

Chapter 1

Future Changes in Rainfall and Temperature Under Emission Scenarios over India for Rice and Wheat Production



P. Parth Sarthi

Abstract Indian Summer Monsoon (IMS) prevails during June–July–August–September (JJAS) and 80% of the annual precipitation is received during JJAS. The spatial and temporal variability of ISMR and surface temperature has been influencing agriculture and water resources. The changes in earth’s surface temperature is affecting the patterns of weather and climate and influencing the agriculture. The Coupled Model Inter comparison Project 5 (CMIP5) models output data is generally of higher resolution with different emission experiments and therefore rainfall and surface temperature over India is analyzed under CMIP5 which may be used for agricultural purposes.

The Indian Summer Monsoon Rainfall (ISMR) in simulation of BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(FASTCHEM), CESM1(WACCM), and MPI-ESM-MR for the period of 2006–2050 under RCPs 4.5 and 8.5 at 99% confidence shows possibility of excessrainfall over homogeneous monsoon regions of NWI, NEI, WCI and PI, while deficit rainfall over NWI, NEI, WCI, CNI and PI. At 99% and 95% confidence levels, deficit rainfall is found over CNI, NWI and PI. The CMIP5 model GISS-E2-H, BCC-CSM1.1 m and GISS-E2-H-CC for Tmax; GFDL-CM3, MRI-CGM3 and MRI-ESM1 for Tmin; and CESM1 (CAM5) for T under Representative Concentration Pathways (RCPs) 4.5 and 8.5 for the period of 2021–2055 shows possible significant warming of 0.5°C–0.7°C at 99% confidence level over homogeneous temperature regions of NC, NW, and WC. The warming of 0.2°C–0.5°C might be possible at other locations.

These future projections may be used in crop simulation models which may assist adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies.

Keywords Rainfall · Temperature · Future projections and GCMs

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1.1 Introduction

The summer monsoon season in India lasts during June-July-August-September (JJAS) (Rao 1976) and 80% of the annual rainfall occurs during JJAS. The Indian Summer Monsoon Rainfall (ISMR) spatial and temporal variability has been largely influencing agriculture and water resources. As well as, rapid increase in earth's surface temperature is affecting the patterns of weather and consequently influencing the agriculture production.

Under warming conditions, ISMR simulated in different Global and Regional Climate Models have been studied by various researchers; however, uncertainties exist in the regional climate projections due to biasness in the global climate models (Meehl and Washington 1993; Lal et al. 1994, 1995; Rupa Kumar and Ashrit 2001; May 2004; Kripalani et al. 2003; Rupa Kumar et al. 2002, 2003). The variability of ISMR has great importance over the Gangetic plain for agriculture, but it is poorly simulated in many climate models (Lal et al. 2001; Rupa Kumar and Ashrit 2001; Rupa Kumar et al. 2003)., Kripalani et al. (2007a) suggested significant increase in mean monsoon precipitation of 8% and possible extension of the monsoon period, in doubling of CO₂ experiment of Coupled Model Inter Comparison Project Phase 3 (CMIP3). Further, Kripalani et al. (2007b) applied t test and F ratio and suggested possible significant changes in future rainfall from -0.6% for CNRM-CM3 to 14% for ECHO-G and UKMO HadCM3 for East Asian monsoon. Menon et al. (2013a, b) suggested increase in all-India summer monsoon rainfall (AISMR) per degree change in temperature of about 2.3% K⁻¹, which is similar to the projected increase in global mean precipitation per degree change in temperature in CMIP3. Sarthi et al. (2012) suggested, under A2, B1 and A1B experiments of CMIP3, a future projected change in spatial distribution of ISMR which shows deficit and excess of rainfall in Hadley Centre Global Environment Model version 1 (HadGEM1), European Centre Hamburg Model version 5 (ECHAM5), and Model for Interdisciplinary Research on Climate (MIROC) (Hires) over parts of western and eastern coast of India. Multi-models average of CMIP5 simulations, less uncertainty in CMIP5 projections of rainfall and temperature.

The global mean surface air temperature has been increased by 0.60°C in 20th century experiment of Intergovernmental Panel on Climate Change (IPCC)'s Third Assessment Report (AR3), while as per IPCC's Fourth Assessment Report (AR4), it is estimated to have increased by 0.74°C and could rise up to 1.1°C–6.4°C during twenty-first century depending on a range of possible scenarios (IPCC 2007). In IPCC's Fifth Assessment Report (AR5), increment in temperature are largely due to anthropogenic emissions (IPCC 2014). In IPCC (2014), increase in global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to increase in the range of 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5) in CMIP5. Lal et al. (2001), Rupa Kumar et al. (2003, 2013), and Pattanayak et al. (2015) have analyzed projected surface temperature in various coordinated climate models experiments such as CMIP3 and CMIP5.

Lal et al. (2001) has been suggested projected mean warming of 1.0°C–1.4°C and 2.2°C–2.8°C by 2020 and 2050, respectively over the Indian subcontinent (IPCC, 2014). In 21st century, increase in temperature is particularly conspicuous after the 2040s over India and suggested an increase in T_{min} (up to 4°C) all over the country, which might be more in Northeast India (Rupa Kumar et al. 2003). Overall increase in surface temperature by 4.8°C, 3.6°C and 2.2°C in A2, A1B, and B1 emission scenarios, may be possible at the end of 21st century experiment of CMIP3. Extremes in T_{max} and T_{min} are also expected to increase over the West-Central India in different scenarios (Rupa Kumar et al. 2013). Pattnayak et al. (2015) have analyzed the six CMIP5 model's namely GFDL-CM3, GFDL-ESM2M, GFDL-ESM2G, HadGEM2-AO, HadGEM2-CC and HadGEM2-ES in RCPs 4.5 and 8.5, which are able to capture spatial distribution of temperature with an increasing trend over most of the regions over India. Chaturvedi et al. (2012) worked on multi-model and multiscenario temperature projections over India for the period of 1860–2099 using CMIP5 under RCPs 6.0 and 8.5 scenarios, it is found that mean warming in India is likely to be in the range of 1.7–2°C by 2030s and 3.3–8 4.8°C by 2080s relative to preindustrial times.

Under [World Climate Research Programme \(WCRP\)](#), [Working Group on Coupled Modelling \(WGCM\)](#), Climate models are integrated out for past, present and future climate under different emission scenarios in Coupled Model Inter comparison Project 5 (CMIP5) and simulated rainfall and surface temperature area analyzed for agriculture purposes in this paper Section 1.1 deals with Introduction and literature survey; data and methodology is in Sect. 1.2. Results and discussion is placed in Sect. 1.2 while conclusions are in Sect. 1.4.

1.2 Data and Models

The gridded observed rainfall of India Meteorological Department (IMD) at resolution of 1°×1° during 1961–1999 and observed rainfall of Global Precipitation Climatology Project (GPCP) at resolution of 2.5°× 2.5° during 1979–1999 is considered for validating the model's performance. Table 1.1 and 1.2 shows list of CMIP5 models considered under RCP 4.5 and 8.5 experiments for analysis of rainfall and surface temperature T, T_{max} (for March, April, May) and T_{min} (December, January, February). RCPs 4.5 and 8.5 experiments are very likely that world will follow these mild and high emission scenarios in future time periods. The simulation of a Historical experiment in CMIP5 is equivalent to 20th century experiment (20C3M) of CMIP3; 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.

For rainfall, the period of historical experiment is 1961–2005 and for future project is 2006–2050; for surface temperature, the period for historical experiment is 1971–2005 and for future project is 2021–2055.

Table 1.1 List of CMIP5 models their surface resolution and available RCPs experiment for rainfall analysis

Serials No.	Models	Surface Resolution	RCP 4.5	RCP 8.5
1	BCCCSM 1.1(m)	320 × 160	√	√
2	CCSM4	288 × 192	√	√
3	CESM1(CAM5)	288 × 192	√	√
4	CESM1 (BGC)	288 × 192	√	√
5	CESM1 (WACCM)	144 × 96		√
6	MPI-ESM-MR	192 × 96	√	√
7	CESM1 (FASTCHEM)	288 × 192		

Table 1.2 List of CMIP5 models their surface resolution and available RCPs experiment for T, Tmax, and Tmin

	Models	Surface Resolution	RCP 4.5	RCP 8.5
T	BCCCSM 1.1(m)	320 × 160	√	√
Tmax	GISS-E2-H-CC	144 × 90	√	√
	BCCCSM1.1(m)	320 × 160	√	√
	GISS-E2-H-CC	144 × 90	√	√
Tmin	GFDL-CM3	144 × 90	√	√
	MRI-CGCM3	120 × 120	√	√
	MRI-ESM1	120 × 120	√	

1.3 Results and Discussions

Fig. 1.1 shows 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). Fig. 1.2 depicts Temperature homogeneous regions namely North East (NE), North West (NW), North Central (NC), East Coast (EC), Peninsula India (IP), Western Himalaya (WH), West Central (WC) of India. To analyze the reduced uncertainty in future projection of rainfall and temperature, students T test at 99% and 95% confidence levels is applied on the projected values.

A large number of CMIP5 models under Historical experiment is evaluated with observed rainfall of IMD and GPCP (Fig. not shown) and only BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(FASTCHEM), CESM1 (WACCM), and MPI-ESM-MR performed well and therefore used for analyzing future projections of ISMR in June-July-August-September (JJAS) under RCPs 4.5 and 8.5 emission scenarios. The spatial distribution of future projected percentage changes in JJAS (mm/month) 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 Figs. 1.3a–k at 99% and 95% confidence levels using student t-test. In Figs. 1.3a–b, an excess of 5–25% rainfall at 99% and 95%

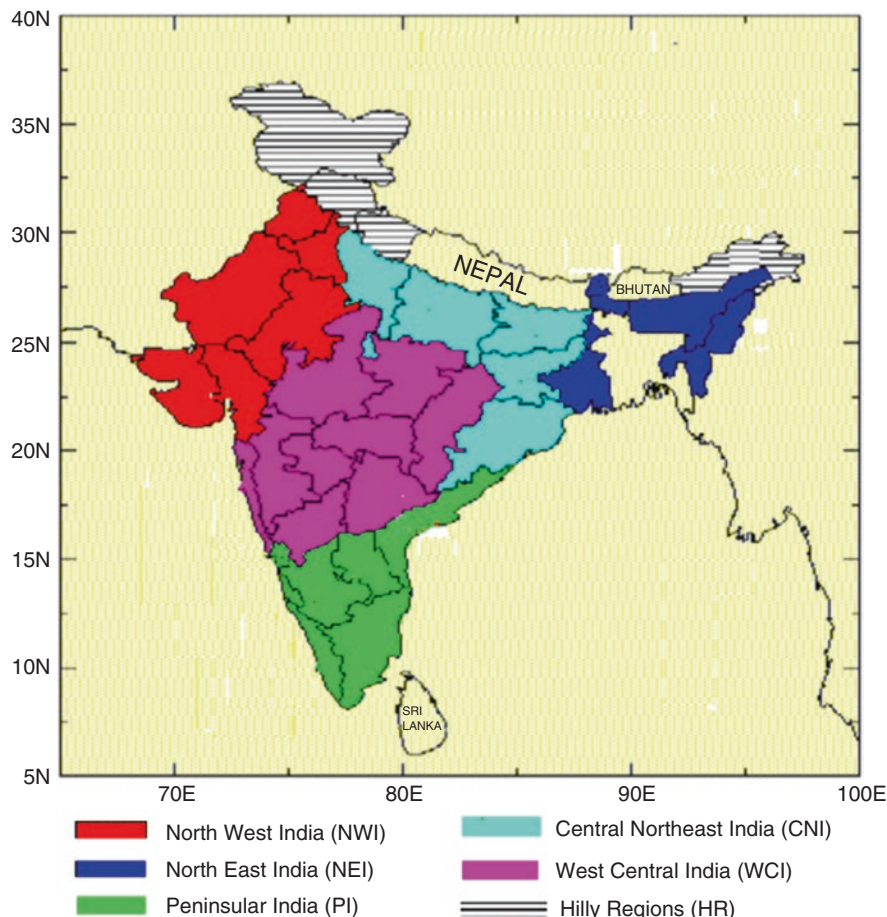


Fig. 1.1 Homogeneous monsoon regions of India (Source: India Institute of Tropical Meteorology, Pune, India)

confidence levels may be possible over the parts of NWI, Gangetic plain of CNI and PI. Figs. 1.3c–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 (Figs. 1.3e–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) (Figs. 1.3g–h). 5–10% deficit rainfall at 99% confidence level over NWI is simulated in both RCPs. In MPI-ESM-MR simulations (Figs. 1.3i–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. 1.3k, CESM1 (WACCM) shows, 10–15% excess rainfall at 99% confidence level over parts of

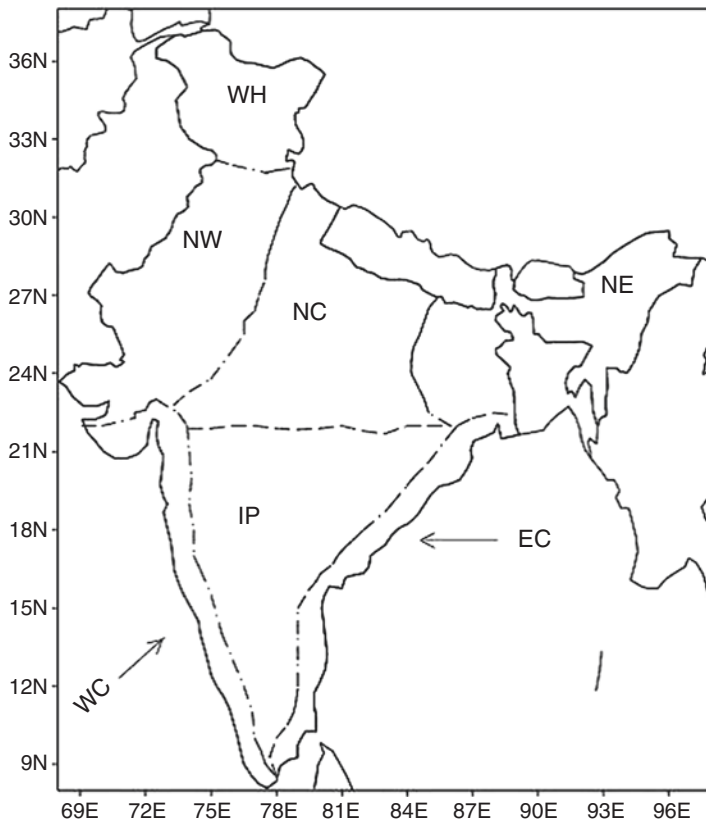


Fig. 1.2 Temperature Homogeneous Regions of India (Source: IITM, Pune, India)

NE – North East NW – North West

NC – North Central EC – East Coast

IP – Peninsula India WH – Western Himalaya WC – West Central

NEI and PI. Out of seven models, six models shows possibility of excess rainfall in JJAS at 99% and 95% confidence levels in future time periods over rice production regions of CNI and PI. If distribution of rainfall within JJAS is taking place equally in months of june, july, august and september, then it would be favourable for production of rice. Further analysis of rainfall variability within rainy months is important over these regions.

In simulating surface temperature, models evaluation shows that model CESM1 (CAM5) for T, GISS-E2-H, BCC-CSM1.1 m, and GISS-E2-H-CC for Tmax and GFDL-CM3, MRI-CGCM3, and MRI-ESM1 for Tmin are relatively better performing than other models. Figs. 1.4a–n shows future projected changes in Tmax, Tmin and T during 2021–2055 under RCPs 4.5 and 8.5 with respect to Historical experiment (1971–2005). Student's t-test at 99% and 95% confidence levels is

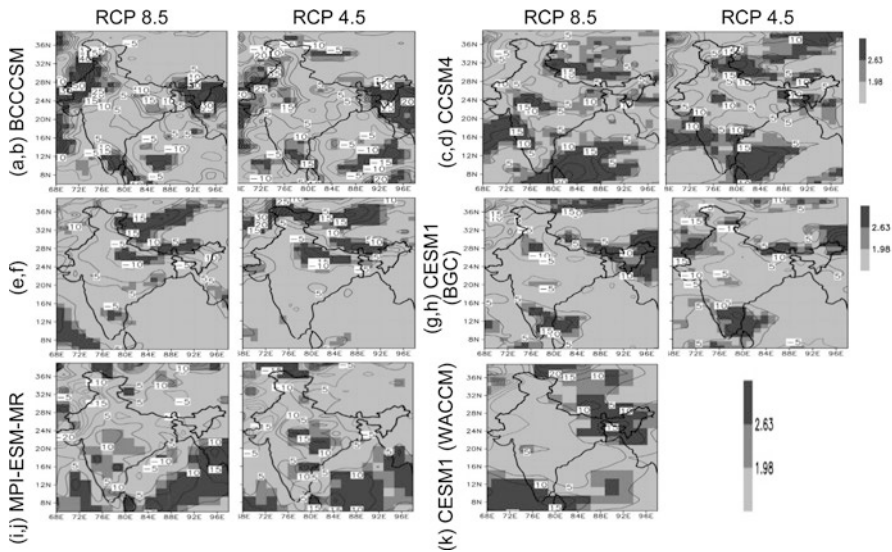


Fig. 1.3 (a–k) Percentage change in JJAS rainfall (mm/ day) for the period of 2006–2050 under RCPs 4.5 and 8.5 with respect to Historical experiment for the period of 1961–2005 at 99% confidence level (in dark blackish grey color) and at 95% confidence level (in masked with light grey color) at student’s t test

applied to know the significance of future projected changes. In Figs. 1.4a–n, 99% and 95% confidence levels are masked with dark gray and medium gray color respectively, while non-significant area is masked with light gray color. GISS-E2-H, GISS-E2-H-CC projected Tmax (Figs. 1.4c–f) shows possibility of 0.3°C–0.4°C warming over NW and NC and 0.6°C–0.7°C over NW and the Gangetic plain under RCPs 4.5 and 8.5. The model BCC-CSM1.1 m (Figs. 1.4a–b) shows possible warming of 0.4°C–0.5°C at 99% confidence level over the entire region of India except over the central west region while 0.25°C–0.45°C over southern India at 99% confidence level. In Figs. 1.4g–i, GFDL-CM3, MRI-CGCM3, and MRI-ESM1 simulated Tmin in RCPs 4.5 and 8.5 shows possible warming of 0.3°C–0.7°C over major parts of India, but more warming is seen over northwest and southeast part at 99% confidence level while 0.4°C–0.6°C at 95% confidence level is depicted over whole India. In simulation of CESM1(CAM5), future projected T in RCPs 4.5 and 8.5 (Fig. 1.4m–n) shows a significant warming of 0.4°C–0.5°C over NC and the Gangetic plain at 99% confidence level, and the same magnitude of warming at 95% confidence level may be possible over whole India except WC and EC. The projected increase in Tmin over northwest and other parts of India may not be supportive for wheat production and diseases may be possible in wheat grains. It would be important to understand the variability of Tmin within December, January and February and its relations to the wheat production.

Further, the significant projected change of rainfall and temperature in CMIP5 models may be used as inputs to Crop simulation models over the Gangetic plain

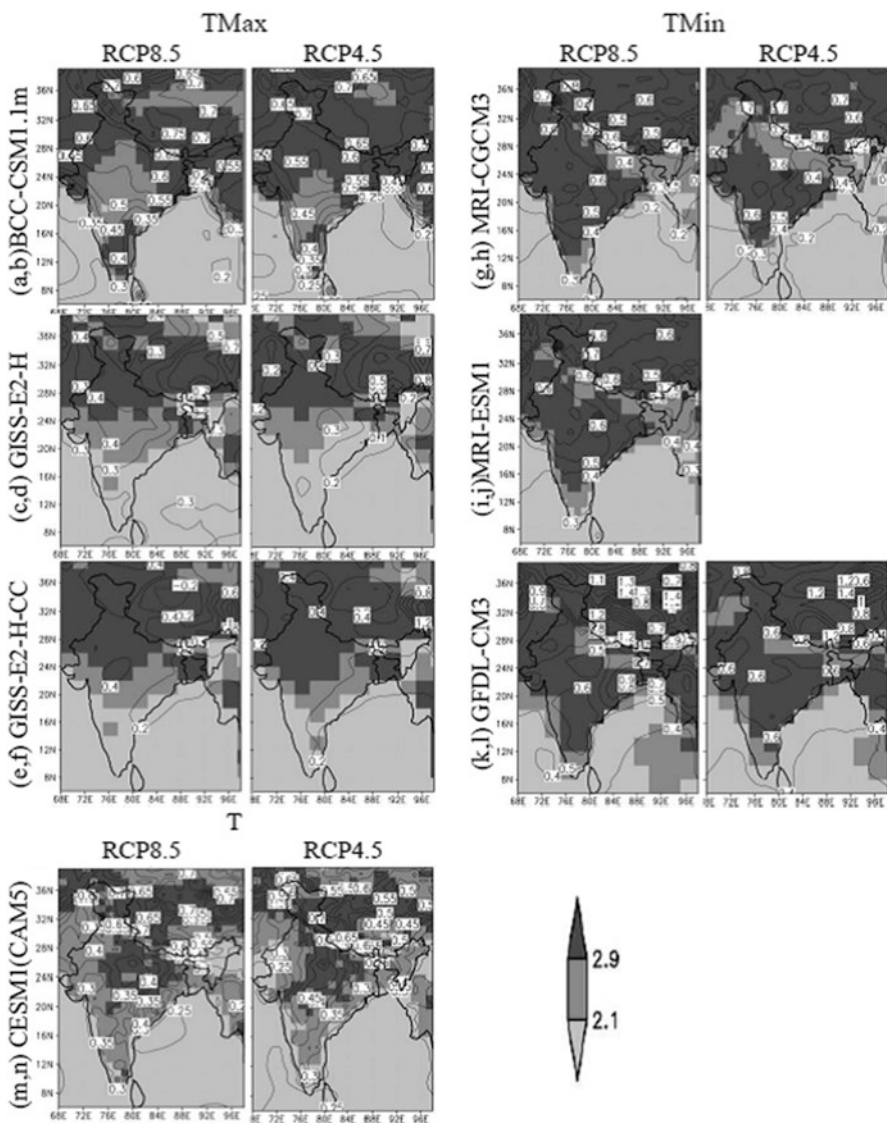


Fig. 1.4 (a–n) Future Projected Changes in Tmax, Tmin, and T (°C) for the period of 2021–2055 under RCP 4.5 and 8.5 with respect to Historical experiment for the period of 1971–2005. (Regions with statistically significant at 99% (cut off t value ≥ 2.9) confidence level (masked with dark grey color) and is 95% (cut off t value equals to 2.1) confidence level (masked with medium grey color) on two-tailed student's t test). The light grey shade shows the area with confidence lesser than 95%

which is more scientific approach to study the impact of climate change on agricultural production. Such study may help in framing adaptation to climate change—through changes in farming practices, cropping patterns, and use of new technologies which may reduce impacts of climate change.

1.4 Conclusions

These seven (7) models namely BCC-CSM1.1 (m), CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (FASTCHEM), CESM1 (WACCM), and MPI-ESM-MR simulated future projected percentage changes in JJAS rainfall for the period of 2006–2050 under RCPs 4.5 and 8.5 at 99% confidence level is analyzed which shows possibility of excess rainfall over homogeneous monsoon regions of NWI, NEI, WCI, CNI and PI. CMIP5 models GISS-E2-H, BCC-CSM1.1 m and GISS-E2-H-CC for Tmax; GFDL-CM3, MRI-CGM3 and MRI-ESM1 for Tmin; and CESM1 (CAM5) for T are close to observation for the period of 1961–2005. In RCPs 4.5 and 8.5 experiments for the period of 2021–2055 with respect to historical experiment for the period of 1961–2005, significant warming of 0.5°C–0.7°C at 99% confidence level may be possible over homogeneous temperature regions of NC, NW, and WC. The changes of 0.2°C–0.5°C might be possible at other locations.

These future projections of rainfall and Tmin may be used in assessment of rice and wheat production and assist adaptation to climate change through changes in farming practices, cropping patterns, and use of new technologies.

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