



Seasonal prediction of ISMR and relationship with EL-NINO and IOD in ECMWF system 4 coupled model

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General Note



Article is recommended to print as color version in recycled paper. *Save Trees, Save Climate.*

ABSTRACT

This study evaluates various probable factors that govern the predictability of Indian summer monsoon rainfall (ISMR) and their teleconnections with ISMR. Furthermore, extensive analysis has been performed to evaluate factors leading to the predictability aspects of the ISMR using European Centre for Medium-Range Weather Forecasts (ECMWF) System 4 coupled model for the time domain 1982-2013. It is found that the ECMWF system 4 has well captured the latitudinal variation of rainfall along with sun movement and the spatial climatology of precipitation with respect to observation. The signal to Noise ratio shows that the predictability of the ISMR is better for the oceans as compared to land points of India especially over the central India where the value of signal is least. The prediction of teleconnections between Sea surface temperature anomaly and the ISMR is realistically

represented in the system 4. It is found that the system 4 is able to capture the teleconnections of El Nino Southern Oscillation (ENSO) with ISMR is realistically well as compared to Indian Ocean Dipole (IOD) for the time domain of 1982-2013. In case of 1997 El-Nino, the warming over the equatorial Pacific Ocean is well captured by system 4 but the prediction of rainfall over the land points of India is poor as compared to observation. The rainfall prediction of this year is poor in system 4 because it is unable to capture the IOD event of this year. A dichotomous forecast skill measure is also performed by calculating predictive skill measures like accuracy, bias, probability of detection (POD), false alarm ratio (FAR), probability of false detection (POFD), threat score (TS), equivalent threat score (ETS) and Heidke skill score (HSS) for model produced ISMR, Nino 3.4 and IOD from system 4. This dichotomous forecast skill shows that the model is better in prediction of ISMR and Nino 3.4 as compared to IOD.

Keywords: ISMR, System 4, ENSO, IOD

1. INTRODUCTION

The Indian summer monsoon rainfall directly influenced a population of one billion during June-July-August-September (JJAS) which provide the 80% of annual rainfall over the Indian subcontinent. The India Meteorological Department (IMD) engaged in giving seasonal forecasts of rainfall over India using different statistical prediction schemes and also found the significant correlation between the seasonal rainfall and various regional and global climate phenomena (Walker, 1924; Biswas Roy *et al.* 2015; Magreth Bushesha, 2015). Several previous studies show that the developing or decaying El Nino (La Nina) events have been significantly influence the rainfall over the South Asian Summer monsoon (Kumar *et al.* 1999; Kripalani and Kulkarni 1999; Xie *et al.* 2009; Chowdary *et al.* 2012). It is observed by many authors that the strength and sifting of Walker Circulation depends on the warming and cooling of tropical Pacific Ocean which Influence the rainfall of South East Asia (Ju and Slingo 1995; Soman and Slingo 1997). Tropical Indian Ocean also plays a significant role for ISMR along with the warming and Cooling of Pacific Ocean. Indian Ocean shows the east-west SST anomlies gradient which is known as Indian Ocean dipole (IOD) during the devloping phase of ENSO events (Saji *et al.* 1999; Webster *et al.* 1999). Several previous studies shows that IOD (30%) events develop in conjunction with ENSO events which play a significant role in the prediction of ISMR and the teleconnection between ISMR and ENSO (Ashok *et al.* 2001; Rishma *et al.* 2015).

In past studies, Atmospheric general circulation models (AGCMs) have been used to simulate and predict the South Asian summer monsoon (Kang and Shukla 2006) but there performance over monsoon region is not appropriate (Kang *et al.* 2002, 2004; Wang *et al.* 2004; Alok Kumar Mishra *et al.* 2015; Atul Srivastava *et al.* 2015). Coupled models are suggested to be more suitable for better simulation of the ISMR and its teleconnection with ENSO and IOD because of the crucial role played by the ocean-atmosphere interaction (Wang *et al.* 2005). The regional and global climate variations in a coupled ocean-atmosphere model are more meaningful due to which the teleconnections are captured well.

In present study we analyzed the prediction skill of the ECMWF System 4 coupled model for the seasonal prediction of ISMR and its teleconnections with El-Nino and IOD. We have also used the different categorical forecast skill measures for forecast verification of discrete prediction. In such verifications we begin with contingency that shows the frequency "yes" and "no" for forecast and real event. The contingency table is prepared using the area average is calculated for observation and as well as model produced variables and normalized by dividing its respective standard deviation (SD). Obviously the SD of normalized data set will be 1 so condition for "Yes" is define as if the forecast is greater(less) than 1.0(-1.0) and the condition for "no" is defined as if forecast is less (greater) than 1.0(-1.0). In this way we get four combinations of forecast (yes or no) and event given below:

(h) Hit: forecast to occur and did occur, (m) Miss: forecast not to occur but did occur, (f) false alarm: forecast to occur but did not occur, (n) correct negative: Event forecast not to occur and did occur. In this way a contingency table is generated for model forecast. Several scalar measures are in common use which are defined below:

(i) Accuracy = $\frac{n+n}{total}$ where total = $(h + m + n + f)$.

(ii) Bias = $\frac{n+f}{h+m}$

(iii) Probability of detection (POD) = $\frac{h}{h+m}$.

(iv) False Alarm ratio (FAR) = $\frac{f}{h+f}$.

(v) Probability of false detection or false alarm rate (POFD) = $\frac{f}{n+f}$.

(vi) Threat score or critical success index (TS) = $\frac{h}{(h+m+f)}$.

(vii) Equitable Threat Score or Gilbert skill score (ETS) = $\frac{h-h_{random}}{h+m+f-h_{random}}$ where $h_{random} = \frac{(h+m)(h+f)}{total}$.

(viii) Heidke skill score (HSS) = $\frac{(h+n)-(correct)_{random}}{total-(correct)_{random}}$ where $correct_{random} = \frac{1}{total} [(h+m)(h+f) + (n+m)(n+f)]$.

The model and data used in this paper are described in section 2. The prediction of ISMR, relationship between Rainfall and SST, teleconnection of ISMR with ENSO and IOD, simulation of 1997 El-Nino, Categorical forecast Skill Measure of System will be presented in section 3. Conclusions are described in section 4.

2. MODEL AND DATA SET

ECMWF System 4 is a coupled general circulation model that provides operational seasonal predictions since November 2011. The forecast system includes a coupled atmosphere–ocean model, a data assimilation scheme to create initial conditions for the ocean, and a strategy for ensemble generation. The atmospheric model used for System 4 is cycle 36r4 (Cy36r4) of the ECMWF Integrated Forecast System (IFS). The horizontal resolution of the atmospheric model is TL255, with a corresponding grid mesh resolution of 0.7°. There are 91 levels in the vertical, extending to ~0.01 hPa or a height of approximately 74 km. The ocean model used in System 4 is NEMO version v3.0, with some local modifications (dynamic memory, more flexible output, surface flux forcing, closure of fresh water budget). The resolution remains effectively 1°×1° in mid-latitudes, with equatorial refinement). There are 42 levels in the vertical 18 of which are in the upper 200m. A sophisticated ocean data assimilation system is used to prepare ocean initial conditions for the forecasts. The re-forecasts will have 15 ensemble members and initialized in the months of February, May, August and November and the length of each forecast is seven months. We have used ECMWF model output produced from the initialization in the month of May for 32 years (1982–2013) in the present work. Details for the ECMWF system 4 can be found in Molteni et al. (2011). There are two observation datasets is used in this study for verification (i) monthly mean SST from the National Oceanic and Atmospheric Administration Extended Reconstruction SST(ERSST, v3b)(Smith et al. 2008) and (ii) Monthly mean precipitation from Global precipitation climatology Project(v2.1), (Alder et al. 2003) datasets. All the data sets of model and observation used in present studies are at 2.5X2.5 resolutions and the domain of our study, 1982–2013.

3. RESULTS AND DISCUSSION

3.1. Prediction of ISMR

In figure 1(a,b), we have shown that the latitudinal variation of mean rainfall average over the longitude 70°E–90°E for each month. It is a well known fact that the Indian summer monsoon developed in the month of June over the Indian subcontinent and moves continuously northwards and reach at the northern limit of Indian subcontinent during July and August and rapidly withdraw in September. This northward movement of rainfall band (figure 1(a;b)) with time is the unique feature of ISMR and it is related to seasonal oscillation of ITCZ(Inter Tropical Convergence Zone) which is the response of seasonal migration of Sun from north-south-north. The spatial distribution of seasonal rainfall of Indian summer monsoon is well simulated by System 4(figure not shown). A large amount of variability is present in the spatial distribution of JJAS rainfall due to orographic and different atmospheric features. The JJAS mean climatology of rainfall over the Indian Monsoon region (50°E–110°E, 10°S–35°N) is well represented by system 4 as similar to GPCP observation. The model shows maximum rainfall over the east head of Bay of Bengal and Western Ghats along with the Arabian Sea and shows less rainfall over the maximum land points of India as similar to GPCP observation. Furthermore, we have analyzed the predictability of ISMR over Indian monsoon region (50°E–110°E, 10°S–35°N) using signal to noise ratio in System 4. In figure 2, we have observed that the prediction skill of System 4 is higher over the ocean as compared to land portion of India. The signal is dominant over the Himalayan region, Northeast India, Arabian Sea, Bay of Bengal, equatorial Indian ocean and 10°S of equatorial regions. Central India region has shown least signal as compared to other region of Indian summer monsoon which shown that the prediction skill of ISMR over the land point of India is poor in System 4. It is well known from previous studies that the coupled general circulation model has poor prediction skill for precipitation over the Indian land mass (Pattnaik et al. 2013).

Indian Summer Monsoon Rainfall (ISMR) index is used for the representation of Interannual variability of precipitation over the Indian summer monsoon region. We have calculated the ISMR index over the land points of India as well as over the Indian monsoon region (50°E–110°E, 10°S–35°N). This index is defined as the area averaged precipitation over Indian land mass and Indian monsoon region during JJAS (June–September) and it is widely accepted for accessing the performance of seasonal precipitation.

We have calculated the Interannual variability of Indian summer monsoon on seasonal time scale for ECMWF system 4. The area average precipitation index over the Indian land points in system 4 shows poor prediction skill ($cc=0.29$) for the precipitation. Signal to Noise ratio shows that the predictability over the ocean regions is better as compared to land points of India. Thus, we have considered a large region ($50^{\circ}\text{E}-110^{\circ}\text{E}$, $10^{\circ}\text{S}-35^{\circ}\text{N}$) for the accurate prediction of interannual variability of ISMR. The prediction skill of the System 4 significantly improved when ocean part is included ($cc=0.75$). This result shows that the ocean parts compensate the deficient precipitation over land point of India due to which the prediction skill of system 4 is significantly improved for ISMR.

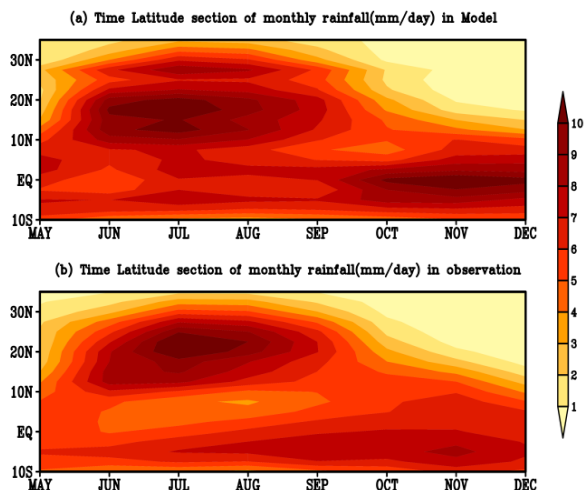


Figure 1 Time–latitude section of monthly rainfall (mm/day) for (a) System 4 and (b) observation (GPCP) averaged over 70°E – 90°E for the time domain of 1982–2013.

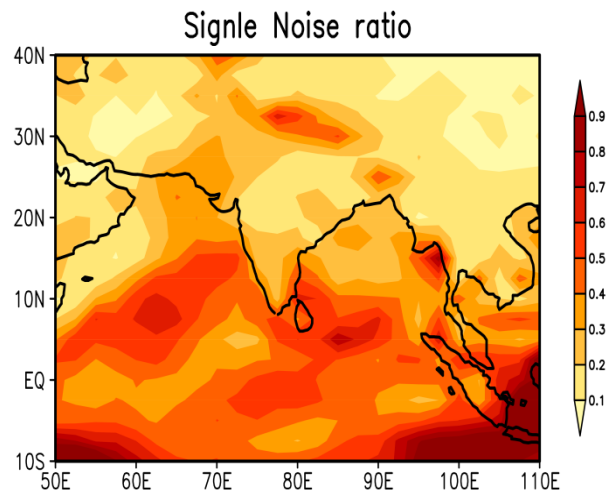


Figure 2 Signal to Noise ratio for JJAS rainfall anomaly (mm/day) in System 4 over Indian Monsoon region (50°E – 110°E , 10°S – 35°N) for the period of 1982–2013.

3.2. Relationship between Rainfall and SST

The relation between air and ocean plays a crucial role for Indian summer monsoon as we know that ISMR is coupled land–ocean–atmosphere system. We have observed that both the model and observation shows high positive correlation over the tropical Indian and Pacific Ocean except Western Pacific ocean and east head of Bay of Bengal (figure not shown). The model is unable to capture the negative correlation over the South China Sea as seen in the observation. A significant positive and negative correlation between the rainfall and tropical SST during JJAS shows that ocean (atmosphere) of these regions plays a major role in determining the atmospheric (ocean) response (Wang et al. 2005). A high positive correlation over the tropical regions shows that the large positive SST anomalies with excess rainfall due to enhanced surface evaporation and low level moisture convergence that show the fast response of atmosphere to SST anomalies (Wang et al. 2005). Similar to other coupled models such as CFS, ECMWF System 4 also well capture the SST–rainfall relationship over the Pacific and Indian Ocean but it shows positive correlation over the large region of this ocean as compared to the observation.

3.3. Teleconnection of ISMR with ENSO and IOD

The Interannual variability of ISMR is controlled by SST anomalies over the Pacific Ocean and atmospheric pressure difference between Tahiti and Peru which is known as southern oscillation. The combine effect of this atmospheric–ocean phenomenon is known as ENSO and it is responsible for the maximum number of drought in India (Kripalani and Kulkarni 1996). Thus realistic simulation of this relation holds the key for better seasonal prediction. In figure 3 we have showed one point correlation between NINO3.4 (SST averaged over 120°W – 170°W , 5°S – 5°N) and global JJAS rainfall. It can be observed from figure 3(b) for observation that the NINO3.4 SSTs are inversely related with rainfall over Indian–subcontinent region including some part of Arabian Sea and Bay of Bengal. System 4 (figure 3(a)) well captured the ENSO–ISMR inverse relationship and shows the large negative correlation as compared to the observation. The positive correlation between Nino 3.4–rainfall confined over the equatorial Pacific Ocean and negative over the maritime and Indian subcontinent. This result shows that during strong El-Nino year an excess rainfall is found along the equatorial central and eastern Pacific Ocean and deficient rainfall over Indian subcontinents. It is a well known fact that the SST of Pacific ocean inversely influences the ISMR but this relationship have weakened in recent years due to which the prediction

of 1997 El-Nino year is failed (Ashok et al. 2001). Saji et al. 1999 showed that the Indian Ocean SST anomalies also play an important role in the prediction of ISMR. Positive and negative SST regions formed in Indian Ocean which is known as Indian Ocean Dipole (IOD) which is important for the prediction ISMR (Saji et al. 1999). The relationship between ISMR and IOD cannot be ignored because in recent years the frequency of positive IOD is increased (Rao et al. 2012) which is the indicator of good monsoon (Behera et al. 1999). In order to explore the relationship between ISMR and IOD, we have calculated one point anomaly correlation of JJAS rainfall over each grid box with IOD for both the observation and the model. A positive correlation is found over the equatorial Pacific Ocean, western equatorial Indian Ocean and central India including head Bay of Bengal in observation (figure 4b). Similar pattern is also observed in model (figure 4a) except central India where model shows negative correlation between IOD SST and ISMR.

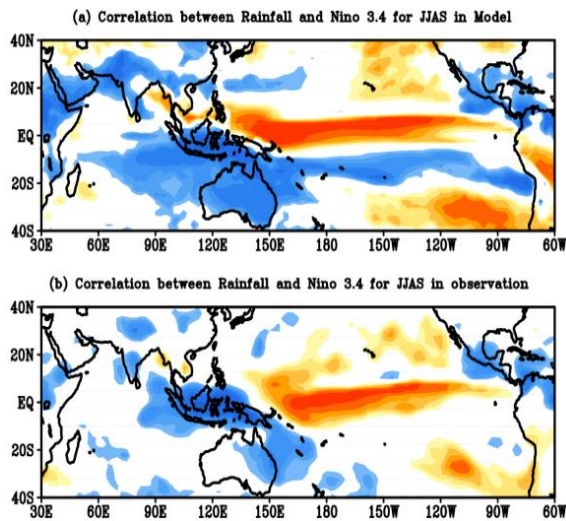


Figure 3 One point correlation between JJAS rainfall anomalies and Nino 3.4 index for (a) System 4 and (b) observation.

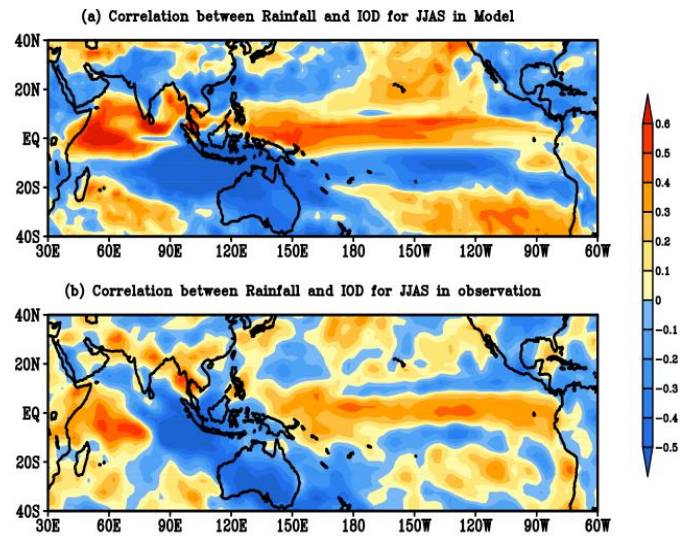


Figure 4 One point correlation between JJAS rainfall anomalies and IOD index for the time period of 1982-2013, (a) System 4 and (b) Observation.

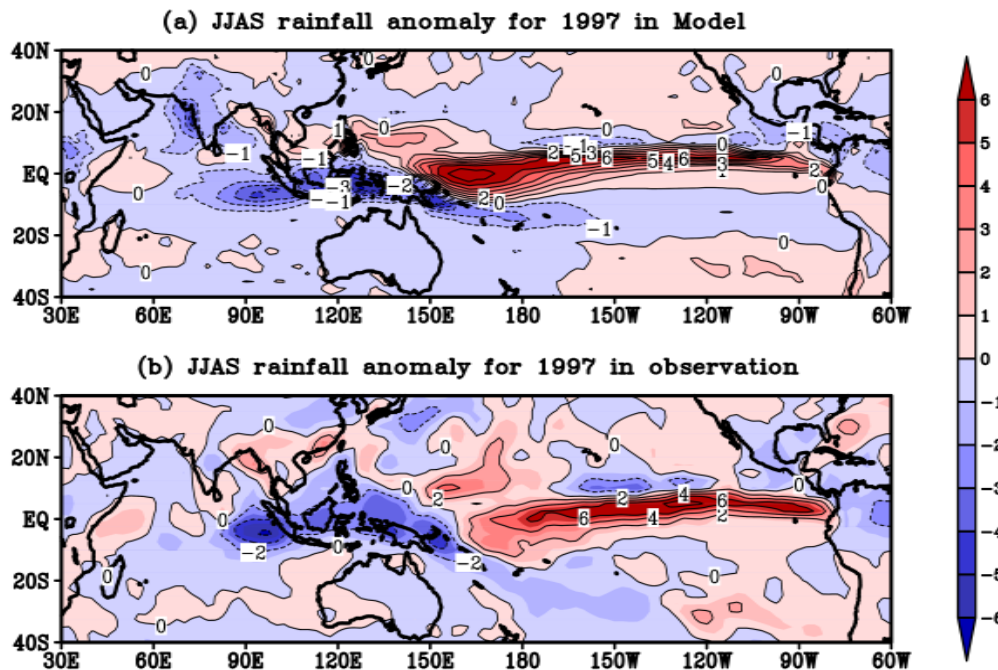


Figure 5 JJAS rainfall anomaly(mm/day) for 1997 El-Nino year in Shaded as well as in contour for (a) System 4 and (b) Observation.

A significant correlation observed over central India in observation but system 4 unable to capture this significant correlation. In case of El-Nino-ISMR relationship we observed negative correlation over the central India same as the IOD-ISMR and significant positive correlation over the equatorial Pacific ocean. This result shows that most of the IOD event co-occurs with ENSO therefore dominance of El-Nino signal is prominent in System 4.

3.4. Simulation of 1997 El-Nino

El-Nino (La-Lina) represents the warm (cold) phase of SST over the central and eastern equatorial Pacific Ocean which strongly influences the ISMR. In this paper we have considered the strongest El-Nino (1997). In case of 1997 El-Nino year almost all the Coupled Models were unable to predict the ISMR as this was a positive ISMR year. Generally, El-Nino years show deficient rainfall over the Indian subcontinent. We have observed from figure 5(a), System 4 represents large negative rainfall anomaly over entire Indian subcontinent where in the observation (figure 5(b)) it is found only over the central India in 1997 El-nino year.

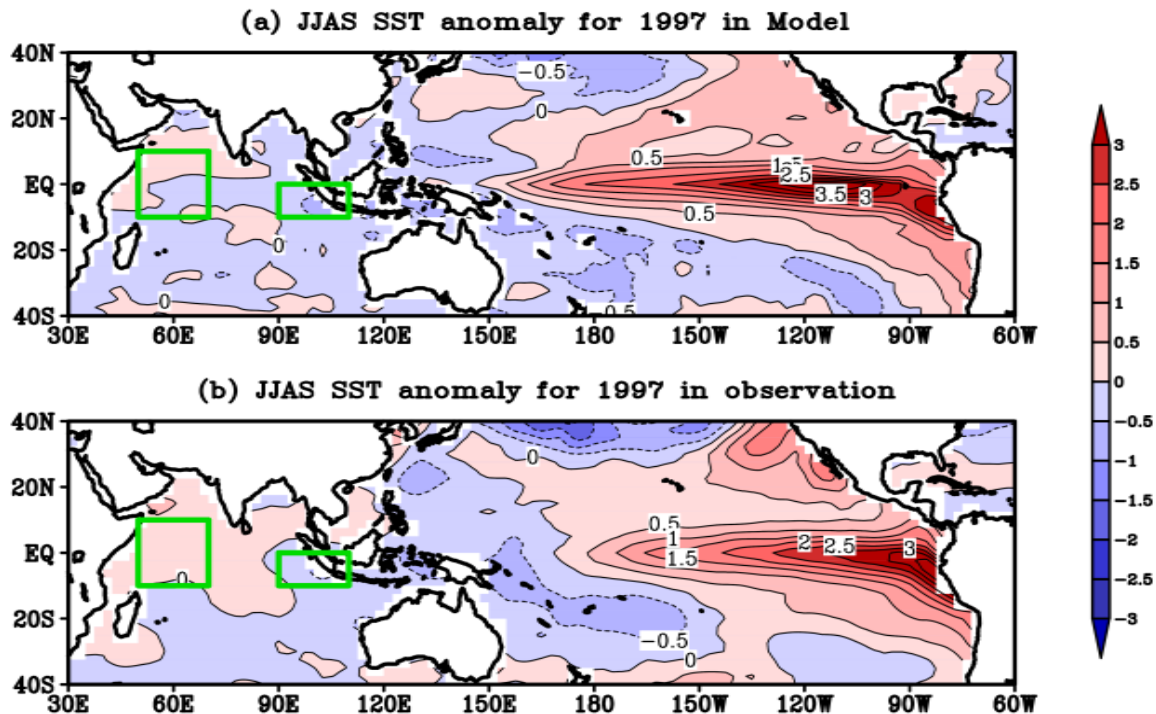


Figure 6 JJAS SST(°C) anomaly for 1997 El-Nino year in in Shaded as well as in contour for (a) System 4 and (b) Observation.

A positive rainfall anomaly is found over Central and Eastern tropical Pacific Ocean has in the model as well as in observation(Figure 5a, 5b). A positive rainfall anomaly is found over the Southern India in the observation but model is unable to capture this appropriately.1997 is a strongest El Nino year co-occur with IOD event. As we know that most of the coupled models well simulate the ENSO events as compared to IOD events (Rajeevan et al. 2012) and in the above discussion we have also obtained this result and thus we can say that System 4 unable to capture the contradicting result of El-Nino over the Indian Subcontinent for this year. Positive IOD compensating the adverse effects of El Nino on this year due to which Indian subcontinent found normal rainfall during JJAS Season (Rajeevan et al. 2012). It has been observed that system 4 shows weak IOD and strong El Nino in 1997 as shown in figure 6(a). We have already discussed above the prediction skill of El-Nino is good as compared to IOD in System 4. System 4 shows the large negative rainfall anomaly over Indian region as a response of strong positive SST anomalies over the equatorial central Pacific Ocean. On the basis of above results we can say that System 4 has similar problem as in other coupled models in simulating ISMR when El-Nino co-occurs with IOD as for El-Nino year of 1997.

3.5. Categorical forecast Skill Measure of System 4

We have used the dichotomous skill scores to check the performance of System 4 for ISMR, IOD and Nino 3.4 indices. These indices explain the relationship between ISMR and SST anomalies of Indian and Pacific Ocean and therefore we have used these three indices. This categorical forecast verification is performed during forecast period of 1982-2013. Contingency Table based on yes and

no forecast has been generated (Table not shown) for the ISMR, IOD and Nino 3.4 respectively. The forecast verification has been quantified by calculating dichotomous forecast skill measure for the ISMR, IOD, and Nino 3.4 in table 1. It has been observed from table 1, the accuracy shows that the model forecast for ISMR, IOD, and Nino 3.4 are 81%, 53% and 78% were correct. Bias value for all these three indices is less than 1 in System 4; it is argued that the System 4 is under forecast. Probability detection (POD) is higher for ISMR and Nino3.4 as compared to IOD, which indicate that System 4 is better in prediction of ISMR and Nino 3.4 rare events as compared to IOD.

Table 1 Categorical statistics computation for ISMR, IOD and Nino3.4 from the contingency table of ECMWF system 4

Indices	AC	Bias	POD	FAR	POFD	TS	ETS	HSS
ISMR	0.81	0.64	0.55	0.14	0.05	0.5	0.46	0.80
IOD	0.53	0.92	0.33	0.63	0.35	0.21	0.008	0.46
Nino3.4	0.78	0.90	0.60	0.34	0.13	0.46	0.31	0.48

FAR envisages that the model predicted rare events but it is not and it is found that FAR is larger for IOD as compared to ISMR and Nino 3.4. It can be concluded that failure of rare events are more for the IOD as compared to ISMR and Nino 3.4. Probability of false detection is small for ISMR and Nino 3.4 which indicates that the fraction of 'no' events which were incorrectly forecast as 'yes' is negligible in system 4 whereas it is larger for IOD. Since FAR is larger for IOD as compared to ISMR and Nino 3.4 so as the POFD is larger for IOD. Threat Score (TS) measures the accuracy when the correct negative have been removed from the forecast and it is found higher for the ISMR and Nino3.4 as compared to IOD which indicates that System 4 is better in the prediction of ISMR and Nino 3.4 compared to IOD for the time domain of 1982–2013. Since, ETS and HSS are also higher for ISMR and Nino3.4 as compared to IOD which indicate that the System 4 well captures the IMR and Nino 3.4 events as compared to IOD.

4. CONCLUSION

This study examined the seasonal prediction skill for Indian summer monsoon rainfall and its relationship with El-Nino and IOD using the output of ECMWF system 4 for the time domain of 1982–2013. System 4 has well captured the latitudinal oscillation of rainfall from north-south-north along with sun movement and the spatial climatology of precipitation with respect to observation. We have also observed that the predictability of ISMR is better for the oceans as compared to land points of India especially over the central India, where the value of signal is least. The relationship between the atmosphere (rainfall) and ocean (SST) shows that the equatorial Indian and Pacific Ocean play a crucial role for global rainfall especially over the Indian monsoon region. It is found that the System 4 has well represented the anti-correlation between Nino 3.4 and ISMR. However, the faithful representation of observed relationship between IOD and ISMR is not up to the mark in model for the time domain of our study. System 4 model simulations show deficient rainfall during year 1997 which was an El-Nino year. Generally during El-Nino years, Indian monsoon region receives less rainfall as compared with normal years, but surprisingly in 1997 Indian monsoon region received normal rainfall, which is evident by observational rainfall data. The most probable reason behind this strange event is positive IOD which is probably not captured by System 4. The dichotomous skill scores are used to investigate the performance of System 4 in the prediction of ISMR, IOD and Nino 3.4 indices. On the basis of dichotomous skill scores we can say that the model is better in predicting the ISMR and Nino 3.4 as compared to IOD which is also observed in the above discussion. The above result indicates that ECMWF System 4 has good prediction skill of El-Nino and its relationship with the ISMR as compared to the IOD.

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