TURBULENT DIFFUSION, ADVECTION, AND WATER STRUCTURE IN THE NORTH INDIAN OCEAN

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ABSTRACT

Contraction of volume that occurs when sea waters mix is shown to be the mechanism which controls density structure at intermediate depths in the North Indian Ocean.

This is the main result of a study in which mean annual distributions of temperature, salinity, dissolved oxygen, and density in the North Indian Ocean are considered to represent a steady state, and delineation of the significant physical processes responsible for the distributions is attempted.

Strong lateral mixing is evident, but cannot be accounted for by current shear in the mean annual pattern of geostrophic flow. At the density of the Red Sea salinity maximum in the Arabian Sea (700 m depth) there are monsoonal variations, with typical current speeds of 10 cm s^{-1}, which result in intensive lateral mixing. The horizontal coefficient of eddy diffusivity is 7×10^7 cm^2 s^{-1} for mixing at a length scale of 200 km, or 3×10^8 cm^2 s^{-1} for a length scale of 1000 km.

Considerations of the conservation of heat and salt lead to definition of three depth zones: a layer of uniform vertical advection, deeper than 1700 m; a layer of

constant vertical diffusive flux from 400 to 1200 m depth; and an intermediate transition zone.

In the deep zone of uniform vertical advection, the water properties are exponential functions of depth. The vertical exchange coefficient has the constant value 2.5 $cm^2\ s^{-1}$. Ascending motion of 4×10^{-5} $cm\ s^{-1}$ occurs from 3000 m depth in the Arabian Sea, and from 2100 m depth in the Bay of Bengal, and near the equator. The upward transport of $4 \times 10^6\ m^3\ s^{-1}$ is supplied by northerly flow at depths 2000 m and greater. Near 2500 m depth, North Atlantic Deep Water probably penetrates northward to the equator in the western North Indian Ocean, and to the head of the Bay of Bengal in the east. At the equator, maximum southward return flow of speed 0.2 $cm\ s^{-1}$ occurs near 1000 m depth, within the zone of constant vertical diffusive flux.

In the layer of constant diffusive flux, which is uniformly turbulent with r.m.s. turbulent velocity 10^{-2} $cm\ s^{-1}$, the mean distribution of density is a linear function of the logarithm of depth. However, temperature and salinity are not similarly distributed in this logarithmic zone. Both the mixing length and the vertical exchange coefficient increase directly with the depth. The vertical exchange coefficient ranges from 8 $cm^2\ s^{-1}$ at 400 m to 24 $cm^2\ s^{-1}$ at 1200 m depth. The uniform downward mass flux is $1.2 \times 10^{-7}\ g\ cm^{-2}\ s^{-1}$.

Increase of mixing with depth in the logarithmic zone is due to contraction of volume during mixing. Between 800 and 1400 m depth, vertical mixing increases density faster than lateral mixing. Near 600 m, lateral mixing is most significant, consistent with the fact that, at that depth gradients of temperature and salinity are those for which maximum contraction occurs during lateral mixing. Neutral stability to vertical mixing exists only in the Gulf of Aden, which is the source region for logarithmic structure, and from which the structure is propagated laterally. The southward flow in the logarithmic zone maintains continuity of mass, offsetting density increases due to contraction on mixing.

Contraction on mixing accounts for the observed increase of density in the direction of flow in the oxygen minimum and Red Sea Water core layers in the North Indian Ocean.