

Sea temperature variations in the northeastern Arabian Sea in relation to the southwest monsoon

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The structure and variability of the temperature in the upper layers (0–200 m) of the northeast Arabian Sea have been studied in relation to the southwest monsoon over the Indian peninsula. Data from repeated bathythermograph (BT) lowerings at three-hourly intervals at a station around 18° N, 67° E during the periods 28 to 31 May 1973 and 29 June to 2 July 1973 (representing conditions before and after the onset of the monsoon) have been used for these studies. Mean temperature differences and autocorrelation coefficients have been computed and analysed for assessment of short-period variations.

The mixed layer was well developed with an average thickness of about 70 m during the monsoon period, while its thickness was about 40 m during the premonsoon period. The thermal structure reveals the presence of internal waves in the thermocline.

Studies of short-period variations indicate that changes of temperature occur in the upper part of the thermocline during the premonsoon and monsoon periods; however, the maximum temperature changes for the monsoon period are generally larger (ranging from 0.8 °C for a 3-hour interval to 1.2 °C for 9-hour and 12-hour intervals) than those for the premonsoon period, which are of the order of 0.8 °C for time intervals up to 12 hrs. Autocorrelation values reveal significant correlation (at the 1 % level) in the upper part of the mixed layer for intervals greater than 3 hours, the feature being more prominent during the monsoon period. Within the thermocline, significant correlation has been found around 170 m depth for intervals greater than 6 hours during the premonsoon period and

around 80 m depth for intervals greater than 3 hours during the monsoon period. The magnitude of the temperature changes do not seem to bear any definite relationship to the degree of correlation.

32.1 Introduction

Sea temperature varies with depth and time as a result of several factors, such as insolation, wind mixing, internal waves, advection of waters of different temperatures, tidal currents, etc. (La Fond, 1954). Changes in sea temperature are generally significant in the upper few hundred metres only. Notable among the earlier works describing the nature of temperature variability in the upper layers of the sea, are those reported by La Fond and Moore (1960 and 1972) for the regions off the coasts of Southern California and Andhra.

Studies based on the data collected during the International Indian Ocean Expedition (IIOE) have revealed that the interaction of the southwest monsoon with the Arabian Sea is quite strong and significantly affects the thermal structure of the sea, especially in the upper layers (Colon, 1964; Sastry and D'Souza, 1970; Wyrki, 1971). A detailed investigation of the variability of temperature in the upper layers of the Arabian Sea in relation to the southwest monsoon is, therefore, of special interest.

During May–July 1973, a joint Indo-Soviet Monsoon Experiment (ISMEX) was conducted in the northwestern Indian Ocean (including the Arabian Sea) to gather more information on the meteorological and oceanographic conditions associated with the various phases of the southwest monsoon as a prelude to the detailed study to be carried out during the International Monsoon Experiment (MONEX) planned for 1979.

In this chapter, a comparative study of the vertical temperature structure in general, and short-period temperature variations in particular, in the upper layers of the northeastern Arabian Sea is attempted using the bathythermograph (BT) data collected near a buoy positioned in the area during the ISMEX.

32.2 Data and methods

Data from repeated BT lowerings at three-hourly intervals, carried out on board the Soviet research vessel *Priliv* near a buoy station at 18° N,

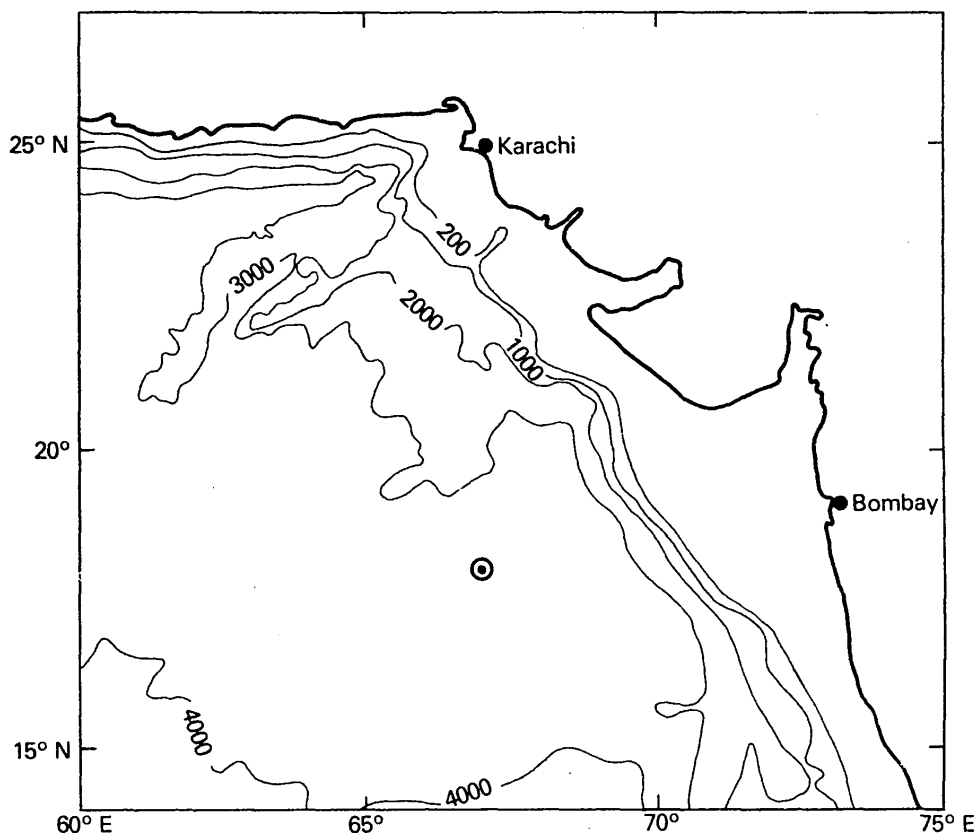


Fig. 32.1. Station location (lower left of centre). The contours of ocean depth are labelled in metres.

67° E (Fig. 32.1), are used in the present study. Data collected during the periods 28 to 31 May and 29 June to 2 July are chosen to represent the premonsoon and monsoon conditions respectively. With the processed BT data, vertical time sections of temperature up to 200 m depth are prepared for the two periods to compare and evaluate the gross changes in the vertical temperature structure.

Methods of power spectrum and harmonic analysis are considered to be appropriate for describing short-period variations when a long series of data is available. But, in the present study, as the data are for a short duration (3 to 4 days for each situation) two different methods (La Fond and Moore, 1960), employing mean differences and autocorrelation coefficients, have been used for assessing the short-period temperature variations. The computations have been carried out using the BT data processed for 10 m depth intervals.

In the differences method, the average change of temperature in a given time interval at a particular depth is computed from

$$D_\lambda = \frac{\sum_{i=1}^{N-\lambda} |(X_i - X_{i+\lambda})|}{N-\lambda},$$

where D_λ is the average magnitude of the temperature differences ($^{\circ}\text{C}$) in a given time interval, X_i and $X_{i+\lambda}$ are the temperatures ($^{\circ}\text{C}$) at the beginning and end of a given time interval, λ is the time interval used (in the present case 1, 2, 3 and 4 corresponding to 3-hours, 6-hours, 9-hours and 12-hours intervals respectively), and N is the total number of temperature readings at a given depth ($N = 28$ for the first period, $N = 31$ for the second period in the present case).

In the second method, the general dependence of the temperature values at one time on the values observed at another time for a particular depth, is evaluated by computing the autocorrelation coefficient, R_λ , given by

$$R_\lambda = \frac{(N-\lambda) \sum_{i=1}^{N-\lambda} X_i X_{i+\lambda} - \sum_{i=1}^{N-\lambda} X_i \sum_{i=1}^{N-\lambda} X_{i+\lambda}}{\left[(N-\lambda) \sum_{i=1}^{N-\lambda} X_i^2 - \left(\sum_{i=1}^{N-\lambda} X_i \right)^2 \right]^{\frac{1}{2}} \left[(N-\lambda) \sum_{i=1}^{N-\lambda} X_{i+\lambda}^2 - \left(\sum_{i=1}^{N-\lambda} X_{i+\lambda} \right)^2 \right]^{\frac{1}{2}}}$$

32.3 Results and discussion

Vertical time sections of temperature for the premonsoon and monsoon periods are shown in Figs. 32.2a and b respectively. A comparison of the two sections reveals that the mixed layer† is well developed with an average thickness of about 70 m during the monsoon period, while its thickness is only about 40 m during the premonsoon period. A significant fall (about 1°C) of the temperature of the surface mixed layer from the premonsoon period to the monsoon period is noticed. These features, which could be attributed to the effects of strong winds, clouding and rain associated with the monsoon, are in agreement with those reported earlier by Ramesh Babu *et al.* (1976) and Gangadhara Rao *et al.* (1976). The spreading of thermocline in its lower part, resulting in relatively weak thermal gradients at 100 to 150 m depth, is significantly different during

† In the present study, a vertical temperature gradient of $2^{\circ}\text{C}/(25\text{ m})$ is taken as the lowest limit of the thermocline, after Schott (La Fond and Rao, 1954) and the warm top layer of relatively low gradients of temperature above the thermocline is referred to as the mixed layer.

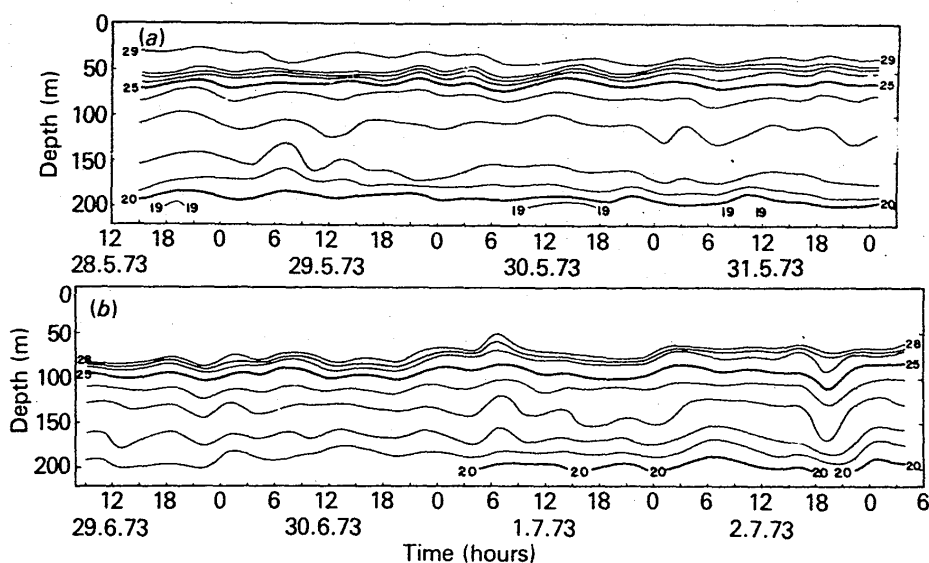


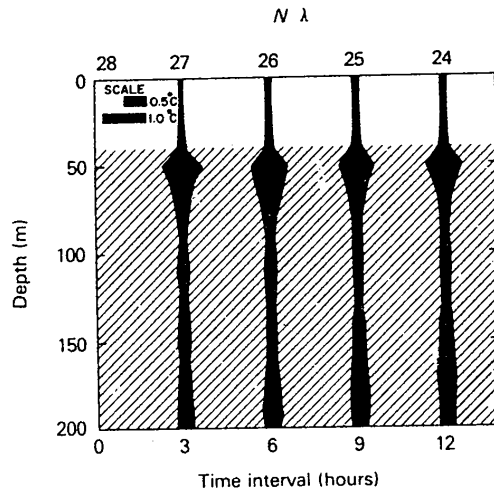
Fig. 32.2. Vertical time sections of temperature for: (a) 28 to 31 May 1973; and (b) 29 June to 2 July 1973. Contours are labelled in $^{\circ}\text{C}$.

the premonsoon and monsoon periods. The presence of internal waves is indicated by the regular wavy pattern exhibited by the isotherms of the thermocline during both periods.

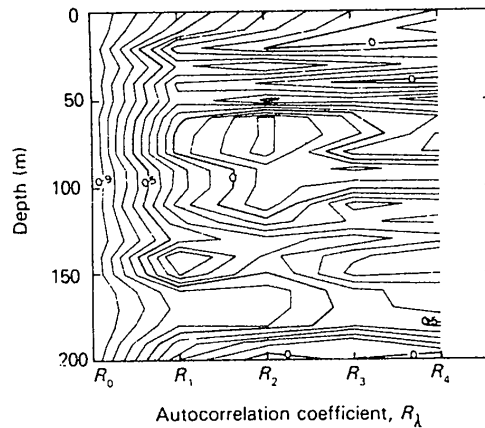
The results of a statistical analysis of the two sets of data describing the short-period temperature variations during the premonsoon and monsoon periods are presented in Figs. 32.3 and 32.4 respectively.

Figs. 32.3a and 32.4a show the average temperature differences (D_{λ}) for intervals of 3 hours, 6 hours, 9 hours and 12 hours. The effect of instrumental (and scaling) errors on the variation depicted by this method can be taken as very small because only the differences are considered here and not the actual temperatures. The width of the solid line is proportional to the average temperature difference, D_{λ} , at that depth for the time shown. The upper limit of shading represents the depth of the thermocline. The relatively wide range in the depth of the thermocline observed during the monsoon period is indicated in Fig. 32.4a by shading with alternate short and long diagonals.

In the mixed layer, the average temperature differences were of the order of 0.2°C during the premonsoon period. They were less than 0.1°C (which is the limit of accuracy of the instrument) during the monsoon period, reflecting rather steady environmental conditions which result in the persistence of a well-developed mixed layer for a longer duration during this period. Within the thermocline, the differences varied with



(a)



(b)

Fig. 32.3. Short-period variations of temperature 28 to 31 May 1973. (a) Average differences (D_λ); (b) autocorrelation coefficient (R_λ) for $\lambda = 0, 1, 2, 3, 4$.

depth, the maximum differences being encountered in the upper part of the thermocline (where stronger temperature gradients exist) during both periods. The maximum differences for the monsoon period were generally more (ranging from about 0.8°C for a 3-hour interval to 1.2°C for 9-hour and 12-hour intervals) than those for the premonsoon period, which were of the order of 0.8°C for time intervals up to 12 hours.

A secondary maximum of average differences (of the order of 0.4°C) was observed at around the 180 m depth, where the thermal gradients were relatively higher during both the periods (Fig. 32.2). These features, which are more prominent during the monsoon period, reflect the effect

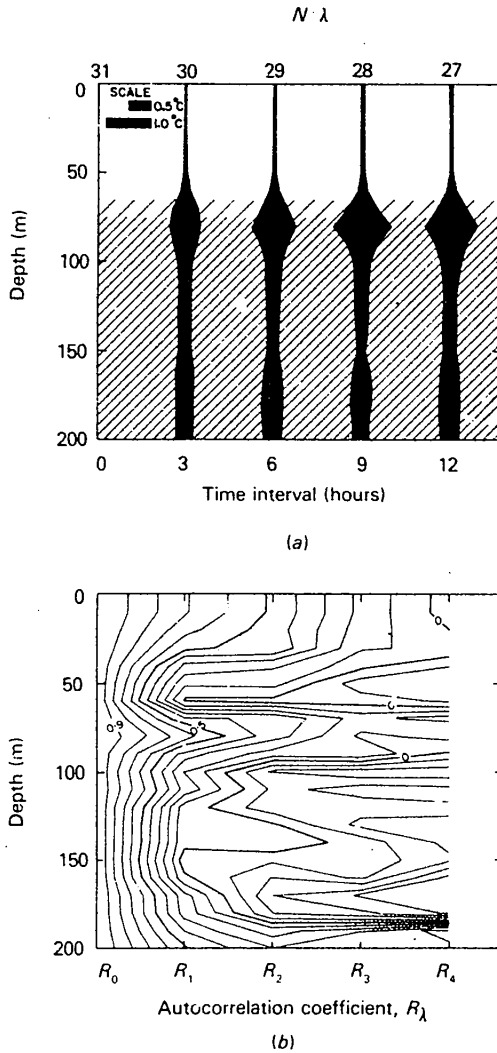


Fig. 32.4. Short-period variations of temperature 29 June to 2 July 1973. (a), Average differences (D_λ); (b) autocorrelation coefficient (R_λ) for $\lambda = 0, 1, 2, 3, 4, 0, 1, \dots, 4$.

of vertical oscillations associated with internal waves in the thermocline region (La Fond and Rao, 1954).

Analyses of autocorrelation coefficients (R_λ) for the two periods are shown in Figs. 32.3b and 32.4b. Autocorrelation values R_1 to R_4 have been contoured using linear interpolations with respect to time and depth. For a significant (1%) level of correlation, R_λ works out to be about 0.5 for both sets of data. The areas with less significant values are stippled in these figures.

In the upper part of the mixed layer, significant correlation between successive values was encountered for intervals of more than 3 hours,

beyond which the correlation decreased with time. This feature is more prominent during the monsoon period than in the premonsoon period. A general increase in correlation was observed in the lower part of the mixed layer during the premonsoon period, while no such increase was noticed during the monsoon period. In the upper part of the thermocline, where the maximum average differences were encountered, an increase in correlation is noticed during both the periods, the feature being more prominent (with significant correlation for more than 3 hours) during the monsoon period. It is interesting to note that significant correlation was maintained for intervals much larger than 6 hours around the 170 m depth during the premonsoon period, suggesting a possible intense mixing in this layer.

The preceding discussion confirms that methods employing temperature differences and autocorrelations to describe temperature variability are quite useful, generating estimates which provide a basis for discussion of the physical processes responsible for the variability. The magnitudes of the temperature changes do not seem to be necessarily related to the degree of correlation.

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