where κ is the turbulent diffusivity and u is the fluid velocity. The equation appears similar to that of an ideal age tracer (A), governed by

$$\vec{u} \cdot \nabla A = \nabla(\kappa \nabla A) + 1$$

except for the presence of the unsteady (time derivative) term and the last term on the right. The unsteady term arises from the fact that the parent distributions are changing with time, and the age distribution is adjusting accordingly. The last term appears more as a pseudovelocity that is a direct manifestation of the nonlinear mixing behavior exemplified in the two-water-mass thought experiment described earlier. Although the equation appears complex, the key point is that all the terms are observable. That is, given field observations of the tracers, the terms can be computed to within a value of κ. The effects on the shallowest surfaces are small. Analysis of actual distributions within the shallow North Atlantic, for example, shows that deviations from 'ideal' behavior are negligibly small. Moreover, combining the age distributions with other tracers, for example salinity, and with geostrophic constraints, permits the determination of absolute velocities within the main thermocline to a resolution of order $0.1\,\mathrm{cm\,s^{-1}}$.

See also

Elemental Distribution: Overview. Ekman Transport and Pumping. Ocean Subduction. Thermohaline Circulation. Water Types and Water Masses.

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TROPHIC LEVELS

See **FIORDIC ECOSYSTEMS; LARGE MARINE ECOSYSTEMS; MARINE MAMMAL TROPHIC LEVELS AND INTERACTIONS; NETWORK ANALYSIS OF FOOD WEBS; OCEAN GYRE ECOSYSTEMS; POLAR ECOSYSTEMS; UPWELLING ECOSYSTEMS**

TSUNAMIS

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Tsunamis are long-period waves generated primarily by submarine earthquakes. The name comes from a Japanese word meaning 'harbour wave', however, it is now used in the scientific literature to exclusively describe seismic sea waves.

Tectonic activity in the seafloor creates a vertical movement in the seafloor and a resultant vertical movement across a wide area of the sea's surface. This leads to the formation of a train of long-period waves. Periods of over an hour are not uncommon. These waves can travel very large distances from the earthquake's epicenter and, as they near the coast, their amplitude is increased by local topographic features.

Considerable damage to property and loss of life have been recorded as the result of tsunamis. Warning systems have been developed mainly around the Pacific Ocean, where the risk is greatest. Provided the epicenter and the time of occurrence are known good estimations can be made of the time the tsunami will reach coastal areas.

See also

Seismic Structure.

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TURBIDITY CURRENTS

See **NON-ROTATING GRAVITY CURRENTS**

TURBULENCE IN THE BENTHIC BOUNDARY LAYER

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Introduction

Fluids do not slip at solid boundaries. The fluid velocity changes from zero to one that matches the 'far field' in a transition, or boundary, layer where friction and shear (the rate of change of velocity with distance from the boundary) are strong. The thickness of the ocean bottom (benthic) boundary layer is determined by the bottom stress and the rate of rotation of the earth. The benthic boundary layer is usually thin ($O(10\,\mathrm{m})$) compared to typical ocean depths of $\sim 4000\,\mathrm{m}$. However, in coastal regions which are shallow, and where currents and thus friction are relatively strong compared to the deep ocean, the benthic boundary layer may span most of the water column.

The boundary layer can be separated into several layers within which some forces are much stronger than others. Neglect of the weaker forces leads to scaling and parameterization of the flow within each layer. The benthic boundary layer is usually considered to consist of (1) an outer or Ekman layer in which rotation and turbulent friction (Reynolds stress) are important, (2) a very thin ($O\ (10^{-3}\,\mathrm{m})$) viscous layer right next to the boundary where molecular friction is important, and (3) a transitional layer between these, usually called the logarithmic layer, in which turbulent friction is important (**Figure 1**). The pressure gradient is an important force in all three layers. Because the velocity profile within the logarithmic layer must match smoothly with both the Ekman layer above and the viscous layer below, it will be considered last.

The Ekman Layer

Most of the open ocean is essentially frictionless, or geostrophic, and well described by a balance between the Coriolis force which pushes the flow to the right (in the Northern Hemisphere) and the pressure gradient which keeps it from veering (**Figure 2A**). This picture changes as the bottom is approached. Friction acts against the flow and decreases the velocity U. However, the pressure gradient remains and is not completely balanced by the Coriolis force fU. The current backs leftward so that friction, which is directed against the current, establishes a balance of forces in the horizontal plane (**Figure 2B**). Progressively closer to the bottom, the increasing friction slows the flow and brings it to a complete halt right at the bottom