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Vertical Temperature Structure of 250 M. Water Layer around Sri Lanka at the Tail-end of the North-East Monsoon

By

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Introduction

THE thermal stratification of the tropical and subtropical oceans is chaıacterized by two principal layers. The upper layer known as the oceanic troposphere, extends from the sea surface down to about 600–1000 m. and shows rapid changes in the vertical temperature distribution. It's uppermost layer down to about 100 m. is subject to atmospheric disturbances and is always more or less in a mixed state giving rise to nearly isothermal strata below which the temperature generally decreases rapidly towards the lower limit of the troposphere. This abrupt change of temperature, or the thermorcline, is distinguished from the small temperature-depth variation of the cold water layer termed oceanic stratosphere which extends from the bottom of the troposphere right down to the sea bed.

The two fold subdivision of the thermal structure giving rise to a marked thermocline of quasi-stationary nature in the tropical and subtropical oceans is attributed to the fact that the warm upper water layer, whose topmost portion is more or less in thermal equilibrium with the atmosphere exchanging nearly constant amount of heat by virtue of the constant altitude of the sun and high cloudiness right throughout the year, mixes with the underlying subtrophospheric and stratospheric water which thereby gain heat but are eternally kept at a relatively low temperature by cold water of polar origin.

The prolonged existance of the thermocline layer at subsurface depths in tropical and subtropical oceans throughout the year is detrimental to its productivity in that the strong thermal stratification prevents the advection and mixing of nutrient enriched deep water with the upper layers where there is sufficient sunlight to bring about the photosynthesis of phytoplankton.

Northern part of the Indian ocean is subject to the influence of the monsoonal wind system which is a peculiar feature not common to the otheı oceans. This unique feature is responsible, to a considerable extent, for the main characteristics of the temperature—water regime (Lukjanov and

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Moiseev, 1961). As the annual changes in the upper 50 meters were generally so small relative to those found in the other oceans, Rochford (1968) concluded that in their genesis the advecation and mixing must have been less important than the climatic changes.

Most of the early oceanographical work in the Bay of Bengal were executed by Sewell and the research workers of Andhra University, India. Sewell (1929) during the years 1914–21, carried out a series of observations on the temperature and salinity of surface waters from the southern extremity of Sri Lanka to the Bay of Bengal along the longitude 80°E. La fond's (1958a) work on the circulation of sea surface layers off the east coast of India which accounts foı the mixing of different water masses prevailing in the Western Bay of Bengal, renders possible to explain the seasonal variation of the temperature distribution off the east coast of Sri Lanka. La Fond (1958b) also observed the seasonal cycle of the sea surface temperatures and salinities along the east coast of India. Ramasastry (1959a) worked out the distribution of temperature, salinity, and the circulation during the post south-west monsoon season in the Arabian Sea off the Indian coast between Cochin and Cape Comorin. Murthy (1965) studied for seven years, the surface mixed layer and its associated thermocline off the west coast of India. Ramasatry (1959b) classified the water masses of the upper layers of the South-eastern Arabian Sea. Ramamirtham and Jayaraman (1958) grouped their hydrographical data collected during the years 1958–59, in the continental shelf waters off Cochin into five seasons. Patil and Ramamirtham (1961) investigated the hydrography of Laccadive's off-shore waters in winter conditions. Laccadive waters was also explored by Jayaraman, Ramamirtham, Sundraram and Aravindakshan (1959). Ramamirtham and Patil (1962) again worked out the hydrography of the west coast of India from Rathnagiri up to Cape Comorin in the pre-monsoon period. The work carried out on board the research vessel SRTM " OPTIMIST " which was engaged in a joint fishery survey in the period of March–December, 1972 round the island in accordance with an agreement between the Government of Sri Lanka and the USSR, contributed an appreciable amount of oceanographical data (Anonymous, 1972).

Material and Methods

The data embodied in this paper were collected during the cruises of the vessel " Hoyo Maru " of the Japan Marine Fishery Resources Research Centre, during it's fisheries survey mission to Sri Lanka. Two cruises were made from 8th to 29th January and from 4th February to 2nd March 1975. First cruise covered the areas off the west coast and the Gulf of Mannar (stations 1-11) and the second cruise swept the waters from Colombo, round the southern coast, to as far as the Pedro Bank (stations 12—28 ; Fig. 1). Hydrographic sampling was, in all, carried out at twenty eight stations.

The temperature-depth variation of the upper 250 meters was observed by means of a bathythermograph (depth range 0-250m.). The surface water samples for the measurement of temperatures were collected with an insulated water bucket by lowering it over the ship's side, away from the cooling water outlet. The temperatures of the samples were measured with a mercury-in-glass thermometer graduated at 0.1°C intervals and the bathythermographic temperature readings were subsequently corrected. The depth error of the bathythermograph was corrected by subtracting 5 meters from every depth reading on the depth scale.

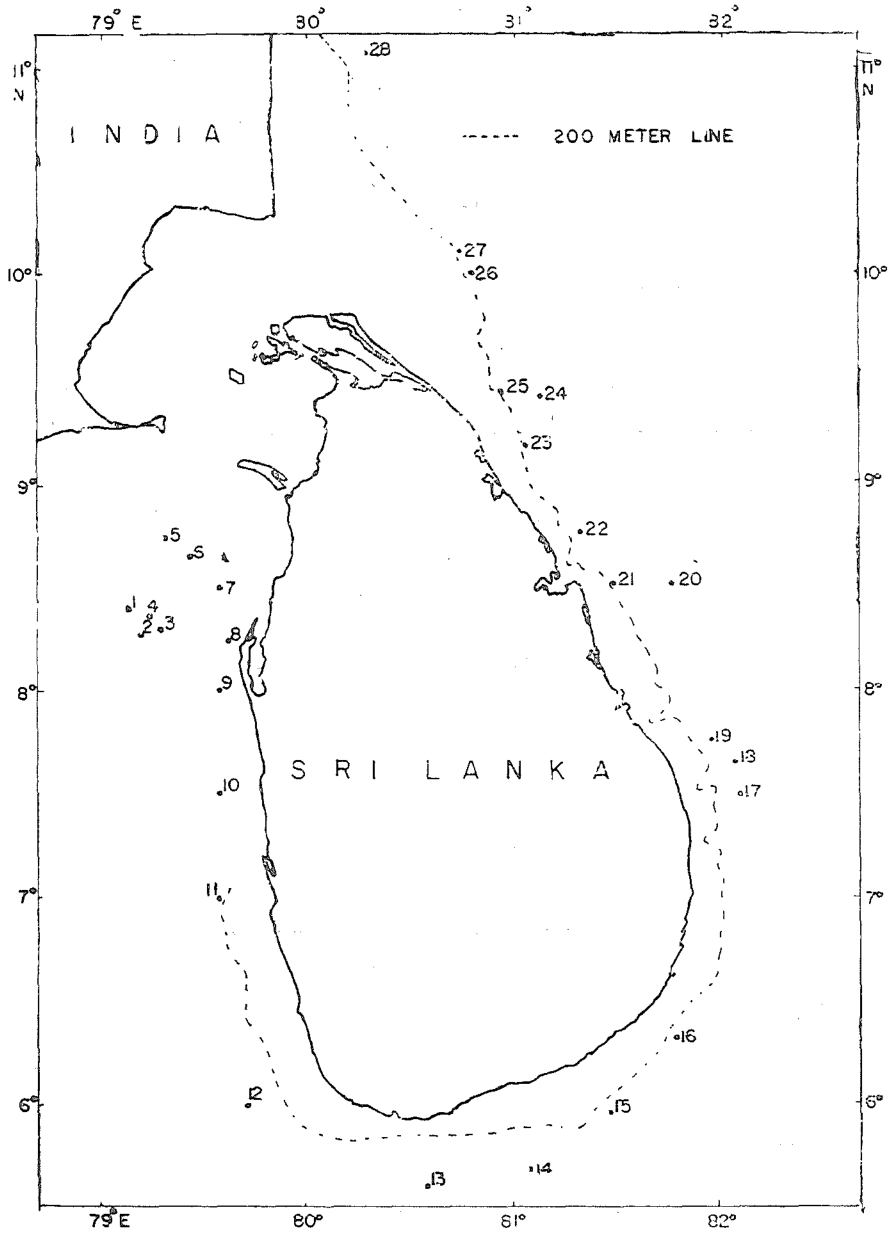

Fig. 1.—Map showing the locations of the hydrographic Stations.

Four vertical sections passing through the stations, numbers of which are indicated on top of each section, are given in Fig. 2 (a and b). It should be noted that the sections in Fig. 2a and 2b are curved. Bathythermograms and surface temperature data have been utilized in plotting the isotherms and in some cases the distances between successive stations were too far apart to interpolate homothermic surfaces. Hence it should be borne in mind that the sections drawn depict the approximate vertical distribution of temperature.

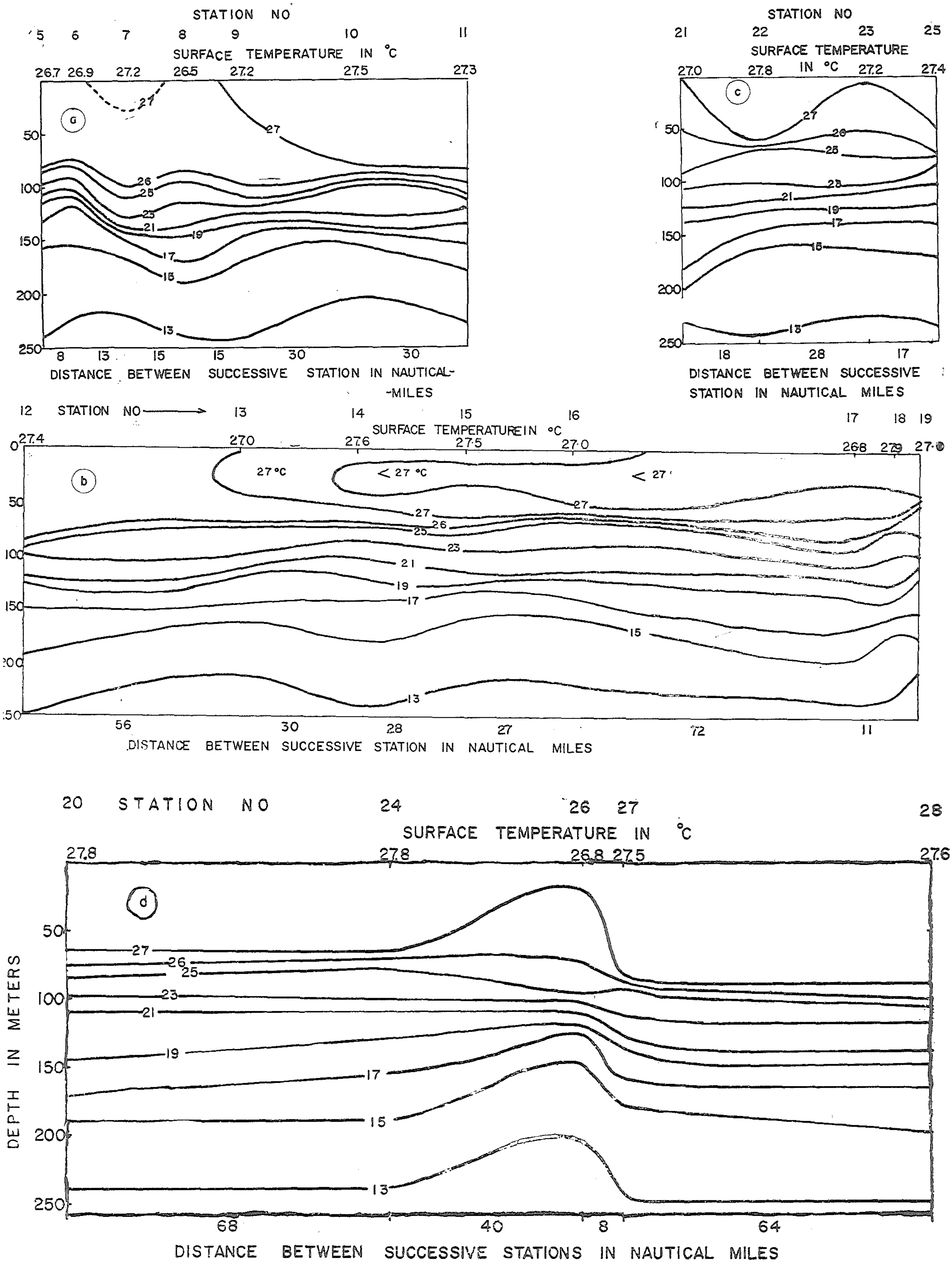

Fig. 2.—Vertical sections of the upper 250 m layer : Isotherms.

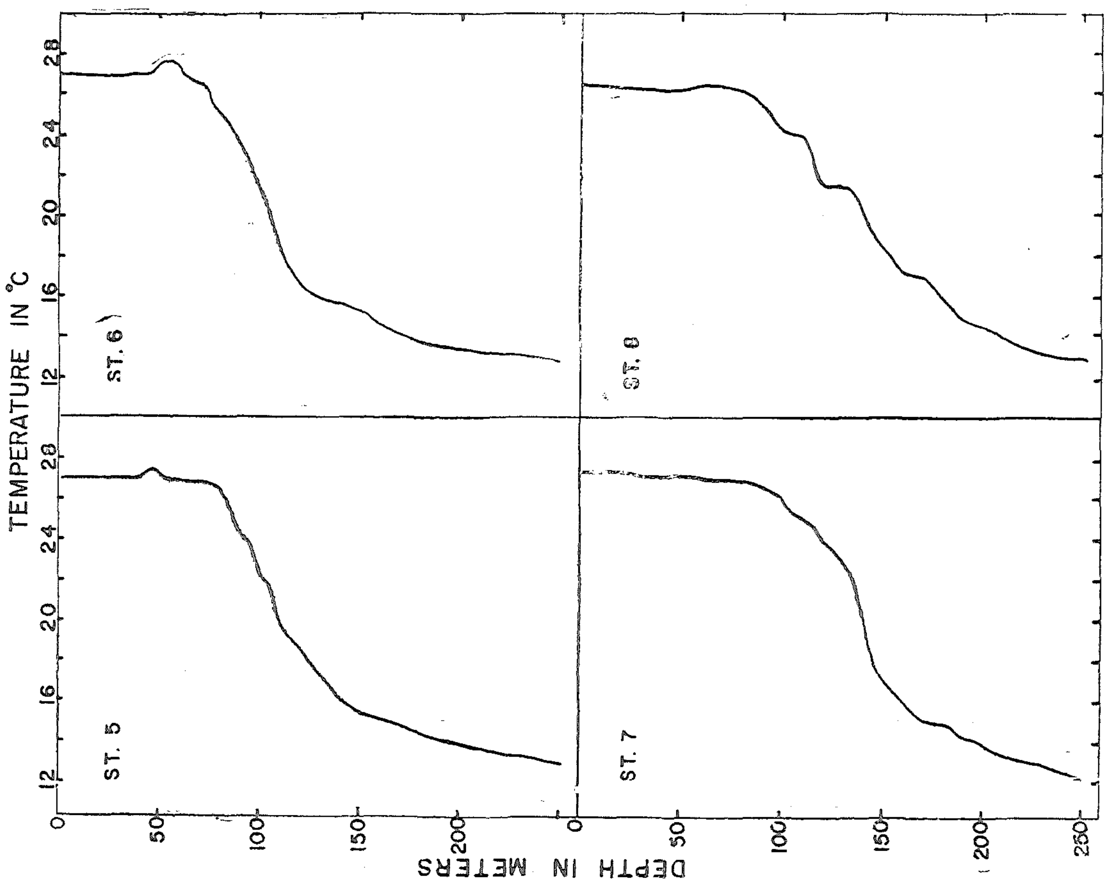

Fig. 3.—(b) Bathythermograms of the hydrographic stations, 5–8.

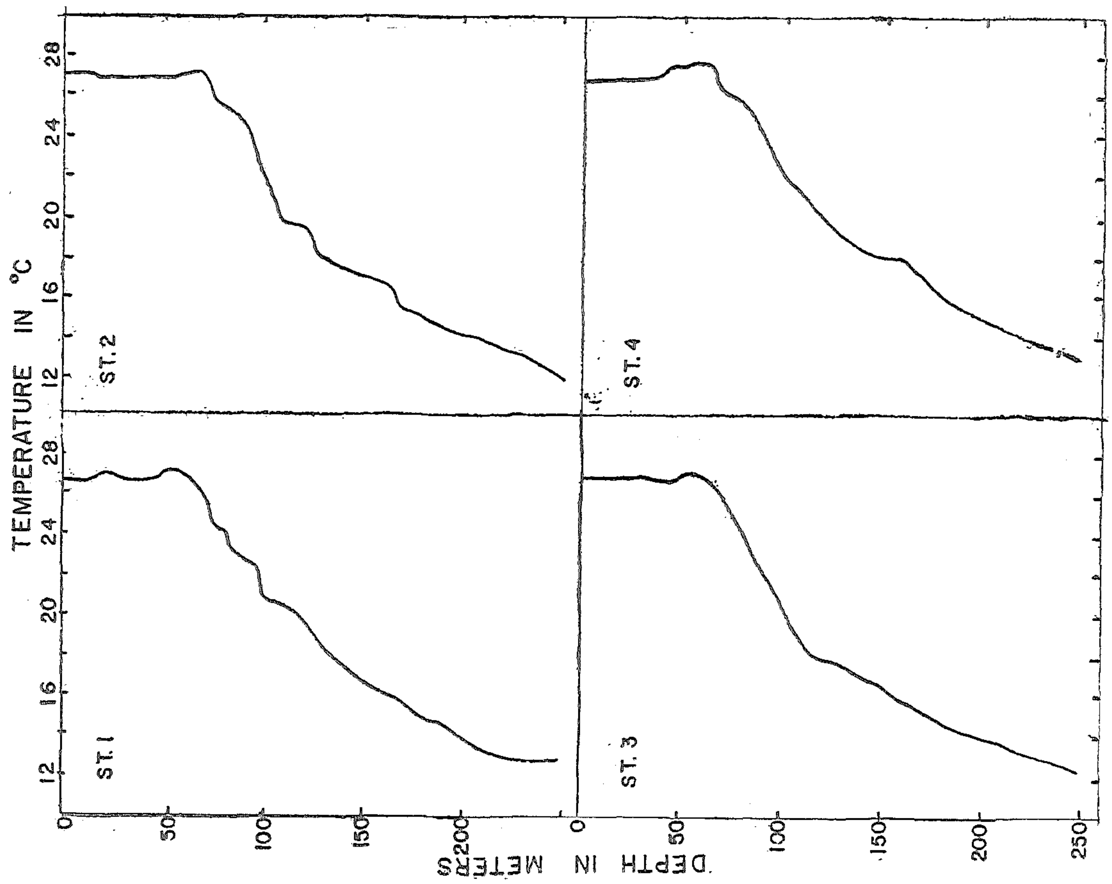

Fig. 3.—(a) Bathythermograms of the hydrographic stations, 1–4.

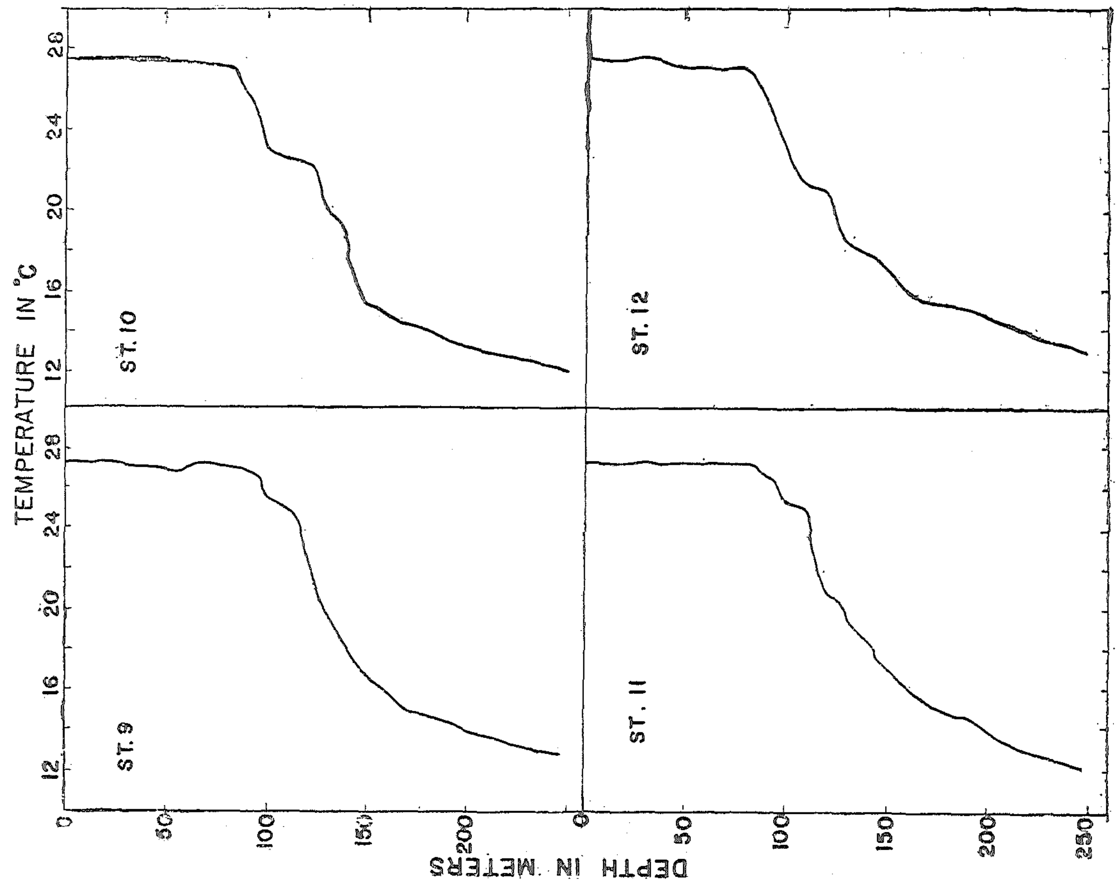

Fig 3.—(c) Bathythermograms of the hydrographic statio:s, 9-12.

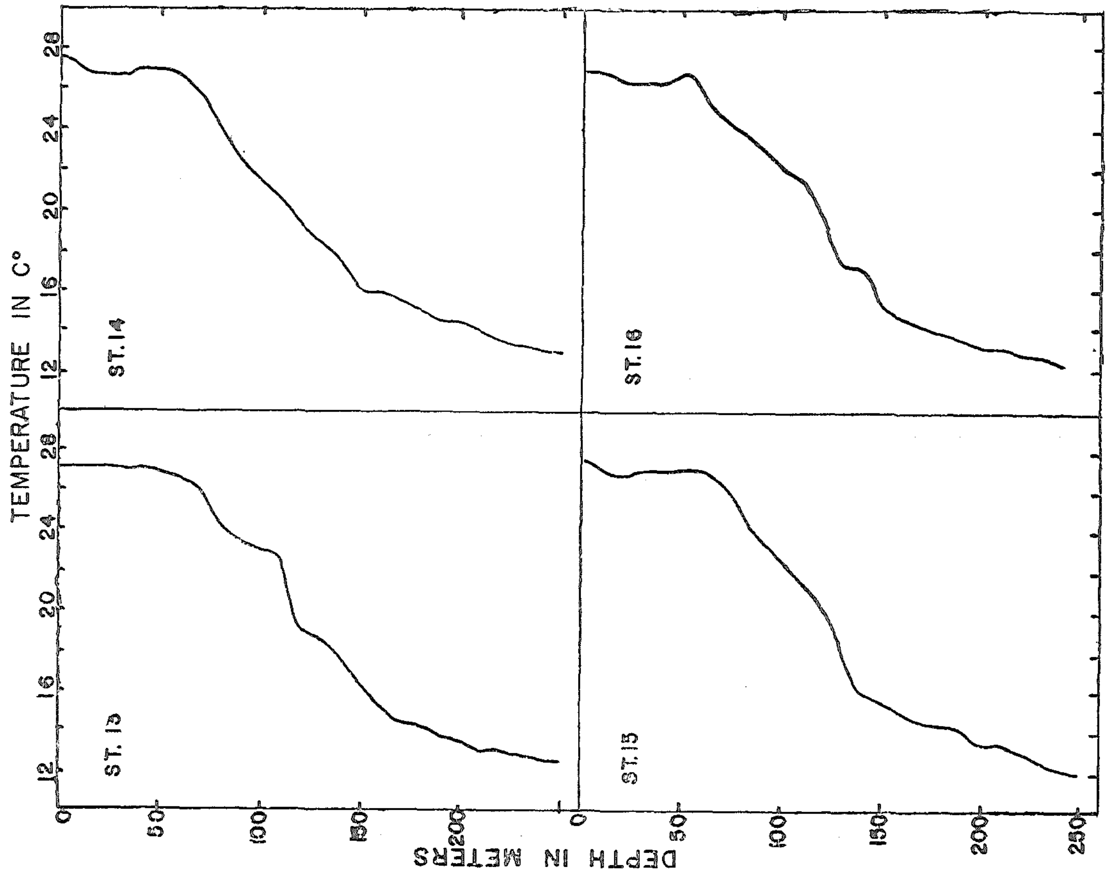

Fig. 3.—(*d*) Bathythermograms of the hydrographic stations, 13-16.

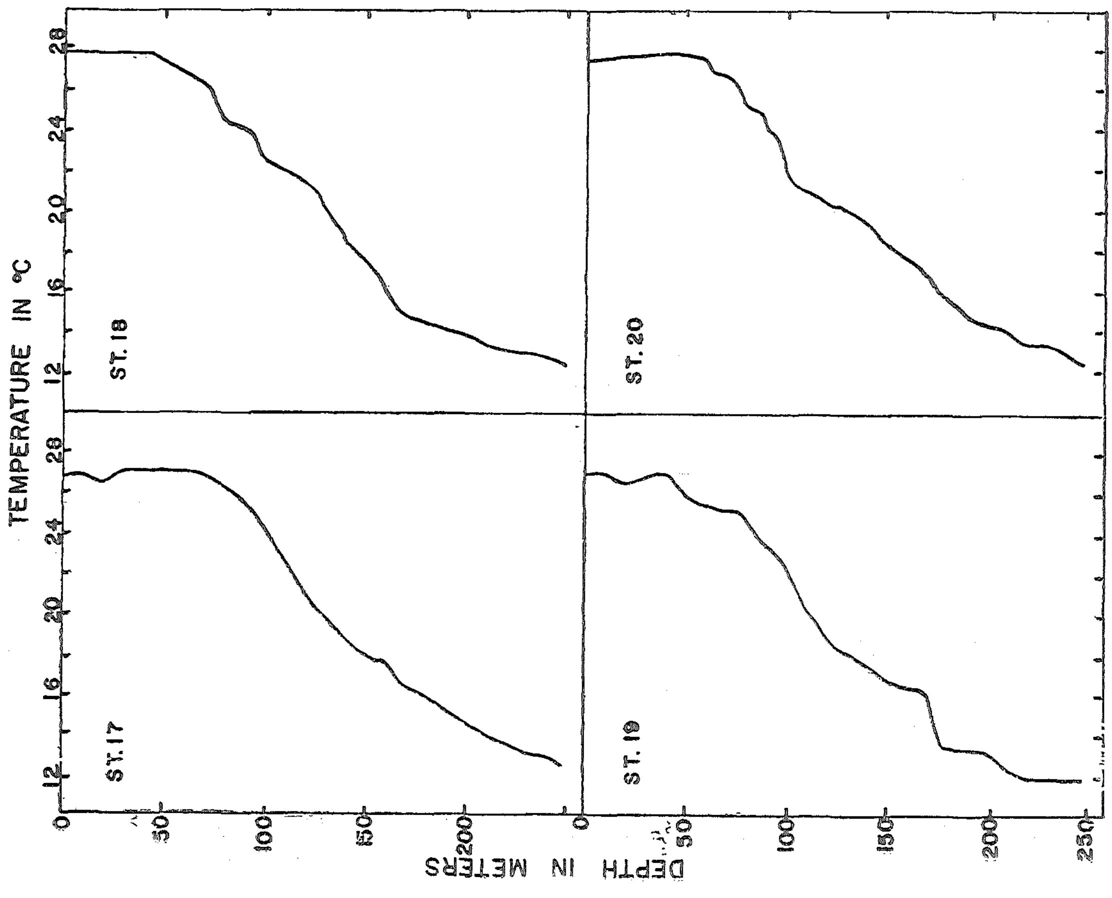

Fig. 3—(e) Bathythermograms of the hydrographic stations 17-20.

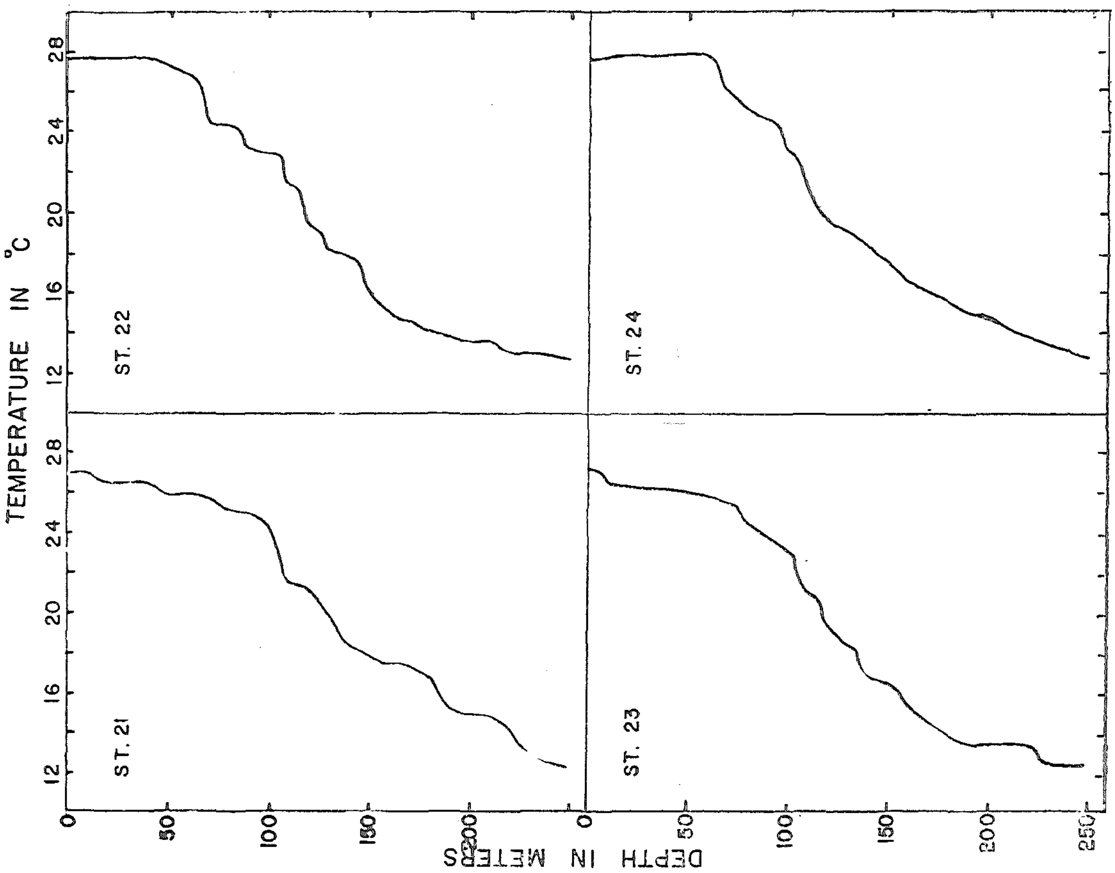

Fig. 3.—(f) Bathythermograms of the hydrographic stations 21-24.

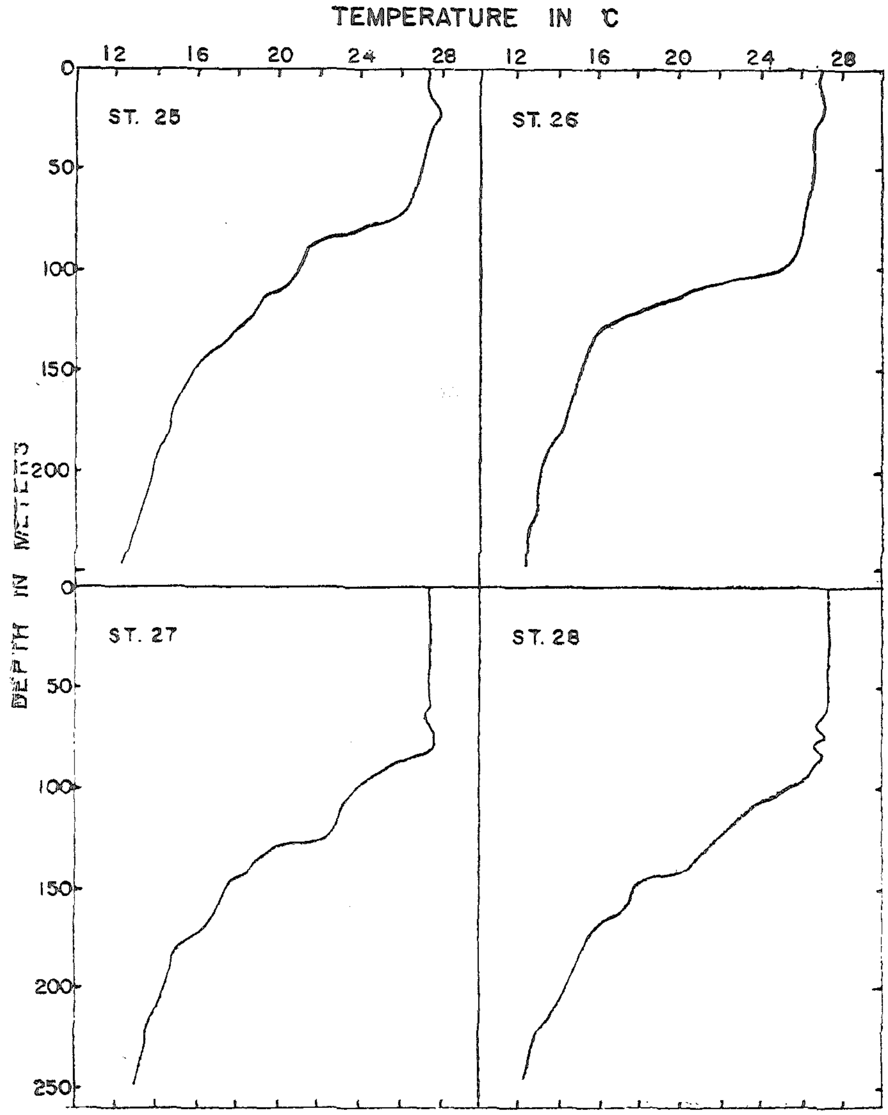

Fig. 3.—(*g*) Bathythermograms of the hydrographic stations, 25–28.

DISCUSSION

Temperature Profile

As shown by the bathythermograms (Fig. 3) the vertical temperature variation around the island is generally anothermic (i.e., temperature decreases with increasing depth) which character is typical for the open ocean.

The depth of the thermocline at the twenty-eight stations round the island ranged from 40 to 100 meters. In the gulf of Mannar the thermocline starts from about 60—70 meters and the upper limit is well defined. The existence of a thin warm water layer of approximately 15 meters thickness at a depth of about 50 meters is evident from the bathythermograms of the stations 1, 2, 3, 4, 5 and 6. At the stations 7, 9, 10 and 11 the thermocline is found at 100, 100, 80 and 80 meters respectively. At the stations 10 and 11 the mixed layer has a uniform temperature of 27.2°C down to the upper limit of temperature discontinuity layer. From the station 8 towards 11 the 27.0°C isotherm gradually slopes from the surface down to 80 meters along the transect while the lower isotherms are nearly parallel (Fig. 2a). Although, in the upper layers a negative temperature gradient can, in general, be expected due to prolonged heating of the calm waters to the west of the island during the North-east monsoon, the surface mixed layer at almost all stations on that side showed nearly constant temperature from the surface down to the layers as deep as 100 meters indicating strong mixing within the layer. From the station 12 towards 16 the upper limit of the thermocline layer rises gradully from 80 to 50 meters. This uplift of the thermocline may be attributed, to the fact that the stations 15, 14 and 16 are closer to the continental edge than the others.

At the stations situated between the latitudes 07°30′ N and 11′10′ N in the eastern waters of the island the depth of the upper limit of the themocline ranges from 40 to 100 meters. The shallowest thermocline is encountered at the station 19 off the east coast. The upper limit of the thermocline goes up from 80 meters at station 17 to about 40 meters at stations 18 and 19. A cold water tongue of temperature slightly less than 27°0′C surrounded by a warm water body of 27°0′C and extending from the surface down to about 70 meters is found between the stations 13 and 19 along the transect (Fig. 2b). In this transect the isotherms are nearly parallel except between the stations 18 and 19 and the stratification is strong. The temperature profiles at the stations 19, 21, 22 and 23 are more irregular than those at the other stations and the upper limit of the thermocline is not well defined at stations 19 and 21. The depth of 27°0′C isotherm at these four stations is highly variable ranging from 0 to 60 meters but the lower isotherms do not show much of a depth variation (Fig. 2c). It has been noted that the location of the stations 17, 18 and 19 roughly corresponds to the area where the clockwise surface current of the Bay of Bengal which prevails from February through March separates from the North-east monsoon drift which continues to move westwards (Anonymous, 1970).

Thermoclines at the stations 20 and 24 are at 60 metres while at the stations 21, 23 and 25 despite the fact that these stations are closer to the shore and are consequently at shallower depths, they are found at deeper layers between 70 and 100 meters. At the stations 20 and 24 the temperature slightly increases as one moves deeper into the mixed layer up to the thermocline. The prominent feature at the station 26 is the crest of the isotherms north of which all isotherms are found at lower levels than those extending towards south of the transect (Fig. 2d). The uplift of the cold water layers at the station 26 is reflected in the surface temperature distribution too. The mixed layers at the stations 27 and 28 have a constant temperature of 27°6′C from the surface to about 60 meters below which the temperature variation is irregular down to the upper limit of the thermocline.

The depth of the upper limit of the thermocline off the west coast of India between the latitudes 07°00′ N and 13°00′ N varies from 10 to 100 meters within a year. Within the period from June through September the thermocline in the southern half of the region is found at shallow depths ranging from 10 to 40 meters and during the period from November through February, over the entire area it sinks down to a range of 50–100 meters. In the months of March–May the thermocline is found between 20 and 100 meters and the depth of the upper limit of the thermocline increases away from the shore (Murthy, 1965).

The upwelling commences off Cochin in the middle of August and the thermocline appears to start right from the surface. Thermal gradient is very sharp below 20 meters. Upwelling takes place till about the end of October and by November the upper 50 meters become typically isothermal and the thermocline is formed at a depth of 75–100 meters. The formation of the sharp upper limit of the thermocline at the depths of 100–120 meters in deeper waters with sinking. In March and April which is the period of stable conditions a fairly sharp thermocline is present at 100 meters. During May further warming up of the upper water layers takes place and the top of the thermocline is found at depths of 75–100 meters (Ramamirtham and Jayaraman, 1958).

The changes in the depth of the temperature discontinuity layer off the west coast of India between the latitudes 07°00′N and 14°00′N are related to upwelling in the period of February-August and to sinking in the period September/January. In the months of November through February the upper limit of the thermocline generally appears at deeper layers between 40–140 meters. The limit is deepest in January and February and does not exceed 140 meters. In March and April the temperature discontinuity layer starts its uplift till it reaches the layers almost near the surface. In September and October a slight increase in the depths of the upper limit of the thermocline is apparent. Northerly coastal current flowing in November and December is responsible for sinking whereas southerly coastal current, flowing in the period of May–August, favours upwelling (Sharma, 1965).

The depth of the thermocline upper limit in the Gulf of Mannar and off the west coast of the island ranged from 60 to 100 meters in January which is more or less the same as that observed in the case of the off shore waters west of India, in winter. Similar pattern for the seasonal variation of the thermocline depth can be expected for the Gulf and off the west coast of the island, assuming similar prevailence of upwelling and sinking as the coast lines are nearly parallel and are under the influence of the same wind system. It should also be noted that the coastal currents partly affect upwelling and sinking but such information about the coastal and off shore waters of the island is not available. However, Silva (1963) has shown, by means of marine bacterial indicators, the occurrence of upwelling during the North-east monsoon at two transects off Chilaw and Balapitiya on the west coast of the Island.

Research vessel SRTM " OPTIMIST " reported a range of 20–50 meters for the thermocline upper limit ofthe southern off shore waters of the island during the period from mid April to mid-May, 1972. At some off stations in south-east region the thermocline was found to start from the surface itself. In August, in the same year, it was formed at a depth of about 10–30 meters at most of the " OPTIMIST " stations around the continental shelf edge and in deep waters below the latitude 08°00′N and south of Cape Comorin. At eight sparsely distributed stations lying approximately over the continental shelf edge between the Island and India, south of the latitude 09°00′N and during the period from mid-November to mid-December, 1972, the mixed layer extended down to the layers as deep as 70 to 100 meters. The above ranges of depths of the upper limit of the thermocline as observed during " OPTIMIST " cruises in various seasons are in conformity with the general pattern of those brought out by Murthy (1965), Ramamirtham and Jayaraman (1958) and Sharma (1965).

In the few of the bathythermograms obtained in the present investigation, the temperature gradient within the thermocline is so variable as to show several layers although in most cases it is not well marked.

The phenomenon is clearly apparent on the bathythermograms obtained at the station 10 off the west coast, 12 and 13 off the south coast and 27 off the east coast while at the stations 2, 8 and it is not remarkable. Ramamirtham and Patil (1962) reported the existence of the two-layered nature of the thermocline in the waters off the west coast of India, between the latitudes 08°00′N and 13°00′N in the period from January to May.

Surface Temperature

The surface temperatures observed at the twenty eight BT stations ranged from 26.5°C to 27.9°C (Table). Minimum temperature was found at station 8 in the Gulf of Mannar whereas the maximum was observed at the station 18 off the east coast. The surface temperatures found in the Gulf (Stations 1–9) were rather lower than those in the other areas and ranged from 26·5° C to 27.2°C, The temperatures observed at the other stations (10–28) were, in general, relatively higher, having a range of 27.0-27.9°C, except for the low temperature reading 26.8°C at the two stations 17 and 26. These relatively high sea surface temperatures may be attributed to the inflow of warm water from the mouth of the Bay of Bengal and from the equatorial region. With the onset of the North-east monsoon a strong flow of water from the Pacific Ocean to the Indian Ocean, through the straits of Sumatra, comes into being. North-east monsoon drift bathes the south coast of Sri Lanka and then runs up the west coasts of the island and India (Sewell, 1937). The 'clockwise current', also known as the 'transparent current' which is characterized by the high salinity, high transparency, rich nutrients and which prevails during the months January—May, brings oceanic waters into the Bay of Bengal and sweeps along the east coast of the island (Gnanapathy and Satyanarayana Rao, 1959). It should be noted that the stations 10 to 28 of relatively higher surface temperatures are located in the path of these currents.

The surface temperatures recorded at the stations in the Gulf of Mannar during the month of January were slightly higher than the mean surface temperature of 25.2°C at Mandapan (Western approach to Adams bridge between India and Sri Lanka) for the same month of the years 1950-53 (La fond, 1958b).

TABLE

Date	*Station No.*	*Position*	*Surface temp.°C*	*Vertical temp. gradient °C/10m.*
22.1.1975	1	08°23.5′N 79°08.6′E	26.6	1.4
23.1.1975	2	08°16.5′N 79°11.6′E	27.0	2.6
21.1.1975	3	08°17.1′N 79°18.0′E	26.9	1.8
20.1.1975	4	08°22.4′N 79°14.6′E	26.7	1.3
18.1.1975	5	08°44.6′N 79°19.5′E	26.9	1.7
17.1.1975	6	08°39.7′N 79°26.7′E	26.9	2.7
29.1.1975	7	08°30.0′N 79°35.0′E	27.2	1.7
20.1.1975	8	08°14.0′N 79°37.6′E	26.5	1.2
29.1.1975	9	08°00-0′N 79°35.0′E	27.2	1.8
29.1.1975	10	07°30.0′N 79°35.0′E	27.5	2.6
29.1.1975	11	07°00.0′N 79°35.0′E	27.3	1.7
4.2.1975	12	06°00.0′N 79°43.0′E	27.4	1.4
5.2.1975	13	05°36.0′N 80°35.0′E	27.0	1.2
5.2.1975	14	05°41.0′N 81°05.0′E	27.6	1.1
5.2.1975	15	05°57.0′N 81°28.0′E	27.5	1.5

TABLE—*contd.*

Date	*Station No.*	*Position*	*Surface temp. °C*	*Vertical temp. gradient °C/10 m.*
5.2.1975	16	06°18.5′N 81°46.5′E	27.0	1.6
6.2.1975	17	07°30.0′N 82°06.0′E	26.8	1.3
19.2.1975	18	07°38.7′N 82°03.7′E	27.9	1.1
7.2.1975	19	07°45.0′N 81°57.8′E	27.0	0.9
20.2.1975	20	08°30.7′N 81°46.8′E	27.8	1.0
8.2.1975	21	08°30.0′N 81°30.0′E	27.0	1.0
17.2.1975	22	08°45.2′N 81°19.6′E	27.8	1.2
9.2.1975	23	09°10.0′N 81°04.3′E	27.2	1.3
16.2.1975	24	09°24.3′N 81°08.1′E	27.8	1.3
21.2.1975	25	09°26.5′N 80°57.0′E	27.4	2.2
12.2.1975	26	10°00.0′N 80°48.0′E	26.8	2.8
22.2.1975	27	10°06.2′N 80°45.0′E	27.5	1.3
23.2.1975	28	11°05.5′N 80°17.0′E	27.6	1.5

The surface temperatures off Trincomalee reach the peaks in April/May and November which are inter-monsoonal periods and the minimum temperatures are found in February and August/September which roughly fall on the tail ends of the North-east and South-west monsoons respectively. The average surface temperatures observed at three stations close to the edge of the continental shelf due east of Trincomalee, during the months of February in the three years 1969–71, were around 29.3, 27.2 and 26.5°C (Jinadasa, 1972). The surface temperatures at the stations 20, 21 and 22 were recorded to be 27.8, 27.0 and 27.8°C respectively. Although the pattern of the seasonal variation obtained by Jinadasa (1972) is the same in the above three years, the actual average values for the same months were remarkably different. The maximum difference was in February and towards the middle of the year this difference tended to decrease.

Vertical Temperature Gradients

The maximum vertical temperature gradients for the twenty eight stations were found between 50 and 150 meters and ranged from 0.9° C/10m., to 2.8° C/10m., the mean value being 1.5(7)° C/10m. (Table.). In the Indian ocean the maximum vertical temperature gardient is, in general, found between 100 and 200 meters with a mean value of nearly 0.47° C/10m. and that for all the three oceans is 0.45° C/10m. (Defant, 1961). It is therefore clear that the vertical temperature gradients at the stations during the period of observation were very steep. In the Indian ocean off the west coast of India, between the latitudes 07° 00'N and 13° 00'N, the mean vertical temperature gradient was found to be

1.54° C/10m during the winter (November-February) (Murthy, 1965) and is comparable with the mean value obtained for the 28 stations. Those values for the periods of summer (March-May) and monsoon (June-September) were 1.29° C/10m. and 1.99° C/10m. respectively.

In the oceanic waters adjacent to the island, the vertical temperature gradients between 75 and 200m. were observed to be very high with a mean value of 1.0° C/10m. as averaged for several months in 1972 (Anonymous, 1972).

In most of the cases the vertical temperature gradient within the mixed layer is almost zero and in a very few cases it is small in magnitude and does not exceed 0.03° C/10m.

Although the number of BT stations taken on the two cruises alone is insufficient to draw conclusions on the general depth of the thermocline, by comparing it with the general pattern of the seasonal variation of the depth of the thermocline off the coasts of India and the island, it is apparent that the upper limit of the thermocline of the off shore waters of the island at the tail end of the North-east monsoon is fairly deep and ranges from 50 to 100 meters approximately, neglecting the lower values which may be attributed to local upwelling.

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