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A study on north-east monsoon rainfall over India

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सार – उत्तरी–पूर्वी (उ.पू.) मानसून भारतीय जलवायु तंत्र के महत्वपूर्ण घटकों में से एक है। उत्तरी –पूर्वी मानसून के वायवीय विस्तार प्रायः दक्षिणीपूर्वी प्रायद्वीपीय भारत में फैले हुए हे। उत्तरी–पूर्वी मानसून ऋतु अर्थात् अक्तूबर से दिसंबर तक की अवधि के दौरान भारत के निम्नलिखित पाँच मौसम वैज्ञानिक उपखंडों अर्थात् तटीय आंध्रप्रदेश, रायलसीमा, कर्नाटक के दक्षिणी अंदरूनी भाग, केरल और तमिलनाडु में वर्षा अत्याधिक मात्रा में हुई। इस शोध–पत्र में वर्ष 1875–1997 की दीर्घावधि आँकड़ों की श्रृखलाओं का उपयोग करते हुए दक्षिणीपूर्वी प्रायद्वीपीय और समूचे भारत में उत्तरी–पूर्वी मानसून वर्षा की भिन्नताओं का अध्ययन किया गया है। इसमें एल–नीनों और ला–नीना वर्षों सहित उत्तरी–पूर्वी मानसून की वर्षा का भी अध्ययन किया गया है। इस दौरान यह देखा गया है कि एल–नीनों (ला–नीना) के वर्षों में दक्षिणीपूर्वी प्रायद्वीपीय भारत में उत्तरी–पूर्वी मानसून की वर्षा सामान्य से अधिक (न्यून) है। इसके साथ ही एल–नीनों के वर्षों के दौरान अधिक अथवा सामान्य रहते हुए इस क्षेत्र में उत्तरी–पूर्वी मानसून वर्षा की संभावना बहुत अधिक अर्थात् 0.93 रही।

ABSTRACT. The North-East (NE) monsoon is one of the important components of Indian climate system. The aerial extent of NE monsoon generally extends over south-eastern peninsular India. The following five meteorological sub-divisions of India *viz*. coastal Andhra Pradesh, Rayalaseema, south interior Karnataka, Kerala and Tamil Nadu receive significant amount of rainfall during the NE monsoon. In the present study, using a long period data series 1875-1997, the variability of NE monsoon rainfall over south-eastern peninsula and whole India, is studied. The association of NE monsoon rainfall with El-Nino and La-Nina years is also analysed. It is observed that, the NE monsoon rainfall, over the south-eastern peninsular India is higher (lower) than normal, during El-Nino (La-Nina) years. Also, the probability of NE monsoon rainfall over this region being excess or normal during El-Nino years is very high, 0.93.

Key words – Northeast Monsoon, El-Nino years, La-Nina years.

1. Introduction

The North-East (NE) monsoon season (October to December) is the principal rainy season for the southern region of the Indian peninsula, particularly, the eastern half of it. In the state of Tamil Nadu, it is the main rainy season which accounts for about 60% of the annual rainfall in the coastal districts and about 40% to 50% of the annual rainfall in the interior districts of the state [Srinivasan and Ramamurthy (1973b)]. The aerial extent of the NE monsoon generally extends over the five meteorological sub-divisions of India *viz*., coastal Andhra Pradesh, Rayalaseema, south interior Karnataka, Kerala and Tamil Nadu (Fig. 1). Though the NE monsoon is marked by a limited aerial extent and gives relatively lesser quantum of rainfall as compared to that during the South-West (SW) monsoon, it is important for the agriculture and hydrology of the Indian southern peninsula.

There have been a number of studies discussing the statistical properties of NE monsoon [Srinivasan and Ramamurthy, (1973 a&b); Rao (1953); Dhar *et al*. (1982 a&b); Sontakke (1993); Singh and Sontakke (1999)]. De *et al.* (1992), have studied the intra-seasonal variation of rainfall during NE monsoon in relation to circulation features for the period 1975-85. They observed that, even during the years of normal or above normal rainfall, spells of above normal rainfall occurred for only two to three weeks in a season over the southern peninsula. This study has also shown that there is no significant periodicity in the rainfall in the NE monsoon season and the auto-correlations decrease very rapidly with increasing time. Ropelwski and Halpert (1987) have reported an enhanced ENSO-related winter monsoon precipitation in extreme southern India. Sridharan and Muthuswamy (1990) have observed that on 90% of occasions, El-Nino years resulted in normal or above normal rainfall over Tamil Nadu during NE monsoon period. Singh and Sontakke (1999)

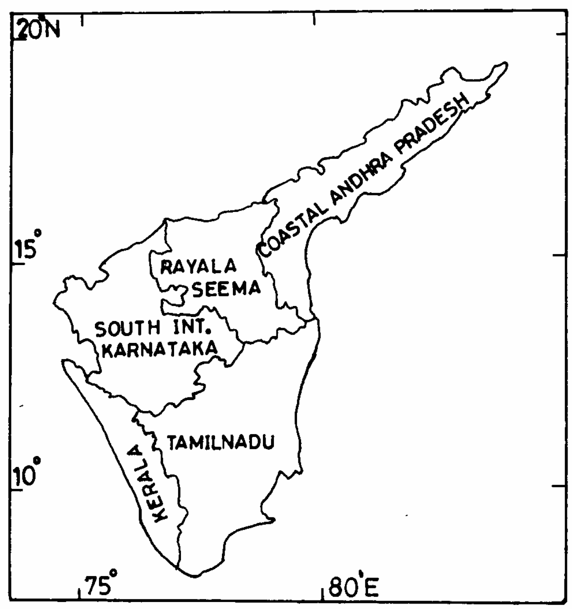


Fig. 1. Meteorological sub-divisions of India receiving significant rainfall during NE monsoon season

have proposed the region demarcated by the Indian Peninsula south of 15° N, as the region of 'South Peninsula' in the context of studies on variability of NE monsoon season rainfall. This region constitutes about 12% of the total area of India. De and Mukhopadhyay (1999) have found that an ENSO year is associated with enhanced NE monsoon precipitation while an anti-ENSO year is associated with reduced precipitation. Jayanthi and Govindachari (1999) have reported that, out of 22 El-Nino years during 1901-1997 in 17 years (on 77% of occasions) Tamil Nadu received above normal rainfall. With this backdrop, a study of variability of NE monsoon over India and its related aspects are presented in this study.

2. Data and methodology

The principal aim of this study is to build up a long time (1875-1997) data series of the area weighted rainfall for the NE monsoon season, October-November-December (OND) for the five meteorological subdivisions of India, forming the core region of NE monsoon and India as a whole. It is also aimed to examine the possible linkage between the activity of NE monsoon and El Nino, if any. For this purpose, the composite NE monsoon rainfall for the El Nino and La-Nina years under study, is assessed. Also, the coefficients of correlation between the NE monsoon rainfall and the Sea Surface Temperature (SST) over the Pacific Ocean are computed and analysed. For the computation of area-weighted rainfall for the whole India and for the five meteorological sub-divisions, the sub-divisional rainfall data for 1875 to 1997, archived by the India Meteorological Department are used. From these data, the following two long-time series of rainfall for October to December (October-November-December : OND) season and the months of October, November and December are computed (1) for all-India (2) for five meteorological sub-divisions forming the core region of NE monsoon area *viz*., coastal Andhra Pradesh, Rayalaseema, south interior Karnataka, Kerala and Tamil Nadu. This series is hereafter, referred to as the 'sub-divisional NE Monsoon Rainfall'. From these data, the Standardized Rainfall Anomaly (SRA) of the seasonal (October to December) rainfall is computed for each year of the period 1875 to 1997. This SRA is defined as,

$$\mathrm{SRA} = \frac{X - \overline{X}}{\sigma},$$

where X : the seasonal OND rainfall of any year,

$\overline{X}$: Mean OND rainfall for 1875 to 1997, and

σ : Standard deviation of the rainfall series.

3. Discussion

3.1. *Variability of NE monsoon rainfall*

Figs. 2 and 3 depict the values of SRA for all-India and sub-divisional rainfall respectively.

The years for which the SRA is > +1 are designated as the years of excess rainfall and those years for which the SRA is < –1 are designated as the years of deficient rainfall. The rest of the years are designated as the years of normal rainfall. With this criterion, there are in all 24 excess years (1880, 1883, 1884, 1887, 1893, 1898, 1902, 1903, 1922, 1930, 1932, 1939, 1940, 1944, 1946, 1956, 1969, 1972, 1977, 1987, 1993, 1994, 1996 and 1997) and 19 years of deficient rainfall (1875, 1876, 1881, 1897, 1899, 1900, 1904, 1908, 1909, 1926, 1927, 1938, 1947, 1949, 1951, 1974, 1984, 1988, 1989), during the period under study. The highest value (55.19 cm) of the seasonal rainfall is observed in 1993 while the lowest value (10.12 cm) is observed in 1876. Thus the range of the rainfall is 45.07 cm. A similar criterion for the all-India rainfall series yields 15 years of excess rainfall (1894, 1903, 1916, 1917, 1928, 1931, 1946, 1955, 1956, 1958, 1977, 1985, 1987, 1990 and 1997) and 16 years of deficient rainfall (1875, 1876, 1881, 1891, 1896, 1899, 1900, 1905, 1907, 1908, 1909, 1918, 1920, 1926, 1935 and 1965), during the period under study. The highest value of All-India NE Monsoon Rainfall (AINMR) (21.26 cm) occurred in 1956 and the lowest value (5.15 cm) occurred in 1908. Thus, the range of the rainfall is 16.11 cm.

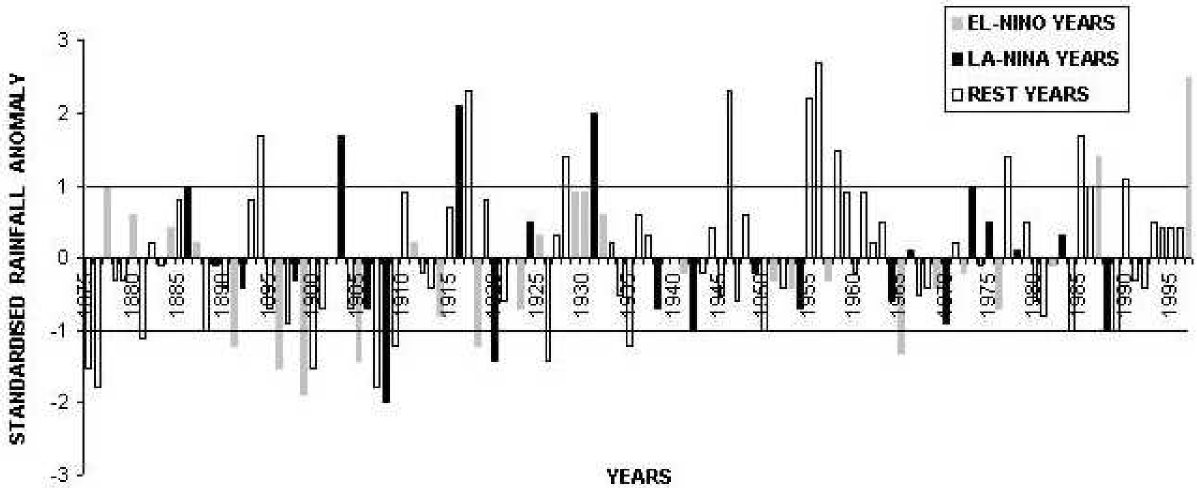


Fig. 2. Interannual variability of all-India NE monsoon (October to December) rainfall (1875-1997)

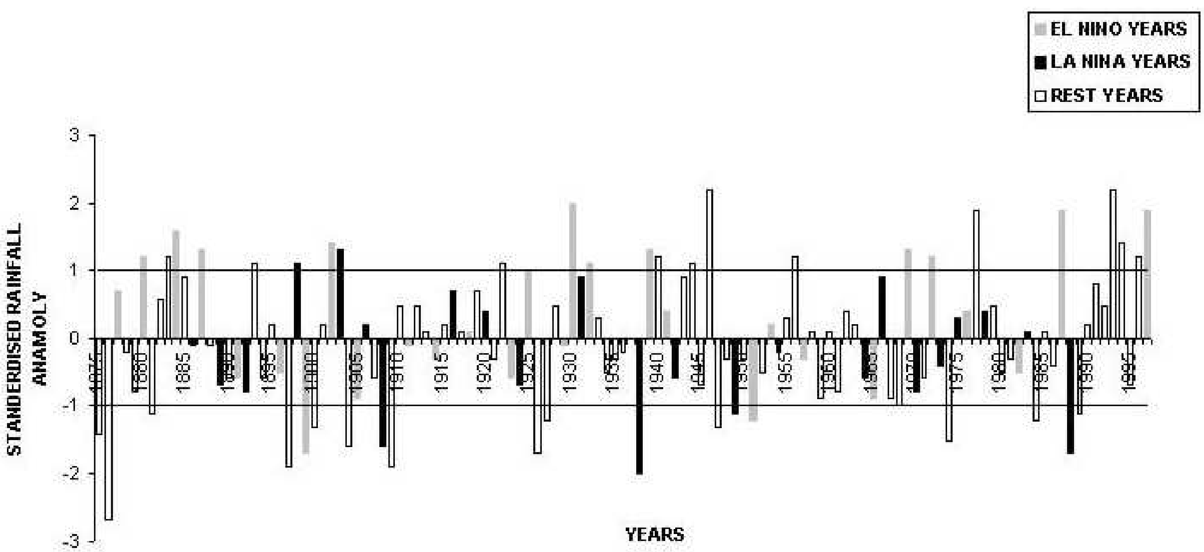


Fig. 3. Interannual variability of NE monsoon (October to December) rainfall (area-weighted for five sub-divisions) (1875-1997)

From Table 1, it is evident that, the all-India mean rainfall during NE monsoon season (October to December) is 12.0 cm and its standard deviation is 3.4 cm. Thus, the coefficient of variation works out to be 28%. For sub-divisional NE monsoon rainfall, the mean rainfall is 34.9 cm with standard deviation 9.3 cm. Interestingly, the coefficient of variation for both, all-India and sub-divisional NE monsoon rainfall is almost the same. During the period 1875-1997, there are 29 El-Nino years [as identified by Quinn, *et al*. (1987) and Rasmusson and Carpenter (1983) and later updated] and 23 La-Nina years [as identified by Van Loon and Shea (1985)]. The list of these El-Nino and La-Nina years [Mooley (1997)] is presented in Table 2.

The composite sub-divisional NE monsoon rainfall for El-Nino years is 11% higher than the Long Period Average (LPA) whereas the composite rainfall for La-Nina years is 6% lower than the LPA. The difference between the composite sub-divisional NE monsoon rainfall for El-Nino and La-Nina years, has been tested for significance by applying the non-parametric Mann-Whitney Rank statistics test. It is observed that, this difference is significant at 5% level. For AINMR, the composite for El-Nino years is lower than the LPA by 5% and that for La-Nina years is lower than the LPA by 1%. The difference between the composite all-India NE monsoon rainfall, for El-Nino and La-Nina years, however, when tested for significance by application of

TABLE 1

Statistical details of sub-divisional and All-India rainfall during NE monsoon season (1875-1997)

Parameter	Sub-divisional rainfall	All-India rainfall
Mean	34.9 cm	12.0 cm
Standard deviation	9.3 cm	3.4 cm
Coefficient of variation	27%	28%
Mean composite for deficient years	20.6 cm	7.0 cm
% of LPA	–41%	–42%
Mean composite for excess years	48.2 cm	18.4 cm
% of LPA	+ 38%	+ 53%
Mean composite for El-Nino years	38.7 cm	11.5 cm
% of LPA	+ 11%	–5%
Mean composite for La-Nina years	33.0 cm	11.9 cm
% of LPA	–6%	–1%

TABLE 2

List of El-Nino and La-Nina years (1875-1997)

El-Nino Years	La-Nina Years
1877	1886
1880	1889
1884	1892
1887	1898
1891	1903
1896	1906
1899	1908
1902	1916
1905	1920
1911	1924
1914	1931
1918	1938
1923	1942
1925	1949
1929	1954
1930	1964
1932	1966
1939	1970
1941	1973
1951	1975
1953	1978
1957	1983
1965	1988
1969	
1972	
1976	
1982	
1987	
1997	

TABLE 3

Coefficients of Correlation (CC) between the monthly (Oct, Nov & Dec) and seasonal (OND) Rainfall over India as a whole and over the five meteorological sub-divisions

	All-India rainfall	Sub divisional rainfall
(a) CC between monthly and seasonal rainfall		
Oct – OND	0.8	0.6
Nov – OND	0.5	0.8
Dec – OND	0.3	0.5
(b) CC between All-India and sub-divisional rainfall		
Oct	0.5	
Nov	0.8	
Dec	0.6	
OND	0.6	

Mann-Whitney test is observed not to be statistically significant.

Table 3(a) depicts the Coefficients of Correlation (CC) between the monthly and seasonal sub-divisional rainfall. The CCs are positive. It is observed that, for the sub-divisional rainfall, all the months (October, November and December) contribute significantly to the seasonal rainfall, the CC between November and OND rainfall being the highest. For AINMR, the highest correlation is observed for the month of October. These CCs are significant at 5% level of significance. Table 3(b) depicts similar table for the AINMR and sub-divisional rainfall. This correlation is the highest for the month of November.

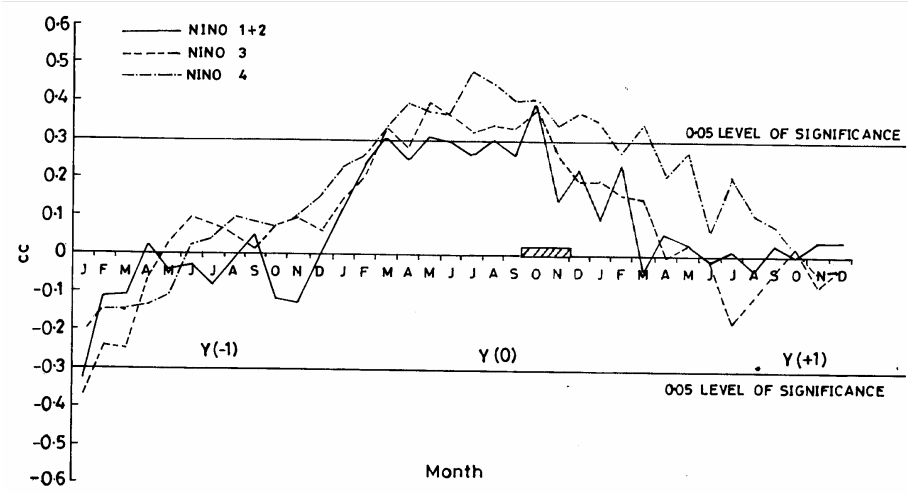
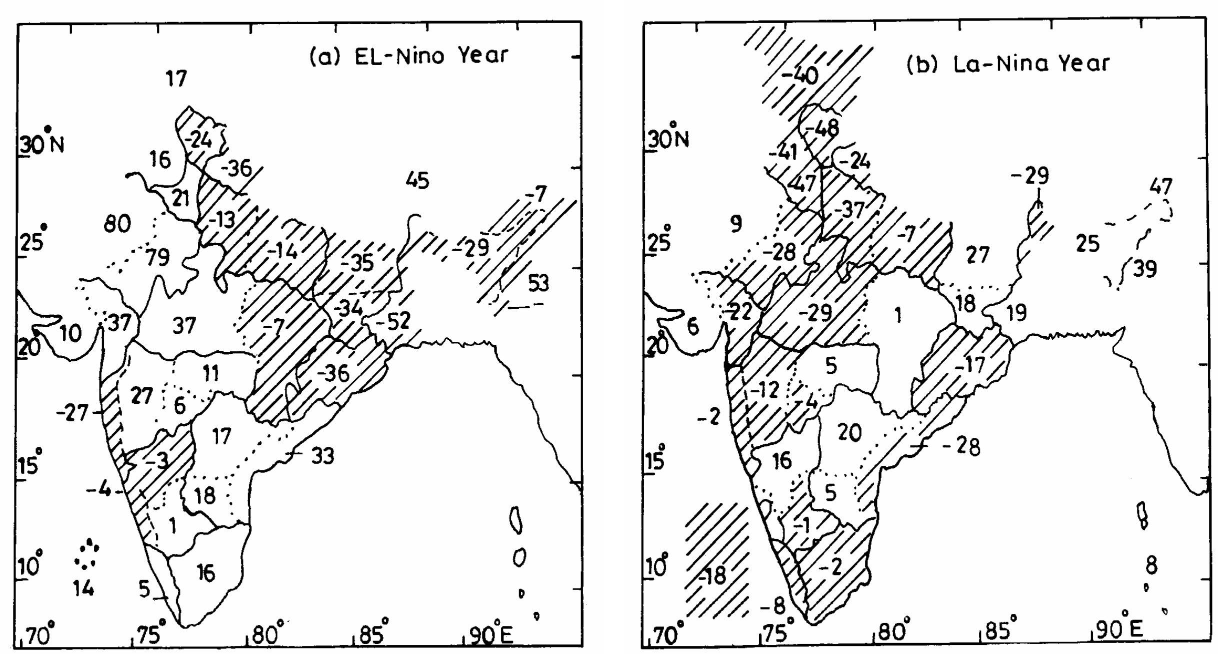


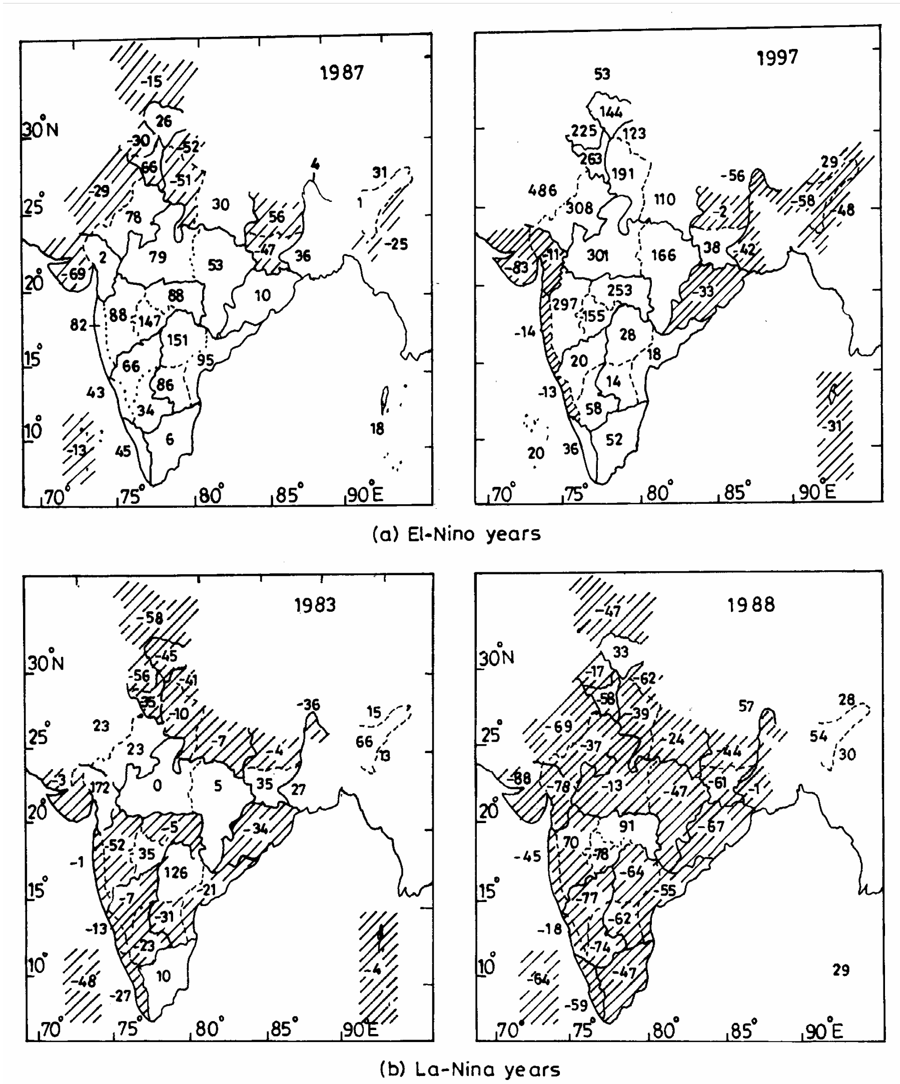
Fig. 4. Coefficients of correlation (CC) between NE monsoon (OND) rainfall and SST over Nino regions (1961-98)



Figs. 5(a&b). Spatial distribution of composite NE monsoon (October to December) rainfall (percentage departure from normal) over India (1961-97). The area of negative departure is hatched

3.2. *Association between the sub-divisional NE monsoon (October to December) rainfall and the sea surface temperature over Pacific*

The association of rainfall over India with various El-Nino Southern Oscillation (ENSO) parameters is the highest during the post-monsoon season [Walker (1924), Chattopadhyay and Bhatla (1996)]. Hence, in order to examine the relationship of the rainfall during post-monsoon season (October to December) with ENSO, the coefficients of lag correlation between the SRA of sub-divisional rainfall (OND) and the Sea Surface Temperature (SST) anomaly over the three key regions of Pacific *viz.*, Nino 1+2, Nino 3 and Nino 4 are computed,



Figs. 6(a&b). Spatial distribution of NE monsoon (October to December) rainfall (percentage departure from normal) over India for two cases each of (a) El-Nino years and (b) La-Nina years. The area of negative departure is hatched

for the period 1961 to 1997. The data of SST anomaly over the three Nino regions of the Pacific ocean have been obtained from the Climate Analysis Centre, Washington, USA. Fig. 4 depicts these Coefficients of Correlation (CCs).

From Fig. 4, it is observed that, for all the three Nino regions, the nature of evolution of the CCs is similar. The CCs during the pre-monsoon months (March to May) of the previous year are negative (but, not statistically significant), these become positive thereafter and continue to increase. Statistically significant positive CCs are observed during May to October of the concurrent year. The CCs decrease rapidly, thereafter, and become insignificant. Thus, warmer (cooler) than normal SSTs over the central and eastern Pacific during May to October are conducive for higher (lower) winter monsoon rainfall over the peninsular India.

Figs. 5(a&b) depicts the composite NE monsoon rainfall (percentage departure from normal) over India for El-Nino years and La-Nina years during 1961 to 1997 respectively. (Table 2), They show contrasting features. The composite for El-Nino years shows positive rainfall departure (indicating higher than normal rainfall) over all the five meteorological sub-divisions, forming the core region of NE monsoon area. The north eastern region of India shows lower than normal NE monsoon rainfall, as indicated by negative rainfall departure values [Fig. 5(a)]. On the other hand, the composite for La-Nina years shows

TABLE 4

Sub-divisional rainfall (Oct to Dec) during El Nino and La-Nina years (1875-1997)

	Excess Rainfall years	Normal Rainfall years	Deficient Rainfall years	Total
El-Nino years	11	16	2	29
La-Nina years	2	17	4	23
Neither El-Nino nor La-Nina years	11	47	13	71
Total	24	80	19	123

negative rainfall departure (lower than normal rainfall) over peninsular India and positive rainfall anomalies (higher than normal rainfall) over north eastern India [Fig. 5(b)]. A similar kind of rainfall features are observed in case of the individual El-Nino and La-Nina years, forming the respective composites. As an example, two cases of each El-Nino years (1987 and 1997) and La-Nina years (1983 and 1988), are presented in Fig. 6. In 1987 as well as in 1997 (both being El-Nino years), the rainfall over south-eastern peninsular region of India was higher than normal. On the other hand, in 1983 and in 1988, the rainfall over south-eastern peninsular region of India was lower than normal (except over Tamilnadu, in 1983) and rainfall over the north-eastern India was higher than normal.

A study by De and Mukhopadhyay (1999) has revealed that the tracks of low-pressure systems in the Bay of Bengal, during the ENSO years, are more westerly than those during anti-ENSO years. Thus, during El-Nino years, the number of low-pressure systems affecting the Tamil Nadu/Andhra Pradesh coasts is higher than that during La-Nina years, during which, the low-pressure systems have a higher tendency to recurve. Also, during the La-Nina years, the surface wind anomalies in Indian Ocean are westerly indicating weaker than normal NE monsoon circulation. (Ropelwski and Halpert, 1989). These factors may contribute to higher (lower) than normal rainfall over the south-eastern peninsular region of India during El-Nino (La-Nina) years.

Table 4 shows the contingency table of the sub-divisional NE monsoon rainfall activity during El-Nino and La-Nina years for the period 1875-1997.

It is observed from Table 4 that, the probability of the sub-divisional rainfall being excess or normal during El-Nino years is very high (0.93). The probability of NE monsoon rainfall being excess in La-Nina years is very low, only about 0.09.

4. Conclusions

(*i*) The composite area-weighted rainfall for the five meteorological sub-divisions forming the core region of the NE monsoon area, shows statistically significant difference for El-Nino years and La-Nina years. The composite NE monsoon rainfall for El-Nino years during 1875-1997 is 11% higher than the respective Long Period Average (LPA) whereas the composite NE monsoon rainfall for the La-Nina years is 6% lower than the LPA.

(*ii*) On the other hand, the composite all-India north-east monsoon rainfall does not show statistically significant difference in the rainfall between El Nino and La-Nina years. This seems to indicate that the rainfall outside the south-eastern peninsula (core region of north-east monsoon area) is influenced, to a greater extent, by other parameters.

(*iii*) The lagged correlations between the area-weighted NE monsoon rainfall for the five meteorological sub-divisions receiving the NE monsoon rainfall and the monthly SST anomalies over the three Nino regions of the Pacific Ocean oscillate with time. The correlations during the winter and pre-monsoon months (January to April) of previous year are negative, which change to positive during May to October of the concurrent year and then subsequently changing to negative values. The correlation during May to October of the concurrent year is positive, significant at 95% level of significance.

(*iv*) An analysis of the spatial distribution of the composite rainfall for El-Nino (La-Nina) years shows higher (lower) than normal rainfall over peninsular India. This effect is more prominently observed for the five meteorological sub-divisions forming the core region of the NE monsoon area. In 1997 (a year of the most intense El-Nino event of the 20th century), this effect was the most spectacular.

(*v*) The probability of the sub-divisional NE monsoon rainfall being excess or normal (deficient) during El-Nino (La-Nina) years is very high (low).

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References

Chattopadhyay, J. and Bhatla, R., 1996, "A re-examination of ENSO/Anti-ENSO events and simultaneous performance of Indian summer Monsoon", *Mausam*, **47**, 1, 59-66.

De, U. S., Joshi, K. S. and Lele, R. R., 1992, "Intra-seasonal variation in circulation and rainfall during northeast monsoon", *Vayu Mandal*, 3-4.

De, U. S. and Mukhopadhyay, R. K., 1999, "The effect of ENSO/Anti – ENSO on northeast monsoon rainfall", *Mausam*, **50**, 4, 343-354.

Dhar, O. N., Rakhecha, P. R. and Kulkarni, A. K., 1982a, "Fluctuations in northeast monsoon rainfall of Tamil Nadu", *J. Climatol*., **2**, 339-345.

Dhar, O. N., Rakhecha, P. R. and Kulkarni, A. K., 1982b, "Trends and fluctuations of seasonal and annual rainfall of Tamil Nadu", Proc. Indian Acad. Sci (Earth Planet Sci), **91**, 97-104.

Jayanthi, N. and Govindachari, S., 1999, "El Nino and NE monsoon rainfall over Tamil Nadu", *Mausam*, **50**, 2, 217-218.

Mooley, D. A., 1997, "Climate variability from historical and instrumental records", Lecture Notes, Vol.1, Fourth SERC school on Advanced Geophysical Fluid Dynamics : Dynamics of climate and its variability, Indian Institute of Tropical Meteorology, Pune, 1-25.

Quinn, W. H., Neal, V. T., Santiago, E. and De Mayolo, 1987, "El-Nino occurrences over the past four and a half centuries", *J. Geophys. Res*., **92**, C13, 14449-14461.

Rao, P. R. K., 1953, "Rainfall of Madras state with special reference to Tamil Nadu and Rayalaseema", Memories, India Meteorology Department, 30, Part I, 1-60.

Rasmusson, E. M. and Carpenter, T. H., 1983, "The relationship between eastern equatorial Pacific sea surface temperature and rainfall over India and Sri Lanka", *Mon. Wea. Rev.*, **111**, 517-528.

Ropelwski, C. F. and Halpert, M. S., 1987, "Global and regional scale precipitation patterns associated with the El Nino/Southern Oscillation", *Mon. Wea. Rev.*, **115**, 1606-1626.

Ropelwski, C. F. and Halpert, M. S., 1989, "Precipitation patterns associated with the high index phase of Southern Oscillation", *J. Climate*, **2**, 268-284.

Ropelwski, C. F. and Halpert, M. S., 1996, "Quantifying southern oscillation precipitation relationships, *J. Climate*, **9**, 1043-1059.

Singh, N. and Sontakke, N. A., 1999, "On the variability and prediction of rainfall in the post monsoon season over India", *Int. J. Climatol*., **19**, 309-339.

Sontakke, N. A., 1993, "Fluctuations in NE monsoon rainfall over India since 1871, In: Advances in tropical meteorology", (R. N. Keshavmurty and P. C. Joshi, (Eds), Tata Mc Graw Hill, New Delhi, 149-158.

Sridharan, S. and Muthuswamy, A., 1990, "NE Monsoon rainfall in relation to El-Nino, QBO and Atlantic hurricane frequency", *Vayu Mandal*, **20**, 3-4, 105-111.

Srinivasan, V. and Ramamurthy, K., 1973a, "Comprehensive articles on selected topics, Northeast Monsoon", FMU Report, No. IV, 18.4, India Meteorological Department.

Srinivasan, V. and Ramamurthy, K., 1973b, "Weather over the Indian seas during the post monsoon season", FMU Report, No. 4.1, India Meteorological Department.

Van Loon, H. and Shea, D. J., 1985, "The southern oscillation, Part : The precursors south of 15° S to the extremes of oscillation, *Mon. Wea. Rev*., **113**, 2063-2074.

Walker, G. T., 1924, "Correlation in seasonal variation of weather", IX-A further study of world weather, Memories India Meteorological Department, 24, Part IX, 275-332.