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L E T T E R S

551.541 : 551.463.5 : 551.578.1

ANALYSIS OF SEA LEVEL PRESSURE AND SEA SURFACE TEMPERATURE ANOMALIES IN THE MONTH OF MAY FOR THE EXCESS AND DEFICIT INDIAN SUMMER MONSOON RAINFALL

1. The intensity of All India summer monsoon rainfall is to a large extent controlled by the gradient of Sea Level Pressure (SLP) and the distribution of Sea Surface Temperatures (SST) over the Arabian Sea and it is further accentuated by those over the Bay of Bengal. An attempt is made in this work to bring out this effect during May, in particular, which is the terminal month of pre-monsoon and also to highlight their intraspatial variations. The sea level pressure (SLP) and sea surface temperature (SST) distributions have been obtained from the marine meteorological data for the month of May 1981-2010 on 5 degree grid-meshes over north Indian Ocean covering the area of 0° - 25° N, 50° - 100° E. An attempt has been made to study the variation of SLP and SST over north Indian ocean covering over the area during the years of excess Indian summer monsoon rainfall (1983, 1988 and 1994) and the years of deficit Indian summer monsoon rainfall (1982, 1986, 1987, 2002, 2004 and 2009).

The role of the sea surface temperature (SST) over the Arabian Sea on southwest monsoon over India has been an everlasting subject of curiosity. Two different possibilities exist. First, the variations of SST over this region can influence the monsoon rainfall through variations of available moisture supply. On the other hand, variation of the monsoon circulation itself can produce variations in the SST over this region through the changes in evaporative cooling and changes in cloud cover. Significant correlations between SST anomalies over Arabian Sea during pre-monsoon months March, April and May (MAM) and monsoon rainfall have been brought by Shukla and Mishra (1977), Weare (1979), Cadet (1983). Shukla (1975) suggested that colder SST anomalies over western Arabian sea and Somali coast may cause reduction in monsoon rainfall over India and neighborhood. Rao and Goswami (1988) showed that March-April SSTs of homogeneous regions in southeastern Arabian Sea are significantly positively correlated with seasonal rainfall over India. Ocean and atmosphere are closely linked and interaction in different space and time scales in produce weather and climate on the planet. Khole (2000), Khole and De (2001) and Rajeevan *et al*. (2000) have studied some features of monsoon variability and related Sea Surface Temperature (SST) variations during recent years of the last century. The increasing trends in SST over the equatorial Indian Ocean and their association with the cloud cover have been reported by Rajeevan *et al*. (2001).

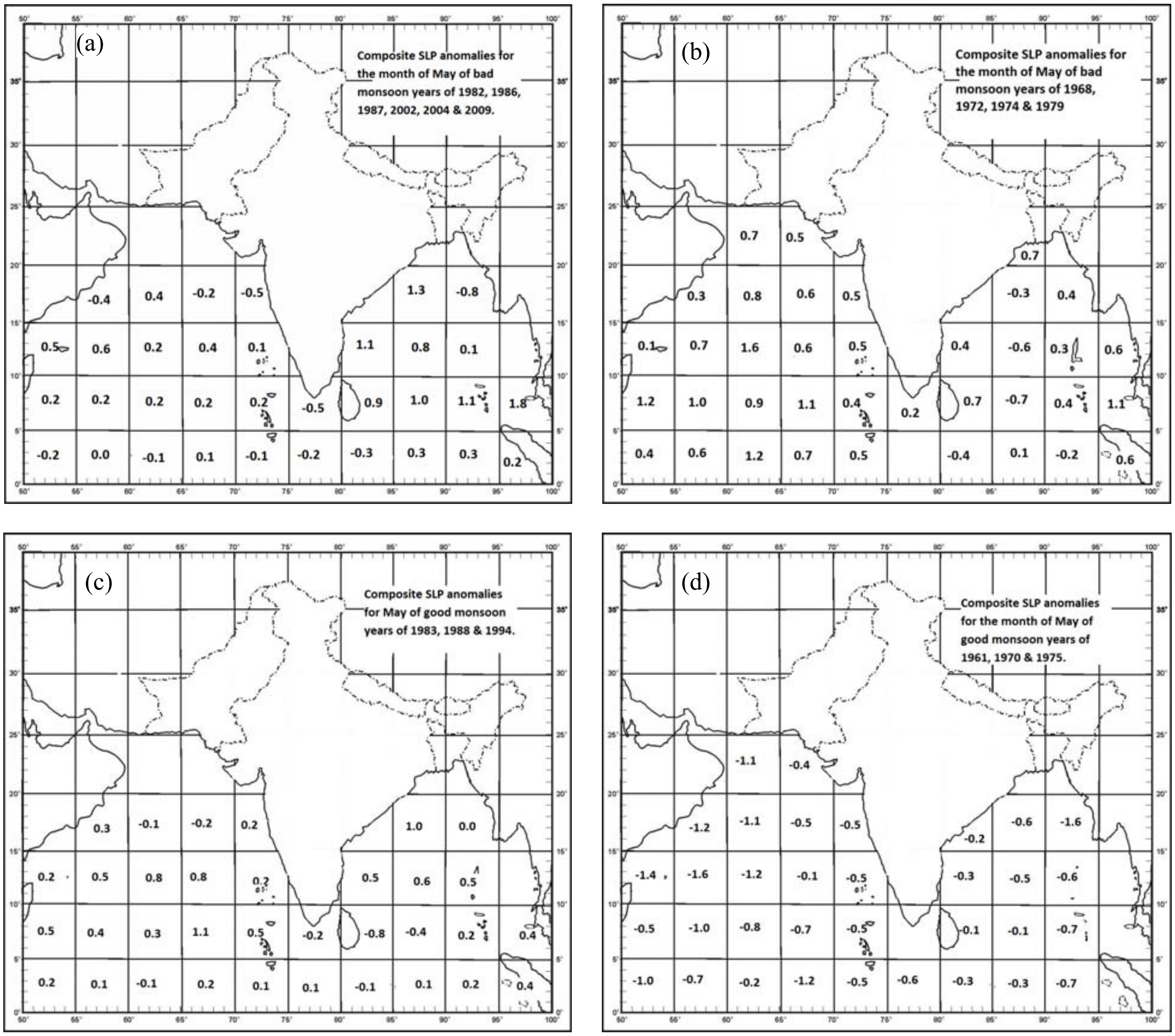
TABLE 1

Coefficient of correlation between the mean SLPs of different latitudinal belts and all India rainfall departure for Summer monsoon

S. No.	Predictor	CC with the rainfall departure
1	Mean SLP over 0° - 5° N	-0.02
2	Mean SLP over 5° - 10° N	-0.08
3	Mean SLP over 10° - 15° N	-0.04
4	Mean SLP over 15° - 20° N	-0.04
5	Mean SLP over 20° - 25° N	0.18

The inter-annual variability in Indian summer monsoon rainfall is well established. The SST and mean SLP have got significant influence over the monsoon rainfall over India. The objective of this paper is to study the variability of SLP and SST during the composite good monsoon years (1983, 1988 and 1994) and composite bad monsoon years (1982, 1986, 1987, 2002, 2004 & 2009). Singh (1998) studied the association between north Indian ocean and summer monsoon rainfall over India and found that SST gradient over the Arabian sea and Bay of Bengal between 7.5° N - 17.5° N during the month of May have significant positive correlation with Indian rainfall of subsequent months. Shukla and Mishra (1977) have brought out the correlation of SST and wind speed over central Arabian Sea with the monsoon rainfall over India. Singh (1993), Singh and Joshi (1993) explained how meteorological and oceanographical conditions prevailing over the north Indian ocean before the commencement of summer monsoon season influence the subsequent monsoon rainfall over India.

2. *Relationship between SLP fields during May over the Arabian Sea and Bay of Bengal and the rainfall activity* - It is seen from the Table 1 that there exists a negative correlation between SLP of May over Indian ocean (north of equator) and subsequent Indian summer monsoon rainfall. The mean SLP of equatorial



Figs. 1(a-d). Composite SLP anomalies (hPa) for the month of May (a) bad monsoon years of 1982, 1986, 1987, 2002, 2004 & 2009. (b) bad monsoon years of 1968, 1972, 1974 & 1979, (c) good monsoon years of 1983, 1988 & 1994 and (d) good monsoon years of 1961, 1970 & 1975

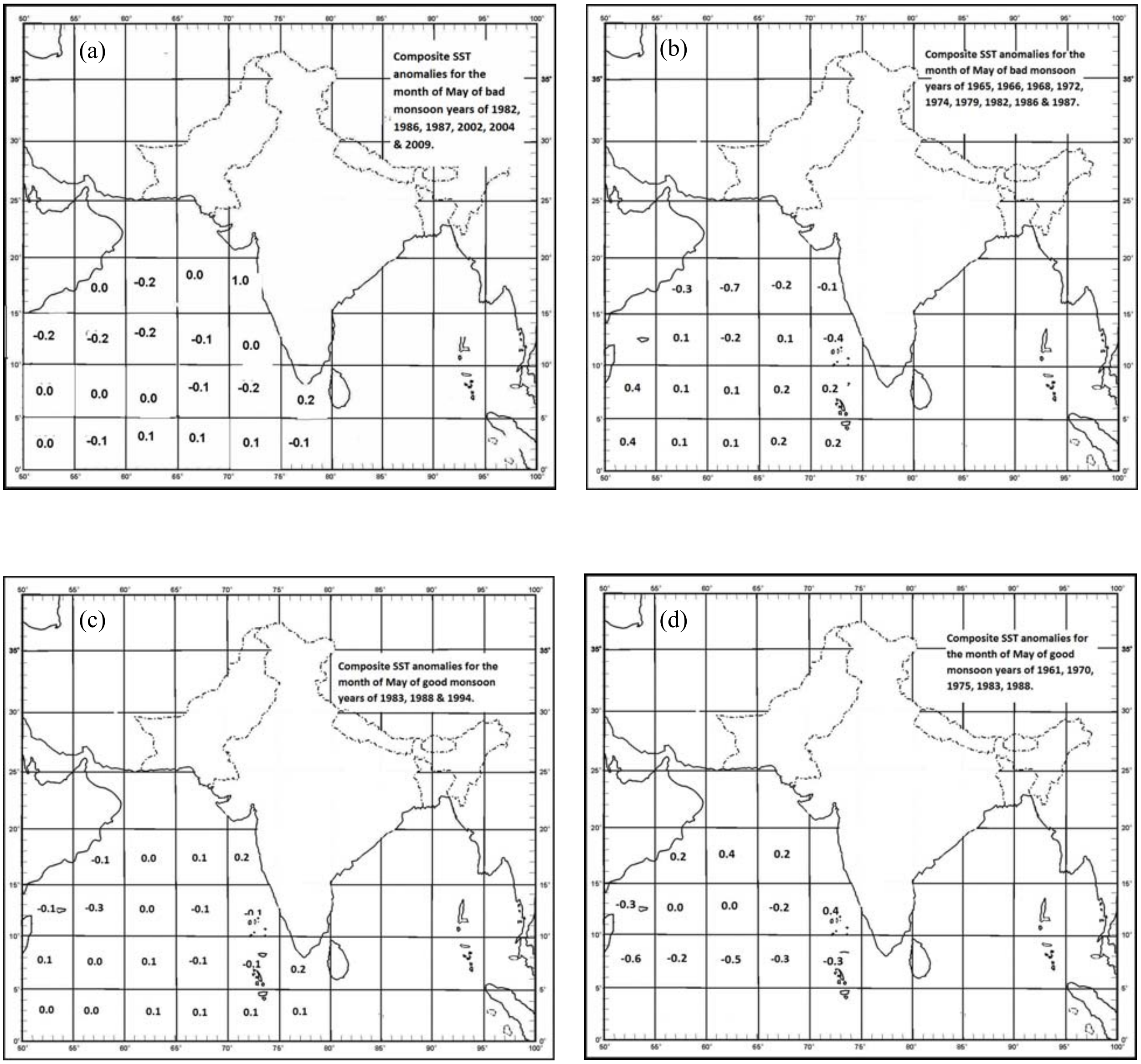
North Indian ocean 0° - 5° N, 5° - 10° N, 10° - 15° N, 15° - 20° N and 20° - 25° N does not show any significant correlation with monsoon rainfall. Since the lower magnitudes of CC for SLP were found, the probable correlation between north-south SLP gradient over the Arabian Sea and Bay of Bengal, and the monsoon rainfall were looked into, but no significant correlations could be found. The computed CCs are given in Table 2. The CC between the SLP gradient from Head Bay to extreme southwest Arabian Sea and monsoon rainfall is + 0.19.

The gridwise composite of SLP anomalies for bad summer monsoon and good summer monsoon are given in Figs. 1 (a&c). The composite of SLP for bad summer

TABLE 2

Coefficient of correlation between the mean SLP gradient for May and the succeeding departure from monsoon rainfall over India

S. No.	SLP parameter	CC with monsoon departure
1	Mean SLP gradient over the Arabian sea between 22.5° - 2.5° N	-0.04
2	Mean SLP gradient over the Bay of Bengal between 17.5° - 2.5° N	-0.15
3	Mean SLP gradient over the Head Bay of Bengal and southwest Arabian sea	0.19



Figs. 2(a-d). Composite SST anomalies (in °C) for the month of May (a) bad monsoon years of 1982, 1986, 1987, 2002, 2004 & 2009, (b) bad monsoon years of 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1986 & 1987, (c) good monsoon years of 1983, 1988 & 1994 and (d) good monsoon years of 1961, 1970, 1975, 1983, 1988

monsoon and good summer monsoon by Singh (1998) are given in Figs. 1 (b&d). The good summer monsoon has been defined as the year during which the summer monsoon rainfall exceeded 110% of the normal and the bad monsoon year as the one during which all India monsoon rainfall was less than 90% of the normal rainfall. Thus during the period of 30 years from 1981-2010 the years 1983, 1988, 1994 were taken as good monsoon years whereas the years 1982, 1986, 1987, 2002, 2004 and 2009 as bad monsoon years**.**

Bad monsoon years

The Fig. 1 (a) describes the composite of years of 1982, 1986, 1987, 2002, 2004 and 2009, where SLP anomaly for the area 5° - 10° N, 50° - 75° E is more than the SLP anomaly for the area 0° - 5° N, 50° - 75° E hence weakening of wind flow.

Singh (1998) showed that in the composite SLP anomalies of bad summer monsoon years of 1968, 1972, 1974 and 1979 positive anomalies prevailed in oceanic area of Arabian Sea and Bay of Bengal Fig. 1(b).

Good monsoon years

The Fig. 1(c) portrays the composites of 1983, 1988, 1994 wherein the SLP anomalies over the area 5° - 10° N, 60° - 75° E were more than the SLP anomalies over the area 0° - 5° N, 50° - 75° E.

Singh (1998) showed that in the composite SLP anomalies of good summer monsoon years 1961, 1970 and 1975, the entire oceanic area of Arabian Sea and Bay of Bengal was dominated by negative SLP anomalies Fig. 1(d).

3. *Relation between SST distribution during May over the Arabian Sea and rainfall activity in subsequent summer monsoon over India* - The CC between SSTs of May over different latitudinal belts of Arabian Sea and all India percentage departure for subsequent summer monsoon season have been given in Table 3. There exists a positive correlation between SSTs of May over the latitudinal belts of 5° - 10° N, 10° - 15° N, 15° - 20° N and all India percentage departure for subsequent summer monsoon rainfall respectively.

The composite of SST anomalies (°C) for bad and good monsoon are given in Figs. 2(a&c). The composite of SST for bad summer monsoon and Good summer monsoon by Singh (1998) are given in Figs. 2 (b&d). The grid wise SST normal have been obtained using 30 year period from 1981-2010. During the period of study, the years 1983, 1988 and 1994 are taken as good monsoon years and 1982, 1986, 1987, 2002, 2004 and 2009 were taken as bad monsoon years.

Bad monsoon years

The composites of SST anomalies of 1982, 1986, 1987, 2002, 2004 and 2009 are brought out in Fig. 2(a) wherein positive SST anomalies prevailed over the south Arabian Sea area between 0° - 5° N, 50 - 70° E whereas negative anomalies over the latitudinal belts 10° - 20° N, 50° - 70° E during May month of bad monsoon years. Thus, the south Arabian Sea belt 0° - 5° N , 50° - 70° E showed warmer tendencies where as north and adjoining central Arabian Sea belt between 5° - 20° N, 50° - 75° E were cooler than 0° - 5° N, 50° - 70° E; thus wind flow was confined to southwest Arabian Sea.

TABLE 3

Coefficient of correlation between the mean SSTs of different latitudinal belts for May and all India rainfall departure for summer monsoon

S. No.	Predictor	CC with Rainfall departure
1	Mean SST over the Arabian sea between 5° - 10° N	+0.07
2	Mean SST over the Arabian sea between 10° - 15° N	+0.21
3	Mean SST over the Arabian sea between 15° - 20° N	+0.41

The composite of SST anomalies for bad summer monsoon by Singh, 1998 are given in Fig. 2 (b). It shows that positive SST anomalies prevailed over the south Arabian Sea area between 5° to 10° N, whereas the anomalies were negative over the latitudinal belt 15° to 20° N during May month of bad monsoon years. Thus south Arabian Sea between 5° - 10° N showed cooler tendencies whereas north and adjoining central Arabian Sea between 15° - 20° N showed warmer tendencies before the commencement of bad summer monsoons.

Good monsoon years

The composites of SST anomalies of good monsoon years during the period 1983, 1988, 1994, are shown in Fig. 2(c). The south Arabian Sea was consistently dominated by negative anomalies, in the region of 10° - 15° N, 55° - 75° E whereas north and adjoining Arabian sea between 15° - 20° N and 60° - 75° E was covered by positive SST anomalies during May month of good monsoon years. The latitudinal belts 10° - 15° N appears to be dominated by negative anomalies in the range -0.1 °C to -0.3 °C, Thus the Arabian sea between 0° - 20° N and 55° - 60° E tends to be cooler than the area 0° - 20° and 60° - 80° E thereby increasing the wind flow and thus enhancing the rainfall activity.

The composite of SST anomalies for Good summer monsoon by Singh 1998 are given in Fig. 2 (d). It is seen that south Arabian Sea area between 5° - 10° N was consistently dominated by negative anomalies whereas in north and adjoining central Arabian Sea the positive anomalies were observed in the area 15° - 20° N. The anomalies ranging from -0.3 °C to +0.4 °C from west to east were seen in latitudinal belt 10° - 15° N. The highest negative anomaly (-0.6 °C) was observed over extreme southeast Arabian Sea, between 5° - 10° N, 50° - 55° E whereas highest positive anomaly (+0.4 °C) was observed over the areas 15° - 20° N, 60° - 65° E and 10° - 15° N, 70° - 75° E. Thus south Arabian Sea between 5° - 10° N tends to be cooler than normal and the north and adjoining central Arabian Sea between 15° - 20° N tends to be warmer than normal during May month of good monsoon years.

4. *Conclusion* - (*i*) The mean SLP over western Arabian Sea (0° -25° N, 50° - 65° E) during the month of May for the years of deficit rainfall 1982, 1986, 1987, 2002, 2004, 2009 was found to be less than that over eastern Arabian sea (0° -25° N, 65° - 85° E).

(*ii*) Bad monsoon years were preceded by warmer temperatures in southwest Arabian Sea relative to that of east-central Arabian Sea in the month of May whereas in good monsoon years cooler temperatures prevailed in east-central Arabian sea (10° - 15° N, 50° - 55° E) in the month of May.

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S. B. GAONKAR
P. C. S. RAO
P. A. KORE
S. P. JOSHI,
P. R. ABHANG
*U. P. SINGH

India Meteorological Department, Pune.
**India Meteorological Department, New Delhi*
(*6 February 2012, Modified 16 May 2012*)
e mail : sbgaonkar@gmail.com