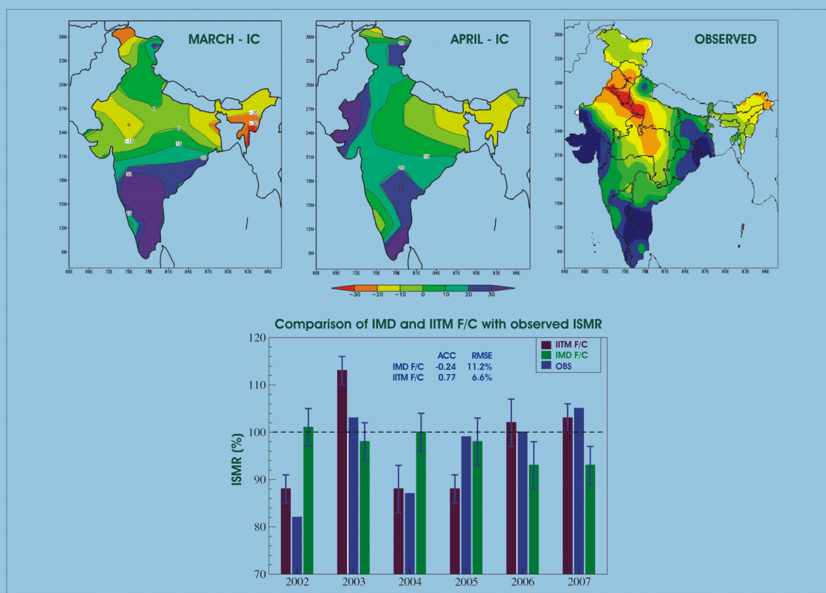
ISSN 0252-1075
Contribution from IITM
Research Report No. RR-120

Experimental Seasonal Forecast of Indian Summer Monsoon 2007 : Statistical and Dynamical Models



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November 2007

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NOVEMBER 2007

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CONTENTS

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ABSTRACT

The Climate modeling group at the Institute (IITM) is actively involved in developing the (experimental) forecast of the seasonal rainfall over India during the summer monsoon (in research mode) in the past few years and attempting the forecast with a two tier approach using statistical models and dynamical General Circulation Models. The statistical model is based on global SST correlation based predictors assuming a significant role played by the slowly varying boundary (SST) forcings on Indian summer monsoon following Charney and Shukla hypothesis. The statistical model performance is robust in the development period and the verification period and is also able to make real time skillful prediction of the seasonal rainfall anomaly during the recent years. The forecast of the statistical model is also compared with the India Meteorological Department (IMD) operational forecast. While both the model needs more improvement, the IITM model has captured the droughts of 2002 and 2004 with more fidelity than the IMD operational model.

The other component of our forecasting experiment consists of attempting seasonal monsoon forecast from a dynamical General Circulation Model (GCM). For the dynamical seasonal prediction (DSP) experiments, Portable Unified Model (PUM) from Hadley centre for climate prediction and research, U.K. has been used. Experimental seasonal prediction of recent ISMs using PUM forced with May SST persistent was communicated earlier. For the year 2007, for the first time, we have used PUM GCM coupled with a slab Ocean and seasonal forecasting experiment was conducted. Though the spatial structure of rainfall differ considerably from observation during the monsoon months (June – Sep), the sign of the seasonal anomaly was correctly forecasted well in advance. In the near future a proper validation of the model forecast from the coupled GCM will be attempted using 20 year simulation with 10 member ensemble.

1. Introduction

The Asian summer monsoon (ASM) is a major component of the general circulation involving large-scale exchange of air between the Northern and the Southern Hemispheres. The importance of the Asian summer monsoon as a planetary-scale feature playing a major role in the general atmospheric circulation and thereby affecting climate predictability has been recognized in the CLIVAR (CLImate VARiability and predictability study), GOALS (Global Ocean-Atmosphere-Land System) programme of the WCRP (World Climate Research Programme). Clearly, predicting the intensity of the Indian Summer Monsoon Rainfall (ISMR), a major component of the ASM, a few months in advance is not only a regional challenge, but is also relevant in the framework of a global seasonal forecasting system.

The ISMR is the total rainfall received during the months of June to September over the country and accounts for around 80% of the total annual rainfall. It is manifested by its associated droughts and floods on inter annual time scales. The Indian summer monsoon (ISM) or southwest monsoon has a strong hold on the Indian economy, agriculture and, consequently, the livelihoods of a vast majority of the rural population. Thus prior knowledge of monsoon behavior will help Indian farmers and policy makers to take advantage of good monsoons and also to minimize crop damage and human hardship during adverse monsoons. In addition to the importance of the seasonal mean monsoon rainfall, the intra-seasonal variability is also crucial. Even if the seasonal mean rainfall is normal, the delay in the monsoon onset and the unusual monsoon lulls or breaks in between may cause severe disruption of agricultural activities, hydroelectric power generation and even drinking water supply. What farmers need is the location and time-specific information about the monsoon behaviour. As a result, forecasting the monsoon on time scales of weeks to seasons is a major scientific issue in the field of monsoon meteorology. However, forewarning of seasonal mean rainfall for the country as a whole (large scale droughts and floods) is still demanded by the policy makers as it adversely affects country's agricultural production and economy.

The complexity involved in the variability of ISMR makes its accurate prediction a challenging task to the meteorological community, in spite of major advances in prediction over the past few decades. Traditionally the long-range prediction of ISMR in India is based on statistical methods. The first long-range prediction of seasonal mean monsoon rainfall over India has been made in 1886 using statistical method (Blanford, 1884). Since then, many statistical/empirical forecasting models (Thapliyal 1981; Shukla and Paolino 1983; Mooley et al. 1986; Bhalme et al. 1986; Shukla and Mooley 1987; Gowariker et al. 1991; Navone and Ceccatto 1994; Goswami and Srividya 1996; Sahai et al. 2000, Sahai et. al. 2002, 2003; Rajeevan et.al. 2007) have been developed and used. Empirical forecasting of the ISMR has been performed using combinations of climatic parameters including atmospheric pressure, wind, snow cover, Sea Surface Temperature (SST) and the phase of ENSO. It was shown (Krishna Kumar et. al., 1995) that among the various predictors, ENSO plays a dominant role in the forecasting of the ISMR. Almost all the statistical seasonal prediction schemes of the ISMR rely heavily on the change in the magnitude of various ENSO indices from winter (December to February) to spring (March to May) prior to the start of monsoon season. However, studies (Kripalani and Kulkarni, 1997 and Krishna Kumar et.al., 1999) have shown that ENSO-ISMR relationship is weakening in recent years, which, in turn, makes the prediction a difficult job.

Therefore, a question arises about causes of the interannual variability (IAV) of ISMR in recent years as well as in periods in the past when the ENSO-ISMR relationship was weak. In fact, it is also associated with oceanic regions other than eastern tropical Pacific. Krishna Kumar et.al. (2006) have shown that in the recent years Central Pacific is more dominant in regulating ISMR. Other regions of the global oceans have already been explored by various researchers to be associated with ISMR, such as the warm pool of the west Pacific Ocean, the northwest Pacific Ocean (Ju and Slingo 1995; Soman and Slingo 1997) and the Indian Ocean (Nicholls 1983, Saji et al. 1999, Gadgil et.al. 2004). Furthermore, the SST- ISMR relationship has shown a biennial variability along with the multiyear (3-7 years) ENSO-related variability. Therefore, instead of calculating various indices from the tropical Pacific Ocean and using only 6 months lag (December to May) for prediction of the ISMR, it is logical to include all oceans in different seasons with longer lags. An attempt in this regard has been made by Clark et al. (2000), who combined various indices from three regions in the Indian Ocean in different seasons, to develop a combined index with long-lead time that shows stable relationship throughout the period 1945-1997. Recently, this attempt has been further extended by (Sahai et. al. 2002, 2003), who have shown a comprehensive mechanism to select predictors and predict ISMR considering various regions of global oceans with sufficient lag.

Though statistical models have shown some skill in predicting ISMR, their skill is limited in providing evolution in temporal and spatial scales. Dynamical models, particularly general circulation models, have the advantage over the statistical models in the way that they can provide time evolution and spatial distribution of rainfall at the model's spatial and temporal resolution. Cause-and-effect relationship among various processes (like atmosphere- ocean interaction through sea surface temperature variations, atmosphere- land interactions through albedo, soil moisture and vegetation changes, etc.) represented in the model can also be analyzed. The inherent limitations of the statistical models and advantages of dynamical models gave birth to dynamical prediction using state-of-the-art climate models. The fundamental factors governing the IAV of monsoon are internal dynamics and slowly varying boundary forcing such as SST, soil moisture, snow/ice cover and sea ice (Charney and Shukla, 1981). While the variability due to internal dynamics is inherently unpredictable, the variability arising from boundary forcings can be predicted to a certain extent. Long range forecast is based on this premise. IAV in the tropics is dominated by such slowly varying boundary conditions (Charney and Shukla, 1981) and SST is identified as one of the important lower boundary forcing. Thus level of predictability is much higher for tropical region unlike extra-tropical region which is more chaotic. However, within the tropics there are regions where the internal variability is important, Asian Summer Monsoon (ASM) being prime example. Higher resolution Atmospheric General Circulation Model (AGCM) simulations (Sperber and Palmer 1996, Sugi et.al.1997, Goswami 1998, Brankovic and Palmer 1997, Brankovic and Palmer 2000, Sperber et. al. 2001, Kang et. al. 2004) have established that the internal variability over the monsoon region is considerably larger than that was shown by Charney and Shukla (1981). Therefore, dynamical approach using AGCMs with perfectly known ocean conditions specified, as well as coupled models are reported to have insignificant forecast skill over ASM (Gadgil et.al.2005). This suggests the requirement of large member ensembles to separate the boundary forced response from internal dynamics.

At Indian Institute of Tropical Meteorology (IITM), Pune, our group has been attempting statistical and dynamical seasonal prediction of monsoon in research mode. For statistical experimental forecast of ISMR of the country as a whole and for the period 2002-2007, we have used the method described in Sahai et.al. (2002, 2003). Empirical forecasts using this method can be obtained one season in advance based on the predictors selected only from the SST. For the dynamical seasonal prediction (DSP) experiments, Portable Unified Model (PUM) from Hadley centre for climate prediction and research, U.K. has been used. Experimental seasonal prediction of recent ISMs using PUM forced with May SST persistent has been reported by Mandke et.al., 2005. The DSP procedures currently used are grouped into Tier-two and Tier-one systems (Kang et.al., 2004). The Tier-two system considers the atmosphere and the ocean (represented by SST) separately. This system utilizes atmospheric GCM integrated with prescribed (either observed or predicted or persisted) SST boundary conditions and atmospheric initial conditions. The Tier-one system use coupled ocean-atmosphere model. 'Tier-one' and 'Tier-two' approaches with PUM model have been used.

The all India mean seasonal monsoon rainfall for the year 2007 is observed as 105% of its long period average (http://www.imd.ernet.in/main_new.htm). The summer of 2007 was dominated by the positive phase of the Dipole Mode over the Indian Ocean, and the La Nina phase of the El Nino Southern Oscillation over the Pacific. Thus both the Indian Ocean and the Pacific Ocean were conducive for summer monsoon activity. These may have had some role to play in the enhanced monsoon activity over India during summer of 2007 (Sabade et al, 2007). The official IMD forecast was not able to foreshadow these features and hence the monsoon. Therefore, we need to look into the IMD forecasts of recent few monsoons and compare with IITM's SST based statistical model forecasts and also with dynamical model experimental forecasts with especial emphasis on development of monsoon forecast strategy at IITM.

In this communication, we report the forecasts which were either provided as input to IMD before preparation of the operational long-range forecast or reported elsewhere. The details of statistical and dynamical forecasts are provided in section 2 and section 3 respectively. The summary is given in section 4.

2. Forecast with Statistical Model

A. DATA AND METHODOLOGY

The ISMR data, from June to September for the period 1871-2006 was obtained from the IITM (Parthasarathy et al., 1994). The monthly SST data was obtained from the GISST 2.3b (Rayner et al., 1996) for the period January 1871 to February 2003. The GISST dataset was used for the prediction of ISMR 2002 and 2003. This dataset is not being updated since February 2003. Therefore SST from ERSSTv2 dataset was used for the prediction of ISMR of 2004 and 2005. There was considerable error in the magnitude of 2005 forecast obtained using ERSSTv2 data, compared to observation; therefore we decided to use OISST for prediction of 2006 and 2007 ISMR. Since this dataset is available only from 1980, we merged this data with GISST and extended up to 1949.

The model developed for prediction in 2002 and 2003 has been discussed in detail in Sahai et.al. (2002, 2003). The model for predicting ISMR of 2004 and 2005 was on similar lines only the SST dataset was changed and hence the regions selected. Similarly the present model which has been used for predicting 2006 and 2007 ISMR uses different regions and will be discussed here in brief.

- OISST monthly data was extended up to 1949 by superimposing its anomalies calculated from the climatology of the period 1980-2000 upon the climatology of the same period of GISST2.3b SST and then considering the later from January 1949 to February 2007.

- The dataset was divided into two sets - forecast and development. The forecast set was selected randomly consisting of 11 years (1954, 1957, 1962, 1971, 1974, 1984, 1991, 1993, 1995, 2002, 2004) and rest of the data 1951-2005 (44 years) were kept in the development set.

- Lag correlations between ISMR and global SST field were calculated for the model development period from 3 months prior to the start of monsoon season up to 2 years. Those regions were selected which were sufficiently large in area (in this case more than 5000 Sq. Km.) and seasons (in this case span of 3 months) were selected for which correlations coefficients (CC) between ISMR and SST were significant and/or correlation with seasonal tendency (indicative of reversal of sign of CC) were significant.

- Total no. of 44 predictors (comprising different region at different lags) were identified.

- The stepwise regression in combination with leave-one-out cross validation was used to select the best set of predictors. (Wilks, 1995, Sahai et.al. 2002). The best subset of 10 predictors (Table-1, Fig.1) has been selected.

- The number of predictors (10) is still high and also may have the problem of multi co-linearity. Therefore, to minimize the redundancy among the predictors and to reduce the number, the empirical orthogonal function (EOF) analysis was performed on the above described 10 selected predictors for the model development period and principal components (PCs) were calculated for the entire period. First 2 PCs (explaining more than 40% variance) were used for prediction.

B. PERFORMANCE OF THE LATEST MODEL

Forecast models are developed for the model development period using first 2 PCs. We assume here that there may be some uncertainty in the observed time series of predictors (PC1 and PC2) and predictand (observed rainfall). Therefore we developed 1000 multiple regression equations by randomly perturbing each time series 1000 times. This was achieved by adding each time series with a random number between plus half and minus half times of their standard deviations. Thus we get 1000 forecasts for each year. Then for each year the actual forecast is taken as the mean of 25th and 75th percentile. Also the 5th and 95th percentiles respectively have been taken as the lower and upper limits (error values) of the forecasts. Forecasts obtained in this manner for model development and verification period is shown in Fig.2. In this figure we plotted the observed and the predicted rainfall departure from normal in percentage from 1950 to 2005. The model verification years are also indicated inside the figure. While some of the negative years (1951, 1979, and 1981) in the development set are highly underestimated some positive years (like 1961 and 1975) are also underestimated. For the randomly chosen verification period, some years like 1974, 1984, 1995 and 2004 the forecasted rainfall underestimates the observed rainfall. However, the overall signs of the forecast are correctly matched with the observed. The anomaly correlation coefficient (ACC) and the root mean square error (RMSE) are also indicated in the figure which indicates the higher fidelity of the forecast. We have also shown, in Fig. 3, the temporal skill of the model by plotting 11-year sliding correlation of observed rainfall with PC1, PC2 and forecasted rainfall respectively. The sliding correlation between PC1 and the observed rainfall remained above 0.5% significant line most of the time (except between 1975-1980 and 1995-2000), while the same for the PC2 oscillate around 5% level of significant line. It may be seen that when the correlation between the observed rainfall and both the PCs fell below 5% level of significance, the correlation between the forecast and the observed rainfall becomes lower (e.g. around 1980 and around 1995). Most of the time the correlation between the observed rainfall and PC1 follows the correlation between the observed and forecasted rainfall. Also in recent years (after 1995) all the correlation plots show an increasing trend.

C. COMPARISON OF REAL TIME FORECASTS

The results of the forecasting experiments of ISMR from 2002-2007 using the statistical model are plotted in Fig. 4. These forecasts were also provided to IMD during preparation of the operational forecast in the respective years. The filled bar is the observed rainfall in percentage of the long-term mean monsoon rainfall (LTMR) from June to September. The forecast experiments for SST based model (IITM model) and the IMD official forecasts are plotted as dotted bars and blank bars respectively. The corresponding error margins of the models are also indicated (vertical lines). It may be seen from Fig.4 that out of the six years shown here, 2002 and 2004 are acute drought years (cumulative rainfall below 90% of the LTMR), 2003 and 2007 are slightly excess with cumulative rainfall 103% and 105% of the LTMR respectively while 2005 and 2006 closely follow LTMR. We note that the IITM statistical model is able to foretell one season in advance (in March) the overall nature of the seasonal mean: whether it is normal, below normal or above normal. The deficient rainfall in 2002 and 2004 is well captured by the model. The seasonal forecast of the years 2006 and 2007 are also in tune to the observed rainfall. However, for the year 2003, rainfall is overestimated and for the year 2005 the rainfall is underestimated (though the sign of anomalies are same). However, here it should be noted that up to 5th September 2005, all India mean ISMR was -7% below LTMR and it was heading towards a drought year. But two simultaneous low pressure systems formed around 10th September in Bay of Bengal and Arabian Sea, converted into depressions and moved northward right up to the Punjab and lasted till 18th September. This period has contributed substantially in making 2005 a normal monsoon year. From the IMD operational forecasts (red bars) it may be seen that the IMD forecast highly overestimates 2002 and 2004 cumulative rainfall during the corresponding monsoon seasons. The severe droughts could not be forecasted using the operational model. In comparison, the IITM model has performed better in the drought years of 2002 and 2004. The anomaly correlations (ACC) for the six years (2002-2007) and the root mean square error (RMSE) of the two models are also shown in the top of the figure. Clearly, the IITM model based on SST explains ~50% of the annual rainfall variability with less RMSE and scores better than the IMD operational forecast. Also a comparison of fig. 4 with fig. 2 shows that the ACC and the RMSE for real time operational forecast are comparable to the model development and verification set.

3. Forecast with Dynamical Model

A. Model

The General Circulation Model from Hadley centre for climate prediction and research, U.K., named as 'Portable Unified Model' (PUM), version 4.5, is installed on ORIGIN-350 machine at IITM, Pune. PUM is a global grid point model with horizontal resolution of 3.75° long. X 2.5° lat. This version of the model is the atmospheric component of the coupled ocean-atmosphere climate model - HadCM3 (Gordon et. al. 2000). There are 19 levels in vertical in hybrid coordinate system. Basic formulation of the first unified forecast/climate model is described in Cullen (1993).

B. Model Experiments for previous monsoons

The experiments for monsoon prediction are made with PUM4.5 that consists of a number of ensemble members. The members of ensemble for a particular monsoon season are forced with same SST forcing while differ in starting atmospheric state. Here we will present the chronology of the development and improvement in our seasonal forecast strategy, summarized in Table-2.

2004:

Since the PUMv4.5 model was installed in 2003, we attempted experimental forecast of ISM of 2004 using this model for the first time. Twelve member ensembles run were made starting from model dumps corresponding to 1st April of different years. The model dumps are obtained from long term integration of the same model forced with climatological SST. SST for monsoon season in all twelve member ensembles was created by persisting May 2004 SST anomalies on climatology of June-September. The model is integrated from 1st April to 30th September.

2005:

Similar experimental forecast as in 2004 was obtained for ISM 2005, using same initial conditions as in 2004, but April 2005 SST anomaly was persisted for rest of the month.

Subsequently, the improvement was made in the prediction of ISM 2005 by introducing observed initial atmospheric states that are created from daily NCEP reanalysis data. Observed NCEP reanalysis data of 1st May 2005 is perturbed to create twelve atmospheric states. NCEP reanalysis data and its details are available on http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html. Twelve member ensembles run, were made. The boundary forcing of SST is obtained by superposing May 2005 SST anomalies on climatology of June -September. Monthly mean Optimum Interpolated SST (OISST) (version v2) and sea- ice data downloaded from NCEP website (http://www.ncep.noaa.gov) has been used in DSP of 2004 and 2005. Details of OISST are described in Reynolds et.al. (2002).

After the end of the season hindcast for 2005 ISM was made using the same twelve perturbed real initial conditions but with observed SST.

2006:

The preliminary results of a multi-institutional project on Seasonal Prediction of Indian Monsoon (SPIM), funded by Department of Science and Technology (DST), Govt. of India, have shown that PUMv4.5 is one of the best model in simulating mean climatology as well as inter annual variability. SPIM was aimed to assess the skill of all dynamical models being used in India for dynamical seasonal prediction. Encouraged with the results of SPIM, DST have asked IITM to prepare 2006 ISM forecast till mid April 2006. Since SPIM experiments were carried out with observed SST, it was not possible to do the same in 2006. Also there is no meaning in persisting March SST anomalies for the rest of the months, as almost every region of the globe, there is drastic change in SST in the months of April-May. Therefore we decided to use forecasted SST. Forecasted monthly SST anomalies (obtained from NCEP CFS model forecast, available at ftp://tgftp.nws.noaa.gov) from April to September 2006 were superimposed on the observed climatology of respective months over the region 40°S to 40ºN. Then the model was integrated with observed six observed initial conditions at the end of March 2006 (Table-2).

Systematic improvement (Table-2) in the forecast of ISM 2005 (from April persistence, May persistence to observed SST) and skillful forecast of ISM 2006 using forecasted SST lead us to think about coupled models. Since the PUMv4.5 numerical modeling system is designed in such a way that it can be run in atmosphere only, ocean only or in coupled with slab or full ocean mode. We decided to do forecast experiments with AGCM coupled with slab. The details of the slab ocean component of PUM model are described in Williams's et. al. (2000). The slab model consists of a mixed layer (constant depth 50m) ocean model together with simple ice model. In atmosphere only run, data for SST, ice depth and concentration at sea points is provided from observations. SST and sea ice is computed interactively during model integration with atmospheric model coupled to slab ocean. In order to obtain a realistic representation of SST and sea-ice, a corrective heat flux called the 'heat convergence' must be included to account for the lack of ocean dynamics and errors in surface fluxes. Slab calibration run is required to generate this data. In calibration run, slab model is coupled with atmosphere model, and SST and ice parameters are computed and after every 5 day SSTs are restored to climatology provided by an ancillary file and the corrective heat flux required to do this is stored. At sea-ice points, SST under the ice is reset but no correction is applied to the ice depth. The heat convergence ancillary file is made from these corrective heat fluxes. Calibration run for 10-years with slab model is made to create heat convergence. Now this model was ready to do seasonal forecast experiments since 2007.

In the coming subsections we will concentrate on the forecasting of ISM 2007 with AGCM coupled with slab.

C. Summer monsoon climatology

For a GCM to be useful for monsoon diagnostic and prediction studies, it is important that prime features of the mean monsoon are simulated well. Thus, precipitation climatology of model is compared with corresponding observation from CMAP (Climate Prediction Center Merged Analysis of Precipitation). CMAP precipitation data is based on a blend of gauge data with satellite products. CMAP data is available on www.cdc.noaa.gov and is described by (Xie and Arkin (1997)). Atmospheric model climatology is based on integration for summer monsoon seasons of 1984-2004, each run for set of six member ensemble, forced by monthly observed OISST. Atmosphere-slab ocean coupled model climatology is based on single long run from 1984-2003. Summer monsoon precipitation climatology are depicted in Figs. 5a and 5b respectively for 'AGCM' and 'slab' model and CMAP climatology in Fig. 5c. Chief features of the precipitation distribution are reasonably well reproduced by the model; though regional details differ partially from the observed counterparts, such as overestimation of precipitation over West coast of India and Bay of Bengal. The location of precipitation maximum over west coast is to the north of its observed position, while that over Bay of Bengal is to the south of its observed position. In general, precipitation over Indian land region is overestimated in both 'AGCM' and 'Slab' model.

D. Prediction of ISM 2007

Dynamical prediction of monsoon 2007 was done using AGCM coupled with slab ocean. Experimental forecast was obtained using a set of six ensemble members. NCEP reanalysis daily data of 0 GMT corresponding to 26^{th}-31^{st} March 2007 are used as initial atmospheric state for six member ensembles. Forecast is updated with a set of six-member run using initial atmospheric states from NCEP reanalysis daily data of 0 GMT corresponding to 26^{th}-31^{st} April 2007. Description of model experiments and rainfall forecast for ISM 2007 is provided in Table-3.

The spatial features of model precipitation forecast for monsoon 2007 over India and observations from IITM (www.tropmet.res.in/MOL) are shown in Fig. 6. Fig. 6a and 6b show the spatial distribution of rainfall anomaly using end of March and end of April 2007 initial states, respectively. Observations are shown in Fig. 6c. Peninsula, parts of west and East India received large rainfall. Below normal precipitation is seen over Northeast India. Both experimental forecasts show large positive precipitation anomaly over peninsular India. Fig. 6b (April end initial conditions experiments) show positive rainfall anomaly over West India. There is an indication of below normal precipitation over Northeast India in slab experiment with end of March initial conditions but the magnitude of departure is much smaller and position differs from observation.

The SST JJAS climatology based on 20-years integration for the period 1984-2003 made with PUM AGCM coupled to slab ocean (figure 7a) is compared with corresponding observed climatology from OISST depicted in figure 7b. The chief features are well captured like highest temperatures over northern tropical Indian and Pacific oceans that decreases polewards. However, the model slightly (~1^0C) underestimates the maxima over tropical Indian and Pacific oceans (figures 7a and b). The SST forecast for JJA 2007 over global oceans from 60°S-60°N obtained from model experiments with end of March and end of April initial conditions are shown in figures 8a and 8b respectively. For comparison corresponding observed SST anomalies obtained from OISST are shown in figure 8c. Observation (Figure 8c) shows La Nina over East Pacific with negative SST anomalies of the order of 0.5°-1°C. Both the model experiments also indicate La Nina situation. However model SST forecast differs from observation over rest of the regions over global oceans as seen from anomalies of opposite sign to that observed.

E. Intraseasonal variability during monsoon 2007

The all India mean monthly ISMR anomalies(%) for 2007 obtained from slab Ocean coupled with AGCM for March end initial conditions, April end initial conditions and actual observations are given in Table-4. The model is able to simulate excess rainfall for the month of June and Septmber and also near normal rainfall anomalies for the rest of the months. It can be also noted that there is improvement in the forecast compared to the observation, if April end initial conditions are used rather than those of March end.

Ensemble mean daily precipitation anomalies averaged over Indian land region during 1st June-30th September from slab ocean experiment with end of March and end of April initial conditions are shown in Fig. 9a and 9b respectively and compared with its observed counterpart obtained from IMD, Pune(Dr. Rajeevan, personal communication). Overall, the observed anomalies are 4 times larger than the model forecasts. There may be two reasons for this; one may be the ensemble averaging and the other the restoration time of 5 days for climatological SSTs during the model run. Observed anomalies are large positive from June till beginning of July. Large positive anomalies are also seen in both model experiments from June to mid-July. Though, model anomalies are very small throughout the rest of the season, but April IC forecast are showing some matching of sign with observed anomalies.

4. Summary

We reported here the statistical and dynamical forecast strategy for the prediction of rainfall of very recent monsoons, and discussed in detail the models used for the prediction of 2007 monsoon. Observed 2007 monsoon seasonal rainfall for the country as a whole is 105% of its long period average (http://www.imd.ernet.in/main_new.htm). The prediction of ISMR 2007 by the statistical approach (+3%) and dynamical method using slab model starting from end of April 2007 atmospheric states (+7.4%) are closer to the observed value.

The performance of the new statistical model shows that the skillful prediction of seasonal rainfall averaged over the entire country is possible three months in advance using SST data only. It is worth to mention that the selection of region depends upon the development period and SST data set. Therefore, it is possible to generate an ensemble of forecasts for real time application. The success of the SST based model reaffirms the Charney-Shukla (1981) hypothesis that slowly varying boundary conditions play an important role in the seasonal prediction of ISMR. However, though this model may be able to forecast the seasonal all India mean rainfall it can not be used to forecast spatial and temporal evolutions. This determines the limit of the statistical method and need of dynamical model.

An attempt is made here to record the various stages of development of a dynamical seasonal prediction system at IITM. The latest stage involving an AGCM and slab Ocean is used to make real time prediction of 2007 monsoon. Though the seasonal forecast of 2007 was found to be closer to the observation for the country as a whole but there are lots of differences on spatial scale. Rigorous verification of seasonal forecasts is required in the case of coupled AGCM-slab ocean model. There is some promise on the extended range prediction (monthly scale), however the magnitude of daily anomalies is much less than the observed ones. In our future activity, we propose to conduct coupled AGCM-slab ocean model experiments with more number of ensemble members and for at least 20 seasons in the past to come up with skill statistics for seasonal and extended range forecast with this model. We also propose to do some sensitivity experiments concentrated upon the climatological SST restoration time for 5 day, 15 day, and 25 day.

Acknowledgements

We thank Dr. R. Krishnan, Dr. J. R. Kulkarni and Dr. Milind Mujumdar, all from Climate and Global Modeling Division, IITM, Pune, for their suggestions, encouragement and interest. Thanks are due to Mr. S. P. Gharge, Climate and Global Modeling Division, IITM, Pune, for the technical help. The slab model run of PUM was possible due to ancillary datasets as well as other details required for slab model setup, provided by Dr. Gill Martin of Hadley Centre for Climate Prediction and Research, UK. We acknowledge her support. We are grateful to Dr. M. Rajeevan, Director, IMD, Pune, for providing daily all India summer monsoon rainfall for 2007. Thanks are also due to Prof. Sulochna Gadgil, Indian Institute of Sciences, Banglore, for her interest in seasonal prediction and suggestions. One of the authors (Susmitha Joseph) is thankful to CSIR for financial support. Finally, we thank Dr. R. H. Kripalani for his critical review and Mr. S. K. Jadhav for his valuable inputs.

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Table 1: Details of region, season and year lag of 10 selected predictors.

SN	Region	Year Lag	Season
1	20-15ºS, 115-125ºE	0/-1	DJF
2	25-40ºN, 215-235ºE	0/-1	NDJ-ASO
3	35-30ºS, 230-240ºE	-1/-1	JAS
4	35-25ºS, 350-360ºE	-2/-2	AMJ-JFM
5	35-10ºS, 95-115ºE	-2/-2	JFM
6	40-45ºN, 190-205ºE	-2/-2	MJJ-FMA
7	20-30ºN, 270-275ºE	0/-1	NDJ-ASO
8	30-35ºN, 140-150ºE	-1/-1	OND-JAS
9	35-45ºN, 5-10ºE	0/-1	DJF-SON
10	25-35ºN, 280-290ºE	0/-1	NDJ-ASO

Table-2: Details of experimental dynamical seasonal forecast of recent ISMs

Monsoon season	Model	Initial condition	SST	% departure (forecast)	% departure (observed)
2004	Atmosphere	Model dumps (12 members)	May 2004 SST anomalies persisting on the climatology of rest of the months	-3.13	-13.0
2005	“	“	April 2005 SST anomalies persisting on the climatology of rest of the months	-5.8	-1.0
2005	“	1st May2005 from NCEP data and its perturbations (12 members).	May 2005 SST anomalies persisting on the climatology of rest of the months.	-3.4	-1.0
2005	“	. “	Monthly observed SST from May to September.	-3.0	-1.0
2006	“	26th-31st March 2006 from NCEP reanalysis (6 members)	Forecast monthly SST anomalies (from NCEP CFS model forecast)	+1.4	0.0
2006	Atmosphere coupled to slab ocean	Calibration run for 10 years have been completed. Now the model could be run in coupled mode for seasonal prediction.			

Table-3: Dynamical seasonal prediction of monsoon 2007

Model	Initial condition	SST boundary forcing	Forecast % departure	Observed % departure
Atmospheric model coupled to slab ocean	26^{th} -31^{st} March 2007 from NCEP data	SSTs and ice are computed interactively during the run	+8.0	+5.0
Atmospheric model coupled to slab ocean	25^{th} -30^{th}April 2007 from NCEP data	SSTs and ice are computed interactively during the run	+7.4	”

Table 4: Dynamical prediction of monthly precipitation 2007

Model	Initial condition	June	July	August	September
Atmospheric model coupled to slab ocean	26^{th} -31^{st} March 2007 from NCEP data	+36.7%	+6.9%	-5.8%	+0.7%
Atmospheric model coupled to slab ocean	25^{th} -30^{th} April 2007 from NCEP data	+25.0%	+2.75%	-3.0%	+8.1%
OBSERVED (IMD)		+19.0%	-2.0%	-2.0%	+18.0%

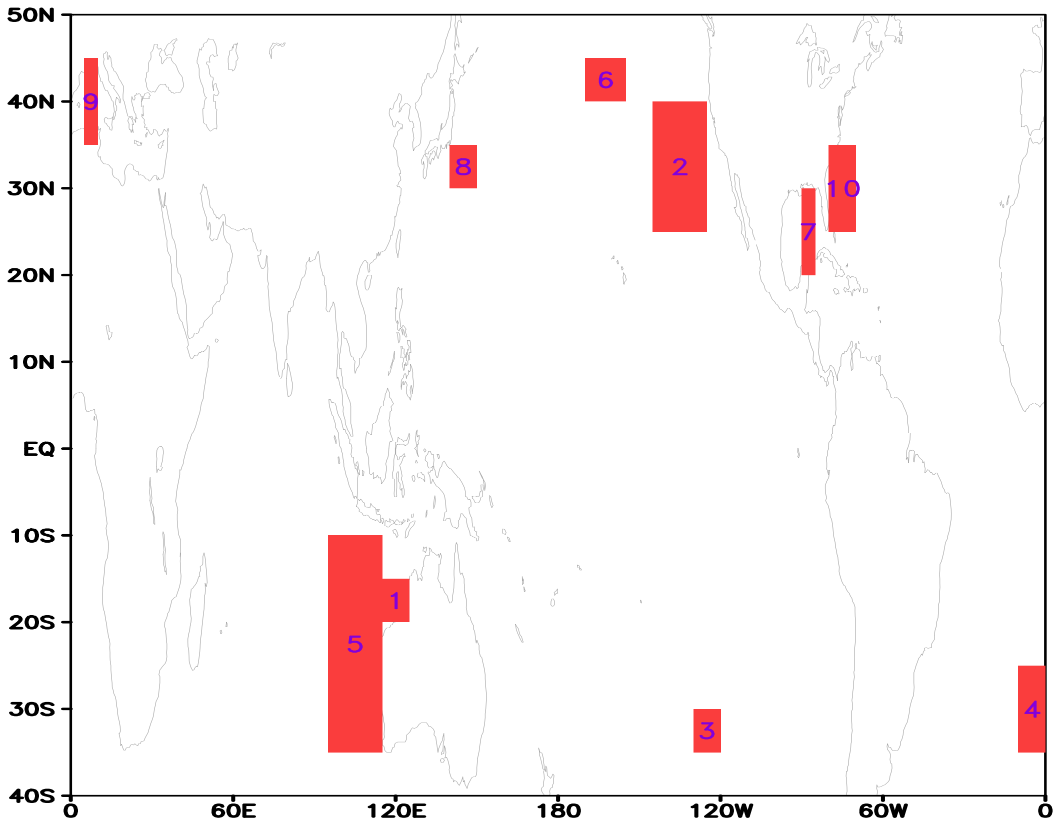

Fig. 1: Spatial distribution of the selected regions given in Table-1. Area averaged SST over these regions were calculated for the seasons given in Table -1 and were used as predictors.

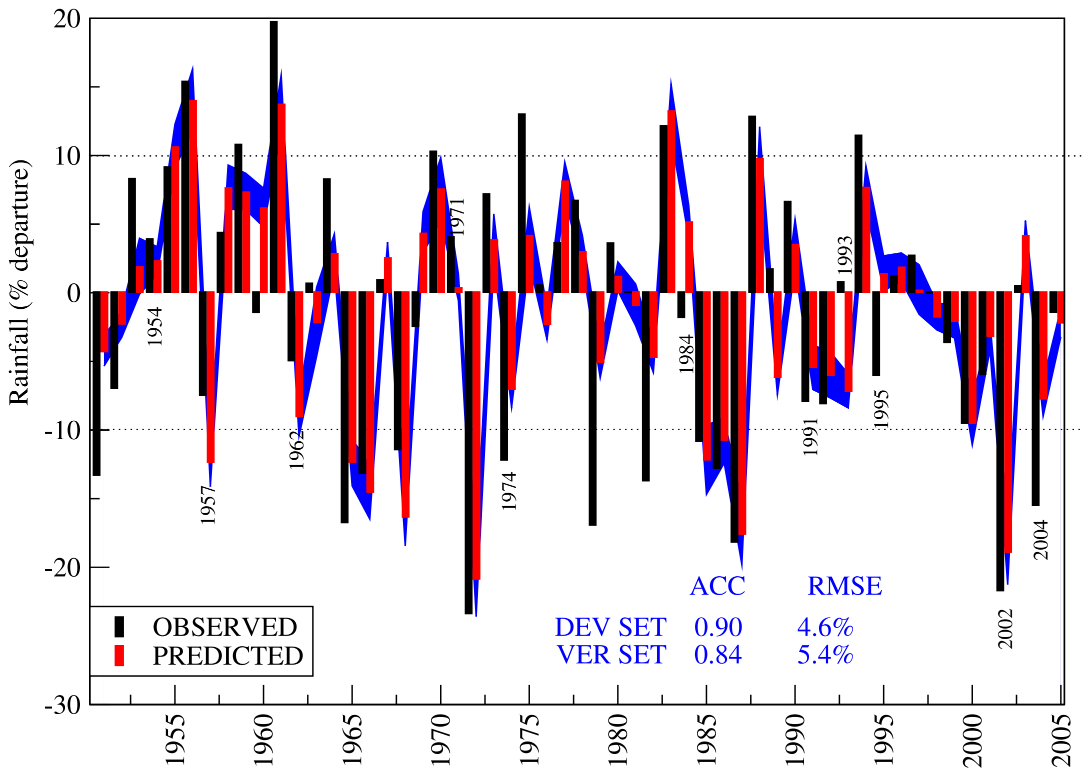

Fig. 2: Comparison of observed and predicted rainfall anomaly (%) for the model development and model verification period. Also shown are the spread (blue) of the forecasts. The 11 years of verification period are marked on the plot. Also shown are the values of anomaly correlation coefficient (ACC) and root mean square error (RMSE) for both the periods.

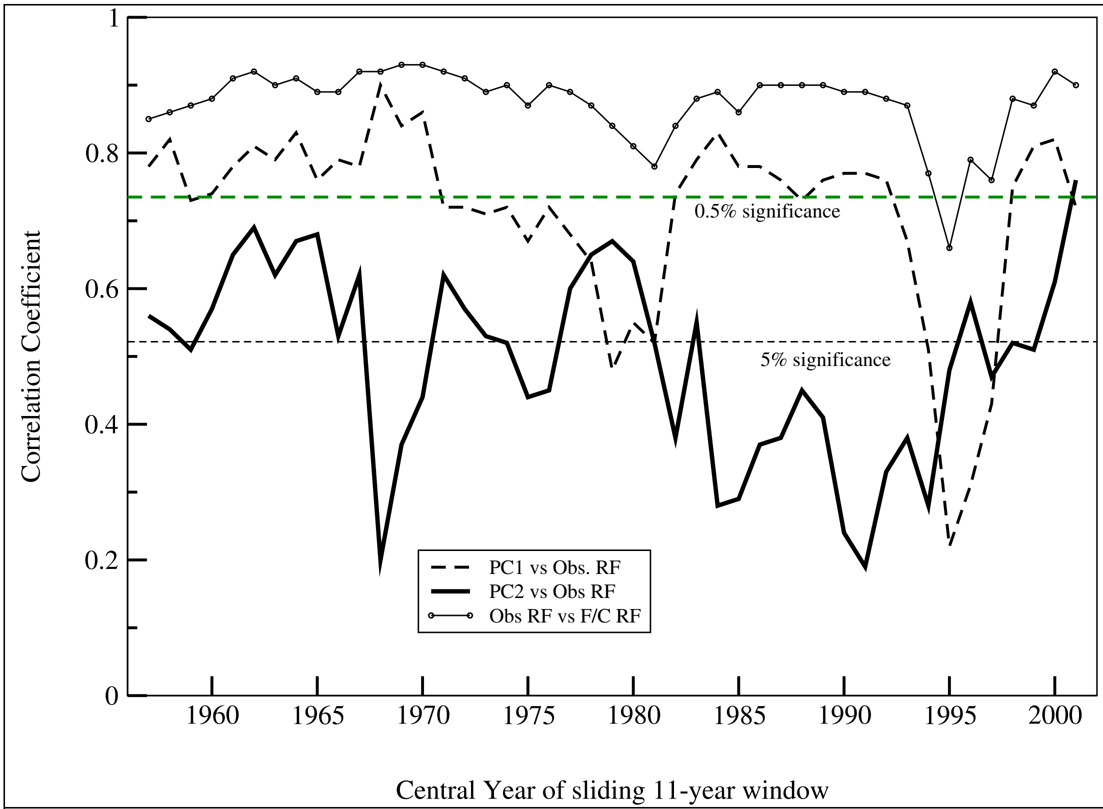

Fig. 3: Plot showing 11-year sliding CC between PC1 and observed rainfall, PC2 and observed rainfall and observed and forecasted rainfall. Also shown are the lines of 0.5% and 5% significance level.

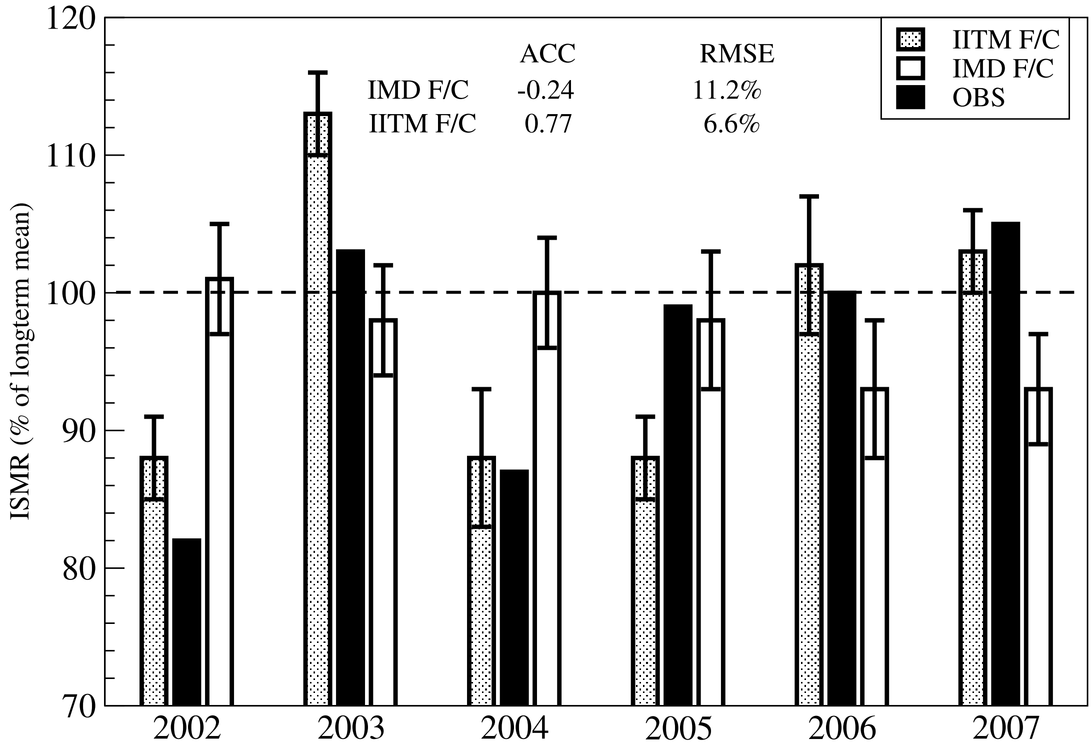

Fig. 4: Comparison of the IITM model and IMD official forecast with IMD observations during the period 2002-2007. Vertical bars denote model errors.

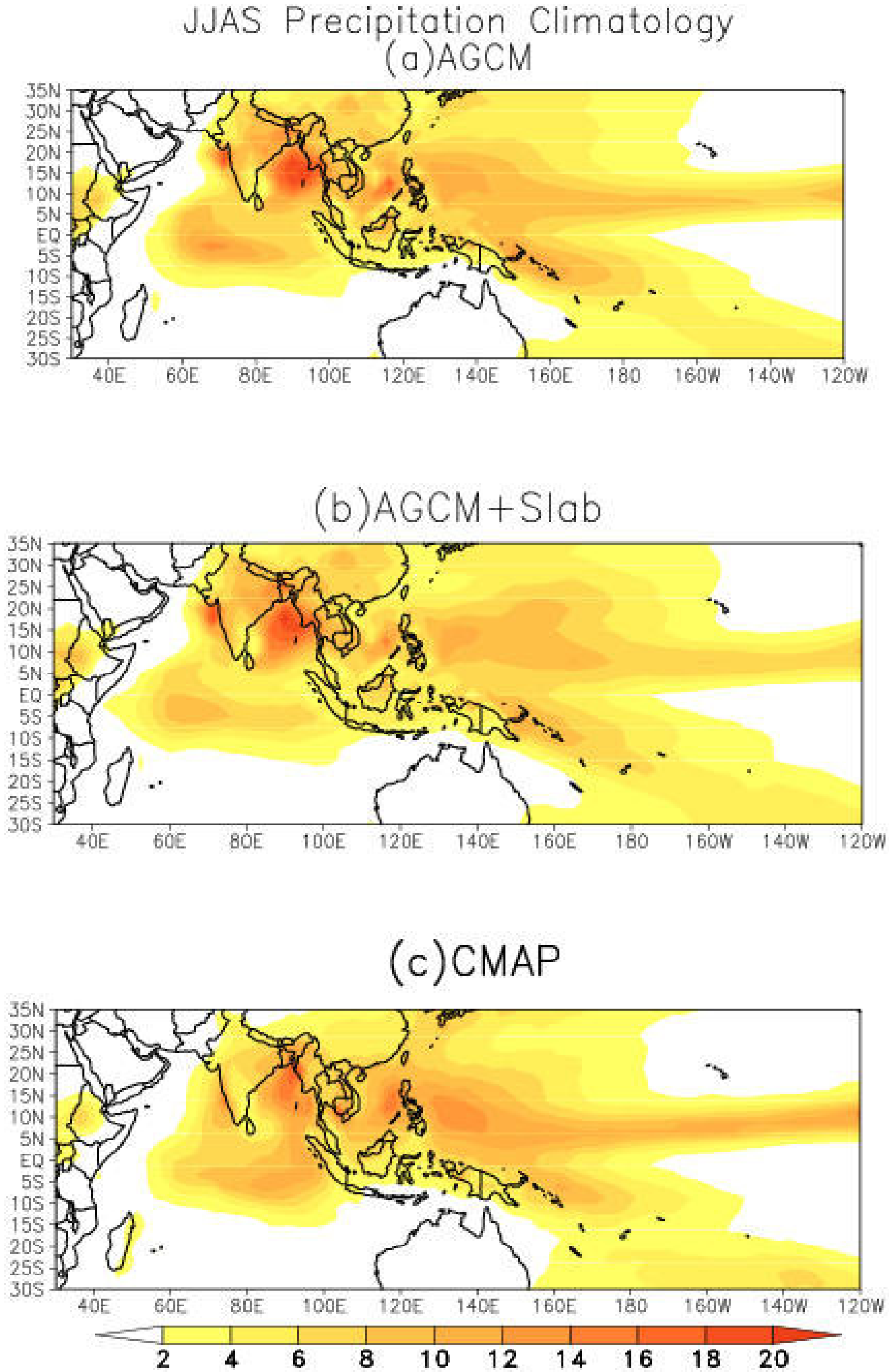

Fig. 5: Precipitation summer monsoon climatology. (a) PUM 'AGCM', (b) PUM 'AGCM coupled to slab Ocean' and (c) observed (CMAP) .

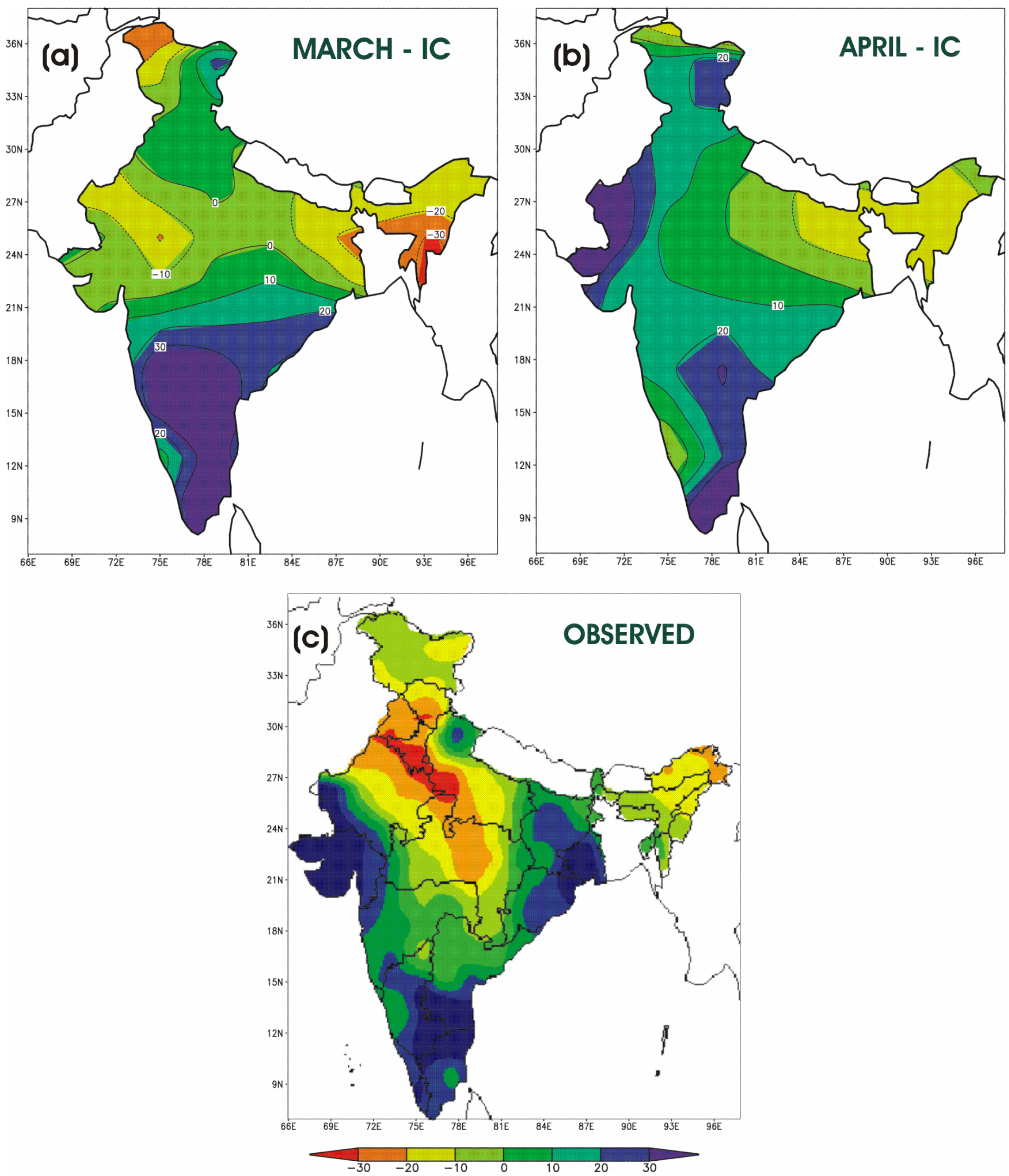

Fig. 6: Ensemble mean % anomaly of precipitation obtained with AGCM coupled with slab Ocean model experiments for ISM 2007. (a) 26-31st March 2007 initial conditions, (b) 26-30th April 2007 initial conditions and (c) Observed anomalies (IITM).

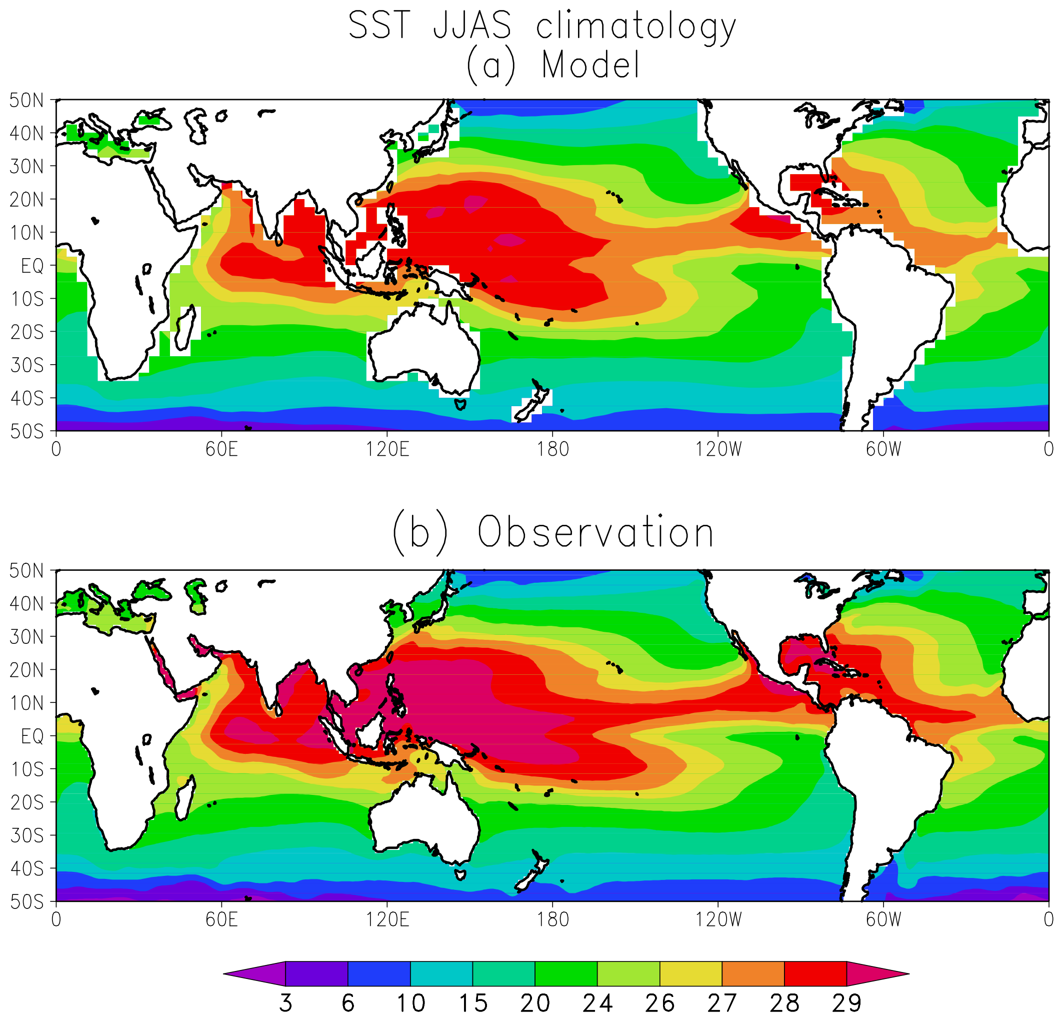

Figure 7: SST JJAS climatology (a) PUM AGCM coupled with slab ocean model based on long run for 20-years (1984-2003) (b) observed (OISST)

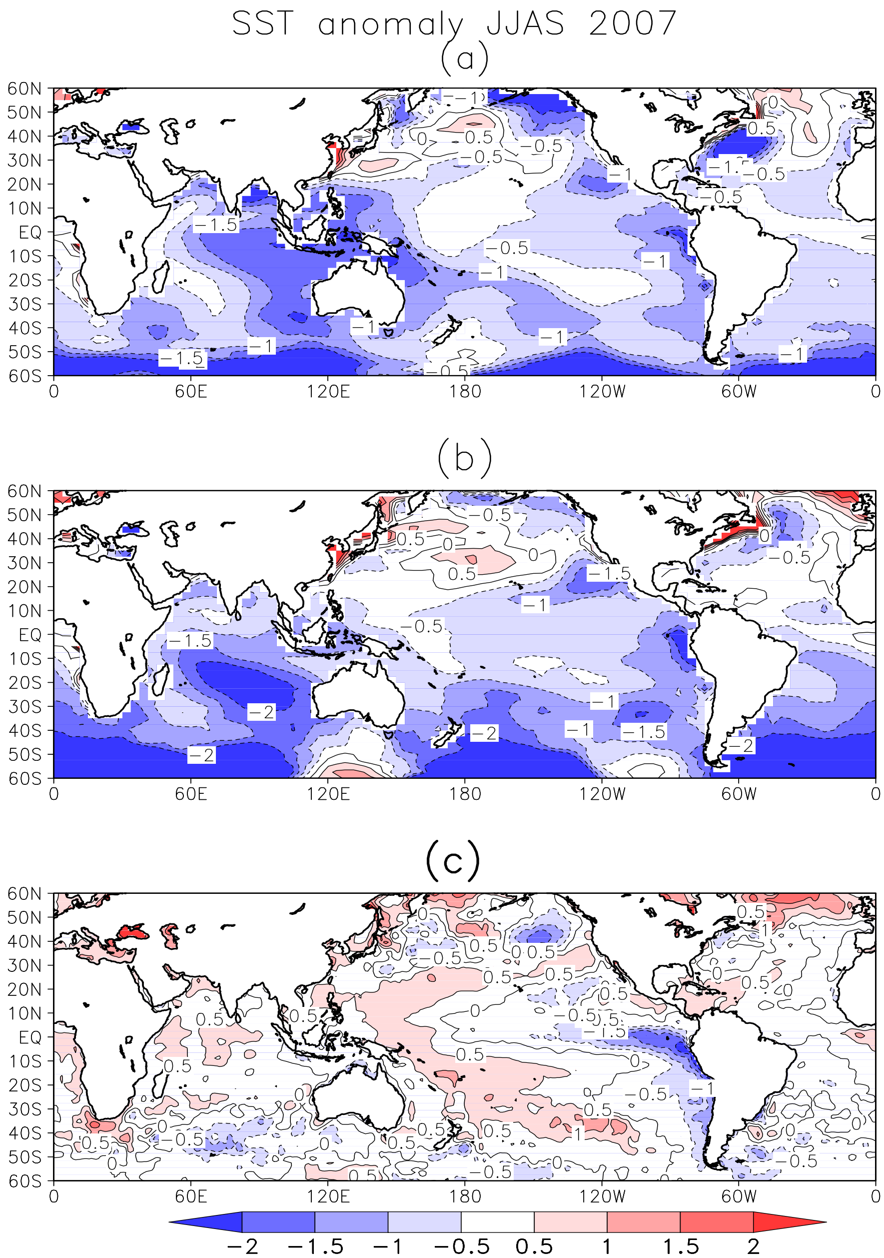

Figure 8: SST anomaly for JJAS 2007. (a) PUM AGCM coupled with slab ocean model experiment with 26-31st March 2007 initial states (b) Same as in figure 8a except 25-30th April 2007 initial states (c) Observed (OISST).

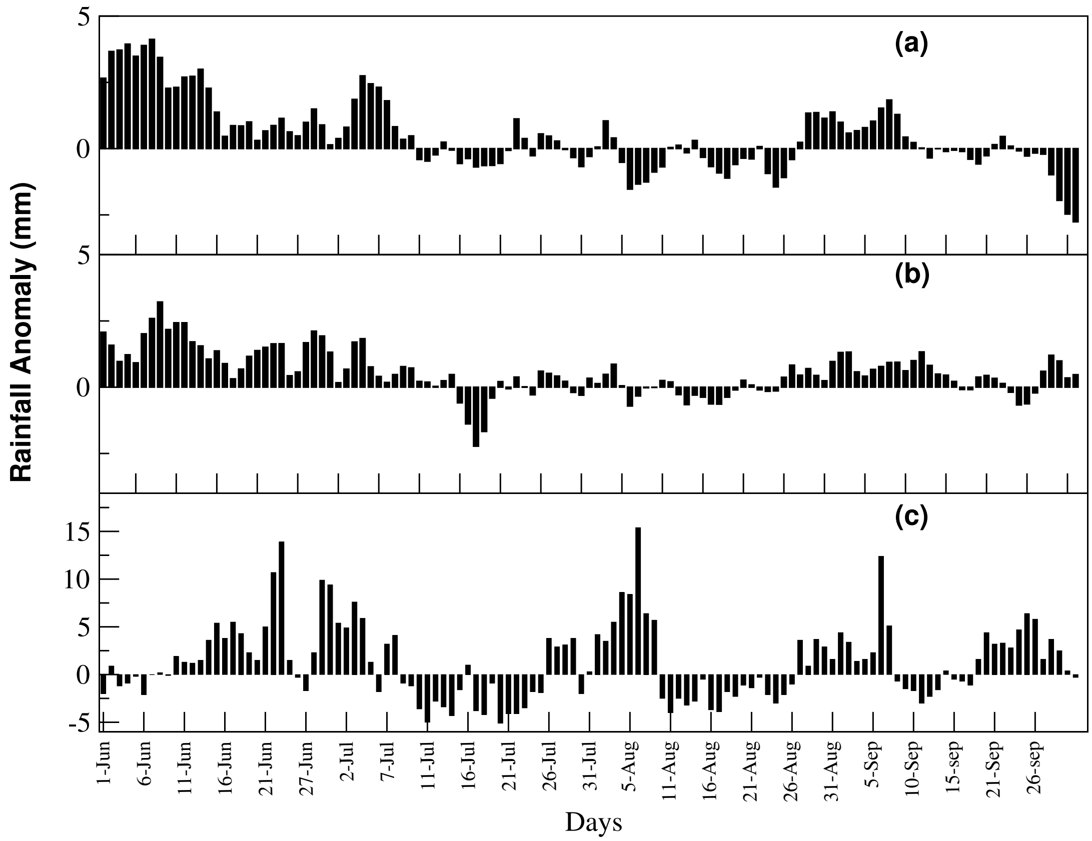

Fig. 9: Daily precipitation anomalies over Indian land region during summer monsoon 2007 from six member ensemble mean. (a) 26-31st March2007 initial conditions (b) 26-31st April2007 initial conditions (c) Observation (IMD)