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Possible future projection of Indian Summer Monsoon Rainfall (ISMR) with the evaluation of model performance in Coupled Model Inter-comparison Project Phase 5 (CMIP5)

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ABSTRACT

The Indian Summer Monsoon (ISM) is crucial for agriculture and water resources in India. The large spatial and temporal variability of Indian Summer Monsoon Rainfall (ISMR) leads to flood and drought especially over northern plains of India, so quantitative and qualitative assessment of future projected rainfall will be important for policy framework. Evaluation of models performance in simulating rainfall and wind circulation of the Historical experiment (1961–2005) and its future projected change in RCPs (2006–2050) 4.5 and 8.5 in CMIP5 are carried out. In the Historical experiment, the model simulated rainfall is validated with observed rainfall of IMD (1961–2005) and GPCP (1979–2005) and only six (6) models BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(WACCM), and MPI-ESM-MR are found suitable in capturing ISMR and JJAS wind circulation at 850 & 200 hPa as in NCEP reanalysis, which shows anticyclonic circulation over Arabian Sea at 850 hPa and cyclonic circulation at 200 hPa along with excess and deficit rainfall over monsoon regions of NWI, NEI, WCI, CNI and PI at 99% & 95% confidence levels. Future projected change of JJAS wind shows anticyclonic circulation over Arabian Sea at 850 hPa and cyclonic circulation around 40° N,70°E-90°E at 200 hPa which may be a possible cause of changes in JJAS rainfall over Indian regions.

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1. Introduction

The Indian Summer Monsoon (ISM) produces around 80% of its rainfall during the months of June-July-August-September (JJAS). The early or late onset of ISM and large spatial and temporal variability of Indian Summer Monsoon Rainfall (ISMR) causes floods and droughts (IPCC, 2007) and greatly affects agriculture and water resources in northern plain of the country.

In recent decades, spatial and temporal variability of rainfall have been supposed to change, but no clear evidence of global warming impact on long term series of All India Summer Monsoon Rainfall (Mooley and Parthasarathy, 1984; Kripalani et al., 2003; Guhathakurta and Rajeevan, 2008) is noticed. However, some significant trend is found at regional levels (Kumar et al., 1992; Goswami et al., 2006). The global model inter-comparison activities began in late 1980s (Cess et al., 1989) and continued with the Atmospheric Model Inter-comparison Project (AMIP) (Gadgil and Sajani, 1998; Gates et al., 1999). Researchers have examined the skill of climate models in simulating rainfall variability and the inherent bias in representation of mean monsoon rainfall and its variability on different time scales (Meehl and Washington, 1993; Kitoh et al., 1997; Gadgil and Sajani, 1998; Hu et al., 2000; Cubasch et al., 2001; Lal et al., 2001; Kang et al., 2002; May, 2002; Wang et al., 2004; Fan et al., 2012). Gadgil and Sajani (1998) have used twenty (20) Atmospheric Global Circulation Models (AGCMs) under AMIP and shows that models have not evolved to a stage where year-to-year variation of ISMR can be represented, since models have their own limitations in capturing the regional rainfall accurately (Turner and Annamalai, 2012). However, modeling studies have been carried out under different emission scenarios for the study of future summer monsoon rainfall. Very little change in All India Summer Monsoon Rainfall is noticed in climate models experiments (Lal et al., 1994, 1995; Mahfouf et al., 1994; Timbal et al., 1995). Climate models experiments have also been carried out under the Coupled Model Inter-comparison Project (CMIP) (Meehl et al., 2000; Kang et al., 2002; Covey et al., 2003; Achuta-Rao et al., 2004; Kucharski et al., 2008). In 1990s, World Climate Research Programme (WCRP) coordinated CMIP to perform control runs and idealized 1% per year CO_2 increase experiments in climate models (Meehl, 1997). Several additional phases of the CMIP, termed as CMIP2 and CMIP2+ (Meehl et al., 2000, 2005; Covey et al., 2003) were also carried out.

Kripalani et al. (2007a) have studied changes in East Asian monsoon mean precipitation and its variability in Coupled Model Intercomparison Phase 3 (CMIP3) and conducted t-test and F-ratio respectively to evaluate their statistical significance. The changes in mean precipitation

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Table 1
List of CMIP5 models in Historical experiment.

Serial no.	Center/Country	Models	Resolution
1	Beijing Climate Center, China	BCC-CSM1.1	128 × 64
2	Beijing Climate Center, China	BCC-CSM1.1(m)	320 × 160
3	College of Global Change and Earth System Science (GCESS), China	BNU-ESM	128 × 64
4	Canadian Centre for Climate Modelling and Analysis(CCCMA), Canada	CanCM4	128 × 64
5		CanESM2	128 × 64
6	National Center for Atmospheric Research (NCAR)/United States	CCSM4	288 × 192
7	Community Earth System Model Contributors (NSF-DOE-NCAR), USA	CESM1(BGC)	288 × 192
8		CESM1(CAM5)	288 × 192
9		CESM1(FASTCHEM)	288 × 192
10		CESM1(WACCM)	144 × 96
11	National Centre for Meteorological Research, France	CNRM-CM5	256 × 128
12		CNRM-CM5-2	256 × 128
13	Commonwealth Scientific and Industrial Research Organization (CSIRO-MK3L-1-2), Australia	CSIRO-Mk3L-1-2	192 × 96
14	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, IAP,China	FGOALS-g2	128 × 60
15	The First Institute of Oceanography (FIO), China	FIO-ESM	128 × 64
16	NASA Goddard Institute for Space Studies (NASA GISS), USA	GISS-E2-H	144 × 90
17		GISS-E2-H-CC	144 × 90
18		GISS-E2-R	144 × 90
19		GISS-E2-R-CC	144 × 90
20	National Institute of Meteorological Research/Korea Meteorological Administration (NIMR/KMA), Korea	HadGEM2-AO	192 × 145
21	Met Office Hadley Centre (MOHC), United Kingdom	HadGEM2-ES	192 × 145
22	Institute for Numerical Mathematics (INM), Russia	INM-CM4	180 × 120
23	Institut Pierre-Simon Laplace (IPSL), France	IPSL-CM5A-LR	96 × 96
24		IPSL-CM5A-MR	144 × 143
25		IPSL-CM5B-LR	96 × 96
26	University of Tokyo, National Institute for Environment Studies, Japan	MIROC4h	640 × 320
27		MIROC5	256 × 128
28	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan	MIROC-ESM	128 × 64
29		MIROC-ESM-CHEM	128 × 64
30	Max Planck Institute for Meteorology (MPI-M), Germany	MPI-ESM-LR	192 × 96
31		MPI-ESM-MR	192 × 96
32		MPI-ESM-P	192 × 96
33	Meteorological Research Institute (MRI), Japan	MRI-CGCM3	320 × 160
34		MRI-ESM1	320 × 160

varied from −0.6% for CNRM-CM3 to 14% for ECHO-G and UKMO-HadCM3. Kripalani et al. (2007b) also examined South Asian Summer Monsoon precipitation variability in models of International Panel on Climate Change Assessment Report 4 (IPCC AR4). Only nineteen (19) models, out of twenty two (22) models of IPCC AR4, could capture 500–900 mm rainfall during summer monsoon season. This simulated mean precipitation in IPCC AR4 varies from 500 to 900 with coefficient of variation from 3 to 13%. An increase of 8% in mean monsoon precipitation is projected under doubling of CO_2 scenario. Sabade et al. (2010) used CMIP3 data set in scenarios B1, A1B, A2 and examined responses of South Asian summer monsoon to a transient increase in future anthropogenic radiative forcing for the period of 2031–2050 and 2081–2100. Selected ten (10) models have been examined for projected changes in seasonal monsoon rainfall and found an increase in precipitation over western equatorial Indian Ocean and southern parts of India. Parth-Sarthi et al. (2012) studied the possible future changes in ISMR in A2, B1 and A1B scenarios in CMIP3 data. Ashfaq et al. (2009) used a high resolution nested model and suggested suppression of ISMR in future time periods due to weakening of the monsoon circulation.

Table 2
List of CMIP5 models in RCPs experiment.

Serials No.	Models	RCP 4.5	RCP 8.5
1	BCCCSM 1.1(m)	√	√
2	CCSM4	√	√
3	CESM1(CAM5)	√	√
4	CESM1 (BGC)	√	√
5	CESM1 (WACCM)		√
6	MPI-ESM-MR	√	√
7	CESM1 (FASTCHEM)		

Interannual variability of the monsoon and its interaction with the seasonal processes and teleconnections in the tropics is an important objective of CMIP5 (Cook et al., 2012; Lee and Wang, 2012; Li et al., 2012; Meehl et al., 2012). The CMIP5 Multi-Model Mean (MMM) is more skillful than the CMIP3 MMM with respect to observations (Sperber et al., 2013). Research work is carried in many ways on Indian Summer Monsoon using CMIP5 and CMIP3 data. In CMIP5, the RCP 4.5 experiment (2075–2099), an increase occurs in global mean precipitation of around 3.2%/K (Hsu et al., 2013) and there is a larger increase in annual mean precipitation over the Asian monsoon region with less uncertainty as compared to CMIP3 models (Lee and Wang, 2012). Taylor et al. (2011) studied precipitation in monsoon regions under various radiative forcings in 21st century of CMIP5 and Cherchi et al. (2011) analyzed global monsoons in a fully coupled atmosphere-ocean general circulation model and suggested intensification of summer monsoon in future in response to the increased moisture under CO_2 forcings. The Hamburg COSMOS model shows a complex behavior with changing skewness of the rainfall distribution and an associated increase in monsoon failure events (Schewe and Levermann, 2012). Preethi et al. (2012) evaluated performance of climate models in simulating observed variability of ISMR in CMIP5 data and estimated future projections of ISMR. Menon et al. (2013b) studied variability of ISMR in twenty (20) models in CMIP5 for mid 19th century to the end of 21st century and suggested significant increase in ISMR and sub-seasonal variability under unmitigated climate change (Menon et al., 2013a). Kitoh et al. (2013) evaluates global monsoons in CMIP5 historical and climate change simulations, including statistical testing of changes in the pattern of Asian summer monsoon rainfall. Bandgar et al. (2014) demonstrates the importance of Northwest Pacific (NWP) circulation variability in predicting summer monsoon precipitation over South Asia and addressed cyclonic circulation and associated

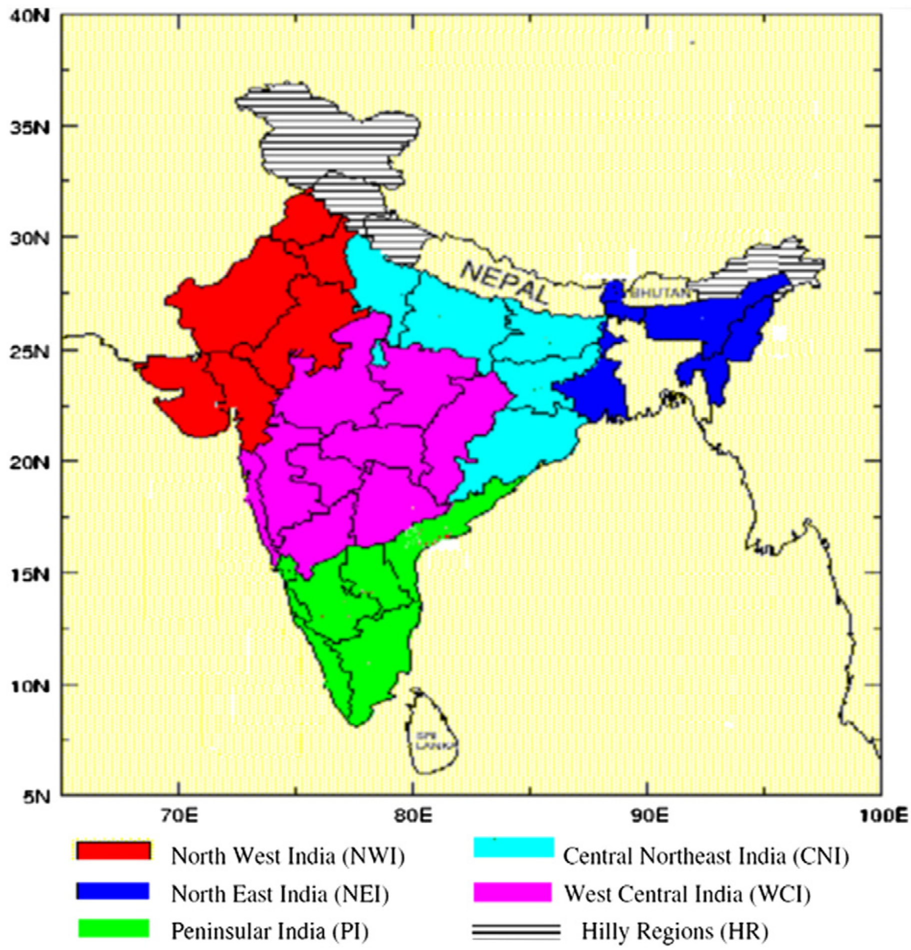


Fig. 1. Homogeneous monsoon regions of India (Source: India Institute of Tropical Meteorology, Pune, India).

deficit of ISMR. Subodh et al. (2014) tries to extensively assess the capability of CFSv2 in simulating the ISMR and prioritizes areas which require considerable improvement for the better prediction skill of Indian summer monsoon. They have carried out 30 years of forecast system free runs to understand improvements in the prediction skill in CFSv1 and CFSv2 models with present-day initial conditions. Thus, the intraseasonal and interannual variability simulated by the model can be assessed along with the observations.

Previous studies, projected rainfall and wind circulation in CMIP5 data does not require much attention over the homogeneous monsoon regions of India. The present paper is aimed to evaluate the model's performance in simulating rainfall and wind circulation and their future projected changes over homogenous monsoon regions in RCPs 4.5 and 8.5 of CMIP5. The details of models, data and experiments are given in Section 2. Section 3 describes CMIP5 models performance in simulating rainfall and wind circulation under Historical Experiment while Section 4 deals with possible future projected changes of rainfall and wind circulation in RCP 4.5 and 8.5. Conclusions are discussed in Section 5.

2. Models, data and experiments

Tables 1 and 2 show list of models used in Historical and RCPs of 4.5 and 8.5 in CMIP5 data. The Historical experiment is equivalent to the 20th century simulation (20C3M) of CMIP3 and models are integrated from 1850 to 2012 with external forcing changing with time. The external forcing includes GHGs, the solar constant, volcanic activity, ozone and aerosols. The forcing data for 1850–2005 is taken from observation. To evaluate model's performance, simulated rainfall in Historical experiment for the period of 1961–2005 is compared with observed gridded (resolution of $1° \times 1°$) rainfall of India Meteorological Department (IMD) for the period of 1961 − 2005 and observed rainfall (resolution of $2.5^0 \times 2.5^0$) of GPCP (Adler et al., 2003) for the period of 1979 − 2005, respectively. The NCEP/NCAR Reanalysis project is used to state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present. This reanalysis NCEP/NCAR grided data set (Kalnay et al., 1996) of wind at 2.5^0x 2.5^0 resolutions for period of 1961–2005 is used for JJAS wind at 850 and 200 hPa.

The RCPs of 4.5 and 8.5 represent radiative forcing of 4.5 and 8.5 Watt /m^2 by 2100, respectively. In RCPs simulation, no volcanic forcing is included. The GHGs, solar constant, ozone and aerosol are all a function of time. The RCPs experiments are based on multi-gas emission scenarios (Fujino et al., 2006; Smith and Wigley, 2006; Clarke et al., 2007; Riahi et al., 2007, 2011; Van-Vuuren et al., 2007; Hijioka et al., 2008; Wise et al., 2009; Masui et al., 2011; Thomson et al., 2011; Van-Vuuren et al., 2011a). An overview of RCPs is explained by Van-Vuuren et al. (2011b). In the current study, future projected rainfall and wind is considered for the period of 2006–2050 of RCPs of 4.5 and 8.5.

3. Evaluation of CMIP5 model's performance

Fig. 1 depicts homogeneous monsoon regions namely North West India (NWI), Central Northeast India (CNI), North East India (NEI), West Central India (WCI), Peninsular India (PI) and Hilly Regions (HR) (Das, 2009). Averaging of rainfall over the Indian land region is done

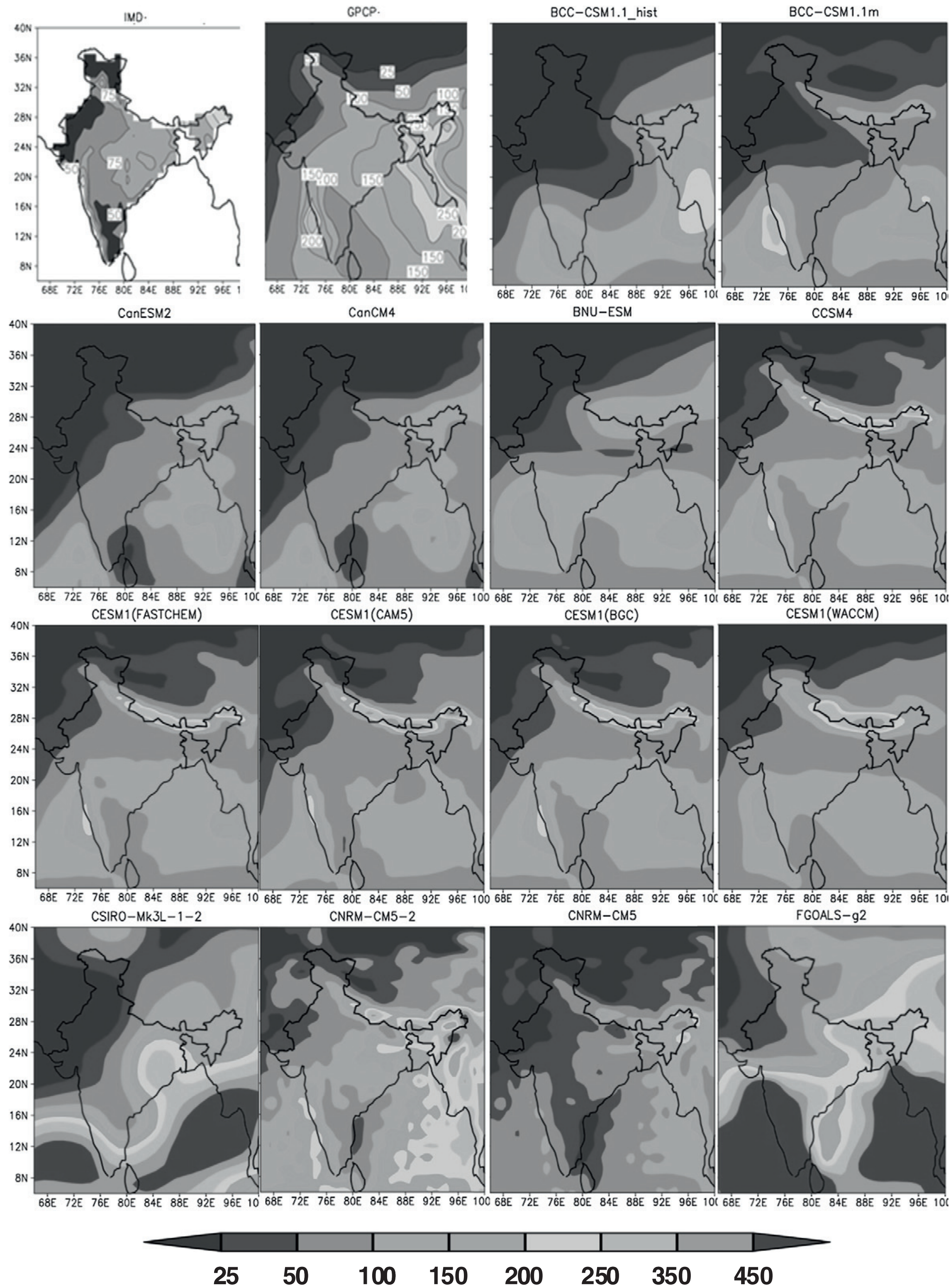


Fig. 2. Spatial distribution of accumulated anomalies JJAS Summer monsoon rainfall (mm month^{-1}) in observation of IMD, GPCP and in Historical experiment listed in Table 1.

by averaging rainfall on those grids which represents the land regions. The validation of CMIP5 models in simulating rainfall is done with IMD and GPCP observations.

Fig. 2 depicts the spatial distribution of JJAS rainfall (mm month^{-1}) in simulation of thirty four (34) models of Historical experiment and observation of IMD, GPCP. Fig. 3 shows annual cycle of simulated rainfall in thirty four (34) climate models of Historical experiment, in observation of IMD (black dotted line) and of GPCP (Red dotted line). It is difficult to get information about a particular model (Sperber and Annamalai, 2014); however it may be summarize that how well each model simulated rainfall is comparable with observation of IMD and GPCP. Therefore, Taylor's diagram method (Taylor, 2001) is used in assessing relative performance (quantatively) of models simulated rainfall over observation. In Fig. 4a-b, the diagram shows the degree of similarity

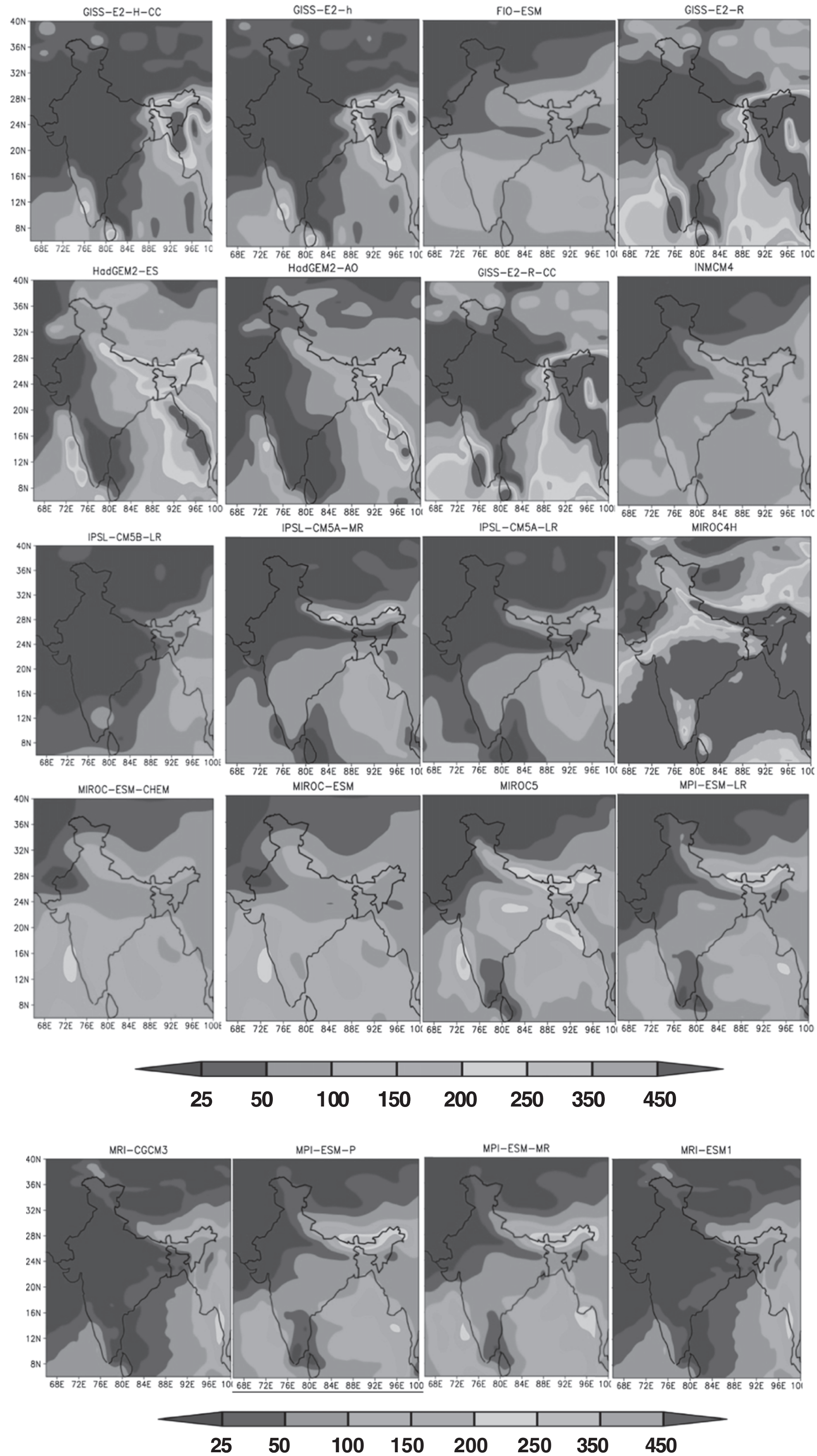


Fig. 2 (*continued*).

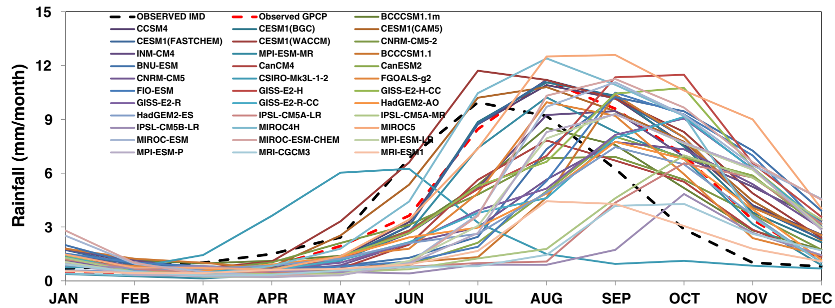
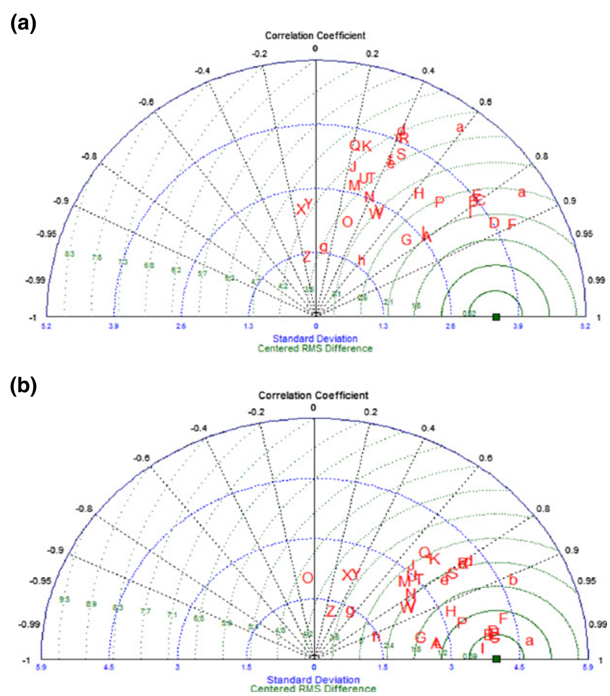


Fig. 3. Annual cycle of rainfall (mm month^{-1}) over Indian land region of all model in Historical experiment (1961–2005) of CMIP5.



A	BCCCSM1.1m	H	INM_CM4	O	CSIRO-Mk3L-1-2	V	HadGEM2-AO	c	MIROC-ESM
B	CCSM4	I	MPI_ESM_MR	P	FGOALS-g2	W	HadGEM2-ES	d	MIROC-ESM-CHEM
C	CESM1_BGC	J	BCCCSM1.1	Q	FIO-ESM	X	IPSL-CM5A-LR	e	MPI-ESM-LR
D	CESM1_CAM5	K	BNU-ESM	R	GISS-E2-H	Y	IPSL-CM5A-MR	f	MPI-ESM-P
E	CESM1_FASTCHEM	L	CanCM4	S	GISS-E2-H-CC	Z	IPSL-CM5B-LR	g	MRI-CGCM3
F	CESM1_WACCM	M	CanESM2	T	GISS-E2-R	a	MIROC4H	h	MRI-ESM1
G	CNRM-CM5-2	N	CNRM-CM5	U	GISS-E2-R-CC	b	MIROC5		

Fig. 4. a-b Taylor diagram of 34 models in Historical experiment displaying statistical relation with observed rainfall of (a) IMD and (b) GPCP respectively. The radial distance from the origin is proportional to the standard deviation of a pattern. The centered RMS difference between the test and reference field is proportional to their distance apart (in the same units as the standard deviation). The correlation between the two fields is given by the azimuthal position of the test field.

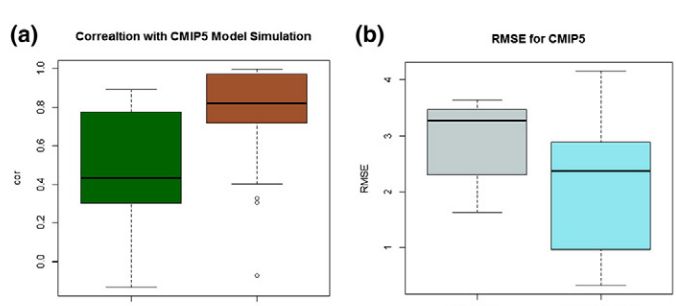


Fig. 5. a-b Boxplots showing the distribution of models scores in CMIP5 for (a) correlation between observed (IMD, GPCP and CMIP5 simulation). (b) RMS error(IMD, GPCP and CMIP5 simulation). The box shows the inter-quartile range and circles are outliers.

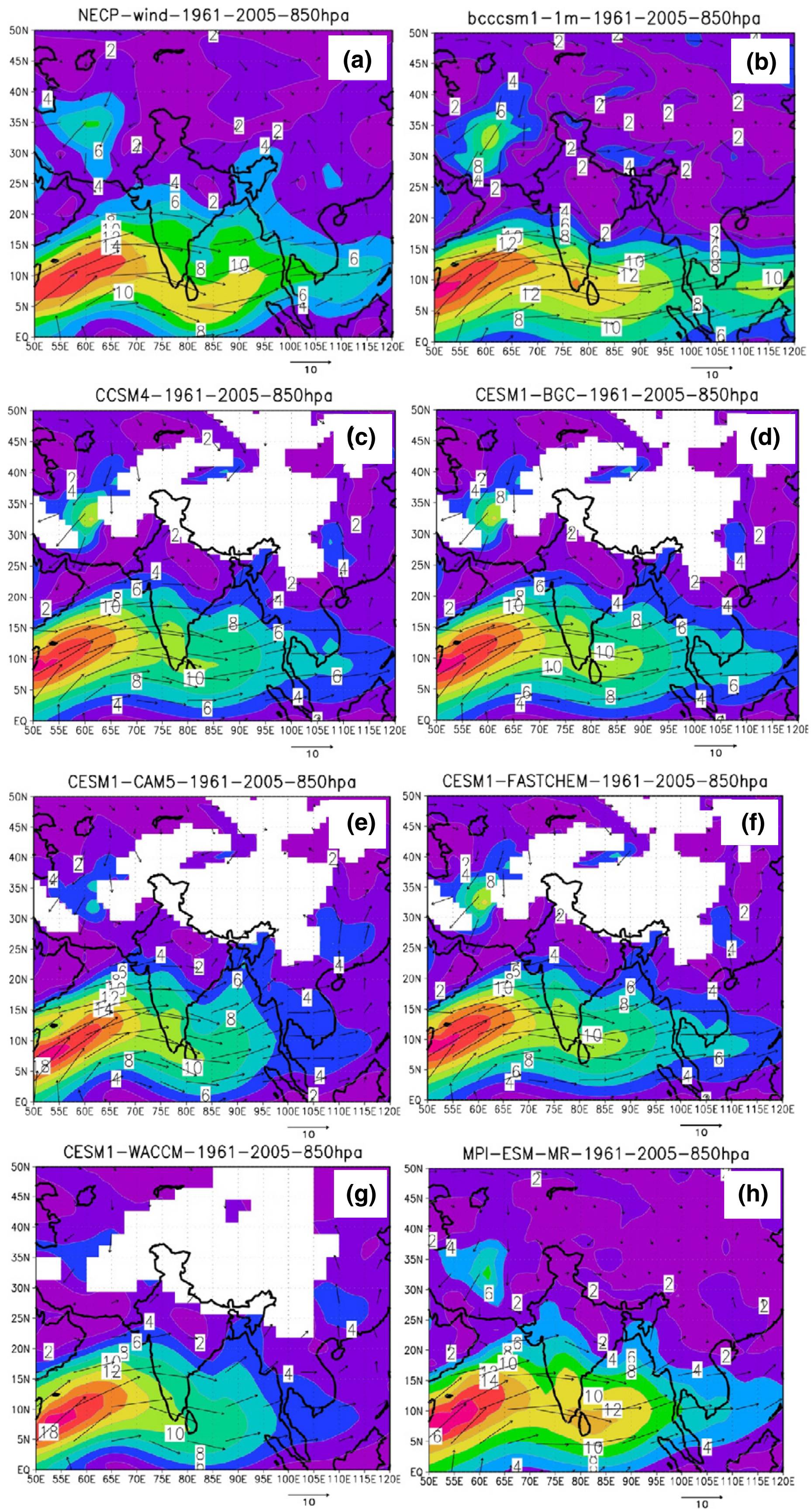


Fig. 6. a-h Mean JJAS (m s^{-1}) wind at 850 hPa during period of 1961–2005 in Historical experiment; (a) NCEP; (b) BCC-CSM1.1 m; (c) CCSM4; (d) CESM1-BGC; (e) CESM1-CAM5; (f) CESM1-FASTCHEM; (g)CESM1-WACCM; (h) MPI-ESM-MR.

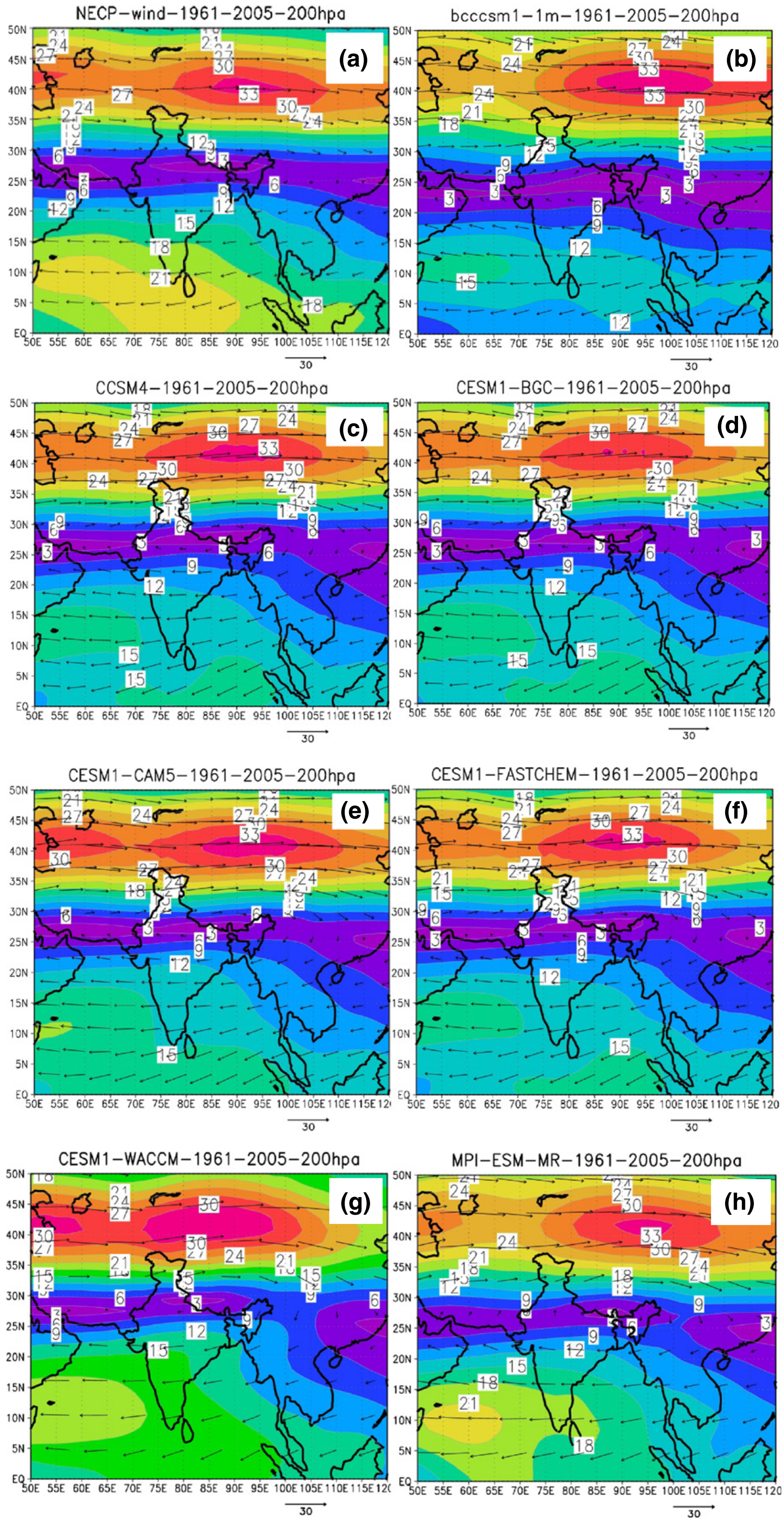


Fig. 7. a-h Mean JJAS (m s^{-1}) wind at 200 hPa during period of 1961–2005 in Historical experiment; (a) NCEP; (b) BCC-CSM1.1 m; (c) CCSM4; (d) CESM1-BGC; (e) CESM1-CAM5; (f) CESM1-FASTCHEM; (g)CESM1-WACCM; (h) MPI-ESM-MR.

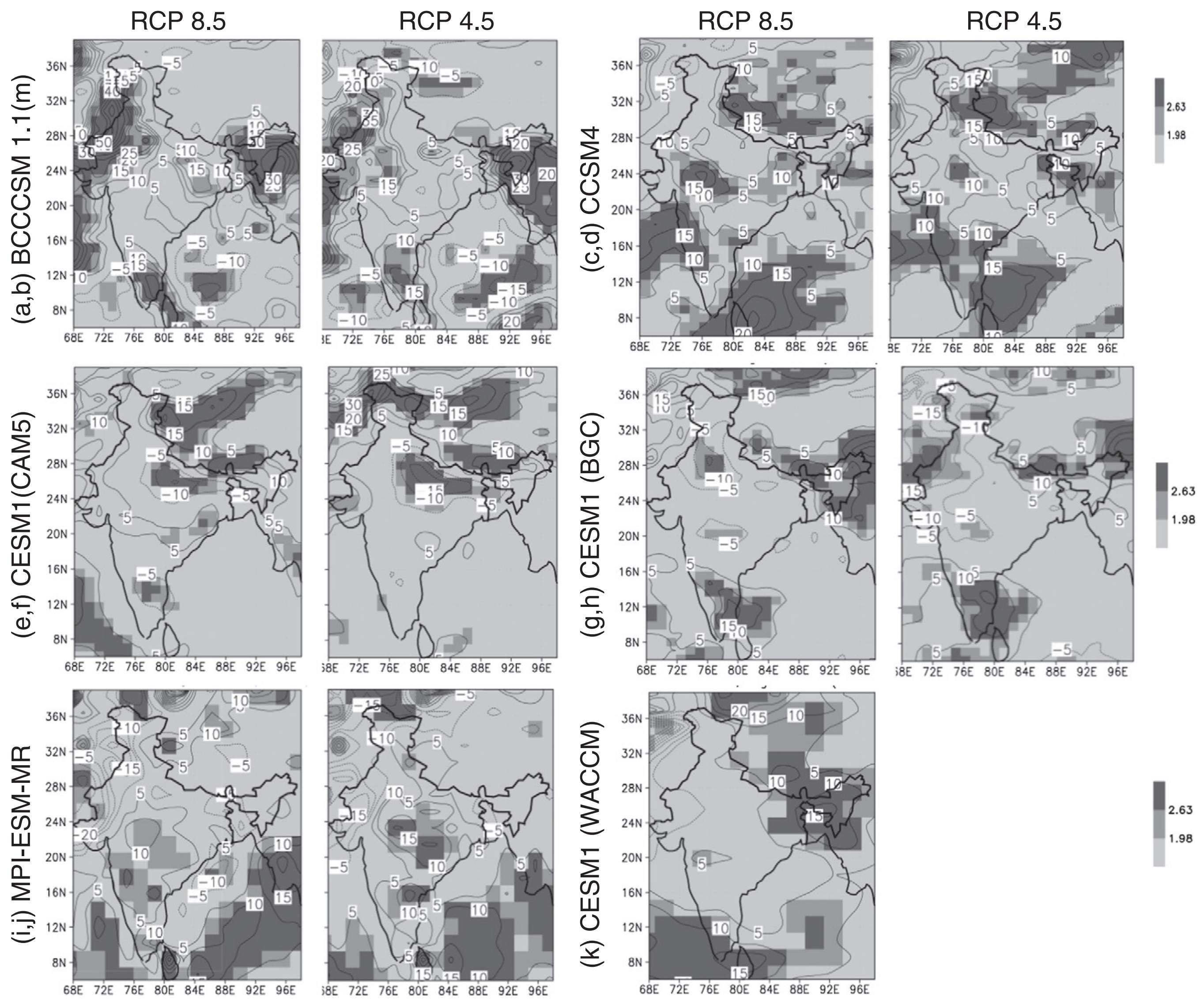


Fig. 8. a-k Composite percentage changes in JJAS rainfall (mm day^{-1}) for the period of 2006–2050 under RCP 4.5 and 8.5 with respect to Historical experiment for the period of 1961–2005. 99% confidence level in student t-test is masked with dark blackish grey color while 95% confidence level is masked with light grey color.

between models simulation of Historical experiment and the observations of IMD and GPCP. The simulated pattern of each model, marked with letters, sounds better with observations will lie nearest the point marked with rectangle (indicating observed rainfall) on the positive X-axis. The simulation is assumed close to observation, when there would be relatively high correlation, low RMS errors and minimum difference of standard deviation with respect to observed. In Fig. 4a, BCC-CSM1.1(m), CESM1(CAM5) and CESM1(WACCM) models simulation show high correlation (0.8 to 0.9) with IMD observation while CESM1(CAM5) and CESM1(WACCM) show relatively higher variability. In Fig. 4b, CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(FASTCHEM) and MPI-ESM-MR simulated rainfall is high correlation (0.9) with observation of GPCP. CCSM4, CESM1(BGC), CESM1(CAM5) and CESM1(FASTCHEM) show SD of 3.9 mm month^{-1} which is close to GPCP, while MPI-ESM-MR show less SD in compare to GPCP.

The variation of correlation and RMSE in observations (IMD & GPCP) and Historical experiment is shown by box plotting in Fig. 5a–b. The spacing between the different parts of the box indicates the degree of dispersion (spread), skewness and outliers in models simulated rainfall. The simulated rainfall approaches to GPCP observation with greater correlation and lower RMSE, while it is not well captured in IMD observations.

Fig. 6a–h shows JJAS wind (m/s) at 850 hPa for the period of 1961–2005 in NCEP and Historical experiment of BCC-CSM1.1 (m), CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (WACCM), CESM1 (FASTCHEM) and MPI-ESM-MR. The magnitude of 15 m/s of cross

Table 3
Areas of excess and deficit in rainfall (mm month^{-1}) at 99% and 95% confidence levels using student t-test for the future scenario of RCP 4.5 and 8.5.

Models	Areas at 99 % confidence level		Areas at 95% confidence level	
	+ ve percentage changes	− ve percentage changes	+ ve percentage changes	− ve percentage changes
BCCCSM 1.1(m)	NWI, NEI, PI		NWI,NEI,PI,CNI	
CCSM4	WCI, HR		WCI, HR,CNI	
CESM1(CAM5)	HR	CNI, PI	HR	CNI, PI
CESM1 (BGC)	PI	NWI	PI	NWI,HR
MPI-ESM-MR	WCI,PI		WCI,PI	
CESM1(WACCM)	NEI,PI		NEI,PI	

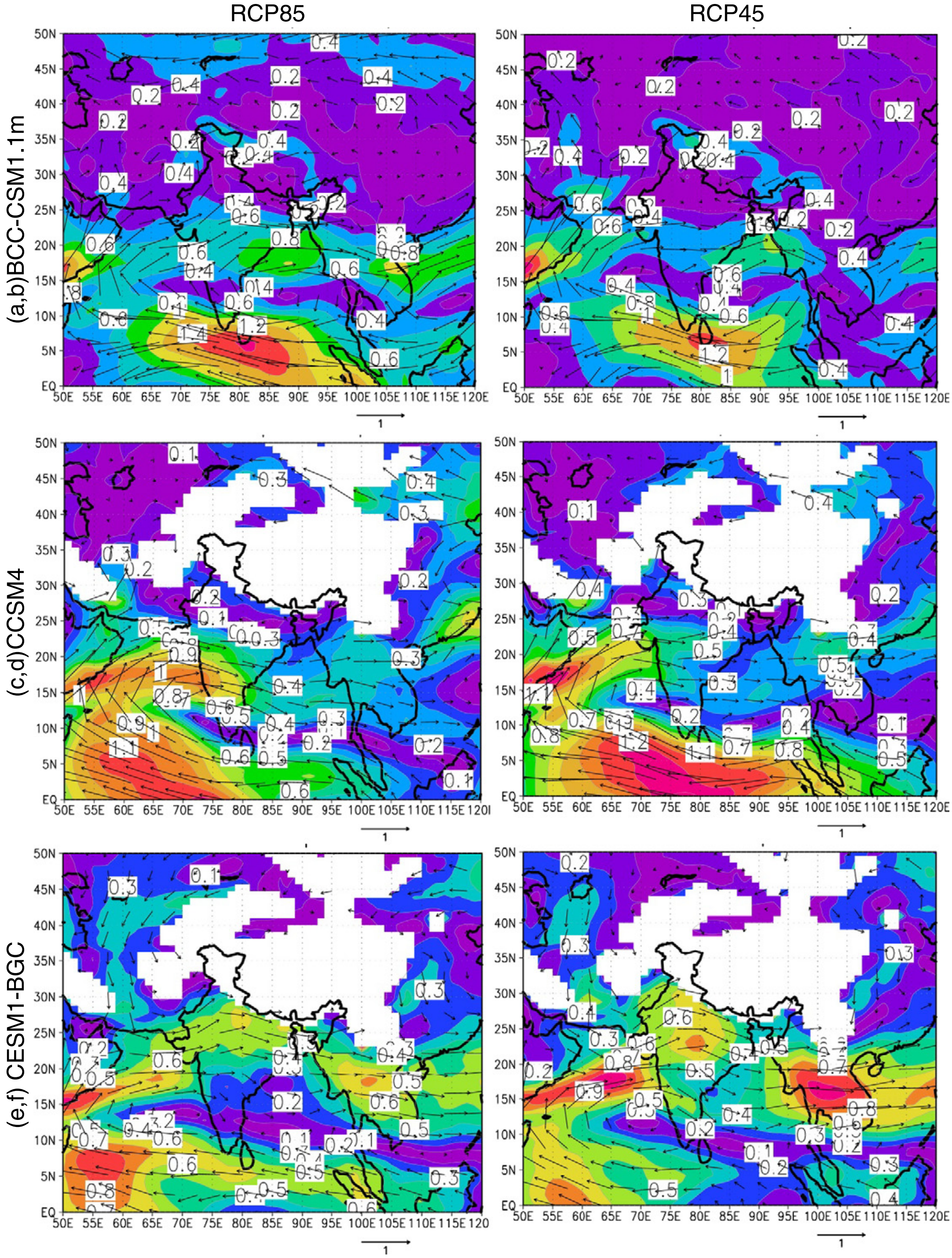


Fig. 9. a-l Future Projected Changes of JJAS (m s^{-1}) wind at 850 hPa during period of 2006–2050.

equatorial wind flow at 850 hPa in the Arabian Sea are captured in simulations of CCSM4 and MPI-ESM-MR. Other models simulation shows that magnitude of cross equatorial flow is an over estimation of magnitude in NCEP reanalysis. Fig. 7a–h shows JJAS wind (m/s) at 200 hPa for the period of 1961–2005 in NCEP and Historical experiment of BCC-CSM1.1 (m), CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (WACCM), CESM1 (FASTCHEM) and MPI-ESM-MR. The magnitude of 21 m/s of easterly wind over the Arabian Sea in NCEP reanalysis reasonably agree with MPI-ESM-MR simulation. But it is not well simulated in other models. It seems that CCSM4 and MPI-ESM-MR simulated wind at 850 and 200 hPa is close to NCEP reanalysis.

4. Future projected changes in rainfall

The future projected percentage changes in JJAS (mm month^{-1}) rainfall during 2006–2050 in RCPs of 4.5 and 8.5 of BCC-CSM1.1 (m), CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (WACCM), CESM1 (FASTCHEM) and MPI-ESM-MR with respect to Historical experiment (1961–2005) is shown in Fig. 8a-k. As discussed in Section 3, these seven (7) models have shown good agreement with observed rainfall (IMD and GPCP), but the RCPs experiments data of CESM1 (FASTCHEM) is not available (Table 2), therefore is not discussed here. To test statistical significance of future projected percentage changes in rainfall,

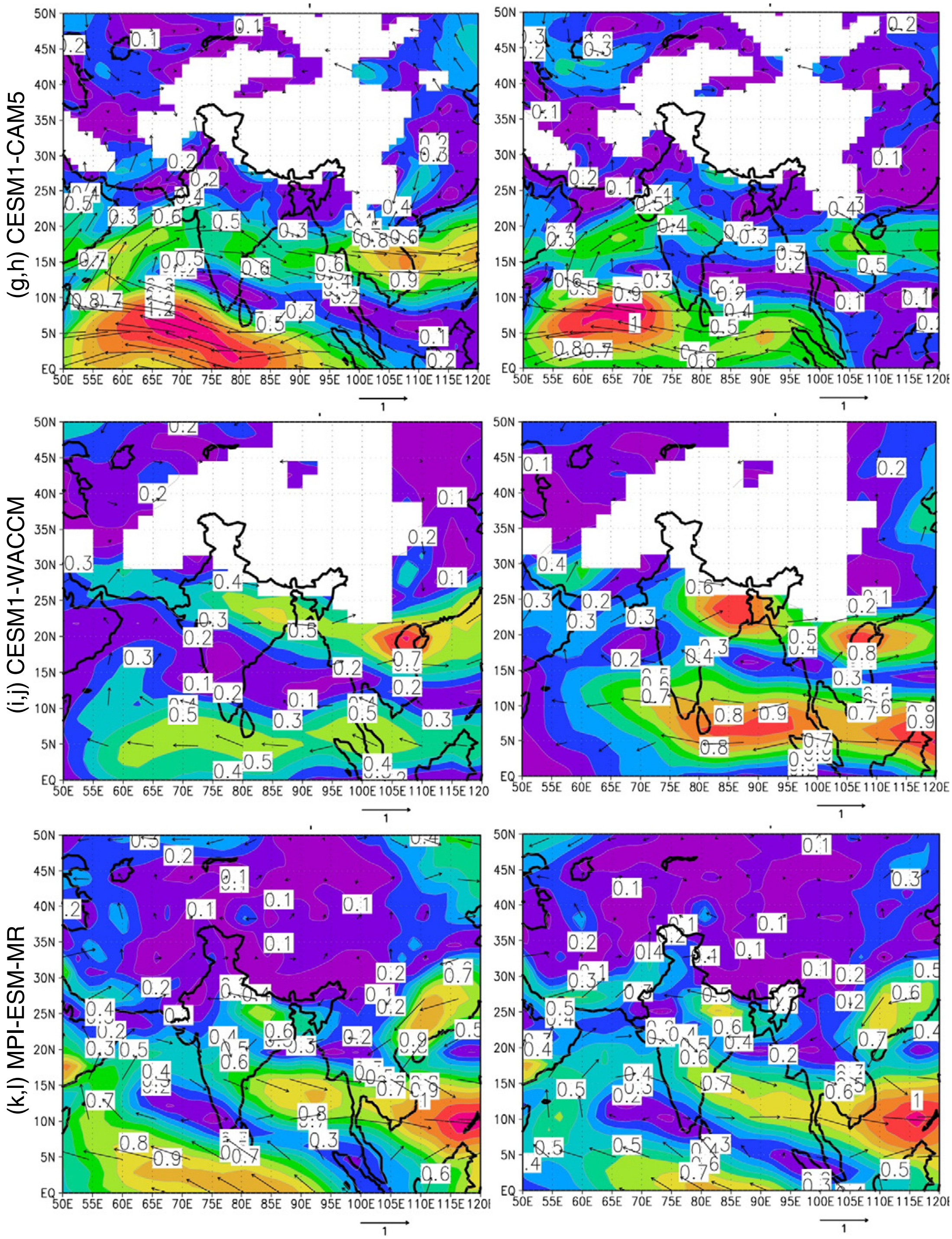


Fig. 9 (*continued*).

student t-test is carried out at 99% and 95% confidence levels in RCPs 4.5 and 8.5 simulations of six (6) models namely BCC-CSM1.1 (m), CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (WACCM) and MPI-ESM-MR. BCC-CSM1.1 (m) (Fig. 8a-b), 5–25% excess rainfall at 99% and 95% confidence levels is projected over parts of NWI, Gangetic plain of CNI and PI. Fig. 8c-d shows possibility of 5–15% excess rainfall at 99% and 95% confidence levels over Western Ghat, parts of WCI and Gangetic plain of CNI, in simulations of CCSM4. In CESM1 (CAM5) simulations (Fig. 8e-f), 5–15% deficit rainfall at 99% and 95% confidence levels may be possible over the Gangetic plain of CNI and 5% deficit rainfall at 95% confidence over PI. Excess rainfall of 5–15% at 99% and 95% confidence levels may be possible over parts of CNI and PI in CESM1(BGC) (Fig. 8g-h). 5–10% deficit rainfall at 99% confidence level over NWI is simulated in both RCPs. In MPI-ESM-MR simulations (Fig. 8i-j), 10–15% excess rainfall at 99% and 95% confidence levels may be possible over WCI, while 5–10% deficit rainfall over parts of NWI and CNI. In Fig. 8k, CESM1 (WACCM) shows, 10–15% excess rainfall at 99% confidence level over parts of NEI and PI. Table 3 summarizes future projected changes of rainfall over homogeneous monsoon regions at 99% and 95% confidence levels in RCPs 4.5 and 8.5 simulations of six (6) models.

Fig. 9a-l depicts future projected changes of JJAS wind (m/s) during 2006–2050 at 850 hPa in RCPs 4.5 and 8.5 simulations of models BCC-

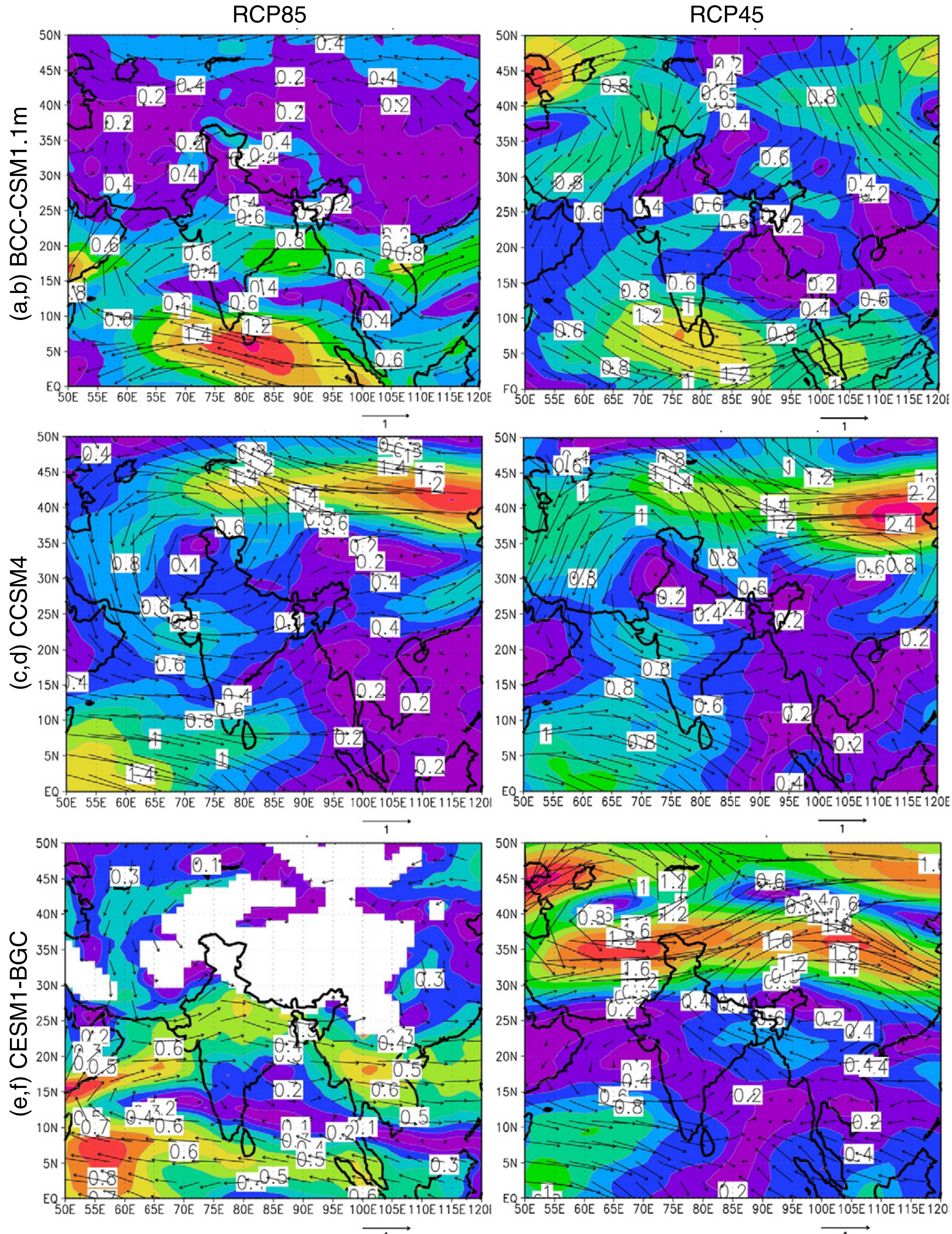


Fig. 10. a-l Future Projected Changes of JJAS (m s^{-1}) wind at 200 hPa during period of 2006–2050.

CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(WACCM), and MPI-ESM-MR. Simulated anomalous anticyclonic circulation over Arabian Sea may be seen in all six (6) models which may lead to establishment of easterly wind and disappearance of cross equatorial wind over the Arabian Sea. Fig. 10a-l shows future projected changes of JJAS wind (m/s) during 2006–2050 at 200 hPa in RCPs 4.5 and 8.5 simulations of models BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(WACCM), and MPI-ESM-MR. Anomalous cyclonic circulation is simulated in BCC-CSM1.1 (m), CCSM4, CESM1 (WACCM) and MPI-ESM-MR which may lead to establishment of westerly wind in place of easterly flow over the Arabian Sea. Such anomalous wind is not seen in simulations of other models.

5. Conclusions

CMIP5 models simulated rainfall of Historical experiments is validated with observed rainfall of IMD and GPCP. Models BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(FASTCHEM), CESM1(WACCM), and MPI-ESM-MR shows closeness with observation (IMD and GPCP) by Taylor diagram. Models CCSM4 and MPI-ESM-MR are able to reproduced

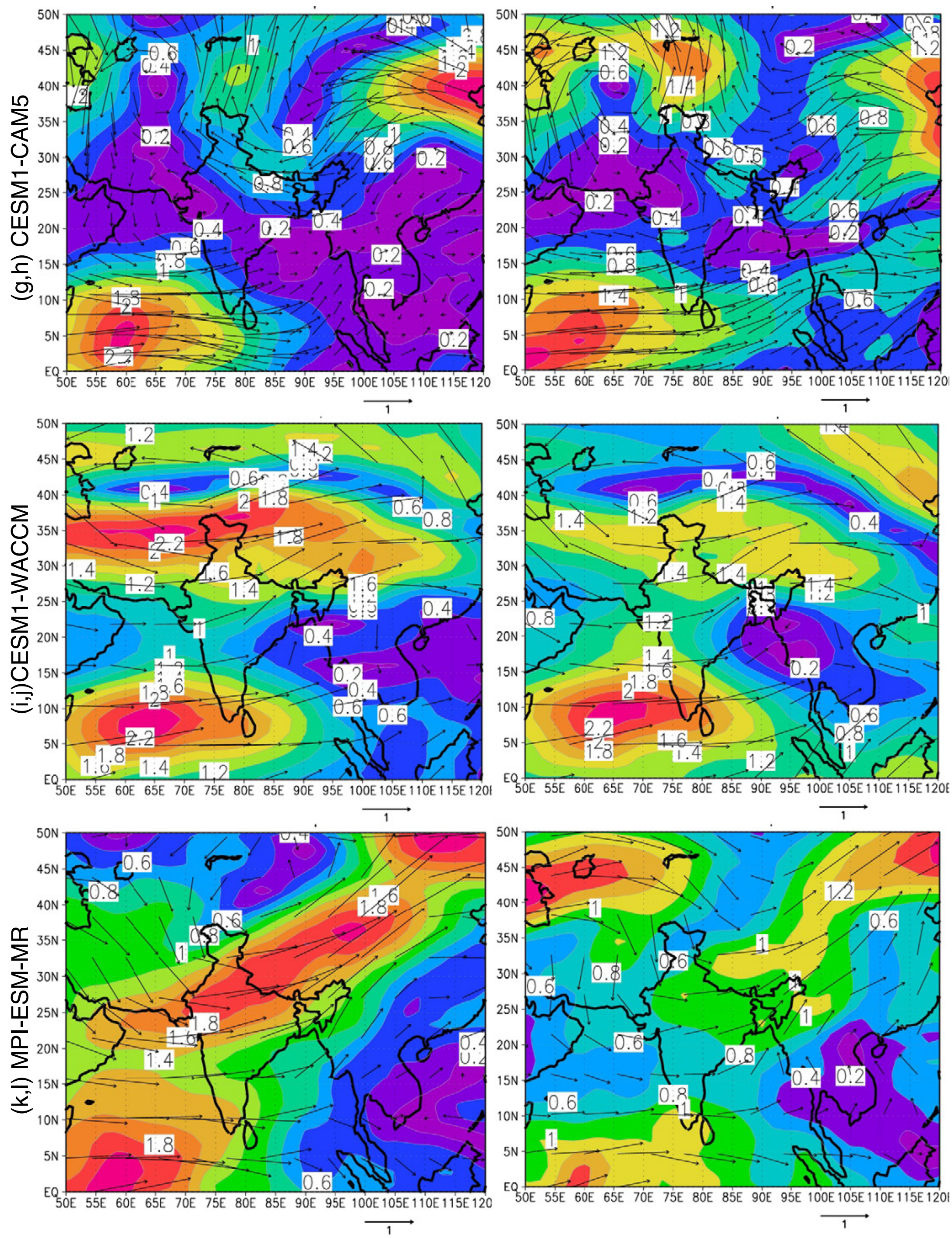


Fig. 10 (*continued*).

JJAS wind at 850 and 200 hPa as shown in NCEP reanalysis data. These six (6) models future projected percentage changes in rainfall for period of 2006–2050 in RCPs of 4.5 and 8.5 at 99% confidence level shows excess rainfall over homogeneous monsoon regions of NWI, NEI, WCI and PI, while deficit rainfall is seen over NWI, NEI, WCI, CNI and PI. At 99% and 95% confidence levels, deficit rainfall is found over CNI, NWI and PI. The mixed signal of excess/deficit rainfall over same homogeneous monsoon regions may be due to individual models characteristics. It seems that future projected changes in JJAS anomalous anticyclonic circulation over Arabian Sea and cyclonic circulation around 40^0 N, 70^0E–90^0E at 850 and 200 hPa respectively may be responsible for spatial and temporal changes in JJAS rainfall. CCSM4 and MPI-ESM-MR future projected anomalous anticyclonic and cyclonic JJAS wind at 850 and 200 hPa would be responsible for future projected rainfall deficit over Gangetic plain of CNI and excess rainfall over NWI.

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