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Morphology of intra-seasonal oscillations in the Indian summer monsoon

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सार — ग्रीष्म मानसून के दौरान आन्तर-ऋतु परिवर्तनों को अनेक शोधकर्त्ताओं द्वारा उल्लेखित किया गया है। हाल में, 10-15 दिनों तथा 30-50 दिनों के समय मापों में कम बारम्बारता दोलनों का व्यापक अध्ययन हुआ है। प्रादेशिक आधार पर (भारतीय उपमहाद्वीप के ऊपर) आन्तर-ऋतुनिष्ठ न्यूनाधिकता के रूपविचार का अध्ययन माध्य परिसंचरण प्राचलों के उपयोग से किया गया है। कम बारम्बारता दोलन (30-50 दिन) और वर्षा की न्यूनाधिकता पर इसके प्रभाव का विवेचन किया गया है। वर्षा में अधिकांश आन्तर-ऋतुनिष्ठ दोलन के लिए व्याख्या देने के रूप में सिनॉप्टिक पैमाना (3-5 दिन) दोलन और द्विसाप्ताहिक दोलन, अपेक्षाकृत अधिक उपयुक्त प्रतीत होता है।

ABSTRACT. Intra-seasonal variations during the summer monsoon have been documented by various workers. Recently, low frequency oscillations in the time scale of 10 - 15 days and 30 - 50 days have been extensively studied. The morphology of intra-seasonal fluctuations on a regional scale (over the Indian sub-continent) has been studied using mean circulation parameters. The low frequency oscillation (30 - 50 days) and its contribution to the fluctuations of rainfall have been discussed. Synoptic scale (3 - 5 days) oscillation and the quasi-biweekly oscillation appear more relevant as a tool of explanation for the major intra-seasonal oscillation in rainfall.

1. Introduction

The regional monsoon circulation exhibits variability on various time scales, *e.g.*, the synoptic mode, the quasi-biweekly mode, near forty-day mode and the inter-annual mode (Shukla 1985). Monsoon rainfall having considerable economic impact for India, forecasting on short, medium and long range are important. In the present investigation an examination has been made of the intra-seasonal variation of the summer monsoon rainfall over India for the period 1979-83. The year to year variations of the onset and advance and active and break cycles are discussed. Studies by Yasunari (1981), Sikka and Gadgil (1980) have shown that cloudiness over an extensive zone in the Asian summer monsoon domain shows a periodic oscillation in the time scale of 30-50 days. It has also been claimed that this mode is capable of explaining the major active-break cycle in monsoon rainfall. Murakami *et al.* (1984) have shown that over the monsoon region spectral peaks with periods shorter than 10 days are quite prominent in the lower troposphere, in the v' spectrum, while at 200 hPa u' fluctuations in the 40-50 day period are not significant over the Indian sub-continent. u' and v' are the intra-seasonal transient variations in the wind component as defined by Murakami *et al.* (1984). The central question is, therefore, to understand the relative effect of short period synoptic scale oscillation and low frequency planetary oscillations on the summer monsoon maintenance. However, examination by Murakami *et al.* (1984) was confined to only the FGGE level III B data for 1979. In this paper, a critical examination is made about the role of 30-50 days cycle in modulating the rainfall over India by considering five years data, 1979-83.

Observational evidence have been examined for identifying this mode in the rainfall during the summer monsoon season by Rama Sastry *et al.* (1986). It was shown that the near forty-day mode is variable from year to year. It is also not seen all over the Indian subcontinent and the mode is masked beyond 20° N. In the present paper the morphology of the intra-seasonal oscillation has been examined by utilizing the mean circulation charts and weekly rainfall departures. Spatial and temporal variation in these are discussed.

2. Methodology

The weekly rainfall departure for different subdivisions in India have been collected for the summer monsoon season (Jun-Sep) from 1979 to 1983. This

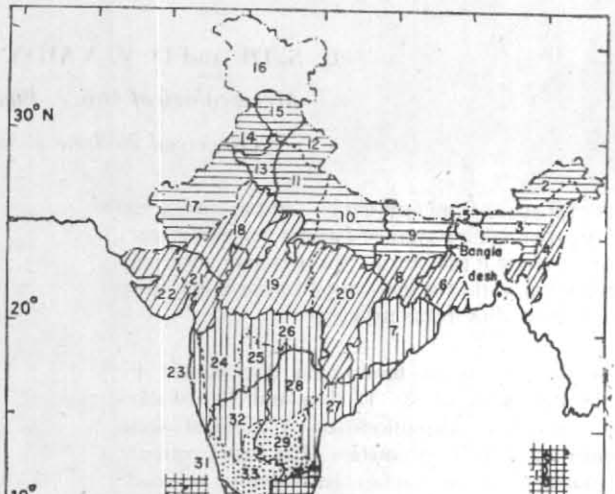

Fig. 1. Demarcation of zonal belts for averaging rainfall

TABLE 1

Year	Dates of onset over Kerala	Dates when covered entire country
1979	11 June	11-15 July
1980	1 June	26 June
1981	30 May	10 July
1982	28 May	22 July
1983	12 June	18 July

has been arranged into nearly zonal strips and the rainfall departures, have been worked out with complete meteorological sub-divisions of India as the smallest unit (Fig. 1). The zonal belts are :

Belt No. I — From the southern tip of the country upto about 10° N (Including Arabian Sea and Bay Islands).

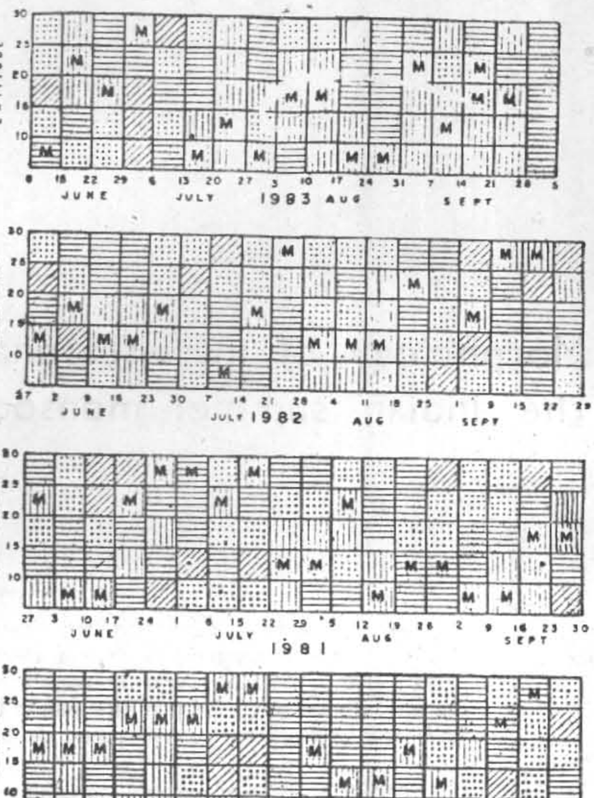

Fig. 2. Latitude time-section of weekly rainfall anomalies

TABLE 2

Auto-correlation for different zonal belts for different lags

	1 wk lag	2 wk lag	3 wk lag	4 wk lag	5 wk lag	6 wk lag	7 wk lag
Belt I	0.35*	0.05	—0.13	—0.01	0.09	0.05	0.00
Belt II	0.42*	0.09	—0.09	—0.04	0.05	0.07	0.27**
Belt III	0.39*	0.03	—0.11	—0.11	—0.03	0.19	0.29**
Belt IV	0.27*	0.07	.0.13	—0.05	0.05	0.14**	0.08
Belt V	0.09**	0.00	0.04	0.15*	0.05	—0.12	0.05

*Max. auto-correlation for the zone, **Next highest auto-correlation (+ve)

Belt No. II — Area approximately between 10° & 15° N over land.

Belt No. III — Area approximately between 15° & 20° N over land.

Belt No. IV — Area approximately between 20° & 25° N over land.

Belt No. V — Area approximately between 25° & 30° N over land.

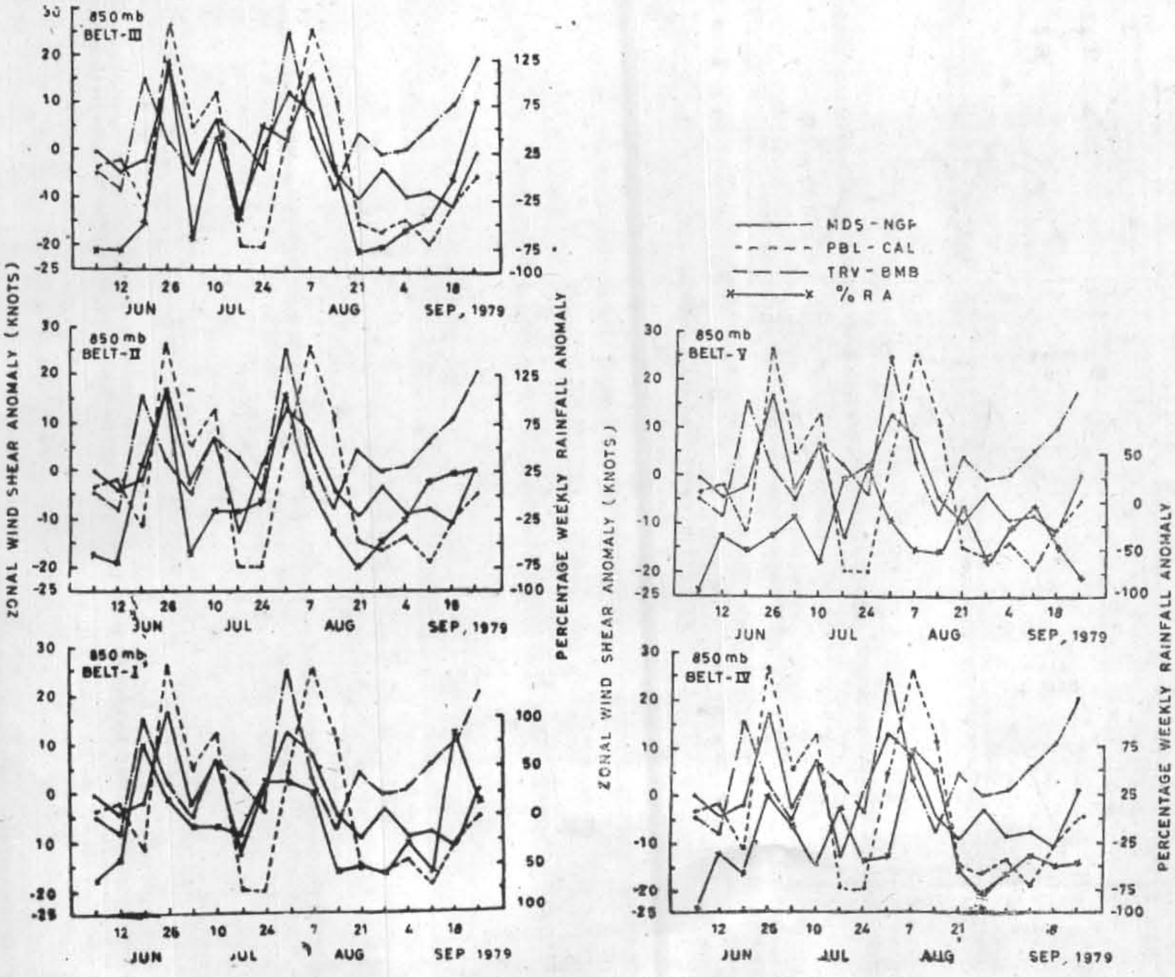

Fig. 3 (a). Weekly zonal shear anomaly and percentage rainfall anomalies for different zonal belts (1979)

The percentage of rainfall departures in each belt for different weeks for the five years 1979-83 are shown in Fig. 2 as a latitude-time section. The data set used is essentially same as that of Rama Sastry *et al.* (1986). The weekly rainfall departures of each belt *vis-a-vis* the zonal shear anomaly along 75° E(TRV-BMB), along 80° E (MDS-NGP) and 90° E (PBL-CAL) are shown in Figs. 3 (a) & (b). The rainfall departures in each belt and its auto-correlation with different lags are shown in Fig. 4.

3. Discussion

The latitude-time cross-section bring out the major intra-seasonal fluctuations in each of the five years studied. The zone of maximum positive departure of rainfall (MZR) in a week is marked M. This zone originates in the southernmost belt corresponding to the date of onset of monsoon over Kerala. But its northward movement is often irregular, *e.g.*, the zone of maximum rainfall in 1983, first appeared in the period 8 to 15 June over the southernmost belt and covered the whole country practically reaching the northernmost belt up to 30° N by 6 July. Similar rapid progression is also seen during 1981.

Table 1 gives the dates of onset of monsoon over Kerala and the date when it covered the whole country.

As discussed earlier in 1983 the zone of maximum rainfall first appeared in the period 8 to 15 June over the southernmost belt and covered the whole country practically reaching the northernmost belt up to 30° N by 6 July. Similar rapid progression is also seen during 1981.

The MZR moved from the southernmost part to 30°N by 6 July but the second spell which commenced on 20 July in belt I was irregular and remained stationary in the belt III between 3 and 17 August.

The onset in 1982 over Kerala occurred a couple of days earlier than the normal date but the MZR moved to the northernmost region by last week of July. The second spell commenced in belt I on 4 August but MZR remained stationary from 4 to 8 August on belt II.

In 1981, the onset over Kerala was on 30 May and was complete over the entire country by 10 July. The next spell of active rainfall over the southernmost belt appeared from 22 July, *i.e.*, there was a continuous

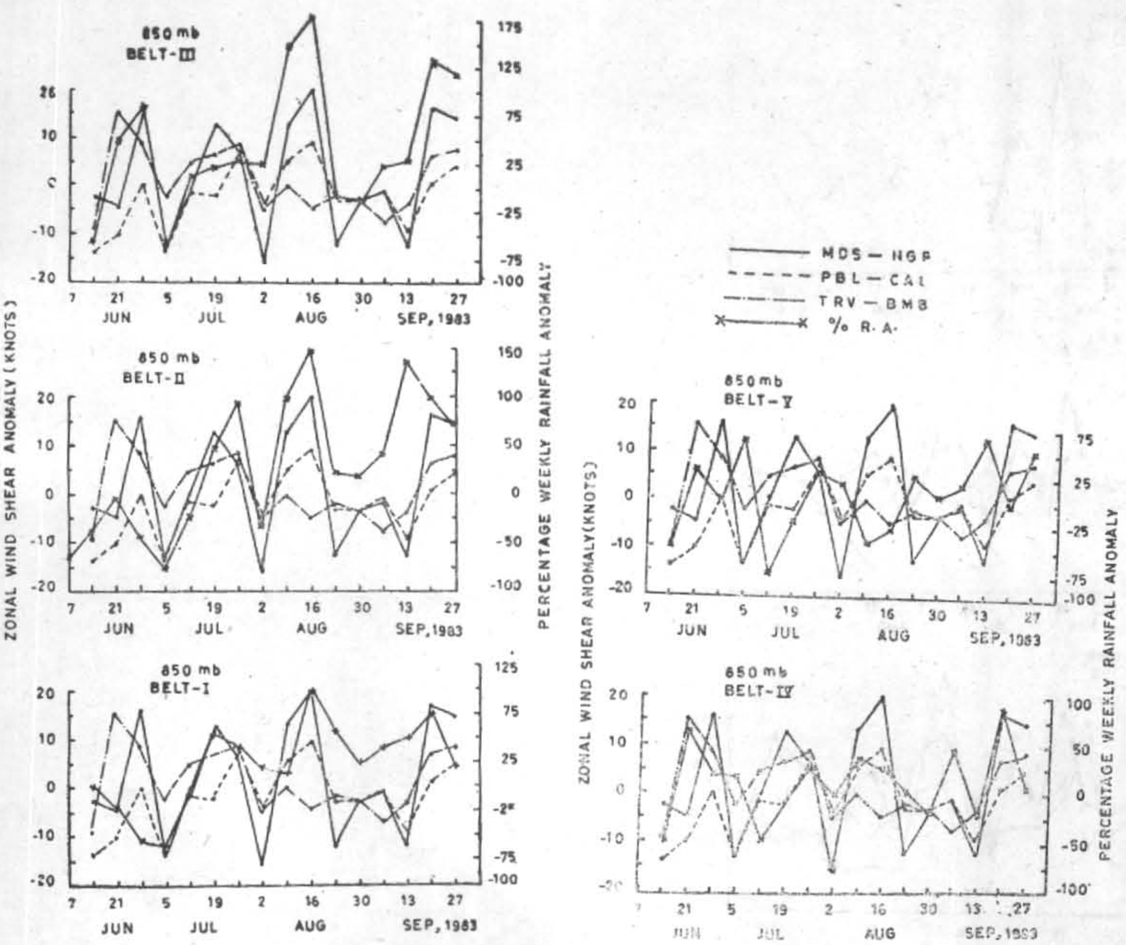

Fig. 3(b). Weekly zonal shear anomaly and percentage rainfall anomalies for different zonal belts (1983)

suppression of rainfall in its southern belt upto 15° N between 10 and 22 July.

The onset in 1980 occurred on 1 June and was complete by 25 June for three consecutive weeks from 4 to 18 June the MZR was stationary in belt III and from 25 June to 9 July in belt IV. Interestingly, there was no suppression of rainfall except during week ending 18 June in belt I and 8 July in belt II during this three-week period.

1979 is, perhaps, the only year in which there is a near regular northward progression of MZR from 13 June to about 18 July from extreme south to 30°N. The onset of monsoon over Kerala occurred on 11 June and the entire country was covered by 15 July. A second northward propagating mode could also be seen between 18 July and 22 August. It, therefore, shows that a fresh northernmost moving pulse from south does not necessarily start with a periodic or quasi-periodic regularly.

In the years 1979 and 1982 which were bad monsoon years the onset and appearing of rainfall maxima in its southern belt was delayed in 1979 only, but the whole country was covered by the summer monsoon by about second week of July, while in 1982 the onset over Kerala occurred a couple of days earlier than the normal date but the zone of maximum rainfall moved to the northernmost region by the last week of July. Thus, during the onset phase the near forty-day mode is found to vary considerably from one year to the other. The analysis of Sikka and Gadgil (1980) showed that the northward movement of zone of maximum cloudiness is not gradual but occurs as an abrupt shift after persisting at the same latitude for a few days. An analysis of weekly rainfall data shows that the MZR during the summer monsoon does not show a regular periodic northward movement. Thus, the period of occurrence of MZR in a fixed belt never showed a definite lag with the appearance of the zone in the southernmost belt.

In order to examine the presence of any periodicity in the weekly rainfall departures for each of these five zonal belts auto-correlation coefficients with lags varying from one to seven weeks were computed, these are shown in Fig. 4. In belts I to IV the maximum auto-correlation is with one week lag. The magnitude of auto-correlation for one week lag is between 0.09 and 0.4 as shown in Table 2. This explains a maximum of about 17% of the variance. The next maxima in the auto-correlation occurs with a lag of five weeks in belt I, and seven weeks in belts II and III, with six weeks in belt IV and with four weeks in belt V. However, the maximum auto-correlation coefficient with lag of four to seven weeks

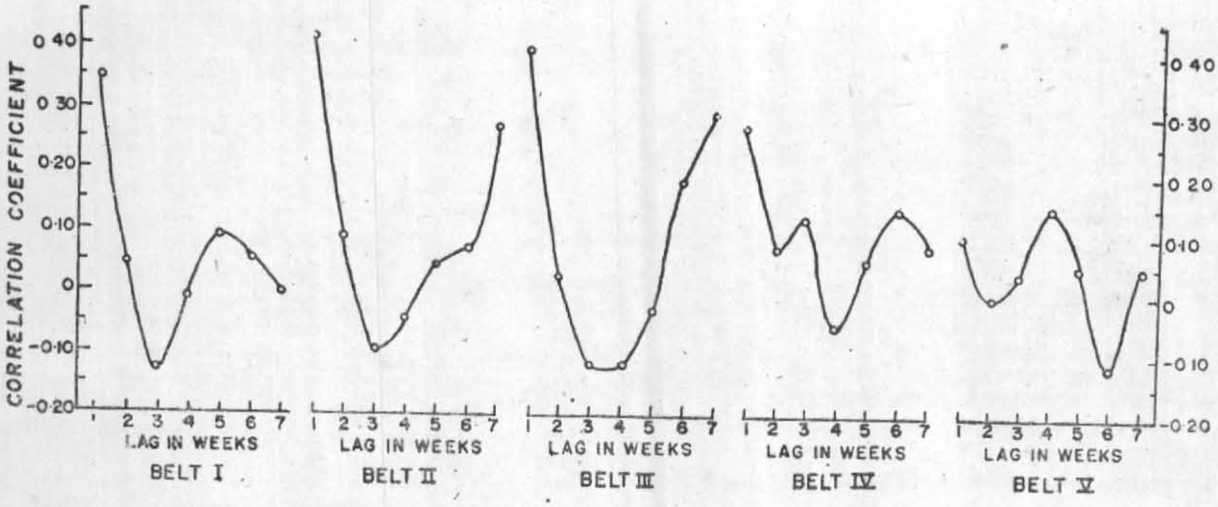

Fig. 4. Auto-correlation of rainfall anomaly for different zonal belts

TABLE 3

Lag correlation between different belts

	I	II	III	IV	V
I	0	0.63*	0.37	0.03	—0.10
	1	0.46**	0.49	0.34	0.16
	2	0.14	0.19	0.24	0.24
	3	0.01	0.12	0.15	0.16
	4	—0.02	—0.01	—0.01	0.05
	5	0.11	0.17	0.21	0.12
	6	0.28	0.12	0.12	0.07
	7	0.23	0.15	0.10	—0.14
II	0		0.60*	0.33	0.14
	1		0.42**	0.41	0.17
	2		0.11	0.19	0.04
	3		0.01	0.17	0.05
	4		—0.03	0.04	0.16
	5		0.08	—0.01	0.05
	6		0.07	0.07	—0.03
	7		0.23	—0.07	—0.33
III	0			0.45*	0.11
	1			0.44**	0.24
	2			0.15	0.07
	3			0.11	—0.03
	4			—0.09	0.06
	5			—0.01	0.09
	6			0.12	0.01
	7			0.09	−0.12
IV	0				0.44*
	1				0.25**
	2				—0.01
	3				—0.05
	4				0.13
	5				0.20
	6				—0.03
	7				—0.16

*Maximum lag correlation between adjacent belts.
**Next highest lag correlation.

is found to be 0.289 for belt III and this could explain a variance of less than 10% of the weekly rainfall. It can be concluded that these periodic oscillation in the rainfall having a period 30 to 50 days (4-7 weeks—Rama Sastry *et al.* 1986 *loc. cit.*) have very low auto-correlation and are capable of explaining less than 10% of the weekly variation in the rainfall.

To examine the northward propagation of this mode in the weekly rainfall inter-correlation between the five belts with different lags (0 to 7 weeks) have been worked out and are shown in Table 3.

In general, it is observed that maximum lag correlation values decreased towards north and maximum correlation between two adjacent belts occurs with no lag as far rainfall of a whole week is considered. This can be interpreted as the north-south movement of the rainfall belt over a space of five degress or so, is quite regular and is well marked in the southern belts. The maximum correlation between two adjacent belts is found between belts I and II and minimum between IV and V.

Maximum correlation with one week lag occurs between belts I and III. It explains about 25 % of the variation of the rainfall in one belt. Maximum correlation with two weeks lag occurs between belt I and belt V but it accounts for only about 6% of the variation of rainfall in the belts. Thus, the importance of the northward propagating mode decreases as one moves from belt I to belt IV.

The variation of auto-correlation and the inter-correlation between two belts clearly shows that only a very small fraction ($\approx$ 10%) of the fluctuation in weekly rainfall could be attributed to the low frequency mode (30 to 50 days). Furthermore, the maximum auto-correlation in most of the belts occur with one week lag. This brings out clearly the importance of synoptic scale oscillation in the summer monsoon. This study also confirms the earlier findings of Rama Sastry *et al.* (1986) that the low frequency mode is masked beyond 15° or 20° N due to the interaction with transient westward moving disturbances in the lower tropospheric monsoon westerlies.

4. Analysis of Weekly Mean Zonal Shear Anomaly (WMZSA)

The circulation during the summer monsoon has been studied using weekly mean circulation charts. The mean zonal shear along three different longitudes (75° E, 80° E, 90° E) have been computed by taking the zonal shear anomaly: TRV-BMB; MDS-NGP and PBL-CAL. The mean zonal shear anomaly is worked out by subtracting the mean zonal component of the wind (based on long term upper wind normals) from the actual mean zonal component for that week and then taking the difference between pairs of stations as indicated in Figs. 3(a) and 3(b).

In 1979, the WMZSA was below normal in all the three belts up to 12 June. It was largely above normal from 26 June to 10 July in all the three belts. Spells of below normal WMZSA generally occurred in one or two belts at a time. From 14 August till end of September the WMZSA was below normal in the two belts (MDS-NGP and PBL-CAL). Spells of active cyclogenesis in the Bay occurred between 23 & 26 June, 28 June & 1 July, 7 & 8 July, 6 & 10 August and 12 & 15 August. WMZSA along PBL-CAL showed strong positive anomaly during all these epochs.

During 1983, WMZSA was below normal along PBL-CAL from 14 June to 19 July and from 2 August to 13 September along TRV-BMB. Interestingly, the WMZSA values were below normal in all the three belts from 23 August to 13 September. Such simultaneous occurrences are rather infrequent. Two spells of cyclogenesis in the Bay, *i.e.,* from 24 June to 27 June and 19 July to 21 July occurred when WMZSA along PBL-CAL showed rising trend although the values were not very large. Similar features were noted during 1980, '81 and '82 also, details of which are not included for the sake of brevity. Monitoring daily and weekly lower tropospheric zonal shear anomalies appear to hold some promise in forecasting the events in the Bay.

The oscillations in the WMZSA showed an inverse relationship with rainfall in belt V (the northern belt over India, 25-30° N). This was due to the movement of the low level monsoon trough to the north causing decrease in the zonal shear to the southern belts. On the other hand, the rainfall in the belt 15°-20° N was found to vary almost concurrently with the oscillations in the WMZSA. It is of interest in this connection to note the findings of Prasad *et al.* (1986) regarding the existence of an inverse relationship between the activity of the southern hemispheric equatorial trough (SHET) and the rainfall in the belt 15°-20° N.

5. Conclusions

(*i*) The low frequency mode in summer monsoon rainfall (30-50 days) shows considerable variation from year to year. The northward propagation of the mode also appears to be irregular. The zone of maximum rainfall departure (MZR) also remains stationary along certain belts which is caused due to spasmodic nature of the advance of the monsoon.

(*ii*) The zone of maximum rainfall shows northward progression with variable speed and the movement is often abrupt. After the onset phase the appearance of the second or third epoch in the cycle is also irregular.

(*iii*) The auto-correlation analysis shows that the maximum auto-correlation for all the five belts is with a lag of one week. Auto-correlation with a lag of four to seven weeks are rather low for almost all the belts. Thus, major intra-seasonal oscillations in rainfall are due to synoptic scale disturbances. The low frequency mode appears capable of explaining only 1-10% of the observed variance in the rainfall. The variance in rainfall explained by this mode showed considerable variation in different belts.

(*iv*) The circulation in the lower troposphere along the three meridians (75° E, 80° E and 90° E) in the monsoon flow also showed the relative dominance of the synoptic mode over the low frequency mode. Intensification in the circulation depended more on synoptic disturbances; than on the position and intensity of low frequency mode. This is in agreement with the findings of Murakami *et al.* (1984) using spectral analysis of 850 and 200 hPa flow fields for 1979.

(*v*) The oscillation in WMZSA showed concurrent variation in same sense with the rainfall anomaly in belt III and in the opposite sense with belt V.

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