# Chapter-5

## Onset and Withdrawal

NE monsoon advances into the south Peninsula in October/November after the Southwest monsoon completely withdraws from the country. India Meteorological Department (IMD) made the following criteria in August 1988 for declaring NE monsoon onset, which was further amended in August 2006 (IMD, 2008).

The criteria are:

1) Withdrawal of Southwest monsoon up to Latitude $15^0$N
2) Onset of persistent surface easterlies over Tamil Nadu Coast
3) Depth of easterlies up to 850 hPa over Tamil Nadu Coast
4) Fairly widespread rainfall over coastal Tamil Nadu, South Coastal Andhra Pradesh and adjoining areas.

The withdrawal criteria of SW monsoon up to $15^0$N becomes a constraint in some years. If due to operational constraints, the SW monsoon is not withdrawn, NEM could not be declared on real time basis even if conditions 2 to 4 above are satisfied (Raj, 2012).

IMD started announcing withdrawal dates of NEM only from the year 1993 and prior to that no such declaration appears to have been made. IMD has declared cessation of NEM rainfall by considering rainfall and may be a few other parameters such as depth of moisture, temperature etc. in a subjective way but no objective criteria or guidelines to determine NEM have so far been published (Raj 2012).

The IMD dates of NE monsoon onset and withdrawal are given in Table-5.1. The climatological NE monsoon onset date is 22 October with a standard deviation of about 7 days. The earliest onset date from 1977-2020 is 5 October in 1984. The most delayed onset date is 02 November which occurred in 1988, 1992 and 2000. The climatological withdrawal date is 04 January with a standard deviation of about 11 days. The earliest withdrawal date was 14 December 1994, and the most delayed withdrawal is 19 January

2021. The mean duration of the NE monsoon season is about 75 days. The smallest duration of 51 days occurred in 1992 and the highest duration of 98 days occurred in 2005. However, there is no statistical correlation of NE monsoon seasonal rainfall with either monsoon onset date, withdrawal date or duration. The highest correlation is between the monsoon onset and NE monsoon seasonal rainfall, which is -0.305, statistically significant only at the 90% significance level.

Raj (1992, 2003) and Geetha and Raj (2011) extensively studied the onset and withdrawal of NE monsoon. Geetha and Raj (2011) re-determined the onset and withdrawal dates of NE monsoon for the 100- years of 1901-2000 based on the daily rainfall data of 25 rain-gauge stations. Stations of south Coastal Andhra Pradesh and coastal Tamil Nadu which were located within a distance of 100 Kms from the coast were considered. The comparison of the dates thus identified are compared with the IMD dates. There is a negligible difference in respect of onset dates. However, the difference in respect of withdrawal dates is quite substantial over several years. The onset and withdrawal dates determined by Geetha and Raj (2011) and Raj (2012) are also given in Table-5 for comparison with the IMD onset and withdrawal dates. As per the data of Raj (2012), the mean onset date is 20 October with a standard deviation of about 8 days and mean withdrawal date is 29 December with a standard deviation of about 14 days. Mean duration of the NE monsoon season is about 70 days.

We follow the onset and withdrawal dates as determined by IMD for further analysis and discussions. In the following sections, more analysis with respect to NE monsoon onset and withdrawal dates is discussed.

**Table 5.1**

**NE monsoon onset and withdrawal dates as determined by IMD and Raj (2012)**

| Year | Onset Date (IMD) | Onset Date (Raj, 2012) | Withdrawal Date (IMD) | Withdrawal Date (Raj, 2012) |
|---|---|---|---|---|
| 1977-78 | 14-Oct | 10-Oct | | |
| 1978-79 | 23-Oct | 21-Oct | | |
| 1979-80 | 22-Oct | 22-Oct | | |
| 1980-81 | 11-Oct | 10-Oct | | |
| 1981-82 | 23-Oct | 23-Oct | | |
| 1982-83 | 19-Oct | 18-Oct | | |
| 1983-84 | 24-Oct | 24-Oct | | |
| 1984-85 | 05-Oct | 03-Nov | | |
| 1985-86 | 25-Oct | 25-Oct | | |
| 1986-87 | 27-Oct | 26-Oct | | |
| 1987-88 | 30-Oct | 20-Oct | | |
| 1988-89 | 02-Nov | 03-Nov | | |
| 1989-90 | 27-Oct | 29-Oct | | |
| 1990-91 | 19-Oct | 18-Oct | 10-Jan | 27-Dec |
| 1991-92 | 20-Oct | 19-Oct | 24-Dec | 23-Dec |
| 1992-93 | 02-Nov | 02-Nov | 22-Dec | 09-Dec |
| 1993-94 | 20-Oct | 13-Oct | 11-Jan | 01-Jan |
| 1994-95 | 18-Oct | 18-Oct | 14-Dec | 24-Dec |
| 1995-96 | 23-Oct | 23-Oct | 22-Dec | 13-Dec |
| 1996-97 | 11-Oct | 10-Oct | 23-Dec | 19-Dec |
| 1997-98 | 13-Oct | 13-Oct | 31-Dec | 23-Dec |

| | | | | |
|---|---|---|---|---|
| 1998-99 | 28-Oct | 28-Oct | 22-Dec | 04-Jan |
| 1999-00 | 21-Oct | 04-Oct | 28-Dec | 12-Jan |
| 2000-01 | 02-Nov | 05-Nov | 06-Jan | 02-Jan |
| 2001-02 | 16-Oct | | 11-Jan | |
| 2002-03 | 25-Oct | | 27-Dec | |
| 2003-04 | 19-Oct | | 08-Jan | |
| 2004-05 | 18-Oct | | 25-Jan | |
| 2005-06 | 12-Oct | | 18-Jan | |
| 2006-07 | 19-Oct | | 28-Dec | |
| 2007-08 | 22-Oct | | 10-Jan | |
| 2008-09 | 15-Oct | | 31-Dec | |
| 2009-10 | 29-Oct | | 18-Jan | |
| 2010-11 | 29-Oct | | 17-Jan | |
| 2011-12 | 24-Oct | | 10-Jan | |
| 2012-13 | 19-Oct | | 11-Jan | |
| 2013-14 | 21-Oct | | 18-Jan | |
| 2014-15 | 18-Oct | | 04-Jan | |
| 2015-16 | 28-Oct | | 07-Jan | |
| 2016-17 | 30-Oct | | 04-Jan | |
| 2017-18 | 27-Oct | | 15-Jan | |
| 2018-19 | 01-Nov | | 02-Jan | |
| 2019-20 | 16-Oct | | 10-Jan | |
| 2020-21 | 28-Oct | | 19-Jan | |

Fig. 5.1 shows the super-epoch analysis of rainfall with respect to IMD NE monsoon onset date. Super epoch analysis is a composite analysis (averaging over many years) in which the origin is taken as the monsoon onset date and 50 days before and

after the onset date are considered. Rainfall data in the box 79-81$^0$ E, 10-14$^0$ N have been used for this analysis for the period 1977-2020. The analysis shows a very sharp rise of rainfall on the monsoon onset date over the coastal areas of Tamil Nadu and coastal Andhra Pradesh. Before the onset date up to 50 days, the mean daily rainfall over this region is around 6 mm/day. Just after the monsoon onset, mean rainfall over this region sharply increases to around 14 mm/day, which persists almost for two weeks. We can observe strong intra-seasonal activity even in this super-epoch analysis. For example, after about 20 days after the onset rainfall activity is reduced and it picks up again around 40 days after the monsoon onset.

Fig. 5.2 shows super epoch analysis of rainfall with respect to IMD NE monsoon withdrawal date. Rainfall data in the box 79-81$^0$ E, 10-14$^0$ N have been used for this analysis for the period 1977-2020. This super epoch analysis shows a reduction (not very sharply as we see with respect to monsoon onset) of rainfall activity just after the monsoon withdrawal. Raj (2012) suggested that the monsoon withdrawal date decided by IMD is done subjectively and no official objective definition exists. However, there is a sharp decline in rainfall activity associated with the withdrawal date of Raj (2012), as these dates are determined in hindcast mode using only rainfall criteria.

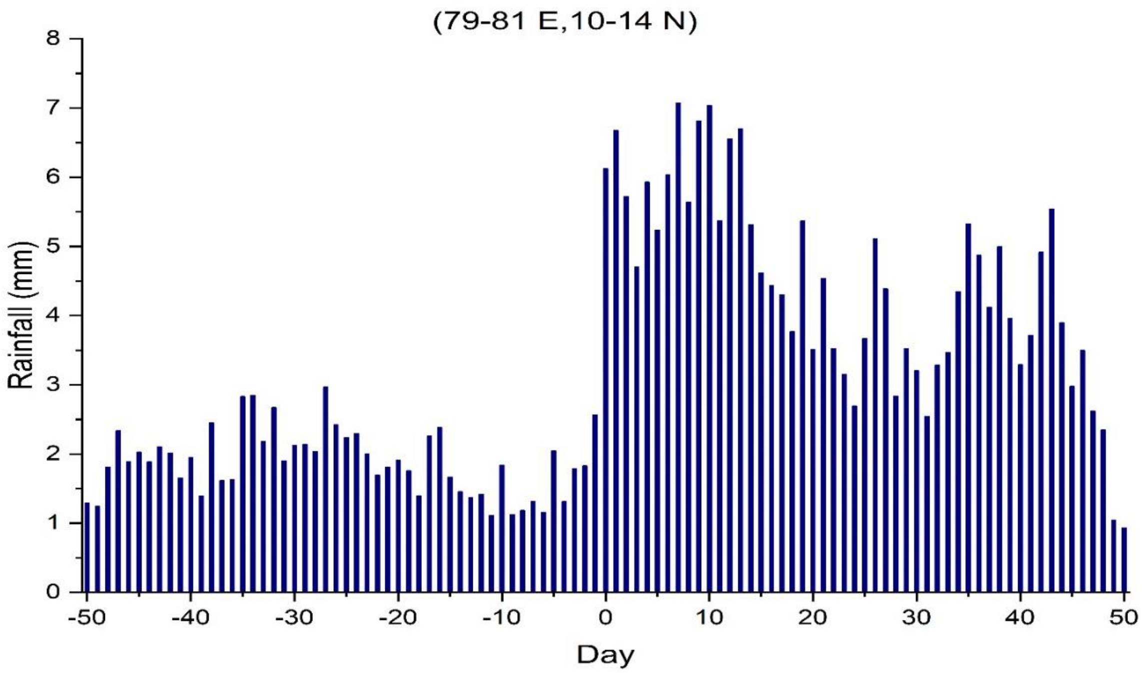


Fig. 5.1. Super epoch analysis of rainfall with respect to IMD NE monsoon onset date. Rainfall data in the box 79.5-80.5$^0$ E, 10-14$^0$ N have been used for this analysis. Period of analysis: 1977-2020.

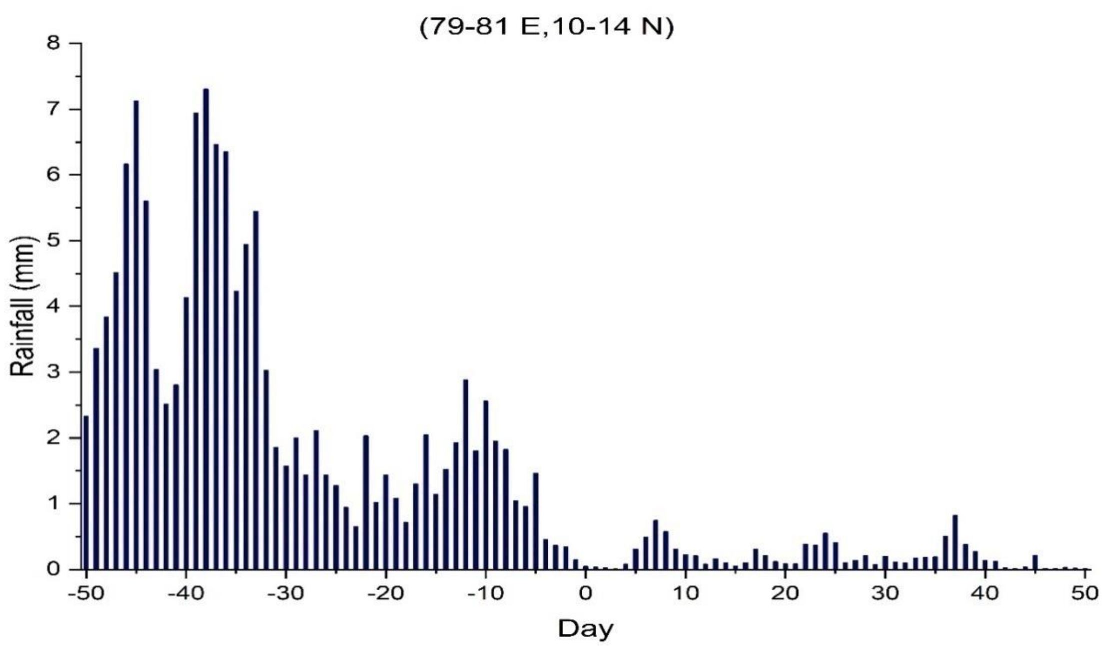


Fig. 5.2. Super epoch analysis of rainfall with respect to IMD NE monsoon withdrawal date. Rainfall data in the box 79.5-80.5$^0$ E, 10-14$^0$ N have been used for this analysis. Period of analysis: 1977-2020.

5.1. **Composite meteorological features associated with the monsoon onset**

To understand the changes in dynamical and thermodynamical parameters occurring associated with the NE monsoon onset, a composite analysis was made with Mean Sea Level Pressure (MSLP), winds at 1000, 850 and 700 hPa level, Outgoing Longwave Radiation (OLR), and precipitable water content. The analysis was made as a pentad (5 days) composite with the onset date as the central date. The other dates in the pentad are two days before the onset and two days after the onset date. Such composites will provide useful information on the dynamical and thermodynamical changes occurring in the region associated with the monsoon onset. Also, they will provide clues for some important parameters to be considered for developing criteria to declare the monsoon onset.

Fig. 5.3 shows the composite MSLP pattern associated with the NE monsoon onset. It clearly shows the presence of a low-pressure area over the southwest Bay of Bengal, off the Tamil Nadu coast, suggesting an area of convergence and associated rainfall activity. However, the surface pressure gradient over the South Bay of Bengal is not strongly associated with the monsoon onset. Instead, a trough of low pressure at the surface extends from the northwest Arabian sea across the southern part of the peninsula to the southeast Bay of Bengal.

Fig. 5.4, 5.5 and 5.6 show the composite mean wind flow at 1000, 850 and 700 hPa levels associated with the monsoon onset. These maps clearly show the presence of east-west trough (ITCZ), from south-west Arabian sea to south-east Bay of Bengal across south Peninsula right from 1000 hPa to 700 hPa. At 1000 hPa, there is a cyclonic circulation over southwest Bay of Bengal associated with the low-pressure area observed at the mean sea level (Fig. 5.3). At 850 hPa and 700 hPa levels, the east-west trough across south peninsula is very prominent. At 850 hPa and 700 hPa levels, the east-west trough passes across south peninsula around $9^0$N. It may be also noted that the strong easterlies north of the trough line, between $12^0$N and $20^0$N and strong westerlies south of the trough line, between the equator and 5$^0$N. Therefore, the east-west trough zone is an area of strong horizontal wind shear and associated convergence.

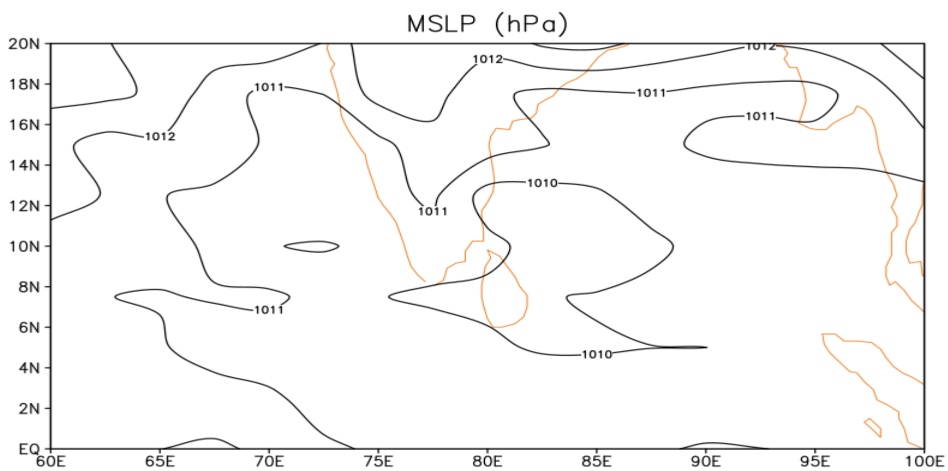


Fig. 5.3. Composite Mean Sea Level Pressure (MSLP) during the pentad of monsoon onset date. The onset date is the central date of the pentad. Onset dates of 1977-2020 were considered for the analysis. Data source: NCEP/NCAR reanalysis.

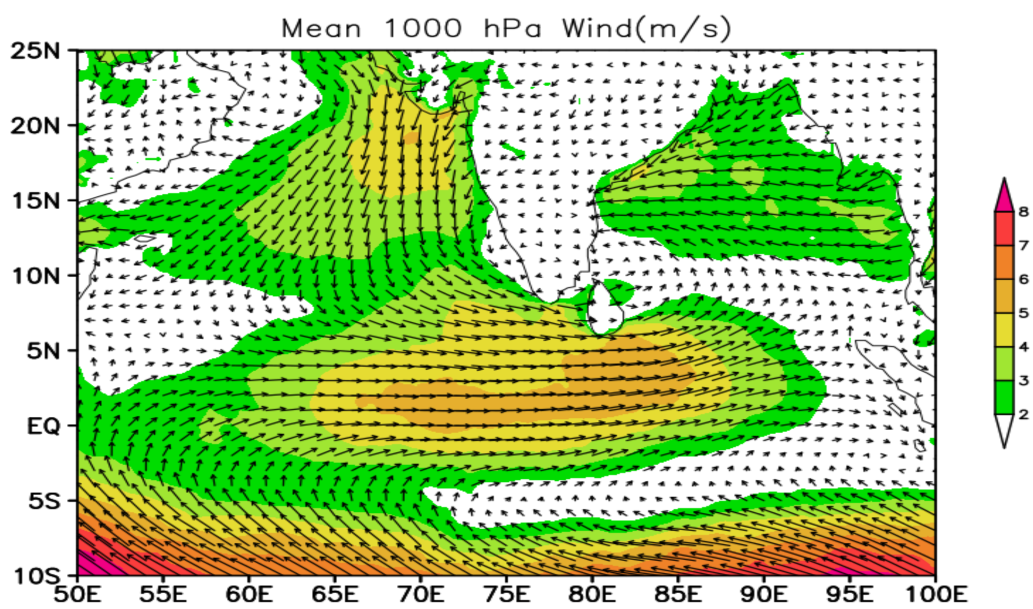


Fig. 5.4. Composite wind flow at 1000 hPa during the pentad of monsoon onset date. The onset date is the central date of the pentad. Onset dates of 1977-2020 were considered for the analysis. Data source: NCEP/NCAR reanalysis.

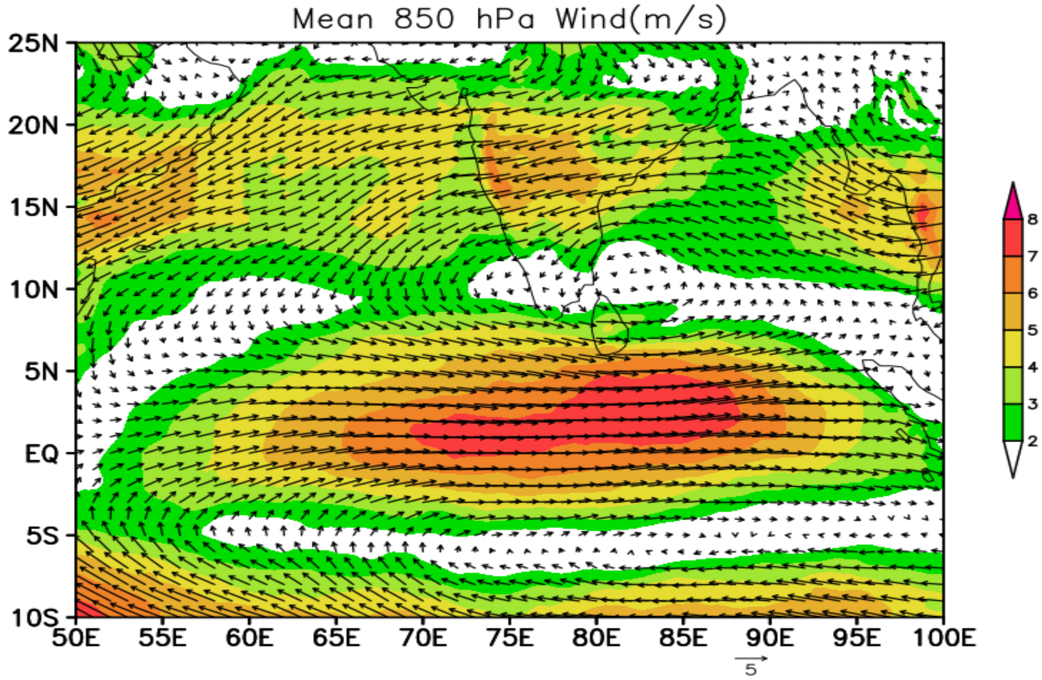


Fig. 5.5. Same as Fig 5.4, but for 850 hPa winds.

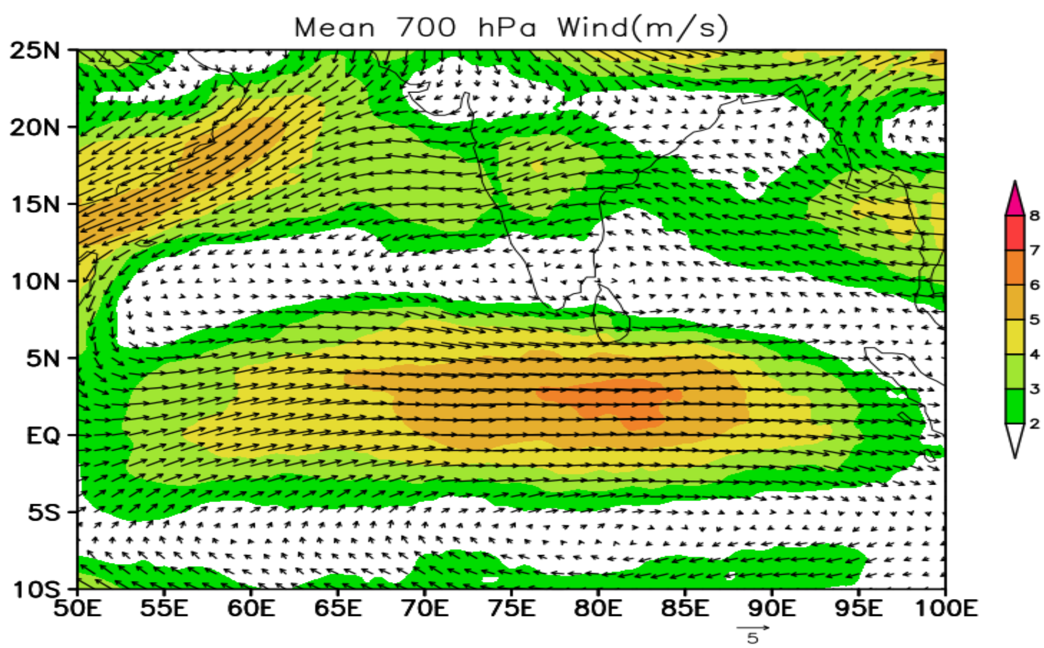


Fig. 5.6. Same as Fig 5.4, but for 700 hPa winds.

Fig. 5.7 shows composite latitude-height distribution of zonal winds averaged between $80^0$E-$90^0$E. There is an easterly wind maximum from 975 hPa to 700 hPa between $13^0$-$17^0$E. At the surface the zero zonal wind line is close to $10^0$N, which suggests the presence of the east-west trough line. Between the equator and $5^0$N, there is a maximum of westerly zonal winds. The zonal wind pattern clearly shows a small southward tilt with height.

Fig. 5.8 shows the pentad composite OLR pattern associated with the NE monsoon onset. This plot was made using observed OLR data derived from National Oceanographic and Atmospheric Administration (NOAA) satellites (http://psl.noaa.gov). The plot shows the southern part of Peninsula, especially the eastern coast is covered with large scale convection with OLR values less than 220 $Wm^{-2}$.

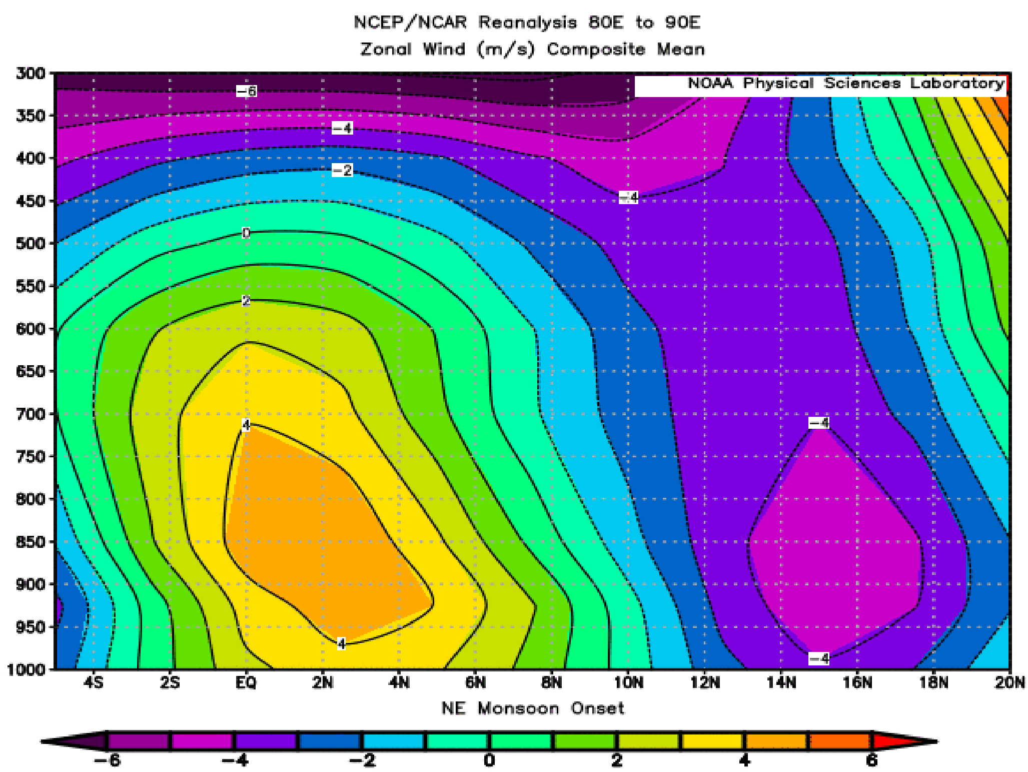


Fig. 5.7. Composite Latitude-Height distribution of zonal winds averaged between 80-90E during the pentad of monsoon onset. The onset date is the central date of the pentad. Data source: NCEP/NCAR reanalysis.

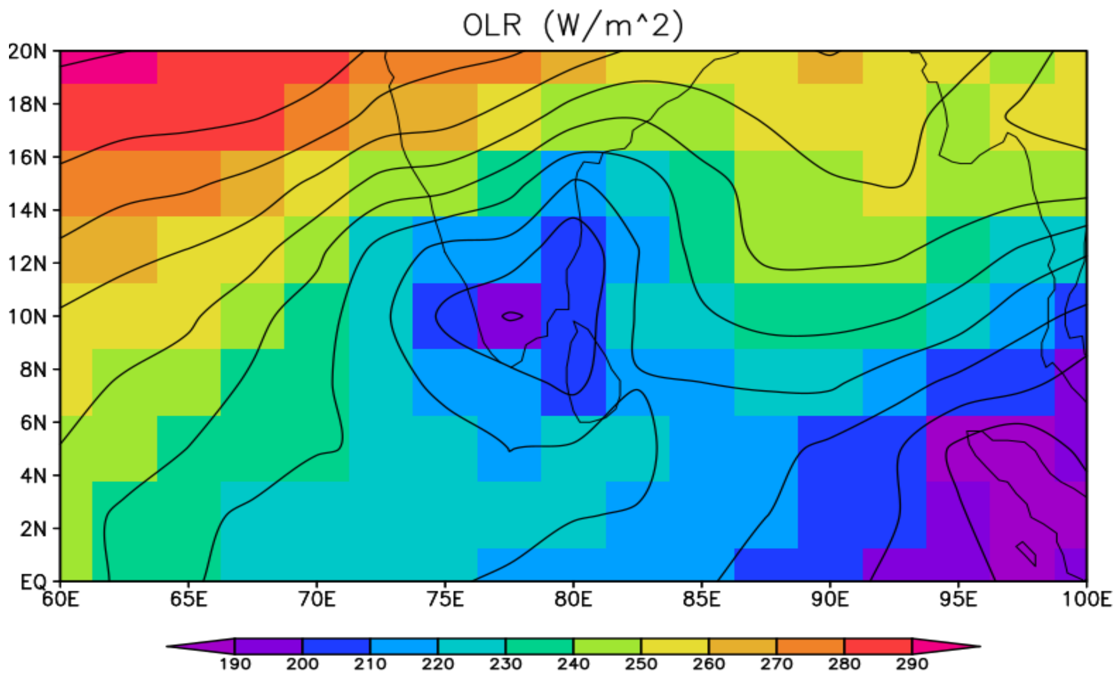


Fig. 5.8. Composite Outgoing Long Wave Radiation (OLR) during the pentad of monsoon onset date. The onset date is the central date of the pentad. Onset dates of 1977-2020 were considered for the analysis. Data source: NOAA OLR Data.

Over the eastern coast of Tamil Nadu (up to $14^0$N) the composite OLR value is less than 210 $Wm^{-2}$ suggesting severe convection over the region. Therefore, the NE monsoon onset is associated with large scale convection (with low OLR) over southern part of peninsula covering up to $16^0$N or so. The monsoon onset is also associated with the presence of large amount of precipitable water content (moisture content) over the region (Fig. 5.9). Over the extreme southern parts of peninsula and east coast of Tamil Nadu, high amount of PWC values (exceeding 42 $kg/m^2$) is observed. Fig. 5.10 shows the spatial distribution of vertically integrated moisture convergence over the region associated with the NE monsoon onset. This plot also shows abundance of moisture flux off- east coast of south peninsula. Therefore, the monsoon onset is associated with the presence of large amount of moisture flux and large-scale convection over the region.

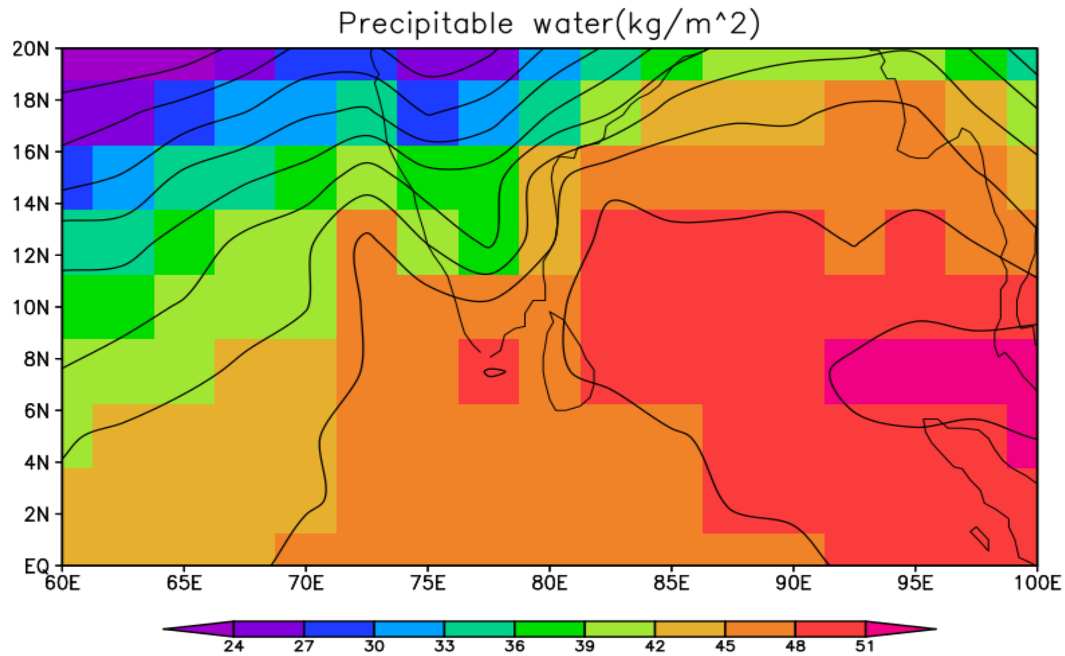


Fig. 5.9. Composite precipitable water content (PWC) (in $Kg/m^2$) during the pentad of monsoon onset date. The onset date is the central date of the pentad. Onset dates of 1977-2020 were considered for the analysis. Data source: NCEP/NCAR reanalysis.

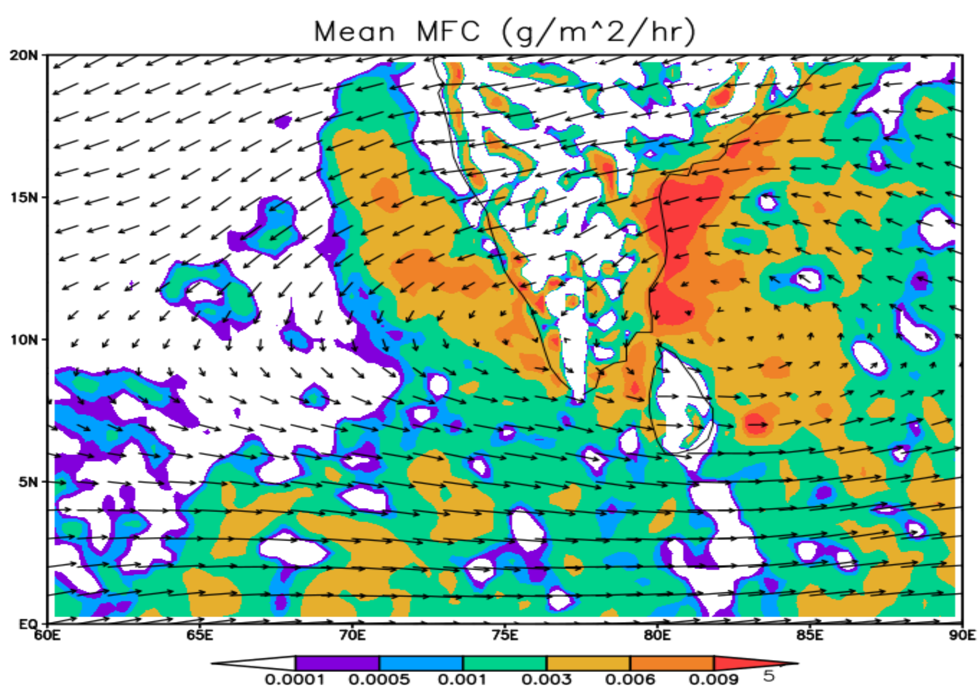


Fig. 5.10. Mean moisture flux convergence (shaded) along with 850 hPa vector winds associated with NE Monsoon Onset.

5.2. **A new method for declaring NE Monsoon Onset**

In this section, a new method is proposed for objective declaring the NE monsoon onset. In this objective method, in addition to information on spatial distribution of rainfall, information of large-scale convection and wind patterns are also considered.

In the previous section, we have noted that the monsoon onset is associated with the presence of ITCZ as an east-west trough in the lower levels across south peninsula (Fig. 25 b-d) along $10^0$N. Large scale easterly wind flow is observed north of the trough. The emergence of this trough and easterlies are primary indications of the NE monsoon onset over south Peninsula. The monsoon onset is also associated with large scale convection over the region (Fig. 26 a), in which OLR values over the east coast of Tamil Nadu are less than 220 $Wm^{-2}$. Therefore, in the new method of declaration of the NE monsoon onset, information about easterly zonal winds, OLR and spatial distribution of rainfall are considered.

For deriving information about these parameters, the following methodology is adopted. For calculating zonal wind, an area of 12-$16^0$N, 85-$90^0$E is considered to calculate zonal winds at 850 hPa. For calculating OLR, an area of 09-$14^0$N, 79-$82^0$E is considered. For spatial distribution of rainfall, following 25 rain-gauge stations of IMD are considered:

1) Adiramapatnam 2) Chengalpattu 3) Chidambaram 4) Cuddalore 5) Kodavasal 6) Madurabthagam 7) Minambakkam 8) Muthupet 9) Nagapattinam 10) Needamangalam 11) Nungambakkam 12) Pamban 13) Ponneri 14) Ramanathapuram 15) Srimushnam 16) Sriperumudur 17) Thiruvallur 18) Thirvararur 19) Thondi 20) Thoothukudi 21) Thiruchendur 22) Vanur 23) Vedaranniyam 24) Sulurpet and 25) Nellore

After analyzing the data for all the years from 1981-2020, the following objective criteria are proposed as a new method for identifying/declaring the monsoon onset.

1) The NE monsoon Onset is declared on any date after 10 October, provided the Southwest monsoon is completely withdrawn from the country.

2) Easterly trade winds should prevail north of $12^0$N up to $20^0$N (approx) and extending from surface up to at least 700 hPa level. The zonal wind at 850 hPa, averaged over the box ($12\text{-}16^0$N, $85\text{-}90^0$E) should be moderately negative at least for three consecutive days. Due to its large variability, a quantitative measure of the strength of easterlies could not be identified.

3) There is large scale convection over the south eastern peninsula region as seen in satellite pictures, with OLR value less than 210 $Wm^{-2}$, averaged over the box ($09\text{-}14^0$N, $79\text{-}82^0$E).

4) At least 50 per cent of the above mentioned 25 IMD rain-gauge stations should report rainfall of 2.5 mm or more. This is equivalent to at least fairly widespread rainfall activity over the region.

5) The first day is taken as the monsoon onset date, provided conditions (1) to (4) are satisfied.

With these objective criteria, a new onset date has been fixed for each year and the new onset dates thus estimated are given in Table-6 below.

The mean onset date of IMD is 22 October with a standard deviation of 6.6 days and the mean onset date from this new method is 24 October with a standard deviation of 8.5 days. The correlation coefficient between the IMD onset date and the new onset date is 0.60, which is statistically significant at the 99% significance level.

**Table 5.2**

New Onset Dates along with the IMD Onset Date and

Onset Dates identified by Raj (2012).

| Year | IMD Onset Date | Onset Date by Raj (2012) | New Onset Date | Difference between the IMD date and new date |
|---|---|---|---|---|
| 1981 | 23-Oct | 23-Oct | 23-Oct | 0 |
| 1982 | 19-Oct | 18-Oct | 18-Oct | 1 |
| 1983 | 24-Oct | 24-Oct | 25-Oct | -1 |
| 1984 | 05-Oct | 03-Nov | 06-Nov | -32 |
| 1985 | 25-Oct | 25-Oct | 25-Oct | 0 |
| 1986 | 27-Oct | 26-Oct | 26-Oct | 1 |
| 1987 | 30-Oct | 20-Oct | 20-Oct | 10 |
| 1988 | 02-Nov | 03-Nov | 03-Nov | -1 |
| 1989 | 27-Oct | 29-Oct | 29-Oct | -2 |
| 1990 | 19-Oct | 18-Oct | 19-Oct | 0 |
| 1991 | 20-Oct | 19-Oct | 27-Oct | -7 |
| 1992 | 02-Nov | 02-Nov | 03-Nov | -1 |
| 1993 | 20-Oct | 13-Oct | 12-Oct | 8 |
| 1994 | 18-Oct | 18-Oct | 18-Oct | 0 |
| 1995 | 23-Oct | 23-Oct | 28-Oct | -5 |
| 1996 | 11-Oct | 10-Oct | 10-Oct | 1 |
| 1997 | 13-Oct | 13-Oct | 13-Oct | 0 |
| 1998 | 28-Oct | 28-Oct | 28-Oct | 0 |
| 1999 | 21-Oct | 04-Oct | 15-Oct | 6 |
| 2000 | 02-Nov | 05-Nov | 19-Nov | -17 |
| 2001 | 16-Oct | | 26-Oct | -10 |

| | | | | |
|---|---|---|---|---|
| 2002 | 25-Oct | | 30-Oct | -5 |
| 2003 | 19-Oct | | 19-Oct | 0 |
| 2004 | 18-Oct | | 26-Oct | -8 |
| 2005 | 12-Oct | | 11-Oct | 1 |
| 2006 | 19-Oct | | 19-Oct | 0 |
| 2007 | 22-Oct | | 20-Oct | 2 |
| 2008 | 15-Oct | | 12-Oct | 3 |
| 2009 | 29-Oct | | 29-Oct | 0 |
| 2010 | 29-Oct | | 29-Oct | 0 |
| 2011 | 24-Oct | | 25-Oct | -1 |
| 2012 | 19-Oct | | 19-Oct | 0 |
| 2013 | 21-Oct | | 21-Oct | 0 |
| 2014 | 18-Oct | | 18-Oct | 0 |
| 2015 | 28-Oct | | 28-Oct | 0 |
| 2016 | 30-Oct | | 01-Nov | -2 |
| 2017 | 27-Oct | | 30-Oct | -3 |
| 2018 | 01-Nov | | 02-Nov | -1 |
| 2019 | 16-Oct | | 20-Oct | -4 |
| 2020 | 28-Oct | | 13-Nov | -16 |
| | | | Difference | -2.0 days |
| | | | Correlation | 0.607 |
| Mean | 22-Oct | 21-Oct | 24-Oct | |
| Std. Dev | 6.65 | 8.57 | 8.65 | |

In general, the new onset dates and IMD onset dates are closer in most of the years. Both the onset dates are exactly the same in 14 years. However, there are differences too. The largest difference for 10 days or more is found in years like 1984, 1987, 2000, 2001, and 2020. The mean difference between IMD onset date and New Onset date is about 2 days.

The new method of fixing the onset date is further discussed using a case study of the 1986 monsoon onset. Fig. 5.11 shows the time series of percent of stations reporting 2.5 mm or more, Outgoing longwave radiation (OLR) in $Wm^{-2}$ and the zonal wind at 850 hPa. As per the new method, the onset date in 1986 is 26 Oct. On this day, 63 percent stations reported 2.5mm or more rainfall, thus indicating fairly widespread rainfall activity. Enhanced rainfall activity continued for almost 10 days. OLR, which is a proxy for convection, started reducing a couple of days before the onset date. This suggests starting of large-scale convection over South peninsula associated with the monsoon onset. OLR values near the onset were less than 200 $Wm^{-2}$, which persisted for almost one week. By $16^{th}$ itself, easterlies were set in and strong easterly zonal winds were prevailing during the onset date and subsequent 10 days. But the zonal wind component has shown large day to day variations.

The NE monsoon onset of 2020 is now discussed with a similar time series plot. Fig. 5.12 shows the similar variation of parameters (as in 1986) from 24 Oct to 20 Nov. The IMD onset date in 2020 was 28 Oct and the new onset date as per the revised criteria was 13 Nov. On $28^{th}$ October, only 14% of IMD stations reported rainfall and OLR values were more than 240 $Wm^{-2}$, suggesting not enough convection over the region. Weaker easterly winds had just set in. Thereafter, there was not much rainfall activity over the region. Rainfall activity again picked up on 12 November. Easterly winds started strengthening and OLR values started dipping below 210 $Wm^{-2}$. The new criteria with the inputs on easterly winds and OLR values were completely satisfied on 13 Nov, which is the new monsoon onset date. Therefore, the new objective criteria could identify the real onset date which is associated with large scale convective activity over the region.

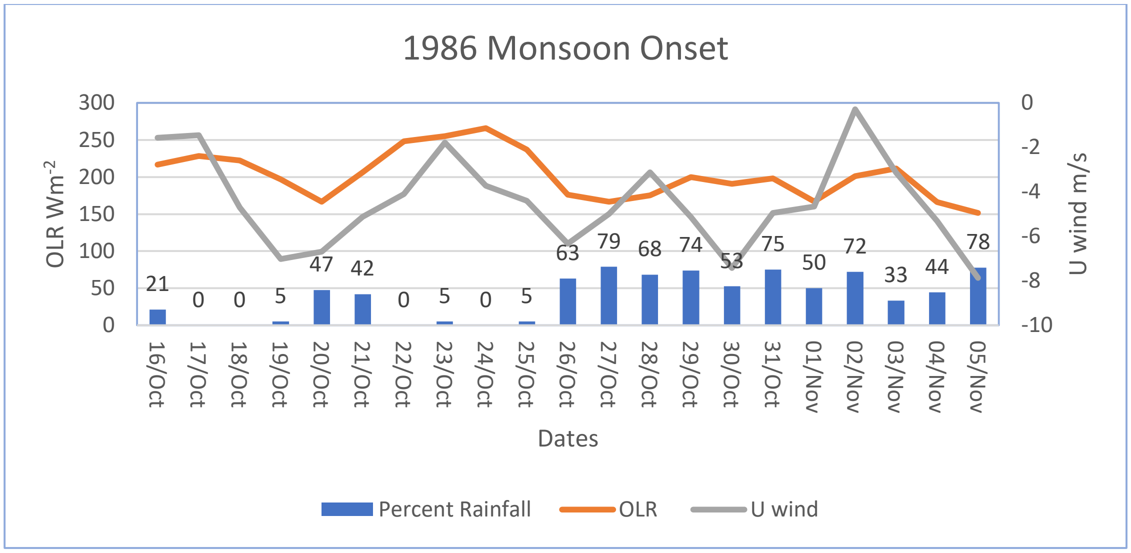


Fig. 5.11. Monsoon Onset in 1986. Time series of percent of stations reporting rainfall of 2.5 mm or more (Vertical bars in blue), OLR value (Orange colour) and zonal wind at 850 hPa during 16 Oct to 05 Nov, 1986.

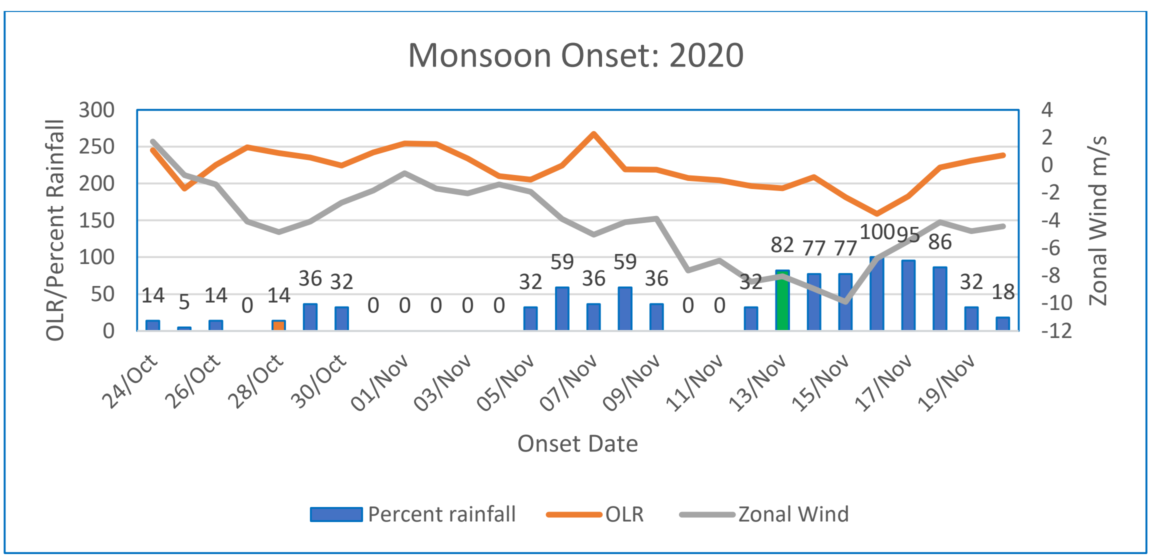


Fig. 5.12. Monsoon Onset in 2020. Time series of percent of stations reporting rainfall of 2.5 mm or more (Vertical bars in blue), OLR value (Orange colour) and zonal wind at 850 hPa during 24 Oct to 20 Nov 2020. The IMD Onset date, 28 Oct is shown as red vertical bar and the new Onset date is shown as green vertical bar.