Mausam, (1982), **33**, 4, 451-458

551.524.33 : 551.48(267)"1977"

On time varying currents and hydrographic conditions in the central Arabian Sea during summer monsoon-1977

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(Received 20 October 1981)

सार – केन्द्रीय अरब सागर बहुभुज मानसून–77 प्रयोगों में सोवियत रूस अनुसंधान जलयान द्वारा उतरी तथा दक्षिणी स्थितियों पर सतह से 1000 मीटर की निश्चित गहराई पर धाराओं के समय प्रत्यावर्तन, तापमानों तथा लवणता के आंकड़ें एकत्र किए गए। इन परिणामों की ग्रीष्म मानसून के प्रादुर्भाव व अभ्युदय के संबंध में विवेचना की गई है। सतही परतों के उष्मी संरचना के विचरण पर भीषण चक्रवाती तूफानों के प्रभावों का भी विवेचन किया गया है।

ABSTRACT. Time variations of currents, temperatures and salinities at specified depths from surface to 1000 m have been studied using the hydrographic and current data collected by the USSR research ships at northern and southern locations of the central Arabian Sea polygon of Monsoon-77 experiment. The results are discussed in relation to the onset and progress of the summer monsoon. The influence of a severe cyclonic storm on the variation of thermal structure in the surface layers is also discussed.

1. Introduction

The annual visit of summer monsoon and subsequent changes at the surface and subsurface waters of the Arabian Sea as well as of the entire north Indian Ocean have been receiving much attention by several groups of workers in recent years. Earlier studies carried out over the Arabian Sea using the data collected during International Indian Ocean Expedition (IIOE 1960-65) mostly revealed the spatial variations of various oceanographic parameters (Rochford 1964, Sastry and D'souza 1970, '71, '72, Sundara Ramam *et al.* 1968). Time series observations on several oceanographic and meteorological parameters are obtained in ISMEX-73 (Indo-Soviet Monsoon Experiment) and Monsoon-77 expeditions. Either of these two is considered as a prelude to the International MONEX-79 (Monsoon Experiment) programme and these expeditions are carried out with the collaboration of USSR and India. Ramesh Babu *et al.* (1977) have studied the influence of southwest monsoon on the upper layers (upto 200 m) of the Arabian Sea based on ISMEX data.

In the present study hydrographic and current data collected at northern (R.V. *Okean*) and southern (R.V. *Priliv*) locations of the central Arabian Sea polygon of Monsoon-77 experiment are utilised to discuss time variations of currents, temperatures and salinities at specified depths from surface to 1000 m with reference to the progress of summer monsoon. A severe cyclonic storm which had passed over the central Arabian Sea during second week of June 1977 and the subsequent changes noticed in water characteristics at surface and below layers are also discussed in this paper.

2. Data and methods

The station locations of USSR research ships of the Arabian Sea polygon of the Monsoon - 77 expedition are shown in Fig. 1. The experimental programme was conducted in two phases : Phase I from 7 to 20 June and Phase II between 29 June and 15 July. 3-hourly observations on temperatures, salinities and currents obtained at the northern and southern ships of the polygon are used for the present study. Moored buoys were deployed and current meters were attached to the mooring lines at different depths upto 1000 m to monitor continuous measurements of currents during this expedition. The Hydrographic and current data were not collected at the northern ship (*Okean*) from 10 to 14 June due to a severe cyclonic storm which had passed over this region.

In the present investigation 3-hourly current vectors are resolved into zonal and meridional components and the corresponding daily average values are shown (3-hourly values are not shown

TABLE 1

Vectorial and arithmetic phase average currents

Depth (m)	Average component: zonal (cm/sec)	Average component: Meridional (cm/sec)	Vectorial average of current: Dir. (°)	Vectorial average of current: Speed (cm/sec)	Arithmetic average current (cm/sec)
Southern ship, Priliv, Phase I					
50	9	—40	165	41	61
100	14	—17	140	23	41
150	11	—15	145	19	31
200	11	—6	120	13	29
500	9	4	65	10	14
1000	3	4	35	5	8
Northern ship, Okean, Phase I					
50	—2	—2	225	3	49
100	—9	4	295	10	45
200	—6	3	295	8	17
500	—5	5	315	7	11
1000	—2	2	315	3	5
Northern ship, Okean, Phase II					
50	4	—15	165	16	52
100	—6	—10	210	12	38
150	—3	—1	250	4	14
200	—1	1	315	2	13
500	2	—2	135	3	9
800	3	—3	135	4	9

Note — Current speeds rounded-off to nearest 1 cm and directions to nearest 5°

as lot of variations in current direction and speed are observed) at specified depths between 50 and 1000 m. Vectorial and arithmetic averages of currents are also evaluated for each depth separately during Phases I &II and they are given in a tabular form. Daily and phase averages of 3-hourly temperature and salinity values are calculated for different depths from surface to 1000 m and the temporal variations of 3-hourly observations along with the average values are plotted to study the non-stationary behaviour of these parameters at different levels of the ocean on a synoptic scale basis.

3. Results and discussion

3.1. *Currents*

Time variations of currents (daily averages) for the period 7 to 19 June at the southern and northern locations and during 30 June to 14 July at the northern locations of the ploygon are shown in Figs. 2 (a-c). The arithmetic and vectorial phase averages of current velocities together with the phase averages of zonal and meridional components for specified depths are presented in Table 1. The variations in current

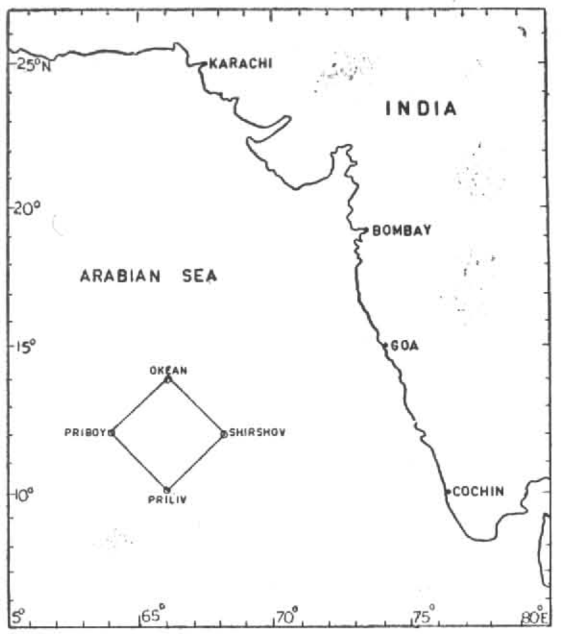


Fig. 1. Station locations of USSR research ships in Arabian Sea during Monsoon-77

speed and direction at the northern location are more at all depths than at the southern location. During Phase I at the southern position an average southerly component of 40 cm/sec at 50 m depth is noticed. As the depth increases the average vectorial current speed decreased to 5 cm/sec at 1000 m and the direction gradually shifted from S to NE through SE. In other words, it may be stated there is a counter-clockwise shift in the current direction with the increase of depth. For the same period unlike at the southern position, the currents are weak and a maximum speed of 10 cm/sec is found at 100 m at northern position. Here the current in SW direction at 50 m gradually changed to W and NW with increasing depth which indicates a clockwise shift in its direction. Even in Phase II the vectorial averages of currents at the northern end of the polygon show very weak current with a maximum speed of 16 cm/sec at a depth of 50 m and more or less a clockwise shift in current direction as the depth increases, is being observed like in Phase I. The low magnitudes of vectorial averages of currents which are noticed during both the phases at the northern location are due to the high frequency oscillations of the currents. The large differences between arithmetic and vectorial averages (*see* Table 1) very clearly depict the inconsistency of the current direction. A comparative study on the structure of currents at the northern and southern positions indicates a southerly component at the surface layers (upto 100 m) and a northerly component at deeper depths (>500 m) whereas at intermediate levels an easterly component at southern location and a westerly component at northern location have prevailed.

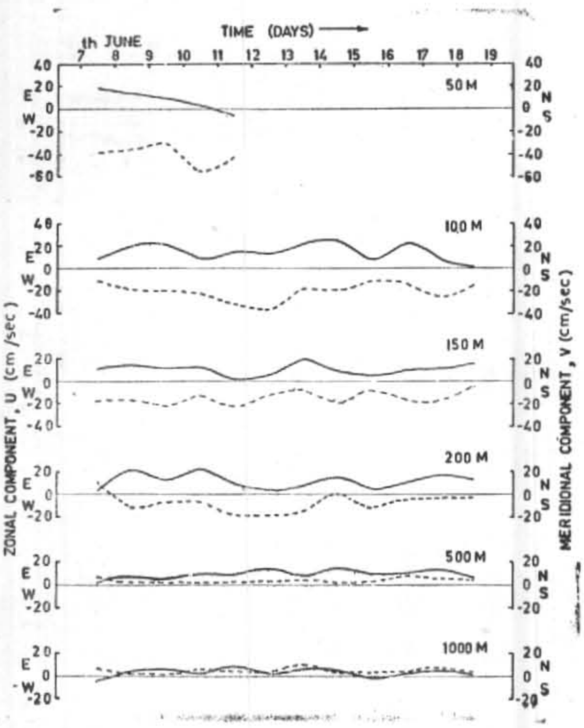


Fig. 2 (a). Southern location, Phase I

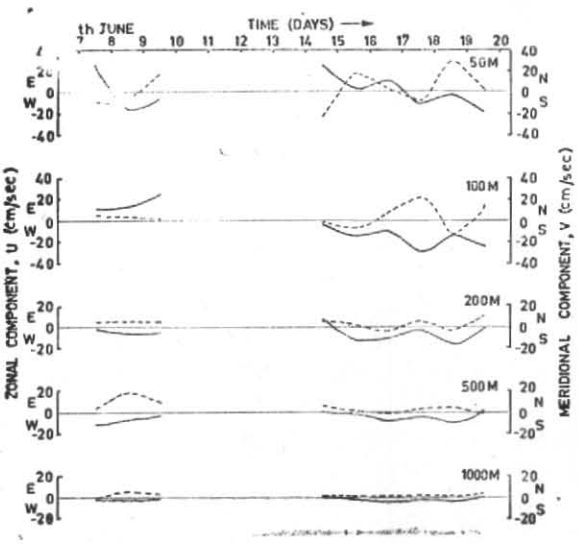


Fig. 2 (b). Northern location, Phase I

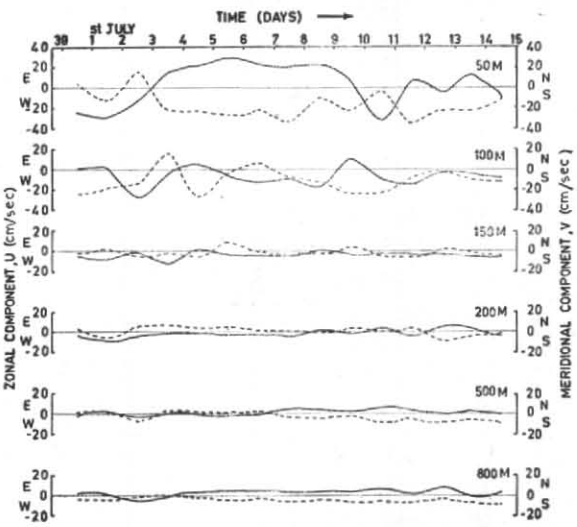


Fig. 2 (c). Northern location, Phase II

Figs. 2 (a-c). Time variation of currents (daily averages). Solid line shows the zonal component U, Dotted line shows the meridional component, V

3.2. *Temperatures*

Figs. 3 (a-c) present the time variations of 3-hourly temp. obsn. against phase mean and daily mean values for Phases I and II at southern and northern positions of the polygon. At the northern ship, *Okean*, during 7-10 June a continuous fall in sea surface temperature of more than 1 °C has been noticed and the same trend of decreasing temperature is observed at all depths upto 200 m. The observations from 14 June indicate the deepening of the surface mixed layer to a depth of 50 m or even more but not greater than 75 m. The exact depth of the mixed layer in this case could not be evaluated as the water bottle data are available at standard depths only. Below the surface mixed layer the daily average curves of temperature at 75 and 100 m (thermocline region) also exhibit an increasing trend. On going through IDWR charts supplied by India Meteorological Department, with a view to understand the synoptic meteorological situation for the above period, it is found that a low pressure area has formed over east central Arabian Sea off Karnataka-Goa coasts on 7 June and later intensified into a cyclonic storm by 9 June and moved in northerly direction. This was further intensified into a severe cyclonic storm with a strong core of hurricane winds and moved WNW towards Oman coast through central Arabian Sea by 12 June. Hence in the present case the observed cooling of waters at the surface and sub-surface layers and the consequent increase in mixed layer depth might be due to these severe cyclonic winds which had passed over this region during the above period (Leipper 1967, Elsberry *et al.* 1976). From the surface heat budget calculations carried out for the same period and same area Ramanatham *et al.* (1977) had shown that the net heat gain by the sea surface was negative between 8 and 11 June and changed its sign on 12th. Further they concluded that the latent heat of flux from sea to air is twice during the cyclone period than that of energy transfer during normal conditions. However, the retention of these deep mixed layers during latter part of Phase I can be explained through the processes of convective and wind mixing which might have been caused by the monsoon conditions prevailing over this area. The thermal conditions at the southern location

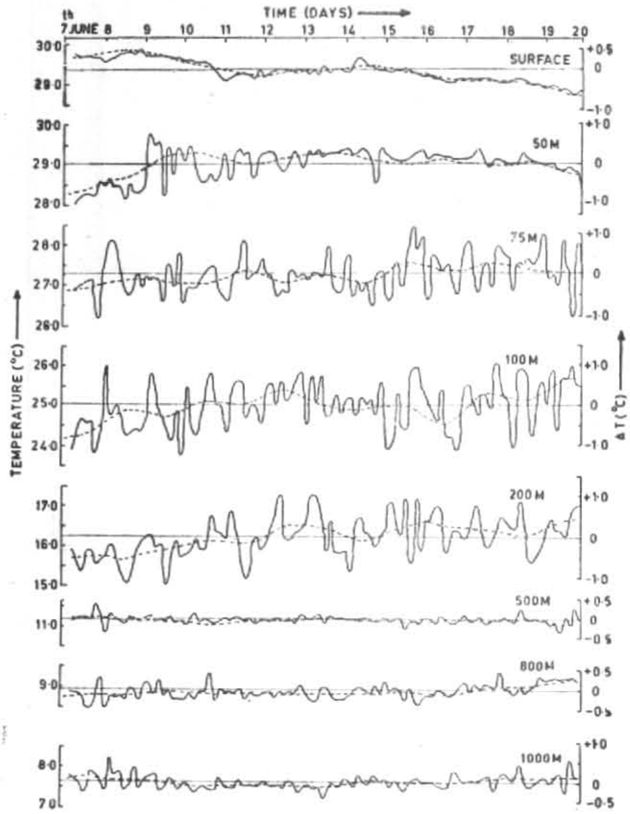


Fig. 3 (a). Southern location, Phase I

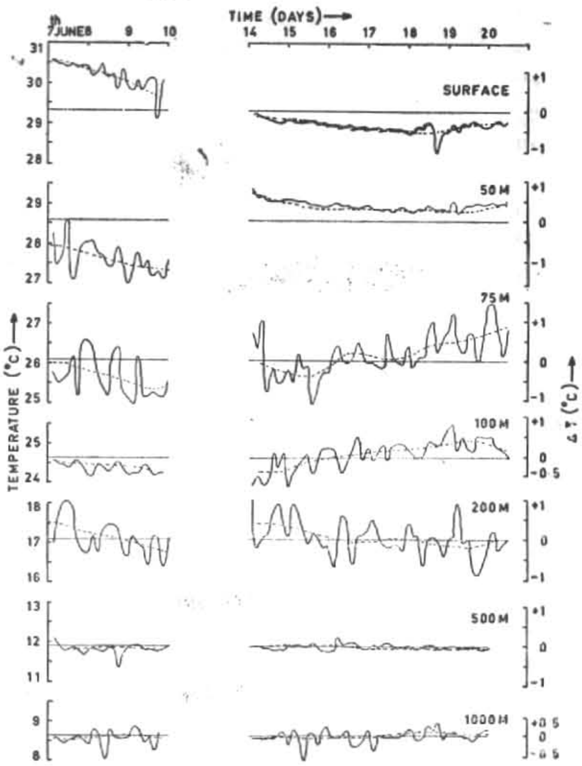


Fig. 3(b). Northern location, Phase I

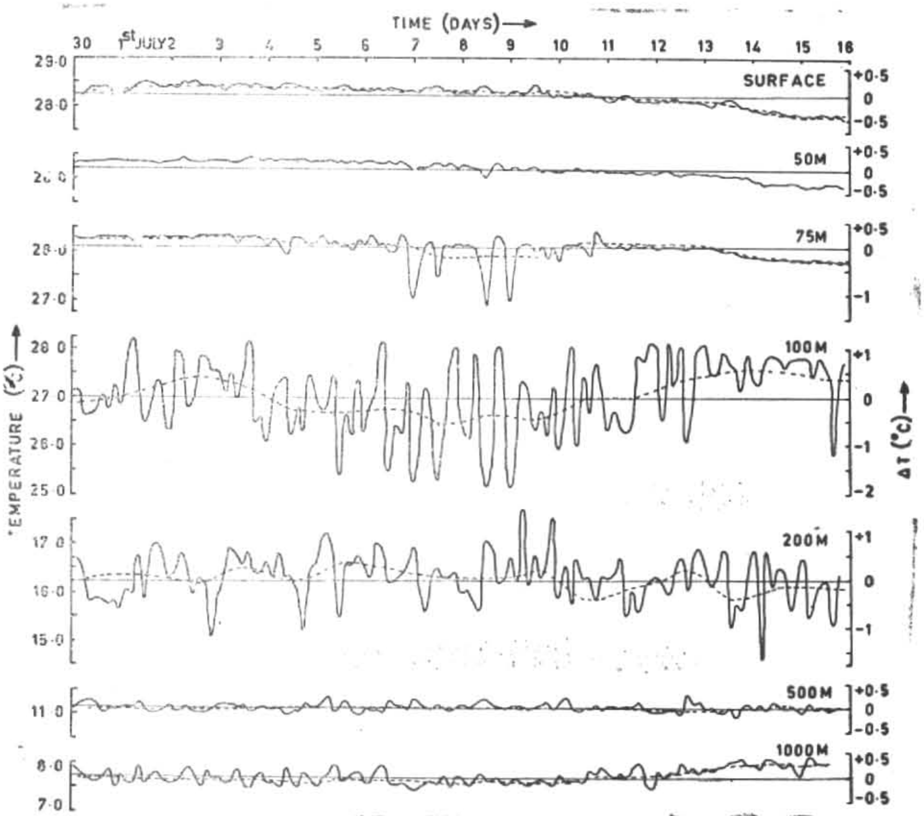
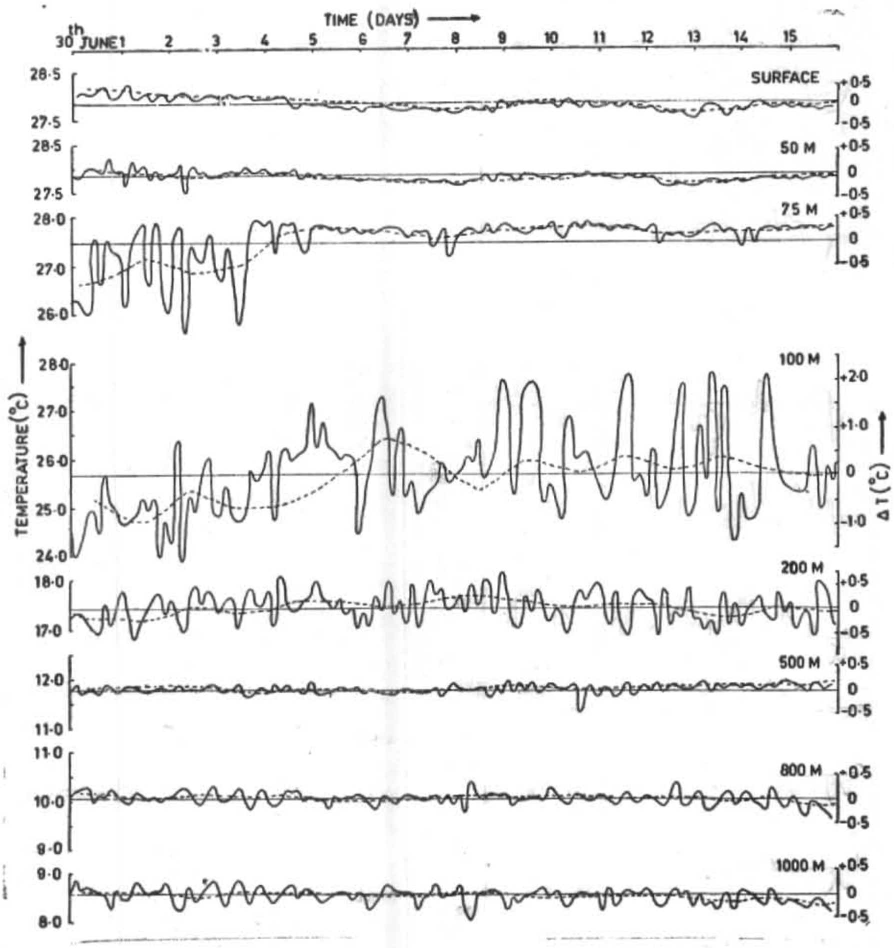


Fig. 3 (c). Southern location, Phase II



Fi . 3 (d). Northern location, Phase II

Figs. 3 (a-d). Time variation of temperatures. Thick curve shows 3-hourly values. Dotted curve shows daily average values. $\triangle T$ (Right side scale) gives variations from phase mean

during the above period are not influenced by the cyclonic storm and an increase in temperature is observed at the surface and sub-surface depths (upto 200 m) between 7 and 9 June. The surface mixed layer of an approxmiate depth of 50 m is seen from 12 June till the end of this phase. At the beginning of Phase I the surface waters at the northern position are warmer by about 1 °C than at the southern position but at the end of this phase the sea surface temperatures at both the locations are found to be same, which shows the spread of the summer monsoon in northerly direction.

In Phase II the sea surface temperatures at southern and northern locations have appeared same and they are almost steady throughout, except for a slight dip in the surface temperature noticed towards the end of the phase at the southern location. The mixed layer is as deep as 75 m at southern position while it is only upto 50 m depth at northern location.

During both the phases at so uthern and northern positions, in the thermocline region the variation in temperature including the deviations of 3-hourly values of temperature from daily mean and phase mean are quite high compared to the variations at surface and deeper depths. At deeper depths, 500 m and below, no considerable changes in temperature are noticed from Phase I to Phase II and temperatures are slightly higher at the northern point than at the southern point of observations.

3.3. *Salinities*

Figs. 4(a-c) show the time variations of 3-hourly salinity observations against daily and phase average values for Phases I and II at the southern and northern ships. Higher salinity values are observed at almost all depths from surface to 1000 m at northern location than at the southern location. The observations at the southern ship at surface and 50 m depths indicate an increase in salinity of 0.3 to 0.4‰ from 7 to 13 June and during the latter part of the phase (upto 18th) the daily average salinity values remain more or less steady. The increasing trend of salinities from the beginning till the end of the phase at this location can also

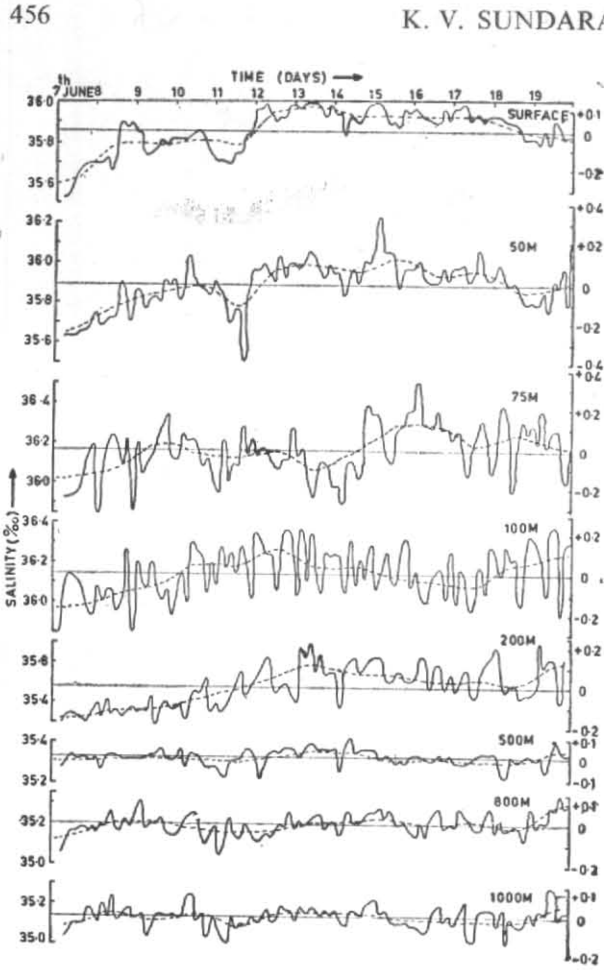


Fig. 4 (a). Southern location, Phase I

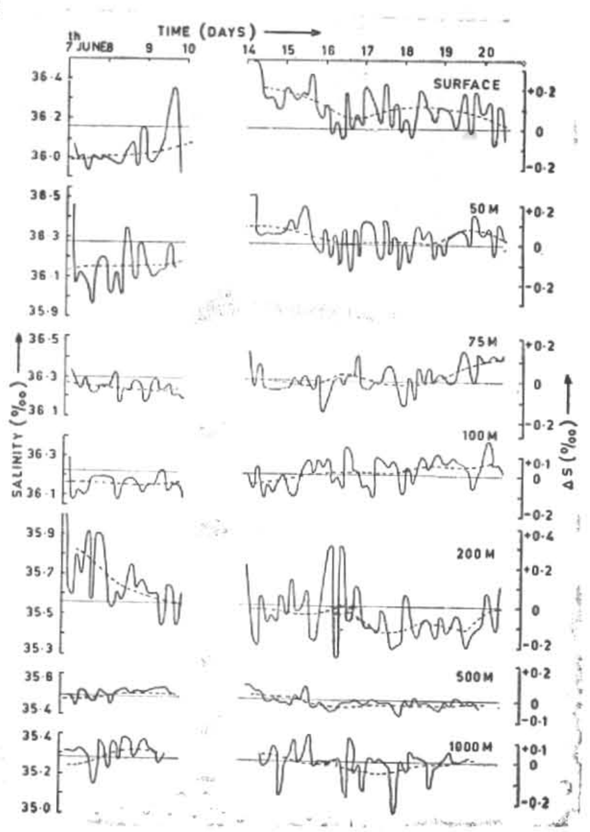


Fig. 4 (b). Northern location, Phase I

be seen at 75, 100 and 200 m depths. At the northern ship a similar raise in salinity from 36.0 to 36.3 ‰ from 7 to 14 June is observed at surface and 50 m depths.

During Phase II at southern position the surface salinity values show a consistant raise from 36.0 to 36.5 ‰ between 30 June and 15 July. Similar trend of increase in salinity towards the end of the phase has also appeared at 50 m and 75 m depths. In contrast the salinity values at the northern position at surface and 50 m remain almost steady throughout this phase.

The total increase in surface salinity by about 1‰ at southern end and 0.7‰ at northern end of the polygon during the entire period of observations (*viz.*, 7 June to 15 July) cannot be attributed to the surface evaporative process alone. The rough estimates of evaporation made over this region for the above period have revealed, only 1/4th of the total increase in salinity can be caused due to evaporation. Hence there must be an advective flow at surface and sub-surface levels of high saline waters entering into this area. In the absence of adequate data especially with more spatial coverage and with the limited observations used for the present investigation it is hardly possible to make any guess over the origin of these high saline waters. However, from the present observations on currents and salinities it may be mentioned that the southerly current at surface levels at southern and northern positions, the higher salinities prevailing throughout the observation period at northern position than at southern position and a continuous increase of salinity values from the beginning of Phase I to the end of Phase II at southern location are in favour of surface flow of high saline waters through northern position towards southern position of the polygon. Rochford (1964) found a salinity maxima at the surface of the central Arabian Sea and the higher salinity values of more than 36 ‰ were recorded at very shallow depths between 25 and 75 m. He classified these waters as Arabian Sea high saline waters. So it may be postulated that the present observations which indicate a flow of high saline waters at surface levels in southerly direction might have originated in the central Arabian Sea itself. However, it needs confirmation with more data collected at various parts of the central Arabian Sea during summer monsoon period.

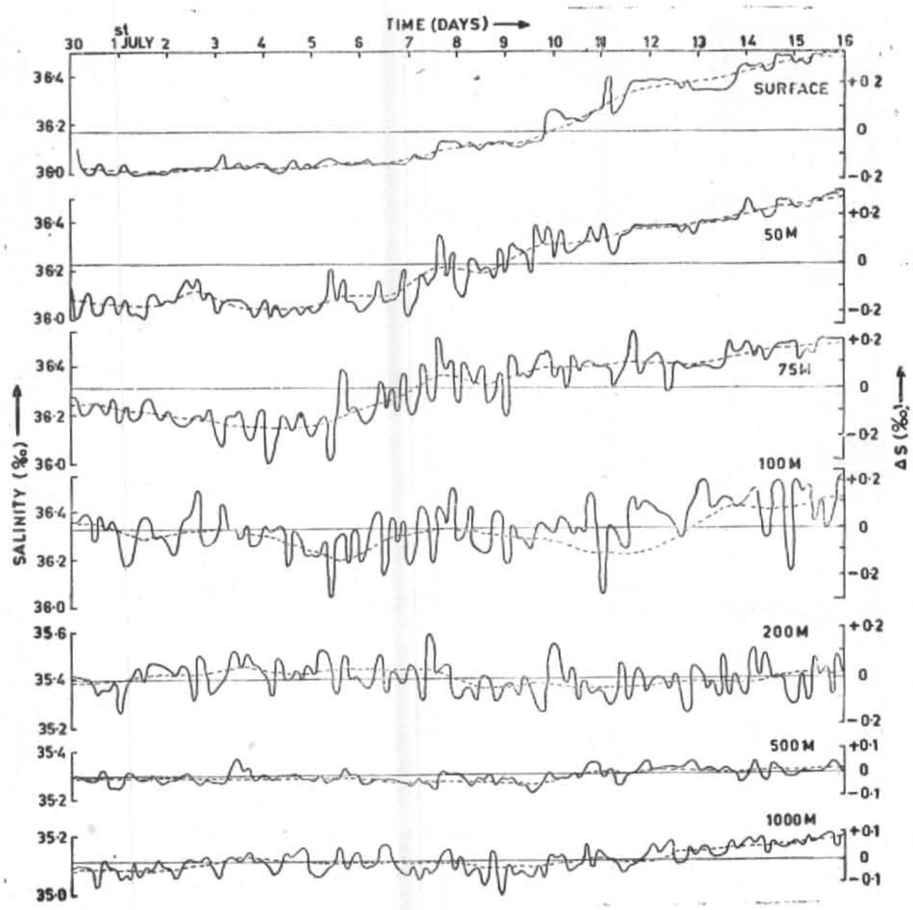


Fig. 4 (c). Southern location, Phase II

4. Conclusions

(1) The current directions are very inconsistant and at the northern point the currents are weak while compared to the southern point of the polygon. Southerly component of current at surface layers (upto 100 m) and northerly component at deeper depths (>500 m) are prevailing at both the observation points.

(2) The thermal structure in the surface layers upto 200 m at the northern location is being influenced due to the transit of a severe cyclonic storm. Consequently the fall in sea surface temperature of more than 1°C and deepening of mixed layer have occurred at this location.

The surface waters at the northern location are warmer by 1°C than that of the southern location before the onset of monsoon, and the water temperatures have appeared to be same at both the locations as the monsoon advanced to the northern part.

(3) Higher salinities are prevailing at all depths from surface to 1000 m at the northern location when compared to the southern location. The salinity has gradually increased in the surface layers during both the phases at the southern location whereas the similar raise is seen at the northern location only in Phase I. High saline waters are flowing in southerly direction from the surface high salinity waters of the central Arabian Sea.

Acknowledgements

The authors are thankful to Dr. D. Srinivasan, Director, Naval Physical and Oceanographic Laboratory, Cochin for providing necessary facilities to carry out the research work. They are also grateful to the Project Director, MONEX, New Delhi for making available the data for this study.

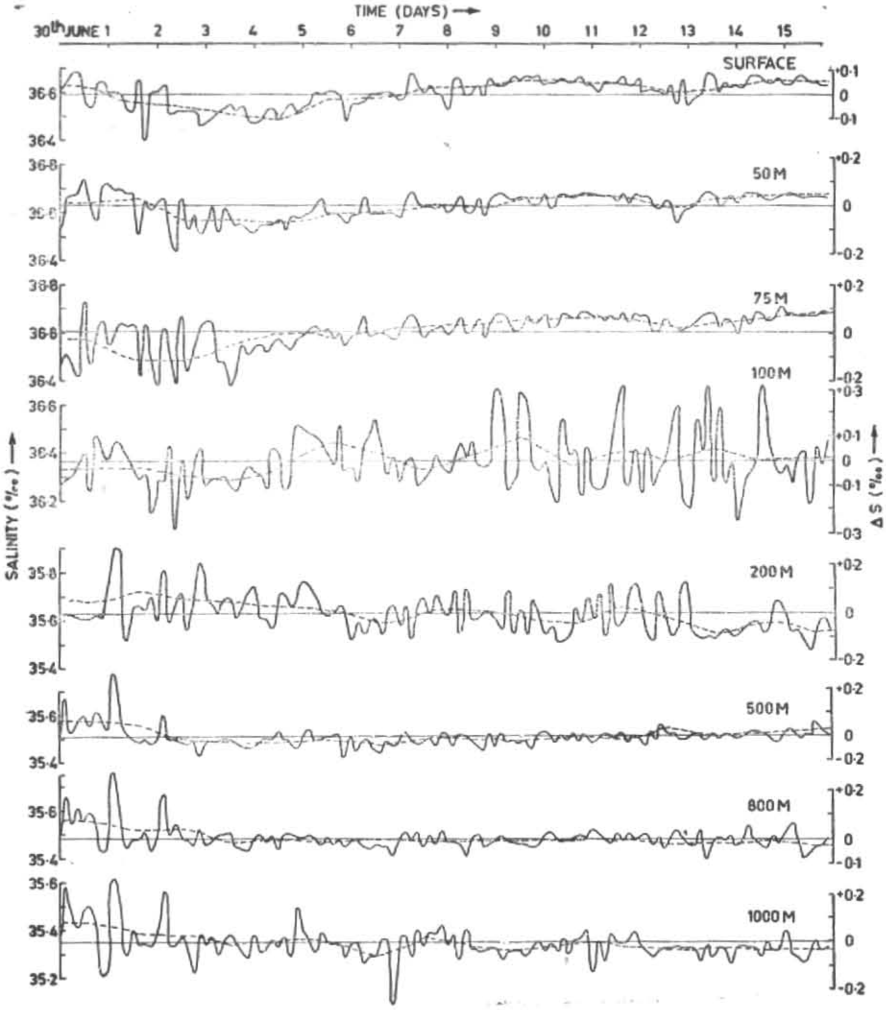


Fig. 4 (d). Northern location, Phase II

Figs. 4 (a-d). Time variation of salinities. Thick curve shows 3-hourly values. Dotted curve shows daily average values. $\triangle S$ (Right side scale) gives variations from phase mean

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