

## NOTES AND CORRESPONDENCE

**Relationship Between Sea Surface Temperature, Southern  
Oscillation, Position of the 500 mb Ridge along 75°E in April  
and the Indian Monsoon Rainfall**

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**Abstract**

Relationships between the seasonal sea surface temperature values of four oceanic regions, namely the western Arabian Sea, the eastern Arabian Sea, the Bay of Bengal and the sea off Somalia coast with the Southern Oscillation Index, position of the 500 mb ridge along 75°E in April and the summer monsoon rainfall for the period 1948 to 1972 are studied. There is positive and significant relationship between the preceding winter sea surface temperatures in the Bay of Bengal and the 500 mb ridge position along 75°E in April. The study further shows that sea surface temperature anomalies in the Arabian Sea and the north Indian Ocean during the summer monsoon are caused by the monsoon circulation/monsoon activity over India rather than vice versa. It was also found that the premonsoon sea surface temperature values in three of the above study areas are useful for predicting the monsoon rainfall.

## 1. Introduction

Meteorologists and oceanographers have been trying to improve the long range forecasting of the Indian monsoon rainfall, as the summer monsoon is of vital importance to the economy of the country, as about 70 to 90% of the annual rainfall for the various meteorological subdivisions of the Indian subcontinent is received during this period (June to September). The role of sea surface temperature (SST) on the summer monsoon has not yet emerged, even though several authors (Weare, 1979; Ranjith Singh, 1980; Ramesh Kumar *et al.*, 1986a & 1986b; Joseph, 1983; Rao and Goswami, 1988) have given contradicting theories and hypothesis.

Weare (1979) found that warmer Arabian Sea (AS) or Indian Ocean is weakly associated with the decreased rainfall over most of the meteorological subdivisions by performing an empirical orthogonal function analysis on the Indian Ocean data for the period 1949–1972. Study of Ranjith Singh (1980) showed that the zones of the warmest SST dur-

ing the premonsoon months of April and May are found at the northern latitudes in good monsoon years (1961, 1964) than in bad monsoon years (1965, 1966).

Joseph and Pillai (1986) have correlated the monthly mean SST time series for the period 1961–1973 of three selected regions with the monsoon rainfall over the Indian subcontinent. Their study revealed that the correlation between the monsoon rainfall and SST of the preceding winter and premonsoon seasons was positive but not significant. The correlations were found to change sign in the monsoon season (concurrent correlation), but was not significant except for one area (western AS). However, they found that the monsoon rainfall was negatively and significantly correlated (at 97% level) with the SST of the following post monsoon season of the above study areas.

Ramesh Kumar *et al.* (1986a) using a limited data set have shown that the premonsoon SST off Somalia coast were positively and significantly related to the summer monsoon rainfall and hence can be used as useful predictor. Ramesh Kumar *et al.* (1986b)

using the satellite derived SST data have shown that the zonal anomaly of SST off the Somalia coast is negatively and significantly correlated with the monsoon rainfall over the central and western parts of the country, whereas, the zonal anomaly of central Indian Ocean SST was positively and significantly correlated with the monsoon rainfall over the above regions.

Rao and Goswami (1988) using the data for the period (1900–1979) have showed that the SST over two five degree squares in the southeastern AS during the premonsoon months correlates most strongly, positively and significantly with the monsoon rainfall. They further showed that except over one square in the Bay of Bengal (between 10° and 15°N; 90–95°E) the June to August SST over most of the north Indian ocean does not significantly correlate with monsoon rainfall. The post monsoon SST correlates negatively over most of the oceanic regions and spatial homogeneity of the correlation field was high, with the highest and significant correlations occurring in the western and northern AS.

In the present study we have tried to relate the mean seasonal SST of four oceanic regions namely western AS (represented by Marsden Square (MSQ) 67); eastern AS (represented by MSQ 65); Bay of Bengal (represented by MSQ 64) and off Somalia coast region (MSQ 31) with the monsoon rainfall, the position of the 500 mb ridge in April along 75°E and the Southern Oscillation Index (SOI). The reason for choosing the above squares have been mainly the data density and its uniform distribution within the study period (1948–1972). The four Indian seasons being (i) Winter (January and February) (ii) Premonsoon (March, April and May) (iii) Monsoon (June, July, August and September) (iv) Post monsoon (October, November and December).

## 2. Data and methodology

The data needed for the present study have been extracted from the unpublished data set of Bunker for the Indian Ocean. The data set consisted of meteorological parameters like sea surface temperature, air temperature, mixing ratio, air-sea temperature difference, cloud cover, wind speed, sea level pressure *etc.*. In addition, it contained of time series of monthly averages of latent and sensible and radiational heat fluxes and the momentum fluxes at the surfaces of the north and south Indian Oceans calculated from ship weather observations for the period January 1948 to December 1972. Figure 1 presents the study area (shaded area) along with Marsden square numbers (10° × 10° square grids) used in the study.

The quality of the SST observations have been thoroughly checked in this study using the criteria followed by Joseph (1983) (*i.e.*, SST observations in the range 15°C to 35°C were accepted. No check was

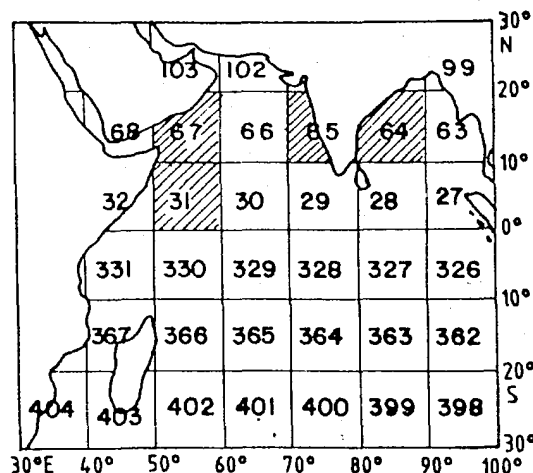


Fig. 1. Study area (shaded area) along with Marsden square numbers (10° × 10° square grids).

made of the method of SST observation, whether bucket or engine intake method *etc.*). Whenever, the SST values exceeded the range limits they were rejected.

The rainfall data for the study have been taken from Mooley and Partahasrathy (1984). Average rainfall over the plains of India for each monsoon season (June to September) is obtained by weighting each station rainfall by the area of the distribution in which the station is located. Data pertaining to about 306 stations evenly distributed over the plains of India were used.

The data pertaining to the SOI, has been taken from Shukla and Paolino (1983). Here the SOI refers to the difference in pressure between April and January sea level pressure at Darwin. Darwin is located near one of the nodes of the southern oscillation (SO), we have also used the pressure tendency rather than the actual pressure in this study following Shukla and Mooley (1987).

The data on the position and location of the 500 mb ridge along 75°E in April, for the study period 1948–1972 have been extracted from Mooley *et al.* (1986).

## 3. Results and discussion

From an analysis of the correlation between the seasonal SST of the western AS, monsoon rainfall, 500 mb ridge position and the SOI for the period 1948 to 1972 (Table 1) we found that the preceding winter SST (WSST) does not have any significant relation with the monsoon rainfall but it is weakly and positively (at 80 % level) correlated with the 500 mb ridge position. The WSST were negatively and significantly (at 95 % level) correlated with the SOI. Suppiah (1988) also obtained a similar result between Indian Ocean SST anomalies and SOI, he

Table 1. Correlation between seasonal SST's in the western AS (MSQ 67), monsoon rainfall, 500 mb ridge position along 75°E in April and SOI.

Parameters —	Monsoon rainfall	500 mb ridge position in April	SOI
Seasons			
Winter	0.01	0.29 <sup>1</sup>	-0.41 <sup>3</sup>
Premonsoon	0.41 <sup>3</sup>	0.30 <sup>1</sup>	-0.20
Monsoon	-0.30 <sup>1</sup>	-0.29 <sup>1</sup>	0.12
Post monsoon	-0.38 <sup>3</sup>	-0.45 <sup>4</sup>	0.35 <sup>2</sup>

Where the superscripts 1, 2, 3, 4, and 5 stand for 80 %, 90 %, 95 %, 98 % and 99 % confidence levels respectively.

found strong negative correlations in the winter half of the year but weak negative correlations in the summer half. The latter, he feels may be due to the influence of summer monsoon. The premonsoon SST (PMSST) of this area are positively and significantly (at 95 % level) correlated with the monsoon rainfall. Wu (1984) has also obtained weak positive correlations between PMSST over a large oceanic area (Equator-15°N; 50-75°E) of the AS and the summer monsoon rainfall. Rao and Goswami (1988) feels that the reason for weak correlations may be inclusion of the month of May. They feel that this month should be excluded from the premonsoon season as they think that the 30-50 day mode starts influencing the AS from May. The PMSST were weakly and positively (at 80 % level) correlated with position of the 500 mb ridge. The summer monsoon SST (MSST) were weakly and negatively (at 80 %) correlated with the monsoon rainfall and 500 mb ridge. The postmonsoon SST (POMSST) of this oceanic region were found to be negatively and significantly correlated with the monsoon rainfall (at 95 % level), and 500 mb ridge (at 98 % level) and it is positively and significantly correlated with SOI (at 90 % level).

Table 2 gives the relationships for the eastern AS. The PMSST of this area was positively and significantly correlated with the monsoon rainfall and 500 mb ridge (at 95 % level). Joseph and Pillai (1986) have also obtained a similar result. It was negatively and significantly correlated with the SOI (at 90 % level). The MSST were negatively and significantly correlated with the rainfall and the position of the 500 mb ridge in April (at 95 % level). The POMSST were negatively and significantly correlated with the monsoon rainfall (at 98 % level) and 500 mb ridge (at 90 % level) respectively. The POMSST were positively and significantly correlated (at 95 % level) with the SOI.

Table 2. Correlation between seasonal SST's in the eastern AS (MSQ 65), monsoon rainfall, 500 mb ridge position along 75°E in April and SOI.

Parameters —	Monsoon rainfall	500 mb ridge position in April	SOI
Seasons			
Winter	0.09	0.14	-0.16
Premonsoon	0.40 <sup>3</sup>	0.39 <sup>3</sup>	-0.35 <sup>2</sup>
Monsoon	-0.40 <sup>3</sup>	-0.39 <sup>3</sup>	0.00
Post monsoon	-0.49 <sup>4</sup>	-0.34 <sup>2</sup>	0.44 <sup>3</sup>

Where the superscripts 1, 2, 3, 4, and 5 stand for 80 %, 90 %, 95 %, 98 % and 99 % confidence levels respectively.

We do not have any physical explanation as to why the PMSST in the AS and Somalia areas are positively and significantly related to the monsoon rainfall. The reason for negative and significant correlation between MSST and the monsoon rainfall may be due to the lowering of SST in the monsoon months over AS, which in turn could strengthen the high pressure over the oceanic area and this could consequently develop a strong pressure gradient between the AS and the Indian subcontinent which would result in an enhanced monsoon circulation and good monsoon rainfall.

There exists a strong teleconnection between the Indian summer monsoon rainfall, the walker circulation and the southern oscillation as indicated by several studies. The SO is characterized by switching of the pressure systems between the eastern and western equatorial pacific ocean and also an eastward shift of walker circulation. This pressure change is associated with a shift in the warm pool from the western part of the equatorial pacific to the east. This warm pool, according to Bjerknes (1969) is a region of large scale upward transport of moisture and is the main branch of walker circulation. An examination of the global SST distribution shows that an arm of this warm water pool extends to the Indian Ocean through Bay of Bengal (Gopinathan and Rao, 1985). We feel that similar type of walker type of circulation during winter may be responsible for the positive and significant correlation between WSST and monsoon rainfall over India.

The correlation between the seasonal SST of Bay of Bengal, monsoon rainfall, 500 mb ridge position in April and SOI are presented in Table 3. The WSST were positively and significantly correlated with the monsoon rainfall (at 98 % level), the position of the 50 mb ridge in April (at 95 % level). They were weakly and negatively (at 80 % level) correlated with the SOI. The MSST were negatively and

Table 3. Correlation between seasonal SST's in the Bay of Bengal (MSQ 64), monsoon rainfall, 500 mb ridge position along 75°E in April and SOI.

Parameters	Monsoon rainfall	500 mb ridge position in April	SOI
Seasons			
Winter	0.47 <sup>4</sup>	0.36 <sup>3</sup>	-0.29 <sup>1</sup>
Premonsoon	0.13	-0.02	-0.15
Monsoon	-0.43 <sup>3</sup>	-0.03	0.19
Post monsoon	-0.53 <sup>5</sup>	-0.38 <sup>3</sup>	-0.07

Where the superscripts 1, 2, 3, 4, and 5 stand for 80 %, 90 %, 95 %, 98 % and 99 % confidence levels respectively.

significantly correlated with the monsoon rainfall (at 99 % level) and 500 mb ridge position (at 95 % level).

Table 4 gives the correlation coefficients of the relationships between the seasonal SST off Somalia coast and other parameters. The preceding WSST were weakly and negatively (at 80 %) correlated with the SOI. The PMSST were positively and significantly correlated with the monsoon rainfall (at 95 % level), and 500 mb ridge (at 90 % level). The MSST were negatively and significantly correlated with the 500 mb ridge position (at 95 % level). They were weakly and positively (at 80 %) correlated with the SOI. The POMSST were negatively and significantly correlated (at 95 % level) with the position of the 500 mb ridge.

#### 4. Conclusions

The present study of the relationships between the seasonal SST of various oceanic regions, monsoon rainfall, position of the 500 mb ridge along 75°E in April and the SOI have brought out the following results:

- (1) The PMSST of the three oceanic areas, namely the western AS, eastern AS and off the Somalia Coast regions are positively and significantly correlated with the monsoon rainfall and hence can be thought of as useful predictors for the summer monsoon rainfall.
- (2) The SST anomalies in the AS and Indian Ocean are result of the monsoon circulation/monsoon activity rather than vice versa, because the POMSST of all the study areas were found to be negatively and significantly correlated with the monsoon rainfall and position of the 500 mb ridge along 75°E in April.
- (3) The preceding WSST of the Bay of Bengal were found to be positively and significantly correlated with the position of the 500 mb ridge in April along 75°E.

Table 4. Correlation between seasonal SST's in the Somalia coast (MSQ 31), monsoon rainfall, 500 mb ridge position along 75°E in April and SOI.

Parameters	Monsoon rainfall	500 mb ridge position in April	SOI
Seasons			
Winter	0.17	0.06	-0.27 <sup>1</sup>
Premonsoon	0.41 <sup>3</sup>	0.36 <sup>2</sup>	-0.11
Monsoon	-0.15	-0.43 <sup>3</sup>	0.29 <sup>1</sup>
Post monsoon	-0.21	-0.39 <sup>3</sup>	0.11

Where the superscripts 1, 2, 3, 4, and 5 stand for 80 %, 90 %, 95 %, 98 % and 99 % confidence levels respectively.

- (4) The SOI was found to be weakly and negatively correlated with the WSST over the areas Bay of Bengal and off Somalia coast whereas it was significant (at 95 %) over the western AS. The PMSST over the eastern AS was found to be negatively and significantly correlated with the SOI (at 90 % level).

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## 海面水温、南方振動、及び4月における東経75度の500 MB リッジ位置と

### インドモンスーン降雨量との関連

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東西アラビア海、ベンガル湾、及びソマリア沖の海洋における海面水温と、南方振動示数、4月における東経75度の500 MB リッジ位置と夏のモンスーン降雨量との関連を1948年から1972年の期間について調べた。先立つ冬のベンガル湾の海面水温と、4月における東経75度の500 MB リッジ位置の間には顕著な正の相関が存在する。当研究では、更に夏のモンスーン期のアラビア海と北インド洋における海面水温偏差は、モンスーン大気循環/モンスーン活動度によって引き起こされたものであることが示される。上記の海域のうちの3領域におけるモンスーン開始前の海面水温はモンスーン降雨量の予測に有用であることが見いだされた。