Impact of ENSO and the Indian Ocean Dipole on the Northeast Monsoon Rainfall of Tamil Nadu state in India

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Abstract:

Tamil Nadu state, located in the southeastern part of Peninsular India receives most of its rainfall during October through December which is referred to as Northeast monsoon rainfall (NEMR). The onset and distribution of NEMR plays a crucial role on both agriculture and economy of the Tamil Nadu State of Indian subcontinent. It is interesting to note that Tamil Nadu Southwest monsoon rainfall (SWMR) received between June and September months has positive correlation with SOI, while NEMR shows negative correlation with SOI. A study was undertaken to investigate the relationship between global tele-connection signals viz. El-Nino- Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), and precipitation over Tamil Nadu during the northeast monsoon season. The results indicated that NEMR of Tamil Nadu had the highest positive correlation with Nino-3 SST for the month of July indicating that whenever there is a rise in sea surface temperature in Nino-3 region, there is an increase in NEMR and vice-versa. The results also indicated that under extreme negative July SOI condition Tamil Nadu received 17.7 % more than the normal NEMR and that of the extreme positive condition 17.9 % less than the normal NEMR. To understand the relationship and/or local dynamic structure, composites of circulation field for the extreme El Nino/La Nina years are compared with the mean state. Composite circulation analysis clearly showed that in extreme El Nino years (SOI < -10) Bay of Bengal has a positive sea level pressure (SLP) anomaly and Arabian sea has a negative SLP anomaly, which resulted in strong northeasterly wind to the southern part of India. The strengthened Northeast monsoon brings more moisture and precipitation to the Tamil Nadu region in the El Nino years. The opposite case is also true. A strong negative anomaly is observed in the Bay of Bengal during the La Nina years (SOI > 10), which resulted in weak NE monsoon.

Keywords : Northeast monsoon rainfall; India; El-Nino- southern oscillation; Indian Ocean Dipole

INTRODUCTION

Rainfall during the 4 months period of June to September is termed as the Indian summer monsoon season in a general large-scale sense; however, the actual rainy period differs widely over different parts of the Indian subcontinent. Over Tamil Nadu region, located in the southeastern part of Peninsular India (Fig.1), the most important rainfall season is autumn and winter. Rainfall during October through December over India is referred to as Northeast monsoon rainfall (NEMR) when southwesterlies of summer monsoon are replaced by northeasterlies.

The increase in rainfall activity over Coastal areas of Tamil Nadu, which takes place in the middle of October, is generally considered as the 'setting in of the North-East Monsoon'. The normal date of the onset of the monsoon onset is around October 20th

with a deviation of about a week on either side. It plays a crucial role on both agriculture and economy of the Tamil Nadu State of Indian subcontinent (Srinivasan and Ramamurthy, 1973). As shown in Figure 2, major rains of Tamil nadu is received between September to December, hence, it is important to understand the NEMR activity and to investigate the relationship between global tele-connection signals and precipitation over Tamil Nadu during the northeast monsoon season.

Fig. 1 Geographic location of Tamil Nadus state of India.

There are large variations from place to place and year to year in NEMR. According to Bhatnagar (2003), the reason for the difference in rainfall from place to place has become inherent because when the monsoon system sets in, it brings in distributed rainfall at different places: Distribution and the amount of NEMR is influenced by various parameters including El-Nino- Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). There are several studies, which have examined the relation between Southern Oscillation Index (SOI) and Indian summer monsoon rainfall that occur between June and September months (Sikka 1980; Rasmusson and Carpenter 1983; Shukla and Paolino 1983; Parthasarathy and Panth 1985; Ropelewski and Halpert 1989, Mooley 1997 and Krishna Kumar *et al* 1999). Studies of the influence of ENSO and IOD on NEMR are, however, meager (Pant and Rupa Kumar 1997, Kripalani and Kumar, 2004).

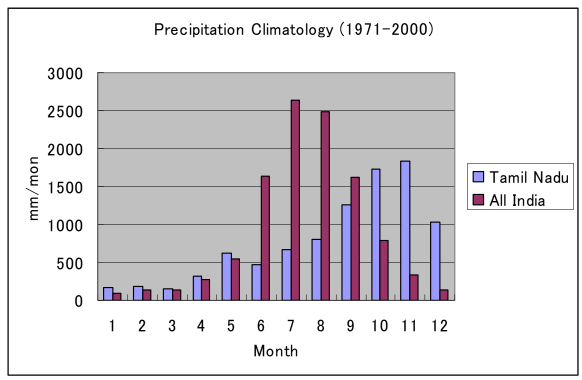

Fig. 2 Seasonal variation of precipitation climatology averaged for the 40 years (1961-2000) over Tamil Nadu state and All India. Data source is Indian Institute for Tropical Meteorology (IITM, http://www.tropmet.res.in/)

According to the previous studies which investigated the relationship between ENSO and global precipitation signals (Ropelewski and Halpert 1987, 1989; Curtis et al., 2001), most part of India has less (more) rainfall during ENSO (La Nina) years. In contrast to this, the southernmost part of India shows opposite signals which tends to have wet anomalies during the ENSO (SOI negative) years.

Recent investigations on the relationship with SOI and Nino-3 SST on NEMR of Tamil nadu concludes that the SOI is negatively correlated with NEMR in Tamil Nadu (Geethalakshmi et al, 2005) and Nino-3 SST is positively correlated (Geethalakshmi et.al, 2003) which imply that autumn-winter precipitation over Tamil Nadu is influenced by the global climatological signals. Recently, Zubair and Ropelewski (2006) pointed out the the relationship between ENSO and NEMR is strengthening. Since length of growing period and distribution of rainfall during Northeast monsoon season is important for agricultural production over Tamil Nadu (Geethalakshmi, 2003), detailed analysis between global signals to the local precipitaton is necessary for crop planning activities.

In the last decade of twentieth century, Indian summer Monsoon rainfall was normal or above normal during the two major ENSO events witnessed (Kumar et al., 1999), although it was widely recognized that less summer monsoon rainfall tended to be observed during the ENSO years. Therefore, it is necessary to investigate the relationship between ENSO and precipitation over Tamil Nadu from a long-term point of view.

Recently, Indian Ocean Dipole (IOD) has been catalogued as one of the major ocean-atmosphere coupled phenomena in the tropical Indo Pacific sector (*Saji et al.*, 1999, *Webster et al.*, 1999). In this paper an attempt is made to evaluate the influence of ENSO and IOD on NEMR over Tamil Nadu region of India.

In terms of climate application study, localized or synoptic patterns those are more directly related to the precipitation of Tamil Nadu is necessary. Here we also show some composite charts of precipitation and water vapor flux those are compiled recently as given below.

DATA

The sources of India and Tamil Nadu precipitation data sets used in this study are RMC, Chennai for NEMR, (October - December) over Tamil Nadu and regional averaged monthly precipitation dataset created by Indian Institute of Tropical Meteorology (IITM, http://www.tropmet.res.in/). The Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD) indices were compiled by the Bureau of Meteorology, Australia. The period of the data sets of rainfall, IOD and SOI used for this study are 100 years (1901 - 2000). Sea Surface Temperature (SST) of five different regions viz., Nino3 (150W-90W, 5N-5S); Eastern box of Saji's dipole (50E-70E, 10S-10N); Western box of Saji's dipole (90E-110E, 10S-Eq); Eastern box of Webster's dipole (45E-55E, 5N-5S) and Western box of Webster's dipole (95E-105E,10S-Eq) were used in this study.

For composite analysis of precipitation anomalies, India Meteorological Department (IMD) daily gridded precipitation (Rajeevan et al. 2005) was used. The two meteorological reanalysis dataset compiled by the European Centre for Medium-range Weather Forecasts, namely so-called ERA15 (Gibson et al. 1997) and ERA40 (Uppala et al. 2005) were also used in this study. The computational procedure of vertically integrated precipitable water, moisture flux and its divergence of ERA15 (Figs. 3 and 4) is the same as that used in Yatagai (2003).

RESULTS

General Features

Figure 2 shows the seasonal change of monthly precipitation averaged for the year 1961-2000. Different from the most part of India, southern peninsular India get their maximum rainfall during the northeast monsoon season. Conventionally, October to December is treated as the northeast monsoon season over India, which is mainly affecting the states of Tamil Nadu and Kerala. The rainfall over the Indian state of Tamil Nadu during the months from October to December accounts for about 48% of the annual rainfall in the region.

Large-scale hydrological conditions over India are shown in Fig. 3 (for July) and in Fig. 4 (for November) to show both SW monsoon and NE monsoon characteristics. In July, cross-equatorial moisture flow over the Arabian Sea brings moisture to the Indian sub-continent. Moisture evaporated over the Arabian Sea brings moisture to the west coast of India due to the westerly (or southwesterly) in lower troposphere. Two centers of moisture flux convergence (negative divergence in Fig.3c) are observed, and these match the maxima of precipitation (Fig. 3d). Tamil Nadu is located under the lee ward side of the Western Ghats and hence, SWMR is not large. As a mean state, moisture from Bay of Bengal brings precipitation to the northeastern part of India and Bangladesh, during SW monsoon season.

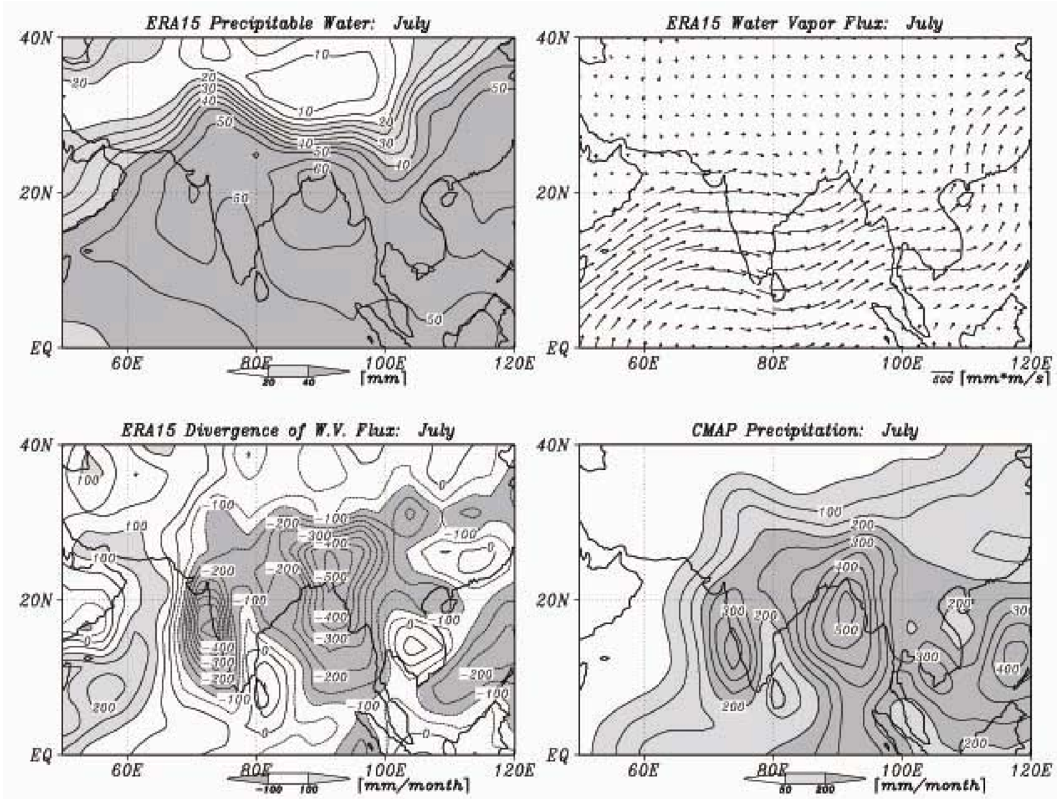

Fig. 3 Climatological mean (a) precipitable water (mm), (b) vertically integrated moisture flux (mm m s-1), and (c) its divergence (mm/month) estimated by ERA15 for July. Climatological precipitation (mm/month) given by CMAP is shown in (d).

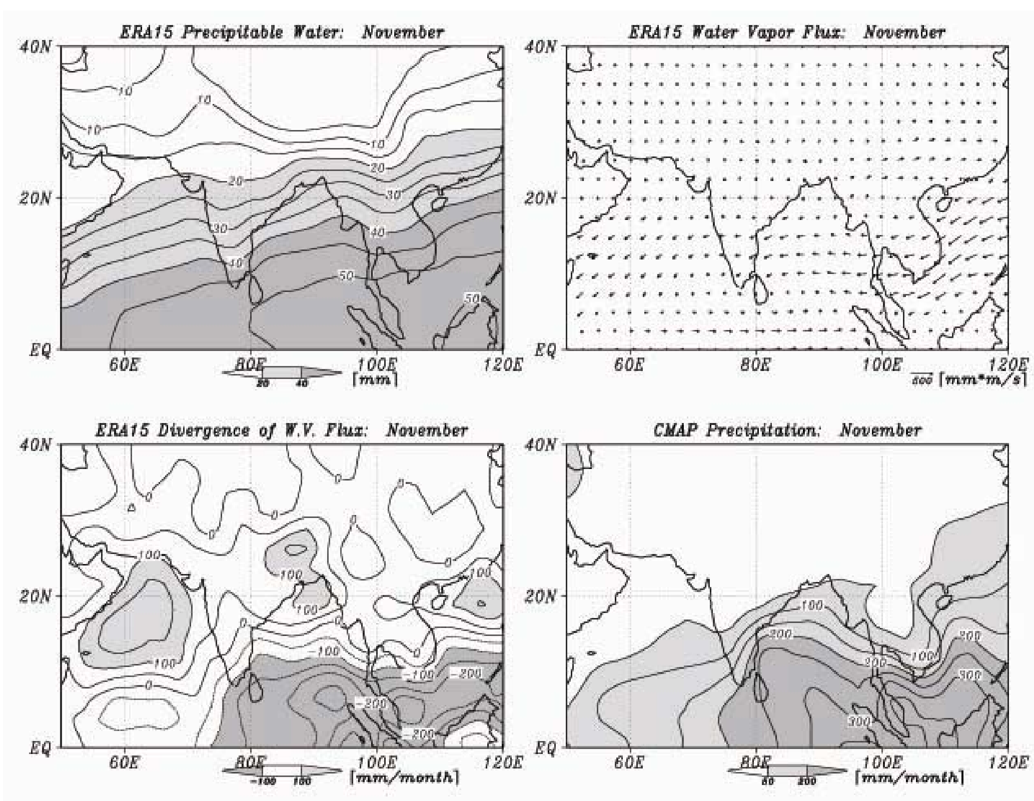

Figure 4. As for Figure 3, but for November.

By contrast, lower dominant wind is northeasterly (or easterly) to the India in November (Fig. 4), and total moisture around India and Bay of Bengal are much less than that in July. In this season, surface pressure over the ocean is lower than that over the land. Convection center locates not over land, but locates around the Maritime continent. Due to the low pressure over south of India (cf. Fig.13 top/center), northeasterly from Bay of Bengal brings moisture/precipitation to the Tamil Nadu state.

Probabilities of monthly rainfall of Tamil Nadu were worked out and presented in Fig.5. The variability of rainfall was also higher during this period which creates many problems in agricultural management. Therefore, it is important to know the pre-cursor signals those have significant relationship to the NEMR of Tamil Nadu.

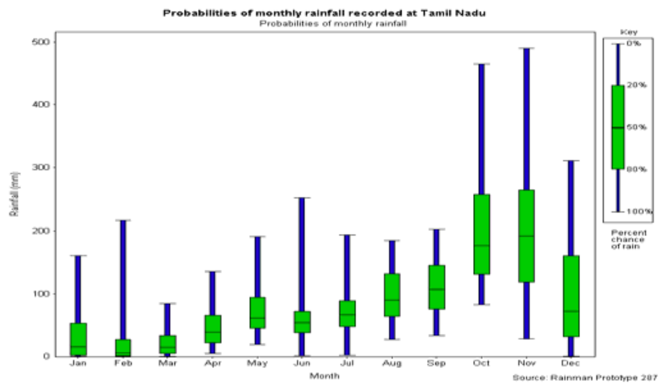

Figure 5. Probabilities of Monthly rainfall of Tamil Nadu, India. Individual bar indicates the variability of rainfall in term of rainfall quantity as well as probability of occurrence of rainfall which ranges from 0 to 100 per cent. The topmost value in the bar indicates the 0 % chance of occurrence and the bottom most value in the bar indicates 100% chance of occurrence of rainfall quantity in that particular month. With respect to the box within the bar, the topmost quantum of rainfall is expected with 20 % probability of occurrence and the bottom most value in the box indicates 80 % chance of occurrence. The horizontal line shown within the bar indicated the median rainfall i.e. 50% chance of occurrence of rainfall.

Relationship between NEMR and El Nino/Southern Oscillation (ENSO)

As the major rainfall of Tamil Nadu is received in Northeast monsoon season, the analysis was done for NEMR. Correlation coefficient between climate indices (SOI and SST at different regions) of different months (January to September) and NEMR are given in Table-1. The results exhibited that NEMR of Tamil Nadu had the highest positive correlation with Nino-3 SST for the month of July indicating that whenever there is raise in sea surface temperature in Nino-3 region, there is an increase in NEMR and vice-versa. There was also a significant negative correlation between SOI of summer monsoon season (June-September) and NEMR in the sense that NEMR is higher during negative SOI. These statistics show that in El Nino (La Nina) condition of boreal summer season is related to the wet (dry) NEMR over Tamil Nadu.

Table 1. correlations between NEMR over Tamil Nadu and SOI, SST in different months. A hundred year (1901-2000) data was used to compute the correlation coefficients.

Particulars	Region (SST)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
SOI		-0.064	-0.092	-0.111	-0.195*	-0.210*	-0.314**	-0.384**	-0.318**	-0.375**
Nino-3	150W-90W, 5N-5S	0.209*	0.191	0.301**	0.326**	0.314**	0.321**	0.388**	0.334**	0.344**
Saji-E	50E-70E, 10S-10N	0.124	0.033	-0.023	0.017	0.067	0.203*	0.111	0.139	0.115
Saji-W	90E-110E, 10S-Eq	0.080	0.151	0.113	0.198*	0.164	0.011	-0.126	-0.100	-0.112
Webster-E	45E-55E, 5N-5S	0.152	-0.105	-0.058	-0.008	0.014	0.075	0.029	0.098	0.034
Webster-W	95E-105E, 10S-Eq	0.105	0.142	0.123	0.193	0.151	-0.015	-0.117	-0.079	-0.104

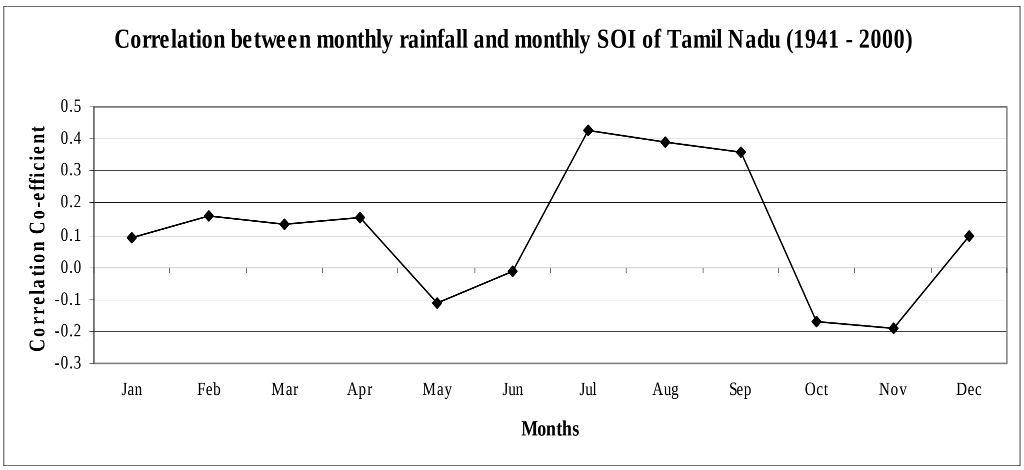

Figure 6. Simultaneous Correlation between monthly rainfall of Tamil Nadu and monthly SOI (1941-2000).

Figure 6 shows simultaneous correlation between monthly rainfall of Tamil Nadu and monthly SOI (1941-2000). A significant positive correlation was found during the Southwest monsoon season (July-September). On the contrary, a negative correlation coefficient was observed during the Northeast monsoon season (October-November). Historical analysis has shown clear evidence of an association between the weak SWMR , large negative southern oscillation index and El Nino events, and also between the strong monsoon, large positive southern oscillation index and absence of El Nino events (Sikka, 1980; Pant and Parthasarathy, 1981; Parthasarathy and Sontakke, 1988). The positive correlation during the Southwest monsoon season (i.e. less SWMR for the El Nino years) for Tamil Nadu has consistent signals with the most part of India.

Figure 7 shows precipitation anomaly over Tamil Nadu during SW monsoon season (June-September) for El Nino/La Nina period based on station data. For this composite, 12 El-Nino years (1963, 1965, 1969, 1972, 1982, 1987, 1991, 1992, 1993, 1994, 1995 and 1997) and 8 La-Nina years (1964, 1971, 1973, 1974, 1975, 1989, 1996 and 1998) were chosen. In most par of Tamil Nadu state, less (more) precipitation is observed during the Southwest monsoon on the El Nino (La Nina) years. On the contrary, during the Northeast monsoon season (Fig. 8), more precipitation to the normal is observed for the El Nino Years. For La Nina years, it tends to show negative biases, but results are not as clear as for El Nino Years.

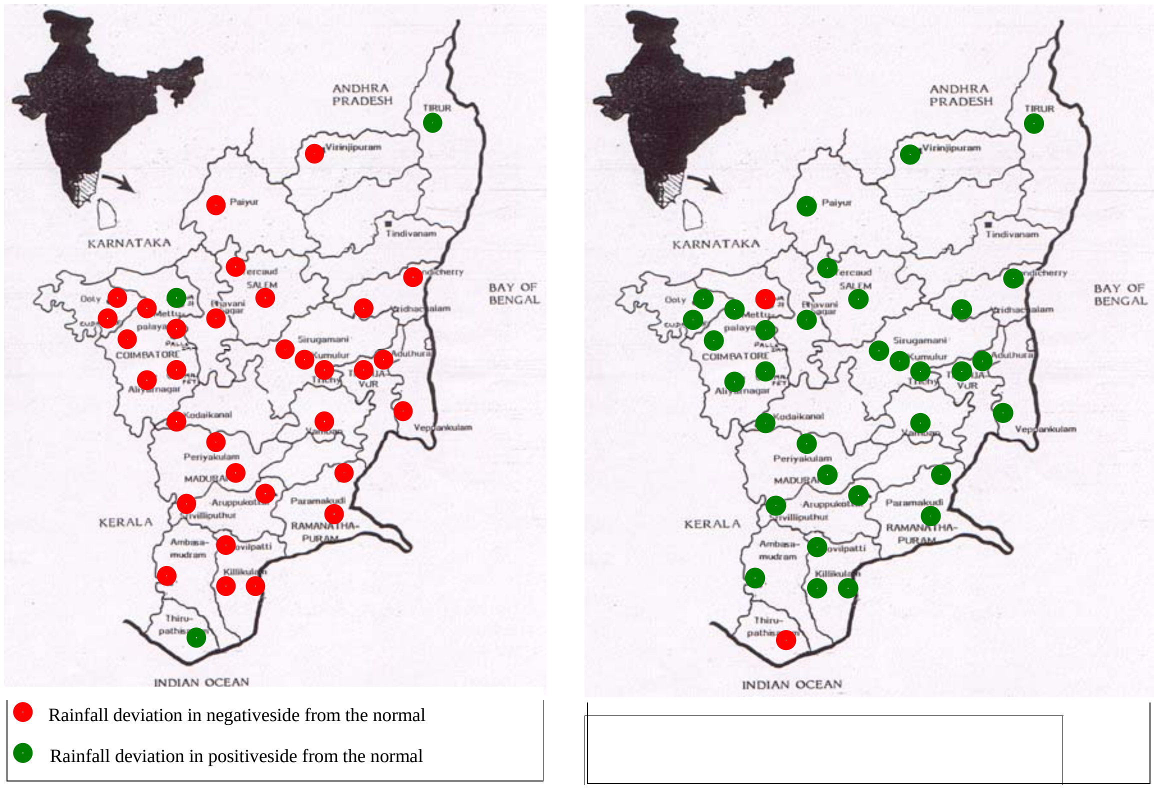

Figure 7. Precipitation anomaly during the SWMR (June-September) for El Nino (left) and La Nina (right) period.

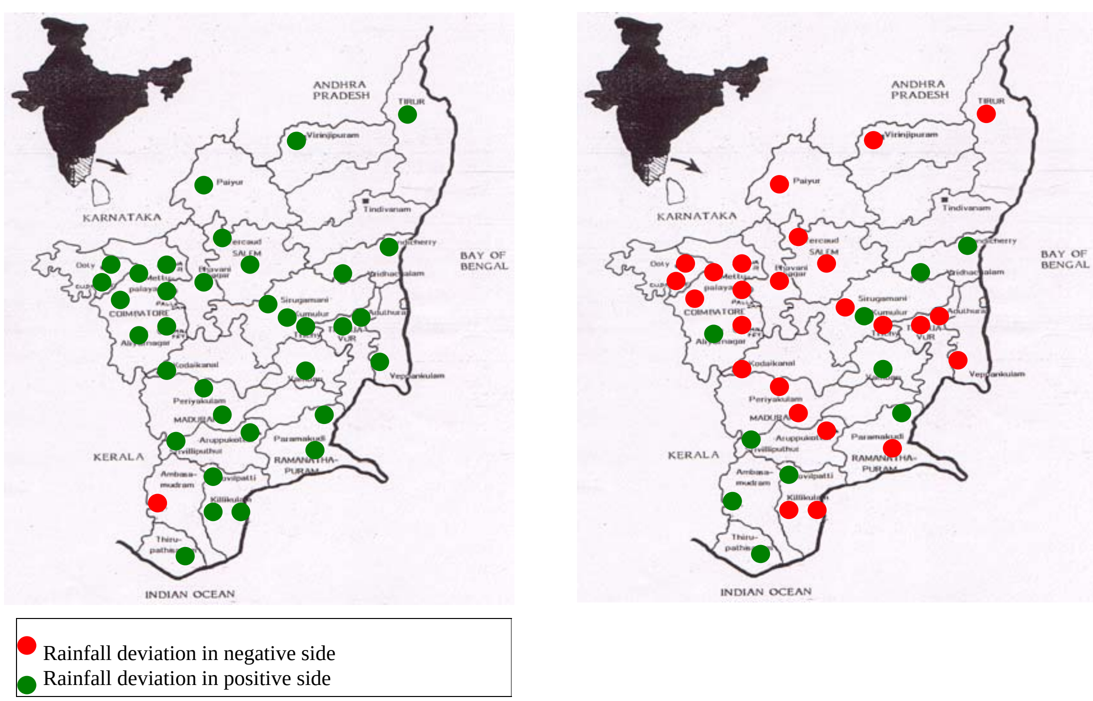

Figure 8. The same as Fig.5 but for NWMR (October-December).

Long-term Changes

The relationship between the NEMR and SOI is susceptible to decadal changes. *Krishna Kumar et al.,* 1999 has reported that the ENSO impact on SWMR is now weakening. Correlation between July month IOD of Nino-3 region and NEMR over a period of 100 years from 1901 to 2000 is only 0.338. To check the consistency of these relationship, decadal correlations between climate indices (SOI & IOD of Nino-3 region) of July month and NEMR of Tamil Nadu was done and presented in Fig. 9. The results clearly indicate that there is a consistent negative correlation between SOI of different months of SW monsoon season (June – Sep) and NEMR of Tamil Nadu except in the decade of 1901-1910 and 1951-60. Twenty year sliding correlations between NEMR over Tamil Nadu and SOI in different months was also done and the results are presented in Table -2. Among the different months, strong correlation could be seen from July month with NEMR which can serve as a viable predictor for the ensuing NEMR. It is interesting to note, in the last decade (1991-2000), correlation between July SOI and NEMR is not as high as that it was in the earlier decades indicating the weakening of the relationship between SOI and NEMR in the recent decade. However, the relationship between IOD of Nino-3 region and NEMR is not as strong as that of SOI with NEMR in different decades studied in general (Fig. 9). Hence further in depth analysis was done only to understand the influence of SOI on NEMR.

Extreme Conditions

July month SOI values above +10 and below -10 were assumed as extreme SOI conditions, and their impact on corresponding year NEMR was studied (Fig. 10). In the 100 year study period, there were 17 extreme negative and 14 extreme positive SOI conditions prevailed in the month of July. Normal NEMR averaged over the study period is 481 mm. Average rainfall received during the extreme negative July SOI condition is 566 mm which is 17.7 % more than the normal NEMR and that of the extreme positive condition is 395 mm which is 17.9 % less than the normal NEMR. Under negative extreme condition, only in 2 out of 17 events recorded lesser than average NEMR. This indicates a shift towards wetter (drought) conditions in relation to the extreme negative (positive) SOI in July over Tamil Nadu region.

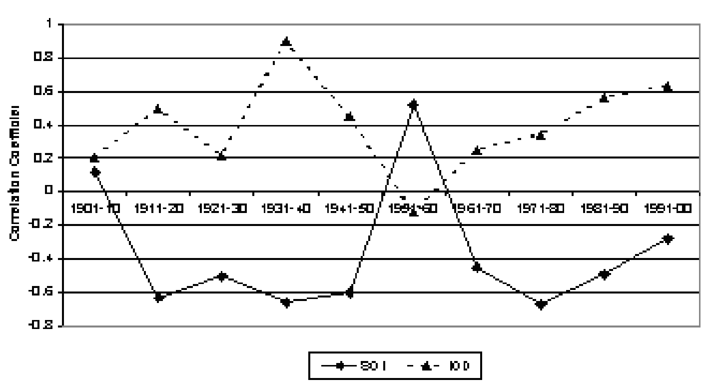

Figure 9. Decadal correlations between climate indices (SOI & SST of Nino3 region (150W-90W, 5N-5S)) of July month and NEMR of Tamil Nadu.

Table 2. Twenty year sliding correlations between NEMR over Tamil Nadu and SOI in different months. The left column (Year) indicates the first year of a 20 year time series subjected to take a correlation.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1951	-0.09	-0.03	0.20	-0.30	-0.11	-0.15	-0.16	-0.07	-0.19
1952	0.03	0.10	0.24	-0.19	-0.13	-0.12	-0.25	-0.04	-0.18
1953	0.02	0.11	0.23	-0.33	-0.23	-0.23	-0.39	-0.18	-0.33
1954	0.03	0.10	0.21	-0.34	-0.40	-0.25	-0.40	-0.28	-0.39
1955	-0.22	-0.11	-0.08	-0.40	-0.44*	-0.22	-0.47*	-0.28	-0.45*
1956	-0.19	-0.14	-0.11	-0.43*	-0.48*	-0.30	-0.55**	-0.35	-0.50*
1957	-0.22	-0.17	-0.13	-0.49*	-0.62**	-0.38	-0.62**	-0.39	-0.49*
1958	-0.25	-0.08	-0.24	-0.55**	-0.69**	-0.52*	-0.67**	-0.49*	-0.53*
1959	-0.38	-0.27	-0.31	-0.59**	-0.59**	-0.47*	-0.59**	-0.45*	-0.55**
1960	-0.42	-0.28	-0.32	-0.60**	-0.56**	-0.45*	-0.61**	-0.50*	-0.54**
1961	-0.44*	-0.30	-0.25	-0.49*	-0.51*	-0.44*	-0.59**	-0.48*	-0.49*
1962	-0.49*	-0.28	-0.40	-0.44*	-0.54**	-0.50*	-0.60**	-0.52*	-0.52*
1963	-0.50*	-0.26	-0.41	-0.41	-0.46*	-0.35	-0.49*	-0.34	-0.39
1964	-0.43*	-0.22	-0.37	-0.42	-0.46*	-0.34	-0.49*	-0.33	-0.37
1965	-0.44*	-0.25	-0.30	-0.41	-0.42	-0.23	-0.48*	-0.31	-0.34
1966	-0.44*	-0.24	-0.30	-0.38	-0.42	-0.22	-0.51*	-0.30	-0.34
1967	-0.42	-0.18	-0.25	-0.36	-0.32	-0.27	-0.53**	-0.27	-0.30
1968	-0.47*	-0.21	-0.27	-0.34	-0.29	-0.27	-0.52*	-0.29	-0.31
1969	-0.44*	-0.15	-0.29	-0.34	-0.29	-0.20	-0.54**	-0.35	-0.40
1970	-0.40	-0.14	-0.33	-0.34	-0.27	-0.22	-0.54**	-0.32	-0.36
1971	-0.41	-0.13	-0.32	-0.34	-0.28	-0.23	-0.54**	-0.32	-0.36
1972	-0.41	-0.16	-0.40	-0.43	-0.29	-0.24	-0.55**	-0.37	-0.40
1973	-0.41	-0.24	-0.43*	-0.41	-0.20	-0.18	-0.49*	-0.34	-0.34
1974	-0.43*	-0.26	-0.42	-0.49*	-0.26	-0.29	-0.53*	-0.42	-0.37
1975	-0.29	-0.12	-0.26	-0.41	-0.19	-0.26	-0.45*	-0.38	-0.29
1976	-0.27	-0.09	-0.27	-0.28	-0.09	-0.22	-0.45*	-0.35	-0.26
1977	-0.24	-0.09	-0.25	-0.23	-0.08	-0.14	-0.41	-0.31	-0.23
1978	-0.17	-0.05	-0.24	-0.28	-0.16	-0.18	-0.36	-0.37	-0.27
1979	-0.19	0.06	-0.27	-0.30	-0.31	-0.23	-0.39	-0.38	-0.27
1980	-0.18	-0.01	-0.30	-0.30	-0.37	-0.31	-0.36	-0.39	-0.31

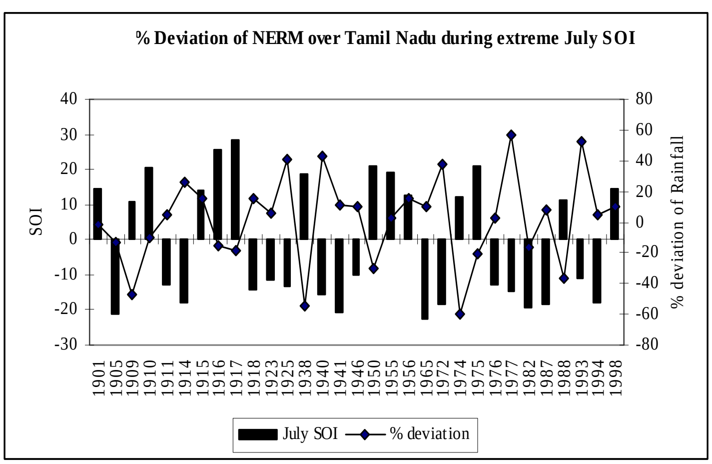

Figure 10. Comparison between July SOI and NEMR of Tamil Nadu. Only for the years of strong SOI > 10 (SOI <-10) are shown.

Circulation/Precipitation patterns

As Tamil Nadu SWMR has positive correlation with SOI and NEMR shows negative correlation with SOI, composites of circulation field for the extreme El Nino/La Nina years are compared with the mean state to understand the relationship and/or local dynamic structure. Since the ERA40 data is available after 1957, the 8 El Nino years (1965, 1972, 1976, 1977, 1982, 1987, 1993 and 1994) and 4 La Nina years (1974, 1975, 1988 and 1998) were chosen by the July SOI values as shown in the previous sub-section and Fig.10.

Figure 11 shows July mean circulation field and precipitation, anomalies of El Nino condition (difference between the average of the 8 years and climatology), and anomalies of La Nina condition (difference between the average of the 4 years and climatology). The climatology (top diagrams) were computed as an average of 40 years (1961-2000). During El Nino (La Nina) condition, there is less (more) precipitable water over Arabian Sea and northern part of India. Wind field of El Nino condition shows more divergent structure over the Tamil Nadu as well as whole of India.

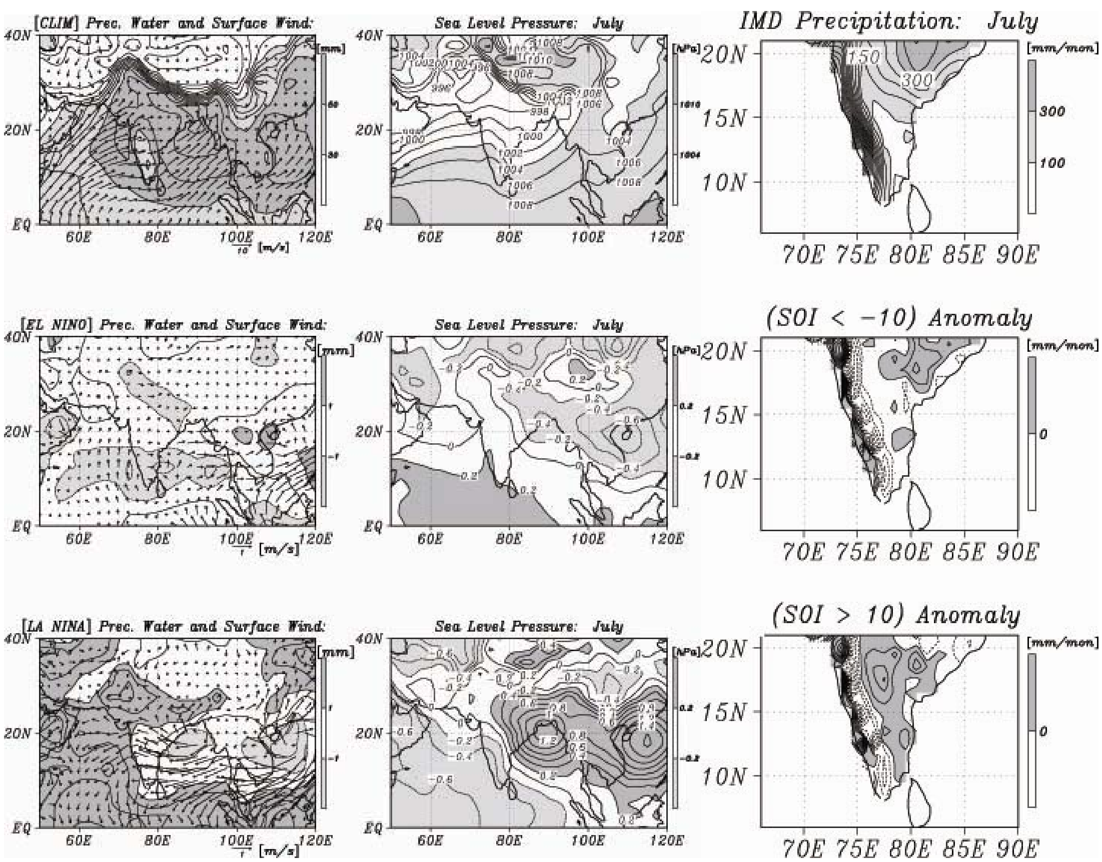

Figure 11. (Top left) Climatological mean precipitable water (mm) and surface wind (m/s) for July given by ERA40. Regions exceeding 30 mm month-1 (50 mm month-1) are lightly (darkly) shaded. Contours are spaced every 10 mm. (Top center) climatological mean sea level pressure. Regions exceeding 1002 hPa (1010 hPa) are lightly (darkly) shaded. Contours are spaced every 2 hPa. (Top right) Climatological mean precipitation (mm/month) given by IMD. Contours are spaced every 50 mm. (Middle diagrams) Anomaly composite for the year of extreme El Nino (SOI < -10). Positive (negative) strong anomaly are darkly (lightly) shaded as shown in the scales in the left and center diagrams. Positive precipitation anomaly areas are shaded, while negative precipitation anomaly areas are not shaded. (Lower diagrams) Anomaly composite for the year s of extreme La Nina (SOI > 10).

In order to see the continuation of the anomaly, the circulation field for September was checked before moving on to the November condition. Figure 12 shows, clearer difference of the circulation field than that of in Figure 11. In September (Fig. 12), less (more) precipitable water and higher (lower) sea level pressure are observed over India in El Nino (La Nina) condition. These resulted in drier (wetter) SWMR for El Nino (La Nina) years over Tamil Nadu as well as whole India in September.

In November (Fig. 13) anomaly of pressure gradient pattern is not identified with those in Fig. 11 and Fig. 12. In El Nino years, a positive sea level pressure (SLP) is observed in Bay of Bengal and a negative SLP anomaly is observed in Arabian Sea, which results in strong East-West pressure gradient over southern part of India. This gradient causes strong northeasterly (NEMR) in Tamil Nadu as well as southern part of India. During the La Nina phase, the opposite situation is observed.

From these composite analysis it is clarified that circulation anomalies over India, Bay of Bengal and Arabian Sea do not continue during the extreme SOI signal in July. This implies that the physical mechanisms of positive correlation with SOI in SWMR and negative correlation with SOI in NEMR are not the same each other. For the NEMR, the pressure gradient (or di-pole signals) between Bay of Bengal and Arabian Sea affects the precipitation anomaly over Tamil Nadu more directly to the SOI signals.

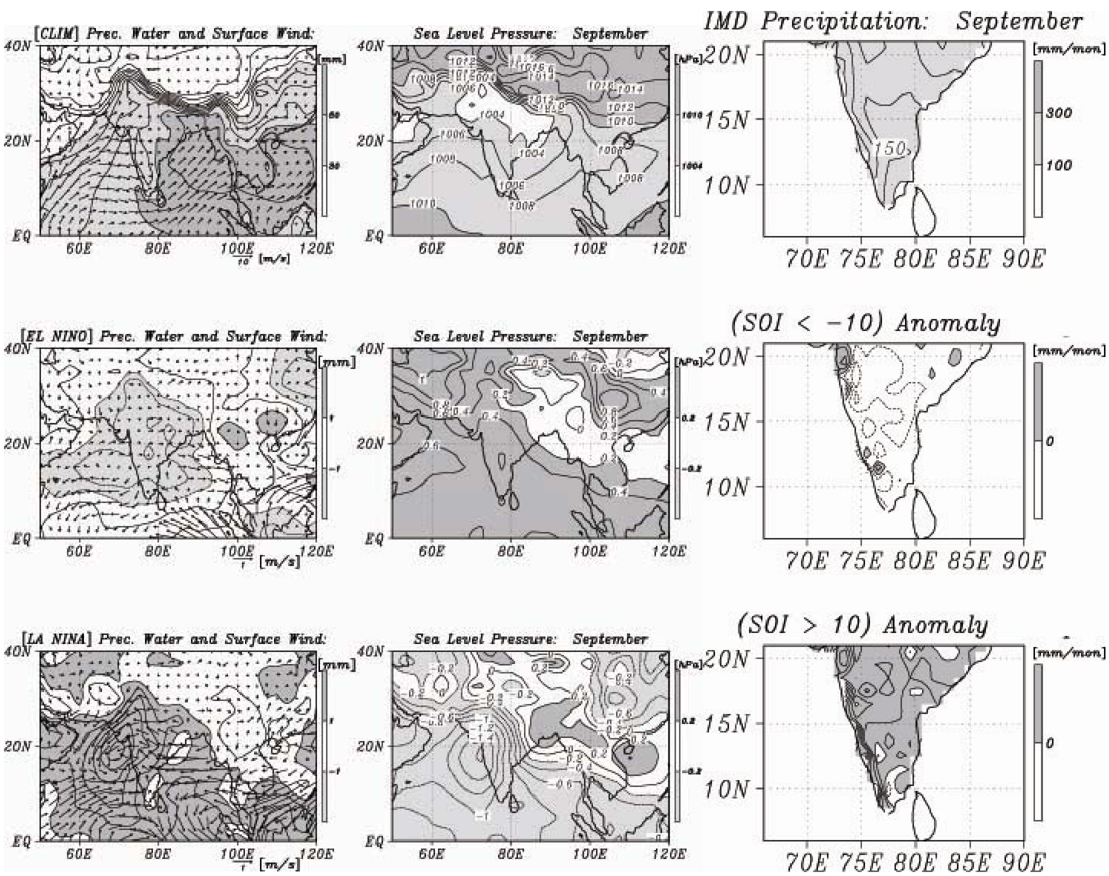

Figure12. As for Figure 11, but for September.

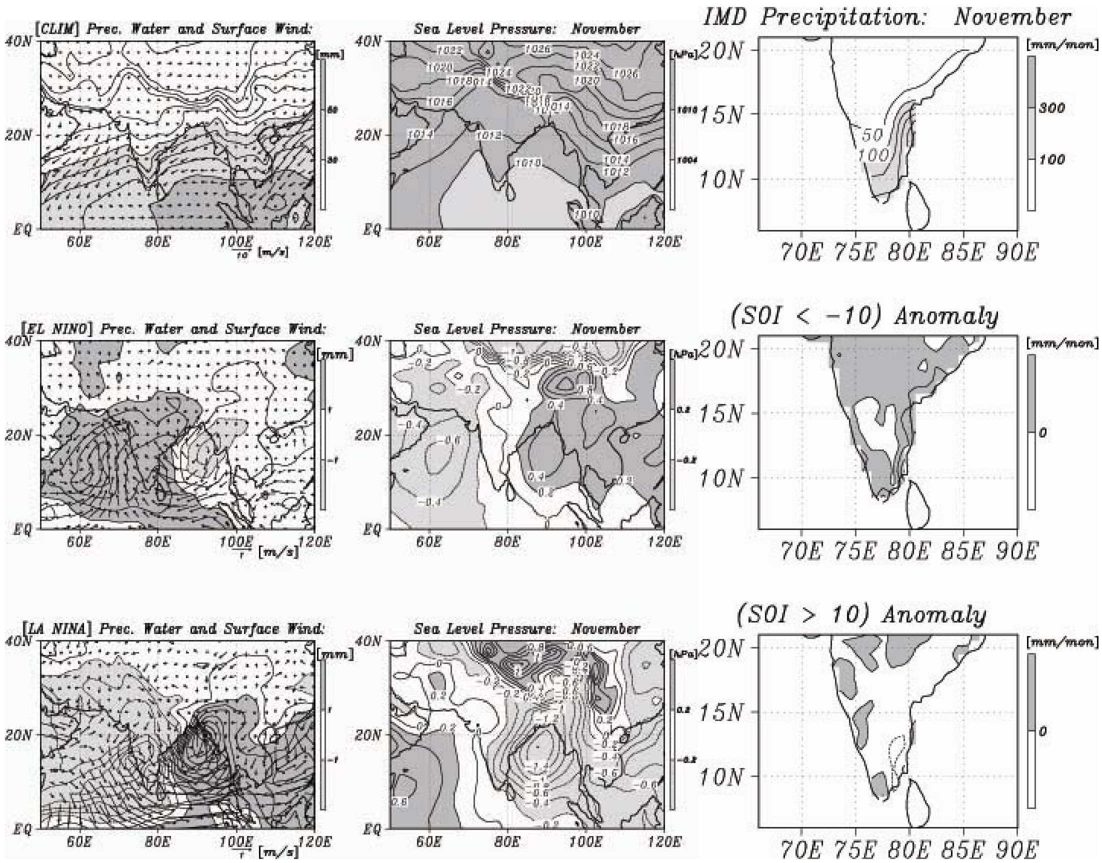

Figure 13. As for Figure 11, but for November.

CONCLUSIONS

From the above study it could be concluded that SOI and Nino-3 SST are having significant influence on NEMR. Among different months, July month SOI and Nino-3 SST has significant relationship with NEMR. July SOI is negatively correlated with the NEMR and the extreme negative SOI (El Nino years) resulted in wetter than average conditions during NEMR. SW monsoon rainfall over Tamil Nadu has significant positive correlation with simultaneous SOI, that is drier condition occurs in SW monsoon season in El Nino years.

Composite circulation analysis clearly showed that in extreme El Nino years (SOI < -10), Bay of Bengal has a positive sea level pressure (SLP) anomaly and Arabian sea has a negative SLP anomaly, which resulted in strong northeasterly wind to the southern part of India. The strengthened NE monsoon brings much moisture and precipitation to the Tamil Nadu region in the El Nino years. The opposite case is also true. A strong negative anomaly is observed in the Bay of Bengal during the La Nina years (SOI > 10), which resulted in weak NE monsoon.

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