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Seasonal prediction skill of Indian summer monsoon rainfall in ECMWF system 4 model

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ABSTRACT
This study evaluates the seasonal prediction skill for the summer monsoon rainfall (JJAS) over India from European Centre for Medium-Range Weather Forecasts (ECMWF) System 4 Model for the time domain of 1982-2013. The model overestimates the precipitation over the Indian Ocean, maritime continent, west-coast and some part of the Indian land point and underestimates the precipitation over the northeastern part of India. The cold bias of SST is found over the Arabian Sea including Western Ghats, Bay of

Bengal and southern Indian Ocean region (65°E-115°E, 20°S-12°S). The equatorial western and equatorial southern eastern Indian Ocean is warm-biased area. The model shows robust prediction skill of precipitation for the Indian summer monsoon region (ISMR; 50°E-110°E, 10°S-35°N) as the correlation coefficients (CC) between the observation and model is found to be +0.74 but the model failed to show significant predication skill of precipitation over the IMR region (CC=+0.29). We have also observed that the model is able to capture the inter-annual variability of precipitation over the IMR and ISMR region with lower magnitude as compared to the observation. The prediction skill of SST indices of Indian and Pacific Ocean is reasonably good. The model is able to capture the strong El-Niño (1982, 1997) and La-Niña (1988, 2010) events with high skill. The model is also able to simulate the TNI and EMI index with the interannual CC between the observed and model is +0.89 and +0.89 respectively. We have found that the significant relationship of the ISMR with Niño indices and EMI, while the relationship of the IOD with IMR and ISMR is insignificant. We have also found that the model overestimates the effect of SST indices on the IMR but is in good agreement with the observation for the ISMR.

Keywords: Indian Summer Monsoon, Niño, IOD, TNI, EMI

1. INTRODUCTION

The southwest monsoon during June-July-August-September season is the major rainy season in India which contributes to about 80% of the annual rainfall and it is necessary to forecast the southwest monsoon rainfall from monthly to seasonal scale accuratly for the policy planning (Magreth Bushesha, 2015; Biswas Roy et al. 2015). The understanding the monsoon and its simulation and prediction has remained a challenge for the scientific community till date. Blanford (1984) was initiated the long range forecasting for Indian summer monsoon rainfall, there are many methods adopted for the same, which include; statistical, empirical and dynamical (Rishma *et al*. 2015; Alok Kumar Mishra *et al*. 2015; Atul Srivastava *et al*. 2015; Lokesh Kumar Pandey *et al*. 2015). The statistical forecasts have been moderately successful (Krishna Kumar et al. 1995), but accurate dynamical seasonal prediction has thus far proven elusive (Branković and Palmer 2000). The main tools for dynamical seasonal scale prediction are Atmospheric General Circulation Models (AGCMs) and Coupled GCMs (CGCMs). It has been established during the recent years that the CGCMs that include ocean-atmosphere interactions are better in simulating the South Asian summer monsoon (Wang et al. 2005; Krishna Kumar et al. 2005). However, Kang et al. (2002) reported that the GCMs are not able to simulate the mean and the interannual variability of Indian summer monsoon. In last few years, we reduce the error in seasonal forecast through the combinations of the ensemble members forecast (Brankovic et al. 1990; Krishnamurti et al. 1999; Wu et al. 2002).

In the present work we have tried to investigate the seasonal prediction skill of ECMWF System 4 Model for SST and precipitation for the time domain of 1982-2013 using the May initial condition. The seasonal prediction skill and interannual variability of various SST indices and their relationship with Indian summer monsoon have also been explored.

The model and data used in the present work are described in section 2. The simulation of SST and precipitation are described in the section 3 and 4 respectively. SST indices and its relationship with the IMR and ISMR has been described in section 5 and the summary and conclusions are given in section 6.

2. MODEL & DATA DESCRIPTION

We have used European Centre for Medium-Range Weather Forecasts (ECMWF) System 4 which is fully coupled general circulation model (GCM) that provide operational seasonal predictions since November 2011. 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. Details for the ECMWF system 4 can be found in Molteni et al. (2011). We have used ECMWF System 4 model output produced from the initialization in the month of May for 32 years (1982-2013) in the present work. There are several observation datasets also used in this study for verification which are (i) The monthly mean observed SST dataset from the Hadley Centre sea ice and sea surface temperature (HadISSTv1.1) during 1982-2013 (Rayner et al. 2003). (ii) The Monthly mean observed precipitation dataset have been taken from Global precipitation climatology Project (v2.2) during 1982-2013 (Adler et al. 2003). All the data sets of model and observation used in present studies are at 2.5X2.5 resolutions and the domain of our study is 1982-2013.

3. SIMULATION OF SEA SURFACE TEMPERATURE (SST)

The spatial pattern of JJAS mean SST climatology obtained from model and observation during the time domain of 1982-2013 is shown in Figure 1(a) and 1(b) respectively. It can be observed that the model is able to simulate the warm equatorial eastern and western Indian Ocean with slight variation in spatial pattern of SST. We have also observed that the model failed to simulate warm SST over Arabian Sea and Bay of Bengal region accurately. The difference between the predicted and observed SST climatology is shown in Figure 1(c). The cold bias of SST is found over the Arabian Sea including Western Ghats, Bay of Bengal and Southern Indian Ocean (SIO) region (65°E-115°E, 20°S-12°S). However, warm bias is observed for the equatorial western and equatorial southern eastern Indian Ocean (Figure1c).

In order to investigate the prediction skill of model over the Indian and Pacific Ocean SST we have calculated the IOD, IODW, IODE, Niño, TNI and EMI indices for JJAS season during 1982-2013. The detailed descriptions of the above indices are given in Table 2. The interannual variability of IOD (IOD, IODW and IODE) and Niño (Niño1+2, Niño3, Niño3.4 and Niño4) indices derived from the observed and model simulated SST are shown in Figure 2 and 3 respectively. Similarly, the interannual variability of TNI and EMI index derived from the observed and model simulated SST are shown in Figure 4. We have computed the Standard Deviation (SD) for the time series of SST indices for model and observation and shown in Table 1. We observed that the model is able to capture the inter-annual variability of SST indices of Indian (IOD, IODW and IODE) and Pacific (Niño indices, TNI and EMI) Ocean with slight difference in the magnitude as compared to the observation (shown in Table 1).

We have computed the interannual correlation coefficient (CC) between the time series of observed and model-forecasted Niño, IOD, IODW, IODE, TNI and EMI indices and shown in Table 1. It seems that the model has better skill in the simulation of phase of variability of IODW (CC=+0.73) and IODE (CC=+0.76) indices. The prediction skill of IOD index in model is satisfactory with the interannual CC of +0.54 between observation and model. It has been seen that IODW and IODE region is better simulated by the model. A similar results was also been obtained by Wang et al. (2008) and Pattanaik and Kumar (2010) for the different coupled models. The model is able to simulate the some positive IOD (Figure 2a) events like 1982, 1991, 1994, 1997, 2006 and 2011. The model performance is poor in the simulation of negative IOD years; however recent negative IOD event (2010) is better simulated by the model. The interannual CC between the Niño indices for observation and the model are high (CC>0.80), this indicates that the prediction skill of model to simulate the Niño indices is good (Table 1). We have also observed that the Niño 1+2 index has high prediction skill with the interannual CC between model and observation is +0.90, and model skill decreases gradually when we move towards Niño3, Niño3.4 and Niño4, respectively (Table 1). The strong El-Niño events (1982, 1997) and La-Niña events (1988, 2010) are well captured by the model with high skill (Figure 3). The model is also able to simulate the TNI and EMI index with the interannual CC between the observed and model is +0.89 and +0.89 respectively (Table 1). We can conclude that the model performance over the Pacific Ocean is robust and is fairly good over the Indian Ocean.

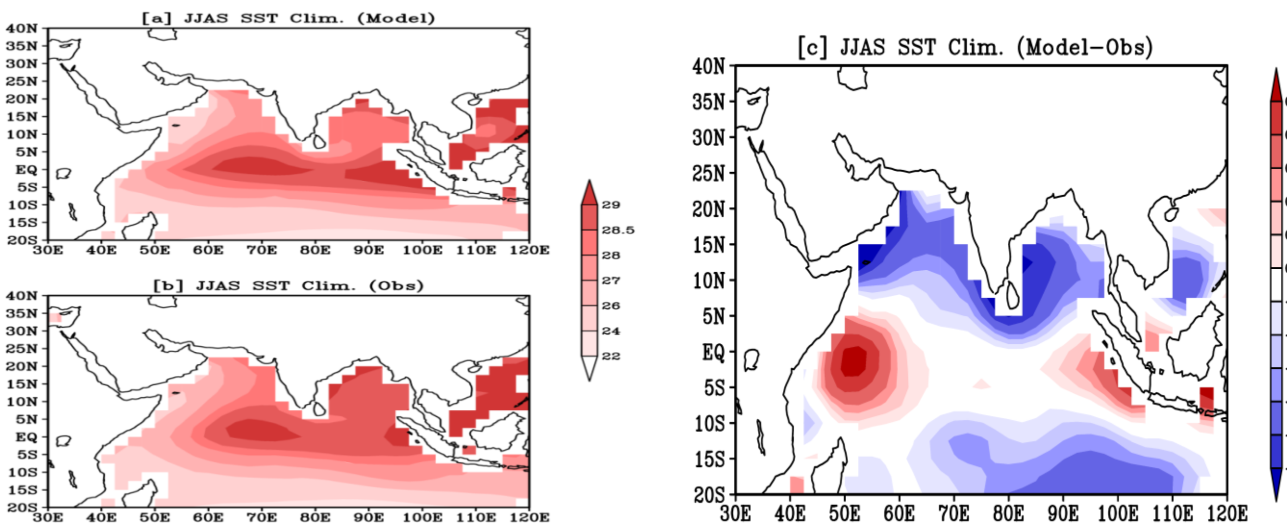
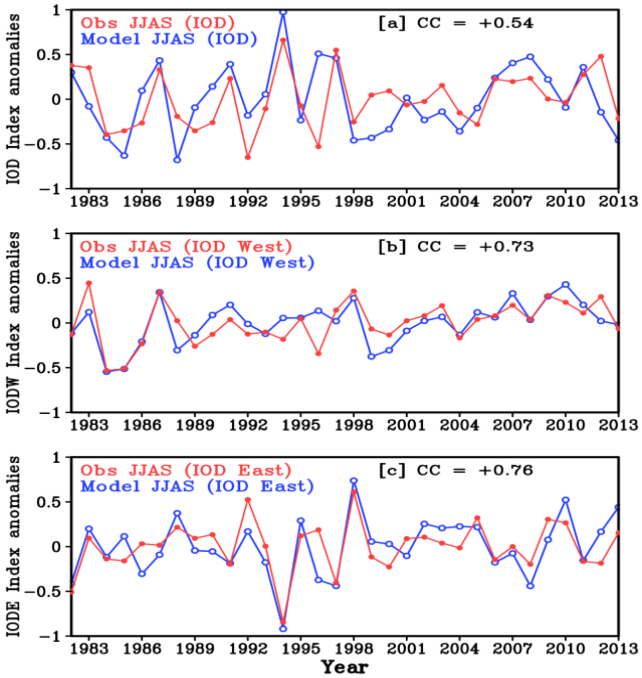


Figure 1 The SST (°C) climatology obtained from the **(a)** model, **(b)** observation and the **(c)** corresponding bias (model-observation) in the SST climatology for the JJAS season during 1982-2013

Table 1

Correlation coefficient (CC), Standard Deviation (for model as well as observation) between observed and model simulated SST (°C) and precipitation (mm/day) indices for the JJAS season during 1982-2013

Indices	CC	SD (Model)	SD (Obs)
Niño 1+2	+0.90	+1.00	+1.13
Niño 3	+0.86	+0.95	+0.75
Niño 3.4	+0.82	+0.84	+0.66
Niño 4	+0.80	+0.57	+0.48
IOD	+0.54	+0.38	+0.32
IODE	+0.76	+0.32	+0.28
IODW	+0.73	+0.23	+0.23
TNI	+0.89	+1.00	+1.15
EMI	+0.89	+0.45	+0.47
IMR	+0.29	+0.30	+0.70
ISMR	+0.74	+0.26	+0.32



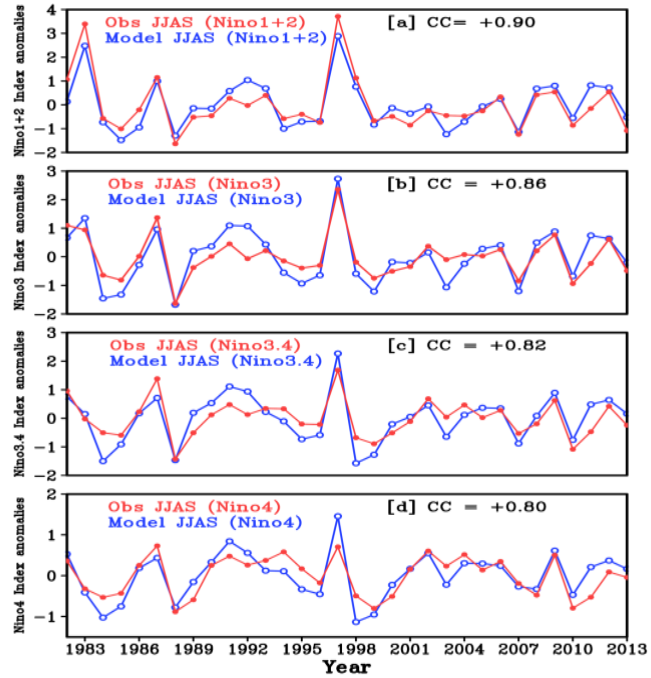


Figure 2 The interannual variability of SSTA (°C) averaged for **(a)** IOD, **(b)** WEIO and **(c)** EEIO regions derived from the observation (Red) and model (Blue) for the JJAS season during 1982-2013; **Figure 3** The interannual variability of SSTA (°C) averaged for **(a)** Niño1+2, **(b)** Niño3, **(c)** Niño3.4, and **(d)** Niño4 regions derived from the observation (Red) and model (Blue) for the JJAS season during 1982-2013

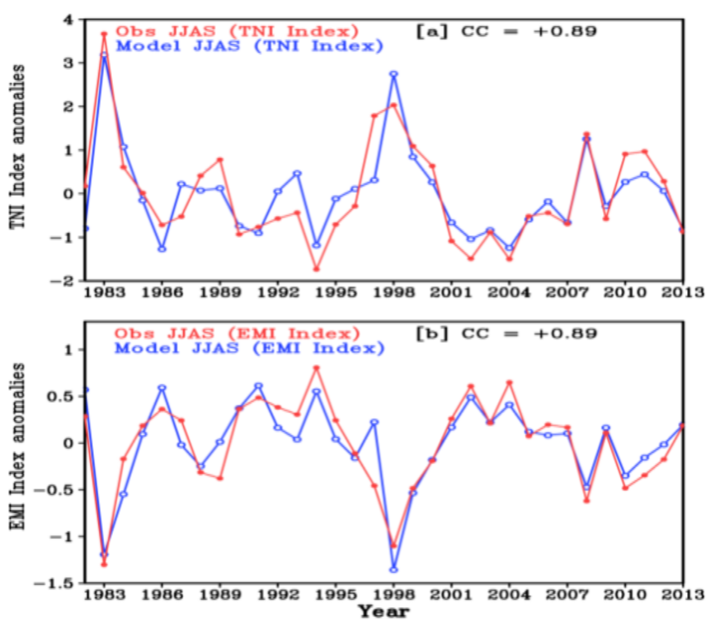


Figure 4 The interannual variability of SSTA (°C) averaged for **(a)** TNI and **(b)** EMI regions derived from the observation (Red) and model (Blue) for the JJAS season during 1982-2013

4. SIMULATION OF PRECIPITATION

The spatial pattern of JJAS mean precipitation climatology for model and observation during the time domain of 1982-2013 was computed and shown in Figure 5(a) and 5(b) respectively. The spatial pattern of observed and model simulated precipitation climatology shows the maxima of precipitation over west coast region and the north-eastern part of India (including the region of Bay of Bengal). Figure 5(c) shows the difference between the model forecasted and the observed precipitation climatology for JJAS season during 1982-2013. It seems that the model overestimates the precipitation over the Arabian sea (including the western Ghat), Bay of Bengal, maritime continent and some part of Indian land points and underestimates the precipitation over the north-eastern part and south-eastern coastal part (Tamil Nadu) of India (Figure 5c). The maximum value of precipitation bias is found over the western-coast, Bay of Bengal and north-eastern part of India (Figure 5c). We have calculated the IMR and ISMR index based on the region defined in the Table 2. We have computed the SD for the time series of IMR and ISMR index for model and observation and shown in Table 1. It seems that the interannual variability in the model (+0.30) over the IMR region is less as compare to the observation (+0.70) (Table 1). However, the interannual variability over the ISMR region in the model (+0.26) is consistent with the observation (+0.32) (Table 1).

We have also computed the interannual CC between the time series of observed and model-forecasted IMR and ISMR indices and shown in Table 1. The model shows robust prediction skill of precipitation for ISMR region as the CC between the observation and model is found to be +0.74 (Table1, Figure 6b), but the model failed to show significant predication skill of precipitation over the IMR region (Table1, Figure 6a) (CC=+0.29). It is also observed that the prediction skill of precipitation for ISMR region is very high during 1995-2013 as the CC between the observation and model is found to be +0.90 (Figure 6b).

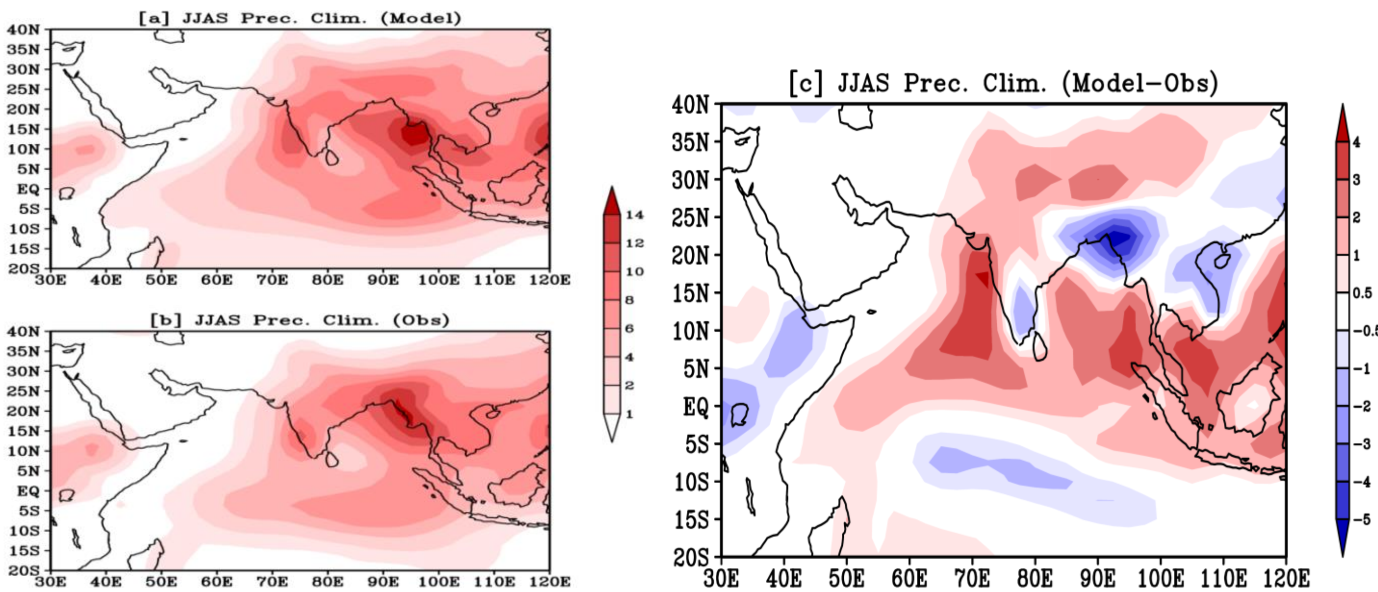


Figure 5 The precipitation (mm/day) climatology obtained from the **(a)** model, **(b)** observation and the **(c)** corresponding bias (model-observation) in the precipitation climatology for the JJAS season during 1982-2013

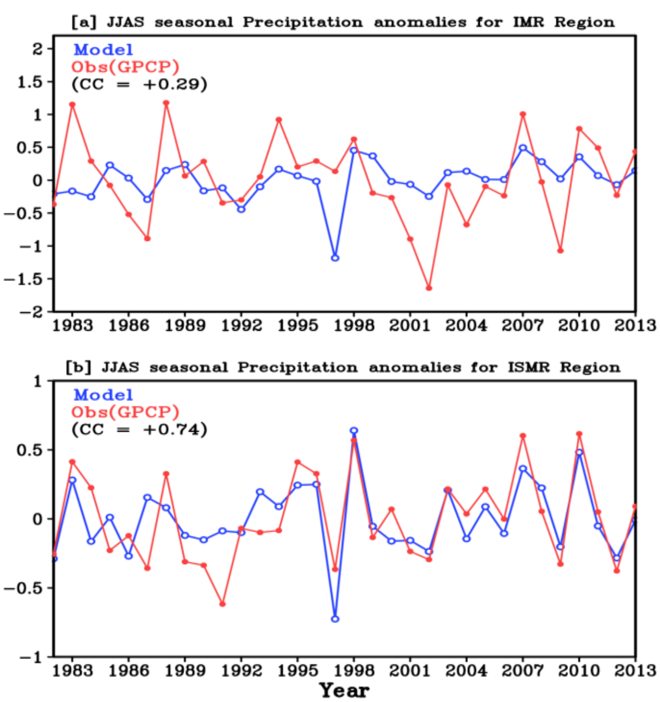


Figure 6 The interannual variability of precipitation anomalies (mm/day) averaged for **(a)** IMR (only the land point of India) and **(b)** ISMR regions derived from the observation (Red) and model (Blue) for the JJAS season during 1982-2013

5. SST INDICES AND ITS RELATIONSHIP WITH THE IMR AND ISMR

We have computed the interannual CC between SST indices (EMI, TNI, Niño, and IOD) and precipitation indices (ISMR and IMR) for both model as well as observation for the JJAS season during 1982-2013, and results obtained from the observation are compared with the model (Table 3). We observed that the EMI, Niño3, Niño3.4, Niño4 indices are significantly negatively correlated with the ISMR in the observation and it is well represented by the model, however the relationship between the Niño1+2 index and ISMR is week in observation and it is also reflected in the model (Table 3). We have also found that the relationship of IOD with IMR and ISMR is week in the observation as well as model. This result is consistent with the previous work done by the Ashok et al. (2001) they concluded that the IOD and the El Niño Southern Oscillation (ENSO) events complementary affected the interannual variability of ISMR, that means whenever the ENSO-ISMR correlation is low (high), the IOD-ISMR correlation is high (low). The significant positive relationship between the TNI and ISMR is found in the observation and model, but the relationship is week between the TNI and IMR in model as well as observation (Table 3). We have also observed that the model overestimates the effect of Niño indices on the IMR but is in good agreement with the observation for the ISMR.

Table 2 Descriptions of Different SST and Precipitation indices

Index Name	Definition
Niño1+2	Defined as the area-averaged Sea Surface Temperature anomalies (SSTA) over the region (90°W-80°W, 10°S-Eq).
Niño3	Defined as the area-averaged SSTA over the region (150°W-90°W, 5°S-5°N).
Niño3.4	Defined as the area-averaged SSTA over the region (170°W-120°W, 5°S-5°N).
Niño4	Defined as the area-averaged SSTA over the region (160°E-150°W, 5°S-5°N).
Indian Ocean Dipole (IOD) Index	Defined as the difference of SSTA between a Western equatorial Indian Ocean (**IODW**; 50°E-70°E, 10°S-10°N) and a Eastern equatorial Indian Ocean (**IODE**; 90°E-110°E, 10°S-Eq) regions [Saji et al., 1999].
Trans-Niño Index (TNI)	Defined as the difference of normalized SSTA between a Niño 1+2 and Niño 4 regions [Trenberth and Stepaniak, 2001].
El Niño Modoki Index (EMI)	EMI is defined as; EMI = $[SSTA]_A - 0.5\times[SSTA]_B - 0.5\times[SSTA]_C$ where the square brackets with a subscript represent area-averaged SSTA averaged over each of the region A (165°E-140°W, 10°S-10°N), B (110°W-70°W, 15°S-5°N), and C (125°E-145°E, 10°S-20°N), respectively [Ashok et al., 2007].
Indian monsoon rainfall (IMR) Index	Defined as the area-averaged precipitation anomalies over the land points of India.
Indian summer monsoon rainfall (ISMR) Index	Defined as the area-averaged precipitation anomalies over the region (50°E-110°E, 10°S-35°N).

Table 3 Anomaly CC between SST indices (EMI, TNI, Niño, and IOD) and Precipitation indices (ISMR and IMR) for observation as well as model (in parenthesis) for the JJAS season during 1982-2013

Correlation Coefficient Obs (Model)	ISMR	IMR
EMI	-0.43 (-0.55)	-0.27 (-0.27)
TNI	+0.30 (+0.41)	+0.20 (+0.10)
Niño1+2	-0.20 (-0.23)	-0.13 (-0.62)
Niño3	-0.51 (-0.46)	-0.35 (-0.69)
Niño3.4	-0.62 (-0.63)	-0.44 (-0.70)
Niño4	-0.53 (-0.64)	-0.36 (-0.67)
IOD	-0.22 (-0.10)	+0.10 (-0.22)

6. CONCLUSIONS

The prediction skill to simulate the SST over the Indian and Pacific Ocean, and Precipitation over the Indian summer monsoon region has been analysed using the ECMWF System 4 Model during the time domain of 1982-2013. The seasonal (JJAS) SST climatology obtained from the System 4 model shows similar pattern to the observed SST climatology having cold bias around the Indian land mass, SIO region and the warm bias near the equatorial east coast of Afirca and west coast of Sumatra. The prediction skill of the simulation of IOD index is satisfactory while the TNI, EMI and Niño indices are robust in the System 4 model. The strong El-Niño events of 1982, 1997 and La-Niña events of 1988, 2010 are well captured by the System 4 model with high skill. The robust relationship between the TNI and EMI is observed in the observation and it is well represented by the System 4 model. The System 4 model show the excessive precipitation over the west-coast of india, Bay of Bengal, maritime continent and some part of Indian land point and deficient precipitation over the north-eastern part and south-eastern coastal part (Tamil Nadu) of India. We have also observed that the model has robust prediction skill of precipitation for ISMR region but low skill for IMR region. The significant negative relationship of the ISMR with EMI and Niño indices is observed in the observation and it is well represented by the System 4 model. The insignificant relationship between the IOD with IMR and ISMR is observed in the observation and model. We have also observed that the model overestimates the effect of SST indices on the IMR but is in agreement with the observation for the ISMR.

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