Sea Temperature Variations Off the East Coast of India

E. C. LAFOND
Naval Undersea Centre, San Diego, California 92132, USA

and

A. T. MOORE
Scripps Institution of Oceanography, La Jolla, California 92037, USA

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Analysis of variation of temperature with time, made from repeated bathythermograms taken at three locations off the east coast of India, indicates that the greatest changes in temperature occurred at a depth related to that of the thermocline. It is suggested that the combination of temperature differences and auto-correlation values might be used to express variability and to provide a clue to the processes contributing to variability in the area.

Changes in temperature at the sea surface and at various depths are generally attributed to several factors, among which are the advection of water of different temperatures into a given area, radiation from the sun, mixing by wind, tidal current, internal waves, and a number of others. As so many factors are continually changing the sea temperature, it is difficult to adequately describe its structure and variability. Two approaches, viz. one in terms of temperature differences and the other in terms of auto-correlation values, are used in this paper.

Data

Many temperature data were available for the analysis because it has been the practice to measure sea temperatures by means of a bathythermograph on all oceanographic cruises conducted by the Andhra University. The data selected as most suitable for a study of variability are three sets of repeated hourly observations as follows:
(i) Cruise 2, INS Konkin, Stations 24, 24 A-Z, 24 AA in deep water off the edge of the continental shelf off the Andhra coast, 29-30 October 1952.
(ii) Cruise 4, INS Bengal, Stations 126 A-X, on the outer part of the continental shelf, 17-18 February 1953.

Previous analyses of these and similar data have been reported.

For the present work, temperatures from the bathythermograms taken at the deeper stations were scaled off every 20 ft from the surface to 400 ft. Temperatures from the near-shore station were scaled off at 10 ft intervals to 60 ft, the depth of the bottom at this location. All the scaled temperature values were punched on IBM cards and computations carried out by means of electronic computers.

Results

Differences — The first measure used for analysing the data was the average magnitude of increase or decrease of temperature at a given depth in a given time; this measure was computed by the formula.

\[
D_A = \frac{\sum_{i=1}^{N-\lambda} (X_i - X_{i+\lambda})}{N-\lambda}
\]

where \(D_A\) is the mean of the temperature differences (\(^{\circ}\)F) in a given time interval; \(X_i\) and \(X_{i+\lambda}\) are the temperatures (\(^{\circ}\)F) at the beginning and end of a given time interval; \(\lambda\) is the time interval used in hours (\(\lambda\) is 0, 1, 2, 3 and 4 for all three sets of data); and \(N\) is the total number of temperature readings, at a given depth and location (\(N\) is 26 for all three sets of data).

Statistical analysis of the three sets of data by means of this measure is given in Figs. 1A, 2A and 3A. Some of the variation must be attributed to instrumental factors, for example, thermal and pressure lag, mechanical friction, and hysteresis. However, it is believed that instrumental (and scaling) errors amount to less than 0.2\(^{\circ}\)F. An important factor keeping such errors small is that differences are considered rather than the actual temperature.

Fig. 1A is for winter conditions in deep water just off the continental shelf off the central east coast. The width of the solid line in Fig. 1A is proportional to the average temperature difference, \(D_A\), at that time and depth. The fine diagonal lines represent the depths of the thermocline. The figure shows that, above the thermocline, the average difference was less than 0.4\(^{\circ}\)F. However, in the thermocline, differences ran from 1.1\(^{\circ}\)F for 1 hr to as much as 2.6\(^{\circ}\)F for 4 hr. This larger change indicates a disturbance such as vertical oscillations or internal waves at the thermocline.

A similar presentation of average temperature differences for the station over the outer part of the shelf is given in Fig. 2A. In the upper 100 ft above the thermocline, the average difference was less than 0.4\(^{\circ}\)F. In the thermocline, the temperature variation was greatest amounting to 1.4 and 1.5\(^{\circ}\)F in 4 hr around 300 ft where the thermocline was sharpest. Since the temperature gradient in the thermocline varied with depth, so did the change in temperature vary with depth. Again, this result indicates possible internal waves in the thermocline.
The average temperature differences at the nearshore station are shown in Fig. 3A. They were very small, from the surface to bottom. After 1 hr, the maximum average difference at any level was only 0.1°F which is almost the limit of accuracy of the instrument. The greatest differences were at the surface, but these averaged only 0.3°F in 4 hr.

**Autocorrelations** - The second method used for expressing variability was by means of autocorrelation coefficients. The technique is to correlate one temperature with the next observed temperature at that depth level, for intervals of half or whole hours, using the following expression:

\[
R_A = \frac{(N-\lambda) \sum X_i X_{i+1} - \sum X_i \sum X_{i+1}}{\left[ (N-\lambda) \sum X_i^2 - (\sum X_i)^2 \right]^{1/2}}
\]  

where \( R_A \) = autocorrelation coefficient. For a significant (1%) level of correlation, and \( R \) is 0.51 for 25 values.

Autocorrelation values \( R_1 \) to \( R_4 \) were contoured, using linear interpolations, with respect to time and depth; the results are presented in Figs. 1B, 2B and 3B.

The deep water data show that, although the changes of temperature with time were exceedingly
small near the surface, these changes were apparently random, and the correlation between values for successive intervals fell off greatly with time (Fig. 1B). However, in the lower part of the 'mixed layer', around 200 ft, the correlation was significant for more than 4 hr. Below this level, an abrupt change took place at the top of the thermocline, and still deeper, the correlation decreased rapidly with time.

Autocorrelation of sea temperatures at over the outer continental shelf varied greatly with depth. In the middle of the 'mixed layer' as in the previous case, there was no significant correlation in 1 hr. Similarly, just above the thermocline, a significant correlation lasted for 4 hr. But at levels corresponding to the upper part of the thermocline, the correlation was very low in only 1 hr. It improved and declined at lower levels with the most significant correlations just above the sharpest gradient in the thermocline.

Although the temperature differences at the near-shore station were maximum near the surface, the correlation values were the most significant at that level, and the least significant at 60 ft, near the bottom. In other words, the near-bottom temperatures, in this case, were more random and thus more variable.

Other means of expressing variability, such as the use of power spectra and harmonic analysis, are more appropriate for longer series of data and are not considered here.

Conclusion

The above analysis of the variation of temperature with time from repeated bathythermographs at three locations off the east coast of India indicates that the greatest temperature change occurred at a depth related to that of the thermocline. The average magnitude of the change was about 1°F in 1 hr, and it increased with time. The change was as much, or 2.8°F in 4 hr for the offshore example. The near-shore 'mixed' water had a maximum average temperature difference of only 0.31°F in 4 hr. The magnitude of change is not necessarily related to the degree of correlation. In fact, in most cases, the reverse is true.

The most significant development is that with a supposed 'winter mixed surface layer', there is a wide variation in the correlation between temperatures with respect to depth, as shown in all figures. In cases where there was a thermocline, the value of $R$ for the lower part of the overlying mixed layer was considerably higher than the near-surface values. This indicates that the lower part of the layer was less turbulent than the upper part which experiences small random fluctuations attributed to meteorological factors. The near-shore station experienced more variability near the bottom. Since the station was occupied during a period of southerly coastal drift, the temperature variability at the bottom can be attributed to turbulence at that depth.

References

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