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Inter-annual variability of Indian monsoon rainfall in the JMA's seasonal ensemble prediction system in relation to ENSO and IOD

KAILAS SONAWANE, D. R. PATTANAIK* and D. S. PAI**

Savitribai Phule Pune University, Pune – 411 007, India

**India Meteorological Department, Delhi – 110 003, India*

***India Meteorological Department, Pune – 411 005, India*

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e mail : ksonawane.1985@gmail.com

सार - जापान की मौसम विज्ञान एजेंसी (JMA) मौसमी एनसेम्बल प्रिडिक्शन सिस्टम द्वारा जून से सितंबर (JJAS) के दौरान भारतीय ग्रीष्मकालीन मानसून वर्षा के मौसमी पूर्वानुमान कौशल का विश्लेषण किया जाता है। इस अध्ययन में मार्च, अप्रैल और मई के वर्षा के आधार पर जून, जुलाई, अगस्त, सितम्बर (JJAS) की वर्षा के लिए एक मान्य hindcast आउटपुट 32 साल (1979-2010) की अवधि के प्रत्येक 5 असेम्बल का उपयोग किया गया है। अल नीनो के महत्वपूर्ण पूर्वानुमान कौशल के साथ, समूचे भारत में ग्रीष्मकालीन मॉनसून वर्षा (एआईएसएमआर) का कुशल पूर्वानुमान अप्रैल के एनसेम्बल (99% के स्तर पर सही) में पाया गया है, इसके बाद मार्च और मई में भी सही रहा है। JMA मॉडल वर्षा में कमी वाले वर्षों जैसे 1982, 1987 और 2009 तथा अधिक वर्षा वाले वर्ष 1988 के दौरान AISMR पूर्वानुमान को यथोचित रूप से अच्छी तरह से समझ सका है। हालाँकि, 1983 के मानसून के मौसम में इस मॉडल को अच्छे से समझा नहीं जा सका। इसी तरह, 1997 में मामूली सकारात्मक एआईएसएमआर के प्रत्यंतर से जुड़े सबसे मजबूत एल नीनो वर्ष भी जेएमए मॉडल समझ से परे रहे। सामान्य वर्षा वाले वर्ष (1997), अतिरिक्त वर्षा वाले वर्ष (1983) और वर्षा में कमी वाले वर्ष (2002) के दौरान मानसूनी वर्षा के अनुकरण में जेएमए मॉडल का प्रदर्शन बेहतर समझा गया जब अल नीनो, हिंद महासागर डिपोल (आईओडी) और भूमध्यरेखीय हिंद महासागर का परिवर्तनशीलता (EQUINOO) मॉडल पर एक साथ विचार किया जाता है।

ABSTRACT. The seasonal forecast skill of the Indian summer monsoon rainfall during June to September (JJAS) by the Japan Meteorological agency (JMA) Seasonal Ensemble Prediction System is analysed. The hindcast output valid for JJAS rainfall based on March, April and May initial conditions for a period of 32 years (1979-2010) with 5 ensembles each have been used in this study. In conjunction with significant forecast skill of El Nino the skilful forecast of All India Summer Monsoon Rainfall (AISMR) is found in April ensembles (Significant at 99% level) followed by that of March and May ensembles. The JMA model could capture the AISMR forecast reasonably well during major deficient years like 1982, 1987 and 2009 and the excess year of 1988. However, the excess monsoon season of 1983 was not captured in the model. Similarly, the strongest El Nino year of 1997 associated with slight positive AISMR departure was also not captured in the JMA model. The performance of JMA model in simulating the monsoon rainfall during normal year (1997), excess year (1983) and deficient year (2002) was better understood when the variability of El Nino, Indian Ocean Dipole (IOD) and Equatorial Indian Ocean Oscillation (EQUINOO) in the model are considered simultaneously.

Key words – Indian monsoon, Ensemble prediction system, Seasonal forecast, Coupled climate models, El Nino, IOD, EQUINOO.

1. Introduction

Indian summer monsoon (ISM) is an important component of the tropical climate system with regular seasonality and abundance of rainfall over the vast landmass of the country. In India, the droughts and floods are the two extremes of the year-to-year variation of the mean seasonal rainfall, which has devastating effect on people of this region and hence on the agricultural output and economy of this region. Due to this in India, the success or failure of the crops and water scarcity in any year is always viewed with the greatest concern. About 80% of the annual rainfall over India is received during the southwest monsoon season (June to September). Regional rainfall has large year to year fluctuations. The observed variability spectrum of all India Summer

Monsoon Rainfall (AISMR) during June to September (JJAS) in last 115 years (1901-2015) ranges from a highest negative departure of about -25% in 1918 to about +23% in 1917 from its long period average (LPA) of ≈ 89 cm. Even a small fluctuation in the seasonal rainfall can have devastating impacts on agricultural sector. The variability in the onset, withdrawal and characteristics of rainfall during the Indian summer monsoon season has profound impacts on water resources, power generation, agriculture, economics and ecosystems in the country (Rajeevan *et al*., 2011). As shown by (Gadgil *et al*., 2005) the deficient monsoon rainfall during the recent years (2002, 2004) had an adverse impact on India's economy. The drought of 2009 was not predicted well by both statistical and dynamical models. The poor skill of the seasonal forecast models (both statistical and dynamical models) during this year stressed the need for accurate seasonal prediction of rainfall over India. The demand for prediction of seasonal monsoon rainfall is overwhelming.

The monsoon prediction in seasonal time scale is mainly done by using statistical and dynamical models. Sir H. F. Blanford, the founder Head of India Meteorological Department (IMD), made the first attempt for estimating the prospective rains by utilizing the indications provided by the preceding winter and spring snowfall over the Himalayas (Blanford, 1884). Later Sir Gilbert Walker (1923, 1924) introduced the objective models based on a regression approach in 1920s by. Since then, India Meteorological Department's operational long-range forecasting system has undergone many changes in its approach from time to time. The recent India Meteorological Department's operational forecasts have been mainly based on statistical methods (Rajeevan, 2001; Rajeevan *et al*., 2004; Rajeevan and Pai, 2007). For the prediction of AISMR many other statistical models have also been developed (Shukla and Mooley, 1987; Gowariker *et al*., 1991; Sahai *et al*., 2003a,b; Rajeevan *et al*., 2004; Pattanaik *et al*., 2005). As indicated (Rajeevan, 2001; Gadgil *et al*., 2005) the known problems and limitations with the statistical models are the variation in relationship between the predictors and predictand. Further, the statistical forecasting method employed by IMD has met with varying degree of success but with no significant improvements in the forecast skill over a long period particularly, in forecasting an extreme rainfall season.

On the other hand, the dynamical prediction models have evolved over the years and it has reached to a stage where coupled General Circulation Models (CGCMs) are now employed for routine seasonal climate prediction by some operational forecasting centers. Starting from the Atmospheric Model Inter-comparison Project (National Center for Environmental Prediction (NCEP), Climate Forecast System Version1 (CFSv1) (Saha *et al.*, 2006) and Climate Forecast System Version2 (CFSv2), Japan Meteorological Agency (JMA), Centre for Ocean-Land-Atmosphere (COLA), Global Ocean Data Assimilation System (GOADS), Predictive Ocean Atmosphere Model for Australia (POAMA) & Atmospheric Model Inter-comparison Project (AMIP) I and II; Lawrence *et al.*, 1999) many other projects were considered by different groups for study of prediction of monsoon using dynamical models. Bracco *et al.* (2007) and Wang *et al.* (2005) demonstrated the problems in simulating the monsoon-ENSO teleconnection with AGCMs alone and highlighted the importance of air-sea coupling. Wang *et al.* (2005) showed that AGCMS when forced by observed sea surface temperature are unable to simulate properly Asian-Pacific summer monsoon rainfall. Recent study (Sonawane *et al*., 2015) has evaluated the performance of Indian monsoon forecast during JJAS based on the hindcasts of March, April and May initial conditions from the Japan Meteorological Agency's seasonal ensemble prediction system. As shown in their study, the hindcast climatology during JJAS simulates the mean monsoon circulation at lower and upper tropospheres reasonably well with March, April and May ensembles with more realistic simulation of Webster and Yang's (1992) broad scale monsoon circulation index. Although the variability of Indian monsoon rainfall is driven by many atmospheric and oceanic forcing such as, SST over different oceanic regions, snow cover, land-sea contract etc, in the present study the monsoon-ENSO teleconnections as simulated in the JMA EPS model is investigated during the period from 1979 to 2010 with March, April and May initial conditions to understand the simulated interannual variability. Further, in order to understand the simulated interannual variability in the model JMA EPS the role of Indian Ocean SST as another driving force for the Indian monsoon variability is also examined during the same period.

2. Data and methodology

2.1. *Observed analysis used for verification*

The reanalysed data of wind at lower and upper troposphere from the NCEP reanalysis during the 32-year (1979 to 2010) of hindcast (Kalnay *et al*., 1996) have been used for the verification of monsoon circulation during JJAS in the JMA model with different lead time. For the verification of simulation of Sea Surface Temperature (SST) over the Nino 3.4 region by the JMA model the most recent version of the Extended Reconstructed Sea Surface Temperature (ERSST.v3) analysis has been used (Smith *et al*., 2008). The SST anomalies are computed with respect to the SST climatology of 1971-2000 (Xue *et al*., 2003).

For the quantitative verification of AISMR the observed rainfall departure based on the surface stations over the Indian land mass obtained from IMD is used in the present analysis. Based on the rainfall observations over the Indian land stations available from IMD, the JJAS mean rainfall over India landmass is found to be 881 mm with a Standard Deviation (SD) of about 88 mm (10%). Based on ± 1 standardized anomalies of AISMR, the year-to-year variation of rainfall during 1979 to 2010 indicates many extreme years *viz.*, 1979, 1982, 1986, 1987, 2002, 2004, 2009 are considered to be deficient years and 1983, 1988 & 1994 are considered to be the excess years.

The global numerical models simulate rainfall over land as well as over water body (over the whole domain of interest). Due to this the skills of the model need to be verified over the whole monsoon region including the oceanic region. Thus, the verification of rainfall forecast during JJAS is performed not only over the Indian land region but also over the extended Indian Monsoon region covering the Indian landmass and adjoining oceanic regions. Hence for the verification of rainfall forecast over the bigger monsoon domain covering both Indian land mass and surrounding Oceanic region known as the Indian Monsoon Region (IMR) bounded by (50° E-110° E and 10° S-35° N), the gridded rainfall from the Global Precipitation Climatology Project (GPCP) have been used, which is based on rain gauge and merges satellite source data having resolution of 2.5° × 2.5° (Huffman *et al*., 2001).

2.2. *Details of the JMA model and its hindcast configuration*

The seasonal ensemble prediction system (EPS) of Japan Meteorological Agency (JMA) used for the long-range forecasting of monsoon is the coupled ocean-atmosphere general circulation model (CGCM), consisting of the AGCM and the ocean general circulation model (OGCM) from the Meteorological Research Institute Community Ocean Model (MRI.COM). The equivalent horizontal resolution of AGCM considered here is nearly a 180 km (T95L40) Gaussian grids and 40 sigma layers in the vertical. The horizontal domain for the ocean model is quasi-global extending from 75° S to 75° N. The zonal resolution is 1° and the meridional resolution is 0.3° to 1° between 75° S and 75° N, having vertical 50 layers. The atmospheric and oceanic initial conditions are obtained from the JMA Climate Data Assimilation System (JCDAS). The OGCM is the MRI Community Ocean Model (MRI.COM) described in Ishikawa *et al*. (2005). Initial perturbations based on the Breeding of Growing Modes (BGM) method are estimated for both the atmosphere and the ocean. The analysis scheme is a multivariate ocean three-dimensional variational estimation (MOVE) type with vertical coupled temperature-salinity empirical orthogonal function (EOF) modes (Usui *et al*., 2006). The Land surface climatological conditions are used as the initial conditions for the CGCM. In addition, a land surface model coupled to the AGCM is used for the prediction of land surface conditions. For the simulation of the inter-annual variability of Indian summer monsoon rainfall the grid value product (GVP) of JMA's EPS model forecast for 32 years (1979-2010) with initial conditions of March (lead-3), April (lead-2) and May (lead-1) with 5 ensemble members each are considered.

3. Results and discussion

3.1. *Simulation of Inter-annual variability of Nino3.4 SST*

The tele-connection between Indian monsoon rainfall and SST anomalies over equatorial and central Pacific has been documented by many earlier research studies (Rasmusson and Carpenter, 1983; Pant and Parthasarathy, 1981, etc.). As pointed out by them there is a close correspondence between deficit monsoon rainfall with El Nino and excess monsoon rainfall and La Nina. The classical relation between El Nino-Southern Oscillation (ENSO) and AISMR indicates that in the majority of years during the warm (cold) ENSO events the AISMR tends to be below (above) normal. Considering the ENSO as the main driving force of inter-annual variability of AISMR the better forecast skill of El Nino in a coupled model can enhance the forecast skill of AISMR. To capitalize on the predictive skill inherent in the ENSO, it is necessary to quantify the predictive skill of El Nino/La Nina in the JMA EPS. For the ENSO prediction we focussed on the SST prediction over the Nino3.4 (5° S-5° N; 170° W-120° W) regions of the tropical Pacific, which cover both eastern and central Pacific. Fig. 1 compares the observed Nino3.4 SST anomaly index from ERSST with the corresponding forecasts SST anomaly valid for June to September in the JMA model for the period from 1979-2010 with initial conditions of March, April and May. As seen from Fig. 1 the El Nino/La Nina prediction shows very useful skills with the major El Nino events like 1982, 1987, 1991, 1994, 1997, 2002, 2004 and 2009 are captured well in the JMA forecasts. Similarly the major La Nina years like 1988, 1998 and 1999 are also well captured in the JMA EPS (Fig. 1). The anomaly correlation of Nino3.4 SST prediction is also highly significant (above 99.9% level) with March, April and May ensembles with best skill of Nino3.4 SST prediction is found to be with May ensembles of JMA compared to the other two ensembles with March and April initial ensembles (Fig. 1).

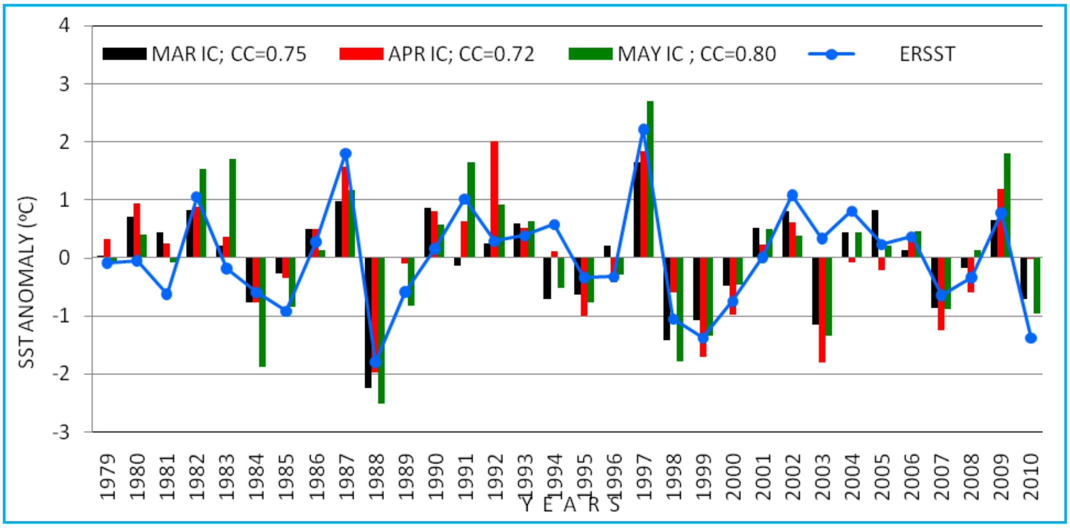


Fig. 1. Year-to-year variation of observed (ERSST) and JMA forecast SST anomalies with March to May initial conditions for the Nino3.4 (5° S-5° N, 170° W-120° W) regions along with the correlation co-efficient

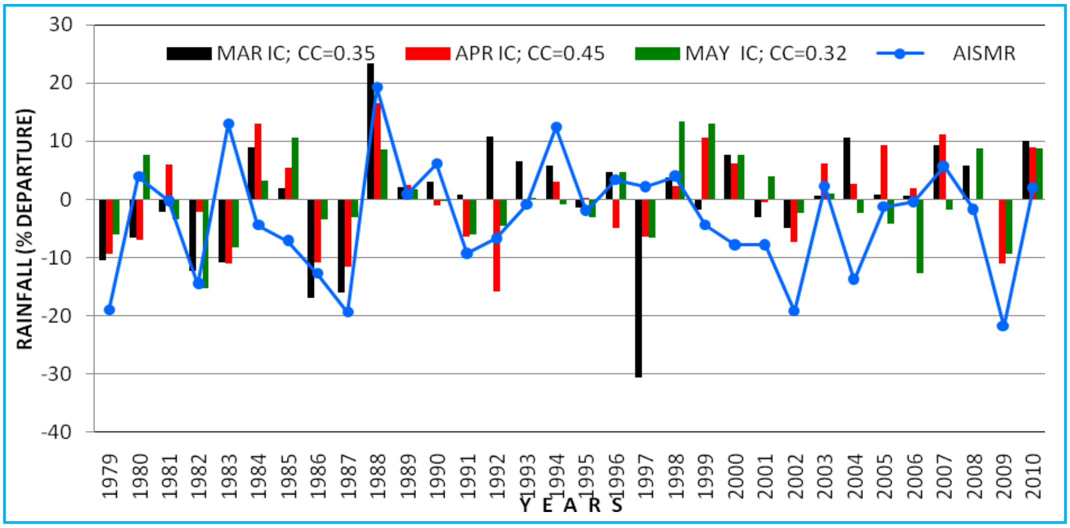


Fig. 2. Year-to-year variation of observed and JMA seasonal EPS forecast rainfall departure with March to May initial conditions for the All India Summer Monsoon Rainfall regions along with the correlation coefficient

3.2. *Inter-annual variability of monsoon rainfall*

Similar to real observation the GCM has a "mean" behaviour or climatology in large spatial and temporal scale. As model integration proceeds, there is a tendency for results to increasingly resemble the model climatology, which introduces a systematic bias into the forecasts. Due to this the forecasts are expressed in terms of deviations from the GCM's own climatology - A process referred to as calibration to remove the bias. In the present case, the deviation of the model from its own climatology is compared with the deviation in the observed variable from its climatology. In order to investigate the forecast skill of AISMR for individual years, the rainfall departure over the Indian land mass during June to September (known as AISMR) obtained from IMD is plotted against the hindcast rainfall departure over Indian land grid points during JJAS with all the three sets of initial conditions (Fig. 2). The excess and deficient year is identified based on the departure of ± 1 standardized anomalies of AISMR, where the Standard Deviation (SD) in the present case is about 10% of mean rainfall. Based on this criteria, the extreme years *viz*., 1979, 1982, 1986, 1987, 2002, 2004, 2009 are considered to be deficient years and the year's *viz*., 1983, 1988 and 1994 are considered to be the excess years. As seen from Fig. 2, the contrasting monsoon of 1987 and 1988 are very well captured in the JMA EPS model forecast with all the

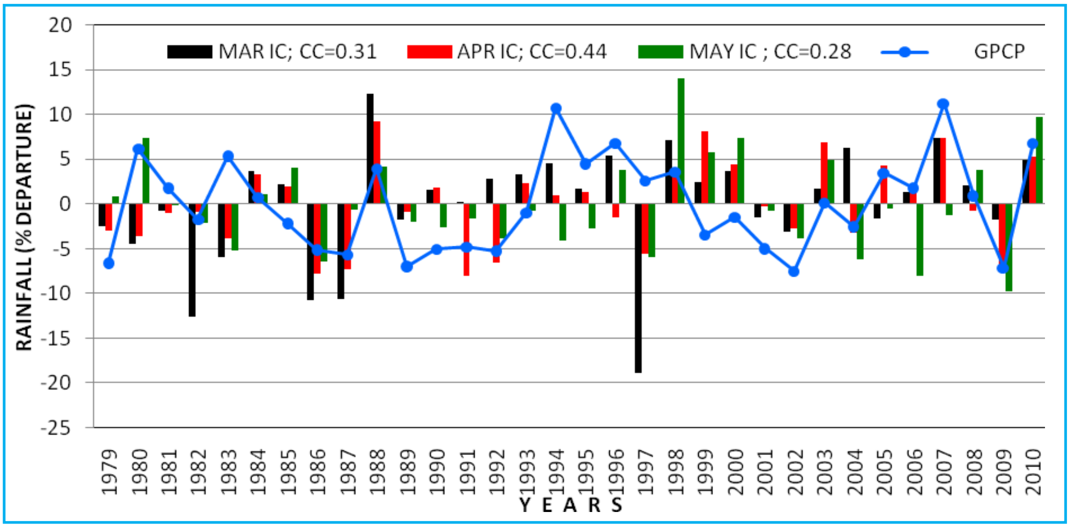


Fig. 3. Year-to-year variation of observed and JMA seasonal EPS forecast rainfall departure with March to May initial conditions for the IMR (50° E-110° E, 10° S-35° N) regions along with the correlation coefficient

three ensembles of March, April and May. However, the JMA EPS model could not capture the observed rainfall departure during the La Nina year of 1983, although it captured the El Nino year of 1982 very well. In addition, the other deficient years like 1979, 1986, 2002 and 2009 are also reasonably well captured in the JMA EPS model. However, as shown by many studies the strongest El Nino year of 1997 associated with slight positive observed rainfall departure over India was not captured in the JMA model (Fig. 2), which was also not captured by many other coupled models like in the NCEP CFS (Pattanaik and Kumar, 2010) and UKMO GloSea model (Pattanaik *et al.*, 2011). Overall, the inter-annual variability of AISMR is simulated well by the JMA EPS model as indicated by significant CC between observed AISMR departure and JMA forecast rainfall departure with April ensemble is found to be the best (Significant at 95% level) compared to that of March (Significant at 95% level) and May (Significant at 90% level) ensemble. It is also mentioned here that with respect to AISMR forecast the highest CC is found with April initial condition compared to that with March and May initial condition in NCEP CFS coupled model (Pattanaik and Kumar, 2010)

The forecast skill of monsoon rainfall from JMA EPS model during JJAS over a bigger domain *viz*., the Indian monsoon region (IMR; 50° E-110° E and 10° S-35° N) covering adjacent ocean part and land part of India is also compared with the observed rainfall departure obtained from GPCP (Fig. 3). Over the IMR region the forecast rainfall departure and the observed rainfall departure almost matches the sign and magnitude during the contrasting years of 1987 & 1988 and 2009 & 2010 (Fig. 3). As seen from (Fig. 3) the CCs with March, April and May ensembles for the JJAS rainfall forecast over the IMR is found to be slightly lower than corresponding CCs for AISMR over the Indian land only region (Fig. 2). In case of IMR the CC is having similar pattern with April ensembles having the highest CC significant at 98% level followed by that of March ensemble significant at 90% level and the May ensemble not significant.

3.3. *Inter-annual variation of IOD and EQUINOO*

Like the association of Indian monsoon with El Nino the Indian Ocean Dipole (IOD) and associated atmospheric component of it, which is commonly known as the equatorial Indian Ocean oscillation (EQUINOO) make significant contribution to the interannual variation of Indian monsoon rainfall (Gadgil *et al*., 2007). The drought of monsoon 2002 showed that in addition to ENSO, the phase of the EQUINOO also plays an important role in the interannual variation of ISMR. As indicated the study (Saji *et al*., 1999) a positive Indian Ocean Dipole (IOD) year is defined by positive (negative) anomalies of SST over the equatorial west (east) equatorial Indian Ocean. The difference of SST anomaly over the western equatorial Indian Ocean (50°-70° E, 10° S-10° N; hereafter called as IOD West Index) and eastern equatorial Indian Ocean (90°-110° E,0°-10° S; hereafter called as IOD East Index) is defined as IOD index (Saji *et al*., 1999). The characteristics of the positive phase of the IOD are associated with suppression of convection over the eastern equatorial Indian Ocean and enhancement over the western part of equatorial Indian Ocean. As indicated by earlier study (Gadgil *et al*., 2007) enhanced convection over the western part of the equatorial Indian Ocean and reduced convection over the eastern part are associated with easterly (*i.e.*, from the east to the west) anomalies in the equatorial zonal wind; whereas the reverse case, *i.e.*, with enhanced (suppressed) convection over the eastern (western) part, is associated with westerly anomalies of the zonal wind at the equator. The oscillation between these two states is the Equatorial Indian Ocean Oscillation (EQUINOO). The index used for EQUINOO is EQWIN, which is based on the surface zonal wind over the central equatorial Indian Ocean. This index of EQUINOO is based on the zonal component of the surface wind averaged over the central equatorial Indian Ocean (CEIO; 60°-90° E, 2.5° S-2.5° N). This zonal wind index (henceforth EQWIN) is defined as the negative of the anomaly of the surface zonal wind over CEIO, normalized by its standard deviation. As shown by some earlier studies (Gadgil *et al*., 2004, 2007) the development of the positive IOD in 1997 and associated favourable equatorial Indian Ocean oscillation (EQUINOO) was primarily responsible for nullifying the adverse effects of El Nino and making the Indian monsoon near normal. They have also shown that the year with favourable EQUINOO (EQWIN is >0.2), there are no droughts and when it is unfavourable (EQWIN <–0.8) there are no excess monsoon seasons.

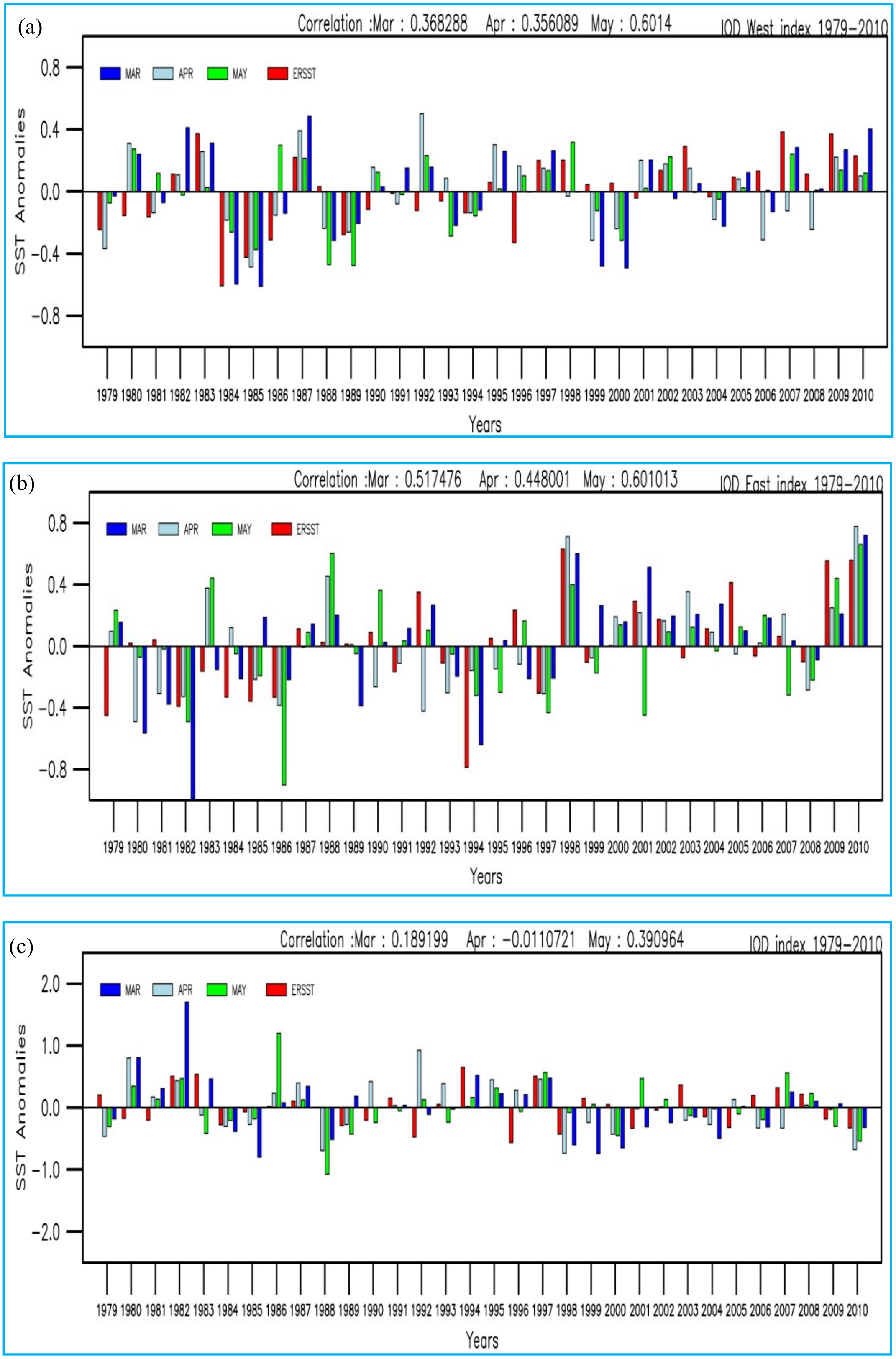
In order to see the performance of IOD forecast in the JMA EPS model the western equatorial SST anomalies (IOD West index), eastern equatorial SST anomalies (IOD East index) and the IOD index as simulated in the JMA model during the whole 32 years period is shown in Figs. 4(a-c) respectively along with the corresponding observed IOD indices. Similarly, the EQUINOO index as defined by Gadgil *et al*., 2004 is also shown in Fig. 5. It is also seen from Figs. 4(a&b) that the significant CCs for the monsoon IOD is also noticed with March and April initial conditions in the JMA model with east IOD index is comparatively better simulated compared to that of simulation of west IOD index in the JMA model with March and April initial condition. As shown by Wang *et al*. (2008) and Pattanaik and Kumar (2010) the simulation of eastern IOD index is more crucial compared to western IOD index with regard to the simulation of AISMR. The better simulation of both western IOD and eastern IOD index in JMA model is indication of better SST simulation in the Indian Ocean. As seen from Fig. 4(c) the JMA model simulated the IOD index very well during the monsoon season with significant CC with May initial condition compared to that of March and April initial conditions. Similarly with respect to the simulation of EQUINOO index it is better with CC significant at 95% level only with April initial condition (Fig. 5).

3.4. *Inter-annual variation of AISMR in relation to ENSO, IOD and EQUINOO*

As shown in Fig. 2 the skill of seasonal forecasts of AISMR in JMA model for the period 1982-2010 is positive but below the 95% significance level and it is because of some years where the observed departure and forecast departure of AISMR deviates. In this section we tried to investigate the reason of the poor performance during these years particularly in response to the SST variations over the Pacific (ENSO) and Indian Ocean. For this purpose three monsoon seasons (1997, 1983 and 2002) have been identified, where the JMA seasonal ensemble prediction system (EPS) model forecasts were significantly different from the observations. Among these three years 1997 was a normal monsoon year (AISMR departure was within ± 1 SD), 1983 was an excess year and 2002 was a deficient year. In order to see the spatial patterns of SST forecast in the JMA model for the year 1997 the SST anomalies forecast during the 1997 monsoon season (JJAS) based on March, Apr and May initial condition along with the observed SST anomalies for the same season are shown in Figs. 6(a-d). Similarly, the corresponding SST anomalies for the year 1983 and 2002 are also seen in Figs. 7(a-d) and Figs. 8(a-d) respectively.

3.4.1. *Model simulation for the normal monsoon of 1997*

As shown in Fig. 2(a) the JMA seasonal EPS model predicted a severe deficient monsoon in 1997 over India particularly with March initial condition, whereas the forecast for 1997 with April and May initial conditions indicated negative departure of rainfall. However, the observed rainfall departure of AISMR during 1997 was about +2%. Thus, the simulation was not properly captured in the model. In order to understand the factors responsible for the poor performance of the model we have to examine the SST forecasts in the model. As seen from Fig. 6(a) the year 1997 was associated with strong anomalous warming of SST over the central and eastern equatorial Pacific Ocean associated with strong El Nino and the warming was mostly dominated towards the eastern equatorial Pacific. The JMA Ensemble model predictions suggest extended positive SST anomalies exceeding 1.0 °C over the eastern and central Pacific extending upto the west off the date line. However, the observed SST anomalies show positive anomalies exceeding 1.0 °C confined towards the eastern Pacific extending westward upto around 170° W. As the 1997 monsoon simulation was not captured properly in the model it could be due to the fact that Indian monsoon is more responsive to positive SST anomalies over the central Pacific region compared to that of the east



Figs. 4(a-c). (a) SST anomalies for West IOD index during the period from 1979-2010 for JMA Model with March, April and May ICs compared with ESST, (b) Same as 'a' but for East IOD index and (c) Same as 'a' but for IOD index

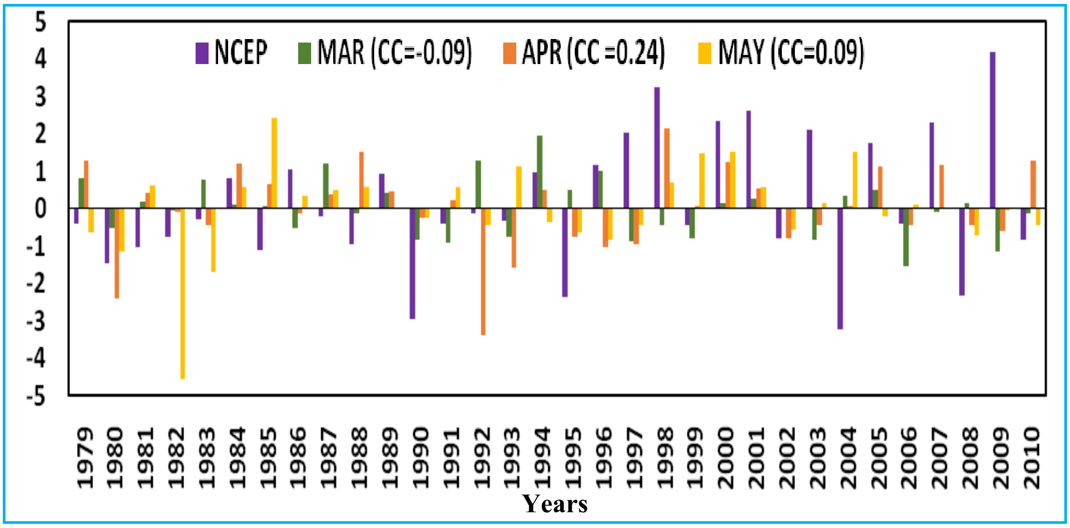


Fig. 5. The NCEP anomaly, EQWIN for all summer monsoon seasons for the period 1979-2010 along with JMA simulation with respect to March IC, April IC and May IC

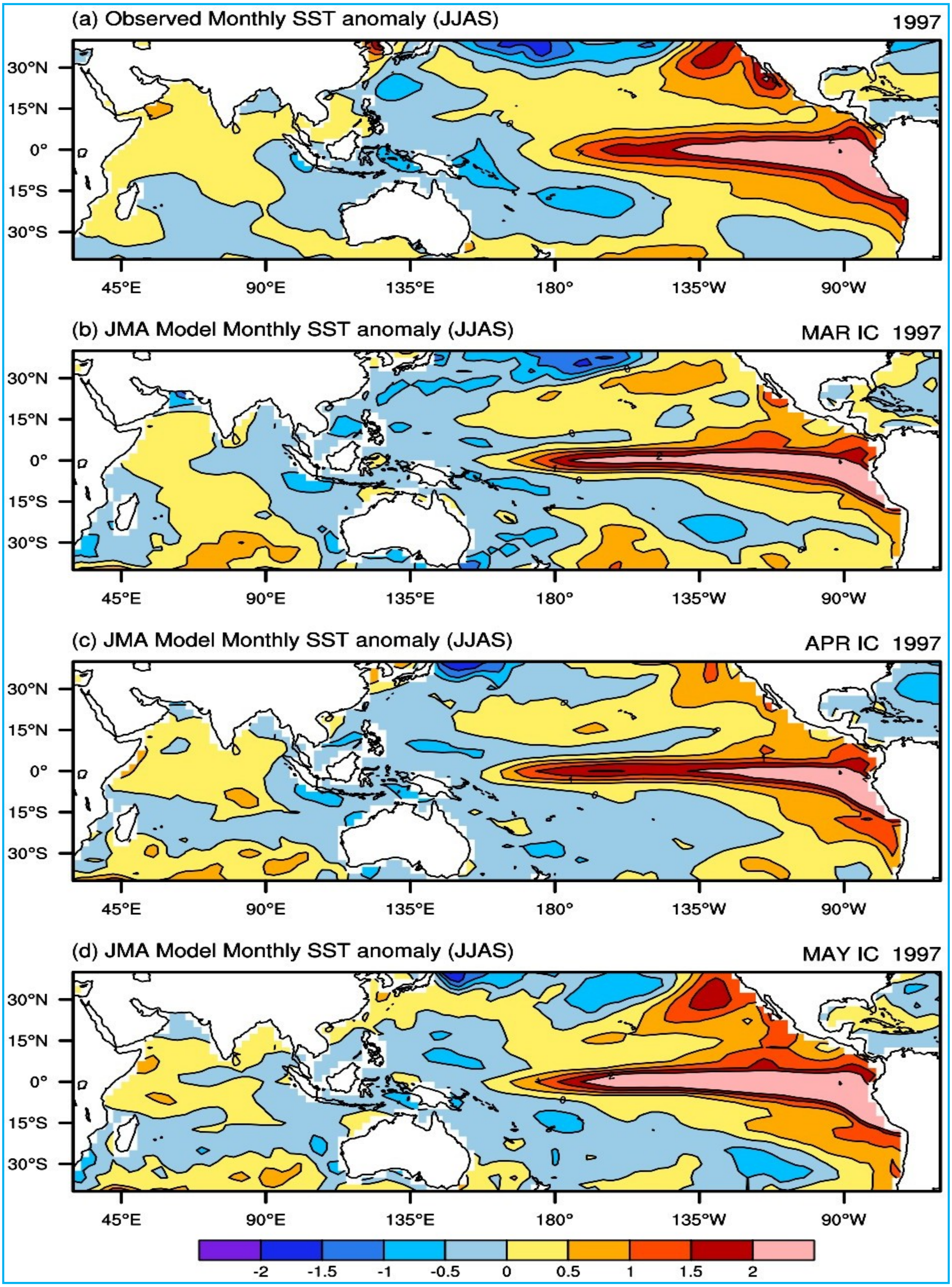
equatorial Indian Ocean (Keshavamurthy, 1983; Kumar *et al*., 2006; Rajeevan and Pai, 2007). Past records suggest that the central Pacific El Nino events influence the Indian monsoon to a greater extent than those in the east Pacific.

Over the Indian Ocean the SST patterns simulated reasonably well in the JMA model when compared with observation, however with slight variations during March, April and May initial conditions. As it is also seen from Fig. 4 the 1997 was associated with positive IOD, which countered the negative impact of El Nino and as a result the El Nino did not have negative impact on AISMR and the observed AISMR departure was slightly on the positive side of its long period average (Fig. 2). Further it is also seem that simulation of EQUINOO during JJAS was not captured correctly in JMA model during 1997 with March, April and May initial conditions as shown in Fig. 5.

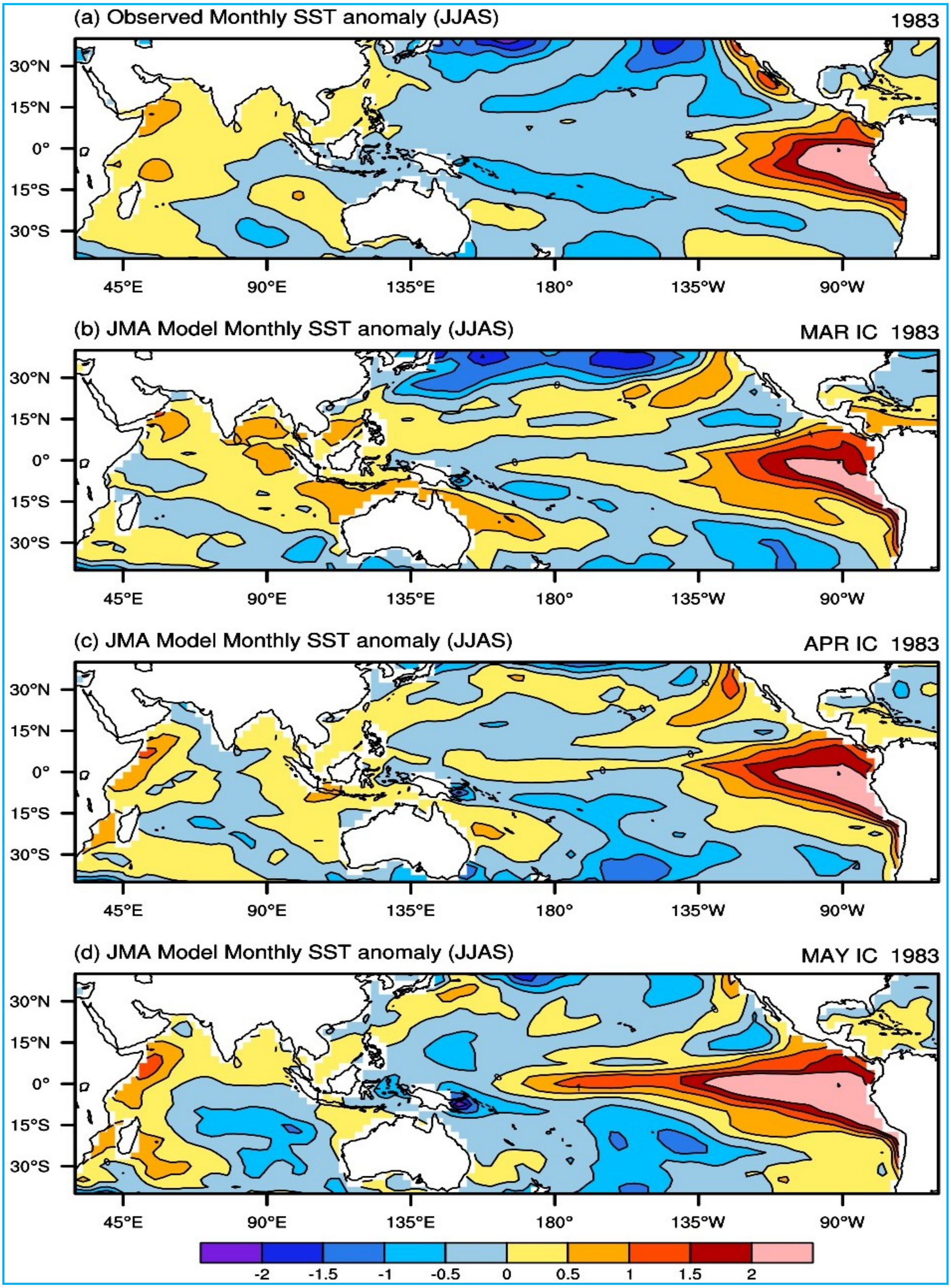
With respect to the forecast of Indian monsoon rainfall in JMA models in 1997, although it was relatively better captured with April and May initial conditions compared to that of March initial condition, however, all the three simulations (March, April and May ensembles) indicated AISMR departure on the negative side. Thus, the JMA EPS model could not captured the departure of monsoon rainfall during 1997 particularly because of EQUINOO being not correctly captured in model although the IOD simulation was relatively better and also the ENSO was mainly over the central Pacific in the JMA simulation against the pattern of ENSO over the eastern Pacific in the observation.

3.4.2. *Model simulation for the excess monsoon of 1983*

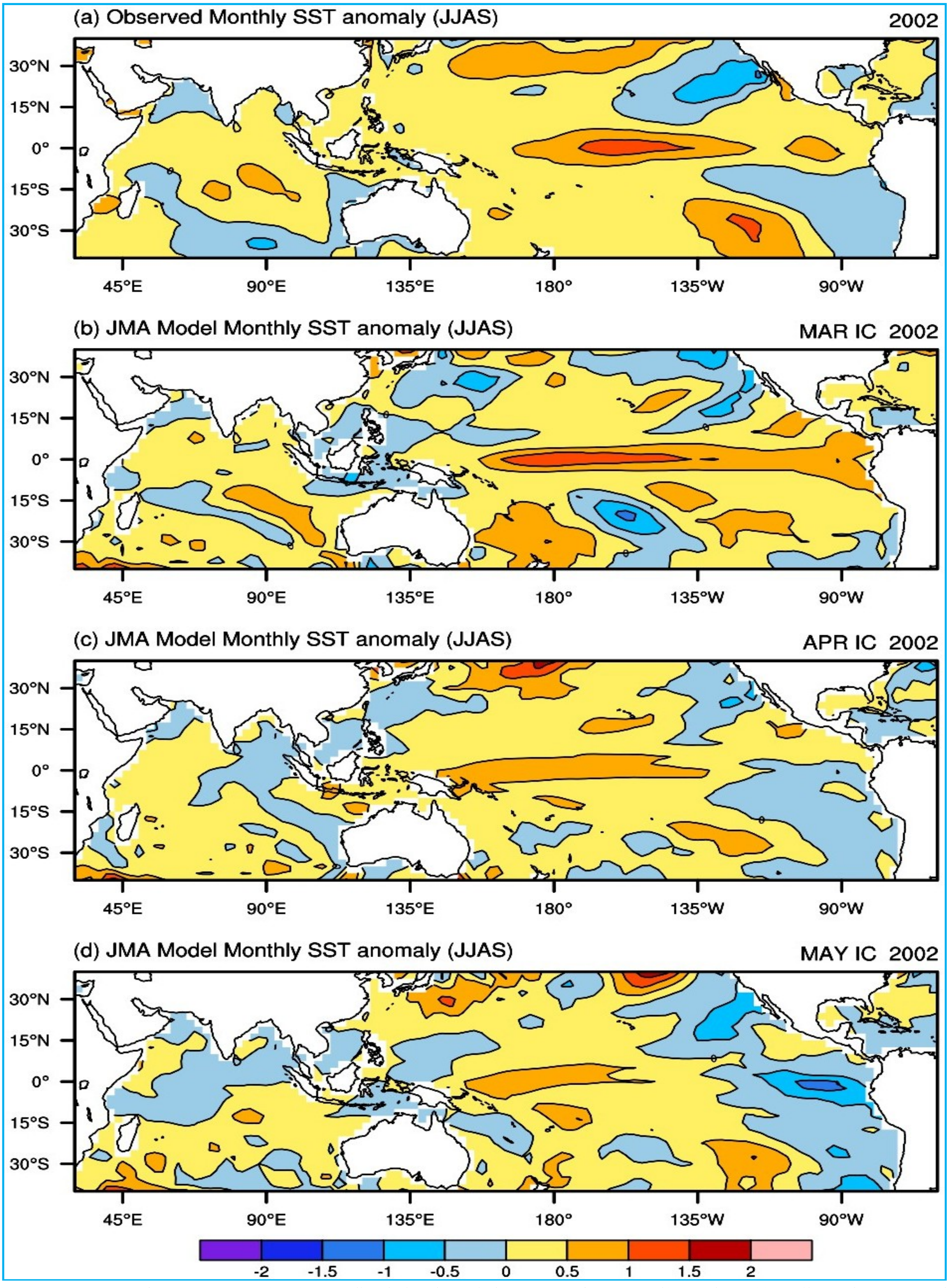
Another notable feature seen from Fig. 2 was the failure of JMA EPS coupled models in predicting the excess monsoon year of 1983. The AISMR departure in 1983 was 13% above the long period average due to above normal rainfall received during the second half of the season (32% above the long period average during August and September). After the El Nino event of 1982, positive SST anomalies over the central and eastern Pacific were in the cooling phase during the 1983 monsoon season from June to September with negative SST anomalies over the west-central Pacific [Fig. 7(a)]. Positive SST anomalies were confined only over the east Pacific Ocean. As observed in the previous studies (Shukla and Paolino, 1983), Indian monsoon is predisposed to excess conditions during the cooling phase of ENSO. The JMA EPS model predicted SST anomalies during the JJAS period of 1983 are shown in [Figs. 7(b-d)] and the corresponding observed SST anomalies are shown in Fig. 7(a). Thus, the observed SST anomalies during JJAS 1983 shows moderate La Nina and the corresponding JMA EPS model forecast with March to May initial conditions could not capture the central Pacific cooling very well. The JMA EPS coupled model predicted positive SST anomalies over the eastern Pacific and in terms of its spatial extension the positive SST anomalies were extended more to the west towards the central Pacific Ocean in the model compared to the negative SST anomalies over the central Pacific in the observed field. The May initial condition indicated the El Nino conditions to remain during JJAS 2003 with warming over the central Pacific. Thus, JMA EPS model could not capture the ENSO patterns reasonably well.



Figs. 6(a-d). Sea Surface Temperature (SST) anomalies during the period JJAS 1997 from JMA (b) March IC, (c) April IC, (d) May IC and (a) observed data



Figs. 7(a-d). Sea Surface Temperature (SST) anomalies during the period JJAS 1983 from JMA (b) March IC, (c) April IC, (d) May IC and (a) observed data



Figs. 8(a-d). Sea Surface Temperature (SST) anomalies during the period JJAS 2002 from JMA (b) March IC, (c) April IC, (d) May IC and (a) observed data

With respect to the simulation of IOD index in JMA model it is seen from Fig. 4(c) that IOD simulation with March initial condition was reasonably well, however, the April and May initial condition could not capture the Indian Ocean SST patterns reasonably well, which is also seen in Figs. 7(b-d). The JMA model simulation of EQUINOO index was also not captured reasonably well (Fig. 5). Thus, the simulation of AISMR during the moderate La Nina year of 1983 was not captured and it predicted a subdued monsoon in the JMA model, which can be attributed to the El Nino, IOD and even EQUINOO not simulated well in the model. Some of the earlier studies have also indicated the difficulties in simulating the excess AISMR during 1983 in different models (Pattanaik *et al*., 1999).

3.4.3. *Model simulation for the deficient monsoon of 2002*

There was a testing time for all long range forecasting model for the year 2002. The monsoon season of 2002 witnessed severe drought over India. In July 2002, the country experienced a severe drought due to a prolonged monsoon break. The rainfall deficiency in July 2002 was close to -50%, thus making the year, a severe drought year with a seasonal departure of -19%. Even though the JMA (EPS) model predicted a negative departure for the monsoon rainfall during 2002, the predicted negative departure was much lower compared to the actual negative departure (Fig. 2). In order to understand this we have to examine the simulation of SST over the Pacific and Indian Ocean basins. The coupled model predicted SST anomalies during the JJAS period of 2002 are shown in [Figs. 8(b-d)] and the corresponding observed SST anomalies are shown in Fig. 8(a). The year 2002 was an El Nino year with the warming (exceeding 1.0 °C) concentrated mostly over the central Pacific. North Indian Ocean was also warmer by more than 0.5 °C. As seen from Fig. 1 the El Nino simulation was also very well in the JMA model. With respect to the SST simulation over the Indian Ocean it is seen from Figs. 4(a-c) that the IOD was well captured in the JMA model along with the reasonably well simulation of negative phase of EQUINOO (Fig. 5). Thus, the JMA model could capture the subdued rainfall during 2002 as the El Nino, IOD and EQUINOO was reasonably well captured in the model, although the negative departure are underestimated in the model simulation.

4. Summary and conclusions

In this study, we have evaluated the performance of the JMA (EPS) seasonal prediction model for the seasonal forecasts of Indian summer monsoon variability and its association with the simulation of El Nino, Indian Ocean Dipole (IOD) and Equatorial Indian Ocean Oscillation (EQUINOO) in the model. The JMA model indicated highly significant forecast skill of El Nino during the southwest monsoon season from June to September. Consequently, the skilful forecast of all India summer monsoon rainfall (AISMR) during JJAS during the 32 years period with March, April and May ensembles indicated significant correlation with observed AISMR with April initial condition is found to be the best followed by that of March and May ensembles. The JMA model could capture the AISMR forecast reasonably well during the deficient years of 1982, 1987 and 2009 and the excess year of 1988. However, the excess year of 1983 was not captured in the model. Similarly the strongest El Nino year of 1997, which was associated with a slight positive rainfall departure of AISMR was also not captured in the JMA model correctly.

When the performance of JMA model in simulating the monsoon rainfall during normal year (1997), excess year (1983) and deficient year (2002) are examined in relation to variability of El Nino, Indian Ocean Dipole (IOD) and Equatorial Indian Ocean Oscillation (EQUINOO) in the model it is found that the model performance depends on simulation of not only El Nino but also the IOD and EQUINOO. The AISMR simulation during strongest El Nino year of 1997 was not correctly captured in the model as it could not capture the El Nino patterns and EQUINOO correctly although it could capture the IOD simulation correctly.

The simulation of AISMR during the moderate La Nina year of 1983 was not captured in the JMA EPS model and it predicted a subdued monsoon compared to observation, which can be attributed to no reasonable simulation of the El Nino, IOD and EQUINOO in the model. On the other hand the JMA EPS model could capture the subdued rainfall during the deficient monsoon of 2002 as the El Nino, IOD and EQUINOO were reasonably well captured in the model. It is further to be stated that, although the model performed reasonably well with April ICs, still there are many years particularly after 2000, where the model could not capture the sign correctly and hence its improvement is needed so that the same can be used for operational forecast.

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