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The El Nino-Southern Oscillation and winter precipitation extremes over India

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ABSTRACT: Daily rainfall data for the winter season October–December for the long period of 102 years 1901–2002 over southeast peninsular India have been used to study the characteristics of daily precipitation extremes. The frequency and intensity of extreme precipitation events do not show statistically significant long-term trend. The relationship of El Nino-southern oscillation index with these extremes shows that this index can be used to predict frequency and intensity of extreme precipitation events, 4–6 months in advance. However spell lengths of continuous wet/dry days are not modulated by variations in Pacific sea surface temperatures. Copyright © 2007 Royal Meteorological Society

KEY WORDS Nino3.4 SST; intensity; frequency; spell length

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1. Introduction

The rainfall received over the southeastern tip of the Indian peninsula during boreal winter period of October–December is referred to as the northeast monsoon or winter monsoon. It plays a vital role in the agricultural activities over five meteorological subdivisions over India comprising coastal Andhra Pradesh, Rayalseema, south-interior Karnataka, Kerala and Tamilnadu (Srinivasan and Ramamurty, 1973; De and Mukhopadhyay, 1999). This region receives more than 50% of the annual rainfall during October–December and hence this rainfall is crucial especially when the summer-monsoon rainfall fails.

The El Nino Southern Oscillation (ENSO) is known to be a major forcings of the earth's year-to-year climate variability. Association between ENSO and summer-monsoon rainfall over India has been rigorously studied (Sikka, 1980; Rasmusson and Carpenter, 1983; Parthasarathy and Pant, 1985; Mooley, 1997). It has been observed that this relationship has been weakening in recent two decades (Kripalani and Kulkarni, 1997; Krishna Kumar *et al*., 1999). Studies of influence of ENSO on winter-monsoon rainfall (WMR) are however meagre. Jayanthi and Govindachari (1999) have shown that Tamilnadu received record rainfall in 1997 that happened to be one of the strongest El Nino episode where very high positive sea surface temperature (SST) anomalies continued throughout the year over equatorial Pacific. Nageshwar Rao (1999) has depicted the inverse relationship between Darwin sea level pressure during July–August and WMR. The southern oscillation index in preceding summer (March–April–May) is positively correlated with winter rainfall over southeast India (Singh and Chattopadhyaya, 1998).

The heavy rainfall events play a dominant role in deciding the total rainfall strength. There is general agreement within the climate community that changes in the frequency and/or intensity of extreme climate events would have profound impacts on nature and society. One of the most significant consequences of global warming would be an increase in magnitude and frequency of extreme precipitation events brought about by increased atmospheric moisture levels, thunderstorm activity and/or large scale storm activity. Model studies indicate that tropospheric warming leads to an enhancement of moisture content of the atmosphere and is associated with an increase in heavy rainfall events. In India, large agricultural economy increases the importance of any changes in precipitation distribution. Variability of winter precipitation over India is known to be associated with temperature variability over equatorial Indian ocean (Kripalani and Kumar P, 2004) as well as over the Pacific (Kumar P *et al*., 2007). Extreme rainfall results in flash floods and crop damage that have a major impact on society, the economy and the environment. Inspired by Goswami's study (2006), one of the main purpose of this study is to identify any possible long-term trend in daily extreme winter precipitation over South-east Indian domain. We also attempt to study the changes in frequency and intensity of extreme winter precipitation events over India and their modulation by temperatures over equatorial Pacific.

Section 2 describes the data and method of analysis. In Section 3, we discuss the statistical properties of extreme indices. Section 4 gives the relationship between extremes and ENSO indices. Finally the conclusions are given in Section 5.

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2. Data and method of analysis

Daily precipitation data provided by the India Meteorological Department for 27 stations well-distributed over the southeast Indian region (Figure 1) for the period of 102 years (1901–2002) have been used in this analyses. The stations are selected based on length of available data, its quality, and homogeneity (Aguilar *et al*., 2005).

Monthly SST data prepared by Hadley Center, UK (HadSST) for the period 1901–2002 is also used. The SSTs averaged over NINO3.4 region (5°N–5 °S; 120 °W–170 °W) are used to study their relationship with extreme winter precipitation events.

This study uses extreme indices based on percentile thresholds, calculated on daily data as well as indices defined with respect to some fixed threshold value of daily rainfall. For computations of percentiles, daily data are used with the base period 1961–1990 and only rainy days (daily rainfall >1 mm) are considered. We have a total of 92 daily rainfall values (1st October to 31st December) for each of 30 years (1961–1990). We compute 85th, 75th and 65th percentiles of rainy days out of 2792 days (30 years × 92 days). The number of rainy days for individual stations vary from 233 to 1024, on an average 590 rainy days are available.

We compute three major indices of precipitation extremes for frequency, intensity, and spell duration. These are described in Table I.

The mean and standard deviation of daily rainfall over these 27 stations are reasonably homogeneous. Also trend analysis of the various extreme indices (Figure 2) show that all the stations have trends of the same sign. Thus, all the stations show striking similarity in the occurrence of extremes and hence simple arithmetic mean of extreme indices at all stations can provide an index of regional precipitation extremes. A simple arithmetical mean across 27 stations, of the annual values of each index, was calculated for each year of 1901–2002. These areal average extreme indices were then correlated with NINO3.4 SSTs. The correlations are computed starting from 12 months before the start of the year to which extreme indices apply.

3. Statistics of the extreme indices

As given in Table I, we compute nine frequency extreme indices out of which six are based on fixed threshold and three based on percentile threshold; two intensity extreme indices (one-day and five-day maximum precipitation) and two indices based on spell length of continuous dry days and continuous wet days. Goswami *et al*. (2006) have analysed the extreme rainfall events over the central Indian region based on fixed thresholds. Following Goswami *et al*. (2006), we fixed thresholds for daily rainfall to be 5–30 mm

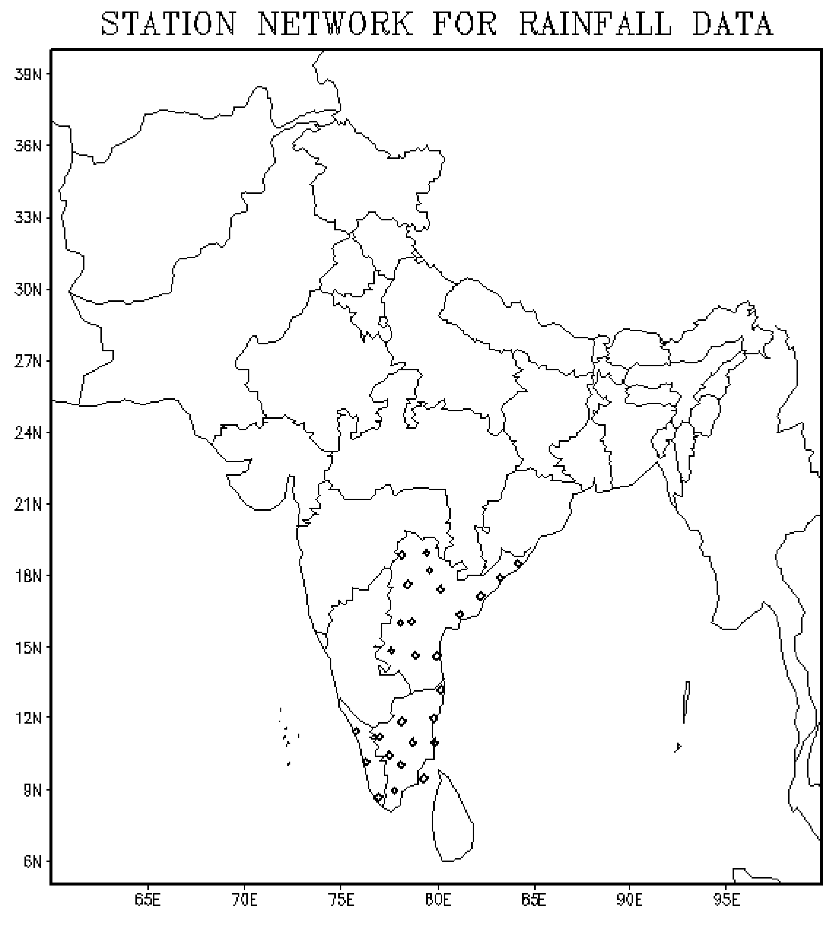

Figure 1. Locations of stations used in the study.

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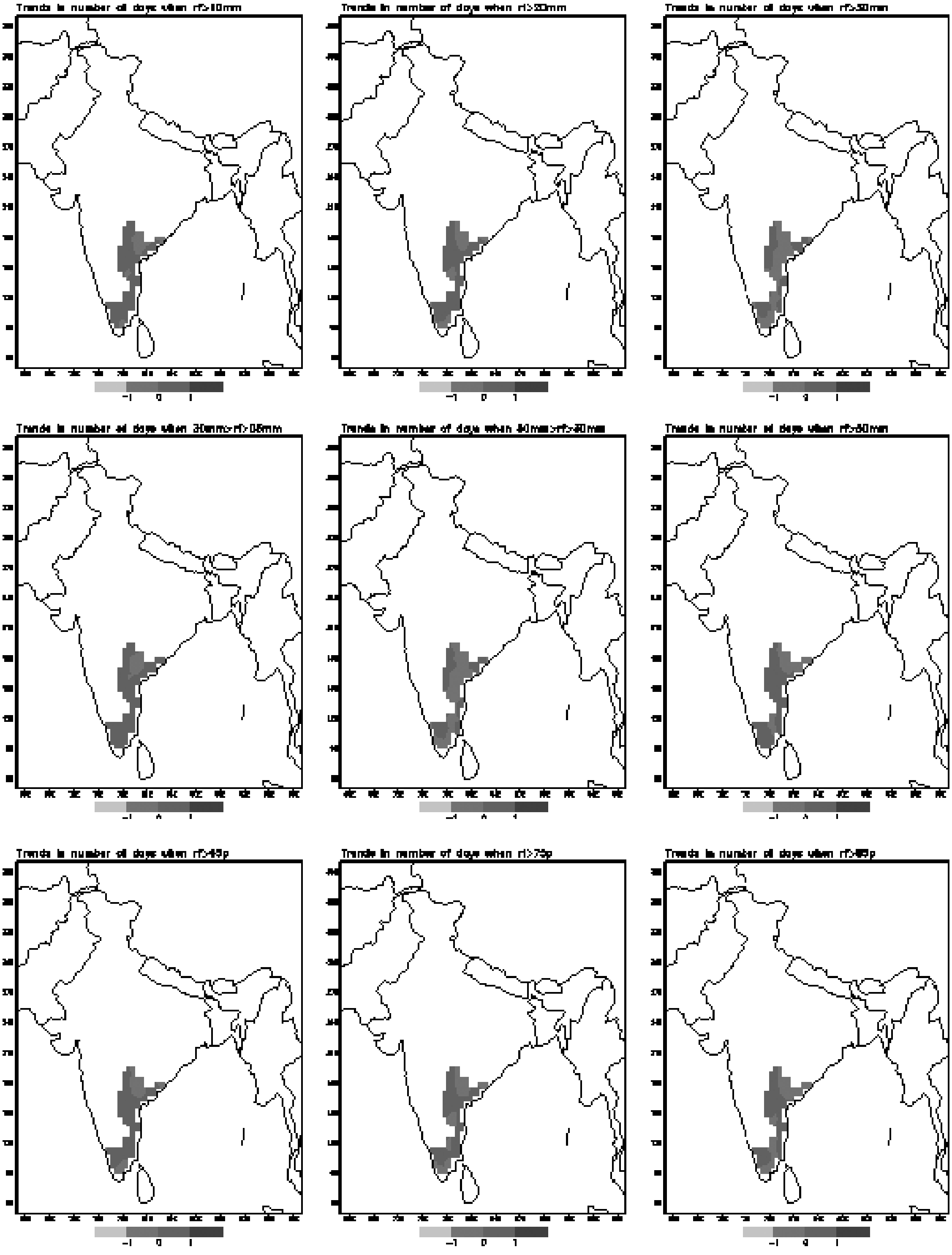

Figure 2. Trends in frequency of extremes over the region based on 1901–2002.

(moderate), 30–50 mm (heavy) and more than 50 mm (very heavy) and compute the frequency in each class. The probability density function of daily rainfall over the 27 stations show that on an average probability that the daily rainfall is 5–30 mm is 25%, 5% times it is 30–50 mm while very heavy events (more than 50 mm) are very rare with only 1.5% probability. Percentiles are computed based on 1961–1990. Some statistical properties of these indices are described in Table II.

Obviously as the rainfall threshold increases, average frequency reduces. It is also seen that the variability is also reducing. On an average continuous dry days are thrice as much as continuous wet days. Thus dry conditions are more prominent over the southeastern tip of India during the winter season.

3.1. Trend analysis

Figure 3(a) depicts the time series of frequencies based on percentile thresholds, 65th, 75th and 85th percentiles.

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Table I. Indices of precipitation extremes used in the study (Peterson *et al*., 2001).

Index	Description	Definition
R10mm	Frequencies in days	Number of days in the season with rainfall >10 mm
R20mm	Frequencies in days	Number of days in the season with rainfall >20 mm
R30mm	Frequencies in days	Number of days in the season with rainfall >30 mm
R5–30mm	Frequencies in days	Number of days in the season with rainfall between 5–30 mm
R30–50mm	Frequencies in days	Number of days in the season with rainfall between 30–50 mm
R50mm	Frequencies in days	Number of days in the season with rainfall >50 mm
R65p	Frequencies in days	Number of days in the season with rainfall >65 p (with baseline period 1961–1990)
R75p	Frequencies in days	Number of days in the season with rainfall >75 p (with baseline period 1961–1990)
R85p	Frequencies in days	Number of days in the season with rainfall >85 p (with baseline period 1961–1990)
RX1day	Intensity in mm	One-day maximum precipitation
RX5day	Intensity in mm	Five-day maximum precipitation
CDD	Spell duration in days	Continuous dry days (rf <1 mm)
CWD	Spell duration in days	Continuous wet days (rf >1 mm)

It is clearly seen that all these time series are free from persistence (lag 1 autocorrelation insignificant) and also they do not depict any long-term trend. The number of years having frequencies more than average are much more than those having frequencies, less than average. The time series for the 75th percentile (middle panel) shows slight decreasing tendency.

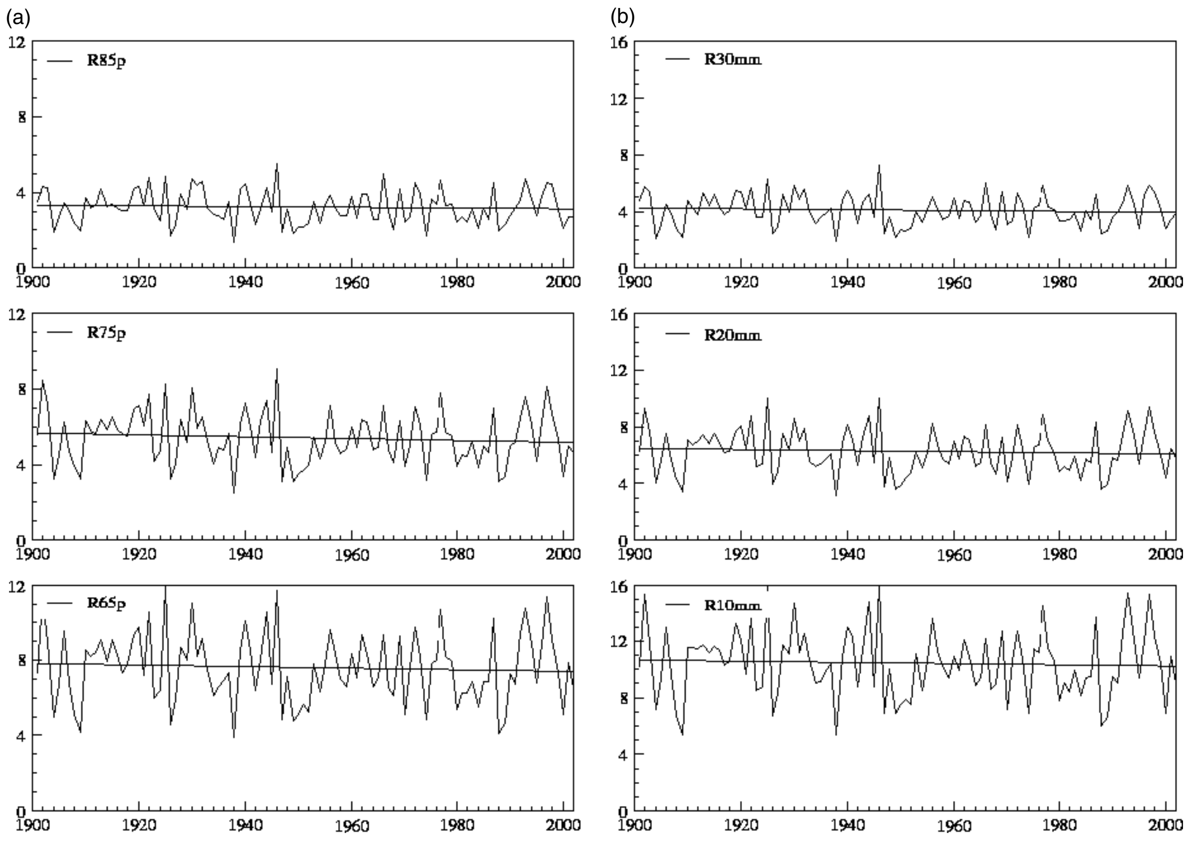

Figure 3. (a) Time series of frequencies based on percentiles for the period is 1901–2002. Base period for computations of percentiles is 1961–1990. (b) Same as Figure 3(a) but for frequencies based on fixed thresholds 10, 20 and 30 mm for the period 1901–2002. (c) Same as Figure 3(b) but for daily rainfall 5–30 mm, 30–50 mm and more than 50 mm for the period 1901–2002. This figure is available in colour online at www.interscience.wiley.com/ijoc

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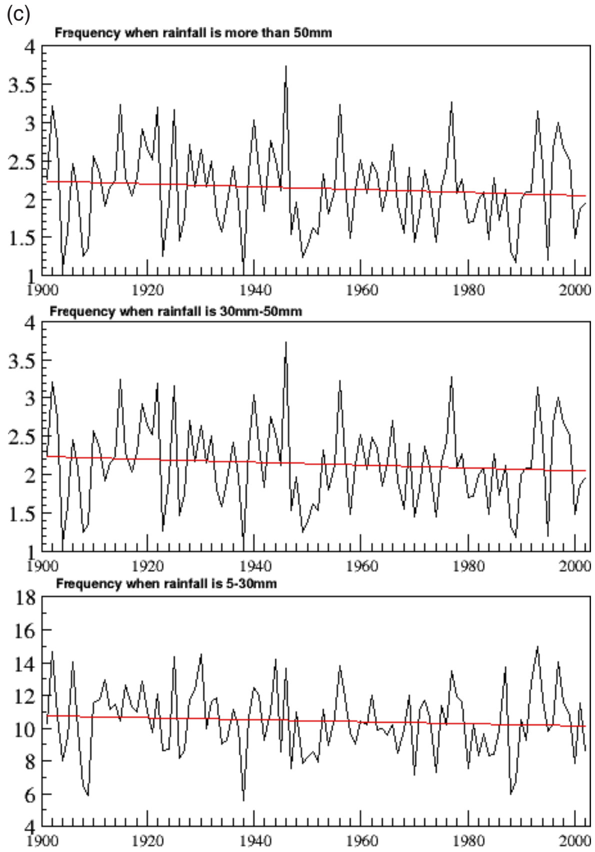

Figure 3. (*Continued*).

The time series of frequencies based on fixed thresholds of 10, 20 and 30 mm daily rainfall are depicted in Figure 3(b). These also do not have any long-term trend and also more number of years have more than average frequency.

Figure 3(c) depicts time series of frequencies based on different thresholds. These thresholds are defined following Goswami *et al*. (2006). The time series have been plotted for 1901–2002. Goswami *et al*. (2006) have done the analysis of extreme rainfall events over Central India during the summer-monsoon period June–September over the period 1951–2002. The frequencies of moderate events (daily rainfall 5–30 mm) and very heavy events (daily rainfall more than 50 mm) show decreasing tendency while the heavy rainfall events (daily rainfall 30–50 mm) are stable over the century. It is observed that during the decade of the 1980s, all the three events occur less frequently implying that during this decade, the events of daily rainfall less than 5 mm over south peninsular India during winter are more frequent. In the decade of the 1990s, the heavy rainfall events are more frequent as seen in all three panels of Figure 3(c). Eleven out of the 12 years 1991–2002 happen to be the hottest years. The warming environment enhances the moisture content of the atmosphere resulting in more frequent heavy rainfall events.

The time series for intensity of one-day and five-day maximum precipitation are shown in Figure 4. The one-day maximum precipitation is highly random series without any trend, however five-day maximum precipitation do show a decreasing trend, significant at the 5% level. This implies that the intensity of five-day maximum precipitation is decreasing in the recent period.

In Figure 5, the time series for number of continuous dry days (CDD, to panel) and continuous wet days (CWD, bottom panel) are shown. Spell length of CDD is much more and variability is also more as compared to that of CWD. The continuous wet days are seen to be between 3 and 7 days while we can observe the (bottom panel) maximum dry spell of 35 days (1966) while minimum is of 9 days (1995). The CWD time series shows decreasing trend, significant at the 5% level. Hence continuous wet days are substantially decreasing in recent period. A Similar type of analysis has been done by Nicholls *et al*. (2005) for hot/cool days and warm/cold nights.

Table II. Average and standard deviation of extreme precipitation indices.

Index	Mean	Standard deviation
R10 mm	10.4	2.4
R20 mm	6.3	1.6
R30 mm	4.1	1.1
R5–30 mm	10.3	1.9
R30–50 mm	2.1	0.5
R50 mm	1.9	0.6
R65p	7.6	1.8
R75p	5.4	1.4
R85p	3.2	0.9
RX1 day	82.6	14.1
RX5 day	154.5	26.6
CDD	17.5	4.5
CWD	5.6	1.1

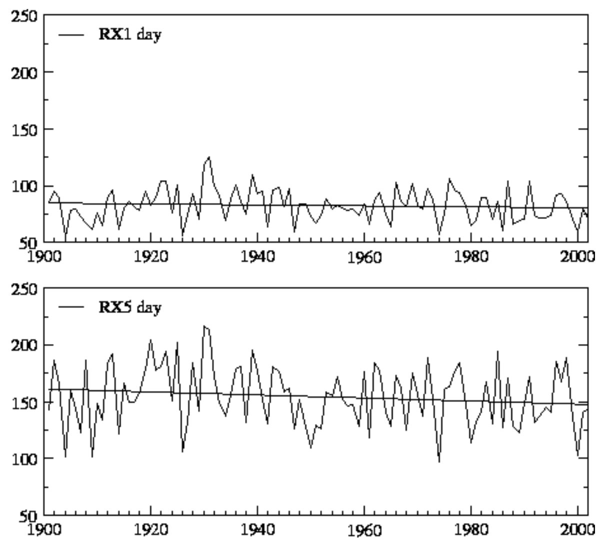

Figure 4. Time series of one-day and five-day maximum precipitation for the period is 1901–2002.

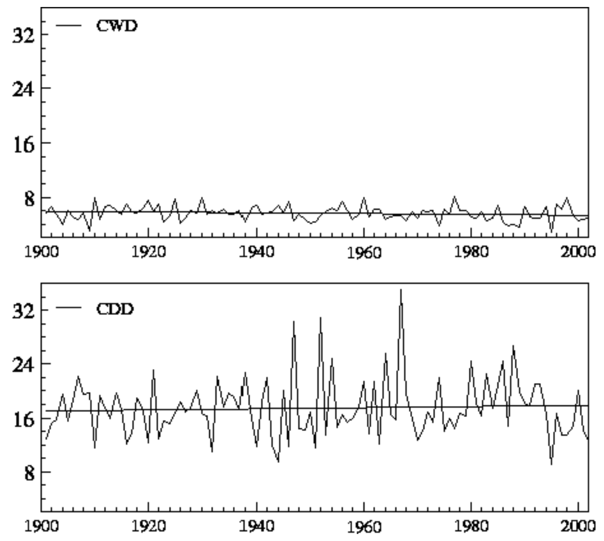

Figure 5. Time series of spell lengths of continuous dry days and continuous wet days for the period 1901–2002.

4. Relationship with ENSO

A number of studies have shown that there is a strong positive correlationship between the SSTs over NINO3.4 region and the winter-monsoon rainfall (Oct-Nov-Dec) over the south-eastern tip of the Indian land mass. Normally this region gets rainfall in October–December period due to weather systems like tropical cyclones, depressions, North–south trough activity and coastal convergence. During El Nino years, the wind flow at lower levels are predominantly easterlies with strong westerlies aloft. This situation generates a vertical wind shear in this region, which is the inhibitive factor for cyclone genesis, hence strong easterly waves are associated with excessive rainfall over the region. Singh and Chattopadhyaya (1998) have shown that the seasonal spring (March–April–May) southern oscillation index is positively correlated with rainfall over the southeast Indian region of Tamilnadu, coastal Andhra Pradesh and Rayalseema.

The correlation between monthly NINO3.4 SSTs and the frequencies of extremes are shown in Figure 6. The top panel shows correlation with frequencies based on percentiles. These correlations are based on the 30-year period 1971–2000. The frequency for the 65th percentile shows maximum correlation coefficient (CC) with July SSTs (CC = 0.54) while the 75th percentile frequency has maximum relationship (CC = 0.55) with May SSTs and the 85th percentile frequency with April SSTs (CC = 0.52). The relationship assumes significance

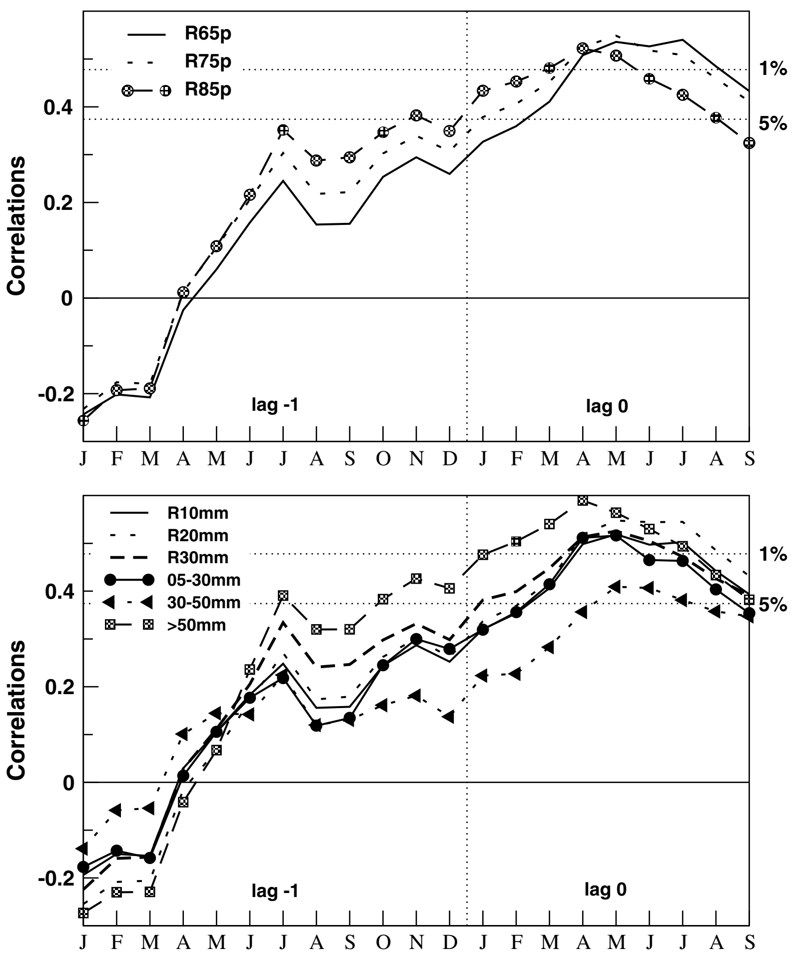

Figure 6. Correlations of NINO3.4 SSTs with frequency of extremes based on percentiles (top panel) and fixed thresholds (botton panel) based on 1971–2000. The dotted horizontal lines are significant correlation coefficients at the 1and 5% level.

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from July–August of the previous year; it goes on strengthening as time progresses and reaches its maximum, thus, 5 (April), 4 (May) and 3 (June) months before the winter monsoon (October–December) sets in.

Similarly, for fixed thresholds of 30, 20 and 10 mm, the NINO3.4 SSTs, in the month of May before the onset of winter monsoon are strongly correlated (CC = 0.52, 0.55 and 0.52 respectively) with respective frequencies. The correlations are significant at 1% level (>0.478)

The frequencies obtained by using different thresholds as suggested by Goswami *et al*. (2006) are also correlated with Nino3.4 SSTs and they give very encouraging results. The frequencies of moderate events are strongly related with NINO3.4 SSTs, the CC is of the order of 0.5 in the month of April before winter monsoon. Whereas, the heavy rainfall events (30–50 mm) are weakly correlated with NINO.3.4 SSTs. The number of days with very high precipitation amounts (more than 50 mm) show a strong relationship in previous April (CC = 0.59) implying that the number of very high rainfall days can be very well predicted 5 months in advance with the help of NINO3.4 SSTs.

The correlation analysis shows that the prediction of number of extreme rainfall events in winter season can be made with reasonably good skill from NINO3.4 SSTs as early as April–May–June.

The correlations between the intensity of 1-day and 5-day maximum precipitation with monthly NINO3.4 SSTs are shown in Figure 7. The 1-day maximum precipitation has significant relationship with preceeding April SSTs, then the relationship goes on strengthening and is maximum of the order of 0.45 in the month June–July, two months before the winter monsoon starts. The correlation of 0.45 is significant at 5% level for the sample of 30.

Also 5-day maximum precipitation has the CC of order of 0.38, with preceeding January SSTs, significant at 5% level. 5-day precipitation intensity is not as strongly related with NINO3.4 SSTs, as 1-day precipitation intensity. Hence NINO3.4 SSTs in the month of June can be used to get some idea of 1-day maximum precipitation in the coming winter monsoon.

The spell lengths of continuous dry/wet days do not show good relationship with NINO3.4 SSTs (hence figure is not presented). Spell lengths of continuous dry (wet) days are negatively (positively) correlated with NINO3.4 SSTs since previous June–July, which is obvious since winter precipitation is known to be positively related with NINO3.4 SSTs and the good winter precipitation is characterized by more number of long wet spells.

5. Conclusions

The El Nino-southern oscillation has been shown to be strongly related with variations in frequencies of extreme precipitation in winter season over India. The number of extreme events increases in the year after the onset of El Nino events. Strong correlations exist between the frequency and intensity of extreme precipitation events and NINO3.4 SSTS 4–6 months in advance but no relationship exists for spell lengths of continuous wet/dry days and an index of ENSO. Very heavy rainfall events posses very strong relationship with April SSTs over NINO3.4 region hence it is possible to predict very heavy rainfall events well in advance.

It is necessary to examine the variation in relationships between extremes and ENSO to understand the mechanisms leading to increase in frequency and intensity of extreme precipitation events after the ENSO events. Also the stability of relationship is to be studied by extending the analyses over a longer time period.

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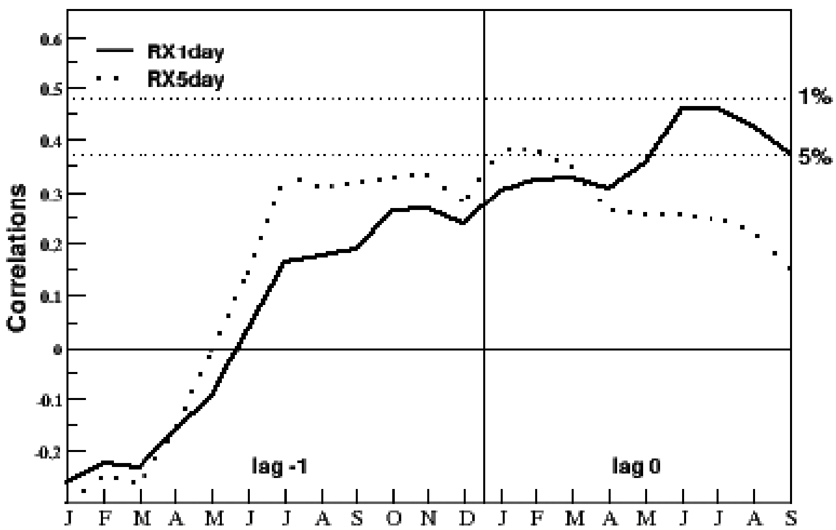

Figure 7. Same as Figure 6 but for intensity of 1-day and 5-day precipitation.

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