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Extended Range Prediction System and its Application

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ABSTRACT

The demand for prediction of weather and climate in the extended range (i.e. 2-3 weeks in advance) is quite visible now a day in the sectors depending on water resources, city planning, dam management, health management (e.g. protection against heat death) etc.. The demand has grown up manifold in the last five years with the experimental implementation of dynamical extended range prediction system (ERPS) by Indian Institute of Tropical Meteorology (IITM), Pune. At the heart of ERPS is a forecast system based on the NCEP-CFSv2 Ocean-Atmosphere coupled dynamical model (hereafter CFS), which is configured to run in two resolutions (T382 and T126) and an atmospheric only version (hereafter GFS) configured to run with CFS sea surface temperature (SST) boundary condition that is bias corrected with observations. The initial conditions to run the model are generated through an in-house developed perturbation technique using NCEP GODAS data assimilation system. From every initial condition the model is run for the next 28 days and a multi ensemble forecast run is created. Forecast product variables are then separated for sector specific application with suitable post processing and downscaling based on advanced statistical techniques. The article gives a brief overview of ERPS keeping the focus on few sector specific applications.

Key Words: Extended Range Prediction, Cold/Heat Wave, Active/Break Monsoon, MISO and MJO

1. Introduction

The practical realm of forecasting of weather events over Indian Region has seen a massive expansion in the last few years with the introduction of dynamical models and newer strategies to improve the forewarning systems beyond weather scale(Sahai et al. 2015). The extended range forecasting system is one such example where statistical and numerical models have made an unambiguous advancement to predict weather beyond medium range to raise the prediction horizon up to 2-3 weeks(Abhilash et al. 2013b; Waliser et al. 2003; Borah et al. 2015; Sahai et al. 2013, 2015). Theoretically, the Lorentz chaos experiments (Lorenz 1965; Palmer 1993)tell us that the evolution of the weather and climatic state is non-linear and chaotic beyond 3-5 days. Thus the weather and climatic states are predictable with deterministic accuracy until 3-5 days. However, later studies have shown that the growth of error saturates after sufficiently long time scales so that the signal gains predictability in the seasonal range (Charney-Shukla hypothesis(Charney and Shukla 1981)).

The predictability of weather or meteorological phenomena depends on several factors. The initial conditions and boundary conditions play a significant role in this regard for dynamical model predictions(Collins and Allen 2002; Reichler and Roads 2003; Abhilash et al. 2015, 2013a). Certain events are seen to be more predictable than the others. The predictability of a dynamical flow is deterministic if it is forced by a deterministic forcing.On the other hand, a stochastic or quasi-periodic or multi-periodic (existence of multiple scales of motion) forcing or an indeterminate initial condition would lead to the divergence of flow from the predictable tracks after a certain time. The time after which the flow in phase space gets diverged so that the error is equivalent to the signal itself is known as the limit of predictability. Multi-periodic forcing also sets off scale interaction in multiple scales that occasionally leads to multiple scale convective organization and clustering during monsoon season(Goswami and Mohan 2005; Goswami et al. 2003). These effects are in turn influenced by teleconnections in the boundary forcings such as for example tropical and other extra-tropical boundary forcing (Chattopadhyay et al. 2015; Sahai et al. 2008), the net effects of which ultimately determines the predictability of a signal.

In the intermediate forecast range for monsoon season, i.e., beyond weather scale but within the seasonal scale, the operational predictability depends on the quasi-periodic intraseasonal oscillations (Goswami 2012). During monsoon, the intraseasonal oscillations show a clear periodic propagation from the Indian Ocean to the central Indian region where semi-permanent monsoon trough exist giving rise to the active and break spells (Sikka and Gadgil 1980; Goswami 2012; Rajeevan et al. 2010). This is northward propagating intraseasonal oscillation, that explains up to 50% variance of seasonal mean flow and shows quasi-periodicity in the 30-60 day range(Goswami and Mohan 2001; Goswami 2012). Hence it is a significant source of predictability beyond weather scale in the intermediate range. Together with this, there is clear westward propagating events or super synoptic events with quasi-periodicity in the 10-20 day range(Chatterjee and Goswami 2004). Thus, these quasi-periodicities give hope of increased forecast horizon in the extended range beyond weather and medium range scale during the monsoon season. Such increased forecast horizon during the monsoon season has substantial economic value for agricultural activity, rural and city planning, dam management during monsoon season which is the peak activity season for these stakeholders.

Similarly, extreme events arising due to troughs embedded in quasi-periodic flows are observed during other seasons also. The quasi-periodic intrusions of cold air related to extra-tropical wave activity and oscillations occasionally intrude over India region causing sudden drops in temperature over Indian region and give anomalously colder weather causing fog and other large-scale public life disruptions(Pai et al. 2017; Bedekar et al. 1974). Heat waves are other such events that occur during April to June which cause large scale heat deaths and public inconvenience(Rohini et al. 2016; Ratnam et al. 2016; Chaudhury et al. 2000; Bedekar et al. 1974). The extended range forecast can forewarn such events before a week or so which gives enough time gap for disaster preparedness. Another example is the information on cyclogenesis potential and prediction of the amplitude and track of a cyclone. The first guess of such cyclones over India region with a larger lead-time helps for administrative preparedness.

Thus extended range forecast product has many applications that can cater to the need of stakeholders depending on weather and climate forecasts in various field. With the implementation of high performance computing resources and adoption of a coupled dynamical model (i.e. climate forecast system or CFS) from NCEP, US, and Indian Institute of Tropical Meteorology, Pune (IITM) has started producing experimental extended range prediction in real time under the NMM (National Monsoon Mission) program of Ministry of Earth Sciences, Govt. of India (http://www.tropmet.res.in/monsoon/). The current review will indicate how the extended range forecasts are being generated by IITM run models and how these forecasts could be potentially useful to people in several sectors.

2. Extended Range Forecast Technique

As part of INDO-US collaboration under national monsoon mission (NMM) program towards improving Indian monsoon region prediction capabilities, a multi-model ensemble (MME) prediction system has been developed at Indian Institute of tropical Meteorology (IITM). For generating the MME, we have used the latest version of NCEP's CFSv2(Saha et al. 2006, 2014). The atmospheric component, Global Forecast System (GFS) is coupled to an ocean model, sea-ice model, and land surface model. For its ocean component, the CFSv2 uses the GFDL Modular Ocean Model version 4p0d (MOM4; (Griffies et al. 2004)). The initial conditions have been prepared from coupled data assimilation system (CDAS) with T574L64 resolution atmospheric assimilation and MOM4 based oceanic assimilation, a real-time extension of the CFSR(Saha and Coauthors 2010).

The standalone GFS with slightly different physics options is forced with daily bias corrected forecasted SST from CFSv2. Bias correction involves subtracting the climatological bias as a function of a calendar day and lead time, with Optimum Interpolation Sea Surface Temperature (OISST) observations(Reynolds et al. 2007) as the reference. We call this two-tier forecast as GFSbc, with 'bc' indicating bias corrected boundary conditions(Abhilash et al. 2015).

Although there are several technical methods to generate ensembles of different initial conditions for various scales of the forecast, we use an approach which is similar to the ‘complex-and-same-model environment group’ as classified in Buizza (2008). An ensemble of 10 perturbed atmospheric initial conditions was developed in addition to one actual initial condition. Each ensemble member was generated by slightly perturbing the initial atmospheric conditions. We perturb the wind, temperature and moisture fields and the amplitude of perturbation for all variables are consistent with the magnitude of the variance of each variable at a given vertical level. More details of the ensemble generation techniques can be found from Abhilash etal., (2014). More model and experimental details and skills of GFSbc, CFST126, and CFST382, can be found in Abhilash et al., (2013a, 2014) and Sahai et al.,(2015).

To increase model diversity within a manageable code base, this MME uses a suite of different variants of theCFSv2 and its atmosphere component, GFS with different resolutions, parameters, and coupling configurations (to address coupled SST biases), motivated by the different physical mechanisms thought to influence monsoon forecast errors in the extended range (10-20 day lead times). Based on performance experience, and aiming to maximize the operational skill for our available computer resource, we choose to pool 4 variants based on CFS: 11 members of CFST126 (~100km), 11 members of CFST382 (~38km), and 11 members each from GFSbc at two resolutions forced with bias corrected forecasted SST from CFS. Realizing the importance and usefulness of this extended range prediction (ERP) system, Indian Meteorological Department (IMD) adopted this for operational ERP over Indian region (refer Fig. 1 for a flow chart of the prediction strategy).

Various customized forecast products are being disseminated from this ERP which includes, extended range prediction of active-break spells of Indian summer monsoon, monsoon onset, progression, withdrawal, heat-cold wave, monitoring of Monsoon intraseasonal Oscillations (MISO) and Madden-Julian Oscillation (MJO), Cyclogenesis and many other. Now this ERP system is capable of generating extended outlook for various sector-specific applications such as agriculture, hydrology, energy, insurance, re-insurance, urban planning, health, etc. The Fig.1 shows schematic of the end-to-end forecast and dissemination system developed and implemented for operational ERP.

3. Extended Range Forecast Products of IITM

Since the inception of the EPS, the forecast for southwest monsoon season (June-September) is being disseminated. The initial focus was mainly on the onset, progression, active/break spells and withdrawal of the monsoon. Subsequently, the forecast products are extended to other seasons and several event specific forecast products are available.

3.1 Products tuned for monsoon season

Several applications of monsoon extended range forecasts are related to the monsoon season. For predicting the monsoon onset over Kerala (MOK), an objective criterion has been developed(Joseph et al. 2015b) using circulation as well as rainfall information from the 16 May initial conditions of the CGEPS. Three indices are defined for this purpose, one from rainfall observed over Kerala and the others based on the strength and depth of the low-level westerly jet over the Arabian Sea. While formulating the criterion, the persistence of both rainfall and low-level wind after the MOK date has been considered to avoid the occurrence of ‘‘bogus onsets’’ that are unrelated to the large-scale monsoon system.

Monsoon intraseasonal oscillations are large scale systems those require particular attention as they give rainfall over larger parts of central India and have a dominant role in the maintenance of monsoon trough. For predicting and tracking monsoon intraseasonal oscillations (MISOs), we use the MISO index defined by Suhas et al., (2012) based on the extended empirical orthogonal function (EEOF) of daily rainfall.

Prediction of monsoon active and break spells associated with MISO is another important task for extended range prediction as these spells are predictable in this time scale. Other than the prediction of the active/break spells of monsoon, the deterministic, as well as probabilistic prediction of heavy rainfall events, are also being generated. Although the forecasts have some spatiotemporal errors w.r.t heavy rain events, still it can be used as guidance on the coming events.

3.2 Forecast products for all round the year

Considering the promising performance of the EPS in the prediction of the southwest monsoon, the forecast has been extended in 2015 to other seasons like post-monsoon, pre-monsoon, summer and winter seasons as well. The model forecast outputs like rainfall, minimum/maximum temperature, soil moisture, relative humidity, lower/upper-level winds, 850 hPavorticity, 200 hPa divergence and 500 hPageopotential height from the MME has been used to generate various customized forecast products such as heat/cold waves, Madden-Julian Oscillation, cyclogenesis, etc.

These products are useful in providing a general outlook on the weather for the next

15-20 days and have sector-specific applications in agriculture, hydrology, energy, insurance, urban planning, health, etc. A few of these products are described below.

(i) Product for extreme event forecast

Any unexpected, severe or unseasonal weather that causes damage to life and property such as droughts, floods, heavy rainfall events, heat waves, cold waves, tropical cyclones, thunderstorms, tornadoes, etc. can be termed as an extreme event. It is expected that with the increasing climate change/global warming, the frequency and duration of extreme events will increase (IPCC Report 2008). Extreme events can impact on vulnerable human and natural systems; can lead to disasters, especially in the absence of a responsive social system. Accurate and timely forecast of the extreme events is essential to respond effectively to such incidents. If the extreme events are embedded within the large scale systems, their predictability increases. In such cases, ERP at 15-20 days lead time can better serve as guidance about the impending extreme events, thereby substantially minimizing the loss of lives and damage to property. The IITM-ERPS has shown reasonable skill in providing an outlook on such incidents, as discussed in the following sub-sections.

(ii) Products for heavy rainfall events

The monsoon system in the form of low-pressure systems when interacts with mid-latitude systems can instigate heavy downpours in the orographic region, as in the cases of Uttarakhand rain event in June 2013, Kashmir flood in August 2014, etc. In addition, monsoon in its active phase can lead to the enormous amount of rainfall in the form of low-pressure systems and mid-tropospheric cyclones. Prediction of such events is a major challenge in the extended range. However, the present EPS has shown reasonable skill in predicting such events, albeit with small degrees of spatiotemporal errors.

(*iii) Products for anomalous events: e.g. extended active or extended break spells*

Longer duration monsoon break spells with little rain and hot sunny days can cause water stress and eventually depletion of ground water table. Prediction of such spells at least 10-20 days in advance has large applications in agriculture, dam management, policy making, etc. The IITM-ERPS is remarkably skillful in predicting the extended break spells.

(iv) Products for heat/cold waves

Heat waves are one of the devastating extreme weather events with widespread impacts on health, transportation, agriculture, water management, energy, and infrastructure. In India, heat waves occur during April to June with high frequency over north, northwest, central and the eastern coastal regions of the country. The favorable conditions for heat waves are different for different regions. As our focus is over Indian region, keeping in mind the criteria developed by IMD (which is based on station data), the IITM-ERPS started giving real-time ERP of heat waves since 2016 using a heat wave index based on maximum and minimum temperatures. It is found that the defined index could realistically predict the heat wave episodes during April-June 2016.

(v) Products for cyclogenesis

Cyclogenesis refers to the development/strengthening of a low-pressure region or cyclonic circulation in the atmosphere, over the warm waters of tropical oceans. Once they approach land, they pose a threat to thickly populated coastal areas. Therefore, an extended range warning on the impending cyclonic storms can be of great help to the coastal administration to take precautionary measures. The IITM-ERPS has developed a cyclone tracker based on the

NOAA-GFDL vortex tracker and is found to be skillful in predicting the genesis, track and intensity of cyclonic systems "Ashobaa" and "Roanu" that formed over the northern Indian Ocean in June 2015, and May 2016 respectively.

4. Real-Time Applications of Extended Range Forecast: Case Studies for Few Sectors

4.1 Skills of IITM extended range forecast

Any forecasting system has to be operationally reliable. In order to develop the extended range forecast products of IITM into a reliable one, we have computed the hindcast skills of various events those could be forecasted in the extended range. This is shown in Fig. 2 for IMD subdivisions based on the forecast data for the years 2001-2014**.** The skills are presented for the monsoon rainfall forecast, *maximum temperature* (T_{max}) forecast during April-May-June (AMJ) and *minimum temper*ature (T_{min}) forecast during NDJF for the P1-P3 lead-time.

4.2 Applications in the monsoon onset forecast

Monsoon onset over Kerala (MOK) has tremendous operational importance, and its forecasts are generated in real-time for last few years. A criterion is generated based on model hindcasts(Joseph et al. 2015b) and forecasted MOK for the period 2001-2014 is shown in **Table-1**. The onset date (MOK) based on rainfall over Kerala (ROK) and strength of zonal wind over the Arabian Sea (uARAB) is plotted in Fig.3 based on forecast run from 16th May initial condition for few selected years**.** Also, the triad composite of wind and rainfall pattern based on the multi-model ensemble (MME) forecast is shown in the figure and can be compared with observation (OBS). The plot shows an excellent fidelity of matching of the spatial pattern during the onset phase.

4.3 Applications in monsoon Intraseasonal Oscillations and Madden-Julian Oscillations

Monsoon intraseasonal oscillations are strong northward propagating oscillations that explain a significant (~50%) part of the seasonal mean variance. It organizes rainfall in a very large scale, and clustering of synoptic scale events is quite frequently seen. IITM forecasts have been successfully applied to predict the intraseasonal monsoon oscillations. A few application of IITM forecasts is shown in Fig.4**.**The MISO propagation and the forecast from the 15th July 2013 initial conditions are shown here as an example when MISO was very strong. Similar skills were obtained for many other events (refer the skill plot in Fig.2j).

The MJO is another important tropical intraseasonal oscillation that contributes significantly to the tropical variability and is linked to cyclogenesis and other weather disturbance in the equatorial tropics. IITM extended range forecast is applied to the forecast of MJO events for the last few years and an example from the DYNAMO observation period (de Szoeke et al. 2014; Yoneyama et al. 2013)is shown in Fig.5**.**The plot shows capturing the October-November MJO event and its extended range forecast.

4.4 Applications in agriculture

Interests are growing rapidly for the Intra-seasonal prediction/Extended range prediction (defined here as the time varies from weeks to months) because prediction in this period range has a great societal application. Extended range prediction has the potential to provide valuable information well in advance to decision makers that may have huge socio-economic benefit. Predicting episodes of abundant rainfall (active periods) and reduced rainfall (break periods) of south Asian monsoon at least few weeks in advance is crucial for agronomic planning, it has great sociological importance. As most of the agricultural lands are rain-fed, the monsoon is very crucial for food security. Indian economy depends heavily on agricultural yield, and hence Indian GDP is highly correlated with agronomic production.

Since we all know Weather affects every farm operation such as ploughing, land preparation, irrigation, weeding, spraying, harvesting, etc. hence agricultural yield is highly dependent on weather condition, so skillful extended range prediction of expected weather is extremely useful for agricultural activity, it helps in high-cost decision making such as whether to undertake or withheld sowing operation, when to irrigate the crop, when to apply fertilizer and so on.

Although human does not have a control on the occurrences of unusual weather which may have an adverse effect on agriculture, however, it is possible to mitigate the adverse effect if we have a skillful forecast of expected weather at least few weeks in advance. Skillful prediction of rainfall, snow, maximum, minimum and dew point temperatures, relative humidity, wind speed and direction, low pressure areas, different intensities of depressions, cyclones, extreme events like heat and cold waves etc. in extended range are of utmost importance for agronomic planning as well as to mitigate the adverse effect of weather vagaries(Rathore 2013). The ever increasing demand for food to support growing population needs the maximum utilization of the extended range forecast product. The highest use of weather forecasts in agriculture is possible if weather forecasters are aware of the requirements of the farming community and the agricultural community knows how to make the best use of available weather forecasts. In India, the agro-meteorological forecast is made through a real-time input of meteorological forecast to the agricultural scientist who then forecasts the same based on crop modeling for a particular season or interval (e.g. refer Fig.6).

4.5 **Applications in extreme event forecast**: **Uttarakhand Extreme event**

The Uttarakhand extreme rainfall event during the monsoon season of 2013 (June16-17)and associated landslides caused serious damages and claimed many lives. The extended range forecast was applied to study the same event (Joseph et al. 2015a). The study examined the skill of the ensemble prediction system in predicting the Uttarakhand event on extended range time scale. The EPS is implemented on both high (T382) and low (T126) resolution versions of the coupled general circulation model CFSv2. Although it was shown earlier that the models predicted the large-scale features associated with the event 10–12 days in advance, they failed to predict the midlatitude influence on the event. Nevertheless, monsoon-related extreme events show some hope of prediction with advanced lead time. The extended range forecast of rainfall over Uttarakhand region based on T382 and T126 forecast run from 5th June initial condition is shown in Fig.7a(top). Similarly, the plots for the 850hPa wind (streamline) and mean sea level pressure anomaly (shaded) are shown in Fig.7b. Both the model's runs are simultaneously compared with observation. It may be seen that the ensemble means from CFST126 version run grossly underestimates rainfall amplitude. Although it is improved in the CFST382 run (ensemble mean), it is still much below the observed amplitude of rain. The model is partly successful in capturing the event as it has captured (with T382 forecast with stronger amplitude thanT126 runs) the movement of troughs (refer shaded amplitudes in Fig.7b) from the Bay of Bengal region. It, however, does not show any interaction with midlatitude troughs which has actually happened at that time (Joseph et al. 2015a)

4.6 Applications in heat wave and cold waves

Extremes of heat and cold events during the non-monsoon season have a broad and far-reaching set of impacts on the nation. These include significant loss of life and illness, economic costs in transportation, agriculture, production, energy, and infrastructure.

In India, Cold waves occur during boreal winter months from November to February. Earlier studies showed that cold waves occur mostly due to the intrusion of cold air from northern latitudes into the northwestern parts of India. The cold wave conditions over the northern parts of India are often associated with the passage of western disturbances(Bedekar et al. 1974). The health impacts of extreme cold are greater in terms of mortality in humans.For example, the cold wave that occurred in January 2003 resulted in the death of about 900people(De et al. 2005)[2].It appears that the relevant mechanism for cold-related fatality is not so much a single cold snap as it is a longer term chronic exposure. Predictions of coldwave temperature anomalies are thus critical in the extended range. An example is shown in Fig.8 (right panels) when the operational ERPS has shown practical skill in predicting the below normal temperatures during 11-17 January 2017 from 1 January initial condition. During this time the intrusion of westerly trough triggered cold wave conditions over north and central India(bottom panels in right columns).

On the other side of the coin, Heat waves can be more devastating than all other weather-related disasters, and the severe heat waves have caused catastrophic crop failures, thousands of deaths. According to the international disaster database, the heatwave of 2015 caused deaths of 2248 people in various parts of India. Generally heat waves occur during April to June with high frequency over north, northwest, central and the eastern coastal regions of India.

The favorable conditions for heat or cold waves are different for different regions. Since our focus is over Indian region, keeping in mind the criteria developed by IMD (which is based on station data) to predict the heatwaves over India, The IITM ERPS has defined a heat wave index based on maximum and minimum temperatures that can be applied not only for analysis of gridded observation data but for the real-time prediction of heat waves using the dynamical coupled models as well.

From 2016 onwards, the ERP system is providing real-time predictions of heat waves in form of probability of Occurrence for Extreme Heat such as HOT condition, Heat Wave and Severe Heat Wave conditions (daily evolution as well as pentad-wise), Chance for Heat Wave along with Maximum Temperature (Actual & Anomaly) and Temperature Histogram for 4-homogeneous regions (Central, North & West, North-East and South Peninsular India) of India in 2-3 weeks in advance. An example of heat wave forecast during April 2016 s given in Fig.8.

5. Discussion and Conclusions

From the examples discussed above, it is clear that the theory of monsoon extended range prediction has been set on a strong footing so that technical implementation of the same could be achieved in several sectors. The prospects of predictability in the extended range come from both the initial conditions and the boundary conditions. The development of an in-house method to generate initial condition and a method to correct boundary conditions of sea surface temperature are primary factors that have enhanced the skill of extended range prediction in IITM ERPS. Additional factors are shown to be necessary for the extended range. For example, the local air-sea interaction and the biases in sea surface temperature have been shown earlier to contribute to the predictability skill of intraseasonal oscillations. The fundamental improvements in this approach are made in applying the different suite of the model which has a same dynamical core, thus helping in generating a divergent range of forecast using same model code architecture. Uncertainties arising due to such change in inherent core architecture are thus reduced.

Several sectors specific applications have been discussed in this article to highlight the application potential. In the agriculture sector, it has been now used for past 2-3 years by agro-meteorological divisions of IMD and several other national agencies and institute for generating crop forecast and crop modeling. The most important application is that the forecast would help the farmers to plan the sowing of seeds conveniently, select the type of seeds suitable for a particular forecast scenario, plan the sprinkling of fertilizer, spray pesticide, etc. For the dam and flood management, the 2-3 week forecast would help the concerned stakeholder to plan earlier when to release the dam water or when to store it. This would help to prevent the potential flood scenarios due to excess release of flood water or drying up of dams due to excess release. Similarly, the prediction of heat waves and cold waves would help the civil administration to manage the supply of rescue and relief materials. The method of forecasting would also contribute to reducing the extreme event related disaster. The early forecasting of cyclone generation and its track would help to alarm the common people who could be potentially affected by this event.

There are several fields where the extended range predictions may be potentially applied. One of them is the energy sector where the generation of electricity through conventional and unconventional sources may be regulated and modulated with the knowledge of rainfall, insolation, wind speed, etc. An applicatio n in this sector is yet to start. Similarly, the area of health can use the forecast data to reduce heat deaths, predict the period of mosquito breeding, etc.

Several future advancements in extended range forecasts are being taken up. The most important would probably be the development a downscaled version of the forecast product so as to give the forewarning in the more localized region. Certain uncertainties are best described through probabilistic information, the output of extended range forecast are tuned to provide maximum probabilistic information. Similarly to reduce the error growth with an increase in lead-time forecast runs are proposed to in different spatial resolution in various lead time. High-resolution forecast runs are generated at the start, and lower resolution forecast would be produced as the lead time progresses. Validation and feasibility of such runs are going on.

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Table 1 Forecasted and actual MOK for the years 2001-2014

Year	Actual MOK	Forecasted MOK	SD among ensemble members	Difference between real and forecasted MOK
2001	23 May	25 May	2	2
2002	29 May	21 May	5	8
2003	08 Jun	30 May	5	9
2004	18 May	18 May	1	0
2005	05 Jun	05 Jun	3	0
2006	26 May	25 May	2	1
2007	28 May	02 Jun	8	5
2008	31 May	01 Jun	7	1
2009	23 May	24 May	2	1
2010	31 May	30 May	5	1
2011	29 May	01 Jun	2	3
2012	05 Jun	04 Jun	4	1
2013	01 Jun	29 May	2	3
2014	06 Jun	05 Jun	6	1

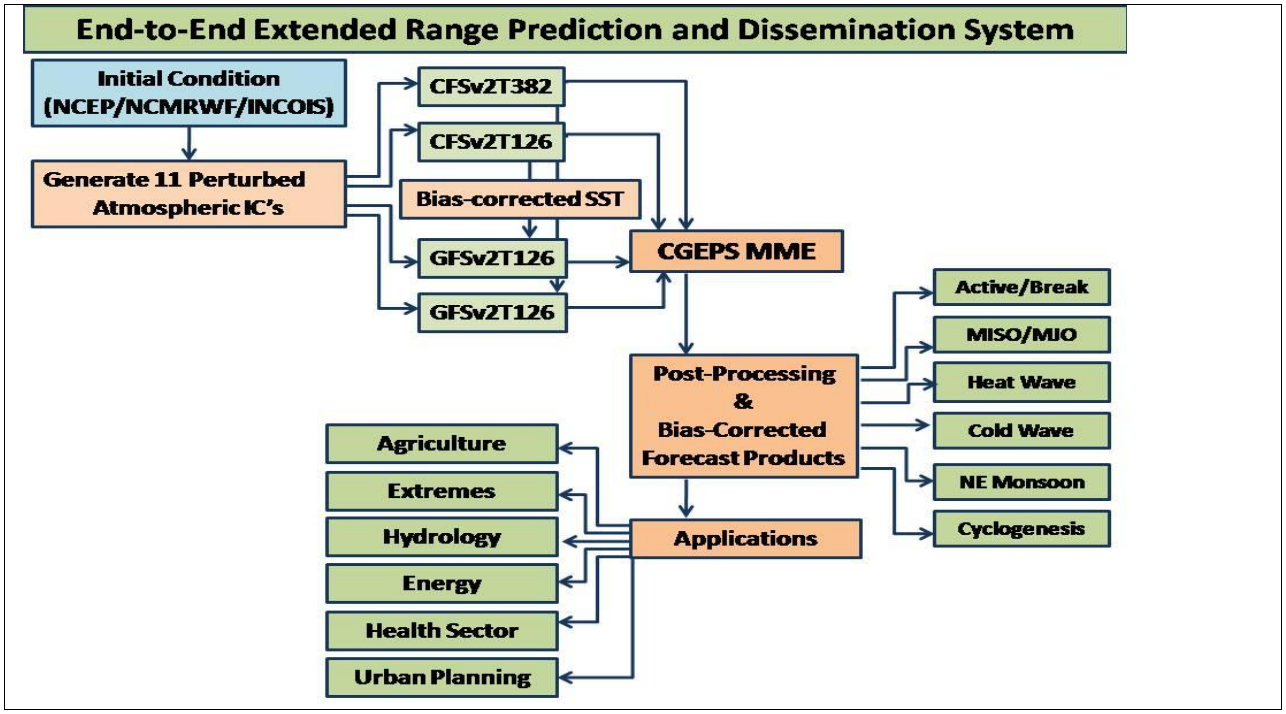
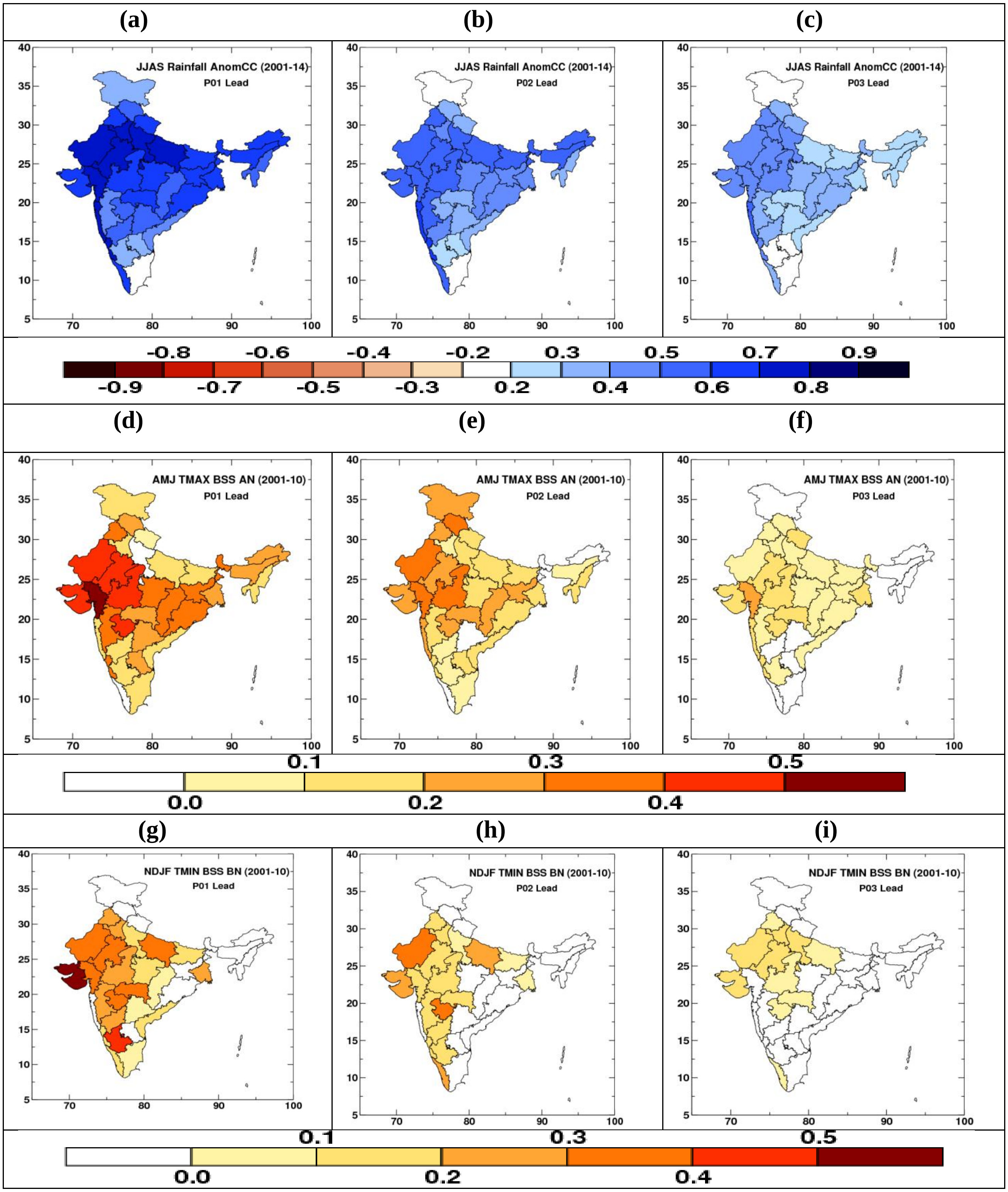


Fig.1: Schematics of the end-to-end forecast and dissemination system implemented for ERP


(a)
(b)
(c)
JJAS Rainfall AnomCC (2001-14)
P01 Lead
P02 Lead
P03 Lead
-0.8
-0.6
-0.4
-0.2
0.3
0.5
0.7
0.9
-0.9
-0.7
-0.5
-0.3
0.2
0.4
0.6
0.8
(d)
(e)
(f)
AMJ TMAX BSS AN (2001-10)
P01 Lead
P02 Lead
P03 Lead
0.1
0.3
0.5
0.0
0.2
0.4
(g)
(h)
(i)
NDJF TMIN BSS BN (2001-10)
P01 Lead
P02 Lead
P03 Lead
0.1
0.3
0.5
0.0
0.2
0.4
40
35
30
25
20
15
10
5
70
80
90
100

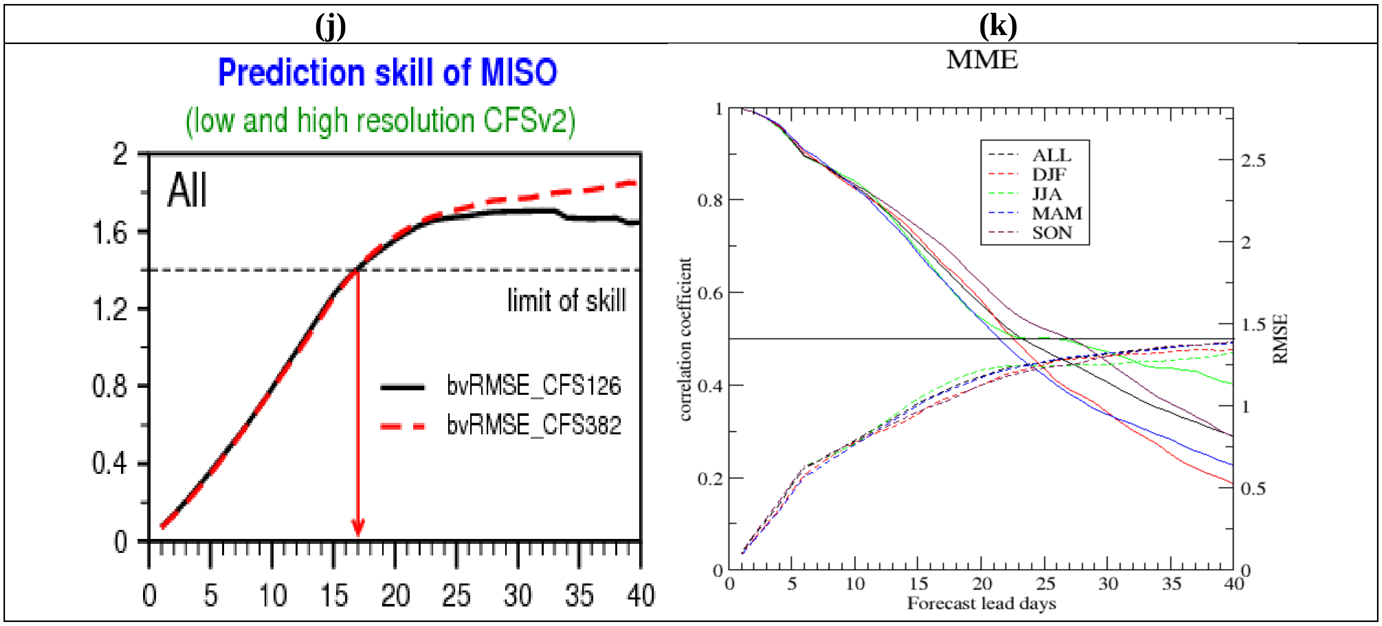

(j)
(k)

Fig.2: Skill statistics of extended range forecast during P1-P3 lead-time based on IITM-CFSv2. Subdivision wise (a)-(c): rainfall prediction skill, (d)-(f) *Brier Skill Score* for Tmax during AMJ (g)-(i)Tmin during NDJF (j) MISO prediction skill and (k) MJO prediction skill as a function of lead-time

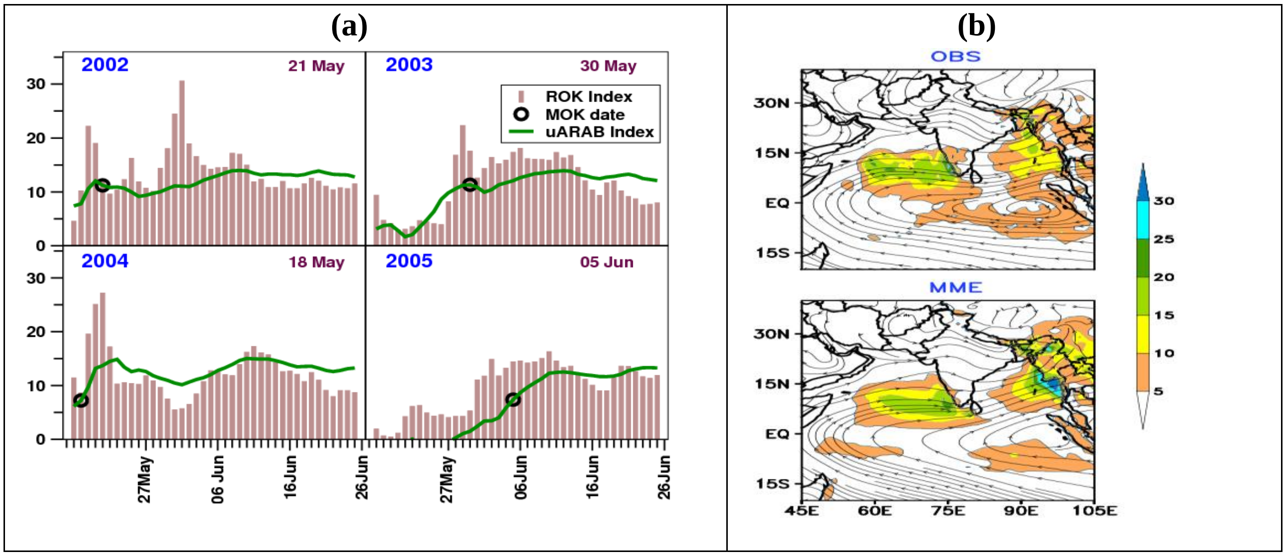


Fig.3: **(a) Example of extended range forecast: onset of monsoon based on indigenously developed criteria. (b) 3 day composite (lag -1,0 +1) of 850hPa wind and rainfall (shaded) based extended range forecasts (MME) during the onset date (taken as lag 0) and its comparison with observation (OBS) during 2001-2014**

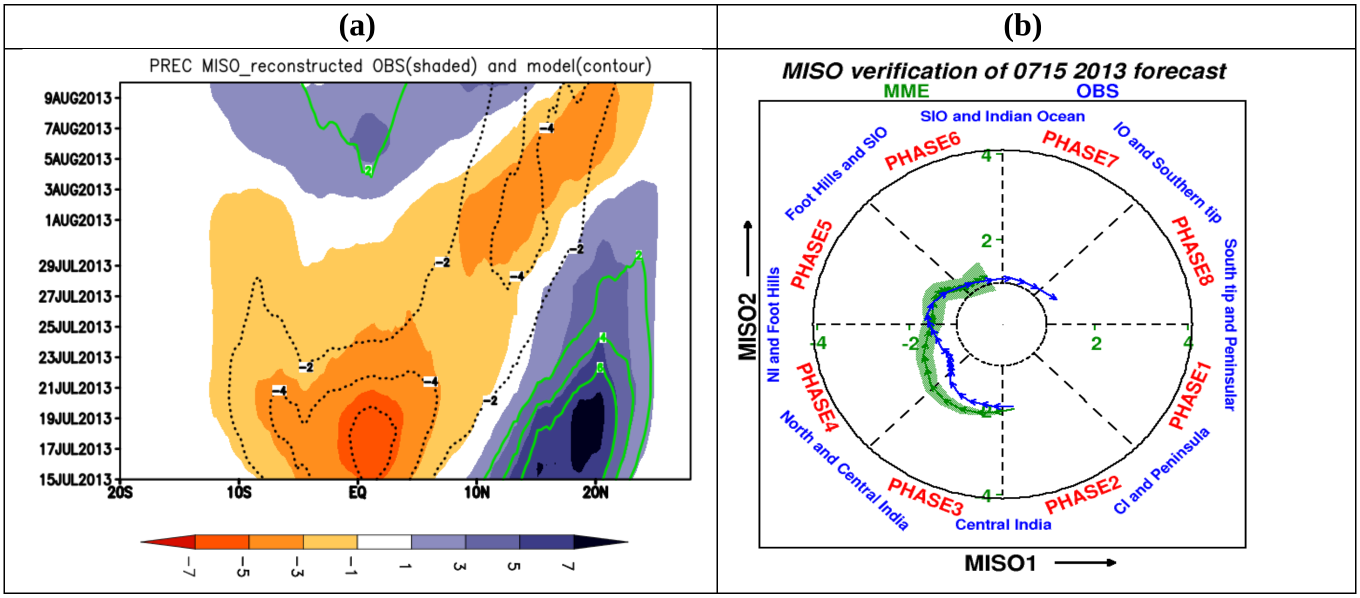


Fig.4: A case of northward propagation of MISO during 2013 monsoon season (a) and (b) its forecast of amplitude in real-time. Reconstruction based on a projection of observed MISO indices onto the observed data is shaded in (a), and projection of forecasted MISO indices onto the observed data is contoured. The reconstruction is based on the following formula:

$RF(lon, lat)_{recons} = A1(lon, lat) * PC1 + A2(lon, lat) * PC2$**, where** $RF(lon, lat)_{recons}$ **is the reconstructed rainfall at any grid point (lon, lat). A1 and A2 are regression coefficients from observation data and PC1 and PC2 are the first two extended principal components fom model or from observation. For more details refer** (Sahai et al. 2016)

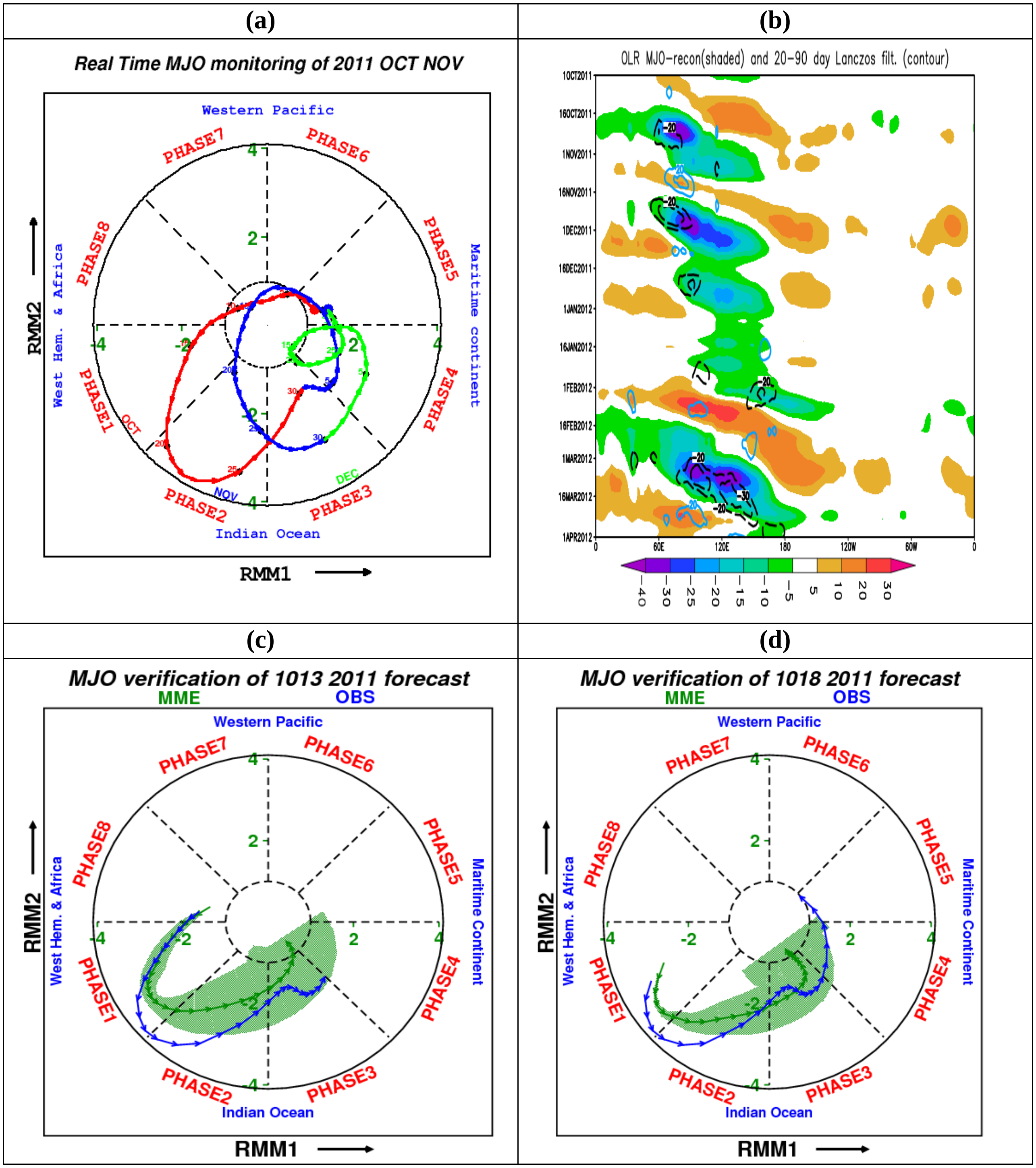


Fig.5: (a) Real-time monitoring of MJO during the DYNAMO observation period. (b) Reconstruction of the same MJO and (c)-(d) real-time forecasts based on IITM extended range prediction system.

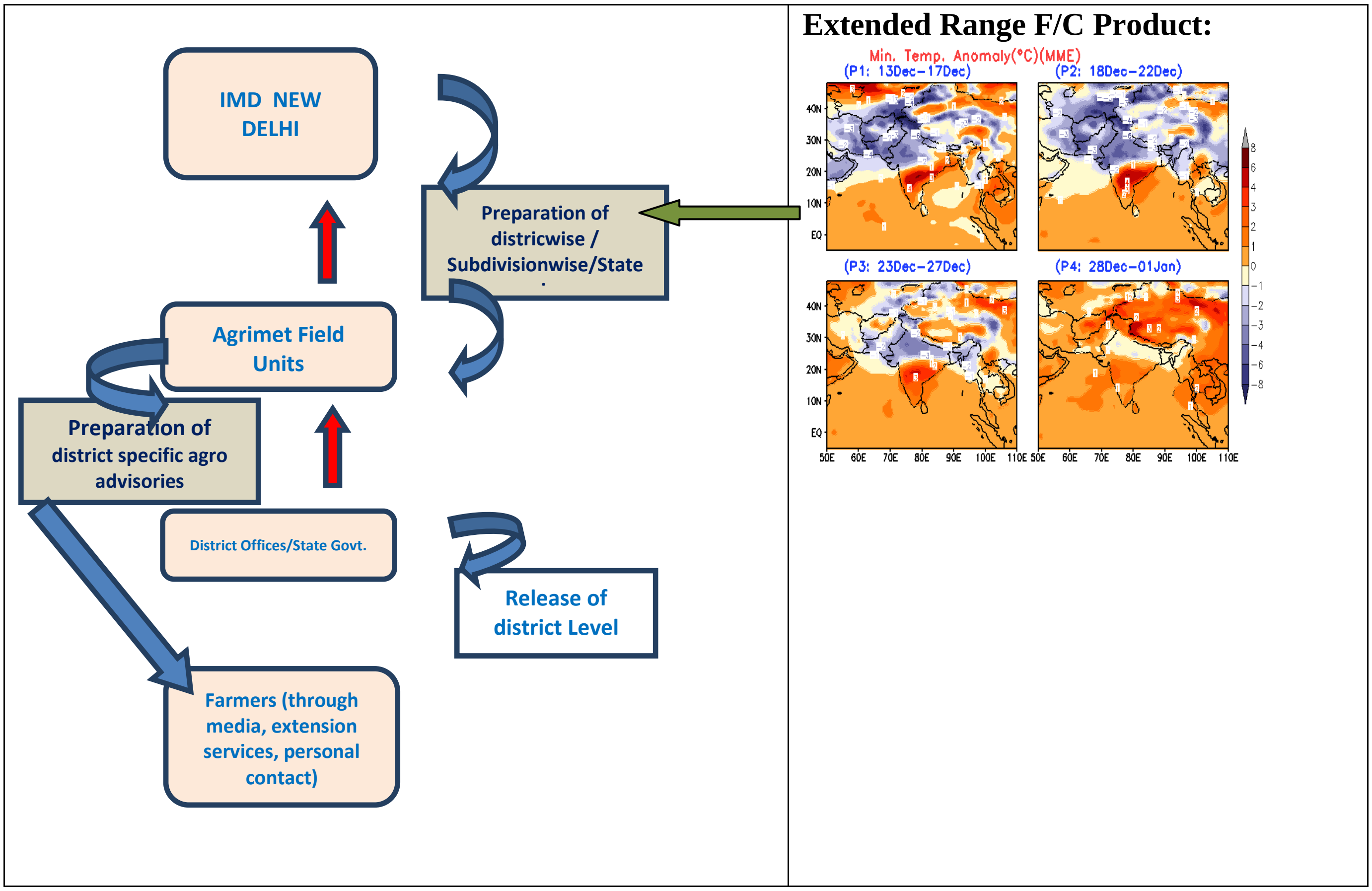


Fig.6: A block diagram showing operational agricultural applications of meteorological forecasts. After a prediction is generated (as shown in right panel), information flow is streamlined into operational field offices.(Rathore 2013)

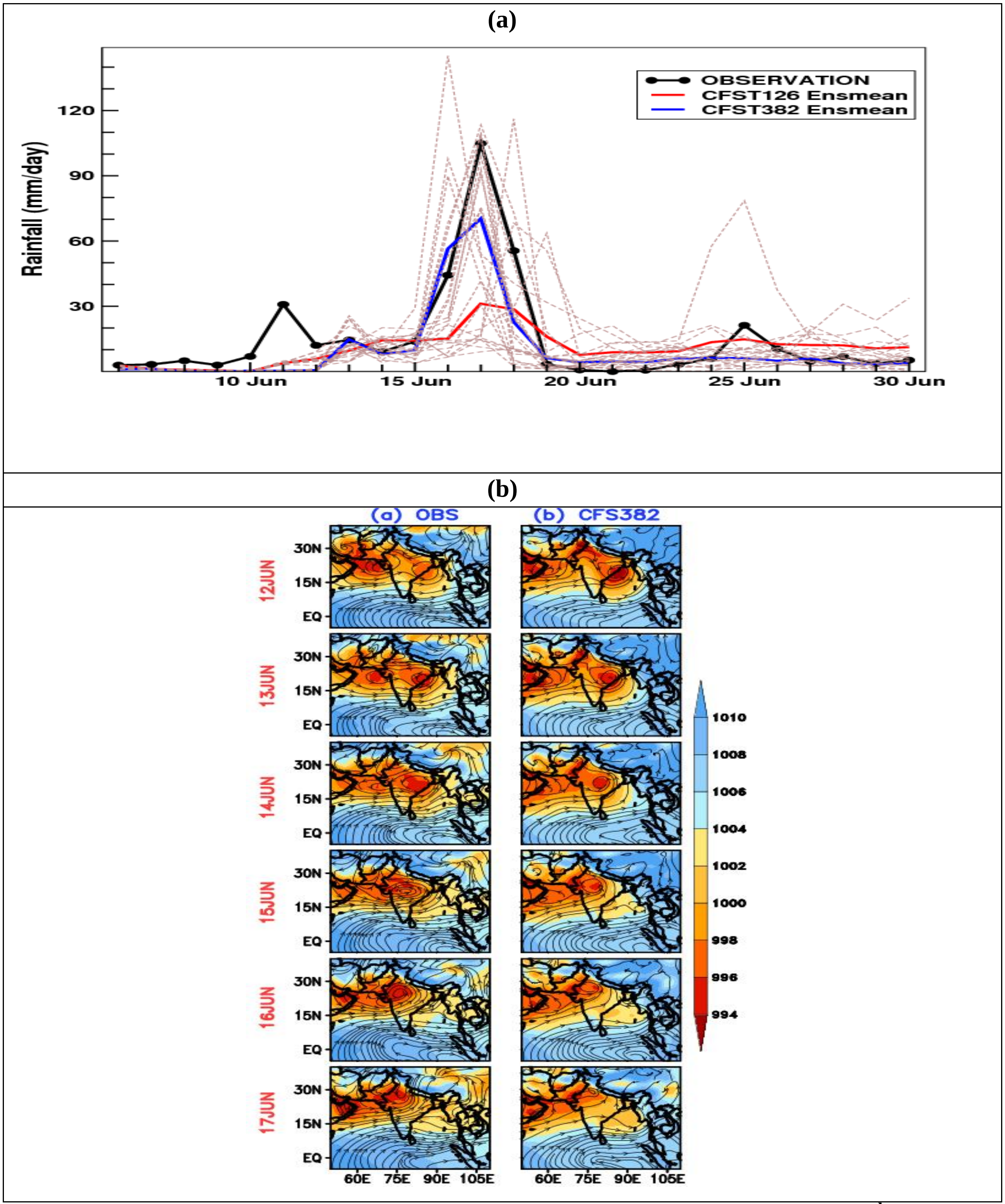


Fig.7(a): Extended range forecast of Uttarakhand Extreme Events based on 5th June initial condition. (b)Spatial patterns of mean sea level pressure anomaly (shaded) and zonal winds at 850hPa (*contours*).

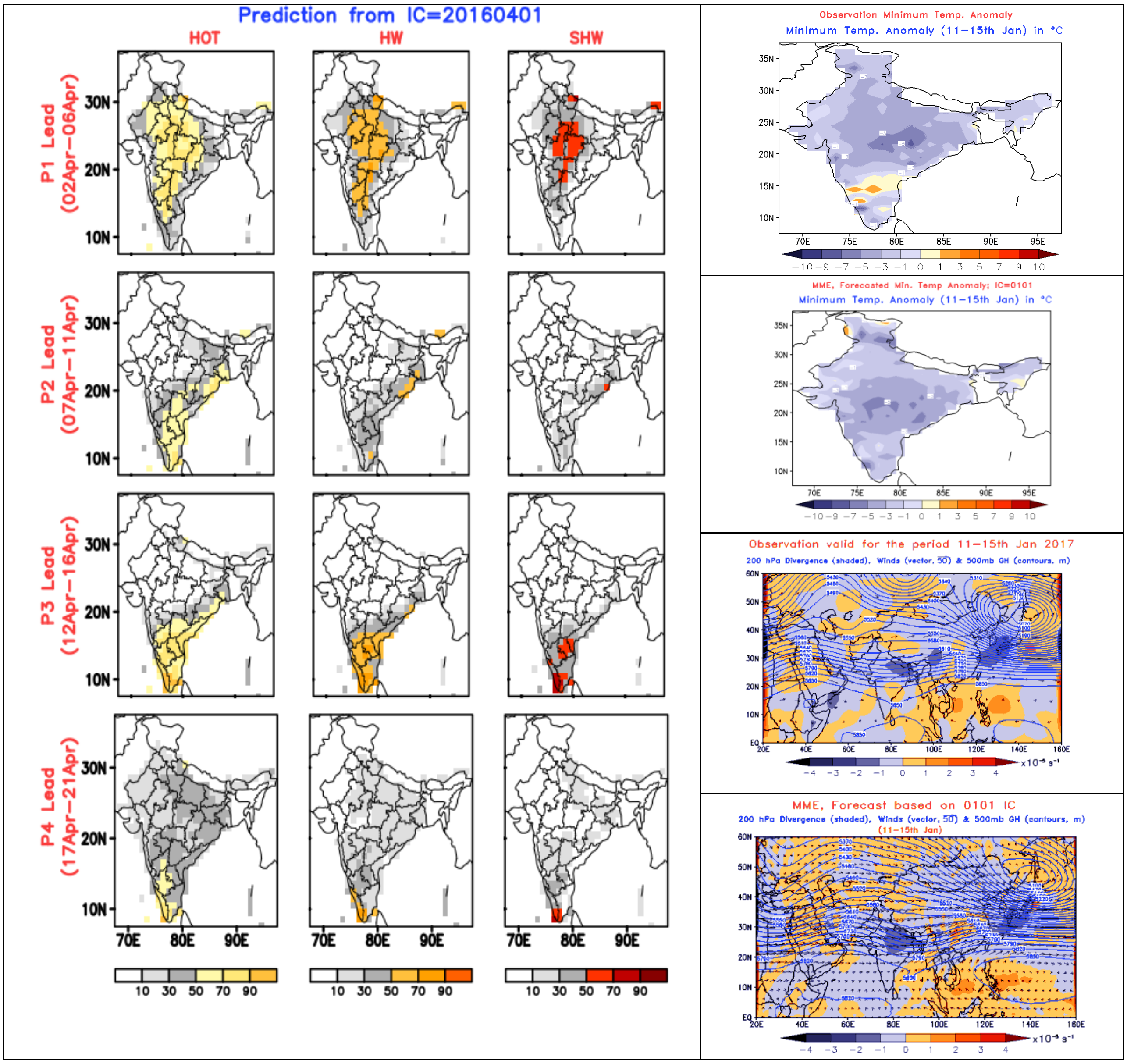


Fig.8: Application of IITM extended range prediction in heat Wave forecast based on 01-Apr-2016 initial condition (left columns) and cold wave conditions (TMin and various upper-level fields based on 01-01-2017 (right panels). OBS implies observation and MME imply ensemble mean ERPS forecast product