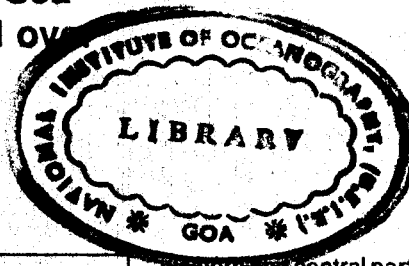


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Influence of eastern Arabian Sea on summer monsoon rainfall over West coast of India

V.RAMESH BABU, M.SUBBA RAO* AND M.V. RAO**

National Institute of Oceanography,
Donapaula, Goa



Sea surface temperature (SST) anomalies have been assigned as one of the boundary conditions in the global circulation models for simulation of climatic changes. The effects of SST anomalies on the summer monsoon simulations are both of local and distant nature. In order to realise the model results and the influence of Arabian sea in the context of long range forecasting of monsoon rainfall, we have examined the correlation between the rainfall over west coast of India and pre-monsoon thermal anomaly field in the eastern Arabian Sea where larger atmospheric convection as compared to that over other parts of the water body normally takes place during the summer monsoon season. The present results based on observations during ten years' period (1975-1984) have not shown local influence (higher SSTs causing higher rainfall) of the sea. On the contrary, a negative association has been observed in the sense that monsoon activity at west coast of India is more likely to be less when abnormal pre-monsoonal warming takes place in the eastern Arabian Sea.

Western and central parts of the Arabian Sea with the following strong (weak) monsoon activity. However, his study is based on climatological data summarised at few grids located in the Arabian Sea during four years only. Joseph and Pillai (1984) in their study on inter-annual variability of SST have further indicated that positive correlations exist between monsoon rainfall and pre-monsoon SST anomaly at some selected representative areas of north Indian Ocean. On the other hand, the statistical studies of Weare (1978) on the influence of the Indian Ocean surface temperatures over the monsoon have suggested that the warmer Arabian Sea is associated with decreased rainfall and increased sea surface level pressures over the Indian sub-continent.

In this investigation, the eastern Arabian Sea has been considered as the study area since it is a region of higher convergence along with an ascending limb of a zonal circulation cell (Ghosh et al, 1978). During the monsoon season, the fluctuations in the thermal regime particularly in the eastern Arabian Sea rather in its central part have indicated significant correlations with the variations in the monsoon activity at Goa as shown by Ramesh Babu et al (1985). It is seen that the surface area of the sea bounded by 27 and 28°C isotherms is positively correlated with the rainfall observed after 15 days interval during a good monsoon year whereas such correlation is very low during a bad monsoon year. Their results suggest that global SST maps obtained routinely as one of the satellite data products may be consulted to monitor short-term changes in the thermal regime in the eastern Arabian Sea for issuing short range forecast of monsoon activity over western India. It could be possible to see whether the effects of SST anomalies on the rainfall patterns are of local or distant nature as seen in the results of the numerical model experiments taking the advantage of regular rainfall observations made at a nearby area which is, in this case, the west coast of India.

1. Introduction

Though the search for predictors has been initiated hundred years ago in the context of long range (seasonal) forecasting of the Indian monsoon rainfall, studies linking the Indian summer monsoon with sea surface temperature (SST) anomalies are of recent nature and started only after realising the dependence on global climatic changes on bottom boundary heat sources. The effect of the Arabian Sea SST anomaly on the Indian summer monsoon has been examined through simulations with different general circulation models and the SST anomalies. For example, Shukla (1975) has hypothesised that the cold SST anomaly over the western part of the Arabian Sea would decrease the rainfall over India while Washington et al (1977) have illustrated no substantial changes in precipitation patterns over Indian sub-continent when SST anomalies at different parts of the Arabian Sea are prescribed. Anjaneyulu (1980) has shown the association of observed warm (cold) SST anomalies during May over the

We have presented here an analysis of pre-monsoon SST anomaly field over the eastern Arabian Sea and have examined the influence of the eastern Arabian Sea on the ensuing summer monsoon activity over the west coast of India in the context of long range forecasting of rainfall.

2. Data Analysis

The SST data taken from ship weather reports over the eastern Arabian Sea during pre-monsoon months (April and

Present address: * Department of Meteorology, University of Nairobi, Kenya.

** National Remote Sensing Agency, Hyderabad.

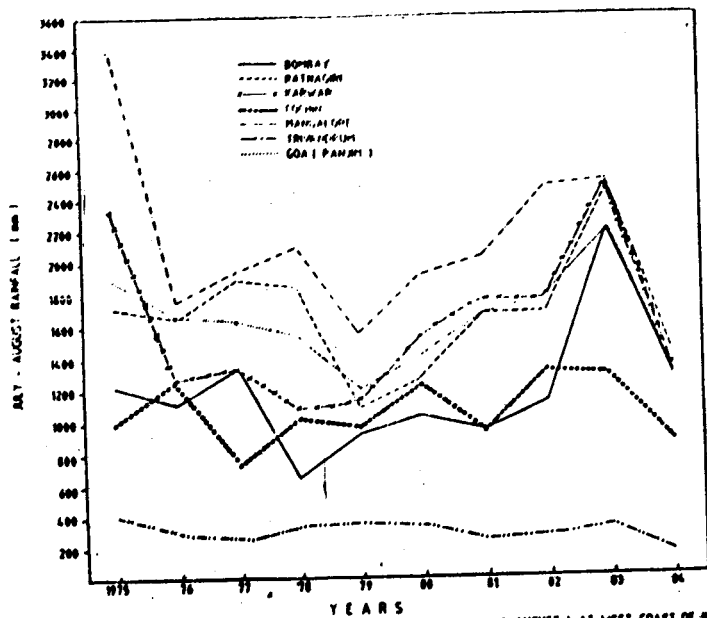


FIG 1 INTER-ANNUAL VARIABILITY OF MONSOON RAINFALL (JULY AND AUGUST) AT WEST COAST OF INDIA

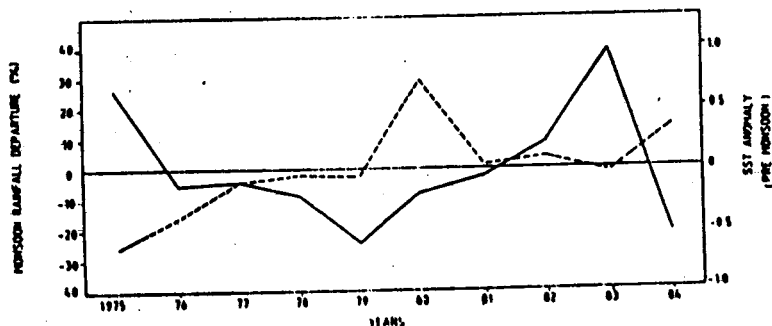


FIG 2 PERCENTAGE OF DEPARTURE OF MONSOON RAINFALL (JULY-AUGUST) AT WEST COAST OF INDIA (—) AND PRE-MONSOON (APRIL-MAY) SST ANOMALY (°C) IN THE EASTERN ARABIAN SEA (- - -) BASED ON DECADEAL (1975-84) MEAN

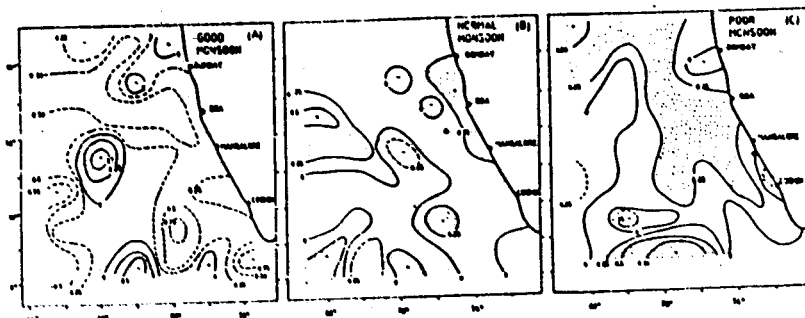


FIG 3 PRE-MONSOON (APRIL - MAY) SST ANOMALY (°C) BASED ON DECADEAL (1975-84) MEAN DURING (A) ACTIVE (B) NORMAL AND (C) POOR MONSOON YEARS WARM POOLS (ANOMALY $> 0.25^{\circ}\text{C}$) ARE STIPPLED DASHED LINES INDICATE NEGATIVE ANOMALIES

May) for a 10-year period (1975-84) are grouped into 2° square grids between 6-20° N and 65-77° E. The monthly SST averages for each grid are worked out and average monthly anomalies are obtained based on the decadal mean instead of long-term mean. This helps in eliminating the effects of long period trends in the anomaly and it is possible to examine exclusively the association of the fluctuations in the anomaly with those in rainfall intensity at west coast of India between Bombay and Trivandrum, which are again obtained with reference to decadal mean. We have considered here the rainfall during the period July-August representing the activity of the monsoon since the chances for uniform presence of monsoon along the entire west coast are less during June and September months. The SST observations made in April and May months are merged together and anomalies representing the pre-monsoon season in general are obtained since some grids do not contain adequate data.

3. Results and discussion

3.1. Interannual Variability of Rainfall at West Coast of India:

Fig.1. shows the variations in the rainfall during July-August period for the years 1975-84 at seven stations on the west coast of India. The necessary information on rainfall has been extracted from Indian Daily Weather Reports. The fluctuation show strong variability from Bombay to Mangalore compared to that at southern coastal stations. In general, there is a quasi-biennial oscillation superimposed on a long term trend - a decreasing one till 1979 and an increasing one upto 1983. At Cochin, the strength of this low-frequency mode in the rainfall signal is comparatively weak and further to the south at Trivandrum, it is very much diminished. In fact at Trivandrum, a slight increase in the monsoon activity around 1979 is seen while deficit rainfall is well-pronounced at the same time at northern and central coastal stations. It is interesting to note that the interannual fluctuations at northern and central parts of the coast are more or less in the same phase. This indicates that major part of the coast is under the influence of relatively uniform conditions responsible for rainfall. We recall here that the monsoon winds directly strike the northern and central parts of the coast from westerly or southwesterly direction whereas in the southern part of the coast, they grace the coast with lesser normal wind components.

The average percentage of rainfall departure is worked out by taking into consideration all seven stations of the west coast of India based on decadal mean and this is compared with average pre-monsoon SST anomaly computed for the entire study area of the eastern Arabian Sea (Fig.2). It is seen that there is a general trend in SST anomalies to become less negative during the first half of the decade whereas there is a simultaneous tendency for the rainfall to be more deficit. This is a quite interesting result and is contrary to the model results. When warm (cold) SST anomalies are well-pronounced, the

model rainfall is expected to increase (decrease) while in the present study it is seen that highest pre-monsoon negative anomaly (0.26°C) associates with one of the active monsoon year 1975 during the decade. The most active rainfall year 1983 has not followed any pre-monsoon abnormal warming event in the eastern Arabian Sea. The correlation coefficient between observed pre-monsoon SST anomaly in the entire eastern Arabian Sea and the west coast monsoon rainfall is found to be -0.39. However, this is not significant (< 90 %) for prediction purpose.

3.2 SST Anomaly Distribution:

Fig.3 shows the distribution of pre-monsoon SST anomalies over the eastern Arabian Sea averaged separately for good monsoon years (rainfall departure: >+20%), normal monsoon years (departure between +20 and -20%) and for the poor monsoon years (departure: <-20%). During this decade, two years of excessive rainfall (1975 and 1983) and two years of deficit rainfall (1979 and 1984) are observed (Fig.2). It is clearly seen in Fig.3 that the activity of monsoon at the west coast of India is likely to be less in association with abnormal pre-monsoon warming in the eastern Arabian Sea.

A physical explanation for the negative association of rainfall with SST anomalies over the eastern Arabian Sea is sought in the sense that pre-monsoonal thermal regimes seem to be controlled by abnormal sinking and rising motions in the atmospheric column. When the atmosphere is abnormally dominated by subsidence, the sky would relatively be cloud-free and the winds would comparatively be weak. These conditions further help in causing more net radiation and less evaporation rates at the sea surface and as a result, higher net heat gain takes place. The warm SST anomalies would then appear. Recently the authors in their studies on the pre-monsoonal heat budget of the east central Arabian Sea, have found about 80% of the rise in the heat content of the upper layer (0-50 m) to be on account of the net surface heat gain (Table 1). From empirical orthogonal function analysis, Weare (1978) showed that abnormal Indian Ocean SSTs follow abnormal Indian Ocean surface pressures indicating the effect of higher subsidence in the atmosphere. He has further indicated that the anomalous higher Indian Ocean surface pressures also lead the warm Pacific Ocean SSTs. These warm Pacific SST anomalies of the order of 3°C tend to weaken the east-west Walker circulation considerably and thereby would strengthen the subsidence over the Indian Ocean region (Keshavamurthy, 1980). Thus warm pre-monsoon SST anomalies in the eastern Arabian Sea seem to be related to the effects of higher subsidence in the overlying atmosphere.

One should be very much cautious while following the general belief that higher SSTs over the Indian Ocean, in particular over the Arabian Sea, during pre-monsoon season would intensify the ensuing monsoon activity. Probably, their influence on rainfall may be expected on seasonal time scales

when local convergence due to lateral boundary effect is available after the onset of monsoon over the area of study.

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TABLE -1
PRE-MONSOONAL HEAT BUDGET OF THE EAST CENTRAL ARABIAN SEA

Unit: Watts/m²

	PARAMETERS	Value
1.	Net Radiative Heat Flux	293.1
2.	Evaporative Heat Flux	189.7
3.	Sensible Heat Flux	20.1
4.	Net Heat Gain	83.3
5.	Heat Advection	8.6
6.	Heat Content Change (0-50 m)	67.5