Pakistan Journal of Marine Sciences, Vol.4(1), 1-4, 1995.

SEASONAL VARIATION OF MIXED LAYER DEPTH IN THE NORTH ARABIAN SEA

Arshad Ali, Naeem Ahmed Syed, Labeed I. Kazi, Mohsin Tabrez and Shahid Amjad
National Institute of Oceanography, ST.47, Block-1, Clifton, Karachi-75600, Pakistan.

ABSTRACT: The Arabian Sea is unique due to the extremes in atmospheric forcing that lead to the semi-annual seasonal changes. The reversing winds of summer and winter monsoon induce the variation in the characteristics of mixed layer depth. The importance of mixed layer depth is recognised in studying the biological productivity in the ocean. In this paper variability of mixed layer depth in the north Arabian Sea have been discussed. The study is based on the data collected under North Arabian Sea Environment and Ecosystem Research (NASEER) programme. The results of the study indicate that there is a significant variation in the mixed layer depth from summer to winter monsoon as well as coast to offshore.

KEY WORDS: Mixed layer depth - thermocline - upwelling - north Arabian Sea ; monsoon - productivity.

INTRODUCTION

The Arabian Sea experiences extreme in atmospheric forcing that lead to the semi-annual seasonal variability observed in any ocean basin. The reversing winds of summer and winter monsoon induce the variation in the underlying characteristics of mixed layer depths (Sonia *et al.*, 1991). The monsoon response of the Arabian Sea's mixed layer is typically considered as a one dimensional problem (Niiler, 1975). The importance of mixed layer depth has been recognised in studying biological productivity of the ocean. Seasonal changes in the distribution of phytoplankton pigment along Somali coast demonstrate a strong relationship with depth of mixed layer (Hitchcock and Olson, 1991).

The present study provides a spatial picture of mixed layer depth in the north Arabian Sea during winter (January) and summer (August). The results have been discussed on the observations undertaken during first two cruises conducted under the North Arabian Sea Environment and Ecosystem Research (NASEER) Programme.

Earlier studies on mixed layer dynamics of the Indian Ocean were confined mainly in the region southward of 20°N. Northward of 20°N, available informations are sketchy and are based on historical data. The notable studies of the region are Wyrtki (1971), Hastenash and Lamb (1979), and Banse (1984), Rao *et al.*, (1989), Molinari *et al.* (1986).

MATERIALS AND METHODS

National Institute of Oceanography undertook an oceanographic research programme of the North Arabian Sea Environment and Ecosystem Research in collaboration with US scientists. In the first two cruises during 1991-1992, a track of 1500 nautical miles long (Fig. 1) was covered, along which the data of different parameters related to physical,biological and chemical oceanography were collected.

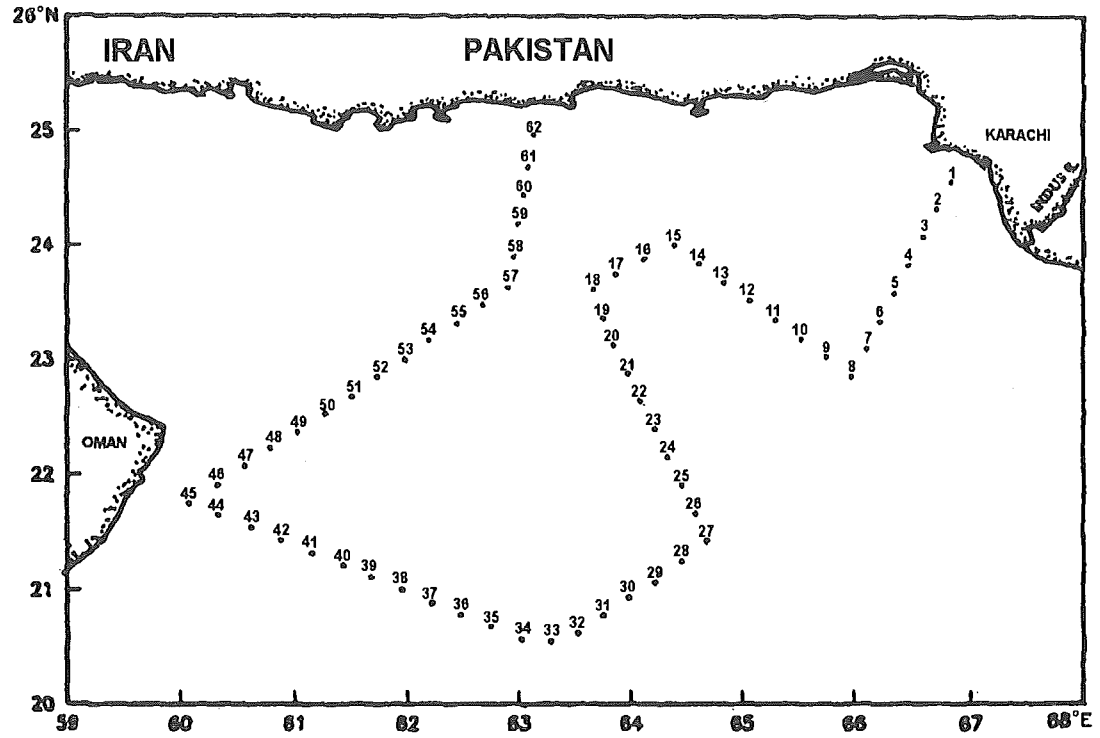

Fig. 1. Station location map of XBT profiles taken during summer and winter monsoon.

Subsurface temperature data are used for mixed layer study in this paper. A Sea Bird Temperature Conductivity Depth (CTD) profiler SBE 25 and Sippican expandable bathythermograph MK12 system were used to take observations. Both equipments have accuracy better than $\pm 0.05^{\circ}C$ in temperature and ± 2 m in depth.

Two methods were employed for the estimation of mixed layer depths. In the first method, the shallowest 5 m interval with a temperature difference of at least $0.5^{\circ}C$ was found. In second method, the mixed layer is assumed to be the depth at which the temperature was $1.0^{\circ}C$ lower than the surface. Statistical mean is calculated where both methods were applied. The spacing between the XBTs observations were used at an interval of 15 nautical miles along the cruise track, and 5 stations were chosen for repeated observations to obtain diurnal picture. Fortran 77 programme was developed on 486 machine to process the data for obtaining mixed layer depth. The mixed layer depth results obtained from processed data were used for distribution contouring. Before processing the data, error check was performed on the data of the graph profiles of CTD and XBT.

RESULTS AND DISCUSSION

The thermal structure during January and August showed a strong thermocline with temperature gradient of about $0.03^{\circ}C/m \pm 0.005^{\circ}C$ during summer monsoon (Fig. 2a), whereas a relatively weak thermocline with gradient of $0.007^{\circ}C/m \pm 0.001^{\circ}C$ was seen during winter monsoon (Fig. 2b). The spatial distribution of mixed layer depth

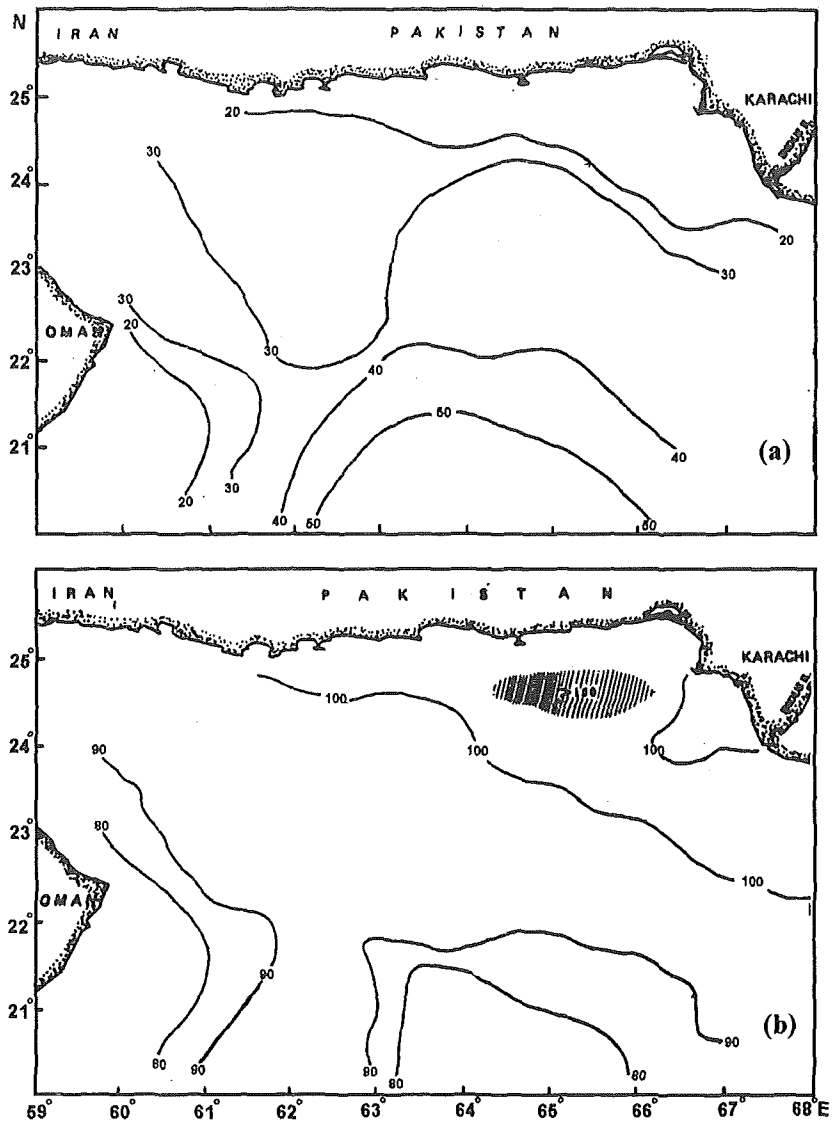

Fig. 2. Mixed layer depth contours; (a) summer monsoon and (b) winter monsoon.

during the month of January (NE monsoon) and August (SW monsoon) are shown in figures 3a & 3b, respectively. A marked variation in mixed layer depth is found during summer and winter monsoons. Longitudinally shallower depths of mixed layer are found in summer and deep layer in winter.

The results for January show that the depth of mixed layer varies around 100 meters which is in confirmation with the Wyrtki (1971) bi-monthly charts for the months January/February. Molinari *et al.* (1986) reported that during the month of December the mixed layer depth on the eastern side is greater than the western side. The results of this study confirm the pattern. However, during the month of August (summer monsoon), the distribution of the mixed layer depth increases from coast to offshore.

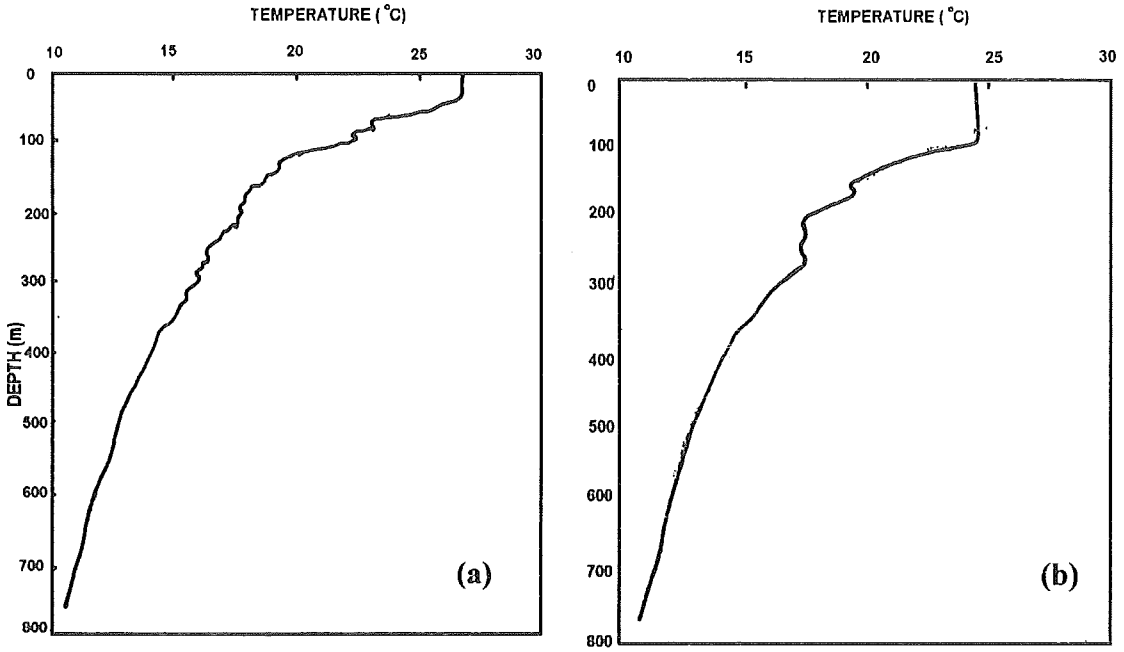

Fig. 3. Temperature profile from XBT station; (a) summer and (b) winter monsoon.

Shallower mixed layer depths are found near Pakistan and Oman coasts. The maximum depth of mixed layer was found 40±5 m in August. The results show that 15 m mixed layer depth exists along the northern shelf of Pakistan and near upwelling area of Oman which is in agreement with the study of Banse (1984) in selected areas along Pakistan shelf. The height of mixed layer depth during summer decreases towards the axis to strong wind.

REFERENCES

Banse, K. 1984. Overview of the hydrography and associated biological phenomena in the Arabian Sea, off Pakistan. *In: Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan.* (Eds.: Haq, B.U. and J.D. Milliman). Van Nostrand Reinhold Company Inc. New York. Pp.271-303.

Hasternrath, S. and P.J. Lamb, 1979. *Climatic atlas of the Indian Ocean, part I: surface climate and atmospheric circulation.* University of Washington Press, 97 charts.

Hitchcock, G.L. and D.B. Olson, 1991. NE and SW monsoon conditions along the Somali coast during 1987. *In: Oceanography of the Indian Ocean* (Ed.: Desai, B.N.). Oxford & IBH Publishing Co. (Pvt.) Ltd, 66 Jan Path, New Delhi 110001. Pp.583-593.

Molinari, R.L., J.F. Festa and J.C. Swallow. 1986. *Mixed-layer and thermocline depth climatologies in the western Indian Ocean.* NOAA Technical Memo, ERL AOML-64, Pp.1-40.

Niiler, P.P. 1975. Deepening of the wind mixed layer. *Journal of Marine Research* 33: 405-422.

Rao, R.R., R.L. Molinari and J.F. Festa 1989. Evolution of the climatological near-surface thermal structure of the tropical Indian Ocean. *Journal of Geological Research* 94: 10.801-10.815.

Sonia, B., G.L. Hitchcock and D.B. Olson, 1991. Influence of monsoonally-forced Ekman dynamics upon surface layer depth and plankton biomass distribution in the Arabian Sea. *Deep-Sea Research* 38:521-553.

Wyrtki, K. 1971. *Oceanographic atlas of the International Indian Ocean Expedition*, National Science Foundation, Washington, DC.

(Received: 4 July 1994)