Operational Extended Range Forecast Activity in IMD and its Applications in Different Sectors

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ABSTRACT

In this review article various aspects of real time extended range forecast (ERF) based empirical models and dynamic models including the Multi-model Ensemble (MME) generated by India Meteorological Department (IMD) of southwest monsoon, northeast monsoon, cyclogenesis over the Bay of Bengal (Bob) and maximum and minimum temperature during the period from 2009 to 2014 have been discussed. The prospects of its application in different sectors are also analysed.

The performance of extended range forecasts for the southwest monsoon seasons clearly captured the delay / early onset of monsoon over Kerala, active / break spells of monsoon and also withdrawal of monsoon in the real time in providing guidance for various applications. The MME based ERF also provides encouraging results to provide useful guidance for 2/3 weeks about northeast monsoon during October to December (OND), tropical cyclogenesis over the north Indian Ocean during OND and maximum and minimum temperatures during winter and summer. However, there is a lot more need to be done to provide this in smaller spatial scales.

In order to further strengthen IMD's capability of real time ERF, it has started collaborative work with other national and international partners.

Keywords: *Multi model ensemble, cyclogenesis, madden Julian Oscillation, climate forecast system.*

1. Introduction

Just like the interannual variability of monsoon rainfall the Indian summer monsoon precipitation during June to September (JJAS) shows clear intraseasonal variation as large-scale convective anomalies propagates northward from the equator with in the season. This northward propagation is known to be accompanied by eastward propagation of convective activity along the equator (Madden Julian Oscillation; MJO) through the Rossby wave propagation. The MJO is the leading mode of tropical intraseasonal climate variability and is characterized by organization on a global spatial scale with a period typically ranging from 30-60 days (Madden and Julian, 1971;1994, Zhang, 2005) The active/break cycles of monsoon are manifestations of sub-seasonal fluctuations of the northward propagating intertropical convergence zone (ITCZ; Sikka and Gadgil 1980; Krishnamurti and Subrahmanyam 1982; Pattanaik 2003; see Goswami 2005 for a review). Thus, the forecast of this active/break cycle of monsoon, commonly known as the Extended Range Forecasts (ERF) is very useful. The agriculture sectors like farmers are very much benefited if accurate outlook of monsoon conditions are provided to them in the extended range. Webster and Hoyos (2004) suggested that forecasts of precipitation on this intermediate timescale are critical for the optimization of planting and harvesting. Prediction of monsoon break 2 to 4 weeks in advance, therefore, is of great importance for agricultural planning (sowing, harvesting, etc.), which can enable tactical adjustments to the strategic decisions that are made based on the longer-lead seasonal forecasts, and also will help in timely review of the ongoing monsoon conditions for providing outlooks to farmers. It is not only the Agriculture sector which is benefited from the proper outlook of extended range forecast (Tyagi and Pattanaik 2012; Pattanaik et al., 2013a; Pattanaik 2014), a skillful extended range forecast can also be very useful for reservoir operation in reducing floods Pattanaik and Das (2015). They have recently demonstrated usefulness of extended range forecast in a pilot study over the Mahanadi River basin in Odisha in case of 2011 flood.

The ERF in the tropics are one of the most challenging tasks in atmospheric sciences. It fills the gap between medium-range weather forecasting and seasonal forecasting, is certainly a difficult time range for weather forecasting, since the timescale is sufficiently long so that much of the memory of the atmospheric initial conditions is lost. On the other hand, monthly mean time average is not large enough for the atmospheric signal associated with the ocean anomalies to emerge over the atmospheric noise. In last few decades, many groups throughout the world is working in developing empirical models for predicting the MJO signals, which can be utilized for the intra-seasonal fluctuation of rainfall over India. In addition, there are many global modeling centers like ECMWF, NCEP, JMA etc. are also running atmospheric General Circulation Model and coupled atmosphere-ocean models operationally. The latest generation coupled models are found to be very useful in providing skillful guidance on extended range forecast.

In addition to monsoon associated heavy rainfall over India during JJAS, the months of October-December (OND) are known to produce tropical cyclones (TCs) of severe intensity in the Bay of Bengal (BoB), which after crossing the coast cause damages to life and property over many countries surrounding the BoB including India. The strong winds, heavy rains and large storm surges associated with tropical cyclones are the factors that eventually lead to loss of life and property. Heavy rains associated with cyclones are another source of damage. In India, many studies have demonstrated the utility of TCs forecasts up to 3 days using Global and regional models (Sikka 1972; Singh and Saha 1978; Mohanty and Gupta 1997; Prasad and Rama Rao 2003; Pattanaik and Rama Rao 2009 etc). However, the forecasting of genesis of TC and associated rainfall in the extended range time scale (about 2 weeks in advance) is very useful in many respects (Pattanaik et al., 2013b); Pattanaik & Mohapatra, 2014). The post-monsoon cyclone season during OND is also known as the northeast monsoon season. The withdrawal of southwest monsoon and commencement of northeast monsoon over southern Peninsula is linked to one another. Tyagi and Pattanaik (2012) have demonstrated the utility and skill of ERF of the northeast monsoon rainfall over Tamil Nadu as it is the main rainy season of the year (IMD, 1973; Raj 2003).

Like the utility of ERF of Indian monsoon rainfall, cyclogenesis, northeast monsoon, the ERF of surface air temperature (hereafter denoted as temperature) of two weeks to monthly scale has a wide range of applications in agriculture, energy, health, insurance, power, financial sector etc. In May 2003 the heat wave claimed over 1,600 lives throughout the country with some 1,200 (Bhadram et al., 2005) individuals died in the state of Andhra Pradesh alone. Like in 2003, during 2005 also India was under the grip of severe heat wave towards the third week of June (Pattanaik et al., 2013c) over the country covering the state of Odisha and neighbourhood. The prediction of heat waves and cold waves with significant accuracy can save lives and prevent damage to property from these dangerous weather events. Tyagi and Pattanaik (2012) have demonstrated the utility of extreme temperature forecasting (heat wave and cold wave) during 2010 and 2011 winter and summer seasons using the outputs from coupled model. Pattanaik et al. (2008) using the hindcast from the UK Met office coupled model have shown that, although the model has got warm bias the skill of forecasting of year-to-year variation of maximum temperature during the hot weather seasons from March to June during the period from 1987 to 2002 is reasonably good.

IMD has been issuing experimental extended range forecast since 2009 using available products from statistical as well as dynamical models outputs from various centres in India and abroad. A brief review of the operational ERF issued by IMD along with its skill and usefulness during the period from 2009 onwards and prospects of its application in different sectors are presented in this review article. This review article also discusses the future prospect of the real time ERF in IMD. In Section 2 the different products viz., empirical models, dynamical models and MME based on dynamical models used by IMD for operational extended range forecast since 2009 is discussed. Section 3 discusses the performance of ERF of southwest monsoon rainfall during JJAS over India during last 6 years (2009 to 2014) on different spatial and temporal domains. The ERF skill of other events, like the cyclogenesis during post monsoon season, northeast monsoon rainfall, extreme temperatures etc are also discussed in Section 4. The proposed collaborative ERF product to be generated from 2015 monsoon season is discussed in Section 5. Finally, a summary of the main results are discussed in Section 6.

2. Details of Model Products used for Real Time ERF Forecast

After the commencement of operation ERF forecast by IMD in 2009, initially both the models (empirical and dynamical) outputs were. Subsequently, with the improvement in dynamical models in recent years the MME based on the dynamical models outputs are only used for the preparation of real time ERF. The products used by IMD are presented below :-

2.1 Empirical model products for real time extended range forecast

2.1.1 Pentad OLR anomalies forecasts

The outgoing long-wave radiation (OLR) pentad forecasts based on the method adopted by Xavier and Goswami (2007) was used initially for the guidance to forecasters. The methods adopted by them are based on the analogs of the OLR anomalies at lead time period of 1 pentad to 4 pentads. The forecast in the form of OLR anomalies are generated for 4 pentads, which was generated by Long Range Forecasting Division of the IMD, Pune. In addition to this forecast the pentad OLR anomaly forecast based on Jones et al., (2004) were also used.

2.1.2 Multivariate MJO indices

The group at Bureau of Meteorological Research Centre (BMRC) Australia also adopted two approaches to empirical prediction of MJO. Two real-time Multivariate MJO indices "RMM1 and RMM2" are used for the current state of MJO as (available from http://cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR_modes/index.htm) discussed in Wheeler and Hendon (2004). The two indices are defined by projection of daily observations onto combined EOFs of OLR, u850, and u200. It is convenient to view the state of the MJO in the two-dimensional phase space defined by the two EOFs. The future MJO states in term of RMM1 and RMM2 indices are obtained through multiple regression as discussed in Maharaj and Wheeler (2005) and Jiang et al. (2008).

2.1.3 Forecast based on the Self Organising Map (SOM)

Recently IITM, Pune had also developed another empirical model for predicting intra-seasonal rainfall activity based on the non-linear pattern recognition technique known as the Self Organizing Map (SOM) (Sahai and Chattopadhyay 2006). The Kohenen's SOM falls under the class of unsupervised learning of synapses in an Artificial Neural Network algorithm. The wind, geopotential height, specific humidity and the mean sea level pressure are used for the SOM classification of rainfall. The basis of this model is that the non-linear combinations of all the indices sufficiently represent the complex Intra-seasonal variation of the monsoon rainfall and the indices themselves have the capability of capturing the seasonality. They used the dynamical indices from the NCEP data in real time mode for the forecast of rainfall anomalies till 4 pentads.

2.2 Dynamical model products for real time extended range forecast

For the real-time monitoring of intra-seasonal monsoon rainfall, subsequently more emphasis was given to Coupled model outputs. IMD utilizes the products from three well known coupled models viz., the ECMWF monthly forecast system, the NCEP's Climate Forecast System (CFS), the JMA's ensemble prediction model (EPS) and the Multi-model ensemble (MME) of these models. A brief details of the models and the methodology of MME are discussed here.

2.2.1 ECMWF monthly forecast system

The products from the ECMWF monthly forecasting system is based on 32-day coupled ocean–atmosphere integrations set up at ECMWF. This system has run routinely since March 2002. The GCM used in this study has a much finer resolution (T639L62 for first 10 days and T319L62 beyond 10 days). The ECMWF monthly forecasting system is forced by persisted SSTs for first 10 days and the atmosphere-ocean coupling started beyond days 10 and is having 51 ensemble members Frederic (2004).

2.2.2 NCEP's Climate Forecast System (Version 1 and Version 2)

MJO monitoring and prediction is also carried out at Climate Prediction Centre, NCEP, USA by using the dynamical model outputs from Climate Forecast System (CFS; version 1; Saha et al., 2006). The atmospheric component of the operational CFSv1 is the NCEP atmospheric GFS model (T62L64). The oceanic component is the GFDL Modular Ocean Model V.3 (MOM3). There is no flux correction in atmosphere-ocean coupling and CFSv1 is a tier-1' forecast system. Many recent studies have demonstrated useful forecast skill of CFSv1 for the prediction of Indian monsoon on the seasonal and monthly scale (Pattanaik and Kumar, 2010; Pattanaik et. al., 2010; Pattanaik et. al., 2012a, Pattanaik et. al., 2012b). The second version of the NCEP CFS (CFSv2) was made operational at NCEP in March 2011. The CFSv2 has upgrades to nearly all aspects of the data assimilation and forecast model components of the system. The atmospheric model has a triangular truncation of 126 waves (T126) in the horizontal (»100 Km grid resolution) and a finite differencing in the vertical with 64 sigma-pressure hybrid layers. The CFSv2 runs with 16 members per day (Saha et. al., 2014; Pattanaik and Kumar 2014).

2.2.3 Ensemble Prediction System (EPS) from JMA

The other model used for ERF is the is an atmospheric general circulation model (AGCM) that is a low-resolution version (TL159) of the global model used for short- and medium-range forecasting by JMA with 50 ensemble members. Like in the ECMWF model the JMA model also generate forecasts for 32 days based on every Thursday.

2.2.4 Multi-model ensemble (MME) forecast

Based on the respective hindcasts climatology of each of the three models the weekly anomaly field is calculated from ECMWF, CFSv1/CFSv2 and JMA model with forecast period valid for days 5-11 (here after called week 1), days 12-18 (week 2) and days 19-25 (week 3) based on every Thursday and converted into uniform latitude-longitude grid (0.5° x 0.5°). The MME (Fig. 1) is prepared with giving equal weights to all the three models. The forecast is generated on every Friday with forecast

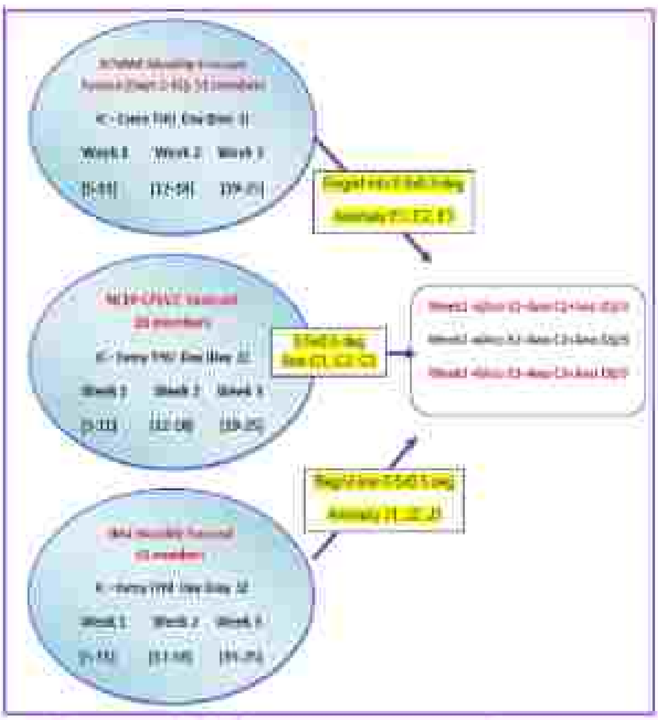


Fig 1 MME extended range forecast.

anomaly for week 1 (Monday to Sunday) to week 3 (subsequent Monday to Sunday). The intra-seasonal monsoon forecast during recent years show useful skill in MME (Tyagi and Pattanaik 2012; Pattanaik et al., 2013a; Pattanaik 2014).

3. Operational Extended Range Forecast of Monsoon during 2009-2014

3.1 Operational extended range forecast during drought year 2009

The seasonal drought as well as the unprecedented deficiency of July (» -51%) rainfall over India during 2002 was not able to forecast by any operational centre (Kalsi et al., 2003). Like 2002, 2009 monsoon season also witnessed large deficiency in seasonal rainfall (» -22% of long period average). The drought year of 2009 was associated with many dry spells of monsoon and some transition phases of monsoon from weak phases to active phases and vice versa (As seen from the daily and weekly all India rainfall departure in Figs. 2a-b). It was noticed that various climate research centers in India and abroad using statistical and dynamical models could not predict the extent of deficiency of 2009 seasonal monsoon rainfall during JJAS. However, a proper real time monitoring of intra-seasonal fluctuation of monsoon rainfall during 2009 monsoon season by IMD was quite useful in assessing the extent and gravity of drought situation of the country (Tyagi and Pattanaik 2010). As shown by them and also shown in Fig. 3 the long dry spell of June was very much predicted by the model from the beginning of June (initial condition of 4th June). They have also demonstrated that the dry spells of monsoon during almost the entire June, 1st half of August and 2nd half of September 2009 were well anticipated in the model forecasts, thus, was very useful in the real time forecasting of these dry spells of monsoon 2009.

3.2 Operational extended range forecast during monsoon seasons (2010-2014)

After the encouraging result we got from the monitoring and forecasting of 2009 monsoon in real time the quantitative verification of ERF forecasts during the monsoon seasons from 2010 to 2014 was performed. Although the products from some of the empirical models were also in use the operational ERF product prepared by IMD was based on the MME forecasts. The performance of real time ERF of monsoon during 2010 to 2014 monsoon seasons over India are discussed below:

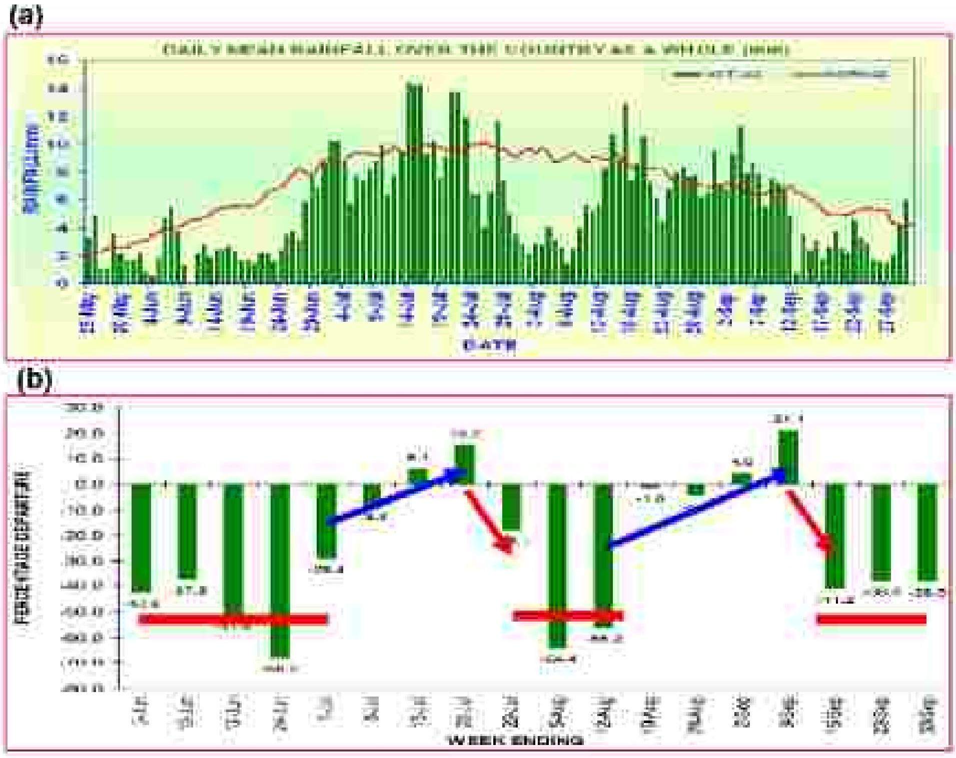


Fig.2 (a) All India averaged daily rainfall during 1st June to 30 September, 2009. (b) The weekly all India area weighted rainfall during June to September 2009.

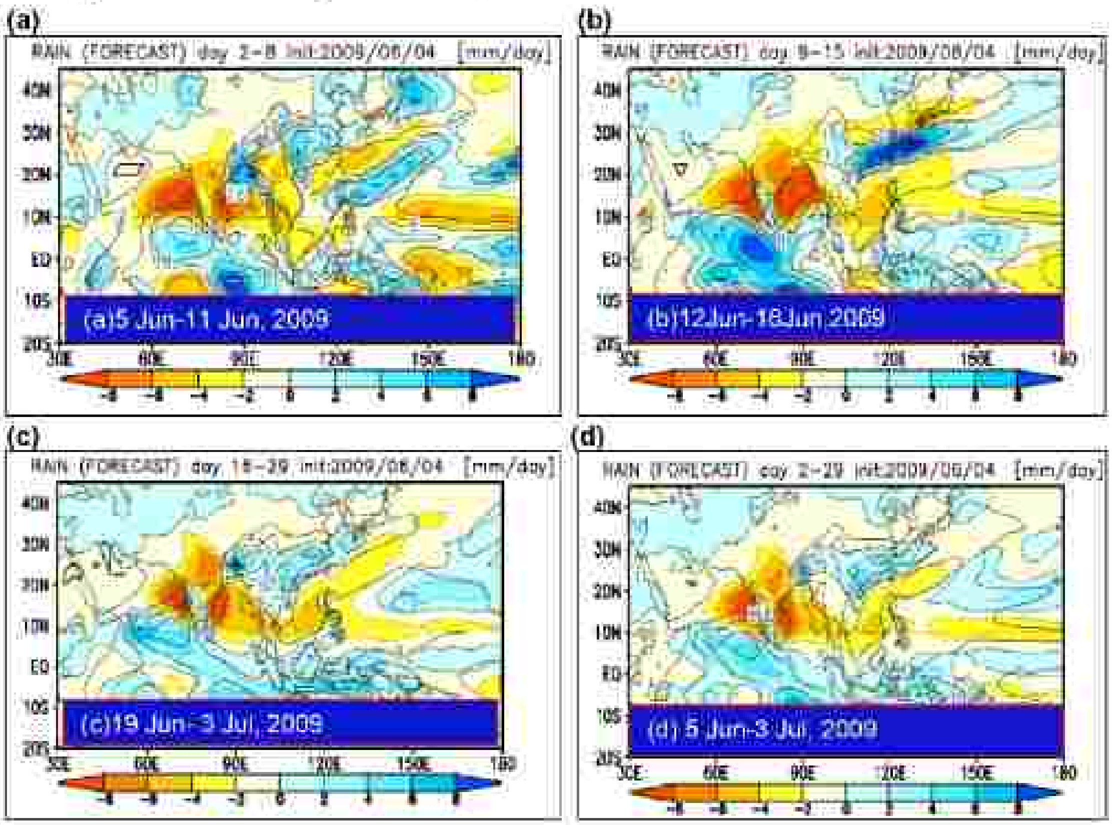


Fig.3 Forecast rainfall anomaly for 28 days (from JMA) based on initial condition of 4th June, 2009. (a)for week 1 valid for 5-11 June, (b)for week 2 valid for 12-18 June, (c)for week 3&4 valid for 19 June-3 July, (d) for day 2 –day 29 valid for 5 June- 3 July, 2009.

3.2.1 Southwest monsoon rainfall over the country as a whole and 4 homogeneous regions

Although IMD is not running coupled model on operational basis the MME based ERF for 3 to 4 weeks is being prepared. The seasonal monsoon rainfall during 2010 to 2014 witnessed year to year variation. The monsoon seasons of 2010 and 2011, with almost identical seasonal total rainfall [»101% of long period average (LPA) during 2010 and »102 % of LPA during 2011] over India during JJAS are associated with slightly different patterns of intra-seasonal rainfall. Similarly, the year 2012, with relatively less seasonal rainfall (»93% of LPA) compared to 2010 and 2011, also witnessed intra-seasonal rainfall fluctuations, leading to drought-like situations over some parts of the country (Pattanaik et al., 2013a). The 2013 monsoon season rainfall over the country as a whole was »106% of LPA but showed strong spatial and temporal variability (Devi and Yadav, 2014; Pattanaik and Bhan, 2014). The recent monsoon of 2014 witnessed deficient rainfall for the country as a whole with its departure » -22% of LPA with 12 meteorological sub-divisions out of 36 remained were deficient. The MME forecast rainfall departure for country as a whole for three weeks during 2010 to 2014 monsoon seasons along with the observed rainfall departure is shown in Figs. 4a-e respectively.

As seen in Figs. 4a-e the MME forecast performed well in predicting the intra-seasonal rainfall activity including the dry spells of monsoon, transitions of monsoon and also the delay withdrawal of monsoon during 2010, 2011, 2012 (Pattanaik et al., 2013a) and 2013 (Pattanaik and Bhan, 2014) monsoon seasons. Also during the deficient year of 2014 the performance of MME forecast clearly captured the delayed onset of monsoon over Kerala, dry spell of June, revival of monsoon during 2nd half of July, transition of monsoon from active to weaker phase during middle of August and transition of monsoon from weak to active phase during early part of September (Fig. 4e), which has been discussed in details by Pattanaik et al., (2015a). The corresponding quantitative forecast verification plot in terms of anomaly correlation coefficient (CC) for weekly rainfall departure over whole of India during the monsoon seasons from 2010 to 2013 shows significant CC at least up to 2 weeks (Fig. 5a). As also seen from Fig 5a there is slight improvement in forecast skill during week 2 and week 3 during 2012 and 2013 monsoon seasons compared to that of 2010 and 2011 seasons.

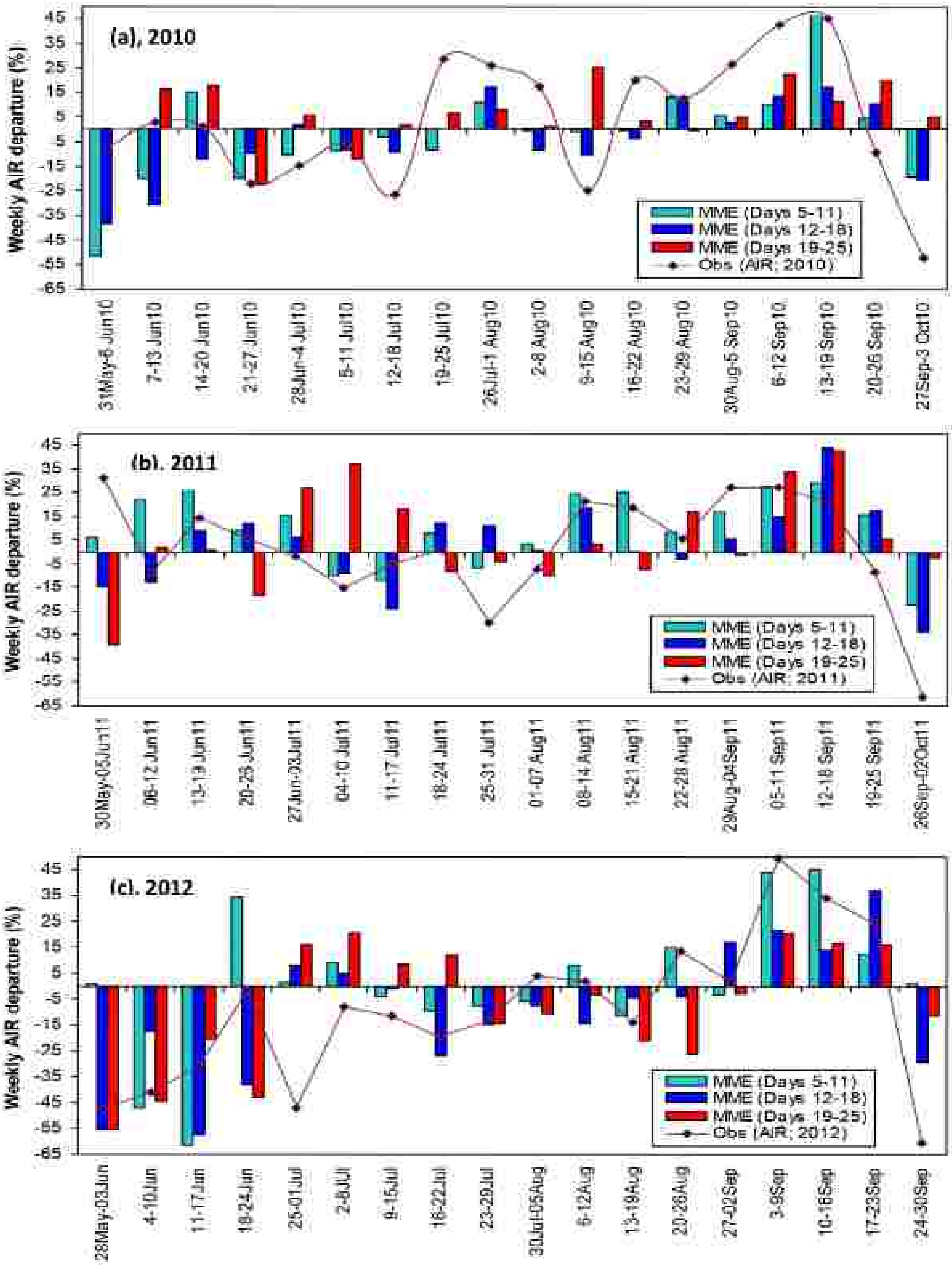
The similar CC for 2014 monsoon season for whole of India and 4 homogeneous regions of India is shown in Fig. 5b. The 4 homogeneous regions are; Northeast India, Northwest India, Central India and South Peninsula India (*shown in Fig. 9b later*). It shows that the MME based ERF for 2014 monsoon indicates that significant CC between observed and forecast rainfall departure at least for 2 weeks for all India rainfall. Over the homogeneous regions of India the MME forecast shows significant CCs till two weeks, except in case of Northeast India, which shows significant CC till week-1. The performance of monsoon forecast over the homogeneous regions during the other years (2010 to 2013) also indicates lower skill over Northeast India (Pattanaik et al., 2013a; Pattanaik 2014).

As shown by (Pattanaik et al., 2013a) the mean CC for all the three monsoon seasons (2010-2012) between observed all India rainfall departure and the corresponding forecast all India rainfall departure shown in Figs. 5a-c is given in Table 1. As seen from Table 1 the mean CC is found to be significant at least above 98% level till week 2 (12-18 days) forecast, even with slight positive CC for week 3 (days 19-25) forecast. As shown by Pattanaik (2014) during the monsoon season 2012 also shows significant CCs (above 95% level) over the 4 homogeneous regions of India up to 2 weeks (till 18 days) except in case of Northeast India, which shows significant CC for week 1 (days 5-11) only.

TABLE 1

Average correlation coefficient (CC) between weekly observed all India and 4 homogeneous regions rainfall departure with the corresponding MME forecast rainfall during 2010, 2011 and 2012. Superscript indicated the significance level with 'a' for 99%, 'b' for 98%, 'c' for 95% and 'd' for 90% significance level.

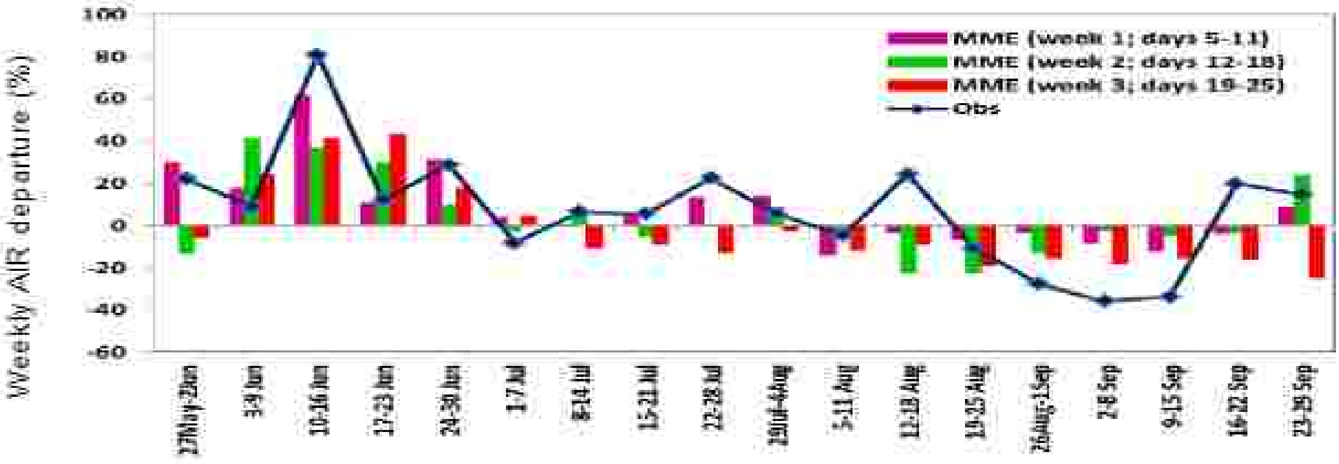
	Mean CC of (2010, 2011 and 2012)		
Region	Week 1 (Days 5-11)	Week 2 (Days 12-18)	Week 3 (Days 19-25)
All India	0.66^{a}	0.57^{b}	0.22
NEIndia	0.61^{a}	0.35	-0.04
NW India	0.47^{c}	0.54^{b}	0.30
CE India	0.57^{b}	0.42^{d}	0.20
SP India	0.37	0.29	-0.03



(a), 2010
Weekly AIR departure (%)
45
35
25
15
5
-5
-15
-25
-35
-45
-55
-65
MME (Days 5-11)
MME (Days 12-18)
MME (Days 19-25)
Obs (AIR; 2010)
31May-6 Jun10
7-13 Jun10
14-20 Jun10
21-27 Jun10
28Jun-4 Jul10
5-11 Jul10
12-18 Jul10
19-25 Jul10
26Jul-1 Aug10
2-8 Aug10
9-15 Aug10
16-22 Aug10
23-29 Aug10
30Aug-5 Sep10
6-12 Sep10
13-19 Sep10
20-26 Sep10
27Sep-3 Oct10
(b), 2011
Weekly AIR departure (%)
MME (Days 5-11)
MME (Days 12-18)
MME (Days 19-25)
Obs (AIR; 2011)
30May-05Jun11
06-12 Jun11
13-19 Jun11
20-26 Jun11
27Jun-03Jul11
04-10 Jul11
11-17 Jul11
18-24 Jul11
25-31 Jul11
01-07 Aug11
08-14 Aug11
15-21 Aug11
22-28 Aug11
29Aug-04Sep11
05-11 Sep11
12-18 Sep11
19-25 Sep11
26Sep-02Oct11
(c), 2012
Weekly AIR departure (%)
MME (Days 5-11)
MME (Days 12-18)
MME (Days 19-25)
Obs (AIR; 2012)
28May-03Jun
4-10Jun
11-17Jun
18-24Jun
25-01Jul
2-8Jul
9-15Jul
16-22Jul
23-29Jul
30Jul-05Aug
6-12Aug
13-19Aug
20-26Aug
27-02Sep
3-9Sep
10-16Sep
17-23Sep
24-30Sep

Fig 4 (a, b & c)

(d) 2013



(e) 2014

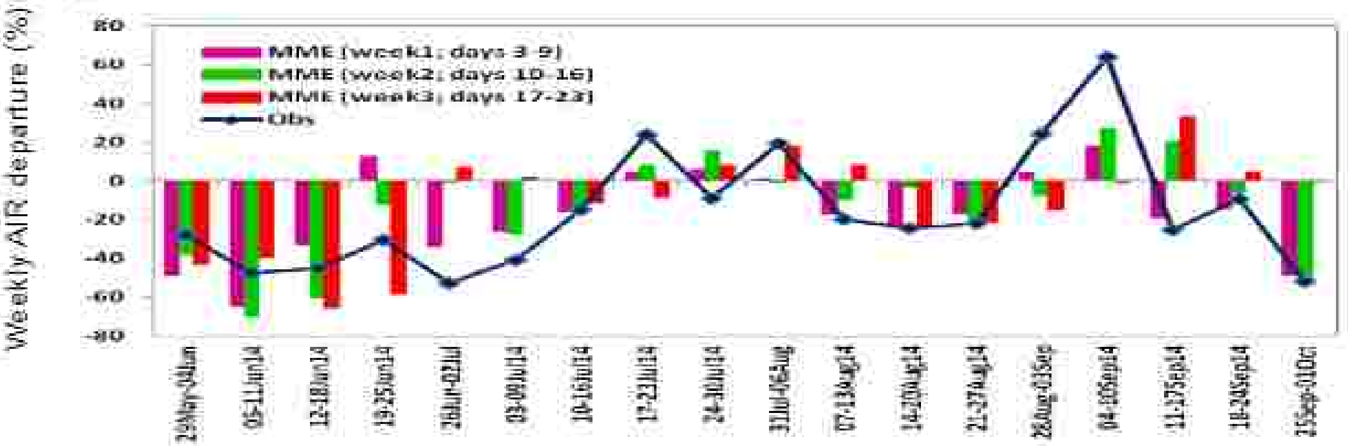


Fig.4 Weekly observed all India rainfall (AIR) and corresponding MME forecast rainfall till days 25 (a) 2010, (b) 2011, (c) 2012, (d) 2013 and (e) 2014.

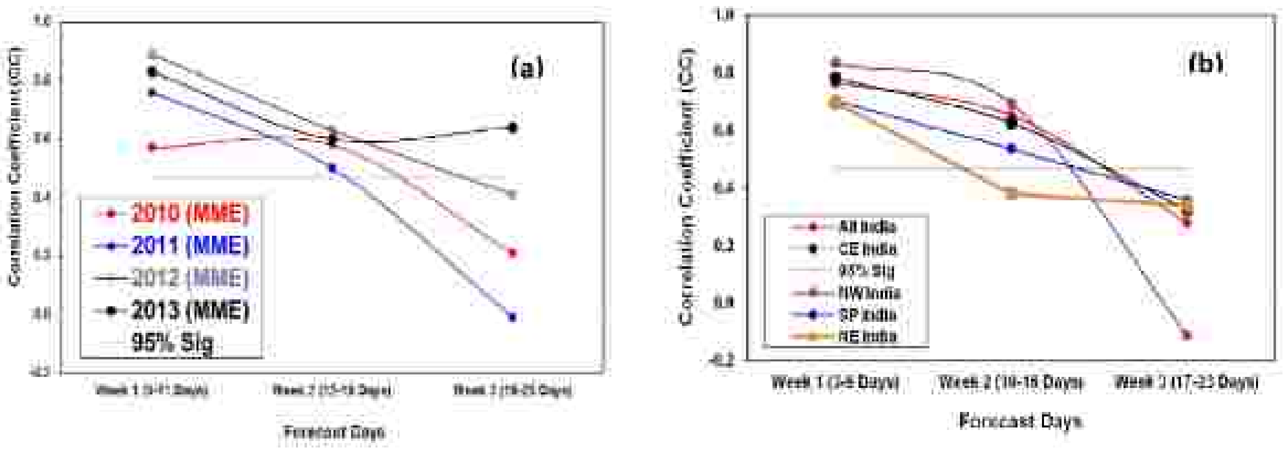


Fig.5(a) CC between forecast all India rainfall departure and corresponding observed rainfall departure during 2010 to 2013 monsoon seasons. (b) Same as 'a' but for 2014 monsoon season including that over the 4 homogeneous regions of India.

3.2.2 Forecasts of different episodes during the southwest monsoon seasons

The real time MME forecast performed well in predicting the intra-seasonal rainfall activity including the dry spells of monsoon, transitions of monsoon, onset and withdrawal of monsoon, revival of monsoon etc during the monsoon seasons of 2010 to 2014 (Tyagi and Pattanaik 2012; Pattanaik et al., 2013a, Pattanaik and Bhan, 2014, Pattanaik 2014, Pattanaik et al., 2015a). Performance of ERFs during some typical monsoon features are discussed below.

(i) Delayed withdrawal of monsoon during 2010

One of the reasons for 2010 having above normal (H˜101%) rainfall was basically due to the contribution of September rainfall (H˜115% of LPA). With the development of La Nina condition from the beginning of the season around June, the positive impact was very prominent in September. It is also seen from the spatial distribution of rainfall that wide spread rainfall continued over most parts of India during three weeks of September from 06-12 Sep, 13-19 Sep and 20-26 Sep (Fig. 6a-6c) with positive anomaly over northwest India continued during 20-26 September and consequently the withdrawal of monsoon from northwest India was delayed as it started from west Rajasthan on 27th September (Pattanaik et al., 2015b). With respect to the MME forecast the three weeks forecast based on the initial conditions of 2nd September 2010 indicated above normal rainfall distribution over most parts of India with an indication of delayed withdrawal (no withdrawal till 26th September) of monsoon from northwest India (Figs. 6d-f), which was very useful information to the organizer of Commonwealth Games 2010 as they were involved in outdoor work pertaining to the Commonwealth Games preparation (The Commonwealth Games held in Delhi during 3-14 October, 2010).

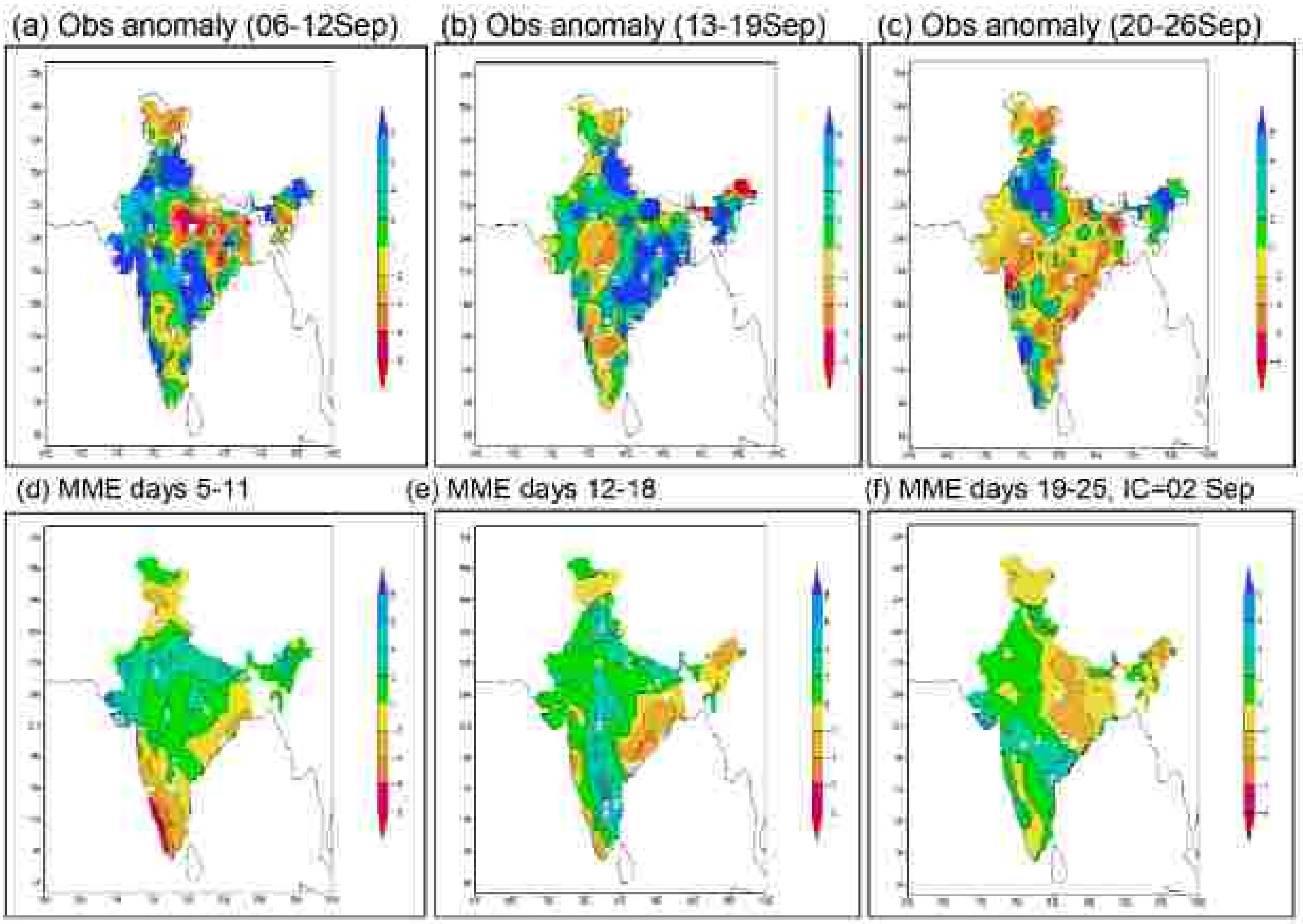


Fig.6 (a-c) Observed weekly rainfall anomalies (mm/day) during 06-12, 13-19 and 20-26 Sep, 2010, (d-f) Corresponding MME forecasts rainfall anomalies for 3 weeks based on 2nd Sep, 2010.

(ii) Severe flood over Pakistan 2010

It is also evident that during 2010 monsoon season there was unprecedented flood occurred over Pakistan associated with heavy rainfall during July end-beginning of August. As shown by Webster et al., (2011) while the total rainfall over Pakistan during 2010 monsoon season was not unprecedented, the number and intensity of extremely heavy rains over northern Pakistan was very unusual. Hauze et al., (2011) have also shown that this flood storm of 2010 was of a more oceanic character. This event was of a very regional nature in a typical monsoon circulation. Hauze et al., (2011) have further shown that the low pressure area over the northwest and adjoining west central Bay of Bengal during 28 July to 1st August provided the moist environment across the subcontinent to the Arabian Sea and favored the occurrence of a synoptic-scale channel of anomalously moist flow toward the mountain barrier. The areal coverage of these wide raining systems contributed to the huge runoff and flooding.

As shown by Pattanaik et al., (2013a) the MME forecast had reasonably captured this rainfall event. The observed low level circulation during the period 26 July-01 August, 2010 indicated very active monsoon trough extending from northern part of Bay of Bengal to south Pakistan (Fig. 7a). The associated weekly rainfall during this period obtained from TRMM is shown in Fig. 7b, which indicated heavy rainfall over northern Pakistan that caused severe flood conditions over Pakistan. The MME forecast in terms of weekly mean and anomaly rainfall for two weeks valid for period 26 July to 1 August, 2010 are shown in Figs. 7c-d. The week 1 forecast (5-11 days) based on 22nd July clearly captured the heavy rainfall over north Pakistan (Figs. 7c-d). However, the week 2 forecast valid for days 12-18 based on the initial condition of 15th July (Fig. not shown), although indicated pocket of high rainfall, its magnitude is underestimated compared to observed rainfall shown in Fig. 7b. Thus, the forecast with lead time of about one week had indicated heavy rainfall over north Pakistan.

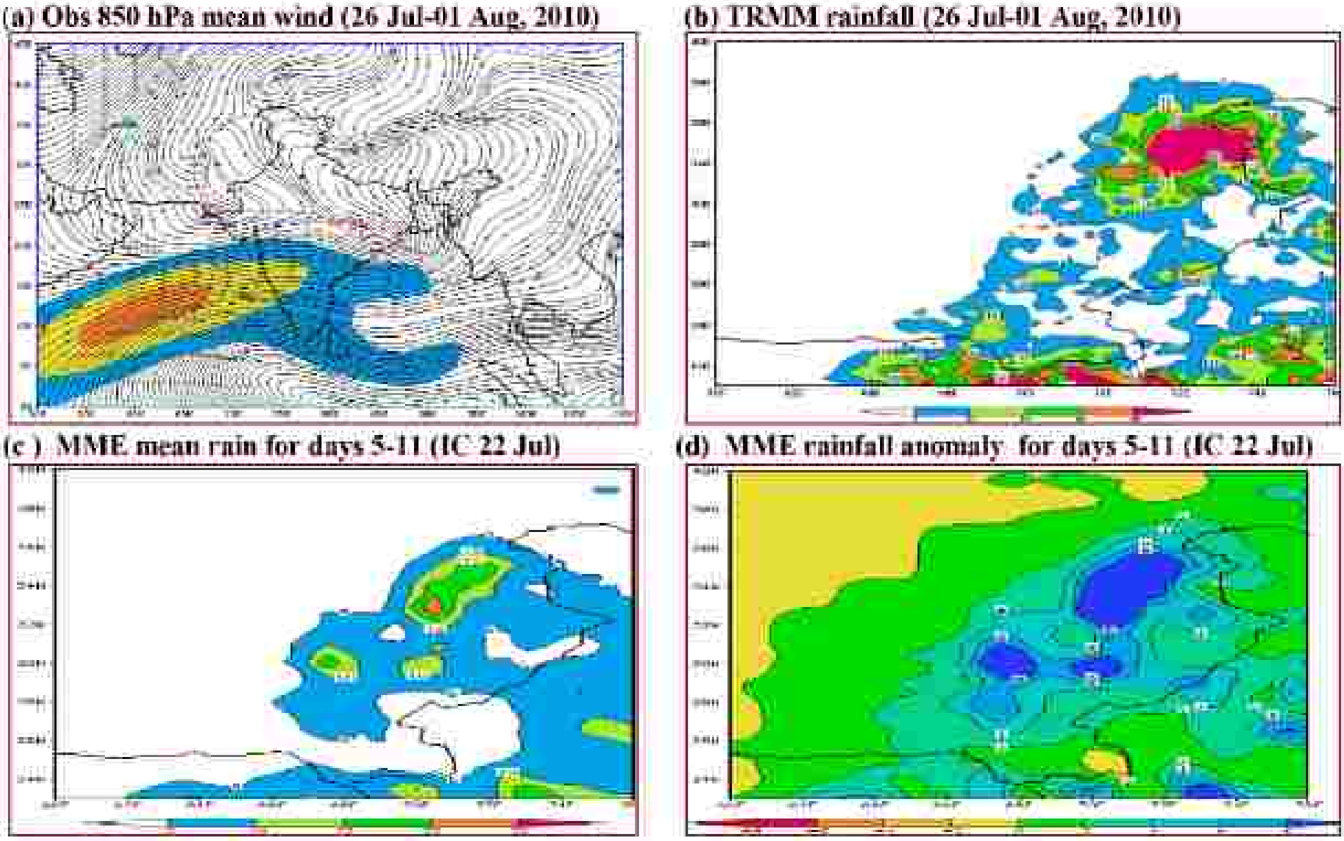


Fig. 7(a) Observed 850 hPa mean wind during 26 July to 1 August, 2010. (b) The observed rainfall from TRMM (mm/day) valid for same period. (c) & (d) MME forecast (IC 22 July) for days 5-11 mean and anomaly rainfall valid for the same period.

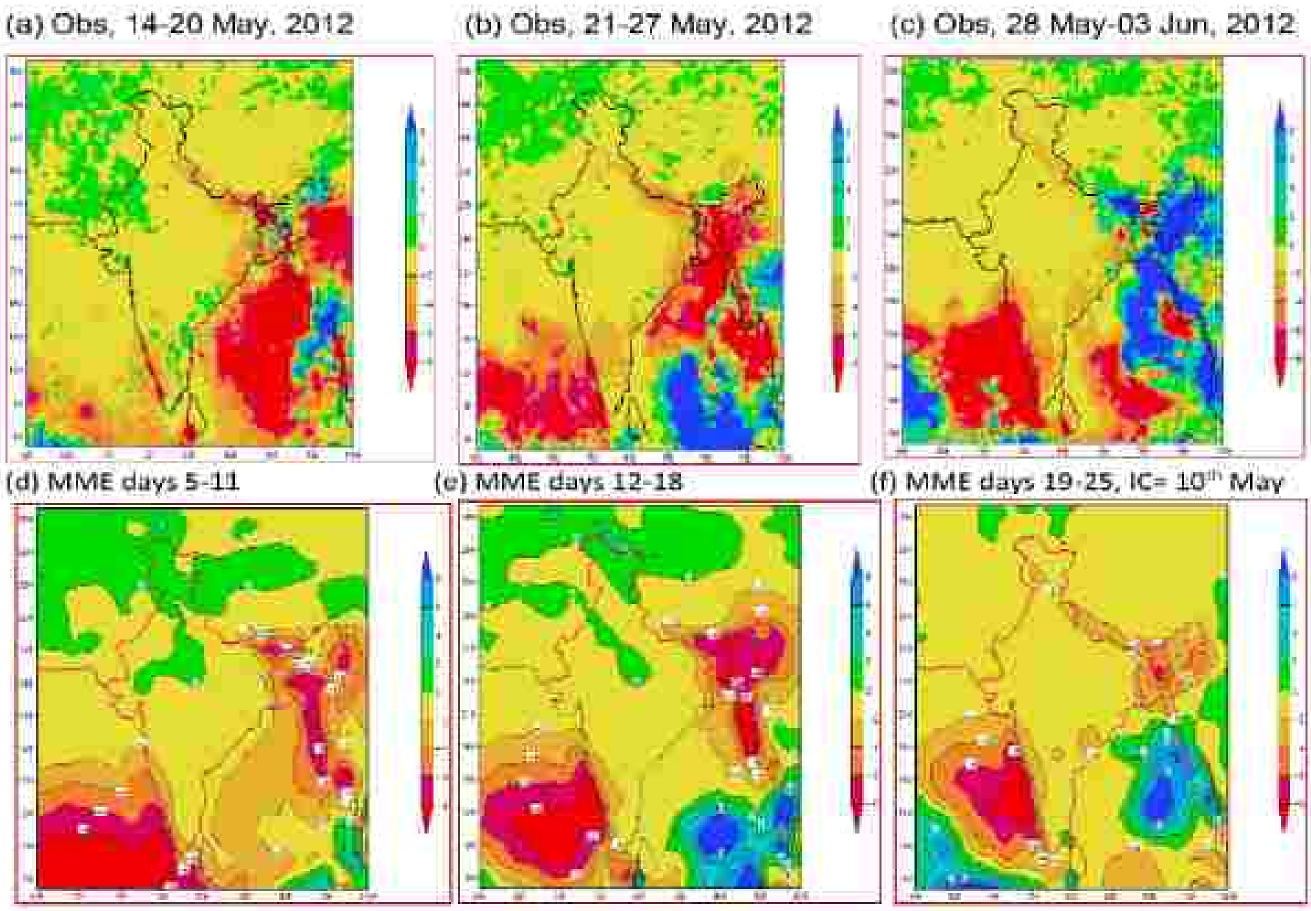


Fig.8 Observed rainfall anomaly for (a) 14-20 May,(b) 21-27 May and (c) 28 May-03 Jun, 2012. MME forecast rainfall anomalies based on 10th May, 2012 and valid for (d) days 5-11 (14-20 May), (e) days 12-18 (21-27 May) and (f) days 19-25 (28 May-03 Jun).

(iii) Delayed onset of monsoon over Kerala during 2012

During 2012, southwest monsoon current advanced over the Andaman Sea on 23rd May with a delay of about 3 days and set in over Kerala on 5th June, 4 days later than its normal date of 1st June (Pattanaik 2014). The observed weekly rainfall anomalies obtained from TRMM during the period from 14-20 May, 21-27 May and 28 May to 3 June, 2012 (Figs 8a-c) indicated large negative anomalies of rainfall over Kerala coast, over southern tip of India and adjoining Arabian Sea region thereby no onset of monsoon till 3rd June. The corresponding MME forecast rainfall anomalies patterns also indicated delayed arrival of monsoon over Kerala based on the initial condition of 10th May, 2012 and valid for three weeks forecasts coinciding from 14th May to 3rd June, 2012 (Figs. 8d-f). The forecast rainfall anomalies clearly indicated no onset of monsoon till week ending 3rd of June 2012. This is discussed in details in Pattanaik (2014).

(iv) Rapid progress of monsoon and heavy rainfall over Uttarakhand during June 2013

The southwest monsoon normally sets in over Kerala around 1st June and it advances northwards, usually in surges, and covers the entire country around 15 July. The northern limit of monsoon (NLM) is the northern most limit of monsoon upto which it has advanced on any given day. One of the unusual features of monsoon 2013 is the rapid progress of monsoon from southern tip of India as a result the NLM moved northward very fast and the monsoon covered entire India by 16 June (Fig. 9a). The pace of advance of southwest monsoon in 2013 had been the fastest during the period 1941-2013 as it took only 15 days to cover the entire country after its normal onset on 1st June. Associated with this rapid progress of monsoon northward there was also very unusual heavy rainfall over Northwest (NW) India particularly over the meteorological subdivision of Uttarakhand during this onset phase as seen from the met subdivision monthly rainfall departure during June, 2013 (Fig. 9b). The meteorological subdivisions over NW India indicating excess rainfall (a departure ≥ 20%) with Uttarakhand reported a departure of 191% (marked in Fig. 9b) during June 2013. The unprecedented rainfall over Uttarakhand can also be seen from the daily rainfall shown in Fig. 10. This rapid advance of monsoon with vigorous rainfall activity is associated with movement of a monsoon low from NW Bay of Bengal across central India to NW India during this period (Devi and Yadav, 2014;Pattanaik et al., 2015c). The rainfall anomaly during these periods from 3 June to 23 June, 2013 indicates positive rainfall anomalies with particularly positively anomaly over entire northern and western parts of India during the period from 10-16 June, 2013 indicating the coverage of monsoon over entire India by 16th June, 2013 (Figs. 11a-c). The week during 10-16 June indicates heavy rainfall over Uttarakhand and adjoining region as also seen in Fig. 10.

As discussed by Pattanaik et al., (2015c) the MME based ERF in fact had captured this unusual behavior. The MME forecast based on the initial condition of 30th May clearly indicated rapid progress of monsoon and coverage over the entire country by 16th June, 2013 as seen from the anomaly plots of rainfall shown in Figs. 11d-f. The MME forecast for week 3 valid for the period from 17-23 June also captured the heavy rainfall over many parts of northern India (Figs. 11f). Thus, the unusual behavior of rapid progress of monsoon during 2013 was very much captured in the coupled models. However, on sub-division level over Uttarakhand the positive departure of rainfall forecasted by the model was much less than that of observed departure. The underestimation of heavy rainfall in the model is due to the fact that it could not capture the interaction of upper level westerly trough with the low level convergence in the model. However, useful skill of monsoon forecast in the extended range is observed on all India level and also over the NW India in capturing its rapid progress and associated heavy rainfall.

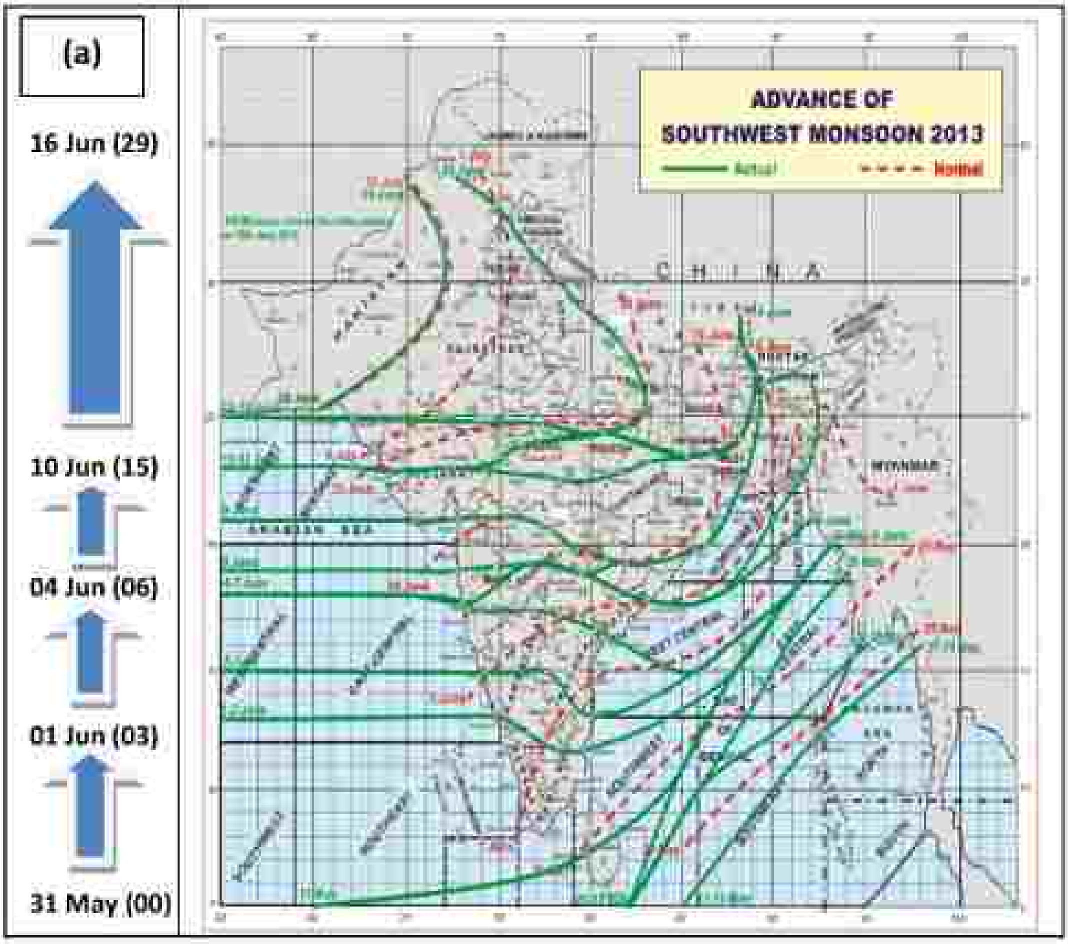


Fig.9(a)

Fig.9(a) Onset and progress of monsoon over India during 2013. (b) Met-subdivision wise rainfall during June with circle in red indicated the meteorological sub-division of Uttarakhand. The four homogeneous regions (NWI: northwest India; NEI: northeast India; CEI: central India; SPI: south-peninsular India).

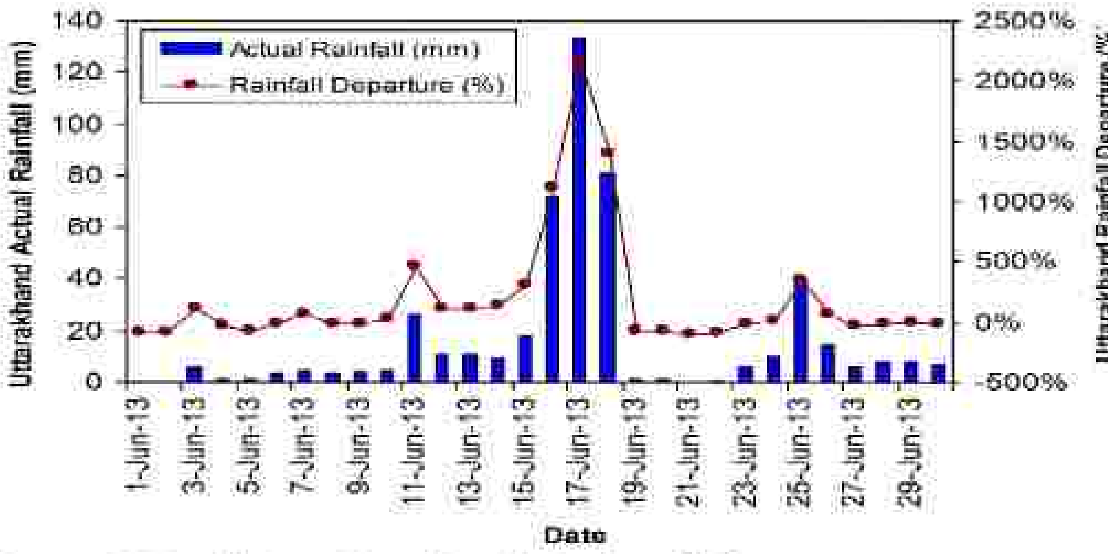


Fig.10 Observed daily rainfall over Uttarakhand during June 2013.

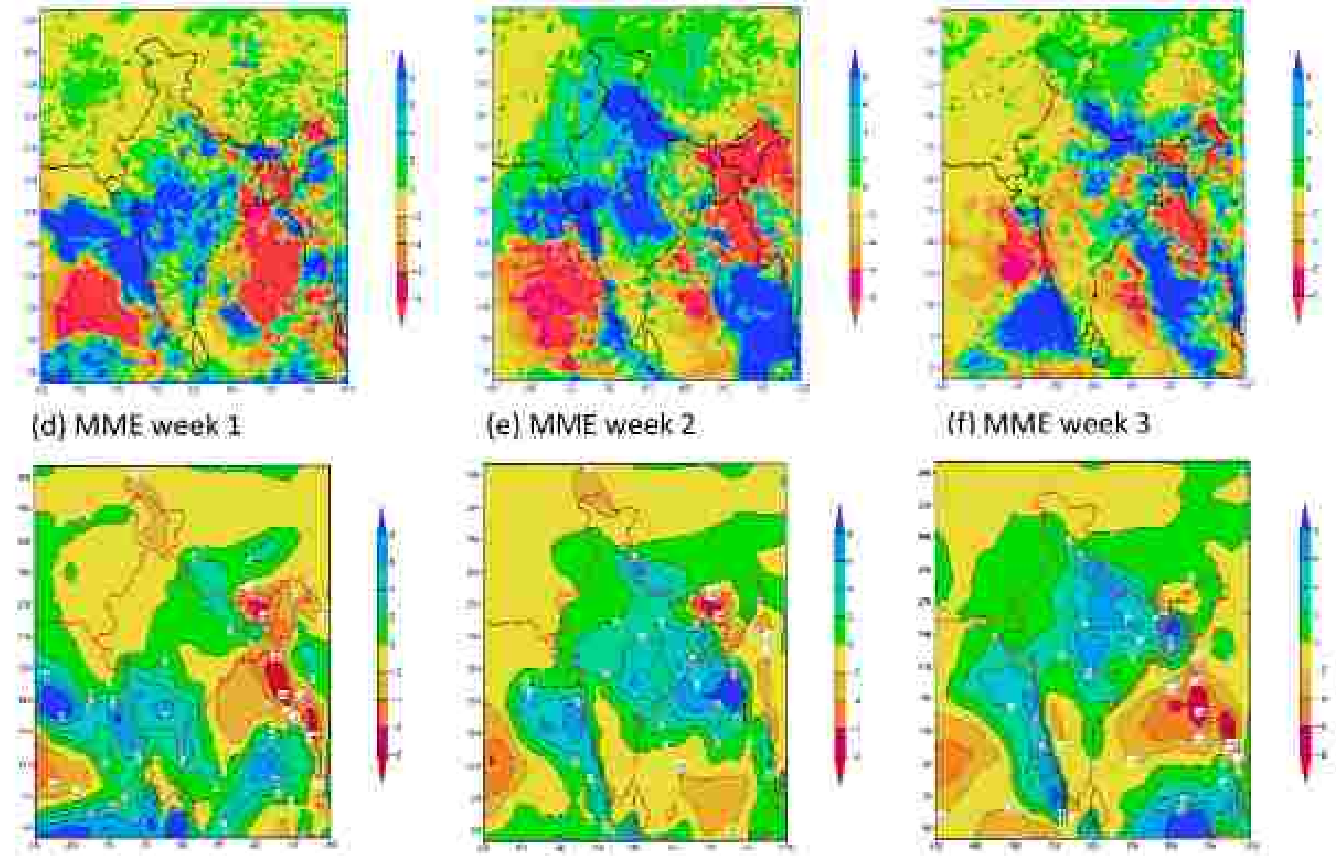


Fig.11 Observed (TRMM) and forecasts rainfall anomaly (mm/day) from MME based on 30 May, 2013 and valid for week-1(3-9 June), week-2(10-16 June) and week-3(17-23 June).

3.2.3 Southwest monsoon rainfall on the Met. Subdivision level.

As seen in the previous sub-section, the performance of weekly rainfall forecast for all India level and also for the four homogeneous regions of India performed reasonably well at least up to 2 weeks (upto days 18). However, due to increase variability the skill will be very low to forecast the actual rainfall departure on smaller spatial scales. Thus, for verification purpose over 36 met-subdivisions, in place of actual rainfall departure the category of the met-subdivision based on the observed rainfall departure is compared with the MME forecast category of the met-subdivision as given in Table 2. Pattanaik (2014) has demonstrated the present skill of MME forecast on Met-subdivision level. As shown by him the mean percentage of correct forecast, partially correct forecast, wrong forecast and the not-usable forecast for 18 weeks of monsoon season 2012 for 36 met-subdivisions is given in Fig. 12. As it is seen from Fig. 12 the correct percentage is about 45% for week 1 forecast and is about 39% for week 2 and 32% for week 3 forecasts. On individual weekly basis there are many weeks when the performance was much higher than the mean value. It may be mentioned here that in case of normal MME forecast (when all the met-subdivisions are considered to be normal (N) category in the MME forecast) the mean percentage of correct forecast during the 18 weeks period for 2012 monsoon score the MME based met-subdivision level forecast is better than climatology forecast till three weeks up to 25 days. It is also seen from Fig. 12 that the partially correct category forecast is about 45% of the met-subdivisions, although with slight variations during week 1 to week 3 cases. Fig. 12 further indicates that the wrong category and the not usable category of the forecasts together amounting to 13% during week 1, 17% during week 2 and 24% during week 3 forecasts and hence the correct to partially correct category forecasts is found to be 87% met-subdivisions for week 1, 83% for week 2 and 76% for week 3.

TABLE 2

Classification of forecast category for the met-subdivision level based on rainfall departure over the met sub-division.

Forecast →	Excess (E)	Normal (N)	Deficient (D)	Scanty + No Rain (S) + (NR)
(E)	Correct (C)	Partially Correct (PC)	Wrong (W)	Not Usable (U)
(N)	PC	C	PC	W
(D)	W	PC	C	PC
(S) + (NR)	U	W	PC	C

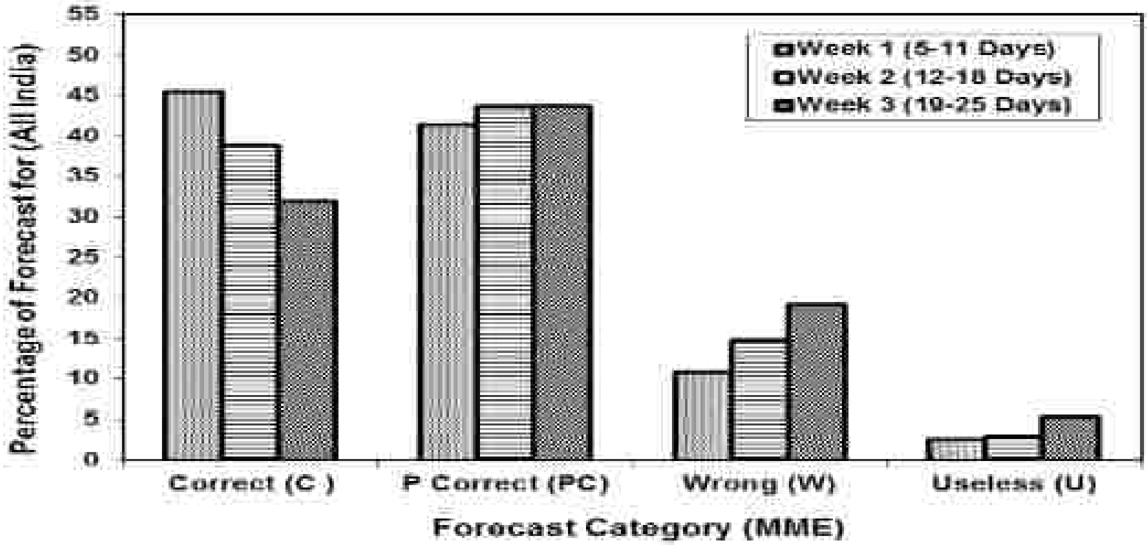


Fig 12 Performance of met-subdivisions level forecast during the monsoon season of 2012.

3.3 Prospect of use of monsoon ERF for Hydro-Meteorlogical Operations

Every year many parts of India suffer from severe floods caused due to heavy rainfall, particularly during the monsoon season. Nearly 40 million hectors (mha) of the country is prone to floods. Floods occur in India with heavy rainfall in the upper catchments of major Rivers basins such as Narmada, Sabarmati, Yamuna, Mahanadi, Krishna, Godavari, Ganga, Brahmaputra and Tista. In central India, Rivers like the Mahanadi, the Brahmani, and the Baitarni have a common delta and cause damage in parts of eastern states of India due to floods associated with the heavy rainfall during the monsoon season. The movement of synoptic scale systems from the Bay of Bengal region to the central parts of India (Rao 1976; Gadgil 2000; Sikka 2006; Pattanaik 2007; Pattanaik and Thapliyal 2004; Mohapatra and Mohanty 2005, 2006 etc.) contributes most of the heavy rainfall over different parts of central India including the state of Odisha. In water resource management sector a reliable medium to extended range forecast of such heavy rainfall event can be a vital input for the reservoir operations and hence on managing the floods condition. Thus, the ability to provide reliable and accurate medium to extended range hydrological forecasts is fundamental for the effective operation and management of water resources systems, which can be used for tactical adjustments to the strategic decisions about the storage level of water in any reservoir and timely release of water particularly for reducing flood conditions. The better decision making process will enables the dam authorities in moderating the flood by keeping the reservoir at appropriate level with likely scenarios of rainfall conditions for next around two weeks periods.

Pattanaik and Das (2015) demonstrated prospects of usefulness of ERF in the management of reservoir flow in a way to reduce the risk of flood conditions by taking a pilot study over the Mahanadi River basin, which witnessed severe flood conditions over Odisha during the late August and early September 2011 due to abnormally high rainfall in the upper catchment of Mahanadi River basin leading to simultaneous release of huge volume of water from the Hirakud reservoir. The synoptic analysis of the observed rainfall patterns demonstrated that the heavy rainfall was associated with active monsoon circulation during late August and most parts of September, 2011 with presence of low pressure systems and anomalous cyclonic circulations at lower level. The ERF based on the initial condition of 25th August, 2011 valid for week 1 (days 5-11) and week 2 (days 12-18) indicate strong monsoon conditions associated with heavy rainfall over the Mahanadi River basins during the period from 29 August to 11 September 2011. The model also indicated positive rainfall departure of about +30% over the Mahanadi River basin scale, which is much less than the actual rainfall departure. As shown by Pattanaik and Das (2015) for the particular week from 5 to 11September, 2011, the model could able to forecast rainfall departure of 36.8% and 27.8 % over the upper and lower Mahanadi catchments, respectively at least a week in advance. Thus, although the models are capable of giving extended range forecast for active phase of monsoon, the actual quantitative value of rainfall on a very smaller domain of River basin scale may be a very difficult problem, a mechanism to use such climate forecast in the decision making process will be very useful for effective management of reservoir operation particularly during this difficult period (Pattanaik and Das 2015).

4. The ERF of Cyclogenesis, Northeast Monsoon and Temperatures

Like the performance of real time forecast skill of southwest monsoon in extended range time scale is discussed above, the forecast skill of other weather events like the cyclogenesis during post monsoon season, northeast monsoon rainfall, extreme temperature etc. are discussed in this section.

4.1 Cyclogenesis over north Indian Ocean

Over the North Indian Ocean (NIO), the months of October-December are known to produce tropical cyclones (TCs) of severe intensity in the Bay of Bengal, which after crossing the coast cause damages to life and property over many countries surrounding the Bay of Bengal. The strong winds, heavy rains and large storm surges associated with tropical cyclones are the factors that eventually lead to loss of life and property. The combination of a shallow coastal plain along with a thermodynamically favorable environment allow TCs to impart high surface winds, torrential rains and significant wave heights (wave setup plus storm surge) as these systems move inland. In India, many studies have demonstrated the utility of TCs forecasts up to 3 days using Global and regional models. However, the forecasting of genesis of TC and associated rainfall in the extended range time scale (about 2 weeks in advance) is very useful in many respects. There have been very limited works done in the area of predictability of NIO TCs using the latest generation of global numerical weather prediction systems. Pattanaik et al., (2013b) in their recent study have demonstrated useful skill in predicting tropical cyclogenesis over the north Indian Ocean using present generation coupled models for 2010 post-monsoon season over north Indian Ocean. Similarly the ERF of cylogenesis during 2011 post-monsoon season is also discussed by Pattanaik and Mahapatra (2014). The contrasting patterns of cyclogenesis during 2010 and 2011 post-monsoon seasons indicate active Bay of Bengal during 2010 and active Arabian Sea during 2011 (Figs. 13a-b). As shown by Pattanaik et al., (2013b) and also shown here in Figs. 14a-d the genesis of the cyclone "Jal" during first week of November, 2010 was very much captured in the MME forecasts of wind and vorticity for week 1 and week 2 based on initial condition of 28 October and 21 October respectively. As also shown by them the MME forecasts also clearly indicated large positive rainfall anomalies over Tamil Nadu coast and adjoining coastal Andhra Pradesh region like that of observed rainfall anomalies. Thus, the extended range forecast indicates useful skill in predicting the genesis and also the associated rainfall distribution due to the tropical cyclones of post-monsoon season of 2010.

Pattanaik and Mohapatra (2014) have also demonstrated that the MME extended range forecast (2 to 3 weeks) based on coupled models indicate very well the genesis of the system and associated rainfall distribution due to the tropical cyclonic disturbances of post monsoon seasons

2011. The forecast for days 5-11 (week 1) of dynamical parameters like the low-level vorticity, low level circulation and the model rainfall clearly demonstrated the genesis of the tropical cyclone "Kaila" over the Arabian Sea during 28 Oct-04 Nov, 2011. The genesis of the very severe cyclone "Thane" was also indicated in week 1 (days 5-11) MME forecast valid for the period from 19-25 December and its intensification during the period 26 December-1 January, 2012. Thus, an active Arabian Sea and inactive Bay of Bengal was very much indicated in the MME forecast based on 27th October initial condition and forecast valid for the period from 31 Oct-13 November, 2011.

Thus, the present generation coupled models are capable of providing useful guidance in the extended range for the tropical cyclogenesis potential for about 15 to 18 days. However, more work is needed to define an appropriate forecast genesis potential index to distinguish developing system in to cyclone and non-developing system (dissipated as depression) by considering additional dynamical and thermo-dynamical parameters like wind shear, convergence, middle tropospheric humidity and the phase and amplitude of MJO etc.

(a)

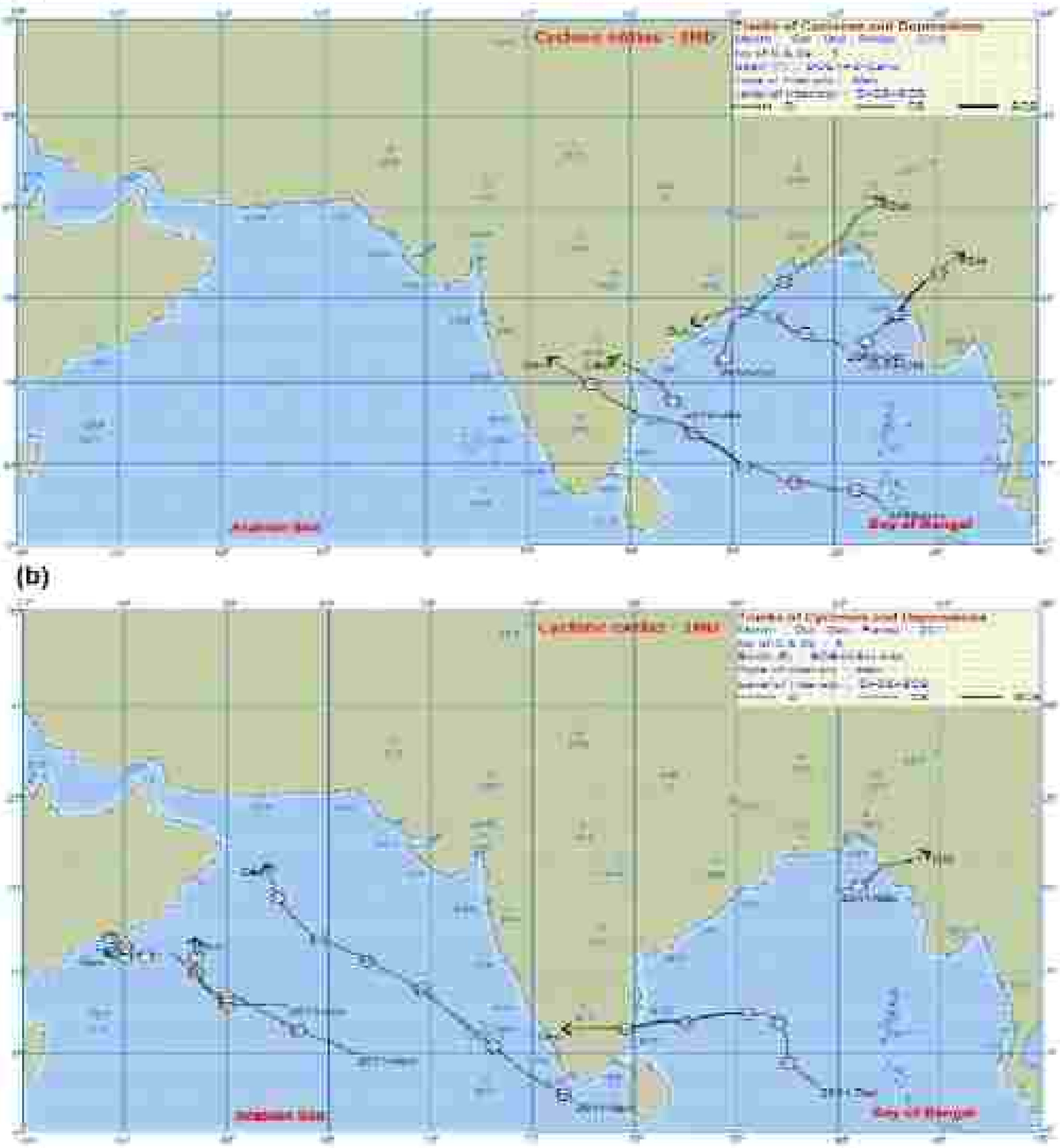


Fig 13(a) Cyclonic disturbances of post monsoon season from October-December, 2010. The dark black lines indicate two severe cyclones "Jal" and "Giri" over Bay of Bengal. (b) Cyclonic disturbances of post monsoon season from October-December, 2011.

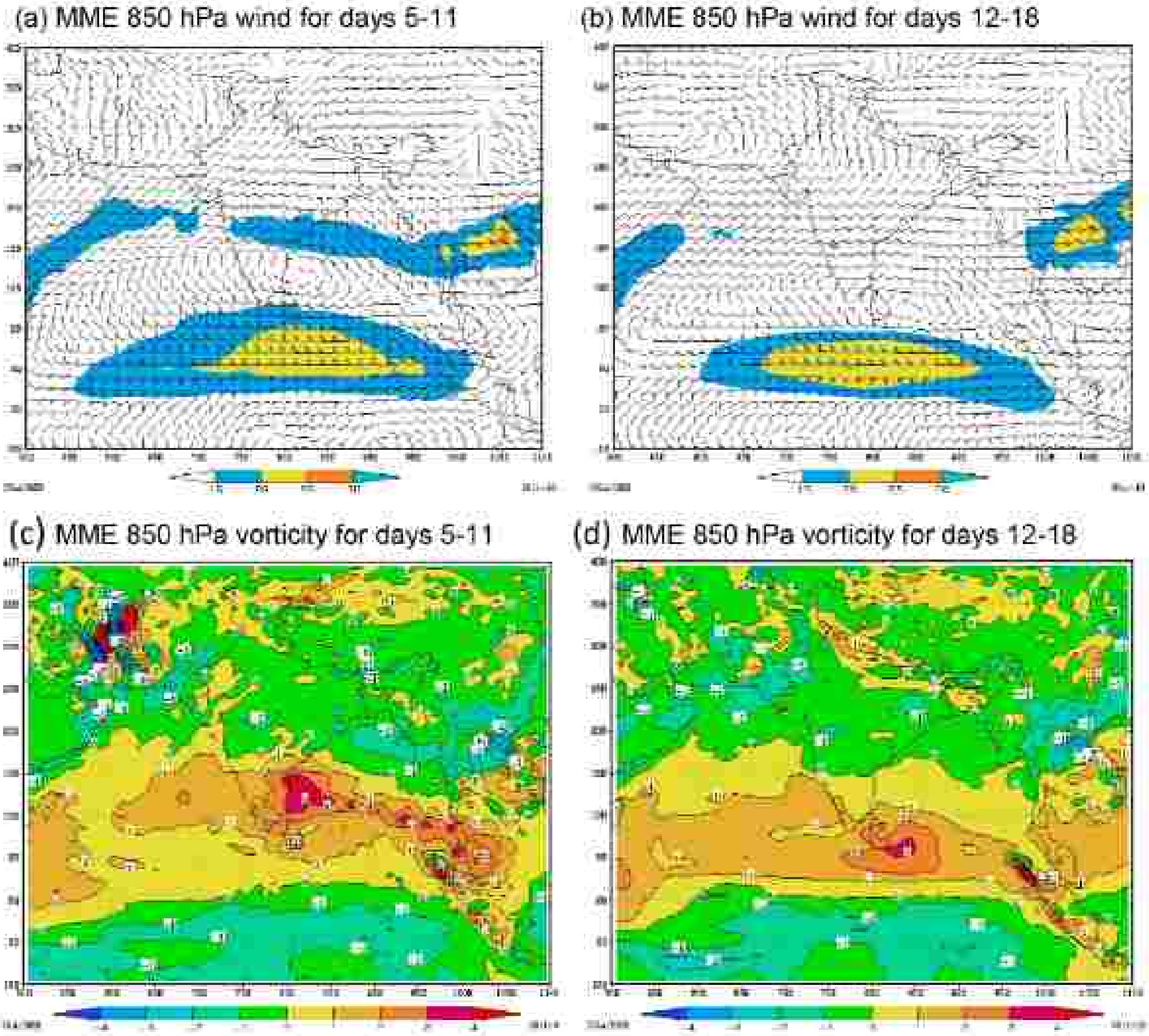


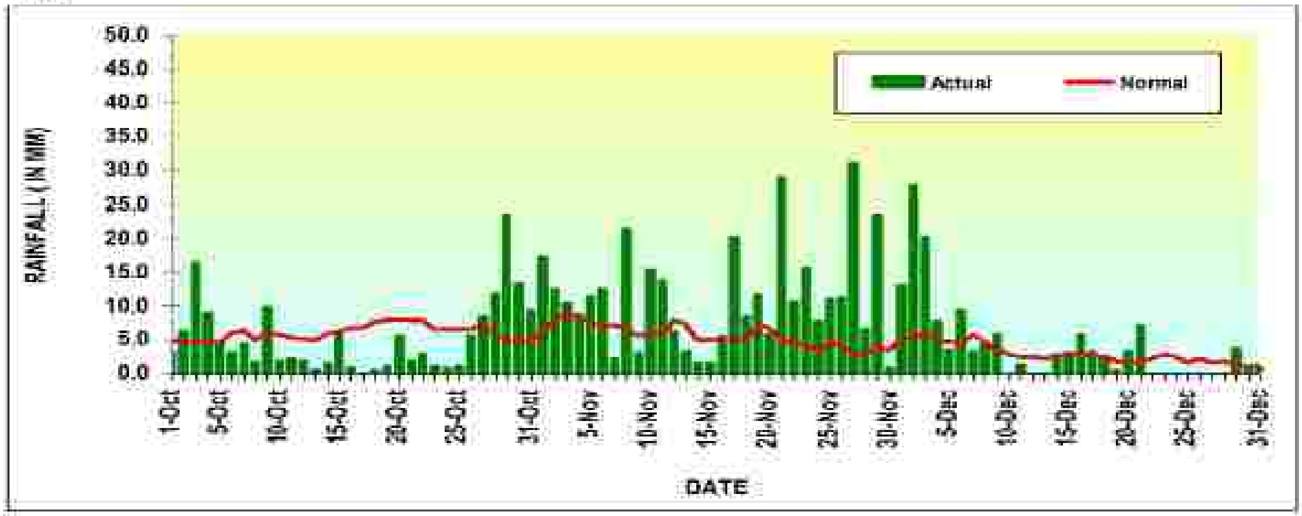
Fig 14 MME 850 hPa forecast mean winds valid for 01-07 Nov 2010. (a) Based on 28 Oct (days 5-11 forecast) and (b) Based on 21 Oct (days 12-18 forecast). MME 850 hPa mean relative vorticity (1×10^{-5} Sec^{-1}) valid for 18-24 Oct 2010. (c) Based on 28 Oct (days 5-11 forecast) and (d) Based on 21 Oct (days 12-18 forecast).

4.2 Northeast monsoon rainfall over south peninsula

The period from October to December is generally known as the post monsoon season or northeast monsoon season. The withdrawal of southwest monsoon and commencement of northeast monsoon is linked to one another. The five meteorological subdivisions of India where the northeast monsoon activity occurred are Coastal Andhra Pradesh, Rayalaseema, South Interior Karnataka and Kerala and Tamil Nadu with Tamil Nadu is the main area where most of the annual rainfall occurred during this period of northeast monsoon season. The onset of northeast monsoon is declared after any date of 10th October when the withdrawal of south west Monsoon takes place upto 15°N, having fairly widespread rainfall over the coastal Tamil Nadu and adjoining areas and persistent surface easterlies over Tamil Nadu coast up to 850 hPa. As shown by Tyagi and Pattanaik (2012) the arrival of northeast monsoon over Tamil Nadu was delayed in 2010. The onset was on 29th October, 2010 against its normal date of about 20th October. As documented by them associated with delay withdrawal of southwest monsoon during 2010, the onset of northeast monsoon over Tamil

Nadu was also delayed by about 9 days. The onset was on 29th October, 2010 against its normal date of about 20 October. After the onset of northeast monsoon the rainfall activity over Tamil Nadu remain above normal on most of the days from last week of October to first week of December, 2010 (Fig. 15a). The comparison of MME forecast rainfall with observed rainfall over Tamil Nadu on weekly basis is shown in Fig. 15b. As seen from Fig. 15b many weeks, out of 13 weeks, the observed rainfall over Tamil Nadu is matching with that of MME forecast rainfall valid for week 1 and week 2 forecasts. The correlation co-efficient (CC) between observed and forecast rainfall shown in Fig. 15b is found to be 0.5 for days 5-11 and 0.2 for days 12-18. Considering the difficulty of forecasting the rainfall in the extended range scale over a met subdivision scale, the realised skill of northeast monsoon rainfall forecast is found to be reasonably good, although it need further improvement for week 2 forecast.

(a)



(b)

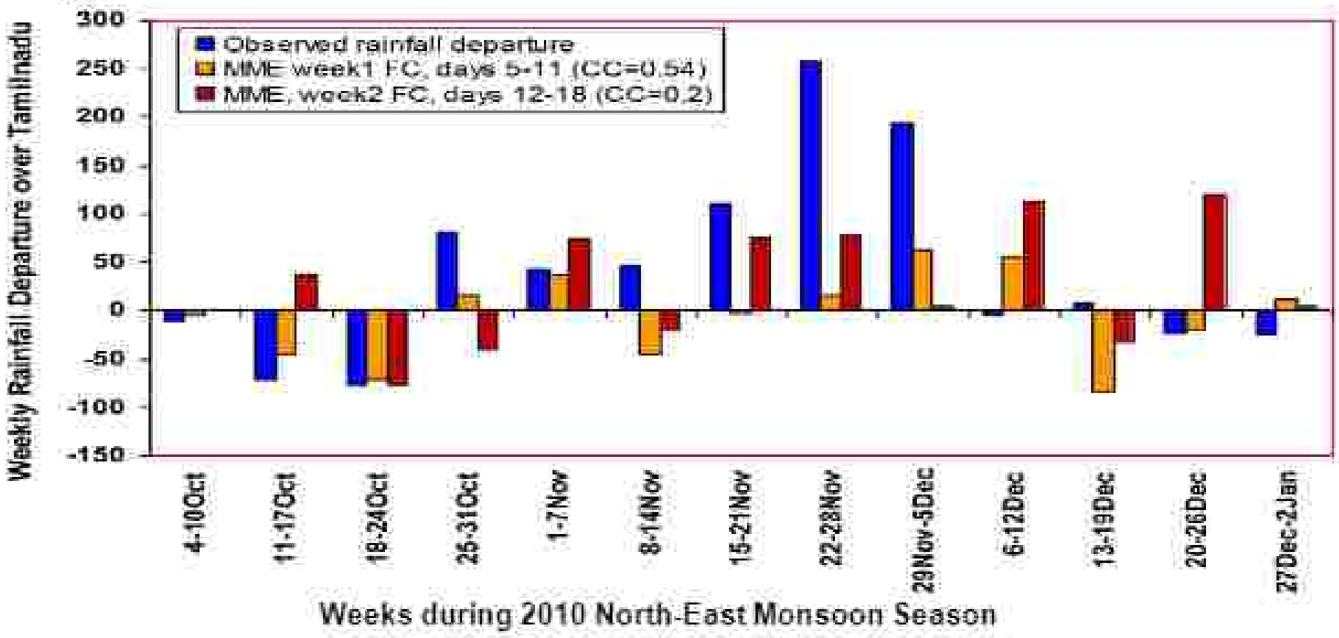


Fig. 15(a) Daily actual and normal rainfall over Tamil Nadu meteorological subdivision during October to December 2010. (b) Weekly observed and MME forecast rainfall over Tamil Nadu during 2010 northeast monsoon season from October to December 2010.

During the season the two weeks from 22 November to 5 December is found to be the period of active northeast monsoon rainfall over Tamil Nadu as seen from the observed rainfall obtained from TRMM (Fig. 16a &d). The active week of 22 to 28 November is very well captured in the MME forecast for days 5-11 and days 12-18 (Fig. 16b-c). During the active week of 29 November to 5th December, the MME forecast rainfall performed better in days 5-11 forecasts (Fig. 16e) compared to that of days 12-18 forecast (Fig. 16f). Thus, the main results are :-

- Operational extended range forecast captured the onset and active phases of northeast monsoon during 2010 reasonably well.
- The coupled models and MME are very useful particularly for days 5-11 forecast over Tamil Nadu, followed by days 12-18 forecasts with a significant CC for days 5-11 forecast.
- Further analysis over other met. Subdivisions of northeast monsoon rainfall will through light on skill of extended range prediction over the north east monsoon region.

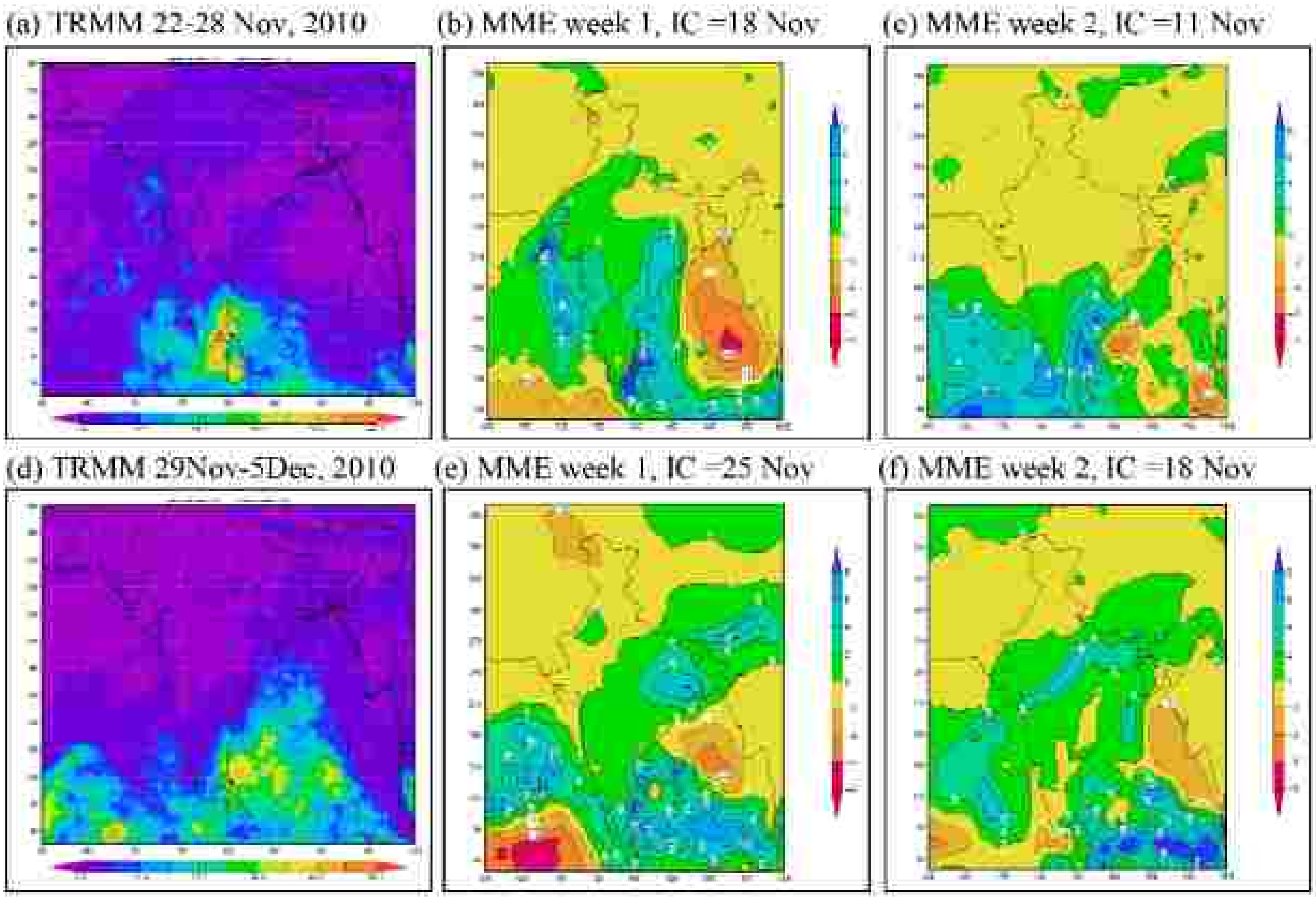


Fig.16 TRMM observed rainfall (mm/day) during (a) 22-28 November, 2010, (d) 29 Nov-05 Dec, 2010. (b) & (c) MME forecast for days 5-11 and days 12-18 valid for 22-28 Nov, 2010 (e) & (f) MME forecast for days 5-11 and days 12-18 valid for 29 Nov-05 Dec., 2010.

4.3 Extreme temperatures

An agro-economic country like India places great importance on the climate forecasting of precipitation and surface air temperature on extended range time-scale for policymaking and strengthening the national economy. Like the utility of ERF of Indian monsoon rainfall as discussed above, the extended range forecasting of surface air temperature (hereafter denoted as temperature) on two weeks to monthly scale has a wide range of applications in agriculture, power, health, insurance, financial sector etc. As temperature also plays a crucial role at some stages of growth of the plant, skillful forecasting of maximum and minimum temperature in the extended range time scale can also benefit farming community particularly for winter crop. In May 2003 the heat wave claimed over 1,600 lives throughout the country with some 1,200 individuals died in the state of Andhra Pradesh alone. Like in 2003, during 2005 also India was under the grip of severe heat wave towards the third week of June and about 200 people died in the eastern parts of the country covering the state of Orissa and neighbourhood. The prediction of heat waves and cold waves (during summer and winter) with significant accuracy can save lives and prevent damage to property from these dangerous weather events. The forecasting of these extreme temperatures is also very useful for power sector, as it will be utilized to optimize the power requirement and distribution. Tyagi and Pattanaik (2012) discussed the performance of the operational extreme temperature forecasts (maximum and minimum temperature) in the weekly to monthly scale for few cases of abnormally high & low temperatures during 2010-2011.

4.3.1 Fall in maximum & minimum temperature during 3-16 Jan 2011

During the two weeks period from 3 to 9 and 10 to 16 January, 2011 there was sudden fall in minimum temperature over many parts of India as shown from the observed minimum temperature anomalies in Fig. 17a and Fig. 17b respectively. As seen from Fig. 17a the fall in minimum temperature was noticed in large parts of India during the period from 03-09 January, and subsequently the anomalies shifted little southward during 2nd week from 10-16 January, 2011 (Fig. 17b). The 05-11 days forecast and 12-18 days forecast of minimum temperature anomalies based on the initial condition of 30 December, 2010 also indicated fall in minimum temperature in the northern parts in week 1 from 03-09 January, 2011 (Fig. 17c) and migration southward during week 2 from 10-16 January (Fig. 17d). Thus, the sudden fall in minimum temperature during the first fortnight of the New Year 2011 was well captured in the extended range forecast.

It is not only the fall in minimum temperature, but also fall in the maximum temperature was noticed during the period from 03-16 January, 2011 particularly over the northern India. As shown by Tyagi and Pattanaik (2012) the fall in maximum temperature was also clearly captured in the MME forecast field based on the initial condition of 30 December, 2010.

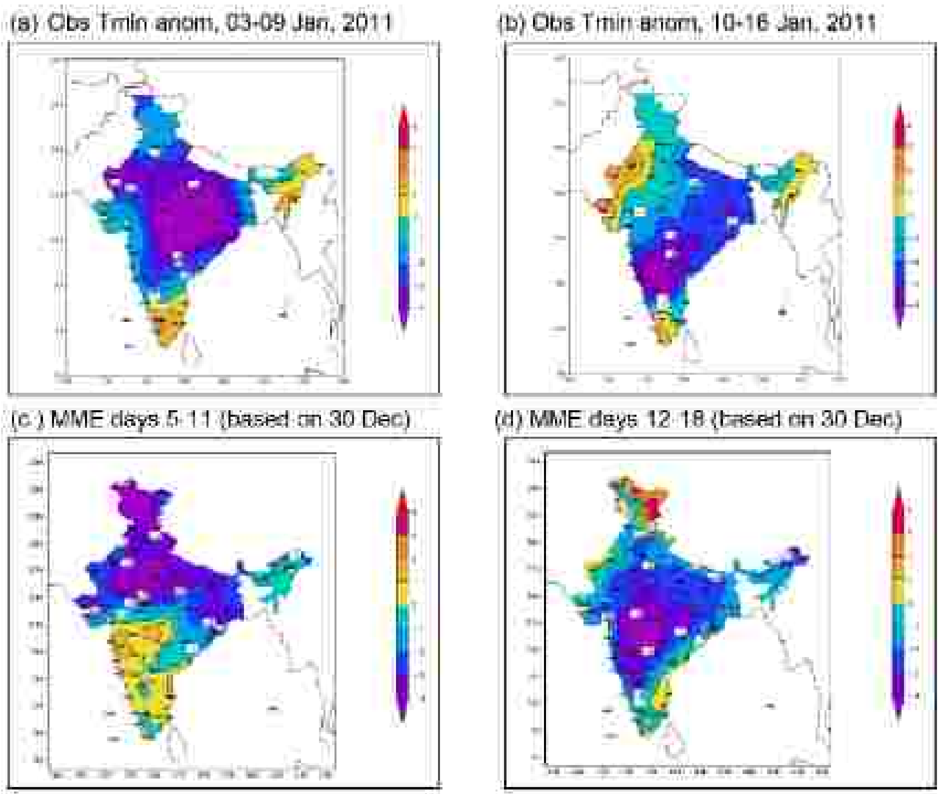


Fig 17 Observed minimum temperature anomalies during the period (a) 03-09 January, 2011 and (b) 10-16 January, 2011. The corresponding forecast minimum temperature anomalies based on 30 December and valid for (c) 03-09 January, 2011 and (d) 10-16 January, 2011.

4.3.2 Rise of maximum and minimum temperature during 3-16 May 2010

Unlike the 2011 pre-monsoon season the pre-monsoon season of 2010 was a relatively warmer season with occurrence of many spells of heat wave during the period. The guidance about this extreme high temperature will not only help to know about the impending heat waves but also for the Agricultural purpose as some time high maximum and high minimum temperature can cause damage to certain crops and affect its productivity.

During the period from 3 May to 16 May 2010 there was occurrence of high temperature (both high maximum and high minimum temperature) as seen from the observed weekly anomalies of maximum temperature (Fig. 18a-b). The positive anomaly of maximum temperature during the period from 3-9 May, 2010 is mainly over western, central and southern parts of the country. The maximum temperature further increased and the warming of more than 4^{0}C was reported over the entire country except the parts of northeast India during the period from 10-16 May 2010 (Fig. 18b). The corresponding forecast maximum temperature anomalies for two weeks with a lead time of 4 days as shown in Fig. 18c and Fig. 18d also indicated warming over large parts of India during 3-9 May 2010 and it further ncreased during the period from 10-16 May 2010. Like the maximum temperature anomalies the minimum temperature anomalies during the two weeks period from 3-16 May, 2010 also indicated warming by 3^{0}C to 4^{0}C over most parts of India. As shown by Tyagi and Pattanaik (2012) the

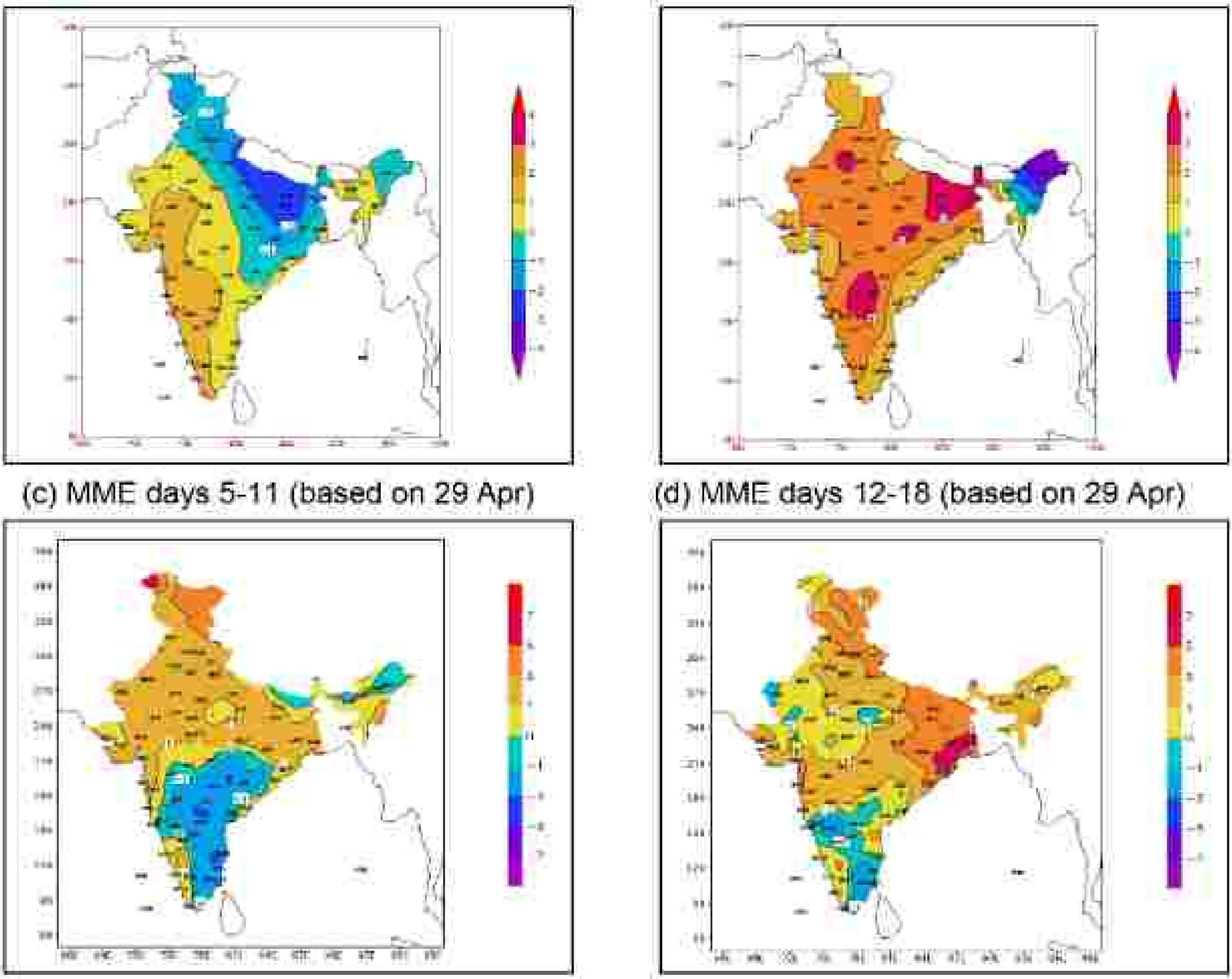


Fig.18 Observed maximum temperature anomalies during the period (a) 03-09 May 2010 and (b) 10-16 May 2010. The corresponding forecast maximum temperature anomalies based on 29 April, 2010 and valid for (c) 03-09 May, 2010 and (d) 10-16 May , 2010.

corresponding forecast minimum temperature anomalies during the two week periods also indicated the large-scale rise in minimum temperature, although the spatial distribution of positive and negative anomalies are not matching very accurately.

5 Proposed Operational MME ERF Forecast from 2015 Monsoon Season

After the monsoon season 2014 the experimental MME forecast is being prepared based on the model outputs available from IITM and other international centres. For the preparation of weekly forecast real time outputs from three different models are considered viz., The output of coupled model run operationally at IITM, Pune once in every five day, which is the NCEP Climate Forecast System version 2 (CFSv2) coupled model at two horizontal resolutions (»38km and 100km respectively). IITM also runs the atmospheric component of CFSv2 model i.e the Global Forecast System (GFS) at two different resolutions (»38km and 100km respectively). The atmospheric model GFS is forced with the bias corrected SST from the CFSv2 run. Using these suites of models IITM is generating the extended range prediction of active/break spells of Indian summer monsoon up to 4 pentads (Abhilash et al., 2014a; Sahai et al., 2013; Borah et al., 2013). The details about the Ensemble Prediction System (EPS) of IITM can be found in Abhilash et al. (2014b) and Borah et al. (2013). As shown by Joseph et al., (2014) the EPS run at IITM, Pune based on two versions of CFSv2 (T382 and T126) is able to predict the rapid progress of monsoon during 2013 and associated heavy rainfall over Uttarakhand about 10 days in advance. However, the model could not capture the mid-latitude influence on the event.

The other model included in the MME forecast is the real-time outputs from EPS of the Japan Meteorological Agency (JMA), which is a low-resolution version (TL159) of the Global Spectral Model (GSM). The horizontal resolution is about 110 km with 60 vertical layers and it run on every Wednesday with 50 ensemble members. Similarly the NCEP also runs the CFSv2 model every day with 16 ensemble members (Saha et al, 2014), which is being used for preparation of extended range forecast. Thus, it is proposed to use the following outputs for preparation of real time extended rainfall from 2015 monsoon season.

i. CFSv2_T382 with 11 ensemble members
ii. CFSv2_T126 with 11 ensemble members
iii. GFSbc_T382 with 11 ensemble members
iv. GFSbc_T126 with 11 ensemble members
v. NCEP_CFSv2_T126 with 16 ensemble members
vi. JMA_EPS with 50 ensemble members

For the first four run performed at IITM the Ocean and Atmospheric ICs are obtained from the NCEP and the model is integrated for 45 days with 11 ensemble members each for T382 and T126. The average ensemble forecast anomaly of both model runs of 11 members each is calculated by subtracting corresponding 10-year model hindcast climatology.

From JMA model outputs based on every Wednesday initial condition and the outputs from nearest pentad initial conditions from the CFS run of IITM at two resolutions are used for the preparation of mean and anomaly forecast on every Thursday, which is valid for 4 weeks for days 3-9 (week1; Friday to Thursday), days 10-16 (week 2 ; Friday to Thursday), days 17-23 (week 3 ; Friday to Thursday) and days 24-30 (week 4 ; Friday to Thursday). Similarly the CFSv2 run of NCEP is available every day with 16 ensemble members.

6 Summary of Results

The performance of real time extended rage forecasts generated by IMD are discussed since its commencement in 2009. The outputs from the coupled models like that of ECMWF monthly forecast, NCEP CFS coupled model, Japan Meteorological Agency (JMA) model are used for preparing Multimodel ensemble (MME) forecast for a period of about 3 weeks. Various aspects of extended range forecast of southwest monsoon, northeast monsoon, cyclogenesis over the Bay of Bengal and also the extended range forecasting of maximum and minimum temperature have been discussed. The active and break cycle prediction of southwest monsoon from June to September, the extended range forecast of northeast monsoon during October to December, extended range forecast of tropical cyclogenesis over the north Indian Ocean and finally extended range forecast of maximum and minimum temperature during the period from 2010 to 2014 have been discussed. • With respect to the operational extended range forecast of southwest monsoon rainfall first encouraging results were obtained in 2009 when it could forecast the dry spells of monsoon during almost the entire June, 1st half of August and 2nd half of September. The MME forecast performed well in predicting the intra-seasonal rainfall activity including the dry spells of monsoon, transitions of monsoon, onset and withdrawal of monsoon, revival of monsoon etc during the monsoon seasons of 2010 to 2014. Performances of these typical monsoon episodes are also discussed. In particular, the delayed withdrawal of monsoon during 2010, severe flood over Pakistan in 2010, delayed onset of monsoon over Kerala during 2012 and rapid progress of monsoon and heavy rainfall over Uttarakhand during 2013 were well captured in the model. Quantitative verification indicates that the MME forecast of all India rainfall shows significant CC between observed and forecast rainfall departure at least for 2 weeks. Over the homogeneous regions of India the MME forecast shows significant CCs till two weeks, except in case of Northeast India, which shows significant CC till week-1 (days 5-11 only). On meteorological sub-division levels the MME based met-subdivision level forecast is found to be better than climatology forecast till three weeks up to 25 days.

- With respect to the application of MME based extended range forecast on river basin scale for application in reservoir operation during monsoon season, it is found that such forecasts can be used in the decision making process for effective management of reservoir operation particularly for managing flood.
- The real time extended range forecast of northeast monsoon during October to December, tropical cyclogenesis over the north Indian Ocean and finally extended range forecast of maximum and minimum temperature based on MME also provides useful guidance to various users. However, a more detailed quantitative verification is required for getting the magnitude of the errors and also the skill scores.
- The real time extended range forecast capability of IMD is being strengthened through the collaborative work with IITM, NCMRWF, NCEP and JMA. The CFSv2/GFSbc models run at IITM, CFSv2 run at NCEP and EPS of JMA are being used in the MME forecast prepared by IMD.

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