Intra-Seasonal Oscillations of Indian Monsoon: Dynamics through NCEP/NCAR Reanalysis Data

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INTRODUCTION

The summer monsoon (June through September) rainfall variability over India is partly due to the external surface boundary forcing and partly due to its internal dynamics. Slowly varying surface boundary conditions such as sea surface temperatures (SST), snow cover, soil moisture in the preceding winter and the pre-monsoon season are believed to constitute a major forcing on the year-to-year variability of the Indian monsoon rainfall. The variability due to internal dynamics is highly unpredictable. Several recent modeling studies have shown that a significant fraction of inter-annual variability of the seasonal mean Indian summer monsoon is governed by internal chaotic dynamics. The intra-seasonal variability dominant during the monsoon season constitutes this internal dynamics.

It is well known that the rainfall distribution over India during the summer monsoon season varies considerably from day-to-day. Over major parts of the country rain occurs in spells under the influence of favorable circulation conditions. This intermittent behaviour of rainfall is associated with a hierarchy of quasi-periods, namely 3-7 days , 10-20 days and 30-60 days. While 3-7 days periodicity is associated with the oscillation of monsoon trough over the Indo-Gangetic planes, the 10-20 days periodicity or the quasi-biweekly oscillations are associated with the westward moving waves originating in the Pacific or the synoptic scale convective systems generated over the warm Bay of Bengal, propagating inland and contributing substantial amount of rainfall. The 30-60 days periodicity is linked with the globally eastward moving wave numbers 1 and 2 in the tropics in particular over the equatorial regions. This eastward moving mode is designated as Madden-Julian oscillation (Madden and Julian 1971, Sikka and Gadgil 1980). These two periods 10-20 days and 30-60 days have been related with the active and break cycles of the monsoon rainfall over Indian subcontinent. The 30-60 days oscillations are also characterized by northward movement of weather anomalies over Indian longitudes during summer monsoon season (Singh and Kripalani 1985, 1986, 1990, Kripalani et al 1991, 1992). Thus the inter-annual changes in the intra-seasonal variability are an important potential source of inter-annual fluctuations of the strength of the summer monsoon rainfall over India (Kulkarni et al 2006)

Thus the monsoon strength may depend on the frequency and duration of the spells of active and break periods associated with the fluctuations of various intra-seasonal time scales. Thus the predictability of the seasonal mean Indian monsoon depends on the extent to which the intra-seasonal oscillations influence the seasonal mean relative to the externally forced component. Hence the primary objective of the present study is to bring out how and to what extent the intra-seasonal oscillations (ISOs) affect the seasonal mean and its inter-annual variability.

DATA

The data sets used in this analysis are as follows :

(i)Gridded daily rainfall for 52 blocks each of 2.5^{o} lat x long uniformly spread over India for the period 1June to 30 September for 1901-1989 were prepared earlier (Kripalani et al 1991; Singh et al 1992). This is based on 365 stations well spread over the country. The original daily station rainfall data were acquired from the India Meteorological Department (IMD). Average daily rainfall of the 52 blocks represents the intensity of rainfall (mm/day) over the country for that particular day.

(ii)Daily rainfall data for India as a whole for the period 1 June to 30 September for 1990-2007 have been updated from the All India Weather Summary prepared by IMD. Day to day rainfall is based on approximately 120 to 150 stations. The daily rainfall anomalies for each of 1901-2007 based on the entire period constitute the basic data for our analysis.

(iii)The time series of seasonal (June through September) Indian monsoon rainfall (IMR) for the above 107 years (1901-2007) has been downloaded from the website (www.tropmet.res.in) of the Indian Institute of Tropical Meteorology. This series is the measure of the intensity of the whole monsoon over the Indian region during summer monsoon season.

(iv)The NCEP/NCAR reanalysis data set (Kalnay et al 1996) for the 850 hPa vector winds for the period 1948-2007 is used to examine the dynamic circulation features associated with the extreme phases of the ISOs. Large scale circulation features over the Indo-Pacific region are very well depicted by this data set .

(v)Data for the 10-parameters used by IMD in operational long-range forecasts for IMR for 1958-2003. More details about these parameters are available in Rajeevan et al (2004).

INTENSITY OF THE INTRA-SEASONAL OSCILLATIONS

For examining the intensity of ISOs, Butterworth's band-pass filter (Murakami 1979) with peak response around the dominant periods are used. Thus half power points at 3 and 7 days for the 3-7 days oscillations, at 10 and 20 days for quasi-biweekly oscillations and at 30 and 60 days for Madden-Julian Oscillations is applied to the time series of daily rainfall anomalies. The strength of the ISOs are identified by first computing the unfiltered variance. The percentage of the original variance retained by the filtered time series is then determined. Thus the percent variance contained in the three periodicities is a measure of the intensity of these three oscillations. The standardized IMR series determines the seasonal monsoon strength. The IMR series of 1901-2007 has long-term mean of 852mm with standard deviation of 83 mm. We define an excess (deficient) monsoon when standardized IMR is greater (less) that +1.0 (-1.0).

To examine the relationship of the intensity of ISOs with the total seasonal monsoon rainfall, scatter plots and the correlation analysis between the percent variance in each band and the standardized IMR are determined.

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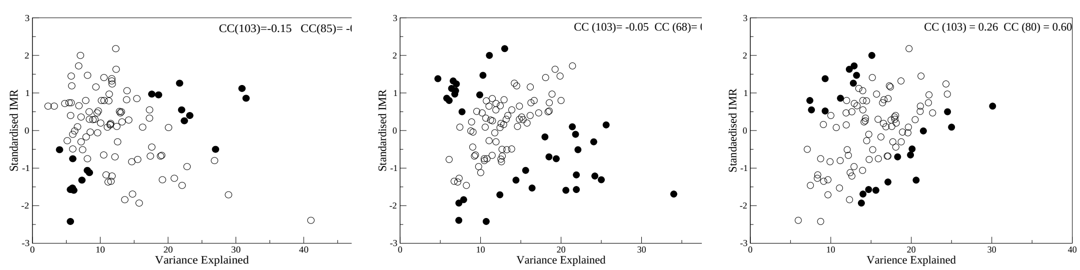

(a) (b) (c)

Fig 1 : Scatter plots of variance explained by (a) 3-7(b)10-20 and (c)30-60 days mode on X-axis and Standardised Indian monsoon rainfall on Y-axis

Fig 1 (a) shows the scatter between the standardised IMR and the intensity of the 3-7 days mode. The scatter plot suggests the positive relationship (+0.26). However if some contradictory points (solid dots) are removed, the correlation enhances to +0.60 based on 80 values which is highly significant. Similar scatter plots for 10-20 days and 30-60 days mode are shown in Fig 1(b) and Fig1 (c) . The relationship of IMR is positive (negative) with 10-20 (30-60) days mode. Again if some points contradicting the relationship are deleted then the correlation shoots up to +0.67 from -0.05 and = -.53 from -0.15 for 10-20 and 30-60 days mode respectively. In summary it can be inferred that the positive relationship between the intensity of 3-7 and 10-20 days mode with IMR suggests that the dominance of these modes during the monsoon season will favor monsoon activity over Indian region. On the other hand the negative relationship between the intensity of 30-60 days mode with IMR suggests that the monsoon activity will not be favored when this particular mode prevails, indicating a significant control by the ISOs in determining the seasonal rainfall. Kripalani et al (2004) have shown the similar results for contrasting monsoons of 2002 and 2003. Whether ISOs modulate the seasonal monsoon strength through the intensification or weakening of the large-scale monsoon flow is examined in the next section.

CIRCULATION PATTERNS ASSOCIATED WITH THE EXTREME PHASES OF THE MODES

To study the associated circulation with these two modes we first identify the 5 most intense and most weak phases of 30-60 and 10-20 days oscillations. These years and the associated standardized IMR for 30-60 days mode are tabulated in Table 1 while those for 10-20 days are tabulated in Table 2.

Table 1 : 5 strongest and weakest episodes of 10-20 days mode. Values in the brackets are associated standardized IMR.

EXTREME INTENSE AND WEAK 10-20 MODE			
MAXIMUM 10-20		MINIMUM 10-20	
YEARS (Std IMR)	VE %	YEARS (Std IMR)	VE %
1956 (+1.8)	21.4	1982 (-1.4)	7.2
1988 (+1.5)	19.9	1972 (-2.4)	7.3
1953 (+1.0)	18.9	1986 (-1.3)	7.3
1957 (-0.7)	18.5	2002 (-1.9)	7.3
1971 (+0.5)	18.5	1981 (+0.1)	7.4

Table 2 : 5 strongest and weakest episodes of 30-60 days mode. Values in the brackets are associated standardized IMR.

EXTREME INTENSE AND WEAK 30-60 MODE			
MAXIMUM 30-60		MINIMUM 30-60	
YEARS (Std IMR)	VE %	YEARS (Std IMR)	VE %
1972 (-2.4)	41.1	1993 (+0.7)	2.3
1979 (-1.7)	28.9	1949 (+0.8)	5.4
1986 (-1.3)	20.9	1988 (1.5)	5.7
1998 (+0.1)	20.1	1970 (+1.2)	5.8
1966 (-1.3)	19.2	1984 (-0.1)	5.9

10-20 days mode

The vector wind composites based on the years in Table 1 are prepared. Fig 2 upper (center) panel shows the vector wind composite anomalies associated with the intense (weak) phase of 10-20 days oscillation. These two patterns are remarkably contrasting over Indian as well as Pacific ocean. An anomalous anticyclonic circulation centered around 10N,70E over the Arabian sea is evident during the intense phase of this mode. This pattern suggests a transfer of moisture from the equatorial Indian ocean region and the Arabian sea towards the Indian sub-continent enhancing rainfall activity. Also the establishment of monsoon trough is seen around 20N. On the other hand the anomalous cyclonic circulation around 5N, 80E prevails during weak phase of this oscillation. This pattern clearly inhibits moisture supply towards Indian mainland. Over the Pacific easterly (westerly) flow is evident in the intense (weak) phase of this oscillation which resembles La Nina (El Nino) phase of the ENSO phenomenon over the Pacific. It is interesting to note that the easterly flow during the intense phase may transport moisture from the west Pacific through Southeast asia and Bay of Bengal. The difference between these two composites are tested using t test and are shown in Fig2 (bottom panel). The significant difference is seen over equatorial Pacific region and not over Indian ocean suggesting that the remote Pacific ocean is modulating the behaviour of this mode more than neighbouring Indian ocean.

30-60 days mode

Similar composites for extreme phases of 30-60 days mode (Table 2) are also prepared and presented in Fig 3. It is seen that anomalous anticyclonic flow prevails over Indian ocean in the itense phase of this mode which inhibits the moisture supply from the Indian ocean/Arabian sea towards Indian landmass. A similar reverse circulation pattern is also visible over Pacific ocean.While the westerly flow dominates the equatorial Pacific for the intense phase of this mode, easterly flow dominates for the weak phase. Again the composites show significant difference over the Pacific (Fig 2, bottom panel).In summary the intense phase of the 10-20 days mode and the weak phase of 30-60 days mode is associated with anti-cyclonic circulation over the Indian ocean, easterly flow over the equatorial Pacific ocean resembling the cold phase of ENSO and the weakening of North pacific Subtropical High. On the other hand the weak phase of 10-20 days mode and the intense phase of 30-60 days mode shows remarkable opposite flow patterns. Development of both these modes appears to be in remote Pacific Ocean rather than the neighbouring Indian Ocean. These results suggest some influence of the boundary forcing, here ENSO , on the intra-seasonal behaviour of the monsoon.

PREDICTABILITY OF THE MODES

To foreshadow the behaviour of these modes the circulation features during preceeding winter and spring have been examined. For the 10-20 days mode the vector wind patterns during May give clear picture while for 30-60 days mode the April winds are more clear. It is observed that there is tendency for the flow patterns observed in pre-monsoon months to persist during monsoon months. Some indications of the behaviour of these modes during the monsoon season could be foreshadowed from the spring season circulation patterns.

RELATIONSHIP BETWEEN INTENSITY OF MODES AND LRF PARAMETERS

All of these studies indicate that the intra-seasonal monsoon fluctuations represent internal modes of the system and are therefore not necessarily related to the slowly varying surface boundary forcings such as SST anomalies, hence unpredictable (Goswami and Shukla 1984; Gadgil and Srinivasan 1990). In this section we examine the relationship between the intensity of the modes and the long-range forecasting (LRF) parameters used operationally by the IMD to see whether the predictors of IMR contain any information about the intermittent behavior of rainfall. The number of parameters have been used to predict seasonal IMR such as Arabian sea SST, Eurasian snow cover, NW Europe temperature, NINo3 SST anomalies, East Asia Pressure, NH 50 hPa wind pattern, Europe pressure gradient etc. We compute the correlations between the

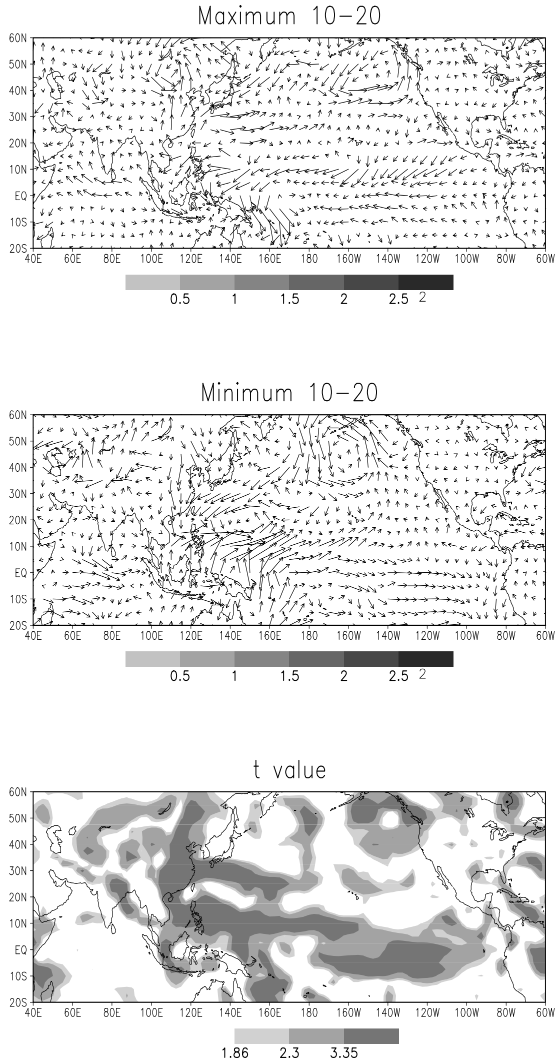

Fig 2: Composite vector wind anomalies (JJA) based on extreme phases of 10-20 days oscillations and the t value of difference. The significant Values at 10%, 5% and 1 are shaded

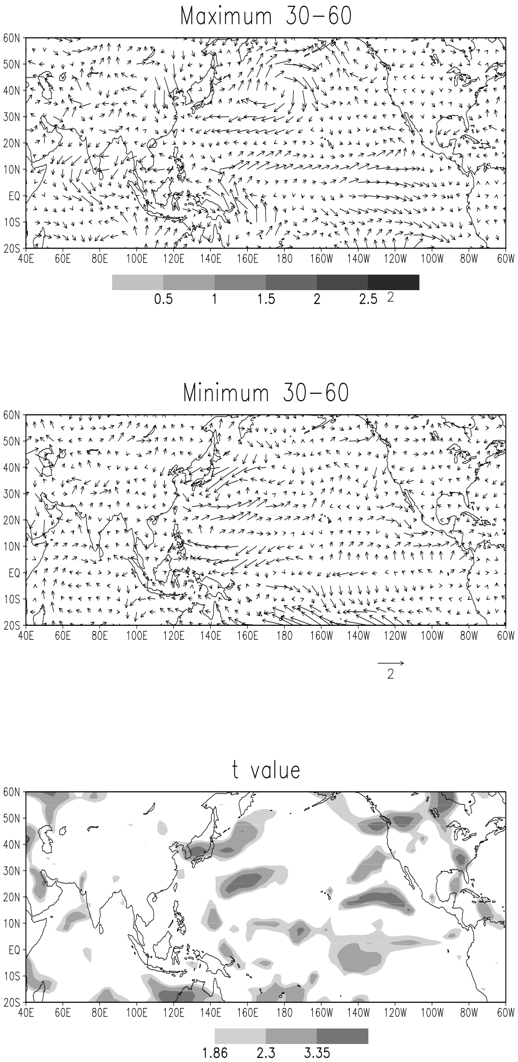

Fig 3: Same as Fig 2 but for 30-60 days oscillations

variance explained by the 3 modes of intra-seasonal variability and these parameters based on 1958-2003. The east asia pressure in prceeding February+march shows the strongest relationship with these modes. The CC is -0.44 (0.55) with the intensity of 30-60 (10-20)days oscillations based on selected 40 (28) years (selected in Fig 1) which are highly significant at 1% level. Hence the predictors for IMR do contain some skill in foreshadowing the behavior and nature of ISOs.

CONCLUSIONS

From the above study we conclude that dominance of 10-20 (30-60) days mode in monsoon season favors (do not favor) the monsoon activity over India. The intense phase of 10-20 days oscillation and a weak phase of 30-60 days oscillation is associated with anti-cyclonic circulation over Indian Ocean, easterlies over

Pacific ocean and weakening of NPSH leading to intensification of Indian monsoon and weakening of East Asian monsoon. The flow patterns during premonsoon months April and May do persist during monsoon season hence spring season patterns help to foreshadow the behaviour of ISOs. East Asia pressure (Feb+Mar) is the most important predictors for intra-seasonal behaviour of monsoon.

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