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Tele connections between Indian summer monsoon rainfall on regional scale and sea surface temperature over equatorial Pacific Ocean

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सार – इस शोध–पत्र में भूमध्यवर्ती प्रशांत महासागर में एलनिनो की अनियमित उष्णता को, समूचे भारत की ग्रीष्मकालीन मानसून वर्षा (ए.आई.एस.एम.आर.) के साथ एक महत्वपूर्ण दूर संयोजन के रूप में ज्ञात किया गया है। स्थानिक विविधता के माध्यम से समूचे भारत की ग्रीष्मकालीन मानसून वर्षा (ए.आई.एस.एम.आर.) की विशेषता बताई गई है। ए.आई.एस.एम.आर. में अत्याधिक विविधता भारत के उन क्षेत्रों में पाई गई है जहाँ वर्षा बहुत कम होती है। अतः भारतीय ग्रीष्मकालीन मानसून वर्षा की विविधता का अध्ययन क्षेत्रीय स्तर पर किया जाना आवश्यक है। इस तथ्य का मूल्यांकन करते हुए, इस अध्ययन में भारत के पाँच समरूपी क्षेत्रों की आई.एस.एम.आर ख्पार्थसारथी द्वारा निर्धारित (1995), तथा पूर्वी भूमध्यवर्ती प्रशांत महासागर के समुद्र सतह तापमान के बीच संबंध की जाँच करने का प्रयास किया गया है। इस क्षेत्र में हाल ही में किए गए कुछ अध्ययनों के आधार पर, 1970 के दशक के मध्य के बाद भूमंडल की उष्णता के कारण क्षेत्रीय स्तर पर एनसो–मानसून के संबंध के कमजोर होने की जाँच करने का भी प्रयास किया गया है। यह ज्ञात हुआ है कि प्रशांत महासागर के निनो वाले क्षेत्रों में समुद्र सतह तापमान की विसंगतियाँ भारत के पाँच समान क्षेत्रों में ग्रीष्मकालीन मानसून वर्षा के साथ पश्चायित सहसंबंध दोलन की तरह के होते हैं। यह संबंध अत्यंत प्रबल है और भूमंडल के उष्ण होने से पहले की अवधि (1951–1975) में आँकड़ों की दृष्टि से यह महत्वपूर्ण है और भूमंडल के उष्ण होने के बाद (1976–2000) इसका सही निरूपण नहीं किया गया।

ABSTRACT. El-Nino – anomalous warming over equatorial Pacific – has been identified as one of the major teleconnections of All-India Summer Monsoon Rainfall (AISMR). The AISMR is characterized by a considerable spatial variability. The largest variance in AISMR is observed over the regions of India that receive the least rainfall. As such, it is necessary to study the variability of Indian Summer Monsoon Rainfall (ISMR) on a regional scale. Appreciating this fact, an attempt is made in this study to examine the relationship between the ISMR over the five homogeneous regions of India [identified by Parthasarathy, *et al.,* (1995)] and the Sea Surface Temperature (SST) over central and eastern equatorial Pacific Ocean. Also, an attempt has been made to investigate on weakening of the ENSO-Monsoon relationship, on regional scale, owing to global warming, after mid-1970s, in view of some recent studies in this field. It is observed that, the SST anomalies over the Nino regions of the Pacific show an oscillatory type of lagged correlations with the summer monsoon rainfall over the five homogeneous regions of India. This relationship is very strong and statistically significant during the pre-Global Warming period (1951-75) and rather ill-defined during the post-Global Warming period (1976-2000).

Key words – Tele connections, Equatorial Pacific, SST, Summer monsoon, Rainfall.

1. Introduction

Walker (1924), for the first time, demonstrated the possible linkage between the Southern Oscillation (SO) and Indian Summer Monsoon Rainfall (ISMR). Thereafter, there have been several studies, assessing various aspects of the relationship between ISMR and El-Nino Southern Oscillation (ENSO) [Khandekar (1979); Sikka (1980); Rasmusson and Carpenter (1982, 1983); Shukla and Paolino (1983); Verma (1990); Ropelwski and Halpert (1987, 1989); Parthasarathy and Sontakke (1988); Kane (1997, 1998, 1999)]. These studies have inferred that, in general, ISMR is inversely correlated with Sea Surface Temperature (SST) over equatorial central and eastern Pacific. In majority of El-Nino years, ISMR is observed to be below normal. Mooley (1997) has observed that the mean ISMR for El-Nino years during 1871-1990 is 8% below normal. Thapliyal *et al.,* (1998) have showed that lagged correlations between the ISMR and the anomalies of SST over the three key Nino regions (Nino 1+2, Nino 3 and Nino 4) of Pacific oscillate with time.

The All-India Summer Monsoon Rainfall (AISMR) is used in many studies as an indicator of the strength of the monsoon circulation over India. However, AISMR is characterised by considerable spatial and temporal variability. The largest variance in AISMR is observed to occur over the regions that receive the least amount of rainfall. As such, AISMR, though a reasonable indicator of the total Indian summer monsoon activity, does not provide the high-resolution details of rainfall variations over India, especially on a regional scale. Appreciating this fact, several investigators have defined various

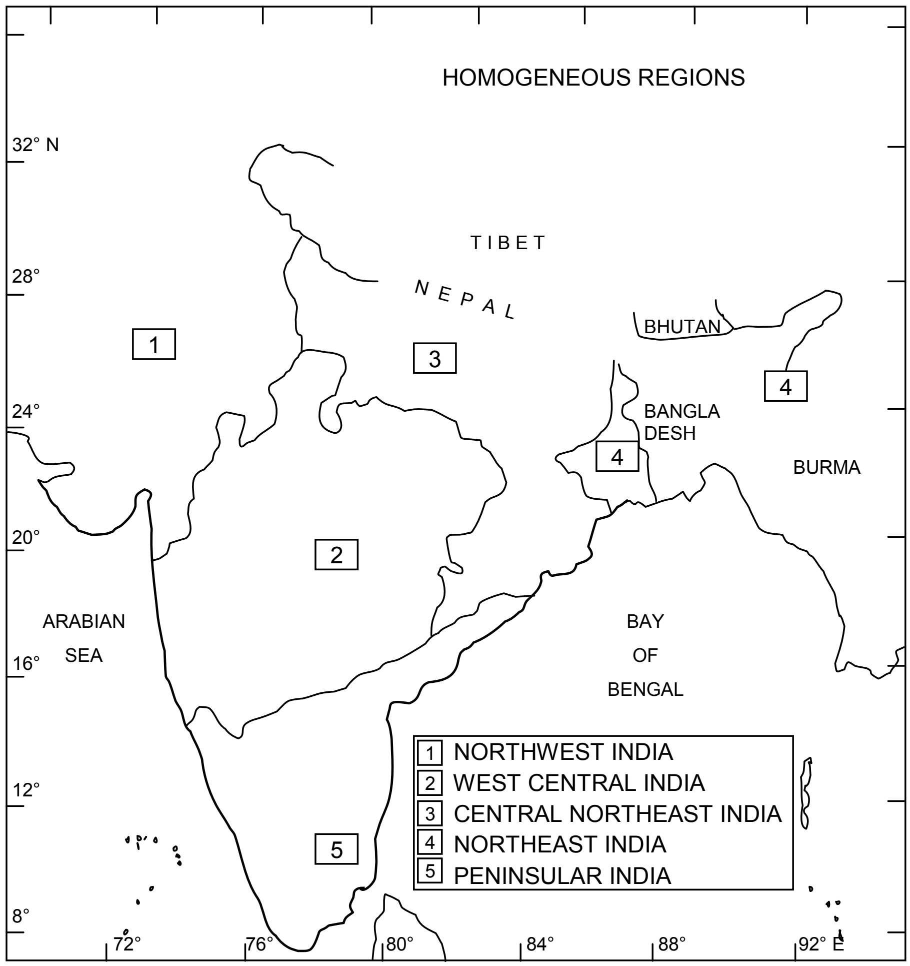


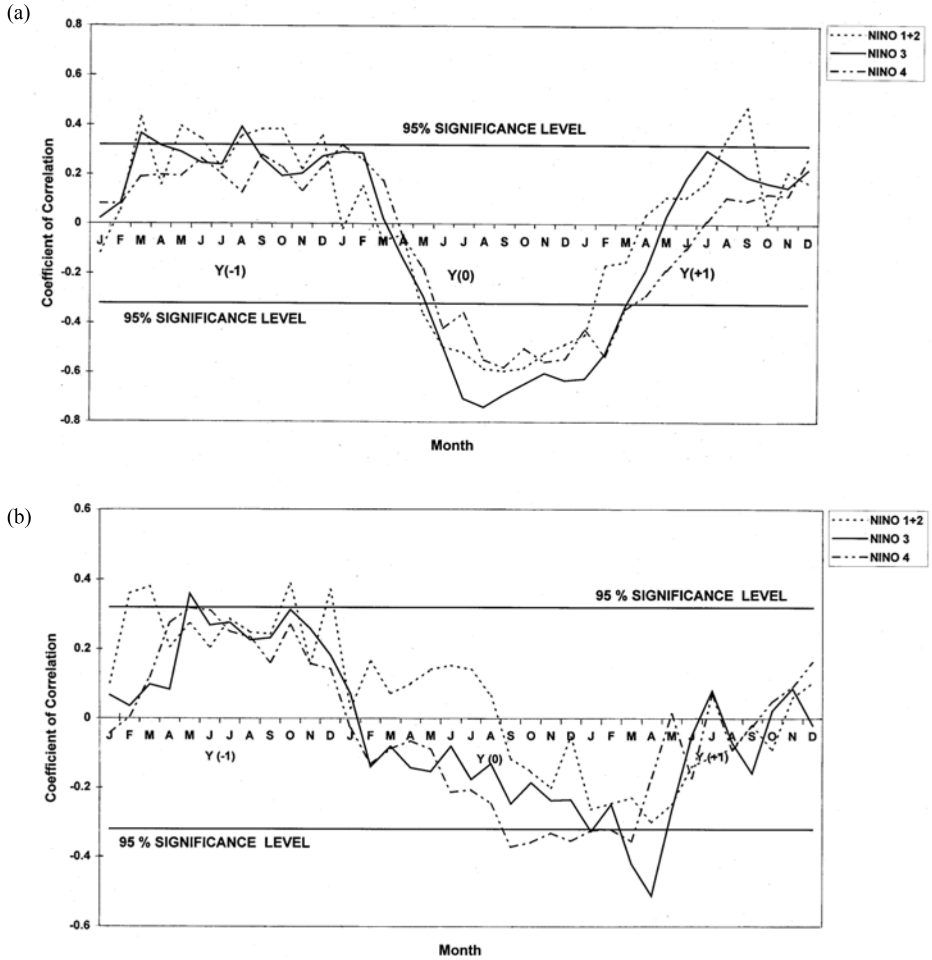
Fig. 1. Homogeneous regions of India as identified by Parthasarathy, *et al*., (1995)

macro-regions of India based on various statistical techniques [Gregory (1989); Parthasarathy *et al*., (1993)]. Parthasarathy *et al*., (1995) have classified the Indian region into five homogeneous regions based on the basis of their statistical properties, inter-correlations and teleconnections with the relevant regional and global circulation patterns. Fig. 1 shows these regions. Based on this classification, an attempt has been made in this study, to examine the relationship between the ISMR on a regional scale and the SST over equatorial central and eastern Pacific.

Recently, there have been reports of some studies demonstrating a weakening of the ENSO-Monsoon relationship. According to such studies as those by Kripalani and Kulkarni (1997) and Kripalani, *et al*., (2001), this weakening may be attributed to the decadal variability of Indian Summer Monsoon rainfall. On the other hand, the studies by Krishna Kumar *et al*., (1999), Ashrit *et al*., (2001), attempt to explain this weakening having occurred due to global warming. An attempt has been made in this study to analyse this issue more elaborately.

2. Data and methodology

In order to study the association between the regional ISMR and SST over equatorial central and eastern Pacific, monthly SST data for the period, 1951-2000, averaged over the three Nino regions of Pacific (Nino 1+2 region: 0-10° S, 90° W-80° W, Nino 3 region: 5° N-5° S / 150° W – 90^0W and Nino 4 region: 5° N-5° S / 160° E-150° W), have been used. The data were obtained from Climate Analysis Centre, USA. The area-weighted Summer Monsoon Rainfall (SMR) (June to September) for the five homogenous regions is computed on the basis of rainfall data for individual meteorological sub-divisions for the same period. These computations are done for the area-



Figs. 2(a&b). Temporal evolution of coefficients of correlation between summer monsoon rainfall over NW India and sea surface temperature over three Nino regions of the Pacific (a) (1951-75) and (b) (1976-2000)

weighted rainfall on regional scale for five homogeneous regions identified by Parthasarathy *et al.,* (1995). These regions are : (*i*) North-West (NW) India, comprising of six meteorological sub-divisions *viz*., Haryana – Chandigarh and Delhi, Punjab, west Rajasthan, east Rajasthan, Gujarat region and Saurashtra & Kutch. (*ii*) West-Central (WC) India, comprising of eight meteorological sub-divisions *viz*., west Madhya Pradesh, east Madhya Pradesh, Konkan & Goa, Madhya Maharashtra, Marathwada, Vidarbha, Telangana and Rayalseema. (*iii*) North East (NE) India, comprising of four meteorological subdivisions *viz*., Assam & Meghalaya, Nagaland-Manipur-Mizoram & Tripura, Sub-Himalayan West Bengal & Sikkim and Gangetic West Bengal. (*iv*) Central North East (C. NE) India comprising of five meteorological sub-divisions *viz*., Orissa, Bihar Plateau, Bihar Plains, east Uttar Pradesh and Plains of west Uttar Pradesh. (*v*) Peninsular India, comprising of six meteorological sub-divisions *viz*., Coastal Andhra Pradesh, Rayalseema, Tamil Nadu & Pondicherry, Coastal Karnataka, South Interior Karnataka and Kerala.

In recent times, there have been reports of some studies demonstrating a weakening of the ENSO-Monsoon relationship. The studies by Krishna Kumar *et al.,* (1999), Ashrit *et al.,*(2001), attempt to explain this weakening having occurred due to global warming. An attempt has been made in this study to investigate this issue more elaborately. The recent Intergovernmental Panel on Climate Change (IPCC) report (2001) provides an evidence of occurrence of global warming since mid-1970s. Hence, the data period is split into two periods, *viz*., (*i*) pre-Global Warming Period: 1951-75 and (*ii*) post-Global Warming Period : 1976-2000. The values of coefficients of lagged correlation between the SMR over the five homogeneous regions of India and the monthly SST anomaly over the three Nino regions of the Pacific Ocean are computed, from the preceding year Y(–1) to the following year Y(+1) through the concurrent year; Y(0). These computations of Coefficients of Correlation (CCs) are carried out separately for the above-mentioned two periods, in order to investigate, whether, does the global warming, occurred after mid-1970s, have any impact on the ENSO-Monsoon relationship. Figs. (2-6) depict the temporal evolution of CCs thus computed.

Also, for each year, the Standardized Rainfall Anomaly (SRA) is computed for all the five homogenous regions as follows :

$$\text{SRA} = \frac{R_i - \overline{R}}{\sigma}$$

where,

R_i = Rainfall for i^{th} year

$\overline{R}$ = Mean rainfall

σ = Standard deviation

A year is defined to be the year of Above Normal (AN) SMR if the SRA for that year is > +1 and the year of Below Normal (BN) SMR if the SRA for that year is < –1. A year is defined to be normal if $-1 \leq \text{SRA} \leq +1$. This criterion is in conformity with that used by other workers in the past, *viz*., Shukla (1987); Bhalme *et al*., (1983); Chowdhury *et al*., (1989) and Chattopadhyay and Bhatla (1996). The composite anomalies of SSTs over the three Nino regions are computed for the years of Below Normal and Above Normal SMR for each of the five homogeneous regions. These computations are done on seasonal basis, from the season September-October-November (SON) of the preceding year, Y (–1) to the season SON of the concurrent year Y(0). Figs. 7 (a-e) depicts the temporal evolution of anomalies SSTs computed in this manner.

3. Discussion

3.1. *Relationship between the SMR of the five homogeneous regions of India and the monthly SSTs over the Pacific*

From Figs. (2-6), it is observed that, during the period 1951-75, the SST anomalies over the three Nino regions (*viz*., Nino 1+2, Nino 3 and Nino 4 regions), on a monthly scale, show an oscillatory type of lagged correlations with the SMR over the five homogeneous regions of India. For North-West India, West-Central India, Central North-East India and Peninsular India, statistically significant negative correlations are observed, between the respective regional SMR and SST over Nino 3 region, during June to December of the concurrent year Y(0) and January to March of the following year Y(+1).

The temporal evolution of the CCs between the Summer Monsoon Rainfall over the homogeneous regions of India and SST over Nino3 region (which is considered as a broad representative area of Central and Eastern Pacific Ocean to describe El-Nino phenomenon), for the two separate periods (1951-75 and 1976-2000) is briefly discussed in the following text.

(a) *North-West (NW) India*

(*i*) 1951-75

From Fig. 2(a) it is observed that, the CCs are positive in the preceding year and winter of the concurrent year. They change the sign rapidly from the winter of concurrent year to July of concurrent year. Statistically significant negative CCs are observed during July to December of concurrent year and winter of following year. The maximum value of negative CC (-0.74) is observed in August of concurrent year. After January of following year, the CCs start changing rapidly, becoming positive in May of following year and continuing to be positive thereafter, till December of following year. A similar, oscillating, type of evolution of CCs is observed for SSTs over the other two Nino regions of the Pacific. However, out of the three Nino regions, the highest negative CC value is observed for SST over Nino 3 region.

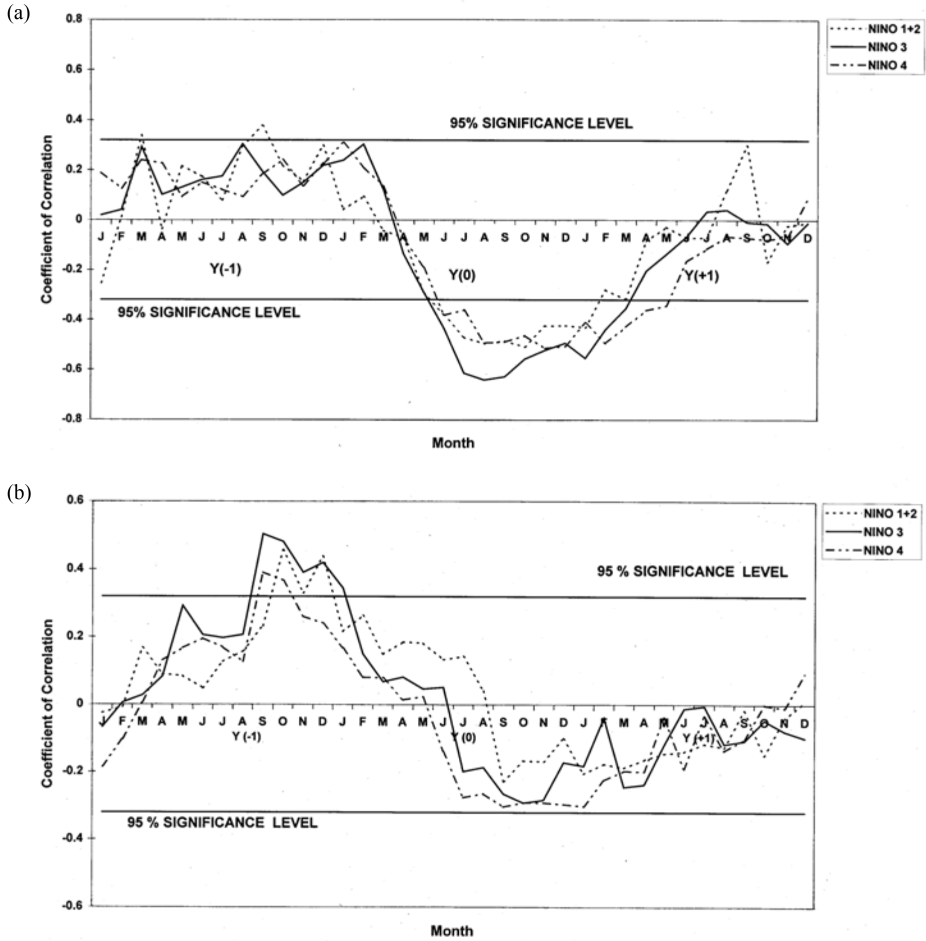
(*ii*) 1976-2000

From Fig. 2(b) it is observed that, the CCs are positive in the preceding year and January of the concurrent year. They are negative since February of concurrent year till May of following year and thereafter, they are positive till December of following year. However, the evolution of CCs shows very strong fluctuations, indicating clearly, the absence of a systematic evolution, observed for the pre-Global Warming period, 1951-75, as described above.

(b) *West-Central (WC) India*

(*i*) 1951-75

From Fig. 3(a) it is observed that, CCs are positive in the preceding year Y(–1) and during winter of the concurrent year Y(0). They change the sign rapidly thereafter to July of concurrent year. Statistically



Figs. 3(a&b). Temporal evolution of coefficients of correlation between summer monsoon rainfall over WC India and sea surface temperature over three Nino regions of the Pacific (a) (1951-75) and (b) (1976-2000)

significant negative CCs are observed during June to December of concurrent year and up to March of following year. The maximum value of negative CC (–0.64) is observed in August of concurrent year. After January of following year, the CCs start changing rapidly, becoming positive in June of following year.

(*ii*) 1976-2000

From Fig. 3(b) it is observed that, the CCs are positive in the preceding year and up to June of the concurrent year. They are negative thereafter till December of following year. However, the evolution of CCs shows very strong fluctuations, indicating clearly, the absence of a systematic evolution, for the pre-Global Warming period, 1951-75, as described above.

(c) *North-East (NE) India*

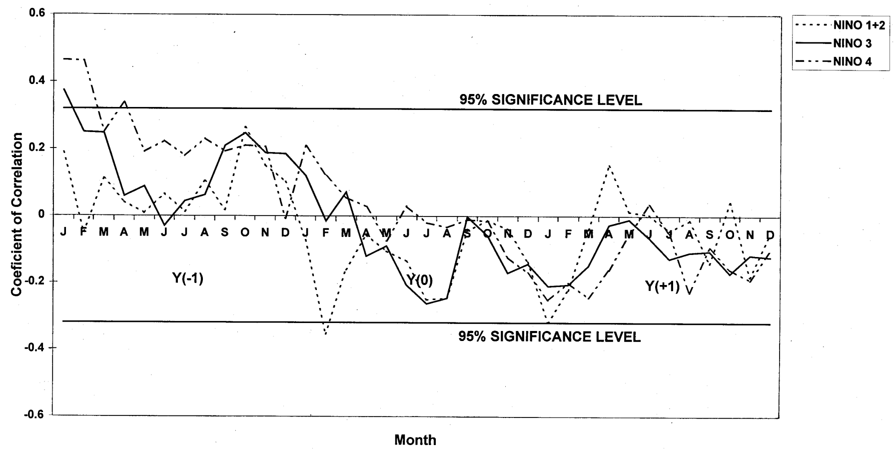
(*i*) 1951-75

From Fig. 4(a) it is observed that, CCs are positive throughout the preceding year Y(–1) and winter of the concurrent year Y(0). They are negative from April of concurrent year up to December of following year. The evolution of CCs exhibits very rapid fluctuations.

(*ii*) 1976-2000

From Fig. 4(b) it is observed that, the CCs are positive in the preceding year and up to March of the concurrent year. They are negative thereafter till December of following year, being statistically significant during February to December of the following year.

(a)



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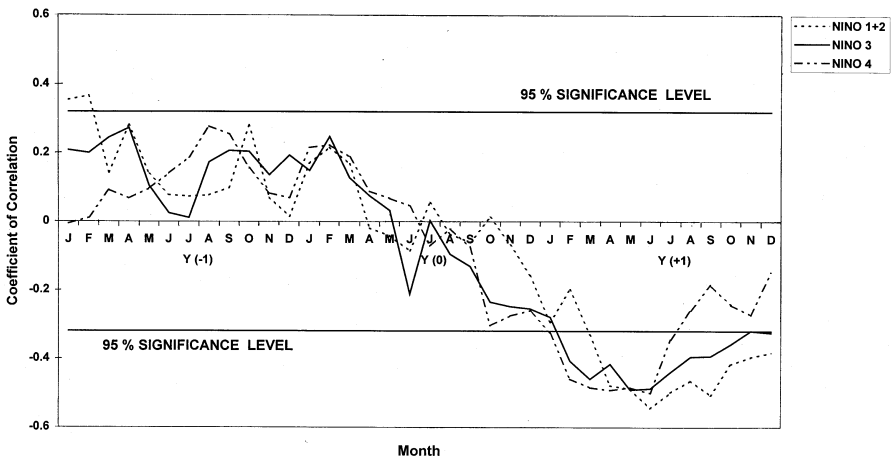


Figs. 4(a&b). Temporal evolution of coefficients of correlation between summer monsoon rainfall over NE India and sea surface temperature over three Nino regions of the Pacific (a) (1951-75) and (b) (1976-2000)

(d) *Central North-East (NE) India*

(*i*) 1951-75

From Fig. 5 (a) it is observed that, CCs are negative throughout the preceding year Y(-1), the concurrent year Y(0) and winter of following year Y(+1). Statistically significant negative CCs are observed during June to December of concurrent year and up to January of following year, with the maximum value of negative CC (–0.57) in October of concurrent year. After January of following year, the CCs start changing rapidly, becoming positive in May and continuing to be positive thereafter, up to December of following year.

(*ii*) 1976-2000

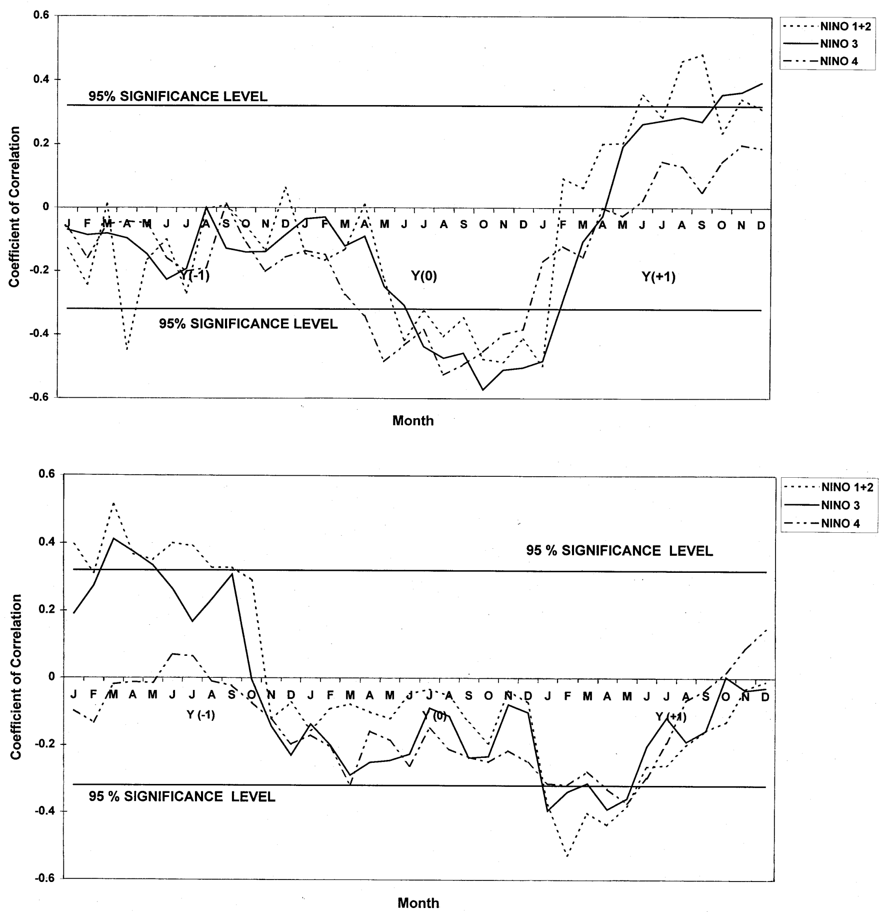
From Fig. 5(b) it is observed that, the CCs are positive till October of the preceding year. They are negative thereafter till December of following year. However, the evolution of CCs shows very strong fluctuations, indicating clearly, the absence of a systematic evolution, for the pre-Global Warming period, 1951-75, as described above.

(e) *Peninsular India*

(*i*) 1951-75

From Fig. 6(a) it is observed that, CCs are positive in winter and pre-monsoon season (March to May) of the

(a)
(b)



Figs. 5(a&b). Temporal evolution of coefficients of correlation between summer monsoon rainfall over central NE India and sea surface temperature over three Nino regions of the Pacific (a) (1951-75) and (b) (1976-2000)

preceding year Y(–1). They change the sign and become negative from September of preceding year. The value of CC decreases rapidly from April of concurrent year. Statistically significant negative CCs are observed during July to December of concurrent year and up to January of following year. The maximum value of negative CC (–0.48) is observed in August of concurrent year. After April of following year, the CCs start increasing rapidly, reaching zero in June of following year and being positive thereafter, till December of following year.

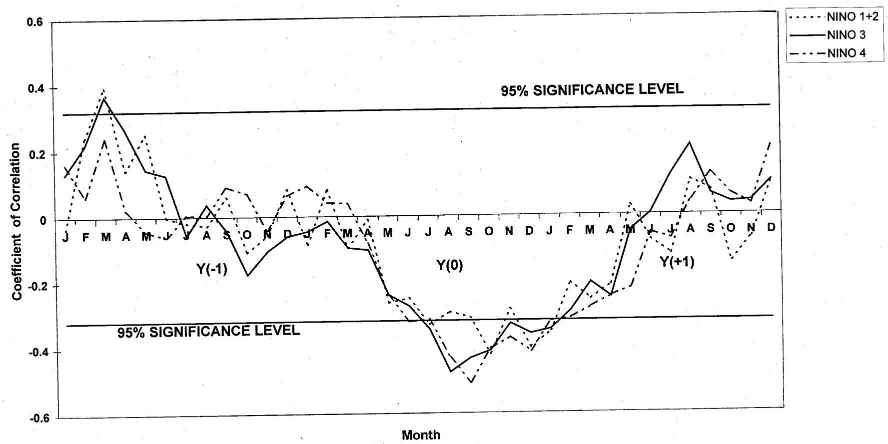
(*ii*) 1976-2000

From Fig. 6(b) it is observed that, the CCs are positive in the preceding year and negative from the April of the concurrent year up to April of the following year. They are positive thereafter till December of following year, being statistically significant during November and December of the concurrent year and January of following year.

For all the five homogeneous regions of India, the temporal evolution of CCs between the Summer Monsoon Rainfall and SSTs over the other two Nino (Nino 1+2 and Nino 4) regions is, by and large, similar to that of the CCs between the Summer Monsoon Rainfall and SSTs over Nino 3 region [Figs. (2-6)].

Thus, in general, for NW India, WC India and Peninsular India, the CCs are positive in preceding year Y(–1) and later half of following year Y(+1) and negative during the intervening period. Statistically significant CCs are observed during the second half of concurrent year Y(0) and winter of following year Y(+1). It, thus, shows a systematic evolution of CCs. This systematic evolution of CCs is very significant for CCs computed for the period

(a)



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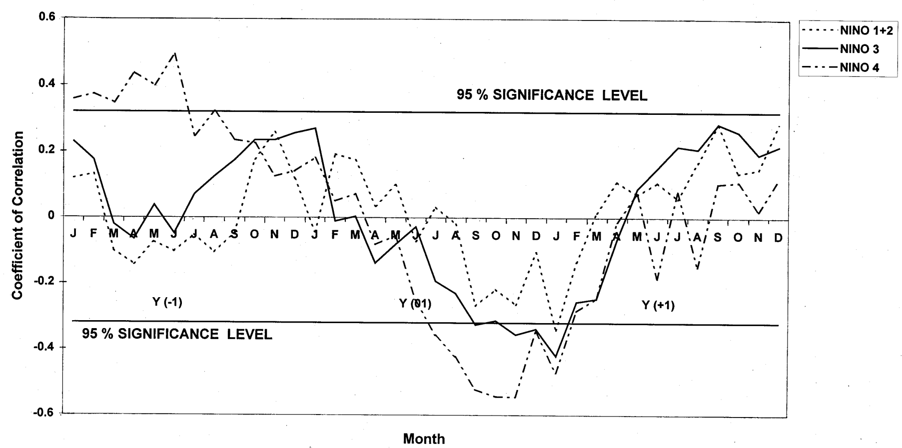

Figs. 6(a&b). Temporal evolution of coefficients of correlation between summer monsoon rainfall over peninsular India and sea surface temperature over three Nino regions of the Pacific (a) (1951-75) and (b) (1976-2000)

1951 to 1975. However, for the CCs, computed for the period 1976-2000, such a systematic evolution is not observed. This may, probably, be a manifestation of the weakening relationship between the Indian Summer Monsoon Rainfall, on a regional scale and ENSO, similar to the one observed for Indian Summer Monsoon Rainfall on all-India scale, as has been brought out by some of the recent studies, Krishna Kumar, *et al.*, (1999), Ashrit, *et al.*, (2001), etc.

As discussed above, the evolution of the CCs between the summer monsoon rainfall over the NW India, WC India, Peninsular India and SST over the three Nino regions of the Pacific Ocean, carried out for the period 1951-75 (pre-Global Warming period) demonstrates that the CCs in the preceding and succeeding year are opposite in sign, to those in the concurrent year. This may, probably, be attributed to the quasi-biennial nature of summer monsoon rainfall over these regions. Such a temporal evolution is not observed for NE India and Central NE India. This observation may suggest that, the quasi-biennial nature of summer monsoon rainfall over these regions is not strong. However, such a quasi-biennial nature of summer monsoon rainfall is not significant during the period 1976-2000 (post-Global Warming period), even over the NW India, WC India, Peninsular India, as is evident from the Figs. 2(b), 3(b) and 6(b). Thus, it appears that, during the post-Global Warming period, 1976-2000, not only does the ENSO-Monsoon relationship seem to have weakened, but also, the strong quasi-biennial characteristics of summer monsoon rainfall (significantly

TABLE 1

Coefficients of correlation (CC) between All-India summer monsoon rainfall and summer monsoon rainfall over the five homogeneous regions of India

CC	All-India	NW India	WC India	NE India	C. NE India	Peninsular India
			(a) 1951-2000			
All-India	1	0.82*	0.91*	0.09	0.63*	0.64*
NW India		1	0.74*	-0.14	0.46*	0.47*
WC India			1	-0.04	0.48*	0.56*
NE India				1	-0.02	-0.08
C. NE India					1	0.12
Peninsular India						1
			(b) 1951-75			
All-India	1	0.89*	0.94*	0.06	0.70*	0.69*
NW India		1	0.86*	-0.10	0.59**	0.62*
WC India			1	-0.01	0.57**	0.63*
NE India				1	-0.02	-0.21
C. NE India					1	0.30
Peninsular India						1
			(c) 1976-2000			
All-India	1	0.80*	0.84*	0.10	0.60*	0.57**
NW India		1	0.67*	-0.17	0.33$	0.42#
WC India			1	-0.14	0.44***	0.42#
NE India				1	0.01	-0.01
C. NE India					1	0.01
Peninsular India						1

(* : Significant at 99.9% significance level)
(** : Significant at 99% significance level)
(*** : Significant at 98% significance level)
(# : Significant at 95% significance level)
($: Significant at 90% significance level)

observed during the pre-Global Warming period, 1951-75), seems to have been altered, especially, for NW India, WC India and Peninsular India. A possibility of linkage between these two can also not be denied.

However, the CCs between summer monsoon rainfall over NE India and Central NE India and SST over Nino regions of the Pacific, do not exhibit such a systematic evolution, as described above, even during the pre-Global Warming period, 1951-75. For NE India, the CCs are positive till March of concurrent year Y(0) and negative thereafter, till December of following year Y(+1) Fig. 4(a). For Central NE India, the CCs are negative throughout the preceding year Y(–1), the concurrent year Y(0), till April of the following year Y(+1) Fig. 5(a). This, probably, suggests a rather weak or near absence of the quasi-biennial nature of the summer monsoon rainfall over NE India and Central NE India.

Also, as discussed above, for NE India, the evolution of CCs differs from that for NW India, WC India, and Peninsular India, even during the period 1951-75. In order to examine on this further, the computations of coefficients of correlation, between the summer monsoon rainfall on All-India scale and on regional scale have been carried out. These computations are carried out for three different periods, *viz*., (*i*) 1951-2000, (*ii*) 1951-75 and (*iii*) 1976-2000, in order to explore the possibility of an evidence of the change in the relationship, prior to and later than the Global Warming (mid-1970s). The results are summarised in Table 1. The above-mentioned change in the temporal evolution of CCs for NE India may,

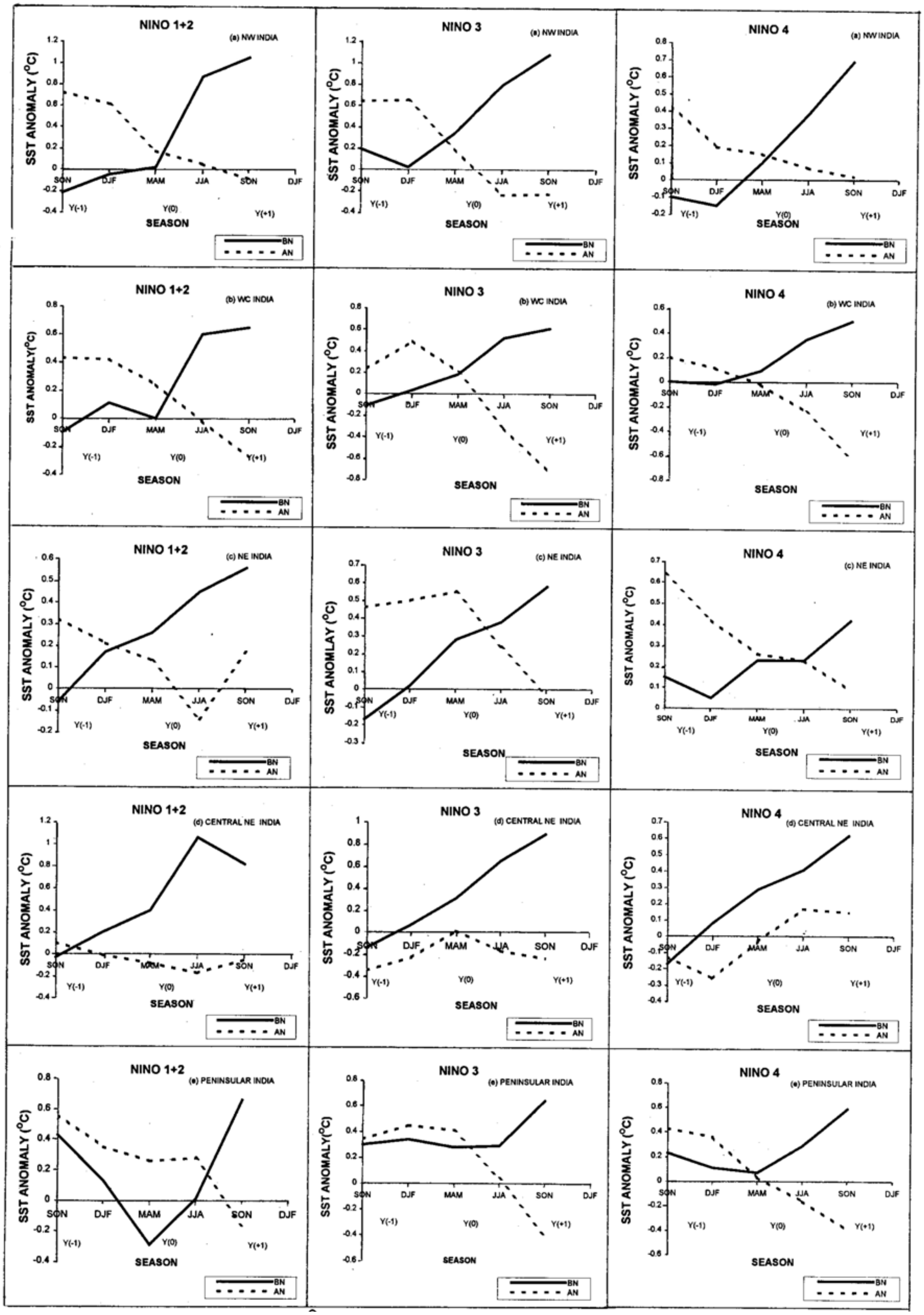

Fig. 7. Composite anomalies (°C) over three nino regions for the years of above normal (AN) and below normal (BN) SMR over five homogeneous regions of India

perhaps, be attributed to the negative correlation the summer monsoon rainfall over NE India bears with that over the other homogeneous regions of India. It is also seen from the Tables 1(a-c) that, the Summer Monsoon Rainfall over NE India bears negative correlation with that over other four homogeneous regions of India, although it bears positive correlation with the All-India Summer Monsoon Rainfall. Also, it is observed from Tables 1(a-c) that, CCs between Summer Monsoon Rainfall over various homogenous regions of India, show a fall in their values from the period 1951-75 to 1976-2000, except for NE India.

3.2. *Composite SST anomalies over Pacific for the years of Below Normal and Above Normal SMR over five homogeneous regions of India*

As described in the preceding section, composite SST anomalies over the three Nino regions computed for the years of Below Normal (BN) and Above Normal (AN) rainfall over the five homogeneous regions of India. It is observed from Fig. 7 that, during BN (AN) years, the SST anomalies over all the three Nino regions of the Pacific, show a warming (cooling) trend from the preceding to the following year. These contrasting trends in SSTs begin from the end of the preceding year and continue till the end of the concurrent year. Interestingly, the maximum difference between the values of SST anomalies is observed after the monsoon season, *i.e.*, during September-October-November (SON) of the concurrent year (Fig. 7). The most remarkable feature of the ENSO-Monsoon relationship is the inverse relationship that persists for about two seasons after the monsoon season. This has been confirmed by many studies, Shukla (1987), Chattopadhyay and Bhatla (1996), Verma (1990), etc. Thus, the observation in the present study, *viz*., Sea Surface Temperature anomalies over the Pacific being maximum, during September-October-November (SON), is yet another manifestation of the fact that the inverse relationship between summer monsoon rainfall over India and SSTs over the Pacific, is the most dominant during the season, following the monsoon season, even on a regional scale.

4. Conclusions

(*i*) The Sea Surface Temperature (SST) anomalies over the three Nino regions of the Pacific Ocean, on a monthly scale, show an oscillatory type of lagged correlations with the SMR over the five homogeneous regions of India.

(*ii*) The inverse relationship between the All-India Summer Monsoon Rainfall and SST over Nino regions of the Pacific is observed on the regional scale as well. The summer monsoon rainfall over NW India, WC India and Peninsular India shows strong, statistically significant inverse relationship with sea surface temperature over Nino regions of the Pacific Ocean, during the concurrent season and almost two seasons following the monsoon season.

(*iii*) The inverse relationship between the summer monsoon rainfall over India, on a regional scale and SSTs over the Pacific is very well-defined and statistically significant during the pre-Global Warming period, 1951-75 and ill-defined during the post-Global Warming period, 1976-2000. This may further confirm the weakening of ENSO-Indian Summer Monsoon relationship, as has been brought by some recent studies, even on a regional scale.

(*iv*) The composite SST anomalies over the three Nino regions for BN (AN) summer monsoon rainfall over NW India, WC India and NE India show warming (cooling) trend from about six months prior to the monsoon season.

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