An index for predicting the onset of monsoon over Kerala

S. S. Puranik, K. C. Sinha Ray, P. N. Sen and P. Pradeep Kumar*

Department of Atmospheric and Space Sciences, University of Pune, Pune 411 007, India

Forecasting the onset of southwest monsoon over Kerala is one of the important events in the operational forecasts of the India Meteorological Department. There are several criteria followed across the forecasting community to achieve this. In this article, we propose an index (Monsoon Onset Forecast Index; MOFI), developed with averaged outgoing longwave radiation (OLR) and averaged kinetic energy as proxies. Twenty-year composite analysis shows significant increase in the kinetic energy and decrease in the OLR five days before the onset, and the MOFI becomes positive. Application of this index has been tested for 13 subsequent years and it is found that the index performs well.

Keywords: Forecasting index, kinetic energy, monsoon, outgoing longwave radiation.

SUMMER monsoon is a crucial part of life in India. Sixty per cent of the country's population derives its livelihood from agriculture[1]. Therefore, any failure or even late arrival of monsoon rains has a strong impact on the economy. Every year the India Meteorological Department (IMD) declares the onset of monsoon over Kerala operationally. Although there is no precise definition of the onset of monsoon, conventionally Indian meteorologists identify the date of onset over the Kerala coast based on a sharp increase and characteristic persistency of the rainfall[2].

Normal date of onset of the monsoon over Kerala is 1 June, with a standard deviation of eight days. An east–west-oriented band of deep convection can be noticed during the onset period across the southern tip of India[3]. The onset is accompanied by significant changes in circulation features, the vertical distribution of moisture, cloud characteristics, the state of the sea, etc. which are difficult to quantify in terms of criteria for onset. Thus the choice of proper diagnostic criteria for determining the onset day has recently been the focus of much attention[4,5].

The changes in circulation during the onset and precursors which have forecasting values have received considerable attention. Several studies[6–11] have mentioned that large-scale changes occur in the circulation features (e.g. northward shifting of west wind maximum in the upper troposphere[2], setting up of the upper tropical easterly jet stream (TEJ)[12] and Somali jet over the Arabian Sea[13]) in association with the onset phase of the Indian summer monsoon. Krishnamurti and Ramanathan[14] declared that the evolution of the summer monsoon is well illustrated by the time-history of the kinetic energy (KE) of low-level flow. They found that there is an explosive increase in the kinetic energy over the Arabian Sea (50–70°E and 4°S–20°N) one week prior to the onset of monsoon rains over central India. These studies were carried out using limited number of onset events, which made it difficult to generalize essential features of the phenomenon of onset over India[15]. There is also a deficiency of knowledge between the influence of local as well as large-scale dynamics and the rainfall over Kerala[4]. Difficulty also arises in differentiating the rainfall due to pre-monsoon thundershowers from the monsoon rain. The purpose of the present study is to prepare an index for forecasting the onset of monsoon over Kerala with lead time of 5 days.

Onset of monsoon over Kerala

The dates for onset of the monsoon season have been defined using a wide range of criteria that include rainfall, surface and upper level winds, outgoing longwave radiation (OLR) indices, upper tropospheric water vapour, brightness temperature, etc. India Meteorological Department (IMD) declares the date of monsoon onset over Kerala operationally every year on the basis of criteria suggested by Ananthakrishnan *et al.*[2] and Ananthakrishnan *et al.*[16], which are based on rainfall. The criteria are as follows: After 10 May, if any five out of the following seven stations, viz. Colombo, Minicoy, Thiruvananthapuram, Allapuzha, Kochi, Kozhikode and Mangalore receive rainfall of 1 mm or more in 24 h (old criterion) for two consecutive days, the onset of monsoon over Kerala may be announced on the second day. These criteria were followed till 2005. In 2006, IMD adopted new criteria regarding the onset of monsoon over Kerala which includes rainfall, wind field and OLR[3,17]. Here importance has been given not only to the sharp increase in rainfall, but also to the setting up of large-scale monsoon flow and extension of westerlies up to 600 hPa before declaring the onset[17]. It may be mentioned here that the above criteria are for declaring the onset and not for forecasting with any lead period.

*For correspondence. (e-mail: ppk@physics.unipune.ac.in)

Ananthakrishnan and Soman[6] defined the Indian summer monsoon onset for north and south Kerala from 1901 to 1980 using conventional rainfall data. Soman and Krishna Kumar[11] indicated that the build-up of moisture occurs a few days prior to the onset. Zeng and Lu[18] suggested a criterion for globally unified summer monsoon onset dates based only on the global daily 1° × 1° normalized precipitable water data with the threshold value of 0.618. The onset of South China Sea monsoon has been defined using the satellite-derived high cloud amount[19], zonal wind and OLR[20] and an objective criterion based on 850 hPa zonal winds averaged over the central South China Sea[5] (5–15°N and 110–120°E). Fasullo and Webster[4] used an index based on the vertically integrated moisture transport (VIMT) for determining the onset day and withdrawal day and called it hydrological onset and withdrawal index (HOWI). According to them, the mean onset day is 4 June with a standard deviation of about 7.4 days. Boos and Emanuel[21] made a scalar index of jet intensity by computing the square root of twice the spatial mean kinetic energy of 850 hPa horizontal wind over the Arabian Sea in the domain 5°S–20°N and 50–70°E and found that the mean date of onset of Somali jet is 5 June with a standard deviation of 9 days.

A delay in the monsoon onset over Kerala is generally associated with a delay in onset at least over the southern states, including the city of Mumbai. In spite of its importance, there are not many studies related to the prediction of the date of monsoon onset over Kerala.

The method put forward in this article to predict the onset of monsoon was developed using the local features over the Arabian Sea. Though indirectly local features are influenced by large-scale features, it is expected that this method will be useful for forecasting the date of onset of monsoon operationally with a lead time of at least four to five days. The existing method of IMD does not give any medium-range forecast. IMD declares onset on the basis of precipitation field or circulation field. However, in the present study we provide a method with which forecast of the onset date can be made with a lead time of five days.

Data

For this study we have used the NCEP–NCAR daily wind data[22] at standard pressure levels, on a 2.5° latitude–longitude grid. There are mainly four categories in which the outputs of NCEP–NCAR data have been classified, depending on the relative influence of the observational data and the model used on the gridded variable. Wind data fall under category A, which indicates that the variable is strongly influenced by the observed data and hence it is in the most reliable class[21]. However, Annamalai *et al.*[23] showed that a substantial difference exists between NCEP and the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis products, particularly around the Somali jet region. To get the strength of the convective heating of the atmosphere we have used National Oceanic and Atmospheric Administration (NOAA) interpolated OLR data. The interpolated OLR data are provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from its website at http://www.esrl.noaa.gov/psd/. The dates of monsoon onset over Kerala are taken from IMD.

Methodology

In this study, we derive predictive signals from the OLR and low-level wind over the Arabian Sea region. The spatial resolution of these data is 2.5° × 2.5° (latitude × longitude) grid for the region 30°S–30°N and 30–120°E. The daily OLR and wind from 1 May onwards for each year of the 20-year period (1980–99) in each 2.5° × 2.5° grid over a region from 30°S to 30°N and longitude 30°E to 120°E were examined. IMD operational date of onset of monsoon over Kerala for a particular year was considered to be zero day; the previous day was considered to be –1 day; two days before the onset was considered to be –2, etc. Similarly, after the onset the next three days were considered as +1, +2 and +3 days. We have examined 20-year (1980–99) composites of OLR, zonal and meridional wind as well kinetic energy at 925 and 850 hPa levels till (or from 10 May onwards) 30 days prior to the date of onset of monsoon and three days after the onset to find out the predictive skill.

Composite analysis

Precursor for onset of monsoon from composite outgoing longwave radiation and wind field

Composites of 20 years starting from 1980 to 1999 have been prepared for this study. In the composites almost 20 days before the onset of monsoon (Figure 1 *a*) a small band of convection extending from 95°E to 100°E and light westerly winds are noticeable in the latitudinal belt from the equator to 5°N region both at 925 and 850 hPa levels respectively (Figures 2 *a* and 3 *a*). Figure 2 *a* also shows the beginning of cross-equatorial flow about 20 days before the onset of monsoon up to 5°N only in the northern hemisphere. In the southern hemisphere wind maxima can be noticed at the northern tip of Madagascar (from 5°S to 15°S). Commencement of the convective activity near 5° on both sides of the equator (Figure 1 *b*) with light westerlies in the equator to 5°N slightly extending northward is observed about 15 days before the onset (Figures 2 *b* and 3 *b*). Westerly winds are more pronounced at 925 hPa than that at 850 hPa level. But as we approach the onset day rapid transition takes place. Convective activity is noticeable ten days earlier over the region from the equator to 5°N and 60–75°E (Figure 1 *c*).

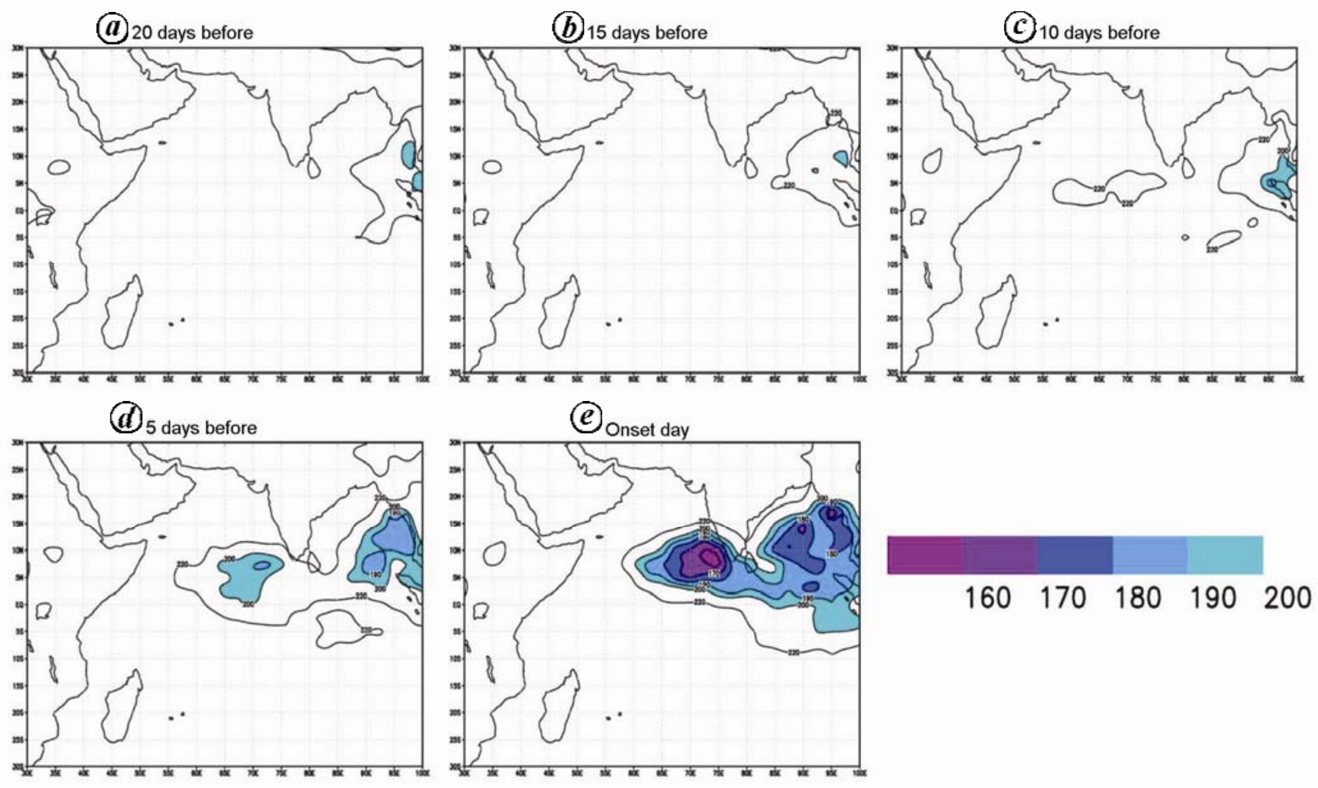

Figure 1. Mean outgoing longwave radiation (OLR; W/m^2) for –20, –15, –10, –5 and onset day as a composite of 20 years (1980–99). Contours from 300 W/m^2 and less are shown at intervals of 20 W/m^2.

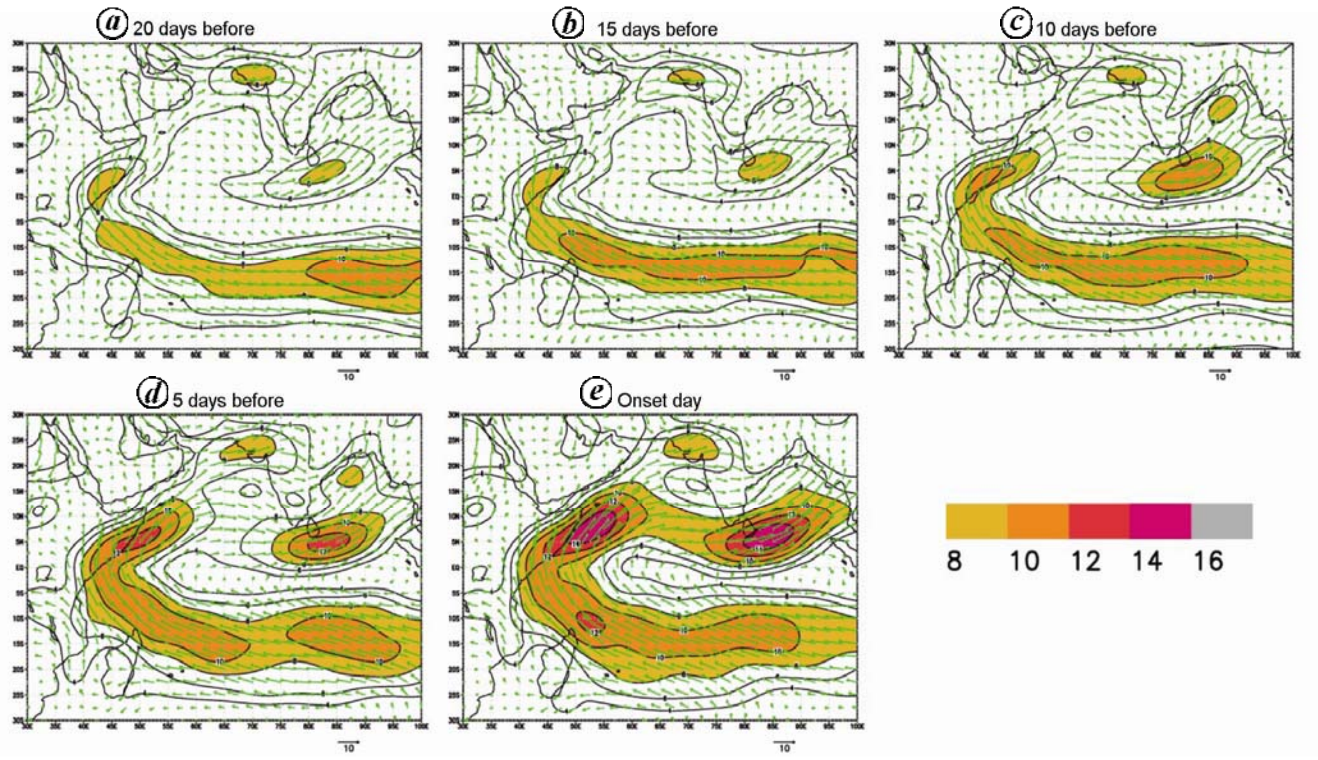

Figure 2. The 925 hPa pressure level mean wind (m/s) for –20, –15, –10, –5 and onset day as a composite of 20 years (1980–99). Contours from 4 m/s and more are shown at 2 m/s intervals. Winds of 8 m/s and more are shown as shaded.

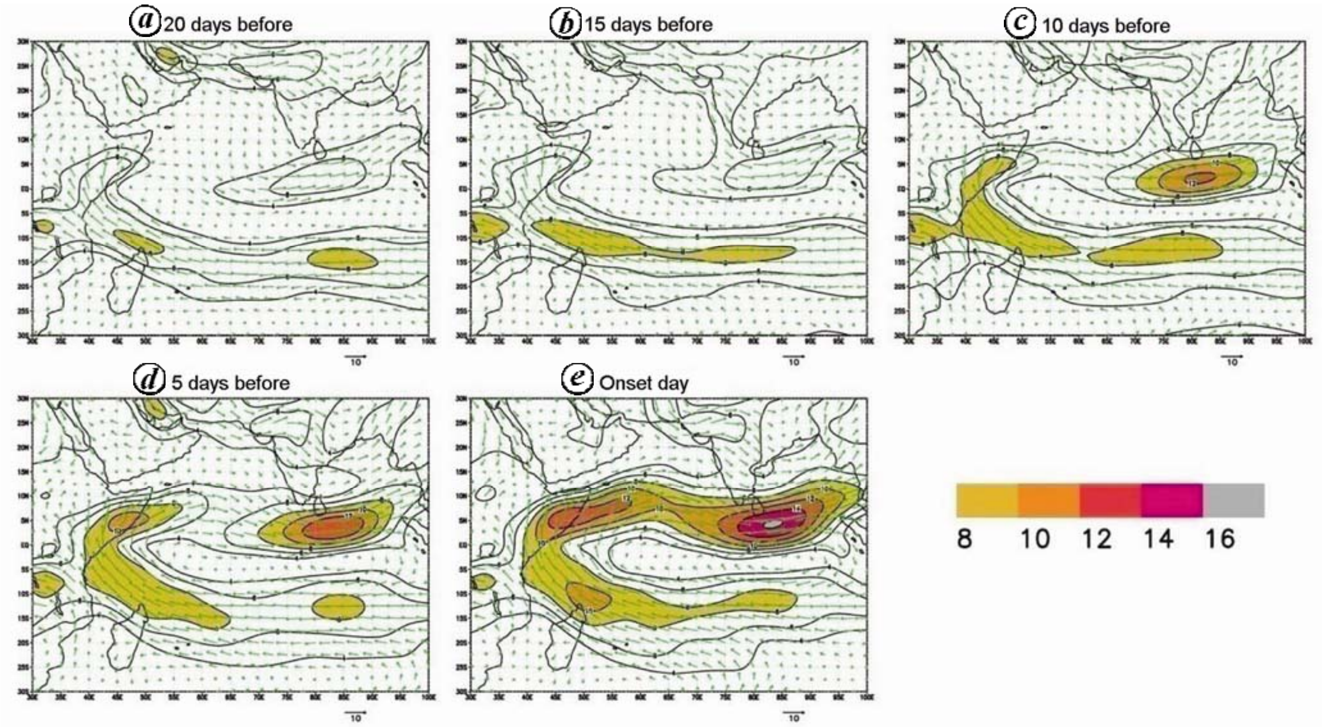

Figure 3. Same as Figure 2, but for 850 hPa pressure level.

Also the cross-equatorial flow increases in strength at 925 hPa level. Winds begin to build up at both the levels (Figures 2 *c* and 3 *c*). Just five days before strong convection is seen over the region between equator 10°N, and 65°E and 75°E (Figure 1 *d*) and at 850 hPa westerly winds reach up to the Sri Lankan territory (Figure 3 *d*). On the day of onset, deep convection gets aligned to the Kerala coast along with fully established westerly winds at 925 and 850 hPa levels respectively (Figures 2 *e* and 3 *e*).

Precursor for onset of monsoon from composite kinetic energy

Figures 4 *a* and 5 *a* show the evolution of KE almost 20 days prior to the onset of monsoon over Kerala at 925 and 850 hPa levels respectively. It is seen that there are two maxima located in the southern hemisphere, one over the region 15–20°S and 85–95°E and the other over the northern tip of Madagascar (5–15°S and 45–55°E). While in the northern hemisphere two secondary maxima which are slightly low in strength (20–25 m^2/s^2) are found over Kenya and the adjoining Somalia region and another to the south of Sri Lanka. A rapid change is seen in the northern hemispheric KE maxima as we approach the onset day. Ten days before the onset, the secondary maxima located to the south of Sri Lanka doubles in strength and a westward shift in the position of maxima is clearly seen at 925 and 850 hPa levels (Figures 4 *c* and 5 *c*). Also at 925 hPa level an appreciable increase in KE is seen over Kenya, Ethiopia as well as the adjoining oceanic region of Somalia, while there is no variation observed at 850 hPa level over the same region. Just five days before the onset significant increase in KE is observed over the western Arabian Sea region and the Somalia region simultaneously at both 925 and 850 hPa levels (Figures 4 *d* and 5 *d*). On the onset day, succession between the Somali maxima and maxima over the southern Sri Lankan region gets completed (Figures 4 *e* and 5 *e*). Analysis reveals that there exists a possibility of receiving some clues for the prediction of the onset of monsoon with considerable lead time.

An index for declaring the onset

Yearly analysis has been conducted for finding a suitable region which will provide the precursor for declaring the onset. For each year daily OLR and KE have been analysed for the period of 20 years, i.e. from 1980 to 1999. During analysis it was found that there is some modulation of the OLR field ≤ 200 W/m^2 within the selected region. On the basis of the yearly analysis we could find two regions: (i) 5–7.5°N and 65–72.5°E and (ii) 2.5–5°N and 70–72.5°E where there is a steep decrease in OLR values five days prior to the date of onset. The same procedure was adopted for KE and we were able to find the region 2.5–7.5°N and 45–52.5°E where KE shows increment five days before the onset.

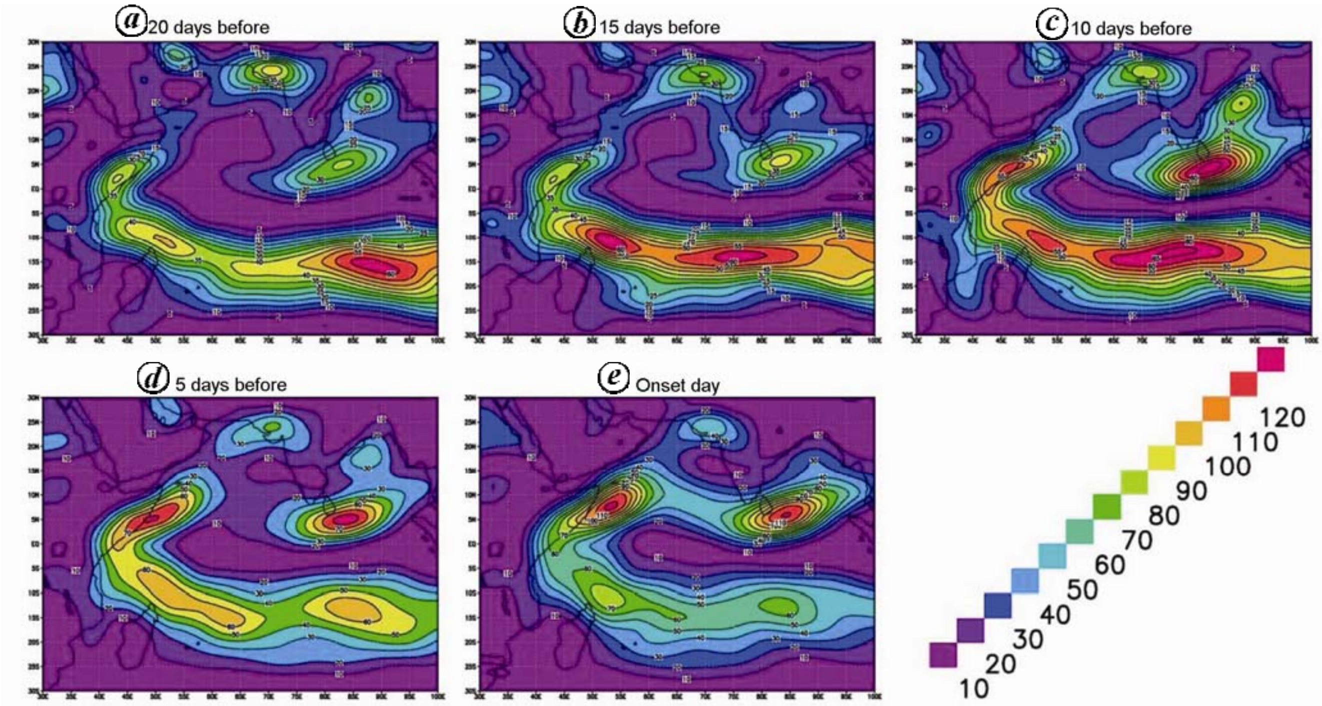

Figure 4. The 925 hPa pressure level kinetic energy (KE; m^2/s^2) for –20, –15, –10, –5 and onset day as a composite of 20 years (1980–99).

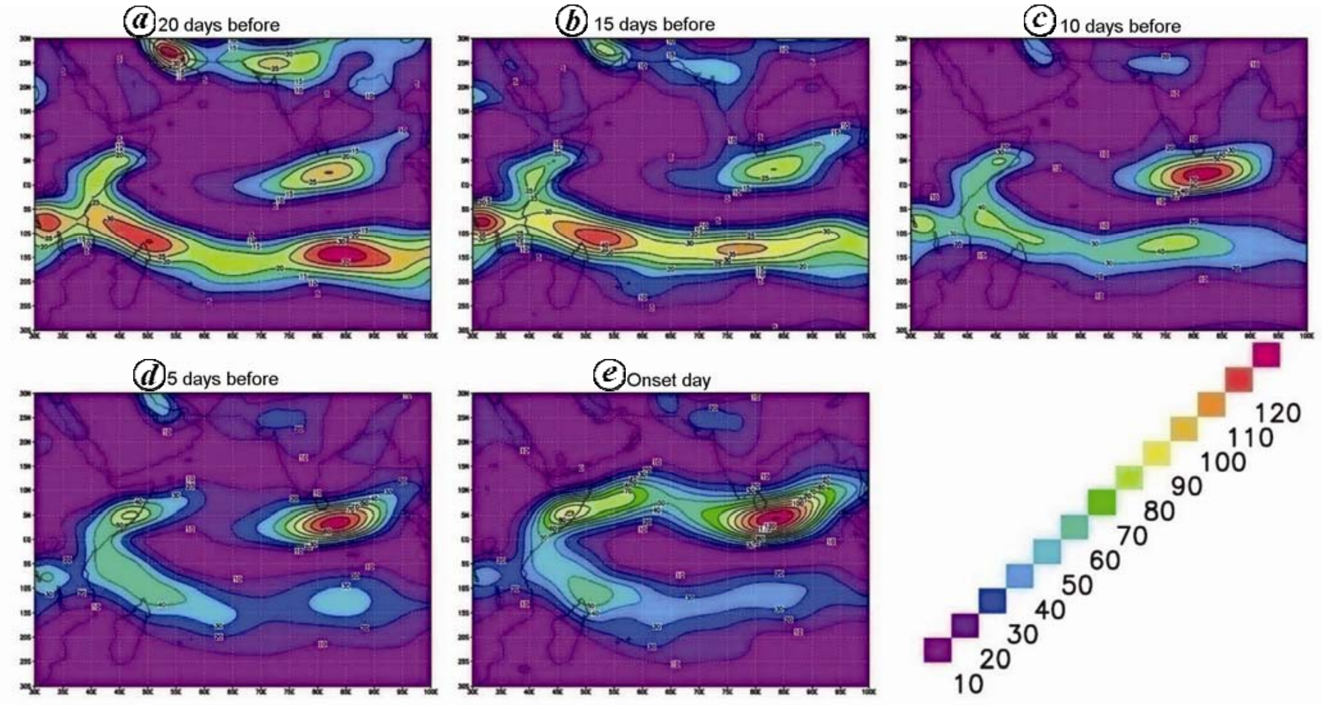

Figure 5. Same as Figure 4, but for 850 hPa pressure level.

It may be noted here that we have considered a large area of low OLR so that discrete pre-monsoon convective activity is discarded. Thus, bogus onset dates are also eliminated. Sometimes the minimum OLR occurs much earlier due to thunderstorm activity before the onset, but as KE is ≤ 50 m^2/s^2 over the chosen region, it discards the possibility of bogus onset declaration. In the present study we have avoided bogus onset declaration (pre-monsoon rainfall).

After examining the data of wind and OLR field for 20 years, we have found a region five days prior to onset where the OLR is minimum and KE exceeds a particular threshold value. Earlier studies have only declared the onset on the basis of some criteria; they do not forecast onset in a medium-range scale. In this study instead of taking a small region for monitoring convective activity, we have considered a large-scale region of convective activity to avoid the pre-monsoon cloudiness which is sporadic by nature. It is known that large-scale convective system moves in a systematic manner unlike the sporadic convection.

The wind field supplies the necessary kinetic energy for the barotropic instability to the system and large-scale convective activity is an indication of cloud development which is reflected in the OLR field. We have forecasted the onset on the basis of movement of large-scale convective region and increase in the wind field which is systematic by nature. For example, the convective system follows the wind current and then turns eastward due to the Coriolis force and slowly approaches the Kerala coast. Also during the onset period there is influx of kinetic energy which can be tracked ahead. This gives instability which is initially barotropic by nature and it results in subsequent rainfall.

While formulating an index, instead of taking into consideration kinetic energy of a particular pressure level the average KE of two layers, i.e. of 925 hPa and 850 hPa levels has been taken into consideration. Figure 6 shows the time-section plot of the average OLR and average kinetic energy starting from 15 days before till the date of onset of the monsoon over Kerala. It is clearly seen from the figure that there is steep decrease (≤ 200 W/m^2) in the average OLR field and increase (≥ 50 m^2/s^2) in the average kinetic energy over the chosen regions. The threshold for OLR (≤ 200 W/m^2) and KE (≥ 50 m^2/s^2) has been derived from composite analysis of both the fields. Therefore, keeping this point in mind a monsoon onset forecast index (MOFI) has been formulated as follows:

$$\text{MOFI} = \left(\frac{200 - \text{OLR}}{200}\right) + \left(\frac{\text{KE} - 50}{50}\right).$$

Figure 7 shows the time-section plot of the index starting from 15 days before the onset till the onset day. It is clearly seen from the figure that the MOFI becomes positive just five days 3 before the onset and it continues to rise as we approach the onset day. The MOFI is formulated on the basis of 20 years of data, i.e. from 1980 to 1999. For declaration of onset, the index has to remain positive for at least two days with a minimum value of 0.1 W/s^2. We tested the MOFI for declaring onset for 13 years, i.e. from 2000 to 2012. It was found that the index performs well and has a standard deviation of 5.24 days.

Performance of the index during two different years – 2002 drought and 2008 (good monsoon)

The behaviour of the 2002 monsoon was intriguing. The year 2002 was the first all-India drought year after a continuous spell of 14 good monsoons that followed the previous all-India drought year of 1987. In 2002 the onset of the southwest monsoon over Kerala was on 29 May, three days before the normal date of 1 June. There was feeble convection over the southeast Arabian Sea in a small region on 29 May. This area was possibly generated by pre-monsoon thunderstorm activity as discussed by Flatau *et al.*[24]. This fact was also clearly brought out in our forecast of the onset of monsoon. According to the MOFI (Figure 8), we predicted onset on 6 June which is

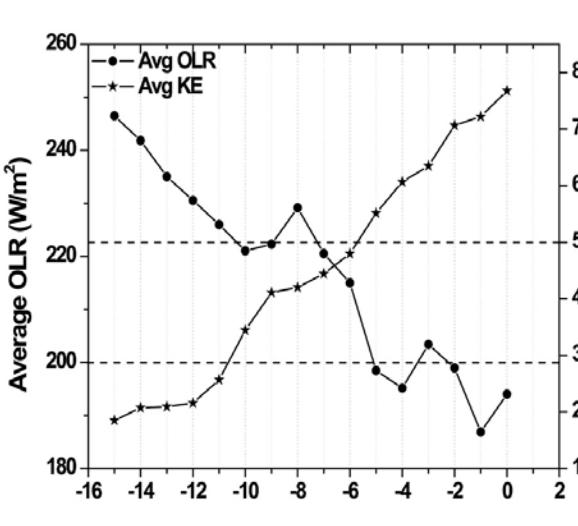

Figure 6. Time-section plot of OLR averaged over the region 2.5–5°N and 70–72.5°E; 5–7.5°N and 65–72.5°E and KE averaged over the region 2.5–7.5°N and 45–52.5°E based on the 20 years composites. On the *x*-axis, the days marked as negative and positive represent before and after the monsoon onset respectively.

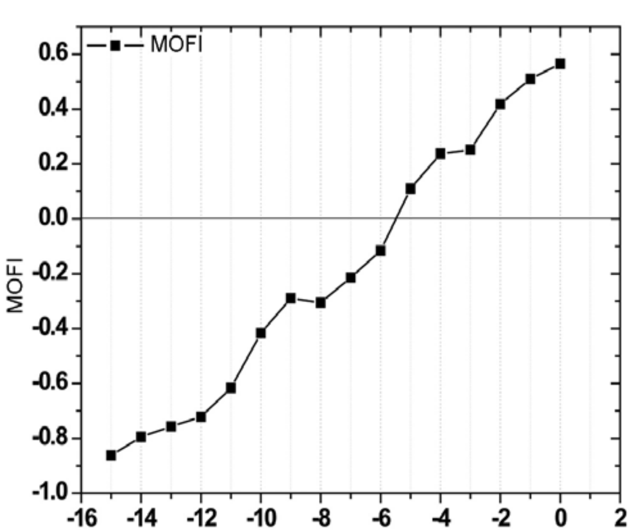

Figure 7. Daily monsoon onset forecast index (MOFI) for the 20 year (1980–99) composites with respect to the date of onset of monsoon over Kerala. On the *x*-axis the days marked as negative and positive represent before and after the onset respectively.

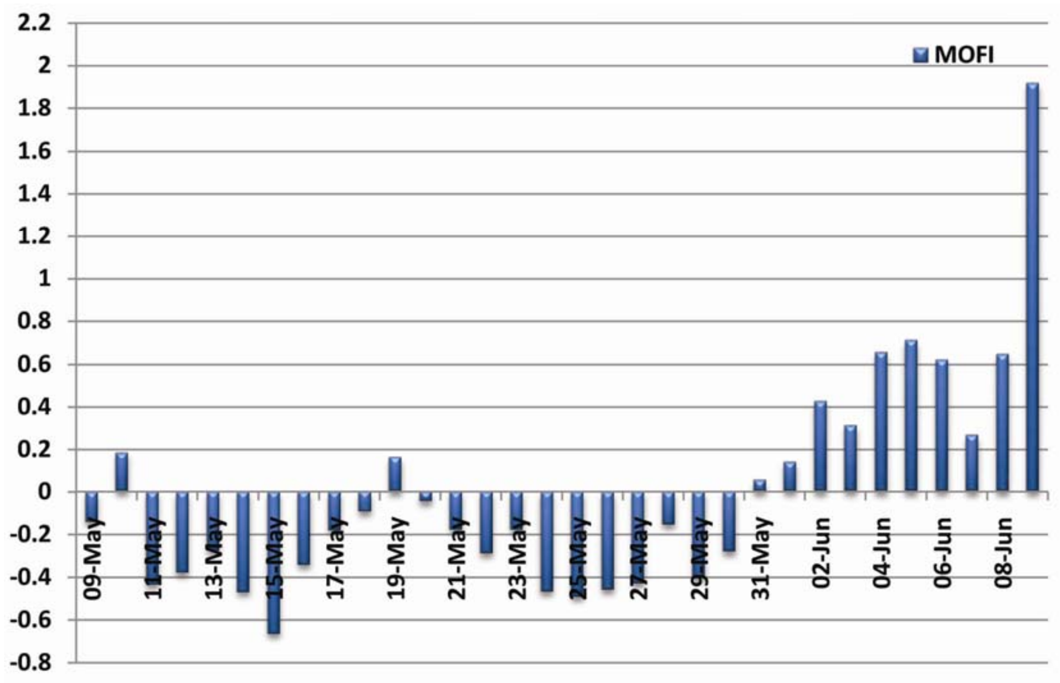

Figure 8. Daily MOFI from 9 May to 9 June 2002.

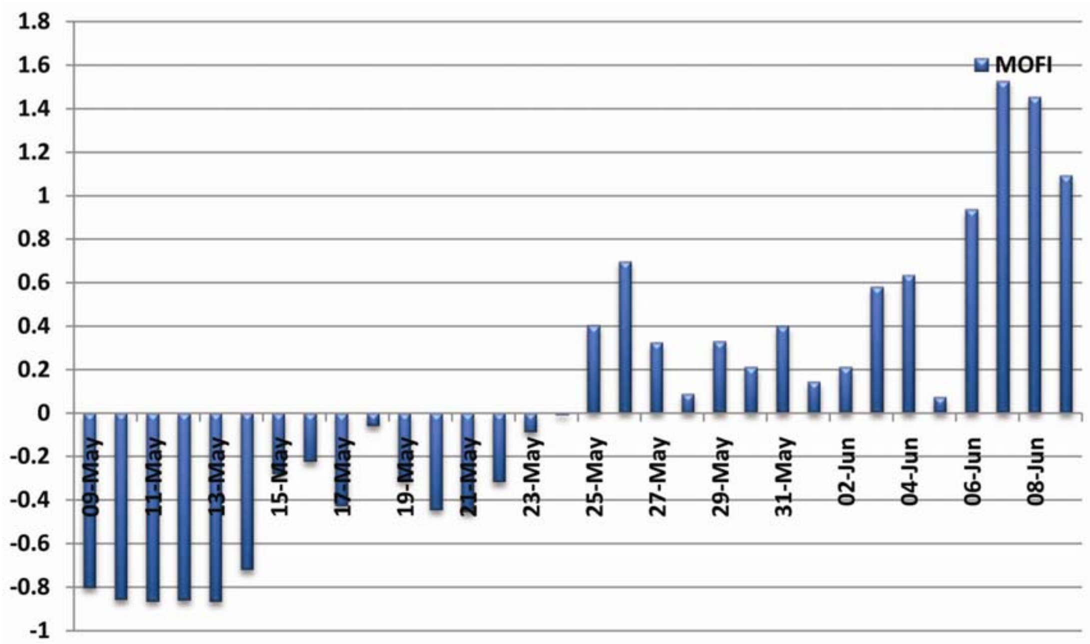

Figure 9. Daily MOFI from 9 May to 9 June 2008.

eight days later than the date declared by IMD. From the analysis of rainfall over the grid, 6 June appears to be correct.

During the 2008 southwest monsoon season (June–September), rainfall for the country as a whole was near normal. In 2008, the onset of the southwest monsoon over Kerala was on 31 May, one day before its normal date of 1 June. Convective activity was noticed almost one week before the onset and started to strengthen from 25 May onwards. This is also evident from the MOFI computed for the year 2008 (Figure 9). Figure 9 shows that from 25 May onwards the MOFI changes sign, i.e. it becomes positive and is more than 0.1 W/s^2. Therefore, with the help of the MOFI we have forecasted the onset of monsoon over Kerala on 30 May, which is just one day ahead of the date operationally declared by IMD.

Table 1. Comparison between the date of monsoon onset over Kerala declared using the devised monsoon onset forecast index (MOFI) and that declared operationally by India Meteorological Department (IMD)

	Date of onset of monsoon over Kerala	
Year	By IMD	Using MOFI
2000	1 June	24 May
2001	23 May	20 May
2002	29 May	6 June
2003	8 June	8 June
2004	18 May	25 May
2005	7 June	5 June
2006	26 May	29 May
2007	28 May	1 June
2008	31 May	30 May
2009	23 May	26 June
2010	31 May	27 May
2011	29 May	1 June
2012	5 June	2 June

These two cases offer insight into the monsoon onset declaration using the MOFI. Thus we have predicted the date of onset of monsoon using this index and verified the same with the operational date given by IMD. The MOFI was verified for individual years. Table 1 shows the year-wise comparison between the MOFI forecasted date of onset and that operationally declared by IMD.

Conclusion

The summer monsoon over the mainland of India arrives first over Kerala around 1 June with a standard deviation of about eight days[3,17]. However, large year-to-year variations are observed with respect to the dates of monsoon onset over Kerala. Therefore, we need a method for the prediction of monsoon onset over Kerala. On the basis of rigorous analysis of individual years we devised an index (MOFI) for the prediction of monsoon onset over Kerala with the help of OLR and kinetic energy. Using this index we were able to predict the onset of monsoon over Kerala coast five days in advance. The standard deviation for the monsoon onset date forecasted is 5.24 days and the root mean square error is 5.02.

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