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ON THE LOWERING OF THE SURFACE TEMPERATURES IN THE
ARABIAN SEA WITH THE ADVANCE OF
THE SOUTHWEST MONSOON SEASON

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ABSTRACT

Utilising all the available bathythermograph data, mean bathythermograms for the months of May, June and July for each 5° square in the zonal belt of 10° and 15° N between Africa and India have been constructed. The basic features are : (1) The sea surface temperatures (SSTs) are high during May - June while a lowering of SST is observed in the month of July which ranges from 1° C to as much as 4.5° C, (2) In the area west of 60° E, the surface layer is more or less uniform during the entire period. East of 60° E, the surface layer shows a phenomenal increase in its thickness in the month of July, and (3) The heat content of the surface layer shows a similar variation.

After reviewing various oceanographic features of the Arabian Sea, the variations of the above features are discussed in relation to Somali upwelling, wind mixing etc.

1. Introduction

An examination of the sea surface temperature charts (La Violett and Mason, 1967; Miller and Jefferies, 1967; Wyrtki, 1971 etc.) suggests a lowering of sea surface temperature (SST) in the Arabian Sea with the advance of the northern summer, in contrast to the other regions similarly situated in the world oceans where the SSTs tend to increase. The SST is nearly 30° C during May and June over the Arabian Sea but by July it drops considerably.

Recent studies (Saha, 1970, 1974 and Shukla, 1975) suggest that the colder SSTs off Somali coast and in the western Arabian Sea may cause a reduction in the rainfall over India and the neighbourhood. This is to be expected since the SST forms one of the bottom boundary conditions to the planetary boundary layer and the water vapour fluxes, amongst other things, depend upon the meteorological and oceanographic parameters at the interface. The present investigation is an attempt to study the possible oceanographic factors within the upper layers of the Arabian Sea responsible for the lowering of the SSTs.

2. Data and Analysis

All the available bathythermograph data for the months of May, June and July in the zonal belt of 10-15°N between Africa and India have been pooled into 5° squares and the mean vertical bathythermograms have been constructed for each grid and are shown in the figure. Wherever the data are meagre, temperature data from the hydrocasts have been utilised. From these profiles, the thickness of the mean surface layer, and the mean thickness of the thermocline have been read (Table 1).

TABLE 1

Property	50°-55°E			55°-60°E			60°-65°E		
	May	June	July	May	June	July	May	June	July
Surface Temp. °C	28.7	28.9	26.3	29.5	29.4	24.8	30.3	30.9	27.6
Depth of 15°C Isotherm (m)	222	242	182	220	215	-	218	210	244
Thickness of surface layer (m)	20	22	25	36	40	48	30	30	100
Thickness of thermocline (m)	202	220	157	184	175	-	188	180	144

TABLE 1 (continued)

Property	65° - 70°E			70° - 75°E		
	May	June	July	May	June	July
Surface Temp. °C	30.0	29.7	27.9	30.8	29.2	28.1
Depth of 15°C Isotherm (m)	220	216	236	204	198	186
Thickness of surface layer (m)	34	44	86	33	49	50
Thickness of thermocline (m)	186	172	150	171	149	136

The heat content of the water column in the surface layer and the upper 100 m column has been computed and these values are tabulated in Table 2.

TABLE 2

HEAT CONTENT IN THE UPPER 100 m. (K. Cal)

Month	50°-55°E		55°-60°E		60°-65°E		65°-70°E		70°-75°E	
	S.L. 100 m col.		S.L. 100 m col.		S.L. 100 m col.		S.L. 100 m col.		S.L. 100 m col.	
May	62	257	105	230	50	276	101	240	100	237
June	63	251	116	269	92	269	129	275	145	270
July	65	230	113	235	276	276	239	275	139	283

+ Surface layer thickness.

3. Results

In grid 1, the SSTs during May and June are about 28.8°C while in July it is about 26.3°C and the slopes of these bathythermograms remain nearly the same during the three months. Thus, in the depth range of 0-250 m, the July temperatures at any depth are lower, by about 2°C than those at the corresponding depths during May and June. The mean bathythermograms for May and June in Grid 2 are similar to those of the earlier grid. The SST during these two months is about 29.4°C . However, in July, the SST drops to about 24.8°C . The July bathythermogram, however, shows a decrease in the vertical temperature gradients.

In grid 3, the May - June SSTs range between 30° and 31°C and the July SST is around 27.6°C . The July bathythermogram undergoes a phenomenal change with the development of an isothermal layer (80m) and steep temperature gradients are observed below this layer while the temperatures tend to decrease gradually from the surface during May - June. Below 60 m the July temperatures at any depth are higher by $3-4^{\circ}\text{C}$ than the corresponding values during May and June.

A similar pattern at the sea surface is observed in grid 4. However, below the surface layer, large differences in temperatures are not seen. In grid 5, the bathythermograms indicate a gradual lowering of SST during the entire period. The bathythermogram for the month of May upto a depth of about 200 m, indicates relatively higher temperatures compared to those during June and July.

The thickness of the surface layer (defined as the layer at the bottom of which the temperature is less by 1°C at the sea surface) varies between 20-30 m in May over the entire region. While it remains nearly the same in grid 1 during the period, it increases differentially in other zones with the advance of the season. It shows a slight increase in grid 2. In the central regions, the thickness of surface layer increases to maximum values and further east it tends to decrease.

The heat content of the water column (Table 2) shows a net loss of heat in the western grids while it remains same in the central regions in the upper 100 m. However, in the eastern grid, the heat content tends to decrease. In the upper 100 m, the variation in the heat content during May and June are negligible.

Thus, during the period May-July, the SSTs show a considerable decrease with the advance of the season and the lowering is not uniform over the region and is accompanied by change in the thickness of the surface layer.

4. Discussion

Surface cooling may result due to the various processes :

(1) evaporative cooling, (2) deepening of mixed layer, (3) spreading of cold waters from some other regions and (4) convergences and divergences that may develop due to wind-induced circulation.

All the above processes seem to operate in some way or the other in the Arabian Sea. During the southwest monsoon season southwest winds, occasionally exceeding 30 kts, blow over the regions off Somali and Arabia. Further eastwards, the strength of the wind decreases. The Somali current prevailing during this season turns eastwards between 7° and 9° N and associated with this intense upwelling (Swallow and Bruce, 1966, Bruce, 1970 and Warren et al, 1966) brings cold subsurface water to surface which spreads over extensive areas off the Somali coast. Further, the annual evaporation is considerable (150 cm) over the entire area (Venkateswaran, 1955). The basic features of the near surface circulation during the southwest monsoon season is the formation of several cyclonic and anticyclonic vortices in the entire zonal belt (Bruce, 1968, Duing, 1970 and Sastry and D'Souza, 1970 and 1971 a). Associated with these gyres which may change in intensity and location within the season, the vertical motions (both upwelling and sinking) develop. In addition, complex intermingling of several water masses is known to take place. In the eastern Arabian Sea, east of about 60° E, the maximum temperature gradients develop around 5° N and the vertical exchange of properties are somewhat enhanced on either side of 5° N (Sastry and D'Souza, 1970, 1971 b). These are in brief the processes that govern the dynamics of the upper layers of the Arabian Sea.

Thus, any explanation of the thermal structure necessarily depends upon the above processes. With the limited data at hand, it is difficult to assess the individual contributions of the above processes.

A plot of the 25° C isothermal surface (Sastry and D'Souza, 1971 b), extending in a nearly southwest-northeast direction off the

Somali coast in an extensive area, indicates that the cold upwelled water spreads over large areas, lowering the SSTs considerably. Intense upwelling off the Arabian coast and further spreading of this upwelled water may also affect the region. One would expect in such a case the lowest SSTs close to the upwelling region. However, the maximum lowering of SST is found in grid 2 indicating that the spreading of upwelled water may not be the only process. In grid 1, the thickness of the surface layer during the three months is almost the same, even though the winds are quite strong in the region. Wind mixing does not seem to extend to deeper waters. When upwelling sets in, the water column remains stable and vertical mixing is inhibited. Thus, the shallow nature of the surface layer as well as the lowering of the SSTs is clearly due to the intense upwelling and the stable character of the water column. In grid 2, the lowest SSTs were observed and the maximum lowering of SST occurs between June and July. The surface layer thickness increases considerably. This zone is partly located in the great clockwise gyre that develops during the southwest monsoon season. The temperature at the surface (Sastry and D'Souza, 1970) shows a tongue of cold water having less than 24°C between $55-60^{\circ}\text{E}$ in the region. Further, their studies show a cyclonic circulation in this region (Sastry and D'Souza, 1971 a). It is possible that surface divergence may result, bringing in the cold subsurface water to the surface. Thus, upto about 120 m, the July temperatures are predominantly lower than the corresponding values for the months of May and June. Further, this process seems to set in by about June, first in the subsurface layers.

Further eastward (Grids 3 and 4) the July temperatures show an isothermal layer. The July temperatures below the surface layer are $3-4^{\circ}\text{C}$ higher than the May-June values at corresponding depths in grid 3 while in grid 4, the difference between May-June and July temperature is about $1.0-1.5^{\circ}\text{C}$ respectively. It is felt that in these regions, the effect of direct wind mixing and the indirect effect of wind-induced circulation are probable causes. The effect of wind is two fold : (1) to develop a nearly homogeneous surface layer and (2) to develop a wind induced circulation. The data in grid 3 suggest that the direct wind mixing is limited to about 80 m. In that depth range, the May-June temperatures decrease from 31.0°C at the surface to about 25.0°C at about 80 m. A complete mixing of this water column could result in an isothermal layer of about 27.5°C as observed in the figure.

Associated with the wind induced circulation strong convergences may develop at this region thereby pushing down the water column to 200 m deep. Thus the large differences in temperature at corresponding depths during May-June and July appear partly due to wind mixing and partly due to convergence. In grid 4, the structure of the mean bathythermograms indicates similar features. However, the vertical circulation does not seem to extend to greater depths.

Adjoining the west coast of India, the winds are relatively weak, and the thickness of surface layer shows a tendency to increase from May-July. The May temperatures are everywhere greater than the June-July temperatures. Several investigators pointed out that adjoining the southwest coast of India upwelling takes place during the southwest monsoon season (Banse, 1959 and 1968; Barbyshire, 1967; Sharma, 1968; Sastry and D'Souza 1971 b). Even though there are some differences of opinion as regards the actual processes taking place here, it seems to be fairly well established that upwelling does take place. In addition, the cloud cover during the months of June and July cuts off the incident solar radiation. Further, considerable land drainage may also aid in the lowering of the SSTs here.

The variation in heat content presented in Table II appears to be in consonance with the thermal structure.

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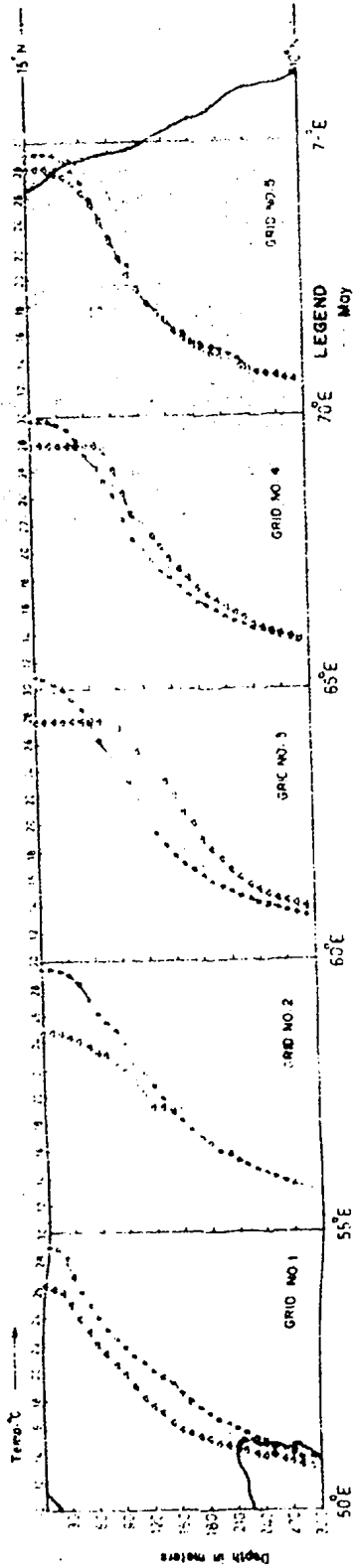
Data : All the data utilized in this investigation have been supplied by NOIC, Washington D.C.

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MEAN DEPTH-TEMPERATURE PROFILES

Note: Solid line and numbers are approximate