SEASONAL VARIATIONS IN THE HYDROGRAPHIC FEATURES ALONG THE SOUTHWEST COAST OF INDIA

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ABSTRACT

The seasonal variations of the hydrographic features in a quasimeridional hydrographic section from Cape Comorin to Karwar is presented and discussed. The average depth up to which the investigations are extended is 300 metre. The paper embodies data for the period 1957-1967, which have been averaged. Attention is drawn to the latitudinal and bathymetric variation in the hydrographic features.

INTRODUCTION

The hydrographic features along the west coast of India have been investigated by a number of workers (Sastry *et al* 1959, Carruthers *et al* 1959, Sastry 1959, Ramamirtham *et al* 1960, 1963 and 1965, Ramamirtham 1967 and 1968, Sharma 1966 and 1967, Patil *et al* 1964, Rao *et al* 1964, Murty 1967), but an integrated picture is wanting. A preliminary study in a hydrographic section off Cochin has been made by Ramamirtham *et al* (1959). Rao *et al* (1973) have studied the surface hydrographic features in relation to the pelagic fisheries along the west coast of India. In the present paper, the data for the ten-year period (1957-1967), collected by the Central Marine Fisheries Research Institute, from the region 8° N to 15° N between the coast and the vertical plane in a quasi-meridional direction, extending up to 300-metre depth have been taken into consideration.

MATERIALS AND METHODS

The data for nearly 3000 hydrographic stations collected during the cruises of the erstwhile Indo-Norwegian Project vessels, R. V. *Kalava* and R. V. *Varuna* have been analysed for this purpose. The hydrographical parameters namely temperature, salinity and dissolved oxygen content have been averaged out monthwise for each depth for each zonal belt, considering all the stations falling between the reference latitudes. The values are presented as monthly distribution charts for the arbitrary meridional section, in the vertical plane.

DISTRIBUTION OF PROPERTIES

January (Fig. 1A)

During January, a clearly demarcated mixed layer, which is mostly isothermal, is observed between 0 and 60 m along the whole section. The meridional

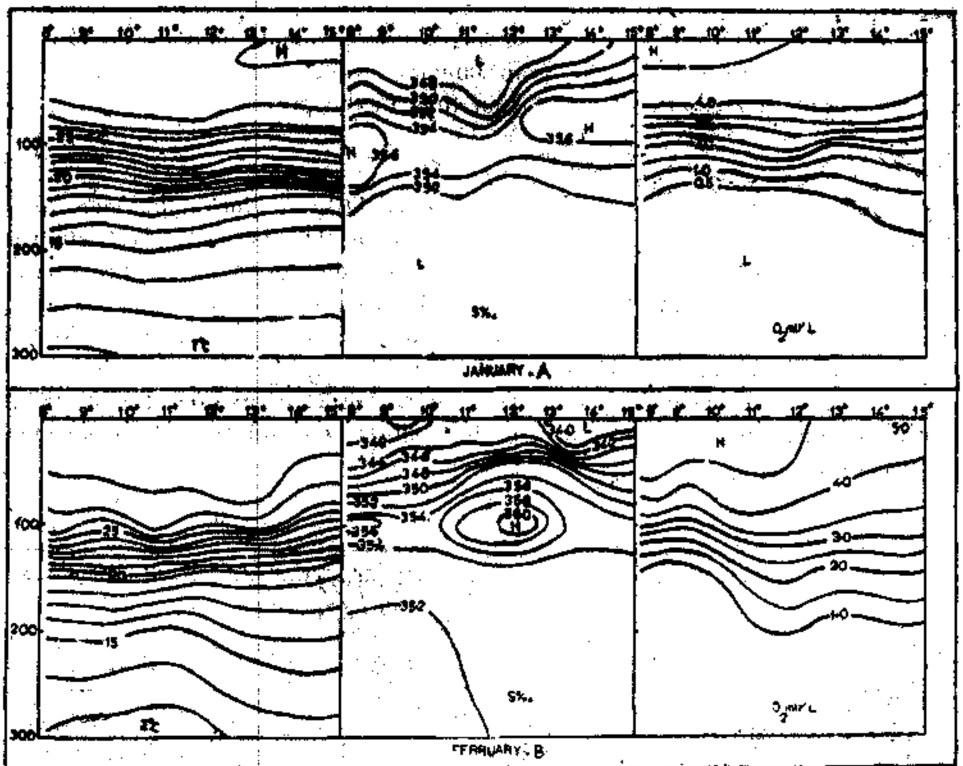

FIG. 1. Distribution of temperature, salinity and dissolved oxygen in the meridional section during January and February.

distribution in the subsurface layers is also uniform. The well-stratified thermocline is conspicuous from 75 m downwards to 200 m. The salinity distribution shows two high-saline zones within the thermocline in the extreme north and south. Towards the south, the distribution of salinity in the mixed layer is more or less uniform, but, due north of 13° N, a northward increase in salinity is observed. A steady ascendant is observed from the top of the thermocline down to 200 m, below which the values are lower and the distribution is uniform. The oxygen dificit layer starts from the top of the thermocline, and the oxygen minimum zone is conspicuous between 150 and 300 m.

February (Fig. 1B)

The vertical extent of the surface mixed layer is found to be slightly reduced during February, although the temperature ranges are comparable to those during January. The surface layers are slightly warmer than those in January, and the thermocline starts at about 80 m and extends down to 200 m. An overall decrease in salinity is observed during this month as can be noticed from the low saline zones in the extreme north and south. The intensity of the salinity maximum is clearly high and the juxtaposition of the same is similar to that in January. The distribution of dissolved oxygen in the mixed layer and the thermocline are mostly the same as in January while the values within the oxygen-minimum zone are a little higher than in the previous month.

March (Fig. 2A)

The vertical extent of the surface mixed layer is almost the same as in January and the thermocline starts at about 80 m. The vertical stratification of the thermocline is more stronger. In contrast to the previous months, salinity values are distinctly higher towards the north, from 11° N. Even in the mixed layer an ascendant is observed downwards and the salinity maximum is located within a tongue proceeding south, in the region of the thermocline. The salinity values in the mixed layer are greater than in the previous months. Below 150-m depth, the distribution is uniform. The distribution of dissolved oxygen is similar to that of February.

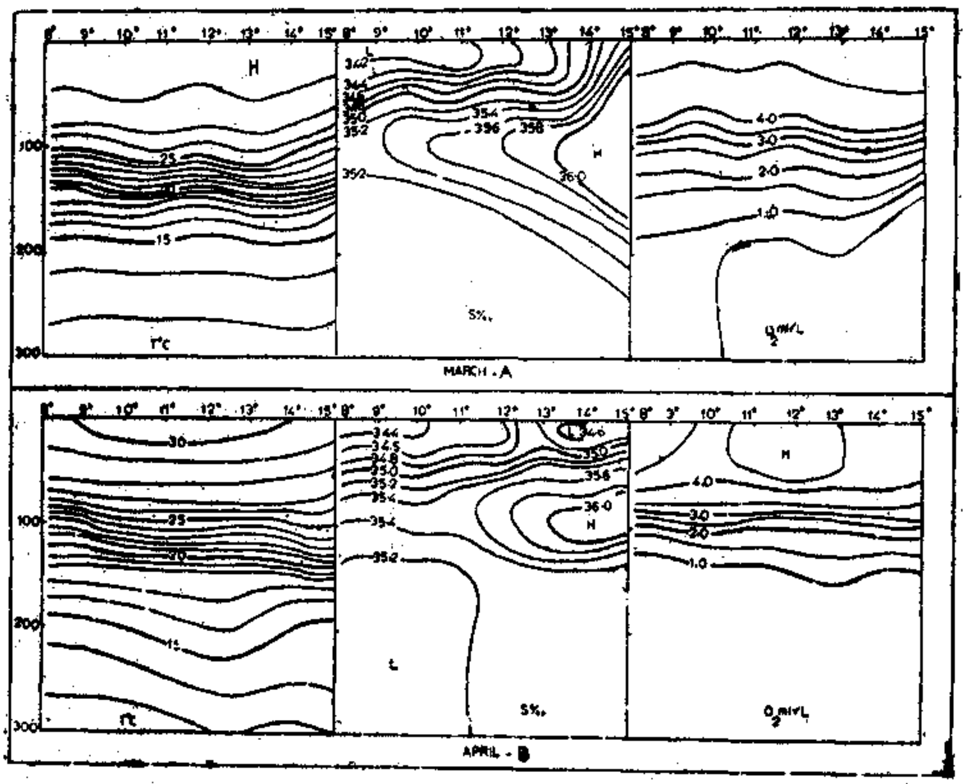

FIG. 2. Distribution of temperature, salinity and dissolved oxygen in the meridional section during March and April.

April (Fig. 2B)

By the approach of summer, during April, the waters have become warmer along the coast and thus there is an increase of 2°C in the temperature in the mixed layer, which is not so well defined as in March. The temperature discontinuity starts from 65-m depth, and consequently, the vertical extent of the well stratified thermocline which extends down to 200 m is observed to be greater. A sinking of the northern high-saline water towards the south is conspicuous, and the dissolved-oxygen content in the mixed layer are higher than those existing in March. The oxygen-minimum layer is observed below 150-m depth.

May (Fig. 3A)

The distribution of temperature during May is characterised by the formation of vertical gradients in the mixed layer, a feature quite dissimilar to that occuring during the previous months, except April, when it is found that it occurs with lesser intensity. Thus, the mixed layer, in the strict sense, is comparatively thinner. The surface waters are again warmer than the previous

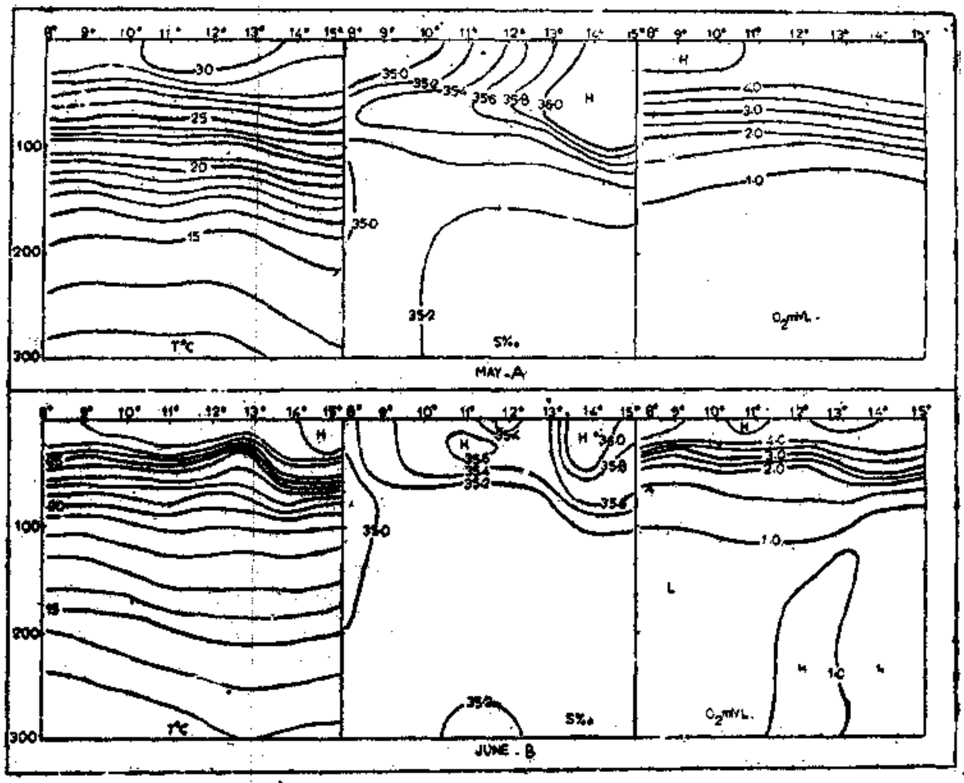

Fig. 3. Distribution of temperature, salinity and dissolved oxygen in the meridional section during May and June.

months. The thermocline appears to start at about 50 m and extends down to 200 m. The salinity pattern indicates the presence of a tongue of high-saline water extending from north to south in the upper part of the thermocline. This gives rise to the southward gradients of salinity in the surface layers. The dissolved-oxygen values are again higher as in April. The oxygen-minimum layer is now found below 150-m depth.

June (Fig. 3B)

By the onset of the southwest monsoon, during June, the temperature values in the mixed layer have decreased. Thus the temperature of the mixed layer have gone down by two degrees, compared to the month of May. The vertical extent of the mixed layer has also reduced and the latter extends only up to 25 m on an average from the surface. The thermocline starts at an average depth of 25 m and the vertical stratification of the same is comparatively weaker below 100 m than the region above it. Thus an upward migration of the thermocline as a whole is conspicuous during June. The tongue of high salinity observed during May has dissipated and cell-like formations are evident in the surface layers. In the northern regions a tongue-like pattern is observed with a high-saline core within the tongue. Values decrease southwards and around 8° N, the value is nearly less by 1% than the northern regions. Spreading of the thermocline in the lower strata is reflected in the oxygen distribution also. Thus the oxygen-deficit layer is much thinner compared to May, and the oxygen-minimum layer starts at 100 m, whereas in the former months it was observed at 150 m. The vertical extent of the oxygen-minimum layer is more during June than the previous months.

July (Fig. 4A)

During July, the vertical stratification of the thermocline has become weaker, although the vertical extent of the thermocline is more. As in June, the higher temperatures of 28°C upward are observed in the northernmost regions and the mixed layer is virtually absent in the southern regions. Thus, the thermocline is observed at lower depths than those at which it occurred in June. The southward tongue-like extension of high saline waters is observed, with the salinity maximum in the northern regions (36.0%°). Below 100-m depth, the distribution of salinity is highly uniform. The upward migration of the thermocline is again reflected in the gradients in oxygen values which start even from 10 m downwards in the southern regions. The effect of the monsoon in bringing up the subsurface waters is not so conspicuous in the northern regions as can be seen from the temperature and oxygen distribution patterns.

August (Fig. 4B)

The discrepancy noticed in the temperature distribution in the northern regions during July, is found to be absent during this month. But the stratification of the thermocline is weaker and thus spreading of the thermocline is noticed.

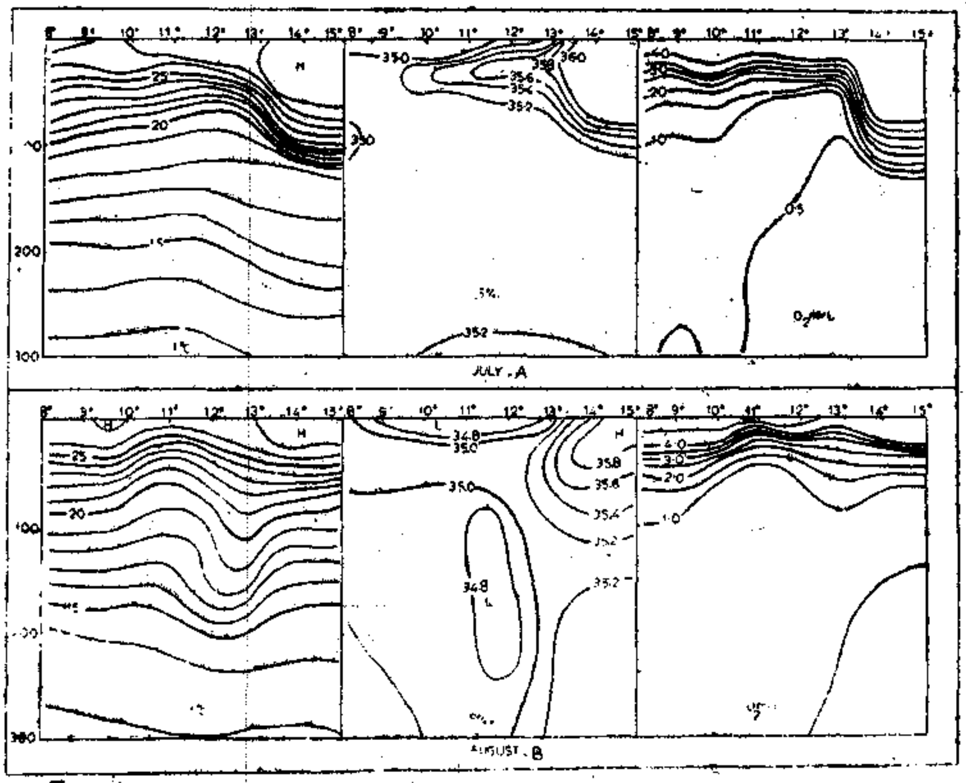

FIG. 4. Distribution of temperature, salinity and dissolved oxygen in the meridional section during July and August.

Except for two small high temperature cells in the extreme north and south, the vertical temperature gradients are observed from even 10 m downwards. Thus the mixed layer is mostly obliterated. The distribution of salinity in the upper layer in the northern regions is comparable to conditions in July. An overall decrease in the salinity values is observed in the upper layers. The distribution of dissolved-oxygen content is similar to that of the temperature, in the sense, that the oxygen discontinuity layer is found to have migrated even up to the surface layer. A well-defined oxygen-deficit layer is observed from 75 m downwards. The upward migration of the oxygen and temperature discontinuity layers is maximum conspicuous between 11° and 12° N.

September (Fig. 5A)

With a similar trend of distribution in temperature, the vertical stratification of the thermocline is more well-defined during September than in August. The spreading of the thermocline is more conspicuous in its lower strata. A tongue-like southward extension of salinity is observed in the upper layers in the northern region with a lesser core value than during August. A more or less uniform distribution of salinity is observed below 100-m depth. The oxygen discontinuity layer is also strongly stratified as is the case with the thermocline.

October (Fig. 5B)

The absence of the surface mixed layer is characteristic of the temperature distribution during October. The reduced intensity of the stratification of the thermocline is observed in the southern regions and this spreading of the

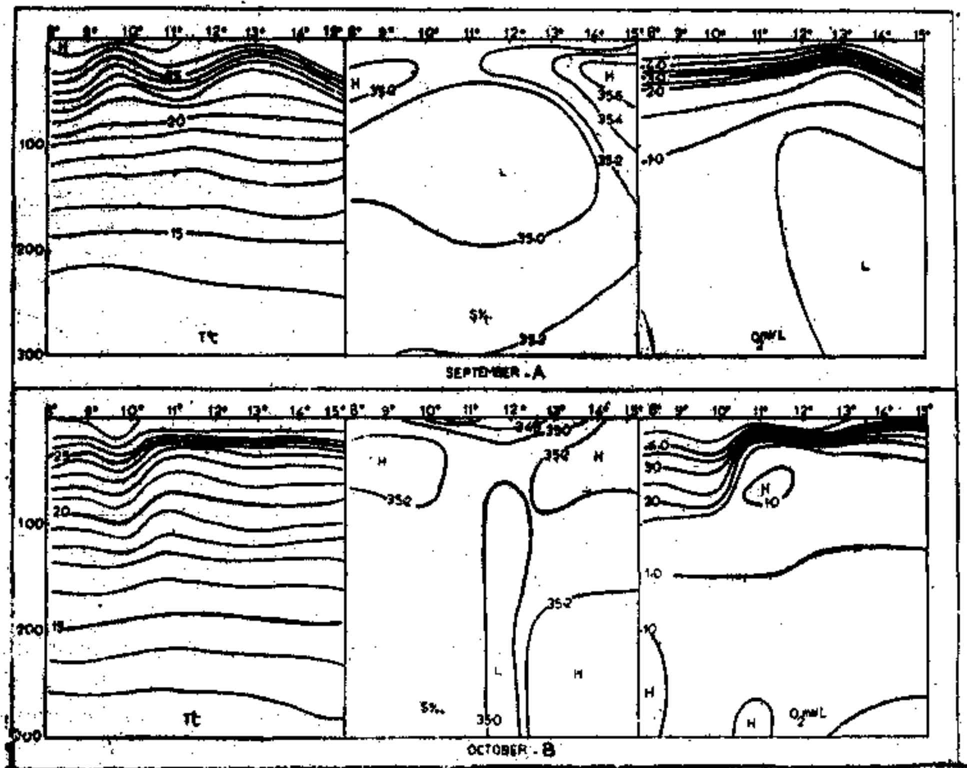

FIG. 5. Distribution of temperature, salinity and dissolved oxygen in the meridional section during September and October.

thermocline is reflected in the oxygen distribution also. The oxygen-deficit layer is found to have migrated downward to about 150 m. An overall reduction in salinity is conspicuous during October. The high salinity tongue in the northern regions seems to have dissipated and the core value of the high saline zone is much less than that in September. The surface salinity values between 10° N and 14° N are also low.

November (Fig. 6A)

During November, the effect of the southwest monsoon appears to have completely disappeared and this results in the downward migration of the thermocline and the formation of the surface mixed layer. The thermocline starts at an average depth of 75 m and extends down to 200 m with a stronger vertical stratification in the northern regions. The salinity-maximum layer has also migrated down with core values greater than 36‰. An overall increase in salinity values is also observed. The distribution of dissolved oxygen is more or less similar to that during October.

December (Fig. 6B)

During December the surface mixed layer gets completely well defined, especially in the regions south of 14° N. The thermocline is well defined and its stratification is also stronger than in November. Two high-saline cells are found to have developed in the northern and southern extremities in the section and the southward tongue-like extension is no more present. As usual, these high saline zones are found at the top of the thermocline and sinking of surface waters from about 13° N towards the south is also observed. This lowers the surface salinity values in the southern regions by 1‰ less than the northern waters.

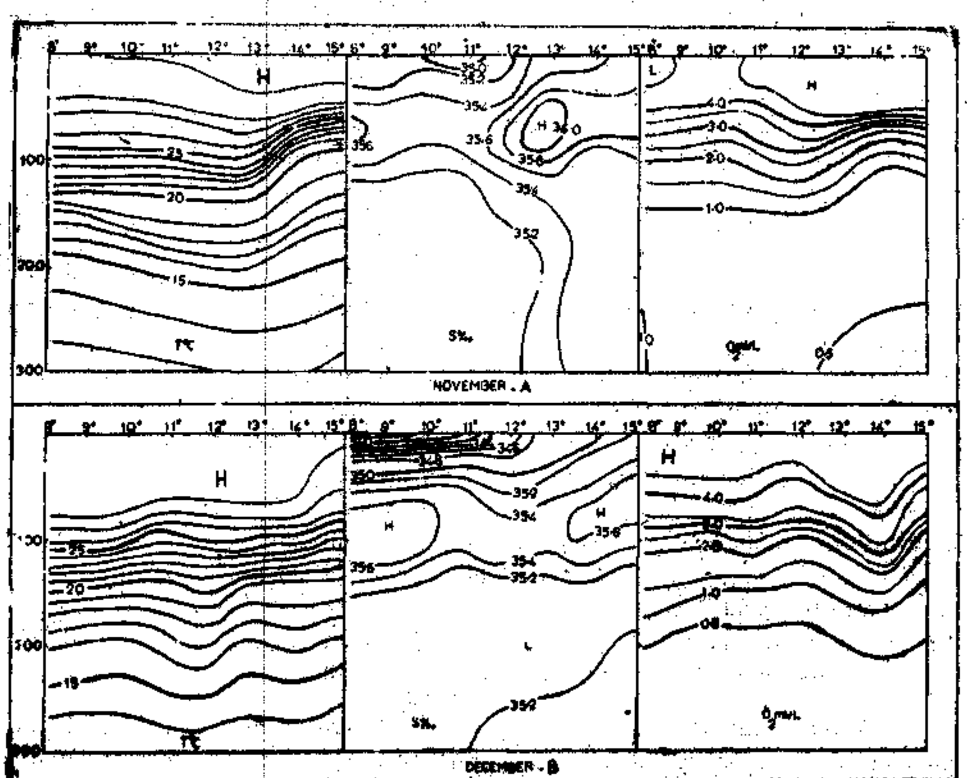

Fig. 6. Distribution of temperature, salinity and dissolved oxygen in the meridional section during November and December.

Similar to the temperature distribution, the high-oxygen zones within the surface layers are well developed during December when the top of the oxygen-deficit layer has also migrated down to about 200 m.

Discussion

The hydrographic conditions along the west coast of India undergo considerable changes with seasons. Commencing with the onset of the southwest monsoon, it may be observed that the temperature-discontinuity layer starts at a very shallow level of 20 m. The maximum temperature noticed is 28°C. The general survey of the conditions during July and August reveals that the surface mixed layer (roughly the surface isothermal layer) is more or less completely obliterated and the temperature maximum is reduced to 26.5°C on an average. The distribution patterns of dissolved oxygen content offer additional data from which it is observed that the oxygen-discontinuity layer migrates sometimes up to the surface. All these features point to the fact that coastal upwelling is existent along the west coast during the peak period of the monsoon. Gunnar (1972), while discussing the upwelling along northwest Mexico region, has stated that a close connection between the cold water regions and the divergence of Ekman transport can be expected only in areas where the vertical stability does not vanish and where there is insignificant coastal flow in the mixed layer. This hypothesis is applicable to our coast as well, when during the monsoon the thermocline is in evidence (stability noticed in the stratified layer) and thus cold water cores are observed in the upper layers during the monsoon, thereby confirming the divergence in the deeper layers.

A consideration of the distribution patterns of temperature and oxygen during July and August reveals that the intensity of the upwelling phenomenon is maximum around 11° and 13° N latitudes, (i.e., off Calicut and off Mangalore). By September, the phenomenon extends throughout the investigational belt with lesser intensity in the region south of Quilon. Thus it can be inferred that the upwelling starts in the northern regions first. Ramamirtham *et al* (1974) have shown a similar trend in upwelling along the southwest coast. In the present text, the juxtaposition of the arbitrary section being quasimeridional, the shoreward upslope of the isotherms and the oxygen-discontinuity layer as observed in zonal sections, will not be evident. But the effect of the phenomenon in lifting up the thermocline and thereby the oxygen-discontinuity layer to the surface layer can be observed. Again the coastal southward drift which is observed during monsoon also cannot be deduced from the present charts.

Another important feature deserving consideration is the surface sinking phenomenon. A study of the temperature- and salinity-distribution patterns during December shows that the southwards sinking of the surface water occurs meridionally. Ramamirtham *et al* (1965) have postulated that the region around

13° N is one where an abrupt increase in the salinity values occur northwards. Thus, sinking of isohalines in the region between 11° N and 14° N can clearly be observed during November and December.

During February, the sinking phenomenon mostly subsides and the spreading of the mixed isothermal layer is observed. The summer heating is most conspicuous in April and May. The observed thermal gradients in the mixed layer during this month may be due to the solar heating of the surface layer coupled with the static nature of the immediate subsurface waters as evidenced from the data available.

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