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Usability of the low frequency mode in southwest monsoon circulation for long range prediction of rainfall activity over central India

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सार—कुछ स्टेशनों को उपरितन वायु आंकड़ों के आधार पर, निम्न आवृत्ति मोड़ (30-60 दिन) तथा इसकी उत्तर दिशा की ओर प्रसरण की अन्तर्वार्षिक परिवर्तितता का अध्ययन किया गया। इस मोड़ में उल्लेखनीय आवर्तिता की आवृत्ति विशाखापट्टनम और मद्रास के लिए अपेक्षाकृत अधिक है। चुनी हुई सिरीज में अंक्षाशीय पट्टी के साथ बिना किसी वरीयता के अधिकतम कोणांक की, बृहत्त रूप में, अन्तर-वार्षिक परिवर्तिता प्रकट होती है। इस मोड का, उत्तर दिशा की ओर प्रसरण भी बृहत्त अन्तरवार्षिक परिवर्तिता दर्शाता है। कुछ वर्षों में यह प्रसरण बिलकुल विद्यमान नहीं है। विशाखापट्टनम की चुनी हुई सिरीज में फेज परिवर्तन मध्य भारत में साप्ताहिक वर्षा क्रम के परिवर्तनों के समरूप हैं। और मध्य भारत में मानसून सक्रियता की क्रियाशीलता के पूर्वानुमान के लिए, सम्भवतः इसका उपयोग भी किया जा सकता है।

ABSTRACT. The inter-annual variability of the low frequency mode (30-60 days) and its variations in the northward propagation have been studied on the basis of upper air data of a few stations. The frequency of occurrence of significant periodicity in this mode is relatively high for Visakhapatnam and Madras. There appears a large inter-annual variability of the maximum amplitudes of the filtered series with no special preference to any latitudinal belt. Northward propagation of this mode also shows large inter-annual variability. In some years the propagation was totally absent. The phase changes in the filtered series of Visakhapatnam matched with the changes in weekly rainfall activity over central India and this may, perhaps, be used to foreshadow the activity of the monsoon over central India.

Key words — Low frequency mode, Southwest monsoon, Long range prediction, Inter-annual variability, Periodicities, Active monsoon, Weak monsoon.

1. Introduction

The existence of a significant low frequency model oscillation of global nature associated with the zonal component of tropospheric winds was confirmed by Madden and Julian (1972). From the analysis of cloudiness fluctuations Yasunari [1979, 1980, 1981(a) and 1981 (b)] has shown that a predominant periodicity of 30-40 days in quasi-stationary mode exists over India and neighbourhood during the summer monsoon period. It is also shown that the geopotential and windfield in the lower troposphere propagate northward from the equatorial zone towards the Himalayas whereas in the upper troposphere such propagation is seen only in the windfield as the geopotential field in these levels showed a standing oscillation over India. Sikka and Gadgil (1980) studied the daily variation of the maximum cloud zone and have shown the existence of 4-6 weekly mode in the movement of maximum cloud zone over India. Ramasastry *et al.* (1986) have found that the near 40 days mode has large year-to-year variation and is not the dominant mode. They have also shown that the northward progression of rainfall peaks from south to north is not very regular. De *et al.* (1988) investigated the upper winds of a number of radiosonde stations for the period 1979-1984 and have found that the low frequency mode (30-60 days) shows considerable inter-annual variability and that this mode, in general, accounts for less than 30% of the variance in a season and does not have a stable period. They have also indicated that the waves propagate inconsistently northwards and on a few occasions a southward propagation is also seen. Kasture and Keshavamurthy (1987) found that the 30-50 day oscillation extends throughout the troposphere and has a slow northward movement and has some inter-annual variability. Keshavamurthy and Kasture (1990) found that the low frequency mode has a meridional wavelength of 20-25 deg latitude and a slow northward phase speed of 0.6 to 0.8 deg latitude/day. Krishnamurti and Subramanyam (1982) found that the family of low frequency waves in the time scale 30-50 day have a meridional propagation speed of roughly 0.75 deg latitude/day and a meridional separation between troughs and ridges of about 15 deg latitude. The sequence of meridionally propagating trough/ridge lines is seen as early as the first week of May.

i.e., well prior to the onset of monsoon over the Indian subcontinent. Tsing-Chang-Chen (1990) found that the northward travelling 30-50 day troughs and ridges interact with the Indian monsoon trough situated over central India to cause its deepening and filling. This modulation process results in the intensification and the weakening of the Indian monsoon and establishes the life cycle (onset-active -break-revival-retreat) of the monsoon.

It is proposed to investigate in this study the usefulness of the northward propagation of the low frequency mode (30-60 days) to foreshadow the active/break cycles of the monsoon over central India well in advance.

2. Data

The upper air data of six stations ,*viz.*, Thiruvananthapuram (TRV), Madras (MDS), Visakhapatnam (VSK), Bhubaneswar (BWN), Calcutta (CAL) and Guwahati (GHT) for the levels between 900 & 200 hPa at intervals of 100 hPa for the period May-September (153 days) have been used to prepare individual time series for the 8-year period from 1972 to 1979. The data of these six stations for the 5-year period 1975-1979 have been studied to understand the nature of propagation of the low frequency mode (40-day period) in the tropospheric wind field and its inter-annual variation. The graphs of the filtered time series of individual stations have been examined to get an idea regarding the phase and amplitude for all the levels and an attempt is made to roughly relate these variations to the period of occurrence of active/weak cycles of the monsoon of corresponding years.

3. Periodicities in the tropospheric wind field

The upper winds of these six stations for all the levels have been resolved into zonal and meridional components. As a rough approximation, the missing values in their time series have been substituted by their corresponding monthly mean values. Power spectrum analysis using Blackman and Tukey procedure (WMO 1966) has been performed on both the wind components.

Compared to the zonal winds, the meridional winds do not show significant periodicities in the low frequency mode in the range of our interest. This is quite understandable as the tropospheric monsoon flow is dominated by zonal flows (westerlies in lower levels and easterlies in the upper levels). In view of this, we propose to concentrate our analysis and discussions only on zonal wind flow.

The presence or otherwise of the significant periodicities in the low frequency mode in the zonal flow of all the six stations for the period 1972-1979, for all the levels from 900 hPa to 200 hPa levels, have been used to construct frequency tables to explain the level to level and year-to-year variability in the low frequency mode (Tables 1 and 2).

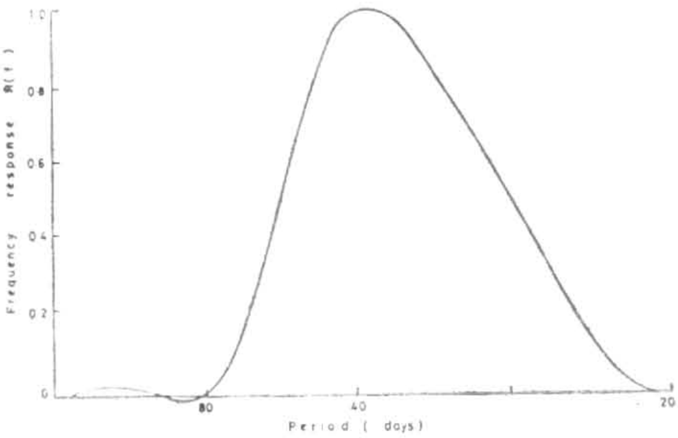


Fig. 1. Frequency response of the "Band-Pass" moving average filter

TABLE 1

Number of years showing the presence of significant periodicity in low frequency mode (30-60 days) for various levels (hPa) during the period 1972-1979

Station	Levels							
	900	800	700	600	500	400	300	200
GHT	5	5	5	4	3	5	6	6
CAL	3	5	5	4	3	3	3	5
BWN	5	5	6	4	4	2	4	7
VSK	7	7	6	7	7	4	4	5
MDS	2	7	7	7	7	5	3	4
TRV	5	5	8	4	4	2	3	4

TABLE 2

Number of levels showing presence of significant periodicity in the low frequency mode (30-60 days) during the period 1972-1979

Station	Years							
	1972	1973	1974	1975	1976	1977	1978	1979
GHT	0	6	5	6	2	8	4	8
CAL	2	5	4	6	3	2	3	6
BWN	0	5	3	8	8	5	6	2
VSK	1	6	6	8	6	8	6	6
MDS	6	6	7	5	1	7	4	6
TRV	2	6	1	5	5	8	1	7

TABLE 3

Maximum amplitudes of filtered series (mps) during July

Station	Years				
	1975	1976	1977	1978	1979
			Level (800 hPa)		
GHT	3.5	1.6	2.8	0.5	5.5
CAL	4.2	2.6	1.0	3.0	4.8
BWN	3.6	3.8	4.2	4.3	3.0
VSK	5.3	3.3	5.8	2.8	5.6
MDS	5.0	2.2	3.7	1.2	7.6
TRV	2.0	3.3	3.9	0.6	5.5
			Level (200 hPa)		
GHT	2.1	4.6	5.6	2.0	2.8
CAL	4.3	2.2	3.7	1.0	3.0
BWN	3.7	0.4	3.1	1.5	2.8
VSK	1.8	1.2	0.9	1.6	5.1
MDS	3.1	3.1	1.9	2.4	1.7
TRV	4.5	4.8	4.1	4.4	4.2

TABLE 4

Number of occasions of different types of rainfall occurrence associated with the passage of troughs/ridges

Year	Trough		Ridges	
	Excess or Normal	Deficient or Scanty	Excess or Normal	Deficient or Scanty
1975	1	2	1	1
1976	0	3	2	1
1977	1	2	2	1
1978	1	2	2	1
1979	0	3	1	2
1980	2	1	3	1
1981	1	2	2	0
1982	2	0	3	1
1983	2	1	3	0
1984	0	3	1	1

The frequency table of number of years in which significant periodicity in the low frequency mode is observed for different levels is shown in Table 1. It is seen that for 5 years or more out of 8, periodicity in the low frequency mode is significant in at least 5 out of 8 levels for Guwahati, Visakhapatnam and Madras whereas in respect of Bhubaneswar, Calcutta and Thiruvananthapuram it is significant in only 3-4 levels.

The frequency table showing the number of levels indicating significant periodicities in the low frequency mode for all the years is given in Table 2. The periodicity in the frequency mode is significant for 5 levels or more in 6 to 7 years for Visakhapatnam and Madras, in 5 years for Guwahati, Bhubaneswar and Thiruvananthapuram and in only 3 years out of 8 for Calcutta. The above discussions made it clear that the frequencies of occurrences of significant periodicity in the low frequency mode in respect of Visakhapatnam and Madras are relatively high both in terms of number of years and number of levels.

4. Inter-annual variability in the amplitudes of the low frequency mode

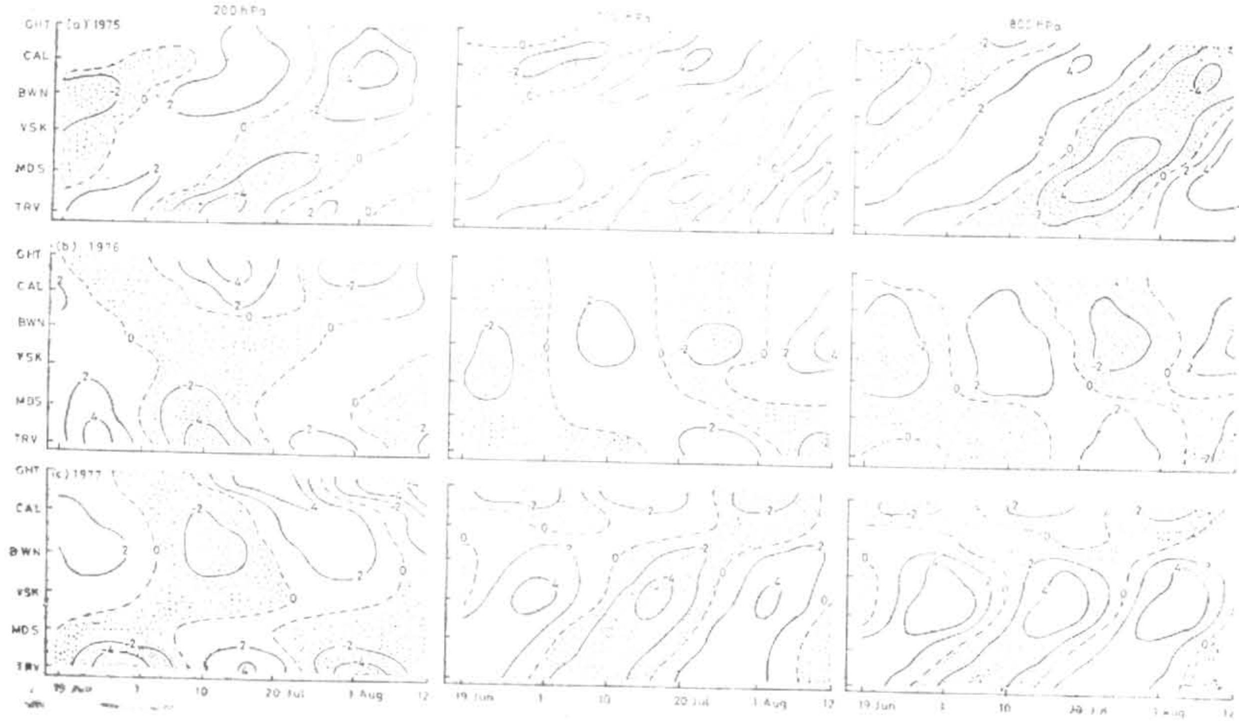
The original time series are filtered using an appropriate band-pass filter for the 40-day mode. The response function curve for this band-pass filter is given in Fig. 1 (WMO 1966).

The graphs of the filtered series for individual years for the six stations for 800 hPa and 200 hPa levels are examined which are representative of the lower and upper troposphere. To obtain a better smoothing, a large number of weights (99) were selected and the filtered series covered the period from 19 June to 12 August. The maximum amplitude during July for all the 5 years for these stations for these two levels are given in Table 3.

The significant features noticed on the inter-annual variabilities in the amplitudes of the filtered series are discussed below.

Lower troposphere (800 hPa) — During 1979 all the six stations showed large amplitudes of 5 mps or more except Bhubaneswar, the maximum amplitudes over Madras being 7.6 mps. During 1975 and 1977 the maximum amplitudes of 5.3 mps and 5.8 mps respectively were noticed over Visakhapatnam. Bhubaneswar showed maximum amplitudes of 3.8 mps and 4.3 mps during 1976 and 1978 respectively. Thus, there appears a large inter-annual variability of the maximum amplitudes of the filtered series with no special preference of any latitudinal belt for its occurrence. Individual stations also showed large inter-annual variability in maximum amplitudes.

Upper troposphere (200 hPa) — In most of the year Thiruvananthapuram showed large amplitudes of the order of 4-5 mps without much inter-annual variability. Maximum amplitudes of the filtered series showed large year-to-year variations in respect of all other stations. Visakhapatnam showed a maximum amplitude of 5.1 mps in 1979, Calcutta of 4.3 mps in 1975 and Guwahati of 4.6 mps and 5.6 mps in 1976 and 1977 respectively.



Figs. 2(a-c). Phase propagation of the low frequency mode in the filtered series of zonal winds (mps) for the years (a) 1975, (b) 1976 and (c) 1977

5. Phase propagation of the low frequency mode

To understand the phase propagation on the low frequency mode (40-day) from the filtered series of individual stations, meridional cross-section charts from Thiruvananthapuram to Guwahati as discussed by Yasunari (1981 a&b), were prepared for the period 1975–1979 for all the levels. However, the results for 800 hPa, 700 hPa and 200 hPa levels only are presented in Figs. 2 (a-e).

(*a*) *800 hPa* — During 1975 and 1979, the northward propagation of the 40-day mode was clearly noticed from Thiruvananthapuram to Guwahati. There were variations in the locations of maximum amplitude of the filtered series as discussed earlier. In 1977, the northward propagation was seen only upto Bhubaneswar. There were no indications of a systematic northward propagation of the 40-day mode during 1976 and 1978. Instead a weak north to south propagation was seen.

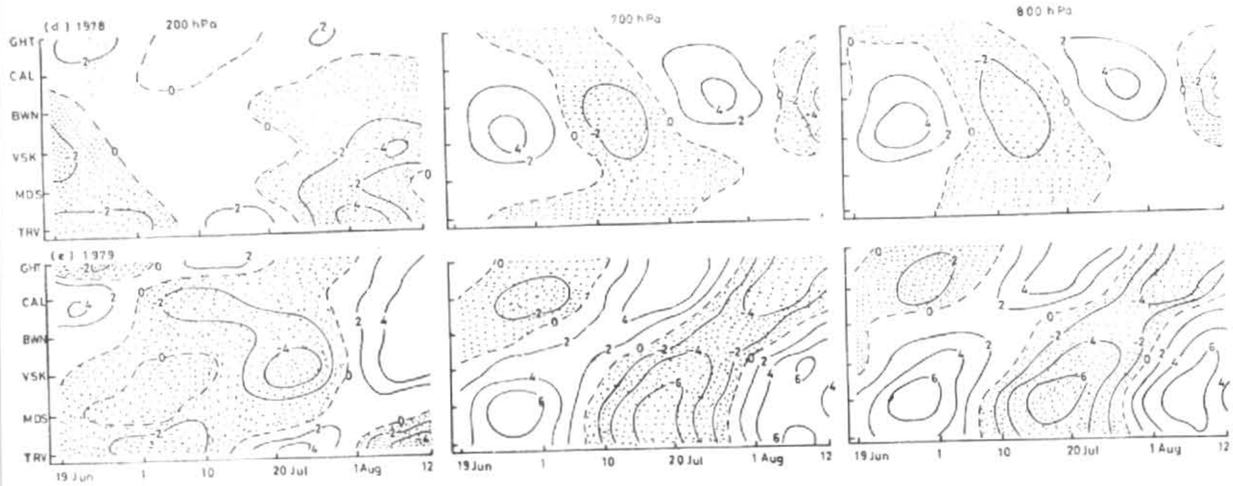
(*b*) *700 hPa* — The south to north propagation of the 40-day mode was clear during 1975 and 1979 and was absent during 1976 and 1978. The propagation was noticed only upto Calcutta in 1977. As in 800 hPa a weak north to south propagation was seen during the years 1976 and 1978.

(*c*) *200 hPa* — A clear south to north propagation of the 40-day mode was seen in 1975 whereas in 1979 such propagation was seen only from the middle of July. In 1977 a north-south propagation was seen from Guwahati to Visakhapatnam. During the remaining two years the propagation of the 40-day mode was not clearly noticed.

From the above discussion, it is seen that the propagation of the 40-day mode show large inter-annual variability. If they are present they are clearly depicted in lower tropospheric levels. The location of the maximum amplitude of the 40-day mode also show year-to-year fluctuations. In 1979 the amplitude at lower tropospheric levels showed a fairly high value as compared to other years. The propagation of the 40-day mode in upper tropospheric zonal winds was, however, not very clear as seen in lower tropospheric levels.

6. Speed of propagation of the low frequency mode

We have already seen that the propagation of the low frequency mode shows large inter-annual variability. In some years, it was not noticed at all at certain latitudinal belts. Hence to study the speed of propagation of the 40-day mode over India only those latitudinal belts which show pronounced south to north propagation were considered for different years. Though a first hand knowledge about the speed of propagation can be obtained from the phase variations of the filtered series of different stations another effective method would be on the basis of lag correlation coefficients between adjacent filtered series. The number of days that is lapsed for the translation of maximum correlation coefficient between any two stations is considered as the time taken for the propagation of that wave



Figs. 2(d-e). Phase propagation of the low frequency mode in the filtered series of zonal winds (mps) for the years (d) 1978 and (e) 1979

in that latitudinal belt. This process is continued by considering all the six stations in pairs. From these individual values, mean values of speed of propagation for different latitudinal belts are calculated.

It is seen that the total number of days taken for a wave to propagate from south (Thiruvananthapuram) to north (Guwahati) covering about 18 deg latitude was about 23 days which means that the average speed of propagation of that wave was about 0.78 deg/day which agrees well with the results obtained by Krishnamurti and Subrahmanyam (1982) and Keshavamurthy and Kasture (1990). Considering the different latitudinal belts bounded by the stations under examination it is seen that the speeds of propagation from Thiruvananthapuram to Madras, from Madras to Visakhapatnam and from Visakhapatnam to Madras were about 1.0 deg/day. For the latitudinal belt between Bhubaneswar and Calcutta, the speed of propagation was rather slow and was of the order of 0.4 deg/day. This may be due to the oscillation of higher frequency modes affecting that particular latitudinal belt. For the belt between Calcutta and Guwahati it was about 0.8 deg/day.

7. Relationship between the low frequency mode variations and active/weak or break monsoon cycles over central India

Considering the pattern of variations of this mode over the years, when they are prominently seen, it may perhaps, be possible to link the phase changes in the filtered series of some of the stations with the changes in monsoon activity over some parts of the country as discussed by Krishnamurti and Subrahmanyam (1982). They have shown a good relationship between the rainfall activity over central India in different phases of the monsoon (like onset, break in monsoon rains, withdrawal etc.) and the passage of troughs and ridges of the filtered series at 15 deg latitude. An attempt has, therefore, been made to see whether such relationship existed in other years also in which dominant periodicities in the low frequency mode were noticed. The filtered series of the zonal winds for 800 hPa of Visakhapatnam for the 10-year period 1975-1984 from 19 April to 12 September (147 days)

TABLE 5

Contingency table depicting rainfall activity over central India in association with the passage of troughs and ridges in the low frequency mode

Passage of	Nature of central India rainfall during the week		
	Deficient or scanty rainfall	Excess or normal rainfall	Total
Ridge	9 (14)	20 (15)	29
Trough	19 (19)	10 (10)	29
Total	28	30	58

Chi-square=6.90 (d.f.-1), Significant at 1% level.
Expected cell frequencies are given in brackets

were examined. This station was selected as the frequency of occurrence of periodicities in low frequency mode is relatively high both in terms of number of levels and number of years as compared to other stations. Weekly rainfall activity over central India (consisting of meteorological subdivisions, east and west Madhya Pradesh and Vidarbha) for the monsoon period have been examined.

During this ten years' period we have noticed the passage of 29 ridges (maximum positive amplitude) and 29 troughs (maximum negative amplitude) in the filtered series of 800 hPa zonal winds over Visakhapatnam. Yearwise distribution of weekly rainfall pattern over central India during the passage of the troughs and ridges is given in Table 4. It is seen that the passage of troughs were generally associated with deficient or scanty rainfall over central India in 19 out of 29 occasions (65 per cent) and the passage of ridges were associated with excess or normal rainfall over central India in 20 out of 29 occasions (69 per cent). A contingency table is prepared using this data (Table 5) for testing the significance of the association between the passage of troughs/ridges and the nature of weekly rainfall activity over central India on the basis of Chi-square test. It is seen that the Chi-square value of 6.90 for 1- degree of freedom is significant at 1% level. This shows that there is a good relationship between the passage of troughs/ridges in the low frequency mode with the weekly rainfall activity over central India.

8. Predictability of the active weak or break monsoon cycles over central India

In view of the inter-annual variabilities in respect of location and northward propagation of the low frequency mode it may not be possible to use this mode for the long range prediction of monsoon rains over the country with great confidence. However, from the type of relationship seen in the variations of the low frequency mode and the rainfall activity over central India we can infer that if by the middle of June we are in a position to get an idea about the approximate phase of the filtered series of 800 hPa zonal winds over Visakhapatnam, the same can be used in the prediction of rainfall activity over central India. It is also seen that the phase variations in low frequency mode appear explicitly in the filtered series of Thiruvananthapuram from the end of April or during the first half of May itself. The phase propagation of the low frequency mode from Thiruvananthapuram to Visakhapatnam is about 10 days as discussed earlier. Using the filtered series of Thiruvananthapuram one can then roughly project the possible phase changes in the filtered series over Visakhapatnam by assuming the period of the low frequency mode of about 40 days. An exercise of this type was taken up for the 10-year period (1975-1984) and it is found that the deviations of the actual date and projected date for the passage of troughs/ridges in August/September were within about 10 days in most of the years (7 out of 10) whereas similar deviations during June/July were somewhat high. The oscillations in higher frequencies may, perhaps, be responsible for these large deviations.

9. Conclusions

From the above discussions the broad conclusions on the following lines are significant :

(*i*) Compared to the zonal winds, the meridional winds do not exhibit significant periodicities in the low frequency mode.

(*ii*) The frequency of occurrence of significant periodicity in the low frequency mode is relatively high for Visakhapatnam and Madras both in terms of number of years and number of levels.

(*iii*) There appears a large inter-annual variability of the maximum amplitudes of the filtered series with no special preference to any latitudinal belt for its occurrence both in the upper and lower tropospheric levels.

(*iv*) Northward propagation of the 40-day mode shows large inter-annual variability and in some years the propagation is not seen at all.

(*v*) The propagation of the low frequency mode is seen clearly in lower tropospheric levels as compared to upper tropospheric levels.

(*vi*) The speed of propagation was about 0.78 deg/day to cover the whole latitudinal belt from Thiruvananthapuram to Guwahati. However, the speed showed variation in intermediate latitudinal belts, the lowest being noticed for the region between Bhubaneswar and Calcutta (0.4 deg/day) and the highest for the belt between Thiruvananthapuram and Visakhapatnam.

(*vii*) The phase changes in the filtered series of Visakhapatnam matched with the changes in rainfall activity over central India. Due to this, prior information about phase variations can be used to foreshadow the activity of the monsoon over central India.

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