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Association between mid-latitude circulation and Indian monsoon rainfall

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सार — भारत में तथा 500 hPa स्तर पर मध्य अक्षांशीय सामान्य परिसंचरण के बीच 1971 से 1989 तक की अवधि के दौरान हुई ग्रीष्म कालीन मानसून वर्षा के सांख्यिकीय संबंध की जांच की गई है। सामान्य परिसंचरण लक्षणों को परिलक्षित करने के लिए प्रयुक्त की गई सूची विभिन्न भौगोलिक क्षेत्र तथा गोलार्द्ध में 35°उ. - 70°उ. के अक्षांशीय बैंड के लिए क्षेत्रीय प्रवाह (रेखांशिक से क्षेत्रीय सूची का अनुपात) का क्षोभ है। यह देखा गया है कि भौगोलिक क्षेत्र 1(45°प. – 90°पू.) में गत जनवरी के दौरान क्षेत्रीय प्रवाह का क्षोभ अनुवर्ती भारतीय ग्रीष्म मानसून वर्षा के साथ विपरीत ढंग से सार्थक संबंध दर्शाता है। अतः गत जनवरी के दौरान भौगोलिक क्षेत्र 1 में मध्य अक्षांशीय परिसंचरण का क्षोभ अनुवर्ती भारतीय मानसून वर्षा के लिए उपयोगी पूर्वसूचक प्रतीत होता है। क्षेत्र 2 (90°पू.- 160°प.) में जुलाई से सितम्बर के मध्य अक्षांशीय क्षेत्रीय प्रवाह के क्षोभ तथा उत्तरी पश्चिमी भारत की ग्रीष्मकालीन मानसून वर्षा के बीच महत्वपूर्ण समकालिक विपरीत संबंध भी हैं।

ABSTRACT. The statistical relationship between the summer monsoon rainfall over India and mid-latitude general circulation at the 500 hPa level was investigated for the period 1971-1989. The index used to characterise general circulation feature is the perturbation of the zonal flow (ratio of meridional to zonal index) for the latitudinal band 35°N- 70°N over different geographical area and the hemisphere. It was found that the perturbation of the zonal flow during preceding January over the geographical sector 1 (45°W-90°E) shows significant relationship with the subsequent Indian summer monsoon rainfall in an inverse manner. Thus, the perturbation of the mid-latitude circulation during preceding January over the geographical sector 1 seems to be a useful predictor of the subsequent Indian monsoon rainfall. Significant simultaneous inverse relationship also exists between perturbation of mid-latitude zonal flow during July to September over Sector 2 (90°E- 160°W) and summer monsoon rainfall over northwest India.

Key words—Zonal index, Meridional index, General circulation, Indian summer monsoon, Long range forecasting.

1. Introduction

During the peak of the southwest monsoon season *i.e.*, July and August, the northern hemispheric mid-latitude westerlies in the upper troposphere remain confined to the north of 35°N (*i.e.*, outside Indian subcontinent) in the longitudes of Indian region. The southwest monsoon predominates south of these hemispheric westerlies. Hemispheric heat and momentum balance requires interaction between tropics and extratropics. Such interaction between tropics and midlatitude circulation occurs through quasi-stationary and transient non periodic long waves. This interaction results in a quasi-periodic fluctuation of the mid-latitude general circulation between high and low zonal index circulation known as index cycle. An extremely high or low index situation rarely persists for over a month resulting in abnormal weather throughout the world (Wada 1975). Over Indian region, interaction occurs mainly in the middle and upper troposphere due to the presence of the Himalayas.

Several studies do in fact indicate that there might be significant influence of the atmospheric circulation over the northern hemispheric mid-latitude on the simultaneous performance of the Indian monsoon and its rainfall. Ramaswamy (1965) was the first who showed synoptically that there is a close relation between the Indian monsoon rainfall and the zonal index. Wada (1971) found significant positive correlations between monthly rainfall for July and August in Calcutta and zonal indices at 500 hPa over the eastern hemisphere. Winstanley (1973) also observed increasing (decreasing) zonal circulation to be associated with increasing (decreasing) monsoon rainfall over India and Sahel Raman and Rao (1981) associated prolonged breaks in Indian monsoon with upper tropospheric blocking ridges over east and west Asia. Several studies have been made of the relation between monsoon rainfall and the position of

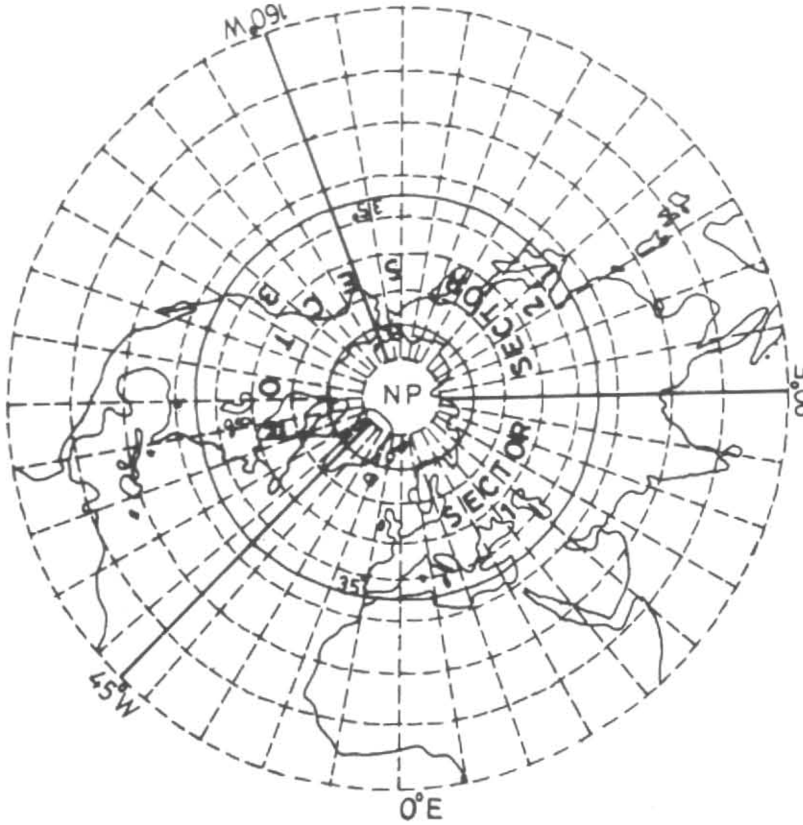

Fig.1. Schematic illustration of the three sectors over which the circulation indices are defined

500 hPa subtropical ridge axis at 75°E over India (Banerjee *et al.* 1978, Mooley *et al.* 1986, Shukla and Mooley 1987). Thus, the non periodic ultra long waves in the mid troposphere over middle latitudes exchanging heat and momentum over the northern periphery of the monsoon appears to have a great effect on the monsoon circulation patterns and rainfall during individual years. Not only that it might as well be proposed that the meridional flow in the troposphere in the premonsoon season resulting in heat exchanges between different latitude belts and thus equalising the temperature difference between tropics and extratropics, should disturb the behaviour of the succeeding monsoon circulation and rainfall. This has been suggested by several studies in India.

In this paper the relationship between changes in the general circulation over mid-latitude and Indian monsoon rainfall will be examined from the viewpoint of interannual variability. The time lead/lag relationship between the above two components of the general circulation will also be studied to explore its potential as predictor of monsoon rainfall activities.

Kats (1960) devised various indices as a measure of changes in strength of the mid-latitude circulation accompanying tropic extratropical mass exchanges *viz.* a zonal index (I_z) and a meridional index (I_m) over a geographical sector and the hemisphere, as two components of general circulation. Another index, the ratio $I'(=I_m/I_z)$ has also been devised which defines the general character of the circulation and is a measure of the perturbation of the zonal flow. The appellation zonal or meridional is then given to cases where the I_m/I_z is less than or greater than its overall average value. Kats considers character of the circulation as meridional where $I' > 1$ and as zonal where $I' < 1$.

Lamb (1972) has also explained the Kats indices of general circulation. Important relationships between the first two of the above indices *viz.*, zonal and meridional indices and Indian monsoon rainfall were discussed in earlier papers (Chattopadhyay and Bhatla, 1994, Chattopadhyay *et al.* 1994). It was felt that since I' indicates in what measure the intensity of inter- meridional transfer surpasses the inter-zonal circulation, the correlations might improve if I' is used instead of I_z and I_m. To assess this objectives, in the present study further quantification of the Indian monsoon/mid-latitude circulation relationships is performed through the use of the third index referred to above *viz.*, general character of the circulation I' doing so, we hope the establish a useful predictor for the long range forecasting of Indian monsoon rainfall.

2. Details of data

The basic data used are the monthly mean perturbation of the mid- latitude zonal flow available from the Synoptic Bulletins for the northern hemisphere published by the

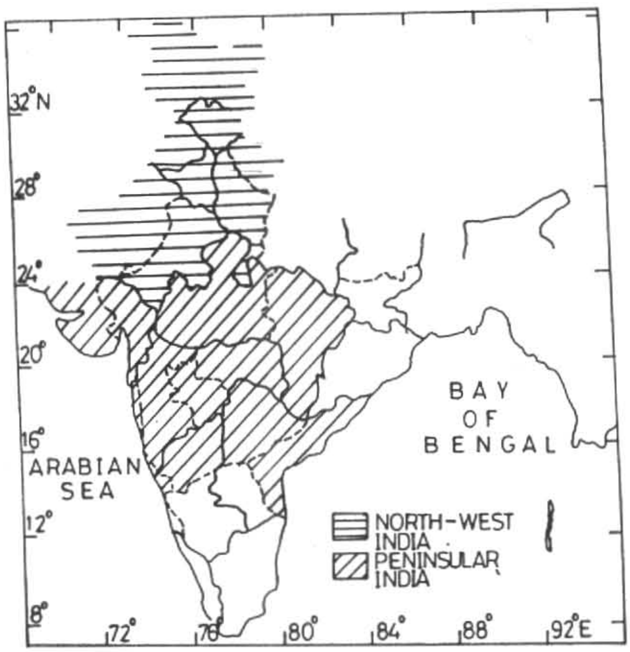

Fig.2. Location of two sub-regions over India

department of world weather, Hydrometeorological Centre of USSR, over the period of 19 years from 1971-1989. The indices I' refer to 500 hPa level for the latitudinal band 35°-70°N, for the following four geographical sectors:

Sector 1—45°W-90°E, Sector 2—90°E-160°W, Sector 3—160°W-45°W, Sector 4—Northern Hemisphere.

The zonal (I_z) and meridional (I_m) indices which are measures of the strength of the zonal westerlies and meridional southerlies respectively at 500 hPa over different sectors defined above, are taken here as the average of the 500 hPa contours (in decameters) intersecting the meridional (in the case of I_z) or the latitude circle (in the case of I_m) per equatorial degree (*i.e.* per 111 km). As already discussed in section 1, the I' is the ratio of I_m to I_z and it defines the general character of the circulation whether intermeridional transfer is more than interzonal circulation or *vice-versa* over different geographical sectors referred to above.

Sector 1 covers the whole of Europe and half of Asia including most of the Indian monsoon region while sectors 2 and 3 cover mainly the western Pacific and eastern Pacific ocean respectively. A northern hemispheric perturbation of the zonal flow has also been calculated by taking the area weighted monthly mean values over sector 1, 2 and 3. Fig. 1 shows the partitioning of various sectors on the world map. As the data are readily available in published form over these sectors only, the study has to make use of the same.

Chattopadhyay and Bhatla (loc. cit.) computed three summer monsoon rainfall series over India. These are summer monsoon rainfall over all India (AIR), two of its subregions northwest India (NWR) and peninsular India (PIR). These rainfall series were prepared by area weighting of sub-divisional rainfall over India and over the two subregions. The sub-divisional rainfall data were obtained from India Meteorological Department and the journal Mausam. The two subregions are shown in Fig.2. The monsoon season rainfalls for the period 1971-89 have mean values 84.9, 53.8, 87.8 cm and corresponding standard deviations are 10.2, 13.1 and 13.9 cm for all India, northwest India and peninsular India respectively. The rainfall values from 1971 to 1989 are expressed as percentage departures from their respective means (ΔR) and used in this study.

3. Procedure and results

To study the relation between seasonal summer monsoon rainfall over India and the character of mid-latitude circulation, correlation analysis upto several months and seasons prior to monsoon and several months and seasons after the monsoon have been computed using 19 years data from 1971-1989. The months considered are from previous December to the following February and the seasons con-

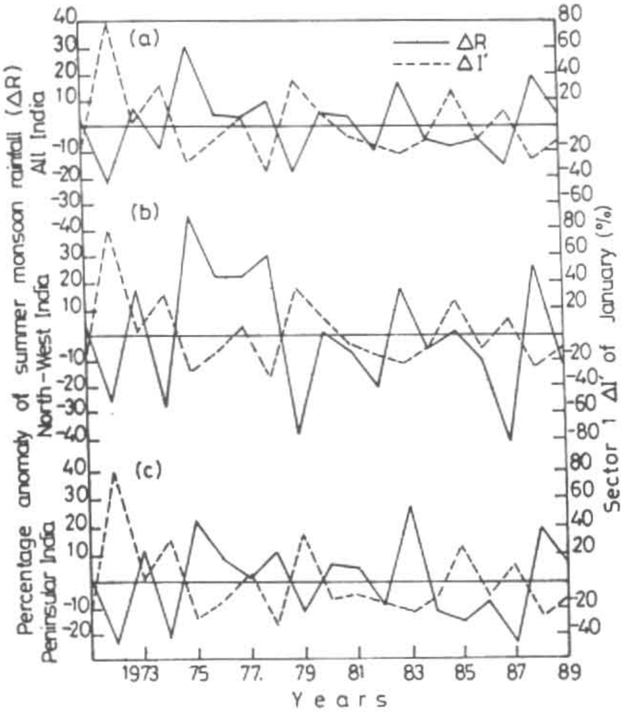

Fig.3. The year-to-year relationship between the percentage anomaly of perturbation of mid-latitude zonal flow (ΔI') over sector 1 during previous January and anomaly of summer monsoon rainfall (ΔR) over (a) all India (b) northwest India and (c) peninsular India [ΔR-solid line, ΔI' - dashed line]

sidered are the all possible overlapping preceding, concurrent and following three month periods starting from previous December to the following December. Autocorrelation analysis of the three Indian monsoon rainfall series showed virtually no significant autocorrelation. Hence, conventional statistics are adequate to assess the significance of these correlations (Elliott and Angell 1987). The statistical significance of the correlation coefficients (CCs) were thus calculated using the conventional 't' test.

The results are encouraging and are summarised in Table 1. While several series show significant CCs, only a few show strong relationships. Only those correlations are presented here which are significant at .1, 1 and 2 percent levels in any month/season/sector. The table reveals very strong negative correlation between all the three rainfall series and the preceding January perturbation of the zonal flow over sector 1 (- .77, -.63 and -.73). The previous JFM (Jan, Feb, Mar) season over sector 1 also shows relatively strong inverse relationships but less than that of January and may be considered as reflection of January feature itself.

The authors also found significant inverse relationship between preceding December/January meridional index and the three rainfall indices (Chattopadhyay and Bhatla 1994) with CCs of -.64, -.45 and -.66 over sector 2 during December and -0.59, and -0.57 over sector 1 during January. Chattopadhyay *et al.* (1994) also found significant direct cc between January zonal index over sector 1 and the all India rainfall index and peninsular India rainfall index with CCs of 0.53 and 0.58 respectively. The remarkable finding from the present correlation analysis is that among the three forms of mid-latitude circulation, I_z, I_m and I', perturbation of the zonal flow (I') during the antecedent January shows the maximum correlation with the three rainfall indices (- 0.77, -0.63 and -0.73). It is not immediately clear why the CC is lowest over NW India although this region could have been more related.

The above relationship explains 59 percent rainfall variability over all India, 40 percent rainfall variability over northwest India and 53 percent rainfall variability over peninsular India. The negative association shows that when perturbation of the zonal flow is stronger (weaker) over sector 1, the summer rainfall over India will be less (more) than the normal. The interannual variation of sector 1 perturbation of the zonal flow and the monsoon rainfall over all India, northwest India and peninsular India are shown graphically in Fig.3 as anomaly from the 19 years mean. The figure shows the remarkable inverse relationship between them. It can be seen from the figure that 13 years out of 19 years for all India rainfall, show strong inverse relationship with perturbation of mid-latitudinal zonal flow of antece-

TABLE 1

Correlation coefficients (CC) between the summer monsoon rainfall over India and perturbation of zonal index for different months and seasons

S.No.	Month/season	AIR			NWR			PIR		
		CC	sig.level (%)	sector	CC	sig. level (%)	sector	CC	sig. level (%)	sector
1.	Jan(-)	-0.77	.1	1	-0.63	1	1	-0.73	.1	1
								-0.58	1	4
2.	Apr(-)	-	-	-	0.54	2	3	-	-	-
3.	May(-)	-	-	-	0.59	1	3	-	-	-
4.	JFM(-)	-0.57	2	1	-0.56	2	1	-0.67	1	1
								-0.57	2	4
5.	JAS (0)	-	-	-	-0.58	1	2	-	-	-

Note:(-) and (0) indicate antecedent and concurrent month/season respectively.

dent January. The above association leads us to conclude that perturbation of mid-latitude zonal flow during previous January over sector 1 is a better related to long range prediction of India summer monsoon rainfall than meridional or zonal index only.

Significant direct correlation are also obtained between I' of previous April and May over sector 3 and northwest Indian rainfall also, showing that perturbation of mid-latitude zonal flow over sector 3 immediately before the Indian summer monsoon season (April and May) may influence the northwest Indian monsoon rainfall only.

Looking for the existence of simultaneous relationship, it can be seen from Table 1 that I' of JAS (July to September) season over sector 2 shows significant inverse association with northwest Indian monsoon rainfall (cc = -.58) significant at 1 percent level. This result suggests stronger (weaker) perturbation of mid-latitude zonal flow [*i.e.*, weaker (stronger) zonal flow] during the monsoon season over sector 2, result in weaker (stronger) monsoon rainfall over northwest India. This study shows significant influence of mid-latitude circulation regime on the summer monsoon season rainfall over India. However, this is not the only factor associated with the rainfall and several other factors also play important role. As such it would not be proper to build a linear regression equation for foreshadowing the Indian rainfall based on this factor alone and for this reason the regression equation is not presented.

4. Conclusion

The present investigation relating Indian summer monsoon rainfall with perturbation of mid-latitude circulation leads one to speculate that anomalous behaviour of the mid-latitude circulation bring a change in the monsoonal flow pattern over India which correspondingly influences the rainfall distribution over India. The study has brought out the following important results.

(*i*) A significant and strong inverse correlation exists between Indian monsoon rainfall and perturbation of mid-latitude zonal flow over sector 1 during previous January.

(*ii*) A moderate significant direct correlation exists between perturbation of mid-latitude zonal flow over sector 3 during previous April and May and northwest Indian monsoon rainfall.

(*iii*) A moderate inverse simultaneous correlation exists between the perturbation of mid-latitude flow and over sector 2 during JAS season north west Indian monsoon rainfall.

(*iv*) Since summer rainfall over India is related to several ocean, land and atmospheric circulation factors, no attempt is made to build a linear regression equation for foreshadowing monsoon rainfall with the help of the mid-latitude under suggested in this favour. However, this factor has been isolated as a possible candidate for use in the multiparameter model.

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