1970. The Clean Air Act Amendments led to the development of regulatory programs including the National Ambient Air Quality Standards (NAAQS), state implementation plans, new source performance standards, and national emissions standards for hazardous air pollutants. At the same time that this legislation was adopted, the Environmental Protection Agency (EPA) was being developed through the National Environmental Policy Act of 1970. The EPA was officially launched in 1971. Between the Clean Air Act and its 1970 amendments, Congress enacted the Air Quality Act (1967), which enhanced procedures to monitor interstate air pollution transport and expanded studies of air pollution emissions and control techniques.

A series of additional amendments was passed as the Clean Air Act Amendments of 1977, which were concerned with maintenance issues regarding NAAQS. In 1990, the authority and responsibilities of the government to regulate air quality were increased through the Clean Air Act Amendments of 1990. New programs were created to control acid rain and emissions that compromised atmospheric ozone. The 1990 revisions increased research programs and the federal government's authority to enforce standards. The 1990 amendments also established permit program requirements.

• Foreign Operations Appropriations Act

The Foreign Operations Appropriations Act was signed into law in 2002, providing funding to support U.S. foreign policy objectives. It required the president to submit a report of expenditures on climate change activities and constituted a major amendment to the Clean Air Act of 1990. Also formulated in 1990 was the United States' first Na-

Enacted U.S. Legislation Relating Directly to Climate Change

Year	*Act*	*Effect*
1978	National Climate Program Act	Establishes a nationally coordinated program of climate monitoring and prediction
1990	Global Change Research Act	Funds research into global climate change
1997	Byrd-Hagel Resolution	Expresses the sense of the Senate that the United States should join only those climate change treaties that do not harm the domestic economy and that require developing nations, as well as developed nations, to take action against global warming
2005	Energy Policy Act of 2005	Supports voluntary reductions in carbon-intensive activities and the export to developing nations of technologies to reduce carbon intensity

Proposed U.S. Legislation Relating Directly to Climate Change

Congress	*Years in Session*	*Number of Bills Relating to Climate Change*
106th	1999-2000	27
107th	2001-2002	67
108th	2003-2004	92
109th	2005-2006	106
110th	2007-2008	235

Source: Pew Center on Global Climate Change.

tional Environmental Action Plan (NEAP). It was established both to manage existing environmental issues and to devise ways to anticipate and meet future challenges.

• U.S. Stance on International Agreements

The first significant international agreement related to climate change was the Montreal Protocol, which entered into force in 1989. Its goal was to eliminate the use of substances that deplete the ozone layer. In 1997, the Kyoto Protocol was adopted as an amendment to the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC recognized that climate resources are shared among nations and that the stability of Earth is dependent upon all countries' compliance with efforts to reduce emissions of GHGs. The UNFCCC outlined intergovernmental efforts necessary to provide financial and technological cooperation in adapting to the impacts of global warming.

The Kyoto Protocol required industrialized nations to limit GHG emissions and set 2008-2012 targets for each country relative to that country's 1990 emissions. The GHGs targeted for reduction were carbon dioxide (CO_2), methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). The protocol also created mechanisms that would allow the industrialized nations to fulfil their reduction targets in part by funding environmentally friendly projects in developing nations, in lieu of making actual reductions at home. Nations that reduced their emissions to below their target level could also sell excess emission credits to nations whose emissions exceeded their targets. U.S. president George W. Bush rejected the Kyoto Protocol in 2001, because he opposed mandatory emission-reduction requirements. However, in April of 2008 he articulated a goal to decrease GHG emissions by 2025.

• Twenty-First Century

The focus of legislation at the beginning of the twenty-first century—particularly in the wake of the terrorist attacks in the United States on September 11, 2001—was on ensuring national security, but legislation was also passed to fund commissions to study climate change. In the first decade of the new millennium, executive or legislative commissions examined the consequences of climate change. Efforts were made to implement mandatory reporting of GHG emissions and economy-wide GHG reductions and standards.

In Alaska, for example, a Climate Impact Assessment Commission addressed ways to reduce the impacts of climate change. Other states taking similar initiatives included Montana, Arizona, Oregon, Washington, California, and New Mexico. In 2005, the North Carolina Legislative Commission on Global Climate Change was created to study the issues related to global warming, and a similar commission was formed in Arkansas, called the Arkansas Governor's Commission on Global Warming. The Arizona Climate Action Initiative and an executive order in Kansas established advisory groups to recommend ways to reduce GHG emissions.

State climate action plans have been developed to reduce GHGs. The first was the Maine Climate Action Plan (2003), followed by the Connecticut Climate Action Plan (2004). In 2007, the Colorado Climate Action Plan and the Florida Energy and Climate Action Plan were established. Each plan identified cost-effective ways to reduce GHG emissions based on the characteristics of its particular state, including the state's political structure, economy, and resource base.

In addition, registries that aim to measure and report emissions have been established. In Wisconsin, the Voluntary Greenhouse Gas Registry (1999) required the Department of Natural Resources to establish and operate systems to register decreases in GHGs, and the Wisconsin Mandatory Greenhouse Gas Reporting legislation required the reporting of emissions and air containment. In 2000, the California Climate Action Registry was established. It created specific penalties for violations of emissions requirements. In 2007, the West Virginia Inventory and Reporting program was established to inventory emissions and reductions in GHGs, and the Climate Registry established a general reporting protocol.

Economy-wide GHG reductions have also been targeted. In Hawaii, the goal has been to reduce GHG emissions by 2020. A Minnesota bill (2007) involved conservation efforts, and a California bill (2006) required a state board to adopt regulations to report and enforce the rules, establishing economy-wide GHG reductions, with targets for the entire state.

Just as important as the need to establish commissions, boards, action plans, and registries is the need for standards to ensure that all electricity used in a state is produced within regulations. In 2006, California prohibited electric utility companies from establishing any agreements that did not comply with GHG requirements. That same year, a bill was passed to prohibit the recovery of certain costs of electricity services in Minnesota. In 2007, Washington State passed legislation to increase green jobs and reduce GHG emissions.

Standards for vehicles have also been established in California. A 2002 act related to air quality was passed, reducing GHG emissions in machines. Other states have adopted or begun the process of adopting these standards, including Arizona, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington. The states projected to adopt California's standards were planning to apply them to 2009 and later models of cars and light trucks to control emissions from tailpipes. A report released in 2004 (two years after California's law was passed) provided light vehicle regulations to consider for adoption. These standards were adopted in September of 2004.

The auto industry opposed these regulations, arguing that GHG emissions and fuel economy standards should be set only by the U.S. Department of Transportation. Interestingly, analysis of the impact of these regulations indicated only a small national effect on energy demand and fuel prices. Results depend on the number of states that adopt the program, as well as the response of consumers and manufacturers. The required improvements in car fuel economy are more stringent than those required for light trucks. Both New Jersey and Washington State passed legislation to establish standards related to vehicle emissions, and in 2008 Washington also passed an act to create a framework to reduce GHG emissions in the transportation sector.

In 2005, the Climate Stewardship Act and the New Apollo Energy Act were passed, focusing on achieving reductions in greenhouse gases. Requirements would be broader than in the past, applying to the electricity, transportation, industry, and commercial sectors. These federal acts were similar to those already enacted on a state level. In the same year, the Energy Policy Act established the first national energy plan in over a decade. It was intended to encourage energy efficiency and energy conservation through the promotion of efficiency in the home, as well as through the promotion of alternative and renewable energy sources for the federal government. It also sought to reduce U.S. dependence on foreign sources of energy while supporting continued research and offering tax credits for making home improvements (using residential solar energy systems). It also included tax credits to consumers for purchasing hybrid cars.

The Safe Climate Act of 2006 granted the EPA broad authority to establish regulations. It was followed by several proposed amendments to existing acts, including the Climate Security Bill of 2007, a global warming bill considered by the U.S. Senate to reduce greenhouse gases. Also known as the Lieberman-Warner bill (because it was introduced by Senators Joseph Lieberman, independent of Connecticut, and John Warner, Republican of Virginia), this bill was filibustered and effectively killed in June of 2008, with forty-eight senators voting to invoke cloture and end debate, thirty-six opposing that motion, and sixteen abstaining or absent. However, because six of the absent senators indicated that they would have supported the cloture motion, the 2008 vote represented the first time that a majority of the U.S. Senate seemed to support legislation mandating GHG reductions through a cap-and-trade system. In such a system, limits are placed on total permissible GHG emissions, and permits are issued to polluters to emit specific amounts of GHGs. These permits are tradable commodities, so the market functions to motivate emission reductions.

In 2007, President Bush signed the Energy Independence and Security Act, which was designed to improve vehicle fuel economy and increase incentives to create subsidies for alternative fuels. The act mandated energy efficiency of lightbulbs, changed the efficiency standards for appliances, and aimed to reduce total energy use in federal buildings by 30 percent.

Following the inauguration of President Barack Obama in 2009, passage of cap-and-trade legislation became a top priority of the new administration. In May of 2009, U.S. representatives Henry Waxman of California and Edward Markey of Massachusetts introduced a new cap-and-trade bill, the American Clean Energy and Security Act of 2009, known informally as the Waxman-Markey bill. The economic crisis of 2008-2009 rendered the bill controversial, however. Critics worried that the bill would increase the cost of producing energy and thereby increase the price of every manufactured and transported good. Supporters minimized the immediate impact of the bill on prices and emphasized the urgency of addressing global warming while it was still possible. The bill narrowly passed the House in June by a vote of 219 to 212, marking the first time either house of Congress had passed a cap-and-trade law.

• Context

Although U.S. legislation since the 1960's has attempted to decrease the negative effects of climate change, the causes of and solutions to climate change problems are not clear-cut. In fact, there is still controversy about the nature, extent, causes, and very existence of global warming. What is clear is that all countries must assess and understand the roles they need to play in decreasing the risk of serious consequences, including incorporating a collaborative international response and thinking globally.

Because the United States is among the top GHG emitters, and particularly because the United States plays a global leadership role, it is especially important that Americans lead the way both in developing policies that can address the negative impacts of climate change and in working collaboratively with world nations to implement action that meets the needs of many stakeholders. Doing nothing could have catastrophic effects on the environment, while taking action could harm the national economy. Legislation must balance these concerns.

Gina M. Robertiello

• Further Reading

Hua, Chen, et al. "Effects of Land-Cover Change on Terrestrial Carbon Dynamics in the Southern United States." *Journal of Environmental Quality* 35 (2006): 1533-1547. Analyzes the effects of cropland expansion and forest regrowth on carbon dynamics.

Litz, Franz T. *Toward a Constructive Dialogue on Federal and State Roles in U.S. Climate Change Policy*. Arlington, Va.: Pew Center on Global Climate Change, 2008. Compares federal and state action to address climate change.

Negra, C., et al. "Indicators of Carbon Storage in U.S. Ecosystems." *Journal of Environmental Quality* 37 (2008): 1376-1382. Focuses on accountability for carbon trading programs and the need for detailed information to understand their effects.

Rabe, Barry G. *Race to the Top: The Expanding Role of the U.S. State Renewable Portfolio Standards*. Arlington, Va.: Pew Center on Global Climate Change, 2006. Covers state renewable portfolio standards, including climate strategies in Massachusetts, Nevada, Pennsylvania, and Colorado.

Zeng, Ning, et al. "Sustainable Development: Climate Change—The Chinese Challenge." *Science* 319, no. 5864 (2008): 730-731. Review of ways to control carbon dioxide emissions without hindering economic development.

Zyla, Kathryn, and Josh Bushinsky. *Designing a Cap-and-Trade Program for the Midwest*. Arlington, Va.: Pew Center on Global Climate Change, 2008. Provides a general overview of what a cap and trade program does, as well as what entities and what emissions might be regulated.

See also: Air quality standards and measurement; Byrd-Hagel Resolution; Clean Air Acts, U.S.; Energy Policy Act of 1992; National Climate Program Act.

Venice

- **Category:** Geology and geography

Venice is susceptible to episodic flooding, owing to a concurrence of high tides, storm surges, and excessive rainfall. Therefore, Venice serves as an excellent indicator of long-term changes in sea level, such as those due to global warming.

• Key concepts

acqua alta: Italian for high water—flooding

Lidi: the chain of barrier islands protecting the Venetian lagoon

MOSE: abbreviation for *modulo sperimentale elettromeccanico*, a prototype sea gate; the name also alludes to Moses, punning on his ability to part the seas

storm surge: high water associated with a storm, especially that caused by wind action

subsidence: lowering of land surface owing, for instance, to compression by the weight of overlying land or depletion of an aquifer

Venetian lagoon: the body of water in which Venice, formerly an island, is situated

• Background

On November 4, 1966, Venice was inundated by a flood of 1.94 meters above mean high water. This remains the record for high water (*acqua alta*) in the city. The extent of the flood reflected the combination of high lunar tides, heavy rainfall, and fierce, persistent winds. The storm surge overwhelmed the Lidi, destroying sea walls. Meanwhile, flooding rivers poured freshwater into the brackish lagoon, causing ecological harm. Bases of historic buildings were immersed in lagoon water for two days, producing considerable damage.

• Sensitivity to Flooding

Venice is a particularly sensitive indicator of long-term changes in sea level, because several factors causing the lagoon water to rise, or the land level to sink, are poised against human interventions, such as dike building and diversion of rivers. Sources of flood waters are rivers that originally emptied into the lagoon, including the Piave and the Sile in the east and the Brenta and Bacchiglione in the west. All these rivers have been diverted away from the lagoon, but during episodes of heavy rainfall they manage to overflow into the lagoon anyway. Heavy rains over the ocean can also augment storm surges in raising sea level.

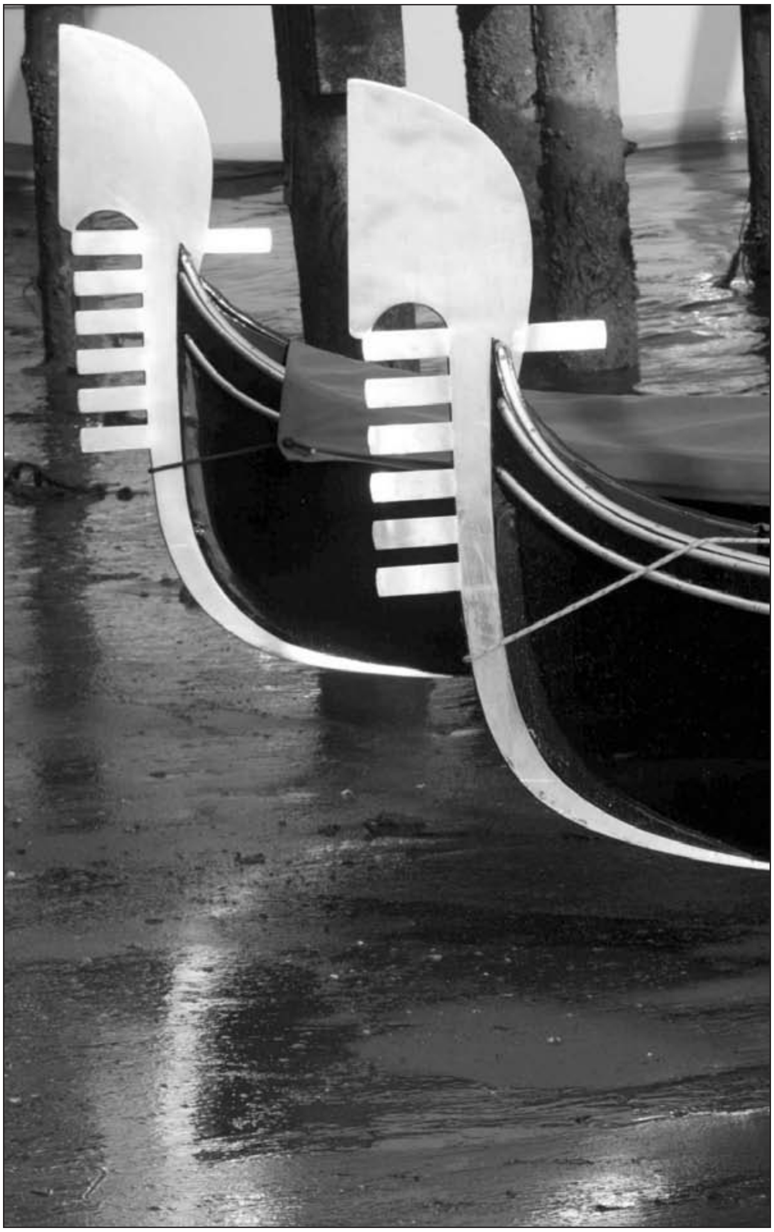
Venice itself, meanwhile, has been sinking in a process called subsidence. Subsidence can be natural, as when sediment is compressed by the weight of soil and water above it, or artificial, caused, for example, by removal of water from an underlying aquifer for industrial purposes. Such removal was forbidden by statute in the 1970's, and Venetian subsidence has been substantially reduced as a result.

• Historical Remediation Efforts

Throughout its long history, Venice has been both threatened and protected by the proximity of its lagoon, and its citizens have acted to minimize threats while promoting protection. Thus, the lagoon has been kept intact but with efforts to prevent storm-related changes in sea level. One task has centered on the rivers that could otherwise transport sediment and gradually convert the lagoon into dry land with pockets of freshwater, which would harbor malaria-transmitting mosquitoes. The island town of Torcello succumbed in medieval times to a combination of silt from the Sile river and resulting malaria. Therefore, the courses of the several rivers in the area were progressively diverted to avoid the lagoon, beginning in 1324 with a canal receiving water from the Brenta. Additional links were completed in 1507 and 1613, the last one allowing the waters from several rivers to flow into the Adriatic Sea through a common mouth. Meanwhile, dikes and seawalls were built, including the great St. Mark's Dike to the north of the lagoon (1534) and others protecting the barrier islands (Lidi).

Acqua alta episodes in the twentieth century led to demands for government intervention, resulting in Special Law 798. Earlier such special laws had been ineffectual, but this one was different. It called for creation of a committee (the Comitatone, or "big committee") with the prime minister as chair. The committee proposed several interventions, the most dramatic of which was a system of movable sea gates in the three passages separating the barrier islands.

To investigate this strategy, a prototype gate, the *modulo sperimentale elettromeccanico*, or MOSE, was constructed and towed into place in one of the channels. It spent from 1988 until 1992 in place and, by most accounts, performed well. The principle of its operation was simple: Most of the time, the gates would be submerged owing to the weight of water in their tanks. When a flood threatened, the water would be expelled and the gates would rise to block any storm surge. The single MOSE gate cost the equivalent of about 13.3 million dollars, and a total of about eighty gates would be required for the entire system to function.



Gondolas lie beached in the Venetian canals in February, 2008, after the canals plunged to 80 centimeters below average sea level. (Manuel Silvestri/Reuters/Landov)

In addition to the great cost of the project, critics have questioned its adequacy, especially in light of the rate of sea-level rise from global warming. They fear that, on its proposed completion in 2013, the gate system will already need to be deployed so often that the lagoon will have insufficient time to flush itself, and shipping will be seriously hindered.

• Changing Frequency of *Acqua Alta* Events

In the early 1900's, St. Mark's Square on the Venetian island was flooded seven times per year; in the 1950's, the frequency was twenty times per year. In 1996 alone, it was flooded ninety-nine times. This progression reflects two aspects of climate change: a general rise of sea level and a related increase in the number and severity of storms. In all events, the frequency of *acqua alta* occurrences seems to provide a measure of climate warming and to support the notion of Venice as a useful indicator of its extent.

• Context

Venice is not the only location in the world vulnerable to sea-level rise. Many cities are located on estuaries and coastlines and thus are affected by even modest sea-level rise. For instance, London is situated on the Thames estuary and has experienced repeated floods throughout its history. Small wonder that a storm-surge barrier has been under discussion through most of the twentieth century, was begun in 1973, and was completed in 1983. As climate-related sea-level rise proceeds, more and more coastal cities will become at risk, and many will not have the option of an estuarine barrier. For many of these cities, moving a sizable population will be the only remedy, with great cost and social dislocation. Much worse will be flooding of low-lying agricultural lands in countries such as Bangladesh, where extreme poverty and cultural dependence on rice culture will give rise to widespread suffering. Finally, coral-based Pacific island nations will simply vanish beneath the waves. It appears that the only available solution to such calamity is a worldwide reduction of greenhouse gas emissions.

John L. Howland

• Further Reading

Fletcher, C. A., and T. Spencer, eds. *Flooding and Environmental Challenges for Venice and Its Lagoon.* New York: Cambridge University Press, 2005. Multi-author treatise on all aspects of protecting Venice against the sea. Illustrations, index, and suggested additional reading.

Keahey, John. *Venice Against the Sea: A City Besieged.* New York: St. Martin's Press, 2002. Nontechnical account of Venice's plight and attempts to remedy it. The ambitious MOSE project receives special attention. Illustrations, maps, references, index.

Norwich, John Julius. *A History of Venice.* New York: Vintage Books, 1989. Excellent source of background information. The author is a well-known popular historian specializing in post-medieval Europe who has written several books about Venice. Illustrations and index.

Nosengo, Nicola. "Venice Floods: Save Our City." *Nature* 424 (August 7, 2003): 608-609. Concise view of the MOSE project, emphasizing controversial aspects such as cost, environmental impact, and questions concerning the likelihood of long-term effectiveness.

See also: Barrier islands; Coastal impacts of global climate change; Italy; Sea-level change.

Volatile organic compounds

• **Category:** Chemistry and geochemistry

• Definition

Volatile organic compounds (VOCs) are substances consisting primarily of a carbon backbone, with most or all of the remaining bonds being occupied by hydrogen atoms. Organic compounds may also contain atoms such as sulfur, oxygen, nitrogen, or chlorine. VOCs are volatile in that they evaporate under the conditions typically found at Earth's surface. As a result, VOCs generally include compounds with 12-14 or fewer carbon atoms. Compounds that evaporate more slowly are often referred to as semivolatile organic compounds, or SVOCs, and typically include 10-18 carbon atoms, with or without oxygen or other atoms.

Carbon dioxide (CO_2) does not fit the definition of a VOC, because it is not organic; methane, by contrast, does. However, because methane is more abundant than almost all other VOCs (by a factor of ten or more), is removed from the atmosphere more slowly than other VOCs (by a factor of fifty or more), and is itself an important greenhouse gas (GHG), methane is generally not included in the category of VOCs. The term VOC is nevertheless more commonly used than is the more precise term "nonmethane organic compounds," or NMOCs. The bulk of VOCs that are released into the atmosphere are members of the subclass hydrocarbons and thus are frequently termed nonmethane hydrocarbons, or NMHCs.

• Significance for Climate Change

VOCs are, like methane, very strong absorbers of infrared light and have the potential to contribute to greenhouse warming. They have short lifetimes, however, ranging from minutes to months, and thus have low concentrations except very close to their sources. As a result, their direct contribution to climate change is small. Their indirect contributions are significant, however. Ozone, the third ranking GHG, is not released into the atmosphere but is rather formed in the atmosphere from reactions of VOCs, oxides of nitrogen, and sunlight.

U.S. VOC Emissions by Source Sector

Source Sector	*Total Emissions (tons)*
On-road vehicles	4,660,578
Solvent use	4,267,952
Fires	3,036,428
Nonroad equipment	2,623,774
Industrial processes	1,680,541
Residential wood combustion	1,222,840
Miscellaneous	1,199,065
Waste disposal	464,152
Fossil-fuel combustion	146,198
Electricity generation	49,110
Fertilizer and livestock	42,192
Road dust	1

Data from the U.S. Environmental Protection Agency.

VOCs also affect the Earth's climate by forming secondary organic aerosols (SOAs). The formation of these aerosols is not understood well enough to determine whether the burden of SOAs has changed appreciably as a result of human activities. Because the organic aerosols are so prevalent, they make a large contribution to the Earth's energy balance and are thus critical to accurate predictions of changes in the Earth's climate.

VOCs generally enter the atmosphere as compounds containing carbon and hydrogen and are progressively oxidized, so they contain increasing amounts of oxygen and nitrogen, forming ozone as a by-product. As the reacting VOCs collect more and more oxygen and nitrogen, they become less and less volatile and eventually enter the condensed phase. The resulting tiny aerosol particles are clear and act to cool the Earth system by scattering and reflecting incoming sunlight.

About 1.3 quadrillion grams of VOCs are released annually by natural sources and human activities combined. Of this amount, about 1.2 quadrillion grams are natural in origin, and about 100 trillion grams are anthropogenic. In the temperate, developed nations, the contribution of human activities to VOC levels is larger; for example, in the United States, anthropogenic VOC emissions are roughly equal to those from natural sources: Each class of sources produces about 15 to 20 trillion grams per year.

At least 95 percent of the natural global VOC burden arises from vegetation, primarily trees. Deciduous trees release more VOCs than do evergreen trees, the former releasing roughly 1 percent of the CO_2 fixed in photosynthesis as VOCs. These natural VOCs are dominated by species with structures common in plant biosynthetic pathways. Vegetation releases isoprene (2-methyl-1,3-butadiene); its $C_{10}H_{16}$ dimers, known as terpenes; and $C_{15}H_{24}$ trimers, known as sesqueterpenes; and a wide variety of closely related compounds, some with alcohol and carbonyl groups attached. Deciduous trees preferentially emit isoprene, and evergreen trees preferentially emit terpenes. Many of the terpenes and their derivatives are easily recognized by their characteristic odors of pine, turpentine, lemon, orange blossom, and many other plant-derived scents.

In the Earth's atmosphere, VOCs react primarily with the hydroxyl radical (OH). They react repeatedly until they are removed from the atmosphere—whether by colliding with a surface such as a leaf or an aerosol particle, by being intercepted and removed by rain drops, or by being completely oxidized to become CO_2 (oxidized VOCs are a negligible source of CO_2). The speed at which molecules react determines both their concentration in the atmosphere and their ability to generate ozone and SOAs. The quantity of ozone formed depends on the concentration of its VOC and NO_x precursors, but after being released VOCs are constantly diluted in the atmosphere, so species that react more rapidly can generate higher quantities of ozone.

Each VOC has a different ability to generate ozone and SOA; however, several generalizations can be made. Alkanes, molecules consisting only of carbon-carbon single bonds, react relatively slowly and have lifetimes in the atmosphere of several hours to several days. The bulk of the anthropogenic VOCs are alkanes; examples include ethane, isobutane, and n-octane.

Alkenes are molecules with one or more double bonds. Double bonds render molecules much more reactive, and alkenes have lifetimes from minutes to hours. Most of the VOCs released from natural sources (primarily trees) are alkenes, including isoprene and the terpenes. A small fraction of anthropogenic VOCs have double bonds (generally less than 10 percent). Reducing the content of alkenes in motor vehicle fuel is a proven strategy for reducing ozone in urban areas. A very small fraction of VOCs emitted into the atmosphere have triple bonds, and these species react very slowly and are of little concern.

A fourth chemical class of VOCs is aromatics; species with conjugated double bonds arranged in one or more rings. Aromatics are almost entirely anthropogenic and have intermediate reactivities. SOA formation is highest from alkenes, followed by aromatics and then alkanes. A substantial fraction of VOCs from both natural and human sources contain one or more oxygen atoms, including aldehydes, ketones, alcohols, and organic acids. More of these oxygenates form as the VOCs are oxidized as they react in the atmosphere. Aldehydes react rapidly and speed ozone formation, while alcohols and acids frequently form SOA after undergoing one or two reactions.

Suzanne E. Paulson

• Further Reading

Atkinson, R., and J. Arey. "Gas-Phase Tropospheric Chemistry of Biogenic Volatile Organic Compounds: A Review." *Atmospheric Environment* 37, suppl. 2 (2003): S197-S219. Provides a very detailed and comprehensive look at the reactions of biogenic VOCs in the atmosphere, together with up-to-date data on reaction rate constants and branching ratios.

Finlayson-Pitts, Barbara J., and James N. Pitts, Jr. *Chemistry of the Upper and Lower Atmosphere: Theory, Experiments, and Applications*. San Diego, Calif.: Academic Press, 2000. Examines all important reactions of VOCs in the atmosphere, together with overviews of their sources and impacts, and includes many figures.

Guenther, A., et al. "A Global Model of Natural Volatile Organic Compound Emissions." *Journal of Geophysical Research-Atmospheres* 100, no. D5 (May 20, 1995): 8873-8892. One of the most widely cited references in the field. Contains a summary of much scientific data, together with mathematical approximations of emissions and color maps.

See also: Aerosols; Atmospheric chemistry; Greenhouse gases; Methane; Ozone.

Volcanoes

• Category: Geology and geography

• Definition

Volcanic activity has played a major geological and environmental role in the evolution of the Earth since the planet's formation. As the proto-planetary Earth cooled and formed a solid crust, widespread volcanic activity dominated its surface. The Earth's interior at this time retained a considerable amount of heat from accretion and the decay of short-lived radioactive isotopes. With interior temperatures well above the melting point of most Earth materials, high-density metals sank to the Earth's center of gravity, while lower-density, silicate-rich materials were displaced toward the surface. It is believed that this process took place within the first 50 million years of Earth history, resulting in the present crust-mantle-core structure.

Little geological evidence remains of the period between the formation of a solid crust and the beginnings of plate tectonics. Scientists believe that during this 2-billion-year interval, massive volcanic structures gradually built up into continental masses. Plate tectonics, as it is known today, began about 2.5 billion years ago. It may have taken that long for the Earth's upper mantle to become sufficiently hot and fluid to create convection cells that could fracture the crust and spread these huge sections apart from one another. It is along these plate boundaries where the majority of earthquakes and volcanic eruptions take place.

Volcanic eruptions have a significant impact on the environment. During such eruptions, huge amounts of gases and dust are expelled into the atmosphere. Water vapor accounts for over 90 percent of the total expelled gas, with the remainder being a mixture of carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrogen, and fluorine. These gases can become harmful to life. When sulfur dioxide reacts with water droplets in the atmosphere, it becomes acid rain, which is highly corrosive and particularly harmful to vegetation. The tremendous amount of ash thrown from volcanic eruptions can also mix with water to form dangerous mudslides, or it can release fluorine, poisoning the

Mount Soputan, Indonesia, erupts in October of 2008. (AP/Wide World Photos)

animals that graze upon ash-coved vegetation. On a global scale, volcanic ash has its greatest effect on the upper atmosphere, where it prevents transmitted sunlight from reaching the Earth's surface and eventually causes a reduction in global temperatures.

• Significance for Climate Change

Throughout Earth's history, life has been closely associated with volcanic activity. One theory suggests that life on Earth may have had its origin in volcanic hot springs that were rich in organic compounds. Continuous volcanic eruptions also contributed to the water that would later become the oceans. With life flourishing in the oceans and later on land, volcanic activity became a major influencing factor on the continuing evolution and periodic mass extinctions of Earth's biological inhabitants.

One reason for the occurrence of mass extinctions is a dramatic change in the Earth's surface conditions. Most species live in what can be called a "habitable zone" based upon a suitable range in temperature, the availability of sufficient water, and the right amount of sunlight. When a particular species is exposed to conditions outside of this zone, it either adapts to the changing conditions or dies. As compared to life in the oceans, life on land seems to be more fragile and more susceptible to change. Recent theories for the cause of mass extinctions have concentrated on cosmic impacts or extensive volcanic activity. In each case, the apparent mechanism can be related to a blockage of sunlight by the huge amounts of dust and debris that an impact or volcano would eject into the upper atmosphere. The reduction of even a small amount of sunlight could disrupt the photosynthetic process and through it Earth's food chain. A break in the food chain not only affects all the species that depend upon that link for their nourishment, but also all the species that depend on those species, and so on.

Violent volcanic eruptions have also played an important role over the course of human history from both a social and environmental perspective. Perhaps the most famous volcanic eruption in history occurred in 79 C.E., when Mount Vesuvius erupted and buried the Roman city of Pompeii under a thick blanket of ash and debris. As devastating as the Vesuvius eruption was, it was a relatively minor eruption when compared to the eruptions of Mount Tambora in 1815 and Krakatoa (Krakatau) in 1883. Each volcano produced enough ash and dust to affect global climatic conditions for several years after its eruption.

The Indonesian volcano Tambora was the most powerful volcanic eruption in recorded history. Its ash cloud lowered worldwide temperatures by 3° Celsius, particularly affecting the Northern Hemisphere. The following year, 1816, was known as "the year without summer." The United States and Canada experienced killing summer frosts and predominantly cloudy and cool days. Worldwide, with a shorter growing season, many people faced starvation.

Scientific studies of more recent volcanic eruptions, such as those of Mount St. Helens (1980), El Chichon (1982), and Mount Pinatubo (1991), have confirmed how much of an effect a single volcanic eruption can have on global weather conditions. One can only imagine the devastating effects that another giant volcanic eruption such as the one that created the Yellowstone Basin in Wyoming (48 kilometers in diameter) would have on the world.

Paul P. Sipiera

• Further Reading

Blong, R. J. *Volcanic Hazards: A Source Book on the Effects of Eruptions.* Orlando, Fla.: Academic Press, 1984. An excellent reference book dealing with all aspects of volcanic eruptions. Most useful to earth science students at various levels.

Lang, Kenneth R. *The Cambridge Guide to the Solar System.* New York: Cambridge University Press, 2003. Chapter 4 is particularly relevant to the effects of volcanic activity on the Earth's environment. Suitable for a general level science audience.

Marti, Joan, and Gerald J. Ernst, eds. *Volcanoes and the Environment.* New York: Cambridge University Press, 2005. A comprehensive work that examines all aspects of volcanic activity and its effects on the environment. Suitable for a wide range of readers.

See also: Earthquakes; Mount Pinatubo.

Walker, Gilbert
English physicist and statistician

Born: June 14, 1868; Rochdale, Lancashire, England
Died: November 4, 1958; Cousdon, Surrey, England

Walker is best known for his discovery of the Southern Oscillation in 1923. He also pioneered statistical weather forecasting.

• Life
Gilbert Walker was born in England, one of seven children. Growing up in England, he always excelled in mathematics, receiving a master of arts in mathematics in 1893. While in school, he demonstrated great interest in spinning tops and boomerangs, earning the nickname of Boomerang Walker. After applying for a variety of jobs, mainly at universities, he was offered a position at the Indian Meteorological Department in Calcutta, India, in 1901. While he had no background in meteorology or weather, he was recruited because of his strong mathematical and statistical background.

John Eliot, the second director of the Indian Meteorological Department and Walker's predecessor, was seeking a replacement who could apply his mathematical and statistical skills to forecasting the weather, especially in relation to monsoons. The Institute for Meteorological Development had begun to forecast monsoons and related rainfall in 1881 but was quite unsuccessful in its attempts. Eliot felt that a mathematician or statistician would be able to handle more successfully these forecasts and thus recruited Walker even though he had no training in meteorology.

In order to acquaint himself with meteorology, Walker toured several meteorological laboratories throughout the world, including in the United Kingdom, the United States, France, and Germany in 1902 and 1903. After spending much time with Cleveland Abbe, the founding director of the U.S. Weather Bureau, in 1903, he returned to India. On January 1, 1904, he was appointed the director general of observatories in India. Later that year, he received a doctor of science degree from Cambridge, and in 1905 he became a fellow of the Royal Meteorological Society. Walker remained director of the observatories in India until the end of 1923, right after his discovery of the Southern Oscillation. He then returned to England, was knighted by the king, and took a position as professor of mathematics at the Imperial College of Science and Technology. He remained there until his retirement in 1934.

• Climate Work
Walker is best known for integrating statistics into the forecasting of weather and for the discovery of the Southern Oscillation and its related Southern Oscillation Index (SOI). Early in his career at the Institute for Meteorological Development, he collected large amounts of data relating to weather conditions throughout the world. Analyzing these data statistically (mainly using correlations), Walker was able dramatically to advance the field of weather forecasting and to discover the phenomenon known as the Southern Oscillation.

According to Walker, the Southern Oscillation involves the tendency of pressure at stations in the Pacific Ocean to increase, while pressures in the region of the Indian Ocean decrease. It technically is defined as the difference in barometric pressure at sea level between Tahiti and Darwin, Australia. The Southern Oscillation appears causally related to El Niño, which seems to influence the weather throughout the world.

Walker found that there are two distinct patterns of air pressure at sea level in the South Pacific. The SOI measures the monthly or seasonal fluctuations in the differences between the surface air pressure from Tahiti to Darwin, Australia (east-west). When air pressure is higher near Tahiti (east) than it is in Darwin (west), surface air tends to flow westward. When atmospheric pressures change, so that barometric pressure increases in the west (Darwin) and falls in the east (Tahiti), surface winds weaken and retreat eastward. When this set of conditions occurs, it is usually accompanied by El Niño conditions.

The Southern Oscillation was only linked to El Niño in the 1960's (after Walker's death) but is now felt to be one of the major factors in predicting weather throughout the world, including monsoon rainfalls in India and weather patterns over the North American continent in the winter months. Thus, Walker dramatically advanced the field of weather forcasting, as well as scientific understanding of the factors influencing climate throughout the world.

Robin Kamienny Montvilo

- **Further Reading**

Katz, R. W. "Sir Gilbert Walker and a Connection Between El Niño and Statistics." *Statistical Science* 17, no. 1 (2002): 97-112. Discusses Walker's use of statistics to deal with meteorological phenomena, most notably El Niño.

Philander, S. G., J. R. Holton, and R. Dmowska. *El Niño, La Niña, and the Southern Oscillation.* San Diego, Calif.: Academic Press, 2000. Recounts the discovery of the Southern Oscillation by Gilbert and looks at the explanation for different weather conditions based on this concept.

Rajeevan, M., and J. Srinivasan. "Sir Thomas Gilbert Walker." *Resonance* 11, no. 8(2006): 3-5. This brief article presents material on the life of Thomas Gilbert Walker.

Trenberth, K. E., and J. M. Caron. "The Southern Oscillation Revisited: Seal Level Pressures, Surface Temperatures, and Precipitation." *Journal of Climate* 13 (2000): 4358-4365. Presents the Southern Oscillation in light of weather conditions from 1958 to 1998 and indicates that there are many variations across seasons.

See also: Bayesian method; Climate prediction and projection; El Niño-Southern Oscillation.

Walker circulation

- **Category:** Meteorology and atmospheric sciences

- **Definition**

The Walker circulation was discovered and named for Gilbert Walker. The Walker circulation is a cell of airflow across an ocean along the equator. The most well known cell is across the Pacific Ocean but cells also exist across the Indian and the Atlantic Oceans. In the western Pacific or Atlantic, hot air rises carrying moisture and creating a wet climate. As the air travels eastward, it cools and creates a cooler, drier climate in the eastern Pacific. An ocean current follows the same pattern. The water warmed by the Sun flows to the west. The Indian Ocean Walker cell flows in the opposite direction, making the eastern side the warm, moist climate.

- **Significance for Climate Change**

When a Walker circulation weakens or reverses, an El Niño results. The ocean surface temperature is higher than normal and the normal upwelling of cold water is less if at all. This means that plankton are not brought up to the surface and the fishermen from Peru suffer from small catches of fish that eat plankton. A shift in the Walker cell has also been shown to cause drought and flooding in Australia. An El Niño year may cause the central or eastern region of the Pacific to be as warm as the western Pacific. The ocean around Australia is cooler with less moisture in the atmosphere, which causes a drier eastern and northern Australia. A stronger than normal Walker circulation, called La Niña, can cause severe flooding in Australia as the airflow carries more moisture, the ocean is warmer, and there is more rainfall. This also means more cyclones in Southeast Asia, droughts in South America, and colder winters in North America.

An El Niño year will have fewer hurricanes as strong western winds, normally blocked by the Walker circulation, form and disrupt hurricane formation. The drier western Pacific will include not only Australia but also Indonesia. The western Pacific region, such as Chile and Peru, will have greater rainfall. Canada will have colder temperatures but Europe will have wetter, milder winters. A study by the University of Toronto indicates that a weaker Walker cell has such wide-ranging effects as less summer rainfall in West Africa and in north China and a reduced snow accumulation in southern Himalaya. There is evidence that the Walker circulation has been weakening for most of the twentieth century. An article published in *Nature*, May, 2006, assets that global warming is the cause of the weakening of the Walker circulation. If the Walker circulation continues to weaken, it will change the world's climate.

C. Alton Hassell

See also: Atmospheric dynamics; Atmospheric structure and evolution; El Niño-Southern Oscillation; Hadley circulation; La Niña.

Water quality

• **Category:** Water resources

• **Definition**

Water quality refers to the physical, chemical, and biological characteristics of water in relation to the standards created to test its suitability for a particular use, such as irrigating, swimming, fishing, or drinking. Water quality standards for drinking are more stringent than those for any other use.

A variety of impurities or pollutants are able to harm water quality, and they may enter into water bodies from various sources, such as agricultural, industrial, and municipal activities. Typical harmful materials include organic wastes, nutrients, sediments, minerals, persistent synthetic chemicals, toxic chemicals, and radiological waste products. While some pollutants, such as organic wastes, can be assimilated quickly, the others are persistent in water and are therefore designated as nondegradable pollutants. It is the accumulation of excess pollutants that causes damage to the environment, affecting people and ecosystems. In the case of organic wastes, such as fecal matter, crop debris, and foodstuffs, water quality declines, because aerobic bacteria attack the organic matter and consume large amounts of the oxygen available in the surrounding water. The decomposition process may deprive aquatic life of the oxygen it needs to survive.

• **Significance for Climate Change**

Climate change is expected to cause higher water temperatures, sea-level rise, and changes in the frequency and intensity of precipitation and flooding. All these consequences of climate change can impact water quality. Higher water temperature reduces the oxygen available for aquatic life, because warm water is less capable of holding dissolved oxygen than is cold water. Increases in water temperature also cause higher rates of photosynthesis and so increase the number of plants, which eventually die and are decomposed by aerobic bacteria. In addition, higher temperature increases the metabolic rate of aquatic organisms, causing a higher demand for dissolved oxygen. All these factors contribute to deprive aquatic life of the oxygen it needs to survive.

Precipitation—expected to occur more frequently with higher-intensity rainfalls—can increase agricultural runoff and land erosion. As a result, more nutrients and sediments will be transported into rivers, lakes, and groundwater systems, worsening water quality. In addition, flooding can cause large volumes of water to carry pollutants into water bodies.

In addition to higher temperature and precipitation, sea-level rise can affect water quality in a different way: Studies predict sea-level increase in the range from 19 to 58 centimeters by the end of the twenty-first century. Higher sea levels will make salt water intrude into rivers and groundwater systems and so affect freshwater supplies in coastal regions.

To N. Nguyen

See also: Freshwater; Groundwater; Water resources, global; Water resources, North American; Water rights.

Water resources, global

• **Category:** Water resources

Global warming is anticipated to have a significant negative effect on the global supply and quality of water. Potential factors contributing to this effect include warmer winters, changes in precipitation patterns, increasing evaporation, melting snow peaks, rising sea levels, saltwater intrusion into coastal aquifers, dry soil, and increasing storm-water runoff.

Yemeni women collect water from a reservoir and carry it on donkeys back to their village. Yemen's groundwater supply is insufficient to support its growing population. (Khaled Abdullah/Reuters/Landov)

• Key concepts

aquifer: a subsurface formation that is permeable and therefore allows water storage and flow
concentration: the ratio, by weight, of a dissolved chemical compound to its solvent (such as water)
desalination: distillation and reverse osmosis of salt water to obtain freshwater
evaporation: the transformation of a substance from its liquid to its gaseous state
infiltration: the process of surface water entering soil
precipitation: the condensation of atmospheric water, which then falls to Earth's surface
runoff: storm water flowing on Earth's surface
saltwater intrusion: a process along coastlines in which salt water flows inland into a freshwater aquifer
sediment: particulate matter that is transported by water and eventually deposited
sediment load: the quantity of undissolved organic and inorganic particles carried by water
water basin: an area of land where surface water and groundwater flow in the same direction
watershed: an area of land where water flows into the same watercourse

• Background

A water resource is any surface or underground source of water that can be utilized by humans. Typical resources include water basins, aquifers, oceans, rivers, lakes, natural and artificial reservoirs, ice, snow, and wetlands. The hydrologic cycle renews freshwater resources, but these resources decrease when their withdrawal rate is faster than their recharge rate. Increases in population, industrialization, and other factors that increase demand can contribute to this depletion of resources. Environmental degradation and global warming also contribute to the decrease of available water. Water is an important factor in conflicts among stakeholders at the local, regional, national, and international levels. Water conflicts take many forms, but they almost always arise from the fact that the freshwater resources of the world are not partitioned to match political borders, nor are they evenly distributed in space and time.

• Changes in Quantity of Water Resources

The amount of water on Earth undergoes continuous changes due to the hydrologic cycle. The amount of freshwater in an area might increase as a result of higher precipitation or melting ice or snow. However, for water supplies to increase, other requirements must be met that allow freshwater to be captured in aquifers and other stable, uncontaminated reservoirs. These requirements include longer rainy seasons that provide enough time for freshwater to infiltrate aquifers, limitations on the amount of runoff that flows into oceans and other saltwater bodies, and sufficient soil and aquifer permeability and thickness. Aquifer recharge is also increased by relatively cool air temperatures and relatively low rates of evaporation from the ground's surface.

The overall temperature increases caused by greenhouse gases (GHGs) have significant effects on the environment and the quantity and quality of water resources. Higher temperatures increase the evaporation rate, which in turn increases the number and intensity of storms. Dry soil becomes difficult for water to infiltrate, and the violent precipitation of storms erodes soil, further decreasing the permeability of the ground's surface layer. As a result, storm water is unlikely to recharge aquifers, and a high proportion of surface storm water is likely to run off into rivers and oceans. In addition, higher temperatures cause ice caps to melt and raise sea levels, which in some coastal regions can introduce saltwater intrusion into aquifers.

• Changes in the Quality of Water Resources

Climate change can greatly affect water quality. Melting snow in the mountains increases river flow and erosion and transports large amounts of sediment, usually in winter or in rainy seasons. Such increased river flow can create flood hazards and heighten the potential for destruction of dams and levees. On the other hand, reduced river flow in summer can also have severe implications, because demand for water for irrigation, hydropower, and other uses is at its peak in summertime.

Evaporation rates increase with temperature. High evaporation rates in some areas reduce the ratio of water to its solutes, increasing the concentration of salts and chemicals and thereby decreasing water quality. The resulting increases in water salinity can cause changes in the rate of oxygen release into water. These changes in turn affect the plants in water reservoirs and the animals and plants in the surrounding environment. Furthermore, an increase in temperature and a consequent increase in the rate of ice melt can create a positive feedback loop. The melting away of ground ice, which reflects the Sun's rays, decreases regional albedo, causing the ground to absorb more solar energy and raising the temperature of the region.

Water resources can be renewable or nonrenewable. Basins that are consistently recharged by the hydrologic cycle (primarily through precipitation) and thus are not generally affected by water withdrawals and use are renewable. Nonrenewable water resources, are recharged at a rate significantly slower than their rate of withdrawal. Human actions, such as modifying watersheds, cutting forests, or paving land, can affect hydrogeologic balance and reduce the recharge or flow characteristics of a given area, altering the availability and renewability of water. Thus, it is possible for human activity to transform renewable water resources into nonrenewable water resources.

Freshwater helps sustain humans, animals, and plants. Relatively large bodies of water, such as the Great Lakes, affect regional climate and weather conditions. Large-scale withdrawal or transfers may reduce the size or quality of a water body, significantly influencing both climate and ecosystem services. Changes to the timing of river flows may alter ecological conditions. Such changes have led to many ecological and human disasters. For example, changes to the Amu Dar'ya and Syr Dar'ya rivers in Central Asia caused the destruction of the Aral Sea ecosystem, the extinction of the sea's endemic fish populations, shrinking of the sea, and local human health problems attributable to exposure to salt aerosols released into the air when the sea shrank.

Coral bleaching and other diseases of corals increased dramatically beginning in the late twentieth century. The increase of these diseases correlated with concurrent increases in sea surface temperatures. Thus, one consequence of global warming could be the mass destruction of coral reefs caused by emerging coral diseases and by the lack of epidemiological and biochemical information on even the known diseases.

Withdrawals of water from many rivers and streams in North America and Europe have led to reductions and extinctions of many fish populations (particularly anadromous fish). Decreased river flows have severely damaged river deltas and local communities, such as in the Sacramento/San Joaquin delta in California, the Nile River delta in Egypt, and the Colorado River delta in Mexico, where the local Cocopa tribal communities have been affected.

The world's water is unevenly distributed. As a result, complex and expensive water systems have been built over centuries to capture water during wet periods for use during dry periods and to move water from water-rich regions to water-poor regions. Many markets for freshwater have been created by the growing demand generated by the industrial and agricultural sectors. These emerging markets led to the creation of various forms of international water trading and exchange. The continuing growth of water demand in the face of population growth, climate change, and other factors is motivating states and corporations to find new ways to transfer water, including pipelines, bottles, tankers, and giant bags.

The increasing demands placed on the global water supply threaten biodiversity, human food production, and other vital human needs. Water shortages already exist in many regions, and more than one billion people lack adequate drinking water. In addition, 90 percent of the infectious diseases in developing countries are transmitted by polluted water. Agriculture consumes about 70 percent of freshwater worldwide; for example, approximately 1,000 liters of water are required to produce 1 kilogram of cereal grain, and 43,000 liters are required to produce 1 kilogram of beef. New water supplies are likely to result from conservation, recycling, and improved water-use efficiency rather than from large development projects.

The Pacific Island developing countries (PIDCs), which are among the nations least responsible for contributing to the global warming problem, are among those that will most significantly suffer its consequences. These countries are responsible for less than one percent of the world's carbon dioxide (CO_2) emissions; however, it is predicted that they will experience the earliest and the most severe effects of climate change over the next two centuries. In addition to rising sea levels and saltwater intrusion, climate change poses a long-term threat to freshwater quality and availability in these countries. Of the thirty thousand islands in the Pacific Ocean, one thousand are populated. Almost all islands rely on groundwater resources for their freshwater; some high islands, such as French Polynesia, Nauru, Palau, and the Cook Islands, rely on surface water, which does not require pumping, because it is transported by gravity. Rapid increases in population place a strain on limited water resources, and over-pumping of fragile groundwater aquifers will cause saltwater intrusion and the loss of supplies. Rapid urbanization, increases in pollutants, and inadequate sewage disposal infrastructure greatly affect Pacific Island water supply systems, because most such islands have thin and highly permeable soil zones.

Anthropogenic global warming is projected to result in the global temperature increasing by 1.4° Celsius to 5.8° Celsius by the end of the twenty-first century. Global mean sea level is projected to rise by 9 to 88 centimeters during the same period as a result of thermal expansion and loss of mass from melting glaciers and ice caps. Rising sea levels place freshwater resources at risk from saltwater intrusion.

• Context

Based on the predicted impacts of increased GHGs in the atmosphere and observed climate change, a host of national and international organizations has acted to preserve global water resources. The United Nations Framework Convention on Climate Change (UNFCCC), for example, is taking action to reduce GHG emissions and to develop adaptive protection strategies to save and conserve freshwater resources. The following measures are planned to be adapted by the PIDCs:

- Comprehensive projections of future water demand
- A sustainable research program to assess freshwater-resource availability
- Electronic data logging and hydrological data-processing software
- Rehabilitation and maintenance of water catchment and distribution systems to render them capable of surviving violent storms
- Evaluation of proposed development projects and existing infrastructure in terms of their impact upon coastal freshwater resources
- Implementation of leak-control measures in existing water systems

Public awareness and water conservation projects are also being developed in the Middle East to address the critical water issues specific to that region.

Many environmental stressors contribute to ecosystem degradation in general and water-resource depletion in particular. These include rapid population growth and industrialization, increased weather-related water shortages, soil salinization, and contamination by residual pesticides and heavy metals. All such stressors threaten human health. To understand the interdependencies of water, climate, and health, the United States Geological Survey (USGS) developed a program that documents environmental quality along the U.S.-Mexico border by integrating the data sets of both countries. The USGS has also implemented data collection and training programs in such Middle Eastern nations as Jordan and the United Arab Emirates. Such efforts are at the forefront of efforts to analyze, understand, and respond to the increasing need for and decreasing availability of water throughout the globe.

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Further Reading

Gleick, Peter, et al. *The World's Water, 2006-2007: The Biennial Report on the World's Water Resources.* Washington, D.C.: Island Press, 2006. Comprehensive overview of Earth's water resources and their utilization by, importance to, and effects upon humans.

Grayman, Walter M. *Water Resources and Environmental Issues in 2050.* Reston, Va.: ASCE, 2008. A retrospective look toward the future, predicting changes in water resources and environmental planning during the first half of the twenty-first century based on the changes that took place in the last half of the twentieth century.

Raskin, P., et al. *Comprehensive Assessment of Freshwater Resources of the World.* Stockholm, Sweden: Stockholm Environment Institute, 1997. Discusses global freshwater resources, including glaciers, groundwater, wetlands, rivers, and large lakes.

Vicuna, S., J. A. Dracup, and Larry Dale. *Conjunctive Use and Other Adaptation Strategies to the Impacts of Climate Change in California Water Resources.* Reston, Va.: ASCE, 2008. Presents the growing evidence of climate affecting California's hydrology and water resources.

See also: Colorado River transformation; Desalination of seawater; Freshwater; Hydrologic cycle; Water quality; Water resources, North American; Water rights.

Water resources, North American

- **Category:** Water resources

The climate of the western United States has been predicted to become drier with global warming. This could result in the United States asking Canada or even Mexico for additional water supplies.

Key concepts

conservation of water: reduction in the use of water

desalination: removal of salt from seawater or groundwater so that it may be used for drinking or irrigation

hydroelectric power: electricity generated by moving water in turbines

interbasin diversions: water that is removed from one drainage basin to another one so that the water is not available for use within the original basin

preservation of water: protection of usable water resources from contamination and other threats

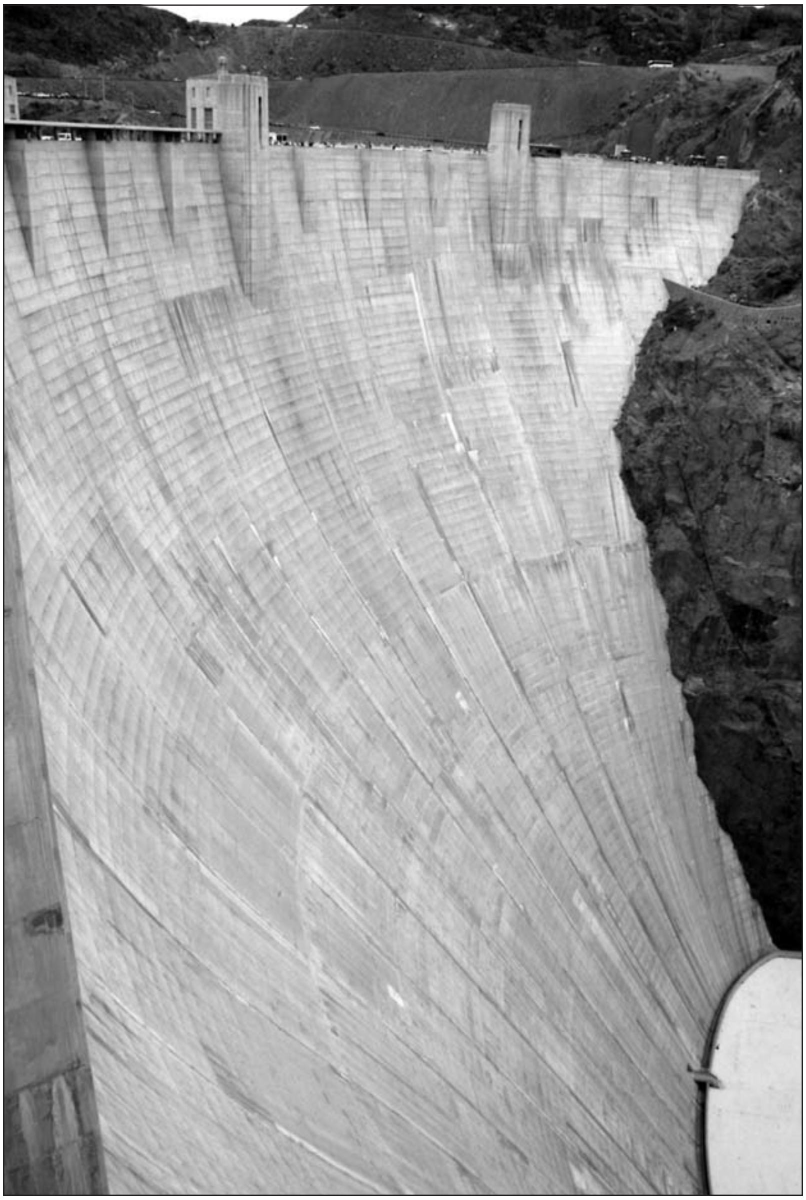
• Background

The United States will need to encourage water conservation in the use of water and potentially move water from wetter areas to drier areas. For example, much of the water from the Colorado River system has been diverted for many years to areas such as southern California to help quench the thirst of the growing population. Even larger scale water diversions have been proposed, such as moving freshwater from the Great Lakes or from other large bodies of water in Canada such as James Bay to the western United States.

• Current Water Agreements and U.S.-Canada Relations

Both the United States and Canada have a reasonable supply of freshwater at about 6.5 percent to 7 percent respectively of the world's freshwater, although it is not always found in the best places. For instance, the central and eastern United States has a reasonable amount of water, whereas the western United States is drier in most places. The water problems in the dry western states are complicated by the many people moving into dry states such as Texas, Arizona, and California and by the lack of water conservation.

Most of the movement of water from more water-rich areas to drier areas has been done locally between water drainage basins for irrigation, water supplies, and hydroelectric power. For example, the movement of water from the Colorado River basin to California was mentioned above. The only water use shared between the United States and Canadian communities has been done locally with small volumes of water. For instance, water has been shared between Point Roberts, Washington, and Vancouver, British Columbia. There is also little movement of bottled beverages between the United States and Canada except for some beer and soft drinks. Canada and the United States have also cooperated on the man-



Hoover Dam provides water and power to more than 20 million people in the American West and Southwest. (Barry Sweet/Landov) agement of water such as the Great Lakes and rivers that flow along or cross the border of the two countries. There has been little discussion between the two governments, however, on the possibility of large-scale exports of water from Canada to the United States. Many Canadians fear what may happen to their water if the United States decides it needs water from Canada.

• Water Conservation in the United States

The United States has not only looked for new sources of water in dry areas, but it has also encouraged or required water conservation to lower water use. Water conservation practices include the recycling of wastewater, drip irrigation, low-water-flow appliances (such as toilets, washing machines, and dishwashers), and the harvesting of rain. San Antonio, Texas, for example, has reduced its use of water per person by forty percent since 1980 by giving rebates to households to conserve water. California has not increased its water use much since 1970 even though its population has doubled. Also, the desalination of seawater along the Pacific Ocean and the Gulf of Mexico has begun to be added to domestic water supplies.

Of course water conservation has not been considered in some actions of the United States government as it continues to give subsidies to grow certain agricultural products. For example, the United States government has given subsidies to farmers in the dry western states to grow a high water consumption product, corn, to be used for ethanol, instead of growing a lower water use product like cotton. This action has led to an increased use of irrigation.

• Long-Distance Transport of Water

If the conservation practices and shorter range transport option for water in the United States are not sufficient to supply the demand for water, then the United States may decide to look for long distance water transport from other regions such as Alaska, Canada, and even Mexico. Alaska, has about a third of the renewable water in the United States, and it has expressed an interest in selling its water to other states. The water could be moved south by large pipelines. There appears to also be excess water in the Columbia River, which borders Washington and Oregon that could potentially be transported to the southwestern states in the Colorado River basin. Mexico is very dry in regions near the United States so that using their limited water supplies would be a last resort.

• Context

If the United States decides it needs more water in the future, then it may turn to Canada or Mexico for use of some of their water. Some have proposed that the United States could pay Canada for their water just north of the boundary between the two countries. The main problem is that most people in Canada live in the southern part of the country and need the water for themselves. The population is less in the northern part of the country, but the rivers flow to the north, so that reversing the flow toward the United States would be expensive.

If none of the above options would work, the United States might consider taking a much larger share of water located along the border of the two countries. The easiest place to take such water would be from the Great Lakes. The United States would not even have to take water directly from Canada since it could simply enlarge a canal already in place in Illinois that drains water from Lake Michigan. The United States has the legal right to take water from Lake Michigan because of a 1909 treaty (Border Water Treaty) between Canada and the United States. At present a United States Supreme Court order (1967), however, has limited any further diversion of water out of Lake Michigan. This could change if the demand for water is great enough.

Robert L. Cullers

• Further Reading

Annin, Peter. *The Great Lakes Water Wars*. Washington, D.C.: Island Press, 2006. Annin describes the problems in water use with a special emphasis on those of the United States; particular focus is on Great Lakes water being transported elsewhere. Photos, figures, index, references.

Quinn, Frank. *Water Diversion, Export, and Canada-U.S. Relations: A Brief History*. Toronto: Munk Centre for International Studies, 2007. Quinn gives his perspective on the planning and policy issues between the two countries. References.

Schmandt, Jurgen. “Bi-national Water Issues in the Rio Grande/Rio Bravo Basin.” *Water Policy* 4 (2002): 137-155. Examines the treaties and joint management between the United States and Mexico along the Rio Grande River. Figures, tables, references.

See also: Colorado River transformation; Freshwater; Water quality; Water resources, global; Water rights.

Water rights

• **Categories:** Water resources; laws, treaties, and protocols

• Definition

Water rights are legal rights to draw water from a particular source, such as rivers, streams, and groundwater, for some beneficial purposes, such as drinking or irrigating. In areas where sources of water are plentiful relative to the demand of the users, the allocation of water rights does not matter. However, in areas where available water is insufficient to meet demand, conflicting claims to that water must be resolved. Over time, population growth together with economic development have increased water demand and consequently inflated the relative scarcity of the resource. In order to resolve conflicts between users of water, there exist various mechanisms across regions to allocate water.

The United States may serve as an example to explain how water right systems evolved over time in response to increasing conflicts over water use. Within the United States, two primary systems of water rights are based on the riparian and prior appropriate doctrines. The riparian doctrine holds that the owner of the land adjacent to water has right to use that water. This principle of property right, derived from English common law, was appropriate in the earliest days of American settlement in the arid western region. At that time, settlements tended nearby sources of water, and they had easy access to the water, so the riparian right system was a practical solution. With population growth and the consequent rise in land scarcity, as well as an increase in the demand for water for other uses such as mining, the riparian doctrine became less appropriate. The prior appropriate doctrine evolved to replace the riparian doctrine, and it allows those who arrive first at a source of water to have the superior claim to that water.

In practice, each region can have its own variations upon these two basic principles, depending on characteristics of geography, custom, culture, and legislation in the region. Some regional authorities devise laws that include elements of both systems. In some cases, government may reserve water rights for special purposes, such as national wildlife refuges, federal forests, and military bases.

• Significance for Climate Change

Climate change can cause higher water temperatures, sea-level rise, and changes in the frequency and intensity of precipitation and flooding. All these consequences of climate change can have effects on the quality and availability of water, which, in turn, heavily affects the competition for water rights. Higher water temperature causes a higher rate of photosynthesis and a consequent rise in the number of plants in an area. When these plants die and are decomposed by aerobic bacteria, more nutrients are released into the ecosystem, which may introduce impurities into the water. In addition, flooding can cause pollution to be washed into existing water sources. Rising sea levels resulting from snowmelt can make salt water intrude into rivers and groundwater systems. Those effects of climate change degrade water quality.

In addition to water quality, water availability can be negatively affected by climate change. Average temperature is predicted to rise globally, but greater increases are generally expected to happen in inland areas and at higher latitudes. Higher temperatures will increase the rate of evaporation and consequently reduce water availability. In addition, increases in temperature can shrink the volume and shorten the duration of snow cover which, in turn, will change the timing of streamflow. Peak

Apple and cherry grower Bob Brammer looks out over the Columbia River. He has been attempting to gain increased water rights to the river for more than a decade. (AP/Wide World Photos)

streamflow may move from late spring to early spring or late winter. It is also expected that higher proportions of winter precipitation may arrive as rain rather than snow. Together, these changes can lead to more frequent and severe summer droughts, especially in snow-fed basins.

While decreasing the availability and quality of a region's water supply, drier climate can inflate the volume of water demanded for such uses as irrigation and drinking. As a result of water shortages, water-related tensions can emerge on various geographical scales: international, national, and local. In fact, disputes and conflicts over water rights have erupted worldwide, especially in arid regions.

On the international scale, drier climate has aggravated the conflict over water rights between upstream and downstream countries that share a river basin. In the Middle East, Egypt has warned neighboring countries that it was prepared to use its army to protect its access to the waters of the Nile, which also runs through Ethiopia and Sudan. Lebanon has several times accused Israel of manipulating the waters of the river Litani. In Asia, Bangladesh is a nation especially vulnerable to changes in climate. As a country lying in a low delta, it would see a decline in available drinking water should sea levels rise. Refugees from such conditions would likely flee across the border into India. In order to protect water rights for their people, Indian officials built a large fence along the border with Bangladesh.

On a national scale, Sudan is an example of a nation where climate change triggers conflicts between different interest groups over water rights. As temperatures rise and rainfall drops, there occur clashes between pastoral herders and agricultural farmers over access to shared water bodies. Even worse, the Sudanese government has diverted limited water in eastern Sudan from grazing land to commercial irrigation, leading to fighting in the region. In the United States, tension over water rights between states is emerging, fueled by climate change. Kansas has fought Wyoming over water right issues. Montana has sued Wyoming. The latter state disagrees with claims by Montana that the Yellowstone River Compact signed in 1950 grants the rights to both surface and underground water sources to Montana.

Although involving some uncertainty, predicted impacts of climatic change offer a glimpse into the likely water quality and availability issues that may arise in this century. Varying by region, the effects in general can lead to water shortages and a consequent rise of water right issues, which will be more pervasive in arid regions.

To N. Nguyen

• Further Reading

Lewis, William M., Jr., ed. *Water and Climate in the Western United States*. Boulder: University Press of Colorado, 2003. Collection of six papers discussing possible effects of climate variability on the consumption and management of water in the Western United States. Argues that old policies and institutions are inadequate in dealing with emerging water issues.

Tietenberg, Tom, and Lynne Lewis. *Environmental and Natural Resource Economics*. 8th ed. Boston: Pearson Addison Wesley, 2009. Undergraduate textbook applying economics to the analysis of environmental and natural resource issues. Chapter 10 is dedicated to water resource issues, including water scarcity, water rights, and efficient allocation of water.

Young, Herbert C. *Understanding Water Rights and Conflicts*. Denver: BurgYoung, 2003. Explains why water supply and availability are so critical to quality of life. Discusses emerging issues of water rights and foreseeable conflicts over access to sources of water.

See also: Colorado River transformation; Desalination of seawater; Freshwater; Groundwater; Siberian river diversion proposal; Water resources, global; Water resources, North American.

Water vapor

• **Category:** Chemistry and geochemistry

• Definition

Water vapor is water in its gaseous state. Water vapor may form by evaporation of liquid water or by sublimation of solid water (ice). Water vapor (H_2O) is a chemical combination of two atoms of hydrogen and one of oxygen in which both the hydrogen and oxygen possess isotopes. Thus, the molecular weight of water vapor may vary from a low of 18 u to a high of (typically) 22 u. A u is equal to 1.66×10^{-27} kilogram. For a sample of water at a given temperature, the molecules of lower mass move with higher speeds than the more massive molecules and therefore more readily evaporate or sublimate. Thus, atmospheric water vapor is enriched in the lighter forms. In epochs of higher average planetary surface temperature, more low-mass water vapor forms, some of which is ultimately deposited as snow and ice in polar regions. The ratio of low-to-high mass water in ice cores yields a profile of how temperature has varied through time.

• Significance for Climate Change

Water vapor is the principle atmospheric gas responsible for greenhouse warming of the Earth's surface. In terms of its ability to absorb infrared radiation, wavelengths from approximately 0.7 micron to 100 microns, water vapor is about one hundred times more effective as a greenhouse gas (GHG) than is carbon dioxide (CO_2) and four times more effective than methane (CH_4). The concentration of water vapor in Earth's atmosphere varies with height and also varies both regionally and seasonally from 0 percent to 4 percent. Normally, it is the third most abundant gas in the atmosphere after nitrogen and oxygen.

The highest concentrations of water vapor in Earth's atmosphere occur in the planet's equatorial regions over the oceans and rain forests. In contrast, over continental deserts such as the Gobi and Sahara the water vapor concentration approaches zero percent as it does in the frigid air of the polar regions. Nearly all of atmospheric water vapor is found within the troposphere, a region of Earth's atmosphere that varies in thickness from about 20 kilometers over equatorial regions and thinning to about 5 kilometers over the poles. The mean persistence time of a molecule of water vapor in the atmosphere is the days before it is precipitated.

Deducing the effects of atmospheric water vapor on global climate change is extremely complex. As the surface temperature rises, the rate of evaporation increases, thus leading to a higher average concentration of water vapor in the atmosphere. This result considered alone suggests that the higher concentration of water vapor would lead to a higher surface temperature, a positive feedback that would amplify the warming caused by some other factor, such as an increase in solar radiation incident on Earth or the increase in concentration of some other GHG. The increase in the amount of water vapor in the atmosphere, however, also contributes to an increase in cloudiness, thus making Earth more reflective and serving to cool the planet by lowering the amount of solar radiation reaching the surface.

The by-products of industrial activity inject small particles into the atmosphere that serve as nucleation centers for the condensation of water vapor, stimulating the formation of clouds. In the condensation process, latent heat of vaporization is released. This deposition of energy within the atmosphere powers convection and the formation of storms that redistribute the energy to cooler regions of the atmosphere. These various effects are notoriously difficult to model.

Human activity contributes significantly to increasing levels of atmospheric water vapor. The combustion of fuels produces both water vapor and CO_2. The most significant deposition of water vapor into the atmosphere, however, does not result from combustion but from the irrigation of land for agricultural purposes. Making marginal regions such as steppes and grasslands agriculturally productive requires intensive irrigation. River and lake water or water from underground aquifers is spread across the landscape where evaporation and transpiration by plants increase the water vapor concentration.

In the case of pumping sequestered underground water to the surface and spreading it over crop fields, water that was formerly removed from the atmosphere and not subject to the global water cycle now participates. For example, the Ogallala Aquifer, located beneath the Great Plains of the United States west of the Mississippi River, is being depleted at a rate of 12 billion cubic meters of water per year, a rate equivalent to eighteen times the flow of the Colorado River. Some 90 percent of the water removed from the Ogallala is used for agricultural irrigation. Most of this water is deposited in the atmosphere; very little percolates back into the ground to recharge the aquifer.

Similarly, the semiarid American Southwest becomes agriculturally productive when irrigated by water removed from the Colorado River and other water transported from the Northwest. As this water evaporates, it enters the atmosphere and contributes to further greenhouse warming. Extensive irrigation projects across the globe, such as China's Three Gorges Project, Libya's Great Man-Made River Project, and the draining of the Caspian Sea, exacerbate global warming.

Anthony J. Nicastro

Water vapor and volcanic gases spew from Mount Redoubt in January, 2009. (MCT/Landov)

- **Further Reading**

Intergovernmental Panel on Climate Change. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007. Comprehensive, quantitative scientific assessment of past, present, and future climate changes and their causes.

Postel, S. *Pillar of Sand: Can the Irrigation Miracle Last?* London: W. W. Norton, 1999. Concentrates on the challenges and effects of maintaining current levels of irrigation to supply water for agriculture and human consumption.

Ruddiman, W. F. *Plows, Plagues, and Petroleum: How Humans Took Control of Climate*. Princeton, N.J.: Princeton University Press, 2005. Historical examination of the impact of humans on global climate. Traces global climate change from the advent of agriculture eight thousand years ago through the Industrial Revolution and up to modern impacts.

See also: Atmosphere; Atmospheric chemistry; Atmospheric dynamics; Atmospheric structure and evolution; Carbon dioxide; Evapotranspiration; Greenhouse effect; Greenhouse gases; Hydrologic cycle; Hydrosphere; Methane.

Wave power

- **Category:** Energy

- **Definition**

Wave-power devices extract mechanical or electric power from the oscillatory motion of water, or from pressure fluctuations below the surface that are due to surface waves. Wave-power plants are set up either on the coast or anchored further out in the ocean. Schemes for extracting steady power from waves are based on the predictable, repetitive nature of waves. However, they must be able to withstand the immense forces of extreme sea states and the corrosiveness of salt water. Installation costs exceed $15 per watt, too high to compete with other power sources.

Waves transmit energy through a medium. Ocean surface waves are usually driven by winds. While this kinetic energy itself is transmitted rapidly, the water propagating the wave moves little. The movement of the water as a wave passes follows an elliptical path around its mean position. The resulting waves are called surface gravity waves, because water rises and falls as a wave passes in an exchange between hydrodynamic pressure and gravity. In deep seawater, defined as deeper than half of the wavelength between successive wave crests, the theoretical value of wave power in kilowatts per meter length along a wave crest is 0.489 times the product of the square of the wave height in meters and the time between waves in seconds, or

$$0.489 \times TH^2$$

where T is the time between waves and H is the height of the wave. Thus, a wave height of 2 meters, repeated every 15 seconds, generates roughly 29 kilowatts per meter. Estimates of coastal wave power range from 20 to 70 megawatts per kilometer. Waves lose energy quickly as they come into shallow water, but the wave height grows.

The most efficient capture of wave power is in a resonant device, whose natural frequency matches that of the waves. The Salter Duck concept claims to extract over 94 percent of the power in ocean waves using actively controlled cam and float devices. Its proponents claim that the maximum stresses in the device never exceed those associated with power extraction, and that the device can survive the largest and sharpest breakers without capsizing or breaking. Full-scale devices are large and complex and require substantial initial costs to construct and deploy. The Energren system comprises several floats and lever arms and extracts energy over a large surface area, repeatedly using each wave. The Pelamis wave energy converter uses hydraulic cylinders that are pressurized using lever arms attached to floats.

Terminator devices extend perpendicular to the direction of wave motion and capture or reflect the power. One version is an oscillating water column, in which seawater passes through submerged inlets, compressing and expanding a trapped air column above it. The alternatively compressed and expanded air is used to drive turbines.

Point absorbers are floating structures with linkages that extract work. The buoyancy of water pushes long vertical cylinders up and down as a wave goes by. An example is the 40 kilowatt, 4 meter diameter, 16 meter long Power Buoy used in a commercial facility at Reedsport, Oregon. The Aqua Buoy tested in Portugal uses the vertical motion due to waves to run a two-stroke pump driving seawater through a continuous turbine. Some large seagoing vessels also direct wave-driven water through turbines and extract electric power.

Overtopping devices use tapered channels to increase wave height and pour water into reservoirs above the mean sea level. When the water is released to fall through turbines, energy is extracted. Attenuator devices are long, floating structures oriented parallel to the direction of the waves, with multiple sections. Height differences of waves along the length of the device, attributed to phase differences between the waves at different points, cause flexing and drive hydraulic pumps. A Pendulor device is a rectangular box open to the sea at one end. A hinged flap swings back and forth and drives a hydraulic pump and generator.

Wave power is also used to run desalination by reverse osmosis. A piston pump anchored to the sea bottom rises and falls, driven by wave action, driving seawater through the membrane. North American wave projects as of 2006 included a single 40 kilowatt Power Buoy deployed at Kaneohe, Oahu, Hawaii in 2004; a set of four Aqua Buoys producing 1 megawatt at Makah Bay, Washington, and a single OWC producing 500 kilowatts at Point Judith, Rhode Island. Some projects are being considered and tested in Europe, including an Aqua Buoy in Portugal.

• Significance for Climate Change

Wave power is clean and renewable. Proponents estimate that over 10 gigawatts of electricity can be brought on-line within a decade and that a potential 250 terawatt-hours can be economically harvested from the U.S. coastline. As a renewable energy source with no emissions to speak of, wave power, to the extent that it is viable, represents a carbon-neutral source of energy and a means to reduce anthropogenic contributions to global warming.

Narayanan M. Komerath

• Further Reading

Craddock, David. *Renewable Energy Made Easy: Free Energy from Solar, Wind, Hydropower, and Other Alternative Energy Sources.* Ocala, Fla.: Atlantic, 2008. Includes a lengthy section on wave power, which both explicates the technology and compares it to other sources of renewable energy.

Mei, C. C. "Basic Gravity Wave Theory." Chapter 2 in *Handbook of Coastal and Ocean Engineering*, edited by John Herbich. Houston: Gulf, 1990. Analyzes sea wave formation, limiting heights for given wind speeds, propagation speeds of waves, and other aspects important to understanding the source of wave power.

Minerals Management Service. "Technology White Paper on Wave Energy Potential on the U.S. Outer Continental Shelf." Washington, D.C.: U.S. Department of the Interior, 2006. Illustrated summary of the various wave power technologies, with references to the literature. Explains the physical principles and gives photos of existing installations. Surveys the environmental impacts of the various concepts as well.

See also: Clean energy; Energy resources; Hydroelectricity; Renewable energy; Tidal power; Wind power.

Weather forecasting

• **Category:** Meteorology and atmospheric sciences

• Definition

Weather forecasting is the branch of meteorology devoted to making short-term predictions about the weather. Early, nonscientific attempts at weather forecasting were based simply on people's past experience and observations. Modern science is based on more detailed understandings of relevant mechanisms and much more precise observations. However, all weather forecasting, scientific or not, is an extrapolation of human knowledge and observations from the past and present into the future.

Advances in science and technology have endowed meteorologists with the ability to make more objective judgments and inferences than were previously possible. Modern weather forecasting includes three components: sophisticated and accurate instruments for making atmospheric observations and measurements, a mathematically precise forecast model, and a powerful computer. Forecasting based on these components is called "numerical weather prediction" (NWP).

Many advanced technologies are employed in modern-day atmospheric observation and measurement, including satellites, aircraft, radar, and lidar. These technologies have made possible more frequent and accurate descriptions of atmospheric conditions, providing a good starting point for predicting the evolution of the atmosphere in the future. The treatment of observed data and the procedure for using these data in a weather-forecasting model are collectively called "data assimilation," and the product resulting from this preprocessing of data is analysis. An analysis provides a complete description of the current weather situation, and it forms the initial set of conditions from which a model projects future conditions.

A forecast model is composed of a set of physical laws governing atmospheric motion and other properties. These laws are typically expressed in a set of mathematical and statistical equations. Such equations can then be digitalized using computer programs, becoming a large set of computer codes. A numerical forecast model typically includes two parts: a dynamics core and a family of physical parameterization schemes. The dynamics core is the central part of the programs that represents the essential physical laws governing atmospheric motion. Physical parameterizations are sets of additional parameterized relations that interpret various physical processes that operate on scales that the discretized forecast model cannot resolve.

Once generated, the computer codes representing a forecast model are fed into a powerful computer. With accurate observations of current atmospheric conditions as the initial data, the computer will run its codes and output solutions representing future atmospheric conditions. Meteorologists then interpret these computer-generated solutions using various weather charts.

• Significance for Climate Change

Climate is an averaged state of long-term weather conditions. Therefore, climate can provide a general reference and guideline for weather forecasting. In fact, meteorologists use climate information in various weather forecasting methods, such as persistence forecasting, trend forecasting, and analog forecasting. On the other hand, weather forecasting may provide researchers with a snapshot of climate change. For example, global warming may manifest itself in alterations in the daily forecast of maximum and minimum temperatures. Although a particular day's weather forecast may vary significantly, a persistent change in weather pattern over some period of time may indicate a change in the Earth's climate system.

One of the issues raised by climate change is its consequences for future day-to-day weather patterns. The Intergovernmental Panel on Climate Change (IPCC) in its 2007 assessment report found that in a future warm climate, global weather would likely exhibit the following changes: higher maximum temperatures; more hot days and heat waves over nearly all land areas; higher minimum temperatures; fewer cold days, frost days, and cold waves over nearly all land areas; more intense precipitation events; increased summer drying over most midlatitude continental interiors and increased associated risks of drought; increases in tropical cyclone peak wind intensities, as well as mean and peak precipitation intensities; intensified droughts and floods associated with El Niño events in many different regions; increased Asian summer monsoon precipitation variability; and increased intensity of midlatitude storms.

These projected changes will certainly pose new challenges for weather forecasting should they come to pass, since models based on past atmospheric dynamics may need to be dramatically refined to respond to a new climate regime. At the same time, refinement of weather-forecasting models will enable climatologists to improve their related long-term climate models as well, increasing the reliability of climate projections alongside weather forecasts. The longest feasible weather forecast range is about two weeks. Error rates in forecasts increase rapidly beyond a two-week threshold. Such short-term projections are useful in helping people plan their daily lives. For climate outlooks and projections to be useful, however, they must operate on timescales of months, seasons, years, or even millennia. More accurate weather data and more sophisticated forecast models will help climatologists develop models reliable on those scales.

Chungu Lu

• Further Reading

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008. Widely used introductory textbook on atmospheric science; covers a wide range of topics on weather and climate.

Henson, Robert. *The Rough Guide to Weather*. 2d ed. New York: Rough Guides, 2007. This book gives quick references of various weather-related topics.

Intergovernmental Panel on Climate Change. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008. Comprehensive overview of global climate change published by a network of the world's leading climate change scientists under the auspices of the World Meteorological Organization and the United Nations Environment Programme.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Introductory textbook that covers a wide range of atmospheric sciences.

See also: Average weather; Extreme weather events; Fronts; Meteorology; Rainfall patterns; Weather vs. climate; World Meteorological Organization.

Weather vs. climate

• Category: Meteorology and atmospheric sciences

Weather is the set of temporally or spatially local meteorological phenomena: It is the concrete set of events that actually occur over time. Climate is an abstraction from weather: It is the set of the averages of meteorological measurements taken in a given place over a given time period. Changes in climate may be used as predictors of future weather patterns.

• Key concepts

archaeological record: the human-made objects and residues of the past that are used by archaeologists to reconstruct history

desert climate: a hot climate characterized by extremely low and sometimes deficit amounts of precipitation

insolation: the amount of solar energy received at a given point on the Earth

orographic barrier: a mountain or a hilly area that acts as a control on the climate on either side

semiarid climate: a climate of low annual precipitation (250-500 millimeters)

tropical climate: a climate generally found in equatorial or tropical regions that exhibit high temperatures and precipitation year-round

west coast marine climate: a mild, annually moist climate found along the western coasts of continents

• Background

The weather is one of the most obvious and tangible aspects of Earth's atmospheric environment. One can see, feel, hear, smell, and even taste weather. It consists of the measurable meteorological conditions of the atmosphere at any given time. In contrast, climate is a concept that is constructed by the averages of the component elements of the weather: temperature, wind, pressure, precipitation, clouds, and visibility. Complicating the understanding of climate is the fact that the Earth's atmosphere reflects many kinds of climates over many different areas at any given time.

• Weather

The term meteorology, the study of the weather, originates from the work *Aristotelous peri geneseōs kai phthoras* (n.d.; *Meteorologica*, 1812), by the Greek philosopher Aristotle (384-322 B.C.E.). Much of what Aristotle wrote was based around his assumptions about how the weather worked; he provided a model that was accepted without question for nearly two thousand years. However, with the advent of weather instruments (1600-1850's) such as the thermometer, barometer, and hydrometer, a science of meteorology slowly emerged. The invention of the telegraph in 1844 allowed for the rapid distribution of weather observations accumulated from a large geographical area. It was the telegraph that assisted meteorologists in constructing the first weather maps and charts.

• Modern Observations

Today, meteorologists depend on a wide range of instruments and communication systems to measure and distribute information about the weather. Weather observations at the surface of the Earth include measurements of wind direction and velocity, air temperature, visibility, types of observed clouds, atmospheric pressure, precipitation amount and type, and humidity. Usually, weather stations record surface conditions. However, some stations take observations of the upper atmosphere with the aid of a balloon (radiosonde). Many stations use Doppler radar. Hourly weather observations are logged at these stations. These observations are then sent to forecasters, who use them to develop long-term forecasts.

Climate is defined as the average amount of precipitation and average temperature at a given location within a given season. A location's climate is determined by its latitude, altitude, and locational characteristics. The latitude of a station determines

Top Weather, Water, and Climate Events of the Twentieth Century

	Year
Top U.S. Events	
Galveston Hurricane	1900
Tri-state Tornado	1925
Great Okeechobee Hurricane/Flood	1928
Dust Bowl	1930's
Florida Keys Hurricane	1935
New England Hurricane	1938
Storm of the Century	1950
Hurricane Camille	1969
Super Tornado Outbreak	1974
New England Blizzard	1978
El Niño episode	1982-1983
Hurricane Andrew	1992
Great Midwest Flood	1993
Superstorm	1993
El Niño episode	1997-1998
Oklahoma/Kansas Tornado Outbreak	1999
Top Global Events	
India Droughts	1900, 1907, 1965-1967
China Droughts	1907, 1928-1930, 1936, 1941-1942
Sahel Droughts, Africa	1910-1914, 1940-1944, 1970-1985
China Typhoons	1912, 1922
Soviet Union Drought	1921-1922
Yangtze River Flood, China	1931
Great Smog of London	1952
Europe Storm Surge	1953
Great Iran Flood	1954
Typhoon Vera, Japan	1958
Bangladesh Cyclone	1970
North Vietnam Flood	1971
Iran Blizzard	1972
El Niño	1982-1983
Typhoon Thelma, Philippines	1991
Bangladesh Cyclone	1991
Hurricane Mitch, Honduras/ Nicaragua	1998

Note: Chosen by NOAA scientists from among the world's most notable tornadoes, floods, hurricanes, climate events, and other weather phenomena, taking into account an event's magnitude, meteorological uniqueness, economic impact, and death toll.

Source: National Oceanic and Atmospheric Administration.

the amount of insolation the station will receive at any given time during the year. Higher latitudes experience less insolation than do stations located within the tropics. Altitude is the elevation of a station. Given the environmental lapse rate, or the general decline in temperature with altitude (4° Celsius per 1,000 meters), stations found at higher elevations exhibit generally cooler climates. A station's climate is also controlled by its location with respect to land and water.

Seattle, Washington, although somewhat high in latitude, is also climatically influenced by its orientation with respect to Puget Sound. Its maritime location keeps Seattle's climate from exhibiting extreme temperatures. In contrast, locations such as Wenatchee, Washington, less than 160 kilometers to the east but on the leeward side of the Cascades, is located in a more continental position. Temperatures there are considerably colder in the winter and warmer in the summer. Additionally, the Cascades act as an orographic barrier to precipitation, making, Wenatchee's climate a desert.

• Climate

To understand climate, scientists must have access to weather data over long periods of time. Relatively accurate weather observations have only been available for a minute period of time. However, past climatic conditions can also be studied by indirectly interpreting the signature left by the movement of animals and plants, as well as the archaeological record of human activity. For example, seven-thousand-year-old cave drawings in the Sahara Desert suggest that in the past this desert region retained a climate that was conducive to habitation. From 400 to 1200 C.E., historic records suggest, the Vikings exploited the warm, ice-free conditions on their coastlines and ventured out in ships in exploratory enterprises, settling Greenland and Iceland during this time. However, historic records are subject to problems of precision and human interpretation. It would not be until the late 1800's that weather records would be scientifically collected in the United States. It is the reliability of these meteorological data that dictates how accurate scientists' understanding of climate can become.

• Climate Classification

Climates on the Earth can be classified and defined by their characteristics and their environmental qualities. However, classification systems are limited by the number of variables they utilize. One way to classify climate is to look at the distribution of different types of animals or plants that live within that climate. For example, the Köppen classification system uses temperature and moisture levels related to plants to define the patterns of climate types. On the other hand, humans are found in every climatic type on Earth.

• Present Climate Distributions

The general categories of climates include: climates of the tropics, equatorial climates, savanna climates in areas such as the African region of the Sudan and Sahel and tropical semiarid climates. Additionally, desert climates can be found anywhere the geographical conditions are right for moisture to be depleted from the air. Monsoonal climates are found in India, Northern Australia, and regions within Southeast Asia. Mediterranean climates are located around the Mediterranean Sea, but they can also be found in Central Chile, California, and South Africa. Humid subtropical climates are found on the eastern margins of continents, in regions such as the southeastern United States, Uruguay, Brazil, Argentina, southern Japan, the Natal of South Africa, Taiwan, and parts of Eastern China.

West coast marine cool temperature climates are found along the west coasts of continents and in the middle latitudes. Seattle is a good example of this climate, which is also found on the Atlantic coasts of France and the United Kingdom. The warm summer continental climates are found in areas such as the central United States, northeastern China, and Korea. Cool summer continental climates are found in the northeastern United States, northern Japan, and Eastern Europe. Steppe climates are found in continental areas of North America, Argentina, and Patagonia. Sub-Arctic climates are known as the Taiga, a Russian term for the coniferous forests found in the areas of Siberia and Canada. Tundra is a cold climate just below the Arctic region. Ice cap climates are found at the North and South Poles. Vegetation does not grow, and precipitation is sparse.

• Context

In contrast to weather, climate is an abstract concept made up of the measured averages and extremes of weather. Climate, then, cannot be experienced firsthand. Over the course of a year, one can experience the change of seasons, but only on the basis of what one might expect the weather for those seasons to bring. Complicating this further is the variation in the types of climate that exist and the limitations to the models by which they are defined. The evidence for changes in climate is clearly found in the fossil record, as well as in geologic structures showing the advance and retreat of ice over the land. Additionally, the archeological record indicates climate change by shifts in cultural activity. Core samples from glaciers can be analyzed to reveal oxygen content and thermal conditions of past atmospheres. Ice from these past periods continues its hold on parts of the globe.

M. Marian Mustoe

• Further Reading

Aguado, Edward, and James E. Burt. *Understanding Weather and Climate.* 4th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007. Survey of meteorology and the formation of climates and climate classifications.

Critchfield, Howard J. *General Climatology.* Englewood Cliffs, N.J.: Prentice-Hall, 1998. Deals with all aspects of the establishment of climate. Discusses climate classification systems and how climate impacts agriculture.

Miller, George R. *Lewis and Clark's Northwest Journey: Weather Disagreeable.* Portland, Oreg.: Frank Amato, 2004. Writings from the log of Lewis and Clark describe how weather observations were taken by these explorers. The weather for the period is contrasted with contemporary climate.

See also: Abrupt climate change; Atmospheric dynamics; Average weather; Climate and the climate system; Climate models and modeling; Climate reconstruction; Climate zones; Climatology; Continental climate; Meteorology; Seasonal changes; Weather forecasting.

Wegener, Alfred

German meteorologist

Born: November 1, 1880; Berlin, Germany
Died: Winter of 1930; Greenland

Wegener's fascination with the late Paleozoic ice age in the Southern Hemisphere led him to formulate the theory of continental drift to explain its geographic extent.

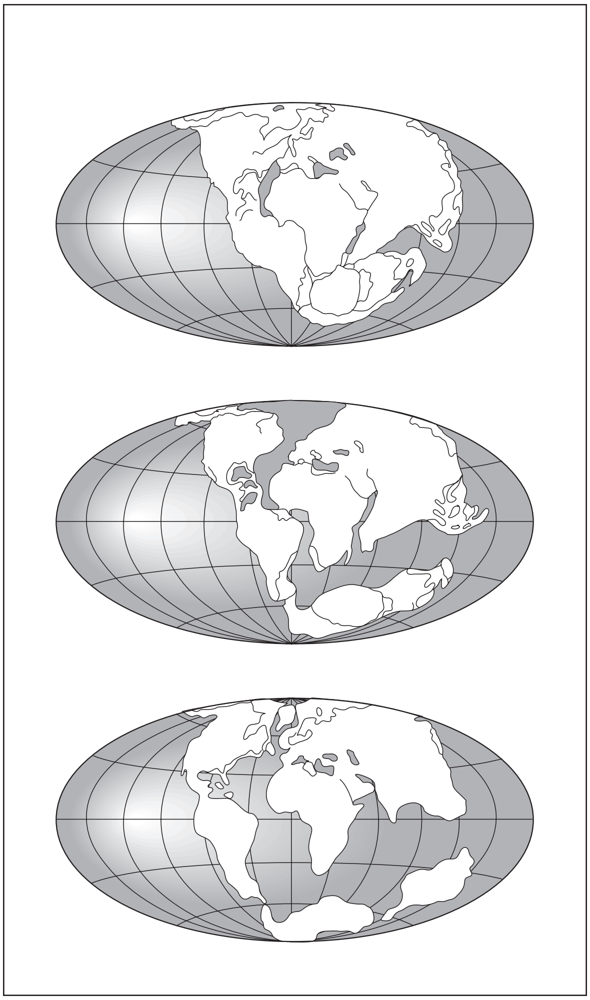
• Life

Alfred Wegener was born in Berlin in 1880, the son of a preacher in an evangelical church. He got his secondary education at the Köllnisches Gymnasium in Berlin and subsequently enrolled at the Universities of Heidelberg, Innsbruck, and Berlin, receiving a Ph.D. in astronomy from the University of Berlin in 1905. Following graduation, he realized that he had lost interest in the field of astronomy, so he decided to pursue a career in the recently established field of meteorology, finding employment as an assistant at the Royal Prussian Aeronautical Observatory at Lindenberg. He experimented with kites and balloons and broke the world's record for long-distance flight in a free balloon, drifting for fifty-two hours across Germany, Denmark, and the Baltic Sea.

Wegener was fascinated with the ice-covered island of Greenland, so when the long-awaited opportunity for a visit presented itself, he resigned his position at the observatory and joined the 1906-1908 Denmark Expedition to Greenland as the official meteorologist. Following his return in 1908, he taught at the Universities of Marburg, Hamburg, and Graz in Austria, with time out for military service in 1914-1915. He also continued his meteorological investigations, and in 1930 he agreed to make another trip to Greenland, this time as leader of the German Inland Ice Expedition. Unfortunately, this expedition cost him his life. In an attempt to rescue starving team members, he and a companion set out for the middle of the ice cap in late October. When the supplies they brought with them were lost en route, he decided to go back before the polar night set in. He never made it, dying en route, possibly of a heart attack. His Eskimo companion sewed his body in a sleeping bag and buried him in the snow with upright skis as a marker. He remains buried there today.

• Climate Work

Wegener used evidence of past climate changes to support his famous theory of continental drift. In this theory, he proposed that the Earth's continents were once joined together in a giant supercontinent named Pangaea. Wegener believed that during the Mesozoic Era, about 200 million years ago, Pangaea fragmented into two parts. Laurasia was the northern part, a supercontinent consisting of North America and Eurasia, which subsequently drifted apart from each other. The southern part became a supercontinent known as Gondwanaland, which subsequently broke apart into the present-day Southern Hemisphere continents of South America, Africa, Australia, and Antarctica, with India drifting north to become part of Eurasia.



Alfred Wegener theorized that the continents began as one great landmass, Pangaea, more than 200 million years ago (top), which drifted apart beginning about 190 million years ago (middle), eventually resembling the world as we know it today (bottom).

Wegener presented his ideas on continental drift in a slender volume, *The Origins of the Continents and Oceans* (1915). He and others who supported the continental drift theory found several lines of evidence to support their point of view. One was the seeming jigsaw-puzzle "fit" of the continental boundaries on opposite sides of the Atlantic Ocean, a conclusion that became more compelling as globes were improved. Similar rock types were found on continents that were now far distant from each other, and geologic features such as mountain ranges ended abruptly on the coast of one continent, only to appear again on the facing coast of a continent across the sea. Wegener was also intrigued by the discovery of certain land-dwelling plants and animals that appeared simultaneously in the fossil record on widely separated continents. The fossil fern Glossopteris and the fresh-water reptile Mesosaurus are the two best-known examples.

Evidence for a late Paleozoic ice age in the Southern Hemisphere provided Wegener with some of the most compelling evidence for his theory. Deposits of ancient glacial debris are found in many localities in South America, Antarctica, Australia, South Africa, and parts of India. They have distinctive features that cannot be mistaken for any other type of sediment. A period of worldwide glaciation cannot explain these deposits, because (with the exception of Antarctica), all of the deposits lie close to the equator today, and there is no evidence for glaciers in the Northern Hemisphere at the time they formed.

Regional mapping of the striations and grooves left by the ancient Southern Hemisphere glaciers suggests that the ice accumulated in the ocean and moved inland, which is impossible. When the Southern Hemisphere continents are grouped together as Wegener proposed, however, then all the glaciated areas are seen to be contiguous, with the flow lines of the striations and grooves moving outward from the South Pole area, where the main ice mass must have been located.

Donald W. Lovejoy

• **Further Reading**

Hamblin, W. Kenneth, and Eric H. Christiansen. *Earth's Dynamic Systems*. 10th ed. Upper Saddle River, N.J.: Prentice Hall, 2004. Details the origin of the continental drift theory and the evidence provided for it by late Paleozoic glaciations in the Southern Hemisphere.

McCoy, Roger M. *Ending in Ice: The Revolutionary Idea and Tragic Expedition of Alfred Wegener*. New York: Oxford University Press, 2006. Summarizes the origin and reception of the continental drift theory; gives special attention to Wegener's life and his expeditions to the Greenland Ice Cap.

Macdougall, J. D. *Frozen Earth: The Once and Future Story of Ice Ages*. Berkeley: University of California Press, 2004. Recounts the history of the Earth's ice ages and how the evidence for these ice ages was discovered and interpreted over time.

See also: Glaciations; Paleoclimates and paleoclimate change; Plate tectonics.

Western Fuels Association

• **Categories:** Organizations and agencies; energy
• **Date:** Established 1973
• **Web address:** http://www.westernfuels.org

• **Mission**

Headquartered in Westminster, Colorado, Western Fuels Association (WFA) is a nonprofit cooperative that provides services to consumer-owned electric utilities, both rural and municipal, in the Great Plains, Rocky Mountains, and Southwest regions. A twelve-member board, selected from its member utilities, oversees the association. Its chief executive officer and staff handle daily operations.

WFA purchases coal and transports it to its member utilities, thus removing the expense for them of maintaining their own procurement staff. WFA supplies approximately 15.4 million metric tons of coal annually from lands leased from the federal government in the Powder River Basin of southeast Montana and northeast Wyoming. It acquires further coal supplies through affiliated companies in Wyoming and Colorado. To move the coal to its members, WFA reserves more than seventeen hundred railroad cars, as well as operating the Escalante-Western Railway in New Mexico. WFA also offers consultation services on management, marketing, mining engineering, location of new coal fields, litigation, regulation, and taxation.

WFA members belong to one of three classes. Class A members rely on WFA for the fuels to generate power; class B members use WFA coal for some power plants; and class C members use WFA transportation and expertise as needed.

• **Significance for Climate Change**

The WFA promotes the use of coal for generating energy in the American West, subscribing to the view that the carbon dioxide produced thereby does not contribute significantly to global warming and may actually be beneficial. WFA's 2006-2007 annual report makes no mention of climate change, although its previous report refers to the uncertainty of environmental issues. However, WFA's web site offers news items and links to organizations that challenge scientific findings about global warming and environmentalist initiatives.

Among the organizations WFA supports is the World Climate Report. WFA's web site describes it as a "concise, hard-hitting and scientifically correct response to the global change reports which gain attention in the literature and popular press." The World Climate Report's Web site champions what it calls the mainstream skeptic point of view, "which is that climate change is a largely overblown issue and that the best expectation is modest change over the next 100 years."

Another organization that WFA supports is the Center for the Study of Carbon Dioxide and Global Change. Its Web site, CO_2 Science, argues that little global warming has occurred during the last seventy years and that the increase of carbon dioxide in the atmosphere may actually improve human health.

Roger Smith

See also: American Association of Petroleum Geologists; Coal; Energy resources; Fossil fuels; Skeptics.

Wetlands

• **Category:** Environmentalism, conservation, and ecosystems

• **Definition**

Wetlands are found from the equatorial region to the arctic regions of Canada. Even in the deserts, wetlands are found near oases. Wetlands are important to society as they provide sanctuary for fish and wildlife, water resources for streams and aquifers, and, in most cases, serve to mitigate the severity of flooding. Wetlands also provide support for fishing, hunting, and other recreational and educational activities such as bird watching, photography, painting, tourism, and research. They provide humans and wildlife with food sources and function as sources of energy and sinks for greenhouse gases (GHGs), sequestering carbon through the formation of peat, a precursor to the formation of coal.

Wetlands can be harbingers for disease-causing insects and may limit some human activities, such as construction and farming. Some wetlands can also contribute to flooding in some cases, as they reduce the rate at which water is removed from the surface. Wetlands are great sources of methane gas, as plants account for about 20 percent of the methane found in wetlands. Wetlands are sometimes referred to as ecotones, transition zones between open bodies of water and land, and sometimes are described as the kidneys of the landscape or as biological supermarkets because of the roles they play.

Because of the varied nature of wetlands, it is often difficult to say what a wetland is and is not. Wetlands have different meanings to different people, depending on their background, exposure, knowledge, and political stand. There is no universal definition of what a wetland is, even within the United States. The main reason wetlands are difficult to define is that they are found in widely varied locations, have different climates, soils, landscapes, water quantity and quality, flora, fauna, and other characteristics, including human disturbances such as dikes, draining, pollution, and so on. The definition of wetland depends on the specific purpose for defining it, such as research studies, general habitat classification, natural resource inventories, or environmental regulations.

All wetland definitions fall into two categories: regulatory definitions and nonregulatory definitions. Because there are myriad, variable definitions and changes in definitions, there is some confusion among legislative and regulatory bodies. This confusion has caused several isolated wetlands to be destroyed, as these wetlands were not connected to navigable waters and may not have seemed to qualify for protection.

Three criteria are necessary to define an area as a wetland: hydrology, hydric soil, and hydrophytes (vegetation adapted to wet conditions). Wetlands are areas that are typically wet most of the time or where the groundwater is very close to the surface. Hydrology is the main factor for identifying wetlands, because not all wetlands exhibit hydric soil conditions. Water quantity and quality determine soil characteristics and which plants and wildlife communities can inhabit the area. The soil, plants, and wildlife affect water quantity and quality.

Wetlands can be broadly divided into two major types: coastal wetlands and inland wetlands. Coastal wetlands are found along the oceans and seas, whereas inland wetlands are found along rivers and streams, near lakes, in low-lying land depressions, or where the groundwater meets the surface. Because of these conditions, the major types of wetlands that have been recognized are bogs, swamps, marshes, fens, potholes, and player lakes.

• **Significance for Climate Change**

Any climate change could modify, create, or eliminate several types of wetlands. With an increase in global warming and sea-level rise, most of the coastal wetlands may be altered, destroyed, or eliminated.

However, with the demise of coastal wetlands, new wetlands would be created in places such as Canada and Siberia's arctic regions as glaciers melt. Change in the climate would affect the effectiveness of wetlands to remove nutrients from flow-through systems such as lakes or riparian wetlands. Aquatic life forms would be lost as a result of prolonged nutrient loading to such wetlands. Wetland values would be altered, as the hydrology regime was altered in those wetlands. Climate change that would involve a sea-level rise would be detrimental to coastal regions and human life.

Many of the world's largest cities, located near coastal areas, have wetlands buffering the effect of ocean waves or flooding. Any meaningful sea-level rise would cause serious problems to these wetlands, changing the water chemistry and thus the flora and fauna. It would also affect those coastal cities by increasing the risk, incidence, and severity of flooding. Global warming would lead to destruction of some coastal wetlands and the creation of new wetlands, mainly in the Northern Hemisphere. Tourism may suffer in places where tourism helps the economy, such as the Florida Everglades, with shifts in locations of wetlands. Southeast Asian wetlands may be decimated with a rise in sea level resulting from climate change.

The wetlands of the Nisqually National Wildlife Refuge in Washington State. (AP/Wide World Photos)

The use of wetlands to reduce GHGs may not be beneficial across the board, as it has been found that developmental strategy may be better for developing nations than emission reduction of GHGs. Specific regions would need to assess their wetlands according to their sustainability and economic persuasions, noting that wetlands play significant roles in relation to carbon and GHGs such as methane. They can be carbon storage sinks, sequestering several metric tons of organic carbon and helping offset carbon emissions elsewhere.

Solomon A. Isiorho

- **Further Reading**

Bullock, A., and A. Acreman. "The Role of Wetlands in the Hydrological Cycle." *Hydrology and Earth System Sciences* 7, no. 3 (2003): 358-389.

McFadden, L., R. Nicholas, and E. Penning-Rowsell, eds. *Managing Coastal Vulnerability*. San Diego, Calif.: Elsevier Press, 2007. Good reading for those interested in coastal vulnerability areas of the world, including wetlands.

Mitsch, W. J., and J. G. Gosselink. *Wetlands*. Edison, N.J.: John Wiley & Sons, 2000. A more technical reading for those interested in the science of wetlands.

Tiner, R. A. *Wetlands Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping*. Boca Raton, Fla.: CRC Press, 1999. A good source of information for identification of wetlands.

See also: Floods and flooding; Methane; Sequestration; Sinks; Water resources, global; Water resources, North American.

WGII LESS scenarios

- **Category:** Laws, treaties, and protocols
- **Date:** Published as part of the Second Assessment Report in 1995

- **Definition**

WGII LESS scenarios were developed for the Second Assessment Report of Working Group II (WGII) of the Intergovernmental Panel on Climate Change (IPCC) to assess low-emissions supply systems (LESS). The mission of Working Group II was to study the physical, ecological, human-health-related, and socioeconomic impacts of climate change. The overall goal of the IPCC is to determine the history, present situation, and likely future of Earth's climate and to make recommendations as to the best climate policies to preserve the health and welfare of the world's peoples and ecosystems. As part of that mission, WGII was tasked to review the technical and economic feasibility of various adaptation and mitigation strategies relevant to climate change.

- **Significance for Climate Change**

WGII examined various cost-effective adaptation and mitigation techniques, beginning with existing commercial-scale technologies that would increase efficiencies in energy generation and distribution by 10-30 percent with little net cost increases. Gains of 50-60 percent in energy efficiency are technically feasible in the developed world, but they would require significant capital expenditures on the global commercial-energy system. Such costs would be prohibitive for the developing world. Even a switch to more efficient energy technology might not lead to an overall reduction in total greenhouse gas (GHG) emissions, given the rising global demand for energy.

The five LESS scenarios explored by WGII are:

- Nuclear-intensive (NI)
- Natural-gas-intensive (NGI)
- Coal-intensive (CI)
- Biomass-intensive (BI)
- High-demand variant (HD)

WGII considered the options involved in switching to low-carbon fossil fuels. This switch would favor electric power generation using oil or natural gas rather than coal. Sufficient technologies exist to allow for the decarbonization of fossil fuel and the storage of carbon dioxide (CO_2) for use in producing hydrogen fuels. Technologies also exist to capture methane emissions in the energy-generation-and-distribution process. Commercial-scale implementation of decarbonization and methane capture are not, however, economically attractive solutions.

WGII considered energy generation by means of nuclear power. This option is technically and economically possible and cost-effective, but it is very unattractive to a segment of the public as a result of problems with reactor safety, radioactive-waste transfer and storage, and a lack of clear authority to force nuclear-reactor builders and operators to adhere to international quality-control standards.

WGII also considered energy generation by means of renewable sources of energy, either exclusively or in combination with fossil-fuel sources. In this area, WGII constructed five scenarios using varying degrees of renewable energy technologies that were then available or could become available on a commercial scale at an economically justifiable cost. Technologies that were not cost competitive for CO_2 LESS up to the year 2100 were eliminated from consideration.

WGII investigated the coal-intensive option using an experimental stem-injected aeroderivative gas turbine developed by General Electric. In comparing the efficiencies of coal and biomass energy generation, WGII found that either a steam-injected or an oxygen-blown gasifier turbine used in conjunction with coal would result in "hot gas" cleanup costs without removing any sulfur in the combustion process. Available technologies do not allow coal to be burned as cleanly as biomass fuels. Research in this area continues, however.

The natural-gas-intensive scenario is based on estimates of recoverable natural gas resources provided by the 1994 U.S. Geological Survey. Should these estimates prove inaccurate, or should the resources prove too expensive to recover, the natural-gas-intensive option will decrease in feasibility. LESS natural-gas-intensive practices include CO_2 sequestration, an additional cost factor.

The high-demand variant scenario is based on a fourfold increase in global energy demand. The HD variant involves a mixture of coal, biomass, and alternative energy sources such as wind and solar power. It also includes decarbonization of coal and natural gas and high degrees of energy efficiency across the board. It was judged to be cost prohibitive given current levels of technology in the developing world.

The biomass-intensive scenario shows much promise for reducing global GHG emissions in a cost-effective manner. Biomass feed stocks must be high-density materials, such as wood chips. In order to combust with maximum efficiency, the wood chips produced from fast-growing trees must be dried using superheated steam, which can then be recovered and utilized in the energy production process. Biomass power plants can be smaller in scale than traditional coal plants and possibly located nearer to energy consumers, thus increasing efficiency in distribution networks.

WGII also considered the use of intermittent renewable energy sources such as solar and wind in combination with other fuels for electricity generation. It determined that up to 30 percent of electrical energy can by produced by renewable sources without significant cost increases in electrical storage capacity.

Information and results from the WGII Second Assessment Report indicate that a combination of different low-emission energy-generating methods, all operating at maximum achievable efficiency in different regions of the world, will be necessary to stabilize and possibly reduce global GHG emissions. Energy demands will increase in the foreseeable future as a result of global population growth and economic development, and no single technology will satisfy those demands, nor is any single technology suitable for universal adoption by all nations. However, the WGII LESS scenarios may help each nation in evaluating the proper combination of clean energy technologies for its needs and increase the global adoption of clean energy.

Victoria Erhart

• Further Reading

Charnovitz, Steve. *Global Warming and the World Trading System.* Washington, D.C.: Peterson Institute for International Economics, 2009. Includes an international study of various carbon-intensive industries around the globe. Examines various ways to reduce GHGs without adversely affecting global trade. Explores many of the economic trade-offs involved in reducing global GHG emissions.

Houghton, John. *Global Warming: The Complete Briefing.* 4th ed. New York: Cambridge University Press, 2009. Comprehensive overview of global warming and related issues, including a discussion of emission scenarios and projections of future effects, both of climate change and of climate policy.

Pittock, A. Barrie. *Climate Change: Turning up the Heat.* Sterling, Va.: Earthscan, 2005. Presents helpful evaluations of climate projections and modeling methods, discussing the trustworthiness of contemporary climatological studies of the past and future.

See also: Carbon dioxide; Certified emissions reduction; Emission scenario; Emissions standards; Greenhouse gases; Industrial emission controls.

Whales

- **Category:** Animals

- **Definition**

Whales are marine mammals that occur in all the world's oceans. They belong to the Order Cetacea, along with dolphins and porpoises. Although all cetaceans may be considered whales, the term "whales" traditionally refers to the members of this order that exceed 6 meters in length. These include the baleen whales, such as the blue whale and right whale, sperm whales, pilot whales and killer whales.

Whales include the largest animals ever to exist. The mass of a blue whale, for example, is several times greater than that of the largest dinosaur known. Despite their fish-like appearance, whales are air-breathing mammals that have hair and mammary glands like other mammals and must come to the surface to breathe. Their ancestors of 50 million years ago were hippopotamus-like creatures distantly related to modern hippos. Modern whales form two distinct groups, the baleen whales—also known as the rorquals—that feed on krill and the toothed whales—such as the sperm whales, dolphins, and porpoises—that feed on fish and larger marine invertebrates.

All the world's whales are carnivores, and therefore many of the great whales are migratory, spending summer months in colder polar waters were food is plentiful and then returning to more tropical or subtropical waters to winter and spawn their calves. California gray whales, for example, feed along the northern pack ice of the Arctic but winter in warmer lagoon waters off Baja, California. Their twice annual seasonal migrations northward along the California coast provide a popular pastime for wildlife enthusiasts, who line the shores to spot these leviathans on their migratory journeys.

- **Significance for Climate Change**

Whaling is the commercial harvesting of whales for food, blubber, oil, whalebone, and other products. Whaling is a centuries-old industry that probably began when native peoples harvested beached whales for food. Whaling as a commercial venture started with the Basques of northern Spain and the peoples of the Azore Islands, who pursued slower whales such as the right whale. The activity soon spread to other European countries. By the nineteenth and twentieth centuries, whaling ships regularly departed from ports in New England, Iceland, Norway, the Netherlands, and other locales for Arctic and Antarctic waters of the Pacific on cruises that lasted many years.

Commercial whaling reached its peak following World War II, when whaling fleets accompanied by floating whale processing factories took to the seas to harvest record numbers of whales. The whale slaughter that resulted from this efficient combination greatly exceeded the recruitment ability of major whaling stocks, and many of the largest whales including blue, fin, sei, and sperm whales drastically declined under this onslaught. Alarmed by the precipitous decline in numbers, the United Nations declared a moratorium on whaling and whale products, and many other nations of the world followed suit. Some countries, such as Japan and Russia, continued whaling activities but on a much reduced scale, although Japan continues to harvest certain species for research purposes. Following curtailment of high-seas commercial whaling, most of the whale populations have slowly recovered, although the threats posed by global warming may once again threaten the population stability of many of the great whales.

The higher temperatures and greater rainfall associated with global climate change are warming surface seawaters and hastening melting of the Arctic and Antarctic pack ice and of the Greenland glacier, all of which is resulting in changes in icy polar habitats and the food supply of most of the world's whales. In the Arctic, the rapid melting of the ice cover is threatening stocks of northern whales such as the narwhale, beluga, and bowhead whales, as well as gray whales that feed in these waters during summer months. Rainwater, along with water from the melting ice, dilutes seawater, sharply reducing its salinity and destroying the populations of marine organisms on which these northern whales depend.

Gray whales returning to their wintering grounds off Baja, California, to breed appear underfed, and their breeding success has declined. Furthermore,

A beached whale in Sarzeau, France. (Thierry Creux/Maxppp/Landov)

the melting of the Arctic ice cover has also awakened prospects for the development of northern sea trade routes and the exploitation of resources that underlie the ocean floor. Russia, Canada, and the United States have already expressed interest in petroleum deposits on their respective continental shelves as the Arctic pack ice melts. Increased trafficking associated with exploration and economic development such as commercial shipping, mining, and oil extraction poses a major threat to the fragile Arctic habitat and its cetacean inhabitants.

At the other end of the Earth, rapid melting of Antarctic pack ice is threatening southern baleen whales that gather to feed in these once krill-rich waters. Krill feed on plankton populations that grow beneath the pack ice and that are disappearing as rapidly as the melting ice. Lack of plankton causes loss of krill, forcing baleen whales northward into warmer subtropical water in desperate search for food that is not there. The lack of krill also results in loss of life-sustaining blubber, increasing susceptibility to both disease and starvation. Overall, the combination of these global warming factors may lead to the loss of the largest animals ever to exist on this planet.

Dwight G. Smith

- **Further Reading**

Carwardine, Mark. *Whales, Dolphins, and Porpoises: Smithsonian Handbook*. Washington, D.C.: Smithsonian Institution Press, 2006. Fact-filled handbook and recognition guide to all the world's cetaceans.

Ellis, Richard. *The Book of Whales*. New York : Knopf, 1980. With many books about giants of the ocean to his credit, Ellis is an acknowledged expert in the field of whales and other giants of the seas.

Kelsey, Elin. *Watching Giants: The Secret Lives of Whales*. Berkeley: University of California Press, 2008. Popular and engaging account of whale life history, ecology, and interactions with humans.

Nowak, Ronald M. *Walker's Marine Mammals of the World*. Baltimore: Johns Hopkins University Press, 2003. Detailed descriptions of taxonomy and ecology of whales and their marine counterparts. Part of a major series about each of the mammal groups.

Perrin, W. W., B. G. Worsig, and J. G. M. Thewissen, eds. *The Encyclopedia of Marine Mammals*. New York: Academic Press, 2002. Well-written, encyclopedic treatment of the world's cetaceans.

See also: Amphibians; Dolphins and porpoises; Endangered and threatened species; Fishing industry, fisheries, and fish farming; Penguins; Plankton; Polar bears.

Wind power

- **Category:** Energy

- **Definition**

Wind power is generated by extracting kinetic energy from the wind. During this process, an oncoming stream of relatively high velocity wind passes through a mechanical device that slows the wind

A wind farm near Dessau, Germany. (Fabrizio Bensch/Reuters/Landov)

down and simultaneously extracts part of the wind's kinetic energy and converts it into useful work. The energy can be used in various ways, such as pumping water, grinding grain, operating machinery, or running a generator to produce electricity. Such devices are commonly called wind turbines, although years ago they were called windmills. The terms are often used interchangeably.

Many types of windmill designs have been proposed, but the most common types in use are the Darrieus wind turbine, Savonius wind turbine, and horizontal axis propeller-type turbine. The Darrieus turbine looks much like a giant eggbeater mounted vertically. It has the advantage of being able to handle wind direction changes without having to move a large mass of windmill structure to reorient itself with the oncoming wind. Its main disadvantage is that it is not self-starting. An external source of energy is required to start the turbine spinning, even if the wind is already blowing.

The Savonius windmill is mechanically very simple but inefficient. It has an "S"-shaped cross section and can be made simply by cutting an oil drum in half vertically and welding the two halves together to create two scoops to catch the wind. In principle, it operates exactly the way the cup-type anemometers commonly used to measure windspeed operate. The propeller-type turbine uses a horizontal-axis propeller with its blades pitched and twisted in such a way that they catch a high velocity stream of wind and slow it down, producing useful shaft torque in the process. A horizontal-axis propeller turbine operates in precisely the opposite way that an aircraft propeller does.

• Significance for Climate Change

Since a wind turbine produces energy without any type of combustion process, it does not contribute to global warming by either rejecting waste heat or generating exhaust gases that contribute to the greenhouse effect. Thus, increasing the use of wind power to produce electricity would slow the progress of global warming. The technology of wind power is well developed, and holds much promise for slowing global warming, but only if some obstacles can be overcome to greatly increase the number of wind turbines in use.

The main obstacle appears to be community acceptance and aesthetics. In principle, most people are supportive of wind turbines, as long as they are situated far away from their homes. However, if wind turbines are to be installed nearby, members of the community often object, because they worry about the noise and appearance. In actual practice, wind turbines are generally quiet. A typical 600 kilowatt machine would produce 40 decibels of noise at a distance of 250 meters. This noise level is midway between that of a conversation and an average office. However, a wind turbine can make a loud noise when it is turning in response to a change in wind direction. Some European nations have overcome the perceived aesthetics problem by working with local communities, providing open disclosure of all aspects of the turbines right from the start, as well as involving the community economically as partial stockholders or owners of the turbines.

Using figures for year 2000 technology, wind turbine energy generation costs (capital investment plus fuel) run from 5 to 7 U.S. cents per kilowatt-hour, which is a similar cost to that of combined-cycle gas turbine plants. For coal steam turbine plants, this cost is between 3 and 4 cents per kilowatt-hour. Solar power plants are still much more expensive. In the United States, wind energy provided less than 1 percent of electrical power in 1997. It is estimated that wind could provide up to 10 percent of that power by 2020. By contrast, in Denmark in 2001, 15 percent of the country's electricity was produced by wind turbines. By 2030, the Danish government's energy plan is to have 50 percent of all electricity production provided by wind turbines.

Environmentalists worry about wind turbines causing bird strikes and disruption of migratory bird flight paths. However, it seems this worry has been exaggerated. The Cape Wind Project, currently in planning for Nantucket Sound, has received preliminary approval from the Massachusetts Audubon Society, indicating that the society finds bird strikes to pose only a small worry. Furthermore, the society strongly supports wind power in general.

Eugene E. Niemi, Jr.

- **Further Reading**

Harrison, Robert, Erich Hau, and Herman Snel. *Large Wind Turbines: Design and Economics.* Chichester, West Sussex, England: John Wiley & Sons, 2000. Presents an overview of wind turbine design factors and how they affect cost. Contains much descriptive material, but also some undergraduate-level mathematics.

Park, Jack. *The Wind Power Book.* Palo Alto, Calif.: Cheshire Books, 1981. General reference on many aspects of wind power, with minimal mathematics.

Pasqualetti, Martin J., Paul Gripe, and Robert Righter. *Wind Power in View.* San Diego, Calif.: Academic Press, 2002. Describes wind power systems in Europe, as well as the process of obtaining community acceptance for the technology. Many photographs and a brief list of additional reading.

Patel, Mukund R. *Wind and Solar Power Systems.* Boca Raton, Fla.: CRC Press, 1999. Provides an overview of the wind and solar power resources available, then delves into system components, energy storage, electrical grid connections, economics, and predictions for future use.

Putnam, Palmer C. *Power from the Wind.* New York: Van Nostrand Reinhold, 1948. One of the early seminal works on wind power; easy to read and illuminative of the history of the technology.

See also: Clean energy; Energy resources; Renewable energy; Solar energy.

World Bank

- **Categories:** Organizations and agencies; economics, industries, and products
- **Date:** Established 1945
- **Web address:** http://www.worldbank.org

• Mission

Named the International Bank for Reconstruction and Development, the World Bank was established in 1945 with the aim of promoting the post-World War II reconstruction. It has since evolved and become strongly focused on worldwide poverty alleviation, in conjunction with its affiliate, the International Development Association. The bank also deals with humanitarian emergencies and post-conflict rehabilitation affecting developing and transition economies.

Actor Harrison Ford participates in the launch of a World Bank-sponsored program to protect the world's tiger population. (Kevin Lamarque/Reuters/Landov)

• Significance for Climate Change

In December, 2007, Robert Zoellick, president of the World Bank Group, said at the Climate Change Conference in Bali, Indonesia: "Climate change is a development, economic, and investment challenge. It offers an opportunity for economic and social transformation that can lead to an inclusive and sustainable globalization." His comment is crucial in two respects: First, it demonstrates that the bank places climate change high in its development agenda. Second, it shows that the bank considers climate change as offering new opportunities for long-term poverty reduction and sustainable development.

The bank takes its climate change agenda seriously, because, according to its own research, a 1° Celsius increase in temperature will lead to a 10 percent loss in average net revenues per hectare in Africa. By 2020, it is estimated that between 75 million and 250 million people in Africa will suffer from water stress due to climate change. These scenarios will affect millions of poor people in developing countries, because they are dependent on natural resources for livelihoods such as agriculture, forestry, and fishing. Water and energy resources are also sensitive to climate change. The expected rise in sea level will also cause loss of farmland and result in migration and increased risk of conflicts over scarce resources. Poor people are least capable of adapting to climate changes because of inadequate infrastructure, low institutional capacity, and poor governance. As a result, climate change will increase vulnerability and malnutrition and lead to the outbreak of diseases. These challenges will undermine efforts to achieve the Millennium Development Goals.

The bank accepts that poor countries are least responsible for climate change and that they need assistance to overcome the threats posed by that change. Accordingly, the bank has developed its Strategic Framework for Climate Change, which aims to make poor nations' development activities more climate-resilient. It intends to integrate climate change policies into poverty and sustainable development strategies and to make climate risk management more consistent with good development practice.

The strategic framework comprises four elements: mitigation, adaptation, finance, and knowledge and capacity building. The bank's mitigation strategies focus largely on the energy sector. According to the Clean Energy Investment Framework and Action Plan, the emphasis will be placed on the transition to low-carbon development and on helping poor countries, especially those in sub-Saharan Africa, to obtain access to energy by investing in clean energy. The bank has launched Carbon Finance to help developing countries create and manage carbon assets. Working with the United Nations Permanent Forum on Indigenous People, the bank will design a carbon fund that will promote sustainable forest management and reduce forest degradation and deforestation.

In the adaptation side, the bank enhances poor countries' capacity to face climate variability. It places emphasis on sustainable and innovative technology in improving the local environment and integrates adaptation into national development planning. For instance, better land-use planning helps reduce construction on coastal regions subject to storm damage and river shorelines subject to frequent floods. Improving building standards can ensure some level of robustness against hurricanes and other extreme events. Creating reservoirs for flood control and dikes to reroute flood water are a few engineering interventions that promote farming practices to withstand climate variability.

Financially, the bank has set up two adaptation funds: the Special Climate Change Fund and the Least Developed Countries Fund, which will provide $150 million to $400 million a year. The Clean Technology Fund, as part of the mitigation strategies, will provide $5 billion to $10 billion. The bank acknowledges that these figures are insufficient to make changes in all developing countries.

Climate change affects countries differently, so the World Bank pays attention to country-specific adaptation strategies. It improves climate information, forecasting, and communication to facilitate disaster-risk assessment. It integrates risk reduction into sector development plans. It reckons the significance of collaborative efforts with other multilateral development banks and partners to assist vulnerable communities. It streamlines existing coordination mechanisms and enhances regional dialogue and cooperation in existing country partnership strategies, such as transboundary water governance.

In achieving mitigation-adaptation synergy, the bank promotes more community-driven development to avoid overgrazing and land degradation. More decentralised policies are implemented, so communities and social groups can develop their own adaptation strategies for climate-related challenges. The private and business sectors provide services and additional funding opportunities. The domestic insurance market, for example, aims to protect poor people against catastrophic losses. The public-private partnership, policy reforms, institutional development, and development of basic knowledge about adaptive technologies create incentives for the private sector.

The bank has, however, been criticised by some nongovernmental organizations and academics for lacking wide consultation with stakeholders and for lacking transparency in implementing climate change strategies. The design process of setting the Climate Investment Funds remains a donor-driven endeavor that can marginalize local communities. The imposition of conditionality in lending is also accused of reinforcing postcolonial power inequalities.

Sam Wong

- **Further Reading**

Tan, Celine. "World Bank's Climate Change Funds Will Undermine Global Climate Action." Penang, Maylaysia: Third World Network, 2008. Provides a critique of the Bank's unfair climate change policies in developing countries.

World Bank. *Climate Change and Adaptation: Envi-*

ronment Matters at the World Bank. Washington, D.C.: Author, 2008. Examines the impact of climate change in different developing countries and the bank's updated adaptation policies.

_______. *IDA and Climate Change: Making Climate Action Work for Development*. Washington, D.C.: Author, 2008. Highlights the bank's mitigation policy and finances in response to climate change.

See also: Asia-Pacific Partnership; Sustainable development; United Nations Division for Sustainable Development.

World Health Organization

- **Categories:** Organizations and agencies; diseases and health effects
- **Date:** Established 1948
- **Web address:** http://www.who.int/en/

• Mission

The World Health Organization (WHO) is the directing and coordinating agency on health within the United Nations system. The WHO is responsible for providing leadership on health issues, supporting and promoting health research, establishing guidelines and standards in health, developing health policies, and building the capacity of countries.

The headquarters of the WHO are in Geneva, Switzerland. It has six regional offices in Copenhagen, Denmark; Cairo, Egypt; Washington, D.C.; Brazzaville, Congo; New Delhi, India; and Manila, Philippines. The membership of the WHO consists of 193 countries and two associate members. Together, they constitute the World Health Assembly, which meets every year in Geneva. During the annual meeting, policies of the organization are decided and a budget is approved. Every five years, the World Health Assembly appoints the director general, who serves as head of the agency. The World Health Assembly also elects a thirty-four-member executive board.

The WHO is responsible for developing international health regulations, the rules that countries must follow to identify disease outbreaks and stop them from spreading. The WHO works closely with countries to ensure that they have the skills and people to carry out this task. In the process, it provides training and shares expertise with countries. The WHO has also formed the Strategic Health Operations Center, which coordinates information and response between countries in times of disease outbreaks and humanitarian emergencies. In terms of environment and climate change issues, the WHO shares its health expertise and collaborates with the United Nations Framework Convention on Climate Change (UNFCCC), World Meteorological Organization (WMO), United Nations Development Programme (UNDP), and United Nations Environment Programme (UNEP).

The WHO also has a Health Action in Crises team that works with member states to minimize suffering and death in crisis situations. The WHO helps build the capacity of countries to manage all types of crises and to deal in an effective and timely fashion with emergencies. The organization helps strengthen local health structures within countries. It also works with member states to plan, educate, and manage the health workforce.

• Significance for Climate Change

In the area of climate change, the WHO has raised awareness; strengthened public health systems to cope with the threats posed by climate change; enhanced the capacity of member countries to respond to public health emergencies; provided technical guidance for global and regional assessments in sectors that include energy, transport, water, and sanitation; enhanced applied research on health protection from climate change; and developed interdisciplinary partnerships. Since 2000, the WHO has convened several workshops on climate change. It has collaborated with the United Nations Development Programme to pilot test approaches in seven countries to protect health under a changing climate.

Since 1990, the WHO has published several reports discussing the health risks from climate change and climate variability. The regional offices and country offices of the WHO serve as foci for partnerships on health impacts from climate change.

The WHO also collaborates with health research organizations and U.N. agencies that are involved in adapting to climate change.

The WHO has several notable accomplishments in the area of health. One of its major achievements was the eradication of smallpox. Between 1967 and 1979, the WHO coordinated a campaign to eradicate smallpox and was successful in completely removing this disease from the world.

The WHO negotiated the first global health treaty on tobacco, the WHO Framework Convention on Tobacco Control (WHO FCTC), which entered into force on February 27, 2005. It sets standards on tobacco control measures, such as tobacco prices and tax increases, advertising and sponsorship, product warning labels, and environmental tobacco smoke.

Manoj Sharma

• Further Reading

Burci, Gian Luca, and Claude-Henri Vignes. *World Health Organization.* The Hague, the Netherlands: Kluwer Law International, 2004. Discusses the genesis, constitution, membership, and structure of the WHO. One of the authors is a former legal counsel of the WHO and the other is a senior official of the WHO's legal office. Intended for scholars and practitioners from a nonmedical background.

Campbell-Lendrum, Diarmid, and Rosalie Woodruff. *Climate Change: Quantifying the Health Impact at National and Local Levels.* Geneva, Switzerland: World Health Organization, 2007. Discusses methods of assessing the effects of climate change upon diseases and injuries at both local and national levels. A good example of the work in the area of climate change done by the WHO.

Powell, Jillian. *World Organizations: World Health Organization.* Danbury, Conn.: Franklin Watts, 2000. This easy-to-read book about the WHO and its work is one in the series of introductory books written on international organizations.

Siddiqui, Javed. *World Health and World Politics: The World Health Organization and the UN System.* Columbus: University of South Carolina Press, 1995. Evaluates the accomplishments of the WHO, including its field effort in the Malaria Eradication Programme. Analyzes WHO policies and programs using internal documents, personal interviews, meeting records, and secondary sources.

See also: Asthma; Diseases; Health impacts of global warming; Skin cancer.

World Heritage Sites

• **Category:** Environmentalism, conservation, and ecosystems

• Definition

World Heritage Sites are locations that have been designated by The United Nations Educational, Scientific, and Cultural Organization (UNESCO) as having "outstanding value to humanity." Locations can be of natural significance, such as Australia's Great Barrier Reef, or cultural significance, such as the Egyptian pyramids. UNESCO encourages the identification and preservation of these locations, keeping them in trust for humanity as a whole, not just for the country in which they are located.

One of the earliest examples of preservation on a global scale was the effort to protect the Abu Simbel and Philae temples in Egypt. The temples, which date back to the thirteenth century B.C.E., were in danger of being flooded by the Nile River during the construction of the Aswan High Dam. In 1959, UNESCO responded to a request for assistance from Egypt and Sudan to preserve the temples. Fifty countries financially contributed to the effort to relocate the monuments to high ground, which was completed in 1968. This global cooperation effort let to similar projects in Venice, Italy; Moenjodaro, Pakistan; and the Borobodur Temple Compounds in Indonesia.

In 1965, a conference at the White House recommended the establishment of a "world heritage trust" to encourage international cooperation to protect similar sites of global significance. A similar plan was proposed by the International Union for Conservation of Nature (IUCN) in 1968. At the United Nations Conference on the Human Envi-

World Heritage Site Distribution

Region	*World Heritage Site Nations*	*Cultural Sites*	*Natural Sites*	*Mixed Sites*	*Total*	*%*
Africa	27	40	33	3	76	9
Arab states	16	60	4	1	65	7
Asia and the Pacific	27	125	48	9	182*	21
Europe and North America	49	372	54	9	435*	49
Latin America and the Caribbean	25	82	35	3	120	14
Total	144	679	174	25	878	100

Source: United Nations Educational, Scientific, and Cultural Organization.
*The Uvs Nuur Basin straddles Europe and Asia. It is counted in this table as part of the Asian region.

ronment in 1972, the two plans were presented, the result being the Convention Concerning the Protection of World Cultural and Natural Heritage, which was adopted by the General Conference of UNESCO on November 16, 1972.

Some 185 nations have ratified the convention and are eligible to nominate locations to be considered for protection under its terms. By doing so, the member nation (called a "State Party") is expected to oversee each location and provide periodic updates. It can also request monetary assistance if needed. This process is overseen by the World Heritage Committee, which consists of twenty-one states that traditionally serve four-year terms and are elected by the General Assembly of State Parties.

As of 2008, there were more than 875 designated World Heritage Sites in 145 countries. To be considered for World Heritage designation, a site must "be of outstanding universal value" and meet at least one of ten selection criteria. For cultural sites, this includes architecture, human settlements, technological achievement, or "a masterpiece of human creative genius." Natural sites must exhibit ongoing ecological or biological processes, contain significant or unique ecological habitat, display stages of Earth's history, or exhibit "superlative natural phenomena or areas of exceptional natural beauty."

• Significance for Climate Change

The process for identifying and protecting World Heritage Sites can be traced back to two separate groups of people: those interested in nature conservation and those interested in protection of natural sites. The goal of the World Heritage Program is to present these sites as worthy of preservation from both natural and cultural standpoints. The sites remain the property of the country in which they are located, but those countries are assisted in maintaining and promoting the site.

There are many benefits to having a site designated as a World Heritage Site, with tourism being the most obvious. Locations that would otherwise go unvisited become known, and some travelers are eager to visit culturally significant sites before they disappear. Tourism benefits local economies, which in turn brings in the revenue needed to maintain the sites, a problem that is especially acute in developing countries. The downside to this is that increased tourist traffic can threaten the integrity of an already-threatened site. World Heritage status can help national and local governments manage the delicate balance between no interest and too much interest. Through the Preservation Fund, World Heritage can provide financial assistance for protection and restoration of designated sites.

One function of the 1972 convention is to identify sites that are in immediate danger. Melting glaciers, deforestation, and pollution are just a few of the environmental factors that can disrupt or destroy an ecologically sensitive site. Warmer sea and ocean temperatures could bring about a loss of biodiversity in an already-threatened location such as Australia's Great Barrier Reef.

Human-made sites are also threatened by the changing climate. Acid rain, changes in temperature and humidity, and rising sea levels can wreak havoc on ancient stone, and some scientists are predicting that the historic city of Venice, Italy, a designated World Heritage Site, could see daily flooding by the end of the twenty-first century.

P. S. Ramsey

• Further Reading

Cattaneo, Mark. *Ancient Civilizations: World Heritage Sites*. New York: White Star, 2004. A focused look at the World Heritage Sites that are significant from an archeological and anthropological standpoint.

Fowler, Peter. *Landscapes for the World: Conserving a Global Heritage*. Bollington, Cheshire, England: Windgather Press, 2004. An overview of World Heritage Sites, with a focus on the importance of these sites to the global community.

Harrison, David, and Michael Hitchcock, eds. *The Politics of World Heritage: Negotiating Tourism and Conservation*. Tonawanda, N.Y.: Channel View, 2005. A collection of essays on various World Heritage Sites, focusing on the difficult balance between tourism and preservation.

Sayre, Carolyn. "The Oscars of the Environment." *Time*, June 22, 2007. A look at the selection process for World Heritage Sites, as well as their significance in the ecological movement.

See also: Australia; Civilization and the environment; International agreements and cooperation; United Nations Conference on the Human Environment; Venice.

World Meteorological Organization

• Categories: Organizations and agencies; meteorology and atmospheric sciences
• Date: Established 1950
• Web address: http://www.wmo.int/pages/index_en.html

• Mission

An international clearinghouse on the weather and the environment, the World Meteorological Organization (WMO) is a principal supplier of scientific information to researchers assessing climate change. The WMO is an agency of the United Nations, dedicated to monitoring Earth's atmosphere, atmospheric interaction with the oceans, climate, and water resources. Headquartered in Geneva, Switzerland, WMO's secretariat, headed by the secretary-general, oversees its daily operations. Its thirty-seven-member executive council meets yearly to review programs and the budget. The World Meteorological Congress convenes every four years, at which time representatives of its 188 member states and territories decide on policies, consider applications for membership, pass regulations, and make long-term plans.

The WMO's purpose is to contribute to the safety of humanity through various programs, such as the World Weather Watch Program, and services investigating the environment. It promotes networks for gathering data about the weather, climate, water resources, and geophysical phenomena, not only to increase fundamental scientific knowledge but also to warn of possible natural disasters. It assists technology transfers to this end, encourages collaboration among the national meteorological and hydrological organizations of its members, and provides information to public weather, agriculture, aviation, environmental, and shipping services. The WMO also holds forums on the status of regional climate to foster consensus among climate experts and help emergency responders and governments in disaster prevention.

• Significance for Climate Change

In 1988, the WMO, in conjunction with the United Nations Environment Programme, established the Intergovernmental Panel on Climate Change (IPCC). The WMO's observational programs supply IPCC scientists with much of the data on which to base their conclusion that Earth's atmosphere is warming because of human activities and that climate change will have many adverse effects on civilization. In April, 2008, Deputy Secretary-General Hong Yan reaffirmed the WMO's support for the IPCC's work as vital to world peace. A statement about climate on the WMO's web site explains,

> Climate affects the lives and livelihoods of people everywhere. Global warming poses threats to society in various ways. Increased and extended droughts are a direct threat to millions of people. Millions more are affected by reduced crop and fishing harvests. Heatwaves, especially in urban situations, have recently caused the death of thousands of people, notably the elderly and infirm. The economy of many countries, especially small island States, depends on tourism. They are particularly vulnerable to sea-level rise, coastal erosion, saltwater intrusion, lack of freshwater, and the destruction of the natural environment, all adverse impacts of climate change.

Roger Smith

See also: American Meteorological Society; Canadian Meteorological and Oceanographic Society; Intergovernmental Panel on Climate Change; United Nations Environment Programme.

World Trade Organization

- **Categories:** Organizations and agencies; economics, industries, and products
- **Date:** Established 1995
- **Web address:** http://www.wto.int

• Mission

Established to reduce the financial and logistical costs to world trade, the World Trade Organization (WTO) faces the challenges of combating global warming. Measures for such combat require increased regulation and costs for new equipment. The WTO facilitates the creation and maintenance of commercial treaties among its 153 member nations, committed to global free trade. It began in 1947 as the General Agreement on Tariffs and Trade (GATT) and focused on removing barriers to trade in goods. In 1995, GATT became the WTO with a purview not only for goods but also services and intellectual property. Located in Geneva, Switzerland, the WTO headquarters monitor and adjudicate the multilateral treaties negotiated at meetings around the world, known as "rounds." The Geneva Round, the first, occurred in 1947 and lasted seven months. It achieved tens of thousands of tariff concessions worth billions of dollars. Rounds have become successively longer with ever weightier consequences. The Tokyo Round, the seventh, lasted from 1973 to 1979 and achieved trade economies in the hundreds of billions dollars. The Uruguay Round of the eighties and the Doha Round, the first after the establishment of the WTO, have further multiplied trade.

• Significance for Climate Change

The WTO has created the modern phenomenon of globalization. Trade requires energy for manufacturing and transportation. During the last third of the twentieth century, energy consumption doubled. Production of energy primarily involved the use of coal, gas, and oil, fossil fuels that release atmospheric carbons when activated. As accumulated carbons have accelerated global warming, the massive role of world trade has emerged as tellingly obvious. However, the WTO is poorly constituted to confront this problem. Among its many agencies, there is an Environment and Trade Committee. However, the committee applies itself only to cases in which the environmental practices of one country interfere directly with the trade prospects of another.

The driving purpose of the WTO is to increase trade by removing or reducing legal and financial barriers. To combat global warming, extensive regulation of carbon emissions is necessary, requiring expensive new factory and automotive equipment. By adding to the cost and logistics of trade, the combating of global warming runs counter to the efficiencies and economies of free trade. In the short run, thereby, measures against global warming burden global commerce. In the long run, nevertheless, they are essential in allowing it to survive.

Edward A. Riedinger

See also: Convention on International Trade in Endangered Species; Institute for Trade, Standards, and Sustainable Development; United Nations Conference on Environment and Development; United Nations Division for Sustainable Development; World Bank; World Health Organization.

Younger Dryas

- **Category:** Climatic events and epochs

- **Definition**

After the Pleistocene epoch ended, Earth's climate began a variable warming trend, punctuated by episodes of cooler temperatures and reglaciations. The Younger Dryas, occurring 12,900 to 11,600 years ago, was a well-defined climatic event during which cool temperatures returned and ice sheets reformed. The term "Dryas" denotes the arctic-alpine herb, *Dryas octopetala*. Early evidence for the Younger Dryas were *Dryas octopetala* macrofossils found in Scandinavian terrestrial deposits that overlie warmer climate deposits.

After the Scandinavian discovery, pollen studies of European lake and bog sediments were undertaken during the 1930's. This field research found that tundra pollen is characteristic of the Younger Dryas and tundra pollen always appears after the deposition of forest pollen (which indicates a warmer climate). The occurrence of the Younger Dryas is documented by vegetation changes; faunal changes; higher dust levels; and elevated atmospheric chemical concentrations, as identified in ice cores.

Since early Younger Dryas evidence was collected in Europe, Scandinavia, and Greenland, it was thought that the Younger Dryas was confined to these northern geographic areas. However, vegetation changes from mixed conifer-deciduous forest to cooler climate boreal trees in southern New England indicate Younger Dryas events occurred in North America as well. The replacement of shrub tundra with herb tundra in northern Nova Scotia along with shrub tundra replacing spruce forest in southern New Brunswick and central Nova Scotia also indicates Younger Dryas occurrence in North America. In addition, Younger Dryas evidence is found in mid-America, on the coast of the Pacific Northwest, British Columbia, and Alaska.

Prior to the onset of the Younger Dryas, glaciers had retreated from Great Britain; Scandinavian and Laurentide ice sheets were in regression; and, according to global sea-level records, ice covered less than 15 percent of Earth's surface. After the inception of the Younger Dryas, glaciers reformed in Europe and North America—from Scotland to the western Rocky Mountains. At the close of the Younger Dryas, temperatures rose quickly, 5°-10° Celsius within ten years. They continued to increase to 15° Celsius warmer than they had been. This abrupt rise in temperatures, as revealed in Greenland ice cores, was surprising to climate scientists. The Greenland cores had revealed other rapid climate changes—the abrupt deglaciation at the end of the Pleistocene.

- **Significance for Climate Change**

Results from ice cores, glaciers, and land and deep-sea sediments disclose that large areas of Earth have had almost synchronous changes from glacial to interglacial in short intervals of ten to thirty years. This means the entire climate regime (cold-warm) can reorganize in less than one lifetime. With the reality of rapid changes in global climate regimes, there is the threat that anthropogenic global climate change might initiate abrupt shifts in climate, leaving human populations unprepared.

Antarctic ice cores indicate a high ratio of oxygen 18 (O^{18}) to oxygen 16 (O^{16}) during interglacials, suggesting that ice formed when atmospheric temperatures were elevated; also, high concentrations of carbon dioxide (CO_2) and methane (CH_4) have been reported. High levels of greenhouse gases (GHGs), trapped in ice core air bubbles, indicate a period of atmospheric warming. GHGs are reduced during glacial periods.

Today, as a result of deforestation and fossil fuel burning, air temperatures, CO_2, and CH_4 levels are all rising. The CO_2 generated before the Industrial Revolution occurred naturally; rising atmospheric CO_2 after 1830 was generated by humans. This can be demonstrated, because the CO_2 isotope of fossil fuels has a characteristic signature that matches current CO_2. Climate models of high CO_2 demonstrate that nighttime low temperatures should increase and that daily temperature variation should be reduced. Climate data collected from the last century confirm this prediction—the effects of global warming.

Research undertaken to discover the cause of the Younger Dryas points to perturbation of the global ocean thermohaline circulation (THC), which transports tropical heat to higher latitudes.

North Atlantic Ocean cooling is triggered by the addition of large amounts of terrestrial freshwater. Cyclic changes in quantities of meltwater (such as glacial lake outbursts or icebergs carrying glacial water), can supply large volumes of freshwater to the northern Atlantic Ocean, causing the THC to slow or stop.

The Younger Dryas event has significance for global warming: At its close, abrupt change of climate from glacial to warm conditions occurred, demonstrating that climatic processes are not gradual but rapid and dramatic, with the potential to plunge human populations, in less than a decade, into cold or warm conditions and back again. The Younger Dryas was initiated by some imbalance in the THC, such as flood waters or lake-bearing icebergs. Global warming may supply copious amounts of melted glacial water, thus triggering a perturbation of the THC and initiating a "Younger Dryas-like" event in the Northern Hemisphere.

Mariana L. Rhoades

• Further Reading

Alley, R. B., et al. "Abrupt Increase in Greenland Snow at the Beginning of the Younger Dryas Event." *Nature* 362 (April 8, 1993): 527-529. Argues that ice core evidence suggests abrupt climate change; reviews deep ocean convection and atmospheric circulation.

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It.* New York: Hill and Wang, 2008. Text on climate science, glaciation, and abrupt climate change; details the consequence of global warming; concluding chapters describe remedies.

Dalton, R. "Blast in the Past?" *Nature* 447 (May 17, 2007): 256-257. Details geophysical research into a bolide explosion on or above the northern ice cap initiating the Younger Dryas; discusses proposed causes of the event; provides physical evidence for impact.

Press, F., R. Siever, J. Grotzinger, and T. Jordan. *Understanding Earth.* New York: W. H. Freeman, 2003. Geology textbook that provides a solid background on glaciation, climate systems, global climate change, and human impact.

See also: Alleroed oscillation; Climate reconstruction; Deglaciation; 8.2ka event; Holocene climate; Industrial Revolution; Paleoclimates and paleoclimate change; Pleistocene climate.

Appendixes

Biographical Dictionary of Key Figures in Global Warming

The figures described below are important in the history of global-warming and climate-change research. Asterisked individuals are covered in greater depth in separate essays within these volumes.

Agassiz, Louis* (1807-1873): Swiss naturalist, paleontologist, geologist, and glaciologist. Agassiz originated the concept of the Great Ice Age, an idea of fundamental importance to the understanding of cyclic change in Earth's climate.

Akasofu, Syun-Ichi (b. 1930): Japanese American geophysicist and director of the International Arctic Research Center at the University of Alaska, Fairbanks, until 2007. Akasofu has argued that the method of study used by the Intergovernmental Panel on Climate Change is fundamentally flawed and that the recovery from the Little Ice Age and the multidecadal oscillation probably caused the recent global warming.

Allègre, Claude (b. 1937): French geochemist and politician. In the 1980's Allègre asserted that human fossil fuel consumption was causing global warming, but in 2007 he reversed himself, saying the causes are unknown. He served as France's minister of education, research, and technology and was a prominent researcher at the Institute of Geophysics in Paris.

Alley, Richard B. (b. 1957): American glaciologist. Alley studies the relation between the Earth's coldest regions and climate change. He authored one chapter of the Intergovernmental Panel on Climate Change's Fourth Assessment Report (2007): "Observations: Changes in Snow, Ice, and Frozen Ground."

Arrhenius, Gustaf* (b. 1922): Swedish American oceanographer and geochemist. Arrhenius determined that ocean sedimentation can reveal what the climate was like in ancient times. This provides a basis for knowing what might happen in modern times.

Arrhenius, Svante August* (1859-1927): Swedish physical chemist. Sometimes called the "father of climate change," Arrhenius was the first to quantify the relationship between enhanced or diminished atmospheric carbon dioxide concentrations and the elevation or depression of the Earth's surface temperature, which later stimulated others to develop more sophisticated mathematical models of global warming.

Axelrod, Daniel* (1910-1998): American paleoecologist. Axelrod showed how past climate change caused the plants of an area to change. Scientists can apply his methods to predict vegetation change likely to result from future changes in climate.

Ball, Tim: Canadian geographer. A retired professor at the University of Winnipeg and head of the National Resources Stewardship Project, Ball is a prominent global warming skeptic. He has denied the role of fossil fuel emissions in global warming and of chlorofluorocarbons in thinning the ozone layer. He argues that global warming could be beneficial to humanity.

Balling, Robert C., Jr. (b. 1952): American geographer and past director of Arizona State University's Office of Climatology, Balling is a prominent skeptic in the global warming controversy. In 2005, however, he wrote that there is substantial evidence of nonsolar control of atmospheric temperatures, for which greenhouse gases are a potential explanation.

Bennett, Hugh Hammond* (1881-1960): American soil conservationist. Bennett recognized that climate influenced soil erosion and incorporated assessments of temperature, precipitation, and other climatic factors in soil conservation techniques.

Bjerknes, Vilhelm (1862-1951): Norwegian meteorologist. A researcher in fluid dynamics and thermodynamics, Bjerknes produced the first mathematical formulas for weather forecasting, which were the basis for modern climate modeling.

Bradley, Raymond S. (b. 1948): English American climatologist. Bradley has argued, on the basis of reconstructions of the temperature record for the past millennium, that natural mechanisms cannot account for the modern warming of the climate.

Bradshaw, William E. (b. 1942): American evolutionary biologist. Bradshaw and his wife, Christina M. Holzapfel, both of the University of Oregon's Center for Ecology and Evolutionary Biology, were the first to find definite evidence that global warming has forced evolutionary changes in a modern species.

Briffa, Keith (b. 1952): English dendroclimatologist. A faculty member of the University of East Anglia's Climatic Research Center, Briffa is a pioneer in studying climate change in Europe during the past ten thousand years by examining tree rings and relative isotope concentrations.

Broecker, Wallace Smith (b. 1931): American geophysicist. A professor at Columbia University's Lamont-Doherty Earth Observatory, Broecker was among the first to warn that humans are causing global warming. He investigates cycles in the oceans, including the thermohaline cycle, in order to compile a record of climate change during the Pleistocene epoch and after.

Bryden, Harry L. (b. 1946): English oceanographer. Bryden, a professor at the University of Southampton, examines the role of ocean heat and freshwater transport in global climate. In 2004 his research team from the National Oceanography Centre found that the Atlantic had slowed its circulation by nearly a third.

Cane, Mark A. (b. 1944): American oceanographer and climate scientist. A researcher at Columbia University's Lamont-Doherty Earth Observatory, Cane was among the researchers who in 1985 used mathematical modeling to forecast accurately the onset of the El Niño-Southern Oscillation. He also studies mechanisms of abrupt climate change.

Carson, Rachel* (1907-1964): American naturalist, ecologist, and writer. Although at the time she published *Silent Spring* (1962) Carson did not attribute global warming to human causes, she was well aware of climate change and held the view that humans were distinguished largely by their power to alter nature, perhaps irreversibly.

Charney, Jule Gregory (1917-1981): American meteorologist. Charney was among the first to use computers to model the hydrodynamics of the atmosphere in order to forecast weather (beginning in 1948), and from 1968 to 1971 he led the Global Atmospheric Research Program, an international effort at systematic observation of global circulation patterns.

Christy, John R. (b. 1951): American atmospheric scientist. A professor of atmospheric science at the University of Alabama, Christy specializes in compiling a temperature record based on satellite observations. He has expressed caution about the human contribution to global warming, saying that it undoubtedly exists but that scientists should refrain from making sensationalist predictions. He has also suggested that global warming from increased carbon dioxide could have a net benefit.

Chylek, Petr (b. 1937): Canadian atmospheric physicist. Chylek is an adjunct professor at Dalhousie University in Halifax, Nova Scotia. He is noted for researching atmospheric conditions related to climate change with remote sensing. He has concluded from his data that the rise in atmospheric carbon dioxide will have a smaller influence on global temperatures than the consensus estimate by the Intergovernmental Panel on Climate Change.

Corell, Robert (b. 1934): American oceanographer. Corell chaired the council of the National Science Foundation that produced the Arctic Climate Impact Assessment. It found average temperatures rising faster and earlier ice-melting than anticipated, and Corell forecast that the next century will see a 50 percent reduction of Arctic sea ice during the summertime.

Cotton, William R. (b. 1940): American physicist and meteorologist. Cotton is a pioneer in computer simulation of cloud dynamics and thunderstorms and in forecasting their effects on agriculture and aviation. He has said that it remains an open question how extensively humans have contributed to climate change.

Crichton, Michael (1942-2008): American writer and physician. Crichton published the best-selling novel *State of Fear* in 2004. Its plot arises from a conspiracy among environmentalists to cause public alarm about global warming, which is portrayed as supported by flimsy evidence. Following the story are pages of footnotes and a bibliography supporting the conspiracy-theory claim.

The novel was embraced by global-warming deniers.

Crutzen, Paul J. (b. 1933): Dutch atmospheric chemist. Crutzen shared the 1995 Nobel Prize in Chemistry for his investigation of the hole in the ozone layer. He proposes strenuous measures to forestall global warming—for instance, by placing sulfur particles in the upper atmosphere to deflect light. With Eugene F. Stoermer, in 2000 Crutzen suggested the current geological era be called the "anthropocene" because of humanity's impact on the environment. *See also* Molina, Mario J.; Rowland, F. Sherwood.

Dansgaard, Willi (b. 1922): Danish paleoclimatologist. Dansgaard discovered that oxygen 18 and deuterium concentrations in glaciers provide information about climate change in the past and used the resulting technique to analyze samples from the Greenland ice sheet. Sequences of abrupt climate change that surfaced in the data are now called Dansgaard-Oeschger events. *See also* Oeschger, Hans.

De Freitas, Chris (b. 1948): New Zealand climatologist. Acknowledging that evidence points to global warming, de Freitas is a spokesperson for the view that emissions from fossil fuels may not be responsible and that natural variation theories of warming are valid. He is a professor at the University of Auckland, New Zealand, and studies tourism climatology.

deMenocal, Peter (b. 1960): American oceanographer and marine geologist. A researcher at Columbia University's Lamont-Doherty Earth Observatory, deMenocal analyzes the chemical components of marine sediments to study climate change during the Holocene epoch in North Africa and the North Atlantic, especially as it relates to human evolution.

Dickens, Gerald R.: American paleoceanographer. Dickens studies the distribution and composition of clathrate hydrates (icy combinations of water and gases, usually methane) on the ocean floors. The Rice University professor found evidence that rapid conversion of clathrates to gas in the past may have contributed to abrupt climate change.

Elton, Charles Sutherland* (1900-1991): English ecologist. Elton was the first person to describe invasions by animals and plants. As the climate changes, all indications are that invasions will be more frequent and have greater effect.

Emanuel, Kerry (b. 1955): American meteorologist. Highly regarded for his research in atmospheric dynamics, Emanuel said in 2008 that a 10 percent increase in hurricane intensity during the previous thirty years was in part caused by global warming, which also may effect a decrease in hurricane frequency.

Emiliani, Cesare* (1922-1995): Italian American paleoceanographer. Emiliani developed the oxygen isotopic abundance method to study the history of the oceans and their climate changes.

England, Matthew (b. 1966): Australian oceanographer and climate scientist. England studies ocean currents, especially in the Southern Hemisphere, and their effects on climate. He helped organize the 2007 "Bali Climate Declaration by Scientists" and codirects the Climate Change Research Centre at the University of New South Wales.

Flannery, Tim (b. 1956): Australian paleontologist. At first a skeptic about anthropogenic global warming, by 2004 Flannery, a professor at Macquarie University, changed his mind and wrote an influential popular account of the problem and possible solutions, *The Weather Makers: The History and Future Impact of Climate Change* (2005).

Fourier, Joseph (1768-1830): French physicist and mathematician. Although best known for his mathematical discoveries, in 1824 Fourier advanced the idea that atmospheric gases warm the planet by trapping infrared energy from sunlight, the phenomenon later called the greenhouse effect.

Fung, Inez Y. (b. 1949): American meteorologist. Fung is codirector of the Berkeley Institute of the Environment at the University of California, Berkeley. She is an expert on the structure of hurricanes, climate modeling, and climate change, and she advocates strict regulation of carbon dioxide emissions.

Glacken, Clarence J.* (1909-1989): American geographer. An environmental historian who specialized in studying the relationships between culture and nature, Glacken was one of the first twentieth century scientists to recognize the connection between human activities and the environment. His masterwork, *Traces on the Rhodian Shore* (1967), analyzes nature and Western human thought from ancient times through the nineteenth century.

Gore, Al* (b. 1948): American statesman and environmental activist. A longtime congressional and administrative governmental advocate for environmental and global-warming issues, former vice president Gore, along with the Intergovernmental Panel on Climate Change, was awarded the 2007 Nobel Peace Prize for his work in raising global environmental awareness. He is the author of *An Inconvenient Truth* (2006) and *The Assault on Reason* (2007).

Hansen, James E. (b. 1941): American physicist and director of the Goddard Institute for Space Studies of the National Aeronautics and Space Administration. Hansen came to the public's attention when he testified before Congress in 1988 that humans were causing global warming. He was already renowned among scientists for correctly predicting warming trends. He is a frequent spokesperson on behalf of measures to curb climate change.

Haug, Gerald H.: Swiss paleoclimatologist. Haug's research corroborated the view that climate in the last two thousand years has been volatile and that extended droughts contributed to the decline of the Mayan civilization.

Haywood, Alan: English paleoclimatologist. The principal investigator for the British Antarctic Survey, Haywood published a paper in 2005 that concluded that increased levels of carbon dioxide three million years ago caused extensive polar ice melting. He points out that the carbon dioxide levels were similar to those of today.

Henderson-Sellers, Ann (b. 1952): Australian physical geographer and director of the World Climate Research Program from 2006 to 2007. Henderson-Sellers is a professor at Macquarie University, heads collaborative measurement projects, and was a lead author for the Intergovernmental Panel on Climate Change's Second Assessment Report (1995).

Hoegh-Guldberg, Ove (b. 1959): Australian marine biologist. Hoegh-Guldberg, a professor at the University of Queensland, published a paper in 1999 reporting that rising sea temperatures are contributing to the destruction of coral reefs worldwide.

Hoerling, Martin P.: American meteorologist. Hoerling and his colleague Arun Kumar at the National Oceanic and Atmospheric Administration's Climate Diagnostics Center published the results of a computer model that suggested global warming would cause pervasive drought at midlatitudes, including large regions in the United States and Africa.

Hoffert, Martin (b. 1938): American physicist and aeronautical engineer. Hoffert is a proponent of a space-based solar power plant as a major replacement for fossil fuels. A retired professor at New York University, he argues that to reduce greenhouse gas emissions significantly, modern industrial society must make drastic infrastructure changes.

Hoffman, Paul F. *See* Schrag, Daniel P.

Holzapfel, Christina M. *See* Bradshaw, William E.

Houghton, John T. (b. 1931): Welsh atmospheric physicist. Houghton cochaired the Intergovernmental Panel on Climate Change when the group received the 2007 Nobel Peace Prize. He is a founder of England's Hadley Center for Climate Change and chairman of the John Ray Initiative, which seeks to find common purpose among scientists and Christians concerning the environment.

Howat, Ian M.: American glaciologist. Howat led a team studying Greenland's Helheim Glacier from 2000 to 2005. They found that the ice had thinned 40 meters, much faster than expected. He is a professor at Ohio State University's Byrd Polar Research Center.

Idso, Craig D.: American geographer. Idso founded and chairs the Center for the Study of Carbon Dioxide and Global Change. He conducts research on carbon sequestration and aspects of environmental change. He argues that atmospheric carbon dioxide does affect air temperature and that it may be good for plant growth.

Idso, Sherwood B. (b. 1942): American physicist. An expert in remote sensing, Idso studies the relation of agriculture to climate and became president of his brother Craig's Center for the Study of Carbon Dioxide and Global Change. He has published papers skeptical of the role of carbon dioxide in global warming.

Inhofe, James (b. 1934): U.S. senator from Oklahoma. Inhofe became the political leader of deniers when in 2003, before the U.S. Senate, he claimed to have compelling evidence compiled by leading scientists that global warming is a hoax.

Jones, Phil (b. 1952): English climatologist. A professor at the University of East Anglia and director of the Intergovernmental Panel on Climate Change's (IPCC) Climate Research Unit, Jones compiled a time series of hemispheric and global surface temperatures, updated monthly, that was foundational evidence for the IPCC's Third Assessment Report in 2001.

Joyce, Terrence: American physical oceanographer. A senior scientist at Woods Hole Oceanographic Institution, Joyce was one of the authors for *Climate Change 2007: The Physical Science Basis*. He monitors data from the Deep Western Boundary Current to test the theory that its alterations reflect large changes in thermohaline circulation in the North Atlantic.

Karl, Thomas R. (b. 1951): American meteorologist. Karl directs the National Oceanic and Atmospheric Administration's National Climatic Data Center, was the cochair of the U.S. National Assessment of Climate Variability and Change, and is an editor of the *Journal of Climate*. He has also been a lead author for the Intergovernmental Panel on Climate Change.

Keeling, Charles (1928-2005): American chemist and oceanographer. Keeling began recording atmospheric carbon dioxide levels atop Mauna Loa in Hawaii in 1958 and compiled the longest continuous record. The data established the Keeling Curve, which shows a steady increase in the gas. It provides basic evidence for global warming related to fossil fuel emissions.

Kumar, Arun. *See* Hoerling, Martin P.

Lamb, Hubert Horace* (1913-1997): English climatologist. Lamb was a pioneer in examining climate change from a historical perspective. He was one of the early students of the human impact on climate. Although some of his interpretations have been superseded, he pioneered the field and enhanced the scientific understanding of the factors that contribute to climate change.

Lambeck, Kurt (b. 1941): Australian geophysicist. Lambeck is president of the Australian Academy of Sciences, professor at the Australian National University, and past director of the Research School of Earth Sciences. He conducts research about the interactions among surface features, such as ice sheets, oceans, and solid earth.

Lash, Jonathan (b. 1945): American lawyer. As president of the World Resources Institute, an influential Washington, D.C., think tank, Lash advocates sustainable practices to prevent environment degradation. As a government official and agent of private organizations, he acquired a reputation for expertise in policy issues related to greenhouse gases.

Lindzen, Richard (b. 1940): American atmospheric physicist. A professor of meteorology at the Massachusetts Institute of Technology, Lindzen is noted for his studies of atmospheric dynamics. He has suggested that a negative feedback loop is activated when increased tropical sea surface temperature results in less cloud cover and more infrared radiation escaping into space, thus slowing global warming. This concept is known as the iris hypothesis.

Lovelock, James E. (b. 1919): English climatologist and inventor. An independent researcher, Lovelock is best known for detecting in the 1960's the increase in chlorofluorocarbons (CFCs) in the atmosphere. These compounds were later implicated in chemical reactions that cause depletion of Earth's protective ozone layer. Lovelock also proposed the Gaia hypothesis, first published in 1970, which proposes that the biosphere and Earth are interrelated in such a way as to be self-regulating, a superorganism.

Lubchenco, Jane (b. 1947): American marine ecologist. A specialist in coastal marine ecosystems and the effects of environmental change on them, Lubchenco was appointed administrator of the National Oceanic and Atmospheric Administration in 2009.

Malthus, Thomas Robert* (1766-1834): English demographer and economist. Malthus is best remembered for his hypothesis that while food supplies increase in an arithmetical progression, populations increase in a geometric progression. Therefore, with the increase in population, the food supply will be insufficient, resulting in famines and increased poverty. Malthus's predictions failed to materialize.

Manabe, Syukuro* (b. 1931): Japanese meteorologist. Manabe pioneered the use of computer models to simulate the impact of greenhouse gases on climate change. In 1967, he and Richard Wetherald demonstrated that increased carbon dioxide in the atmosphere would increase the altitude at which the atmosphere reradiated heat into space, thereby providing supporting evidence for the greenhouse theory.

Mann, Michael E. (b. 1965): American climatologist. A lead author for the Intergovernmental Panel on Climate Change's Third Assessment Report (2001), Mann is prominent in the field of paleoclimatology and helped compile the temperature graph known as the hockey stick graph (1998). Covering the last millennium and based on various data, the graph shows a sudden temperature spike during the last 150 years after a long, gradual decline. The graph has been cited as key evidence in the argument for human-caused global warming, although its accuracy has been questioned and it remains controversial.

Marsh, George Perkins* (1801-1882): American statesman. In his seminal work *Man and Nature*, Marsh put forth the idea that humans, from their very beginning, have been active agents of change upon their environment.

Mayewski, Paul (b. 1946): American paleoclimatologist and director of the University of Maine's Climate Change Institute. An expert in ice-core geochemistry, Mayewski has documented human-caused changes in atmospheric chemistry, ice loss in the Antarctic and the Himalayas, abrupt climate change events, and associations between climate and disruptions to civilizations.

Michaels, Patrick J. (b. 1950): American climatologist. A retired professor at the University of Virginia and fellow of the Cato Institute, Michaels wrote several popular books that expressed moderate skepticism about scenarios related to global warming, arguing that change will be slow and moderate.

Milanković, Milutin* (1879-1958): Serbian mathematician. The Milanković theory begins with a curve demonstrating the variation in intensity of summer sunlight over the past 600,000 years. Thereby past relationships among solar radiation, eccentricity, and climate can be examined and future trends extrapolated. Research into future climate regimes, without considering global warming, predicts that the present interglacial cycle may continue for twenty-five thousand years.

Mitchell, John F. B. (b. 1948): English physicist and climatologist. Chief scientist at England's Hadley Centre for Climate Prediction and Research, Mitchell also served as a lead author for the Intergovernmental Panel on Climate Change and studies extreme events caused by climate change.

Molina, Mario J. (b. 1943): Mexican chemist. Molina shared the 1995 Nobel Prize in Chemistry for discovering that chlorofluorocarbons (CFCs) were destroying Earth's protective ozone layer. In 2004 he founded the Mario Molina Center for Energy and the Environment. *See also* Crutzen, Paul J.; Rowland, F. Sherwood.

Oeschger, Hans (1927-1998): Swiss physicist. Oeschger used the tritium content of firn and ice to gather information about past climates. In Greenland, he helped study ice cores and with Willi Dansgaard detected series of abrupt climate fluctuations, now called Dansgaard-Oeschger events. *See also* Dansgaard, Willi.

Pacala, Stephen. *See* Socolow, Robert.

Pachauri, Rajendra K. (b. 1940): Indian economist. Beginning in 2002, when he became chairman of the Intergovernmental Panel on Climate Change, Pachauri oversaw its influential assessment reports, issued every five or six years. He also became chair of The Energy and Resources Institute (TERI) in New Delhi, India, which promotes research on sustainable development.

Parker, David: English climatologist. Parker heads climate monitoring at the Hadley Centre for Climate Prediction and Research in England and is an expert on the urban heat island effect.

Peltier, William Richard (b. 1943): Canadian physicist. Peltier is a professor at the University of Toronto and director of the Centre for Global

Change Science. He conducts research on atmospheric and oceanic dynamics and on Earth's climate and interior.

Pierrehumbert, Raymond T. (b. 1954): American geophysicist. A professor at the University of Chicago, Pierrehumbert uses mathematical models to study climate as a system on Earth and other planets. He served as a lead author of the Intergovernmental Panel on Climate Change's Third Assessment Report in 2001 and was a coauthor of a National Research Council study of abrupt climate change.

Pinchot, Gifford* (1865-1946): American federal administrator and forester. As first head of the U.S. Forest Service, Pinchot emphasized management of forest and park preserves to maintain healthy forests and to slow deforestation.

Pitman, Andrew (b. 1964): English atmospheric scientist and codirector of the Climate Change Research Centre at the University of New South Wales, Australia. Pitman studies carbon dioxide production and storage and their role in climate modeling. He is also an editor of the *Journal of Climate*.

Rahmstorf, Stefan (b. 1960): German oceanographer. One of the lead authors of the Intergovernmental Panel on Climate Change's Fourth Assessment Report (2007), Rahmstorf is a professor at Potsdam University and an expert on sea-level rise and the thermohaline cycle.

Ramanathan, Veerabhadran (b. 1944): Indian American atmospheric scientist and oceanographer. A professor at the Scripps Institution of Oceanography, Ramanathan studies atmospheric chemistry, circulation, and heat transfer. He participated in the development of the first global circulation models and found that chlorofluorocarbons (CFCs) contribute to the greenhouse effect. In 2007 he coauthored a paper on Project Surya, an attempt to counteract the effects of greenhouse-gas-producing biofuel stoves used in rural India by replacing them with solar cookers.

Revelle, Roger* (1909-1991): American oceanographer. In an article coauthored with Hans E. Suess in 1957, Revelle proposed the idea of the greenhouse effect, indicating that this phenomenon would lead eventually to global warming. Later in his career, Revelle served on the faculty of Harvard University, where he taught Al Gore, among others. *See also* Suess, Hans E.

Romanovsky, Vladimir (b. 1953): Russian American geophysicist. Romanovsky is a professor at the University of Alaska, Fairbanks, and studies the behavior of ice and permafrost. He has found that permafrost in Siberia and Alaska that dates from the last ice age is beginning to melt during the summers and could rapidly release carbon dioxide in large quantities.

Rowland, F. Sherwood* (b. 1927): American chemist. The award of the 1995 Nobel Prize in Chemistry to Rowland, his coworker Mario J. Molina, and Paul J. Crutzen "for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone" is considered a vindication of environmental science, hitherto belittled by mainstream science. *See also* Crutzen, Paul J.; Molina, Mario J.

Sauer, Carl* (1889-1975): American geographer. Sauer's essay "The Morphology of Landscape" established the idea of cultural landscapes. For this work, he is known as the founder of American cultural geography.

Schrag, Daniel P. (b. 1966): American geologist and director of Harvard University's Laboratory for Geochemical Oceanography. Schrag studies climate change based on ocean circulation and marine sediments, compiling temperature records. His research into glaciation 600-700 million years ago led him to formulate, with Paul F. Hoffman, the Snowball Earth hypothesis, which holds that the entire planet was coated with ice for long periods that ended violently under extreme greenhouse conditions.

Schumacher, E. F. (1911-1977): German British economist. Schumacher foresaw the problems that would be caused by societies that embraced the exploitation of resources for immediate gain without considering the long-term effects of such exploitation. His book *Small Is Beautiful* (1973) introduced the development theories of intermediate size and intermediate technology, forerunners of sustainability. Today, the E. F. Schumacher Society is devoted to "strong local economies that link people, land, and community."

Schwartz, Stephen E. (b. 1941): American atmospheric scientist. A researcher at Brookhaven National Laboratory, since 2004 Schwartz has served as senior scientist for the Department of Energy's Atmospheric Science Program, which has the long-term goal of comprehensively understanding the atmospheric processes governing the transport, transformation, and end state of trace chemicals and dust.

Socolow, Robert (b. 1937): American aerospace engineer. A professor at Princeton University, Socolow is co-principal investigator with Stephen Pacala for the Carbon Mitigation Initiative, which focuses on global carbon management and sequestration.

Solomon, Susan (b. 1956): American atmospheric chemist. Solomon is credited as the first scientist to propose that chlorofluorocarbons (CFCs) caused the Antarctic ozone hole, and she led the National Ozone Expedition to McMurdo Sound in 1986. Her results were crucial to creation of the United Nations' Montreal Protocol on Substances That Deplete the Ozone Layer (in force as of 1989). She directs the Chemistry and Climate Processes Group of the National Oceanic and Atmospheric Administration.

Somerville, Richard C. J. (b. 1941): American meteorologist. A professor emeritus at Scripps Institution of Oceanography, Somerville specializes in the physics of clouds and in the theoretical meteorology used in computer simulations of the atmosphere.

Steffen, Konrad (b. 1952): Swiss geographer. Steffen measures temperature changes in the Arctic and uses them to evaluate potential sea-level rise and its effects on climate. He participated in a study of the Greenland ice sheet that found a spike in temperatures and accelerating melting. He directs the University of Colorado's Cooperative Institute for Research in Environmental Sciences.

Stoermer, Eugene F. *See* Crutzen, Paul J.

Strong, Maurice F. (b. 1929): Canadian environmentalist and diplomat. Strong served as secretary-general of the 1972 United Nations Conference on the Human Environment and of its 1992 Conference on Environment and Development (the Earth Summit at Rio de Janeiro), where the first attempts were made to establish a global treaty on the overall environment.

Suess, Hans E. (1909-1993): Austrian chemist. A specialist in carbon 14 and tritium in the oceans and atmosphere, Suess helped calibrate the radiocarbon dating scale and formulated the Suess effect, which concerns the dilution of carbon isotope concentrations in the atmosphere by the addition of carbon dioxide from the burning of fossil fuels. *See also* Revelle, Roger.

Svensmark, Henrik (b. 1958): Danish physicist and director of Sun-climate research at the Danish National Space Institute. Svensmark specializes in cosmic rays and their effect on cloud formation. His findings suggest that cosmic rays have become scarcer over the last century because of increased solar activity, and the result is fewer clouds and rising temperature. He downplays the role of carbon dioxide in global warming.

Sverdrup, Harald (1888-1957): Norwegian oceanographer and meteorologist. The Sverdrup balance, described in 1947, was an important early theory of the relation of wind stress to ocean circulation. Sverdrup directed the Scripps Institution of Oceanography and later the Norwegian Polar Institute. A sverdrup, named in his honor, is a unit of measurement for volume transport in ocean currents.

Tett, Simon: English climatologist. The chair of Earth system dynamics and modeling at the University of Edinburgh, Tett specializes in climate modeling, particularly based on increasing levels of greenhouse gases and sulfate aerosols during the past five hundred years.

Thejll, Peter (b. 1956): Danish astrophysicist and meteorologist. Thejll's work demonstrated that the variations in solar energy after 1980 cannot account for rising global temperatures in the Northern Hemisphere, which implies that the greenhouse effect is responsible. He is a scientist at the Danish Meteorological Institute and fellow of the Niels Bohr Institute.

Thoreau, Henry David* (1817-1862): American philosopher and writer. In *Walden: Or, Life in the Woods* (1854), Thoreau presented an autobiographical account of his solitary life (over a two-year period) on Walden Pond. This work is now viewed as an early guide to global warming solutions from a personal point of view. Thoreau also indicated the need for conservation of natural resources to ensure preservation of the planet and environment.

Trenberth, Kevin E. (b. 1944): New Zealand meteorologist. A lead author for the 1995, 2001, and 2007 assessment reports on climate change for the Intergovernmental Panel on Climate Change, Trenberth has conducted research on the El Niño-Southern Oscillation (ENSO). He directs the Climate Analysis Section of the National Center for Atmospheric Research in the United States.

Walker, Gilbert* (1868-1958): English physicist and statistician. Walker is best known for his discovery of the Southern Oscillation in 1923. He is also recognized as a pioneer in statistical weather forecasting.

Wallace, John Michael (b. 1940): American atmospheric scientist. A professor at the University of Washington, Seattle, Wallace follows the observational data of global climate on a year-to-year and decade-to-decade basis. His work elucidated the dynamics of equatorial winds and the effects of El Niños.

Wegener, Alfred* (1880-1930): German meteorologist. Wegener became fascinated with the late Paleozoic ice age in the Southern Hemisphere and formulated the theory of continental drift to explain its geographic extent. His work laid the foundation for work by Harold Hess and others that led to the widely accepted theory of plate tectonics.

Weiss, Harvey (b. 1945): American archaeologist. A professor at Yale University, Weiss is best known for his theory that major climate changes helped foster some civilizations and caused others to collapse.

Wetherald, Richard. *See* Manabe, Syukuro.

Wunsch, Carl (b. 1941): American oceanographer. A professor at the Massachusetts Institute of Technology, Wunsch researches the effects of ocean circulation on climate. He is noted for warning that, although there definitely is a human component to climate change that poses a major threat to humanity, this human impact is complex and scientists must be wary of predictions about the near future.

Zwally, H. Jay: American physicist. A researcher for the National Aeronautics and Space Administration, Zwally mapped polar ice in Greenland and Antarctica to study its mass and variability. His research confirmed that in West (Lesser) Antarctica and Greenland, melting of the ice sheets is accelerating. He predicted that the Arctic Sea could become ice-free during late summers sometime in the 2010's.

Popular Culture About Global Warming

Much if not most fiction and film about global warming remains highly speculative and sensational. There is, however, a burgeoning subgenre focusing on the potential impacts of climate change. Although the works listed below are to be taken skeptically from a scientific standpoint, they may serve to prompt serious discussion about the social issues surrounding both anthropogenic and naturally induced changes in the global climate and environment. The works below are listed alphabetically by title: fiction first, followed by films.

• FICTION

AD2516: After Global Warming
- *Author:* Noel Hodson
- *First published:* 2005
- *Synopsis:* Two men and a woman are resuscitated five centuries after being frozen in the polar ice cap and are introduced to a well-adjusted world of 11 billion people and sea levels 100 feet higher than today. The scenario serves as a backdrop for social satire of environmentalists' gloomy predictions of the future.

The Apocalypse Rising
- *Author:* Jim Sampson
- *First published:* 2009
- *Synopsis:* Five huge volcanoes erupt simultaneously in Antarctica and worldwide temperature levels zoom, creating chaotic weather. A desperate rescue attempt to remove scientists trapped near the volcanoes is undertaken while colleagues struggle to understand the extent of the climate change that looms.

Arctic Drift
- *Authors:* Clive Cussler and Dirk Cussler
- *First published:* 2008
- *Synopsis:* This twentieth novel in Clive Cussler's series about adventurer Dirk Pitt has him investigating murders and international incidents related to a possible means to reverse global warming with a mysterious mineral, ruthenium: more derring-do and intrigue than science.

At Winter's End
- *Author:* Robert Silverberg
- *First published:* 1988/2005
- *Synopsis:* In this fantasy adventure, a band of humans emerges from underground and struggles to reclaim their lost civilization following a seven-hundred-century winter caused by a natural cataclysm.

Big Ice
- *Author:* Christopher Bonn Jonnes
- *First published:* 2003
- *Synopsis:* A publicity-shunning scientist is chased by ecoterrorists who want to stop him from making public his discovery of a method to predict calving from the Antarctic ice sheet because of global warming and his belief that a major event, which will imperil islands and coastal cities, is imminent. An exaggerated scenario, but within the possibilities of science.

Birmingham, Thirty-five Miles
- *Author:* James Braziel
- *First published:* 2008
- *Synopsis:* Set in 2044, the story follows the characters' attempts to live in the Deep South, rendered arid and barren following shifts in wind patterns and destruction of the ozone layer overhead. The author is concerned with the emotional effects of climate change rather than its causes.

The Carbon Diaries, 2015
- *Author:* Saci Lloyd
- *First published:* 2009
- *Synopsis:* Following a superstorm that hits London, the British government puts the nation on a severe emissions diet; a teenager records her experiences during the rationing and further environmental disasters.

Carbon Dreams
- *Author:* Susan M. Gaines
- *First published:* 2001
- *Synopsis:* Based on realistic science and realistic

depictions of how scientists behave, the plot, set in the early 1980's, follows a scientist battling to test her theory of dating marine sediments while maintaining a relationship with an environmental activist worried about global warming.

A Chilling Warmth: A Tale of Global Warming
- *Author:* Jay Kaplan
- *First published:* 2002
- *Synopsis:* An alien spaceship lands on Earth in 2223. It is a dismal, stormy place devoid of humans because of global warming and nuclear war. Two of the crew intend to return to 2003 in order to persuade a key scientist to change his views on global warming so that the world can avoid catastrophe.

The Doomsday Report: A Novel
- *Author:* Rock Brynner
- *First published:* 1998
- *Synopsis:* A media storm and terrorism erupt after publication of the Belacqua Report, which, based on ostensibly reputable science, proves that human-caused climate change has already doomed humanity within the next half century. The report, however, proves to be false.

Earth
- *Author:* David Brin
- *First published:* 1991
- *Synopsis:* Fifty years in the future sea levels have risen because of global warming, creating millions of refugees, and the thinning ozone layer is causing widespread skin cancer, but these are nothing compared to the danger from a mini-black hole that has fallen into the Earth. In this thriller, prophetic in several ways, scientists, Internet-bound virtual humans, and even aliens struggle to save the Earth.

The Elementals
- *Author:* Morgan Llywelyn
- *First published:* 1993
- *Synopsis:* These four fantasy tales represent the ancient elements of fire, earth, air, and water; one concerns fifty women and three men who reach Ireland and try to reclaim a semblance of civilization after floods decimate humanity worldwide, and a second follows a twenty-first century scientist's attempts to prevent destruction of the atmosphere.

Empire Builder
- *Author:* Ben Bova
- *First published:* 1993
- *Synopsis:* An adventurer-businessman discovers that an environmental disaster looms that will inundate coastal cities, which his enemies hope to use as an excuse to monopolize the world economy. On the lam from Earth to the Moon, he finds a way to expose his enemies in this doomsday-scenario thriller.

Enclave
- *Author:* Kit Reed
- *First published:* 2009
- *Synopsis:* Following environmental devastation, war, and plagues, rich parents seek safety for their spoiled children by sending them to a fortress school, Clotho Academy.

Fallen Angels
- *Authors:* Larry Niven, Jerry Pournelle, and Michael Flynn
- *First published:* 1991
- *Synopsis:* The fallen angels are two astronauts from a space station-based culture who have crash-landed in the United States, which is hostile to technology and spacefarers. A new ice age and rapidly advancing glaciers, somehow "caused by environmentalism," complicate a rescue attempt.

Fatal Climate
- *Author:* David Hood
- *First published:* 2000
- *Synopsis:* This technothriller concerns a secret plot by the president of the United States to suppress, violently, any attempt to publicize the results of a computer simulation predicting imminent collapse of the environment because of global warming.

The Final Warning: A Maximum Ride Novel
- *Author:* James Patterson
- *First published:* 2008
- *Synopsis:* Dodging killer robots and monster storms, a group of mutant kids helps scientists study global warming. Interspersed among the teenage angst, sarcasm, and derring-do are clear, sober passages written about the mechanisms behind climate change and its possible consequences.

Finitude
- *Author:* Hamish MacDonald
- *First published:* 2009
- *Synopsis:* After thirty years of rationing as a means to counteract global warming has taken place, the prime minister of England declares victory, but the story's protagonist, an insurance salesman, has inside information that disaster is coming—and yearns for it—in this comic tale.

Flood
- *Author:* Stephen Baxter
- *First published:* 2008
- *Synopsis:* Anthropogenic global warming induces the release of vast water reserves from Earth's mantle. The oceans rise to cover all land within a generation. An imaginative leap from actual science, the scenario depicts humanity violently decimated and culture permanently transformed.

The Flood
- *Author:* Maggie Gee
- *First published:* 2004
- *Synopsis:* Endless rain over England floods London, but the social elite, safe on high ground, pretends nothing has really happened. The poor suffer as the waters rise. The author uses the scenario to expose the complacency of the privileged and socioeconomic inequities.

Forbidden Light: A Novel of Discovery
- *Author:* Tom Rybolt
- *First published:* 2004
- *Synopsis:* The protagonist, a graduate student, discovers a cheap way to produce hydrogen for fuel. Set in Atlanta, Georgia, in the near future, the plot pits the hero and his solution to the world's energy and global warming problems against the industries and academia dependent on the status quo.

A Friend of the Earth
- *Author:* T. C. Boyle
- *First published:* 2000
- *Synopsis:* In 2025, an ex-ecoterrorist lives on the estate of a wealthy singer who wants to preserve endangered species through a breeding program, but the wild weather created by global warming defeats the project, and the protagonist must flee with his ex-wife to a mountain cabin in hopes of reclaiming some measure of domestic life in an increasingly volatile world.

Frozen Fire
- *Authors:* Bill Evans and Marianna Jameson
- *First published:* 2009
- *Synopsis:* Ecoterrorists blow up drill rigs that a developer is using to exploit methane clathrates for a new energy source, but they overdo it and release massive amounts of methane into the atmosphere, killing many and starting runaway global warming. The protagonists find a way to plug the narrow leak.

Gaia Weeps: The Crisis of Global Warming
- *Author:* Kevin E. Ready
- *First published:* 1998
- *Synopsis:* Ready uses the novel form as a docudrama, featuring deadly droughts, floods, heat waves, and unprecedented weather, to make the threat of global warming visceral rather than an assortment of statistics and experts' assertions.

The Galileo Syndrome
- *Author:* Daniel H. Gottlieb
- *First published:* 2004
- *Synopsis:* The story follows Carlos Jordan, who has grown up under the draconian but insufficient Greenhouse Laws, as he becomes an adult and tries to save some remnant of humanity from an environment ruined by global warming.

Genesis
- *Author:* Bernard Beckett
- *First published:* 2006
- *Synopsis:* Attempts to halt environmental destruction from global warming trigger a war that eventually extinguishes humanity and leaves a society of androids that imitates Plato's *The Republic.*

Global Bogeymen
- *Author:* Charles E. Weaver
- *First published:* 2000
- *Synopsis:* The author writes of scientists and politics suspiciously as the novel tracks the construction of a nuclear waste repository, acts of terrorism, and

natural disasters that compromise the facility's site in North Carolina.

Global Cooling: The World of the Gagababas

- *Authors:* Weng Foo Chua and David Ayala
- *First published:* 2007
- *Synopsis:* Inhabits of the planet Gon, the Gagababas, suffer for the pollution created in their greed for energy. The planet is on the verge of an ice age unless its aged king can find a solution. This is a morality tale for young readers.

Global Reset: A Suspense Novel

- *Author:* Nick Raybourne
- *First published:* 2008
- *Synopsis:* Overpopulation, global warming, and political and cultural conflicts make the world ever more turbulent, and the United States government is behind a plot to bring about a catastrophic event, which the hero, a software entrepreneur, works to prevent.

Global Warming

- *Author:* Paul Zetter
- *First published:* 2001
- *Synopsis:* A businessman attempts to stage a coup in an island nation rich in oil.

Global Warning

- *Author:* Perla Sarabia Johnson
- *First published:* 2008
- *Synopsis:* Hellish temperatures speed up the evolutionary process, enlarging species; protagonists try to protect humanity, now subterranean for safety, from the changes.

Gray/Guardians

- *Author:* Kathy Porter
- *First published:* 2006
- *Synopsis:* Humanity hopes to escape Earth and its degraded, disease-ridden environment, by taking up an offer for refuge from an alien race. However, another alien race warns that it is a trick.

The Great Colorado River War

- *Author:* Melvin Eisenstadt
- *First published:* 2007
- *Synopsis:* In 2020, a visionary Navajo engineer wants to build a solar-powered plant to produce hydrogen (technically feasible) to replace fossil fuels, but his plans to use Lake Powell water for the process starts a struggle among many factions, including organized crime.

Greenhouse Summer

- *Author:* Norman Spinrad
- *First published:* 1999
- *Synopsis:* With melted ice caps and enlarged deserts, Earth supports humanity precariously, and evidence emerges of a runaway greenhouse effect, as on Venus. Nevertheless, factions battle for narrow interests in this grim tale that is concerned with action more than science.

Greensword: A Tale of Extreme Global Warming

- *Author:* Donald J. Bingle
- *First published:* 2009
- *Synopsis:* A group of Three Stooges-like environmentalists, desperate for attention, try to reverse global warming by exploding a thermonuclear bomb on Mt. Rainier, creating an eruption, and blanketing the world in ash. This farce pays almost no attention to science.

Hell on Earth

- *Author:* Mark Tushingham
- *First published:* 2008
- *Synopsis:* This sequel to *Hotter than Hell* follows the travails of a tyrannical American general determined to survive in an environment devastated by heat and drought.

Hello World

- *Author:* Dean Joseph
- *First published:* 2008
- *Synopsis:* An unstoppable computer virus cripples world infrastructure, and chaos ensues. Meanwhile, climate change intensifies humanity's problems.

Hot Planet

- *Author:* Michael Burns
- *First published:* 1994
- *Synopsis:* In the near future, long-standing pollution triggers accelerate global warming and melt ice caps as ecoradicals battle government forces

in the Southwest; plot driven rather than science based.

Hot Sky at Midnight
- *Author:* Robert Silverberg
- *First published:* 1994
- *Synopsis:* Centuries in the future, Earth's hot environment is unsuited to humans, who must either immigrate to another planet or genetically alter themselves radically; factions compete to profit from the options.

Hotter than Hell
- *Author:* Mark Tushingham
- *First published:* 2005
- *Synopsis:* Water shortages exacerbated by global warming inspire an Army general to lead an invasion of Canada as chaos erupts in the United States. The plot rests on a possible, but extreme, interpretation of global warming's potential effects.

The Ice Goddess
- *Author:* Paul Edwards
- *First published:* 1974
- *Synopsis:* In this thriller, droughts and flooding spread through the United States, and the ice caps begin to melt as an elite spy sets out to rescue a beautiful young scientist who may have the explanation for the weather anomalies.

The Ice People
- *Author:* Maggie Gee
- *First published:* 1999
- *Synopsis:* In the near future global warming triggers a negative feedback mechanisms that starts a new ice age. Civilization gradually fails, and Europeans become refugees fleeing to Africa. Told by a member of the last generation to enjoy the benefits of technology and government.

The Last Boy
- *Author:* Robert H. Lieberman
- *First published:* 2003
- *Synopsis:* A kidnapped five-year-old boy unexpectedly returns to his frantic mother after six months, but drastically changed: He cannot stay indoors, will not eat meat, and is mature in many ways. He and his kidnapper, when caught, personify how humanity will have to change to avoid environmental catastrophe.

Lear's Daughters
- *Authors:* Marjorie B. Kellogg and William B. Rossow
- *First published:* 1986/2009
- *Synopsis:* A science expedition, trying to find the means to save an Earth overwhelmed by environmental degradation, studies a volatile planet populated by a seemingly primitive race only to discover that the natives are the survivors of an ancient attempt at environmental engineering.

Lowboy
- *Author:* John Wray
- *First published:* 2009
- *Synopsis:* A schizophrenic teenager believes he can personally rescue the world from the effects of climate change by cooling his own overheated body with sex and, pursued by a missing-person specialist, is on a quest to find the right girl.

The Man Who Made It Rain: A True Story Based on the Experiences of J. Dietrich Stroeh
- *Author:* Michael McCarthy
- *First published:* 2006
- *Synopsis:* Not fiction but a work of dramatic journalism, this book tells the story of a manager of the water district in Marin County, California, who was blamed for an emergency during the drought of 1976 and 1977. The author presents a monitory tale about what may happen with climate change.

The Man Who Watched Trash
- *Author:* Russ Madison
- *First published:* 2001
- *Synopsis:* Despite storms and threats from American spies and Russian submarines, a young environmentalist sails an immense iceberg into New York Harbor to supply drinking water to the city and to raise awareness about the damaged ozone layer.

Mara and Dann
- *Author:* Doris Lessing
- *First published:* 1999
- *Synopsis:* Two children must flee their home on the continent Ifrik in the distant future. They join

refugees from lands plagued by drought, heading toward a northern ocean but are shanghaied into opposing armies in a region where diminishing resources, a cause of climate change, give rise to wars.

Moby and Ahab on a Plutonium Sea
- *Author:* Scott E. Douglas
- *First published:* 2005
- *Synopsis:* A nuclear explosion near South Africa creates international tensions; meanwhile, the effects of global warming on the ice sheet are accelerated, leading to rapid melting in this tale based loosely on the historical Vela Incident but not on science.

The New Revolution
- *Author:* Fredwyn Haynes
- *First published:* 2008
- *Synopsis:* In the 2020's a fascist government in England is expelling immigrants and trying to hold together the nation as it bakes under a permanent heat wave. A meteorology professor has a scheme to save the planet.

Noah's Millennium
- *Author:* Melvin Eisenstadt
- *First published:* 2005
- *Synopsis:* A businessman, an engineer, and a meteorologist team to save the world from fossil fuel emissions and runaway global warming in 2050 by building an orbiting solar power planet to supply energy needs—a technically difficult solution but one that is frequently discussed by scientists.

The North Pole Is Sinking!
- *Authors:* Ethan Khiem Matsuda and Michael Matsuda
- *First published:* 2005
- *Synopsis:* In this tale for children, Santa Claus struggles to keep his toy factory working as global warming melts the ice underneath it at the North Pole.

Nothing Human
- *Author:* Nancy Kress
- *First published:* 2003
- *Synopsis:* Earthlings face the choice of ecological disaster and possible extinction or a solution to climate change from aliens that promises to alter the human race fundamentally.

One World Manga Passages: Volumes 1-6
- *Author:* Annette Roman
- *First published:* 2006
- *Synopsis:* The teenage martial arts hero of this *manga* confronts major modern problems, including global warming, with fantasy bravado and inattention to basic science.

Overshoot
- *Author:* Mona Clee
- *First published:* 1998
- *Synopsis:* An elderly Californian witnesses a new order of society emerge as political tumult and global warming cause the old culture to fail. The author uses the character as a touchstone to compare the old and new ways. The theme is moral rather than scientific: that humanity will have to change to survive.

The Owl and the Oak: The Climate Change Novel
- *Author:* Robert Emmett Morris
- *First published:* 2007
- *Synopsis:* A political thriller about the rise of environmental activists and their struggles with the oil industry as destructive weather intensifies the atmosphere of peril.

Prelude to a Journey
- *Author:* William H. Venable
- *First published:* 2002
- *Synopsis:* The narrator and Smart, a highly intelligent burro, set off on a car trip to discover the extent of problems caused by global warming. Along the way they discuss the socioeconomic solutions necessary to preserve humanity beyond the next couple of generations.

Pump Six and Other Stories
- *Author:* Paolo Bacigalupi
- *First published:* 2008
- *Synopsis:* Two stories provide grim commentary and black humor about the future: "The People of Sand and Slag" is set in a contaminated wasteland, and "The Tamarisk Hunter" concerns water issues in the Southwest, an area further desiccated by global warming.

Reality Crash

- *Authors:* Cyd Ropp and Lou Grantt
- *First published:* 2008
- *Synopsis:* The hero joins ecoterrorists who want to destroy Virtual Vision Network, a computer simulation whose idyllic programs divert people from the environmental catastrophe surrounding them.

The Rising: Journeys in the Wake of Global Warming

- *Authors:* Tom Pollock and Jack Seybold
- *First published:* 2004
- *Synopsis:* Based on cutting-edge science, this tale concerns the effects of global warming. Collapsed ice sheets raise sea levels and causes tsunamis, devastating coasts. In California civil society disintegrates and people must reappraise their fundamental values.

The Road

- *Author:* Cormac McCarthy
- *First published:* 2006
- *Synopsis:* An unexplained catastrophe has destroyed civilization and many species. A father and son walk to the sea despite grotesque adventures, and the father dies there, leaving his son to strangers and a murky future in this dour parable of wasted chances and humanity's self-destructiveness.

Runaway

- *Author:* John A. Topping
- *First published:* 2002
- *Synopsis:* Extrapolating from the possibilities of climate science, this ecothriller concerns a scientist after his discovery that global warming is accelerating. He tries to stop it as the agents of big business and government oppose him.

Science in the Capital series: Forty Signs of Rain (2004), Fifty Degrees Below (2005), and Sixty Days and Counting (2007)

- *Author:* Kim Stanley Robinson
- *First published:* 2004-2007
- *Synopsis:* Each novel portrays a major catastrophic event caused by global warming in the near future: flood, freeze, and rising seas. The science behind it all is realistic; the measures taken to forestall catastrophe are spectacular but within the realm of the possible. However, the real strength of this series is its portrayal of scientists and their relation to government.

Second Atlantis

- *Author:* James Follett
- *First published:* 1998
- *Synopsis:* First published as *Ice* (1978), this fantasy novel concerns a geologist who has discovered gouges in the sea floor left by ancient icebergs and realizes the Antarctic ice sheet could do the same today. He further discovers that the catastrophic event could produce a second Atlantis.

Second Summer: The Turnback Time

- *Authors:* Amelia Walsh and James Stambaugh
- *First published:* 2008
- *Synopsis:* Set in the Pacific Northwest, this fantasy has a race of intelligent dinosaurs awakened by global warming. Humans compete to manipulate the Mesozoic species to their own financial or ideological advantage.

Seeds of Change

- *Editor:* John Joseph Adams
- *First published:* 2008
- *Synopsis:* Nine stories project current problems into the near future and discuss their culture-changing outcomes, including global warming and energy production.

September Snow

- *Author:* Robert Balmanno
- *First published:* 2006
- *Synopsis:* By 2051 climate change has caused havoc. A new eco-centric religion, Gaia, has arisen because of it but has become perverted and tyrannical. A beautiful genius leads a rebellion to topple the theocratic regime and begin an era of healing.

Shelter

- *Author:* Susan Palwick
- *First published:* 2007
- *Synopsis:* A group of family and friends, some human and some created by artificial intelligence, reunite and seek forgiveness for a horrific tragedy in their past while a titanic storm, for which global warming is somehow responsible, devastates San Francisco.

Sinking into Summer's Arms
- *Author:* Tom Slattery
- *First published:* 2000
- *Synopsis:* A mountain glacier, receding because of global warming, reveals a Neanderthal, whose mind is re-created by Dutch scientists. Meanwhile, reactionaries plot to assassinate the United Nations Emergency Secretary for Global Warming, who, to prevent worldwide panic, is trying to keep secret mounting evidence that Earth will slip into a new ice age.

Snowfall Trilogy: Snowfall (2002), Kingdom River (2003), and Moonrise (2004)
- *Author:* Mitchell Smith
- *First published:* 2002-2004
- *Synopsis:* In these fantasy thrillers set six centuries in the future, the remnants of humanity try to survive and rebuild civilization after extreme climate change—caused by an alteration in Jupiter's orbit—has left the world largely frozen.

Snowglobe Seven
- *Author:* Mike Tucker
- *First published:* 2008
- *Synopsis:* In this edition of Dr. Who, ice caps are melting because of global warming. Dr. Who and Martha battle an alien threat and a plague while in a domed habitat cooled by remnants of the polar ice.

Solix Resettles Blue Mountain
- *Author:* Robert E. Dansby
- *First published:* 2006
- *Synopsis:* A dramatization of actual ecological change caused by a warming climate, this book for young readers follows the experiences of birds (especially the protagonist, an owl) and animals.

Solstice
- *Author:* David Hewson
- *First published:* 1999
- *Synopsis:* A rapidly heating atmosphere and record solar storms threaten mass destruction as ecoterrorists make matters much worse by hijacking a deadly satellite. Only an intrepid scientist and a CIA agent prevent the group from destroying modern civilization in its apocalyptic attempt to save Earth from humanity.

State of Fear
- *Author:* Michael Crichton
- *First published:* 2004
- *Synopsis:* A terrorist conspiracy among environmentalists to incite public alarm about global warming, which is portrayed as supported by flimsy evidence, prompts a desperate attempt to stop them on the part of a scientist and a federal agent. Following the story are pages of footnotes and bibliography supporting the contention that global warming is a sham.

The Story of General Dann and Mara's Daughter, Griot, and the Snow Dog
- *Author:* Doris Lessing
- *First published:* 2005
- *Synopsis:* A sequel to *Mara and Dann*, this dreamy cautionary tale follows a small group of young soldiers who try to reclaim lost knowledge and cultural value as the next ice age thaws and the oceans rise to cover their ragged, war-ravaged villages in North Africa.

Terminal Freeze
- *Author:* Lincoln Child
- *First published:* 2009
- *Synopsis:* Studying the effects of global warming on a fast-retreating glacier in Alaska, a team of scientists finds and accidentally releases an ancient monster, which briefly wreaks havoc. Climate change serves as merely the backdrop for this fantasy tale.

Threat to the Life Force
- *Author:* Nelly Comperatore
- *First published:* 2004
- *Synopsis:* In 2065, two scientists develop a space vehicle to preserve life as pollution, environmental degradation wrought by global warming, and disease threaten to destroy humanity.

Ultimatum
- *Author:* Matthew Glass
- *First published:* 2009
- *Synopsis:* A newly elected U.S. president learns that global warming is progressing much faster than heretofore admitted, and he will go to any lengths, including nuclear war, to impose an inter-

national regime of remediation in order to avoid catastrophe for humanity.

Unnatural Sights
- *Author:* Joe Jeney
- *First published:* 2008
- *Synopsis:* Global warming, war, and an energy crisis move an astronaut to accept a mission to Jupiter's moon Europa in search of oil shale. Discovery of life on the moon poses a dilemma because it could be harmed if the oil is extracted.

Venus
- *Author:* Ben Bova
- *First published:* 2000
- *Synopsis:* Late in the twenty-first century a rich man offers a $10 billion reward to anyone who can retrieve his son's body from the surface of Venus. Descriptions of the planet's atmosphere and surface, which is extremely hot because of the greenhouse effect, raise comparisons to global warming on Earth. Sound planetary science serves as the background for this science-fiction thriller.

Water Rites
- *Author:* Mary Rosenblum
- *First published:* 2007
- *Synopsis:* Because of global warming, Earth is arid, and the hero, a major in the U.S. Army Corps of Engineers, must negotiate fiercely competing demands to supply the water needed to preserve civilization in the American West.

Weather Warden series: Ill Wind (2003), Heat Stroke (2004), Chill Factor (2005), Windfall (2005), Firestorm (2006), Thin Air (2007), Gale Force (2008), and Cape Storm (2009)
- *Author:* Rachel Caine
- *First published:* 2003-2009
- *Synopsis:* These fantasy romantic thrillers concern supernatural agents—the weather wardens and djinni—who are supposed to protect humanity from the catastrophic weather phenomena caused by climate change.

Winston of Churchill: One Bear's Battle Against Global Warming
- *Author:* Jean Davies Okimoto
- *First published:* 2007
- *Synopsis:* In this children's book, a polar bear in Churchill, Manitoba, Canada, urges fellow bears to mount a protest against global warming, which is ruining their icy environment.

• FILMS

Addicted to Oil: Thomas L. Friedman Reporting
- *Production company:* Discovery Productions
- *Released:* 2006
- *Synopsis:* A renowned *New York Times* columnist reports on America's dependence on fossil fuels and the alternative energy technologies that could replace them.

After the Warming
- *Production company:* Film Australia
- *Released:* 1989
- *Synopsis:* Through computer simulations James Burke explains past ice ages and warming trends and discusses various consequences that the greenhouse effect may have before 2050.

The Age of Stupid
- *Production company:* Spanner Films
- *Released:* 2009
- *Synopsis:* This British documentary takes place in 2055, when the environment is ruined. An archivist looks at images from the early 2000's—such as melting glaciers and the aftermath of Hurricane Katrina—and wonders why people did not save their world when they could.

Age of Warming
- *Production company:* Columbia Broadcasting System
- *Released:* 2007
- *Synopsis:* An episode of *60 Minutes* takes readers to a glacier in Chile to show the speed with which it is melting because of global warming.

The Antarctica Challenge
- *Production company:* Polar Cap Productions
- *Released:* 2009
- *Synopsis:* This hour-long documentary covers the latest research into global warming on the seventh continent.

The Anti-Global Warming League
- *Production company:* Sterling Video Productions
- *Released:* 2008
- *Synopsis:* This ten-minute spoof has school kids stopping global warming so that they can have a snow day and stay home from school.

Arctic Tale
- *Production company:* Visionbox Pictures
- *Released:* 2007
- *Synopsis:* During the eight years covered by this feature-length documentary, a polar bear cub and walrus pup grow to maturity as global warming melts part of the icy environment that they need to survive.

The Arrival
- *Production company:* Live Entertainment
- *Released:* 1996
- *Synopsis:* Global warming is progressing rapidly in this science-fiction thriller, but it is caused by aliens, not humans, and an astronomer uncovers their plot to take over the earth.

Artificial Intelligence: AI
- *Production company:* Warner Bros. Pictures
- *Released:* 2001
- *Synopsis:* With the ice caps melted, the United States retreats from submerged coastlines and continues its technological advance. The plot concerns household robots, who eventually replace humanity.

The Big Ask
- *Production company:* Friends of the Earth
- *Released:* 2008
- *Synopsis:* In this four-minute short, a small girl, playing on the beach, wonders why she can recognize the perils of global warming but politicians cannot, and she recounts the dangers.

Big Spuds, Little Spuds
- *Production company:* Bullfrog Films
- *Released:* 1999
- *Synopsis:* This documentary examines the effects of climate change and modern agriculture on the production of potatoes in the Andes of Peru.

Blade Runner
- *Production company:* Ladd Company
- *Released:* 1982
- *Synopsis:* This noir science-fiction masterpiece takes place in a vast city with nonstop rain, teeming streets, and a poisoned environment, which the wealthy flee off-planet. Killer androids return to Earth seeking longer life, and it is the job of the hero, a blade runner, to track them down and kill them.

The Burning Season
- *Production company:* Hatchling Productions
- *Released:* 2008
- *Synopsis:* This documentary follows an entrepreneur who is looking for alternative agricultural methods in Indonesia, where locals annually set fires in order to clear their land, emitting a great deal of carbon dioxide into the environment.

Category 7: The End of the World
- *Production company:* Luisa Filmproduktions
- *Released:* 2005
- *Synopsis:* Among other environmental catastrophes spawned by global warming, a superstorm develops, and three scientists rush in to stop it in this credulity-busting disaster story.

Changing Climates, Changing Times
- *Production company:* Cape Drama
- *Released:* 2008
- *Synopsis:* This television drama depicting conditions in 2075 assumes the state of the environment will be much worse than was predicted early in the century, with extreme heat, drought, flooding, and plagues. Although there is political turmoil, various characters carry on with a measure of hope.

Chilly Beach: The World Is Hot Enough
- *Production company:* March Entertainment
- *Released:* 2008
- *Synopsis:* In this animated movie, a pair of Canadians want to attract tourists to their area by building a device to change the climate. However, their invention works too well, threatening to destroy the biosphere, and to escape the onslaught of government agents and cults the pair travel back in time to stop themselves.

Climate Change Cartoon No. 1: Empty Spaces
- *Released:* 2009
- *Synopsis:* This brief animation offers an apocalyptic vision of the world if global warming is ignored.

Climate Chaos
- *Production company:* British Broadcasting Corporation
- *Released:* 2006
- *Synopsis:* Hosted by David Attenborough, this television series examines environmental issues, climate change, places susceptible to disaster, alterations in agriculture, and the politics behind treaties to control greenhouse gas emissions.

The Cloud Mystery
- *Production company:* Mortensenfilm
- *Released:* 2008
- *Synopsis:* This documentary discusses the theories of Danish physicist Henrik Svensmark, who argues that global temperature change is caused by the cosmic rays that influence Earth's cloud cover, and not by the human use of fossil fuels.

The Day After Tomorrow
- *Production company:* Twentieth Century Fox
- *Released:* 2004
- *Synopsis:* Global warming triggers an unbelievably swift deep freeze in the Northern Hemisphere, and a leading scientist sets off to rescue his son trapped in New York City. This thriller was reportedly the source of great hilarity among real climate scientists.

The Day the Earth Stood Still
- *Production company:* Twentieth Century Fox
- *Released:* 2008
- *Synopsis:* In this eco-friendly remake of a 1951 Cold War classic, aliens arrive on Earth to cleanse it from the environmental damage wrought by humanity and to eradicate the race in the process. However, an intrepid astrobiologist and her stepson convince the alien agent in charge to stop the destruction.

The Day the Oceans Boiled
- *Production company:* Equinox
- *Released:* 2001
- *Synopsis:* This television documentary discusses a dramatic rise in global temperature 55 million years ago and then ponders whether Earth today could undergo a similar process.

Designing the New World: Turning Crisis into Potential
- *Production company:* Activist Entertainment
- *Released:* 2009
- *Synopsis:* This opinion piece urges people to take personal responsibility in facing looming crises, such as climate change, in order to improve the future with "mindful living" and not be diverted by the fear-centered tactics of the media.

The Disappearing of Tuvalu: Trouble in Paradise
- *Production company:* Documentary Educational Resources
- *Released:* 2004
- *Synopsis:* The South Pacific island nation of Tuvalu stands to be the first sovereign nation lost beneath the ocean because of global warming, and this feature-length documentary recounts the citizens' struggle to cope as sea water invades their land.

Doomsday Called Off
- *Production company:* Lars Mortensen TV-Produktion
- *Released:* 2004
- *Synopsis:* This Danish documentary critiques the arguments that humanity is causing a potentially disasterous global change in climate.

Earth
- *Production company:* Greenlight Media AG
- *Released:* 2007
- *Synopsis:* This feature-length version of the television series *Planet Earth* follows four families of animals in order to examine how they are affected by climate change.

Earth: The Climate Wars
- *Production company:* British Broadcasting Corporation
- *Released:* 2008
- *Synopsis:* This three-episode documentary ("Battle Begins," "Fightback," and "Fight for the Future") includes interviews with prominent scientists on both sides of the global warming debate.

An Earth Story: An Alternative to Extinction
- *Production company:* Mayan Animations Productions
- *Released:* 2007
- *Synopsis:* This animated documentary argues that humanity has the technology to prevent catastrophic climate change and just needs the will to convert to it and thereby reduce carbon emissions.

The 11th Hour
- *Production company:* Appian Way
- *Released:* 2007
- *Synopsis:* Actor Leonardo DiCaprio takes viewers through an array of interviews of leaders and scientists to explain the peril from climate change and ways to halt it in this feature-length documentary. Stunning footage shows both beautiful and frightening natural scenery.

The End of the World
- *Production company:* Albino Blacksheep
- *Released:* 2006
- *Synopsis:* This animated lampoon of modern anxieties includes jabs at global warming and nuclear winter.

Energy Crossroads
- *Production company:* Tiroir A Films
- *Released:* 2007
- *Synopsis:* This documentary explores looming problems with fossil fuel use, including emissions that cause the greenhouse effect and the possibility of economic collapse after demand exceeds supply.

Energy Report IV: Change in the Air
- *Production company:* Television Trust for the Environment
- *Released:* 2000
- *Synopsis:* This documentary surveys areas of the United States that have undergone environmental change from global warming and damage from pollution.

Environmental Hysteria
- *Production company:* Penn & Teller
- *Released:* 2003
- *Synopsis:* This episode of *Penn & Teller: Bullshit!* debunks the extreme claims of environmentalists.

Everything's Cool
- *Production company:* Toxic Comedy Pictures
- *Released:* 2007
- *Synopsis:* This documentary, featuring dozens of public figures and scientists, recounts the desperate political battles behind the debate about global warming and the difficulty of getting an easily diverted public to pay attention.

Extreme Ice
- *Production company:* Public Broadcasting Service
- *Released:* 2009
- *Synopsis:* This *Nova* episode depicts the melting of arctic glaciers and discusses the causes and likely outcomes.

The Fateful Balance
- *Production company:* Lightscape Motion Picture Company
- *Released:* 1990
- *Synopsis:* Scientists debate the possibility of climate change and how to distinguish natural change from changes induced by human use of fossil fuels in this documentary.

A Floridian's Guide to Climate Change
- *Production company:* BFA Documentary
- *Released:* 2009
- *Synopsis:* Its long, low, and heavily populated coastline leaves Florida particularly vulnerable if

sea levels rise from global warming, as this nine-minute documentary details.

Forecast Earth
- *Production company:* Atlas Media
- *Released:* 2003-2008
- *Synopsis:* This television series addresses such topics as El Niños, destructive storms, alternative fuels, environmentalists, and ecotourism.

Future of the Great Barrier Reef
- *Production company:* Green.tv
- *Released:* 2003
- *Synopsis:* In this Australian documentary, scientists discuss the bleaching of coral reefs caused by rising ocean temperatures, while images reveal blighted underseascapes.

Global Warming: Science and Solutions
- *Production company:* Center Films Ltd.
- *Released:* 2006
- *Synopsis:* In a two-hour presentation, this documentary describes humanity's historical impact on the environment, particularly the warming caused by fossil fuel consumption in the twentieth century. Computer animations clarify the science behind climate change, and alternative fuel sources are discussed.

Global Warming: The New Challenge
- *Production company:* Peacock Productions
- *Released:* 2009
- *Synopsis:* A follow-up on *Global Warming: What You Need to Know.*

Global Warming: The Signs and the Science
- *Production company:* Public Broadcasting Service
- *Released:* 2005
- *Synopsis:* Through interviews with scientists and footage revealing climate change in the United States, Asia, and South America, this documentary explores the consequences of this change and the people who are trying to avert disaster.

Global Warming: What You Need to Know
- *Production company:* British Broadcast Corporation
- *Released:* 2006
- *Synopsis:* News anchorman Tom Brokaw interviews experts about what Americans should expect from global warming and about methods of mitigating its effects.

Global Warming Reflection Video
- *Released:* 2004
- *Synopsis:* Rapid images of environmental devastation are shown as the Finnish power metal band Sonata Arctica sings "Wrecking the Sphere."

Global Warming Song
- *Production company:* Snappy Greetings
- *Released:* 2006
- *Synopsis:* Caricatures of Al Gore and his wife Tipper sing a parody of his global warming message to the tune of "You're the One That I Want."

A Global Warning?
- *Production company:* Pioneer Productions
- *Released:* 2007
- *Synopsis:* In interviews with scientists, alternating with footage of landscapes worldwide, this two-hour television documentary considers whether global warming is part of a natural cycle or is caused by humans.

Global Warning
- *Production company:* Sandorp Pictures
- *Released:* 2008
- *Synopsis:* In this four-minute drama, a clueless businesswoman lives a privileged life, ignoring all signs of environmental trouble, until she suddenly feels its impact.

Global Warning: The Thaw of War
- *Production company:* Lena Film
- *Released:* 2010
- *Synopsis:* This feature-length documentary shows retreating glaciers that reveal soldiers frozen in past wars, and footage of modern wars raises the question about the immediate future: Can nations overcome rivalries in the face of a common environmental threat?

The Great Global Warming Swindle
- *Production company:* WAGtv
- *Released:* 2007
- *Synopsis:* Through interviews with scientists, economists, politicians, and writers, this British documentary seeks to expose global warming as the biggest scam of all time, based on flawed science manipulated by vested interests, especially the Intergovernmental Panel on Climate Change. The British media regulator Ofcom ruled that the film falsified some data to make its claims.

The Great Warming
- *Production company:* Stonehaven Productions
- *Released:* 2006
- *Synopsis:* Interviews with scientists and commentators and dramatic footage of scenery underscore a message of urgency in combating global warming and climate change in this call-to-action documentary based on a 2003 Canadian television series.

Green: The New Red, White and Blue
- *Production company:* Optomen Productions
- *Released:* 2007
- *Synopsis: New York Times* columnist Thomas L. Friedman surveys green technologies to replace fossil fuels and reduce greenhouse gas emissions.

Home
- *Production company:* Elzévir Films
- *Released:* 2009
- *Synopsis:* Aerial footage of fifty-four countries reveals the intimate environmental and cultural interconnections of the world and the extent of problems facing humanity from destructive agriculture and deforestation.

How to Boil a Frog
- *Production company:* Fools Bay Entertainment
- *Released:* 2009
- *Synopsis:* Billed as an "eco-comedy," this documentary promotes personal solutions for surviving the effects of climate change, which is treated as one facet of the larger problem of overpopulation.

I Saved the World from Global Warming!
- *Released:* 2008
- *Synopsis:* This short comedy concerns a man who announces a solution to global warming but finds that nobody cares.

Ice
- *Production company:* Alexander/Enright & Associates
- *Released:* 1998
- *Synopsis:* In this television drama, characters escape from Los Angeles after the entire Northern Hemisphere freezes and board a ship bound for warmer climes.

Ice Bears of Beaufort
- *Production company:* PolarArt Productions
- *Released:* 2009
- *Synopsis:* This documentary concerns the habitat for polar bears in Alaska's Beaufort Sea, threatened by offshore oil wells and by ice melting because of global warming.

An Inconvenient Truth
- *Production company:* Lawrence Bender Productions
- *Released:* 2006
- *Synopsis:* This documentary follows former vice President Al Gore's lecture tour to inform the world about global warming and its consequences. It mixes segments of lectures with entertaining graphics and interviews in a presentation that won two Academy Awards.

Inuit Observations on Climate Change
- *Production company:* International Institute for Sustainable Development
- *Released:* 2000
- *Synopsis:* Inuvialuit hunters on Banks Island in the Arctic note significant changes in their environment—summer heat melting more ice, delayed freezing in winter, and new species—in this forty-two-minute documentary.

Jon Saves the Planet
- *Production company:* Insight Productions Company
- *Released:* 2009
- *Synopsis:* In this episode of Canada's *Jon Dore* comedy series, the hero is upbraided for burning his garbage because it contributes to greenhouse gases.

Just in Case
- *Production company:* Earthworm Productions
- *Released:* 2008
- *Synopsis:* This one-minute animation depicts climate change.

Katastrofin aineksia
- *Production company:* Magic Hour Films
- *Released:* 2008
- *Synopsis:* This Finnish-Danish comedy has a director convince his family to go on a strict regime to reduce their carbon footprint, and they go from one mishap to another trying to maintain their middle-class life.

Knowing
- *Production company:* Summit Entertainment
- *Released:* 2009
- *Synopsis:* In this disaster film, a massive solar flare finishes the job of global warming, incinerating the Earth and all humanity except for a select group of children rescued by aliens.

Lazarus Taxon
- *Production company:* Polar Star Films
- *Released:* 2008
- *Synopsis:* A mixture of horror and science fiction, this short Catalan-language film depicts the gruesome consequences of global warming.

Legacy of the Great Aletsch
- *Production company:* Aletschfilm
- *Released:* 2009
- *Synopsis:* The Great Aletsch is a large glacier in the Swiss Alps, now swiftly retreating because of global warming. This documentary reports its cultural and economic importance to locals.

Live Earth
- *Production company:* Bob Bains Productions
- *Released:* 2007
- *Synopsis:* This film features dozens of recording stars performing in a concert series aimed at highlighting the climate change crisis.

Lost City Raiders
- *Production company:* Tandem Communications
- *Released:* 2008
- *Synopsis:* In this television science-fiction movie, the Earth is largely covered by water. A father-son team salvage valuables from submerged buildings and are sent on a mission by the New Vatican.

Man vs. Nature—Who Will Win?
- *Production company:* VCI Home Video
- *Released:* 1999
- *Synopsis:* This episode of *Secrets of the Millennium* argues that humanity is out of balance with nature, polluting the environment with greenhouse gases, mismanaging resources, and destroying other species. It implies that humanity will have to suffer for its carelessness.

The March
- *Production company:* British Broadcasting Corporation
- *Released:* 1990
- *Synopsis:* Racial conflict and international tensions erupt as global warming forces Africans to migrate to an already overpopulated Europe in this drama set in the near future.

Med Triton I Ishavet
- *Production company:* Danmarks Radio
- *Released:* 2003
- *Synopsis:* In this made-for-television half-hour drama, Danish scientists in a naval vessel investigate dramatic climate change on the northeastern Greenland coast and go ashore on an island heretofore icebound.

Meltdown: A Global Warming Journey
- *Production company:* British Broadcasting Corporation
- *Released:* 2006
- *Synopsis:* This hour-long documentary considers the divergent points of view about global warming in order to separate fact from polemic.

Melting Lands
- *Production company:* HemmingsHouse Pictures
- *Released:* 2008
- *Synopsis:* Ice in the Canadian northlands is melting faster each year, and this documentary examines how an Inuit community is affected by these climate changes.

Nuclear Climate Change
- *Released:* 2008
- *Synopsis:* This documentary explores the benefits and dangers of nuclear power as an alternative to fossil fuels and as a means of reducing greenhouse gas emissions.

The Nuclear Comeback
- *Production company:* Icarus Films
- *Released:* 2007
- *Synopsis:* This documentary surveys the nuclear power industry worldwide, considering whether, as an alternative to fossil fuels, nuclear power is a reasonable way to combat global warming.

Out of Balance: ExxonMobil's Impact on Climate Change
- *Production company:* ADL Films
- *Released:* 2007
- *Synopsis:* Exxon is the world's largest company, according to this documentary, which accuses the oil company of ignoring climate science for the sake of profits. The film also discusses the kinds of social changes that are needed to ensure a livable planet.

Owning the Weather
- *Production company:* 4th Row Films
- *Released:* 2009
- *Synopsis:* With dramatic images of extreme weather and interviews with dozens of scientists, leaders, and citizens, this documentary considers the wisdom of geoengineering to control weather and other effects of global warming.

Proof or Propaganda: Climate Change—It's Not What You Think
- *Production company:* Ceilings Unlimited
- *Released:* 2008
- *Synopsis:* Based on interviews with scientists and business people, this ninety-minute documentary portrays climate change as an opportunity for economic growth.

Rain Shadow
- *Production company:* Australian Broadcasting Corporation
- *Released:* 2007
- *Synopsis:* This television miniseries shows farmers struggling to adapt to an extended drought that is a feature of Australian climate change.

Renewal
- *Production company:* Fine Cut Productions
- *Released:* 2008
- *Synopsis:* The movement in America among religious people to be environmentally conscious is growing, according to this documentary, which offers eight stories about involvement and hope.

Repeat Photography and the Albedo Effect
- *Production company:* Squeaky Wheel Media Arts Center
- *Released:* 2008
- *Synopsis:* Brutal boxing-match scenes segue into a white background as a voice-over discusses the effects of global warming on glaciers in this experimental eight-minute film.

Ribbon of Sand
- *Production company:* Public Broadcasting Service
- *Released:* 2008
- *Synopsis:* Like many low-lying islands, North Carolina's Outer Banks will disappear if sea levels rise, and this short documentary describes the area's natural history as a testimony to what would be lost.

Rising Waters: Global Warming and the Fate of the Pacific Islands
- *Production company:* Bullfrog Films
- *Released:* 2000
- *Synopsis:* Through personal stories, this hour-long documentary reveals the threat that global warming poses to South Pacific islands: bleached corral, distressed fisheries, and inundated territory.

A Sea Change
- *Production company:* Niijii Films
- *Released:* 2009
- *Synopsis:* An outdoorsman investigates the effects of carbon dioxide emissions on the world's oceans and the future consequences for people in this full-length documentary.

Seed Hunter
- *Production company:* 360 Degrees Films
- *Released:* 2008
- *Synopsis:* This documentary concerns an Australian scientist who searches in Central Asia for seeds that will be hardy enough to survive the effects of global warming and will replace regional food crops elsewhere that cannot survive the climate changes.

Serious Arctic
- *Production company:* British Broadcasting Corporation
- *Released:* 2005
- *Synopsis:* In a documentary for young audiences, eight teenage volunteers travel to Grinnell Glacier in the Canadian Arctic to help scientists study the effects of global warming, especially on polar bears.

Silent Sentinels
- *Production company:* Bullfrog Films
- *Released:* 2000
- *Synopsis:* This hour-long documentary considers whether the large-scale bleaching of coral reefs in 1998 constitutes evidence of global warming.

Six Degrees Could Change the World
- *Production company:* National Geographic
- *Released:* 2008
- *Synopsis:* This documentary explains and depicts the possible changes to world climate with each degree of increased average temperature, based on the book *Six Degrees* by Mark Lynas.

Sizzle: A Global Warming Comedy
- *Production company:* Prairie Starfish Productions
- *Released:* 2008
- *Synopsis:* This partly mocking, partly serious documentary interviews various scientists about global warming in an attempt to grasp the public confusion over it.

Split Second
- *Production company:* Challenge Film Corporation
- *Released:* 1992
- *Synopsis:* Because of global warming and melting ice, much of London is underwater in this futurist horror film, and a policeman discovers that a monster has invaded the city.

SUV Taggers
- *Production company:* Stone Harbor Films
- *Released:* 2004
- *Synopsis:* This documentary short shows a pair of eco-vandals adorning large cars with bumper stickers in order to call attention to the polluting emissions of large vehicles.

Tales from the Arctic Circle
- *Production company:* Wonderdog Productions
- *Released:* 2005
- *Synopsis:* Four short films reveal the cultural life in Iqaluit, an Inuit community in the Arctic. Among the problems facing the people are abnormal snow melts and environmental change.

A Terrifying Message from Al Gore
- *Production company:* 20th Century Fox Television
- *Released:* 2006
- *Synopsis:* In an animated short, Al Gore and the *Futurama* robot Bender promote *An Inconvenient Truth.*

They Will Come to Town
- *Production company:* Filmakademie Baden-Württemberg
- *Released:* 2008
- *Synopsis:* This one-minute dramatic animation shows fish swimming in inundated cities.

Too Hot Not to Handle
- *Production company:* Lovett Productions
- *Released:* 2006
- *Synopsis:* This documentary elaborates on possible effects from global warming in the United States: heat waves, melting glaciers, submerged sea coasts, new pests, and catastrophic storms.

Tornado Terror

- *Production company:* Fast (Tornado) Productions
- *Released:* 2008
- *Synopsis:* The premise of this two-hour drama is that global warming will create conditions spawning immense tornadoes, and it focuses on one tornado that appears to have a grudge against New York City.

Turning Down the Heat: The New Energy Revolution

- *Production company:* National Film Board of Canada
- *Released:* 1999
- *Synopsis:* Alternative energy sources could free countries from dependency on foreign oil, provide greater economic justice, and undercut climate change, according to this documentary.

2050

- *Production company:* TV Siete
- *Released:* 2006
- *Synopsis:* Based on a 2004 report from the Pentagon warning of the security dangers that global warming could pose, this documentary concentrates on the consequences of climate change to basic resources.

2012

- *Production company:* Centropolis Entertainment
- *Released:* 2009
- *Synopsis:* In accordance with an ancient Mayan prediction, cataclysmic environmental events threaten to destroy civilization, and characters struggle to cope in this disaster drama.

Under the Sea 3D

- *Production company:* Howard Hall Productions
- *Released:* 2009
- *Synopsis:* This IMAX three-dimensional feature presents the underwater environment around New Guinea and the coral reefs of Australia and considers the threats to these areas from global warming.

The Venus Theory

- *Production company:* Talent House
- *Released:* 2004
- *Synopsis:* A Finish documentary, this hour-long film explains the science behind the claims about global warming and considers whether Earth could experience a runaway greenhouse effect like that of its sister planet Venus.

Wake Up, Freak Out: Then Get a Grip

- *Production company:* RCA
- *Released:* 2008
- *Synopsis:* This short animation explains the positive feedback mechanisms that could accelerate global warming and lead to irreversible, calamitous climate change.

Water Planet

- *Production company:* Tree Media
- *Released:* 2005
- *Synopsis:* In this short documentary, actor Leonardo DiCaprio explains the dangers to the world's freshwater supply from pollution, wasteful use, and the desertification caused by climate change.

Waterworld

- *Production company:* Universal Pictures
- *Released:* 1995
- *Synopsis:* In this futuristic drama, the ice caps have melted and Earth is covered by the oceans. A mutant sailor sets out with a woman and mysterious girl in search of a rumored island as bandits in an oil tanker try to waylay them.

We Are All Smith Islanders: Global Warming in Maryland, Virginia, and D.C.

- *Production company:* MDP Productions
- *Released:* 2004
- *Synopsis:* This documentary follows the watermen of Smith Island in the Chesapeake Bay who are losing the ability to make a living because of damage from global warming, and it considers clean-energy solutions that might reduce the human contribution to the problem.

Weather Report

- *Production company:* Sienna Films
- *Released:* 2008
- *Synopsis:* This thirty-five-minute documentary previews the worldwide effects of climate change by depicting current environmental alterations in India, Kenya, and the Canadian Arctic and by interviewing local residents who are taking measures to adapt.

Time Line

- 4.5 billion years ago

Earth forms

- 65 million years ago

A 10-kilometer-diameter asteroid produces a 180-kilometer-diameter crater on the Yucatán Peninsula. The impact is believed to have penetrated the earth's crust, spewing dust and debris into the atmosphere, causing huge fires and acid rain, increasing already active volcanic eruptions, and setting off tsunamis and storms with high winds. These environmental disasters would have caused most of the species then living, including the dinosaurs, to become extinct.

- 5.1-5.8 million years ago

The Pliocene Epoch: A cooling period leads to the Ice Age.

- 1.8 million years ago to11,000 years ago

The Pleistocene Epoch: Glaciation leads to the Ice Age. Modern humans evolve.

- 11,000 years ago

The Holocene Epoch: The Ice Age ends. Human beings begin to impact the biosphere.

- 9th-13th centuries

The Medieval Warm Period: Temperatures in the Northern Hemisphere, particularly in the North Atlantic region, are warmer than in previous years.

- 15th-19th centuries

The Little Ice Age: Temperatures in the Northern Hemisphere, particularly in the North Atlantic Region, are cooler than during the prior Medieval Warm Period.

- 1643-1653

Europe experiences its severest winters since the Ice Age.

- 1665-1666

Very hot summers in London exacerbate the last plague epidemic.

- 1690

Siberia experiences extreme heat, probably due to southerly winds. At this time, Europe is abnormally cold.

- 1718-1719

Great heat and drought affect most of Europe during the summers of these years.

- June 8, 1783-February 7, 1784

The Laki fissure eruption in Iceland produces the largest lava flow in historical time, with major climatic effects. Benjamin Franklin speculates on its connection to a cold winter in Paris the following year.

- 1798

Thomas Robert Malthus publishes *An Essay on the Principle of Population, As It Affects the Future Improvement of Society*, in which he proposes that population growth will outpace food production, with devastating consequences. The book sets off a public flurry and a debate among intellectuals.

- April 5, 1815

The dramatic explosion of Tambora, 400 kilometers east of Java, the largest volcanic event in modern history, produces atmospheric and climatic effects for the next two years. Frosts occur every month in New England during 1816, the Year Without a Summer.

- 1825

Joseph Fourier postulates that Earth's atmosphere acts "like the glass of a hot-house," dispensing high-energy (ultraviolet) radiation but retaining low-energy (infrared) radiation.

- 1845

Moist, southerly winds and a hot summer provide the perfect growing conditions for the potato blight fungus, resulting in the Irish Potato Famine.

- 1852

Louis Agassiz receives the Cuvier Prize from the French Academy of Sciences. Agassiz originated the concept of a great Ice Age, a period when, amid a series of catastrophes, vast sheets of ice covered much of the earth.

- 1859

Using spectrophotometry, John Tyndall discovers that certain gases, such as water vapor and carbon dioxide (CO_2), have the power to absorb ultraviolet rays.

- August 26, 1883

A cataclysmic eruption of Krakatoa, an island in Indonesia, is heard 4,777 kilometers away. Many die as pyroclastic flows race over pumice rafts floating on the surface of the sea; many more die from a tsunami.

- 1887-1896

Droughts drive out many early settlers of the Great Plains.

- 1895

Svante August Arrhenius, sometimes called the father of climate change, creates the first mathematical model that proves how even small amounts of carbon dioxide in the atmosphere can increase global temperatures.

- May 8, 1902

Mount Pelée, on the northern end of the island of Martinique in the Caribbean, sends violent pyroclastic flows into the city of St. Pierre, killing all but 2 of the 30,000 inhabitants.

- 1910-1915

The first in a series of recurring droughts affects the Sahel region of Africa.

- 1923

English physicist Gilbert Walker discovers the Southern Oscillation, which in the 1960's is linked to El Niño.

- December, 1930

The DuPont Corporation introduces Freon, a nontoxic, nonflammable, chlorofluorocarbon chemical used as a refrigerant. In later years, Freon is shown to harm the earth's ozone shield, creating a potential environmental hazard.

- 1933-1936

Extensive droughts in the southern Great Plains destroy many farms, creating the Dust Bowl, in the worst drought in more than three hundred years in the United States. Between 15,000 and 20,000 die.

- 1938

Guy Stewart Callendar, an English physicist, speculates that increasing carbon dioxide levels are the probable cause for a warming trend in North America and Northern Europe that meteorologists began to observe in the 1880's. He is the first person to assemble a large amount of data from several scientific sources in order to predict significant temperature change from anthropogenic carbon dioxide.

- 1939

American soil conservationist Hugh Hammond Bennett publishes *Soil Conservation*, in which he describes how temperature, wind speed, humidity, and the amount and duration of precipitation affect soil erosion.

- September 8, 1943

On "Black Wednesday," Los Angeles, California, experiences a new and more severe type of air pollution, causing eye irritation, decreased visibility, and plant damage. The episode demonstrates for the first time the extent of the health dangers posed by the area's smog.

- 1951

Rachel Carson, often called the mother of the modern environmental movement, publishes *The Sea Around Us*. One of the book's chapters, "The Global Thermostat," describes how the ocean dominates the world's climate and predicts that a tidal effect will recur around the year 2400, causing global warming.

- December 4-8, 1952

A lethal smog blankets the city of London, causing the death of almost 12,000 residents, asphyxiating cattle and other animals, and creating other health problems. The disaster results in the implementation of strict clean-air legislation throughout the United Kingdom.

• 1957
Oceanographer Roger Revelle and geochemist Hans Seuss propose the concept of the greenhouse effect, describing how it would eventually result in global warming.

• June 23, 1961
The Antarctic Treaty System enters into force. The system protects the continent and provides free access to Antarctica for research scientists, enabling them to conduct research that will improve the understanding of climate change.

• 1963
The U.S. Congress adopts the Clean Air Act, which mandates reductions in various atmospheric pollutants. The act is subsequently amended in 1970, 1977, and 1990, with increasingly stringent standards imposed over time.

• May, 1967
Meteorologists Syukuro Manabe and Richard Wetherald publish an article in the *Journal of Atmospheric Studies* describing the results of greenhouse, or global, warming. They conclude that atmospheric temperatures are much more sensitive to carbon dioxide and ozone content than previous studies had indicated. In particular, they predict an increase of about 2° Celsius for the average temperature if the amount of carbon dioxide in the atmosphere is doubled.

• 1968-1973
The Sahel region of Africa suffers a drought that extends the size of the Sahara Desert, ruins the economies of sixteen countries, and causes widespread famine and emigration. This desertification is the result of large-scale climatic change, intense population pressure, and poor land management.

• February 2, 1971
The Ramsar Convention, the first international treaty on environmental conservation, is signed by eighteen nations. The convention initially seeks to conserve wetlands, but its provisions are subsequently expanded to consider the importance of wetlands in global climate change.

• 1972
A team of scientists at the Massachusetts Institute of Technology develops a computer model, World3, containing a complex set of differential equations which models the environmental impacts of human population growth and the global economy. Their book describing this model, *The Limits to Growth*, issues a dire warning about biological productivity, environmental degradation, increasing population growth, and economic activity.

• June 5-16, 1972
The United Nations Conference on the Human Environment, the first global conference on the environment, is held in Stockholm, Sweden. The meeting, which will later be known as the Stockholm Conference, solidifies public opinion regarding the need to address environmental concerns while making the global community more acutely aware of climate change.

• 1974
American automakers introduce the catalytic converter, a device that uses chemical reactions to reduce air pollution from automobile exhaust gases. Although the device helps decrease carbon monoxide, unburned hydrocarbon, and nitrogen oxide emissions, it does not reduce all automobile pollutants.

• June, 1974
F. Sherwood Rowland and Mario J. Molino, physical chemists at the University of California, Irvine, publish an article in *Nature* demonstrating that chlorofluorocarbon gases may be destroying the earth's ozone layer. Their research will earn them and partner Paul J. Crutzen the 1995 Nobel Prize in Chemistry.

• 1977-1978
The western United States experiences a drought.

• March 17, 1978
The U.S. Consumer Product Safety Commission, Environmental Protection Agency, and Food and Drug Administration ban chlorofluorocarbons in aerosol sprays because these chemicals are harmful to Earth's protective ozone layer.

- September 17, 1978

The National Climate Program Act is signed into law. The act creates an interagency program that conducts climate research, provides climate information, and supports policy decisions in the United States.

- November, 1979

The Geneva Convention on Long-Range Transboundary Air Pollution is signed into law. One of the oldest international environmental treaties, the convention addresses air pollution, including greenhouse gas emissions, and creates procedures for gathering and accessing data.

- May 18, 1980

Mount St. Helens in Washington State erupts with a directed blast to the north, moving pyroclastic flows at velocities of 100 to 300 meters per second—nearly the speed of sound.

- June, 1980

Luis Alvarez and others at the University of California at Berkeley publish an article in *Science* presenting the hypothesis that an asteroid impact caused the extinction of the dinosaurs.

- 1982

English climatologist Hubert Horace Lamb publishes his most influential work, *Climate, History, and the Modern World*, which provides the first scientific explanation of how climate works and fluctuates and lays out a research program for studying historical climate change.

- June, 1982-August, 1983

A destructive El Niño episode is held responsible for more than 2,000 deaths and $13 billion in damages and introduces the public to this Pacific Ocean weather phenomenon.

- May 16, 1985

A group of scientists from the British Antarctic Survey publish a research paper based on several years of measurements of the stratospheric ozone above Halley Bay in Antarctica. The researchers note that the total amount of ozone in early spring decreased by almost 50 percent during the previous ten years. Their discovery spurs many other scientists to study the "ozone hole" above Antarctica and ultimately link ozone depletion to increased concentrations of atmospheric chlorofluorocarbons.

- September, 1987

Twenty-four countries sign the Montreal Protocol, a United Nations agreement to phase out substances which damage the earth's ozone layer—the atmospheric shield which protects the planet's inhabitants from dangerous ultraviolet rays.

- November, 1988

The World Meteorological Organization and the United Nations Environment Programme create the Intergovernmental Panel on Climate Change (IPCC). The panel is charged with studying climate change and analyzing its effects on human beings and the environment.

- 1990

The IPCC predicts that greenhouse gases and carbon dioxide emissions produced by human activity could raise world temperatures by 0.28° Celsius each decade.

- June 29, 1990

Representatives of ninety-three nations meet in London and agree to ban production of most ozone-destroying chemicals by the end of the twentieth century.

- June 12-15, 1991

Mount Pinatubo in the Philippines erupts after having been dormant for four hundred years. The eruption kills more than seven hundred people and injects aerosols into the stratosphere that will affect both the earth's ozone layer and global temperatures.

- June 3-14, 1992

The United Nations Conference on Environment and Development is held in Rio de Janeiro, Brazil. Also known as the Earth Summit, the conference produces the United Nations Framework Convention on Climate Change, an international treaty that aims to stabilize greenhouse gas emissions at a level that might prevent dangerous disruption of Earth's climate.

• June 14, 1992
Agenda 21, a comprehensive plan of action to address global carbon emissions, is adopted by 179 nations participating in the Earth Summit in Rio de Janeiro. The plan mandates cooperation at the global, national, and local levels to reduce emissions in industrialized nations and to slow the rate of emission increase in developing countries. Conference participants also create the Rio Declaration on Environment and Development, a series of principles that support Agenda 21 by elucidating the rights and responsibilities of states.

• August 22-26, 1992
Hurricane Andrew strikes southern Florida, leaving fifty dead and $26 billion in damage.

• October 24, 1992
The U.S. Energy Policy Act of 1992 is signed into law. Title XVI of the act establishes mechanisms for monitoring and addressing climate change and global warming.

• April-October, 1993
Heavy rains and unusually high snowmelt cause midwestern rivers to begin rising in the spring. In the summer, unremitting rainfall leads to record flooding on the Missouri and Mississippi Rivers, as well as many major tributaries. The floods are responsible for fifty-two deaths and more than $18 million in damage.

• December 29, 1993
The Convention on Biological Diversity enters into force. The convention aims to conserve the Earth's biological resources, which are threatened by climate change.

• March 21, 1994
The United Nations Framework Convention on Climate Change, the first comprehensive global agreement seeking to control the atmospheric factors which cause global warming, enters into force. The convention establishes a process through which pollution control agreements, such as the Kyoto Protocol, can be created.

• June 17, 1994
The United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, is adopted by 193 countries. The convention mandates a new approach to combating desertification.

• August, 1994
A severe heat wave and drought parches Japan. Blocks of ice are placed in subway stations so riders can cool their heads.

• 1995
The IPCC predicts carbon dioxide and greenhouse gas emissions will raise Earth's temperatures between 0.8 and 3.3° Celsius within one hundred years.

• March 28-April 7, 1995
The Berlin Mandate is negotiated, establishing a series of international meetings that ultimately will lead to the Kyoto Protocol to the United Nations Framework on Climate Change.

• June-October, 1997
A severe drought in Indonesia, exacerbated by El Niño conditions, delays the autumn monsoon season by two months. In the summer, industrial and subsistence farmers seek to take advantage of this delay; they burn more than the usual amount of land in order to clear it for crops and to increase their profits. These human-caused forest fires rage through the country from June through October, burning millions of hectares, including rain forests. The fires also create smoke that covers Indonesia, Malaysia, Singapore, Thailand, Vietnam, and the Philippines for several months, harming both humans and animals.

• July 25, 1997
The U.S. Senate by a vote of 95-0 adopts the Byrd-Hagel Resolution, declaring that the United States should not agree to limit its greenhouse gas emissions unless developing nations, including China and India, are also required to limit theirs.

• December 1-11, 1997
Representatives of more than 150 nations meet in Kyoto, Japan, to negotiate a protocol committing signatory nations to reduce their production of greenhouse gases over the next fifteen years. A section of this newly created Kyoto Protocol allows countries to collaborate on emissions-reducing projects and to trade and purchase emissions credits.

• January 14, 1998
The Protocol on Antarctic Environmental Protection enters into force. The protocol aims to enhance cooperation among many of the world's countries in order to protect the environment and resources of Antarctica.

• July, 1998
A heat wave hits the southwestern and northeastern United States. Daytime temperatures in Texas hit 43° Celsius, with forty-one days of highs above 38°, causing huge crop losses and 144 deaths.

• July, 1998
Worldwide, July is determined to be the hottest month in history to date.

• August, 1998
India reaches 51° Celsius, causing 3,000 people to die in the nation's worst heat wave in fifty years.

• August, 1998
Record heat in Germany produces severe smog. Cars lacking antipollution devices are banned.

• September 16-29, 1998
Hurricane Georges, with winds exceeding 209 kilometers per hour, strikes in the Caribbean and then the Gulf Coast, leaving 400 people dead.

• October 27, 1998
Hurricane Mitch hits Central America, killing more than eleven thousand people.

• November 11, 1998
The United States signs the Kyoto Protocol; however, in subsequent years, Congress does not ratify the agreement.

• 1999
A major drought strikes the southeastern United States, the Atlantic coast, and New England.

• October 12, 1999
The world's six billionth person is born.

• November 17, 1999
The Scientific Ice Expeditions program, which analyzed decades of data from Arctic Sea ice, reports a significant reduction in the thickness of the ice during the last decade—evidence that the Arctic climate is warming.

• December 22, 1999
The World Meteorological Organization reports that the 1990's were the warmest decade since instrumental measurement started in the 1860's.

• February 23, 2000
The National Climate Data Center reports that Earth has warmed at a rate of 2.2° Celsius in the past twenty-five years—a faster rise than originally predicted.

• May 22, 2000
The U.S. National Oceanic and Atmospheric Administration (NOAA) declares that January through April, 2000, was the warmest period in recorded history.

• August 30, 2000
The World Wildlife Fund reports that one-third of the world's habitat will be lost or dramatically changed due to global warming.

• February 19, 2001
The IPCC reports that the least adaptable and poorest regions of the world will be the most severely impacted by climate change.

• March 26, 2001
Leaders of the European Union write President George W. Bush, seeking his commitment to implement the Kyoto Protocol.

• March 28, 2001
Christine Todd Whitman, head of the Environmental Protection Agency, announces that the United States will not implement the Kyoto Protocol. The announcement draws scorn from environmentalists, scientists, and leaders of many other nations.

• September, 2001
The Greenhouse Gas Protocol, designed to help corporations account for and report greenhouse gas emissions, is published. The protocol, revised in March, 2004, will become more widely used than other similar accounting systems.

• September 4, 2001
Researchers from the National Aeronautics and Space Administration (NASA) report that parts of the Northern Hemisphere have become much greener during the past twenty-one years as a result of rising temperatures. While the data confirm that Russia and Canada will have a longer growing season in which to produce more crops, NASA scientists say the study also indicates an increase in atmospheric carbon dioxide and other greenhouse gases.

• October 4-9, 2001
Hurricane Iris kills thirty-one people and destroys $150 million worth of property in Belize.

• 2002
A severe, long-term drought begins in Australia. Urban areas begin to feel its effects by 2006, as major cities pass heavy restrictions on water usage and Perth constructs a desalination plant.

• February 12, 2002
President George W. Bush proposes a plan that will set goals for the reduction of greenhouse gases based on America's economic growth, while providing companies with incentives to comply with these goals. The plan contrasts with the Kyoto Protocol, which sets tougher mandatory reductions.

• March 19, 2002
British researchers report that an Arctic ice shelf weighing 500 billion tons broke apart in less than a month—the largest single ice shelf retreat in the past thirty years. Scientists describe the speed of the collapse as "staggering."

• May 28, 2002
The U.S. Climate Action Report 2002 is submitted, marking the first time that the Bush administration acknowledges that global warming is influenced by human beings' behavior. The report also acknowledges that unchecked global warming will seriously harm America's environment.

• May 31, 2002
The European Union ratifies the Kyoto Protocol.

• September 4, 2002
Agenda 21 is reaffirmed *(see June 14, 1992)*.

• September 16, 2002
NOAA reports that the average temperature in the United States from June through August, 2002, was 23.3° Celsius, the hottest summer since the Dust Bowl droughts of 1934 and 1936.

• November 7, 2002
In an article in *Nature*, a team of British scientists reports that the wildfires which devastated Indonesia and other parts of Southeast Asia in 1997 released as much as 2.6 billion metric tons of carbon, mostly in the form of carbon dioxide, into the atmosphere—as much carbon as the entire planet's biosphere removes from it in a year.

• July-August, 2003
A heat wave grips all of Europe, especially France, Italy, Spain, and Portugal; as many as 40,000 die from heat-related causes, and drought and wildfires follow.

• September 18, 2003
Hurricane Isabel, a Category 5 storm, makes landfall south of Cape Hatteras, North Carolina, leaving fifty-three dead and property damage of $3.37 million.

• October 21-November 4, 2003
Hot Santa Ana winds fuel at least twelve wildfires stretching from San Diego County north to the sub-

urbs of Los Angeles. Twenty-two people are killed, including fourteen in the 1,137-square-kilometer Cedar Fire—the largest individual blaze in California history. At least 3,450 homes are destroyed.

- 2004

Four Category 5 storms—Charley, Frances, Ivan, and Jeanne—make landfall in the United States, the most in a hurricane season since 1963.

- January 2, 2004

In a report published in *Science*, a team of NASA scientists and other researchers concludes that year-to-year changes in concentration of carbon dioxide and methane can be linked to fire activity associated with the El Niño-La Niña cycle.

- May 28, 2004

The film *The Day After Tomorrow*, a fictional depiction of the advent of a modern ice age, is released, reflecting popular concerns about global warming.

- December 26, 2004

A massive tsunami strikes eleven nations bordering the Indian Ocean, leaving at least 212,000 people dead and almost 43,000 missing.

- February 16, 2005

The Kyoto Protocol enters into force. The protocol sets out clear targets for reducing greenhouse gas emissions, balances national economic development plans with emissions reductions, and sets up free market mechanisms to achieve the targets set by intergovernmental negotiations.

- August 25-September 2, 2005

Hurricane Katrina kills 1,500-2,000 people in Louisiana, Mississippi, Alabama, and Florida and leaves hundreds missing; property damage is estimated at $75 billion. The levees protecting New Orleans are breached, and the city is completely flooded. Two other powerful hurricanes, Rita and Wilma, hit the Gulf Coast shortly afterward.

- December, 2005

In Tehran, Iran, businesses and schools close because of severe smog conditions. Hundreds of people are taken to the hospital.

- December 21, 2005

The administration of California governor Arnold Schwarzenegger begins the lengthy process of obtaining a waiver from the U.S. Environmental Protection Agency to implement standards for state vehicle greenhouse gas emissions which are more stringent than those mandated by federal legislation. Thirteen other states eventually adopt California's tougher emissions standards.

- August, 2006

Former vice president Al Gore publishes *An Inconvenient Truth* and releases a popular film of the same name in which he emphasizes the need to stop global warming in order to prevent the destruction of Earth's natural resources and the accompanying loss of biodiversity.

- October 12, 2007

Gore and the IPCC are awarded the Nobel Peace Prize.

- October 20-November 9, 2007

Flames whipped by Santa Ana winds engulf large portions of Southern California, forcing the evacuation of more than 500,000 people. More than a dozen wildfires burn 1,200 homes and businesses and set fire to about 1,000 square kilometers.

- December 3-14, 2007

Participants in the United Nations Climate Change Conference in Bali, Indonesia, establish a time line for future negotiations aimed at reducing global warming.

- February 7, 2008

The Center for Biological Diversity petitions the U.S. Fish and Wildlife Service to protect the Pacific walrus under the federal Endangered Species Act, arguing that the marine mammal is threatened by global warming and the growth of oil and gas development in its habitat. When the service refuses to process the petition, the center files suit to compel the federal agency to consider its request.

- May 14, 2008

The U.S. Department of the Interior lists the polar bear as a threatened species under the Endangered

Species Act based on evidence that the bear's sea ice habitat is shrinking and will likely continue to shrink during the next several decades.

- March 29-April 8, 2009

Delegates from 182 countries meet in Bonn, Germany, to begin negotiating a successor treaty to the Kyoto Protocol. Additional negotiating sessions will be held in Bonn on June 1-12 and August 10-14; in Bangkok, Thailand, on September 28-October 9; and in Barcelona, Spain, on November 2-6. The negotiators' efforts will culminate in the United Nations Climate Change Conference in Copenhagen, Denmark, on December 7-18.

- May 18, 2009

A federal judge in Anchorage, Alaska, requires the U.S. Fish and Wildlife Service to consider if the Pacific walrus should be protected under the Endangered Species Act. The requirement is part of a settlement between the agency and the Center for Biological Diversity, which is seeking protection for the marine mammal. Under the agreement, the service must make an initial finding on the center's petition for protection by September 10, 2009, and in 2010 must decide if the walrus should be listed as an endangered species.

- May 19, 2009

President Barack Obama announces a plan to raise fuel-economy standards to an industry average of 35.5 miles per gallon in 2016, an increase of more than 8 miles per gallon per vehicle. He estimates these standards will save 1.8 billion barrels of oil over the lifetime of vehicles sold in the next five years.

- May 21, 2009

By a vote of 33-25, the House Energy and Commerce Committee passes the Waxman-Markey climate and energy bill, also known as the American Clean Energy and Security Act—the first time a serious climate-change bill has progressed this far in the legislative process. The bill aims to cut greenhouse gas emissions by roughly 17 percent below 2005 levels by 2020, and by about 80 percent by 2050, while promoting renewable energy and energy efficiency.

- June 16, 2009

NOAA releases a new study, *Global Climate Change Impacts in the United States*, which confirms previous evidence that the global temperature changes in recent decades are created by human activity. Among its findings, the report predicts that heat waves will occur more frequently and will be more intense in the future, increasing threats to human health, transportation, energy, crops, and livestock. The study also predicts the warming climate will increase the number of wildfires and insect infestations, as well as leading to increased rainfall and flooding.

- December 7-18, 2009

The United Nations Climate Change Conference is held in Copenhagen, Denmark.

Glossary

abatement cost: cost incurred when reducing a nuisance such as pollution
accretion: the final process of planetary formation, in which smaller objects are pulled into the nascent planet
***acqua alta*:** flooding; Italian for "high water"
ad hominem argument: an attempt to discredit an idea by discrediting the person espousing it
adaptation: the process through which entities adjust in response to external circumstances
additive processes: human activities that build or enhance Earth's surface topography
aerobic: occurring in or requiring the presence of oxygen
aerodynamic: designed to minimize drag from the air
aerosols: minute particles or droplets of liquid suspended in Earth's atmosphere
afforestation: the creation of new forests on previously unforested land
agricultural drought: lack of sufficient soil moisture for crop growth, leading to partial or total loss of yield
agricultural revolution: the advent, about ten thousand years ago, of human domestication and cultivation of plants and animals and the reorganization of social and economic structures that resulted
ahermatypic corals: non-reef-forming corals
air parcel: a theoretical, house-sized volume of air that remains intact as it moves from place to place
air pollution: anthropogenic or natural degradation of air quality
air quality: atmospheric purity, as measured by the relative concentrations of contaminants, toxins, and other potentially harmful trace elements
Air Quality Index (AQI): a numerical index used to report air pollution and hazard levels to the public
aircraft emissions: gases and particulate matter expelled from aircraft engines
albedo: the fraction of radiation reflected by a surface
algae: a class of predominantly aquatic plants and plantlike organisms
algal bloom: a sudden explosion in the algae population in a given body of water or a localized portion of a body of water; blooms deplete oxygen, killing fish, and they can be caused by chemical fertilizers or other nutrients carried in runoff water
alluviation: soil erosion that results in the filling of watercourses or harbors
alpine glaciers: large masses of ice found in valleys, on plateaus, and attached to mountains
alternative energy or fuels: fuels and other energy resources that are renewable, nonpolluting, or both and have the potential to replace fossil fuels and other traditional energy resources
anaerobic: occurring in, or requiring, the absence of oxygen
anecdotal evidence: isolated instances illegitimately used to establish a logical principle or general rule
Annex A: an annex to the Kyoto Protocol listing the six GHGs covered by the agreement: CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride
Annex B: an annex to the Kyoto Protocol that specifies the GHG reduction targets for Annex I nations and establishes a credit trading system to help them reach those targets
Annex I: an annex to the United Nations Framework Convention on Climate Change that lists the industrialized nations that are parties to the convention; these nations are committed to achieving significant GHG emissions reductions by a certain date, while developing-nation parties are not listed in Annex I and are not committed to achieving such reductions
annular mode: a pattern of change in atmospheric circulation biases that corresponds to changes in the midlatitude westerlies
anomaly: a phenomenon that is outside the realm of normal, predictable occurences in a given context or a datum that fails to fit easily into the data set of which it is a part
anthropocentric: treating human beings and human concerns as the primary source of value
anthropogenic: caused by human activity

anthropogeomorphology: changes to the surface of the Earth brought about intentionally or unintentionally by humans

aqueduct: a human-made channel or pipe that carries water for consumption or industrial or agricultural use

aquifer: a layer of sand, gravel, or permeable rock containing water

Arab oil embargo: a 1973 action by Middle Eastern oil-producing states to stop exporting oil to the United States and other supporters of Israel

archaeological record: the human-made objects and residues of the past that are used to reconstruct history

arid climate: a dry climate in which rainfall is so sparse as to make agriculture difficult or impossible without irrigation

assigned amount units: the GHG emission allowances of Annex I parties

asthenosphere: the ductile layer of the Earth, beneath the lithosphere, defined by mechanical behavior; although solid, it deforms horizontally over tens of millions of years

astronomical forcing: climatic change triggered by changes in solar luminosity, variation in the Earth's orbit, and bolide impact

Atlantic Multidecadal Oscillation: a pattern of cyclical increases and decreases in Atlantic sea temperatures that last for decades

atmosphere: the envelope of gases surrounding a planet

atmospheric chemistry: the chemical composition of and reactions occurring within an atmosphere

aurora: glow released by gases in the upper atmosphere when they are bombarded by charged solar particles

barrier island: an island that runs parallel to a nearby coastline and that protects the coastline from storm surges

base year: a year that is used to set baseline measurements of emissions or other phenomena in order to compare future variations or to determine target levels

baseline: a selected norm from which phenomena deviate

bayou: a small, often intermittent, branch of a river

behavioral economics: the study of the combined economic and psychological principles affecting human behavior and decision making

biocentric: treating all living things as equal in value and as more important than nonliving things

biodiesel: plant-derived oil that can be used to power diesel engines

biodiversity: the total variation within and among all species of life in a given area, ecosystem, or context

biofuels: energy sources derived from recently dead organisms, most commonly plants

biomass: plant and other organic materials that can be used as fuel

biome: a major biological community adapted to a particular climate or area

biosecurity: measures required or taken to protect organisms from risk or danger

biosphere: the totality of Earth's living organisms and ecological zones

biotechnology: techniques and devices that use living organisms to achieve human goals

bloggers: people who publish information or commentary in regularly updated journals or columns on the World Wide Web

brackish: of water, having an intermediate level of salinity, between 5 and 35 parts per thousand

brine rejection: expulsion of salt from freezing seawater, increasing the salinity of the liquid seawater and decreasing the salinity of the forming sea ice

calcium carbonate: a compound of carbon and calcium that forms part of the bodies of small marine organisms, in which carbon may be sequestered

calving: the separation of a large portion of ice from a glacier or ice shelf, creating an iceberg

canopy: the upper layers of vegetation or uppermost levels of a forest where energy, water, and greenhouse gases are actively exchanged between ecosystems and the atmosphere

cap and trade: a system in which a limit is set on the total permissible emissions of a pollutant or class of pollutants and permits to emit a specific amount of pollution are distributed; those permits are then treated as commodities that may be sold or traded

capitalism: an economic system in which the means of production are privately owned and operated with the goal of increasing wealth

capture: to secure and contain harmful substances or contaminants

carbon budget: the total amount of CO_2 emissions that can be sustained, given a target atmospheric CO_2 concentration, and the way in which those emissions are apportioned

carbon-capture-and-storage (CCS) systems: processes that remove CO_2 from combustion products and sequester it—typically in underground storage

carbon cycle: the set of processes through which carbon atoms circulate among Earth's atmosphere, terrestrial biosphere, oceans, and sediments

carbon dioxide (CO_2): a greenhouse gas produced by burning fossil fuels, respiration, and other natural and anthropogenic processes

carbon dioxide equivalent (CO_2e): an expression of a given quantity of GHG's contribution to the greenhouse effect as a function of the amount of CO_2 that would have the same effect

carbon fixation: the conversion of CO_2 into organic molecules through such processes as photosynthesis or calcification and the sequestration of those molecules within living systems

carbon footprint: a measurement of the annual GHG emissions attributable to a specific entity, meant to express the detrimental effects of that entity's actions on the environment

carbon neutrality: the quality of neither subtracting from nor adding to the amount of carbon in the atmosphere

carbon sequestration: removing CO_2 from the atmosphere and storing it, or the carbon atoms within it, somewhere else

carbon sink: an entity that absorbs and stores carbon, thereby removing CO_2 from the atmosphere

carbon tax: a tax on activities that directly or indirectly produce CO_2 emissions

carrying capacity: the maximum population that can be supported indefinitely with the available resources and services of a given ecosystem

catalytic converters: devices that reduce vehicular carbon monoxide exhaust by converting it into carbon dioxide

certified emissions reduction (CER): a unit of GHG reduction, equivalent to 1 metric ton of CO_2e in emissions reduced through the clean development mechanism; CERs may be used to fulfil Annex I nations' obligations under the Kyoto Protocol and may be traded as commodities between nations

chinook/foehn wind: a warm, dry wind that blows on the eastern side of the Rocky Mountains or the Alps

chlorofluorocarbons (CFCs): compounds of chlorine, fluorine, and carbon, popularly known by the trade name Freons

Clean Air Acts: a set of federal laws, passed between 1963 and 1990, that form the basis for the United States' air pollution control efforts

clean development mechanism: a mechanism of the Kyoto Protocol wherein Annex I countries sponsor GHG reduction projects in developing nations in order to earn certified emissions reductions, which they can use to fulfill their treaty obligations or sell to other countries that are in need of credits

climate: long-term, average, regional or global weather patterns

climate canaries: the first victims of world climate change, whose plight serves as an early warning to others

climate change: a lasting, significant change in the average weather of a given area

climate change scenario: a projected set of changes in average weather patterns based on a hypothetical set of changes in meteorological and climatological inputs; used to predict the most likely results of various possible occurrences

climate control: the relatively permanent factors that govern the general climate of a region

climate feedback loops: self-reinforcing and self-negating processes that accelerate or retard climatic trends

climate fluctuations: changes in the statistical distributions used to describe climate states

climate impact: the effects of climate and climate change on the socioeconomic well-being of an area

climate impact statement: an empirical case study designed to help predict future climate impacts

climate normals: averages of a climatic variable for a uniform period of thirty years

climatic envelope: the range of temperatures, precipitation, and other climatic parameters to which a given species has adapted

climatic oscillation: a fluctuation of a climatic variable in which the variable tends to move gradually and smoothly between successive maxima and minima

climatic precession: cycle of variations in the Earth-Sun distance at summer solstice

climatic trend: a climatic change characterized by a smooth, monotonic increase or decrease of the average value in the period of record

climatic variable: a specific, measurable quantity related to climate, such as annual rainfall, night-time temperature, or average humidity

cloud condensation nuclei: atmospheric particles such as dust that can form the centers of water droplets, increasing cloud cover

Coase theorem: assertion that when property rights are properly defined, people are forced to pay for the negative externalities they impose on others and market transactions will produce efficient outcomes

coefficient of performance: a standard measurement of energy efficiency

combustion: the burning of fuels to produce energy

commodity: anything that has commensurable value and can be exchanged

community: a group of people who live and interact within a specific geographic or social sphere

complex interdependence: a situation in which intensive interconnections between transnational actors necessitate cooperation among those actors

compressed air: air that is forced into a small space under high pressure

condensation: the transformation of a substance from its gaseous to its liquid state

congestion charge: a tax levied for driving in the urban core of a large city

conservation: the perpetuation through sustainable use of renewable resources and the development and wise utilization of nonrenewable resources

conservation tillage: practices designed to leave stubble and other crop residues on the land surface to reduce soil erosion and surface runoff

conspiracy: a secret effort by a group to achieve a (usually illegitimate) purpose

conspiracy theory: a theory that some event was engineered by a covert group or that seemingly unrelated entities are secretly working in the service of a common agenda

contiguous zone: area between 22.2 and 44.4 kilometers from a nation's coastline within which the nation enjoys partial but not full sovereignty

continental crust: the uppermost layer of the Earth, granitic in composition, with a density of about 2.7 metric tons per cubic meter

continents: large sections of a planetary surface that are above water and composed largely of low-density rock

convection: motion in a fluid (or atmosphere) that results in the transport and mixing of the fluid's physical properties, such as heat

coral: a colony-forming cnidarian organism that excretes a calcium carbonate exoskeleton

coral atoll: an island or islet composed of a lagoon encircled wholly or partly by a coral reef

coral bleaching: whitening of coral that occurs when it expels a single-celled, symbiotic algae as a result of environmental stress

Coriolis effect: the deflection of moving objects caused by Earth's rotation

cosmic rays: energetic particles bombarding Earth's atmosphere

cosmogenic isotope: an isotope produced when a cosmic ray strikes the nucleus of an atom

coupled atmosphere-ocean models: computer simulations of alterations in and interactions between Earth's atmosphere and oceans

cover crops: domesticated plants grown to cover the land surface for the purpose of managing soil fertility, soil quality, water, weeds, pests, diseases, diversity, or wildlife

crisis: a potential turning point to the worse in a difficult situation

criteria air pollutant: an air pollutant for which acceptable levels of exposure can be determined and ambient air quality standards have been set

crust: the upper portion of the Earth's surface—about 7 to 10 kilometers thick in the oceans and about 25 to 70 kilometers thick on the continents

cryosphere: the portion of the Earth's surface that is composed of frozen water, including snow, glaciers, ice caps, and ice sheets

cyclone: a storm system that rotates about a low pressure area

dangerous climate change: a shift in which a meteorological event that had been occurring only once every one hundred years begins to occur once every ten years

dead zones: areas of deepwater oxygen depletion, in which fish cannot survive, caused by surface algal blooms or disruption of thermohaline circulation

decay constant: a measure of how radioactive an isotope is, determined with a Geiger counter

deforestation: the process by which areas are stripped of forests and tree cover, exposing the underlying soil to erosive forces

delta: a network of distributaries flowing through deposited sediments at the mouth of a river

desalination: removal of soluble salts from water, usually to make it potable or suitable for irrigation

desert: an arid ecosystem in which water resources are unusally scarce

desert climate: a hot climate characterized by extremely low and sometimes deficit amounts of precipitation

desertification: the gradual transformation of habitable land into desert by climate change or destructive land use

detritus: the residue left behind by decay or disintegration

developing nations: poor, incompletely industrialized, primarily agricultural or island nations

dew point: the temperature at which water vapor condenses into liquid water

direct action: nonconventional, confrontational political activity, including protests, demonstrations, and civil disobedience

disability-adjusted life years (DALYs): a time-based quantitative measure of the burden of disease in a population that combines years of life lost to premature mortality and years of life lost to poor health or disability

disaster: a drastic disruption in the functioning of a system

discount rate: the present economic cost of preventing future harms, expressed as a percentage of the future economic cost of allowing those harms to occur

distillation: use of evaporation and condensation to remove solutes from a liquid

distributary: a branch of a river that removes water from the main river, especially near or in a delta

dormancy: the portion of the year during which no growth occurs

drag: friction caused by air as an object passes through it

drainage basin: an area bounded by a continuous and topographically higher divide where water from precipitation drains downhill into a body of water

drought: an extended period of months or years when a region experiences a deficiency in its water supply

dune mobility index: a measure of potential sand mobility as a function of the ratio of the annual percentage of the time the wind is above the sand transport threshold and the effective annual rainfall

Dust Veil Index: a numerical index that quantifies the impact of a volcanic eruption's release of dust and aerosols

dystopia: a fictional world in which living conditions are extremely bad; the opposite of a utopia

easterlies: the prevailing winds in the low latitudes, including the trade winds

ecological niche: the relational position of a species in an ecosystem with respect to all other species, resources, and physical and chemical factors affecting life and reproduction within that ecosystem

economic interdependency: a state of affairs in which the economic processes of a group of nations are mutually dependent

ecosystem: all living organisms within an area, as well as the nonliving area's environment, understood as a coherent functioning unit

ecosystem services: all living and nonliving aspects of an ecosystem that function to sustain life within the ecosystem

ecotage: ecologically motivated sabotage

ecoterrorism: acts of violence against anti-environmental interests, designed to protect the environment from harm

El Niño: weather phenomenon that sends an influx of nutrient-poor, warm water into the normally cold, nutrient-rich surface waters off the coast of Ecuador and Peru

El Niño-Southern Oscillation (ENSO): the combined and related phenomena of El Niño effects in the Pacific Ocean and shifts in sea-level air pressures between the eastern and western Pacific

electric cars: automobiles run completely on electricity, without the need to burn fuels

emission charge: a fixed-rate tax calculated per unit of emissions

emission credits: purchasable shares in an emission-reducing project that are used to measure attempts by an entity to offset its GHG emissions

emission reduction unit (ERU): a unit of credit used to measure the amount of GHG emissions reduced by a joint implementation project under the Kyoto Protocol

emission scenario: a set of posited conditions and events, involving climatic conditions and pollutant emissions, that is used to project future climate change

emissions: gases and particulates released into the atmosphere

emissions trading: a practice in which the right to pollute is turned into an exchangeable commodity, motivating polluters to reduce their emissions so they can profit by selling their rights to others

emissivity: a measure of the ability to radiate absorbed energy

empirical: based on experiential observation

endangered species: a species that is in danger of extinction throughout all or a significant portion of its habitat range

energy: the capacity to do work

energy balance: the equilibrium state of all energy entering and leaving a system, such as the Earth

energy efficiency: the proportion of expended energy that drives work, as opposed to the proportion that is dissipated as waste heat

energy from waste: energy produced from waste materials and substances

energy independence: the ability of a nation to generate energy sufficient for its needs domestically, without relying on foreign imports

energy-intensive: using an unusually large amount of energy, usually in the service of industrial processes

energy resources: the raw materials necessary to produce energy, such as fossil fuels, a waterfall, or a region that enjoys abundant sunlight

enhanced greenhouse effect: increased retention of heat in the atmosphere resulting from anthropogenic atmospheric gases

environmental refugees: people forced to leave their homes by climate change or other environmental disasters

environmental terrorism: violent acts intended to harm the environment or deprive people of environmental benefits or resources

equilibrium: a condition in which all directly competing forces in a system are balanced, resulting in the stability of the system

erosion: the removal or wearing down of solids by wind or water

ethanol: ethyl alcohol, a product of fermentation that can be used as a biofuel

ethics: the application of moral philosophy or principles to real-world decision making

eukaryote: an advanced cell, containing a nucleus and other membrane-bound organelles

evangelical: pertaining to proselytizing Protestants who emphasize individual salvation through faith and place what they consider scriptural authority above church tradition

evaporation: the transformation of a substance from its liquid to its gaseous state

evapotranspiration: the set of processes through which water on surfaces or in plants is lost to the atmosphere

exclusive economic zone (EEZ): a zone extending from a nation's coast up to 370, or even 650, kilometers that is considered that nation's sole legal preserve to regulate and exploit economically

exotic species: a species found in an area where it is not native

extinction: the total disappearance of a species from the Earth

extinction event: an unusually large number of extinctions occurring in a relatively short period of time

extraction: removal of a resource from its natural location

extratropical cyclone: a cyclone originating and subsisting outside the tropics

extreme ultraviolet radiation (EUV): electromagnetic radiation with wavelengths between 10 nanometers and 120 nanometers

extreme weather events: major, potentially damaging weather occurrences, such as hurricanes, snowstorms, or floods

fallacy: a false belief or an argument that looks superficially convincing but is based on logical errors

falsifiability: the ability of a scientific theory to be tested experimentally and disproved with data

feedback: a process in which a change to a system renders that system either more or less susceptible to further changes; positive feedback accelerates changes to and destabilizes the system, whereas negative feedback decelerates changes to and stabilizes the system

fermentation: the biochemical generation of energy from organic compounds in the absence of oxygen

fertilization: a process that increases plant growth, either intentionally through the addition of nutrients to soil or unintentionally through an increase in atmospheric CO_2 concentration

filtration: separation or removal of contaminants from emissions

firn: the intermediary stage between snow and ice

fission, nuclear: the splitting of a heavy nucleus (such as in a uranium atom), accompanied by the release of a relatively large amount of energy

flexible-fuel engine: a motor vehicle engine that is capable of burning more than one type of fuel

flood: the overflowing of a body of water, causing some water to leave it and pour onto land

flux: a shift or flow of energy or matter from one location to another

foehn: *see* chinook/foehn wind

forebulge: an elevated area just beyond the area depressed by an ice sheet

forest clearing: destruction of forests in order to create land suitable for human habitation or use

fossil fuels: carbon-based fuels derived from decayed plants and animals under geologic pressure over millions of years

freedom of the seas: the principle that, outside the water adjoining nations' shorelines, all nations have the right of free passage and use of the ocean's resources

Freon: trade name for CFCs made by DuPont chemical company

Fresnel lenses: small plastic sheets with very small, patterned, concentric circles stamped or milled into them that concentrate sunlight

fuel: an energy source that is burned to release energy

fuel alternative: an energy source that does not require burning and may be used in place of fossil fuels

fusion, nuclear: the combination of two light nuclei to produce a heavier nucleus

gasoline: a fuel, refined from oil, that is used to power automobile and other engines

generator: a mechanical device whose rotational movement around magnets produces an electrical current

geoengineering: the intentional production of large-scale changes to the Earth in order to promote human welfare

geomagnetic storm: magnetic activity caused when charged particles from solar flares strike Earth's magnetic field

geomorphology: the form and shape of Earth's surface features

geostrophic current: a current driven by horizontal gradients in pressure that are balanced by the Coriolis effect

geothermal energy: energy from heat stored in or generated by the Earth

glacial fluctuations: advances and retreats of glaciers in response to warming and cooling of the climate

glacial ice: ice created by the compression of snow into glaciers

glacial isostatic adjustments: vertical motions of Earth's crust to restore it to preglacial elevations

glaciation: the advance of a continental ice sheet

glacier: a mass of ice that flows downhill, usually within the confines of a former stream valley

global climate change: change in Earth's temperature and precipitation patterns over time

global cooling: lowering of the Earth's atmospheric and oceanic temperatures over time

global dimming: a reduction in the amount of sunlight reaching the surface of the Earth

global radiative equilibrium: the state of balance between solar radiation reaching Earth and radiation returned to space

global warming: increase of Earth's atmospheric and oceanic temperatures over time

global warming potential: the climatic impact of a given mass of greenhouse gas, measured as a function of the impact of the same mass of carbon dioxide

globalization: the worldwide expansion and consequent transformation of socioeconomic interrelationships

gradient: the differential between two values, such as temperatures or salinity levels

Great Climate Shift: a sudden shift of global climate in 1977, ending thirty years of global cooling and beginning a period of global warming

green politics: a political orientation founded upon environmental concerns

Green Revolution: a dramatic increase in global food production brought about by the development of new strains of wheat, rice, and corn around 1960

greenhouse effect: a phenomenon in which atmospheric gases act like glass in a greenhouse, allowing ultraviolet solar radiation to reach the ground but trapping infrared terrestrial radiation and heating the planet

greenhouse gases (GHGs): atmospheric gases that trap heat within a planetary system, preventing it from escaping into space

greening: process of becoming more environmentally conscious or responsible, as in the greening of industry

greenwashing: the exploitation and appropriation of environmental concerns and issues by corporations, government agencies, and political operatives to advance self-interested agendas

groundwater: water stored beneath the land's surface

groundwater table: the upper surface of the underground zone that is saturated with water

growing season: the portion of the year during which photosynthesis occurs in a given location

Gulf Stream: the warm current originating in the Gulf of Mexico that travels along the U.S. east coast before turning east to cross the Atlantic Ocean

gyre: a massive ocean-circulation system that flows in a circular pattern around the center of an ocean basin

habitat: the area normally inhabited by a particular species

Hadley circulation: an atmospheric circulation pattern in which a warm, moist air ascends near the equator, flows poleward, descends as dry air in subtropical regions, and returns toward the equator

half-life: the time needed for half of a quantity of a radioactive isotope to decay

halocarbons: a general family of compounds that includes chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, and other molecules in which carbon bonds with halogen atoms

halocline: a gradient of sea salinity, usually vertical

halon: a compound containing bromine, carbon, chlorine, and fluorine

hazardous: poisonous, corrosive, flammable, explosive, radioactive, or otherwise dangerous to human health

heat: the energy, associated with molecular and submolecular motion, that flows from bodies with higher temperatures to bodies with lower temperatures

heat flow: the rate at which thermal energy flows through a surface

heat wave: an extended period of abnormally high temperatures

herbicides: substances or preparations for killing plants

hermatypic corals: reef-forming corals

high-level waste: extremely radioactive fission products and transuranic elements such as plutonium

Holocene: the current interglacial, which began 11,700 years ago

Hubbert's peak: the point at which the rate of production or extraction of an energy resource ceases to increase and begins to decrease

hurricane: a cyclone originating in the tropics
hybrid vehicles: automobiles that run on more than one power source, such as electric batteries and fuel-burning engines
hydroelectric power: electricity generated by moving water in turbines
hydrogen engines: engines that run either on hydrogen-oxidizing fuel cells or on hydrogen combustion
hydrologic cycle: the continuous circulation of solid, liquid, and gaseous water among the oceans, atmosphere, and continents
hydrologic drought: significantly below average water levels in lakes, rivers, reservoirs, and aquifers

ice age: a period during which sea ice and glaciers cover a significant fraction of Earth's surface
ice cap: a domed body of ice covering a highland; smaller than an ice sheet
ice cores: cylindrical samples of ice taken from glaciers or ice caps that provide proxy data relating to past atmospheric compositions
ice sheet: a mass of ice covering a large area of land; larger than an ice cap
ice shelf: a floating body of ice extending from a coast and often attached to an ice sheet
igneous rocks: rocks formed by the crystallization of magma or lava
incinerator: a facility used to burn waste until it is reduced to ash
indigenous: native to a given place
indirect aerosol effect: formation of water droplets in clouds caused by particulate matter
individualization of responsibility: placing responsibility for climate change on individuals rather than on businesses, corporations, or the government
industrial: related to large-scale manufacturing or energy production
Industrial Revolution: the eighteenth and nineteenth century mechanization of mining, manufacturing, and agriculture that transformed national economies
industrialization: development and dissemination of mechanical, mass-production technologies
inefficiency: preventable waste in the use or distribution of resources
infiltration: the process of water on the Earth's surface entering soil
infrared radiation: heat energy transmitted as longwave electromagnetic radiation
inner core: the innermost layer of the Earth, extending from 5,150 kilometers to 6,370 kilometers below the ground and composed mostly of solid iron
insolation: radiant energy received by the Earth from the Sun, or the process of receiving such energy
instability: a state in which one or more normally constant, essential features of a system are in flux
integrated gasification combined cycle (IGCC) systems: electric power generation technology that converts coal to combustible gas before burning it
Inter-Tropical Convergence Zone (ITCZ): a meandering zone of convergence of the northeast and southeast trade winds adjacent to the equator
intercropping: the cultivation of two or more crops simultaneously on the same field
intergenerational equity: relative equality of treatment between present and future generations, including the obligation of present generations to preserve limited resources for the future
interglacial: the warm period between glaciations
Intergovernmental Panel on Climate Change (IPCC): a group of scientists charged by the United Nations to compile data on past, present, and likely future changes in Earth's climate
internal combustion engines: engines that burn fuel in a chamber to generate force
international waters: ocean waters lying beyond the full or partial jurisdiction of any nation and considered open to all nations for all legitimate, nonbelligerent purposes
invasive species: a species whose population grows out of control and negatively affects other species
irrigation canal: a human-made channel or pipe that carries water for consumption or industrial or agricultural use
isotopes: variants of an element that are chemically identical but have different atomic mass numbers and vary in radioactivity

joint development: a system in which Annex I countries can earn certified emissions reduction credits by working on clean development mechanism projects in economically transitional nations, generally one of the former Soviet or Balkan nations

junk science: faulty science that attacks established scientific findings or advances poorly supported theories for a practical goal

Köppen climate classification system: a system for classifying climate based mainly on average temperature and precipitation

Kyoto Protocol: a 1997 international treaty in which industrialized signatories made legally binding commitments to reduce their GHG emissions

La Niña: an ocean-circulation pattern that cools the Pacific Ocean west of Peru, affecting world weather

laissez-faire economic policy: an antiregulation policy that allows markets to operate free of government interference

land management: the oversight and planning of land use and development

land reclamation: modification of unsuitable land to restore it or otherwise make it useful for human projects

land rehabilitation: restoration of land that has suffered environmental degradation

landfill: a site where municipal or industrial wastes are buried in the ground

lapse rate: the rate at which an atmospheric variable changes as altitude increases

late heavy bombardment: a period, about 3.9 to 4.0 billion years ago, when Earth was pummeled by debris from space at one thousand times the normal rate, heating the atmosphere and melting the crust

latent heat: the heat released or absorbed by a change of state, such as condensation or evaporation

latent heat flux: the flux of thermal energy from land surface to the atmosphere that is associated with the evaporation and transpiration of water from ecosystems

latitude: the distance of a point on Earth from the equator, measured in degrees of the planet's curvature

leakage: the shortfall in targeted greenhouse gas emissions reduction caused by industries relocating to jurisdictions with weaker regulation

legal standing: eligibility to bring a civil lawsuit in a specific case, usually as a result of suffering damages

levee: a natural or human-made raised bank along a river

limnetic zone: the upper layers of open ocean through which light penetrates and which thus support photosynthesis by planktonic organisms

lithium-ion batteries: long-lasting, lightweight batteries made from lithium

lithosphere: the solid part of the Earth, comprising Earth's crust and the rigid part of its upper mantle

litigation: disputes in court between parties regarding the meaning and execution of laws

Little Ice Age: a time of drastic global cooling from about 1300 to 1900 that resulted in famines, population migration, glacier expansion, and significant environmental changes

loess: deposits of very fine grained, wind-blown material often associated with glacial deposits

longitude: the distance of a point on Earth from the prime meridian, measured in degrees of the planet's curvature

low Earth orbit (LEO): an orbit situated between 160 kilometers and 1,600 kilometers above Earth's surface

luminosity of Sun: the total energy output of the Sun every second, measured in watts

magma: molten rock and suspended crystals below the Earth's surface

magnetic field: the flow patterns of magnetism that surround a celestial body as a result of an electro-dynamo effect

mainstream media (MSM): an often derogatory term for major journalistic media outlets, including major television networks and newspapers

mantle: the layer of the Earth beneath the crust, peridotite in composition, with a density of about 3,400 kilograms per cubic meter

marine isotope stage: half of a glacial cycle, as identified in the oxygen isotope data from ocean cores; advances are given even numbers, and retreats are given odd numbers

market benefits: positive effects of a given climate policy on production and trade, including prevention or mitigation of damages

mass balance: the difference between the accumulation of snow and the ablation of ice on a given glacial formation

Maunder Minimum: a period from about 1645 to about 1715 when very few sunspots were observed

maximum achievable control technology (MACT) standards: standards designed to limit air pollution from stationary sources (usually heavy industries)

media: all available mass-distributed information sources, from news outlets to books and films

media bias: valuations made or endorsed by mass mediated information sources that are supposed to strive for objectivity

Medieval Warm Period: a time period from around 800 to 1250 when European and possibly global temperatures were generally warming

megacity: an urban area with a total population in excess of 10 million people

megadrought: a drought lasting for years, decades, or centuries, often leading to permanent changes in ecosystems and human societies

megalopolis: a megacity that sprawls over a large area, rather than being concentrated spatially in the manner of traditional cities

meteorological drought: prolonged deficiency of precipitation in an area, as compared to the historical average

methane (CH_4): a gas, the primary component of natural gas, whose greenhouse effect is considerably stronger than that of CO_2

methane hydrates: small bubbles of natural gas trapped in a crystalline ice matrix

microalgae: photosynthetic microorganisms similar to plants

migration: the movement of people and other entities from place to place

Milanković cycles: recurring time periods during which the shape of the Earth's orbit, the tilt of its axis, and the occurrence of its furthest distance from the Sun all change

millennium development goals (MDGs): a set of objectives for economic development adopted by the United Nations in 2000

model: a simplified representation of a complex system used to determine causal relationships and predict future outcomes within the system

monsoon: a seasonal shift in prevailing wind, often associated with significant rainfall

Montreal Protocol: a 1987 international agreement to phase out the manufacture and use of ozone-depleting chemicals

mortality and morbidity: statistics on death and illness in population groups

multiproxy reconstruction: a method of estimating prehistoric climate conditions using a combination of proxy indicators

municipal solid waste (MSW): the trash, refuse, and garbage thrown away from homes and commercial establishments

national action plan: formal plan submitted by a national government to take measures to limit or mitigate the nation's contribution to climate change

National Ambient Air Quality Standards (NAAQS): standards established by the EPA that limit acceptable outdoor air pollution levels throughout the United States

natural climate cycles: alternating global warming and cooling patterns that occur for non-anthropogenic reasons

natural succession: changes in the types of plants that grow in an area over time, starting with grasses and moving through shrubs to trees

Navier-Stokes equation: an equation describing the flow of air (or any other fluid)

negative externality: a situation in which market prices do not reflect the full social costs of some behavior

neoliberalism: school of economic thought that stresses the importance of free markets and minimal government intervention in economic matters

niche: the role of a species within its ecosystem

nissology: the study of islands

nonmarket benefits: positive effects of a given policy on health, social and psychological welfare, and other attributes that are not primarily economic

nonrenewable resource: a resource that, once consumed, cannot be reproduced

North Atlantic drift: a current that diverges from the Gulf Stream, moving warm water northward to areas where it will cool and sink

ocean-atmosphere coupling: the interaction between the sea surface and the lower atmosphere that drives many patterns and changes in Earth's weather systems

ocean basins: large sections of an earthlike planet's surface that have low elevations and higher-density rocks

oceanic rise: linear mountain chains on the ocean floors in which lithosphere is formed by crystallization of magma or volcanism

offsetting: the practice of supporting GHG-reducing efforts elsewhere in order to mitigate the effects of one's own emissions

oil embargo: a refusal on the part of oil-producing nations to sell oil to other nations

oil shale: a fine-grained, sedimentary rock rich in oil, gas, and solid tarlike substances

orbital eccentricity: cyclically variant deformities in a planet's orbit

organic matter: carbon-containing compounds produced by life processes

orographic: triggered by or pertaining to topographic features

orographic barrier: a mountain or a hilly area that acts as a control on the climate on either side

orographic precipitation: precipitation caused by changes in topography that drive air higher, where it cools and condenses

outer core: a liquid layer of the Earth, extending from the base of the mantle at a depth of 2,900 kilometers down to the inner core, at a depth of 5,150 kilometers, and composed mostly of molten iron

ozone: a highly reactive molecule consisting of three oxygen atoms

ozone hole: an area of diminished ozone in the ozone layer

ozone layer: a stratospheric region containing relatively high concentrations of ozone that prevents much potentially harmful ultraviolet solar radiation from reaching Earth's surface

Pacific Decadal Oscillation (PDO): a cycle of decadal changes in Pacific sea surface temperatures between warm and cool modes in the eastern Pacific

paleoclimates: climates of the past for which there are no records of direct, scientifically accurate measurements

paleoclimatology: the study of past climates

palynology: the study of relict pollen from ancient pollen traps

parameterization: the approximation of processes

Pareto optimum: a situation in which it is impossible to improve any individual's condition without worsening that of another individual

particulate matter: small particles, such as fly ash and soot, such as are emitted during the combustion of a carbon-based fuel

parties: countries that have ratified a given international agreement and are bound by its provisions

passive vacuum technology: a method that utilizes gravity and atmospheric pressure, rather than pumps, to create a vacuum, enabling evaporation to occur at lower temperatures, requiring less energy

pathogens: viruses, bacteria, protozoa, or other chemical or biological agents that can infect a human host to produce disease

peak oil: the point at which oil availability and production reaches its zenith, before the Earth's oil resources begin either to dwindle or to become prohibitively expensive to exploit

permafrost: soil, sediment, rock, or other solid ground that has been frozen for at least two years

pesticides: chemical preparations that kill pests, including unwanted animals, fungi, and plants

pests: any of a class of relatively small organisms that damage structures or crops, spread disease, or are otherwise detrimental to human health or endeavors

petrochemical industries: businesses that refine crude oil to create raw materials needed in the manufacture of most chemicals, from fertilizers and pesticides to plastics, synthetic fibers, and medicines

pH: a measure on a fixed scale of the acidity or alkalinity of a solution

photosynthesis: the physiological process in plants that uses carbon dioxide and water to convert solar energy into chemical energy

photovoltaics: devices and technologies that transform sunlight into electricity

plate tectonics: the mechanisms responsible for creating movement in large sections of a planet's surface

Pleistocene epoch: an epoch within the geologic timescale that ended 11,700 years ago

polders: Dutch land areas reclaimed from sea or marsh

policy: the broad set of principles guiding governmental actions and legislation in a specific arena, such as energy or foreign affairs

post-glacial rebound: a rise in the elevation of a land mass after a glacier on top of it melts

power: a source of energy; also, the rate over time at which work is done

Power Dissipation Index: a measure of the total annual energy output of all hurricanes in a region

preadaptation: the ability of a species to move into a new ecosystem or to assume a new niche as a result of adaptations it already possesses

precautionary principle: a policy rule that one should act to prevent severe harm, even if the likelihood of that harm occurring is unknown or potentially low

precipitation: the condensation of atmospheric water vapor that deposits hail, mist, rain, sleet, or snow on the Earth's surface

preservation: keeping a natural area, as nearly as possible, pristine, unaltered, and uncontaminated by human influence

primary air pollutants: harmful substances that are emitted directly into the atmosphere

primary production: the conversion of CO_2 into organic compounds, primarily by photosynthesis

primordial isotope: an isotope that has been present on Earth since the planet formed 4.5 billion years ago

processing: changing a resource into a marketable commodity by milling, refining, and so on

prokaryote: a primitive cell (bacterium) lacking a nucleus and other membrane-bound organelles

prototype: a trial model of a product that a manufacturer is considering mass-producing

proxies: tree rings, fossils, and other artifacts that provide indirect evidence of past climatic conditions

pseudoscience: scientific-sounding claims that are either scientifically false or so poorly supported by evidence that they should not be taken seriously

quantified emission limitation and reduction commitments (QELRCs): the specific GHG reduction targets agreed to by the industrialized parties to the Kyoto Protocol

radiative forcing: a change in the planetary balance between incoming and outgoing radiation that increases or decreases the planet's overall energy balance

radiometric dating: an analytical technique using radioactive isotopes to determine the age of rocks and minerals

rain forest: a tropical area dominated by evergreen trees whose leaves form a continuous canopy and that receives at least 254 centimeters of rain per year

rain shadow: the region on the lee side of a mountain where precipitation is noticeably less than on the windward side

reef: a marine feature lying below the water's surface; often formed by biological activity, as by corals

reforestation: the replacement of forest lost to anthropogenic or natural influences

regenerative braking: process that uses the friction caused by applying a car's brakes to produce energy to help power the vehicle

removal units (RMUs): emission reduction units generated under land use, land-use change, and forestry projects

renewable resource: a resource that can be reproduced, such as a crop, or that renews itself, such as tidal or solar energy

replicability: the ability of an experiment or observation to be repeated and confirmed

reserves: the estimated amount of a nonrenewable resource remaining to be consumed

reservoir: 1) a body of water that forms behind a dam; 2) an object that accumulates, stores, and releases a substance in a box model

resources: entities that—whether renewable or nonrenewable—are finite in amount and usable to achieve human ends

respiration: the physiological process that breaks down organic compounds to obtain energy and that releases CO_2 as a by-product
reverse osmosis: forced passage of a liquid through a membrane to remove solutes
risk: the likelihood of a negative event occurring
runoff: precipitated water flowing over land toward water bodies, including the land surface material dislodged and carried by it

Saffir-Simpson scale: a scale that ranks hurricanes from Category 1 through Category 5, based on their sustained wind velocity
salinity: the concentration of salts in water
salinization: accumulation of soluble salts, as in soil or liquid
saltwater intrusion: process along a coastline in which salt water flows inland into a freshwater aquifer
savanna: grassland with scattered trees characteristic of tropical areas with seasonal rainfall on the order of 50 centimeters per year
scenario: a posited set of conditions used to project the likely consequences of those conditions
scrubbers: liquids that remove pollutants from emissions
sea ice: frozen ocean water
sea level: the theoretical level of the surface of the ocean, halfway between high and low tide
sea-level equivalent (SLE): the change in global average sea level that would occur if a given amount of water or ice were added to or removed from the oceans
secondary air pollutants: harmful substances that result from the reaction of primary air pollutants with principal atmospheric components
sediment: 1) particulate matter that is transported by water and eventually deposited, forming layers on a surface; 2) the layers so formed
sediment load: non-dissolved organic or inorganic particles carried by water
semiarid climates: climates of low annual precipitation (250-500 millimeters)
sensible heat flux: the flux of thermal energy that is associated with a rise in temperature
sequestration: isolation of a substance, such as carbon, in a place or form that prevents it from interacting with or contaminating the atmosphere
signatories: nations that have signed but not yet ratified an international agreement and are thus not yet bound by its provisions
sink: an entity capable of storing a substance and removing it from environmental circulation
smog: the noticeable brown haze created by vehicular and industrial emissions and other fossil emissions; especially prevalent in large cities
snow line: altitude below which snow does not accumulate
snowpack: accumulated snow in mountainous areas that melts during warmer months
socioeconomic drought: a drought severe enough to cause disruption to human societies and economies
soil: the loosely packed mineral and organic substances in which plant life grows on the surface of the Earth
solar irradiance: energy received from the Sun
Southern Oscillation: an oscillation in air pressure between the eastern and western tropical Pacific Ocean; the oscillation is associated with El Niño- and La Niña-related changes in sea surface temperature, and it influences the strength of the Pacific trade winds
stable air: air that resists convectional mixing and uplifting and in which precipitation is unlikely to occur
stoma: a pore in the leaf and stem epidermis of a plant that is used for gas exchange
storm surge: high water associated with a storm, especially that caused by wind action
stratosphere: the atmospheric region just above the tropopause that extends up to about 50 kilometers
subduction: the movement of one lithospheric plate below another
sublimation: the conversion of a solid directly into a gas, bypassing its liquid state
subsidence: land sinkage due to compaction of underlying material
subtractive processes: human activities that reduce Earth's surface topography
subtropical anticyclonic belts: a series of high-pressure belts situated at latitudes 30° north and south of the equator
subtropics: a climate zone found just poleward of the tropics
summer monsoon: a summertime influx over a

continent of unstable, rain-bearing air from over the ocean

sunspots: dark spots on the surface of the Sun caused by solar magnetic activity

surface water: water found on land in such bodies as ponds, lakes, streams, rivers, wetlands, and inland seas

sustainability: the ability of an environmental or environmentally dependent system to continue indefinitely without exhausting the means of its reproduction

sustainable development: the growth of population, industry, and agriculture in a fashion that does not deplete global resources

tar sands: sands containing highly viscous, asphalt-like oil that can be extracted by mixing the sands with hot water or steam

temperature: a numerical measurement on a fixed scale of the molecular and submolecular kinetic energy of a body

territorial waters: the seas within 22 kilometers of a national coast that are considered a nation's exclusive jurisdiction

thermal expansion: a heat-induced increase in the volume of a liquid or gas

thermodynamic disequilibrium: a state of instability in the energy distribution of a system

thermohaline circulation: the rising and sinking of ocean water—caused by differences in density due to differences in temperature and salinity—that drives the world's currents

thermosteric sea-level change: variability in sea level due to changes in water temperature

threatened species: a species likely to become endangered within the foreseeable future

tipping point: the point at which the transition from one state in a system to another becomes inevitable

tornado: a narrowly focused, funnel-shaped, violent windstorm

total equivalent warming impact: a measurement, in mass of CO_2 equivalent, of the global warming potential of an entire system

trade winds: easterly surface winds in the tropics

tragedy of the commons: the perverse collective outcome of self-interested behavior in the absence of property rights

transpiration: the process through which water evaporates from the aerial parts of plants, especially leaves

tree lines: elevations that separate areas of tree growth and areas with no trees

tree rings: layers of new growth added to trees in annual cycles that vary in thickness based on climatic conditions in the years they were formed

tree spiking: hammering a metal or ceramic spike into a tree to discourage logging

tropical climates: climates generally found in equatorial or tropical regions that exhibit high temperatures and precipitation year-round

tropics: a climate zone found close to the equator that lacks a winter season

tropopause: the transition region between the troposphere and the stratosphere

troposphere: the lowest layer of the atmosphere—in which storms and almost all clouds occur—extending from the ground up to between 8 and 15 kilometers high

turbine: an enclosed vessel containing rotating parts turned by the passage of a fluid, such as water or air

United Nations Framework Convention on Climate Change (UNFCCC): a 1992 international agreement creating the overall context for future agreements designed to reduce GHG emissions

unstable air: air that is readily susceptible to convectional mixing and uplifting, which often results in precipitation

upwelling: a rising of warm water to the surface, displacing colder water

urban heat island: an urban region that is significantly warmer than the surrounding rural areas

urbanization: the process of spatial concentration of the human population in cities

varve: an annual layer in a sediment, usually the result of seasonal variation in inputs

viscosity: a measure of how easily a material flows

volatile organic compounds: substances with carbon backbones that evaporate or vaporize easily at room temperature

volcano: a usually mountainous rift in Earth's crust caused by magma erupting through fissures onto the planet's surface

Walker circulation: an atmospheric circulation pattern in the Pacific and elsewhere in which hot, moist air rises, travels eastward, cools and dries, descends, and returns westward

water basin: an area of land where all surface or groundwater flows in the same direction

water rights: the rights of legal entities to contested water supplies

water table: the upper level of groundwater

watershed: the area of land drained by a river and all of its tributary streams

weather: the set of atmospheric conditions obtaining at a given time and place

weathering: a chemical process in which atmospheric carbon dioxide is converted to carbonates through reactions with water and silicate minerals

west coast marine climate: a mild, annually moist climate found along the western coasts of continents

westerlies: the prevailing winds in the midlatitudes, resulting from a combination of vertical circulation patterns in the atmosphere and the rotation of the Earth

wildfire: spontaneously ignited, naturally occurring fire

wildland/urban interface: a region where residential housing is embedded within, or abuts, a wild or nearly wild environment

winter monsoon: a wintertime, large-scale wind system that extends cool, dry, stable air from a continental interior over a large area

zero-emission automobiles: motor vehicles that do not produce toxic pollutants

zooxanthellae: photosynthetic organisms that live in symbiosis with corals and other organisms, providing up to 90 percent of a coral's energy requirements

General Bibliography

This bibliography includes a sampling of works on the scientific, policy, political, and cultural debates relating to global warming, as well as general and focused studies in climatology and related sciences. Readers seeking more narrowly focused sources are encouraged to consult the annotated lists of further reading accompanying the relevant essays in this set.

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• General Studies and Reference Works

Aguado, Edward, and James E. Burt. *Understanding Weather and Climate*. 4th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007.

Ahrens, C. Donald. *Essentials of Meteorology: An Invitation to the Atmosphere*. 5th ed. Belmont, Calif.: Thomson Brooks/Cole, 2008.

_______. *Meteorology Today*. 9th ed. Pacific Grove, Calif.: Thomson/Brooks/Cole, 2009.

Barry, Roger G. *Atmosphere, Weather, and Climate*. 8th ed. New York: Routledge, 2003.

Bridgman, Howard A., and John. E. Oliver. *The Global Climate System: Patterns, Processes, and Teleconnections*. New York: Cambridge University Press, 2006.

Colman, B. R., and T. D. Potter, eds. *Handbook of Weather, Climate, and Water*. Hoboken, N.J.: Wiley-Interscience, 2003.

Critchfield, Howard J. *General Climatology*. Englewood Cliffs, N.J.: Prentice-Hall, 1998.

Geer, Ira W., ed. *Glossary of Weather and Climate*. Boston: American Meteorological Society, 1996.

Glickman, Todd S., ed. *Glossary of Meteorology*. 2d ed. Boston: American Meteorological Society, 2000.

Hamblin, W. Kenneth, and Eric H. Christiansen. *Earth's Dynamic Systems*. 10th ed. Upper Saddle River, N.J.: Prentice Hall, 2004.

Hoffman, Jennifer, Tina Tin, and George Ochoa. *Climate: The Force That Shapes Our World and the Future of Life on Earth*. London: Rodale Books, 2005.

Kump, Lee R., James F. Kasting, and Robert G. Crane. *The Earth System*. Upper Saddle River, N.J.: Prentice Hall, 2003.

Levenson, Thomas. *Ice Time: Climate, Science, and Life on Earth*. New York: HarperCollins, 1990.

Lutgens, Frederick K., and Edward J. Tarbuck. *The Atmosphere*. 10th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2007.

Lynch, John. *The Weather*. Buffalo, N.Y.: Firefly Books, 2002.

Marshall, John, and R. Alan Plumb. *Atmosphere, Ocean, and Climate Dynamics.* Boston: Elsevier Academic Press, 2008.

Mathez, Edmond A., and James D. Webster. *The Earth Machine: The Science of a Dynamic Planet.* New York: Columbia University Press, 2004.

Oliver, John E., ed. *The Encyclopedia of World Climatology.* New York: Springer, 2005.

Oliver, John E., and John J. Hidore. *Climatology: An Atmospheric Science.* 2d ed. Upper Saddle River, N.J.: Prentice Hall, 2002.

Perry, A. *Applied Climatology: Principles and Practice.* New York: Routledge, 1997.

Robinson, P., and A. Henderson-Sellers. *Contemporary Climatology.* Englewood Cliffs, N.J.: Prentice Hall, 1999.

Rohli, R. V., and A. J. Vega. *Climatology.* Sudbury, Mass.: Jones & Bartlett, 2007.

Seinfeld, J., and S. N. Pandis. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change.* 2d ed. Hoboken, N.J.: Wiley, 2006.

Taylor, F. W. *Elementary Climate Physics.* New York: Oxford University Press, 2005.

Walker, Gabrielle. *An Ocean of Air: Why the Wind Blows and Other Mysteries of the Atmosphere.* New York: Harvest Books, 2007.

Wolfson, Richard. *Energy, Environment, and Climate.* New York: W. W. Norton, 2008.

• Overviews of Global Warming and Climate Change

Archer, David. *Global Warming: Understanding the Forecast.* Malden, Mass.: Blackwell, 2007.

Burroughs, William James. *Climate Change: A Multidisciplinary Approach.* 2d ed. New York: Cambridge University Press, 2007.

Christianson, Gale E. *Greenhouse: The Two-Hundred-Year Story of Global Warming.* Washington, D.C.: Walker, 1999.

DiMento, Joseph F. C., and Pamela Doughman, eds. *Climate Change: What It Means for Us, Our Children, and Our Grandchildren.* Cambridge, Mass.: MIT Press, 2007.

Drake, Frances. *Global Warming: The Science of Climate Change.* London: Arnold, 2000.

Emanuel, Kerry. *What We Know About Climate Change.* Cambridge, Mass.: MIT Press, 2007.

Gore, Al. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It.* Emmaus, Pa.: Rodale, 2006.

Haley, James, ed. *Global Warming: Opposing Viewpoints.* San Diego, Calif.: Greenhaven Press, 2002.

Hardy, John T. *Climate Change: Causes, Effects, and Solutions.* New York: John Wiley, 2003.

Henson, Robert. *The Rough Guide to Climate Change: The Symptoms, the Science, the Solutions.* New York: Penguin Putnam, 2006.

Houghton, John. *Global Warming: The Complete Briefing.* 4th ed. New York: Cambridge University Press, 2009.

Johansen, Bruce Elliot. *The Global Warming Desk Reference.* Westport, Conn.: Greenwood, 2002.

Lerner, Brenda Wilmoth, and K. Lee Lerner, eds. *Climate Change: In Context.* Farmington Hills, Mich.: Gale, Cengage Learning, 2008.

Long, Douglas. *Global Warming.* New York: Facts On File, 2004.

McCaffrey, Paul, ed. *Global Climate Change.* New York: H. W. Wilson, 2006.

Maslin, Mark. *Global Warming: A Very Short Introduction.* New York: Oxford University Press, 2004.

O'Hare, Greg, John Sweeney, and R. L. Wilby. *Weather, Climate, and Climate Change: Human Perspectives.* Harlow, England: Pearson Prentice Hall, 2005.

Oldfield, Frank. *Environmental Change: Key Issues and Alternative Perspectives.* New York: Cambridge University Press, 2005.

Silver, Jerry. G*lobal Warming and Climate Change Demystified.* New York: McGraw-Hill, 2008.

• Astronomy and Astronomical Influences on Climate

Brody, Judit. *The Enigma of Sunspots: A Story of Discovery and Scientific Revolution.* Edinburgh, Scotland: Floris Books, 2003.

Emiliani, Cesare. *Planet Earth: Cosmology, Geology, and the Evolution of Life and Environment.* New York: Cambridge University Press, 1992.

Friedman, Herbert. *Sun and Earth.* New York: Scientific American Library, 1986.

Golub, Leon, and Jay M. Pasachoff. *Nearest Star: The Surprising Science of Our Sun.* Cambridge, Mass.: Harvard University Press, 2001.

Hanslmeier, Arnold. *The Sun and Space Weather.*

2d ed. Dordrecht, the Netherlands: Springer, 2007.
Hoyt, D. V., and K. H. Schatten. *The Role of the Sun in Climate Change*. New York: Oxford University Press, 1997.
Odenwald, Sten F. *The Twenty-third Cycle: Learning to Live with a Stormy Star*. New York: Columbia University Press, 2001.
Pap, Judit M., and Peter Fox, eds. *Solar Variability and Its Effects on Climate*. Washington, D.C.: American Geophysical Union, 2004.
Soon, Willie Wei-Hock, and Steven H. Yaskell. *The Maunder Minimum and the Variable Sun-Earth Connection*. River Edge, N.J.: World Scientific, 2003.

• Atmospheric Science and Climatological Studies

Archer, Cristina L., and Ken Caldeira. “Historical Trends in the Jet Streams.” *Geophysical Research Lett*ers 35, no. 24 (2008).
Barry, Roger G. *Synoptic and Dynamic Climatology*. New York: Routledge, 2001.
Bolle, Hans-Jurgen, ed. *Mediterranean Climate: Variability and Trends*. Berlin: Springer, 2003.
Bonan, G. *Ecological Climatology: Concepts and Applications*. New York: Cambridge University Press, 2008.
Copeland, Sebastian. *The Global Warning*. San Rafael, Calif.: Earth Aware Editions, 2007.
Cox, John D. *Climate Crash: Abrupt Climate Change and What It Means for Our Future*. Washington, D.C.: Joseph Henry Press, 2005.
Diaz, Henry F., and Raymond S. Bradley, eds. *The Hadley Circulation: Present, Past, and Future*. Dordrecht, the Netherlands: Kluwer Academic, 2004.
Field, Christopher B., and Michael R. Raupach, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World*. Washington, D.C.: Island Press, 2004.
Hartmann, Dennis L. *Global Physical Climatology*. San Diego, Calif.: Academic Press, 1994.
Hurrell, J. W., et al., eds. *The North Atlantic Oscillation: Climate Significance and Environmental Impact*. Washington, D.C.: American Geophysical Union, 2003.
Kininmonth, William. *Climate Change: A Natural Hazard*. Brentwood, Essex, England: Multi-Science, 2004.
Oke, T. R. *Boundary Layer Climates*. New York: Routledge, 1988.
Pearce, Fred. *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change*. Boston: Beacon Press, 2007.
Rayner, John N. *Dynamic Climatology: Basis in Mathematics and Physics*. Malden, Mass.: Blackwell, 2001.
Somerville, Richard C. J. *The Forgiving Air*. Berkeley: University of California Press, 1996.
Weart, Spencer. *The Discovery of Global Warming*. Rev. and expanded ed. Cambridge, Mass.: Harvard University Press, 2008.
Williams, M. A. J., and Robert C. Balling, Jr. *Interactions of Desertification and Climate*. London: Arnold, 1996.

• Cryology and Glaciology

Benn, Douglas I., and David J. A. Evans. *Glaciers and Glaciation*. New York: Arnold, 1998.
Bennet, Matthew, and Neil Glasser. *Glacial Geology: Ice Sheets and Landforms*. New York: Cambridge University Press, 1997.
Davis, Neil. *Permafrost: A Guide to Frozen Ground in Transition*. Fairbanks: University of Alaska Press, 2001.
Gosnell, Mariana. *Ice: The Nature, the History, and the Uses of an Astonishing Substance*. Chicago: University of Chicago Press, 2007.
Hambrey, Michael, and Jurg Alean. *Glaciers*. New York: Cambridge University Press, 2006.
Melnikov, I. A. *The Arctic Sea Ice Ecosystem*. Amsterdam, the Netherlands: Gordon and Breach, 1997.
Serreze, Mark C., and Roger G. Barry. *The Arctic Climate System*. New York: Cambridge University Press, 2006.
Slaymaker, Olav, and Richard Kelly. *The Cryosphere and Global Environmental Change*. Hoboken, N.J.: Wiley-Blackwell, 2007.
Thomas, David N., and Gerhard S. Dieckmann, eds. *Sea Ice: An Introduction to its Physics, Chemistry, Biology, and Geology*. Malden, Mass.: Blackwell Science, 2003.

• Cultural Studies of Climate and Environmental Change

Anderson, Alison. *Media, Culture, and the Environment*. New Brunswick, N.J.: Rutgers University Press, 1997.

Brown, Neville. *History and Climate Change.* London: Routledge, 2001.

Diamond, Jared. *Collapse: How Societies Choose to Fail or Succeed.* New York: Penguin Books, 2006.

_______. *Guns, Germs, and Steel: The Fate of Human Societies.* New York: W. W. Norton, 1997.

Diaz, Henry F., and Richard J. Murnane, eds. *Climate Extremes and Society.* New York: Cambridge University Press, 2008.

Fagan, Brian. *Floods, Famines, and Emperors: El Niño and the Fate of Civilizations.* New York: Basic Books, 1999.

_______. *The Great Warming: Climate Change and the Rise and Fall of Civilizations.* New York: Bloomsbury, 2008.

_______. *The Long Summer: How Climate Changed Civilization.* New York: Basic Books, 2005.

Glacken, Clarence J. *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century.* Berkeley: University of California Press, 1967.

Heinberg, Richard. *The Party's Over: Oil, War, and the Fate of Industrial Societies.* 2d ed. Gabriola Island, B.C.: New Society, 2005.

Kempton, Willet, James S. Boster, and Jennifer A. Hartley. *Environmental Values in American Culture.* Cambridge, Mass.: MIT Press, 1995.

Lamb, H. H. *Climate, History, and the Modern World.* 2d ed. London: Routledge, 1995.

_______. *Weather, Climate, and Human Affairs.* London: Routledge, 1988.

Meister, Mark, and Phyllis Japp, eds. *Enviropop: Studies in Environmental Rhetoric and Popular Culture.* Westport, Conn.: Praeger, 2002.

Pettenger, Mary A., ed. *The Social Construction of Climate Change.* Burlington, Vt.: Ashgate, 2007.

• Ecology and Environmental Science

Anderson, David E., Andrew S. Gaudie, and Adrian G. Parker. *Global Environments Through the Quaternary: Exploring Environmental Change.* New York: Oxford University Press, 2007.

Ayres, Robert U., and Leslie W. Ayres, eds. *A Handbook of Industrial Ecology.* Cheltenham, Gloucestershire, England: Edward Elgar, 2002.

Bonan, G. *Ecological Climatology: Concepts and Applications.* New York: Cambridge University Press, 2008.

Chapin, F. Stuart, III, Harold A. Mooney, and Pamela Matson. *Principles of Terrestrial Ecosystem Ecology.* New York: Springer, 2002.

Chivian, Eric, and Aaron Bernstein, eds. *Sustaining Life: How Human Health Depends on Biodiversity.* New York: Oxford University Press, 2008.

Commoner, Barry. *Making Peace with the Planet.* New York: Pantheon, 1990.

Cowie, Jonathan. *Climate Change: Biological and Human Aspects.* New York: Cambridge University Press, 2007.

Cox, George W. *Alien Species and Evolution: The Evolutionary Ecology of Exotic Plants, Animals, Microbes, and Interacting Native Species.* Washington, D.C.: Island Press, 2004.

Crossland, Christopher J., et al., eds. *Coastal Fluxes in the Anthropocene.* Berlin: Springer-Verlag, 2005.

Cunningham, William, and Barbara Woodworth Saigo. *Environmental Science: A Global Concern.* 6th ed. New York: McGraw-Hill, 2001.

Elton, Charles S. *The Ecology of Invasions by Animals and Plants.* Reprint. Chicago: University of Chicago Press, 2000.

Ennis, Christine A., and Nancy H. Marcus. *Biological Consequences of Global Climate Change.* Sausalito, Calif.: University Science Books, 1996.

Field, Christopher B., and Michael R. Raupach, eds. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Washington, D.C.: Island Press, 2004.

Freer-Smith, P. H. , M. S. J. Broadmeadow, and J. M. Lynch, eds. *Forestry and Climate Change.* Oxfordshire, England: CAB International, 2007.

Gartland, Lisa. *Heat Islands: Understanding and Mitigating Heat in Urban Areas.* Basingstoke, Hampshire, England: Earthscan/James and James, 2008.

Gash, John H. C. *Amazonian Deforestation and Climate.* New York: John Wiley, 1996.

Gay, Kathlyn. *Rainforests of the World: A Reference Handbook.* 2d ed. Santa Barbara, Calif.: ABC-CLIO, 2001.

Geist, Helmut. *The Causes and Progression of Desertification.* Burlington, Vt.: Ashgate, 2005.

Gitay, Habiba, et al., eds. *Climate Change and Biodiversity.* Technical Paper 5. [Geneva, Switzerland?]: Intergovernmental Panel on Climate Change, 2002.

Gore, Al. *Earth in the Balance: Ecology and the Human Spirit.* Boston: Houghton Mifflin, 2000.

Goudie, Andrew S. *Great Warm Deserts of the World: Landscapes and Evolution.* New York: Oxford University Press, 2002.

_______. *The Human Impact on the Natural Environment: Past, Present, and Future.* 6th ed. Malden, Mass.: Blackwell, 2006.

Graedel, Thomas, and B. R. Allenby. *Industrial Ecology.* 2d ed. Upper Saddle River, N.J.: Pearson Education, 2003.

Hardroy, Jorge E., Diana Mitlin, and David Satterthwaite. *Environmental Problems in an Urbanizing World.* Washington, D.C.: Earthscan, 2001.

Johns, A. G., and J. Burley. *Timber Production and Biodiversity Conservation in Tropical Rain Forests.* New York: Cambridge University Press, 2004.

Kabat, Pavel, et al., eds. *Vegetation, Water, Humans, and the Climate: A New Perspective on an Interactive System.* Berlin: Springer-Verlag, 2004.

Karnosky, D. F., et al., eds. *Air Pollution, Global Change, and Forests in the New Millennium.* Oxford, England: Elsevier, 2003.

Krupa, S. V. *Air Pollution, People, and Plants: An Introduction.* St. Paul, Minn.: American Phytopathological Society, 1997.

Lovejoy, T., and L. Hannah, eds. *Climate Change and Biodiversity.* New Haven, Conn.: Yale University Press, 2005.

Lovelock, James. *The Revenge of Gaia: Earth's Climate Crisis and the Fate of Humanity.* New York: Basic Books, 2007.

McGavin, George C. *Endangered: Wildlife on the Brink of Extinction.* Buffalo, N.Y.: Firefly Books, 2006.

McKinney, Michael L., Robert M. Schoch, and Logan Yonavjak. *Environmental Science: Systems and Solutions.* Sudbury, Mass.: Jones and Bartlett, 2007.

McNeill, J. R. *Something New Under the Sun.* New York: Norton, 2000.

Malhi, Yadvinder, and Oliver Phillips. *Tropical Forests and Global Atmospheric Change.* New York: Oxford University Press, 2005.

Moreno, José, and Walter C. Oechel, eds. *Anticipated Effects of a Changing Global Environment in Mediterranean-Type Ecosystems.* New York: Springer-Verlag, 1995.

Morison, James I. L., and Michael D. Morecroft, eds. *Plant Growth and Climate Change.* Ames, Iowa: Blackwell, 2006.

Morton, Oliver. *Eating the Sun: How Plants Power the Planet.* New York: HarperCollins, 2008.

Nebel, Bernard J., and Richard T. Wright. *Environmental Science: Towards a Sustainable Future.* Englewood Cliffs, N.J.: Prentice Hall, 2008.

Nihoul, J. C. J., P. O. Zavialov, and P. P. Micklin, eds. *Dying and Dead Seas: Climatic Versus Anthropic Causes.* Dordrecht, the Netherlands: Kluwer Academic, 2004.

Peters, Robert L., and Thomas Lovejoy, eds. *Global Warming and Biological Diversity.* New Haven, Conn.: Yale University Press, 1992.

Puhe, J., and B. Ulrich. *Global Climate Change and Human Impacts on Forest Ecosystems.* Ecological Studies 13. Berlin: Springer, 2001.

Ramakrishna, Kiloparti, and George M. Woodwell, eds. *World Forests for the Future: Their Use and Conservation.* New Haven, Conn.: Yale University Press, 1993.

Roston, Eric. *The Carbon Age: How Life's Core Element Has Become Civilization's Greatest Threat.* New York: Walker, 2008.

Samuels, R., and D. K. Prasad, eds. *Global Warming and the Built Environment.* London: E&FN Spon, 1994.

Schlesinger, William H. *Biogeochemistry: An Analysis of Global Change.* New York: Academic Press, 1997.

Spicer, John. *Biodiversity: A Beginner's Guide.* Oxford, England: Oneworld, 1996.

Turco, Richard P. *Earth Under Siege: From Air Pollution to Global Change.* 2d ed. New York: Oxford University Press, 2002.

Unruh, J., M. Krol, and N. Kliot. *Environmental Change and Its Implications for Population Migration.* New York: Springer, 2004.

Wigley, T. M. L., and David Steven Schimel. *The Carbon Cycle.* New York: Cambridge University Press, 2000.

Wohlforth, Charles. *The Whale and the Supercompter: On the Northern Front of Climate Change.* New York: North Point Press, 2004.

Woodward, F. I., ed. *Global Climate Change: The Ecological Consequences.* San Diego, Calif.: Academic Press, 1992.

• Energy Resources, Policy, and Technology

Bent, R., L. Orr, and R. Baker, eds. *Energy: Science, Policy, and the Pursuit of Sustainability.* Washington, D.C.: Island Press, 2002.

Bethscheider-Kieser, Ulrich. *Green Designed: Future Cars.* Los Angeles: Fusion, 2008.

Boyle, Godfrey. *Renewable Energy.* New York: Oxford University Press, 2004.

BP. *Statistical Review of World Energy, June, 2008.* London: Author, 2008.

Bradbrook, A. J., et al., eds. *The Law of Energy for Sustainable Development.* New York: Cambridge University Press, 2005.

Bradley, Robert, Jr., and Richard Fulmer. *Energy: The Master Resource.* Dubuque, Iowa: Kendall/Hunt, 2004.

Carson, Lain, and Vijay Vaitheeswaran. *Zoom: The Global Race to Fuel the Car of the Future.* New York: Twelve, 2007.

Chick, Martin. *Electricity and Energy Policy in Britain, France, and the United States Since 1945.* Northampton, Mass.: Edward Elgar, 2007.

Craddock, David. *Renewable Energy Made Easy: Free Energy from Solar, Wind, Hydropower, and Other Alternative Energy Sources.* Ocala, Fla.: Atlantic, 2008.

Deffeyes, Kenneth S. *Beyond Oil: The View from Hubbert's Peak.* New York: Hill and Wang, 2006.

Duffield, W. A., J. H. Sass, and M. L. Sorey. *Tapping the Earth's Natural Heat.* Washington, D.C.: U.S. Geological Survey, 1994.

Ehsani, Mehrdad, et al. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design.* Boca Raton, Fla.: CRC Press, 2005.

Freese, Barbara. *Coal: A Human History.* Cambridge, Mass.: Perseus, 2003.

Goodell, Jeff. *Big Coal: The Dirty Secret Behind America's Energy Future.* Boston: Mariner, 2007.

Goodstein, David. *Out of Gas.* New York: W. W. Norton, 2004.

Hausman, William, Peter Hertner, and Mira Wilkins. *Global Electrification: Multinational Enterprise and International Finance in the History of Light and Power, 1878-2007.* New York: Cambridge University Press, 2008.

Heinberg, Richard. *The Party's Over: Oil, War, and the Fate of Industrial Societies.* 2d ed. Gabriola Island, B.C.: New Society, 2005.

Herbst, Alan M., and George W. Hopley. *Nuclear Energy Now.* New York: John Wiley, 2007.

Hinrichs, Roger. *Energy: Its Use and the Environment.* 2d ed. New York: Saunders, 1996.

International Energy Agency. *Energy Security and Climate Policy: Assessing Interactions.* Paris: Author, 2007.

_______. *Oil Crises and Climate Challenges: Thirty Years of Energy Use in IEA Countries.* Paris: Author, 2004.

Leggett, Jeremy. *Carbon War: Global Warming and the End of the Oil Era.* London: Routledge, 2001.

_______. *The Empty Tank: Oil, Gas, Hot Air, and the Coming Global Financial Catastrophe.* New York: Random House, 2005.

Mills, Robin. *The Myth of the Oil Crisis: Overcoming the Challenges of Depletion, Geopolitics, and Global Warming.* Santa Barbara, Calif.: Praeger, 2008.

Nikiforuk, Andrew. *Tar Sands: Dirty Oil and the Future of a Continent.* Berkeley, Calif.: Greystone Books, 2008.

Nordhaus, William. *The Efficient Use of Energy Resources.* New Haven, Conn.: Yale University Press, 1979.

Nuttall, W. J. *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power.* New York: Taylor and Francis, 2004.

Pahl, Greg. *The Citizen-Powered Energy Handbook: Community Solutions to a Global Crisis.* White River Junction, Vt.: Chelsea Green, 2007.

Pasqualetti, Martin J., Paul Gripe, and Robert Righter. *Wind Power in View.* San Diego, Calif.: Academic Press, 2002.

Patel, Mukund R. *Wind and Solar Power Systems.* Boca Raton, Fla.: CRC Press, 1999.

Paul, Bill. *Future Energy: How the New Oil Industry Will Change People, Politics, and Portfolios.* Hoboken, N.J.: John Wiley and Sons, 2007.

Quaschning, Volker. *Understanding Renewable Energy Systems.* Sterling, Va.: Earthscan, 2005.

Rosen, L. *Climate Change and Energy Policy: Proceedings of the International Conference on Global Climate Change—Its Mitigation Through Improved Production.* Edited by R. Glasser. New York: American Institute of Physics Press, 1992.

Scheer, Hermann. *The Solar Economy: Renewable Energy for a Sustainable Global Future.* London: Earthscan, 2004.

Schrattenholzer, Leo, et al. *Achieving a Sustainable Global Energy System: Identifying Possibilities Using Long-Term Energy Scenarios*. Northampton, Mass.: Edward Elgar, 2004.

Smil, Vaclav. *Energy at the Crossroads: Global Perspectives and Uncertainties*. Cambridge, Mass.: MIT Press, 2005.

Walker, Niki. *Hydrogen: Running on Water*. New York: Crabtree, 2007.

- **Geology**

Bird, Eric. *Coastal Geomorphology: An Introduction*. Hoboken, N.J.: Wiley, 2008.

Blong, R. J. *Volcanic Hazards: A Source Book on the Effects of Eruptions*. Orlando, Fla.: Academic Press, 1984.

Fowler, C. M. R. *The Solid Earth: An Introduction to Global Geophysics*. 2d ed. New York: Cambridge University Press, 2005.

Marti, Joan, and Gerald J. Ernst, eds. *Volcanoes and the Environment*. New York: Cambridge University Press, 2005.

- **Health Effects of Climate Change**

Baer, Hans A., and Merrill Singer. *Global Warming and the Political Ecology of Health: Emerging Crises and Systemic Solutions*. Walnut Creek, Calif.: Left Coast Press, 2009.

Campbell-Lendrum, Diarmid, and Rosalie Woodruff. *Climate Change: Quantifying the Health Impacts at National and Local Levels*. Environmental Burden of Disease 14. Geneva: World Health Organization, 2007.

Hardoy, Jorge E., Diana Mitlin, and David Satterthwaite. *Environmental Problems in an Urbanizing World*. Sterling, Va.: Earthscan, 2001.

- **Industrialization, Business, Mass Production, and Climate**

Bruinsma, Jelle, ed. *World Agriculture—Towards 2015/2030: An FAO Perspective*. London: Earthscan, 2003.

Charnovitz, Steve, and Gary Clyde Hufbauer. *Global Warming and the World Trading System*. Washington, D.C.: Peterson Institute for International Economics, 2009.

Fineman, Stephen, ed. *The Business of Greening*. New York: Routledge, 2000.

Hasegawa, Yozo, and Tony Kimm. *Clean Car Wars: How Honda and Toyota Are Winning the Battle of the Eco-friendly Autos*. Singapore: John Wiley & Sons, 2008.

Hawken, Paul. *The Ecology of Commerce: A Declaration of Sustainability*. New York: Collins Business, 2005.

Hoffman, Andrew J. *From Heresy to Dogma: An Institutional History of Corporate Environmentalism*. Expanded ed. Palo Alto, Calif.: Stanford Business Books, 2001.

Jorgenson, Dale W., et al. *U.S. Market Consequences of Global Climate Change*. Washington, D.C.: Pew Center on Global Climate Change, 2004.

Mason, John. *Sustainable Agriculture*. 2d ed. Collingwood, Vic.: Landlinks Press, 2003.

Maunder, W. J. *The Human Impact of Climate Uncertainty: Weather Information, Economic Planning, and Business Management*. New York: Routledge, 1989.

Meier, Gerald M., and James E. Rauch. *Leading Issues in Economic Development*. New York: Oxford University Press, 2000.

Pritchard, Seth G., and Jeffrey S. Amthor. *Crops and Environmental Change: An Introduction to Effects of Global Warming, Increasing Atmospheric* CO_2 *and* O_3 *Concentrations, and Soil Salinization on Crop Physiology and Yield*. New York: Food Products Press, 2005.

Ruddiman, William F. *Plows, Plagues, and Petroleum: How Humans Took Control of Climate*. Princeton, N.J.: Princeton University Press, 2005.

Soil and Water Conservation Society. *Climate Change: Soil Erosion and Runoff from Cropland*. Ankeny, Iowa: Author, 2003.

- **International Law and Agreements**

Aldy, Joseph E., and Robert N. Stavins. *Architectures for Agreement: Addressing Global Climate Change in a Post-Kyoto World*. New York: Cambridge University Press, 2007.

Axelrod, Regina S., David Leonard Downie, and Norman J. Vig, eds. *The Global Environment: Institutions, Law, and Policy*. 2d ed. Washington, D.C.: CQ Press, 2004.

Bhatt, S. *The UN Stockholm Declaration of 1972 on the Human Environment: A Global and Federal View of Environmental Protection*. New Delhi: Hamdard University, 1999.

Boyle, Alan E., and David Freestone, eds. *International Law and Sustainable Development: Past Achievements and Future Challenges*. New York: Oxford University Press, 2001.

Caldwell, L. K. *International Environmental Policy: From the Twentieth to the Twenty-first Century*. 3d ed. Durham, N.C.: Duke University Press, 1996.

Chasek, Pamela S., David Leonard Downie, and Janet Welsh Brown. *Global Environmental Politics*. 4th ed. Boulder, Colo.: Westview, 2006.

Douma, W. Th., L. Massai, and M. Montini, eds. *The Kyoto Protocol and Beyond: Legal and Policy Challenges of Climate Change*. West Nyack, N.Y.: Cambridge University Press, 2007.

Fletcher, Susan R. *Global Climate Change: The Kyoto Protocol*. Washington, D.C.: Congressional Research Service, 2005.

Fletcher, Susan R., Larry Parker, and Jane A. Leggett. *Climate Change: Issues Underlying Negotiations at the Bali Conference of Parties*. Washington, D.C.: Congressional Research Service, 2007.

Freestone, David, and Charlotte Streck. *Legal Aspects of Implementing the Kyoto Protocol Mechanisms: Making Kyoto Work*. New York: Oxford University Press, 2005.

The Greenhouse Gas Protocol: The GHG Protocol for Project Accounting. Geneva, Switzerland: World Business for Sustainable Development, 2005.

Grubb, Michael, Christiaan Vrolijk, and Duncan Brack. *The Kyoto Protocol: A Guide and Assessment*. London: Earthscan, 1999.

Le Prestre, Philippe G., ed. *Governing Global Biodiversity: The Evolution and Implementation of the Convention on Biological Diversity*. Burlington, Vt.: Ashgate, 2002.

Luterbacher, Urs, and Detlef F. Sprinz, eds. *International Relations and Global Climate Change*. Cambridge, Mass.: MIT Press, 2001.

Mintzer, Irving M., and Michael J. Chadwick. *Negotiating Climate Change: The Inside Story of the Rio Convention*. New York: Cambridge University Press, 1994.

Newell, P. *The Kyoto Protocol and Beyond: The World After 2012*. New York: Human Development Report Office, 2008.

Orford, Margie. *Climate Change and the Kyoto Protocol's Clean Development Mechanism: Brazil, Bangladesh, Indonesia, South Africa*. London: ITDG, 2004.

Paterson, Matthew. *Global Warming and Global Politics*. New York: Routledge, 1996.

Reed, Alan. *Precious Air: The Kyoto Protocol and Profit in the Global Warming Game*. Overland Park, Kans.: Leathers, 2006.

Robinson, Nicholas A. *Strategies Toward Sustainable Development: Implementing Agenda 21*. New York: Oceana, 2005.

Sands, Phillipe. *Principles of International Environmental Law*. New York: Cambridge University Press, 2002.

Sauvant, Karl P. *Group of 77: Evolution, Structure, Organization*. New York: Oxford University Press, 1980.

Secretariat of the Convention on Biological Diversity. *Interlinkages Between Biological Diversity and Climate Change: Advice on the Integration of Biodiversity Considerations into the Implementation of the United Nations Framework Convention on Climate Change and Its Kyoto Protocol*. CBD Technical Series 10. Montreal: Author, 2003.

Sitarz, Dan. *Agenda 21: The Earth Summit Strategy to Save Our Planet*. Boulder, Colo.: EarthPress, 1993.

United Nations Development Programme. *The Clean Development Mechanism: A User's Guide*. New York: UNDP, 2003.

Verheyen, R. *Climate Change Damage and International Law: Prevention Duties and State Responsibility*. Boston: Martinus Nijhoff, 2005.

World Bank. *Advancing Sustainable Development: The World Bank and Agenda 21*. Washington, D.C.: Author, 1997.

———. *Climate Change and Adaptation: Environment Matters at the World Bank*. Washington, D.C.: Author, 2008.

World Business Council for Sustainable Development, World Resources Institute. *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*. Geneva, Switzerland: World Business for Sustainable Development, 2001.

Yamin, Farhana, ed. *Climate Change and Carbon Markets: A Handbook of Emissions Reductions Mechanisms*. London: Earthscan, 2005.

Yamin, Farhana, and Joanna Depledge. *The International Climate Change Regime: A Guide to Rules, Institutions, and Procedures*. New York: Cambridge University Press, 2004.

- **Measurement and Reduction of Environmental Footprints**

Banister, David. *Unsustainable Transport: City Transport in the New Century*. New York: Routledge, 2005.

Bazzaz, Fakhri, and Wim Sombroek, eds. *Global Climate Change and Agricultural Production: Direct and Indirect Effects of Changing Hydrological, Pedological, and Plant Physiological Processes*. New York: Wiley, 1996.

Bhatti, M. S. *Global Warming Impact of Automotive Air Conditioning Systems*. Warrendale, Pa.: Society of Automotive Engineers, 1998.

Blatt, Harvey. *America's Environmental Report Card*. Cambridge, Mass.: MIT Press, 2005.

Brown, Lester R. *Eco-Economy: Building an Economy for the Earth*. New York: W. W. Norton, 2001.

_______. *Plan B 3.0: Mobilizing to Save Civilization*. 3d ed. New York: W. W. Norton, 2008.

Brown, M. A., F. Southworth, and A. Sarzynski. *Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel*. Washington, D.C.: Author, 2005.

_______. *Shrinking the Carbon Footprint of Metropolitan America*. Washington, D.C.: Brookings Institution, 2008.

Buck, Louise, J. P. Lassoie, and Erick C. M. Fernandes. *Agroforestry in Sustainable Agricultural Systems*. Boca Raton, Fla.: CRC Press, 1998.

Clarke, A. G. *Industrial Air Pollution Monitoring: Gaseous and Particulate Emissions*. Environment Management Series 8. New York: Springer, 1997.

Cline, William R. *Global Warming and Agriculture: Impact Estimates by Country*. Washington, D.C.: Center for Global Development, 2007.

Dokken, David J., et al. *Special Report on Aviation and the Global Atmosphere*. Geneva, Switzerland: World Meteorological Organization, Intergovernmental Panel on International Climate Change, 1999.

Energy Information Administration, U.S. *Emissions of Greenhouse Gases in the U.S.* Washington, D.C.: U.S. Department of Energy, 2006.

Environmental Protection Agency, U.S. Office of Transportation and Air Quality. *Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003*. Washington, D.C.: Author, 2006.

Friedrich, R., and S. Reis, eds. *Emissions of Air Pollutants: Measurements, Calculations, and Uncertainties*. New York: Springer, 2004.

General Accounting Office, U.S. *Aviation and the Environment: Aviation's Effects on the Global Atmosphere Are Potentially Significant and Expected to Grow*. Washington, D.C.: Author, 2000.

Nakicenovic, N., et al., eds. *Special Report on Emission Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press, 2000.

National Academy of Sciences. *Methane Generation from Human, Animal, and Agricultural Wastes*. Washington, D.C.: Author, 2001.

Paustian, Keith, et al. *Agriculture's Role in Greenhouse Gas Mitigation*. Arlington, Va.: Pew Center on Global Climate Change, 2006.

Reay, Dave. *Climate Change Begins at Home: Life on the Two-Way Street of Global Warming*. New York: Palgrave Macmillan, 2006.

Roose, Eric J., et al., eds. *Soil Erosion and Carbon Dynamics*. Boca Raton, Fla.: CRC Press, 2006.

Sperling, Daniel, and James S. Cannon, eds. *Driving Climate Change: Cutting Carbon from Transportation*. Boston: Academic Press, 2007.

Sperling, Daniel, and Deborah Gordon. *Two Billion Cars: Driving Toward Sustainability*. New York: Oxford University Press, 2009.

Steinfeld, Henning, et al. *Livestock's Long Shadow: Environmental Issues and Options*. Rome: Food and Agriculture Organization of the United Nations, 2006.

Tolba, Mostafa Kamal. *Sustainable Development: Constraints and Opportunities*. London: Butterworths, 1987.

Willey, Zach, and Bill Chameides, eds. *Harnessing Farms and Forests in the Low-Carbon Economy: How to Create, Measure, and Verify Greenhouse Gas Offsets*. Durham, N.C.: Duke University Press, 2007.

Wilson, Elizabeth J., and David Gerard, eds. *Carbon Capture and Sequestration: Integrating Technology, Monitoring, and Regulation*. New York: John Wiley and Sons, 2007.

- **Modeling**

Griffies, S. *Fundamentals of Ocean Climate Models*. Princeton, N.J.: Princeton University Press, 2004.

Hooijberg, Maarten. *Geometrical Geodesy: Using Infor-*

mation and Computer Technology. New York: Springer, 2008.

Kiehl, J. T., and V. Ramanathan, eds. *Frontiers of Climate Modeling*. New York: Cambridge University Press, 2006.

Longley, Paul A., et al. *Geographic Information Systems and Science*. 2d ed. Hoboken, N.J.: John Wiley and Sons, 2005.

Monmonier, Mark. *How to Lie with Maps*. 2d ed. Chicago: University of Chicago Press, 1996.

National Geodetic Survey. *Geodesy: Imagine the Possibilities*. Washington, D.C.: U.S. Department of Commerce, 2000.

Randall, David A., ed. *General Circulation Model Development*. San Diego, Calif.: Academic Press, 2000.

Siedler, Gerold, John Church, and John Gould, eds. *Ocean Circulation and Climate*. London: Academic Press, 2001.

• Oceanography, Ocean Climatology, and Ocean Ecology

Bigg, Grant R. *The Oceans and Climate*. New York: Cambridge University Press, 1996.

Black, Kenneth D., and Graham B. Shimmield. *Biogeochemistry of Marine Systems*. Oxford, England: Blackwell/CRC Press, 2003.

Boon, John. *Secrets of the Tide: Tide and Tidal Current Analysis and Applications, Storm Surges, and Sea Level Trends*. Chichester, West Sussex, England: Horwood, 2004.

Carson, Rachel. *The Sea Around Us*. New York: Oxford University Press, 1961.

Douglas, Bruce C., Michael S. Kearney, and Stephen P. Leatherman, eds. *Sea Level Rise: History and Consequences*. San Diego: Academic Press, 2001.

Elderfield, Harry. *The Oceans and Marine Geochemistry*. Amsterdam: Elsevier Pergamon, 2006.

Gerdes, Louise I. *Endangered Oceans: Opposing Viewpoints*. San Diego, Calif.: Greenhaven Press, 2004.

Grotius, Hugo. *The Free Sea*. Reprint. Indianapolis: Liberty Fund, 2004.

Hughes, J. Donald. *The Mediterranean: An Environmental History*. Santa Barbara, Calif.: ABC-CLIO, 2005.

Hurrell, J. W., et al., eds. *The North Atlantic Oscillation: Climate Significance and Environmental Impact*. Washington, D.C.: American Geophysical Union, 2003.

Kunich, John Lynch. *Killing Our Oceans: Dealing with the Mass Extinction of Marine Life*. Westport, Conn.: Praeger, 2006.

Nelleman, Christian, Stefan Hain, and Jackie Alder, eds. *In Dead Water: Merging of Climate Change with Pollution, Over-Harvest, and Infestations in the World's Fishing Grounds*. Arendal, Norway: United Nations Environment Programme, GRID-Arendal, 2008.

Open University. *Ocean Circulation*. 2d ed. Boston, Mass.: Elsevier Butterworth-Heinemann, 2005.

Pew Oceans Commission. *America's Living Oceans—Charting a Course for Sea Change: A Report to the Nation*. Arlington, Va.: Pew Oceans Commission, 2003.

Pilkey, Orrin H., and Mary Edna Fraser. *A Celebration of the World's Barrier Islands*. New York: Columbia University Press, 2003.

Pugh, David. *Changing Sea Levels: Effects of Tides, Weather, and Climate*. New York: Cambridge University Press, 2004.

Royal Society. *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide*. London: Author, 2005.

Schmittner, A., John C. H. Chiang, and Sidney R. Hemming, eds. *Ocean Circulation: Mechanisms and Impacts*. Geophysical Monograph 173. Washington, D.C.: American Geophysical Union, 2007.

Soulé, Michael E., Elliot A. Norse, and Larry B. Crowder. *Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity*. Washington, D.C.: Island Press, 2005.

Toba, Y., ed. *Ocean-Atmosphere Interactions*. Tokyo: Terra Scientific, 2003.

Warrick, R. A., E. M. Barrow, and T. M. L. Wigley, eds. *Climate and Sea Level Change: Observations, Projections, and Implications*. New York: Cambridge University Press, 1993.

• Paleoclimatology and Climate History

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future*. Princeton, N.J.: Princeton University Press, 2000.

Alverson, Keith D., Raymond S. Bradley, and Thomas Pedersen, eds. *Paleoclimate, Global Change, and the Future*. Berlin: Springer, 2003.

Beerling, David J. *The Emerald Planet: How Plants Changed Earth's History*. New York: Oxford University Press, 2007.

Berner, Robert A. *The Phanerozoic Carbon Cycle: CO_2 and O_2*. New York: Oxford University Press, 2004.

Bolles, Edmund Blair. *The Ice Finders: How a Poet, a Professor, and a Politician Discovered the Ice Age*. Washington, D.C.: Counterpoint, 1999.

Burroughs, William James. *Climate Change in Prehistory: The End of the Reign of Chaos*. New York: Cambridge University Press, 2005.

Cronin, Thomas M. *Principles of Paleoclimatology*. New York: Columbia University Press, 1999.

Ehlers, J., and P. L. Gibbard, eds. *Quaternary Glaciations: Extent and Chronology*. 3 vols. San Diego, Calif.: Elsevier, 2004.

Fagan, B. M. *The Little Ice Age: How Climate Made History, 1300-1850*. New York: Basic Books, 2001.

Gillespie, A. R., S. C. Porter, and B. F. Atwater. *The Quaternary Period in the United States*. Developments in Quaternary Science 1. Amsterdam: Elsevier, 2004.

Hallam, Tony. *Catastrophes and Lesser Calamities: The Causes of Mass Extinctions*. New York: Oxford University Press, 2004.

Hughes, Malcolm, and Henry F. Diaz, eds. *The Medieval Warm Period*. Berlin: Springer-Verlag, 1994.

Imbrie, J., and K. P. Imbrie. *Ice Ages: Solving the Mystery*. Short Hills, N.J.: Enslow, 1979.

Kennett, J. P., ed. *Methane Hydrates in Quaternary Climate Change: The Clathrate Gun Hypothesis*. Washington, D.C.: American Geophysical Union, 2002.

Lamb, H. H. *Climate, History, and the Modern World*. 2d ed. New York: Routledge, 1995.

Macdougall, J. D. *Frozen Earth: The Once and Future Story of Ice Ages*. Berkeley: University of California Press, 2004.

Madsen, D. B., ed. *Entering America: Northeast Asia and Beringia Before the Last Glacial Maximum*. Salt Lake City: University of Utah Press, 2004.

National Academy of Sciences. *Surface Temperature Reconstructions for the Last Two Thousand Years*. Washington, D.C.: National Academies Press, 2006.

Nilsson, T. *The Pleistocene: Geology and Life in the Quaternary Age*. Dordrecht, the Netherlands: D. Reidel, 1982.

Pielou, E. C. *After the Ice Age: The Return of Life to Glaciated North America*. Chicago: University of Chicago Press, 1991.

Saltzman, Barry. *Dynamical Paleoclimatology: Generalized Theory of Global Climate Change*. New York: Academic Press, 2002.

Teller, J. T., and L. Clayton, eds. *Glacial Lake Agassiz*. Geological Association of Canada Special Paper 26. Toronto: University of Toronto Press, 1983.

Turney, Chris. *Ice, Mud, and Blood: Lessons from Climates Past*. New York: Macmillan, 2008.

Ward, Peter D. *Under a Green Sky*. New York: HarperCollins, 2007.

Williams, Michael. *Deforesting the Earth: From Prehistory to Global Crisis*. Chicago: University of Chicago Press, 2003.

• Political Studies and Critiques

Adamson, Joni, Mei Mei Evans, and Rachel Stein. *The Environmental Justice Reader: Politics, Poetics, and Pedagogy*. Tucson: University of Arizona Press, 2002.

Adkin, Laurie E. *The Politics of Sustainable Development: Citizens, Unions, and the Corporations*. Buffalo, N.Y.: Black Rose Books, 1998.

Anderson, Terry L., and Donald R. Leal, eds. *Free Market Environmentalism*. New York: Palgrave, 2001.

Bellamy Foster, John. *Ecology Against Capitalism*. New York: Monthly Review Press, 2002.

Bosso, Christopher. *Environment, Inc.: From Grassroots to Beltway*. Lawrence: University of Kansas Press, 2005.

Bowen, Mark. *Censoring Science: Inside the Political Attack on Dr. James Hansen and the Truth of Global Warming*. New York: Dutton Books, 2008.

Brolin, Bert. *A History of the Science and Politics of Climate Change: The Role of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press, 2008.

Bruno, Kenny, and Joshua Karliner. *Earthsummit.biz: The Corporate Takeover of Sustainable Development*. Oakland, Calif.: Food First Books, 2002.

Clapp, Jennifer, and Peter Dauvergne. *Paths to a*

Green World: The Political Economy of the Global Environment. Cambridge, Mass.: MIT Press, 2005.

Clemens, Kevin. *The Crooked Mile: Through Peak Oil, Biofuels, Hybrid Cars, and Global Climate Change to Reach a Brighter Future.* Lake Elmo, Minn.: Demontreville Press, 2009.

Compston, Hugh, and Ian Bailey, eds. *Turning Down the Heat: The Politics and Climate Policy in Affluent Democracies.* New York: Palgrave Macmillan, 2009.

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Climate Change: A Guide to the Debate.* New York: Cambridge University Press, 2006.

Essex, Christopher, and Ross McKitrick. *Taken by Storm: The Troubled Science, Policy, and Politics of Global Warming.* Rev. ed. Toronto: Key Porter Books, 2008.

Garvey, James. *The Ethics of Climate Change: Right and Wrong in a Warming World.* New York: Continuum, 2008.

Glover, Leigh. *Postmodern Climate Change.* New York: Routledge, 2006.

Gore, Al. *The Assault on Reason: How the Politics of Fear, Secrecy, and Blind Faith Subvert Wise Decision Making, Degrade our Democracy, and Put Our Country and Our World in Peril.* New York: Penguin Press, 2007.

Hjelmar, Ulf. *The Political Practice of Environmental Organizations.* Brookfield, Vt.: Avebury, 1996.

Humphreys, David. *Logjam: Deforestation and the Crisis of Global Government.* London: Earthscan, 2006.

McKibben, Bill. *Deep Economy: The Wealth of Communities and the Durable Future.* New York: Times Books, 2007.

_______. *Fight Global Warming Now: The Handbook for Taking Action in Your Community.* New York: Henry Holt, 2007.

Mooney, Chris C. *Storm World: Hurricanes, Politics, and the Battle Over Global Warming.* Orlando, Fla.: Harcourt, 2007.

Northcott, Michael S. *A Moral Climate: The Ethics of Global Warming.* Maryknoll, N.Y.: Orbis, 2007.

Paterson, Matthew. *Global Warming and Global Politics.* New York: Routledge, 1996.

Picolotti, Romina, and Jorge Daniel Taillant. *Linking Human Rights and the Environment.* Tucson: University of Arizona Press, 2003.

Roberts, J. Timmons, and Bradley C. Parks. *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy.* Cambridge, Mass.: MIT Press, 2006.

Sale, Kirkpatrick. *The Green Revolution: The American Environmental Movement, 1962-1992.* New York: Hill and Wang, 1993.

Spencer, Roy W. *Climate Confusion: How Global Warming Hysteria Leads to Bad Science, Pandering Politicians, and Misguided Policies That Hurt the Poor.* New York: Encounter Books, 2008.

Union of Concerned Scientists. *Smoke, Mirrors, and Hot Air: How ExxonMobil Uses Big Tobacco's Tactics to Manufacture Uncertainty on Climate Science.* Cambridge, Mass.: Author, 2007.

Young, Zoe. *A New Green Order? The World Bank and the Politics of the Global Environment Facility.* Sterling, Va.: Pluto Press, 2002.

• Public Policy Studies and Recommendations

Agrawaler, S., and S. Frankhauser, eds. *Economic Aspects of Adapting to Climate Change: Costs and Policy Instruments.* Paris: Organization for Economic Cooperation and Development, 2008.

Ali, Paul A. U., and Kanako Yano. *Eco-Finance: The Legal Design and Regulation of Market-Based Environmental Instruments.* New York: Kluwer Law International, 2004.

Axelrod, Regina S., David Leonard Downie, and Norman J. Vig, eds. *The Global Environment: Institutions, Law, and Policy.* 2d ed. Washington, D.C.: CQ Press, 2004.

Botterill, Linda C., and Melanie Fisher, eds. *Beyond Drought: People, Policy, and Perspectives.* Collingwood, Vic.: CSIRO, 2003.

Campbell, K. M. *The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change.* Washington, D.C.: Center for Strategic and International Studies, 2007.

Cline, William R. *The Economics of Global Warming.* Washington, D.C.: Institute for International Economics, 1992.

Cohen, Stuart, et al. *Cities for Climate Protection Policy and Practice Manual—Green Fleets: A Guide to Increasing Efficiency for Reducing Emissions from Municipal Fleets.* Toronto: International Council for Local Environmental Initiatives, [1996?].

Congressional Budget Office. *Policy Options for Re-*

ducing CO_2 Emissions. Washington, D.C.: Author, 2008.

Dodds, Felix, ed. *The Way Forward: Beyond Agenda 21.* London: Earthscan, 1997.

Faure, Michael, and Marjean Peeters, eds. *Climate Change and European Emissions Trading.* Northampton, Mass.: Edward Elgar, 2009.

Friedman, Thomas L. *Hot, Flat, and Crowded: Why We Need a Green Revolution, and How It Can Renew America.* New York: Farrar, Straus and Giroux, 2008.

Gerrard, Michael B., ed. *Global Climate Change and U.S. Law.* Chicago: American Bar Association, 2007.

Global Environment Facility. *Valuing the Global Environment: Actions and Investments for a Twenty-first Century.* Washington, D.C.: Author, 1998.

Hansjurgens, Bernd. *Emissions Trading for Climate Policy: U.S. and European Perspectives.* New York: Cambridge University Press, 2005.

Harris, Paul G. *Climate Change and American Foreign Policy.* New York: Macmillan, 2000.

Huq, Saleemul, et al. *Mainstreaming Adaptation to Climate Change in Least Developed Countries (LDCs).* London: International Institute for Environment and Development, 2003.

International Energy Agency. *Energy Security and Climate Policy: Assessing Interactions.* Paris: Author, 2007.

Jackson, T. *Mitigating Climate Change: Flexibility Mechanisms.* Amsterdam: Elsevier Science, 2002.

Kiss, Alexandre, and Dinah Shelton. *Guide to International Environmental Law.* Boston: Martinus Nijhoff, 2007.

Klyza, Christopher McGrory, and David Sousa. *American Environmental Policy, 1990-2006: Beyond Gridlock.* Cambridge, Mass.: MIT Press, 2008.

Kushner, James. *Global Climate Change and the Road to Extinction: The Legal and Planning Response.* Durham, N.C.: Carolina Academic Press, 2009.

Lohmann, Larry, ed. *Carbon Trading: A Critical Conversation on Climate Change, Privatisation, and Power.* Uppsala, Sweden: Dag Hammerskjold Foundation, 2006.

McKibbin, Warwick J., and Peter J. Wilcoxen. *Climate Change Policy After Kyoto: A Blueprint for a Realistic Approach.* Washington, D.C.: Brookings Institution, 2002.

Montgomery, W. David. *Toward an Economically Rational Response to the Berlin Mandate.* Boston: Charles River Associates, 1995.

Musil, Robert K. *Hope for a Heated Planet: How Americans Are Fighting Global Warming and Building a Better Future.* New Brunswick, N.J.: Rutgers University Press, 2009.

Nordhaus, William D. *Life After Kyoto: Alternative Approaches to Global Warming Policies.* Washington, D.C.: National Bureau of Economic Research, 2005.

———. *A Question of Balance: Weighing the Options on Global Warming Policies.* New Haven, Conn.: Yale University Press, 2008.

Rabe, Barry George. *Statehouse and Greenhouse: The Emerging Politics of American Climate Change Policy.* Washington, D.C.: Brookings Institution Press, 2004.

Repetto, Robert, et al. *Green Fees: How a Tax Shift Can Work for the Environment and the Economy.* Washington, D.C.: World Resources Institute, 1992.

Robinson, Nicholas A. *Strategies Toward Sustainable Development: Implementing Agenda 21.* Dobbs Ferry, N.Y.: Oxford University Press, 2005.

Rosenbaum, Walter A. *Environmental Politics and Policy.* 7th ed. Washington, D.C.: CQ Press, 2008.

Saltzman, Barry, ed. *Carbon Trading: A Critical Conversation on Climate Change, Privatisation, and Power.* Development Dialogue 48. Sturminster Newton, Dorset, England: Corner House, 2006.

Salzman, James, and Barton Thompson. *Environmental Law and Policy.* 2d ed. New York: Foundation Press, 2007.

Schneider, Stephen Henry, Armin Rosencranz, and John O. Niles. *Climate Change Policy: A Survey.* Washington, D.C.: Island Press, 2002.

Schumacher, E. F. *Small Is Beautiful: Economics as if People Mattered.* New York: Harper & Row, 1975.

Schumacher, E. F., and Joseph Pearce. *Small Is Still Beautiful: Economics as if Families Mattered.* Wilmington, Del.: ISI Books, 2006.

Shogren, Jason F. *The Benefits and Costs of the Kyoto Protocol.* Washington, D.C.: AEI Press, 1999.

Skodvin, Tora. *Structure and Agent in the Scientific Diplomacy of Climate Change: An Empirical Case Study of Science-Policy Interaction in the Intergovernmental Panel on Climate Change.* Norwell, Mass.: Kluwer Academic, 2000.

Smith, Joseph Smith, and David Shearman. *Climate Change Litigation*. Adelaide, S.Aust.: Presidian, 2006.

Steffen, Will, et al., eds. *Challenges of a Changing Earth*. Berlin: Springer-Verlag, 2002.

Steinman, David. *Safe Trip to Eden: Ten Steps to Save Planet Earth from Global Warming Meltdown*. New York: Thunder's Mouth Press, 2007.

Strong, Maurice. *Where on Earth Are We Going?* London: TEXERE, 2001.

Tietenberg, T. H. *Emissions Trading: Principles and Practice*. Washington, D.C.: Resources for the Future, 2006.

Tompkins, Emma L., et al. *Surviving Climate Change in Small Islands: A Guidebook*. Norwich, Norfolk, England: Tyndale Centre for Climate Change Research, 2005.

United Nations Development Programme. *Human Development Report, 2007: Fighting Climate Change*. New York: Author, 2007.

Victor, David G. *Climate Change: Debating America's Policy Options*. New York: Brookings Institution Press, 2004.

Walker, G., and D. King. *The Hot Topic: What We Can Do About Global Warming*. Orlando, Fla.: Houghton-Mifflin Harcourt, 2008.

World Bank. *Five Years After Rio: Innovations in Environmental Policy*. Washington, D.C.: Author, 1997.

_______. *IDA and Climate Change: Making Climate Action Work for Development*. Washington, D.C.: Author, 2008.

Young, Oran R. *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*. Cambridge, Mass.: MIT Press, 2002.

- **Regional and National Studies**

Andersen, Lykke E. *The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon*. New York: Cambridge University Press, 2002.

Benjaminsen, Tor A., and Christian Lund, eds. *Politics, Properties, and Production in the West African Sahel: Understanding Natural Resources Management*. Uppsala, Sweden: Nordic Institute of African Studies, 2001.

Dietz, A. J., Ruben Ruerd, and A. Verhagen, eds. *The Impact of Climate Change on Drylands: With a Focus on West Africa*. Boston: Kluwer Academic, 2004.

Economy, Elizabeth C. *The River Runs Black: The Environmental Challenge to China's Future*. Ithaca, N.Y.: Cornell University Press, 2004.

Giupponi, Carlo, and Mordechai Shechter, eds. *Climate Change and the Mediterranean: Socio-economic Perspectives of Impacts, Vulnerability, and Adaptation*. Cheltenham, Gloucestershire, England: Edward Elgar, 2003.

Glantz, Michael J., ed. *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*. New York: Cambridge University Press, 1999.

Hall, Sam. *The Fourth World: The Heritage of the Arctic and Its Destruction*. New York: Alfred A. Knopf, 1987.

Ichikawa, Atsunobu, ed. *Global Warming—The Research Challenges: A Report of Japan's Global Warming Initiative*. New York: Springer, 2005.

Jaggard, Lyn. *Climate Change Politics in Europe: Germany and the International Relations of the Environment*. New York: Tauris Academic Studies, 2007.

Joyner, Christopher C. *Governing the Frozen Commons: The Antarctic Regime and Environmental Protection*. Columbia: University of South Carolina Press, 1998.

Knill, Christoph, and Duncan Liefferink. *Environmental Politics in the European Union*. Manchester, England: Manchester University Press, 2007.

Lowe, I. *Living in the Hothouse: How Global Warming Affects Australia*. Melbourne: Scribe, 2005.

Magrath, John, with Andrew Simms. *Africa: Up in Smoke 2*. London: New Economics Foundation, 2006.

Mendelsohn, Robert, and James Neumann, eds. *The Impact of Climate Change on the United States Economy*. New York: Cambridge University Press, 1999.

National Assessment Synthesis Team. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. New York: Cambridge University Press, 2000.

Oshitani, Shizuka. *Global Warming Policy in Japan and Britain: Interactions Between Institutions and Issue Characteristics*. Manchester, England: Manchester University Press, 2006.

Peeters, Marjan, and Kurt Deketelaere, eds. *EU Climate Change Policy: The Challenge of New Regulatory Initiatives*. Cheltenham, England: Edward Elgar, 2006.

People's Republic of China. Ministry of Science and Technology, et al. *China's Scientific and Technological Actions on Climate Change*. Beijing: Author, 2007.

Ravindranath, N. H., and Jayanta A. Sathaye. *Climate Change and Developing Countries*. New York: Kluwer Academic, 2008.

Salgado, Sebastiao. *Sahel: The End of the Road*. Berkeley: University of California Press, 2004.

Serreze, Mark C., and Roger G. Barry. *The Arctic Climate System*. New York: Cambridge University Press, 2006.

Triggs, Gillian, and Anna Riddell, eds. *Antarctica: Legal and Environmental Challenges for the Future*. London: British Institute of International and Comparative Law, 2007.

Van Drunen, M. A., R. Lasage, and C. Dorland, eds. *Climate Change in Developing Countries: Results from the Netherlands Climate Change Studies Assistance Programme*. Oxford, England: CAB International, 2006.

- **Research and Scientific Reports on Climate Change**

Archer, David. *The Long Thaw: How Humans Are Changing the Next 100,000 Years of Earth's Climate*. Princeton, N.J.: Princeton University Press, 2008.

Arctic Climate Impact Assessment Scientific Report. New York: Cambridge University Press, 2006.

Ball, Timothy. *The Science Isn't Settled: The Limitations of Global Climate Models*. Washington, D.C.: The George C. Marshall Institute, 2007.

Battarbee, Richard. *Natural Climate Variability and Global Warming: A Holocene Perspective*. New York: Wiley-Blackwell, 2008.

Bily, C. A., ed. *Global Warming: Opposing Viewpoints*. Farmington Hills, Mich.: Greenhaven Press, 2006.

Bowen, Mark. *Thin Ice: Unlocking the Secrets of Climate in the World's Highest Mountains*. New York: Macmillan, 2005.

Braasch, Gary. *Earth Under Fire: How Global Warming Is Changing the World*. Afterword by Bill McKibben. Berkeley: University of California Press, 2007.

Broecker, Wallace S., and Robert Kunzig. *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It*. New York: Hill and Wang, 2008.

Chambers, Frank, and Michael Ogle. *Natural Forcing Factors for Climate Change on Time Scales 10^{-1} to 10^{5} Years*. Vol. 2 in *Climate Change: Critical Concepts in the Environment*. New York: Routledge, 2002.

Dessler, Andrew E., and Edward A. Parson. *The Science and Politics of Global Climate Change: A Guide to the Debate*. New York: Cambridge University Press, 2006.

Ewing, Reid, et al. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Washington, D.C.: Urban Land Institute, 2008.

Faris, Stephan. *Forecast: The Consequences of Climate Change, from the Amazon to the Arctic, from Darfur to Napa Valley*. New York: Henry Holt, 2009.

Flannery, Tim. *We Are the Weather Makers: The Story of Global Warming*. Rev. ed. London: Penguin, 2007.

George C. Marshall Institute. *Climate Issues and Questions*. 3d ed. Washington, D.C.: Author, 2008.

Hoyt, D. V., and K. H. Schatten. *The Role of the Sun in Climate Change*. New York: Oxford University Press, 1997.

Ichikawa, Atsunobu, ed. *Global Warming—The Research Challenges: A Report of Japan's Global Warming Initiative*. New York: Springer Verlag, 2005.

Idso, Sherwood B. *Carbon Dioxide and Global Change: Earth in Transition*. Tempe, Ariz.: IBR Press, 1989.

———. *Carbon Dioxide—Friend or Foe? An Inquiry into the Climatic and Agricultural Consequences of the Rapidly Rising CO_2 Content of Earth's Atmosphere*. Tempe, Ariz.: IBR Press, 1982.

Intergovernmental Panel on Climate Change. *Carbon Dioxide Capture and Storage: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Edited by Paul Freund et al. Geneva, Switzerland: Author, 2005.

———. *Climate Change, 2001—The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by J. T. Houghton et al. New York: Cambridge University Press, 2001.

———. *Climate Change, 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth

Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Susan Solomon et al. New York: Cambridge University Press, 2007.

_______. *Climate Change, 2007—Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry et al. New York: Cambridge University Press, 2007.

_______. *Climate Change, 2007—Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Beth Metz et al. New York: Cambridge University Press, 2007.

_______. *Climate Change, 2007—Synthesis Report: Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by the Core Writing Team, Rajendra K. Pachauri, and Andy Reisinger. Geneva, Switzerland: Author, 2008.

_______. *Land Use, Land-Use Change, and Forestry: A Special Report of the IPCC*. Edited by Robert T. Watson et al. New York: Cambridge University Press, 2000.

King, Michael D., ed. *Our Changing Planet: The View from Space*. New York: Cambridge University Press, 2007.

Kolbert, Elizabeth. *Field Notes from a Catastrophe: Man, Nature, and Climate Change*. New York: Bloomsbury, 2006.

Krupnik, Igor, Michael A. Lang, and Scott E. Miller, eds. *Smithsonian at the Poles: Contributions to International Polar Year Science*. Washington, D.C.: Smithsonian Institution Scholarly Press, 2009.

Leroux, Marcel. *Global Warming: Myth or Reality? The Erring Ways of Climatology*. New York: Springer, 2005.

Lomborg, Bjorn. *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. New York: Knopf, 2007.

_______. *The Skeptical Environmentalist: Measuring the Real State of the World*. New York: Cambridge University Press, 2001.

Lynas, Mark. *High Tide: The Truth About Our Climate Crisis*. New York: Picador/St. Martin's, 2004.

_______. *Six Degrees: Our Future on a Hotter Planet*. Washington, D.C.: National Geographic, 2008.

MacCracken, Michael C., Frances Moore, and John C. Topping, Jr., eds. *Sudden and Disruptive Climate Change: Exploring the Real Risks and How We Can Avoid Them*. Sterling, Va.: Earthscan, 2008.

Mann, Michael E., and Lee R. Kump. *Dire Predictions*. New York: D.K., 2008.

Michaels, Patrick J., ed. *Shattered Consensus: The True State of Global Warming*. Lanham, Md.: Rowman and Littlefield, 2005.

Middleton, N. *Global Desertification: Do Humans Cause Deserts?* Amsterdam, the Netherlands: Elsevier, 2004.

National Academy of Sciences. *Surface Temperature Reconstructions for the Last Two Thousand Years*. Washington, D.C.: National Academies Press, 2006.

National Research Council. *Abrupt Climate Change: Inevitable Surprises*. Washington, D.C.: National Academies Press, 2002.

Organization for Economic Cooperation and Development. *Literature Review on Climate Change Impacts on Urban City Centres: Initial Findings*. Paris: Author, 2007.

Pittock, A. Barrie. *Climate Change: Turning Up the Heat*. Sterling, Va.: Earthscan, 2005.

Rapp, Donald. *Assessing Climate Change: Temperatures, Solar Radiation, and Heat Balance*. New York: Springer, 2008.

Ross, Tom, and Neal Lott. *A Climatology of Recent Extreme Weather and Climate Events*. Asheville, N.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 2000.

Ruddiman, William F. *Earth's Climate Past and Future*. 2d ed. New York: W. H. Freeman, 2008.

Schellnhuber, Hans, et al., eds. *Avoiding Dangerous Climate Change*. New York: Cambridge University Press, 2006.

Silver, Cheryl Simon, with Ruth S. DeFries. *One Earth, One Future: Our Changing Global Environment*. Washington, D.C.: National Academy Press, 1990.

Singer, S. Fred, ed. *Nature, Not Human Activity, Rules the Climate: Summary for Policymakers of the Report of the Nongovernmental International Panel on Climate Change*. Chicago: Heartland Institute, 2008.

Singer, S. Fred, and Dennis T. Avery. *Unstoppable Global Warming: Every Fifteen Hundred Years*. Rev. ed. Blue Ridge Summit, Pa.: Rowman & Littlefield, 2008.

Steffen, Will, et al. *Global Change and the Earth System: A Planet Under Pressure*. Berlin: Springer-Verlag, 2005.

Stern, Nicholas. *The Economics of Climate Change: The Stern Review*. New York: Cambridge University Press, 2007.

United Nations Environment Programme. *One Planet, Many People: Atlas of Our Changing Environment*. Nairobi, Kenya: Author, 2005.

U.S. Climate Change Science Program. *Our Changing Planet: A Report by the Climate Change Science Program and the Subcommittee on Global Change Research for Fiscal Year 2007*. Washington, D.C.: Author, 2006.

Valsson, Trausti. *How the World Will Change with Global Warming*. Reykjavik: University of Iceland Press, 2006.

Van Ham, J., et al., eds. *Non-CO_2 Greenhouse Gases: Scientific Understanding, Control, and Implementation*. Amsterdam, the Netherlands: Kluwer Academic, 2000.

Volk, James. *CO_2 Rising*. Cambridge, Mass.: MIT Press, 2008.

World Commission on Environment and Development. *Our Common Future*. New York: Oxford University Press, 1987.

• Resources, Resource Management, and Resource Allocation

Annin, Peter. *The Great Lakes Water Wars*. Washington, D.C.: Island Press, 2006.

Cech, Thomas V. *Principles of Water Resources: History, Development, Management, and Policy*. Hoboken, N.J.: John Wiley & Sons, 2005.

Daily, Gretchen, ed. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, D.C.: Island Press, 1997.

Gleick, Peter, et al. *The World's Water 2006-2007: The Biennial Report on the World's Water Resources*. Washington, D.C.: Island Press, 2006.

Grayman, Walter M. *Water Resources and Environmental Issues in 2050*. Reston, Va.: ASCE, 2008.

Hayward, Becky. *From the Mountain to the Tap: How Land Use and Water Management Can Work for the Rural Poor*. Hayle, Cornwall, England: Rowe the Printers, 2005.

Heal, Geoffrey. *Nature and the Marketplace: Capturing the Value of Ecosystem Services*. Washington, D.C.: Island Press, 2000.

Hunt, Constance Elizabeth. *Thirsty Planet: Strategies for Sustainable Water Management*. London: Zed Books, 2004.

McFadden, L., R. Nicholas, and E. Penning-Rowsell, eds. *Managing Coastal Vulnerability*. San Diego, Calif.: Elsevier Press, 2007.

Marine Resources Service, Fishery Resources Division, FAO Fisheries Department. *Review of the State of World Marine Fishery Resources*. Rome, Italy: Food and Agriculture Organization of the United Nations, 2005.

Meadows, Donella, Jørgen Randers, and Dennis Meadows. *Limits to Growth: The Thirty-Year Update*. White River Junction, Vt.: Chelsea Green, 2004.

Pearce, Fred. *When the Rivers Run Dry: The Defining Crisis of the Twenty-first Century*. Boston: Beacon Press, 2006.

Raskin, P., et al. *Comprehensive Assessment of Freshwater Resources of the World*. Stockholm, Sweden: Stockholm Environment Institute, 1997.

Sharp, Gary D. *Future Climate Change and Regional Fisheries: A Collaborative Analysis*. Rome, Italy: Food and Agriculture Organization of the United Nations, 2003.

Soroos, Marvin K. *The Endangered Atmosphere: Preserving a Global Commons*. Columbia: University of South Carolina Press, 1997.

Tietenberg, Tom, and Lynne Lewis. *Environmental and Natural Resource Economics*. 8th ed. Boston: Pearson Addison Wesley, 2009.

Yoshimoto, Atsushi, ed. *Global Concerns for Forest Research Utilization: Sustainable Use and Management*. New York: Springer, 1998.

Young, Herbert C. *Understanding Water Rights and Conflicts*. Denver: BurgYoung, 2003.

• Weather and Meteorology

Battan, Louis J. *The Nature of Violent Storms*. Garden City, N.Y.: Doubleday, 1961.

Blanchard, D. C. *From Raindrops to Volcanoes: Adventures in Sea Surface Meteorology*. Mineola, N.Y.: Dover, 1995.

Boken, Vijendra K., Arthur P. Cracknell, and Ronald L. Heathcote, eds. *Monitoring and Predicting Agricultural Drought: A Global Study*. New York: Oxford University Press, 2005.

Burt, Christopher C. *Extreme Weather: A Guide and Record Book*. Cartography by Mark Stroud. New York: W. W. Norton, 2004.

Couper-Johnston, R. *El Niño: The Weather Phenomenon That Changed the World*. London: Hodder and Stoughton, 2000.

D'Aleo, J. S., and P. G. Grube. *El Niño and La Niña*. Westport, Conn.: Oryx Press, 2002.

Glantz, M. H. *Currents of Change: Impacts of El Niño and La Niña on Climate and Society*. 2d ed. New York: Cambridge University Press, 2001.

Henson, Robert. *The Rough Guide to Weather*. 2d ed. New York: Rough Guides, 2007.

Mayes, Julian, and Karel Hughes. *Understanding Weather: A Visual Approach*. New York: Oxford University Press, 2004.

Philander, S. G., J. R. Holton, and R. Dmowska. *El Niño, La Niña, and the Southern Oscillation*. San Diego, Calif.: Academic Press, 2000.

Tidwell, Mike. *The Ravaging Tide: Strange Weather, Future Katrinas, and the Coming Death of America's Coastal Cities*. New York: Free Press, 2006.

Web Sites

Listed below are more than one hundred Web sites that are current as of 2009. In addition to political entities and sources of objective scientific information, this list includes the sites of advocacy groups that seek selectively to interpret such data for polemic purposes. These groups are an important component of the discussion surrounding global warming, but readers are advised to evaluate carefully and independently all sites listed here. Furthermore, although every effort has been made to ensure the accuracy of universal resource locators (URLs), Web sites are continually being updated and there may be changes to the site address listed. A subject or keyword search through any of the major search engines will help locate a new address if the URLs listed below have been changed.

Alliance of Small Island States
- http://www.sidsnet.org/aosis/index.html

American Association for the Advancement of Science
- http://www.aaas.org

American Association of Petroleum Geologists
- http://www.aapg.org

American Astronomical Society
- http://www.aas.org

American Chemical Society
- http://www.acs.org

American Enterprise Institute
- http://www.aei.org

American Geophysical Union
- http://www.agu.org

American Institute of Physics
- http://www.aip.org

American Meteorological Society
- http://www.ametsoc.org

American Physical Society
- http://www.aps.org

Antarctic Climate Evolution
- http://www.csam.montclair.edu/earth/eesweb/scar_ace

Arctic Climate Research at the University of Illinois
- http://arctic.atmos.uiuc.edu

Brundtland Commission and Report
- http://www.un.org/documents/ga/res/38/a38r161.htm

Budongo Forest Project
- http://www.budongo.org

Canadian Meteorological and Oceanographic Society
- http://www.cmos.ca

Cato Institute
- http://www.cato.org

Center for the Study of Carbon Dioxide and Global Change
- http://www.co2science.org

Clean Development Mechanism
- http://cdm.unfccc.int/index.html

Climate Change Adaptation in Africa
- http://www.idrc.ca/en/ev-94424-201-1-DO_TOPIC.html

Climate Change Science Program, U.S.
- http://www.climatescience.gov

Climate Project
- http://www.theclimateproject.org

Competitive Enterprise Institute
- http://cei.org

Congressional Record, U.S.
- http://thomas.loc.gov

Consultative Group on International Agricultural Research
- http://www.cgiar.org

Convention on International Trade in Endangered Species of Flora and Fauna
- http://www.cites.org

Convention on Long-Range Transboundary Air Pollution
- http://www.unece.org/env/lrtap

Cooler Heads Coalition
- http://www.globalwarming.org

Data.gov Geodata Catalog
- http://www.data.gov/catalog/geodata

Department for Environment, Food, and Rural Affairs, British
- http://www.defra.gov.uk

Department of Energy, U.S.
- http://www.energy.gov

Egyptian Environmental Affairs Agency
- http://www.eeaa.gov.eg

Engineers Australia
- http://www.engineersaustralia.org.au

Environment Africa
- http://www.enviroafrica.org

Environment Canada
- http://www.ec.gc.ca

Environmental Protection Agency, U.S.
- http://www.epa.gov

Europa Environment Gateway
- http://ec.europa.eu/environment/index_en.htm

Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, German
- http://www.bmu.de/english/aktuell/4152.php

Food and Agriculture Organization
- http://www.fao.org

Fossil Energy
- http://www.fossil.energy.gov

Fraser Institute
- http://www.fraserinstitute.org

Friends of Science Society
- http://www.friendsofscience.org

Friends of the Earth
- http://www.foe.org

Geological Society of America
- http://www.geosociety.org

George C. Marshall Institute
- http://www.marshall.org

Global Environment Facility
- http://www.gefweb.org

Global Sea Level Observing System
- http://www.gloss-sealevel.org

Government of India, Ministry of Environment and Forests
- http://www.envfor.nic.in

Greenhouse Gas Protocol Initiative
- http://www.ghgprotocol.org

Greenpeace
- http://www.greenpeace.org

Group of 77
- http://www.G77.org

Heartland Institute
- http://www.globalwarmingheartland.org

Heritage Foundation
- http://www.heritage.org

High Park Group
- http://www.highparkgroup.com

ICLEI-Local Governments for Sustainability
- http://www.icleiusa.org

Institute for Trade, Standards, and Sustainable Development
- http://www.itssd.org

Interactive Arctic Climate Map
- http://www.weather.nps.navy.mil/~psguest/polarmet/climate/arcmap.html

Intergovernmental Panel on Climate Change
- http://www.ipcc.ch

International Atomic Energy Agency
- http://www.iaea.org

International Council for Science
- http:/www.icsu.org

International Geosphere-Biosphere Programme
- http://www.igbp.kva.se

International Human Dimensions Programme on Global Environmental Change
- http://www.ihdp.unu.edu

International Institute for Applied Systems Analysis
- http://www.iiasa.ac.at

International Policy Network
- http://www.policynetwork.net

International Union for Conservation of Nature
- http://www.iucn.org

Israel Ministry of the Environment
- http://www.sviva.gov.il

Lavoisier Group
- http://www.lavoisier.com.au

Ministry of Environmental Protection of the People's Republic of China
- http://english.mep.gov.cn

Ministry of the Environment, Government of Japan
- http://www.env.go.jp/en

National Center for Policy Analysis
- http://www.ncpa.org

National Climatic Data Center
- http://www.ncdc.noaa.gov/oa/ncdc.html

National Oceanographic and Atmospheric Administration
- http://www.noaa.gov

National Research Council
- http://www.gefweb.org

National Science Foundation
- http://www.nsf.gov

National Weather Service
- http://www.nws.noaa.gov

Natural Resources Stewardship Project
- http://www.nrsp.com

Nongovernmental International Panel on Climate Change
- http://www.sepp.org

Oregon Institute of Science and Medicine
- http://www.oism.org

Organization of Petroleum Exporting Countries
- http://www.opec.org

Ozone Secretariat
- http://ozone.unep.org

Pew Center on Climate Change
- http://www.pewclimate.org

Reason Public Policy Institute
- http://www.reason.org

Repower America
- http://repoweramerica.org

Science and Public Policy Institute
- http://scienceandpublicpolicy.org

Scientific Alliance
- http://www.scientific-alliance.org

Scientific Committee on Antarctic Research
- http://www.scar.org

Secretariat of the Antarctic Treaty
- http://www.ats.aq/index_e.htm

Sierra Club
- http://www.sierraclub.com

SourceWatch
- http://www.sourcewatch.org

Stratigraphy Commission of the Geological Society of London
- http://www.geolsoc.org.uk

Subsidiary Body for Scientific and Technological Advice
- http://unfccc.int

Union of Concerned Scientists
- http://www.ucsusa.org

United Nations Division for Sustainable Development
- http://www.un.org/esa/dsd/index.shtml

United Nations Environment Programme
- http://www.unep.org

United Nations Forum on Forests
- http://www.un.org/esa/forests/index.html

United Nations Framework Convention on Climate Change
- http://unfccc.int

Western Fuels Association
- http://www.westernfuels.org

World Bank
- http://www.worldbank.org

World Factbook
- https://www.cia.gov/library/publications/the-world-factbook

World Health Organization
- http://www.who.int/en

World Meteorological Organization
- http://www.wmo.int/pages/index_en.html

World Trade Organization
- http://www.wto.int

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