

Some Physical Aspects of the Surface Waters around the Little Andaman Island

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Along with the thermal and haline characteristics of the waters during the peak northeast monsoon period (February), observations on stratifications, inversions, mixed layers, nature and depth of thermocline, wind-induced surface drifts, zones of surface and sub-surface salinity parameters are discussed. The major objective, however, is to present the surface water circulation pattern around this island. It is shown that the surface water around this island flows towards the SSW from the NNE and that the surface water characteristics such as the nature of the mixed layer and the deepening of the mixed layer on the southwestern side of the island result not only as a 'lee' effect but also lends further evidence to the fact that the waters on the western side of the Andaman Island arc as a whole are slightly different from the waters on the eastern side i.e. the Andaman Sea water.

Oceanic Islands or rather a group of islands, far away from continental margins, significantly influence, modify and change the general physico-chemical properties of the waters around them mainly by changing the general circulation patterns and the associated stratification-mixing processes. Especially, with a chain or cluster of such islands forming partial barriers and obstacles, the physical processes and hydrodynamic characteristics of the adjoining waters change in distinctive fashions, more as a rule than as an exception. From the Hawaiian group of Islands to the Andaman-Nicobar Island arc system, there are numerous examples to be found in all the major oceans and the seas. The oceanic islands of the Pacific and Atlantic, at least some of them, have been quite intensively studied from physical, geological and marine biological points of view. The same statement, however, cannot be made with equal emphasis about the islands in the Indian Ocean. Keeping the Andaman group of islands in mind, it would perhaps be an understatement to say that more is known about the southeast Asian waters—from the Phillipines to the Timur Sea and the Strait of Malacca to the Arafura Sea—as would be evident from the NAGA report¹. It would be equally true and disappointing to mention that since the pioneering work of Sewell², more than half a century ago, precious little has been added to our knowledge regarding the Andaman Sea and the Andaman-Nicobar group of islands. Yet, this is the region where the complex air-sea interaction phenomenon releases enormous amount of energy for the genesis of the devastating tropical cyclones which hit the east coast of India and the north and northeastern coasts of the Bay of Bengal almost every year. What makes the seas around these islands even more interesting and a class apart from many other

oceanic islands (barring a few) is the yearly cycle of the N-E and S-W monsoonal wind systems reversing the atmospheric circulation and the surface currents of the Bay of Bengal and the Andaman Sea from December to April and June to October with intervening transitional period. Another feature which demarcates the Andaman Sea from the Bay of Bengal lies in the geological history of emergence and development of these 2 regions. The island arcs form a kind of barrier between the Bay of Bengal which has more or less an even bottom topography and the Andaman Sea with its 3 major basins. Exchange of water between these 2 mainly takes place through 3 main channels, from north to south: (i) the Preparis Channel, (ii) the Ten Degree Channel and (iii) the Great Channel, lying between Great Nicobar Island and Sumatra—in increasing order of depth. The last channel is also the pathway for the Pacific waters to enter the Andaman Sea—Bay of Bengal complex.

The Andaman islands have steeper continental slope on the eastern side compared to the western one which is very irregular and has not yet been fully charted.

Little Andaman lies just north of the Ten Degree Channel south of which lies the Nicobar group of islands. Its northern side is shallow with rocky bottom and is not fully charted for safe navigation. Oriented in a N-S direction between 10°55' and 10°30' N and 92°22' and 92°36' E, this oval-shaped island is indented with several bays (Dugong, Hut, South and West bays and the Jackson Creek). Though its western side has rather irregular bottom topography compared to the eastern side, the shape of the island suits almost ideally to model studies of flow past a submerged obstacle with certain assumptions similar to such works as have been carried out by Hogg³ for Bermuda. However, such studies need a series of observational data on

temperature, salinity, stratification, current measurements, wind stress, etc., which are utterly lacking in the waters around the Little Andaman.

During 51 and 52 cruises of *R V Gaveshani* in Feb. 1979, several measurements were made on currents, temperature, salinity and wind, using BT's, CSTD, current meter and a parachute drogue on 3 sides of the island, except the northern side, which, as has been mentioned earlier, is not a safe area for navigation. This paper presents the surface currents around the Little Andaman Island, the thermal and haline characteristics of the waters, observations on stratifications, inversions, mixed layers, nature and depth of thermocline, wind induced surface drift and zones of salinity maxima among other similar physical features.

Methods

In all, 6 vertical sections were covered on the eastern, southern and western sides of the island each starting around 50 m depth near the coast and radiating seawards beyond 1000 m depth (Fig. 1d). Of these, at 4 deep stations on the outer edge of each section, CSTD profiles were obtained. The remaining 15 stations of the sections were covered for obtaining the BT profiles—the depths being too shallow to call for CSTD casts. Thus, 4 temperature depth sections were obtained—oriented in due E-W directions on the eastern (I and II) and western (V and VI) sides of the island. On the southern side also, 2 similar profiles were obtained—section III being oriented due N-S and section IV in a NNE-SSW direction. The temperature depth profiles are presented in Figs 1a, b and c. In the present study only the temperature profiles (Fig. 2) obtained from CSTD casts are given and discussed in some detail up to a depth of 250 m. Though the salinity profiles are not presented here, some salient features like thickness of isohaline layers and depths of sub-surface salinity maxima are presented (Table 1).

During the entire operation the measured wind showed a more or less persistent NNE direction, there being virtually no land-sea breeze noticeably affecting the steady NE monsoon winds.

On 2 occasions direct measurement of sub-surface currents using a direct reading current meter (Plessey make) and a parachute drogue were also attempted. The parachute drogue was used on an experimental basis. This was lowered at a depth of 20 m where the water column depth was around 60 m. However, for the short period during which it was operational, the track of the drogue clearly gave the subsurface movement of water which flowed in a S-SW direction. This observation was carried out on the eastern side of the island off the Hut Bay. The limited number of readings obtained from the direct reading current

meter showed similar trends compared to the movements of the drogue. These limited observations were, however, found to be of some practical value while deducing the flow patterns near the shorelines.

Results and Discussion

While attempting to provide a general picture of the physical properties of the surface waters around the Little Andaman Island and the flow past and around it we need mention here the constraints which frame the objectives, as well as the opportune time for observations; this would provide allowances for drawing certain conclusions under the almost steady state conditions when the NE monsoon is at its peak and a stable and consistent wind-field is prevailing.

The total period of observations is 11 days (10 to 21 Feb. 1979) and the total number of stations covered is 19 around the east, west and southern parts of the island. However, during January and February the NE monsoon is at maximal and a large anti-cyclonic gyre is formed in the Bay of Bengal⁴. These conditions, while slowly changing, last till March/April. Therefore, in the absence of any sudden weather disturbances like formation or passage of cyclones over this region, it could be assumed with confidence that the surface water properties and current patterns are under almost steady-state condition which was actually the case.

By 'surface water' we mean here the surface column of water from the island coast extending east, south and westward up to depths of about 300 m. Though the 4 stations where the CSTD was lowered covered depths of about 1250 m and more, the 300 m depth limitation is adhered to for the purposes of the present paper. This limit is only overstepped while showing the depths of salinity maxima in Table 1, where the surface wind, air and surface water temperature, surface salinity, isohaline conditions and the halocline are also shown. These were, naturally, obtained at the 4 CSTD stations.

Surface waters of the Bay of Bengal which occupy depths of 100-150 m are easily distinguished by their contrasting properties. Of these 3 water masses—the northern dilute water, a transition water and the southern Bay of Bengal water—it is the latter which occupies the regions surrounding the Andamans during January-February, and by March, the surface water is largely southern Bay of Bengal water⁴. This water has a σ_t value between 21 and 22. However, the N-E part of the Andaman Sea shows lower density (~ 20) which is corroborated by the surface salinity decreasing in a N-E direction towards the Irrawady delta⁵. The western part of the Andaman group of Islands during February, show higher salinities than on the eastern side. The same is true in the case of

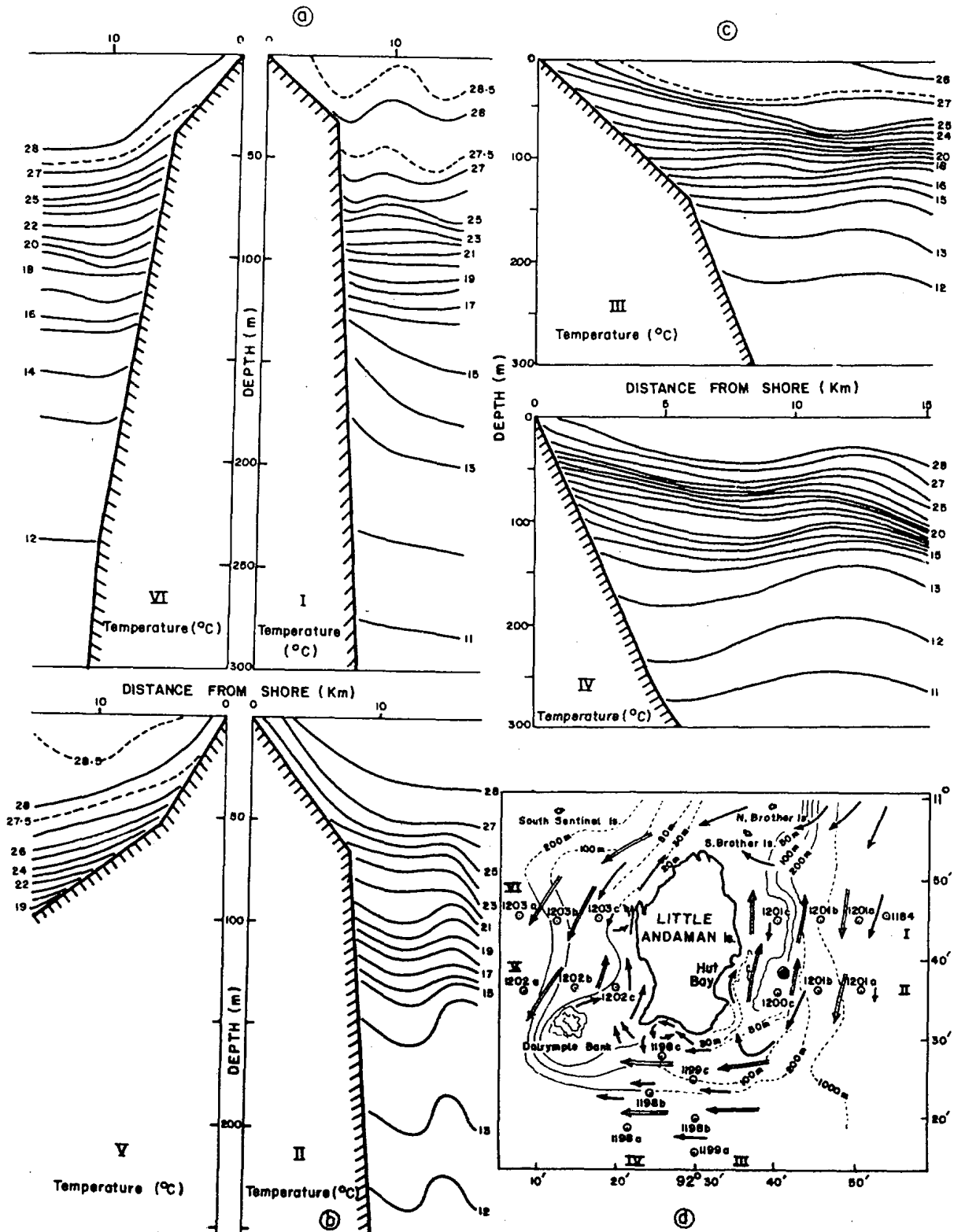


Fig. 1—Station locations (d) around Little Andamans and the surface flow pattern (\Rightarrow indicates flow deduced from thermal structure and \dashrightarrow indicates inferred flows) and thermal structure of the waters along sections VI and I, III and IV, V and II are given in a to c .

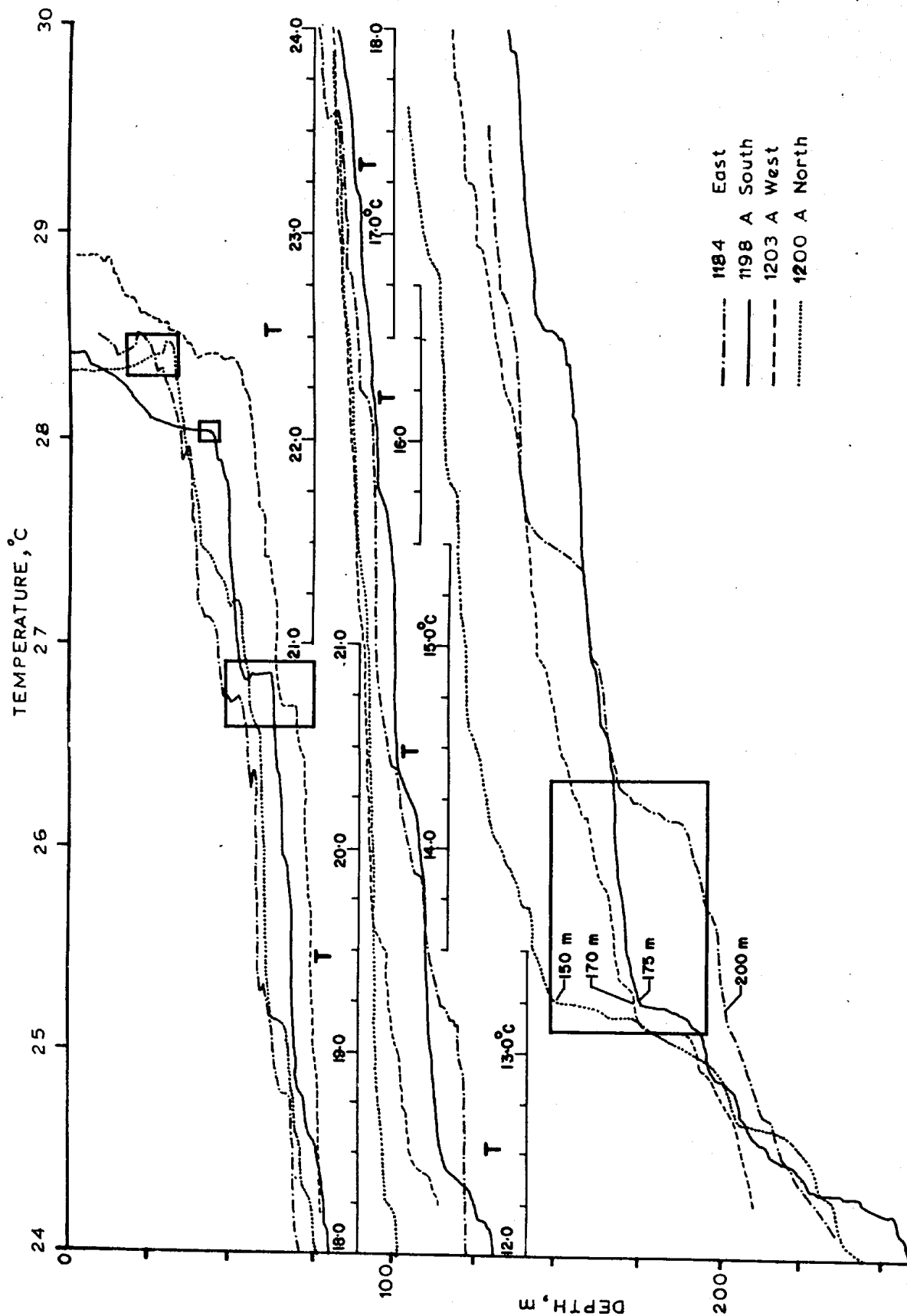


Fig. 2—Temperature versus depth up to 250 m from CSTD records

surface temperature also. This demarcation gets slightly intensified towards March-April.

In the equatorial region, the waters in the deeper levels i.e., generally between 100 and 1000 m, are quite different when one compares the waters of the western side (south of Arabian sea) with the waters on the south of Bay of Bengal. According to Sharma⁶, the flow here is mainly zonal and 'the equatorial Indian Ocean water acts as a barrier to trans-equatorial movement', during the northeast monsoon period, low salinity water flows into the western Indian Ocean from the Pacific and the incursion of Banda sea intermediate waters gives rise to salinity maxima at different levels. Going along with such observations, one would expect that even north of 5°N such salinity maxima could be expected during the NE monsoon, and hence the homogeneous (variation of salinity $\leq 0.3\text{‰}$) water between 100 and 1000 m which is found during the SE monsoon period could not be expected to prevail in the eastern equatorial waters and the Ten Degree Channel south of Little Andaman Island where the flow (NE monsoon) is towards the west would necessarily show regions of inhomogeneity (salinity maxima and the like) in the deeper parts. CSTD records amply justify, in our observations, the latter statement.

After this brief account of the surface waters of the Bay of Bengal and the equatorial waters during the SW and NE monsoons which might provide a backdrop, the findings and observations regarding the surface waters around the Little Andaman Islands during Feb. 1979 would perhaps become a little more clear if, at the same time, we consider the fact that the bottom topography around such islands considerably influence the currents flowing past the island and that the mixing processes are greatly enhanced by bottom friction.

During the peak NE monsoon (Jan-Feb) as has been mentioned earlier, the surface current in the Bay of Bengal flows in a large anti-cyclonic gyre. The eastern part of this gyre flows past the Andaman group of islands and joins the steady westward flow in the Ten Degree Channel (which lies just south of the Little Andaman). During the period of observations, a fairly

steady wind of moderate strength (2.5 to 5.8 m/sec) was blowing from between N and NNE. The air temperature and the surface water temperature were also nearly constant (Table 1). The surface current was of the order of about 2% of the surface wind. This was substantiated by the results obtained from the parachute drogue and the current meter which were operated off the Hut Bay. However, the basic deductions regarding the flow pattern around the island were made from the 6 sections giving the temperature structure around the island (barring its northern side). The isotherms on these sections (Fig. 1a, b & c) sloped up towards the coast on all the 3 sides without exception. Directions of flow are thus easily obtained from following the principle that (in the northern hemisphere) the isotherms slope up towards the coast on the right when looking downstream. Thus, it was possible to arrive at a schematic representation of the current patterns very near the coast for the east, west and southern sides of the island. The flow patterns on the northern side were arrived at from consideration of steady flow past an obstacle by inductive reasoning.

Further away from the coast, however, the isotherms showed wavy natures, suggesting, at places, reversal of current directions (the possibility of existence of internal waves are not considered here for various reasons). Such isotherms could be easily identified in sections II, III and IV, whereas they are seen on the upper layers only in section I and V. Fig. 1d shows the schematic presentation of the surface flow pattern around the Little Andamans. The length of the arrows gives no indication of current speed. However, the arrows with double lines are either deduced directly from the slopes of isothermal lines or from the parachute drogue (e.g. the double arrow pointing SSE near st 1200c). The arrows with single lines fill the gaps based on considerations of continuity, streamlines, the bays and the indentation on the coast and the bottom topography. It is interesting to note that though the flow around the island is southerly on the eastern side, ESE to SE on the western (lee) side and westerly on the southern side (as in the 10° channel), the flow pattern near the coast is in variance with this

Table 1—Data on Air Temperature, Wind, Thickness of Isohaline Layers and Depth of Sub-surface Salinity Maxima

St No.	Date	Time hrs T	Air temp. (°C)		SST (°C)	Wind		Surf. sal. (‰)	Thickness of isohaline layer(m)	Thickness of halocline layer(m)	Sub-surf. sal. max. (‰)	Depth of subsurf. sal. max. (m)
			DB	WB		Speed (m/sec)	Dir. (°TN)					
1184	10.2.79	1115	—	—	—	—	—	—	—	190	34.84	330
1200a	19.2.79	2030	28.5	24.5	28.5	2.5	NE	32.25	25	140	34.84	330
1198a	20.2.79	0815	27.6	24.0	28.5	5.8	NNE	31.95	40	170	34.85	310
1203a	21.2.79	1620	27.0	23.6	28.4	5.0	N	32.00	15	190	34.75	350

general pattern and forms zones of shear and eddies (near bays and shoals). These deviations cannot be attributed either to the tidal currents or the land-sea breeze system, the latter being almost nonexistent and the former of very low magnitude. For the western side, it could probably be said that the lee-effect produces the northerly flow on the south-western side of the island between the coast and the Dalrymple Bank. The same, however, may not be the case in the eastern side of the island where it could be either due to the bottom topography (frictional influence) or a density variation caused by mixing or a combination of both.

Coming to the thermal and haline characteristics of the waters around this island, it should be mentioned at the outset that 'around the group of the Andaman islands the continental shelf is very much wider on the western than on the eastern side and along the western edge of the shelf is a series of coral banks and islands'². The above statement holds good for the Little Andaman Island very significantly. The effect of such bottom topography is clearly reflected in the CSTD profiles apart from the modifications that are superimposed on it by the lee-side effect of the flow around the island. From Table 1, it is evident that the values of the salinity maxima are almost the same on all the CSTD stations whereas the depths at which they occur are not. On the western side, the salinity maxima occur at 350 m whereas on the eastern side they are found at 330 m and 310 m on the southern side. The depth of halocline follows almost a similar pattern with slight variations. The depth of the isohaline layer again shows the lee effect on the western side which is as shallow as 15 m compared to 40 m on the southern and 25 m on south-eastern sides.

In general, the following are evident from the BT and CSTD profiles (Fig. 1a, b & c, and Fig. 2 and Table 1) regarding the nature of the physical properties of the surface waters around this island. The surface mixed layer decreases towards the coast and is more clearly seen in sections I, II and VI. At the farthest offshore stations the mixed layer extends to 30-50 m.

The thermocline has a moderately developed gradient and extends to a maximum depth of 125 m where the temperature is of the order of 15-16°C.

The surface waters appear to be fairly stratified. Salinity at the surface is around 33.5‰ with a sub-surface maxima of 34.3‰ (where the pycnocline starts) at about 40-50 m. Below 150 m the salinity remains fairly stable—between 34.8 and 34.9‰. The surface temperature is fairly uniform and ranges between 28.25° and 28.5°C (2 m below the surface).

On the finer details obtained from BT and CSTD, the following need be mentioned as they contain some interesting features like temperature inversion.

Temperature – depth sections based on BT data—On the northern parts of the island the surface water column is warmer on the eastern compared to the western side. The mixed layer is sufficiently deep on the west as against the eastern side.

The isotherms show an upward tilt towards the nearshore areas on both these sides. The temperature gradients within the thermocline are more or less uniform.

On the southern side the picture is slightly different. The general pattern of the inclination of the isotherms is quite similar to that of the northern section. On the southernmost side of the island where the sections radiate out towards the Ten Degree Channel the sea surface temperatures are slightly higher on the eastward section. The temperature gradients are weaker on the southwesterly section below 150 m depth.

Temperature – depth profiles based on CSTD records—Eastern side of the island: There are marked temperature inversions of low magnitude at 20 and 30 m with the depths of inversion increasing towards the south. A similar feature, with much less pronounced inverse gradient, occurs around 50 m depth. Below 95 m depth the temperature gradient vary significantly though they are more or less uniform. The 18°C isotherm observed around 120 m depth on the north shows a dip at about 95 m on the south. Similarly, the 15°C isotherm moves up to 120 m (south) from 160 m (north). This feature coupled with a near isothermal layer with temperature 13.25°C is clearly seen to move up to 150 m from 250 m depth from north to south on the eastern side of the island.

Western side of the island: Here, the mixed layer column is very much shallow (12-15 m) and the thermocline begins at around 50 m depth. The temperature gradients are almost identical within the upper part of the thermocline. The temperature inversions though noticeably present are of very low magnitude. An isothermal (~ 26.7°C) layer is present between 65-70 m.

A shallowing in the depths of the isotherms with reference to the corresponding values on the eastern side is clearly discernible here—e.g. 18°C—isootherm observed at 100 m on the west is located at 120 m on the northern side and 95 m on the southern side. The 15°C isotherm is at about 140 m on the west whereas on the eastern side it is at 160 m and 120 m on north and south ends of the eastern side of the island respectively.

Southern side of the island: On this side inversions are present at about 5 and 40 m, though they are much less conspicuous. The distribution of temperature with depth is relatively smooth except at 55-65 m level, 140 m and at 175 m when compared to other locations.

It is evident from CSTD records, which show many 'steps' and inversions and differential lowering or rising of isotherms at different sections, that both horizontal and vertical mixing are at play. However, the effect of wind, which is only of moderate strength, and that of tidal currents, as has been mentioned earlier, could only be of minor nature. It is also quite possible that turbulence and formation of eddies due mainly to the shape of the island and the rough bottom topography play vital roles in modifying the processes of double diffusion-that of heat and salt.

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