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THERMOCLINE AS AN INDICATOR OF UPWELLING*†

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INTRODUCTION

THERMAL structure of the oceans in the tropics and the subtropics indicates an upper isothermal layer and a lower stratified stratum with an intermediary transition zone, known as the thermocline, where the temperature gradients in the vertical are maximum with an average value of 5.0°C. per 100 meters (Defant, 1961). This discontinuity layer acts as a barrier to the upward and downward movements of waters. The physical mechanisms which form and maintain the transition layer are thought to be related to the vertical motions.

The speed of the mean vertical motion in the oceans is several orders of magnitude smaller than that of horizontal currents but this motion is essential to the maintenance of life in the sea, since it is the most important process by which the sunlit regions near the sea surface are refertilised with the essential plant nutrients. Hence, vertical motions known as upwelling and sinking are of vital importance.

A topographic representation of thermocline gives a cartographic depiction of the centres of upwelling. In view of the importance of the topography of thermocline the author considered it desirable to explore the seasonal and space variation of upwelling in relation to such charts for the area off the west coast of India covering 73° 30'E. to 77° 30'E. and 07° 00'N. to 14° 00'N. for one year. The principal advantage of the method of presenting the depth of thermocline by topographic charts is that it permits a rapid survey of the major features.

MATERIAL AND METHOD

The hydrographic data collected on board *R.V. VARUNA* during the period of March 1964 to August 1965 have been made use of. Due to lack of data for the months of November and December 1964, the previous year's data for these two months are utilised. In the absence of adequate B.T. data, the hydrographic data have been used in the present study.

The topography of the top of thermocline is mapped for the period April 1964 to March 1965 at an interval of 10 meters. Owing to the uneven distribution of the station positions for the months of November and December, for which months

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the previous year's data are utilised, a combined chart is prepared incorporating a two month average picture, whereas for the remaining ten months separate monthly charts are drawn. In analysing these maps wherever the data are scanty the isolines are extrapolated by broken lines. To confirm the conclusions drawn from the thermocline studies the seasonal variation of thermal structure off Cochin has been presented for the period March 1964 to August 1965. In doing so, the mean temperature at various depths up to the continental shelf are plotted for various months with the assumption that these values are representative at the middle of every month. Isotherms are drawn at an interval of 1.0°C.

Discussion of the Results

The topography of the top of thermocline is presented in Figs. 1 to 11 and the time section of temperature off Cochin is shown in Fig. 12. In considering the pattern obtained in these charts certain limitations are to be borne in mind, because in the hydrographic data continuity of temperature record with depth is absent, especially below 100 meters since the subsequent depths of collection are 150 meters and 200 meters in which case the possibility of committing an error in extrapolating the exact depth of the thermocline is bound to occur. However, certain irregularities arising out of wrong extrapolation are smoothed out in the graphical technique employed in the present investigation.

In course of the discussions for winds over the area the monthly meteorological charts for the Indian Ocean (Anon-1959) are referred to, while data for currents are from the circulation maps of the surface waters in the North Indian Ocean (Varadachari and Sharma, in press).

Seasonal Variation of Thermocline

November and December :

In general, the thermocline is deeper in the nearshore regions. However, this does not hold good in the southern regions, where the winter cooling is not so prominent. The northerly coastal current along the coast may also be partly responsible for sinking in the nearshore area (Varadachari, 1961) as a result of which the thermocline could be deeper.

January and February :

The winter conditions continue to prevail giving rise to deeper thermocline in the coastal regions, with decreasing values of thermocline depth off-shore. One prominent feature is that the isolines representing the thermocline are oriented parallel to the coast (Figs. 2 & 3).

March and April :

The irregular pattern of the topography of the depth of thermocline may be due to the transition between winter to summer conditions and also in the wind circulation. But, it could be clearly noticed (Figs. 4 & 5) that the depth of the discontinuity layer tends to decrease with time.

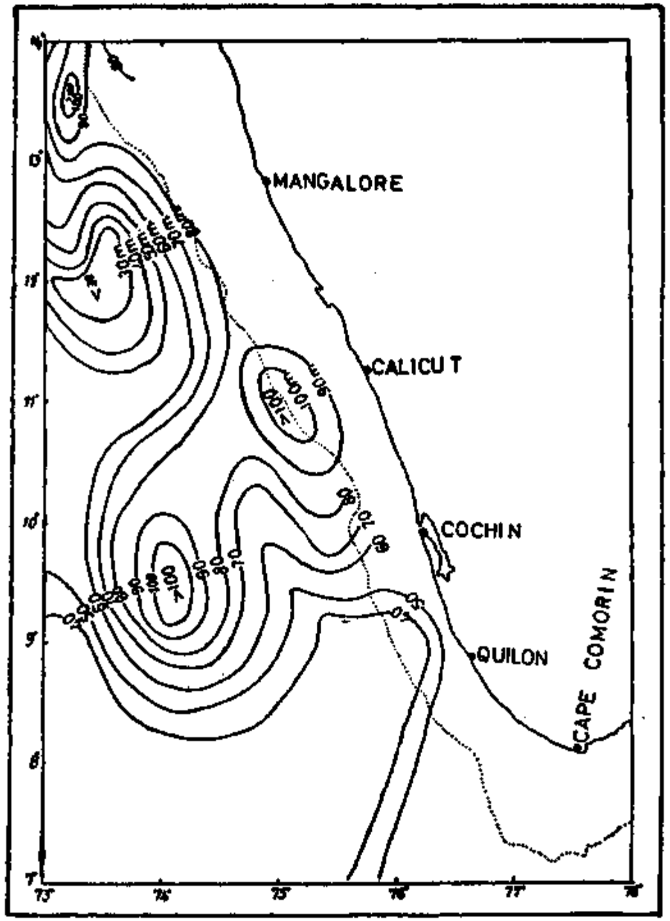


FIG. 1. Topography of the top of thermocline for November and December.

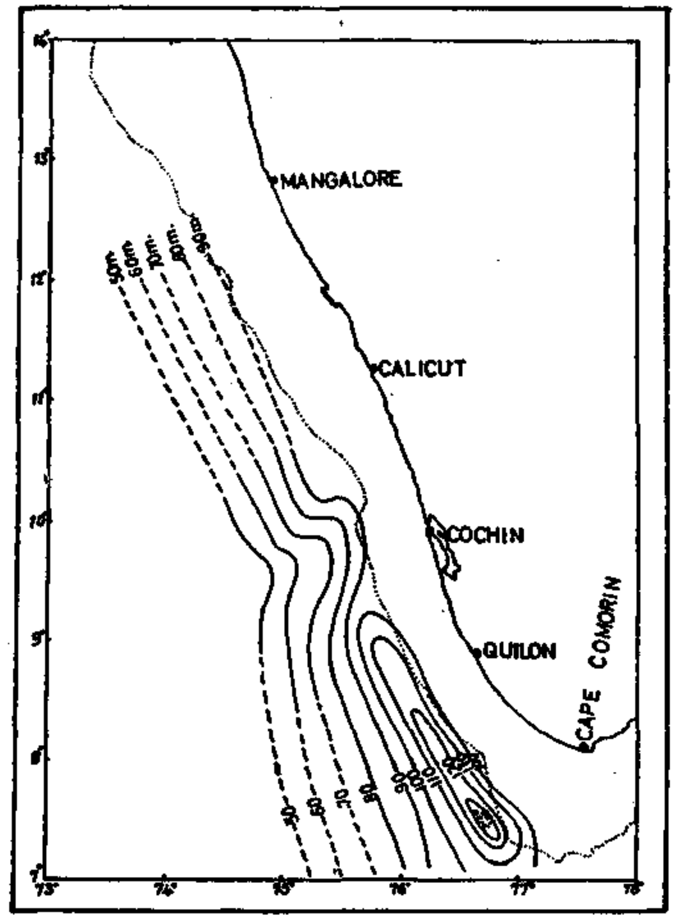


FIG. 2. Topography of the top of thermocline for January.

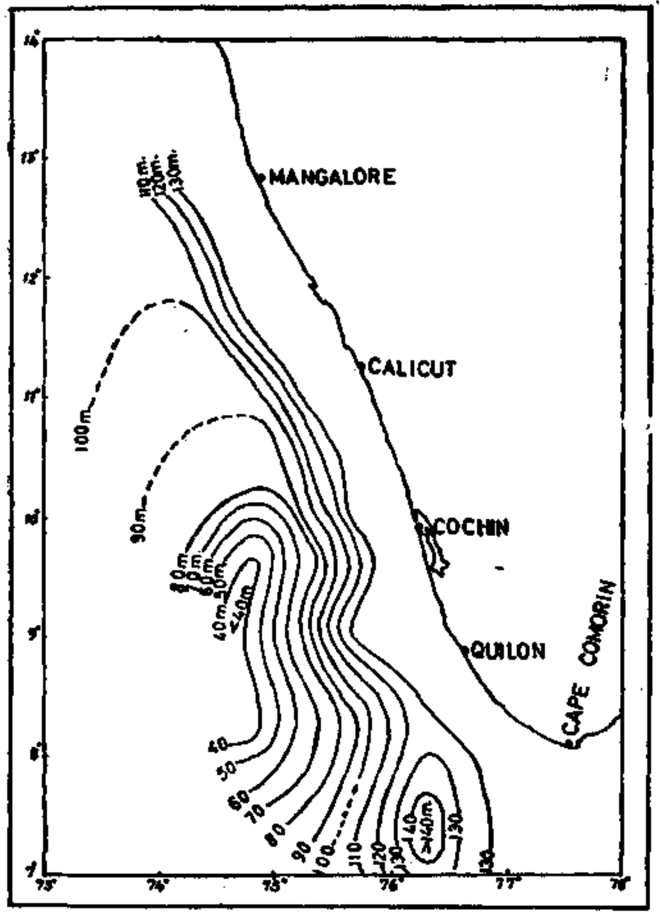
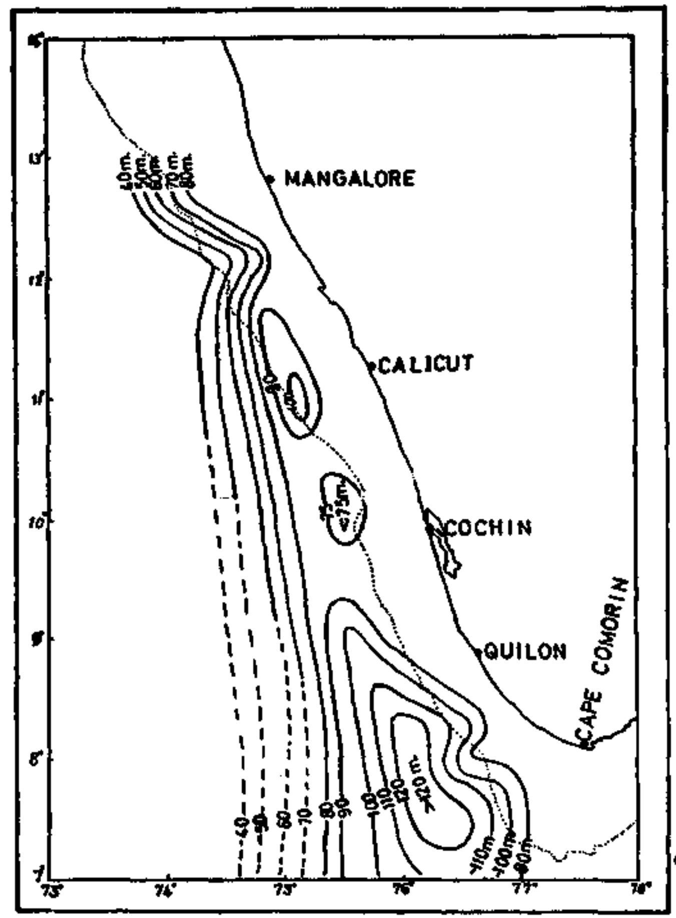


FIG. 3. Topography of the top of thermocline for February.



| FIG. 4. Topography of the top of thermocline for March.

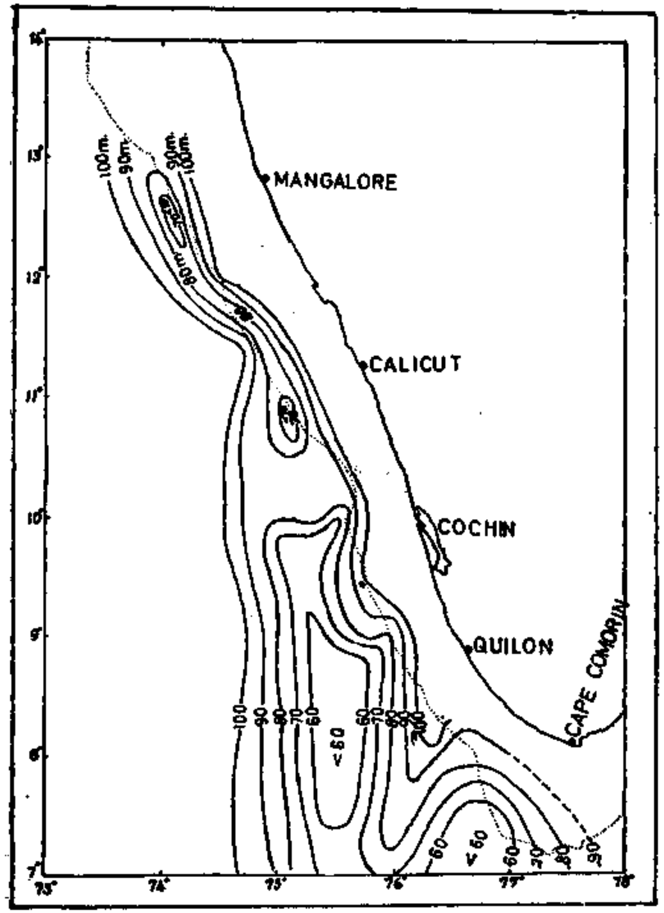


FIG. 5. Topography of the top of thermocline for April.

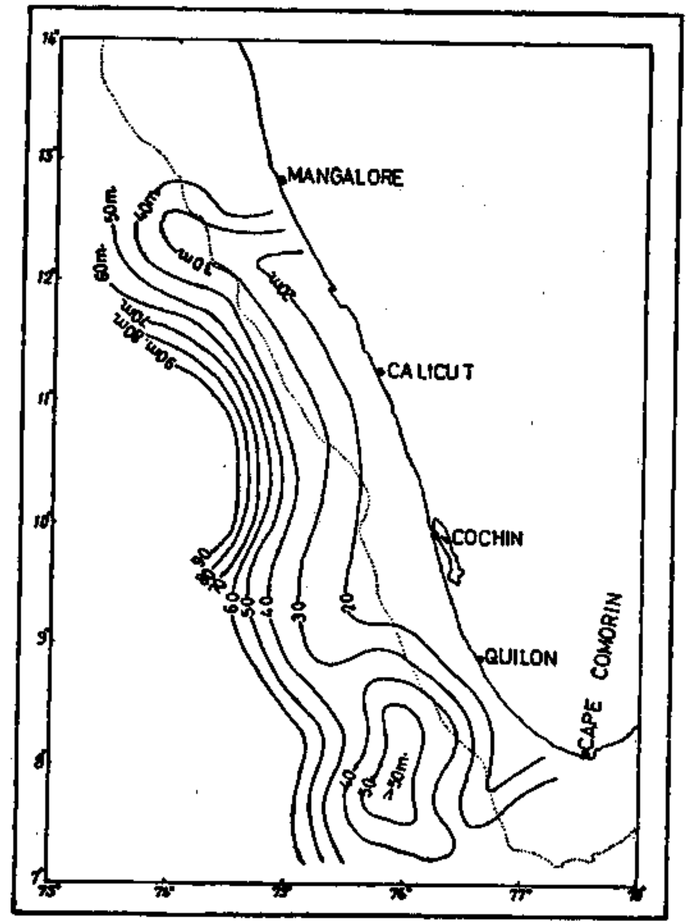


FIG. 6. Topography of the top of thermocline for May.

May, June, July and August :

In all these four months the pattern of the topography is more or less similar. The thermocline is shallower nearshore and deeper off-shore. The isolines run parallel to the coast in the months of June, July and August. A gradual upward movement of the discontinuity layer could also be seen from April to August

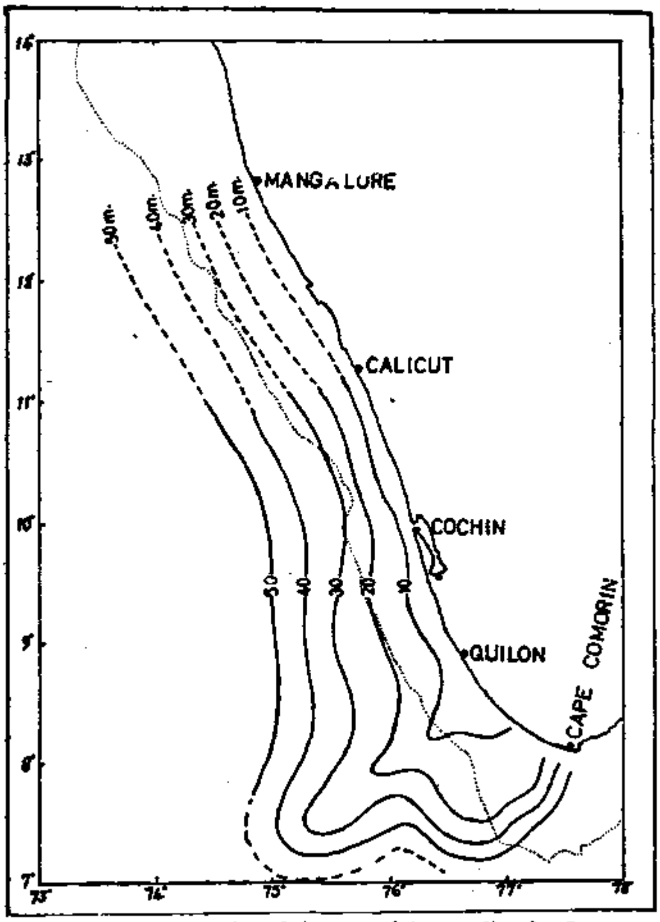


FIG. 7. Topography of the top of thermocline for June.

(Figs. 5 to 9). During this period the thermocline is almost near the surface. This is a clear evidence of upwelling. The coastal current in these months is southerly which favours upwelling. It is surprising that the thermocline is shallower in the nearshore regions during these months in spite of the strong on-shore monsoon winds which should have given rise to thick isothermal surface layer. This shallow isothermal layer seems to be the effect of upwelling.

September and October :

A slight increase of thermocline depths is apparent in September (Fig. 10). The irregular pattern of thermocline depths (Fig. 11) is perhaps due to the

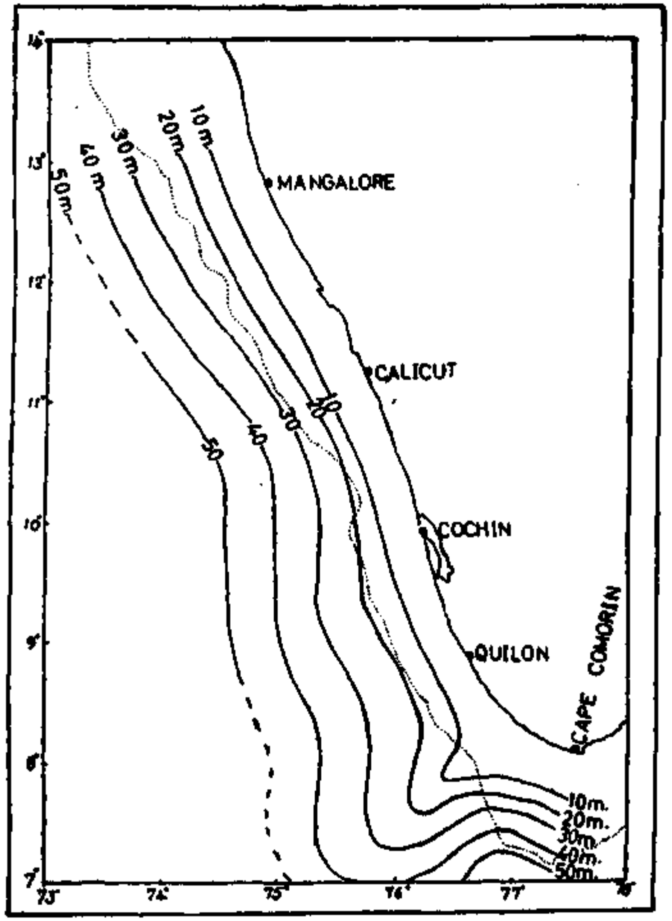


FIG. 8. Topography of the top of thermocline for July.

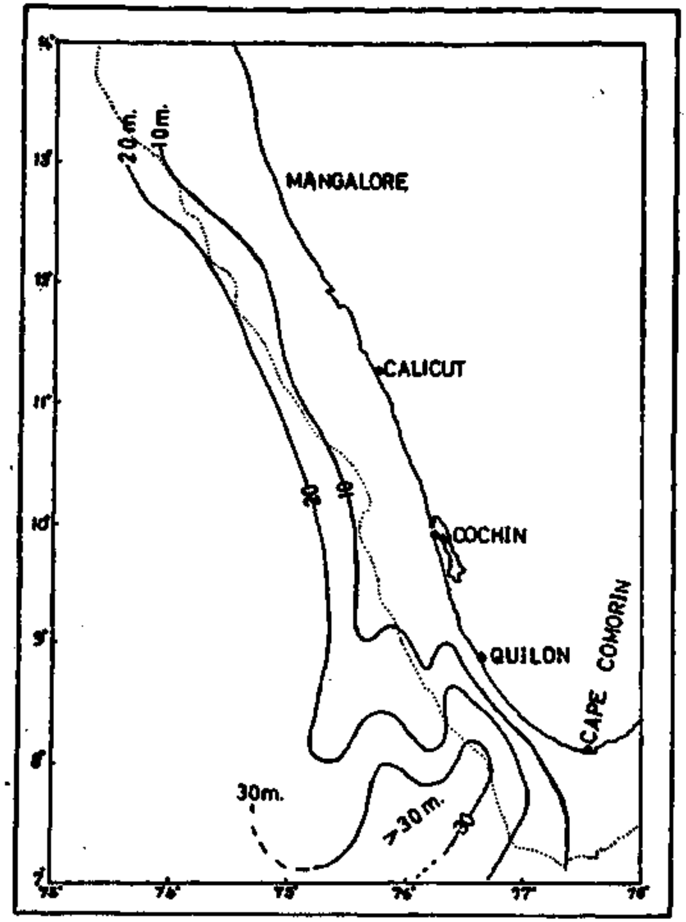


FIG. 9. Topography of the top of thermocline for August.

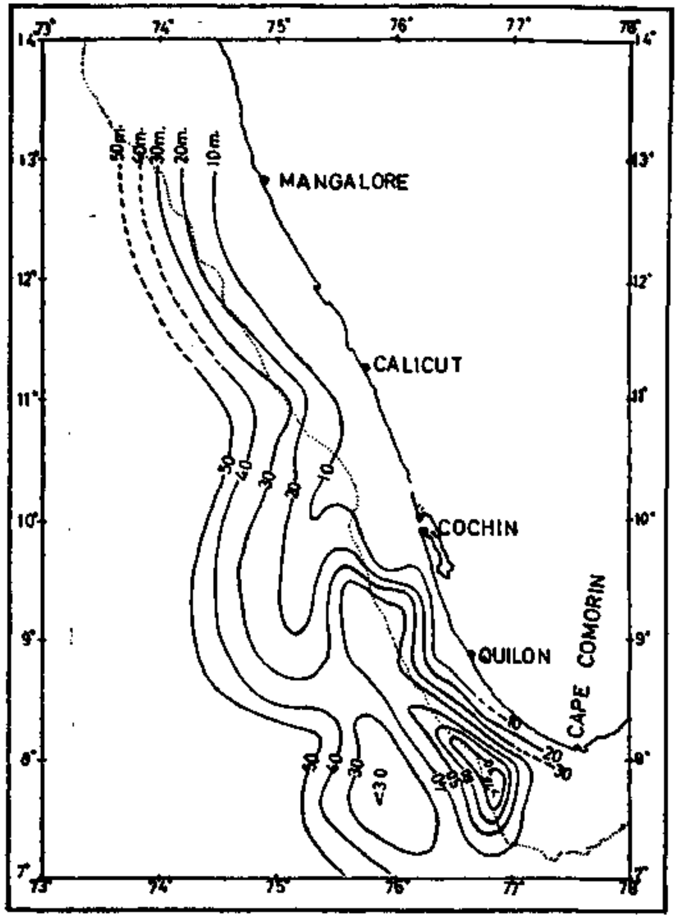


FIG. 10. Topography of the top of thermocline for September.

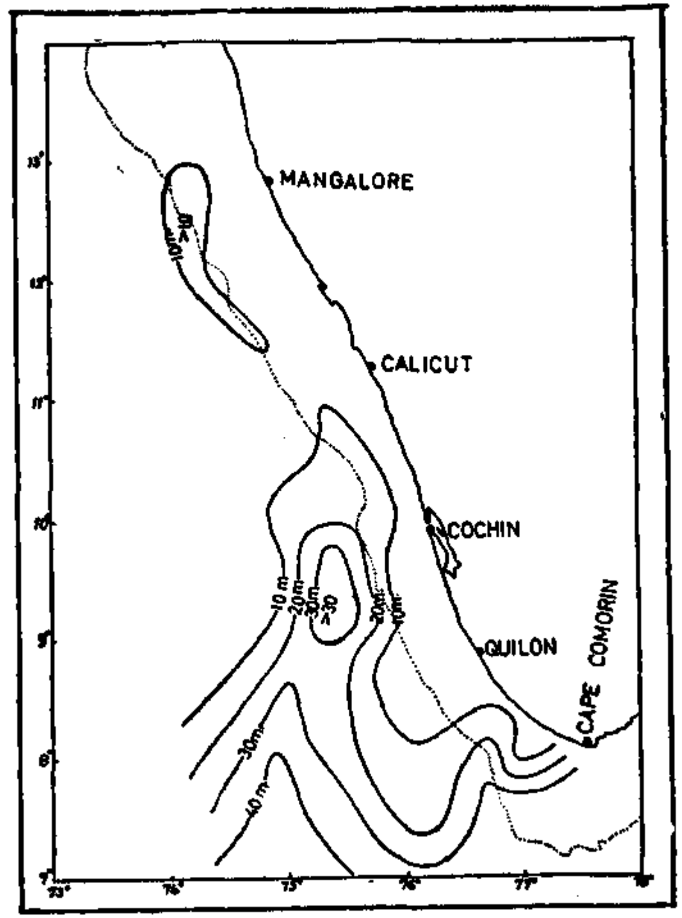


FIG. 11. Topography of the top of thermocline for October.

variation of any one of the various parameters is considered, it is not possible to get a clear picture of the commencement and cessation of upwelling and sinking.

A northerly wind driven current on the east coast and a southerly current on the west coast in the northern hemisphere induce upward motion of sub-surface water near the coast (Varadachari, 1961).

Taking into consideration the various factors that influence upwelling and applying them for the area under study, it is noticed that, in the month of February, the prevailing winds being northerly to north-easterly and with off-shore transport of the surface water, the conditions are favourable for upwelling. In the month of August the winds are south-westerly to westerly and the surface flow few miles away from the coast being easterly to south-easterly turns parallel to the coast owing to the boundary conditions giving rise to a southerly component. Further, the precipitation and river discharge near the coast stratify the surface layers opposing any tendency for upwelling. Except a slight southerly component in the current, in general, all the other conditions are unfavourable for upwelling in August and September. However, the author feels that further dynamical studies are necessary to establish the resultant of various counter balancing factors.

SUMMARY

In this paper the topographic charts representing the depth of thermocline off the west coast of India covering the area 73°30′ E. to 77°30′ E. and 07°00′ N. to 14°00′ N. for one year and also the time section of temperature off Cochin for the period March 1964 to August 1965 are presented to infer upwelling and sinking.

In the area under consideration the thermocline depth does not exceed 150 meters in any month of the year and it is deepest in the months of January and February. There is a gradual upward tilting of the thermocline towards the coast from February onwards and it almost reaches the surface by July indicating an upward movement of water from sub-surface depths. This condition is maintained till the end of August after which the tilting of the thermocline is reversed indicating sinking near the coast.

The vertical variation of temperature with time gives a clear indication of the vertical movements of the waters. The time of commencement of upwelling varies from depth to depth. At depths greater than 100 meters it occurs around February and the upwelled water gradually reaches the surface by May. Upwelling ceases by July/August and sinking is present from September to January.

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