

Relation Between the Arabian Sea Surface Temperature and Monsoon Rainfall on the West Coast of India

Studies that relate the sea surface temperature (SST) of the northern Indian Ocean with the Indian monsoon have been receiving particular attention recently. According to Shukla (1975) and Shukla and Mishra (1977), the SST's over the Arabian Sea are positively correlated with rainfall over western India. Anjaneyulu (1980) has shown that warm (cold) SST anomalies in May precede a good (poor) monsoon season. Gadgil *et al.* (1984) have indicated that correlations between SST and monsoon cloudiness are positive and significant over the western Arabian Sea compared with those over the other regions of the northern Indian Ocean. On the other hand, Joseph and Pillai (1984) have obtained low, positive correlations between SST anomalies of pre-monsoon months and following monsoon rainfall. Pisharoty (1981), on the basis of his study, which was limited to normal monsoon season, has suggested the feasibility of medium-range forecasting of the Indian monsoon from knowledge of the SST anomaly field in the northern Indian Ocean.

In this paper, we present a preliminary investigation of the relationship between SST in the Arabian Sea and rainfall on the west coast of India. The correlation coefficients are examined in both normal and abnormal monsoon years to see whether SST charts are practical for medium-range forecasting of the Indian monsoon activity.

Two regions (Figure 1) were considered in the Arabian Sea to determine any spatial variation of the correlations during the monsoon season. A large evaporative heat flux was characteristic of region I, while region II was seen to have strong precipitation (Rao *et al.*, 1976; Rao *et al.*, 1981).

We considered the monsoon seasons of 1977 and 1979. In 1977, the monsoon activity was normal over most of the country. On the other hand, a late onset of the monsoon resulted in deficit rainfall, in general, over India during 1979. Areas bounded by different temperature ranges

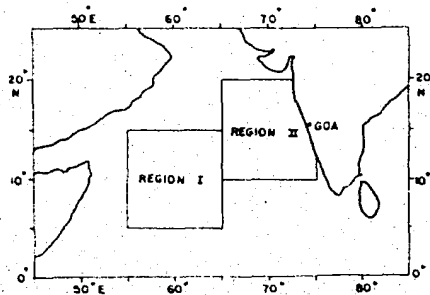


FIGURE 1 (Babu *et al.*)
Location of study area.

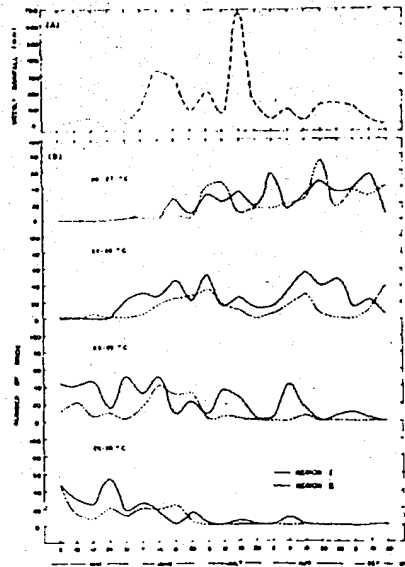


FIGURE 2 (Babu *et al.*)

(A) Seasonal (May to September 1977) variation of weekly rainfall at Goa. (B) Seasonal (May to September 1977) evolution of the areas of different temperature ranges in regions I and II.

were considered, rather than mere SST anomalies, since the magnitudes of the latter were close to the accuracy limit of satellite data, which is $\pm 1^\circ\text{C}$ (Brower *et al.*, 1976; Anjaneyulu, 1980). Each region was divided into grids of 1° latitude \times 1° longitude. The areas covered by various temperature ranges in the two regions, represented as numbers of grids, were obtained during the 1977 and 1979 monsoon seasons from weekly GOSSTCOMP charts supplied by the National Oceanic and Atmospheric Administration (NOAA).

Figures 2 and 3 show the seasonal evolution (May to September) of the areas of various temperature ranges in regions I and II during 1977 and 1979, respectively. The figures also depict the seasonal march of weekly rainfall observed at Goa, which is centrally located on the west coast of India, where the monsoon rainfall is relatively homogeneous. In 1977, the monsoon set in about the first week of June and rainfall varied, having typical oscillations of 2 to 3 weeks' duration. The highest peak in the rainfall occurred during the third week of July. This pulsating characteristic of the monsoon was absent in 1979. However, two long periods of rainfall occurred at 6 week intervals. The areas of different SST ranges show, in general, either an increasing or a decreasing tendency, except in the 27° - 28°C range (Figure 2). As usual, the areas of the

29° - 30°C and 28° - 29°C SST ranges decreased, while the area of the 26° - 27°C range increased. There were few regional differences in the areal variations of the SST ranges in the Arabian Sea during 1977 as compared with the differences observed during 1979 when region II (eastern Arabian Sea), in general, was warmer than region I (central Arabian Sea) (Figure 3).

The correlation coefficients between the areas covered by the temperature ranges and Goa rainfall have been computed at 1 and 2 week lag periods, and are shown in Table 1. The correlation coefficients are positive in 1977 at the 27° - 28°C range and increase with lag. In general, higher correlations can be seen for 1977 than for 1979 at the same temperature range. However, a high correlation coefficient of 0.43 appears at two weeks' lag in 1979 for 28° - 29°C in region I, indicating that the variations in the area of about 28°C bear some relation to the variation of the west coast rainfall. Recently, Gadgil *et al.* (1984) have also indicated 28°C as the threshold temperature for the active generation of monsoon clouds, above which the cloudiness is no longer dependent upon SST. The areas of the 27° - 28°C temperature range seem to be more important than those of other temperature ranges for the medium-range forecasting of the monsoon. In general, the differences in the correlation coefficients between the two contrast years of the monsoon are marked over the eastern Arabian Sea. Thus, the ther-

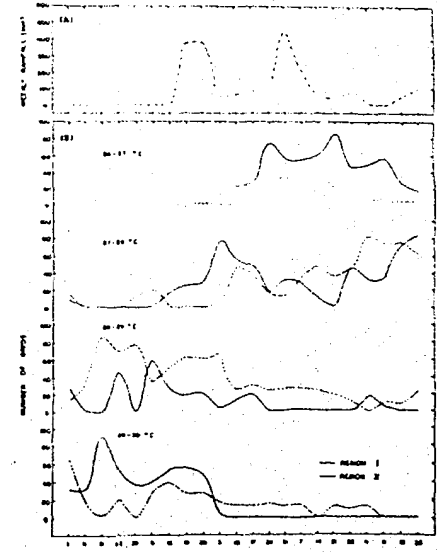


FIGURE 3 (Babu *et al.*)

(A) Seasonal (May to September 1979) variation of weekly rainfall at Goa. (B) Seasonal (May to September 1979) evolution of the areas of different temperature ranges in regions I and II.

TABLE 1 (Babu *et al.*)
Correlation coefficients between Indian west coast rainfall and the areas of various temperature ranges.

Year	Region	Temperature range (°C)	One week lag	Two week lag
1977	I	26-27	-0.08	0.01
		27-28	0.10	0.52
		28-29	0.24	-0.09
		29-30	-0.17	-0.13
	II	26-27	0.26	0.24
		27-28	0.28	0.56
		28-29	0.24	-0.06
		29-30	-0.06	-0.05
1979	I	26-27	0.18	-0.05
		27-28	0.11	0.15
		28-29	-0.09	0.43
		29-30	-0.02	-0.07
	II	26-27	0.36	0.01
		27-28	-0.24	0.01
		28-29	-0.03	-0.10
		29-30	0.17	0.17

mal regime in the eastern Arabian Sea seems to be influencing rainfall on the west coast of India.

Bhumralkar (1978) has shown that there is considerable increase in moisture content downstream of the monsoon air mass over the eastern Arabian Sea before it strikes the west coast of India. Rao *et al.* (1981) have also mentioned, after balancing the precipitation over the sea during monsoon season, that a good part of evaporation (>60%) over the Arabian Sea transports water vapor into India. According to Washington *et al.* (1977), the response of the atmospheric circulation to the SST anomalies is mainly local. Their experimental results show increased (decreased) vertical velocity and precipitation over regions of warm (cold) SST anomalies.

Based on these results, it is expected that anomalous heat content in the upper layers of the eastern, rather than central, Arabian Sea will effect some changes in rainfall pattern at nearby areas, such as the west coast of India.

The present study shows that somewhat high and positive correlations exist between west coast rainfall and the 27°-28°C SST range in the eastern (central) Arabian Sea during a good (poor) monsoon season. The order of correlations as obtained here does not explain the complete variance of rainfall at the west coast of India and, as such, any attempt to forecast the rainfall at the west coast of India quantitatively is undesirable. Further, the significance of the present correlations remains to be examined using the data sets of several contrasting years of monsoon activity. However, the GOSSTCOMP charts, the satellite data product of NOAA, are useful for the monitoring of the areal distribution of waters encountered by the 27°-28°C range, which seems to be critical for monsoon activity.

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