SEASONAL VARIATION OF SOME PHYSICAL FEATURES OF THE COASTAL WATERS OFF WALTAIR

V. V. R. VARADACHARI

Department of Meteorology and Oceanography, Andhra University, Waltair

ABSTRACT

THE seasonal variation of temperature, density and transparency of the coastal waters off Waltair has been studied with the help of the data obtained on the oceanographic cruises of the Andhra University. The studies reveal the following results.

The surface temperature is lowest in December and highest in September. The annual range of temperature is not maximum at the surface but at some depth. In the surface layers, positive temperature gradients occur during the winter months and negative gradients during the remaining period of the year. The thermocline gets deeper and deeper during the period September to January and it begins to move up in February.

The water undergoes large seasonal changes of density at the surface with low values in October and high values in Spring and Summer. The annual range of density decreases with depth in the top fifty metres. The vertical density gradients in the surface layers are small in Spring and Summer and large in the Fall season.

The transparency of the waters changes with season and distance from the coast. The nearshore waters are less transparent than those offshore, throughout the year. The most turbid waters for the year are encountered in April and May, a feature related to upwelling near the coast.

Sinking during the period September to December and upwelling in Spring and Summer take place in nearshore regions.

INTRODUCTION

The earliest studies on the temperature and density of the surface waters of the Bay of Bengal are those of Dallas[1] and Sewell[2]. Recently, Ganapati and Murty[3] studied the salinity and temperature of the surface waters off the Visakhapatnam coast LaFond[4] investigated the seasonal variation of surface temperatures, salinities, and densities in the nearshore waters at four places on the east coast of India[4]. From the T-S plots at the surface and subsurface depths, he assigned names and σ_t limits to the water masses on the east coast of India for the purpose of discussing their distribution and circulation[5]. He gave an account of the environmental factors affecting the vertical temperature structure of the upper layers of the sea[6]. Investigations by Varadachari[7] on the thermal structure of upwelling in Spring in the coastal waters off Waltair[7], by LaFond and Borreswararao[8] on the thermal structure of the waters on the east coast of India, by La Fond and Bhavanarayana[9] on the thermal features of the bottom waters during upwelling on the east coast of India, have increased our knowledge of the temperature of the waters. Studies on the seasonal variation of temperature and density of the waters at subsurface depths are quite meagre.

Our knowledge of the transparency of the waters of the Bay of Bengal prior to 1952 was almost nil. A brief reference to the transparency of the waters was made by Raghu Prasad[10] in 1952. Studies by LaFond and Sastry[11] and by Satyanarayanarao[12] have increased our knowledge of the transparency of the waters on the east coast of India.

But these studies, by their very nature, cannot be expected to give as much detail for the physical features of the coastal waters off Waltair at the surface and subsurface depths as the diagrams now presented by the author.

DATA USED AND THE SCOPE OF STUDY

The data used are the observational material obtained on the oceanographic cruises of the Andhra University during the period 1955 to 1957 and the data obtained by the Zoology department of the University in nearshore regions. The water temperature was obtained by means of a bathythermograph of Spilhaus design[13]. The salinity at different depths was obtained by collecting water samples by Nansen bottles and titrating the samples[14]. The temperatures at the depths of collection of the water samples were obtained accurately by means of reversing thermometers attached to the Nansen bottles[15] $\sigma_{s,t,p}$ which is a measure of water density is obtained at different depths from a knowledge of temperature and salinity. The water transparency was studied qualitatively by means of a Secchi disc of standard size. The Secchi disc readings are liable to be vitiated by errors of vision of the observer, the wire angle deviation, Sun's altitude, weather and conditions of the sea surface. Thus the readings could be used only for some general studies. Only those observations that are obtaind in bright sunlight and clear skies are considered for the present studies. The scope of the study is limited to the coastal waters up to the edge of the continental shelf near Waltair.

DISCUSSION OF THE RESULTS

(a) *Seasonal variation of temperature at different depths*

The seasonal variation of temperature at different depths is shown in figure I, which is prepared from the monthly average of temperatures at different depths for the coastal waters. The data for the subsurface depths is available only for the period September to May. The surface temperature shows a double rise and fall during a year with maxima in May and September. The maximum shifts from September at the surface to October at twenty five metres depth and to November at depths below fifty metres. The winter minimum shifts from December at the surface to January at subsurface depths. At depths greater than hundred metres the minimum temperature does not occur in winter months but in the month of March. The annual range of temperature is not maximum at the surface but it occurs at a depth of hundred metres. This shows that the temperature changes at different depths in these coastal waters are not mainly set up by heating and cooling at the surface. The factors that may be considered as responsible for the variation of temperature at subsurface depths are, the variation in the amount of solar radiation that is directly absorbed at different depths, the effect of heat conduction, the variation of the currents related to lateral displacement of water masses and the effect of vertical motion[16]. Except in the top layer of about ten metres, the temperature at different depths decreases during the period February to March. This decrease may be ascribed to the effect of upwelling. The curves for the surface and ten metres depth do not show any fall of temperature during this period. This shows that the surface layer is subjected to intense seasonal heating which masks the effect of upwelling. The effect of seasonal heating and the advection of warm water into the area due to the northeasterly coastal current in the Spring and Summer months mask the upwelling effect to some extent in the subsurface layers as well. The northeasterly current ceases to flow over the area sometime in August and the upwelling also ceases along with it [17]. Consequently, a sharp rise in temperature probably takes place from August at all depths in these coastal waters.

Vertical temperature gradients and their seasonal variation—Figure I shows that in the top layer, positive gradients (i.e., temperature increasing with depth) occur during the winter months and negative gradients during the remaining period of the year. In the layer between twentyfive metres depth and fifty metres depth, positive gradients show up a month later than in the top layer. The positive gradients are due to the cooling of the sea surface by the northeast winds and the advection of the cold water at the surface by the southwesterly coastal current flowing over the area during this period. Seasonal heating and the advection of warm water by the northeasterly coastal current contribute to negative gradients from February to September. At depths greater than fifty metres, the gradients are all negative. Schott suggests[18] that the thermocline should be defined as one in which the temperature decreases by not less than 2·0°C (or 3·6°F) in a depth of twentyfive metres. Following this definition, it may be said that the thermocline lies below a depth of fifty metres in September and October and below hundred metres in November. The subsurface water of strong negative gradients is pushed deeper and deeper as sinking in the coastal waters continues in the Fall season[19]. During January, the thermocline is below hundred metres depth. This is due to the strong cooling at the surface and mixing in the upper layers. The thermolcine moves upward from January to March which is associated with upwelling.

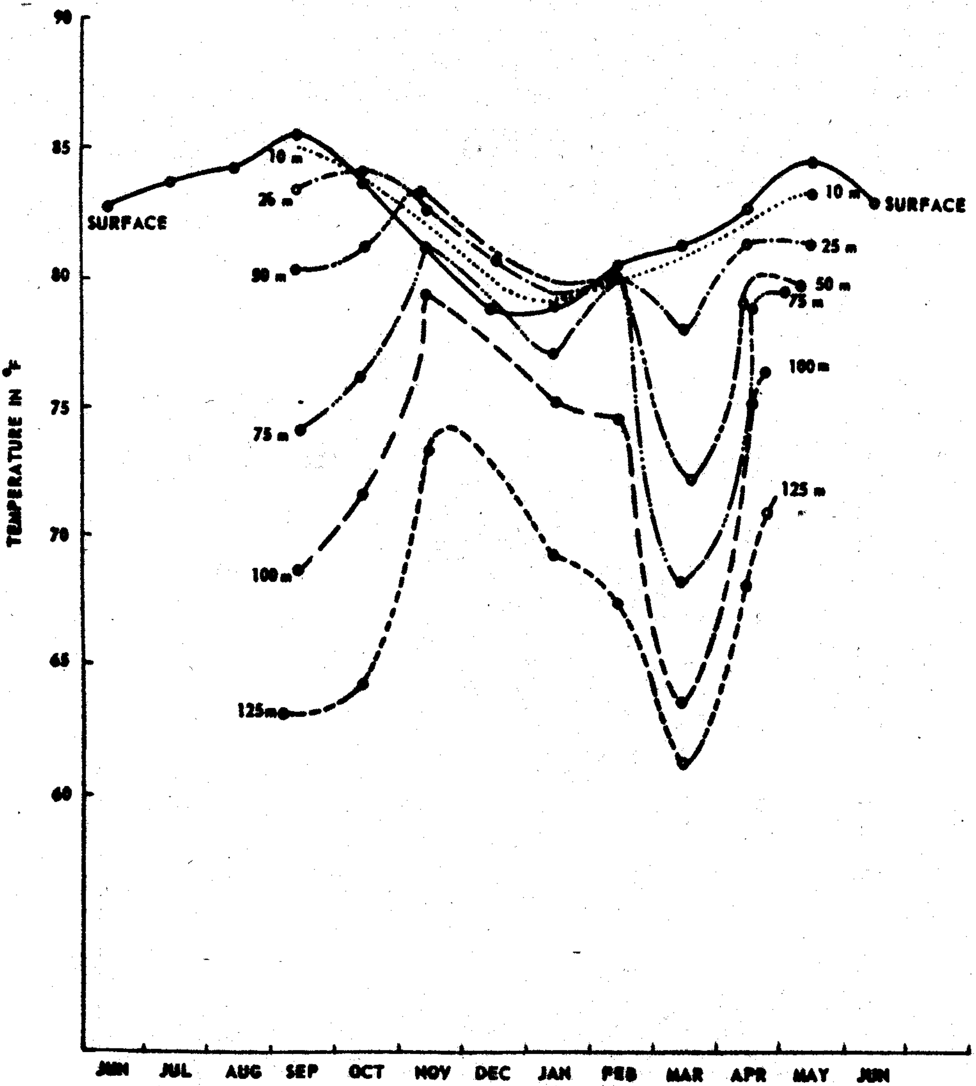

Fig 1—Curves showing Seasonal Variation of Temperature at Different Depths in the Coastal waters off Waltair

(*b*) *Seasonal variation of density at different depths*

Figure 2 represents the density of the waters in different months and at different depths. The surface density shows a large annual variation with high values in January and July and low values in October. The seasonal range of density decreases with depth up to about fifty metres below which the range is practically constant. The surface density rises appreciably from December to January due to the reversal of the coastal current from southwesterly to northeasterly. Similarly, an appreciable fall of surface density takes place during the beginning of the Fall season when the coastal current changes direction from northeasterly to southwesterly and large amounts of northern dilute water are advected into the area. The subsurface data is available only for the period September to May. The northern dilute water ($\sigma_{s,t,p} > 19$) extends to a depth of about twenty metres in September and about fifty metres in November. The surface layer is highly stable with large vertical gradients of density in the Fall season. In December, the northern dilute water is found only in the top layer of about ten metres. The southern Bay of Bengal water ($\sigma_{s,t,p}$ 21 to 22) the upwell water ($\sigma_{s,t,p}$ 22 to 23), the subsurface shelf water ($\sigma_{s,t,p}$ 23 to 24) and the Indian Equatorial water ($\sigma_{s,t,p} > 24$) occur in the coastal waters near Waltair at different depths in different months of the year.

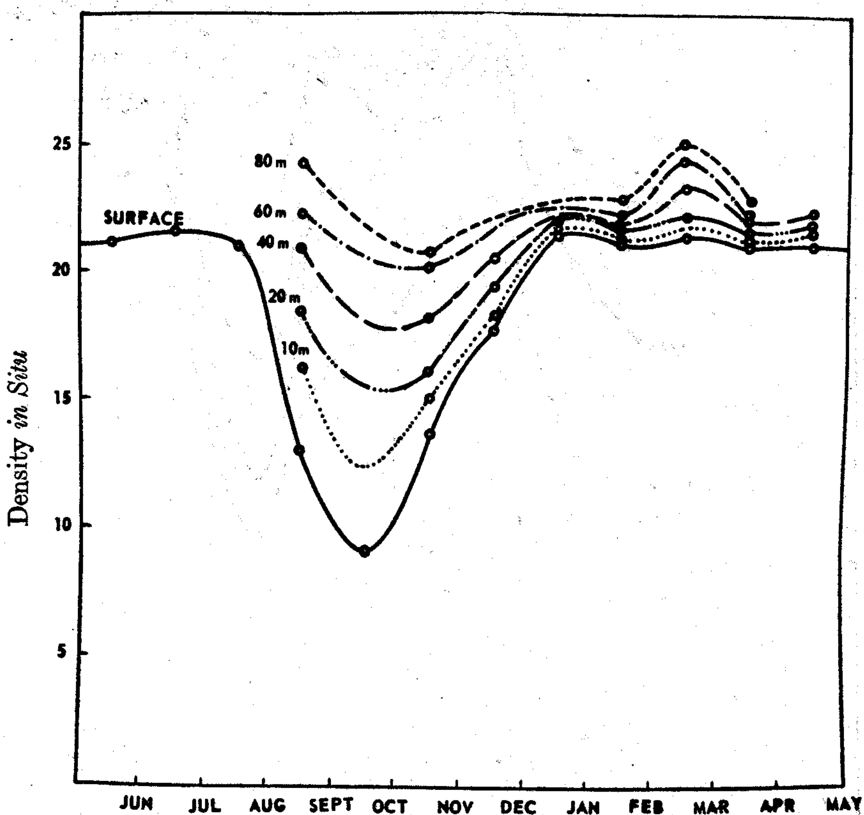

Fig 2—Curves showing the Seasonal Variation of Density at different depths

Vertical density gradients and their seasonal variation—Figure 2. shows that the density gradients are all positive as would be normally expected from stability considerations.

In the surface layer of about twenty metres the gradients are very high in September and October and decrease gradually to low values in February. The northern dilute water floats over the denser water below giving rise to strong gradients in the Fall season. Seasonal cooling and mixing in the winter months reduce the density gradients in the surface layers. The flow of the southern Bay of Bengal water at the surface coupled with upwelling lead to small density gradients near the surface in, the Spring season. Seasonal heating and upwelling work in opposite directions in increasing and decreasing the density gradients in the top layers in Spring and Summer. The increase in gradients at subsurface depths from February to March is due to upwelling. As the upwelling continues in Spring and Summer, the upwell water spreads at the surface and sinks to greater depths offshore during April and May. Hence, the gradients in April are less than in March up to a depth of about eighty metres.

(c) *Water transparency*

Figure 3 shows the variation of the transparency of the waters with distance from the coast in different months. The nearshore waters are less transparent than the offshore waters in all the months of the year. During the period September to November, the transparency of the coastal waters gradually decreases as shown by the upward shift of the

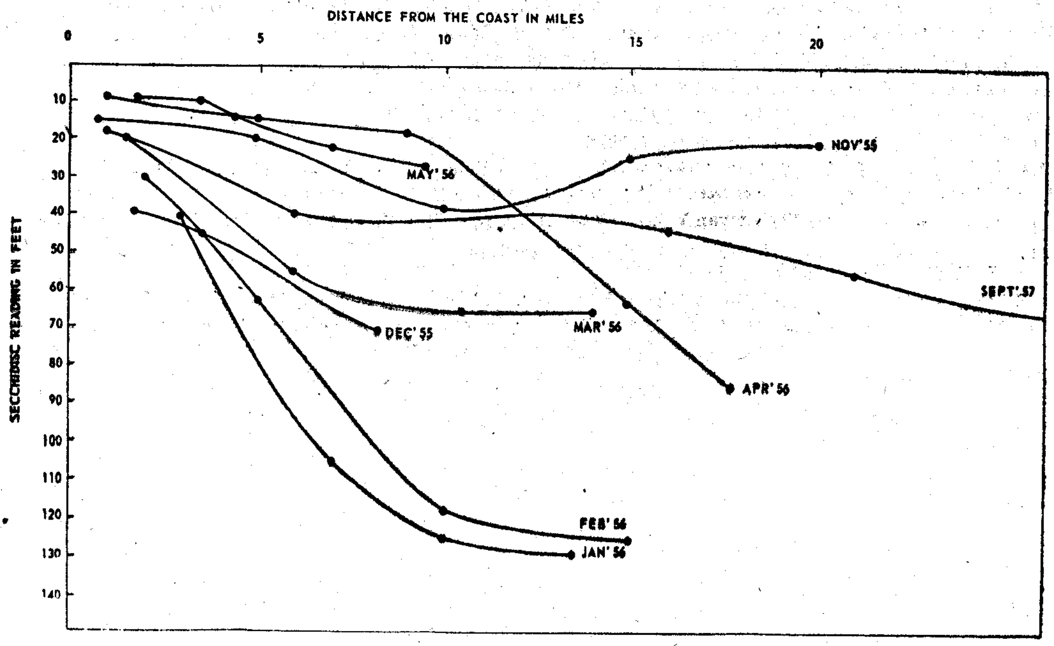

Fig 3—Curves representing the Transparency of the Coastal waters near Waltair in different Months.

curves from month to month. This decrease in the water transparency in the Fall season is associated with the flow of the northern dilute water which brings more and more inorganic suspensoids into the area. From November to January, the transparency increases considerably as shown by the downward shift of the curves. During February to May, the curves shift upward, indicating that the waters get less transparent with the progress of Spring and Summer. The most turbid waters for the year are encountered not during the Fall season when the southwesterly coastal current brings the turbid river waters from the north, but during April and May when the northeasterly coastal current flows over the area bringing clear oceanic water. The high turbidity during April and May is associated with upwelling near the coast and the high production of plankton in the euphotic zone. As this turbidity is due to upwelling near the coast, the waters fifteen or twenty miles offshore are very transparent which is a feature of clear oceanic water.

Acknowledgements—The author wishes to acknowledge the help of the Various staff and students who participated in the oceanographic cruise programme of the Andhra University and the Navy and the Defence department of the Government of India for providing boat facilities to carry on oceanographic research. He is thankful to professors E.C. LaFond, R. Ramanadham and P.N. Ganapati for their help and interest in the work.

REFERENCES

1 DALLAS, W. L., "Charts of the Bay of Bengal and adjacent sea............" *Ind. Met. Dept. Publ.* (1887).

2 SEWELL, R. B. S., *Mem. of the Royal Asiatic Soc. of Bengal*, **9**, 207, (1929).

3 GANAPATI, P. N., and MURTY, V. S. R., *Andhra Univ. Mem. in Oceanography*, **1**, 125, (1954).

4 LAFOND, E. C., *Andhra Univ. Mem. in Oceanography*, **2**, 12, (1958).

5 *Ibid*, pp. I—II (1958).

6 *Ibid*, 1, 94, (1954).

7 VARADACHARI, V. V. R., *Proc. Andhra Univ. Symposium on Oceanography of Bay of Bengal*, May 1956, Central Board of Geophysics, 1956.

8 LAFOND, E. C. AND BORRESWARARAO, C., *Defence Science Organisation, Publ. No. 4/55*, pp. 1—89, (1955).

9 LAFOND, E. C. AND BHAVANARAYANA, P. V., *Ind. J. Met. & Geophys.*, **8**, 209, (1957).

10 RAGHU PRASAD, R., *Proc. Ind. Acad. Sci.* Sec A, **36**, 61, (1952).

11 LAFOND, E. C. AND SASTRY, J. S., *Ind. Jour. Met. & Geophys.*, **8**, No. 2, (1957).

12 SATYANARAYANARAO, T., *Proc. Natl. Inst. Sci. Ind.*, **23** (B), 165, (1957).

13 SPILHAUS, A. F., *J. Mar. Res.*, **1**, 95, (1938).

14 KNUDSEN, M., Hydrographic tables, Copenhagen, by Tutein og Koch, Copenhagen, 1948.

15 LAFOND, E. C., Processing Oceanographic data, *U.S. Navy Hydrographic office Publ.*, No. 614, 1951.

16 SVERDRUP, H. U., *ET AL.*, *The Oceans*, Prentice-Hall, Inc., New York. 1952.

17 VARADACHARI, V. V. R., Mahadevan Volume, May 1961, pp. 159-162, The Osmania Univ. Press, Hyderabad, India.

18 SCHOTT, G., Oceanographic and Maritime Met........, '*Valdivia*', **1**, 1898, 1902.

19 VARADACHARI, V. V. R., 'On some Met. and Oceanographic studies of the coastal waters off Waltair, in relation to upwelling and sinking"—*Thesis approved for the award of D. Sc., Andhra Univ.*, 1958.