biodiversity and regulation will give us better tools to predict where biodiversity changes are likely to occur and why, how these changes will affect other components of marine biodiversity, and the best strategy to mitigate such changes.

See also

Benthic Boundary Layer Effects. Benthic Foraminifera. Benthic Organisms Overview. Deep-Sea Fauna. Demersal Fishes. Macrobenthos. Meiobenthos. Ocean Margin Sediments.

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DOLPHINS

See **MARINE MAMMAL OVERVIEW**

DOUBLE-DIFFUSIVE CONVECTION

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Introduction

The density of sea water is determined by both its temperature and its salt content or salinity. Whereas added heat makes water lighter, added salt makes it denser, so both must be considered when evaluating the gravitational stability of the water column. That is, a given column of water will 'convect' or overturn if dense waters overlie lighter waters. In many parts of the world ocean, the distributions of temperature and salinity are opposed in their effects on density. This arises because of the tendency of warm water to evaporate easily in low latitudes, the predominance of rainfall in cold, high latitude regions, and the deep circulation patterns that bring the cold waters to lower latitudes. The opposing effects of temperature and salinity on density, and the fact that the molecular conductivity of heat is about 100 times as large as the diffusivity of salt in water, makes possible a variety of novel convective motions that have come to be known as double-diffusive convection. In the following, the oceanic double-diffusive mixing phenomena: 'salt fingers', 'diffusive convection', and 'intrusions', are discussed in turn. Observational evidence suggests their importance in all the oceans, and models indicate a substantial impact on water mass structure and the thermohaline circulation.

Salt Fingers

In much of the subtropical ocean, warm, salty water near the surface overlies cooler, fresher water from higher latitudes. If the temperature contrast could be removed there would be a large-scale overturning of the water column, releasing the very substantial energy available in the salt distribution. However, this does not happen except on a small scale, where the greater diffusivity of heat can establish thermal equilibrium in adjacent water parcels that still have strong salt contrasts. A small amount of warm, salty water displaced into the cold, fresh water beneath loses heat, but not much salt to the surrounding water, leaving a cool, salty water parcel that continues to sink. Similarly, a cold fresh parcel displaced upward, gains heat but not salt, becoming warm and fresh and therefore buoyant. This 'salt finger' instability, discovered by M. Stern in 1960, appears as a close-packed array of up and down flowing convection cells which exchange heat laterally but diffuse little salt. The result is an advective transport of salt and, to a lesser extent, heat, in the vertical. Typical cell widths in the ocean are 2–3 cm, the scale for effective heat conduction. The salt finger instability is 'direct', in the sense that initial displacements are accelerated, and can be modeled accurately with an exponential growth rate. When most intense, the fingers tend to exist on high gradient interfaces separating well mixed layers in the adjacent fluid (**Figure 1**).

The role of salt fingers in oceanic mixing is still being determined, but there are clear indications that it is the dominant mixing process in certain regions, and a contributing process within the main thermocline of the subtropical gyres. As could be expected, the propensity toward salt fingering is a strong function of the strength of the vertical salinity gradient. The instability can grow at extremely weak values of the salinity gradient, because the diffusivity of salt is two orders of magnitude less

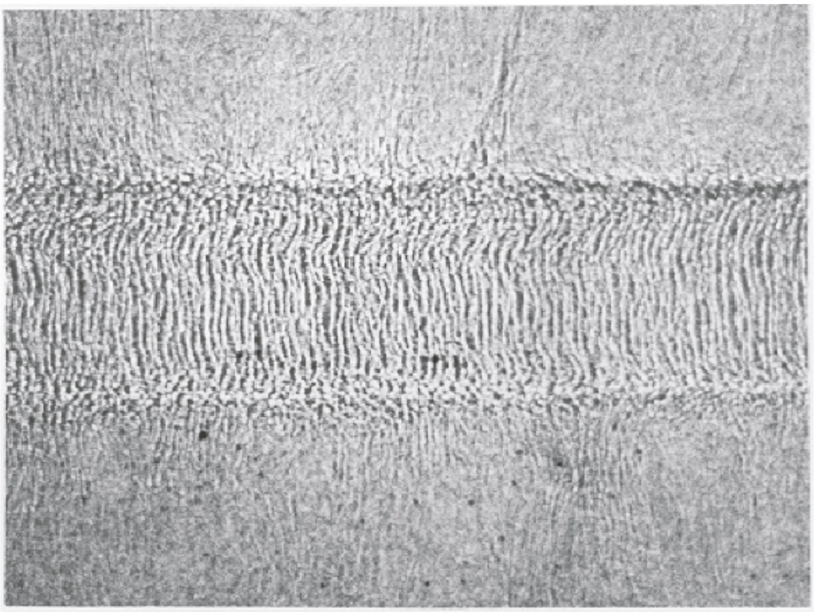

Figure 1 Laboratory shadowgraph of salt fingers formed from a layer of sugar water placed above a layer of salt water. Sugar diffuses at 1/3 the rate of salt in water, so acts like salt in the ocean, while the laboratory salt difference represents the stratification due to the temperature difference in the ocean, which diffuses much faster. The fingering interface has grown to a thickness of 2.5 cm. The narrow fingers within the interface allow efficient diffusive exchange laterally which drives the vertical flow within the fingers. The parallel banding within the interface contrasts with the random convective elements of the mixed layers above and below. Heat-salt fingers in the ocean are 2–3 cm wide, rather than the ~ 1 mm of these salt-sugar fingers.

than the thermal conductivity. When expressed in terms of the effects on density, all that is required is a top-heavy density gradient due to salt that is only about one-one hundredth of the gradient due to temperature. That is, the density ratio, R_ρ, must be less than the diffusivity ratio:

$$1 < R_\rho \equiv \alpha T_Z/\beta S_Z < \kappa_T/\kappa_S \approx 100 \qquad [1]$$

where α, β are the thermal expansion and haline contraction coefficients, T_Z, S_Z are the vertical gradients of temperature and salinity, and κ_S, κ_T are the molecular diffusivity for salt and the thermal conductivity. This criterion is met over vast regions of the tropical and subtropical thermocline. However, while the required salt gradient is very small, the growth rate of salt fingers does not become 'large' until R_ρ approaches 1. Indeed, the primary fine-scale evidence for salt fingers, the 'thermohaline staircase' occurs only when the density ratio becomes low.

Fingers transport more salt than heat in the vertical and have a net counter-gradient buoyancy flux. Since the growth rate and fluxes increase with the strength of the stratification, high gradient regions will harbor greater fluxes than adjacent weak gradient intervals. This leads to a buoyancy flux convergence that can cause the weaker gradient region to overturn and mix. The resulting structure has thin interfaces, containing fingers, separating thicker, well mixed, layers. The layers are continuously mixed by the downward salt flux, and the convective turbulence of the layers serves to keep the interface thin and limits the length of the fingers. Observations of the 'thermohaline staircase' have been reported from several sites with strong salinity gradients. A necessary condition for an organized salt finger staircase seems to be that the density ratio is < 1.7 (**Figure 2**). Such conditions are found occasionally near the ocean surface, where evaporation produces the unstable salinity gradient, but more often at depth where the presence of isopycnal

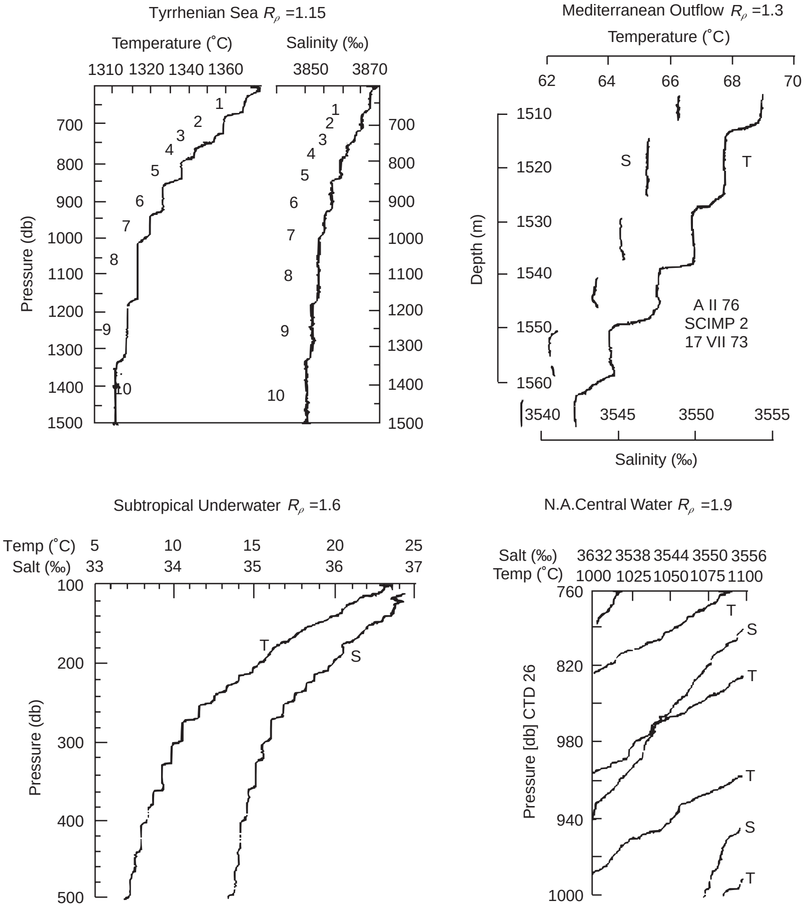

Figure 2 The occurrence of thermohaline staircases as a function of density ratio. The strong staircases have $R_\rho < 1.7$. Irregular stepping characterizes the Central Waters of the subtropical gyres, where $R_\rho \sim 2$. Schmitt RW (1981) Form of the temperature–salinity relationship in the Central Water: Evidence for double-diffusive mixing. *Journal of Physical Oceanography* 11: 1015–1026.

gradients of temperature and salinity can lead to a minimum in R_ρ, provided that there is a component of differential advection (shear) acting on the isopycnal gradients of T and S. Examples of staircases are found beneath the Mediterranean Water in the eastern Atlantic, within the Mediterranean and Tyrrhenian Seas, and beneath the Subtropical Underwater (salinity maximum) of the western tropical Atlantic.

In 1985, a detailed examination of one particular staircase system was made in the C-SALT (Caribbean Sheets And Layers Transects) program. Over a large area in the western tropical North Atlantic ($\sim$1 million km^3) a sequence of $\sim$ 10 mixed layers, 5–40 m thick, can be observed. Data from the 1960s to the 1990s indicate that the layers are a permanent feature of the region, despite layer splitting and merging, and a moderately strong eddy field. One of the most remarkable features from C-SALT was the observed change in layer properties across the region. Layers got colder, fresher, and lighter from north to south (**Figure 3**), the inferred flow direction for the upper layers, which appear to be losing salt to the layers below. This water mass transformation is strong evidence for salt fingers. That is, it can only be due to a flux convergence by salt fingers, which transport more salt than heat; turbulence transports the two components equally and isopycnal mixing, by definition, transports them in density-compensating amounts.

Microstructure measurements taken in the staircase revealed limited amplitude, narrow band temperature structure within the interfaces. The dominant horizontal wavelength was $\sim$ 5 cm, in excellent agreement with the theoretical finger scale. The shape of towed microstructure spectra for this and many other observations is also found to be

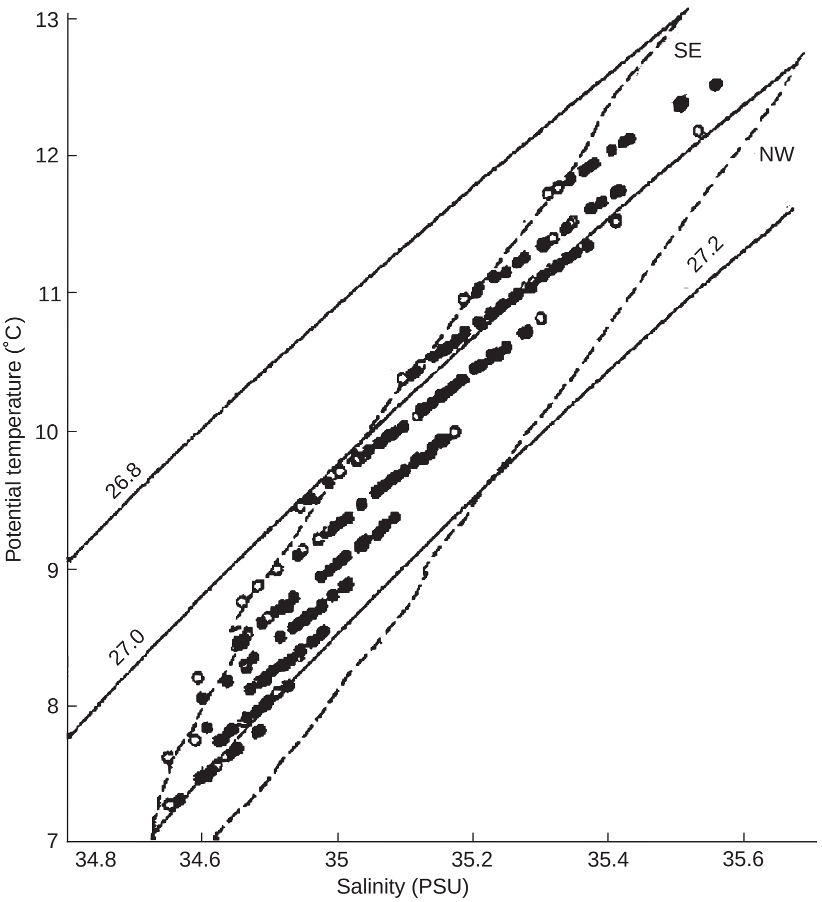

Figure 3 Potential temperature–salinity values of the mixed layers observed during C-SALT. The solid circles are from mixed layers > 10 m thick; the open circles are from layers 5–10 m thick. Temperature–salinity relationships from the north-west and south-east corners of the survey are also shown and labelled (– – –). The evolution of layer properties across the region is such that layers become warmer, saltier, and denser from south east to north west, as would be expected from the vertical convergence of salt finger fluxes. The layer properties cross isopycnals (the 26.8, 27.0, and 27.2 potential density surfaces are shown) with an apparent heat/salt density flux ratio of 0.85. Schmitt RW, Perkins H, Boyd JD and Stalcup MC (1987) C-SALT: An investigation of the thermohaline staircase in the western tropical North Atlantic. *Deep-Sea Research* 4(10A): 1655–1665.

distinctly different from that of turbulence, leading to useful discrimination tests for towed data.

For vertically profiling instruments which measure the dissipation rates of both thermal variance and turbulent kinetic energy, another approach for discriminating between salt fingers and turbulence relies on their relative efficiencies in converting energy sources into changes in the stratification. That is, salt fingers are rather efficient in converting energy from the salt field to the thermal field (~ 70%), with the result that there is relatively little viscous dissipation for the amount of mixing achieved. In contrast, turbulence is rather inefficient, with only ~ 20% of dissipated kinetic energy converted into an increase in potential energy. Salt fingers also lead to a net decrease in potential energy, exactly the opposite to turbulence. This is what allows them to maintain staircase-type profiles, whereas turbulence should ultimately smooth the overall profiles.

A good way to appreciate this difference in mixing mechanisms is to compare the formulae for estimating the vertical diffusivities from microstructure measurements of the dissipation rates of turbulent kinetic energy (ε) and thermal variance (χ). These formulae are contrasted below.

For turbulence (with flux Richardson number, $R_f = 0.17 \pm 0.03$):

$$K_\theta = K_S = K_\rho = \frac{R_f}{1 - R_f}\frac{\varepsilon}{N^2} = \Gamma_t\frac{\varepsilon}{N^2} \approx 0.2\frac{\varepsilon}{N^2}$$

$$K_\theta = K_S = \frac{\chi_\theta}{2\theta_Z} \qquad [2]$$

For salt fingers (with $R_\rho = 1.6$, and flux ratio, $\gamma = 0.7$):

$$K_S = \frac{R_\rho - 1}{1 - \gamma}\frac{\varepsilon}{N^2} \approx 2\frac{\varepsilon}{N^2}$$

$$K_S = \frac{R_\rho}{\gamma}\frac{\chi_\theta}{2\theta_Z} \approx 2.3K_\theta$$

$$K_\theta = \frac{\chi_\theta}{2\theta_Z} = \frac{\gamma}{R_\rho}K_S = \left(\frac{\gamma}{R_\rho}\right)\frac{R_\rho - 1}{1 - \gamma}\frac{\varepsilon}{N^2}$$

$$= \Gamma_f\frac{\varepsilon}{N^2} \approx 0.8\frac{\varepsilon}{N^2} \qquad [3]$$

Note that the 'mixing efficiencies' Γ_t, Γ_f are distinctly different for turbulence and salt fingers, with the fingers being more efficient and dissipating less energy for a given amount of mixing.

A broad-scale microstructure survey capable of addressing these issues was done with the North Atlantic Tracer Release Experiment (NATRE, *see* **Tracer Release Experiments**). This region of the eastern North Atlantic thermocline is susceptible to salt fingers, and optical microstructure imagery revealed that they were the most frequently observed microstructure in the thermocline. In addition, it was obvious in the sensor data that there were many occurrences of the 'high χ, low ε' signature of salt fingers, that contrasted with the high ε signatures of turbulence. A parametric sorting of the mixing events allows classification of the stronger microstructure patches by the value of the local Richardson number and density ratio. Statistically significant variations in the value of the 'mixing efficiency' were observed in this parameter space (**Figure 4**).

When translated into a flux ratio for salt fingers, the data are in excellent agreement with laboratory data. This parametric approach to the microstructure allows a classification of the mixing events as either turbulent (with low efficiency) or salt fingering (with high efficiency). With each occurring at different frequencies in the water column, this translates into differences for the net vertical eddy diffusivities for heat and salt (**Figure 5**). At the depth range of the tracer, the salt fingers provide enough mixing to produce a downward diapycnal velocity, in good agreement with the observed tracer movement. Also, the diffusivity estimated taking salt fingers into account agrees well with the tracer value. Analysis using the conventional turbulence formula yields a diffusivity that is 50% low and a diapycnal velocity of the wrong sign. The magnitude of the fluxes in NATRE can be contrasted with those in the C-SALT staircase. From the substantial rate of dissipation of thermal variance an eddy diffusivity for salinity of $1\text{–}2 \times 10^{-4}\,\mathrm{m^2\,s^{-1}}$ within the staircase can be estimated based on the observed thermal and turbulent dissipation rates. Since the staircase occupies about one quarter of the area of the Atlantic between 10 and 15°N, the vertical salt flux in this high gradient area is predicted to be three or four times as large as the flux in the remaining area of this latitude band. This is because the rest of the area is expected to have a diffusivity 10 times smaller (like NATRE) as well as a weaker salinity gradient. Thus, the staircase areas appear to be very significant sites of enhanced diapycnal exchange.

Diffusive Convection

The 'diffusive' form of double-diffusive convection is realized when the stratification is the opposite of the salt finger situation. That is, cold fresh water

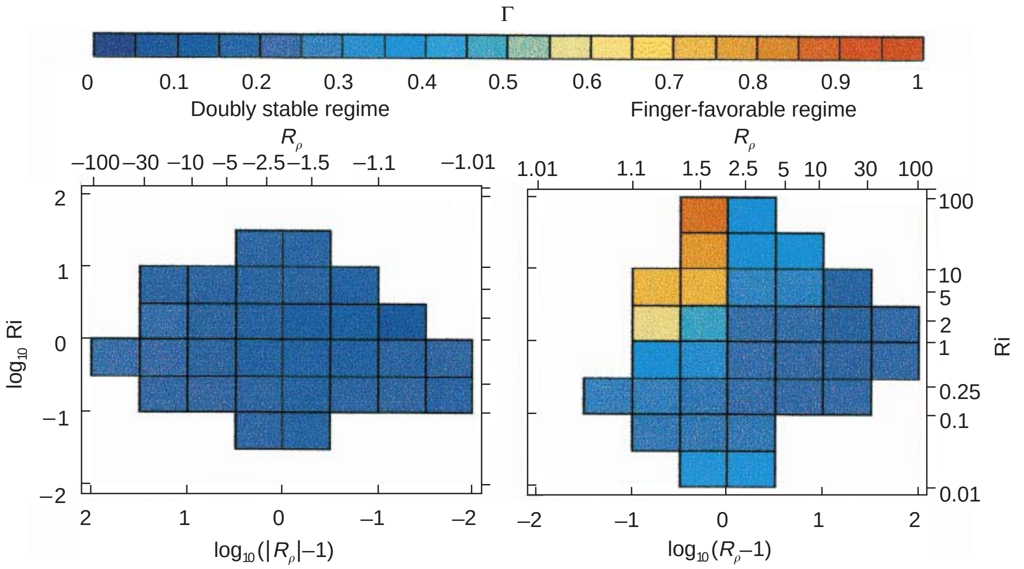

Figure 4 The 'mixing efficiency', Γ, as a function of density ratio and Richardson number, for the microstructure sampled in the main thermocline of the eastern North Atlantic Ocean.

overlies warm salty water, with the salt providing the overall stabilization of the water column. However, there is energy to be released in the 'warm on the bottom' temperature distribution, and the different rates of heat and salt diffusion allow convection to occur.

The essential physics is distinct from salt fingers, as the faster diffusion of heat is releasing energy in its own distribution rather than that of the slower diffusing salt. Again considering movement of small parcels of water, it can be seen that the elevation of warm salty water into the cold fresh water will

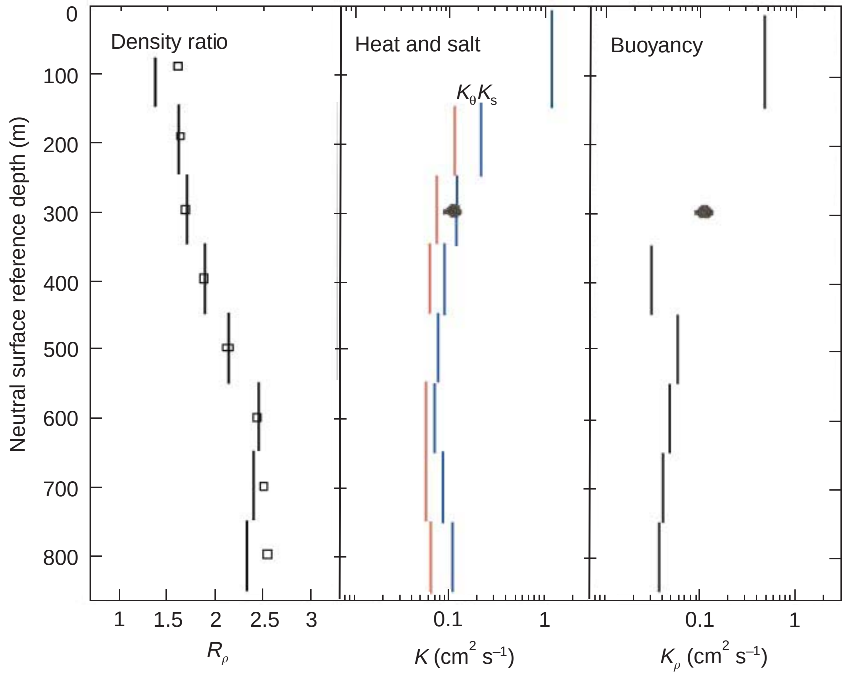

Figure 5 Profiles of density ratio (left), and the eddy diffusivities (middle) and buoyancy (right) estimated for the North Atlantic Tracer Release Experiment. The observed diffusivity of tracer at a depth of 300 m is in good agreement with the salt diffusivity derived from a combination of salt fingers and turbulence, and well above those estimated for heat and buoyancy. St Laurent L and Schmitt RW (1999) The contribution of salt fingers to vertical mixing in the North Atlantic Tracer Release Experiment. *Journal of Physical Oceanography* 29(7): 1404–1424.

cause it to become cold salty water, and thus heavier than when it started upward. Instead of accelerating upward as in a salt finger, it is actually driven back down with greater force than it took to initially displace it. This is termed an 'overstability' and leads to a growing oscillation. However, the oscillatory behavior is hard to observe except in careful laboratory experiments, as it quickly reaches an amplitude where a transition to a layered series of convective cells is realized. This is another form of thermohaline staircase, with temperature and salinity both increasing with depth.

A laboratory experiment that involves heating a stable salt gradient from below easily develops a thermohaline staircase in the diffusive sense. The mixed layers are maintained by convective motions driven by the heat flux from below; the thin, stable, gradient regions are sharp interfaces that conduct heat vertically, but transport little salt. In the ocean such diffusive staircases are mostly found in high latitude oceans, where surface cooling and freshening can set up the necessary gradients. Often, diffusive staircases are found under sea ice (**Figure 6**). It seems that the ice helps to isolate the water column from wind forcing, leading to exceptionally weak internal waves, so that the relatively slow diffusive process can dominate the vertical mixing.

The fluxes for the diffusive staircase are generally less than fluxes for salt fingers. This is because fingers advectively carry heat and salt vertically across the interfaces, whereas a diffusive interface must rely largely on vertical conduction across the horizontal interface. The surface area for heat diffusion is much greater in the convoluted structure of a salt finger interface. In many ways, the fully developed diffusive interface is simply a modified form of Rayleigh-Bernard convection, with fluid boundary conditions and the diffusion of salt acting as a weak drag on the intensity.

The relative effectiveness of heat and salt diffusion across the interface sets the salt to heat flux ratio. Except for density ratios very close to 1, the flux ratio is rather low. This can be understood by considering an interface made sharp by convection. The heat and salt would diffuse into boundary layers on either side, with different thicknesses

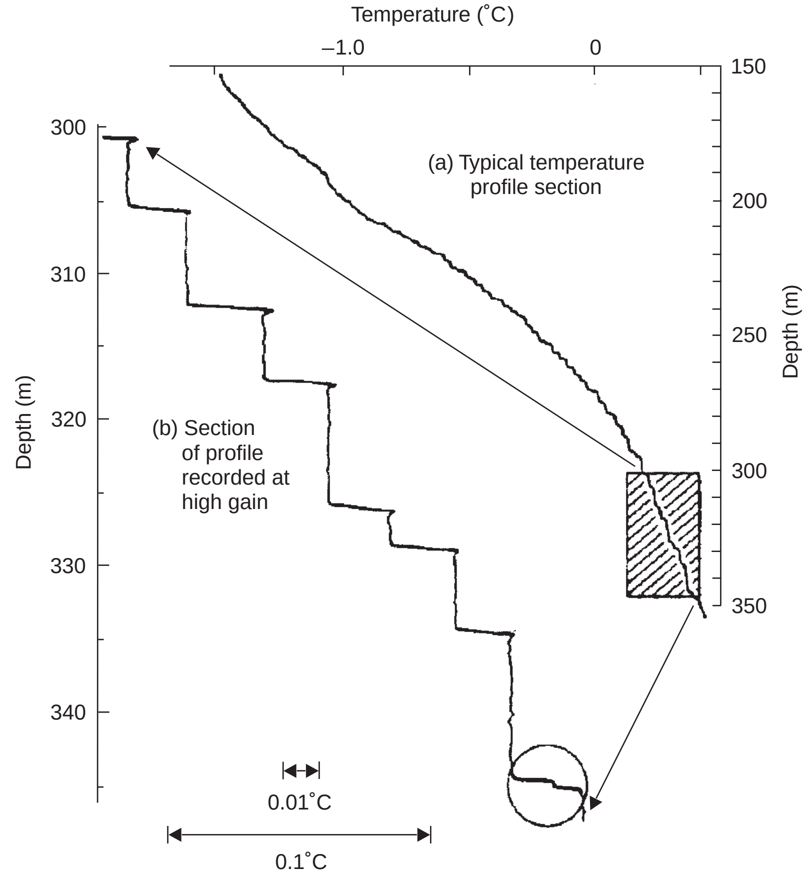

Figure 6 Temperature staircase in the Arctic halocline beneath the ice; 5–10 m mixed layers are seen separated by thin diffusive interfaces across which heat conduction provides a buoyancy flux to stir the adjacent layers. Neal, Neshyba and Denner, *Science*, 166: 373–374.

depending on the square root of their diffusivities. After a certain time, the thermal boundary layer would be thick enough to be unstable and convection would occur, carrying the heat and salt anomalies away from the interface. The relative amounts of salt and heat transported should depend on the square root of the diffusivity ratio (~ 0.1), a number in reasonable agreement with laboratory measurements, so long as the density ratio is not too close to 1. At density ratios closer to 1 the interface is increasingly disrupted by turbulent plumes from the mixed layers, and a more direct transport of both heat and salt occurs, resulting in a higher salt to heat buoyancy flux ratio. Of course, this ratio is limited by the energetics to be < 1.

Strong but localized diffusive staircases are found at the hot, salty brines in topographic deep areas found at oceanic spreading centers. There the separation of heat and salt could be contributing to pooling of the brines in topographic depressions and possibly ore formation as well. The diffusive process also plays a role in intrusions and on the upper side of warm, salty water masses such as the Mediterranean Water in the Atlantic. It may be a factor in the evolution of fresh mixed layers laid down by rain, river inputs, or ice melt. These can create 'barrier layers' whereby the strong salt stratification prevents mixing with underlying water. If the fresh surface layers cool, the conditions for diffusive convection arise at the base of the mixed layer. Diffusive convection transports heat upwards, but not much salt, thus maintaining the stratification. Thus, such barrier layers should persist longer than they would without double diffusion. Barrier layers appear to be important in modifying air–sea interactions in both the tropics and high latitude areas of deep convection such as the Labrador Sea.

However, the most extensive regions of diffusive convection are found beneath the surface layers in the polar and subpolar oceans. Steps under the Arctic ice were first reported in the 1970s, and have been observed to cover much of the Arctic in recent data. A diffusive thermohaline staircase of ~ 200–400 m depth appears to be a ubiquitous feature under most of the Arctic ice field away from the boundaries. It supports a heat flux from the intruding warm, salty Atlantic water to the cooler, fresher Arctic surface waters above. The extensiveness of the staircase may be due to the lack of mixing by internal waves; the internal wave field is especially weak under the ice, perhaps due to the rigid ice lid, but also possibly due to an enhanced wave decay within the convectively mixed staircase. Areas near topography with stronger internal waves and more frequent turbulent mixing events are less likely to harbor a staircase. The down-gradient buoyancy flux from the turbulence (an up-gradient buoyancy flux is necessary to maintain a staircase), and the destruction of the small-scale property gradients by isotropic turbulence, are competing factors to the double diffusion.

The waters around Antarctica also display prominent diffusive staircases. The layers in the Weddell Sea are much thicker (10–100 m) than those found in the Arctic and may support an upward heat flux of 15 W m^{-2} in open waters, if the diffusive interfaces are thin enough, an issue not easily resolved with ordinary instruments. This flux is sufficient to be important in upper ocean heat budgets and may help to maintain ice-free conditions in the summer. Lower fluxes are estimated for the Arctic steps. However, recent observations of a much stronger incursion of Atlantic water into the Arctic are characterized by very extensive double-diffusive intrusions. This suggests that the lateral processes (see next section) may be dominant over vertical in the halocline of the Arctic Ocean, and that the significant climatic changes currently underway there may be mediated by small-scale double-diffusive processes.

The importance of diffusive convection in polar regions lies in its ability to produce a cold, salty and dense water mass without air–sea interaction. That is, heat can be extracted from a subsurface water mass without much change in salinity. The resulting water may be dense enough to become a bottom water. This idea has been applied to the formation of Antarctic Bottom Water and Greenland Sea Bottom Water. The T–S characteristics are in agreement with the model predictions, but quantification of the rates of mixing remains uncertain. This is now viewed as a critical issue, since the upward heat flux may be contributing to the current rapid decay of Arctic sea ice.

Intrusions

In the presence of horizontal variations in temperature and salinity along density surfaces, as is common at oceanic fronts, the small-scale double-diffusive processes can drive horizontal motions on 10–100 m vertical scales. These intrusive instabilities arise because of the buoyancy flux convergences due to the mixing by salt fingers and diffusive interfaces. In the presence of horizontal T and S gradients, these fluxes generate lateral pressure gradients which drive a slow movement of water across the front. This is often manifested as a complex interleaving of warm/salty and cold/fresh water masses (**Figure 7**). The relative motion of each water type relative to the other is an effective means for keeping the double diffusion most intense, as it has a tendency to drive the density ratio toward one. Thus, it is a self-reinforcing (direct) instability or a sort of 'horizontal salt finger'. The sense of the heat and salt flux convergences is such that a warm salty intrusion is expected to lose more salt than heat due to fingering across its lower boundary, and thus should become lighter and rise across density surfaces. Similarly, a cold fresh intrusion should gain more salt than heat and become denser and sink across density surfaces. Such behavior was predicted theoretically by Stern, confirmed in the laboratory by Turner, and observed in numerous observational programs. In situations where the temperature increases with depth, diffusive convection may dominate the mixing, leading to sinking of a warm salty intrusion. Microstructure observations confirm that enhanced dissipation consistent with double diffusion occurs at the interfacial boundaries

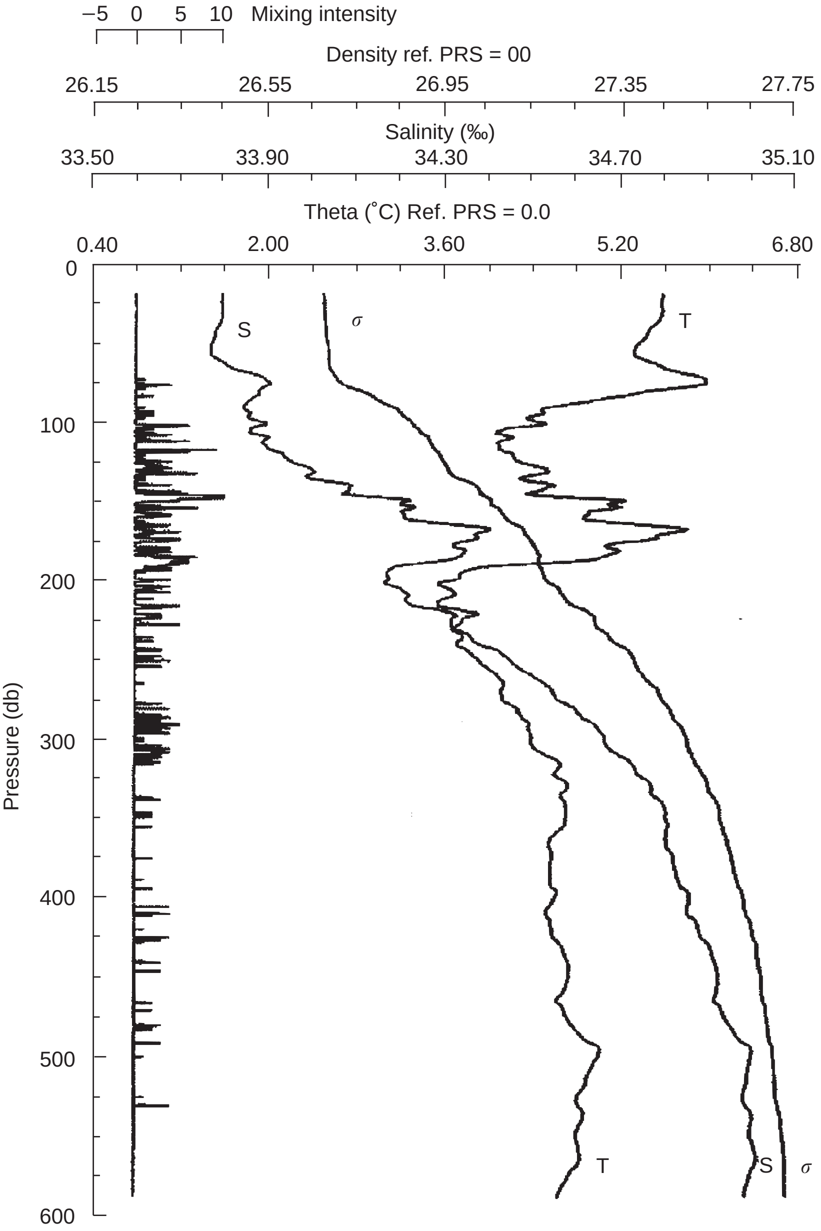

Figure 7 Intrusive fine structure in the front associated with the North Atlantic Current east of Newfoundland. Warm, salty waters from the south interleave with cold, fresh waters from the north to create strong salinity-compensated temperature inversions with an overall stable density profile (σ). An optical microstructure instrument revealed intense double-diffusive mixing at the boundaries of the intruding water masses. Schmitt RW and Georgi DT (1982) Finestructure and microstructure in the North Atlantic Current. *Journal of Marine Research,* Supplement to 40: 659–705.

of such intrusive fine structure. More detail on double-diffusive intrusions can be found in the article **Intrusions**.

Global Importance

It is fair to ask whether the different heat/salt transport rates achieved in small-scale double-diffusive mixing have any influence on the large-scale circulation. In general, ocean models assume that the small scales are available to consume whatever variance necessary, and in particular that there is no difference in heat and salt diffusivities. The presence of double diffusion in the ocean means that this assumption is invalid, and that a variety of effects whereby the differential transport rates feedback on the larger scale structure manifest themselves.

For the intrusive instabilities described above, one effect is the tendency to destroy small-scale anomalies in temperature and salinity. The role of the relative horizontal motion between the vertically arrayed layers (shear) in forcing the density ratio toward 1 is important here, as this keeps the double-diffusive convection most intense. The strong mixing continues driving the anomalous fluid across density surfaces until it reaches a level with matching properties. Thus, intrusions are a powerful mechanism for removing water–mass anomalies and maintaining the tightness of the mean temperature–salinity relationship. The process can occur anywhere, and there is good evidence that it is a major lateral mixing agent in both polar and equatorial latitudes.

Another effect on the T–S relation is due to the strong dependence of the vertical mixing rate on density ratio. The well documented increase in fingering intensity as the density ratio approaches 1 leads to a number of interesting effects. When vertical variations in density ratio arise this dependence leads to fine-scale flux convergences which act to remove the anomaly in density ratio. Since density-compensated T–S anomalies are prominent in the mixed layer, such a differential mixing mechanism is needed to explain the tightness and shape of the T–S relation of the subducted waters in the thermocline. Also, for both salt fingers and diffusive convection, there is a forcing of the density ratio away from unity, unless compensated by vertical fluxes or differential lateral advection. In addition, salt fingers are often the dominant mixing mechanism operating on fine-scale intrusions at fronts. Double-diffusive intrusions may be a dominant mechanism for accomplishing lateral mixing of water masses at the fine scale. Since double diffusion acts preferentially on high gradient regions, it may be responsible for a disproportionately large fraction of the global dissipation of thermal and haline variance, despite modest eddy diffusivities. This is reinforced by the recent discovery that enhanced open ocean turbulence is found mainly in the weakly stratified abyss, where the contribution to dissipation of scalar variance is necessarily small, even though the eddy diffusivities may be large.

In addition to being of regional importance as an enhanced flux site in the thermocline of the tropical North Atlantic, salt fingers may be important in all of the other oceans and many marginal seas. In the Atlantic at 24°N, fully 95% of the upper kilometer of the ocean is salt finger favorable. Indeed, conditions are favorable for fingering in all of the Central Waters of the subtropical gyres. Since it is well established that the strength of the thermohaline circulation is very sensitive to the magnitude of the vertical (diapycnal) mixing coefficient, we must be concerned with the large-scale effects of widespread salt fingering. Model studies show that major features of the steady-state solutions are very sensitive to the ratio of the vertical eddy diffusivities for salinity and temperature. A 22% decrease in the strength of the thermohaline circulation was realized in one model when salt fingers were added to the vertical mixing scheme. Studies in global models with realistic topography and forcing found that double diffusion helps to bring deep temperature and salinity fields into closer agreement with observations. Models also suggest that double diffusion lowers the net interior density diffusivity sufficiently to make the thermohaline circulation more susceptible to collapse. Since collapse of the thermohaline circulation has occurred rapidly in the past, has dramatic impacts on climate, and is predicted to be a possible outcome of future greenhouse warming, it behooves us to seek a better understanding of the double-diffusive mixing processes in the ocean.

See also

Internal Tidal Mixing. Internal Waves. Intrusions. Thermohaline Circulation. Water Types and Water Masses.

Further Reading

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