

# Status of NCEP CFS vis-a-vis IPCC AR4 models for the simulation of Indian summer monsoon

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**Abstract** National Centers for Environmental Prediction (NCEP) Coupled Forecast System (CFS) is selected to play a lead role for monsoon research (seasonal prediction, extended range prediction, climate prediction, etc.) in the ambitious Monsoon Mission project of Government of India. Thus, as a prerequisite, a detail analysis for the performance of NCEP CFS vis-a-vis IPCC AR4 models for the simulation of Indian summer monsoon (ISM) is attempted. It is found that the mean monsoon simulations by CFS in its long run are at par with the IPCC models. The spatial distribution of rainfall in the realm of Indian subcontinent augurs the better results for CFS as compared with the IPCC models. The major drawback of CFS is the bifurcation of rain types; it shows almost 80–90 % rain as convective, contrary to the observation where it is only 50–65 %; however, the same lacuna creeps in other models of IPCC as well. The only respite is that it realistically simulates the proper ratio of convective and stratiform rain over central and southern part of India. In case of local air–sea interaction, it outperforms other models. However, for monsoon teleconnections, it competes with the better models of the IPCC. This study gives us the confidence that CFS can be very well utilized for monsoon studies and can be safely used for the future development for reliable prediction system of ISM.

## 1 Introduction

Simulation of Indian summer monsoon rainfall (ISMR) through numerical weather prediction model has progressed

by leaps and bounds. The last four decades have seen tremendous development in different parts of the globe, in evolution of climate models, starting from stand-alone atmospheric model to fully coupled land–ocean–atmosphere model. Serious parallel efforts were also carried out to evaluate the simulations of these complex models in the form of multi-model inter-comparison project. These evaluations started with Atmospheric Model Inter-comparison Project (Gadgil and Sajani 1998; Gates et al. 1999), thereafter, Coupled Model Inter-comparison Project (CMIP) has taken this task further in the direction of improvement (Meehl et al. 2000, 2007; Achuta Rao et al. 2004). Still lots of efforts are being done on model improvement, especially with respect to better prediction of ISMR. Despite major advances in atmospheric sciences, simulation and prediction of the Indian monsoon remains a challenging task (Gadgil et al. 2005; Nanjundiah 2009). Thus, a thorough understanding of model fidelity for realistic monsoon simulation is the need of an hour. In the similar lines for the fourth Assessment Report of Intergovernmental Panel for Climate Change (IPCC-AR4), climate modeling groups have used the state-of-the-art coupled land–ocean–atmosphere models, and the monsoon features simulated by these models have been extensively analyzed (e.g., Annamalai et al. 2007; Kripalani et al. 2007; Bollasina and Nigam 2009; Rajeevan and Nanjundiah 2009). Annamalai et al. (2007) has, in-depth, discussed about the El Niño–Southern Oscillation (ENSO) and ISMR teleconnections and found that six out of 18 IPCC-AR4 model simulations show these relationships somewhat realistically. They further argued that the basic requirement to capture the inverse relation between ENSO and ISMR depends upon the correct simulation of the timing and location of SST and diabatic heating anomalies in the equatorial Pacific and the associated changes to the equatorial Walker circulation. Kripalani et al. (2007) has shown that seven models out

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of 22 IPCC-AR4 models can simulate the mean, variability, and biennial tendency of monsoon rainfall realistically. Bollasina and Nigam (2009) have clarified that none of the IPCC-AR4 models are able to realistically simulate the summer precipitation, evaporation, and SST in the Indian Ocean, and the bias in these models often surmounts 50 % of the climatological values. Rajeevan and Nanjundiah (2009) have used the simulations of 10 IPCC-AR4 models and shown that overall there exist large biases in mean monsoon simulation using pattern correlation and root mean square error as their metric. They have further shown that all the models suffer in simulating the northward seasonal migration of the inter-tropical convergence zone (ITCZ) into the Indian landmass.

Recently, National Centers for Environmental Prediction (NCEP) Climate Forecast System (CFS) model is selected for future development for a reliable prediction system of ISMR under the ambitious Monsoon Mission Project by the Ministry of Earth Sciences, Government of India. Thus, it is desirable to critically compare simulation of CFS in its all aspect with much known models for simulation of ISMR in IPCC AR4. Again, CFS never participated for CMIP, Development of a European Multimodel Ensemble system for seasonal to interannual prediction (DEMETER, Preethi et al. 2010) or for the Ensemble-based Predictions of Climate Changes and their Impacts (ENSEMBLES, Hewitt 2004) project, thus, a proper evaluation is still required to access the credibility of the CFS as compared with other coupled models for realistic simulation of ISMR and its variability. This manuscript exclusively explores this point of concern and tries to evaluate all facets of monsoon simulation in CFS vis-a-vis IPCC AR4 models. We are just trying to answer how CFS is different from other coupled models of IPCC AR4 and how the difference translates into CFS ability (or lack of it) to realistically simulate ISMR and its variability.

Section 2 describes the model, data, and methodology used in detail. Section 3 elaborates the comparison between different model simulations. Section 4 gives the summarized conclusions.

## 2 Model, data, and methodology

The twentieth century climate simulations organized under the World Climate Research Programme (WCRP)/Climate Variability and Predictability (CLIVAR), WGCM (Working Group on Coupled Models) for assessment in the IPCC AR4 (Meehl et al. 2007) are used for the analysis. These data are archived and made available by the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) at the Lawrence Livermore National Laboratory, USA. The coupled climate models, used for the analysis along with CFS and their key references, are listed in Table 1. Each model is identified by an abbreviation, which is used throughout the text to identify a particular model. Some other description, like the approximate resolution of their atmospheric component, convection scheme used for precipitation parameterization, and the flux correction (if any) used, is listed in the same table. The additional model characteristics are given in Sun et al. (2006) and also available at [http://www-pcmdi.llnl.gov/ipcc/model\\_documentation/](http://www-pcmdi.llnl.gov/ipcc/model_documentation/).

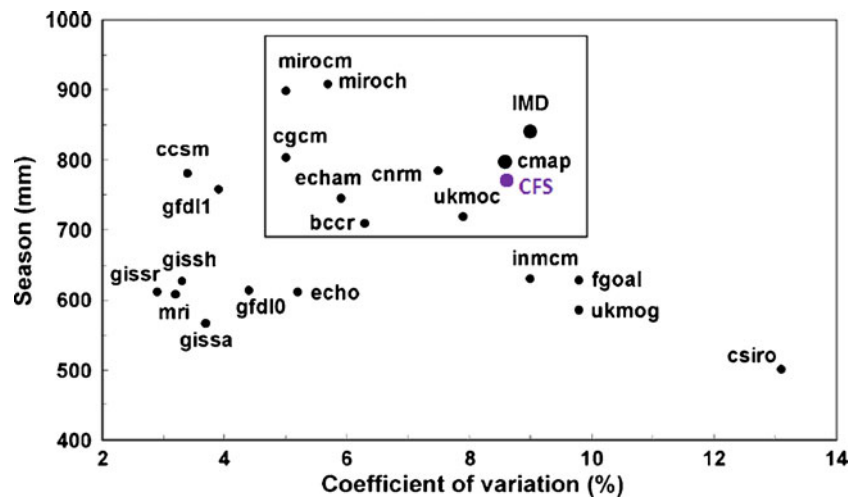
The NCEP CFS (Saha et al. 2006) is a fully coupled ocean–land–atmosphere dynamical seasonal prediction system composed of the NCEP Global Forecast System (GFS) atmospheric general circulation model (Moorthi et al. 2001) and the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model version 3 (MOM3) (Pacanowski and Griffies 1998). The atmospheric component of CFS has a spectral triangular truncation of 62 waves in the horizontal

**Table 1** List of models of IPCC-AR4 and CFS used for comparison (adapted from Kripalani et al. 2007)

No.	Modeling group	Model name	References	Approximate resolution	Convection scheme	Flux corrections
1	Bjerknes Center for Climate research, Norway	BCCR	Furevik et al. (2003)	2.8×2.8	MF	N
2	Canadian Center for Climate Modelling and Analysis, Canada	CGCM	Flato et al. (2000)	3.7×3.7	MC	HW
3	Meteo-France/Center National de Recherches Meterologiques, France	CNRM	Salas-Melia et al. (2005)	2.8×2.8	MF	N
4	Max Plank Institute for Meteorology, Germany	ECHAM	Jungclaus et al. (2006)	1.9×1.9	MF	N
5	Center for Climate System research, University of Tokyo, Japan	MIROCH	K-1 Model Developers (2004)	1.1×1.1	AS	N
6	Center for Climate System research, University of Tokyo, Japan	MIROCM	K-1 Model Developers (2004)	2.8×2.8	AS	N
7	Hadley center for Climate Prediction and research, UK	UKMOC	Jones et al. (2004)	3.7×2.5	MF	N
8	National Centers for Environment Prediction, USA	CFS	Saha et al. (2006)	2.5×2.5	AS	N

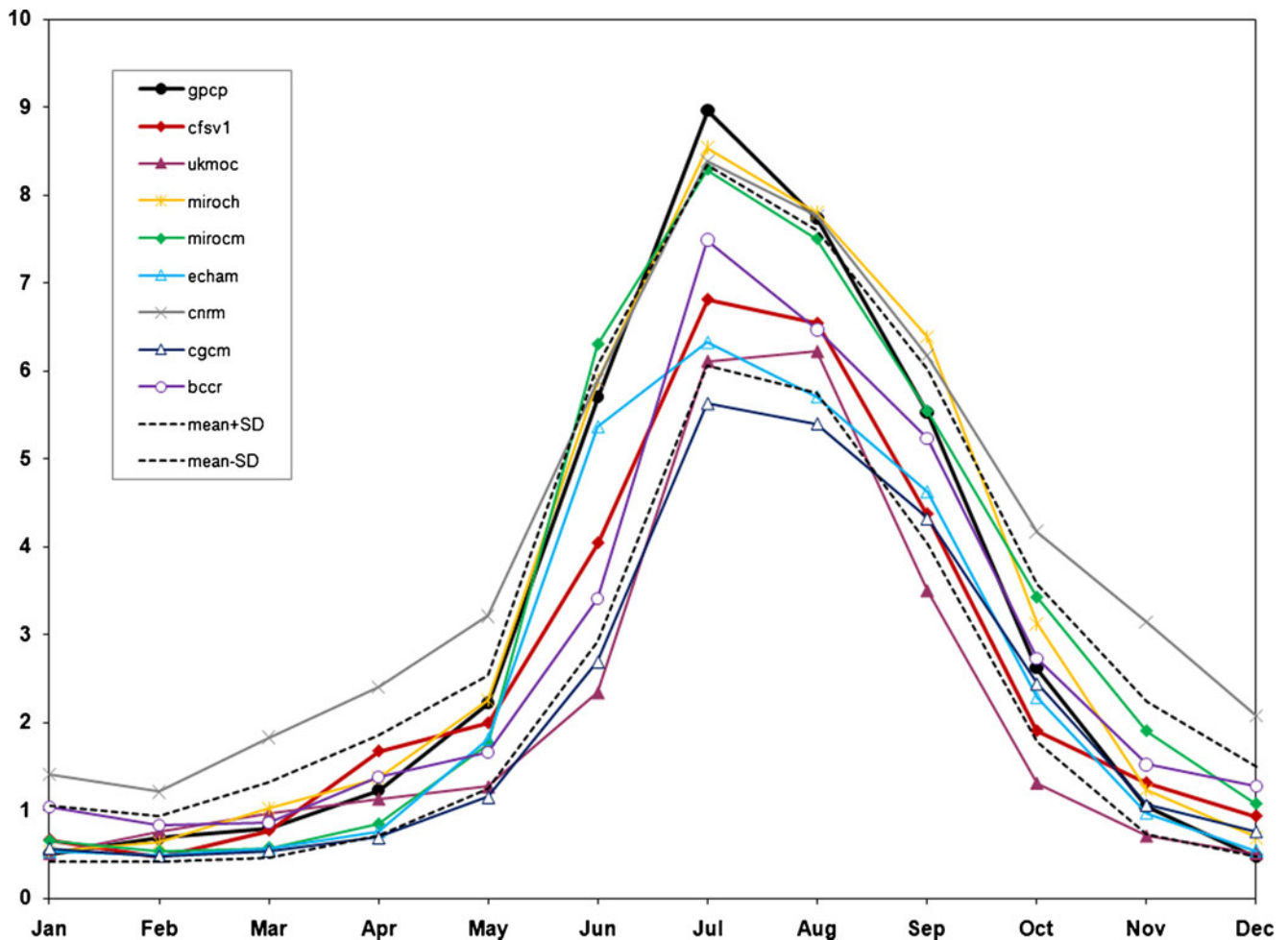
Convection scheme used (*AS* Arakawa-Schubert, *MF* mass flux-based, *MC* moist convection adjustment); flux corrections at the ocean–atmosphere interface (*N* none, *H* heat, *W* water)

**Fig. 1** Scatter plot between the mean seasonal (JJAS) rainfall in millimeters and the coefficient of variation (in percent) for 19 models as per Kripalani et al. (2007) and NCEP CFS model



and a finite differencing in the vertical with 64 sigma layers. The model top is at 0.2 hPa. Model physics include solar radiation following Hou et al. (1996), the cumulus convection scheme of Hong and Pan (1998), gravity wave drag (Kim and Arakawa 1995), and cloud water and ice (Zhao

and Carr 1997). The MOM3 uses spherical coordinates in the horizontal and z coordinate in the vertical. The zonal resolution is 1°, and the meridional resolution is 1/3° between 10°S and 10°N and gradually decreases poleward. No flux correction has been implemented in the CFS. The



**Fig. 2** Mean seasonal cycle of rainfall over Indian land points from all the models. The region between two black dotted lines shows the  $\pm 1$  standard deviation about the mean of all IPCC-AR4 models

atmospheric and oceanic models are coupled in the region between 65°S and 50°N while observed and model climatological SST are used to force the model in the region poleward of 65°S and 50°N. The two components exchange daily averaged quantities, such as heat and momentum fluxes, once per simulated day. The sea ice extent is prescribed from the observed climatology. The CFS has been ported on IBM High Performance Computing system at IITM (Indian Institute of Tropical Meteorology, Pune, India). Twentieth century simulations of CFS are performed by integrating model for 100 years.

The simulated results are validated with the Global Precipitation Climatology Project (GPCP) rainfall data (Adler et al. 2003). For SST, we have used the National Oceanic and Atmospheric Administration (NOAA) Optimal Interpolation (OI) v2 reanalysis (Reynolds and Smith 1994). For convective rain fraction, we have used Tropical Rainfall Measuring Mission-Precipitation Radar (TRMM-PR) 3A25 data (Iguchi et al. 2000).

We have tried to access the CFS capability vis-a-vis models of IPCC-AR4 using Taylor diagram. A Taylor diagram provides information of correlation, root-mean-square difference, and ratio of variances (Taylor 2001). The distance from the origin is the standard deviation of the field, normalized by the

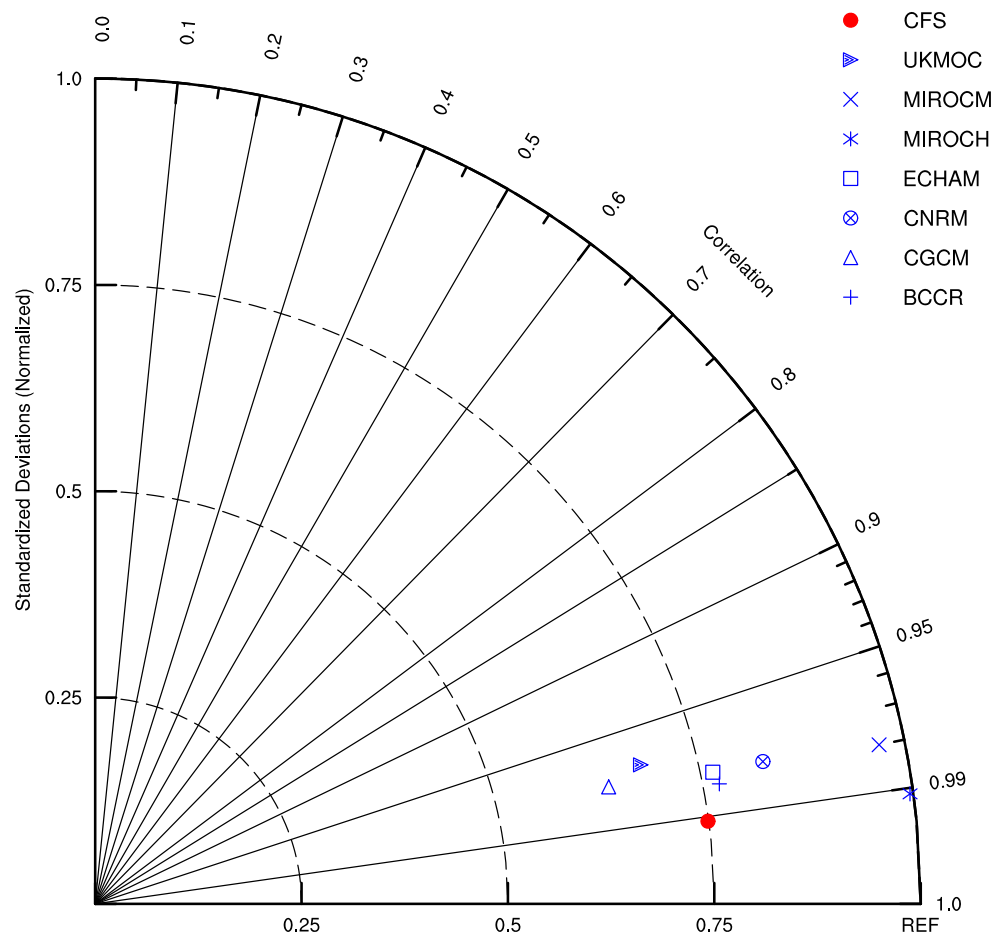
standard deviation of the observational climatology. The distance from the reference point to the plotted point gives the root-mean-square difference (RMSE). The correlation between the model and the climatology is the cosine of the polar angle. Thus, the model which has largest correlation coefficient, smaller RMSE, and comparable variance that will be close to the reference point (i.e., the observation) is considered to be the best among all.

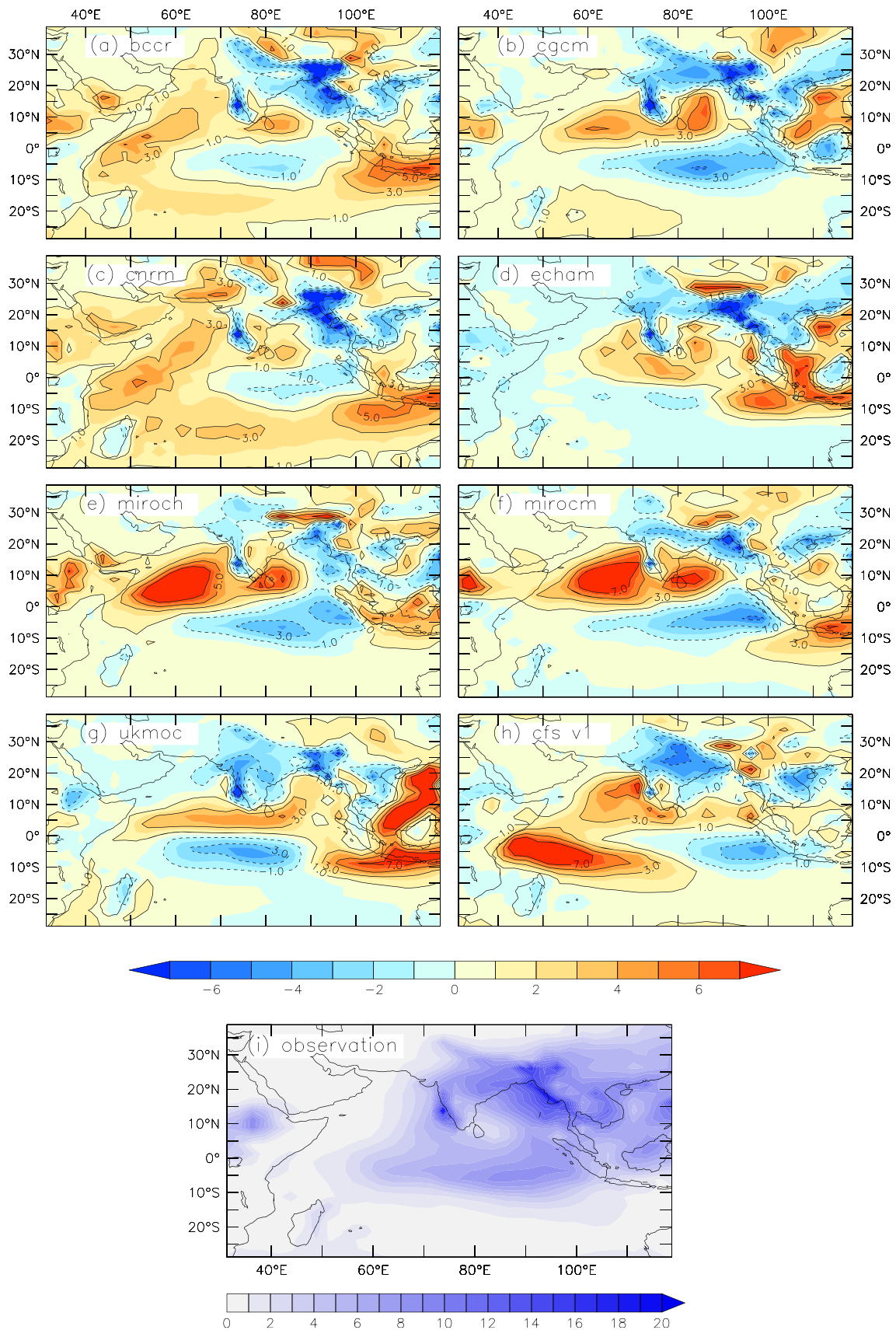
### 3 Results

Kripalani et al. (2007) has used 22 IPCC AR4 models for evaluating South Asian summer monsoon and selected seven models, which are capable of simulating ISMR mean and its variability quite realistically. As a representative of IPCC-AR4 models, we have selected these seven models (given in Table 1; CFS is also listed in the same table) because of the limited computational resources and to avoid redundancy of results.

Before going for in-depth comparison, we tried to check the CFS on the same metric as given by Kripalani et al. (2007). Seasonal averaged rainfall from June to September (JJAS) for the Indian region (5°–35° N, 65°–95° E) is

**Fig. 3** Taylor plot showing the skill of models in simulating mean seasonal cycle over Indian land points





**Fig. 4** Mean seasonal (JJAS) rainfall bias from all the models with respect to GPCP. Dotted (continuous) contours shows negative (positive) bias in the interval of 2 mm/day

calculated to examine the mean seasonal rainfall and coefficient of variability. We have tested CFS performance based on same criterion and found that CFS also satisfies the condition of being a good model (Fig. 1). This gives us the good confidence to proceed forward for exploring further aspects of monsoon dynamics in CFS simulations.

### 3.1 Mean monsoon features

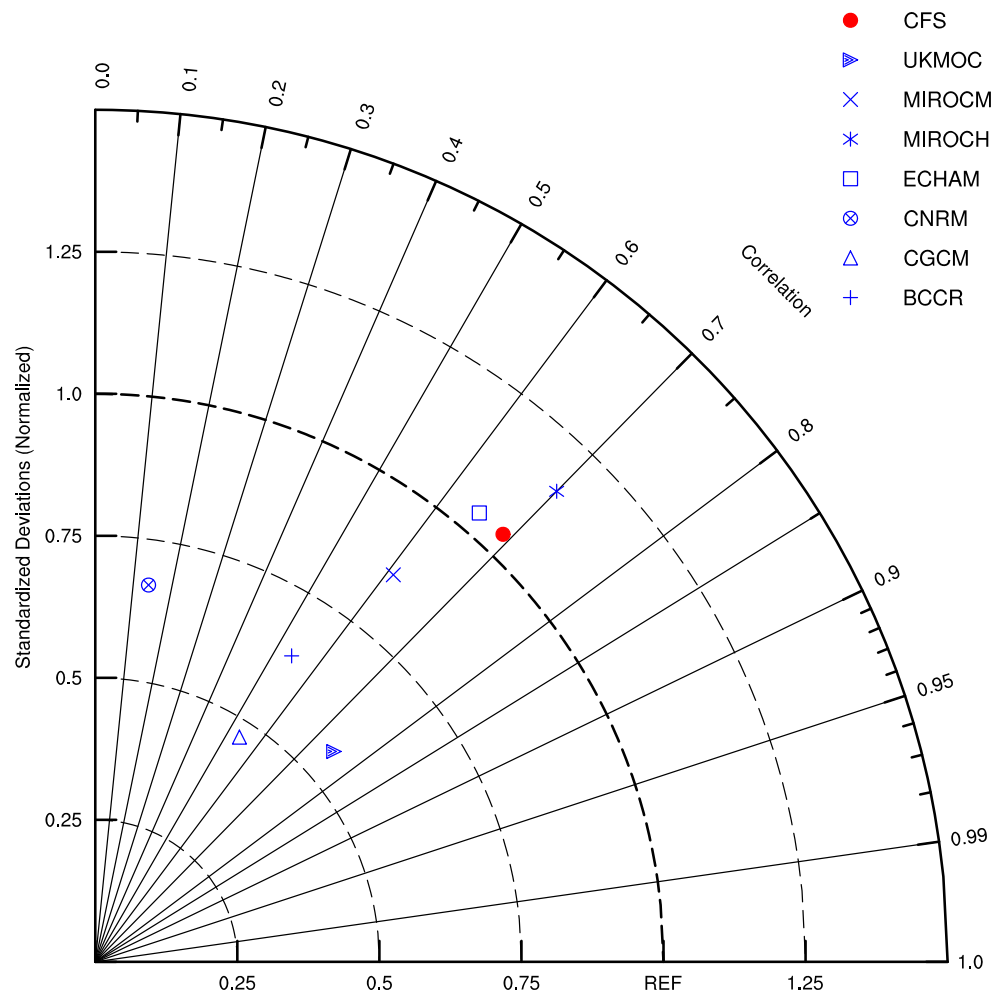
Models fidelity to simulate year to year variation of monsoon depends upon the model's ability to realistically simulate the mean features (Shukla 1984; Fennessy et al. 1994). Thus, as a prerequisite, we have investigated CFS simulation of mean features compared with IPCC-AR4 models. Already, an extensive work has been undergone for mean monsoon comparison with IPCC-AR4 models (Dai 2006; Kripalani et al. 2007; Annamalai et al. 2007; Bollasina and Nigam 2009; Rajeevan and Nanjundiah 2009). The mean feature of CFS is discussed by Achuthavarier and Krishnamurthy (2010). They have shown that CFS simulation shows the spatial structure of the mean and variability of the monsoon rainfall over Indian land region reasonably well,

however, the regional details are inadequate in all simulations. These studies give us the firm foundation to verify our analysis as well as the CFS competence vis-a-vis IPCC-AR4 models for monsoon simulation. To check mean feature of Indian summer monsoon rainfall in any model simulation, it is imperative to check (1) the accuracy of mean seasonal cycle, (2) exact spatial distribution of seasonal rainfall, (3) the proper evolution of seasonal rainfall, and (4) the distribution of exact rainfall types. These features are discussed one by one in the following sub-sections.

#### 3.1.1 Mean seasonal cycle

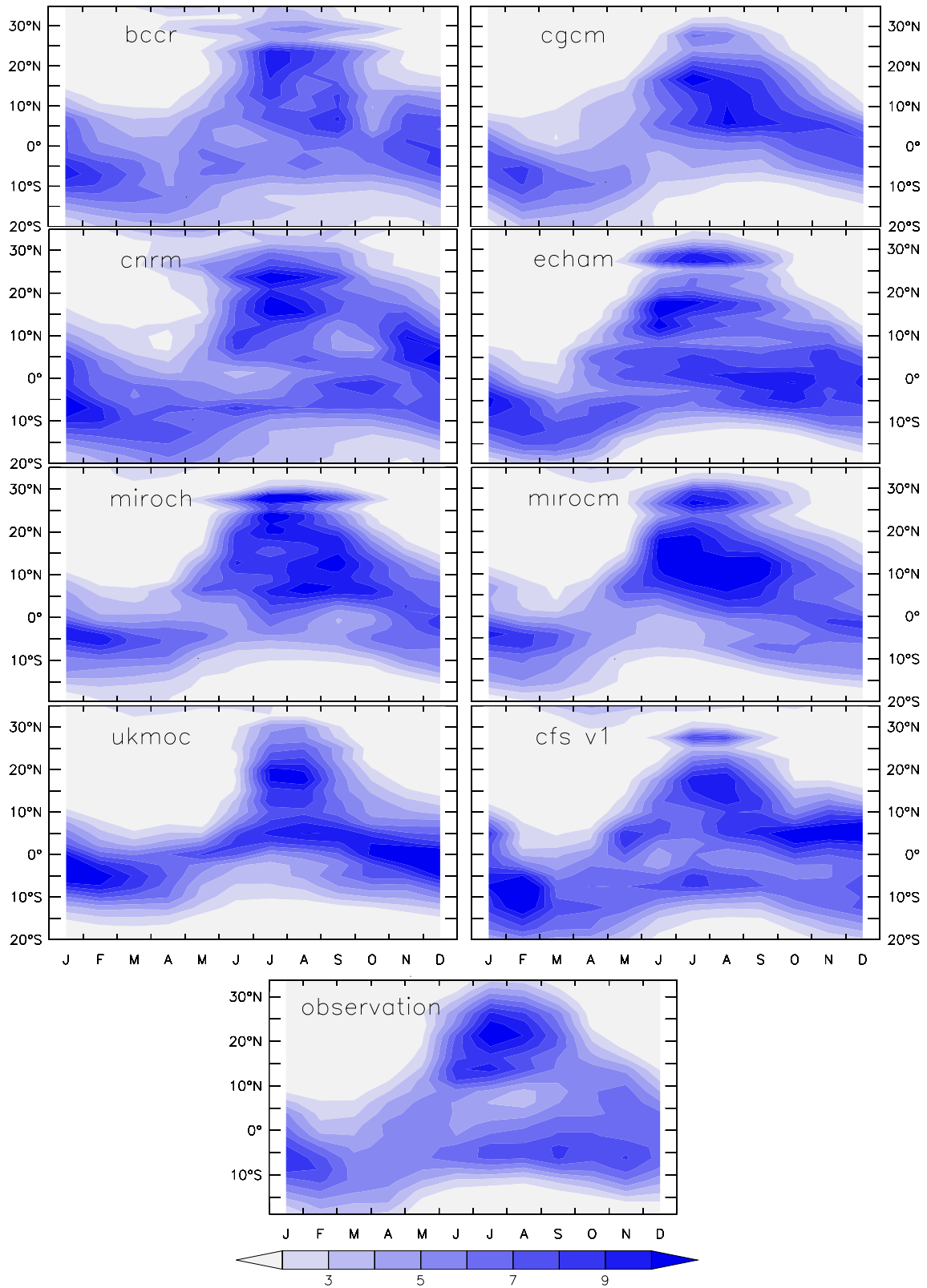
All the models simulate the mean seasonal cycle very well, as evident from Fig. 2 and the corresponding Taylor plot (Fig. 3). The phase of build-up of rainfall within JJAS season is captured properly, however, the difference lies in two aspects, (1) the amplitude of the maximum rainfall (shown by the peak of the curve) and (2) the duration of the rainfall (shown by the width of the curve in the middle). CFS fares little better as compared with CGCM, ECHAM, and UKMOC, however, MIROCH, MIROCM, BCCR, and

**Fig. 5** Taylor plot showing the skill of models in simulating spatial pattern of climatological seasonal mean over Indian land points

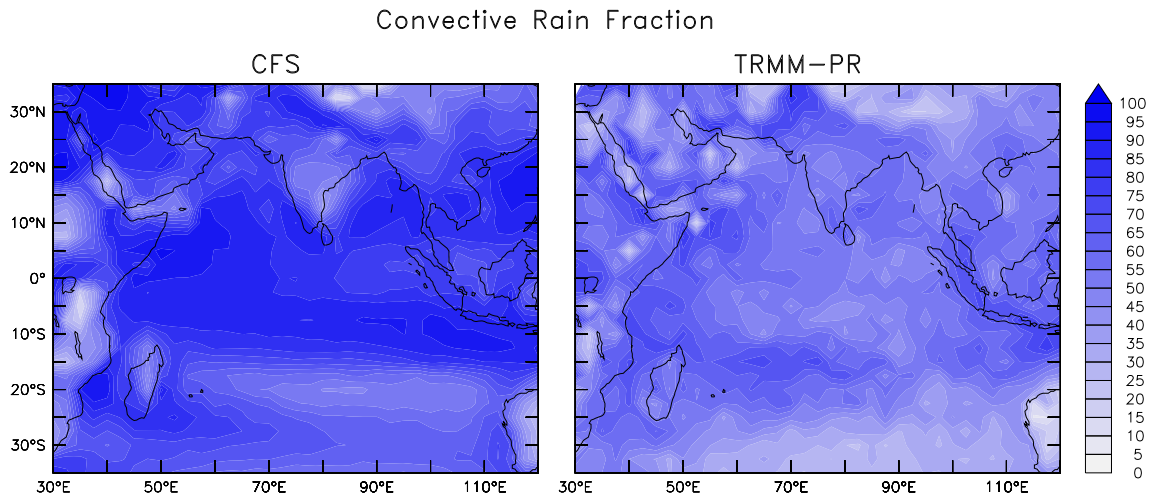


CNRM are slightly on the better side as compared with the CFS. The area between two black dotted lines shows the  $\pm 1$

standard deviation about the mean of all IPCC-AR4 models' simulated mean seasonal cycle (MSC) and thus does not



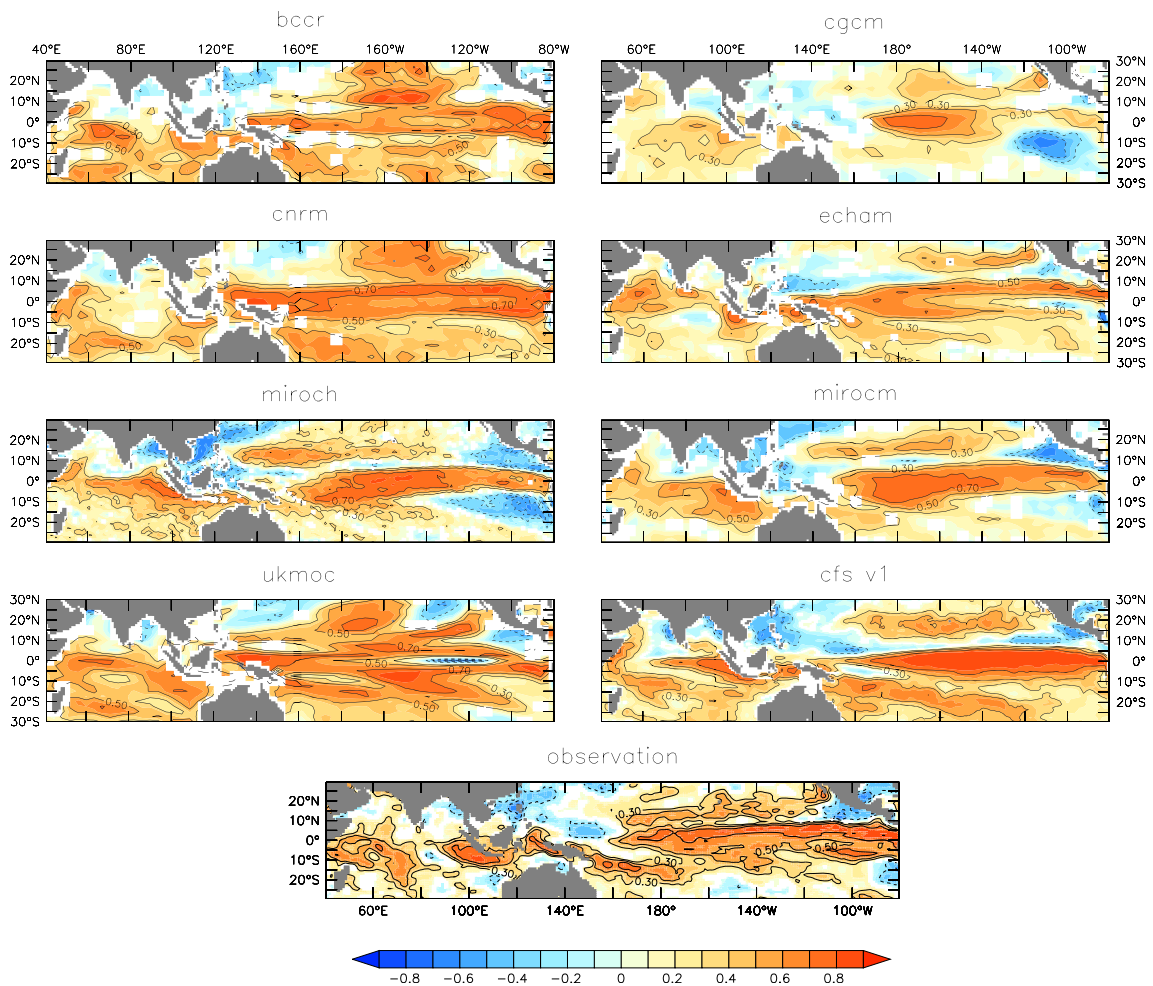
**Fig. 6** Mean monthly rain evolution from all models for the averaged longitudinal belt (70°E–90°E)



**Fig. 7** Mean seasonal (JJAS) convective rain fraction from CFS and TRMM-PR 3A25

include the CFS. It is seen that CFS (thick red line) lies exactly in the middle of this shaded portion and thus is very close to the mean of all the models.

Figure 3 shows the Taylor plot of mean seasonal cycle over Indian land points. It is clear that all models are good in simulating the mean seasonal cycle as the correlations vary



**Fig. 8** Mean seasonal (JJAS) SST–rainfall correlation at 95 % significant level. *Dotted (continuous) contours* shows negative (positive) correlation in the interval of 0.2



from 0.97 to 0.99. CFS and MIROCH have the largest correlation in case of simulating mean seasonal cycle (0.991). However, in case of variance MIROCH, MIROCM and CNRM simulations are much closer to observation as compared with CFS. Considering all aspects (correlation, variance, etc.), the simulated mean seasonal cycle of CFS is reasonable.

### 3.1.2 Spatial distribution of rainfall

The spatial pattern of rainfall distribution is characterized by the intense rain over western Ghat and north-east India, moderate over central India and east-central region, and less rainfall over west, north, and some part of south India (Fig. 4a–i). Almost all the models of IPCC-AR4 including CFS suffers from the dry rainfall bias over whole of the India above 20°N latitude and wet rainfall bias below it. CNRM, MIROCH, and MIROCM have some patches of wet bias over north of 20°N as well. The persistence of dry bias over central India is a very long-standing unresolved problem with all the coupled models of this genre (Rajeevan and Nanjundiah 2009) as well as previous AGCMs (Krishnamurthy and Shukla 2001).

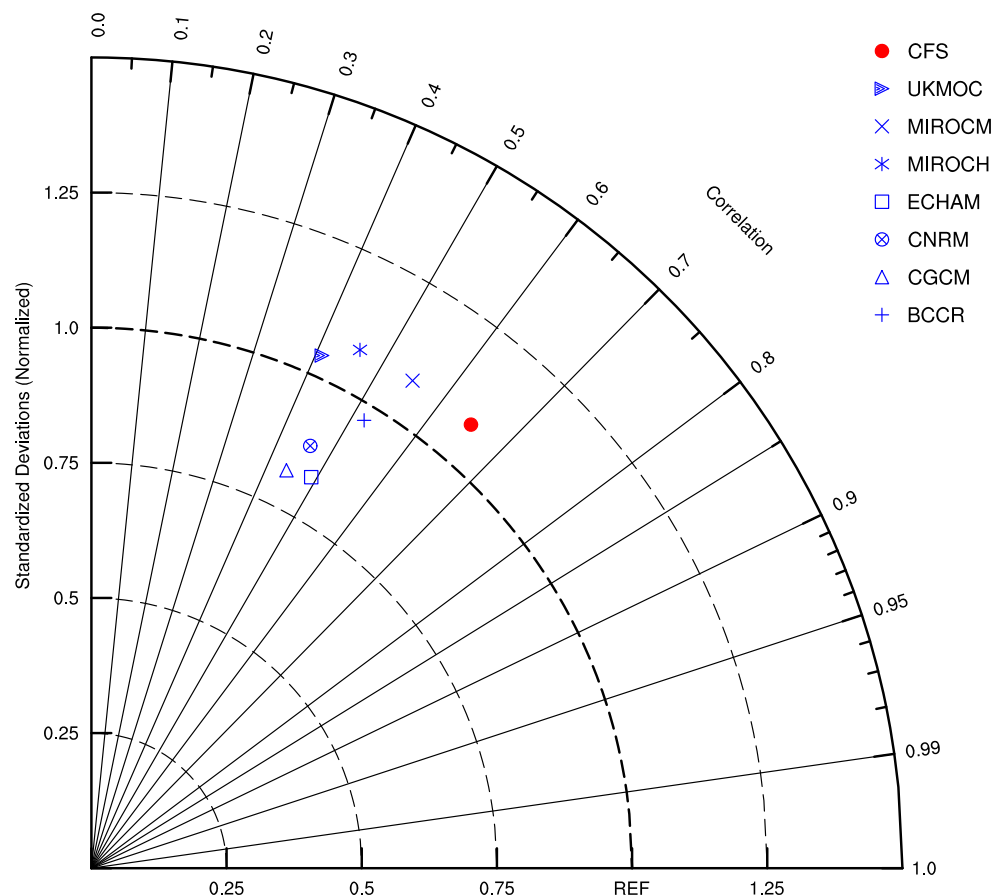
Figure 5 shows the Taylor plot of spatial pattern of climatological seasonal (JJAS) mean rainfall over Indian

land points. UKMOC and MIROCH are slightly better in case of correlation as compared with CFS. However, variance-wise, CFS and ECHAM seems to perform better. So, considering both the aspects, performance of CFS is quite satisfactory as compared with IPCC AR4 models. We have also checked the spatial pattern correlation over the region (5°–35° N, 65°–95° E) and found that CFS stands second (first being UKMOC) in capturing the seasonal mean as compared with the observation (figure not shown).

### 3.1.3 Seasonal evolution

The monsoon rainfall is evolved as a movement of ITCZ from ocean towards Indian subcontinent where it is called continental tropical convergence zone in response to the seasonal variation of the latitude of maximum insolation. Broadly, all the models have captured the swift movement of ITCZ from 10°S to northern latitudes (Fig. 6). However, in most of the models, the movement of maximum rainfall band (>8.5 mm/day) restricts up to 20°N, unlike in observation where it reaches up to 28°N. Study made by Rajeevan and Nanjundiah (2009) also confirms the same results. The exceptions are CNRM and MIROCH. The maximum rainfall band in the simulations of MIROCM and

**Fig. 9** Taylor plot showing the skill of models in simulating SST–rain relationship over the region 30°S–30°N and 40°E to 80°W for mean JJAS season



ECHAM also reaches till  $28^{\circ}\text{N}$ , however, this rainfall band is not uniform, and there is a gap in between (near central India). In case of CFS also, this movement is limited till  $20^{\circ}\text{N}$ , although small patch of rainfall exists in higher latitude, but it is of lesser magnitude and non-uniform.

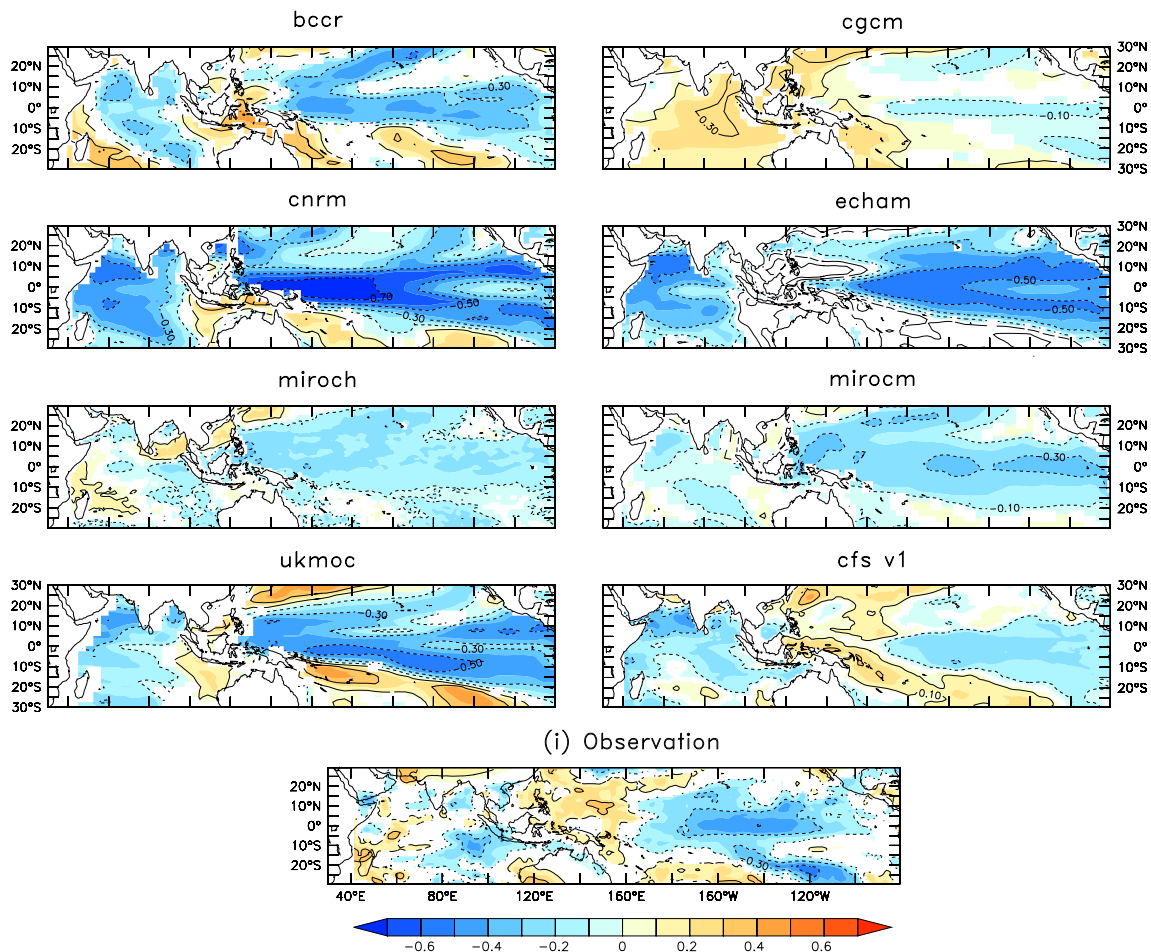
### 3.1.4 Rainfall types

Stratiform and convective rain ratio has a major effect in large-scale circulation and related dynamics through their different vertical heating profiles (Houze 1982, 1989). Thus, exact representation of different types of precipitation is very important for realistic simulation of total tropical precipitation (Tao et al. 1993; Schumacher et al. 2004). Most of the models in IPCC-AR4 have convective-to-total precipitation ratio or convective rain fraction (CRF) more than 90 %, however, the same ratio in TRMM-PR 3A25 data is of the order of 45 % to 65 % (Dai 2006). We have also calculated the CRF from CFS and compared it with TRMM-PR (Fig. 7a–b). The regions where CRF from CFS simulation and TRMM do not agree include the whole Indian

Ocean including Bay of Bengal and Arabian Sea, as well as the Himalayan region. Over these regions, CRF from CFS is in the range of 85–95 %, contrary to 45–65 % from TRMM. The only region where CRF of CFS simulation closely matches with TRMM is over central and peninsular India where it ranges from 45–60 %. CRF of the same region is also well captured in CGCM (60–70 %) and MIROC (45–70 %) simulations (Dai 2006).

### 3.2 Air–sea interactions

Indian summer monsoon is a thoroughly coupled land–atmosphere–ocean system and, to know the yearly deviation from mean monsoon the local coupling between atmosphere and ocean, has to be understood in a much better way over the tropical oceans (Wang et al. 2005; Kang and Shukla 2006). The nature of the local air–sea interaction can be characterized by the correlation between atmosphere variable (e.g., rainfall) and SST (Barsugli and Battisti 1998; von Storch 2000). Relationship between SST and rainfall is governed by SST threshold of  $27.5^{\circ}\text{C}$  in



**Fig. 10** Mean seasonal (JJAS) one-point correlation between ISMR and SST for different models and observation. Only 95 % significant correlation is plotted. Dotted (continuous) contours show negative (positive) correlation in the interval of 0.2

tropical Indian Ocean as this augurs deep convection over these regions (Gadgil et al. 2004). However, other factors like large-scale convergence, SST gradient, etc., also play significant role in determining the SST–rainfall relationship. The information regarding oceanic impact on atmosphere and vice versa is provided by the correlation between SST and rainfall. SST changes can be local and non-local. Non-local part depends on ocean advection and other dynamical factors of ocean. In this study, we shall focus on local changes of SST and its corresponding impact on rainfall.

The grid-wise SST–rain correlation (significant at 95 %) is intensely positive over tropical eastern and central Pacific in all the IPCC-AR4 models and CFS, which is in agreement with observations (Fig. 8). The exception being CGCM, which is not able to simulate the tongue of intense positive correlation over the eastern part, however, it simulates positive correlation over central Pacific. Over these tropical Pacific regions, for given positive SST anomalies, rainfall often increases quickly through enhanced surface evaporation and low-level moisture convergence because of relatively fast (1–2 weeks) atmospheric response to SST anomalies (Wang et al. 2005). The presence of negative correlation in South China Sea, western Pacific, and Bay

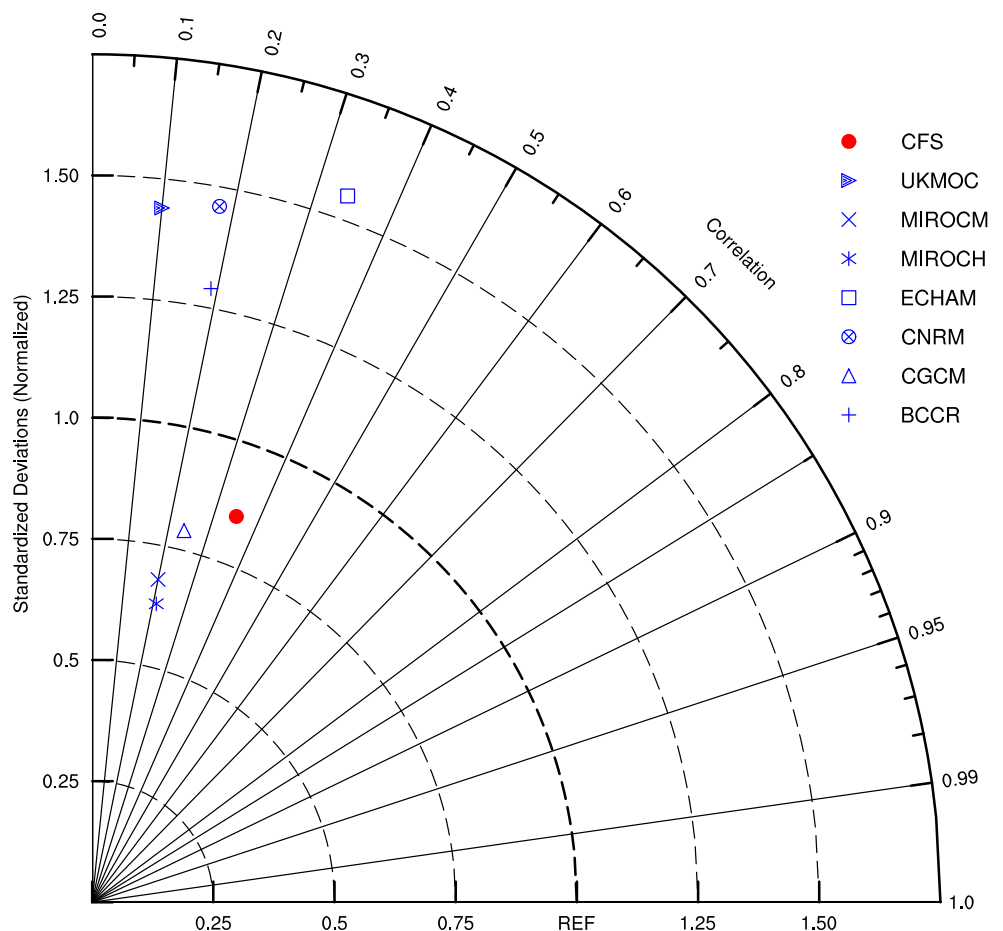
of Bengal region is nicely captured in the simulation of MIROCH, MIROCM, and CFS similar to the observation, which is either not present or reduced in intensity in other models. Thus, local SST–rainfall relationship is more realistic in CFS as compared with IPCC-AR4 models.

The same relation is also explored in terms of Taylor plot in the same region (Fig. 9). CFS has the highest correlation with observation, which indicates that spatial pattern of SST–rainfall of CFS matches better with observation. However, RMSE-wise, BCCR and UKMOC perform slightly better than CFS.

### 3.3 Monsoon teleconnections

Inter-annual variability (IAV) of ISMR is greatly affected by the climate anomalies in Pacific, Atlantic, and Indian Ocean basin. Among them, the primary sources for inter-annual variability of ISMR is ENSO (e.g., Sikka 1980; Nigam 1994; Slingo and Annamalai 2000), North Atlantic Oscillation (Rajeevan et al. 1998), North Pacific Oscillation (Walker and Bliss 1932), Eurasian snow cover (Kripalani and Kulkarni 1999; Bamzai and Shukla 1999), Indian Ocean Dipole (Saji et al. 1999), and Equatorial Indian Ocean Oscillation (Gadgil et al. 2007). The influence of ENSO on the IAV of ISMR is the most as compared with the other climatic anomalies. The

**Fig. 11** Taylor plot showing the skill of models in simulating SST–ISMR teleconnections over the region 30°S–30°N and 40°E to 80°W for mean JJAS season



linear diagnostic analysis reveals that only about 50 % of droughts in India are associated with ENSO (Kripalani and Kulkarni 1996). Annamalai et al. (2007) has elaborated these findings in IPCC-AR4 models. Since local correlation does not consider the impacts of remote forcing, to check the fidelity of models for ENSO–Monsoon teleconnections, one-point correlation between NINO3 SST and rainfall is shown at 95 % significant level over the region 30S–30N and 30E–80W (Fig. 10). For comparison purposes, the observed ISMR–SST correlation is shown in the lowest panel. All models are able to capture the negative correlation over the eastern and central Pacific as shown in the observation. However, the negative correlation is extended to the farther western Pacific in most of the models. The apparent systematic error in the westward penetration of the negative correlations was also identified by Annamalai et al. (2007). The exceptions are CGCM and CFS. Again, in CGCM, the negative correlation over Indian Ocean as seen in observation is completely missing; however, in CFS, the negative correlation is captured, but the patches of positive correlation over western Indian ocean is shifted to southern Indian Ocean.

The Taylor plot of SST–ISMR teleconnection in the region 30°S–30°N and 30°E–80°W during JJAS season is shown in Fig. 11. Correlation-wise, both CFS and ECHAM shares the same value, however, variance-wise, CFS outperforms all other models including ECHAM. So, considering both aspects, CFS stands ahead among the better models for the simulation of SST–ISMR teleconnections.

#### 4 Conclusions

This study attempts to evaluate the status of CFS simulations against the IPCC-AR4 models for monsoon research. Since any model's ability to simulate monsoon variability depends upon its fidelity to realistically simulate the mean features (Shukla 1984), as a start-up, a thorough analysis of rainfall field was done to check its mean seasonal cycle, spatial distribution pattern, seasonal evolution, and lastly, the contribution by different rain types. It is seen that the CFS and MIROC simulated mean seasonal cycle of rainfall correlates better with observation as compared with other IPCC-AR4 models, however, MIROC has less RMSE than CFS. It is also seen that CFS almost resembles the mean of all the models selected for the study in case of mean seasonal cycle. All models suffer by considerable large systematic biases within the Indian subcontinent region. The Taylor plot for spatial pattern of seasonal mean for Indian land points reveals that UKMOC and MIROC have better correlation with observation as compared with CFS; however, RMSE-wise, CFS and ECHAM perform better. The swift movement of ITCZ (precipitating area >8.5 mm/day) from equatorial tropical Indian Ocean to Indian land region is

captured by almost all the models, however, the northern extent of this movement is restricted up to 20°N in CSF, contrary to the observation where it reaches 28°N. The exceptions are MIROC, CNRM, and MIROCM, however, this band is not continuous from 10°N to 28°N as in observation. The convective rain fraction in CFS is very much overestimated as compared with observation. CFS simulation shows that CRF is 80–90 % in Indian sub-continent region, contrary to the observation where it is only 50–65 %; however, the same lacuna creeps in other models of IPCC as well. The only respite is that, it realistically simulated the proper ratio of convective and stratiform rain over central and southern part of India. CGCM (60–70 %) and MIROCM (45–70 %) also able to capture this fraction somewhat realistically over Indian land points. The better part of CFS is its ability to capture the local air–sea interaction in much better way than any model of IPCC-AR4. The Taylor plot shows that, both correlation and RMSE-wise, CFS outperforms all other models, implying the SST–rainfall relationship is much more realistic in CFS. It has great importance since predictability of ISMR depends upon this relationship. In similar lines, the monsoon teleconnections by CFS also fares well as compared with all other models. ECHAM and CFS share much higher correlation among other models, however, RMSE-wise, CFS is better than ECHAM.

Overall, among the models of IPCC-AR4, the mean monsoon simulation is better represented by MIROC, MIROCM, and CFS. In rain types CFS, CGCM and MIROCM perform better. In air–sea interaction, both local and remote CFS, MIROCM, and ECHAM perform the much better. Thus, considering all aspects of monsoon simulations, CFS is listed among the better models of IPCC-AR4.

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