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Forecasting the onset of monsoon over Kerala using the peak in pre-monsoon convective activity over south peninsular India

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सार – मेसोस्केल संवहनी क्रियाकलापों के संवर्द्धन से संबंधित प्रायद्वीपीय भारत के सुदूर दक्षिणी क्षेत्र में मानसून वर्षा ऋतु की अवधि में भूमध्यरेखीय द्रोणी की उत्तराभिमुखी गति में निम्न आवृति दोलनों के योगदान का अध्ययन किया गया है। इस अध्ययन का मुख्य उद्देश्य केरल में ग्रीष्मकालीन मानसून वर्षा ऋतु के आरंभ होने के पूर्वानुमान पहले से ही देने की सूचना की उपयोगिता को सामने लाना है। इस विश्लेषण को करने के लिए सुदूर दक्षिणी प्रायद्वीप भारत के चुनिंदा स्टेशनों पर मार्च–जून के महीनों और 1961–92 तक के वर्षों में आए तूफानों के आँकड़ों का उपयोग किया गया है। इन स्टेशनों पर प्रत्येक वर्ष मानसून ऋतु के आरंभ होने से लगभग 5–8 सप्ताह पहले साप्ताहिक संचयी तूफानों की आवृति विशेष रूप से चरम पर पाई गई जो इन दो घटनाओं से संबंद्ध संवहन में 30–60 दिनों के दोलन के प्रभाव को सूचित करता है। मानसून के आरंभ की तारीख की पूर्व सूचना देने के लिए एक समाश्रयण समीकरण को विकसित किया गया है। 0.1 प्रतिशत स्तर पर यह संबंध महत्वपूर्ण पाया गया है। हाल ही के पाँच वर्षों के स्वतंत्र आँकड़ा समूहों का उपयोग करते हुए ये परिणाम सुसंगत पाए गए हैं। इस क्षेत्र में ओ.एल.आर. मानों में विशेष गिरावट तूफानों की सक्रियता विशेष चरम के साथ सुसंगत तालमेल रखती है जो यह सूचित करते हैं कि मानसून ऋतु के आरंभ होने के पूर्वानुमान के लिए उपयोगी संकेतों का पता लगाने के लिए ओ.एल.आर. एक उपयोगी साधन भी हो सकता है।

ABSTRACT. The role of low-frequency oscillations in the northward movement of the Equatorial Trough during pre-monsoon period over extreme south peninsular India is studied in relation to the associated enhancement of meso-scale convective activities over the region. Main objective of the present study is to bring out usefulness of this information in predicting the onset of summer monsoon over Kerala, well in advance. Thunderstorm data of selected stations over south peninsular India for the months March-June and for the years 1961-92 have been used in this analysis. A characteristic peak in weekly cumulative thunderstorm frequency is seen over these stations about 5-8 weeks prior to the onset of monsoon almost every year, suggesting the dominance of 30-60 day oscillation in the convection associated with these two events. A regression equation has been developed to predict the onset date. The relationship is found to be significant at 0.1% level. The results have been validated using an independent data set of five recent years. A characteristic fall in OLR values over the region, well in correspondence with the characteristic peak in thunderstorm activity suggests that OLR also can be used as a supporting tool in identifying such signal which is useful for the onset prediction.

Key words – Onset of monsoon, Thunderstorm frequency, Characteristic peak, OLR.

1. Introduction

Onset of monsoon is a very important event, since it brings first shower of the season. Knowledge of the onset date, well in advance is essential to the planners, economists and especially to the agriculturists to plan their operations accordingly. Several attempts have been made to predict the onset date. In early fifties Ramdas *et al.* (1954) have used four parameters namely Seychelles rain (April), mean west winds over Agra at 3 km (first half of May), pressure difference between Cochin and Jaipur (April) and south Rhodesian rain (April) for onset prediction. The regression model developed using above parameters however had low multiple correlation coefficient. Later Reddy (1977) has proposed the 50 hPa zonal wind component over Singapore (May) as a predictor for forecasting the monsoon onset while the regression method developed by Kung and Shariff (1982) is based on upper air patterns in the India-Australia region (April) and the SST around India in the pre-monsoon season. Joseph and Pillai (1988) have attempted to predict the onset by using the result of 30-40 day cycle in rainfall. The multiple regression models developed by Thapliyal (1993) are based on nine various regional and global parameters while Rajeevan and Dube (1995) have used mean surface temperatures of the stations Indore, Akola and Sagar (April) and Eurasian snow-cover (December to February) as the predictors. The present study is an attempt to explore a new parameter useful for prediction of the onset of monsoon over Kerala, well in advance.

The onset and advance of monsoon as well as its further progress over the country occurs in spells. It is well known that the monsoon performance is linked with the active-break phases within the season. Such phases are found to be related with the intermittent northward progression of the near equatorial Inter Tropical Convergence Zone (ITCZ) and the associated organized convective cloud zones on the time scale of 30-40 days (Sikka and Gadgil 1980, Sikka *et al*. 1986). Several attempts have been made to study the role of low frequency oscillations in the northward migration of ITCZ over the Indian region within the monsoon season (Yasunari 1980, Lau and Chan 1986, Paul *et al*. 1990 etc.). However, very little information has been documented about such events during pre-monsoon period. Raman and Raghavan (1961) have indicated a northward progression in the maximum thunderstorm activity from southern tip of India in April to northern parts in July. Joseph and Pillai (1988) have discussed the role of 40-day mode in the northward propagating near Equatorial Trough and enhancement of rainfall of the sub-divisions of India lying south of 13° N during the pre-monsoon period. In the present study we have attempted a qualitative analysis of pre-monsoon thunderstorm activity over south peninsular India, which will enable us in identifying these low frequency oscillations during pre-onset and onset phase of monsoon.

Monsoon first strikes the Kerala coast before advancing into the main land of India. It is therefore important to study the activities over south peninsular India during pre-monsoon months to investigate their possible linkage with the onset event. Over this region, the annual frequency of thunderstorm days exceeds 80, of which about 50% occur during the pre-monsoon period (March-May). The contribution of March is very less (about 5 days). On monthly scale, almost three times rise in the activities is seen from March through April (Rao *et al*., 1971). The activities attain maxima over this region during the month of April and are seen to occur mostly in the afternoon hours (16-19 hours IST) of the day (Raman and Raghavan 1961). In the present study, such rise in activities over the southernmost part of the country on weekly time-scale is used to locate the characteristic peak. Satellite-derived Outgoing Longwave Radiation (OLR) data is used to study large-scale convection over the region. Knowledge of such peak and associated enhancement of the convection over the region with preferred periodicity is found to be useful in prediction of the onset.

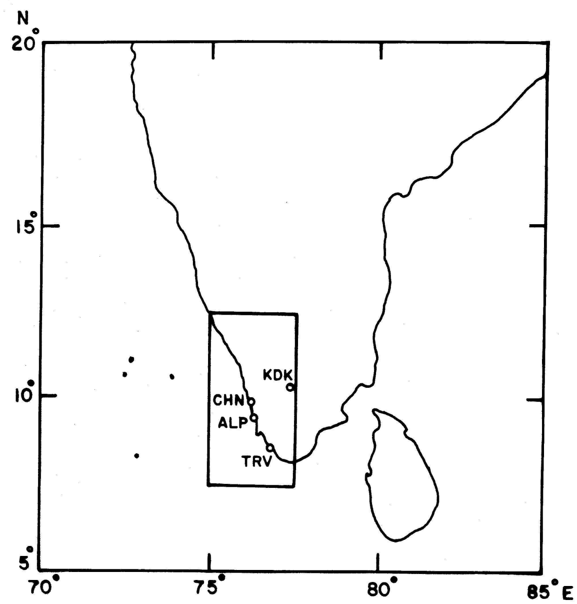

Fig. 1. Region of study

The present study is divided into four sections beginning with a brief introduction in Section 1. The data and method of analysis are given in Section 2. Section 3 discusses the results and validation of the technique developed in the study. The concluding remarks are presented in Section 4.

2. Data and method of analysis

Daily thunderstorm data of four selected stations over south peninsular India *viz.* Thiruvananthapuram (Trivandrum), Cochi (Cochin), Alapuzha (Alleppy) and Kodaikanal for the months March to June for the years 1961 to 1998, (except 1994) from Indian Daily Weather Report (IDWR) have been used in the study. In addition to this, thunderstorm data of all the available stations (23) of south peninsular India lying south of 13° N from IDWR are used for the same months and for the years 1989 and 1998. All occasions of thunderstorm are considered to find out thunderstorm frequency in terms of day with thunderstorm over each station. These are further used to find daily cumulative value over these stations (representing convective activity over the study area), from which weekly cumulative frequencies are obtained. Daily grid point Outgoing Longwave Radiation (OLR) data at each 2.5° × 2.5° obtained by NOAA polar orbiting satellite for the months March-June and for period 1975-86 (except 1978 for which the data is not available due to satellite failure), are also used. Fig. 1 shows the region of study bounded by the latitudes 7.5° N and 12.5° N and the longitudes 75° E and 77.5° E, which includes the selected stations. The

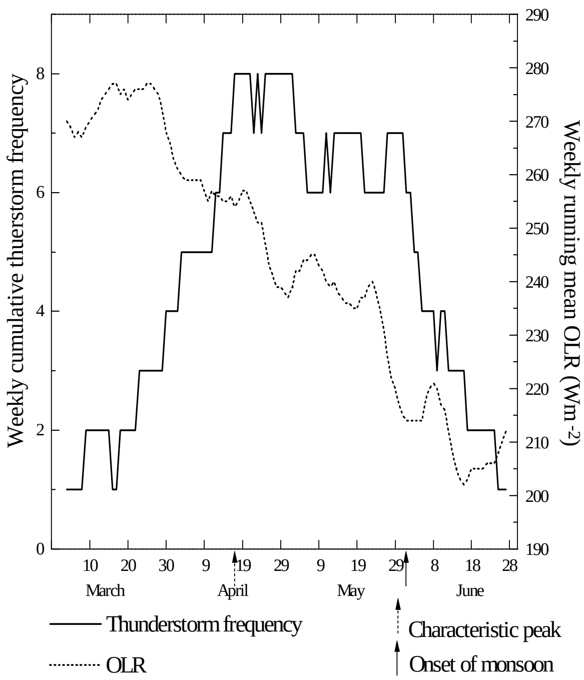

Fig. 2. Time series of Long-term mean (*i*) weekly running cumulative thunderstorm frequency over the selected stations (solid line) and (*ii*) weekly running mean OLR over the study region (dashed line) during the months March to June. The arrows with dashed and solid lines at the time axis indicate the date of the characteristic peak and the normal date of onset over Kerala respectively

weekly mean values of OLR and their anomalies have been computed to study the linkage of the pre-monsoon thunderstorm activity over the stations in response to the large-scale convection over this region. The dates of onset of monsoon over Kerala used in the present analysis are the finalized dates declared by the India Meteorological Department.

3. Results and discussion

Fig. 2 shows (*i*) weekly running cumulative thunderstorm frequencies (solid line) for the four selected stations from March to June, based on the data for the period 1961-92 and (*ii*) weekly running mean OLR (dashed line) over the study region for the months March to June, based on data for the years 1975 to 1986 (except 1978). It is observed that the thunderstorm activity shows rapid increase from second half of March and attains first maxima by third week of April with cumulative value as high as 8 for the week. The activity shows some fall in the second week of May. After 1 June, which is the normal date of onset over Kerala, the activity decreases rapidly as the monsoon starts advancing over the country. The figure also shows a marked fall in the OLR values by the end of March. They further decrease by third week of April below a value of 255 Wm^{-2} during the week in which the first peak in thunderstorm activity over the stations is noticed. A steep fall in OLR is observed in association with the onset of monsoon. Also, on weekly time scale, for each of the peak in cumulative thunderstorm frequencies over the stations, corresponding fall in mean OLR values over the region is noticed. This indicates that such increase in activity may have the influence of large scale convection over the region. This may be occurring in association with the seasonal migration of the ITCZ during pre-monsoon season.

The first characteristic maxima in the thunderstorm frequencies in mean picture is observed about 6 weeks prior to the onset of monsoon over Kerala. Corresponding to this peak the long-period mean OLR values are observed around 255 Wm^{-2} on weekly time scale. Here it is worth noting that Janowiak and Arkin (1991) have established a regression relation using 255.15 Wm^{-2} as a cut-off threshold OLR on pentad scale, for estimation of precipitation from tropical convection. In the present study, for individual years, the fall in OLR corresponding to the characteristic peak of the respective year is found well below 240 Wm^{-2} in most of the cases. Thus two distinct convective episodes have been identified, one prior to the onset which is characterized by enhancement of the thunderstorm activities over the region and the subsequent one in association with the onset of monsoon. This resembles the low-frequency oscillation in the northward propagating near Equatorial Trough during pre-monsoon period and associated convective episodes over the region separated by about 40 days. The onset of monsoon over Kerala normally occurs on 1 June. In order to make further investigation, it is therefore necessary to observe the pre-monsoon thunderstorm activities at least six weeks prior to the monsoon onset. For declaring the onset of monsoon over Kerala, meteorologists generally use the criteria suggested by Ananthakrishnan *et al*. (1967) according to which the rainfall of selected stations is monitored from 10 May onwards. In the past century, the onset has occurred earliest in the year 1918 (11 May) and most delayed in the year 1972 (18 June). It is also observed that except for the years 1961, 1962 and 1990, the onset of monsoon over Kerala has not taken place prior to 26 May during the study period. Owing to this, peaks in the month of March for the individual years are ignored to monitor the right signal associated with the observed low frequency mode antecedent to the monsoon onset.

3.1. *Characteristic peak in thunderstorm activity*

Beginning from 1 March, daily cumulative thunderstorm frequencies are computed over the four stations from which weekly running cumulative frequencies

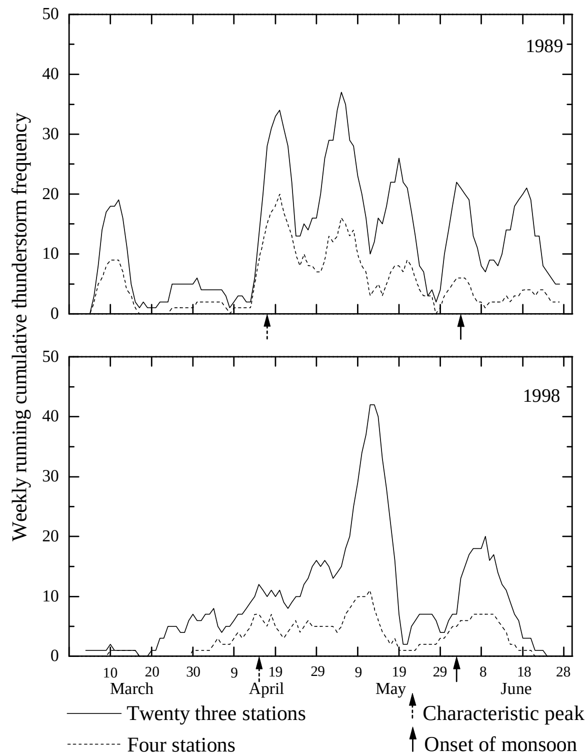

Fig. 3. Time series of (*i*) weekly cumulative thunderstorm frequency over 23 stations, lying south of 13^{o}N (taken from IDWR) and (*ii*) weekly cumulative thunderstorm frequency over the 4 selected stations for the years 1989 and 1998. The date of characteristic peak and the onset of monsoon for each year are marked by same symbol as Figure 2

are evaluated. To identify the characteristic peak on weekly time scale, the cumulative values are monitored from 1 April to 30 April to identify the first week having at least 8 total occurrences over these stations. Such a week is considered as the one having characteristic peak and this information is used in further analysis. To accomplish this, there should be at least one day within that week with two or more stations reporting occurrence of thunderstorm. Thus the week having such characteristic peak over these stations is a qualitative measure of enhancement in the thunderstorm activity over the study region. The day with the highest frequency of occurrences of thunderstorm in that week is identified as the characteristic peak for that year and its date of occurrence is further used in the regression equation.

3.2. *Thunderstorm activity over south India*

The present analysis is based on the data of four selected stations of extreme south peninsular India. Before presenting the actual results, adequacy of the sample is tested to confirm the appropriateness of the selection of the stations. For this, the weekly running cumulative thunderstorm frequencies are computed over 23 well spread stations of south peninsular India (as described in data section) and encompassing the northern boundary of the study region. These are further compared with that over the 4 selected stations for the months March-June and for the years 1989 and 1998. Fig. 3 shows comparison of the two samples. The solid line indicates the cumulative frequencies over south India based on the data of the 23 stations and dashed line is for the 4 selected stations as mentioned above. The first characteristic rise for the year 1989 is observed about seven weeks prior to the respective onset. The peaks for the 4 selected stations (dashed line) are very well tallying with those of the 23 stations over wider region of south India (solid line). Similar features are seen during other years also. Thus it is evident that the 4 stations, which are selected in the present analysis, are sufficient to represent the activity over the region and such sample of stations is adequate to identify the signal useful for onset prediction. The curve for the year 1998 is peculiar. In the present analysis this year is used for validation of the technique only. During this year the characteristic peak has not attained based on the events of month of April. For the validation the peak of this year with 7 total occurrences during a week is used. During this week thunderstorm is reported over at least two stations for 3 days which signifies widespread activity.

The first sharp increase in the activity over the 23 stations may be attributed to the large scale feature such as the movement of the equatorial trough over the region and hence there exists a first burst in terms of pre-monsoon thunderstorm activities over a large area of this region, which may subsequently be followed by some more peaks in activity prior to the onset of monsoon. This event is almost similar to the sudden burst of onset of monsoon which is characterized by abrupt change signal resulting into sharp increase in the rainfall activity over south Kerala coast of India (Mahajan *et al*., 1986).

3.3. *Pre-onset peak and monsoon onset*

The analysis of weekly cumulative thunderstorm frequencies for the individual years shows that after 1 April the first characteristic rise with greater than 7 occurrences is noticed about 5-8 weeks prior to the onset date of monsoon over Kerala. Such peak in activity is observed earliest by 1 April in 1961 and most delayed by 29 April in 1983. The corresponding onset dates are observed to be 18 May and 13 June respectively. Fig. 4 shows (*i*) weekly cumulative thunderstorm frequencies (solid line) and (*ii*) weekly running mean (7-day moving average) OLR anomalies over the region (dashed line) for the period March to June and for the years 1981 to 1985. These curves are showing the inter-

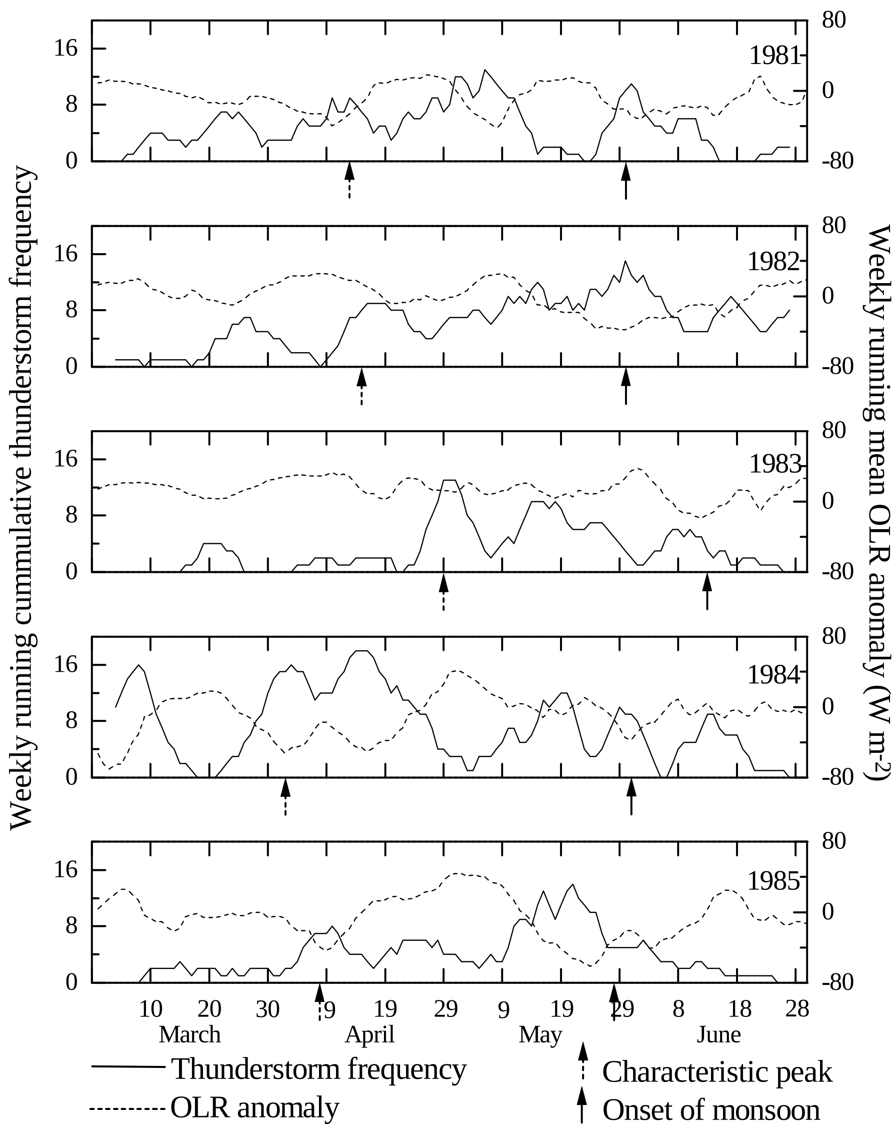

Fig. 4. Time series of (*i*) weekly cumulative thunderstorm frequency over the selected stations (solid line) and (*ii*) weekly running mean OLR anomalies over the study region (dashed line) during the months March to June during the years 1981 to 1985. The date of characteristic peak and the onset of monsoon for each year are marked by same symbol as Figure 2

annual variability of the time of occurrence of the characteristic peaks and the respective onset dates during these years. It is seen from the figure that the events of the characteristic peak and the monsoon onset date are found to be separated by the observed low frequency mode during these years. The characteristic peaks in the thunderstorm activity very well match with the distinct fall in the OLR anomalies.

Beginning from 1 April, the first sharp decrease in OLR anomaly with large negative values is noticed almost tallying with the occurrence of characteristic peak in thunderstorm activity during 1984 and 1985. During 1981 and 1982 such decrease is seen to be associated with increase in the activity in the week of characteristic peak. In 1982 the negative anomalies are not prominent. During 1983 fall in the OLR anomaly is noticed on the day of such peak but negative values are noticed only with the onset of monsoon. In general, a tendency of decreasing anomalies is observed in association with the characteristic peak. Such tendency resulted into characteristic fall with significant negative anomalies (as observed in 1984 and 1985) in most

TABLE 1

The comparison of actual and estimated dates of onset deduced from the date of the characteristic peak (all counted from 1 April) and the error of estimation

S. No.	Year	Date of the characteristic peak	Onset date (Actual)	Onset date (Estimated)	Error of estimation
1	1961	1	48	55	-7
2	1962	3	47	56	-9
3	1963	11	61	61	0
4	1964	17	67	64	3
5	1965	1	56	55	1
6	1966	5	62	58	4
7	1967	17	70	64	6
8	1968	18	69	65	4
9	1969	5	56	58	-2
10	1970	1	56	55	1
11	1971	15	57	63	-6
12	1972	13	79	63	16
13	1973	18	65	65	0
14	1974	6	56	58	-2
15	1975	28	61	70	-9
16	1976	15	61	63	-2
17	1977	6	60	58	2
18	1978	8	59	59	0
19	1979	14	72	63	9
20	1980	5	62	58	4
21	1981	13	60	62	-2
22	1982	15	60	63	-3
23	1983	29	74	71	3
24	1984	2	61	56	5
25	1985	8	58	59	-1
26	1986	21	65	66	-1
27	1987	28	63	70	-7
28	1988	6	57	58	-1
29	1989	17	64	64	0
30	1990	5	49	58	-9
31	1991	12	63	61	2
32	1992	18	66	65	1

of the years during the study period. Thus except for few cases, the characteristic peak in the thunderstorm activity is well supported with a marked fall in OLR anomaly with prominent negative values.

The present analysis discusses the use of thunderstorm data alone and information about the characteristic peak is noted for all the years under study. The peak for the year 1990 is based on 23 stations since the signal from the 4 selected stations was very weak. Figures in columns 1 and 2 of the Table 1 indicate the date count of the characteristic peak and the monsoon onset date over Kerala respectively (measured from 1 April). The duration between these two dates is found to vary between 33 days in 1975 to 66 days in 1972. Thus the first peak in activity is seen to occur with a preferred periodicity of about 30-60 days prior to the onset of monsoon. This shows the dominance of low frequency oscillation in the pre-monsoon convection prior to the onset over the region. Thus, the enhancement of such activities is believed to be in association with the pre-monsoon pulse in the northward progression of the equatorial trough over the region.

3.4. *Statistical analysis*

To make use of above observation, simple regression technique is used to estimate the onset date using the date of the characteristic peak (counted from 1 April). Keeping the date count of the characteristic peak in the weekly cumulative thunderstorm frequency as an independent variable (X) an equation is deduced to give best fit for estimation of the onset date (counted from 1 April) over Kerala (Y) as follows.

$$Y = 0.55 \times X + 54.8$$

The correlation coefficient based on the data period of 32 years (1961-92), between these two variables is found as 0.63, which is significant at 0.1% level having RMS Error (RMSE) of 5.2 days. One of the earlier regression models developed for onset prediction by Joseph and Pillai (1988) had RMSE of 3.9 days based on 25 years of data. The error of present method is slightly higher but is based on longer data period. With the aid of the above equation the onset dates over Kerala are estimated using the information of the characteristic peak and are listed in column 3 of Table 1. The values in the column 4 of Table 2 give the error of estimation (difference of actual and estimated dates of onset) for the period under study. For the years 1962,1972,1975,1979 and 1990, the error of estimation is high, more than a week. During 1972, the onset like situation was observed twice. There was considerable

TABLE 2

Validation of onset date prediction over Kerala using the regression technique

S. No.	Year	Date of the characteristic peak	Onset date (Actual)	Onset date (Predicted)	Error of estimation
1	1993	11 April	28 May	31 May	-3
2	1995	5 April	8 June	28 May	11
3	1996	7 April	3 June	29 May	5
4	1997	9 April	9 June	30 May	10
5	1998	15 April	2 June	2 June	0

difference between the onset date declared on real-time basis (as a temporary advance) and the revised date (about a month). Therefore, the error of estimation is observed as high as 16 days for this year. Due to the large estimation error during some peculiar years like 1972, in present analysis the RMSE is higher. The estimation error can be reduced by identifying the two convective episodes over the region critically, by analyzing OLR data for a long period.

3.5. *Validation of the technique*

The regression relation is validated by applying it to an independent data of recent five years (1993 to 1998 except 1994). Table 2 shows the date of characteristic peak, actual and predicted date of onset and the error of estimation for these years respectively. It is seen from the Table that the onset date for the years 1993, 1996 and 1998 are well predicted. The peak of 1998 is taken from the week with highest frequency (of 7) since the threshold is not observed in April. With availability of OLR data, error in estimation can be reduced. It is expected that the technique developed in the present analysis will be very useful for the prediction of onset of monsoon over Kerala well in advance.

4. Concluding remarks

Analysis of weekly cumulative thunderstorm frequencies over the four stations of south peninsula *viz.* Thiruvananthapuram, Cochi, Alapuzha and Kodaikanal for the months March-June and for period 1961-92 show a characteristic peak in thunderstorm activity about 5-8 weeks (30-60 days) prior to the onset of monsoon over Kerala. Analysis of weekly mean OLR over the south peninsular Indian region for the months March-June and for years 1975-86 (except 1978) show a characteristic fall in a preferred week which coincides very well with the characteristic peak in thunderstorm activity. Thus, the characteristic rise in the weekly cumulative thunderstorm activity can be linked with the large scale convection in association with the seasonal migration of the equatorial trough over the study region with a preferred periodicity of 30-60 days prior to the onset of monsoon. The characteristic peak in the pre-monsoon convective activity over the region is found to be precursor in forecasting the onset of Indian summer monsoon over Kerala well in advance.

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