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Influence of some circulation anomalies on Indian northeast monsoon rainfall

G.P. SINGH and J. CHATTOPADHYAY

Deptt. of Geophysics, Banaras Hindu University, Varanasi-221 005, India

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सार — तमिलनाडु (टी.एन.आर.) तथा दक्षिणी पूर्वी भारत (एस.ई.आर.) के साथ भारतीय उत्तरीपूर्वी मानसून, के संबंधो तथा दक्षिण दोलनों (एस.ओ.आई.) की दो सूचियों भूमध्यरेखीय प्रशान्त महासागरीय विभिन्न नीनो क्षेत्रों की समुद्री सतही तापमान (एस.एस.टी.) विसंगतियों और सात उष्णकटिबंधीय परिसंचरण सूचियों (टी.सी.आई.) का विभिन्न अवधियों में अध्ययन किया गया है। इस अध्ययन में उत्तरीपूर्वी पिछले मानसून वर्षा (टी.एन.आर.) ऋतु में (एम.ए.एम.) मार्च, अप्रैल और मई के दौरान एस.ओ.आई. (आई-डी) के साथ विशेष रूप से विपरीत संबंधों पिछले (जू.जु.अ.) जून, जुलाई और अगस्त के दौरान नीनो 4 क्षेत्र में एस.एस.टी. विसंगतियों के साथ सीधे-संबंधों, तथा पिछले (दि.ज.फ.) दिसंबर, जनवरी और फरवरी के दौरान टी.सी.आई. (सी-एन) के साथ महत्वपूर्ण संबंधों का पता चलता है। उत्तरपूर्वी मानसून वर्षा क्रम विशेष तथा नकारात्मक दोनों रुपों से एस.ओ.आई. (आई-डी), एम.ए.एम. से सम्बद्ध है तमिलनाडु की वर्षा के वर्षा क्रमों में बेहतर सहसम्बद्ध दिखाई देता है। 1961-90 के दौरान प्रबलतम सहसंबंध देखा गया है। एस.एस.टी.ए. के लिए प्रबलतम सहसंबंध 1964-85 के दौरान है तथा टी.सी.आई. के लिए उच्चतम सहसंबंध 1958-82 के दौरान देखा गया है।

ABSTRACT. The relationship between Indian northeast monsoon rainfall over Tamil Nadu (TNR) and southeast India (SER) as well as two indices of southern oscillation (SOI), and sea surface temperature (SST) anomalies over different Nino regions of equatorial Pacific Ocean and seven tropical circulation indices (TCI), have been studied for different periods. The study indicates that northeast monsoon rainfall (TNR) shows significant inverse relationship with SOI (I-D) during previous MAM (March- April-May) season, significant direct relationship with SST anomaliesover Nino-4 region during previous JJA (June-July- August) and significant direct relationship with TCI (C-N) during previous DJF. The SOI (I-D), MAM correlates significantly and negatively with both the northeast monsoon rainfall series, the TNR rainfall series displaying the better correlation. The strongest correlation is observed during 1961-90. For SSTA, the strongest correlation is during 1964-85 and for TCI, the highest correlation is observed during 1958-82.

Key words - Southern oscillation index, Sea surface temperature, Tropical circulation indices, Northeast monsoon, Correlation.

1. Introduction

Southern oscillation (SO) is a global scale phenomenon. It involves the out of phase relationship of atmospheric pressure with centres of action over Indonesia and southeastern Pacific. It is associated to the intensity of Walker circulation and is connected with large inter-annual variations of sea surface temperature and surface wind fields over much of the tropics (Rasmusson and Carpenter 1982). It is also one of the important factors for the interannual variability of the tropical rainfall. The intensity of SO is expressed in terms of Southern Oscillation Index (SOI) and several indices have been devised for denoting the SOI (Walker and Bliss 1932, Troup 1965, Berlage 1966, Wright 1975, Trenberth 1976 and Angell 1981), and that of Climate Analysis Centre (Chen 1982).

Sea surface temperature anomaly (SSTA) in tropical Pacific is one of the most important factors responsible for the interannual variability of the tropical monsoon circulation and climatic variability. Many investigators have demonstrated that SOI and SST anomalies in the equatorial Pacific ocean are related to Indian summer monsoon rainfall (Mooley and Parthasarathy 1984, Mooley *et al.* 1985, Mooley and Paolino 1989). However, studies of SOI and SST anomalies linking northeast monsoon are limited as compared to southwest monsoon. Sridharan and Muthuswamy (1990) studied the relationship between El-Nino years, 30 hPa Quasi-Biennial Oscillation (QBO), hurricane activity over Atlantic and northeast monsoon rainfall over Tamil Nadu.

An extended low pressure area during northern summer occurs over northwest India, Pakistan, Saudi Arabia and even upto northeastern part of Africa. The pressure gradient

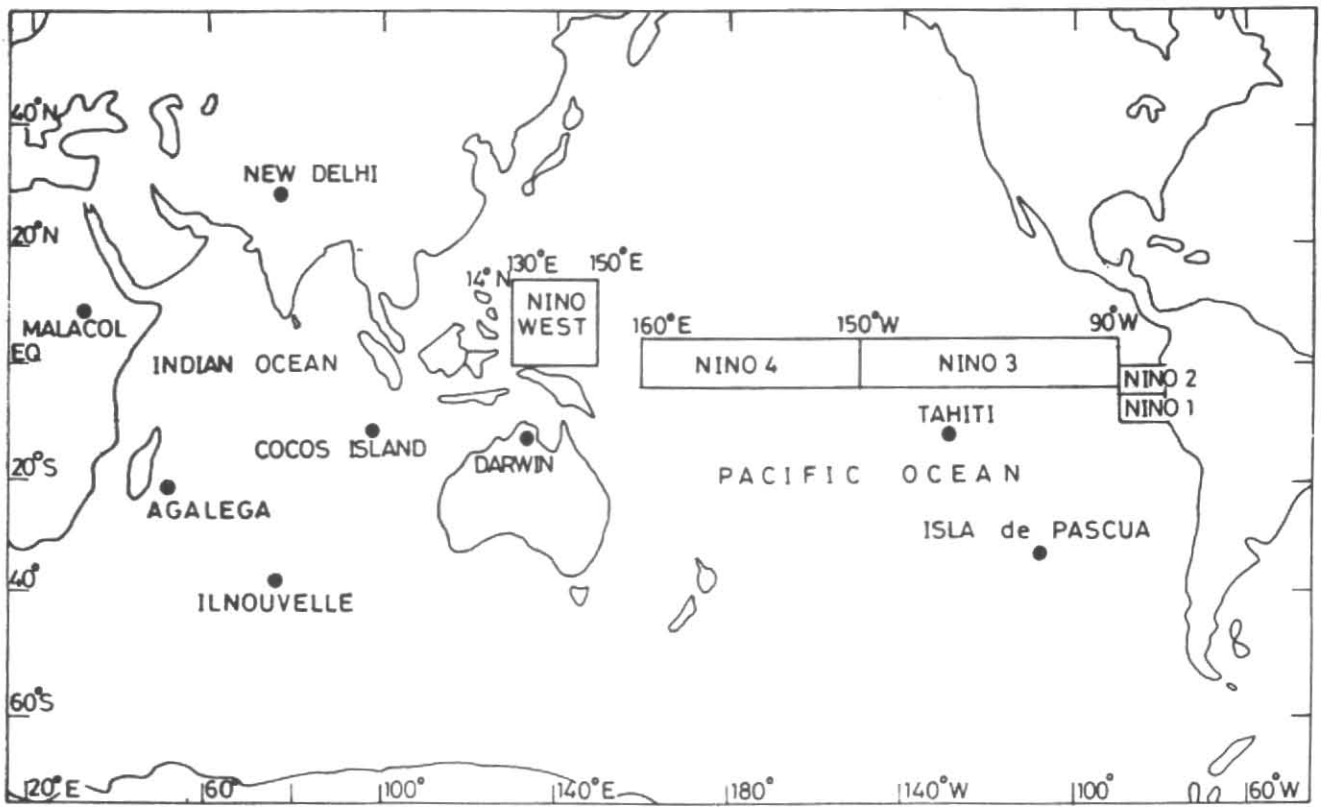

Fig. 1. Locations of different (*i*) Stations used for computing SOI and TCI and (*ii*) Nino regions of equatorial Pacific ocean

created from the Mascarene high region over Indian ocean to this extended low controls the cross equatorial flow. The fluctuations in the cross equatorial flow over the Indian ocean seems to be one of the controlling factors of the strength of the seasonal southwest monsoon rainfall over India (Parthasarathy *et al.* 1990). The reverse situation occurs during the winter monsoon season. In order to examine potential links between Indian northeast monsoon activity and sea level pressure gradient in the tropics and trans-Indian ocean, the correlation of the seasonal northeast monsoon rainfall was found by forming seven tropical circulation indices (TCI) using monthly mean values fo sea level pressure (MSLP) at five selected tropical stations. Here TCI's are a measure of the cross equatorial flow.

2. Data

Both the SOI series, namely, SOI (I-D) and SOI (T-D) were prepared by Chattopadhyay and Bhatla (1993) using monthly surface pressure data of Isla de Pascua, Tahiti and Darwin obtained on tape from National Climatic Data Centre, Asheville, USA and Monthly Climatic Data for the world. The data for SOI (I-D) was from 1942-90 and for SOI (T-D) was from 1933-90. Locations of three stations used for computing SOI are shown in Fig. 1.

Monthly SST anomaly data were obtained from monthly reports on climate system 1991 published by Japan Meteorological Agency and were available over the four sectors 0°- 10°S and 90°-80°W (Nino 1+2), 4°N-4°S and 150°-90°W (Nino-3), 4°N-4°S and 160°E-150°W (Nino-4) and 0°-14°N and 130°- 150°E (Nino-west) respectively. The different sectors of the equatorial Pacific Ocean are shown in Fig. 1. Nino (1+2) is the average over the Nino 1 and 2 area. From monthly SSTA series the seasonal series were formed by simple averaging technique. The data over Nino (1+2) region was from 1951-90 for Nino-3, 1957-90, for Nino-4, 1964-90 and for Nino west was 1953-90.

To compute TCI, mean sea level pressures at the selected stations are first standardized using the standard deviation of the respective anomaly time series. Then the difference of the standardized anomalies is computed. This difference is further standardized by standard deviation of the difference time series. This method is used for all the seven sets of stations for all the twelve months from January to December.

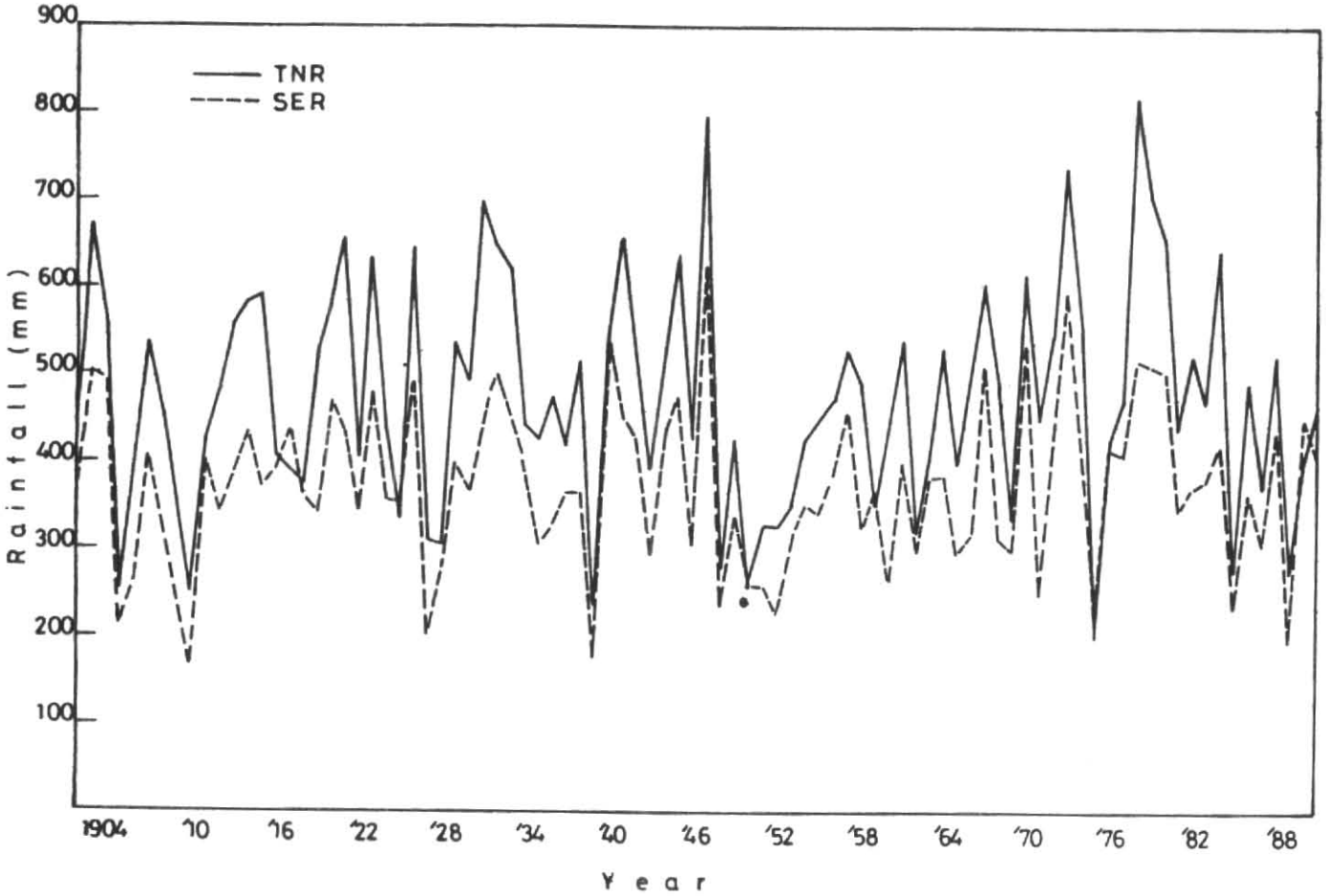

Fig. 2. Time series of northeast monsoon rainfall over Tamil Nadu (TNR marked by ····) and southeast India (SER marked by-----)

From these indices different seasonal series are made. Locations of different stations are shown in Fig. 1.

The northeast monsoon rainfall data sets (October-December) over the subdivisions of Tamil Nadu, Coastal Andhra Pradesh and Rayalaseema for the period 1901-83 were provided by India Meteorological Department (IMD) while the data for the remaining period of 1984-90 were obtained from IMD's quarterly journal "Mausam". The subdivisional data is, however, based on different number of station for different years with the result that the normals for different years are differing significantly. Ignoring this deficiency of quality of data two rainfall series were prepared, one for Tamil Nadu (TNR) and other for southeast India (SER). An area-weighted average of rainfall over Tamil Nadu, coastal Andhra Pradesh and Rayalaseema for the period 1901- 90 is a measure of southeast India rainfall (SER). The two rainfall series are presented in Fig. 2.

3. Analysis and results

In order to investigate the quantitative strength of linear relationship between two variables, which are supposed to be related in space and time, the absolute value of correlation coefficients (CSs) were computed between seasonal inter-annual fluctuations of various circulation anomalies and TNR and SER.

In the analysis 7 seasons are used. There are (*i*) previous winter season (December-January-February), three seasons prior to northeast monsoon season (DJF-lag-3); (*ii*) the previous spring season (March-April-May), two seasons prior to northeast monsoon season, (MAM, lag-2), (*iii*) the previous summer monsoon season (June-July-August), one season prior to northeast monsoon season (JJA, lag-1); (*iv*) the autumn season (September-October- November), concurrent with almost northeast monsoon season (SON, lag 0); (*v*) northeast monsoon season (October-November-December) (OND, lag 0); (*vi*) the succeeding winter season (December-January-February), one season after the northeast monsoon season (DJF+, lag +1) and (*vii*) the succeeding

TABLE 1 (a)

Correlation coefficient (CC× 100) alongwith its stability analysis between northeast monsoon rainfall and seasonal SOI (I-D)

Season	1942-1990		1942-1971		1947- 1976		1952-1981		1957-1986		1961-1990	
	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER
DJF (-)	-13	-14	-5	-7	-11	-17	-5	-7	-13	-16	-13	-27
NAM (-)	-43[1]	-27[5]	-26	-11	-31	-18	-26	-11	-45[2]	-26	-46[1]	-26
JJA (-)	-15	-15	-8	-6	-21	-21	-8	-6	-8	-11	-9	-10
SON(O)	-35[2]	-38[1]	-13	-22	-23	-29	-13	-22	-28	-32	-34	-37[5]
OND(O)	-26	-31[5]	-22	-22	-29	-30	-22	-22	-28	-32	-34	-29
DJF (+)	-14	-15	-14	-16	-11	-13	-17	-21	-13	-16	-13	-20
MAM (+)	-43[1]	-27[5]	-32	-19	-44[2]	-26	-30	-30	-44[2]	-26	-45[2]	-27

TABLE 1(b)

Correlation coefficient (CC × 100) alongwith its stability analysis between northeast monsoon rainfall and seasonal SOI (T- D)

Season	1933-1990		1933-1962		1938- 1967		1943-1972		1948-1977		1953- 1982		1958-1987		1961-1990	
	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER
DJF(-)	-27[5]	-29[5]	-41[5]	-37[5]	-38[5]	-31	-21	-23	-25	-19	-17	-14	-36[5]	-18	-38[5]	-12
MAM (-)	-36[1]	-22	-15	-8	-22	-18	-17	-20	-37[5]	-27	-36[5]	-25	-14	-22	-20	-38[5]
JJA (-)	-40[1]	-31	-44[2]	-33	-43[2]	-30	-38[5]	-28	-38[5]	-20	-30	-14	-32	-1	-21	-11
SON (O)	-39[1]	-38[1]	-47[1]	-46[1]	-49[1]	-40[5]	-34	-31	-29	-19	-29	-22	-31	-6	-29	7
OND(O)	-38[1]	-38[1]	-46[1]	-47[1]	-50[1]	-43[2]	-35	-33	-29	-21	-29	-22	-33	-14	-32	-1

N.B.- Superscripts 1, 2 and 5 stand for 1%, 2% and 5% significant and -, + and O stand for antecedent, following and concurrent seasons.

TABLE 2 (a)

Correlation coefficient (CC × 100) between northeast monsoon rainfall and SSTA over equatorial Pacific over (Nino-3) region

Season	1957-1990		1957-1986		1958- 1987		1959-1988		1960-1989		1961- 1990	
	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER
JJA(-)	37[5]	28	28	26	29	33	39[5]	41[5]	38[5]	41[5]	38[5]	41[5]
SON (O)	34[5]	36[5]	26	31	27	35	32	40[5]	33	40[5]	33	40[5]
OND(O)	36[5]	41[5]	25	28	26	33	32	39[5]	32	39[5]	33	39[5]

TABLE 2 (b)

Correlation coefficient (CC × 100) between northeast monsoon rainfall and SSTA over equatorial Pacific over (Nino-4) region

Season	1964-1990		1964-1985		1965- 1986		1966-1987		1967-1988		1968-1989		1969-1990	
	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER
JJA (-)	53[1]	38	46[5]	34	38	26	37	32	40[5]	35	42[5]	31	44[5]	34
SON (O)	41[1]	30	40[5]	35	31	25	31	32	39	42[5]	39	42[5]	42[5]	46[5]

N.B.- Superscripts 1, 2 and 5 stand for 1%, 2% and 5% significant and - and 0 stand for antecedent and concurrent seasons.

spring season (March-April-May), two season after the northeast monsoon season (MAM+, lag +2).

3.1. *Relationship between Indian northeast monsoon rainfall and SOI*

The details of the two versions of SOI namely SOI(I-D) and SOI (T-D) and their seasonal CCs with TNR and SER are shown in Tables 1 (a & b) alongwith their significance levels. To examine the consistency of SOI (I-D) and SOI (T-D) relationship, the CCs at different lags for overlapping 30-year periods have also been computed and shown in the above Tables.

As far as stability analysis of antecedent MAM (I-D) is concerned, correlation is weak till 1981 and before but strong and significant during the recent years 1957-86 and 1961-90 with TNR only. While stability analysis of SON show that correlation remain significant during recent 1961-90 only for SER. While succeeding MAM SOI(I-D) shows the significant inverse correlation over the period 1947-76 and recent year period 1957-86 and 1961-90 over TNR only.

TABLE 3

Correlation coefficient (CC × 100) alongwith its stability analysis between northeast monsoon rainfall and seasonal TCI

Season	1953-1982		1953-1977		1954-1978		1955-1979		1956-1980		1957- 1981		1952-1982	
	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER	TNR	SER
TCI (A-M) MAM(-)	14	38^5	23	44^5	22	43^5	23	42^5	23	43^5	26	41^5	26	38^5
TCI (C-N) DJF (-)	42^2	29	18	27	21	29	21	29	22	30	28	38^5	31	36
TCI (I-M) JJA (-)	38^5	39^5	16	35	16	35	21	38^5	22	39^5	21	41^5	21	41^5

N.B. Superscripts 2 and 5 stand for 2% and 5% significant and - stand for antecedent.

The stability analysis of seasonal SOI (T-D) indicates that all the seasonal CCs (except MAM) are strong till 1967 and before but have become weak in recent years. From above stability analysis, it appears that preceding MAM series of SOI(I-D) is a better predictor in comparison to SOI (T-D) series because of the significant correlation of the former during recent 30 years (1961-90).

3.2. *Relationship between Indian northeast monsoon rainfall and equatorial Pacific sea surface temperature anomaly (SSTA)*

Tables 2 (a & b) represent correlation coefficient (CCs) along with their significant levels between seasonal SSTA series over eastern equatorial Pacific Ocean over Nino-3 and Nino-4 regions respectively and TNR and SER.

It is seen from the Tables 2(a) that over Nino-3 region, significant positive CCs are obtained between concurrent SON and OND SSTA series and TNR and SER. While antecedent relationships are concerned, above table shows significant positive CC of 0.37 (at 5% level) between the antecedent JJA series with TNR only. As far as Nino-4 region is concerned Table 2 (b) shows that concurrent SON season has a significant CC of 0.41 (at 5% level) with TNR only. Strong and significant positive CC of 0.53 (at 1% level) are found between previous JJA SSTA and TNR.

The analysis of SSTA with TNR and SER show [Table 2(b)] that out of 4 Nino regions, only Nino-3 and Nino-4 show best correlation. Hence stability analysis are done only over Nino-3 and Nino-4 regions. Stability analysis of previous JJA SSTA series shows that the correlation is significant and positive from 1958 to 1990. Also correlations are significant and positive during the period 1959 to 1990 with SER.

As far as the stability analysis over Nino-4 region is concerned, the Table 2(b) shows that the correlations are signficant (except during 1965 to 1987) for previous JJA SSTA and TNR only. While stability analysis of SON show significant positive CC during the period 1964-85, 1967-88, 1968-89 and 1969-90 with SER only. Significantly correlation is also obtained during the recent year 1969-90 for SON and TNR. From the above stability analysis, it appears that previous JJA SSTA over Nino-4 region is a better predictor among all the four Nino regions.

3.3. *Relationship between northeast monsoon rainfall and tropical circulation indices (TCI) over different regions*

Table 3 presents CC along with their significant levels between seasonal TCI series and northeast monsoon rainfall over Tamil Nadu (TNR) and southeast India (SER). As far as concurrent and succeeding relationships are concerned, the Table 3 does not show any significant relationship with all the TCI. However, significant positive CCs are obtained between antecedent MAM TCI (A-M) and SER (C.C. =0.38 at 5% level). Significant positive CCs are also obtained between previous DJF TCI (C-N) and TNR(CC=0.42 at 2% level) and previous JJA TCI(I-M) and TNR and SER (CC =0.38 at 5% level and 0.39 at 5% level respectively). As far as stability analysis of various significant TCI's are concerned, correlation of MAM TCI (A-M) shows strong and significant relationship over various period of study with SER. However, stability analysis of previous JJA TCI (I-M) shows that correlation is significant during the periods 1955-79, 1956-81 and 1958-82 with SER only.

4. Conclusions

Analysis of the association between interannual variability of northeast monsoon rainfall (with some shortcomings in quality of data) over TNR and SER and various circulation anomalies have achieved the following results:

(*i*) Northeast monsoon rainfall shows significant inverse relationship with preceding MAM SOI (I-D). This result may be useful for predicting northeast monsoon rainfall over Tamil Nadu and southeast India.

(*ii*) Out of all the SSTA series, Nino-4 SSTA of antecedent JJA shows strong and direct correlation with northeast monsoon rainfall and Nino-4 SSTA can be used as a predictor for Tamil Nadu rainfall.

(*iii*) Out of seven TCI series, TCI (A-M) of preceding MAM exhibits potential of a predictor for northeast monsoon rainfall.

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