

Hydrographic Characteristics of Central Bay of Bengal Waters during Southwest Monsoon of 1983

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During cruises 120 and 124 of *R V Gaveshani* two sections, viz. Visakhapatnam – Port Blair and Madras – Port Blair, in Bay of Bengal have been covered twice. The sea surface temperature (SST) shows a decrease of about 2°C from premonsoon to postmonsoon. The loss of energy from the sea surface to the atmosphere by evaporational cooling due to strong monsoonal winds and reduction in the incoming solar radiation by clouds may result in a net loss of energy (cooling). During premonsoon the isotherms off Visakhapatnam show an upward slope towards the coast resulting from the Ekman drift, forcing the cooler denser subsurface water to come up under a northerly flow. However, the isothermal pattern during postmonsoon reveals the possibility of a thermal adjustment within the water column by way of advection as manifested by stretching of isotherms. Distribution of relative velocities along the sections indicates the presence of gyres (zones of convergence and divergence). There appears a remarkable variation of these gyral systems from premonsoon to postmonsoon.

Bay of Bengal is characterised by the periodic (cyclic) wind systems. The complex current patterns associated with these reversing wind systems and the immense river run off influence the hydrographic parameters¹. The present study aims at understanding the general distribution of oceanographic parameters and their variability in the central Bay of Bengal, which provide the baseline information to meet the requirement of an operational acoustic tomographic system (OATS)².

Material and Methods

Data collected during 2 cruises of *R V Gaveshani* in the Bay of Bengal during premonsoon (May 24–June 6) and postmonsoon (September 12–October 8) of 1983 (Fig. 1) were used. Data were processed to obtain corrected values of depth, temperature and salinity. Using a comprehensive computer program³ various physical parameters were computed. These parameters included sigma-T, sigma S, T, P, potential temperature, potential sigma, density flux function^{4,5}, thermocline anomaly, specific volume anomaly, sound velocity, stability, Brunt Vaisala frequency, Richardson number, dynamic heights, geostrophic currents and potential vorticity. Relative velocities were computed following geostrophic method⁶. The potential vorticity which is a good indicator of large-scale circulation⁷ was computed.

Results

Premonsoon Period

Temperature (Fig. 2)—Sea surface temperature varies between 30.94°C (st 2737) and 29.77°C (st 2755). The depth of the isothermal layer ranges from ~60 m at st 2758 to ~10 m at st 2750. The isotherms in the thermocline show an upward tilt of about 80 m near Visakhapatnam. The contours are smooth and widely spaced towards the eastern side. Temperature decreases gradually below the thermocline and spatial variations below 1000 m are very small.

Salinity (Fig. 3)—Surface salinity ranges from 34.27×10^{-3} (st 2762) to 32.49×10^{-3} (st 2754). The depth of occurrence of 34×10^{-3} isohaline along track 1 shows maximum variations in depths 0–85 m. A high salinity band (salinity $> 35 \times 10^{-3}$; shown by hatched area) has been observed in the depth range and its thickness varies from ~200 m at st 2759 to ~900 m at st 2757. Near Andaman islands salinity profile showed values $< 35 \times 10^{-3}$.

Thermocline anomaly (Fig. 4)—The general pattern of the isanosters is very much similar to that of the isotherms. The values at the surface range from slightly $< 700 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$ along the western side to slightly $> 800 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$ to the eastern margin. The contours show an upward tilt similar to that of temperature off Visa-

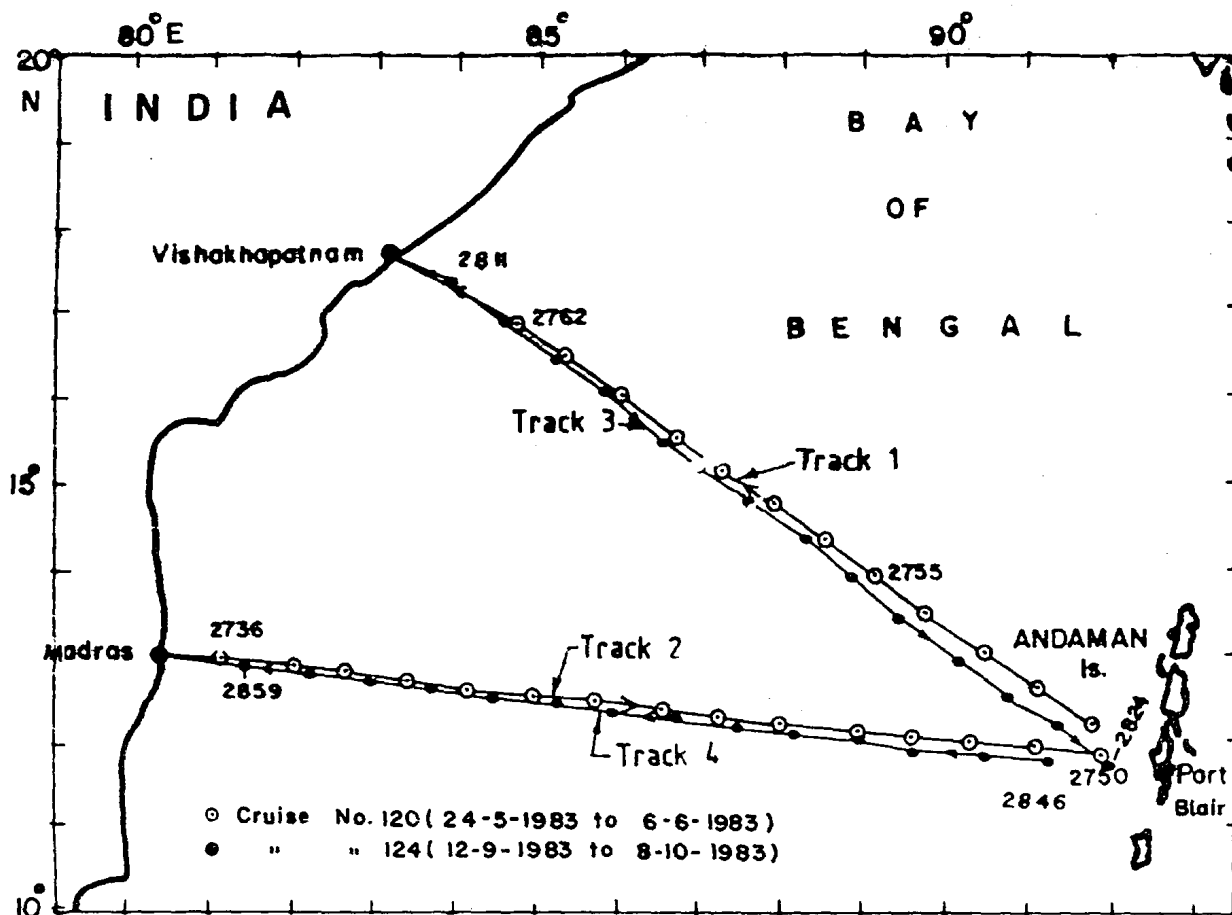


Fig. 1 - Location of stations.

khapatnam while they are gently oscillatory and uniformly spaced towards the eastern end. Below 400 m the contours are smooth and straight along both the sections with gradual decrease except at st 2754 where the $40 \times 10^{-8} \text{m}^3 \text{kg}^{-1}$ contour shows a downward tilt.

Superimposed on the isanosters are contours of density flux function. In the upper 150 m vertical mixing is predominant as seen by the distribution of density flux lines which cross the isosteric surfaces. However, below 100 m they are parallel to the isosters indicating the predominance of horizontal mixing.

Relative velocities (Fig. 5) - For estimating these 1000 m depth surface has been chosen to be the level of least motion. The resulting velocity pattern shows alternate bands of northerlies (northeasterlies)/southerlies/(southwesterlies). Along track 1, maximum northeasterly currents are found between st 2760 and st 2759. Strong southwesterlies are noticed between st 2758 and st 2757. Below 300 m, the magnitudes of the currents are $< 20 \text{ cm. sec}^{-1}$. Along track 2 also alt-

ernate bands are noticed (strong northerly current between st 2738 and st 2739 and strong southerly current between st 2742 and st 2743).

Potential vorticity (Fig. 6) - Potential vorticity ($10^{-11} \text{m}^{-1} \text{sec}^{-1}$) along Visakhapatnam - Port Blair and Madras - Port Blair sections for the premonsoon are plotted against potential density σ_θ (in kg.m^{-3}). Zones of maximum potential vorticity between sts 2762 and 2761 (values higher than $600 \times 10^{-11} \text{m}^{-1} \text{sec}^{-1}$) and between st 2755 and 2754 (values higher than $300 \times 10^{-11} \text{m}^{-1} \text{sec}^{-1}$) on potential density surface at 22.5 kg.m^{-3} indicate zones of strong convergence of isopycnals. Between these two convergence zones, there appears a divergent zone at potential density 23.5 kg.m^{-3} , at st 2757. Fig. 6 also shows a region of inclined isotrophes which are near $\sigma_\theta = 20 \text{ kg.m}^{-3}$ to the east (at the right side of the figure) and deepening to $\sigma_\theta = 21.5 \text{ kg.m}^{-3}$ in the west.

Postmonsoon Period

Temperature (Fig. 2) - SSTs vary between

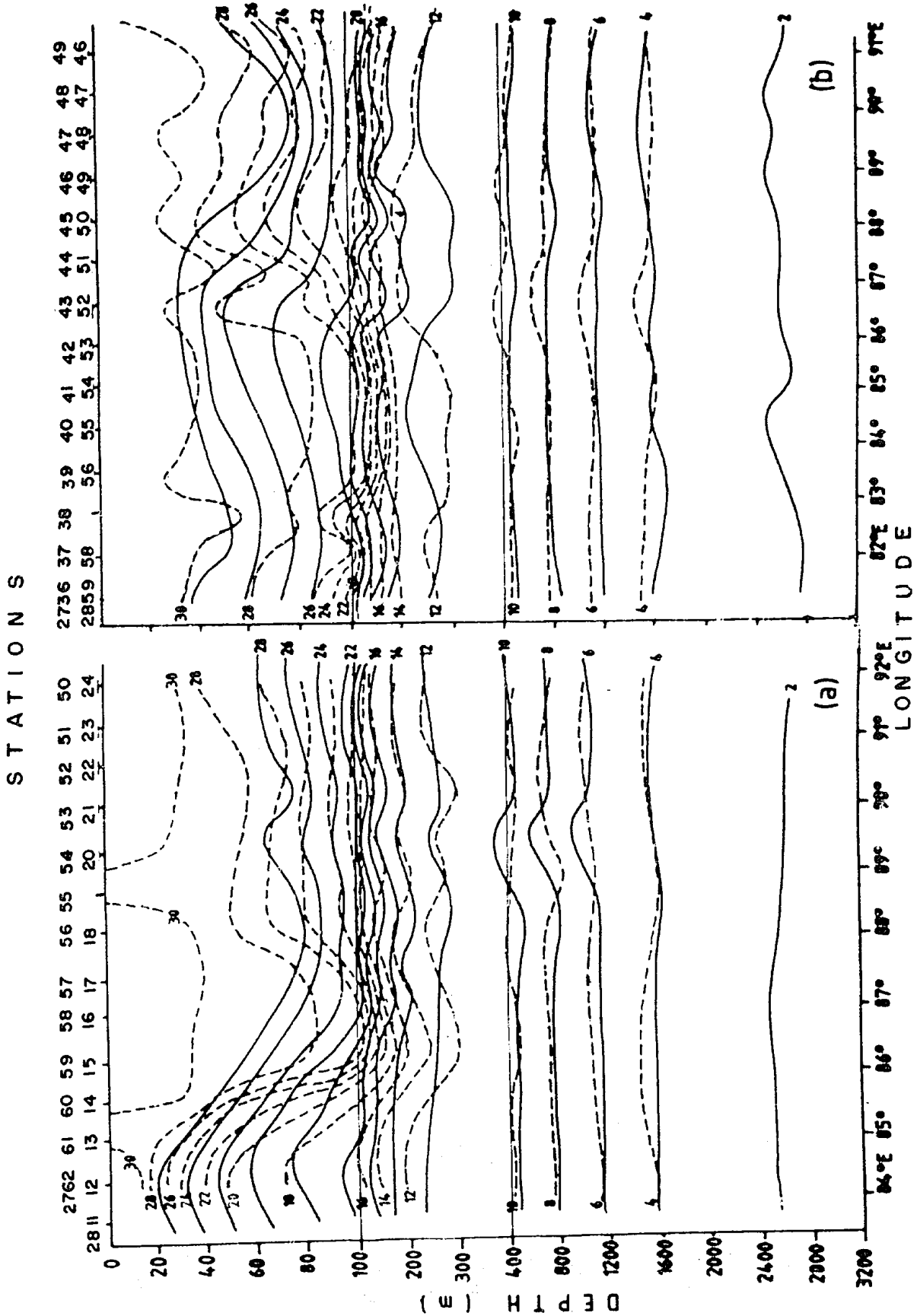


Fig. 2 - Vertical cross-section of temperature during premonsoon (---) and postmonsoon (—) along Visakhapatnam-Port Blair (a) and Madras - Port Blair (b) sections.

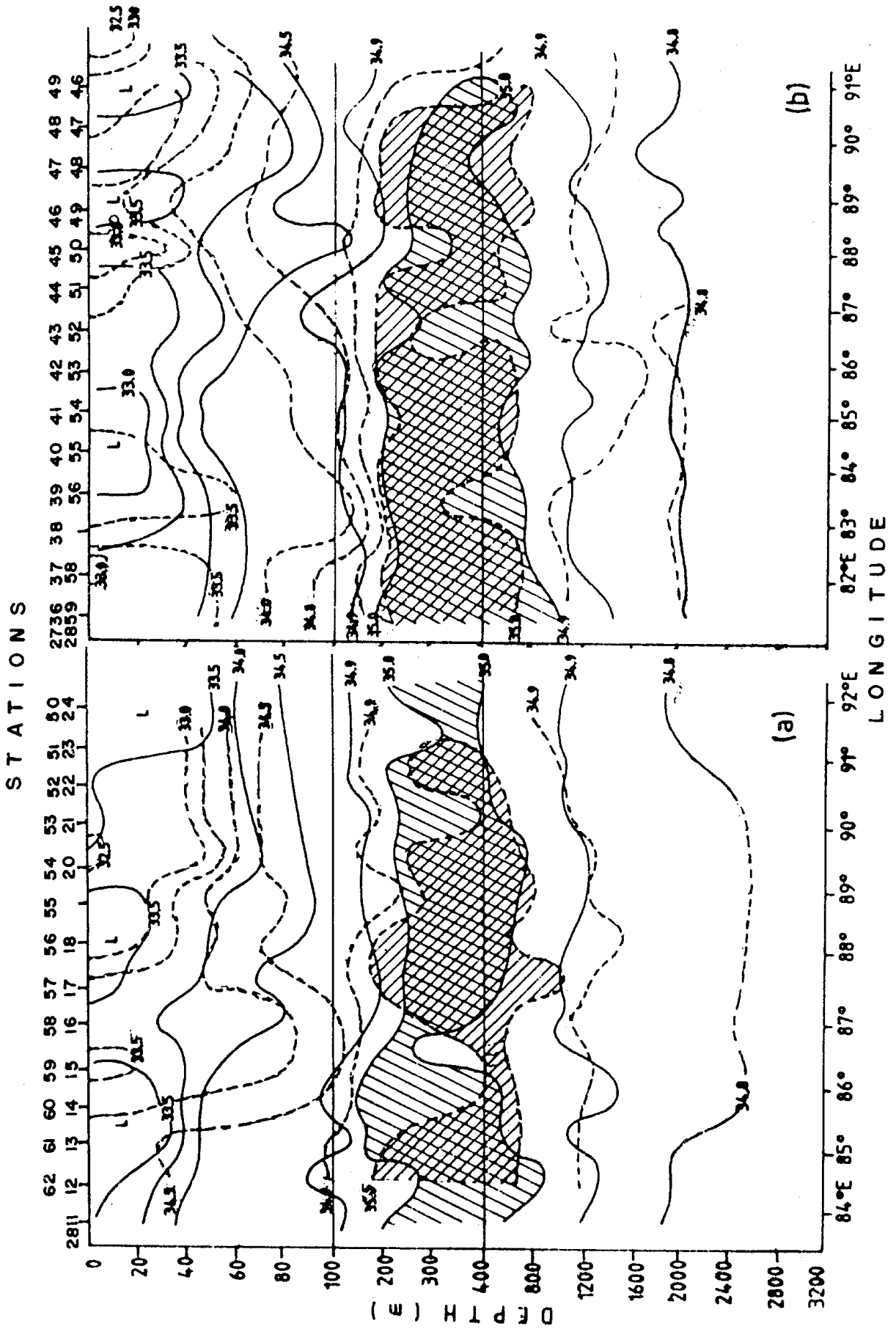


Fig. 3—Vertical cross-section of salinity during premonsoon (---) and postmonsoon (—) along Visakhapatnam - Port Blair (a) and Madras - Port Blair (b) sections

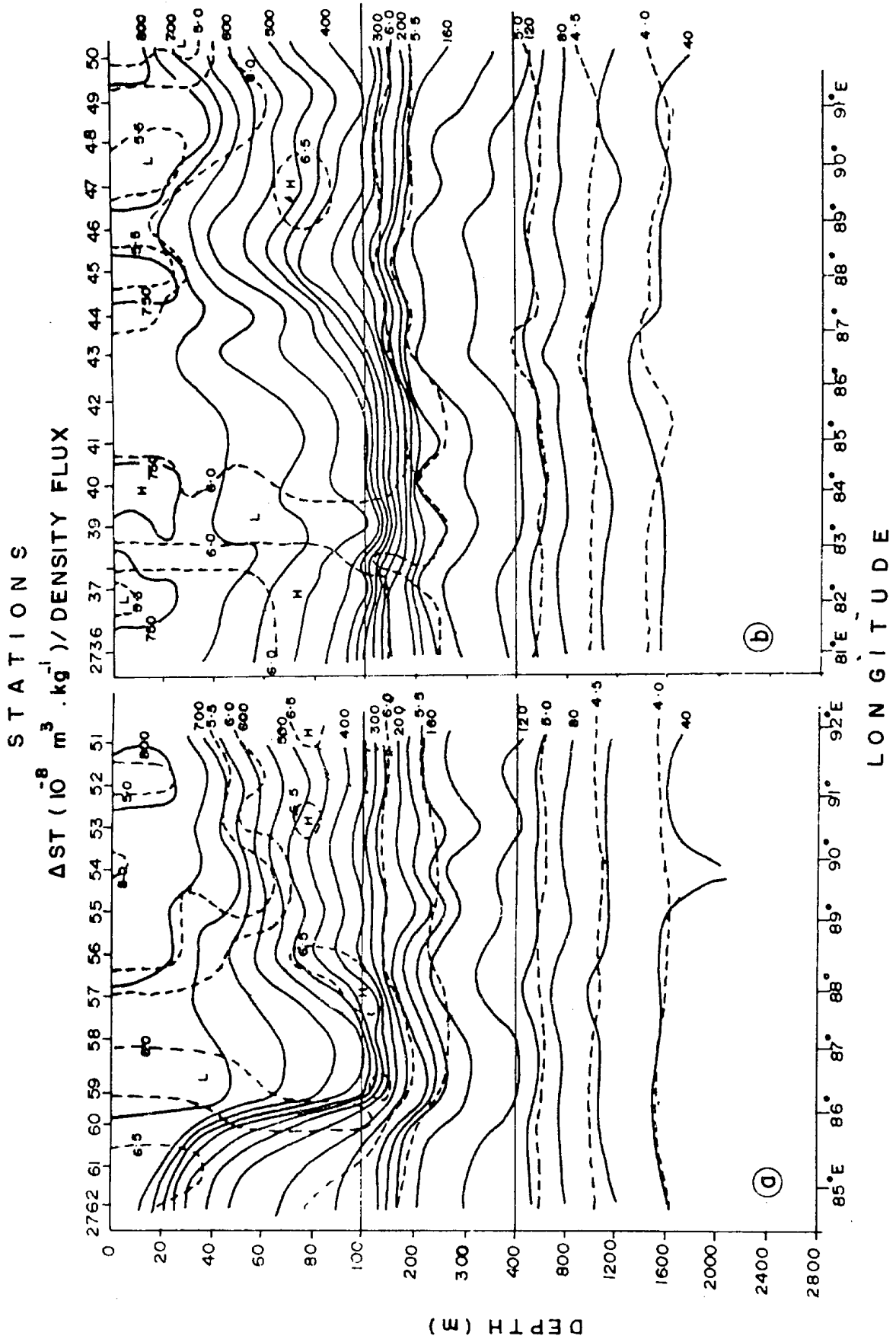


Fig. 4 -- Vertical cross-section of thermocline anomaly (—) and density flux function (---) during premonsoon period along (a) Visakhapatnam - Port Blair and (b) Madras - Port Blair sections

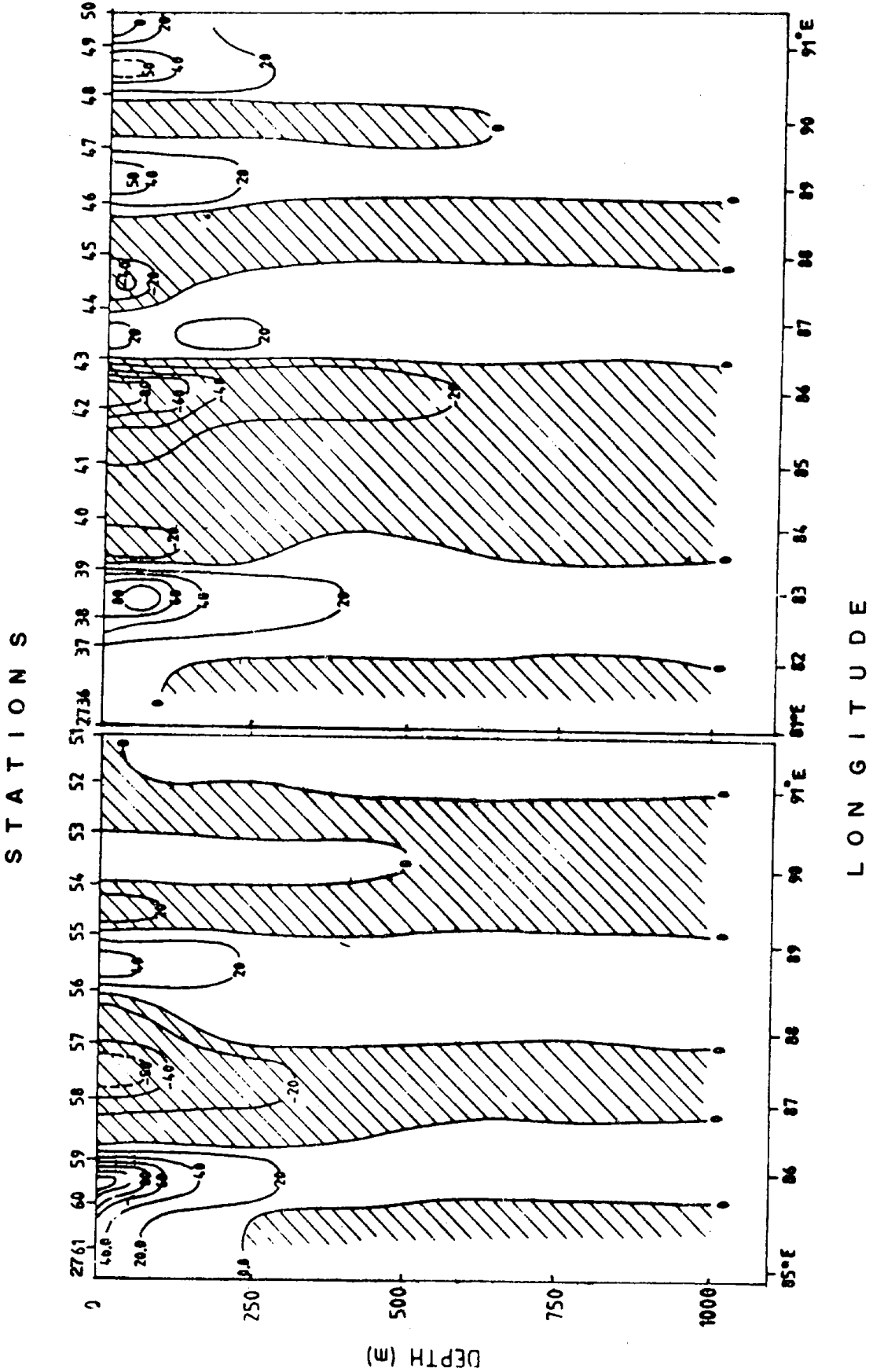


Fig. 5 - Vertical cross-section of relative velocities during premonsoon along (a) Visakhapatnam - Port Blair and (b) Madras - Port Blair sections (Shaded areas = southerly currents and non-shaded areas = northerly currents)

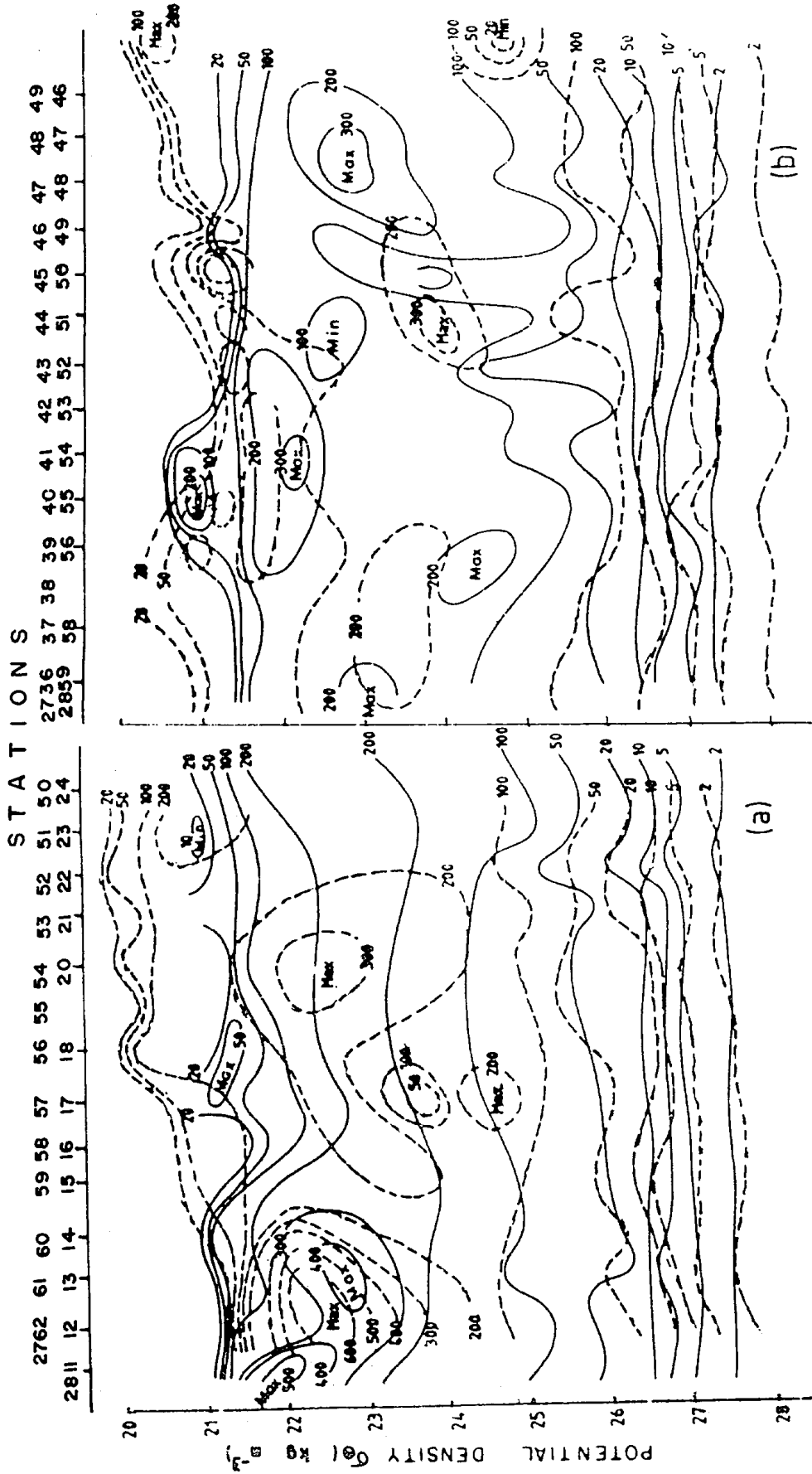


Fig. 6 - Potential vorticity vs Potential density during premonsoon (—) and postmonsoon (---) along (a) Visakhapatnam - Port Blair and (b) Madras - Port Blair sections

28.83°C (st 2824) and 28.29°C (st 2812). The depth of the isothermal layer ranges from ~80 m at st 2818 to ~20 m at st 2812. The isotherms in the thermocline show an upward tilt of ~50 m near Visakhapatnam as compared to 80 m during premonsoon period. Temperature decreases gradually below the thermocline along both the tracks.

Salinity (Fig. 3)—Surface salinity ranges from 33.84×10^{-3} at st 2816 to 32.64×10^{-3} at st 2854. In general, along both the tracks, the 33×10^{-3} isohaline shows a downward slope from west to east. The saline layer ($> 35 \times 10^{-3}$) occurs between 150 and 1000 m with its thickness varying considerably over the tracks. Near Andaman region salinity structure is more or less similar to that of premonsoon season.

Thermosteric anomaly (Fig. 7)—At the surface, values range from $\sim 650 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$ along the western Bay to slightly $\sim 700 \times 10^{-8} \cdot \text{m}^3 \cdot \text{kg}^{-1}$ on the eastern side. The isosters near Visakhapatnam show an upward tilt similar to that of premonsoon. The depth of occurrence of $400 \times 10^{-8} \text{m}^3 \cdot \text{kg}^{-1}$ contour shows a wide range which ranges from ~50 at st 2812 to ~110 m at st 2818. The density flux function shown in the same diagram intercepts the thermosteric surfaces in the upper 150 m indicating the predominance of vertical mixing.

Relative velocity (Fig. 8)—Along track 3 maximum NE-component is found between sts 2812 and -13, st 2814 and -15 and st 1817 and -18 while SW- component is predominant between sts 2821 and -22. Along track 4 maximum northerly components are noticed between sts 2853-52 and sts 2851-50 while southerly components are found to prevail between sts 2858-57 and sts 2850-49.

Potential vorticity (Fig. 6)—The main feature in the distribution of potential vorticity such as zones of maxima are similar to those found during the premonsoon although the magnitudes are time dependent.

Discussion

In the central Bay of Bengal, before the onset of the SW monsoon SST values reach as high as 31°C but with the onset there is a sudden fall of 2°C. This may be due to the loss of energy from the sea surface to the atmosphere by evaporational cooling (due to strong monsoonal winds) and reduction in the incoming solar radiation by clouds resulting in a net loss of energy (cooling) from the sea surface⁷. The depth of the mixed layer increases from premonsoon to postmonsoon. The isotherms show an upward tilting off Visakhapat-

nam which is probably due to Ekman drift forcing the cooler, denser subsurface water to come up under a northerly flow. This in turn results in the formation of zones of convergence followed on either side by divergence. However, during monsoon thermal adjustment takes place within the water column through advection as could be seen from stretching of the isotherms (Fig. 2). Beyond 250 m, thermal structure remains more or less same during both the seasons indicating that the effect of atmospheric forcing can be expressed in very small variations in deeper layers. This reflects that Bay of Bengal is highly stratified which can be visualised as a 2 layered system.

Comparison of surface salinity values with geostrophic current directions indicates that along track 1, NE current flow between st 2762 and 2759 (Fig. 5a) which compares well with relatively higher salinities ($> 34 \times 10^{-3}$) while at st 2754 low salinity ($< 32.5 \times 10^{-3}$) compares well with SW flow between st 2755 and 2754 (Fig. 3a) since high salinities are expected in a N/NE flow and vice versa. East of st 2755 the flow is mainly NE and is well indicated by the low salinity values. Along track 2, a strong southerly flow between sts 2738 and 2739 (Fig. 5b) compares well with higher salinity at st 2738 (Fig. 3b).

During postmonsoon, flow is SW between sts 2811 and 2815 and the salinities are $< 33.5 \times 10^{-3}$ indicating the decrease in salinity from premonsoon due to river discharges along the east coast. East of st 2820 flow is northerly, and the current speeds are $\sim 39 \text{cm} \cdot \text{sec}^{-1}$ at st 2821. The lower values of current speeds during later half of September compared to values during first week of June might indicate the withdrawal phase of SW monsoon. Along Madras – Port Blair section during postmonsoon flow is northerly between st 2858 and st 2856 where speeds are $\sim 23 \text{cm} \cdot \text{sec}^{-1}$. The lower values of salinity between sts 2856 and 2854 are $< 33 \times 10^{-3}$ and the flow is southerly. East of st 2850 flow is again northerly except between sts 2849 and 2848.

During premonsoon, the geostrophic circulation, revealed by dynamic topography of the geopotential surfaces, shows the existence of a prominent anticyclonic gyre extending from south to north with its axis almost parallel to the coast. A strong cyclonic gyre exists towards the coast off Visakhapatnam at the northern edge of the gyre. Towards the eastern part of Bay of Bengal, alternate bands of weak cyclonic and anticyclonic cells are noticed. Under the influence of these gyres, warm saline (denser) waters are brought from the southern latitudes to the central bay by the anti-

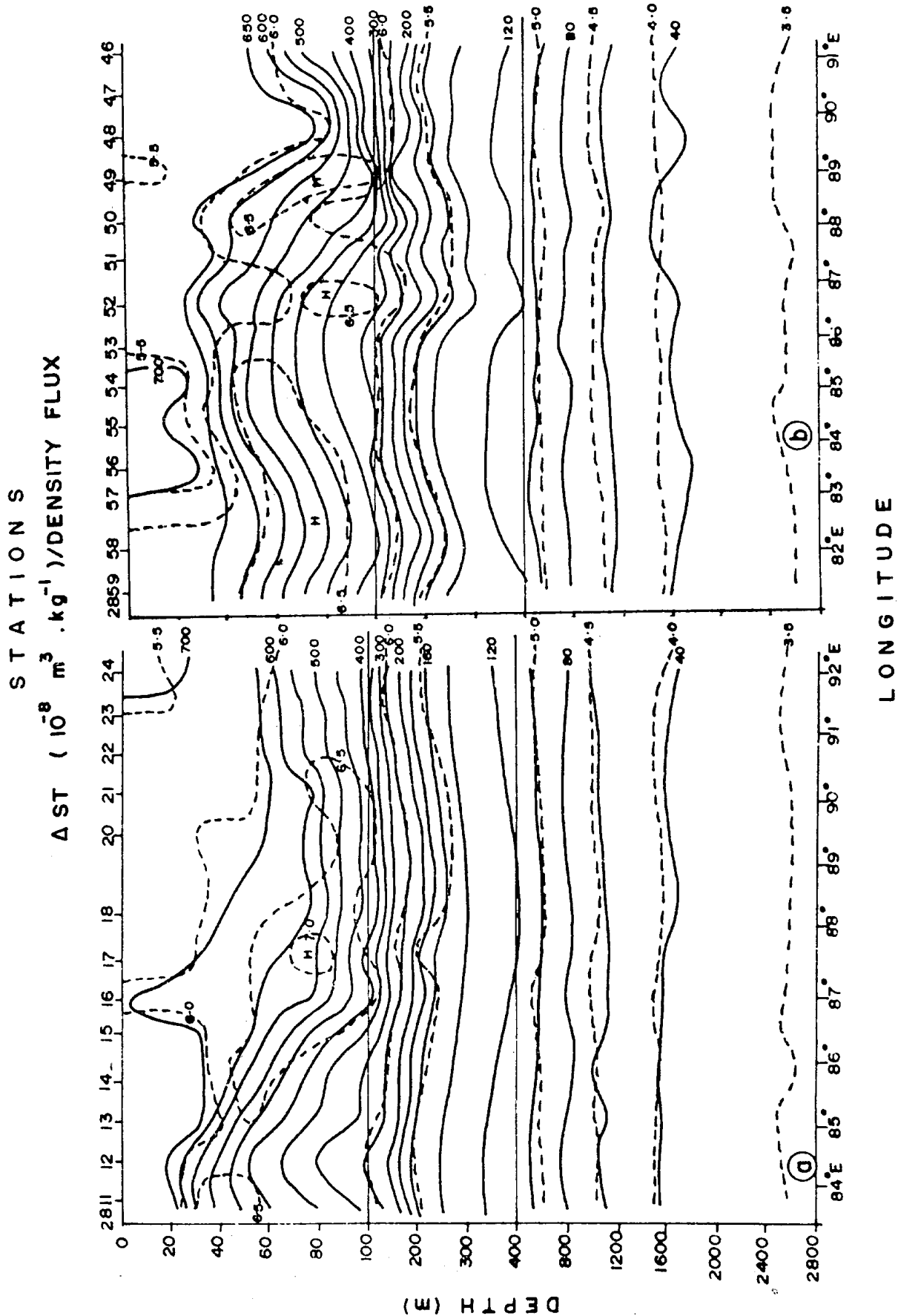


Fig. 7 - Vertical cross-section of thermocline anomaly (—) and density flux function (---) during postmonsoon period along (a) Visakhapatnam - Port Blair section, (b) Madras - Port Blair sections

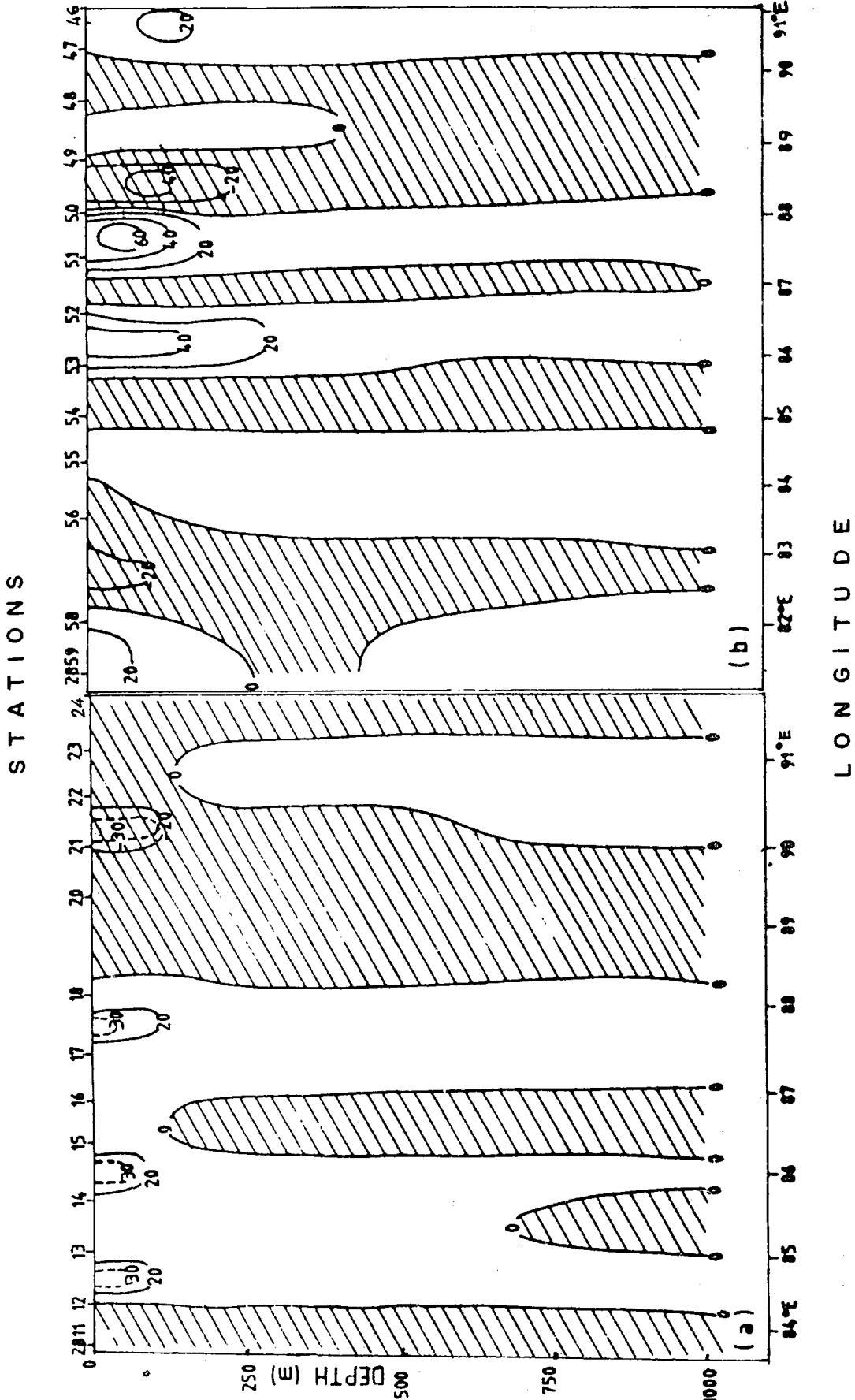


Fig. 8 - Vertical cross-section of relative velocities during postmonsoon along (a) Visakhapatnam - Port Blair and (b) Madras - Port Blair sections (shaded areas = southerly currents; non-shaded areas = northerly currents)

cyclonic gyre while cold less saline waters are brought from the northern bay towards Visakhapatnam coast under the influence of the strong cyclonic gyre. As a consequence of the existence of these gyral systems, strong lateral shear develops leading to the formation of a frontal zone which extends along the coastal boundary between Visakhapatnam and Madras. An earlier study by Gopala Krishna and Sastry⁸, indicated an eastward transport in the frontal zone off Visakhapatnam formed as a result of the waters brought by a southerly flow from the northern bay and a northerly flow from the southern bay. Geostrophic currents also show a similar structure with alternate bands of northerly and southerly flows.

During the postmonsoon, the dynamic topography of the sea surface with respect to 1000 dB surface reveals the replacement of the anticyclonic gyre by a cyclonic gyre off Visakhapatnam and an anticyclonic gyre is located in the central Bay. These gyres may modify/alter the frontal zones. Geostrophic currents also show similar circulation patterns.

The distribution of potential vorticity along Visakhapatnam – Port Blair section during premonsoon and postmonsoon indicated the presence of zones of maximum potential vorticity on potential density surfaces at 22.5 kg.m^{-3} representing strong convergence of isopycnals due to Ekman drift under northerly flow. Between these 2 con-

vergent zones, a divergent zone exists at potential density surface 23.5 kg.m^{-3} . Fig. 6a shows a region of inclined isotherms sloping up from west to east. This may be due to the combined effects of monsoonal winds and converging current off Visakhapatnam resulting in the deepening of isotherms.

The distribution of the main features visible in potential vorticity do not depend on time which is well illustrated by the zones of maxima that are present during premonsoon and postmonsoon.

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