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Relationship between Mid-latitude Circulation Indices and Indian Northeast Monsoon Rainfall

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Abstract—The study presents the results of the statistical relationship between seasonal northeast monsoon rainfall over Tamil Nadu state of India (TNR) and southeast India (SER) and mid-latitude circulation indices viz., zonal index (ZON) meridional index (MER) and the ratio of meridional to zonal index (M/Z) between the geographical area 35°N to 70°N at 500 hPa level over three sectors and hemisphere, based on 19 years (1971–1989) of data. The results indicate that northeast monsoon rainfall over India shows a strong antecedent relationship with the strength of ZON over all the sectors and hemisphere. The best association is observed during antecedent March over sector I (45°W–90°E) where direct and strong correlation coefficients of 0.69 and 0.64 are obtained with TNR and SER, respectively. Antecedent MAM (spring) season over sector I also shows a significant positive correlation with TNR/SER. Thus, the mid-latitude zonal circulation index may have possible use for the long-range forecasting of northeast monsoon rainfall over India.

Key words: Zonal index, meridional index, circulation index, northeast monsoon rainfall, correlation.

1. Introduction

India experiences two monsoons viz. the sea-to-land directed southwest (June to September) monsoon and the land-to-sea directed northeast (October to December) monsoon every year. Although about 80 percent of the annual rainfall over India is received during the southwest monsoon season, the southeastern part of India experiences a large part of its annual rainfall during the northeast monsoon season when the state of Tamil Nadu accumulates 47 percent of its annual rainfall during this season. Damage to crops due to excessive rain or drought during the above season is common. In Tamil Nadu, drought creates acute drinking water shortage and brings disaster. Studies of the relationship between Indian northeast monsoon rainfall and various regional and global parameters may facilitate better methods of long-range prediction and mitigate these problems. Many studies on teleconnection and seasonal forecasting of Indian summer monsoon rainfall have been reviewed by

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DAS (1986), THAPLIYAL (1990), HASTENRATH (1985, 1987, 1991) and HASTENRATH and GREISHAR (1993). Several studies relating mid-latitude circulation indices with Indian southwest monsoon rainfall are also available (CHATTOPADHYAY and BHATLA, 1994a,b). However, studies relating mid-latitude circulation indices with northeast monsoon rainfall are not known.

Hemispheric heat and momentum balance require interaction between tropics and extratropics. Such interaction occurs through quasi-stationary long waves which result in fluctuations of the mid-latitude circulation between high and low index conditions known as index cycle. An extremely high or low index condition may persist, though rarely exceeding one month, resulting in abnormal weather throughout the world (WADA, 1975). The strength of the mid-latitude westerlies in the mid-troposphere is expressed in terms of an index of the zonal circulation called zonal index (ZON) over a particular geographical area. The meridional transport of air between higher latitudes and low latitudes occurs owing to a large outbreak of polar air which transports heat and moisture to higher latitudes. Such interzonal exchanges in the troposphere are expressed in terms of an index of meridional circulation called meridional index (MER) over a particular geographical area. ZON and MER are characterized by two extreme states of the index cycle. One is characterized by a strong zonal westerly circulation with a contracted circumpolar vortex and is representative of a high ZON state or a low MER state. The other is characterized by a strong meridional circulation with meandering or cellular patterns and an expanded circumpolar vortex, representing a low ZON state or a high MER state.

In view of the fact that the mid-latitude circulation indices in some months and seasons and Indian southwest monsoon rainfall show significant association, it is proposed that the fluctuations of Indian northeast monsoon rainfall may also be related to mid-latitude circulation indices. This encouraged us to examine the relationship between mid-latitude circulation indices and northeast monsoon rainfall and explore its potential as a predictor of northeast monsoon rainfall activity over the southeastern region of India.

2. Data and Method

The study is confined to a 19-year period (1971–1989), the period for which the circulation indices data are available. The indices were obtained from the synoptic bulletins for the Northern Hemisphere published by the Department of World Weather, Hydrometeorological Centre of USSR. The indices refer to a 500 hPa level for the latitudinal band 35°N–70°N, for three geographical sectors between 45°W–90°E (sector I), 90°E to 160°W (sector II), and 160°W to 45°W (sector III). The zonal index (ZON) is a measure of the strength of zonal westerlies at 500 hPa over different sectors, and is calculated as the average of the 500 hPa contours (in decameters) intersecting the meridional circle per equatorial degree while the meridional index (MER) is a measure of the strength of meridional southerlies at 500 hPa over different sectors and is obtained by the average of 500 hPa contours (in decameters) intersecting the latitude circle per equatorial degree. Another index namely M/Z defines the general character of the circulation. Cases where $M/Z > 1$ are dominated by meridional circulation whereas other cases $M/Z < 1$ are characterized by zonal circulation. Sector I covers the whole of Europe and half of Asia, including most of the Indian monsoon region, while sectors II and III encompass mainly the western Pacific and eastern Pacific Oceans, respectively. A northern hemispheric index has also been calculated by taking the area weighted monthly mean values over sectors I, II and III. The location of various sectors is shown in Figure 1.

The northeast monsoon rainfall data sets (October-December) over the south Indian state of Tamil Nadu and meteorological subdivisions of coastal Andhra Pradesh and Rayalseema for the period 1971 to 1983 were provided by the Indian Meteorological Department while the data for the remaining period of 1984–1989 were obtained from the journal "Mausam." TNR represents rainfall over Tamil Nadu while SER comprises area weighted rainfall of Tamil Nadu, coastal Andhra Pradesh and Rayalseema. Their locations are shown in Figure 2. The normals were calculated from 19-year data viz. 1971–1989 as 48.0 cm and 37.5 cm for TNR and SER, respectively. The corresponding standard deviations are 13.8 cm and 9.7 cm, respectively.

To investigate the temporal degree of association between northeast monsoon rainfall and ZON, MER, and M/Z over different sectors and hemisphere, concurrent and lead/lag correlation coefficients (CCs) were computed. Thus TNR and SER series were correlated with various months/seasonal indices. These months are (i) the months from the previous January to September antecedent to the northeast monsoon months, (ii) the months of October, November and December concurrent with the northeast monsoon months and (iii) succeeding January, February and March, the months following the northeast monsoon months. The seasons are (i) the previous winter season, three seasons prior to the northeast monsoon, (DJF −, lag − 3), (ii) the previous spring season, two seasons prior to the northeast monsoon season (MAM −, lag − 2), (iii) the summer monsoon season, one season prior to the northeast monsoon season (JJA −, lag − 1), (iv) the northeast monsoon season (OND 0, lag 0), (v) the succeeding winter season, one season after the northeast monsoon (DJF +, lag + 1) and the succeeding spring season, two seasons after the northeast monsoon season (MAM +, lag + 2). The significance of the correlations was tested by conventional "t" test.

3. Results and Analysis

Table 1 shows the CCs between the 3 circulation indices (ZON, MER and M/Z) over different sectors (sectors I, II, III, and hemisphere) and TNR and SER along with their levels of significance. The CCs with only those months/seasons have been presented which are significant at 5 and 1 percent levels. The highlight of Table 1 is that the Indian northeast monsoon rainfall displays a strong and direct relationship with ZON during antecedent March over sector I for both TNR and SER with CCs of 0.69 and 0.64 (significant at 1% level), respectively. In addition, the antecedent ZON of the MAM season also shows significant positive CC of 0.51 and 0.47 (both significant at 5% level) with TNR and SER. Table 1 also illustrates that some significant (at 5% level) antecedent and concurrent correlations are also obtained for ZON over other sectors and MER and M/Z over different sectors.

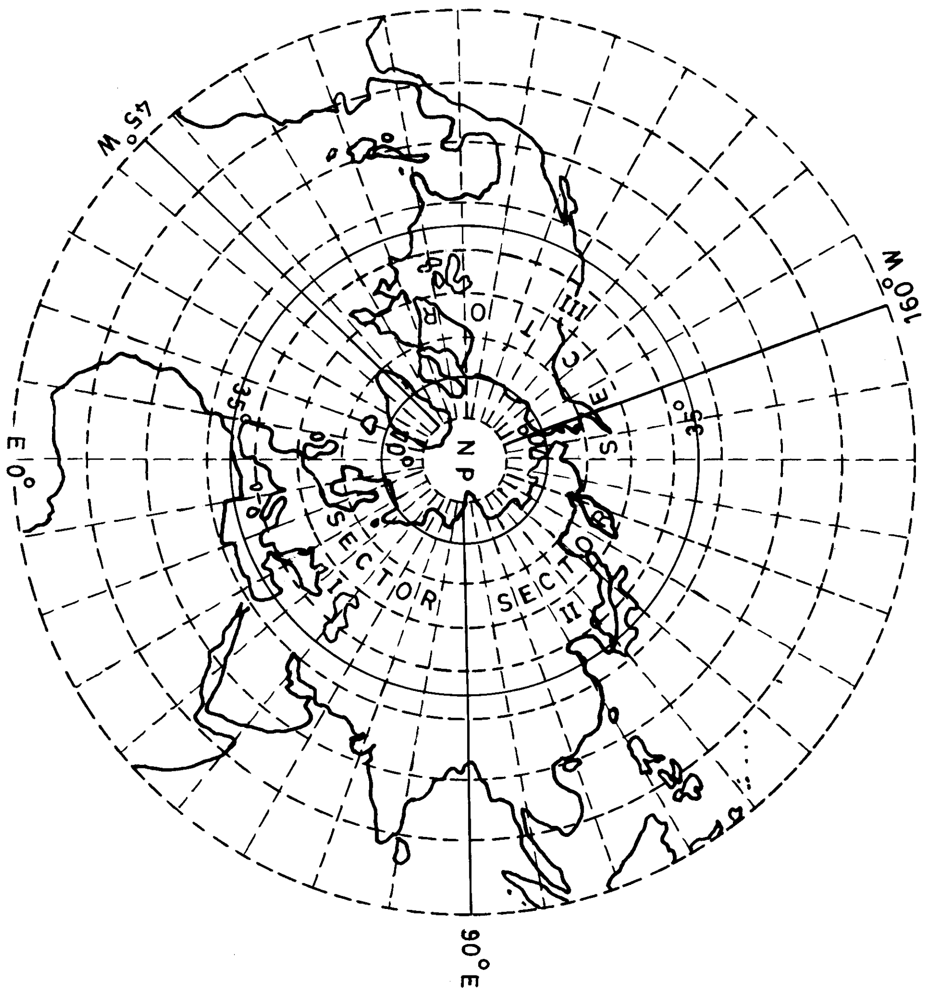

Figure 1
Schematic illustration of the three sectors over which circulation indices are defined.

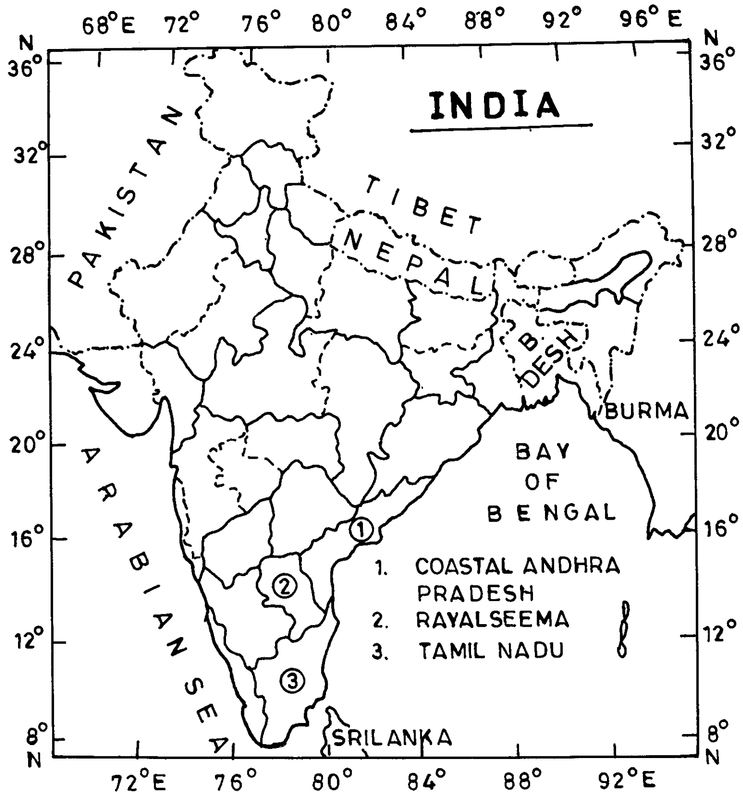

Figure 2
Location of the regions used in the computation of TNR and SER.

However, most of the correlations are small and occur either with TNR or SER and not with both the rainfall series, and hence seem to occur simply by chance. Only antecedent March and spring (MAM) seasons over sector I display a significant and highly positive correlation with TNR and SER and hence appear to be real. This suggests that a stronger (weaker) zonal index over sector 1 during March and the entire spring (MAM) season may result in above (below) normal northeast monsoon rainfall over India.

The Indian northeast monsoon is in fact the retreating southwest monsoon season as per the India Meteorological Department. During October and November the highest temperatures and consequently lowest pressures are found over the Bay of Bengal. The retreating southwest monsoon air circulates around the low and blows over Tamil Nadu and adjoining regions from a northeasterly direction during these months due to that which is also called a northeast monsoon. It does not emanate from the area of surface high pressure over the comparatively cold continent of southern Asia as it is protected by the massive Tibetan plateau.

According to ASNANI (1992) there is also no difference between the southwest monsoon and the northeast monsoon so far as its association with intertropical convergence zone (ITCZ)/near equatorial trough (NET) is concerned.

A monsoon is essentially caused by the annual cycle of diabatic heating and cooling (ASNANI and MISHRA, 1975) which is also accompanied by an annual cycle in all the elements of global circulation including ITCZ/NET. Anomalies in tropical heating create anomalies in different components of monsoon e.g., lagging/leading behind of the ITCZ/NET over the Bay of Bengal and Arabian Sea away from their normal pattern. This in turn causes anomalies in the rising branches of the Hadley and Walker circulation over the monsoon region. This is one of the major causes of interannual variations of monsoon rainfall. One important cause of anomalous heating of the tropical atmosphere is the anomalies in the meridional transport of sensible heat from the tropical region to the extratropical region (ASNANI and AWADE, 1978). PISHAROTY (1981) proposed a hypothesis linking the poleward transport of heat and the activity of the summer monsoon. His hypothesis suggests that an active (subdued) summer monsoon over southeast Asia is preceded by below (above) normal poleward transport of heat in the Northern Hemisphere during the preceding winter and spring months. In other words, the Indian summer monsoon may be conceived of a delayed response to the inadequacy of the poleward transport of heat during the preceding winter and spring seasons. As already stated, the northeast monsoon over India is the same as the retreating summer monsoon. We are of the opinion that PISHAROTY'S (1981) remark for the Indian summer monsoon should be true for the Indian northeast monsoon also.

Table 1

Correlation coefficient between northeast monsoon rainfall and mid-latitude circulation indices during the period 1971–1989

		ZON		MER		M/Z	
Regions	Month/ season	TNR	SER	TNR	SER	TNR	SER
	March (−)	0.69**	0.64**				
Sector I	Feb (−)					−0.33	−0.47*
	MAM (−)	0.51*	0.47*				
Sector II	JJA (−)	0.33	0.46*			−0.52*	−0.42
	Jan (−)	−0.44*	−0.20				
	JJA (−)	0.55*	0.31				
Sector III	Oct (0)					−0.44	−0.48*
	Nov (0)			0.47*	0.34		
Hemisphere	JJA (−)	0.46*	0.30				

*,** denote significant levels at 5 and 1 percent respectively, − and 0 stand for antecedent and concurrent months/seasons.

Our study also corroborates Pisharoty's hypothesis if applied to the Indian northeast monsoon. Then a strong zonal index during the antecedent spring season, creating a strong temperature gradient and subdued meridional transport of heat from the tropics to the extratropics, should be accompanied by a strong northeast monsoon rainfall over India. In other words, a positive correlation should exist between the zonal index of the antecedent months/season and the Indian northeast monsoon rainfall. Our analysis in fact shows significant direct CC of 0.69 and 0.64, respectively between TNR/SER and antecedent March ZON over sector I, and also significant direct CC of 0.51 and 0.47 between TNR/SER and antecedent MAM (spring) season.

4. Conclusions

Analysis of the association between interannual variability of Indian northeast monsoon rainfall and mid-latitude circulation indices ZON, MER and M/Z over various sectors has brought out the following important result.

Out of all three indices, ZON exhibits strong antecedent relationships over all three sectors and hemisphere. The best correlation is displayed over sector I where antecedent March has a strong and direct association with TNR and SER with high CCs of 0.69 and 0.64, respectively at 1 percent level. Antecedent MAM (spring) season also shows a significant positive association with TNR and SER. The strong positive relationship suggests that the March zonal index has potential to be used as a predictor for the following northeast monsoon rainfall over India.

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