CHAPTER 35

WEATHER ELEMENTS

GENERAL DESCRIPTION OF THE ATMOSPHERE

3500. Introduction

Weather is the state of the earth's atmosphere with respect to temperature, humidity, precipitation, visibility, cloudiness, and other factors. **Climate** refers to the average long-term meteorological conditions of a place or region.

All weather may be traced to the effect of the sun on the earth. Most changes in weather involve large-scale horizontal motion of air. Air in motion is called **wind**. This motion is produced by differences of atmospheric pressure, which are attributable both to differences of temperature and the nature of the motion itself.

Weather is of vital importance to the mariner. The wind and state of the sea affect dead reckoning. Reduced visibility limits piloting. The state of the atmosphere affects electronic navigation and radio communication. If the skies are overcast, celestial observations are not available; and under certain conditions refraction and dip are disturbed. When wind was the primary motive power, knowledge of the areas of favorable winds was of great importance. Modern vessels are still affected considerably by wind and sea.

3501. The Atmosphere

The **atmosphere** is a relatively thin shell of air, water vapor, and suspended particulates surrounding the earth. Air is a mixture gases and, like any gas, is elastic and highly compressible. Although extremely light, it has a definite weight which can be measured. A cubic foot of air at standard sea-level temperature and pressure weighs 1.22 ounces, or about $^1/_{817}$th the weight of an equal volume of water. Because of this weight, the atmosphere exerts a pressure upon the surface of the earth of about 15 pounds per square inch.

As altitude increases, air pressure decreases due to the decreased weight of air above. With less pressure, the density decreases. More than three-fourths of the air is concentrated within a layer averaging about 7 statute miles thick, called the **troposphere**. This is the region of most "weather," as the term is commonly understood.

The top of the troposphere is marked by a thin transition zone called the **tropopause**, immediately above which is the **stratosphere**. Beyond this lie several other layers having distinctive characteristics. The average height of the tropopause ranges from about 5 miles or less at high latitudes to about 10 miles at low latitudes.

The **standard atmosphere** is a conventional vertical structure of the atmosphere characterized by a standard sea-level pressure of 1013.25 millibars of mercury (29.92 inches) and a sea-level air temperature of 15° C (59° F). The temperature decreases with height (i.e., **standard lapse rate**) being a uniform 2° C (3.6° F) per thousand feet to 11 kilometers (36,089 feet) and thereafter remains constant at –56.5° C (69.7° F).

Research has indicated that the jet stream is important in relation to the sequence of weather. The **jet stream** refers to relatively strong (≤60 knots) quasi-horizontal winds, usually concentrated within a restricted layer of the atmosphere. There are two commonly known jet streams. The **sub-tropical jet stream (STJ)** occurs in the region of 30°N during the northern hemisphere winter, decreasing in summer. The core of highest winds in the STJ is found at about 12km altitude (40,000 feet) an in the region of 70°W, 40°E, and 150°E, although considerable variability is common. The **polar frontal jet stream (PFJ)** is found in middle to upper-middle latitudes and is discontinuous and variable. Maximum jet stream winds have been measured by weather balloons at 291 knots.

3502. General Circulation Of The Atmosphere

The heat required to warm the air is supplied originally by the sun. As radiant energy from the sun arrives at the earth, about 29 percent is reflected back into space by the earth and its atmosphere, 19 percent is absorbed by the atmosphere, and the remaining 52 percent is absorbed by the surface of the earth. Much of the earth's absorbed heat is radiated back into space. Earth's radiation is in comparatively long waves relative to the short-wave radiation from the sun because it emanates from a cooler body. Long-wave radiation, readily absorbed by the water vapor in the air, is primarily responsible for the warmth of the atmosphere near the earth's surface. Thus, the atmosphere acts much like the glass on the roof of a greenhouse. It allows part of the incoming solar radiation to reach the surface of the earth but is heated by the terrestrial radiation passing outward. Over the entire earth and for long periods of time, the total outgoing energy must be equivalent to the incoming energy (minus any converted to another form and retained), or the temperature of the earth and its atmosphere would steadily increase or decrease. In local areas, or over relatively short periods of time, such a balance is not required, and in fact does not exist, resulting in changes such as those occurring from one year to another, in different seasons and in different parts of the day.

The more nearly perpendicular the rays of the sun strike the surface of the earth, the more heat energy per unit area is received at that place. Physical measurements show that in the tropics, more heat per unit area is received than is radiated away, and that in polar regions, the opposite is true. Unless there were some process to transfer heat from the tropics to polar regions, the tropics would be much warmer than they are, and the polar regions would be much colder. Atmospheric motions bring about the required transfer of heat. The oceans also participate in the process, but to a lesser degree.

If the earth had a uniform surface and did not rotate on its axis, with the sun following its normal path across the sky (solar heating increasing with decreasing latitude), a simple circulation would result, as shown in Figure 3502a. However, the surface of the earth is far from uniform, being covered with an irregular distribution of land and water. Additionally, the earth rotates about its axis so that the portion heated by the sun continually changes. In addition, the axis of rotation is tilted so that as the earth moves along its orbit about the sun, seasonal changes occur in the exposure of specific areas to the sun's rays, resulting in variations in the heat balance of these areas. These factors, coupled with others, result in constantly changing large-scale movements of air. For example, the rotation of the earth exerts an apparent force, known as Coriolis force, which diverts the air from a direct path between high and low pressure areas. The diversion of the air is toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. At some distance above the surface of the earth, the wind tends to blow along lines connecting points of equal pressure called **isobars**. The wind is called a **geostrophic wind** if the isobars are straight (great circles) and a **gradient wind** if they are curved. Near the surface of the earth, friction tends to divert the wind from the isobars toward the center of low pressure. At sea, where friction is less than on land, the wind follows the isobars more closely.

A simplified diagram of the general circulation pattern is shown in Figure 3502b. Figure 3502c and Figure 3502d give a generalized picture of the world's pressure distribution and wind systems as actually observed.

A change in pressure with horizontal distance is called a **pressure gradient**. It is maximum along a normal (perpendicular) to the isobars. A force results which is called **pressure gradient force** and is always directed from high to low pressure. Speed of the wind is approximately proportional to this pressure gradient.

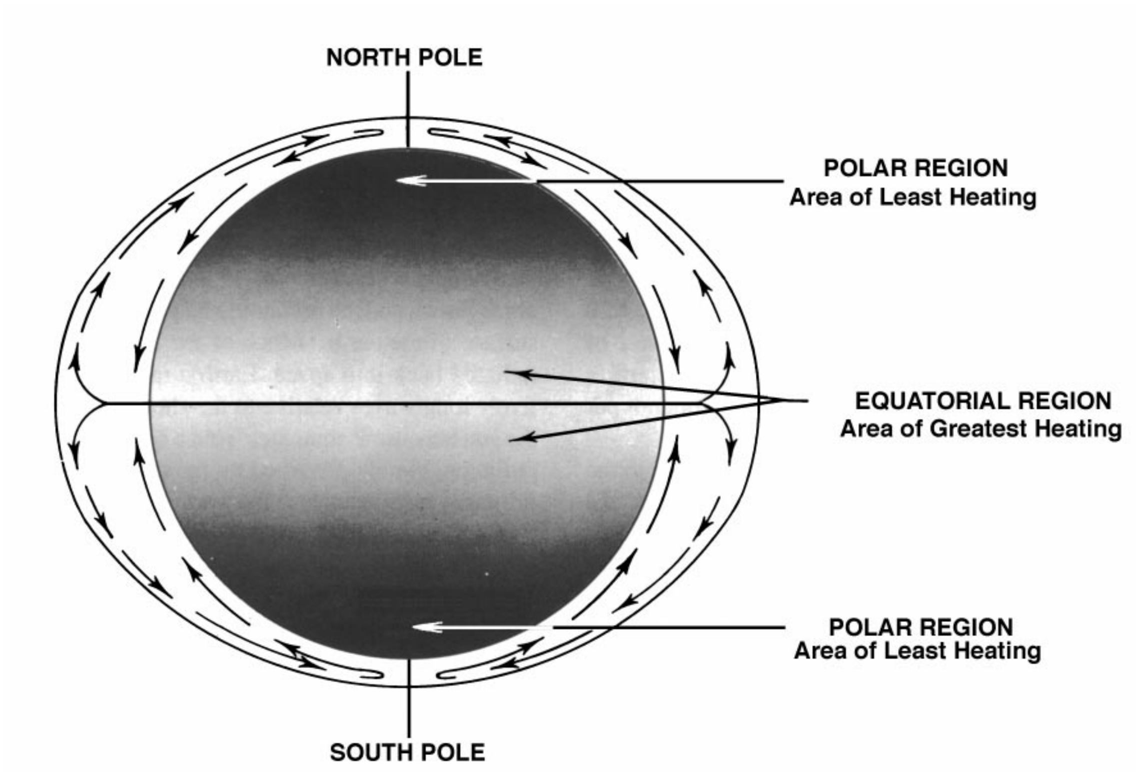

Figure 3502a. Ideal atmospheric circulation for a uniform and nonrotating earth.

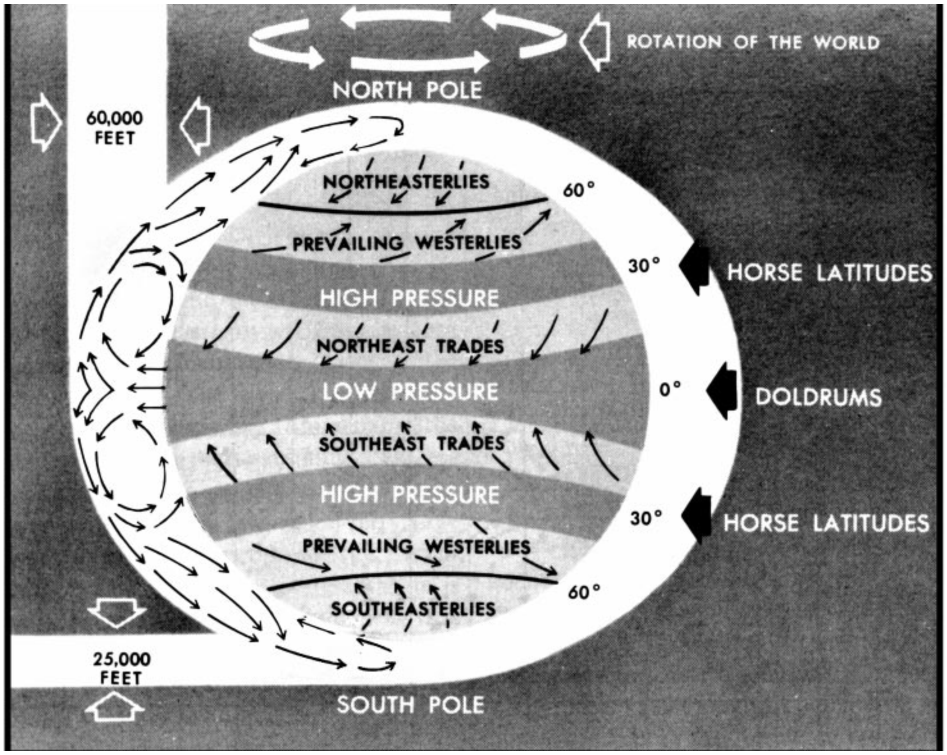

Figure 3502b. Simplified diagram of the general circulation of the atmosphere.

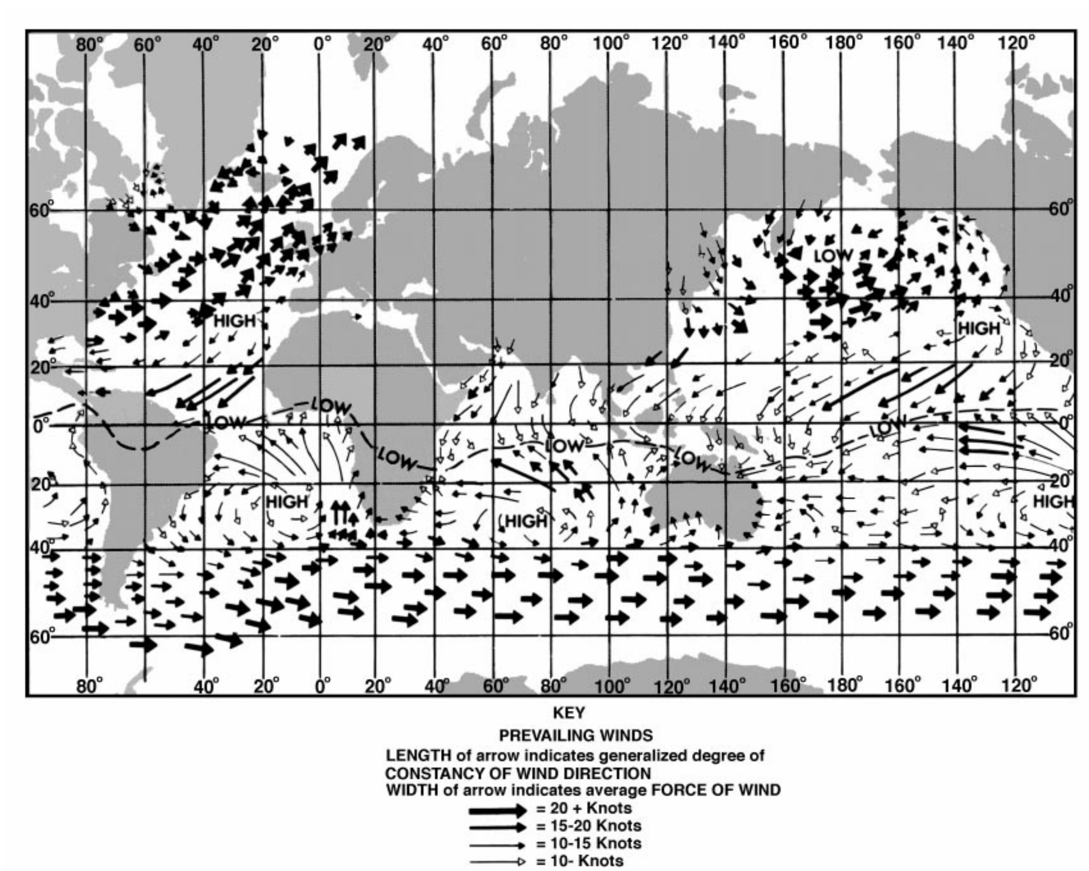

Figure 3502c. Generalized pattern of actual surface winds in January and February.

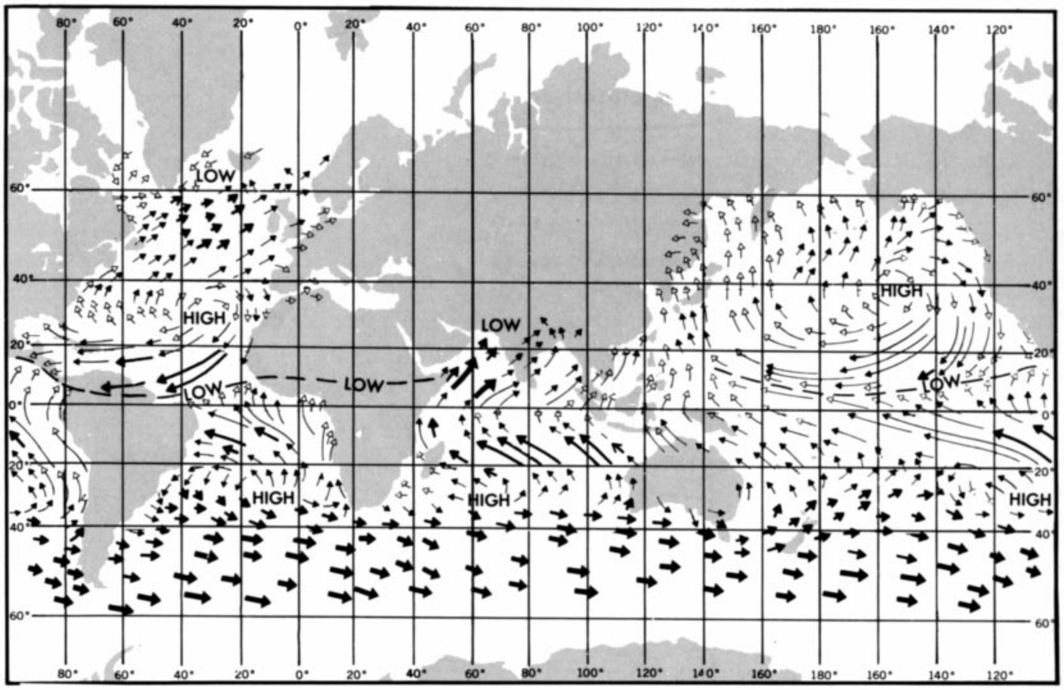

Figure 3502d. Generalized pattern of actual surface winds in July and August. (See key with Figure 3502c.)

MAJOR WIND PATTERNS

3503. The Doldrums

A belt of low pressure at the earth's surface near the equator known as the **doldrums** occupies a position approximately midway between high pressure belts at about latitude 30° to 35° on each side. Except for significant intradiurnal changes, the atmospheric pressure along the equatorial low is almost uniform. With minimal pressure gradient, wind speeds are light and directions are variable. Hot, sultry days are common. The sky is often overcast, and showers and thundershowers are relatively frequent; in these atmospherically unstable areas, brief periods of strong wind occur.

The doldrums occupy a thin belt near the equator, the eastern part in both the Atlantic and Pacific being wider than the western part. However, both the position and extent of the belt vary with longitude and season. During all seasons in the Northern Hemisphere, the belt is centered in the eastern Atlantic and Pacific; however, there are wide excursions of the doldrum regions at longitudes with considerable landmass. On the average, the position is at 5°N, frequently called the **meteorological equator**.

3504. The Trade Winds

The trade winds at the surface blow from the belts of high pressure toward the equatorial belts of low pressure. Because of the rotation of the earth, the moving air is deflected toward the west. Therefore, the trade winds in the Northern Hemisphere are from the northeast and are called the **northeast trades**, while those in the Southern Hemisphere are from the southeast and are called the **southeast trades**. The trade-wind directions are best defined over eastern ocean areas.

The trade winds are generally considered among the most constant of winds, blowing for days or even weeks with little change of direction or speed. However, at times they weaken or shift direction, and there are regions where the general pattern is disrupted. A notable example is found in the island groups of the South Pacific, where the trades are practically nonexistent during January and February. Their best development is attained in the South Atlantic and in the South Indian Ocean. In general, they are stronger during the winter than during the summer season.

In July and August, when the belt of equatorial low pressure moves to a position some distance north of the equator, the southeast trades blow across the equator, into the Northern Hemisphere, where the earth's rotation diverts them toward the right, causing them to be southerly and southwesterly winds. The "southwest monsoons" of the African and Central American coasts originate partly in these diverted southeast trades.

Cyclones from the middle latitudes rarely enter the regions of the trade winds, although tropical cyclones originate within these areas.

3505. The Horse Latitudes

Along the poleward side of each trade-wind belt, and corresponding approximately with the belt of high pressure in each hemisphere, is another region with weak pressure gradients and correspondingly light, variable winds. These are called the **horse latitudes**, apparently so named because becalmed sailing ships threw horses overboard in this region when water supplies ran short. The weather is generally good although low clouds are common. Compared to the doldrums, periods of stagnation in the horse latitudes are less persistent. The difference is due primarily to the rising currents of warm air in the equatorial low, which carry large amounts of moisture. This moisture condenses as the air cools at higher levels, while in the horse latitudes the air is apparently descending and becoming less humid as it is warmed at lower heights.

3506. The Prevailing Westerlies

On the poleward side of the high pressure belt in each hemisphere, the atmospheric pressure again diminishes. The currents of air set in motion along these gradients toward the poles are diverted by the earth's rotation toward the east, becoming southwesterly winds in the Northern Hemisphere and northwesterly in the Southern Hemisphere. These two wind systems are known as the **prevailing westerlies** of the temperate zones.

In the Northern Hemisphere this relatively simple pattern is distorted considerably by secondary wind circulations, due primarily to the presence of large landmasses. In the North Atlantic, between latitudes 40° and 50°, winds blow from some direction between south and northwest during 74 percent of the time, being somewhat more persistent in winter than in summer. They are stronger in winter, too, averaging about 25 knots (Beaufort 6) as compared with 14 knots (Beaufort 4) in the summer.

In the Southern Hemisphere the westerlies blow throughout the year with a steadiness approaching that of the trade winds. The speed, though variable, is generally between 17 and 27 knots (Beaufort 5 and 6). Latitudes 40°S to 50°S (or 55°S) where these boisterous winds occur, are called the **roaring forties**. These winds are strongest at about latitude 50°S.

The greater speed and persistence of the westerlies in the Southern Hemisphere are due to the difference in the atmospheric pressure pattern, and its variations, from the Northern Hemisphere. In the comparatively landless Southern Hemisphere, the average yearly atmospheric pressure diminishes much more rapidly on the poleward side of the high pressure belt, and has fewer irregularities due to continental interference, than in the Northern Hemisphere.

3507. Polar Winds

Partly because of the low temperatures near the geographical poles of the earth, the surface pressure tends to remain higher than in surrounding regions, since cold air is more dense than warm air. Consequently, the winds blow outward from the poles, and are deflected westward by the rotation of the earth, to become **northeasterlies** in the Arctic, and **southeasterlies** in the Antarctic. Where the polar easterlies meet the prevailing westerlies, near 50°N and 50°S on the average, a discontinuity in temperature and wind exists. This discontinuity is called the **polar front**. Here the warmer low-latitude air ascends over the colder polar air creating a zone of cloudiness and precipitation.

In the Arctic, the general circulation is greatly modified by surrounding landmasses. Winds over the Arctic Ocean are somewhat variable, and strong surface winds are rarely encountered.

In the Antarctic, on the other hand, a high central landmass is surrounded by water, a condition which augments, rather than diminishes, the general circulation. The high pressure, although weaker than in the horse latitudes, is stronger than in the Arctic, and of great persistence especially in eastern Antarctica. The cold air from the plateau areas moves outward and downward toward the sea and is deflected toward the west by the earth's rotation. The winds remain strong throughout the year, frequently attaining hurricane force near the base of the mountains. These are some of the strongest surface winds encountered anywhere in the world, with the possible exception of those in well-developed tropical cyclones.

3508. Modifications Of The General Circulation

The general circulation of the atmosphere is greatly modified by various conditions.

The high pressure in the horse latitudes is not uniformly distributed around the belts, but tends to be accentuated at several points, as shown in Figure 3502c and Figure 3502d. These semi-permanent highs remain at about the same places with great persistence.

Semi-permanent lows also occur in various places, the most prominent ones being west of Iceland, and over the Aleutians (winter only) in the Northern Hemisphere, and in the Ross Sea and Weddell Sea in the Antarctic areas. The regions occupied by these semi-permanent lows are sometimes called the graveyards of the lows, since many lows move directly into these areas and lose their identity as they merge with and reinforce the semi-permanent lows. The low pressure in these areas is maintained largely by the migratory lows which stall there, with topography also important, especially in Antarctica.

Another modifying influence is land, which undergoes greater temperature changes than does the sea. During the summer, a continent is warmer than its adjacent oceans. Therefore, low pressures tend to prevail over the land. If a climatological belt of high pressure encounters a continent, its pattern is distorted or interrupted, whereas a belt of low pressure is intensified over the same area. In winter, the opposite effect takes place, belts of high pressure being intensified over land and those of low pressure being

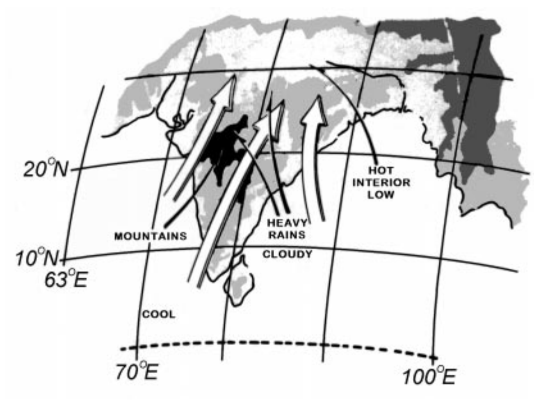

Figure 3508a. The summer monsoon.

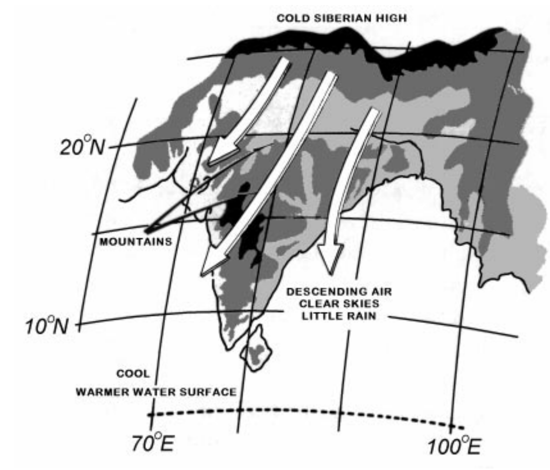

Figure 3508b. The winter monsoon.

weakened.

The most striking example of a wind system produced by the alternate heating and cooling of a landmass is the **monsoon** (seasonal wind) of the China Sea and Indian Ocean. A portion of this effect is shown in Figure 3508a and Figure 3508b. In the summer, low pressure prevails over the warm continent of Asia, and relatively higher pressure prevails over the adjacent sea. Between these two systems the wind blows in a nearly steady direction. The lower portion of the pattern is in the Southern Hemisphere, extending to about 10° south latitude. Here the rotation of the earth causes a deflection to the left, resulting in southeasterly winds. As they cross the equator, the deflection is in the opposite direction, causing them to curve toward the right, becoming southwesterly winds. In the winter, the positions of high and low pressure areas are interchanged, and the direction of flow is reversed.

In the China Sea, the summer monsoon blows from the southwest, usually from May to September. The strong winds are accompanied by heavy squalls and thunderstorms, the rainfall being much heavier than during the winter monsoon. As the season advances, squalls and rain become less frequent. In some places the wind becomes a light breeze which is unsteady in direction, or stops altogether, while in other places it continues almost undiminished, with changes in direction or calms being infrequent. The winter monsoon blows from the northeast, usually from October to April. It blows with a steadiness similar to that of the trade winds, often attaining the speed of a moderate gale (28–33 knots). Skies are generally clear during this season, and there is relatively little rain.

The general circulation is further modified by winds of cyclonic origin and various local winds. Some common local winds are listed by local name below.

Abroholos — A squall frequent from May through August between Cabo de Sao Tome and Cabo Frio on the coast of Brazil.

Bali wind — A strong east wind at the eastern end of Java.

Barat — A heavy northwest squall in Manado Bay on the north coast of the island of Celebes, prevalent from December to February.

Barber — A strong wind carrying damp snow or sleet and spray that freezes upon contact with objects, especially the beard and hair.

Bayamo — A violent wind blowing from the land on the south coast of Cuba, especially near the Bight of Bayamo.

Bentu de Soli — An east wind on the coast of Sardinia.

Bora — A cold, northerly wind blowing from the Hungarian basin into the Adriatic Sea. See also FALL WIND.

Borasco — A thunderstorm or violent squall, especially in the Mediterranean.

Brisa, Briza — 1. A northeast wind which blows on the coast of South America or an east wind which blows on Puerto Rico during the trade wind season. 2. The northeast monsoon in the Philippines.

Brisote — The northeast trade wind when it is blowing stronger than usual on Cuba.

Brubu — A name for a squall in the East Indies.

Bull’s Eye Squall — A squall forming in fair weather,

Bull's Eye Squall (continued) characteristic of the ocean off the coast of South Africa. It is named for the peculiar appearance of the small isolated cloud marking the top of the invisible vortex of the storm.

Cape Doctor The strong southeast wind which blows on the South African coast. Also called the DOCTOR.

Caver, Kaver A gentle breeze in the Hebrides.

Chubasco A violent squall with thunder and lightning, encountered during the rainy season along the west coast of Central America.

Churada A severe rain squall in the Mariana Islands during the northeast monsoon. They occur from November to April or May, especially from January through March.

Cierzo See MISTRAL.

Contrastes Winds a short distance apart blowing from opposite quadrants, frequent in the spring and fall in the western Mediterranean.

Cordonazo The "Lash of St. Francis." Name applied locally to southerly hurricane winds along the west coast of Mexico. It is associated with tropical cyclones in the southeastern North Pacific Ocean. These storms may occur from May to November, but ordinarily affect the coastal areas most severely near or after the Feast of St. Francis, October 4.

Coromell A night land breeze prevailing from November to May at La Paz, near the southern extremity of the Gulf of California.

Doctor 1. A cooling sea breeze in the Tropics. 2. See HARMATTAN. 3. The strong SE wind which blows on the south African coast. Usually called CAPE DOCTOR.

Elephanta A strong southerly or southeasterly wind which blows on the Malabar coast of India during the months of September and October and marks the end of the southwest monsoon.

Etesian A refreshing northerly summer wind of the Mediterranean, especially over the Aegean Sea.

Gregale A strong northeast wind of the central Mediterranean.

Harmattan The dry, dusty trade wind blowing off the Sahara Desert across the Gulf of Guinea and the Cape Verde Islands. Sometimes called the DOCTOR, because of its supposed healthful properties.

Knik Wind A strong southeast wind in the vicinity of Palmer, Alaska, most frequent in the winter.

Kona Storm A storm over the Hawaiian Islands, characterized by strong southerly or southwesterly winds and heavy rains.

Leste A hot, dry, easterly wind of the Madeira and Canary Islands.

Levanter A strong easterly wind of the Mediterranean, especially in the Strait of Gibraltar, attended by cloudy, foggy, and sometimes rainy weather especially in winter.

Levantera A persistent east wind of the Adriatic, usually accompanied by cloudy weather.

Levanto A hot southeasterly wind which blows over the Canary Islands.

Leveche A warm wind in Spain, either a foehn or a hot southerly wind in advance of a low pressure area moving from the Sahara Desert. Called a SIROCCO in other parts of the Mediterranean area.

Maestro A northwesterly wind with fine weather which blows, especially in summer, in the Adriatic. It is most frequent on the western shore. This wind is also found on the coasts of Corsica and Sardinia.

Matanuska Wind A strong, gusty, northeast wind which occasionally occurs during the winter in the vicinity of Palmer, Alaska.

Mistral A cold, dry wind blowing from the north over the northwest coast of the Mediterranean Sea, particularly over the Gulf of Lions. Also called CIERZO. See also FALL WIND.

Nashi, N'aschi A northeast wind which occurs in winter on the Iranian coast of the Persian Gulf, especially near the entrance to the gulf, and also on the Makran coast. It is probably associated with an outflow from the central Asiatic anticyclone which extends over the high land of Iran. It is similar in character but less severe than the BORA.

Norte A strong cold northeasterly wind which blows in Mexico and on the shores of the Gulf of Mexico. It results from an outbreak of cold air from the north. It is the Mexican extension of a norther.

Papagayo A violent northeasterly fall wind on the Pacific coast of Nicaragua and Guatemala. It consists of the cold air mass of a *norte* which has overridden the mountains of Central America. See also TEHUANTEPECER.

Santa Ana A strong, hot, dry wind blowing out into San Pedro Channel from the southern California desert through Santa Ana Pass.

Shamal A summer northwesterly wind blowing over Iraq and the Persian Gulf, often strong during the day, but decreasing at night.

Sharki A southeasterly wind which sometimes blows in the Persian Gulf.

Sirocco A warm wind of the Mediterranean area, either a foehn or a hot southerly wind in advance of a low pressure area moving from the Sahara or Arabian deserts. Called LEVECHE in Spain.

Squamish A strong and often violent wind occurring in many of the fjords of British Columbia. Squamishes occur in those fjords oriented in a northeast-southwest or east-west direction where cold polar air can be funneled westward. They are notable in Jervis, Toba, and Bute inlets and in Dean Channel and Portland Canal. Squamishes lose their strength when free of the confining fjords and are not noticeable 15 to 20 miles offshore.

Suestado A storm with southeast gales, caused by intense cyclonic activity off the coasts of Argentina and Uruguay, which affects the southern part of the coast of Brazil in the winter.

Sumatra A squall with violent thunder, lightning, and rain, which blows at night in the Malacca Straits, especially during the southwest monsoon. It is intensified by strong mountain breezes.

Taku Wind A strong, gusty, east-northeast wind, occurring in the vicinity of Juneau, Alaska, between October and March. At the mouth of the Taku River, after which it is named, it sometimes attains hurricane force.

Tehuantepecer A violent squally wind from north or north-northeast in the Gulf of Tehuantepec (south of southern Mexico) in winter. It originates in the Gulf of Mexico as a norther which crosses the isthmus and blows through the gap between the Mexican and Guatamalan mountains. It may be felt up to 100 miles out to sea. See also PAPAGAYO.

Tramontana A northeasterly or northerly winter wind off the west coast of Italy. It is a fresh wind of the fine weather mistral type.

Vardar A cold fall wind blowing from the northwest down the Vardar valley in Greece to the Gulf of Salonica. It occurs when atmospheric pressure over eastern Europe is higher than over the Aegean Sea, as is often the case in winter. Also called VARDARAC.

Warm Braw A foehn wind in the Schouten Islands north of New Guinea.

White Squall A sudden, strong gust of wind coming up without warning, noted by whitecaps or white, broken water; usually seen in whirlwind form in clear weather in the tropics.

Williwaw A sudden blast of wind descending from a mountainous coast to the sea, in the Strait of Magellan or the Aleutian Islands.

AIR MASSES

3509. Types Of Air Masses

Because of large differences in physical characteristics of the earth's surface, particularly the oceanic and continental contrasts, the air overlying these surfaces acquires differing values of temperature and moisture. The processes of radiation and convection in the lower portions of the troposphere act in differing characteristic manners for a number of well-defined regions of the earth. The air overlying these regions acquires characteristics common to the particular area, but contrasting to those of other areas. Each distinctive part of the atmosphere, within which common characteristics prevail over a reasonably large area, is called an **air mass**.

Air masses are named according to their source regions. Four regions are generally recognized: (1) equatorial (E), the doldrums area between the north and south trades; (2) tropical (T), the trade wind and lower temperate regions; (3) polar (P), the higher temperate latitudes; and (4) Arctic or Antarctic (A), the north or south polar regions of ice and snow. This classification is a general indication of relative temperature, as well as latitude of origin.

Air masses are further classified as maritime (m) or continental (c), depending upon whether they form over water or land. This classification is an indication of the relative moisture content of the air mass. Tropical air might be designated maritime tropical (mT) or continental tropical (cT). Similarly, polar air may be either maritime polar (mP) or continental polar (cP). Arctic/Antarctic air, due to the predominance of landmasses and ice fields in the high latitudes, is rarely maritime Arctic (mA). Equatorial air is found exclusively over the ocean surface and is designated neither (cE) nor (mE), but simply (E).

A third classification sometimes applied to tropical and polar air masses indicates whether the air mass is warm (w) or cold (k) relative to the underlying surface. Thus, the symbol mTw indicates maritime tropical air which is warmer than the underlying surface, and cPk indicates continental polar air which is colder than the underlying surface. The w and k classifications are primarily indications of stability (i.e., change of temperature with increasing height). If the air is cold relative to the surface, the lower portion of the air mass will be heated, resulting in instability (temperature markedly decreases with increasing height) as the warmer air tends to rise by convection. Conversely, if the air is warm relative to the surface, the lower portion of the air mass is cooled, tending to remain close to the surface. This is a stable condition (temperature increases with increasing height).

Two other types of air masses are sometimes recognized. These are monsoon (M), a transitional form between cP and E; and superior (S), a special type formed in the free atmosphere by the sinking and consequent warming of air aloft.

3510. Fronts

As air masses move within the general circulation, they travel from their source regions to other areas dominated by air having different characteristics. This leads to a zone of separation between the two air masses, called a **frontal zone** or **front**, across which temperature, humidity, and wind speed and direction change rapidly. Fronts are represented on weather maps by lines; a cold front is shown with pointed barbs, a warm front with rounded barbs, and an occluded front with both, alternating. A stationary front is shown with pointed and rounded barbs alternating and on opposite sides of the line with the pointed barbs away from the colder air.The front may take on a wave-like character,becoming a “frontal wave.”

Before the formation of frontal waves, the isobars (lines of equal atmospheric pressure) tend to run parallel to the fronts. As a wave is formed, the pattern is distorted somewhat, as shown in Figure 3510a. In this illustration, colder air is north of warmer air. In Figures 3510a–3510d isobars are drawn at 4-millibar intervals.

The wave tends to travel in the direction of the general circulation, which in the temperate latitudes is usually in an easterly and slightly poleward direction.

Along the leading edge of the wave, warmer air is replacing colder air. This is called the **warm front**. The trailing edge is the **cold front**, where colder air is underrunning and displacing warmer air.

The warm air, being less dense, tends to ride up greatly over the colder air it is replacing. Partly because of the replacement of cold, dense air with warm, light air, the pressure decreases. Since the slope is gentle, the upper part of a warm frontal surface may be many hundreds of miles ahead of the surface portion. The decreasing pressure, indicated by a “falling barometer,” is often an indication of the approach of such a wave. In a slow-moving, well-developed wave, the barometer may begin to fall several days before the wave arrives. Thus, the amount and nature of the change of atmospheric pressure between observations, called pressure tendency, is of assistance in predicting the approach of such a system.

The advancing cold air, being more dense, tends to ride under the warmer air at the cold front, lifting it to greater heights. The slope here is such that the upper-air portion of the cold front is behind the surface position relative to its motion. After a cold front has passed, the pressure increases, giving a rising barometer.

In the first stages, these effects are not marked, but as the wave continues to grow, they become more pronounced, as shown in Figure 3510b. As the amplitude of the wave increases, pressure near the center usually decreases, and the low is said to “deepen.” As it deepens, its forward speed generally decreases.

The approach of a well-developed warm front (i.e., when the warm air is mT) is usually heralded not only by falling pressure, but also by a more-or-less regular sequence of clouds. First, cirrus appear. These give way successively to cirrostratus, altostratus, altocumulus, and nimbostratus. Brief showers may precede the steady rain accompanying the nimbostratus.

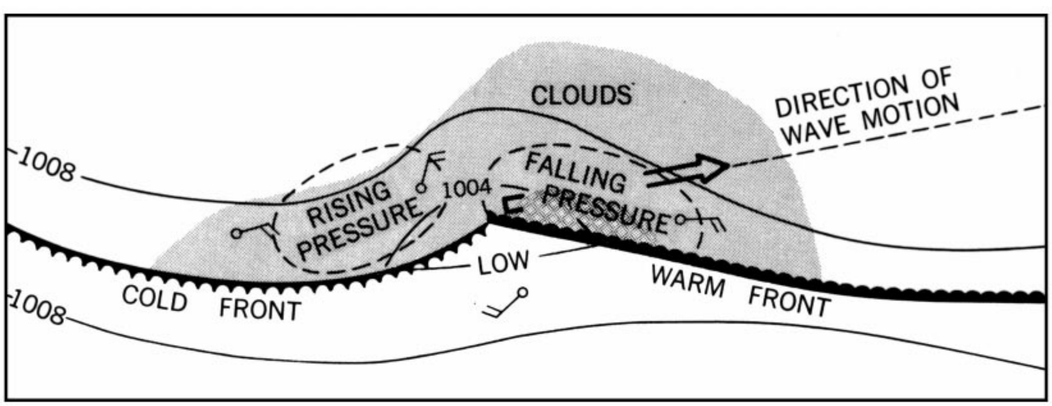

Figure 3510a. First stage in the development of a frontal wave (top view).

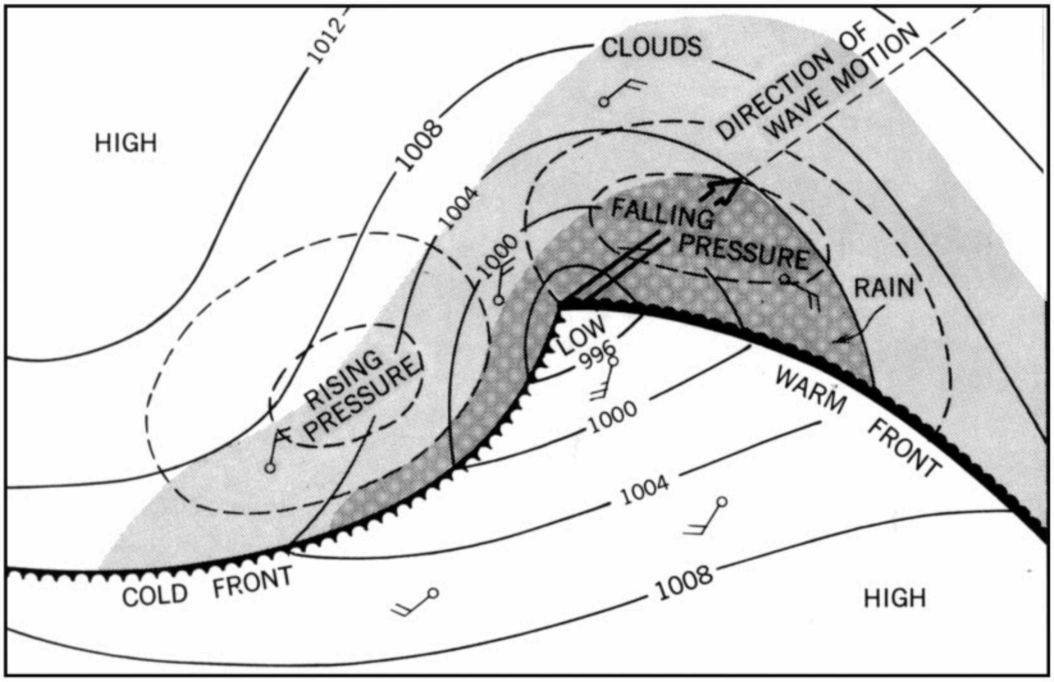

Figure 3510b. A fully developed frontal wave (top view).

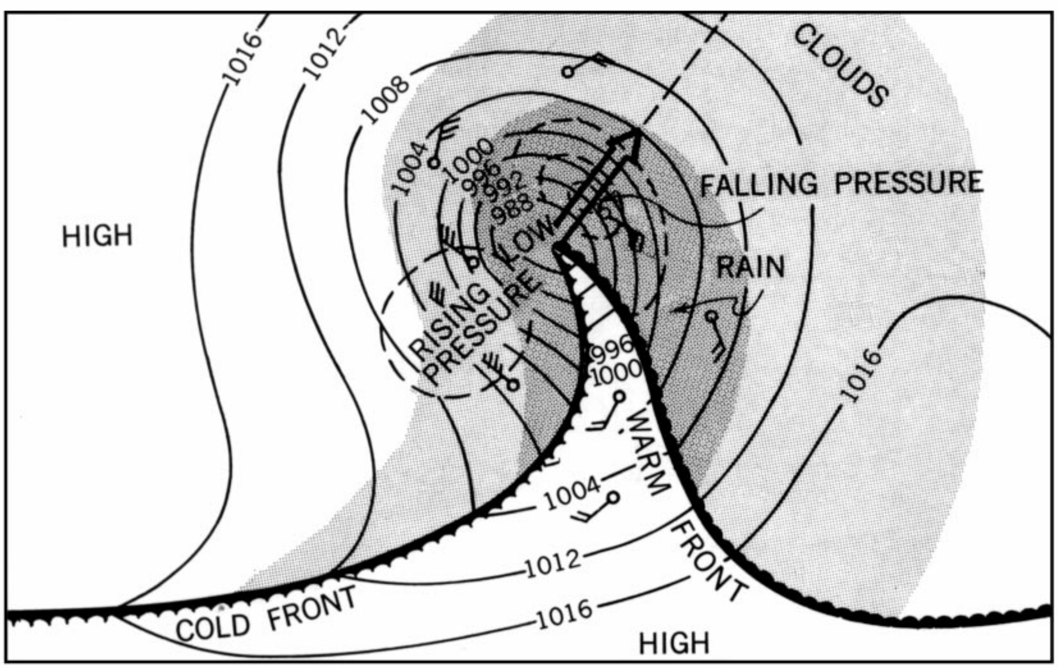

Figure 3510c. A frontal wave nearing occlusion (top view).

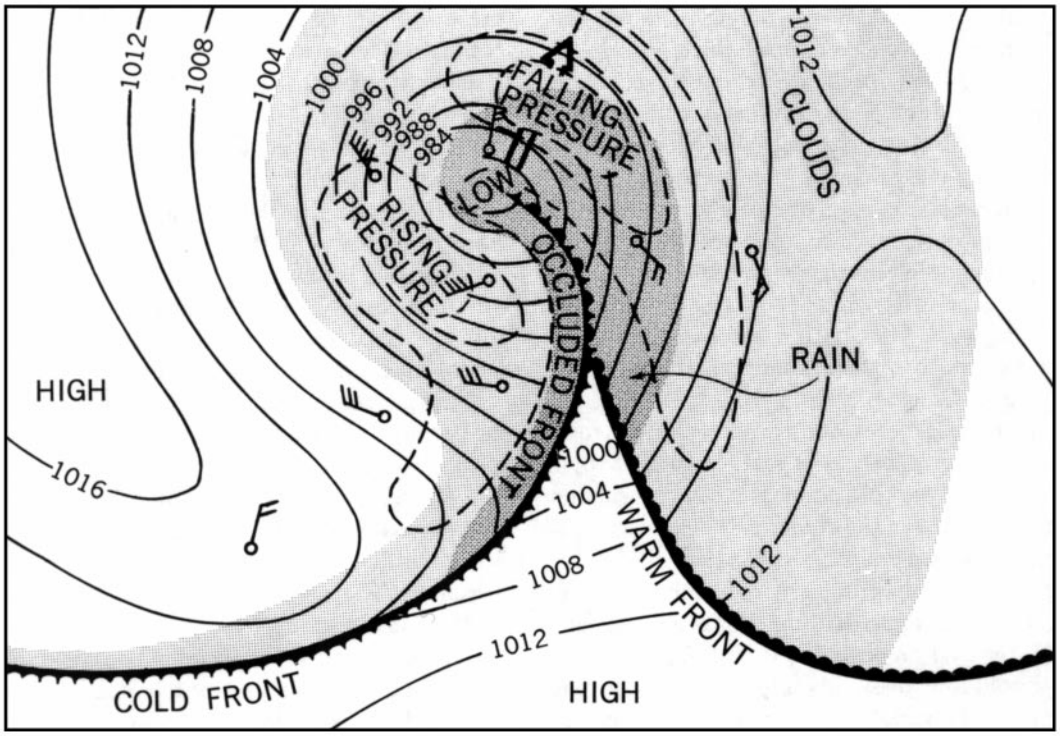

Figure 3510d. An occluded front (top view).

As the warm front passes, the temperature rises, the wind shifts clockwise (in the Northern Hemisphere), and the steady rain stops. Drizzle may fall from low-lying stratus clouds, or there may be fog for some time after the wind shift. During passage of the warm sector between the warm front and the cold front, there is little change in temperature or pressure. However, if the wave is still growing and the low deepening, the pressure might slowly decrease. In the warm sector the skies are generally clear or partly cloudy, with cumulus or stratocumulus clouds most frequent. The warm air is usually moist, and haze or fog may often be present.

As the faster moving, steeper cold front passes, the wind veers (shifts clockwise in the Northern Hemisphere counter-clockwise in the Southern Hemisphere), the temperature falls rapidly, and there are often brief and sometimes violent squalls with showers, frequently accompanied by thunder and lightning. Clouds are usually of the convective type. A cold front usually coincides with a well-defined wind-shift line (a line along which the wind shifts abruptly from southerly or southwesterly to northerly or northwesterly in the Northern Hemisphere, and from northerly or northwesterly to southerly or southwesterly in the Southern Hemisphere). At sea a series of brief showers accompanied by strong, shifting winds may occur along or some distance (up to 200 miles) ahead of a cold front. These are called **squalls** (in common nautical use, the term squall may be additionally

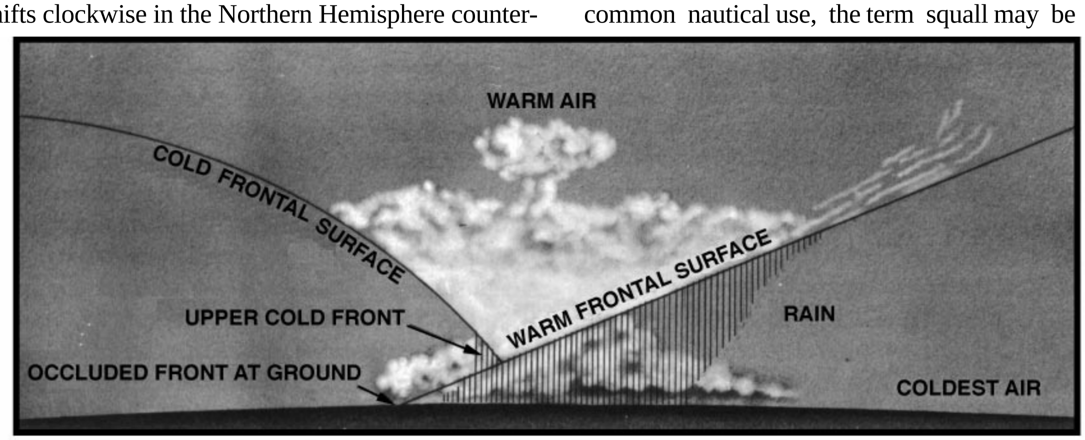

Figure 3510e. An occluded front (cross section).

applied to any severe local storm accompanied by gusty winds, precipitation, thunder, and lightning), and the line along which they occur is called a **squall line**.

Because of its greater speed and steeper slope, which may approach or even exceed the vertical near the earth's surface (due to friction), a cold front and its associated weather pass more quickly than a warm front. After a cold front passes, the pressure rises, often quite rapidly, the visibility usually improves, and the clouds tend to diminish. Clear, cool or cold air replaces the warm hazy air.

As the wave progresses and the cold front approaches the slower moving warm front, the low becomes deeper and the warm sector becomes smaller, as shown in Figure 3510c.

Finally, the faster moving cold front overtakes the warm front (Figure 3510d), resulting in an **occluded front** at the surface, and an upper front aloft (Figure 3510e). When the two parts of the cold air mass meet, the warmer portion tends to rise above the colder part. The warm air continues to rise until the entire frontal system dissipates. As the warmer air is replaced by colder air, the pressure gradually rises, a process called **filling**. This usually occurs within a few days after an occluded front forms. Finally, there results a cold low, or simply a low pressure system across which little or no gradient in temperature and moisture can be found.

The sequence of weather associated with a low depends greatly upon the observer's location with respect to the path of the center. That described above assumes that the low center passes poleward of the observer. If the low center passes south of the observer, between the observer and the equator, the abrupt weather changes associated with the passage of fronts are not experienced. Instead, the change from the weather characteristically found ahead of a warm front, to that behind a cold front, takes place gradually, the exact sequence dictated by distance from the center, and the severity and age of the low.

Although each low generally follows this pattern, no two are ever exactly alike. Other centers of low pressure and high pressure, and the air masses associated with them, even though they may be 1,000 miles or more away, influence the formation and motion of individual low centers and their accompanying weather. Particularly, a high stalls or diverts a low. This is true of temporary highs as well as semi-permanent highs, but not to as great a degree.

3511. Cyclones And Anticyclones

An area of relatively low pressure, generally circular, is called a **cyclone**. Its counterpart for high pressure is called an **anticyclone**. These terms are used particularly in connection with the winds associated with such centers. Wind tends to blow from an area of high pressure to one of low pressure, but due to rotation of the earth, wind is deflected toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere.

Because of the rotation of the earth, therefore, the circulation tends to be counterclockwise around areas of low pressure and clockwise around areas of high pressure in the Northern Hemisphere, and the speed is proportional to the spacing of isobars. In the Southern Hemisphere, the direction of circulation is reversed. Based upon this condition, a general rule, known as Buys Ballot's Law, or the Baric Wind Law, can be stated:

If an observer in the Northern Hemisphere faces away from the surface wind, the low pressure is toward his left; the high pressure is toward his right.

If an observer in the Southern Hemisphere faces away from the surface wind, the low pressure is toward his right; the high pressure is toward his left.

In a general way, these relationships apply in the case of the general distribution of pressure, as well as to temporary local pressure systems.

The reason for the wind shift along a front is that the isobars have an abrupt change of direction along these lines. Since the direction of the wind is directly related to the direction of isobars, any change in the latter results in a shift in the wind direction.

In the Northern Hemisphere, the wind shifts toward the right (clockwise) when either a warm or cold front passes. In the Southern Hemisphere, the shift is toward the left (counterclockwise). When an observer is on the poleward side of the path of a frontal wave, wind shifts are reversed (i.e., to the left in the Northern Hemisphere and to the right in the Southern Hemisphere).

In an anticyclone, successive isobars are relatively far apart, resulting in light winds. In a cyclone, the isobars are more closely spaced. With a steeper pressure gradient, the winds are stronger.

Since an anticyclonic area is a region of outflowing winds, air is drawn into it from aloft. Descending air is warmed, and as air becomes warmer, its capacity for holding uncondensed moisture increases. Therefore, clouds tend to dissipate. Clear skies are characteristic of an anticyclone, although scattered clouds and showers are sometimes encountered.

In contrast, a cyclonic area is one of converging winds. The resulting upward movement of air results in cooling, a condition favorable to the formation of clouds and precipitation. More or less continuous rain and generally stormy weather are usually associated with a cyclone.

Between the two hemispheric belts of high pressure associated with the horse latitudes, called subtropical anticyclones, cyclones form only occasionally over certain areas at sea, generally in summer and fall. Tropical cyclones (hurricanes and typhoons) are usually quite violent.

In the areas of the prevailing westerlies in temperate latitudes, migratory cyclones (lows) and anticyclones (highs) are a common occurrence. These are sometimes called extratropical cyclones and extratropical anticyclones to distinguish them from the more violent tropical cyclones. Formation occurs over sea and land. The lows intensify as they move poleward; the highs weaken as they move equatorward. In their early stages, cyclones are elongated, as shown in Figure 3510a, but as their life cycle proceeds, they become more nearly circular (Figure 3510b, Figure 3510c, and Figure 3510d).

LOCAL WEATHER PHENOMENA

3512. Local Winds

In addition to the winds of the general circulation and those associated with migratory cyclones and anticyclones, there are numerous local winds which influence the weather in various places.

The most common are the land and sea breezes, caused by alternate heating and cooling of land adjacent to water. The effect is similar to that which causes the monsoons, but on a much smaller scale, and over shorter periods. By day the land is warmer than the water, and by night it is cooler. This effect occurs along many coasts during the summer. Between about 0900 and 1100 local time the temperature of the land becomes greater than that of the adjacent water. The lower levels of air over the land are warmed, and the air rises, drawing in cooler air from the sea. This is the **sea breeze**. Late in the afternoon, when the sun is low in the sky, the temperature of the two surfaces equalizes and the breeze stops. After sunset, as the land cools below the sea temperature, the air above it is also cooled. The contracting cool air becomes more dense, increasing the pressure near the surface. This results in an outflow of winds to the sea. This is the **land breeze**, which blows during the night and dies away near sunrise. Since the atmospheric pressure changes associated with this cycle are not great, the accompanying winds generally do not exceed gentle to moderate breezes. The circulation is usually of limited extent, reaching a distance of perhaps 20 miles inland, and not more than 5 or 6 miles offshore, and to a height of a few hundred feet. In the doldrums and subtropics, this process is repeated with great regularity throughout most of the year. As the latitude increases, it becomes less prominent, being masked by winds of migratory cyclones and anticyclones. However, the effect often may be present to reinforce, retard, or deflect stronger prevailing winds.

Varying conditions of topography produce a large variety of local winds throughout the world. Winds tend to follow valleys, and to be deflected from high banks and shores. In mountain areas wind flows in response to temperature distribution and gravity. An **anabolic wind** is one that blows up an incline, usually as a result of surface heating. A **katabatic wind** is one which blows down an incline. There are two types, foehn and fall wind.

The foehn (fãn) is a warm dry wind which initiates from horizontally moving air encountering a mountain barrier. As it blows upward to clear the mountains, it is cooled below the dew point, resulting in clouds and rain on the windward side. As the air continues to rise, its rate of cooling is reduced because the condensing water vapor gives off heat to the surrounding atmosphere. After crossing the mountain barrier, the air flows downward along the leeward slope, being warmed by compression as it descends to lower levels. Since it loses less heat on the ascent than it gains during descent, and since it has lost its moisture during ascent, it arrives at the bottom of the mountains as very warm, dry air. This accounts for the warm, arid regions along the eastern side of the Rocky Mountains and in similar areas. In the Rocky Mountain region this wind is known by the name **chinook**. It may occur at any season of the year, at any hour of the day or night, and have any speed from a gentle breeze to a gale. It may last for several days, or for a very short period. Its effect is most marked in winter, when it may cause the temperature to rise as much as 20°F to 30°F within 15 minutes, and cause snow and ice to melt within a few hours. On the west coast of the United States, a foehn wind, given the name **Santa Ana**, blows through a pass and down a valley of that name in Southern California. This wind is frequently very strong and may endanger small craft immediately off the coast.

A cold wind blowing down an incline is called a **fall wind**. Although it is warmed somewhat during descent, as is the foehn, it remains cold relative to the surrounding air. It occurs when cold air is dammed up in great quantity on the windward side of a mountain and then spills over suddenly, usually as an overwhelming surge down the other side. It is usually quite violent, sometimes reaching hurricane force. A different name for this type wind is given at each place where it is common. The **tehuantepecer** of the Mexican and Central American coast, the **pampero** of the Argentine coast, the **mistral** of the western Mediterranean, and the **bora** of the eastern Mediterranean are examples of this wind.

Many other local winds common to certain areas have been given distinctive names.

A **blizzard** is a violent, intensely cold wind laden with snow mostly or entirely picked up from the ground, although the term is often used popularly to refer to any heavy snowfall accompanied by strong wind. A **dust whirl** is a rotating column of air about 100 to 300 feet in height, carrying dust, leaves, and other light material. This wind, which is similar to a waterspout at sea, is given various local names such as dust devil in southwestern United States and desert devil in South Africa. A **gust** is a sudden, brief increase in wind speed, followed by a slackening, or the violent wind or squall that accompanies a thunderstorm. A puff of wind or a light breeze affecting a small area, such as would cause patches of ripples on the surface of water, is called a **cat's paw**.

3513. Waterspouts

A **waterspout** is a small, whirling storm over ocean or inland waters. Its chief characteristic is a funnel-shaped cloud; when fully developed it extends from the surface of the water to the base of a cumulus cloud. The water in a waterspout is mostly confined to its lower portion, and may

Figure 3513. Waterspouts.

be either salt spray drawn up by the sea surface, or freshwater resulting from condensation due to the lowered pressure in the center of the vortex creating the spout. The air in waterspouts may rotate clockwise or counterclockwise, depending on the manner of formation. They are found most frequently in tropical regions, but are not uncommon in higher latitudes.

There are two types of waterspouts: those derived from violent convective storms over land moving seaward, called tornadoes, and those formed over the sea and which are associated with fair or foul weather. The latter type is most common, lasts a maximum of 1 hour, and has variable strength. Many waterspouts are no stronger than dust whirlwinds, which they resemble; at other times they are strong enough to destroy small craft or to cause damage to larger vessels, although modern ocean-going vessels have little to fear.

Waterspouts vary in diameter from a few feet to several hundred feet, and in height from a few hundred feet to several thousand feet. Sometimes they assume fantastic shapes; in early stages of development an hour glass shape between cloud and sea is common. Since a waterspout is often inclined to the vertical, its actual length may be much greater than indicated by its height.

3514. Deck Ice

Ships traveling through regions where the air temperature is below freezing may acquire thick deposits of ice as a result of salt spray freezing on the rigging, deckhouses, and deck areas. This accumulation of ice is called **ice accretion**. Also, precipitation may freeze to the superstructure and exposed areas of the vessel, increasing the load of ice.

On small vessels in heavy seas and freezing weather, deck ice may accumulate very rapidly and increase the topside weight enough to capsize the vessel. Fishing vessels with outriggers, A-frames, and other top hamper are particularly susceptible.

Figure 3514. Deck ice.

RESTRICTED VISIBILITY

3515. Fog

Fog is a cloud whose base is at the surface of the earth. Fog is composed of droplets of water or ice crystals (ice fog) formed by condensation or crystallization of water vapor in the air.

Radiation fog forms over low-lying land on clear, calm nights. As the land radiates heat and becomes cooler, it cools the air immediately above the surface. This causes a temperature inversion to form, the temperature increasing with height. If the air is cooled to its dew point, fog forms. Often, cooler and more dense air drains down surrounding slopes to heighten the effect. Radiation fog is often quite shallow, and is usually densest at the surface. After sunrise the fog may “lift” and gradually dissipate, usually being entirely gone by noon. At sea the temperature of the water undergoes little change between day and night, and so radiation fog is seldom encountered more than 10 miles from shore.

Advection fog forms when warm, moist air blows over a colder surface and is cooled below its dew point. It is most commonly encountered at sea, may be quite dense, and often persists over relatively long periods. Advection fog is common over cold ocean currents. If the wind is strong enough to thoroughly mix the air, condensation may take place at some distance above the surface of the earth, forming low stratus clouds rather than fog.

Off the coast of California, seasonal winds create an offshore current which displaces the warm surface water, causing an upwelling of colder water. Moist Pacific air is transported along the coast in the same wind system, and is cooled by the relatively cold water. Advection fog results. In the coastal valleys, fog is sometimes formed when moist air blown inland during the afternoon is cooled by radiation during the night.

When very cold air moves over warmer water, wisps of visible water vapor may rise from the surface as the water "steams," In extreme cases this **frost smoke**, or **Arctic sea smoke**, may rise to a height of several hundred feet, the portion near the surface constituting a dense fog which obscures the horizon and surface objects, but usually leaves the sky relatively clear.

Haze consists of fine dust or salt particles in the air, too small to be individually apparent, but in sufficient number to reduce horizontal visibility and cast a bluish or yellowish veil over the landscape, subduing its colors and making objects appear indistinct. This is sometimes called **dry haze** to distinguish it from **damp haze**, which consists of small water droplets or moist particles in the air, smaller and more scattered than light fog. In international meteorological practice, the term "haze" is used to refer to a condition of atmospheric obscurity caused by dust and smoke.

Mist is synonymous with drizzle in the United States but is often considered as intermediate between haze and fog in its properties. Heavy mist can reduce visibility to a mile or less.

A mixture of smoke and fog is called **smog**. Normally it is not a problem in navigation except in severe cases accompanied by an offshore wind from the source, when it may reduce visibility to 2–4 miles.

ATMOSPHERIC EFFECTS ON LIGHT RAYS

3516. Mirage

Light is refracted as it passes through the atmosphere. When refraction is normal, objects appear slightly elevated, and the visible horizon is farther from the observer than it otherwise would be. Since the effects are uniformly progressive, they are not apparent to the observer. When refraction is not normal, some form of mirage may occur. A **mirage** is an optical phenomenon in which objects appear distorted, displaced (raised or lowered), magnified, multiplied, or inverted due to varying atmospheric refraction which occurs when a layer of air near the earth's surface differs greatly in density from surrounding air. This may occur when there is a rapid and sometimes irregular change of temperature or humidity with height.

If there is a temperature inversion (increase of temperature with height), particularly if accompanied by a rapid decrease in humidity, the refraction is greater than normal. Objects appear elevated, and the visible horizon is farther away. Objects which are normally below the horizon become visible. This is called **looming**. If the upper portion of an object is raised much more than the bottom part, the object appears taller than usual, an effect called **towering**. If the lower part of an object is raised more than the upper part, the object appears shorter, an effect called **stooping**. When the refraction is greater than normal, a **superior mirage** may occur. An inverted image is seen above the object, and sometimes an erect image appears over the inverted one, with the bases of the two images touching. Greater than normal refraction usually occurs when the water is much colder than the air above it.

If the temperature decrease with height is much greater than normal, refraction is less than normal, or may even cause bending in the opposite direction. Objects appear lower than normal, and the visible horizon is closer to the observer. This is called **sinking**. Towering or stooping may occur if conditions are suitable. When the refraction is reversed, an **inferior mirage** may occur. A ship or an island appears to be floating in the air above a shimmering horizon, possibly with an inverted image beneath it. Conditions suitable to the formation of an inferior mirage occur when the surface is much warmer than the air above it. This usually requires a heated landmass, and therefore is more common near the coast than at sea.

When refraction is not uniformly progressive, objects may appear distorted, taking an almost endless variety of shapes. The sun when near the horizon is one of the objects most noticeably affected. A **fata morgana** is a complex mirage characterized by marked distortion, generally in the vertical. It may cause objects to appear towering, magnified, and at times even multiplied.

3517. Sky Coloring

White light is composed of light of all colors. Color is related to wavelength, the visible spectrum varying from about 0.000038 to 0.000076 centimeters. The characteristics of each color are related to its wavelength (or frequency). The shorter the wavelength, the greater the amount of bending when light is refracted. It is this principle that permits the separation of light from celestial bodies into a **spectrum** ranging from red, through orange, yellow, green, and blue, to violet, with long-wave **infrared** being slightly outside the visible range at one end and short-wave **ultraviolet** being slightly outside the visible range at the other end. Light of shorter wavelength is scattered and diffracted more than that of longer wavelength.

Light from the sun and moon is white, containing all colors. As it enters the earth's atmosphere, a certain amount of it is scattered. The blue and violet, being of shorter wavelength than other colors, are scattered most. Most of the violet light is absorbed in the atmosphere. Thus, the scattered blue light is most apparent, and the sky appears blue. At great heights, above most of the atmosphere, it appears black.

When the sun is near the horizon, its light passes through more of the atmosphere than when higher in the sky, resulting in greater scattering and absorption of blue and green light, so that a larger percentage of the red and orange light penetrates to the observer. For this reason the sun and moon appear redder at this time, and when this light falls upon clouds, they appear colored. This accounts for the colors at sunset and sunrise. As the setting sun approaches the horizon, the sunset colors first appear as faint tints of yellow and orange. As the sun continues to set, the colors deepen. Contrasts occur, due principally to difference in height of clouds. As the sun sets, the clouds become a deeper red, first the lower clouds and then the higher ones, and finally they fade to a gray.

When there is a large quantity of smoke, dust, or other material in the sky, unusual effects may be observed. If the material in the atmosphere is of suitable substance and quantity to absorb the longer wave red, orange, and yellow radiation, the sky may have a greenish tint, and even the sun or moon may appear green. If the green light, too, is absorbed, the sun or moon may appear blue. A green moon or blue moon is most likely to occur when the sun is slightly below the horizon and the longer wavelength light from the sun is absorbed, resulting in green or blue light being cast upon the atmosphere in front of the moon. The effect is most apparent if the moon is on the same side of the sky as the sun.

3518. Rainbows

The **rainbow**, that familiar arc of concentric colored bands seen when the sun shines on rain, mist, spray, etc., is caused by refraction, internal reflection, and diffraction of sunlight by the drops of water. The center of the arc is a point 180° from the sun, in the direction of a line from the sun, through the observer. The radius of the brightest rainbow is 42°. The colors are visible because of the difference in the amount of refraction of the different colors making up white light, the light being spread out to form a spectrum. Red is on the outer side and blue and violet on the inner side, with orange, yellow, and green between, in that order from red.

Sometimes a secondary rainbow is seen outside the primary one, at a radius of about 50°. The order of colors of this rainbow is reversed. On rare occasions a faint rainbow is seen on the same side as the sun. The radius of this rainbow and the order of colors are the same as those of the primary rainbow.

A similar arc formed by light from the moon (a lunar rainbow) is called a **moonbow**. The colors are usually very faint. A faint, white arc of about 39° radius is occasionally seen in fog opposite the sun. This is called a **fogbow**, although its origin is controversial, some considering it a halo.

3519. Halos

Refraction, or a combination of refraction and reflection, of light by ice crystals in the atmosphere may cause a **halo** to appear. The most common form is a ring of light of radius 22° or 46° with the sun or moon at the center. Cirrostratus clouds are a common source of atmospheric ice crystals. Occasionally a faint, white circle with a radius of 90° appears around the sun. This is called a **Hevelian halo**. It is probably caused by refraction and internal reflection of the sun's light by bipyramidal ice crystals. A halo formed by refraction is usually faintly colored like a rainbow, with red nearest the celestial body, and blue farthest from it.

A brilliant rainbow-colored arc of about a quarter of a circle with its center at the zenith, and the bottom of the arc about 46° above the sun, is called a **circumzenithal arc**. Red is on the outside of the arc, nearest the sun. It is produced by the refraction and dispersion of the sun's light striking the top of prismatic ice crystals in the atmosphere. It usually lasts for only about 5 minutes, but may be so brilliant as to be mistaken for an unusually bright rainbow. A similar arc formed 46° below the sun, with red on the upper side, is called a **circumhorizontal arc**. Any arc tangent to a heliocentric halo (one surrounding the sun) is called a **tangent arc**. As the sun increases in elevation, such arcs tangent to the halo of 22° gradually bend their ends toward each other. If they meet, the elongated curve enclosing the circular halo is called a **circumscribed halo**. The inner edge is red.

A halo consisting of a faint, white circle through the sun and parallel to the horizon is called a **parhelic circle**. A similar one through the moon is called a **paraselenic circle**. They are produced by reflection of sunlight or moonlight from vertical faces of ice crystals.

A **parhelion (plural: parhelia)** is a form of halo consisting of an image of the sun at the same altitude and some distance from it, usually 22°, but occasionally 46°. A similar phenomenon occurring at an angular distance of 120° (sometimes 90° or 140°) from the sun is called a **paranthelion**. One at an angular distance of 180°, a rare occurrence, is called an **anthelion**, although this term is also used to refer to a luminous, colored ring or glory sometimes seen around the shadow of one's head on a cloud or fog bank. A parhelion is popularly called a **mock sun** or **sun dog**. Similar phenomena in relation to the moon are called **paraselene** (popularly a **mock moon** or **moon dog**), **parantiselene**, and **antiselene**. The term parhelion should not be confused with perihelion, the orbital point nearest the sun when the sun is the center of attraction.

A **sun pillar** is a glittering shaft of white or reddish light occasionally seen extending above and below the sun, usually when the sun is near the horizon. A phenomenon similar to a sun pillar, but observed in connection with the moon, is called a **moon pillar**. A rare form of halo in which horizontal and vertical shafts of light intersect at the sun is called a **sun cross**. It is probably due to the simultaneous occurrence of a sun pillar and a parhelic circle.

3520. Corona

When the sun or moon is seen through altostratus clouds, its outline is indistinct, and it appears surrounded by a glow of light called a **corona**. This is somewhat similar in appearance to the corona seen around the sun during a solar eclipse. When the effect is due to clouds, however, the glow may be accompanied by one or more rainbow-colored rings of small radii, with the celestial body at the center. These can be distinguished from a halo by their much smaller radii and also by the fact that the order of the colors is reversed, red being on the inside, nearest the body, in the case of the halo, and on the outside, away from the body, in the case of the corona.

A corona is caused by diffraction of light by tiny droplets of water. The radius of a corona is inversely proportional to the size of the water droplets. A large corona indicates small droplets. If a corona decreases in size, the water droplets are becoming larger and the air more humid. This may be an indication of an approaching rainstorm. The glow portion of a corona is called an **aureole**.

3521. The Green Flash

As light from the sun passes through the atmosphere, it is refracted. Since the amount of bending is slightly different for each color, separate images of the sun are formed in each color of the spectrum. The effect is similar to that of imperfect color printing, in which the various colors are slightly out of register. However, the difference is so slight that the effect is not usually noticeable. At the horizon, where refraction is maximum, the greatest difference, which occurs between violet at one end of the spectrum and red at the other, is about 10 seconds of arc. At latitudes of the United States, about 0.7 second of time is needed for the sun to change altitude by this amount when it is near the horizon. The red image, being bent least by refraction, is first to set and last to rise. The shorter wave blue and violet colors are scattered most by the atmosphere, giving it its characteristic blue color. Thus, as the sun sets, the green image may be the last of the colored images to drop out of sight. If the red, orange, and yellow images are below the horizon, and the blue and violet light is scattered and absorbed, the upper rim of the green image is the only part seen, and the sun appears green. This is the **green flash**. The shade of green varies, and occasionally the blue image is seen, either separately or following the green flash (at sunset). On rare occasions the violet image is also seen. These colors may also be seen at sunrise, but in reverse order. They are occasionally seen when the sun disappears behind a cloud or other obstruction.

The phenomenon is not observed at each sunrise or sunset, but under suitable conditions is far more common than generally supposed. Conditions favorable to observation of the green flash are a sharp horizon, clear atmosphere, a temperature inversion, and a very attentive observer. Since these conditions are more frequently met when the horizon is formed by the sea than by land, the phenomenon is more common at sea. With a sharp sea horizon and clear atmosphere, an attentive observer may see the green flash at as many as 50 percent of sunsets and sunrises, although a telescope may be needed for some of the observations.

Duration of the green flash (including the time of blue and violet flashes) of as long as 10 seconds has been reported, but such length is rare. Usually it lasts for a period of about $^1/_2$ to 2 $^1/_2$ seconds, with about 1 $^1/_4$ seconds being average. This variability is probably due primarily to changes in the index of refraction of the air near the horizon.

Under favorable conditions, a momentary green flash has been observed at the setting of Venus and Jupiter. A telescope improves the chances of seeing such a flash from a planet, but is not a necessity.

3522. Crepuscular Rays

Crepuscular rays are beams of light from the sun passing through openings in the clouds, and made visible by illumination of dust in the atmosphere along their paths. Actually, the rays are virtually parallel, but because of perspective, appear to diverge. Those appearing to extend downward are popularly called **backstays of the sun**, or the sun drawing water. Those extending upward and across the sky, appearing to converge toward a point 180° from the sun, are called **anticrepuscular rays**.

THE ATMOSPHERE AND RADIO WAVES

3523. Atmospheric Electricity

Radio waves traveling through the atmosphere exhibit many of the properties of light, being refracted, reflected, diffracted, and scattered. These effects are discussed in greater detail in Chapter 10, Radio Waves in Navigation.

Various conditions induce the formation of electrical charges in the atmosphere. When this occurs, there is often a difference of electron charge between various parts of the atmosphere, and between the atmosphere and earth or terrestrial objects. When this difference exceeds a certain minimum value, depending upon the conditions, the static electricity is discharged, resulting in phenomena such as lightning or St. Elmo’s fire.

Lightning is the discharge of electricity from one part of a thundercloud to another, between different clouds, or between a cloud and the earth or a terrestrial object.

Enormous electrical stresses build up within thunderclouds, and between such clouds and the earth. At some point the resistance of the intervening air is overcome. At first the process is a progressive one, probably starting as a brush discharge (St. Elmo’s fire), and growing by ionization. The breakdown follows an irregular path along the line of least resistance. A hundred or more individual discharges may be necessary to complete the path between points of opposite polarity. When this “leader stroke” reaches its destination, a heavy “main stroke” immediately follows in the opposite direction. This main stroke is the visible lightning, which may be tinted any color, depending upon the nature of the gases through which it passes. The illumination is due to the high degree of ionization of the air, which causes many of the atoms to become excited and emit radiation.

Thunder, the noise that accompanies lightning, is caused by the heating and ionizing of the air by lightning, which results in rapid expansion of the air along its path and the sending out of a compression wave. Thunder may be heard at a distance of as much as 15 miles, but generally does not carry that far. The elapsed time between the flash of lightning and reception of the accompanying sound of thunder is an indication of the distance, because of the difference in travel time of light and sound. Since the former is comparatively instantaneous, and the speed of sound is about 1,117 feet per second, the approximate distance in nautical miles is equal to the elapsed time in seconds, divided by 5.5. If the thunder accompanying lightning cannot be heard due to its distance, the lightning is called **heat lightning**.

St. Elmo's fire is a luminous discharge of electricity from pointed objects such as the masts and antennas of ships, lightning rods, steeples, mountain tops, blades of grass, human hair, arms, etc., when there is a considerable difference in the electrical charge between the object and the air. It appears most frequently during a storm. An object from which St. Elmo's fire emanates is in danger of being struck by lightning, since this discharge may be the initial phase of the leader stroke. Throughout history those who have not understood St. Elmo's fire have regarded it with superstitious awe, considering it a supernatural manifestation. This view is reflected in the name **corposant** (from "corpo santo," meaning "body of a saint") sometimes given this phenomenon.

The **aurora** is a luminous glow appearing in varied forms in the thin atmosphere high above the earth in high latitudes. It closely follows solar flare activity, and is believed caused by the excitation of atoms of oxygen and hydrogen, and molecules of nitrogen (N_2). Auroras extend across hundreds of kilometers of sky, in colored sheets, folds, and rays, constantly changing in form and color. On occasion they are seen in temperate or even more southern latitudes. The maximum occurrence is at about 64–70° of geomagnetic latitude. These are called the **auroral zones** in both northern and southern regions.

The aurora of the northern regions is the **Aurora Borealis** or **northern lights**, and that of the southern region the **Aurora Australis**, or **southern lights**. The term **polar lights** is occasionally used to refer to either.

In the northern zone, there is an apparent horizontal motion to the westward in the evening and eastward in the morning; a general southward motion occurs during the course of the night.

Variation in auroral activity occurs in sequence with the 11-year sunspot cycle, and also with the 27-day period of the sun's synodical rotation. Daily occurrence is greatest near midnight.

WEATHER ANALYSIS AND FORECASTING

3524. Forecasting Weather

The prediction of weather at some future time is based upon an understanding of weather processes, and observations of present conditions. Thus, when there is a certain sequence of cloud types, rain usually can be expected to follow. If the sky is cloudless, more heat will be received from the sun by day, and more heat will be radiated outward from the warm earth by night than if the sky is overcast. If the wind is from a direction that transports warm, moist air over a colder surface, fog can be expected. A falling barometer indicates the approach of a "low," probably accompanied by stormy weather. Thus, before meteorology passed from an "art" to "science," many individuals learned to interpret certain atmospheric phenomena in terms of future weather, and to make reasonably accurate forecasts for short periods into the future.

With the establishment of weather observation stations, continuous and accurate weather information became available. As observations expanded and communication techniques improved, knowledge of simultaneous conditions over wider areas became available. This made possible the collection of "synoptic" reports at civilian and military forecast centers.

Individual observations are made at stations on shore and aboard vessels at sea. Observations aboard merchant ships at sea are made and transmitted on a voluntary and cooperative basis. The various national meteorological services supply shipmasters with blank forms, printed instructions, and other materials essential to the making, recording, and interpreting of observations. Any shipmaster can render a particularly valuable service by reporting all unusual or non-normal weather occurrences.

Symbols and numbers are used to indicate on a synoptic chart, popularly called a weather map, the conditions at each observation station. Isobars are drawn through lines of equal atmospheric pressure, fronts are located and symbolically marked (See Figure 3525), areas of precipitation and fog are indicated, etc.

Ordinarily, weather maps for surface observations are prepared every 6 (sometimes 3) hours. In addition, synoptic charts for selected heights are prepared every 12 (sometimes 6) hours. Knowledge of conditions aloft is of value in establishing the three-dimensional structure and motion of the atmosphere as input to the forecast.

With the advent of the digital computer, highly sophisticated numerical models have been developed to analyze and forecast weather patterns. The civil and military weather centers prepare and disseminate vast numbers of weather charts (analyses and prognoses) daily to assist local forecasters in their efforts to provide users with accurate weather forecasts. The accuracy of forecast decreases with the length of the forecast period. A 12-hour forecast is likely to be more reliable than a 24-hour forecast. Long term forecasts for 2 weeks or a month in advance are limited to general statements. For example, a prediction may be made about which areas will have temperatures above or below normal, and how precipitation will compare with normal, but no attempt is made to state that rainfall will occur at a certain time and place.

Forecasts are issued for various areas. The national meteorological services of most maritime nations, including the United States, issue forecasts for ocean areas and warnings of approaching storms. The efforts of the various nations are coordinated through the World Meteorological Organization.

3525. Weather Forecast Dissemination

Dissemination of weather information is carried out in a number of ways. Forecasts are widely broadcast by commercial and government radio stations and printed in newspapers. Shipping authorities on land are kept informed by telegraph and telephone. Visual storm warnings are displayed in various ports, and storm warnings are broadcast by radio.

Through the use of codes, a simplified version of synoptic weather charts is transmitted to various stations ashore and afloat. Rapid transmission of completed maps is accomplished by facsimile. This system is based upon detailed scanning, by a photoelectric detector, of illuminated black and white copy. The varying degrees of light intensity are converted to electric energy, which is transmitted to the receiver and converted back to a black and white presentation. The proliferation of both commercial and restricted computer bulletin board systems having weather information has also greatly increased the accessibility of environmental data.

Complete information on dissemination of weather information by radio is provided in *Selected Worldwide Marine Weather Broadcasts*, published jointly by the National Weather Service and the Naval Meteorology and

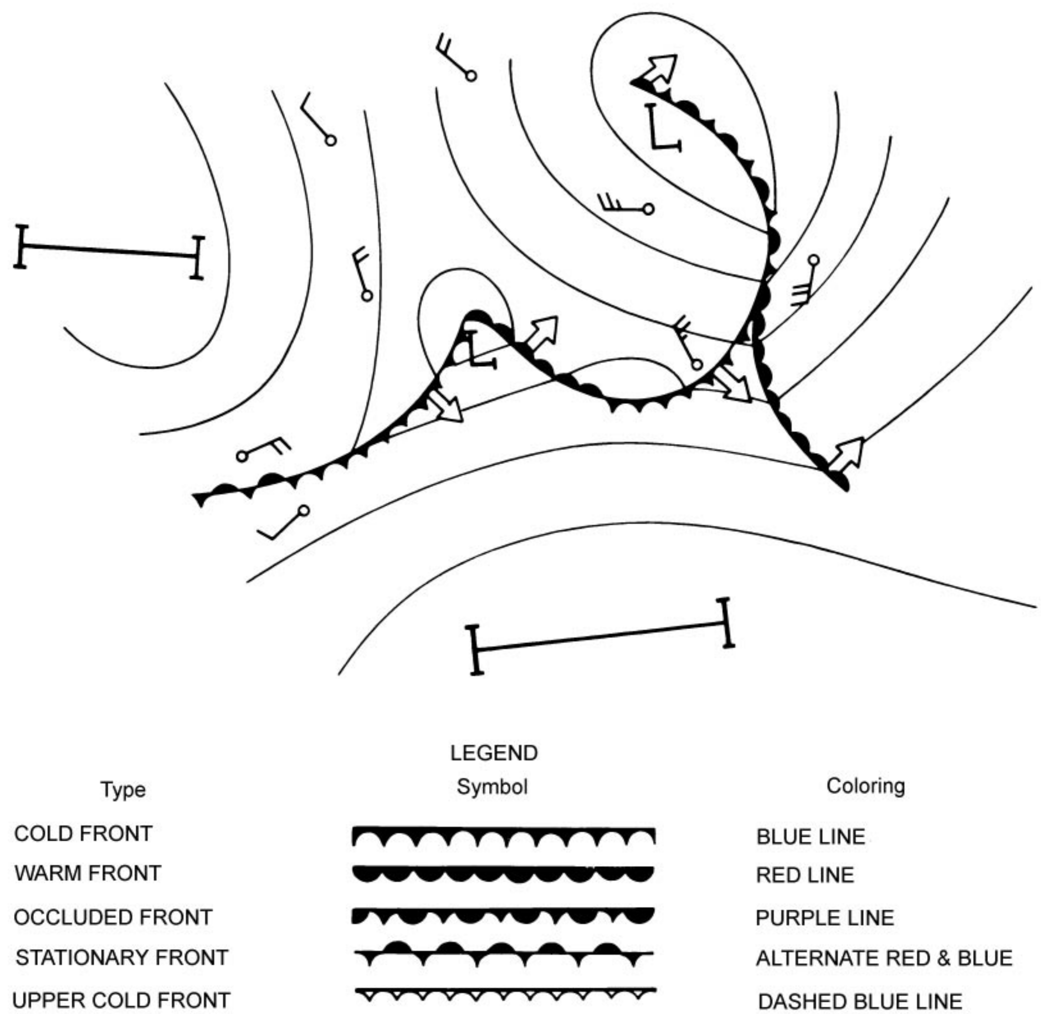

Figure 3525. Designation of fronts on weather maps.

Oceanography Command. This publication lists broadcast schedules and weather codes. Information on day and night visual storm warnings is given in the various volumes of Sailing Directions (Enroute), and (Planning Guide).

3526. Interpreting Weather

The factors which determine weather are numerous and varied. Ever-increasing knowledge regarding them makes possible a continually improving weather service. However, the ability to forecast is acquired through study and long practice, and therefore the services of a trained meteorologist should be utilized whenever available.

The value of a forecast is increased if one has access to the information upon which it is based, and understands the principles and processes involved. It is sometimes as important to know the various types of weather which may be experienced as it is to know which of several possibilities is most likely to occur.

At sea, reporting stations are unevenly distributed, sometimes leaving relatively large areas with incomplete reports, or none at all. Under these conditions, the locations of highs, lows, fronts, etc., are imperfectly known, and their very existence may even be in doubt. At such times the mariner who can interpret the observations made from his own vessel may be able to predict weather for the next several hours more reliably than a trained meteorologist ashore.