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Intra-seasonal oscillations of radio refractive index during southwest monsoon over India

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सार — इस शोधपत्र में दक्षिण-पश्चिम मानसून के दौरान भारत एवं भारतीय समुद्रों में द्वीप समूहों के रेडियो अपवर्तनांक में अन्तः ऋतुनिष्ठ दोलन के क्षेत्रीय और सामयिक परिवर्तन का अध्ययन किया गया है। 1969 से 1986 तक की अवधि के प्रत्येक वर्ष के, तथा 1 जून से 30 सितम्बर तक दैनिक औसत रेडियो अपवर्तनांक के आंकड़ों का हार्मोनिक विश्लेषण किया गया। मानसून के दौरान रेडियो अपवर्तनांक में विभिन्न आवृत्तियों के योगदान का अंवेषण किया गया। 5° उ से 30° उ के मध्य प्रत्येक 5 अक्षांश की पट्टी के लिए विभिन्न वर्षों की विविध आवृत्तियों द्वारा स्पष्ट किए गए प्रसरण की मदद से विभिन्न अंतः ऋतुनिष्ठ दोलन की अन्तः वार्षिक परिवर्तिता का अध्ययन किया गया। मानसून की सक्रियता के सम्बन्ध में, 30 से 60 दिन और 10 से 20 दिनों की आवृति के प्रसरण का अध्ययन किया गया।

30 से 60 दिनों की आवृत्ति का प्रगमन उत्तर और पूर्व की ओर देखा गया। 10 से 20 दिनों की आवृत्ति और अंतराऋतुनिष्ठ आवृत्ति क्रमशः 5° उ-10° उ और 25° उ–30° उ अक्षांश में अधिकतम पाई गई। 10° उ–25° उ के बीच, 30–60 और 10–20 दिनों की आवृत्ति दृष्टिगोचर हुई।

ABSTRACT. The study deals with the spatial and temporal variations of intra-seasonal oscillations in radio refractive index during southwest monsoon season over India and islands over Indian seas. Average daily radio refractive index data from 1 June to 30 September and that of the individual years for the period 1969-1986 were subjected to harmonic analysis to investigate the contributions of various periodicities in monsoon radio refractive index. The inter-annual variability of various intra-seasonal oscillations have been studied for each 5° latitudinal strip from 5°N to 30° N with the help of variance explained by various frequency modes for different years. Variance explained by 30-60 day and 10-20 day modes were studied in relation to monsoon performance.

Tne northward and eastward propagation of 30-60 day mode was noticed. The 10-20 day mode and seasonal mode dominate at latitudinal belts 5°N-10°N and 25°N-30°N respectively. Between 10°N and 25°N, both 30-60 day and 10-20 day modes occur.

Key words — Radio refractive index, Microwave propagation, Inter-annual variability, Intra-seasonal oscillation, Southwest monsoon, Low frequency oscillation.

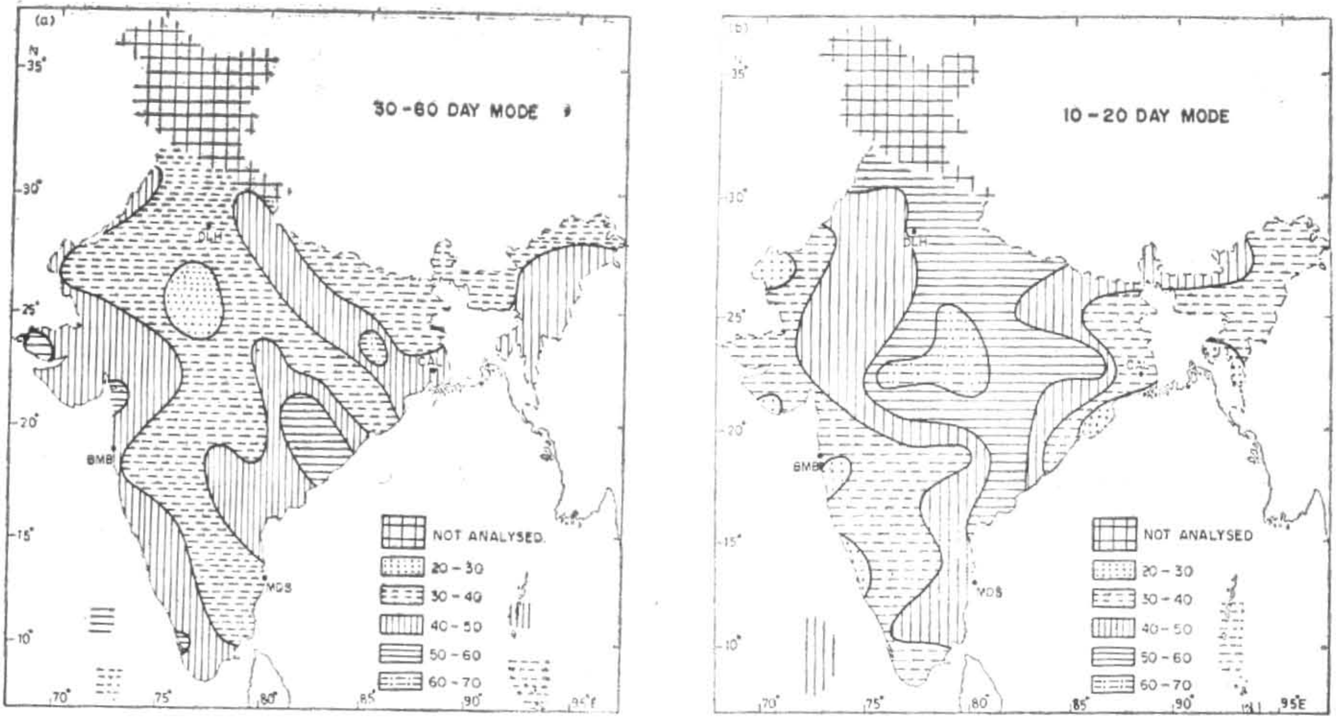
1. Introduction

Monsoon system exhibits variability in many time-scales within the season. Prominent among them are synoptic scale variability of 5 to 7 days and low frequency modes of 10-20 day and 30-60 day. Such oscillations have been reported in rainfall, zonal wind, cloudiness, pressure and other elements.

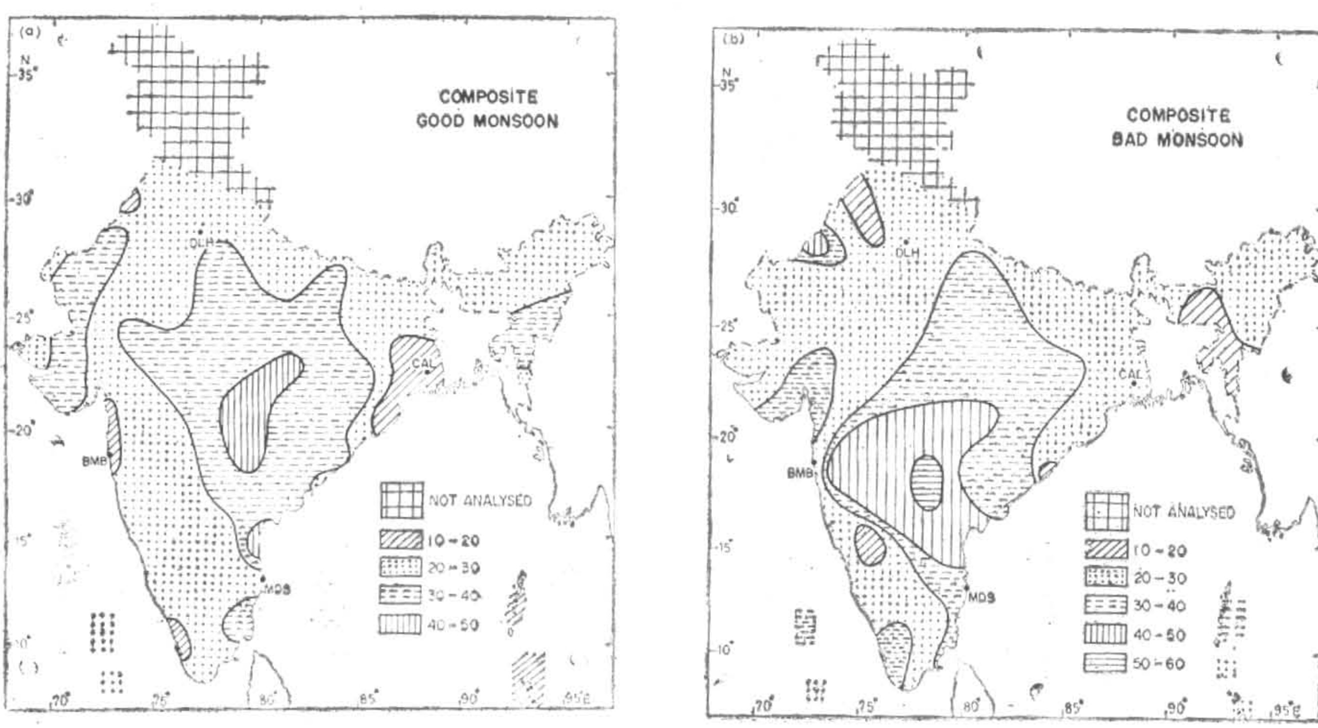
30-50 day oscillation was first found in the equatorial region by Madden and Julian (1971, 1972). These oscillations were found to move slowly eastwards. Chowdhury *et al.* (1990) and Ahlquist *et al.* (1990) with the help of radiosonde data found that most of the variance in monsoon weather comes from intra-seasonal activity with periods longer than 10 days. Sikka and Gadgil (1980), Yasunari (1980) and Chowdhury *et al.* [1988(a)] have shown northward propagation of low frequency mode in satellite cloudiness. De *et al.* (1988) and Singh and Kripalani (1990) have shown that 30-60 day oscillations have considerable inter-annual variability. Lorenz (1990) pointed out that the inter-annual variability is due to the presence of non-linearity in the system.

While earlier studies emphasized the predominance of 30 to 60-day modes during the bad monsoon years as compared to good monsoon, the recent work has shown that the variance explained by 10 to 20-day modes is also prominent [Krishnamurti and Bhalme 1976, Chowdhury *et al.* 1988(b) and Ahlquist *et al.* 1990]. Since radio refractive index measured through the surface refractivity is computed based upon three meteorological elements, it would be interesting to investigate the extent to which the two low frequency modes namely, 10 to 20 days and 30 to 60 days are related to inter-annual variations of the monsoon from he synoptic climatological angle.

Also, since prediction of seasonal signal strength is generally based on the surface refractivity which contributes about 70% of the bending of the microwave, it is of interest to study such inter-annual variability based on the low frequency modes instead of that using annual range and mean refractivity as adopted so far (Bean and Dutton 1968), thereby providing greater physical insight.



Figs. 1 (a & b). Coefficient of variation (%) for radio refractive index : (a) 30-60 day mode, and (b) 10-20 day mode



Figs. 2 (a & b). Variance explained by 30-60 day mode for radio refractive index : (a) composite good monsoon, and (b) composite bad monsoon

Radio refractive index as a parameter for synoptic climatology has been extensively studied with reference to the middle latitude systems (Bean and Dutton 1968). In the Indian region, Maheshwari (1962), Venkataraman *et al.* (1963) and Srivastava (1968) have adopted this parameter for studying western disturbances, tropical cyclones and monsoon depressions respectively. Significant increase in the radio refractive index takes place during the monsoon season all over the country (Srivastava 1965). Hence, inter-annual variations during this season make the interpretation rather difficult in relation to overall monsoon situation over the country. The use of radio refractivity through the frequency domain offers an alternative and better insight to understand inter-annual variations.

2. Method of analysis

Daily station level pressure, dry bulb temperature and dew point temperature data recorded at 72 well distributed stations over India including island stations from 1 June to 30 September for the period 1969-1986 have been considered for this analysis. Daily mixing ratio for each station was computed with the help of formula given by Pruppacher and Klett (1980).

$$\text{Mixing ratio, } m = \frac{0.622 e_s}{p - e_s}$$

where, e_s — Saturation vapour pressure (hPa),

p — Station level pressure (hPa),

$$e_s = \sum_{n=0}^{6} a_n T_d$$

where, T_d — Dew point temperature (°C)

and a_0 to a_6 are constants as given below :

$a_0 = 6.107799961$, $a_1 = 4.436518521 \times 10^{-1}$,

$a_2 = 1.428945805 \times 10^{-2}$, $a_3 = 2.650648471 \times 10^{-4}$,

$a_4 = 3.031240396 \times 10^{-6}$, $a_5 = 2.034080948 \times 10^{-8}$,

$a_6 = 6.136820929 \times 10^{-11}$.

Radio refractivity (N) was calculated using the formula given below :

$$N = \frac{77.6\, p}{T}\left(1 + \frac{7.71\, m}{T}\right)$$

where,

T — Dry bulb temperature (°K),

M — Mixing ratio (gm/kg).

To study the contribution of intra-seasonal variability of different periods, the area under investigation was divided into 5 latitudinal strips of 5° width from 5°N to 30°N. In order to remove short term fluctuations of 2 to 3 days, the data for each latitudinal strip was subjected to 3-day running mean. The data thus obtained for each year were subjected to harmonic analysis for each latitudinal strip separately.

3. Results and discussion

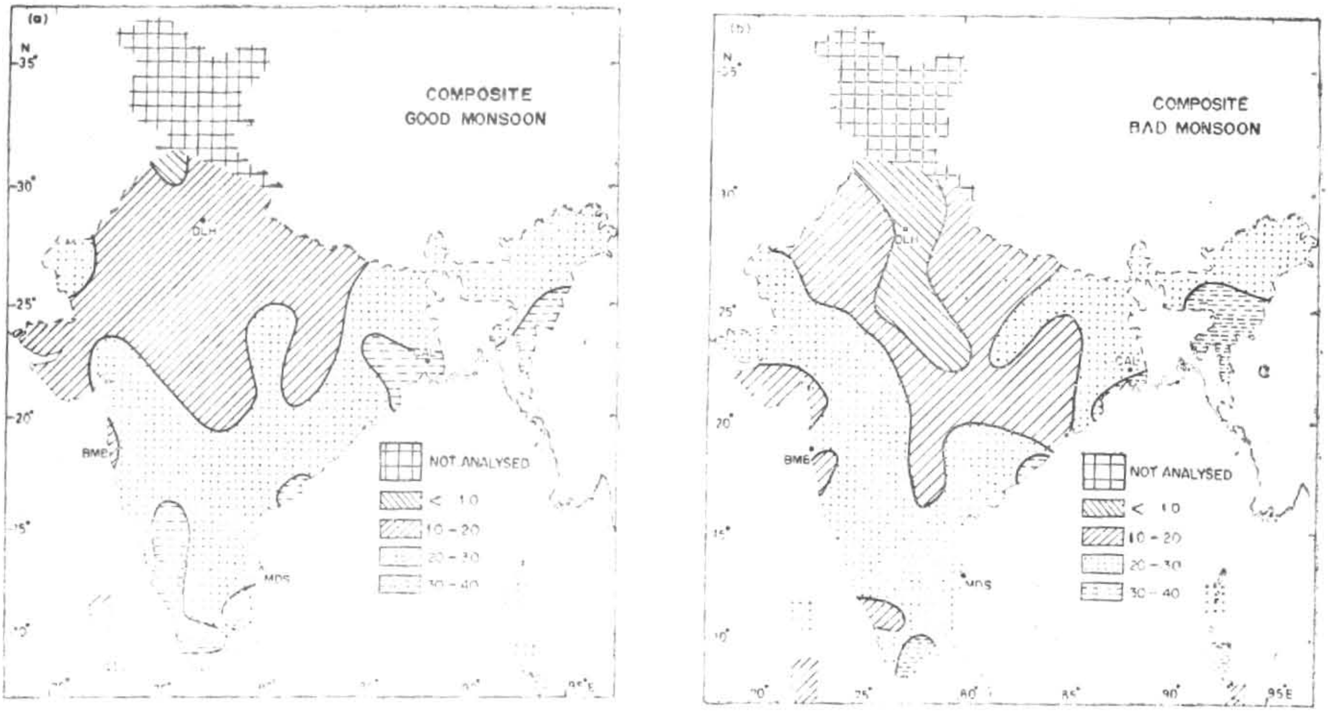
The variance explained by seasonal, 30-60 day, 10-20 day and less than 10-day modes for each year under investigation were studied. Inter-annual variability was noticed in all these modes. Mean contribution of various modes in different latitudinal belts and the coefficient of variability of various modes were also computed.

The mean variance and coefficient of variation of various periods, *viz.*, 120-day, 30-60 day, 10-20 day and less than 10-day for different latitudinal belts are given in Table 1. It is seen that mean variance explained by 30-60 day is predominant over other modes in latitudes 10°N-20°N. Chowdhury *et al.* [1988(a)] found that 30-60 day mode is predominant over interior peninsula between 10°N and 20°N in the daily normal rainfall. The 10-20 day mode dominates at latitudinal belt 5°N-10°N while seasonal mode dominates at 25°N-30°N. From the values of coefficient of variation given in Table 1, inter-annual variability of 10-20 day is found to be less between latitudes 5°N & 20°N. The fluctuations of 30-60 day mode is also not so high and is comparable with 10-20 day mode from 10°N to 20°N. Hence, it can be concluded that between latitudes 10°N & 20°N dominance of both 30-60 day and 10-20 day mode persists. The coefficient of variation explained by seasonal cycle is more, compared to all other frequency modes in each latitudinal belt.

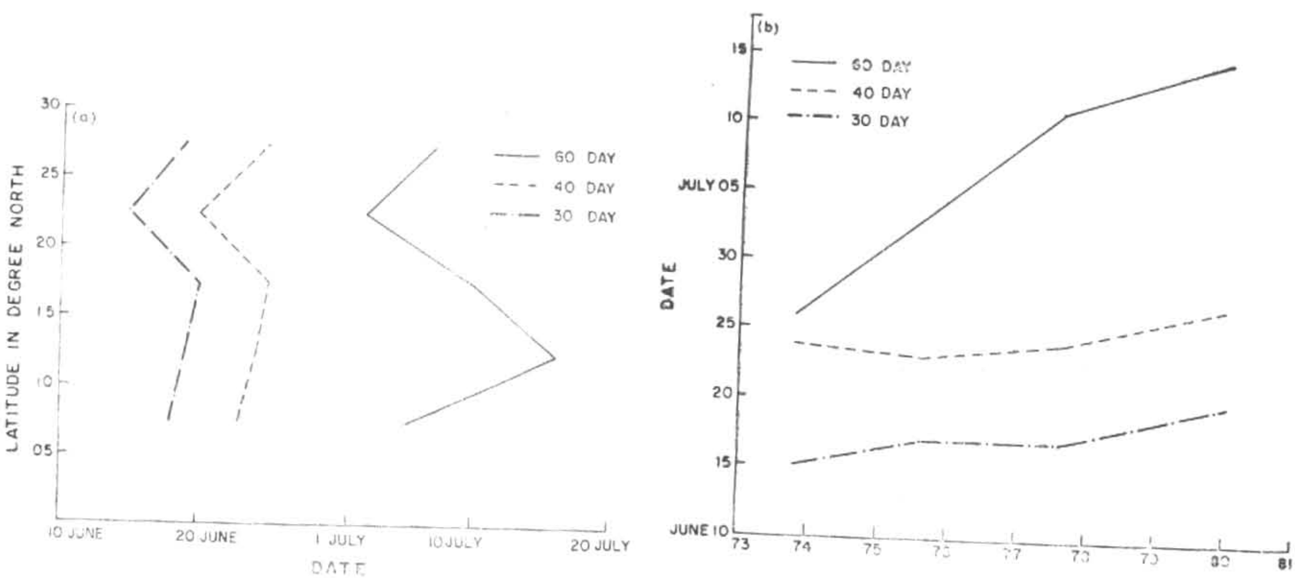
TABLE 1

Variance explained and coefficient of variation (%) of intra-seasonal oscillations

Lat. belt	120 days		30-60 days		10-20 days		<10 days	
(°N)	Mean	C.V. (%)	Mean	C.V. (%)	Mean	C.V. (%)	Mean	C.V. (%)
5-10	17	69	24	50	30	26	22	40
10-15	17	67	37	40	24	39	14	46
15-20	17	80	40	42	22	30	15	74
20-25	22	66	28	46	22	38	22	39
25-30	32	49	25	43	19	47	18	35



Figs. 3 (a & b). Variance explained by 10-20 day mode for radio refractive index : (a) composite good monsoon, and (b) composite bad monsoon



Figs. 4 (a & b). (a) Northward, and (b) eastward propagation of 30, 40 and 60-day mode

The year to year variation of 30-60 day mode is shown in Fig. 1(a). The coefficient of variation is found to be more than 30% from south to north through the central parts of the country with the lowest value of 20% in east Rajasthan. The year to year variation of 10-20 day mode is shown in Fig. 1(b). Maximum variance (60%) of this mode can be found over east Madhya Pradesh. This variation may be due to meandering of monsoon trough and movement of low pressure areas and depressions through the region.

Performance of all India monsoon rainfall was related with the variance explained by low frequency oscillations in satellite cloudiness, monsoon rainfall and zonal wind on regional scale [Chowdhury *et al.* 1988(a), 1988(b), 1990]. Paul *et al.* (1990) have studied the dominance of 10-20 day mode over that of 30-60 day mode during good monsoon years.

In order to find out the differences in variance explained by 30-60 day and 10-20 day modes during the contrasting monsoon years, four composite charts for radio refractive index have been prepared for 30-60 day and 10-20 day modes, two for good monsoon years and other two for bad monsoon years, shown in Figs. 2 (a & b) and Figs. 3 (a & b). For preparing the composite charts for good monsoon, the years 1970, 1975, 1978 and 1983 and that for bad monsoon, 1972, 1974, 1979 and 1982 were considered on the basis of area weighted rainfall over the country as a whole. It may be noted that the variance explained by 10-20 day mode during the good monsoon year is found to be more in north India (especially northwest Madhya Pradesh, Haryana, Punjab) and interior Karnataka than that during the bad year. During the good year, whole north India explained 10-20% variance, while in the bad year, it is below 10% in some parts of north India. During bad monsoon, there is a slight rise in variance explained by 30-60 day mode over Bay islands, Telangana, Marathwada and Vidarbha regions compared to good monsoon. There is, in general, a fall in variance over northeast India during bad monsoon compared to good monsoon while decrease over Gangetic West Bengal and adjoining Orissa during good monsoon compared to bad in 30-60 day mode. However, there is a decrease in variance explained by 30-60 day mode during good monsoon compared to bad monsoon near Konkan and Gujarat coast.

Some authors have shown the northward and eastward propagation of low frequency oscillations in various meteorological elements. A question arises whether similar propagation is noticed in case of surface refractivity. The northward propagation of radio refractive index over Indian region for 30, 40 and 60-day modes were examined. The phase angles for individual year were computed for 30, 40 and 60-day modes separately for each latitudinal strip of 5° width. The mean phase angles for 30, 40 and 60-day modes were computed for each latitudinal belt. The propagation of each mode is shown in Fig. 4(a). It can be seen that from 5°N to 15°N there is a gradual propagation, while from 15°N to 25°N there is a retardation and from 25°N to 30°N there is a northward propagation for 60-day mode. The rate of propagation is 0.5° latitude per day. While in case of 30 and 40-day modes, there is a rapid propagation from latitudes 5 °N to 20°N, at 20°N to 25°N there is a retardation and at 25°N to 30°N, it propagates but with a slow speed of nearly 0.5° latitude per day. The changes in the phase speed and phase locking are complex, not yet properly understood.

To study west-east propagation of 30, 40 and 60-day oscillations, the propagation along 15°N was studied. It may be mentioned that this is the region where 30-60 day mode is most dominant. Four stations near 15°N, *viz.*, Goa, Gadag, Anantapur and Nellore were considered. West-east propagation of this mode is depicted in Fig. 4(b). In the case of 60-day mode, the wave is found to be steadily propagating from west to east with an average speed of 0.5° longitude per day, while the speed is found to be more in the case of 30-40 day (roughly 1° Long. per day). However, the physical mechanism for these modes is yet to be understood.

4. Conclusions

The above study brings out the following results :

(*i*) 30-60 day oscillation in radio refractive index is predominant between latitudes 10°N and 20°N over India.

(*ii*) In the monsoon region, both northward and eastward propagation of 30-60 day mode are noticed. There occasional retardation observed and there is also variation in the speed of propagation.

(*iii*) 10-20 day mode in radio refractive index dominates at latitudes 5°N-10°N while seasonal mode is predominant at north of 20°N.

(*iv*) The variance explained by 10-20 day mode is more in north India in good monsoon (especially northwest Madhya Pradesh, Haryana, Punjab) and interior Karnataka than the bad monsoon year. Also, the variance explained by 30-60 day mode over Bay islands, Telangana, Marathwada and Vidarbha regions is more in bad monsoon as compared to good monsoon.

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