Simulation of Indian summer monsoon using the Japan Meteorological Agency's seasonal ensemble prediction system

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The performance of a dynamical seasonal forecast system is evaluated for the prediction of summer monsoon rainfall over the Indian region during June–September (JJAS) by using hindcast of the Japan Meteorological Agency (JMA) seasonal ensemble prediction system (EPS) model, based on five ensembles of March, April and May initial states for a period of 32 years (1979–2010).

The hindcast climatology during JJAS simulates the mean monsoon circulation at lower and upper tropospheres very well in JMA model using March, April and May ensembles with a more realistic simulation of Webster and Yang's broad scale monsoon circulation index. The JMA hindcast climatology during JJAS simulates the rainfall maxima over the west-coast of India and the head Bay of Bengal reasonably well, although, the latter is slightly shifted southwestward. Associated with better forecast skills of El Nino in the JMA model, the interannual variability of All India Summer Monsoon Rainfall (AISMR) during the 32-year period has also been very well simulated with a high significant (99% level) correlation in April ensemble followed by that of March and May ensembles. Thus, the present analysis indicates that the JMA seasonal forecast model can prove to be a useful tool for the dynamical seasonal forecast of AISMR.

1. Introduction

A major part of India received about 80% rainfall during the southwest monsoon season from June to September (JJAS). The seasonal rainfall varies largely from year to year. The small fluctuation in the seasonal rainfall can have devastating impacts on agricultural sector, water resources, power generation, ecosystems of the country and finally, on the economy of the country. Thus, the prediction of southwest monsoon is important for the national economy and government's various

policy planning. The El Nino-Southern Oscillation (ENSO) is one of the major driving forces of Indian monsoon variability. The classical relation between ENSO and all India summer monsoon rainfall (AISMR) indicates that, in majority of the years during the warm (cold) ENSO events, the AISMR tends to be below (above) normal (Sikka and Gadgil 1980; Pant and Parthasarathy 1981). Several observational and modelling studies (Charney and Shukla 1981; Palmer and Anderson 1994) provide evidence that the boundary forcing in tropics contribute significantly to the internal

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variability of the tropical as well as monsoon circulations.

The long-range forecasting of Indian summer monsoon rainfall was initiated more than a century ago by Blanford (1884). Subsequently, many methods have been adopted for the same, which include empirical and dynamical methods. In the last few decades, many empirical (Shukla and Mooley 1987; Gowardiker et al. 1991; Rajeevan et al. 2003; Sahai et al. 2003a, b; Pattanaik et al. 2005; Pai and Rajeevan 2006) and dynamical methods (Palmer et al. 1992; Chen and Yen 1994; Sperber and Palmer 1996; Soman and Slingo 1997; Shukla et al. 2000; Saha et al. 2006, 2014; Pattanaik and Kumar 2010) for predicting the summer monsoon rainfall have been developed. The scientific basis of these dynamical seasonal forecasting is that, in tropics, the lower-boundary forcings (sea surface temperature (SST), sea-ice cover, land-surface temperature and albedo, vegetation cover and type, soil moisture and snow cover, etc.), which evolve on a slower time-scale than that of the weather systems themselves, can provide significant predictability of statistical characteristics of large-scale atmospheric events (Charney and Shukla 1981).

The main tools for dynamical seasonal prediction are the Atmospheric General Circulation Models (AGCMs) and Coupled General Circulation models (CGCMs). However, AGCMs could not successfully simulate the mean and interannual variability of Indian summer monsoon (Kang et al. 2002). In recent years, the multi-model ensemble (MME) by combining different forecast models is found to have reduced the forecast errors in the seasonal prediction (Brankovic et al. 1990; Brankovic and Palmer 1997). Presently, many international modeling centres are operating the CGCM. The coupled modeling system of the Japan Meteorological Agency (JMA) is one such centre, which is generating the seasonal forecast on real time. In this study, the simulation of Indian summer monsoon using the JMA's seasonal ensemble prediction system (EPS) is investigated. For this purpose, the seasonal mean and interannual variability of Indian summer monsoon rainfall during the JJAS season, the grid value product (GVP) of JMA's coupled model with March, April and May initial conditions are considered. This paper is organized as follows. In section 2, the components of the JMA model's hindcasts along with the data used for the verification of model's performance are described. The skill of JMA in simulating mean and interannual variability of the Indian monsoon rainfall are discussed in section 3. The performance of the JMA model for the seasonal forecast over the Indian region is discussed in section 4. Summary and conclusions are presented in section 5.

2. Data and methodology

2.1 Verification analysis

For the verification of mean monsoon circulation during JJAS in the JMA model with different lead time, the reanalysis data of wind at lower and upper troposphere from the NCEP reanalysis during the same 32-year period (Kalnay et al. 1996) has been used. 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 monthly climatology for the period 1971–2000 (Xue et al. 2003).

For the quantitative verification of AISMR, the observed rainfall departure based on the observations over the Indian landmass obtained from the India Meteorological Department (IMD) has been used in the present analysis. From the IMD's rainfall observations, the JJAS mean rainfall over Indian landmass is found to be 881 mm with a standard deviation (SD) of about 88 mm ($\approx 10\%$). Based on the departure of ± 1 standardized anomalies of AISMR, the year-to-year variation during 1979–2010 indicates many extreme years, viz., 1979, 1982, 1986, 1987, 2002, 2004, 2009 are considered to be deficient years and 1983, 1988 and 1994 are considered to be the excess years. The standardized anomaly for a given year is calculated by dividing the anomaly of seasonal rainfall for that particular year with the standard deviation (Sahai et al. 2003b).

The numerical model simulates rainfall over land as well as over the ocean body (over the whole domain of interest). The forecast skills of the model need to be verified over the whole monsoon region including the Indian landmass and adjoining ocean. 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 adjoining oceanic parts. Hence, for the verification of rainfall forecast over the bigger monsoon domain covering both the Indian landmass and surrounding oceanic region, known as the Indian Monsoon Region (IMR) bounded by 50° – 110° E and 10° S– 35° N, the gridded rainfall from the Global Precipitation Climatology Project (GPCP) is used. The GPCP rainfall is based on rain gauge and it merges the satellite source data having a resolution of $2.5^{\circ} \times 2.5^{\circ}$ (Huffman et al. 2001).

2.2 Details of the JMA model and its hindcast configuration

The JMA's seasonal EPS model for long-range forecasting is the CGCM, which consists of

the AGCM and ocean general circulation model (OGCM) from the Meteorological Research Institute (MRI). The equivalent horizontal resolution of AGCM (T95L40) is nearly a 180 km Gaussian grid and a finite differencing in the vertical with sigma 40 layers. The horizontal domain for the ocean model is quasi-global extending from 75°S to 75°N. The zonal and meridional resolutions are 1° and 0.3°–1° between 75°S and 75°N, having 50 vertical layers. The atmospheric and oceanic initial conditions obtained from the JMA Climate Data Assimilation System (JCDAS) and the new ocean Data Assimilation System (ODAS) is a global system. The OGCM is the MRI Community Ocean Model (MRI.COM) described in Ishikawa *et al.* (2005). Initial perturbations are estimated for both the atmosphere and the ocean, and atmospheric initial perturbations are obtained using the Breeding of Growing Modes (BGM) method. 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, and a land surface model coupled to the AGCM is used for the prediction of land surface conditions. For the simulation of the seasonal mean and interannual variability of Indian summer monsoon rainfall during JJAS, the GVP of JMA's EPS model forecast with five ensemble members each, for 32 years (1979–2010) with initial conditions of March (lead-3), April (lead-2) and May (lead-1) are considered.

3. Results and discussions

3.1 Simulation of mean monsoon

3.1.1 Simulation of mean monsoon circulation

The observed climatology of 850 (200) hPa wind (m/s) averaged for JJAS during the period from 1979 to 2010 together with the 160 ensemble members (5 ensembles×32 years) corresponding to the JMA EPS forecast mean wind for March, April and May initial conditions are shown in figure 1 (figure 2). The difference between the forecast and observed climatology for 850 and 200 hPa wind during JJAS is shown in figure 3 with March, April and May ensembles. The low level strong westerly wind, commonly known as Findlater jet, is a major feature of the lower-tropospheric circulation over the western Indian Ocean during the Indian summer monsoon season (Findlater 1966a, b). The low level monsoon westerly during JJAS at 850 hPa level over the Arabian Sea, which brings the monsoon current over India as seen in the

observed climatology (figure 1a) is well simulated in the JMA hindcasts climatology for JJAS with March, April and May initial conditions (figure 1b–d). Although, the monsoon westerly flow over the Indian region is very well captured in the JMA hindcast climatology, the JMA model simulated a stronger monsoon low level circulation over the Indian region over the west-central Bay of Bengal and adjoining Indian land regions (figure 1b–d) when compared to the observed wind climatology (figure 1a). This strengthening of monsoon circulation over the west-central Bay of Bengal and adjoining Indian land regions in JMA hindcast is very clear from the difference plotted between the forecast and observed climatology wind at 850 hPa shown in figure 3(a–c). This indicates presence of an anomalous cyclonic circulation over the west-central Bay of Bengal and adjoining Indian land-mass with March, April and May ensembles. The difference in climatology at lower level also indicates the presence of an anomalous cyclonic circulation over the southeast Arabian Sea (figure 3a–c) in March, April and May ensembles.

In the upper troposphere during JJAS, the Tropical Easterly Jet appears as a band of strong easterlies extending from southeast Asia across the Indian Ocean and Africa during the southwest monsoon season (Koteswaram 1958a, b). At 200 hPa, the observed wind climatology over the Indian region during JJAS is dominated by the tropical easterly jet over southern India and adjoining equatorial Indian Ocean (figure 2a). Similar to the observed climatology, the JMA hindcast climatology also simulated the tropical easterly jet over the Indian region during JJAS with different lead times (figure 2b–d). The upper level hindcast climatology from the JMA model in March, April and May ensembles shows the strength of easterly jet very close to that of the tropical easterly jet during JJAS over the southern parts of India (figure 3a).

Webster and Yang (1992) defined the broad scale monsoon index (commonly known as WY index) by taking into account the difference of the strength of upper level easterly and lower level monsoon westerly over an extended monsoon region. The intensity of the south Asian monsoon in terms of WY index as the vertical shear of the horizontal mean zonal wind [u (200 hPa)– u (850 hPa)] in the region (40°–110°E, Eq–20°N) is calculated from the observed wind analysis and the JMA model forecast (table 1). As shown in table 1, the low level monsoon westerly during JJAS is stronger in the JMA hindcast climatology compared to that of the observed strength of monsoon westerly as the u_{850} averaged over the above domain gives stronger westerly in the JMA model compared to the strength of the observed monsoon westerly at

Figure 1. 850 hPa wind climatology (m/s) obtained from the NCEP reanalysis and JMA for a period of 32 years from 1979 to 2010 valid for JJAS during (a) verification analysis, (b) March ensemble of JMA, (c) April ensemble of JMA, and (d) May ensemble of JMA.

lower level. The same has been shown in figures 1 and 3(a–c). With respect to the strength of upper level easterly during JJAS, the JMA hindcast climatology simulates the observed strength of easterly very well, although, slightly underestimated (table 1). The observed mean WY index in terms of $u_{200}-u_{850}$ over the above domain is stronger (–24.48) compared to the JMA forecast mean WY index during March, April and May ensemble (–21.98, –22.05 and –21.79, respectively). This indicates the simulated WY index with April ensemble is found to be very close to observed WY index compared to that of March and May ensembles of JMA (table 1). Although, the upper level easterly in JMA model is weaker than the strength of the observed easterly, the mean WY index in

the JMA forecast is found to be very close to that of the corresponding observed WY index since the underestimation of upper level easterly is partly compensated with the increase of low level westerly in the model as shown in table 1.

3.1.2 Simulation of mean monsoon rainfall

The JMA seasonal hindcast rainfall during JJAS is compared with the GPCP rainfall data (hereafter called as verification analysis). The rainfall climatology of verification analysis during JJAS for the period from 1979 to 2010 is shown in figure 4. As seen from figure 4, the verification climatology

Figure 2. 200 hPa wind climatology (m/s) obtained from the NCEP reanalysis and JMA forecast for a period of 32 years from 1979 to 2010 valid for JJAS during (a) verification analysis, (b) March ensemble of JMA, (c) April ensemble of JMA, and (d) May ensemble of JMA.

shows two rainfall maxima; one over the west coast region and the other over the head Bay of Bengal. Along with these two maxima, the observed climatology has a zone of less rainfall over the north-western parts of the country and the rain shadow region of Tamil Nadu situated on the south-eastern coastal state of India. The corresponding rainfall climatology from JMA hindcast during JJAS, based on 32 years (1979–2010) with initial conditions of March, April and May, is shown in figure 5(a–c), respectively. Similar to the verification climatology (figure 4), the JMA forecast rainfall climatology during JJAS captures the spatial pattern of rainfall climatology reasonably well, although, the west coast rainfall maximum shown in verification analysis (figure 4) is underestimated

in the JMA hindcast shown in figure 5(a–c). The rainfall maximum over the head Bay of Bengal and adjoining northeast India seen in the verification analysis in figure 4 is also captured reasonably well in the JMA hindcast; however, its location is to the southwest off its actual location (figure 5a–c). The zone of less rainfall over the northern region of the country and the southern state of India (Tamil Nadu) seen in the verification analysis in figure 4 is also captured well in the JMA hindcast (figure 5a–c). The spatial resemblance between the observed and the JMA seasonal rainfall climatology during JJAS is quantified by calculating correlation coefficient (CC) between verification climatology (figure 4) and the corresponding JMA hindcast climatology over the IMR bounded by 50°–110°E,

Figure 3. JMA forecast wind climatology and observed wind climatology wind (m/s) for a period of 32 years from 1979 to 2010 valid for JJAS with March, April and May initial conditions. (a–c) 850 hPa wind and (d–f) 200 hPa wind.

10°S–35°N (table 2). As seen from table 2, the CC is found to be significant with all the three lead times with May ensemble being the best having the highest CC.

The model bias is calculated by taking the difference between JMA model hindcast climatology of JJAS rainfall with March, April and May ensembles plotted in figure 5(a–c) with the verification analysis shown in figure 4. The JMA model bias is shown in figure 5(d–f) with March, April and May ensemble, respectively. The underestimation of west-coast maximum in the JMA model can

also be seen from the difference plot with negative bias over the west-coast region (figure 5d–f). The underestimation of west-coast rainfall could be due to weakening of monsoon westerly over the region as indicated in the difference plot of 850 hPa wind (figure 3a–c). Further, because of the southwestward shifting of the Bay of Bengal maximum in the JMA forecast, the model bias as shown in figure 5(d–f) indicates negative bias over head Bay of Bengal and adjoining northeastern India, whereas, over the west-central Bay the bias is found to be positive with excessive rainfall over east coast

Table 1. Mean broad-scale circulation index (WY index) from JMA during June to September (JJAS) as measured by wind averaged over the region 40° – 110° E, Eq – 20° N during the period from 1979 to 2010 of March, April and May initial conditions.

Region considered for the mean circulation index (40° – 110° E, Eq – 20° N)	NCEP reanalysis	JMA's hindcast		
		Mar ICs	Apr ICs	May ICs
u(200 hpa) m/s	–17.49	–14	–14	–13.9
u(850 hpa) m/s	6.99	7.98	7.95	7.82
u(200 hpa)–u(850 hpa)	–24.48	–21.98	–22.05	–21.79

Figure 4. The spatial climatological rainfall (mm/day) for a period of 32 years from 1979 to 2010 valid for JJAS obtained from verification analysis (GPCP). Shaded area denotes rainfall with more than 7 mm/day

of India and adjoining central India. This positive bias over the east coast of India and adjoining central India as a result of excessive rainfall over the region is basically due to the model bias at low level circulation, having anomalous cyclonic circulation seen over the region in figure 3(a–c). As shown by Rajeevan and Nanjundiah (2009), although the 10 coupled models simulate the Indian monsoon and particularly the two rainfall maxima (one over the west coast of India and other over the head Bay of Bengal) reasonably well, there are biases of rainfall over the Indian monsoon region and particularly over the continental tropical convergence zone (CTCZ). The underestimation of west coast rainfall maximum and the southwestward shifting of the Bay of Bengal maximum indicated in JMA model are also observed in some coupled models such as GFDL and CCCMA (Rajeevan and Nanjundiah 2009). They have also emphasized that since SST and rainfall are strongly coupled in the tropics, unrealistic simulation of SST distribution may cause unrealistic rainfall distribution and hence the biases.

3.2 Simulation of interannual variability of monsoon

3.2.1 Interannual variability of Nino 3.4 SST

The tele-connection between Indian monsoon and SST anomalies over the equatorial and central Pacific has been documented for a very long time. As pointed by many earlier studies, there is a close relationship between the deficit monsoon rainfall and El Nino (Pant and Parthasarathy 1981; Rasmusson and Carpenter 1983). 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. Since the ENSO is the main driving force of interannual variability of AISMR, the better forecast skill of El Nino in a coupled model will 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. We focus on the prediction of SST in Nino 3.4 (5° S– 5° N; 170° – 120° W) regions of the

Figure 5. The spatial climatological rainfall (mm/day) obtained from JMA for a period of 32 years from 1979 to 2010 valid for JJAS. Shaded area denotes rainfall of more than 7 mm/day. (a) March ensemble, (b) April ensemble, and (c) May ensemble. The corresponding difference between the forecast and observed climatology is shown in (d–f).

Table 2. The correlation coefficients (CCs) between verification rainfall climatology and model hind-cast climatology during the 32-year period from 1979 to 2010 for June to September (JJAS) with initial conditions of March, April and May.

Region	Correlation coefficient (JJAS)		
	Mar ICs	Apr ICs	May ICs
Indian monsoon region (50°–110°E, 10°S–35°N)	0.69	0.69	0.73

tropical Pacific. Figure 6 compares the observed Nino 3.4 SST anomaly index from ERSST with the forecasts SST anomaly in the JMA model for the

period from 1979–2010 with March, April and May initial conditions. The El Nino/La Nina prediction shows similarity with the major El Nino events like

1982, 1987, 1991, 1994, 1997, 2002, 2004 and 2009 which are captured well in the JMA forecasts. Similarly, the major La Nina years like 1988, 1998, and 1999 were also captured well as shown in figure 6. The anomaly correlation of Nino 3.4 SST prediction is also highly significant (above 99.9% level) with March, April and May ensembles with best skill of Nino 3.4 SST prediction being found to be with May ensembles of JMA (figure 6).

3.2.2 Interannual variability of monsoon rainfall

The GCM has an ‘average’ behaviour or climatology similar to the real atmosphere in large spatial and temporal scales. As the model integration proceeds, there is a tendency for the results to increasingly resemble the model climatology, introducing a systematic bias into the forecasts. To overcome this bias, forecasts are expressed in terms of deviations from the GCM’s own climatology – a process referred as calibration. In any current prediction, 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 JJAS (known as AISMR) obtained from IMD is plotted against the hindcast rainfall departure over the Indian land grid points during JJAS with March, April and May initial conditions (figure 7). As mentioned earlier, the excess and deficient years are identified based on the departure of ± 1 standardized anomalies of AISMR. Based on this criteria, the extreme years 1979, 1982, 1986, 1987, 2002, 2004, 2009 are considered to be deficient years and the years 1983, 1988 and 1994 are considered to be the excess years. As seen from

figure 7, the contrasting monsoon during 1987 and 1988 are very well captured in the JMA model with all the three lead times based on March, April and May ensembles. Whereas, like many other models, the JMA model also could not capture the observed rainfall departure during the La Nina year of 1983, although it captured the El Nino year of 1982. In addition, the other deficient years like 1979, 1986, 2002 and 2009 were also reasonably well captured in the JMA model. However, the strongest El Nino year of 1997 associated with slight positive rainfall over India was not captured in the JMA model (figure 7). This 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 was simulated well by the JMA model as indicated by the significant CC between observed AISMR departure and JMA forecast rainfall departure with April ensemble is found to be the best compared (significant at 95% level) to that of March (significant at 95% level) and May (significant at 90% level) ensemble. Even the NCEP CFS model also gives the highest CC with April ensemble for AISMR forecast (Pattanaik and Kumar 2010).

The forecast skill of monsoon rainfall from JMA model during JJAS over a bigger domain, viz., the Indian monsoon region (IMR; 50°–110°E and 10°S–35°N) is compared with the observed rainfall departure obtained from GPCP (figure 8). Over the IMR region, the forecast and observed rainfall departure almost matches the sign and magnitude during the contrasting years of 1987 and 1988, and 2009 and 2010 (figure 8). As seen from figure 8, the CCs with March, April and May ensembles for the JJAS rainfall forecast over the IMR is found

Figure 6. Year-to-year variations of observed and JMA forecast SST anomalies with March to May initial conditions for the Nino 3.4 (5°S–5°N, 170°–120°W) regions during JJAS along with the correlation coefficient.

Figure 7. Year-to-year variations of observed and JMA seasonal EPS forecast rainfall departure with March–May initial conditions for the All India Summer Monsoon Rainfall regions during JJAS along with the correlation coefficient.

Figure 8. Year-to-year variations of observed and JMA seasonal EPS forecast rainfall departure with March–May initial conditions for the IMR (50°–110°E, 10°S–35°N) regions during JJAS along with the correlation coefficient.

to be slightly lower than the corresponding CC for AISMR forecast shown in figure 7. In the case of IMR, CC is having the similar trend with April having the highest CC significant at 98% level followed by that of March ensemble significant at 90% level and May ensemble not being significant.

4. Precipitation forecast skill

In order to determine the forecast skill of monsoon rainfall at each grid point, the spatial correlation between forecast rainfall anomaly during JJAS from JMA model with the corresponding forecast rainfall anomaly from GPCP is calculated. The anomaly correlation coefficient (ACC) and root

mean square error (RMSE) between the GPCP and JMA hindcast rainfall over the IMR region are investigated to determine the spatial distribution of forecast skill. The ACC and RMSE maps between the forecast and the verification anomaly calculated for March, April and May initial conditions (lag-3, lag-2 and lag-1, respectively), are shown in figure 9(a–c). The ACC is higher (more than 0.4; significant at 95% level) over southern India, parts of central India and eastern parts of the country and it is smaller over the isolated pockets of northeastern and western parts of the country (figure 9a–c). The spatial maps for ACC shows almost identical spatial patterns with March, April and May initial conditions. The peak ACC value is

Figure 9. Anomaly correlation coefficient (ACC) between JJAS rainfall from verification analysis (GPCP) and JMA forecast during the period from 1979 to 2010 with (a) March, (b) April, and (c) May initial conditions. Similarly the Bias corrected root mean square error (RMSE) of JMA during JJAS is shown in (d–f).

found to be over different locations with different ensembles with March having peak ACC over central India, which shift southward during April and finally, it is seen over northern India in the month of May (figure 9a–c). The RMSE (figure 9d–f) shows relatively higher values over the west coast and east coast of the country and some isolated pockets over India with a value exceeding 0.3 mm/day. Higher values of RMSE coinciding with higher bias of the JMA model forecast are shown in figure 5(d–f).

It is further seen from figure 9(c) that over central India, the forecast skill is lowest with May ensembles compared to that of March and April ensembles, which is also reflected in figure 7 indicating lowest CC between the forecast AISMR in JMA model with May initial conditions compared to that with March and April initial conditions. This further indicates that shorter lead time does not necessarily improve the rainfall forecast skill, which was also the case in

NCEP CFSv1 model as indicated by Pattanaik and Kumar (2010). It is further mentioned that the forecast skill of AISMR in a model depends on how it captures the Indian monsoon-El Nino teleconnections. Pattanaik and Kumar (2014a, b) have demonstrated that the Indian monsoon-El Nino teleconnection was not very realistic in CFSv2 model particularly with May initial conditions, whereas, it is more closer to realistic with March and April ensembles. Thus, it could be possible that in the present study, the Indian monsoon-teleconnection is not very realistic for May ensembles in the JMA model compared to March and April ensembles, which will be investigated in detail in a separate study.

5. Summary and conclusions

Based on the present study, following conclusions can be drawn. Although the mean monsoon circulation at upper level easterly over the Indian region in the JMA hindcast is slightly underestimated compared to observations, the skill of low level monsoon circulation and the broad scale Webster and Yang monsoon index is realistic in the JMA model climatology. The JMA hindcast climatology valid for JJAS shows similar patterns of mean monsoon rainfall like that of observed JJAS rainfall climatology. The pattern correlation between JMA hindcast climatology and verification climatology over the Indian monsoon region is found to be significant at 95% level. The two rainfall maxima over the west coast of India and head Bay of Bengal are well simulated in the JMA model, although the former are underestimated and the latter is shifted slightly southwestward.

With respect to the simulation of Nino 3.4 SST, the anomaly correlation shows highly significant (>99.9% level) CC with major El Nino and La Nina years are mostly simulated well in the JMA model with all the three ensembles. The May ensemble has the highest CC with the observed SST over the Nino 3.4 region. Associated with better forecast skill of Nino 3.4 SST, the all India monsoon rainfall also shows significant CC during the 32-year period with April initial condition having the highest CC. The JMA hindcast cloud was able to simulate many extreme years such as 1982, 1986, 1987, 1988, 1994, etc. The ACC maps between JMA forecast and observed rainfall anomaly indicate higher CC (>0.4) over southern India, parts of central India and eastern parts of the country and it is lower over the isolated pockets of northeastern and western parts of the country. The spatial distribution of root mean square error (RMSE) over the Indian domain also indicates useful skill of monsoon forecast over many parts of India in the JMA

model. Thus, the present analysis indicates that the JMA seasonal forecast model can be a useful tool for the dynamical seasonal forecast of AISMR.

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