Chapter 3

Prediction of Monsoon Onset over Kerala

3.1 Introduction

Summer monsoon is a crucial part of the life in India and has been the subject of study for centuries. Sixty percent of the country’s population derives their livelihood from agriculture. Indian economy is vitally linked with the monsoon because of its water resources. A large part of the country gets more than 75% of the annual rainfall during the four months; June to September (Monsoon season). Therefore any failure or even late arrival of monsoon rains results in widespread starvation and economic disaster. This fact clearly points out the vital importance of the prediction of the date of onset of monsoon.

Every year India Meteorological Department (IMD) declares the monsoon onset over Kerala operationally. Although, there is no precise definition of the onset of the monsoon, conventionally Indian meteorologists identify the date of onset over the Kerala coast based on a sharp increase and characteristic persistency of the rainfall (Ananthakrishnan et al., 1968). Large scale changes occur in the circulation features in association with the onset phase of Indian monsoon (Ananthakrishnan et al., 1983; Ananthakrishnan and Soman, 1988; Joseph et al., 1994; Joseph et al., 2006; Pearce and Mohanty, 1984; Soman and Krishna Kumar, 1993). During the summer monsoon onset phase, major changes are observed in the atmospheric wind flow at all levels. In association with the monsoon onset, heavy rains lash south peninsula after the cross-equatorial low-level jet is established across the Somali coast into the near-equatorial Arabian Sea.

Normal date of onset of 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 (Pai and Rajeevan, 2007). The onset is accompanied by significant changes in circulation features such as 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 (Fasullo and Webster, 2003; Wang et al., 2004).

The changes in circulation during the onset and precursors which have prognostic values have received considerable attention. Several studies (Ananthakrishnan et al., 1983; Ananthakrishnan and Soman, 1988; Joseph et al., 1994; Joseph et al., 2006; Koteswaram, 1958; Pearce and Mohanty, 1984) have mentioned that large scale changes occur in the circulation features [e.g. northward shifting of west wind maximum in the upper troposphere (Ananthakrishnan et al., 1968), setting up of the upper Tropical Easterly Jet stream (TEJ) (Koteswaram, 1958) and Somali jet over the Arabian Sea (Findlater, 1969b)] in association with the onset phase of Indian summer monsoon.

Krishnamurti and Ramanathan (1982) declared that the evolution of the summer monsoon is very well illustrated by the time history of the kinetic energy 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 (Raju et al., 2005). There is also a deficiency of knowledge between the influence of local as well as large scale dynamics and the rainfall over Kerala (Fasullo and Webster,
2003). Difficulty also arises in differentiating the rainfall due to pre-
monsoon thundershowers from the monsoon rain.

The purpose of the present study is therefore to prepare an index for forecasting the onset of monsoon over Kerala with lead time of five days.

### 3.2 Monsoon Onset over Kerala

The dates for onset of the monsoon season can be defined using a wide range of criteria that include rainfall, surface and upper level winds, OLR indices, upper tropospheric water vapour, brightness temperature, etc. The 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. (1967); Ananthakrishnan et al. (1968) which is based on rainfall. The criteria are as follows: After 10 May, if any five stations out of the following seven stations, viz., Colombo, Minicoy, Thiruvananthapuram, Allapuzha, Kochi, Kozhikode, and Mangalore receive rainfall of 1 mm or more in 24 hr (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. The IMD’s method of arriving at the date of MOK is considered subjective, as no quantitative thresholds are set for the factors used to determine the onset and the factors used are described qualitatively (Joseph et al., 2006). In 2006 IMD adopted new criteria regarding the onset of monsoon over Kerala which includes rainfall, wind field and OLR (Pai and Rajeevan, 2007, 2009). Here the importance has been given not only to the sharp increase in rainfall but also to setting up of large scale monsoon flow and extension of westerlies up to 600hPa before declaring the onset. It may be mentioned here that the above criteria are for declaring the onset not for forecasting with any lead period.
Ananthakrishnan and Soman (1988) defined the Indian summer monsoon onset for north and south Kerala, on the western shores of India, using conventional rainfall data from 1901 to 1980. Soman and Krishna Kumar (1993) indicated that the buildup of moisture occurs a few days prior to the onset. Joshi and Simon (1994) found an unusual temperature increase in the layer 300-200hPa prior to the onset. Zeng and Lu (2004) suggested a criterion for globally unified summer monsoon onset dates based only on the global daily 1°x1° 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 (Tanaka, 1992), zonal wind and OLR (Wang and Wu, 1997) and an objective criteria based on 850hPa zonal winds averaged over the central South China Sea (5-15°N and 110-120°E) (Wang et al., 2004). Fasullo and Webster (2003) used an index based on the Vertically Integrated Moisture Transport (VIMT) for determining the onset day and withdrawal day and called it as 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 (2009) made a scalar index of jet intensity by computing the square root of twice the spatial mean kinetic energy of 850hPa 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 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.
3.3 Methodology

For this study we have used the NCEP–NCAR daily wind data at standard pressure levels, on a 2.5° latitude–longitude grid. Wind data fall under category A, which indicates that variable is strongly influenced by observed data and hence it is in the most reliable class (Kalnay et al., 1996). To get the strength of the convective heating of the atmosphere we have used National Oceanic and Atmospheric Administration (NOAA) interpolated outgoing longwave radiation (OLR) data. The dates of monsoon onset over Kerala are taken from India Meteorological Department (IMD).

An attempt has been made to predict the date of onset of south west monsoon over Kerala using predictive signals derived from the OLR and low level wind over the Arabian Sea region. The spatial resolution of these data is 2.5° x 2.5° (latitude x 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 (1980-1999) in each 2.5° x 2.5° grid over a region from 30°S-30°N and longitude 30°-120°E were examined. IMD operational date of onset of monsoon over Kerala for a particular year is considered to be zero day, the earlier day was considered to be -1 day, two days before the onset considered to be -2 etc. Similarly after the onset the next three days were considered which was +1, +2 and +3 days. We have examined 20 year (1980-1999) composites of OLR, zonal and meridional wind as well Kinetic energy at 925 and 850hPa 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.
3.4 Composite Analysis

3.4.1 Precursor for onset of monsoon from composite Outgoing Longwave Radiation (OLR) and Wind field

Composites of 20 years starting from 1980-1999 have been prepared for this study. In the composites it is seen that almost 20 days before the monsoon onset (Fig.3.1(a)) small band of convection extends from 95°E to 100°E and light westerly winds are noticeable between latitudinal belt of the Equator to 5°N region at both 925 as well 850hPa levels respectively (Fig 3.2(a) and 3.3(a)). Figure 3.2(a) also shows the beginning of cross equatorial flow about 20 days before the onset 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 to 15°S). Commencement of the convective activity near 5° on both side of the equator (Fig.3.1(b)) with light westerlies in the equator to 5°N slightly extending northward is observed about fifteen days before the onset (Fig.3.2(b) and 3.3(b)). Westerly winds are more pronounced at 925hPa level than that at 850hPa. But as we approach towards the onset day rapid transition occurs in the scenario. Ten days before convective activity is noticeable over the region equator to 5°N and 60-75°E (Fig.3.1(c)). Also the cross equatorial flow shows increase in strength at 925hPa level. Now winds have started to build up at both the levels (Fig.3.2(c) and 3.3(c)). Just five days before strong convection is seen over the region equator to 10°N and 65 to 75°E (Fig.3.1(d)) and at 850hPa westerly winds reaches up to Sri-Lankan territory (Fig.3.3(d)). On the day of onset, deep convection gets aligned to the Kerala coast (Fig.3.1(e)) along with fully established westerly winds at 925 as well as 850hPa level respectively (Fig.3.2(e), 3.3(e)).
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Fig. 3.1: Mean outgoing longwave radiation (OLR; W/m²) for -20,-15, -10,-5 and onset day as a composite of 20 years from (1980-1999). Contours from 300W/m² and less are shown at intervals of 20W/m² while shaded contours show region of OLR ≤ 200 W/m².

Fig. 3.2: The 925hPa pressure level mean wind (m/s) for -20,-15,-10,-5 and onset day as a composite of 20 years (1980-1999). Contours from 4 m/s and more are shown at 2 m/s intervals. Winds of 8m/s and more are shown as shaded.
Fig. 3.3: The 850hPa pressure level mean wind (m/s) for -20, -15, -10, -5 and onset day as a composite of 20 years (1980-1999). Contours from 4 m/s and more are shown at 2 m/s intervals. Winds of 8m/s and more are shown as shaded.

### 3.4.2 Precursor for onset of monsoon from composite Kinetic Energy

Krishnamurti and Ramanathan (1982) declared that the evolution of the summer monsoon is very well illustrated by the time history of the kinetic energy of low-level flow. They found that there is an increase in the kinetic energy over the Arabian Sea (50-70\degree E and 4\degree S-20\degree N) one week prior to the onset of monsoon rains over central India.

Therefore, we have tried to investigate whether any clue can be retrieved from lower tropospheric level kinetic energy (KE) for the prediction of monsoon onset over Kerala. For this purpose 20 years composites were prepared. Fig. 3.4(a) and Fig. 3.5(a) show the evolution of KE almost 20 days prior to the onset of monsoon over Kerala at 925hPa and 850hPa 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 other over the northern tip of Madagascar while in the northern hemisphere two secondary maxima which are slightly less in strength are found over the Kenya and 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 towards the onset day.

Ten days before, the secondary maxima located to the south of Sri-Lanka gets almost doubled in strength and westwards shift in the position of maxima is clearly seen at 925hPa and 850hPa levels (Fig. 3.4(c) and Fig. 3.5(c)). Also at 925hPa level an appreciable increase is seen in the KE over Kenya, Ethiopia as well as over the adjoining oceanic region of Somalia, while there is no variation observed at 850hPa level over the same region. Just five days before the onset significant increase in KE is observed over the western Arabian Sea region as well as over the Somalia region at 925 and 850hPa levels simultaneously (Fig. 3.4(d) and Fig.3.5(d)). On the day of onset succession between the Somali maxima and maxima over the southern Sri-Lankan region gets completed (Fig. 3.4(e) and Fig. 3.5(e)). Analysis reveals that there exists a possibility of receiving some clue for the prediction of monsoon onset with considerable lead time.
Fig. 3.4: The 925hPa pressure level kinetic energy (m$^2$/s$^2$) for -20,-15,-10,-5 and onset day as a composite of 20 years (1980-1999).

Fig. 3.5: The 850hPa pressure level kinetic energy (m$^2$/s$^2$) for -20,-15,-10,-5 and onset day as a composite of 20 years (1980-1999).

### 3.5 An index for declaring the onset

Yearly analysis has been conducted for finding the suitable region which will provide the precursor for declaring the onset. For each year daily OLR and kinetic energy (KE) has been analyzed for the
period of 20 years i.e. from 1980-1999. During analysis it is found that there is some modulation of the OLR field within the selected region. On the basis of yearly analysis we could find out two regions between (1) 5 to 7.5°N and 65 to 72.5°E and (2) 2.5 to 5°N and 70 to 72.5°E where there is a steep decrease in OLR values five days prior to the date of onset. Same procedure was adopted for KE and we could find the region 2.5-7.5°N and 45-52.5°E where the KE shows increase five days before the onset.

On the day of onset over Kerala the intense convection extends from the south Arabian Sea to Southeast Asia through Bay of Bengal. While declaring onset IMD takes care, although in a subjective way, of the three factors, rainfall and the strength and depth of the westerly winds (Joseph et al., 2006; Rao, 1976). At onset Kerala experiences rain and wind. Rain is particularly heavy in delayed onset years, which was called as pre-monsoon rain peak, it occurs every year as stated by Joseph and Pillai (1984) and Joseph et al. (1994), and bogus monsoon onset, occurs only in a few years, Flatau et al. (2001). It may be noted here that we have considered here 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 the kinetic energy (KE) ≤ 50m²/s² over the chosen region the possibility of declaring bogus onset gets eliminated. In our study we have avoided the bogus onset declaration (pre-monsoon rainfall).

After examining the data of wind and OLR field for 20 years we have found a region where the OLR is low and KE exceeds a particular threshold value five days prior to onset. 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 small region for monitoring convective activity we have considered large scale region of convective activity to avoid the pre-monsoon cloudiness which
are 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 very systematic by nature. For example, the convective system follows some path following wind current and then turn eastward due to the Coriolis force and slowly approaches towards the Kerala coast. Also during the onset period there is influx of kinetic energy which may lead to barotropic instability and 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. KE of 925hPa and 850hPa level have been taken into consideration. Fig. 3.6 shows the time section plot of the average OLR and average kinetic energy starting from 15 days before till the date of onset of monsoon over Kerala. It is clearly seen from the figure that there is steep decrease (\(\leq 200\text{W/m}^2\)) in the average OLR field and increase (\(\geq 50\text{m}^2/\text{s}^2\)) in the average kinetic energy over the chosen regions. The threshold for OLR (\(\leq 200\text{W/m}^2\)) and KE (\(\geq 50\text{m}^2/\text{s}^2\)) have 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

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

Fig. 3.7 shows the time section plot of the index starting from 15 days before the onset till the onset day and it is clearly pointed out in the figure that the MOFI becomes positive just five days before the onset and it continues to rise as we approach towards the onset day.
The MOFI is formulated on the basis of 20 year data i.e. from 1980-1999. For declaration of onset the index has to remain positive for at least two days with a minimum value of 0.1 W/s², five days after the MOFI becomes positive the onset is declared. We tested MOFI for declaring onset for thirteen years i.e. from 2000-2012 and it has been found that the index performs well and has a standard deviation of 5.24 days.

Fig. 3.6: 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 20 years composites. On the x-axis the days marked as negative and positive represent before and after the monsoon onset respectively.
Fig. 3.7: Daily monsoon onset forecast index (MOFI) for the 20 year (1980-1999) composites with respect to the date of onset of monsoon over Kerala. On the x-axis the days marked as negative (positive) marking shows days before (after) the onset.

### 3.6 Performance of the index during 2002 (drought), 2008 (good) and 2013

The behavior 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, 3 days earlier than its 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. (2003). This also clearly is brought out in our forecast of the onset of monsoon. As per MOFI (Fig. 3.8) we predicted onset on 6 June which is 8 days later than the date declared by IMD. From the analysis of rainfall over the grid, 6 June appears to be correct.
During 2008 Southwest Monsoon season (June to September), the 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 is noticed almost one week before the onset and started to strengthen from 25 May onwards. This fact is also evident from the MOFI computed for the year 2008 (Fig. 3.9). From Fig. 3.9 it can be noticed that from 25 May onwards the MOFI changes the sign i.e. it becomes positive and is more than 0.1 W/s². Therefore with the help of MOFI we have forecasted onset of monsoon over Kerala on 30 May which is just one day before the date operationally declared by IMD.
In 2013 we have tried to predict the date of onset of monsoon over Kerala. From MOFI (Fig. 3.10) it can be seen that index changes the sign and become positive on 25 May and continues till 27 May. Thus on the basis of MOFI we have given forecast that the onset of monsoon over Kerala will be on 30 May. From the press release report, IMD declared onset on 1st June which is just 2 day after the onset forecast made by using MOFI.

These cases offer the insight of the monsoon onset declaration using MOFI. Thus we have predicted the date of onset of monsoon using this index and verified the same with the operational date of onset of monsoon 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 the onset date operationally declared by IMD.
Fig. 3.10: Daily MOFI for year 2013

Table 3.1: Comparison between the date of monsoon onset over Kerala declared by using devised MOFI and the operationally declared by IMD

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<th>Year</th>
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3.7 Conclusion

The summer monsoon over the mainland of India arrives at first over Kerala around 1 June with a standard deviation of about eight days (Pai and Rajeevan, 2007, 2009). However, large year-to-year variations are observed in respect of the dates of monsoon onset over Kerala.

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

In this study instead of taking small region for monitoring convective activity we have considered a large 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 very systematic by nature.

For example, the convective system follows some path following wind current and then turn eastward due to the Coriolis force and slowly approaches towards the Kerala coast. Also during the onset
period there is influx of kinetic energy which can be tracked earlier. 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. KE of 925hPa and 850hPa level have been taken into consideration. It is clearly seen from the study that there is steep decrease ($\leq 200\text{W/m}^2$) in the average OLR field and increase ($\geq 50\text{m}^2/\text{s}^2$) in the average kinetic energy over the chosen regions.

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. We are 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 RMS error is 5.02.