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Short period variations in sea water temperatures

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1. Introduction

This paper covers a study of temperature variability in the sea off the coasts of southern California, USA and Andhra, India.

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 (LaFond 1954). Because so many factors are continually changing the sea temperature, it is difficult to adequately describe its structure and its variability. Two approaches are used in this paper; one is in terms of temperature differences and the other in terms of autocorrelation values (Mode 1951).

2. Data

The ease of measuring ocean temperatures with bathythermographs has made the recording of temperature an integral part of most oceanographic research programs. Therefore, many temperature data are available for analysis. The data chosen for this study were two sets of bathythermograms, one set taken off the southern California coast and one off the Andhra coast. The southern California data were obtained from 52 repeated lowerings at half-hour intervals (12 to 13 July 1950), and the Andhra coast data from 26 lowerings at one-hour intervals (17 to 18 February 1953).

Temperatures for southern California were scaled at 10-foot intervals from the surface to 200 feet, and at 50-foot intervals from 200 to 400 feet. The temperatures for the Andhra coast data were scaled at 20-foot intervals from surface to 400 feet.

3. Results

Differences—The first measure used for analyzing 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—

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

where, D_λ is the mean of the temperature differences (°F) in a given time interval, X_i and $X_{i+\lambda}$ are the temperatures (°F) at the beginning and end of a given time interval, λ=0, 1, 2, 3 and 4. Thus, the time intervals used were: λ half-hours for southern California, and λ hours for Andhra coast. N is the total number of temperature readings, at a given depth and location (N is 52 for the southern California data and is 26 for the Andhra data).

The statistical results of an analysis of the southern California data on the basis of this measure are shown in Fig. 1, and those of an analysis of the Andhra coast data in Fig. 2. Some of the variation must be attributed to

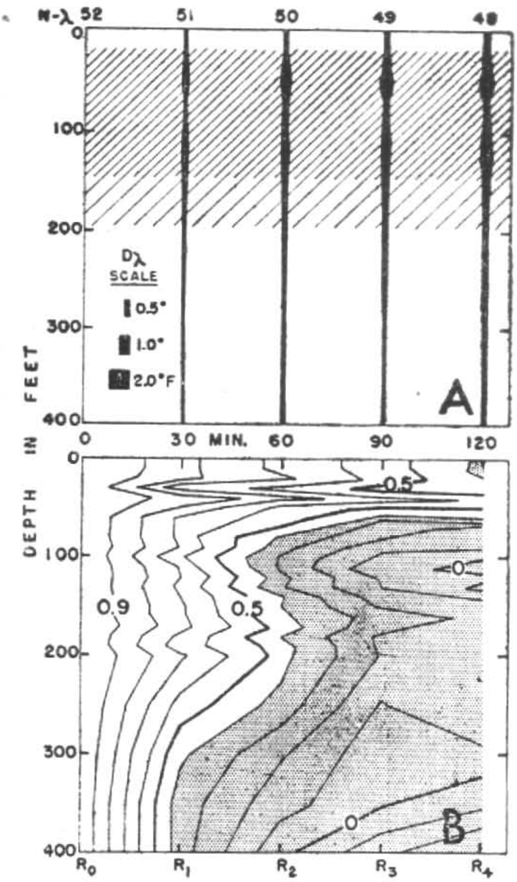

Fig. 1. Southern California coastal summer sea temperatures

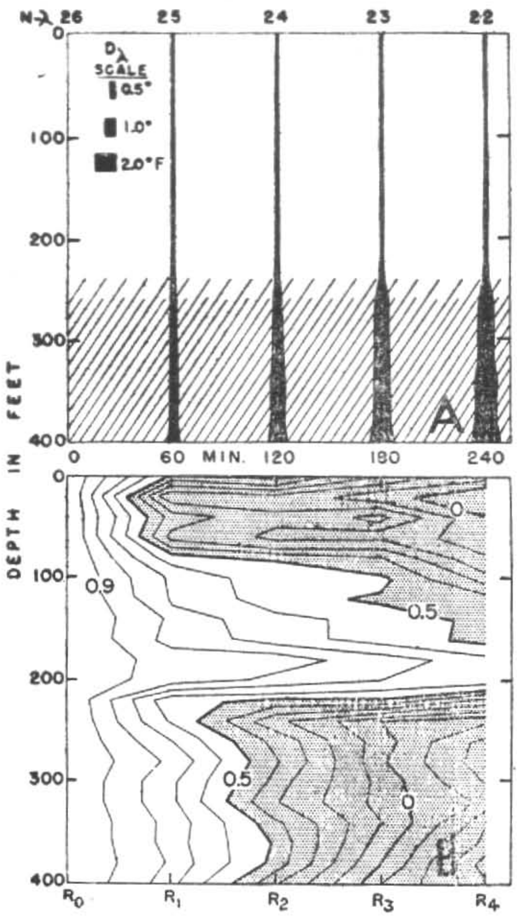

Fig. 2. Andhra coastal winter sea temperatures

A—Average differences (D_λ) for different period of time and depth. The diagonal shading represents the depth of thermocline.

B—Autocorrelation coefficient (R_λ) (contoured) for time and depth.

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°F.

Fig. 1A, for the summer off southern California, shows that the average temperature differences, D_λ, at all depths (to 400 feet) were less than 1 degree for an interval of 30 minutes. With increasing intervals, namely, 60, 90 and 120 minutes, the average temperature differences increased. For a 2-hour interval the average difference at 50 feet, corresponding to the depth of the upper thermocline, was 1·4°F. The maximum differences occurred at the sharp discontinuities in the thermocline and were the result of vertical oscillations of the thermocline.

Fig. 2A presents comparable temperature differences for winter conditions off the Andhra coast. Here, the average temperature differences above the thermocline for time intervals up to 4 hours were less than 0·4°F. However, in the thermocline, differences ran from 1·1°F for 1 hour to as much as 2·8°F for 4 hours. Again, this result indicates internal waves at the thermocline (LaFond and Poornachandra Rao 1954).

Autocorrelation—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—

For a significant (one per cent) level of correlation, R is 0·36 for 50 values and 0·51 for 25 values. For comparison, values of 0·40 and 0·50, respectively, were used for the two sets of data.

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 (Southern California) and 2B (Andhra Coast). Fig. 1B shows that the correlation of temperature with respect to time (R), decreased rapidly at all depths. The level of maximum significant correlation which lasted for more than 2 hours was around 40 feet, or just into the upper part of the thermocline. In the lower part of the thermocline, a significant correlation lasted about one hour and below the thermocline it lasted only about one-half hour.

The Andhra coast data shows that although the changes of temperature with time were exceedingly small near the surface, these changes were apparently random, and the correlation between values of successive intervals fell off greatly with time (Fig. 2B). However, in the lower part of the "mixed layer", the correlation was significant for more than 4 hours. Below this level, an abrupt change took place at the top of the thermocline; and still deeper the correlation decreased rapidly with time.

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

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

where R_λ = autocorrelation coefficient.

4. Summary and Conclusions

The above analysis of the variation of temperature with time indicates that the greatest change occurred at a depth related to that of the thermocline. The average magnitude of the change was about 1°F in one hour, and it increased with time. The change was 1·4°F in two hours for the summer California example, and twice as much or 2·8°F in 4 hours for the winter Andhra example. The magnitude of change is not necessarily related to the degree of correlation. The correlation between successive temperatures was greater above and just below the near-surface summer thermocline than at depths below.

The most significant discovery is that with a supposedly "winter mixed surface layer", there is a wide variation in the correlation between temperatures as shown in Fig. 2B. The value of R for the lower part of the layer was consistently high whereas the near-surface value was low. 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.

These examples of sea temperature differences and autocorrelation values provide a useful measure of temperature variability. In addition, they provide clues to the processes which contribute to the variability.

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