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Low frequency intraseasonal oscillations in Indian rainfall and outgoing longwave radiation

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सार – इस शोधपत्र में 80 वर्षों की अवधि के लिए 290 स्टेशनों के दैनिक वर्षा आंकड़ों का प्रयोग करते हुए, अवधि की अंतरावर्षीय विभिन्नता और मानसून वर्षा में 30-40 दिनों के दोलनों की संघनता का परीक्षण किया गया। वर्षा और कुछ प्रमुख क्षेत्रों के ओ. एल. आर. और अनुवर्ती कुछ पंचकों में पूरे देश में वर्षा के वितरण के मध्य संकरण सहसंबंधों के आकलन द्वारा वर्षा के विस्तारित श्रृंखला के पूर्वानुमान में लगभग 40 दिनों के इन दोलनों की क्षमता का परीक्षण किया गया। अंतिम रूप से 5 दिन के ओ. एल. आर. और वर्षा के मध्य समवर्ती सहसंबंधों का भी अध्ययन किया गया।

ABSTRACT. In this study, the interannual variations of the period and intensity of 30-40 days oscillations in monsoon rainfall are examined by utilising daily rainfall data of 290 stations for a period of 80 years. Their relationship with the overall performance of the monsoon and ENSO phenomenon is also examined. Potential of these oscillations of about 40 days period in extended range forecasting of rainfall is examined by computing the cross-correlations between the rainfall and the OLR over certain key regions and the rainfall distribution over the whole country in subsequent few pentads. Finally concurrent correlations between the 5-day OLR and rainfall are also studied.

1. Introduction

Even during the peak of the monsoon season, it does not rain at most of the places on every day. The rain occurs in spells under the influence of the synoptic systems. The rain spells are interspersed with the spells of no rain. Quite often the rain or no rain spells prolong beyond the life time of an individual synoptic system. Such variations are associated with the low frequency variations of 10-20 day or 30-60 day periods. The latter oscillations (henceforth to be called as low frequency oscillations, LFOs) are associated with globally eastward propagating wave number 1 in the upper troposphere and northward propagating trough/ridge patterns and cloudiness over the Indian monsoon region. Sikka and Gadgil (1980) demonstrated clearly, for the first time, the northward propagation of cloudiness zones by using several years of satellite cloud data over the Indian region. According to them when the monsoon is weak over central India (or when the break occurs), an eastward oriented cloudiness zone forms near the equatorial oceanic areas. This zone gradually moves northward to revive the monsoon over central India. Smith and Sikka (1987) further examined such progressions in rainfall and OLR. According to them and several other authors, such northward progressions of weather anomalies associated with the 40-day oscillation are linked with the active/break cycle of the monsoon. An important feature of these oscillations is that they show considerable intraseasonal and interannual variability in period and intensity (Singh and Kripalani 1985). Therefore, three important questions arise. The first question is whether the interannual variability of the intensity and period of these oscillations are related in some way to the overall performance of the Indian monsoon. The second question relates to the seasonality in their amplitude. If the LFOs exhibit same period and intensity during particular monsoon and preceding pre monsoon seasons, then the observations in the pre-monsoon season can be utilised for inferring the behaviour of the oscillations in the forthcoming monsoon season. The third question is related to the potential of these oscillations in extended range prediction of monsoon rainfall over various parts of India. These questions are examined in the present study by utilising large sets of Indian rainfall and OLR data, described in the next section.

2. Data

Daily rainfall data of 290 uniformly distributed stations are obtained for a period of 80 years (1901-1980) from the India Meteorological Department. 2.5° Lat./Long. block averages have been prepared by taking simple averages of the rainfall of the stations falling in each block. 52 such blocks cover the entire contiguous India. On an average, about 6 stations fall in each such block and the number of stations are sufficient for the kind of analysis carried out in this study. The daily OLR data have been obtained for a 2.5° Lat./Long. grid for the period 1976-1986 from Dr. P.A. Arkin of the Climate Analysis Center, USA. These data have already been corrected for the change of satellites.

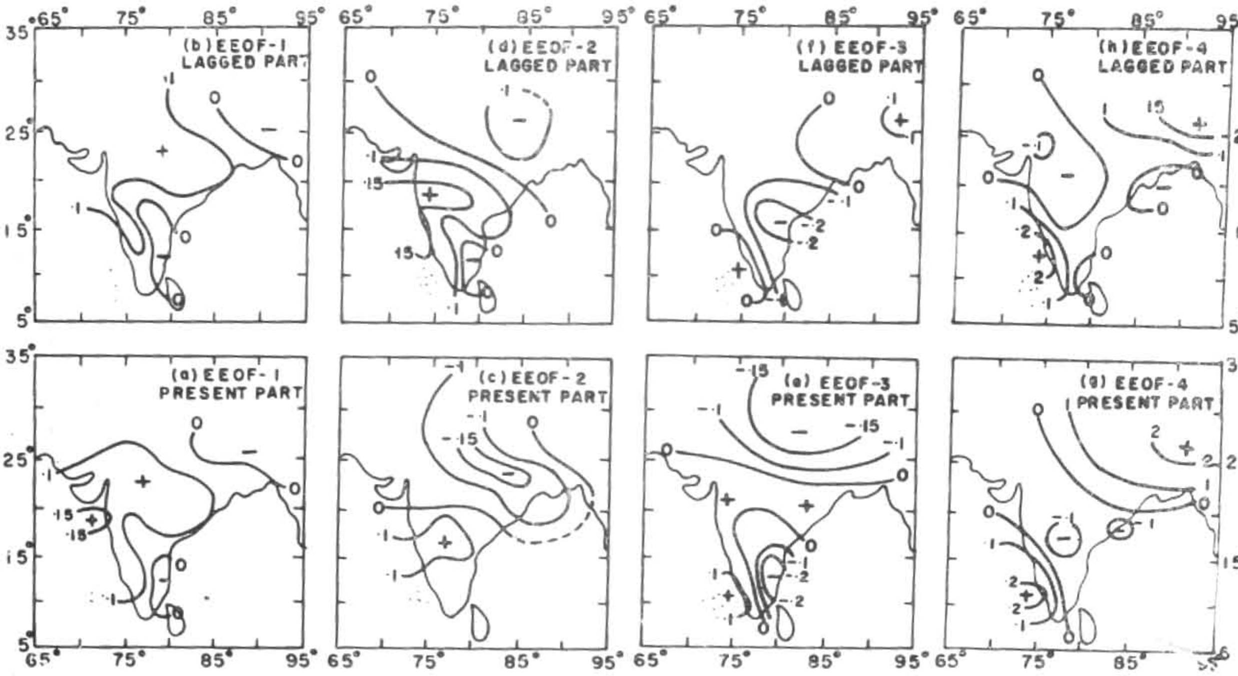

Fig. 1. First 4 EEOFs of 5-day rainfall fields with 1 pentad lag

3. The LFOs in rainfall

3.1. *The spatial and interannual variability of the LFOs*

Our earlier studies have suggested that the intensity of the 40-day oscillations is not uniform over whole India. For further understanding this spatial variability, we have applied the Butterworth's band pass filter (30-60 day) to the daily time series of rainfall of each block in each year. The percentage of variance of original time series explained by the filtered time series are then determined and averaged over the 80 years. When plotted in space, it is found that the 40-day oscillations are strongest over the western parts of the country lying between Lat. 12.5° N & 22.5° N where they explain about 10% variance of the daily time series. If 5-day rainfall time series are considered then the variance explained is found to be about 18% over the same region. The examination of the patterns of the variance explained in individual years, shows that the variance explained over this area varies from about half ($<5\%$) to the double ($>20\%$) of the average value. For examining the relationship of these oscillations with the overall performance of monsoon and the phases of the *El Nino* Southern Oscillation (ENSO), we have prepared the composite maps of the variance explained for about 20 ranked dry/wet years and *El Nino*/*La Nina* years. These composites (not presented) do not differ from the average picture in any recognisable way. This analysis suggests absence of any linear relationship between the seasonal monsoon rainfall over India and the phases of ENSO and the intensity of the 30-60 day oscillations.

3.2. *Spatio-temporal evolution of 5-day rainfall fields*

We have studied the spatio-temporal evolution of 5-day rainfall fields by constructing latitude/time cross-sections (Hovemoller diagrams) and EEOF analysis. The longitude belt 75° E - 80° E is considered for the preparation of these cross-sections. Before preparing cross-sections we have applied Butterworth band pass filter to 5-day rainfall time series. The examination of these Hovemoller diagrams has revealed considerable intraseasonal and interannual variability of the intensity and the period of the LFOs. It is found that the northward progression of the rainfall anomalies associated with the LFOs is not prevalent during all the years. Also, while in about 50% of the years the oscillations are well organised, in the remaining years either they are totally disorganised or are present only during the part of the season. When total period in terms of pentads ($24 \times 80 = 1920$ pentads) is considered the northward progressions can be noted during 75% of the pentads. The speed of these northward progressions, varies from about 0.2° Lat./day to 1.25° Lat./day, with average speed being close to 0.6° Lat./day. This speed is related with the change in the period of the oscillations. This variation in the period occurs not only on the interannual basis but also within a particular monsoon season. The intraseasonal and interannual variability of the intensity and period of the 40-day oscillations and the associated northward progressions impose some limitations on the use of these oscillations for forecasting rainfall by linear extrapolation.

Whereas the Hovemoller diagrams enable us to examine the individual progressions of rainfall anomalies, they do not enable us to study the evolution of the horizontal fields in terms of the variance explained. The EEOF analysis enables us to study the evolution of the meteorological fields in two dimension (and even more) in quantitative terms (Singh and Kripalani 1986). The first four EEOFs of 5-day rainfall fields computed after considering the lag of 1 pentad are presented in Fig. 1. A total of 1840 pentads are used in computation of the EEOFs such that the observations to the variable

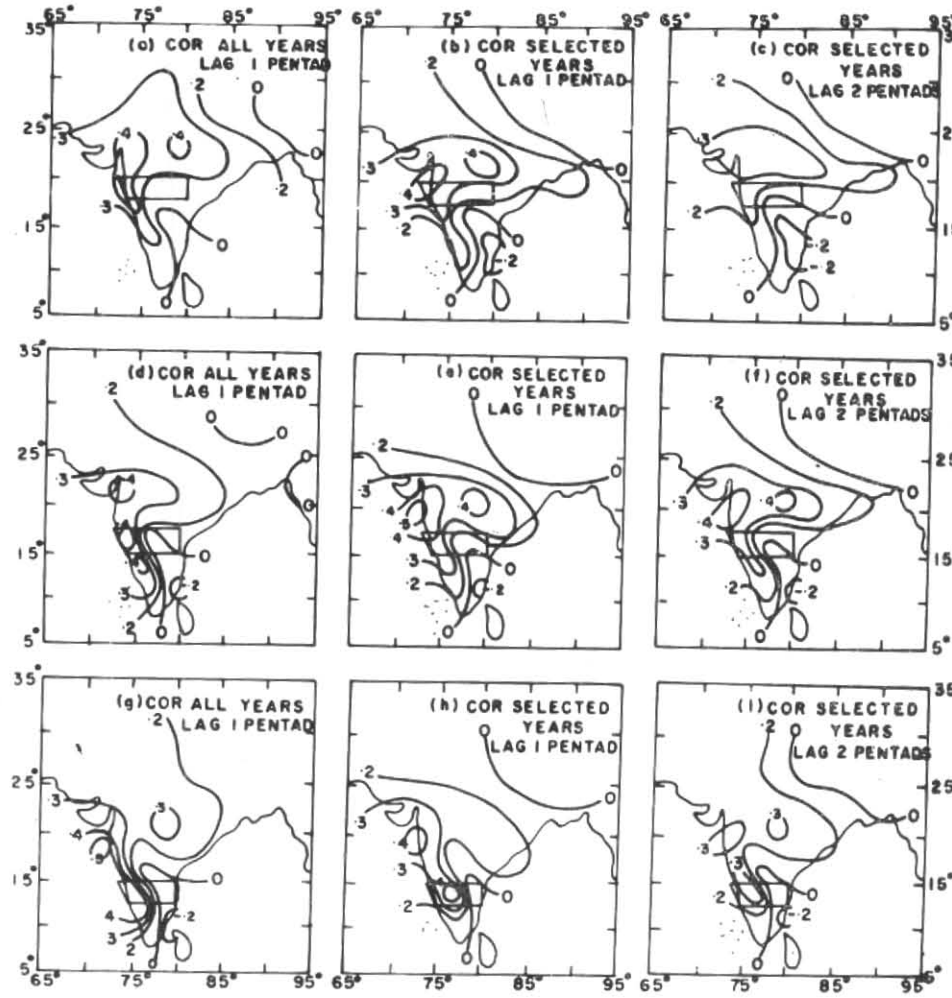

Fig. 2. Lag cross-correlations of 5-day rainfall over 3 key regions (shown by trapezoids) with 5-day rainfall over 52 blocks covering contiguous India

ratio is about 18. These four EEOFs are significant and all show some northward progressions of the loadings from the present pentad to the next pentad. The first EEOF shows northward movement of coherent loadings from near Lat. 20°N (Fig. 1a) to Lat. 22.5° N (Fig. 1b) in the next pentad. The second EEOF (Fig. 1 c and d) shows similar northward movement of the centres of the loadings, but in this case there are two centres of loadings of opposite sign. This EEOF represents the northward progression of rainfall anomalies associated with the same LFO as the first EEOF, but in quadrature with the first EEOF. The third (Fig. 1 e and f) and the fourth EEOFs (Fig. 1 h and g) also show northward movement of loadings but only over the Peninsular region. In these EEOFs the progressive loadings are not so extensive in the east-west direction as in case of the first two EEOFs. Thus, the examination of the four most dominant EEOFs suggests that the most important evolutionary feature of the 5-day rainfall fields over India is the northward progression of anomalies. Our earlier results (Singh *et al.* 1986) have already shown that these northward progressions recur at an interval of about 40 days. As a further test of this observation, the EEOF analysis of the 30-60 day band passed filtered rainfall series has been conducted. This analysis also showed northward progressions of the loadings.

3.3. *Potential in extended range forecasting*

We have examined the linear relationship (correlation coefficient) of several indices of the 40-day oscillations in a particular pentad with the 5-day rainfall in subsequent pentad over all 52 blocks of India. Simple lag cross-correlations with rainfall over some key regions (latitudinal strips) gave similar results as more involved indices, like principal components, spatial gradients and time tendencies. The lag cross-correlations for 3 key regions lying between Lats. 20° N & 12.5° N are shown in Fig. 2 (a, d, g). The key regions are enclosed by trapezoids on the correlation maps. A sample size of 1840 has been used for computation of these correlation coefficients such that a correlation of 0.05 is significant at 5% level. As we see from these figures, the lag correlation coefficients of 0.4 are

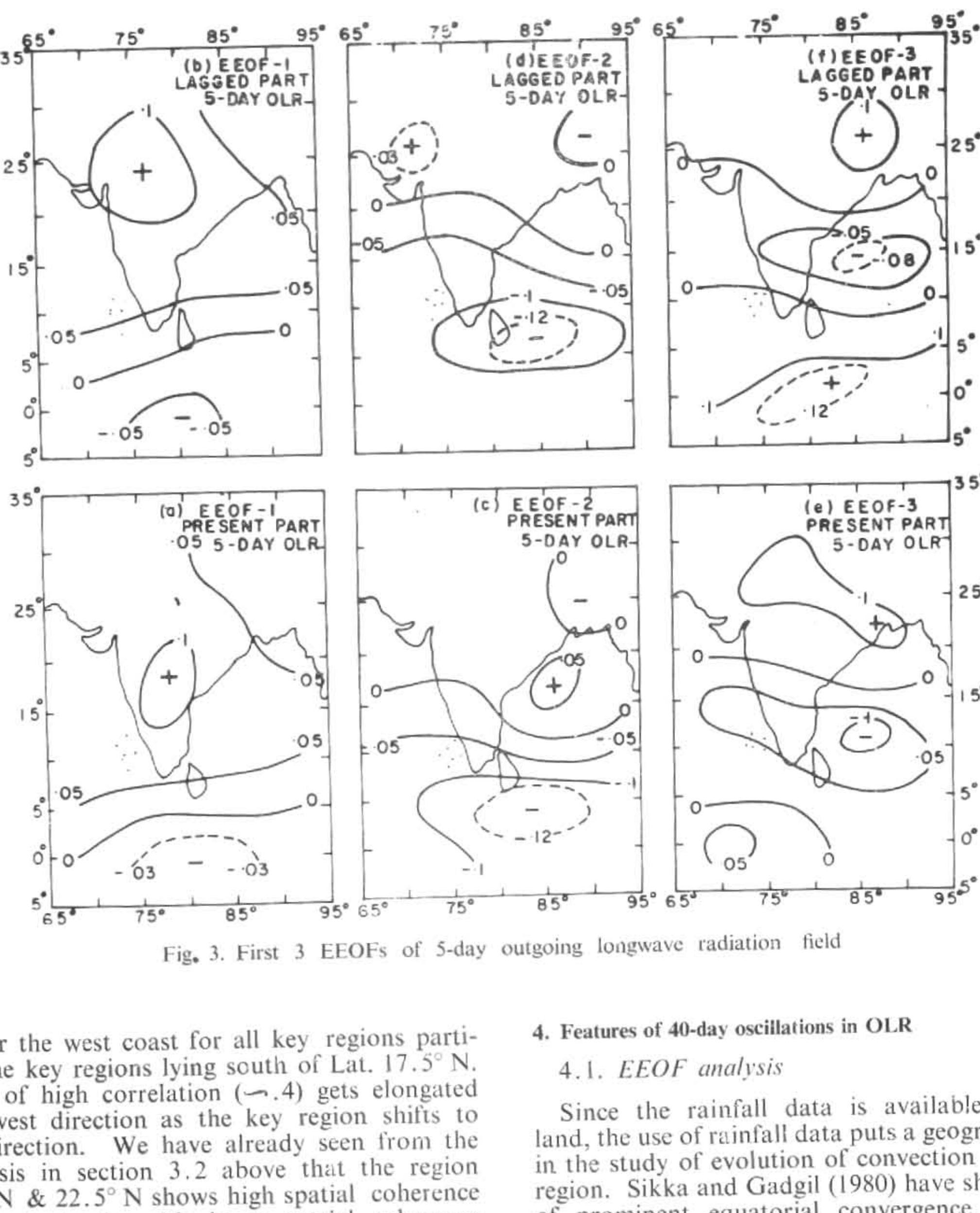

Fig. 3. First 3 EEOFs of 5-day outgoing longwave radiation field

obtained over the west coast for all key regions particularly for the key regions lying south of Lat. 17.5° N. The region of high correlation (−.4) gets elongated in the east-west direction as the key region shifts to northward direction. We have already seen from the EEOF analysis in section 3.2 above that the region between 20° N & 22.5° N shows high spatial coherence in the east-west direction. Maximum spatial coherence between these latitudes occurs, perhaps, due to the normal location of the east-west oriented trough at 700 mb level near these latitudes. Similar cross lag correlations are also computed for lag of 2 pentads. These correlations are, however, considerably lower. The correlations after lag of 2 pentads diminish because the northward progression of the rainfall anomalies is not always prevalent. Therefore, for separating out the effect of progressing and non-progressing type of epoch of the rainfall anomalies on the lag cross-correlations similar correlation charts have been prepared for lag of 1 and 2 pentads by considering the data of only those 30 years in which the northward progressions of the rainfall anomalies are well organised. The correlation charts for the same 3 key regions are presented in Fig. 2 (b, e & h) for lag 1 pentad and in Fig. 2 (c, f & i) for the lag of 2 pentads. It is found that the correlation coefficients for the lag of 2 pentads are as strong as for the lag of 1 pentad when the selected years are considered.

4. Features of 40-day oscillations in OLR

4.1. *EEOF analysis*

Since the rainfall data is available only over the land, the use of rainfall data puts a geographic constraint in the study of evolution of convection over the Indian region. Sikka and Gadgil (1980) have shown occurrence of prominent equatorial convergence zone over the oceanic regions during the phases of weak/break monsoon. Thus, for understanding the important modes of evolution of the convection over the Indian region, including the oceanic region, we have analysed the 5-day OLR fields over the Indian region by EEOF analysis. The first 3 EEOFs are presented in Fig. 3. All three EEOFs show northward progression of loadings and together explain about 45% of the spatio-temporal variance. The first EEOF shows coherent anomalies around Lat. 20° N which move by about Lat. 5° in the next pentad. The second (Fig. 3c & d) and the third EEOF (Fig. 3 e & f) also show northward progression of the coherent loadings over the equatorial oceanic region along about 85° E longitude. The second EEOF shows strong east-west oriented loadings along Lat. 5° N located southeast of Sri Lanka and the third EEOF shows coherent loadings along Lat. 10° N. These features of oceanic convection could not be identified from the analysis of rainfall data in section 3.2, because of the constraints of spatial coverage.

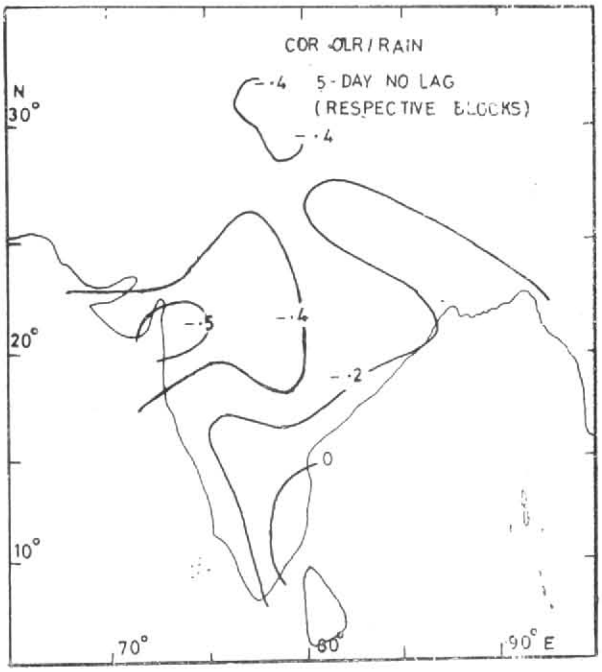

Fig. 4. Concurrent correlation between 5-day rainfall and 5-day OLR

4.2. *Potential in extended range forecasting*

Our experience, with comparison of EOFs of OLR and rainfall, suggests that the OLR has higher spatial coherence than rainfall. Further, as seen in the above subsection 4.1, the variations in the oceanic convection can also be monitored by the use of OLR data. For these reasons it is felt appropriate to explore the potential of OLR over key regions in predicting rainfall over India. For identifying the key regions of OLR fields we have determined the average variance of OLR explained by the 30-60 day band over the Indian and Pacific region as done for the rainfall field in section 3.1.

Two centres of high variance one over the Arabian Sea near Lat. 17.5° N and Long. 70° E and the other over the equatorial region along 85° E are found. We have considered the 5-day OLR over these two regions as index of convection and then correlated them with the 1, 2 and 3 pentad lagged rainfall over whole India. The sample sizes in these correlation have varied from 68 to 60 depending on the lag. The correlation coefficients are stronger for the key region over the Arabian Sea and the belt of significant correlations shifts northward with increasing lag. The correlation coefficients are comparable to those for rainfall for the lag of 1 or 2 pentads. Significant correlations exceeding .3 are found for the region bounded between Lats. 20° and 25° N even for the lag of 3 pentads.

4.3. *Concurrent association between OLR and rainfall*

In several studies related with the 40-day oscillations and tropical mid-latitude teleconnections, OLR is used as proxy for convective heating. Recently the OLR has also been used for estimating the convective heating of the atmosphere in diabatic initialisation for numerical weather prediction. We have examined the concurrent association between the 5-day OLR and the 5-day rainfall over India, for examining this representativeness of the OLR for rainfall. First of all the OLR values are averaged over the grid points surrounding the particular rainfall block. Then concurrent correlations are computed between 5-day OLR and 5-day rainfall by using data of four years (1976, 1977, 1979 & 1980), 3 month seasons (July through September) for which the data of both the fields are available. A sample of 72 pentads is thus used. These concurrent correlations are presented in Fig. 4. It can be seen that the maximum correlations are found over the western parts of central India, along about Lat. 20° N. The first EOF of rainfall as well as OLR fields shows highest organised loadings over this region representing maximum spatial coherence. It is interesting to note that a second centre of high correlation between OLR and rainfall lies over north India near the western parts of the Himalayas. It may be noted further that these regions of high concurrent association between OLR and rainfall remain nearly same when the time period of averaging is increased from 5-day to a month.

5. Conclusions

On the basis of this study the following conclusions are drawn :

(*i*) The 40-day oscillations in rainfall are strongest over the western parts of India near Lat. 20° N. These oscillations explain more than 25% of the spatio-temporal variance of 5-day rainfall. Related with these oscillations, the rainfall anomalies over the country show northward progression with average speed of about 0.6 Lat./day.

(*ii*) These oscillations show considerable interannual variability in the intensity and period which does not seem to be linearly related with the overall performance of monsoon or the phases of ENSO. The oscillations also show considerable intraseasonal variability.

(*iii*) The simple lag cross-correlations of about 0.3 to 0.4 are obtained over central India and west coast up to a lag of 2 to 3 pentads by using the rainfall/OLR averaged over certain key regions.

(*iv*) The OLR fields suggest presence of coherent convective processes over the equatorial oceanic area across Long. 85° E in addition to the one over central India.

(*v*) The concurrent relationship between the rainfall and OLR on 5-day scale is strongest over the western parts of central India.

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