

Long range forecasting of summer monsoon rainfall from SST in the central equatorial Indian ocean

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ABSTRACT

Several prediction techniques have been developed to predict all India summer monsoon rainfall by using different parameters like sea level pressure tendency during January-April at Darwin, 500 mb location along 75°E during April; sea level pressure change at Bombay during Winter to pre-monsoon and Sea Surface Temperature (SST) over Pacific and Indian Ocean regions.

The relationship between SST in the Central Equatorial Indian Ocean (CEIO) and all India Summer Monsoon Rainfall has been examined using the data during the period 1945-1999. The relationship with rainfall over homogeneous regions also has been examined. Online time series rainfall data created by IFTM, Pune and MOHSST-6 SST data have been used to compute 21 and 31 year sliding window correlations. Very strong correlations (significant at 99% level) have been observed between average SST during September-November, (SON SST) of the preceding year in the region, 0-5°N, 80-85°E with the all India summer monsoon rainfall in the following year, during the recent decades. The Correlations are insignificant before 1960 and stable and significant during the recent decades. The correlations for the recent periods, 1978-1999 and 1968-1999 are found to be 0.8 and 0.7 respectively which are significant at >99% level. To see impact of climate shift (warming of Indian Ocean after 1976) on SST - monsoon rainfall relationship, the correlations have been computed for the period, 1977-95. Very high correlation of 0.82 is noticed between SON SST and all India summer monsoon rainfall during the above period. The correlations with rainfall over homogeneous regions also are significant at 99% level except North-Eastern and Central North Eastern regions. The study shows the possibility of predicting monsoon rainfall from SON SST of the preceding year in the region, 0-5°N, 80-85°E.

Key words: Monsoon rainfall, SST, Equatorial Indian Ocean, ENSO, TBO

1. Introduction

Asian summer monsoon influences most of the tropics and sub-tropics of the Eastern Hemisphere and more than 60% of the world's population (Webster *et al.*¹). It also influences atmospheric circulation more than over one-third of the tropical region for several months during the northern summer and involves a substantial exchange of air between the southern and northern hemisphere (Soman and Slingo²). India receives more than 70% of its annual rainfall during southwest monsoon season (June-September). As India's economy mainly depends on agriculture, monsoon rainfall is very important for the country. Besides agriculture, it is the main source for fresh water to millions of people living in the country. Floods

and droughts associated with strong and weak monsoons greatly influence the economy of the country. Most of the droughts and floods are associated with El-Nino and La-Nina respectively (Webster and Yang³ and Krishna Kumar *et al.*⁴). The relationship between ENSO and monsoon rainfall has been studied extensively (Soman and Slingo²; Webster and Yang³; Ju and Slingo⁵; Rasmusson and Carpenter⁶; Goswami; Clark *et al.*⁷ and Ramesh Kumar and Schulz⁸). A study by Krishna Kumar *et al.*⁷, showed that ENSO monsoon relationship has weakened during the recent decades. The discovery of "Indian Ocean Dipole" (IOD) (*i.e.*, low SST off Sumatra Coast and high SST in the Western Indian Ocean) (Saji *et al.*¹¹ Webster *et al.*¹² and Lizuka *et al.*¹³); which is independent of ENSO, intensifies during September – November with a peak in the month of October. It causes heavy rainfall over eastern

Africa and drought over Indonesia. It's relationship with Indian monsoon rainfall is not statistically significant (Saji *et al.*¹¹). In view of the above, the relationship between SST in the central Equatorial Indian Ocean and monsoon rainfall has been re-examined.

Several prediction techniques to forecast all India summer monsoon rainfall have been developed over the last 100 years. A detailed review can be found in Krishna Kumar *et al.*⁴. The role of Eastern (Soman and Slingo²; Rasmusson and Carpenter⁶ and Joseph *et al.*¹⁶), and Western^{26,22,4} Pacific, north Australia-Indonesia region Nicholls^{15,16} and Indian Ocean (Clark *et al.*⁸; Joseph and Pillar¹⁷; Sadhuram¹⁸; Rao and Goswami¹⁹; Sadhuram and Wells²⁰ and Ramesh Kumar *et al.*²¹) on Indian summer monsoon rainfall had been studied. Sadhuram and Well²⁴ also showed a strong correlation between Feb SST (of the previous year) in the Central equatorial Indian Ocean and monsoon indices²⁹ in the following summer monsoon season. In the present study, we have examined the

relationship between SST in the Central Equatorial Indian Ocean with all India monsoon rainfall and rainfall over homogeneous regions by using the 56 years of data from 1945-1999.

2. Data and method

Time series data on rainfall^{17,18} which is available on IITM, website, for the period 1946-99 and the MOHSST 6 data (5°X5° grid) on SST obtained from U.K. Met Office, Brecknell, for the period, 1945-98 have been used in the computations. Based on earlier studies (Clark *et al.*⁸; and Sadhuram¹⁸ and Wells²⁰), we have computed the correlations between September – November SST (SON SST) in the region 0-5°N; 80-85°E (shown as hatched area in Fig. 1) and monsoon rainfall over India and homogeneous regions (shown as 1 to V in Fig. 1) with 21 and 31 year sliding windows. The details of sub-divisions considered for each region are below.

I.	Northwest India	- Subdivision Nos. - 13,14,17,18,21,22
II.	West Central India	- Subdivision Nos. - 19, 20, 23, 24, 25, 26, 28, 32
III.	Central North-east India	- Subdivision Nos. - 7,8,9,10,11
IV.	North-east India	- Subdivision Nos. - 3,4,5,6
V.	Peninsular India	- Subdivision Nos. - 27,29,30,31,33,34

[Out of 35 sub-divisions, 6 (Nos. 1,5,12,15,16,35) are not considered].

All India – 29 subdivisions
 Homogeneous – 14 subdivisions of regions I & II
 Core monsoon region (Munot²⁴ – East Rajasthan , West, M.P., Madhya Maharashtra, Marathwada and Vidhrbha.

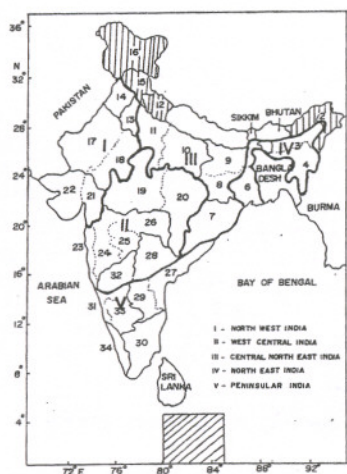


Fig. 1: Homogeneous regions of India. SSTs in the Hatched Region (0°-5°N, 80°-85°E) are used to compute Correlations with Monsoon rainfall over the Homogeneous regions.

Normalised values of rainfall over the above regions and SON SST in the study area (Fig.1) are used to compute 21 and 31 year sliding window correlations. To see the impact of climate shift (Meehl and Arblaster²⁵⁻²⁷ in Indian Ocean after 1976, the correlations between SON SST and monsoon rainfall over the above regions are also computed for the period, 1977-95.

3. Results and discussion

Interannual variability of all India summer monsoon rainfall and SON SST in the study area is shown in Fig. 2. Rainfall is mostly confined between 800 and 1000 mm during the 54 year period except a few years. Variation in SST is not more than 2° C during the above period and mostly varied between 28 and 29° C. A clear biennial oscillation can be seen in both SST and rainfall (Fig. 2). For the same period, the interannual variability of monsoon rainfall over homogeneous regions (I to V), homogeneous India and Core monsoon regions is shown in Fig. 3. Rainfall is

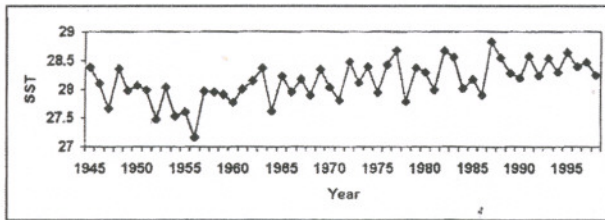
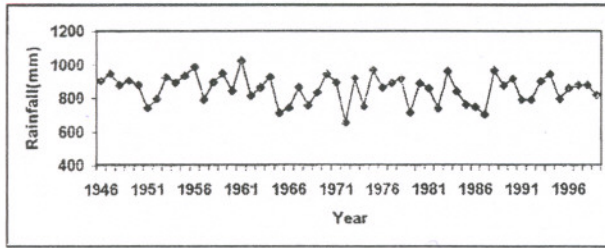


Fig. 2: Time Series data on all India summer monsoon rainfall (top panel) and average SST during Sept - Nov in the region 0-5° N; 8-85° E (bottom panel)

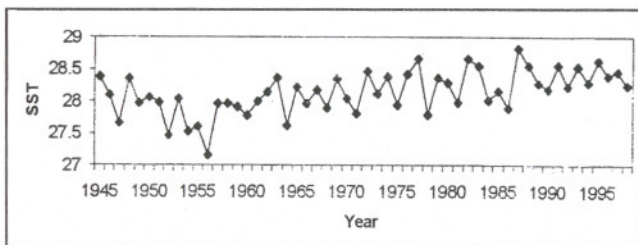
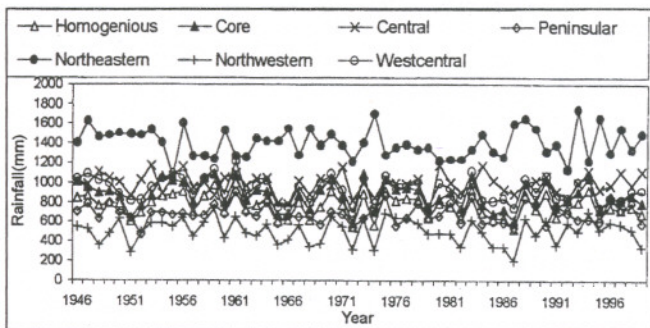


Fig. 3: Time Series data on macro regional monsoon rainfall over homogeneous regions (top panel) and average SST during Sept-Nov in the region 0-5° N; 80-85° E (bottom panel)

mostly confined to 600-1200 mm except region IV which is fluctuating between 1200 and 1600 mm. The rainfall over region I is lower and varying between 200 and 600 mm. This trend is quite obvious.

Fig. 4 shows the 21 year (top panel) and 31 year (bottom panel) sliding window correlations between SON SST with all India, Homogeneous and Core monsoon rainfall. The correlations are insignificant during 1950's and became

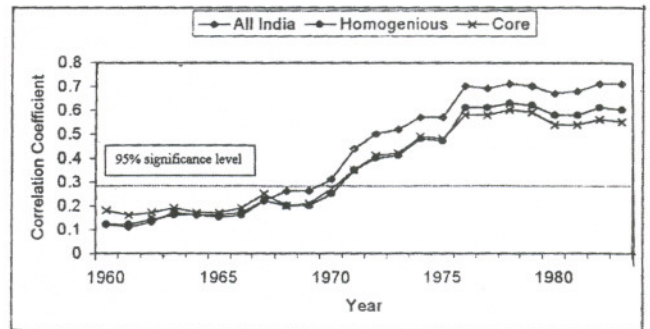
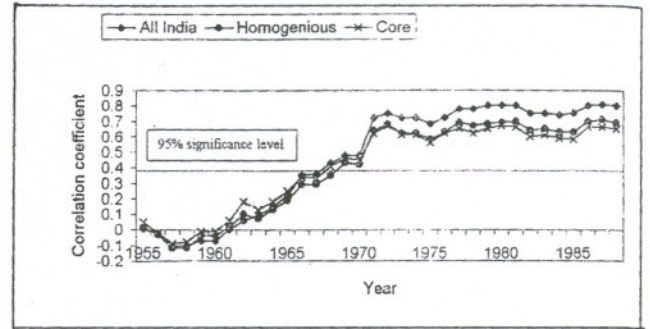


Fig. 4: 21 year (top panel) and 31 year (bottom panel) sliding window correlations between SST during Sept - Nov in the study area and monsoon rainfall.

significant at 95% level from 1960 onwards. They are quite stable and significant at 99% level during the recent decades. The C.C.'s with core monsoon region are lower than with all India rainfall, throughout the period.

The rainfall over homogeneous regions (I,II,III&IV) is strongly and significantly correlated with SON SST except with region IV (Fig. 5). In general, an increasing trend in the correlations started during 1960's and they become significant at 95% level 1970 onwards and reached maximum in 1980's. To examine the impact of climate shift after 1976, the correlations computed for the period 1977- 95 are shown in Table 1. Very high correlation of 0.82 is observed between SON SST and all India rainfall which is close to the value ($r=0.87$) reported by Clark *et al.*⁸ in the nearby area. The correlation with rainfall over region IV is insignificant. All the correlations are positive and significant at 99% level except with the rainfall over regions III & IV. The positive correlations suggest that warm (cold) SON SST in the study area (Fig. 1) result an active (weak) monsoon in the following year. What could be the mechanism behind these strong correlation? Though it is very difficult to answer this question, a tentative mechanism has been proposed here. It appears that the strong correlations between SST and monsoon rainfall could be due to the TBO (Tropical Biennial Oscillation)

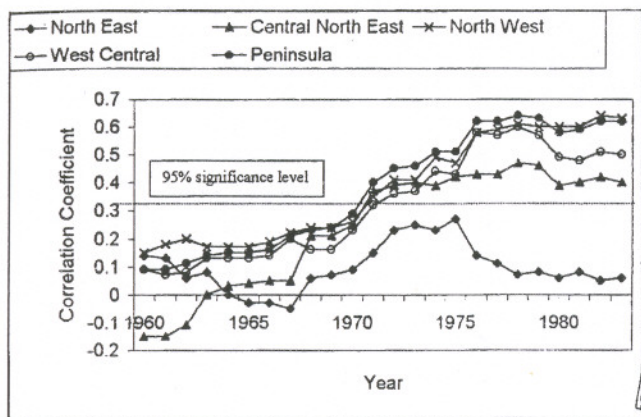
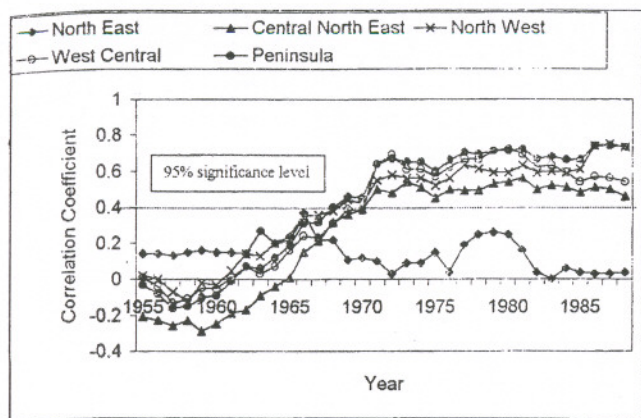


Fig. 5: Same as Fig. 4, but with rainfall over homogeneous regions

which was reported by earlier Mechl and Arblaster²⁵⁻²⁷. A schematic picture (Mechl and Arblaster²⁶) (Fig. 3) showing the atmosphere – ocean – land processes starting from DJF to the following year (DJF+1) explain the link between SST anomalies over Indian and Pacific Oceans in association with Indian and Australian monsoons. Warm SST anomalies observed during September – November helps for a strong monsoon by supplying additional moisture. After a strong monsoon the cold waters from Western Indian Ocean are advected towards east through wartyki's jet and east ward propagating Kelvin waves which results in cold SST anomalies in the study area during September – November of the following year. Cold SST over Indian ocean and east Pacific ocean and warm SST over Indonesian region produces an anomalous atmospheric Rossby wave during DJF with a trough over Indian continent which persists upto MAM (March-May). This trough causes increased snow and reduces the land temperature. By June – Sept (JJAS), the cold SST over Indian and Pacific ocean are replaced by warm SST anomalies. Then the ascending branch of Walker circulation shifts towards East Pacific. This causes rising motion over Equatorial Indian Ocean

Table 1: Correlations between SON SST in the study area and summer monsoon rainfall

	1968-99	1978-99	1977-95
All India	0.71	0.80	0.82
Homogeneous	0.60	0.69	0.73
Core monsoon region	0.55	0.65	0.68
I. North West India	0.63	0.73	0.74
II. West Central India	0.50	0.54	0.64
III. Central Northeast India	0.40	0.46	0.53
IV. North East India	0.06	0.04	0.05
V. Peninsular India	0.62	0.73	0.76

1968-99 : C.C = 0.355(Significant at 95% level) ;
0.456 (Significant at 99% level)

1978-99 : C.C = 0.433(Significant at 95% level) ;
0.549 (Significant at 99% level)

1977-95 : C.C = 0.468(Significant at 95% level) ;
0.59 (Significant at 99% level)

and subsidence over ITCZ which enhances the local Hadley circulation and result in deficit rainfall over India (Goswami⁷ and Krishnamurthy and Goswami²⁸). In 1994 and 1997, the monsoon was active inspite of ENSO. This could be mainly due to the anomalous air-sea coupling processes during these two years as reported (Webster *et al.*¹²). It is interesting to note that when the correlation between Nino 3 SST and monsoon rainfall are found to weaken (Krishna Kumar *et al.*¹⁰), the correlation presented here (Figs. 4&5 and Table 1) are consistent and significant at 99% level during the recent decades. Clark *et al.*² noticed that the correlation between Central Equatorial Indian ocean SST and all India monsoon rainfall has decreased by removing ENSO signal in SST. This suggests that the SST in the study area is influenced by ENSO. They reported that the strong correlation could be due to the warming of eastern Equatorial Indian Ocean after 1976. If the correlation continues in future, it will be possible to predict rainfall over India and homogeneous regions (except region IV) from SON SST in the study area, 6 months before the onset of summer monsoon. However, a detailed modelling study is desirable to exactly

identify the processes behind the strong correlations observed here.

4. Conclusions

1. SST during Sept – November of the previous year in the region, 0-5°N; 80-85°E is strongly and significantly correlated with all India summer monsoon rainfall. The above SST is strongly correlated with rainfall over homogeneous regions also except north-eastern region(IV).
2. High correlation coefficient ($r = 0.82$) is noticed between SON SST and all India summer monsoon rainfall during the period 1977-95 is supported by earlier study (Clark *et al.*⁸).
3. The mechanism behind the strong correlations could be due to TBO as shown by Meehl and Abaster²⁶.
4. The present study shows the possibility of predicting monsoon rainfall over India and homogeneous regions (except region, IV) from SON SST of the previous year in the region 0-5°N; 80-85°E, 6 months in advance, while the present statistical methods are able to predict only 1 or 2 months in advance.

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