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A comparative study of vertical stabilities in the Arabian Sea and Bay of Bengal

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ABSTRACT. Stabilities in the upper 300 m in the Arabian Sea and the Bay of Bengal are computed and presented seasonwise. The water column in the Bay of Bengal is more strongly stratified than that in the Arabian Sea. These studies suggest that the vertical transfer of subsurface nutrients into the surface layer in the Bay of Bengal is greatly inhibited.

1. Introduction

The vertical distribution of any property is the result of turbulent diffusion and the vertical component of the mean current velocities. Vertical mixing envisages transfer of properties without any net vertical transport of water and depends upon the stratification of the water column and the vertical shear of the horizontal current. Several investigators have tried to relate the Richardson number (ratio of the Sverdrup-Hesselberg's stability and the square of the vertical shear of the horizontal current) to the eddy diffusion coefficient. However, no definite relationship between Richardson number and the vertical coefficient of eddy diffusion could be fully established. Studies by Kolesnikev *et al.* (1961) in Atlantic Ocean indicate that in spite of the seasonal differences, the change in coefficient of turbulent diffusion shows an overall regularity which is determined by the effect of stability. Thus, a knowledge of the stability distribution will indicate quantitatively the characteristics of vertical transfer. In this paper, the authors present a comparative study of the stability in the upper 300 m in the Arabian Sea and the Bay of Bengal and thereby discuss the relative transfer of nutrients from the subsurface layers to the surface layers in these two water bodies.

2. Data and analysis

The stability of the water column is generally computed using the formula given by Hesselberg and Sverdrup (1914-15):

$$E = \frac{\partial \rho}{\partial s}\frac{ds}{dz} + \frac{\partial \rho}{\partial T}\left(\frac{dT}{dz} - \frac{d\theta}{dz}\right) \qquad (1)$$

The contribution to 'E' due to change in salinity 's' is given by the 1st term and that due to temperature 'T' is given by the 2nd term on the RHS of the Eqn. (1). ρ, θ and z are respectively the density, potential temperature and depth.

Since our primary interest is a comparison of the stabilities in the upper 300 m, stability is computed using the simplified formula given by Sverdrup *et al.* (1942) :

$$E = 10^{-3}\,(d\sigma_t/dz) \qquad (2)$$

where 'E' is the stability expressed in 10^6 CGS units, density is expressed in terms of sigma-T and z is the depth in metres.

This formula is sufficiently accurate within 1 per cent in the upper layers.

The hydrographic data available at the Data Centre of the National Institute of Oceanography for the Arabian Sea and the Bay of Bengal

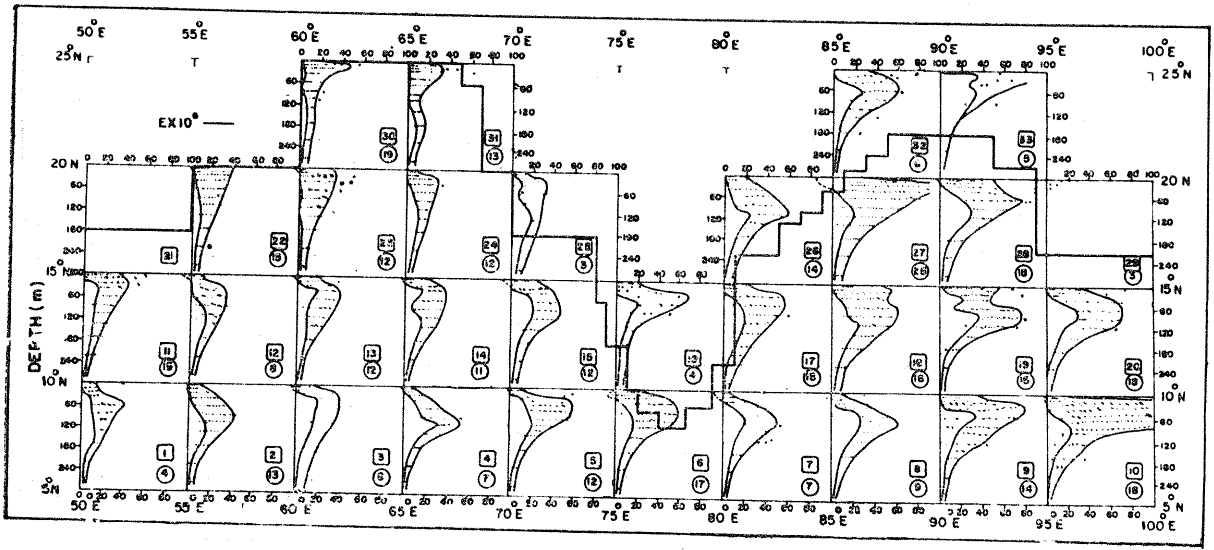

Fig. 1. Distribution of stability in the upper 300 m (March, April and May).

have been pooled seasonwise for each 5 deg. square for the areas north of 5 deg. N. The seasons adopted are :

(*i*) Summer or hot weather season— March, April and May,

(*ii*) Southwest monsoon season — June, July and August,

(*iii*) Post monsoon season — September, October and November and

(*iv*) Northeast monsoon or winter monsoon — December, January and February.

Figs. 1-4 represent the distribution of stabilities in the Arabian Sea and Bay of Bengal. The numbers in the circles indicate the total number of hydrographic stations available in each grid while the numbers in the squares indicate the grid number. The dots in figures represent the stability values at the corresponding depth. Where there are considerable amount of data in any grid, boundaries enveloping the stability pattern have been drawn. When data at a few stations are available in any grid, a mean depth-salinity curve has been drawn. Instabilities, if any, are shown by crosses in the left adjoining square. When the stabilities exceed 100 × 10^6 CGS units, they are represented by arrows at the corresponding depths and their magnitudes are marked along the arrow.

For the purposes of comparison, the two water bodies are divided into four zones:

(*i*) the western regions comprising of grids, 1, 11, 21 and 22 in the Arabian Sea and 6, 7, 16, 17 and 26 in the Bay of Bengal,

(*ii*) the central regions comprising of grids 2, 3, 4, 12, 13 and 14 in the Arabian Sea and 8, 9, 18 and 19 in the Bay of Bengal,

(*iii*) the eastern regions comprising of grids 5, 15 and 25 in the Arabian Sea and 10, 20 and 29 in the Bay of Bengal, and

(*iv*) the northern regions comprising of grids 23, 24, 30 and 31 in the Arabian Sea and 27, 28, 32 and 33 in the Bay of Bengal.

The above classification is based on the similarity of locations of these regions in respect of the land boundaries.

3. Results and discussion

3.1. *Hot weather season*

Fig. 1 shows the vertical distribution of stability during the hot weather season in the Arabian Sea and Bay of Bengal. In the Arabian Sea, the maximum stabilities tend to decrease from south to north. This pattern is in consonance with the meridional variation of temperature gradients in the thermocline (Sastry and D'Souza 1970). According to these authors, the maximum temperature gradients occur at about 7 deg. N and thereafter, the gradients in the thermocline decrease northwards. Except in the easternmost regions of the Arabian Sea, the maximum stabilities to not exceed 40 CGS units.

In the Bay of Bengal, north of 5 deg. N, the stabilities in the mixed layer show a general increase eastwards. A sharp stability maximum zone is seen in the western Bay, whereas, in the central regions, the maximum zone spreads over a greater depth range. During this season, fresh

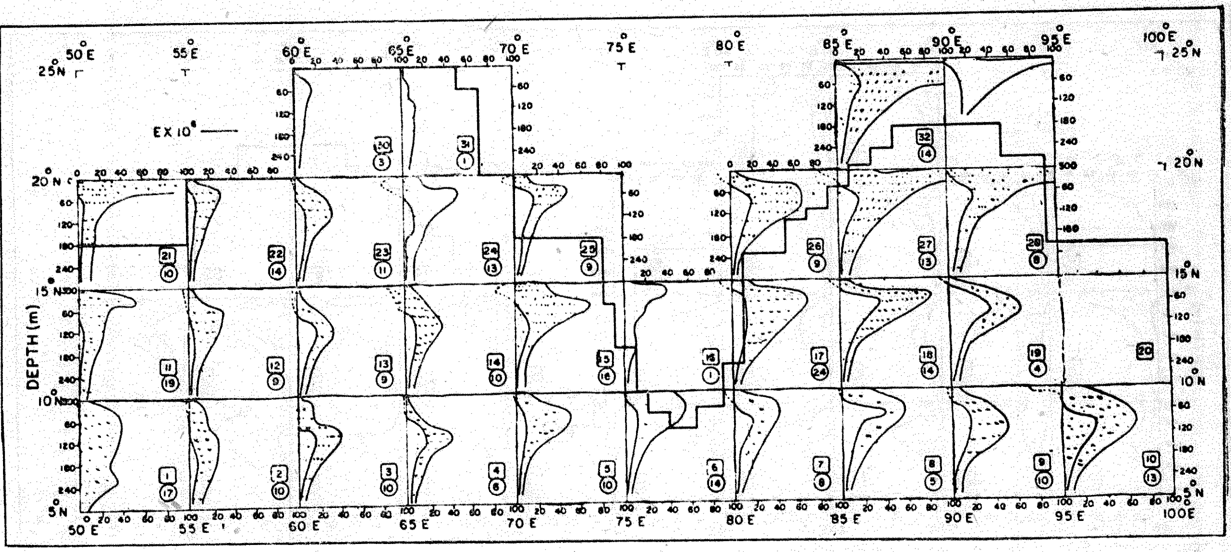

Fig. 2, Distribution of stability in the upper 300 m (June, July and August)

water discharges are negligible into the Bay except in the southeastern regions. The higher stabilities in these regions (grid 10) near the sea surface seem to be the result of this. The maximum stratification shows a slight increase towards north. The degree of stratification averages to around 50 CGS units in the western Bay of Bengal and 60-70 CGS units in the central regions and more than 70 CGS units in the eastern regions. In some of the grids (27, 32 and 33), the stratification exceeds even 100. CGS units in the upper few metres. This type of zonal variation in the stability pattern is not seen in the Arabian Sea. In general, it is seen that the degree of stratification is far less in the Arabian Sea than in the Bay of Bengal as a whole.

3.2. *Southwest monsoon season*

The stability distribution in the Arabian Sea and the Bay of Bengal are presented in Fig. 2 for the southwest monsoon season. During this season, the winds as well as the current patterns undergo marked variation from that of the earlier season. Heavy rainfall over the Indian subcontinent and consequent dilution by fresh water discharges after the stability distribution in these two water bodies.

In the western Arabian Sea, along the African coast, the Somali current develops and intense upwelling is associated with this current. As a consequence, the thermocline reaches the surface layers and strong gradients in temperature are seen close to the sea surface and the stability pattern shows a greater depth range of maximum stability during this season (as seen in grid 1). Similarly, off the Arabian coast, intense upwelling gives rise to fairly high values of stability close to the surface (grid 21). However, in these regions, because of strong upwelling, upward transfer of nutrients is considerable by advective processes and this upwelled water, containing higher concentration of nutrients spreads over the sea surface giving rise to higher concentrations. The very high values of vertical shear in the Somali current region (Swallow and Bruce 1966) also aid the transfer of subsurface nutrients by vertical diffusion processes.

In the central Arabian Sea, the zone of stability maximum appears to shift deeper during the southwest monsoon season, even though, the stabilities over most of the region are of the same order as those in the previous season. The lowering of the zone of maximum stability is due to the development of the surface layer caused by intense wind action as well as due to convergences in the field of motion (grids 2, 3, 4, 12, 13 and 14). Along the west coast of India, the zone of stability maximum shows an increase from that of the earlier season. The heavy land drainage during southwest monsoon period coupled with the divergence due to southerly flow might increase the stabilities in this area, especially along southwest coast of India.

In the western Bay of Bengal, along the east coast of India, the zone of higher stabilities are seen (grids 17 and 26) because of dilution due

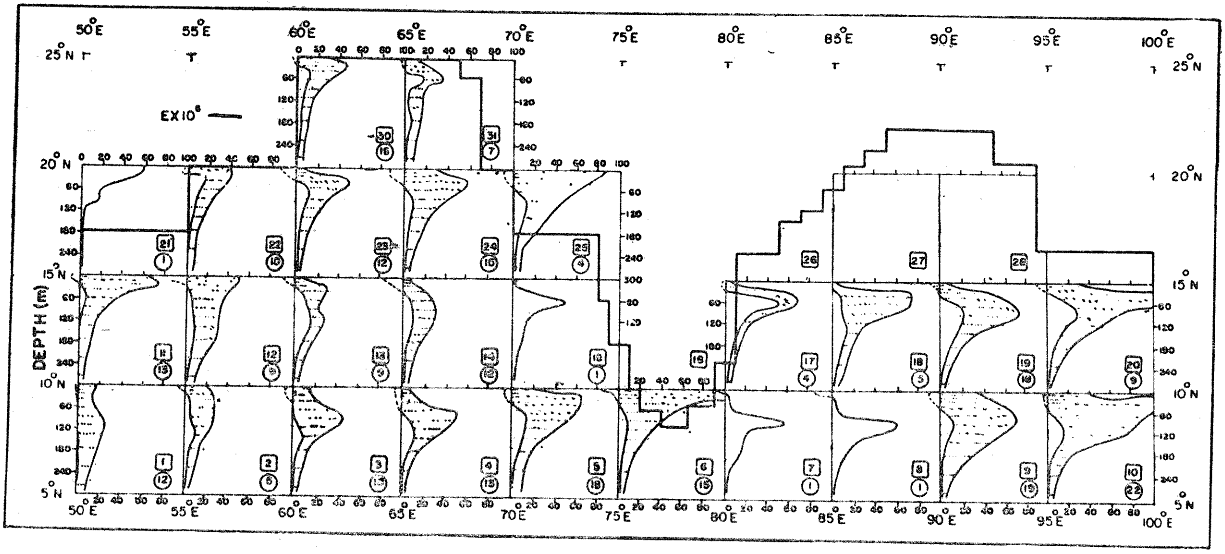

Fig. 3. Distribution of stability in the upper 300 m (September, October and November)

to river discharges. Wind induced upwelling is of a limited extent in the area during this season (Panakala Rao 1977 and Panakala Rao & Sastry 1980). The transfer of subsurface nutrients is primarily governed by the vertical diffusion processes. In the central Bay, especially in grids 18 and 27, the maximum stability increases considerably. Further east, the maximum stability tends to decrease slightly. No data were available adjoining the Burma coast except in grid 10 for this season. Adjoining Sumatra, relatively lower stabilities are found. The data collected on board *Gaveshani* in August 1976 indicate very high stabilities near the sea surface in the northern Bay. This feature is clearly due to heavy run off from the *Ganges* and *Brahmaputra* river systems following heavy precipitation in the catchment areas.

A comparison of the stabilities in both the water bodies indicate that the stratification is more in the Bay of Bengal than in the Arabian Sea, leaving the zones of intense upwelling along African and Arabian coasts.

3.3. *Post monsoon season*

By this season, the southwest monsoon retreats and the winds are variable. There would be change in the associated current pattern in both the water bodies. However, during September and October, there could be considerable run off into the Bay of Bengal. The Somali current weakens by September and when this season is fully established, a weak southerly current off the African coast is sometimes reported (Bruce 1968). As a consequence, the stability over the entire water column in grid 1 decreases (Fig. 3). In general, the stabilities are less and the distribution returns to that of summer season. Along the east coast of India, the zone of stability maximum sharpens over that of the previous season with a decrease in the thickness of the maximum stability layer.

In the central regions, the stability pattern remains almost the same as that of southwest monsoon season. Except in the southern-most grid (grid 6) where the maximum stability exceeds 100 CGS units, the stability decreases considerably along the west coast of India. The increased stability in this region might be the result of prevailing land drainage subsequent to the southwest monsoon. In the eastern Bay, the stabilities increase to more than 100 CGS units.

In the northern region of the Arabian Sea, the stability values are low and range between 40-50 CGS units. In the Bay of Bengal, no data are available in the northern region. However, the environmental features suggest that higher stabilities probably prevail in the upper 100-150 m during this season.

3.4. *Northeast monsoon season*

During this season, fresh water discharges into these water bodies are very much reduced. The surface salinity shows a marked increase in the Bay of Bengal.

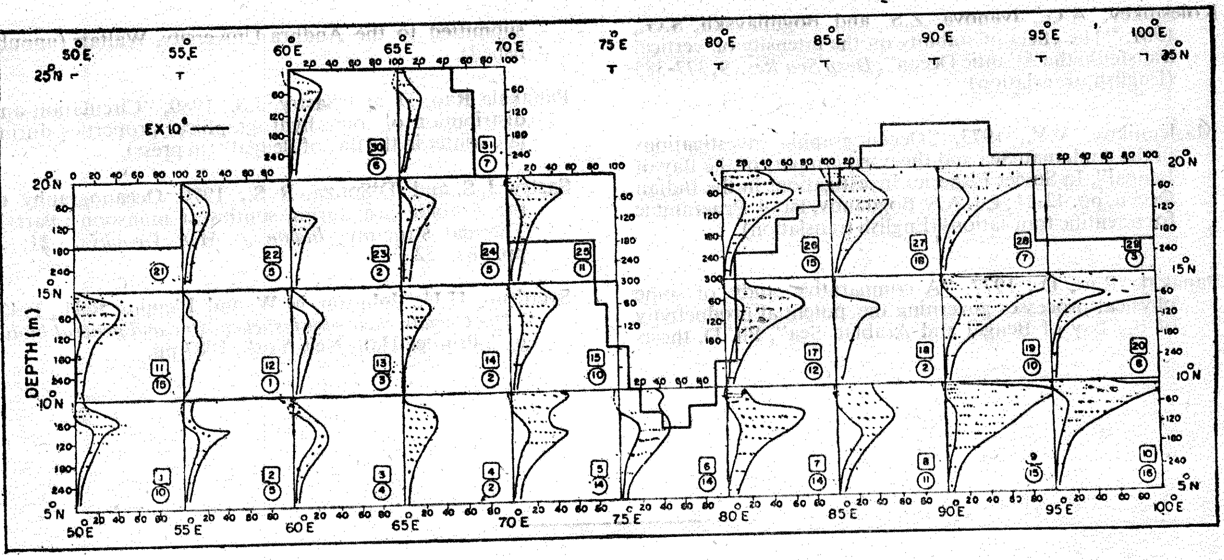

Fig. 4. Distribution of stability in the upper 300 m (December, January and February)

The data coverage in the Arabian Sea is very poor (Fig. 4). The available data shows that the pattern of stratification is similar to that during the hot weather season over the entire Arabian Sea. In the Bay of Bengal, the stabilities are high in the eastern and southern Bay and at the Head of the Bay. In the eastern regions, the stratification exceeds 100 CGS units. The stratification in the western Bay shows a slight increase than that of the hot weather season.

Thus, the distribution of stability with depth shows a normal pattern, generally found in the tropical latitudes. Within the surface layer, the stability, in general, is either uniform or shows a slight increase in the first few metres and with further increase in depth, a zone of maximum stability coinciding with the mass discontinuity layer is seen. Below these maximum stabilities, it decreases to about 10 CGS units at depths of about 300 m. However, in the upper 150 m or so, the degree of stratification shows considerable variation in both the water bodies. Throughout the year, the water column is strongly stratified in the mass discontinuity layer in all the regions in the Bay of Bengal, compared to the corresponding regions in the Arabain Sea. The thickness of the stratified layer is also greater in the Bay of Bengal. These features suggest that the vertical transfer of nutrients from the subsurface layers would be comparably less in the Bay of Bengal than in the Arabian Sea. A comparison of studies by Elizarov (1973) in the Arabian Sea and Malennikov (1973) in the Bay of Bengal and Andaman Sea also confirm that the stabilities in the Bay of Bengal and Andaman Sea are much higher than those in the Arabian Sea which are in good agreement.

4. Summary and conclusions

The general distribution of vertical stabilities in the Arabian Sea and Bay of Bengal shows a normal distribution pattern found in the tropical latitudes. The zone of maximum stability coincides with the mass discontinuity layer. At about 150 m, the degree of stratification shows considerable variation. The Bay of Bengal is more strongly stratified than the Arabian Sea suggesting that the vertical transfer processes would be comparatively less in the Bay of Bengal than in the Arabian Sea.

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