Large Scale Aspects of India–China Summer Monsoon Rainfall

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Received May 4, 1992; revised July 4, 1992

ABSTRACT

This study investigates the dominant modes of variability in monthly and seasonal rainfall over the India–China region mainly through Empirical Orthogonal Function (EOF) analysis. The EOFs have shown that whereas the rainfall over India varies as one coherent zone, that over China varies in east–west oriented bands. The influence of this banded structure extends well into India.

Relationship of rainfall with large scale parameters such as the subtropical ridge over the Indian and the western Pacific regions, Southern Oscillation, the Northern Hemispheric surface air temperature and stratospheric winds have also been investigated. These results show that the rainfall over the area around 40°N, 110°E over China is highly related with rainfall over India. The subtropical ridge over the Indian region is an important predictor over India as well as over the northern China region.

I. INTRODUCTION

The connections between India and China rainfall have been studied by Paolino and Shukla (1986) to some limited extent. Lau et al. (1988) have presented a documentation of seasonal summer monsoon rainfall over East Asia. Similarities and differences between the East Asian monsoon and that of India have been surveyed by Lau and Li (1984). Fu and Fan (1984) have suggested a possibility of two distinct monsoon oscillations: One is the out–of–phase oscillation between the China and India monsoons: a kind of see–saw within the monsoon system during non–El Nino years; the other is an oscillation associated with some El Nino events. Some indications of the interaction between the rainfall regimes of the two countries have been noted in the results of the previous workers. For example, Parthasarathy (1984) and Gregory (1988) have noted negative correlations between rainfall over central India and northeast India. Such inverse correlation between the rainfall over central India and northeast India is also apparent from the EOF analysis of monsoon rainfall (Kulkarni et al., 1992). One may then like to enquire if the inverse anomalies observed over northeast India extend further eastward across East Asia. Such extensive rainfall anomalies covering the Indian subcontinent and China have been occasionally observed, as e. g. in 1989 (Fig. 1–from JMA, 1989). This figure shows the east–west oriented bands of rainfall anomalies extending from India right across east or southeast Asia and beyond.

In the present study we investigate the spatio–temporal variability of the rainfall over India and China taken individually as well as together. We also examine the relationship of some regional and global climatic parameters such as the subtropical ridge, Southern Oscillation (SO), the Northern Hemispheric surface air temperature (NHST) and the stratospheric winds by using data described in Section II. Some general features of the monsoon over the two regions are presented in Section III. The spatio–temporal variability of rainfall and Outgoing Longwave Radiation (OLR) as studied through EOF analysis are discussed on Section IV. Such analysis was conducted by Yoshino and Murata (1988) to study the interrelationship between Baiu rainfall over Japan and the Meiyu rainfall over China. The relationship of the climatic indices with rainfall over both the regions is described in Section V. Some important findings are summarised in Section VI.

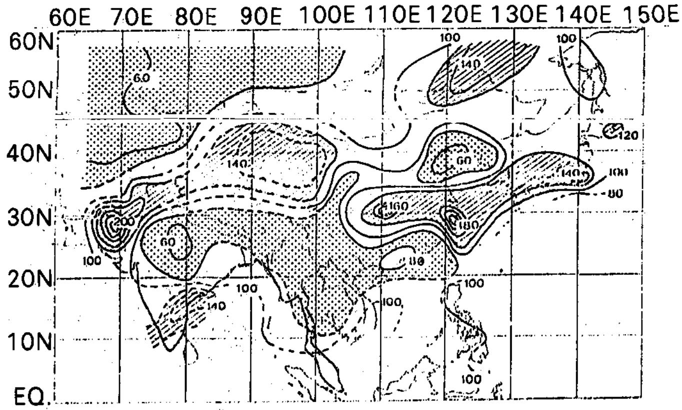

Fig.1. Percentage of normal precipitation in Asia Monsoon area during June through September 1989. Contour interval 20%; Shaded areas 120% or more. Dotted areas 80% or less (From Monthly Report on Climate System–Japan Meteorological Agency, October 1989).

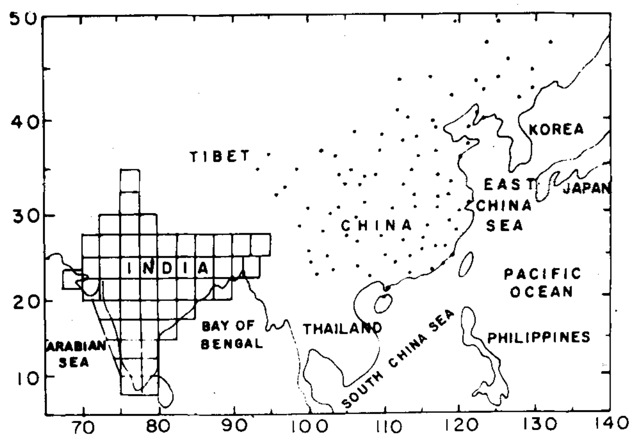

Fig.2. Map showing the location of the 88 stations over China (dots) and the 52 blocks over India.

II. DATA

Following data sets have been utilised:

(i) Monthly rainfall data over the Indian region were available for 306 stations. From this data set averages for the 52 blocks (Fig. 2) for the period 1951–80 are prepared.

(ii) Rainfall data for 88 stations over China (Fig. 2) have been obtained for a 30 year period (1951–80) from Prof. J. Shukla, University of Maryland, USA.

(iii) For Beijing (39.8°N, 116.5°E) and Shanghai (31.2°N, 121.4°E) the rainfall data for a hundred year period (1881–1980) is taken from Domros and Gongbing (1988). The time series of All India Monsoon Rainfall (AIMR) for the same period has been obtained from Parthasarathy et al. (1987).

(iv) The NoAA polar orbiting satellite OLR data at 2.5° Lat. / Long. intersection have been obtained for the period 1974–86 (except 1978) from Dr. Arkin of the Climate Analysis Centre, USA. This data has been corrected for the change of satellites (see Gruber and Krueger, 1984).

(v) The 500 hPa subtropical ridge position along 75°E longitude during April (Indian ridge) and over the western Pacific (average latitudinal position of the ridge line between longitudes 110–150°E). The data for the latter is supplied by Prof. Zhang Yan of the Weather and Climate Research Institute, Beijing.

(vi) NHST average for January and February (Jones et al., 1982).

(vii) MSL pressure difference between January and April for Darwin, in northern Australia representing the state of the SO.

(viii) The 30 hPa wind at Balboa, Canal Zone representing stratospheric winds. Data for (vii) and (viii) have been obtained from Dr. V. E. Kousky of the Climate Analysis Centre, USA.

III. SOME CLIMATIC CHARACTERISTICS OF SUMMER MONSOON OVER INDIA AND CHINA

India and China (or East Asia) which share common geographical boundary also share some common monsoon features. Yet there are clear–cut differences in monsoon behaviour like in the onset and advance process, duration, variability and other dynamical mechanisms over the two regions. Amongst the common features is the cross–equatorial flow and the Tibetan anticyclone which exercises profound dynamical and thermal influence on the monsoons of both regions.

As against one predominant southwesterly flow in case of the Indian monsoon, there are at least 3 wind streams with southerly components affecting the China monsoon. Although a component of the wind flow passing over the Bay of Bengal reaches south and central China, the predominant cross–equatorial flow occurs near 110°E. In addition the West–north Pacific subtropical high forces easterly to southeasterly current from its southern edge, later turning into a southwest current over China.

Though the onset of the Indian southwest monsoon and the beginning of Meiyu at Changjiang–Huaihe River valley, are both the results of sudden change of the large scale atmospheric circulation in June, the Meiyu does not occur when the Indian southwest current arrives at the Changjiang River valley. The Meiyu is a kind of frontal zone resulting due to the confluence of two air masses. Also contrary to the advance of the Indian monsoon, which is fairly regular, the rain belts move from South to North China in sudden shifts. The advance of monsoon in China takes about 3 months as against one month in India. But the retreat from North China to South China takes only 20 days.

The most important semi–permanent weather system in Chinese summer monsoon is the Meiyu front centered along the Changjiang River valley, near about 28°N latitude. The life span of this frontal system is rather small being about 20 days (in some years no Meiyu may be observed) but it contributes to about 70% of the total rains in July and August.

The AIMR shows high positive correlation with the stations over China lying between 35°N and 42°N (Fig.3). The negative correlations over northeast India continue eastward into South China. The long period of data (1881–1980) of Beijing lying in this region also show significant positive correlation (0.34). When we average the rainfall of 13 stations lying between 35°–42°N and 105–120°E, the correlation with AIMR becomes 0.72. Contrary to this, the rainfall over the Changjiang valley shows little correlation with Indian rainfall. Shanghai shows a correlation of −0.011 with AIMR on the basis of 100 years of data, the correlation between Beijing and Shanghai being −0.124.

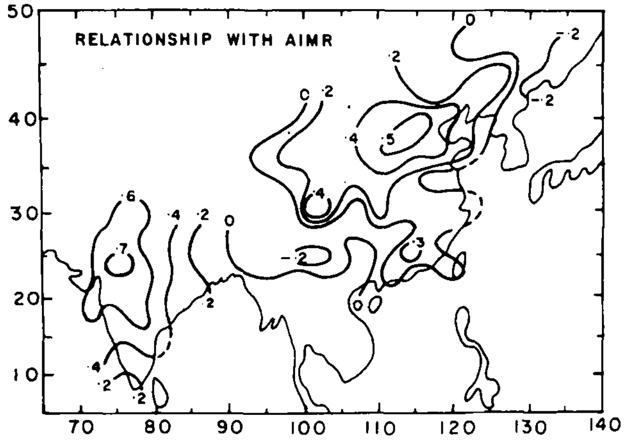

Fig.3. Spatial distribution of the correlation coefficient over the India–China region with AIMR (see text).

Tao and Chen (1987) have noted a link between onset dates of Indian summer monsoon and the beginning dates of Meiyu over the Yangtze River valley, with a slight delay for the latter. Bansod et al. (1991) have examined the correlation between onset dates over Kerala and Bombay and rainfall during the first 5, 10, 15, 20, 25 and 30 days of June and the whole season's rainfall over various parts of India. They found that the onset dates show significant correlation with monsoon rainfall upto about a month over some parts of the country but the seasonal rainfall shows no significant correlation over any part. Likewise, the onset of Meiyu over Changjiang valley also shows low correlation (−0.345) from 30 years of data. However the duration of Meiyu shows high correlation (0.72) with total Meiyu rainfall.

IV. EMPIRICAL ORTHOGONAL FUNCTIONS (EOFs)

EOFs are the most effective tool for describing pasimoniously the spatio–temporal variability of meteorological fields, which explain maximum variability with the constraints of orthogonality. EOFs of rainfall over India and China have been determined separately and by considering the rainfall over both regions for understanding their interactions. We use the correlation matrix because of the involvement of areas of wide variability and latitude range, specially over China.

1. *EOFs of Indian Rainfall*

The EOFs of Indian monsoon rainfall have been determined previously by several workers (e. g. Bedi and Bindra, 1980; Kulkarni et al., 1992). Since the data for China is available only for 30 years (1951–80), we use the data of these 30 years for the Indian region also to facilitate comparison. Table 1 shows the variances explained by the first four dominant EOFs for all the regions considered. Except EOF−4 for the Indian region, all are significant by the test of Overland and Preisendorfer (1982).

EOFs for the Indian region are shown in Fig.4. EOF−1 shows generally same sign of the loadings prevalent over most of the country with maximum values lying over west–central India, near 22.5°N, 80.0°E. This suggests that the most dominant component of rainfall represents similar variations, deficiency or excess, over the whole country. However northeast India we notice the loadings of opposite sign (positive in EOF−1), which may extend further

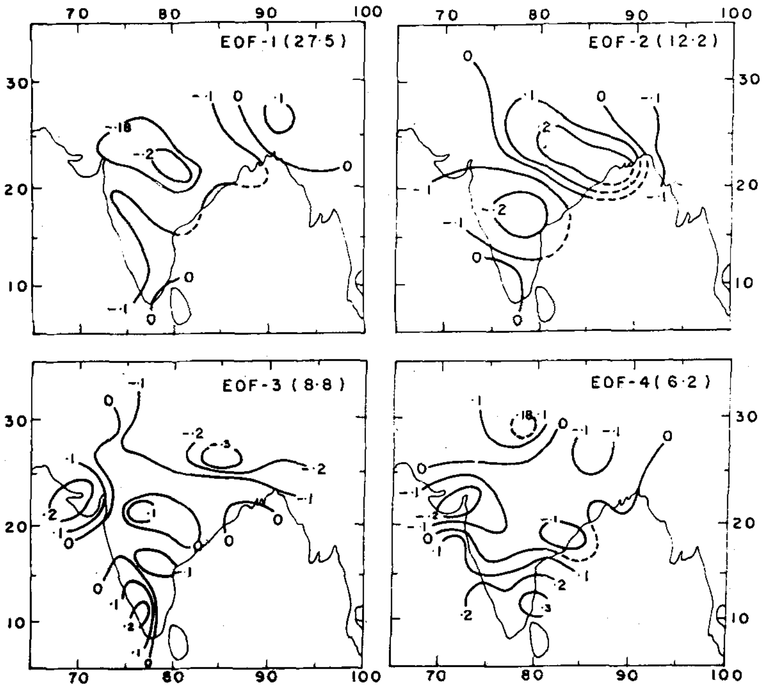

Fig.4. The first four EOFs over the Indian region. Values in brackets are the variances explained.

eastward. The loadings of positive sign can also be noted on the southeast tip of the peninsula.

Table 1. Variance Explained in Percentage by the First Four EOFs

EOF No. EOFs for Region (time scale)	1	2	3	4	Total
India(seasonal)	27.5	12.2	8.8	6.2	54.7
China(seasonal)	12.5	10.9	9.1	6.7	39.2
India–China (seasonal)	13.3	9.9	8.1	7.1	38.4
India–China (monthly)	11.0	8.9	6.6	6.1	31.6
OLR Anomalies 0–30° N, 60–130° E (monthly)	32.5	17.8	13.1	7.4	70.8

EOF–2 shows 4 changes of signs of loadings, starting from the southwest tip of the country to the northeast India. Two centres, one near 17.5°N, 77.5°E and the other near 22.5°N, 85.0°E, are more dominant. It is also apparent that the wavetrain type pattern may

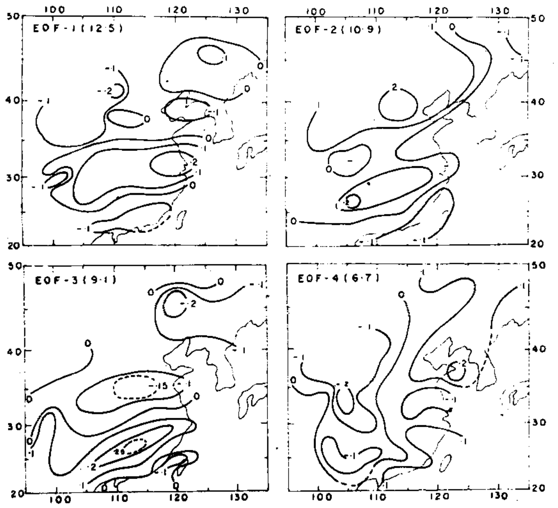

Fig.5. The first four EOFs over the China region.

run'into East Asia through northeast India. This EOF could be related with a progressive wave moving from south to north associated with the Madden-Julian Oscillations, prominentover the Indian region.

EOF-3 also shows four changes of signs across the country. An east-west oriented bandof negative anomalies lies near the foot of the Himalayas with maximum values near the central Himalayas near 85°E. These loadings are strongest in the whole map. Negative anomalies over southeast peninsula are also suggested. In general this pattern shows some resemblance with typical break patterns during which most of central India witnesses total dessicaltion of rainfall and enhancement of rain is observed over the sub-Himalayan regions and the southeast peninsula. EOF-4 shows smaller scale features.

2. *EOFs of China Rainfall*

EOFs of China rainfall have been determined by a large number of Chinese meteorologists. For example Aijun and Shiyan (1989) have determined the EOFs of monthly precipitation and Lough et al. (1987) determined EOFs of annual rainfall. Here we use the data of 3 months (June, July and August) only as the summer rains withdraw from most of China by the end of August. EOFs for the China region are presented in Fig.5.

EOF-1 shows four changes in the signs of loadings in the north-south direction. The loadings of one sign tend to be oriented in east-west direction with their centres approximately along 45°, 38°, 32°, and 24°N latitude as we move from north to south. The loading structures south of 35°N are better organised and the most predominant coherent loadings lie along the Changjiang valley. Occurrence of organised rainfall along the Meiyu front in June may be one of the reasons for such an elongated loading structure. Next in importance are the loadings of opposite sign lying over southern China along the Sikiang valley. Thus the loading structure south of 35°N suggests a seesaw in rainfall belts over central and southern China. This kind of rainfall anomaly pattern can be linked with the presence and movement of the subtropical high over the western Pacific. Most of the bands of the loadings have slight southwest to northeast orientation, corresponding to the orientation of the polar frontal zones over China.

The comparison of the spatial structures of the first EOFs over the two regions shows that whereas over the Indian region there is only one dominant centre of coherent loadings, over China four east–west oriented bands of loadings are observed. This is akin to the northward moving wave type of teleconnection suggested by Nitta (1987).

EOF–2 also shows banded structure but now the loadings of one sign (positive) cover most part of the country from 25°N–45°N. The highest positive loadings lie along 40°N latitude between 110°–115°E longitude, the region which shows highest correlations with the Indian monsoon rainfall. Like EOF–1 the east–west organisation of the loadings is clearer in the southern half of China. This EOF can be considered as the one representing that element of climatic variation which causes similar variation over most of China.

EOF–3 shows negative loadings over the area north of 30°N and positive loadings south of it. The orientation of loadings around 27°N, 112.5°E suggests that these are extensions from the northeast Indian region. This EOF is somewhat similar to the second EOF of Mikami (1987). EOF–4 shows drastically different pattern from the first three EOFs. Now the positive and negative loadings are arranged in north–south direction. Negative loadings are found west of 112.5°E and positive loadings east of this longitude. This pattern resembles somewhat the third EOF of Mikami (1987).

In summary we find the first 3 EOFs of China rainfall show east–west oriented bands of loadings with better organization over southern half (south of 35°N) of China.

3. *EOFs of combined India–China Rainfall*

For computations of the EOFs over the combined region we consider the 3–month season–June, July and August. A few stations (20 out of 88) north of 45°N and over the hilly west regions are omitted. These EOFs are presented in Fig.6.

EOF–1 shows the loadings of only one sign (except over northeast India) over the Indian region, as in the case of the first EOF obtained by analysing the Indian data alone. A coherent zone of the same sign as over India is found over North China with maximum centered near 40°N, 115°E, suggesting that the rainfall variations over India and this area are in phase. This was also noted earlier in Fig.3. Over southern China (south of 30°N) we find an east–west oriented band of weak loadings of opposite (negative) sign running from east coast of China upto 87°E into northeast India roughly along 25°N latitude. This is suggestive of some interaction between monsoon over northeast India and southern China. The Chinese part of the EOF resembles somewhat the first EOF of Lough et al.(1987).

EOF–2 shows similar structure over the Indian region as obtained by independent analysis of the Indian rainfall data. The positve loadings over northeast India seem to continue through China crossing east coast of China near 32°N, suggesting some interconnection. EOF–3 shows stronger positive loadings over northern parts of India and weaker along 31°N latitude over China. EOF–4 shows organised structure over China and almost disorganised loadings over India. The positive loadings over China between 25°–30°N seem to run into India through head Bay of Bengal.

4. *EOFs of Monthly Rainfall Anomalies over the India–China Region*

For enhancing the sample size, we have recomputed the EOFs by using the monthly rainfall anomalies for the months of June, July and August. For focusing on the banded structure of the loadings over the China region and their interaction with the Indian region, over the China region we consider data south of 35°N latitude only. These EOFs are shown in Fig.7.

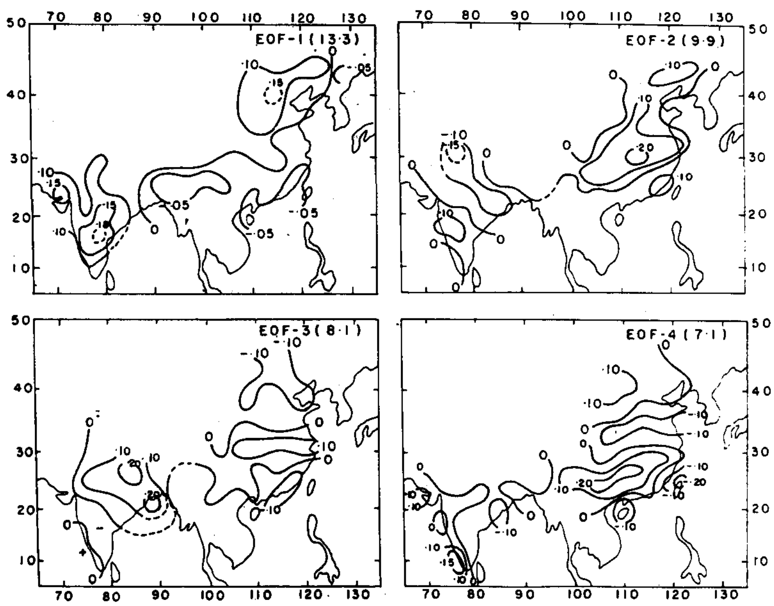

Fig.6. The first four combined EOFs over the India–China region.

In EOF–1, the banded structure of the negative loadings from northeast India runs through South China near about 27°N latitude. The maximum loadings lies near 92°E over the Indian region. Considering the sparse rainfall network and the complex orography over this region, these high loadings are all the more important. This would suggest that the variation over the Indian region extend eastwards and influence the rainfall variations over China.

EOF–2 shows two bands of loadings common to India and China. The positive loadings over the sub–Himalayan region extend northeastward and show a coherent maximum near 32°N, 113°E. Likewise, the negative loadings centered near 21°N, 88°E over the Indian region also run northeastward into South China region near about 25°N latitude.

EOF–3 shows similar features as the third EOF of the seasonal rainfall except that now the loadings over the Indian region are weaker and that over the China region stronger. EOF–4 is also similar to the corresponding EOF of seasonal rainfall with much stronger loadings over the Indian region. However the loadings over western India and China (along 27°N) are in phase and of equal magnitude.

5. *EOFs of Monthly OLR Anomalies*

In the above analysis the rainfall data over Bay of Bengal, Myanmar and Indo–China peninsula are not available with the authors, therefore the continuity of loadings could not be traced south of 20°N latitude. For examining the structure of convection and precipitation over this data void region, we have used the 12 years of NOAA OLR data for the months June through September for the region equator to 30°N and 60°–130°E. Fig. 8 presents these EOFs and the variances explained are shown in Table 1. The high variances here may be due to the high spatial coherence of the OLR fields.

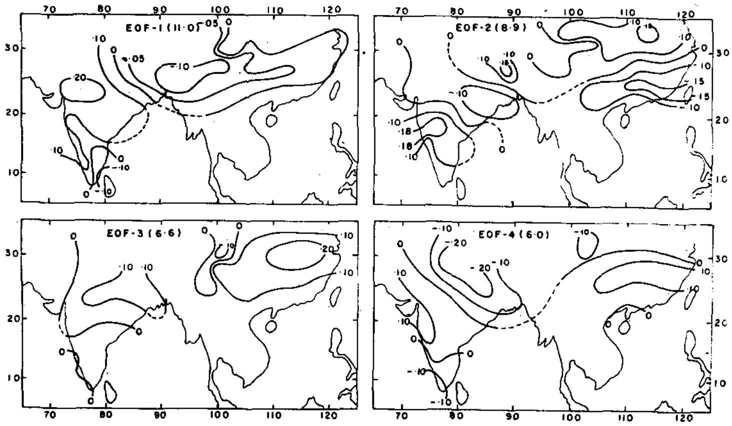

Fig.7. The first four EOFs of the monthly rainfall anomalies over the India–China region.

EOF–1 shows an east–west oriented band of high loadings running about 20°N latitude. There are three centres of loadings in this band viz. (i) central India, (ii) western Myanmar and (iii) South China Sea. The latter two centres could not be identified in the rainfall EOFs because of lack of data. Thus the banded structure of convection running through India, Indo–China peninsula and the western Pacific can be noted.

EOF–2 shows a dipole type structure with one centre over north India around 27.5°N, 77.5°E and the other over South China Sea around 8°N, 113°E. The southern band of loadings is more coherent and elongated. This could be associated with the ITCZ forming during the break periods over central India (Sikka and Gadgil, 1980).

EOF–3 shows in phase variation over the Arabian sea and north Philippines. But the strongest loadings are found along the equator from 80° to 130°E. Therefore all the 3 EOFs, together explaining 63% of the variance bring out different phases (locations) of the east–west oriented ITCZ (being 20°N, 8°N and the equator) over the north Indian Ocean and the western Pacific region. EOF–4 shows a coherent convective zone over East China Sea around 27°N, 130°E and the loadings of opposite sign over the Arabian sea.

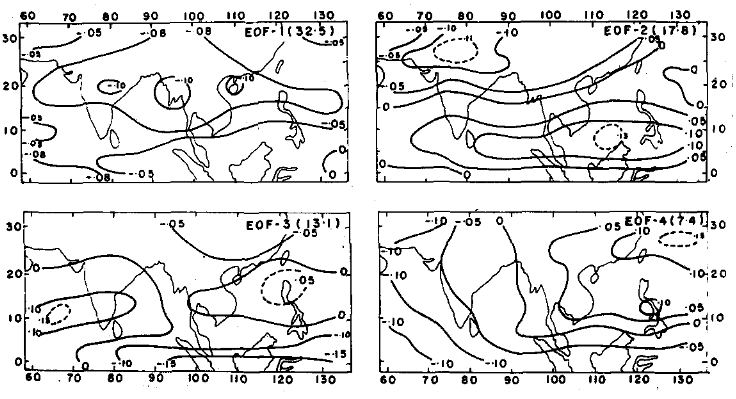

Fig.8. The first four EOFs of the monthly OLR anomalies over the Indo–West Pacific region.

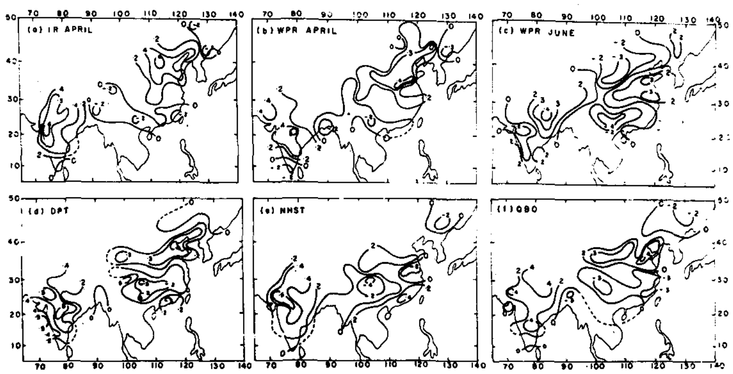

Fig.9. Spatial distribution of the correlation coefficient of seasonal rainfall over India–China region with large scale parameters (IR = Indian Ridge, WPR = West Pacific Ridge, DPT = Darwin Pressure Tendency, NHST = Northern Hemisphere surface Temperature, QBO = Quasi Biennial Oscillation).

On comparison of these EOFs with the corresponding EOFs of rainfall, we find that the loadings in OLR EOFs are stronger and more coherent over the tropical oceanic regions.

V. RELATIONSHIP WITH SOME LARGE SCALE PARAMETERS

We have analysed the spatial predictive relationships of four selected parameters representative of different features of the atmospheric / ocean system, with the seasonal rainfall over India and China. The ridge represents the most important circulation parameter (Singh et al., 1986). Importance of ridge position (subtropical high) over the western Pacific has also been well established (Kurihara, 1989). The NHST represents the global climatic variability and includes to a large extent the large scale trends in the global climatic system as well as surface heating particularly along the middle latitudes. The Darwin pressure Tendency (DPT) represents the SO, the most important cause of the short term fluctuation of the tropical climate system. The relationship between the stratospheric winds, which also exhibits QBO, and the Indian monsoon has also been established (Mukherjee et al., 1985). From the dynamic considerations, these parameters appear to be independent of each other.

1. *The Subtropical Ridge over India*

The spatial distribution of the correlations between this parameter and the seasonal rainfall over the India–China region is shown in Fig. 9a. We find that the correlations over the Indian region are well organised with maximum correlations near 20°N, 75°E. Comparable high correlations are also found over China along 40°N latitude. The spatial extent of the significant correlation is quite large. This suggests that the rainfall over India and the region around Beijing over China have similar interannual varilability. The pattern is similar to EOF–1 presented in Fig.6, as well as the correlations with AIMR (Fig.3). All these results suggest that the most dominant function of rainfall over India and northern China is associated with the variation of the subtropical ridge over India.

One possible reason for the Indian rainfall or a circulation parameter (ridge) showing high correlation with a northerly location (40°N latitud), may be that the rainfall over the southern part of China is primarily controlled by the subtropical high reducing the influence of the Indian monsoon flow, if any. The Indian monsoon continues to show its influenc at higher latitudes. Another possibility may be the better influence of the ridge on the monsoon rainfall of later months (Prasad and Singh, 1992). It is in the later monsoon months (particularly August) that North China experiences monsoon rainfall.

2. *The Subtropical Ridge over the West Pacific*

The results of the latitudinal positions of the ridge during April and June only are presented, since they show organized patterns than other months. The correlation pattern (Fig. 9b) is by and large similar to that obtained for the Indian ridge. The high correlations (>0.4) are now less extensive and shift somewhat southward and eastward. Over China also the correlations reduce in magnitude. The comparison of Figs. 9a and b shows that the subtropical ridge over India in April is more strongly related with the subsequent monsoon rainfall over India and northern China than the ridge over the West Pacific. Correlations for June are shown in Fig.9c. The correlation structures over China are now organized in east–west oriented bands, akin to the loadings of the EOFs. This suggests that the ridge position during June has greater influence on China because of its being nearer to the summer rainy season.

3. *The Southern Oscillation*

The correlation pattern for DPT is shown in Fig.9d. The high correlation zone (≈ 0.5) over west–central India has northwest to southeast orientation. Over the China region the correlations are organized in east–west oriented bands again like the loadings of the EOFs. The area between 34°N and 43°N is positively related and the regions north and south of this zone are negatively related. Positive correlations are again observed over the southeast coast of China. The banded structure of correlations suggests that the SO is influencing the rainfall over China through the West Pacific ridge, which itself is controlled to a large extent through the Pacific–Japan teleconnection pattern (Nitta, 1987) associated with the West Pacific convection and sea surface temperature. The signs of the correlations suggest that when the SO is changing towards high index (lowering of pressure over Darwin) southern China receives heavy reinfall and the Changjiang valley receives low rainfall. Over Yunnan Province, south of the Nanling Mountains the Pacific ridge has better control than the SO. Yang and Lau (1987) have also shown that the relationships between the El–Nino phenomenon and the rainfall for South China and that for central China are in opposite phase. But in North China the relationships are by and large insignificant and uncertain.

4. *NHST*

The correlation pattern (Fig. 9e) for NHST is again similar to that of the DPT. Here again we see that the regions between 33°N to 42°N and along the east coast (20°–27°N) the relations are positive and in phase with the variations over the Indian region.

5. *Stratospheric Winds*

Correlations with the 30 hPa stratospheric winds in April at Blaboa are shown in Fig.9f. In this case also we find positive correlations over almost whole India, with 2 zones of significant correlations, one over the northern parts and another near 15°N latitude. Over China we find negative correlations between 25°–30°N latitude and positive correlations between 30°–40°N latitude. Insignificant positive correlations are found south of 25°N latitude.

The choice of these parameters is based on their relationship with the Indian monsoon rainfall. Hence the correlations over the Indian region are generally higher than those over China. There may be other parameters which may show better relationship with Chinese rainfall.

VI. CONCLUSTONS

The significant findings are discussed in this section:

(i) The most important mode of variability of rainfall over India represents almost simultaneous variability of the same sign over the whole country representing large scale droughts and floods. This variability shows high in phase correlation with the rainfall variability over northern part of China near 40°N, 110°E. The coherent variations over India and in phase variations over North China is the most important mode of variability of the India–China rainfall as suggested by the EOF analysis over the two regions.

(ii) Over China the most important rainfall variations occur in the form of east–west oriented bands with slight tilt in the southwesterly to northeasterly direction. This banded structure is more predominant south of 35°N latitude–suggesting that there are two climatic regimes operating over China north and south of this latitude. The southern regime is more intimately related with the subtropical anticyclone and the SO. The second EOF of the joint analysis of India–China rainfall shows eastwest oriented bands of rainfall anomalies extending from the Indian longitudes to the east coast of China.

(iii) Several large–scale parameters show significant correlations with rainfall over both countries. The correlations are stronger and spatially extensive over India perhaps due to better spatial coherence. Over the Indian region the effect of these parameters shows generally one sign only over wide latitude belt 10–30°N but for the equivalent latitude range (20–40°N) over the China region it shows nearly east–west oriented bands of alternating signs of correlation. Thus whereas we can think in terms of prediction of Idian monsoon rainfall countrywide in terms of droughts and floods, it may be inappropriate to think in terms of prediction of China rainfall for the whole country, as the bands of negative and positive anomalies may compensate each other. Therefore for prediction of rainfall over the Chinese region, it is more appropriate to predict the latitude of anomalous rainfall rather than total rainfall.

(iv) The subtropical ridge position over India shows high correlations with not only rainfall over India but even over North China. These correlations are higher than those shown by the subtropical ridge position over West Pacific. Thus the subtropical ridge over India could also be used as an important predictor for rainfall over North China.

The authors are grateful to the Director, Indian Institute of Tropical Meteorology and Dr. S. S. Singh, Deputy Director and Head, Forecasting Research Division for encouragement and for the facilities provided. They are also grateful to Porfs. Chen Longxun and Ding Yihui for illuminating discussions with the second author during his visit to China in October 1990. The Indian rainfall data were obtained in a processed form by Dr. P. Parthasarathy, who obtained the original data from the India Meteorological Department. The Chinese rainfall data were kindly supplied by Prof. J. Shukla, University of Maryland, USA.

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