

# Climate Projections over Bangladesh Using MPI-ESM-MR Model

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## Abstract

The study has been conducted by analyzing the rainfall and temperature distribution in Bangladesh in recent past years of 1981–2005 and in three future periods of 2025–2049, 2050–2074 and 2075–2099 for MPI-ESM-MR model with RCP 4.5 and RCP 8.5 scenarios, which is a General Circulation Model (GCM) of the Fifth Phase of the Coupled Model Inter-comparison Project (CMIP5). The rainfall is lower for MPI-ESM-MR model than the observed rainfall of Bangladesh Meteorological Department (BMD) during the period of 1981–2005, the temperature is nearly equal to the observation. As the model simulation exposes biases in the monthly mean temperature and rainfall in Bangladesh during the previous period, bias correction for future data has been performed using quantile mapping method. Model indicates that the rate of change of anticipated annual mean rainfall differs significantly throughout Bangladesh. Accordingly, the model annual mean rainfall averaged over Bangladesh is projected to change between -6 to 8% and -15 to 14%, respectively, under RCP 4.5 and RCP 8.5 after bias correction. Similarly, annual rainfall patterns indicate a reduction in rainfall over a large chunk of the southwest and central parts of the country and an increase in the northeast. The model projections indicate that the annual mean temperature over Bangladesh will continue to rise during the twenty-first century. The expected temperature increment is higher in the northwestern and west-central region of Bangladesh. By the end of the twenty-first century annual mean temperature in Bangladesh is projected to rise by 2.1°C (with the range of 0.8–2.9°C) and 4.2°C (with the range of 2.8–5.5°C) respectively for RCP 4.5 and RCP 8.5 scenarios.

**Keywords:** Climate change, Rainfall, Temperature, Future changes, CMIP5 and RCP.

## 1. Introduction

Climate change is now widely recognized as a significant global issue, posing significant challenges to human existence and socioeconomic development, particularly in Bangladesh. The consequences of gradual climate change and extreme weather events may have a detrimental effect on overall socioeconomic development in many regions, and thus the scientific community and policymakers require additional information about the likelihood of such events occurring in the future [1,2].

Currently, the 5th Phase Coupled Model Inter comparison Project is evaluating some climatic characteristics and their anticipated changes. CMIP5 is a widely used standard experimental technique for assessing the output of linked atmosphere-ocean general circulation models (AOGCMs). The World Climate Research Program (WCRP) has generated a multi-model dataset aiming to increase our knowledge of climate, its variability, and change [3]. Climate models, also known as general circulation models (GCMs), are key instruments for studying the climate system's reaction to various forcings, providing seasonal to decadal (near-term) climate predictions, and predicting future climate over the next century and beyond. Many climate researchers collaborate with global modeling centers to share, compare, and analyze the latest global climate model results. The idea of CMIP derives from comparing.

CMIP stands for Coupled Model Inter-comparison Project. Around twenty years ago, CMIP began as a comparison of two early global coupled climate models The JSC/CLIVAR Working Group on Coupled Models created the Coupled Model Inter-comparison Project in 1995 (WGCM) [4]. CMIP is a database of coupled GCM simulations with standardized boundary conditions. Many climate scientists have discussed and reported on the global climate change in many ways, such as causes and effects of global warming, variations of temperatures and rainfall, and the earth atmosphere system. In Bangladesh, due to lack of detailed study on climate projections and the variability of climate changes, its impact on natural disasters and economy is poorly understood. During the summer, the average temperature in the country ranges from 23.90°C to 31.10 °C, and during the winter, the average temperature ranges from 7.20°C to 12.80°C [5]. Maximum temperatures during the summer range from 38 to 41°C, with April being the hottest month. January, on the other hand, is the coldest month. In winter, the country's average temperature is between 16 and 20°C during the day and around 10°C at night. Pre-monsoon temperatures fluctuate in a southwest to northeast orientation, with the warmer zone in the southwest and the cooler zone in the northeast. In winter, the mean temperature gradient is south to north, with the southern section of the country being 5°C warmer than the northern part [6].

The climate of Bangladesh is characterized by heavy rains. The rainfall in Bangladesh varies from 1400 mm in the west to around 4400 mm in the east. The exception is the western part of Rajshahi, which is rather dry with an annual rainfall of 1600 mm. Most of the country receives at least 2000 mm of rain every year. The rainfall gradient is almost 7 mm/km from west to east. The Meghalaya plateau's elevating influence causes more rainfall in the northeast. The moist monsoon winds bring weak tropical depressions from the Bay of Bengal into Bangladesh, causing around 80% of total rainfall. Temperature and precipitation patterns, on the other hand, are critical for an agro-based economy like Bangladesh. These shifts in temperature and precipitation patterns may jeopardize many of Bangladesh's great achievements during the last few years. In light of these changes, it is vital to compile, monitor, and evaluate relevant climatic indices such as temperature and rainfall on a regular and systematic basis in order to determine the effects of climate change.

In this research on the basis of same ensemble member from the models available at CORDEX for South Asia MPI-ESM-MR model is used to assess the recent climate of Bangladesh and to build an algorithm for future climate projections over Bangladesh.

## 2. Data, Model and Methodology

### 2.1 Data

Temperature and precipitation data were acquired from the Bangladesh Meteorological Department (BMD) for 34 stations between 1981 and 2019. The data for the downscaled MPI-ESM-MR model are downloaded from the CCCR (Centre for Climate Change Research) FTP Server ([ftp://cccr.tropmet.res.in/FTPServer/NEX-INDOUS/Data/](ftp://cccr.tropmet.res.in/FTPServer/NEX-INDOUS>Data/)), which serves as the regional data portal for CORDEX (Coordinated Regional Downscaling Experiment) South Asia. The dataset is in the NetCDF format and has a spatial resolution of 0.25 degrees (25 km x 25 km) as downloaded from CCCR. Data are downloaded for historical (1950–2005) and prospective simulations (various RCPs, 2006–2099). Among the four RCPs adopted by IPCC in AR5, RCP 2.6 assumes significant adaptation measures [7]. RCP 2.6 is not included in the climate model ensemble because robust, realistic climate change scenarios are needed to determine adaptation actions. This leaves the choice between RCP 4.5, RCP 6 and RCP 8.5. The optimum solution is to include RCP 4.5 and RCP 8.5, therefore encompassing the complete range of radiative forcing coming from RCP 4.5, RCP 6 and RCP 8.5. So only RCP 4.5 and RCP 8.5 are included in this study.

### 2.2 Overview of MPI-ESM-MR Model

<b>Project</b>	: CMIP5
<b>Institute</b>	: Max Planck Institute for Meteorology (MPI-M)
<b>Name</b>	: MPI-ESM-MR
<b>Long Name</b>	: MPI Earth System Model running on low resolution grid
<b>Type</b>	: Earth System Model
<b>Release Date</b>	: 2009-01-01
<b>Document Author</b>	: Metafor Questionnaire
<b>Document Created</b>	: 2015-06-29
<b>Principal Investigator</b>	: Marco Giorgetta
<b>Funder</b>	: Organisation Bundesministerium fuer Bildung und Forschung

### 2.3 Methodology

This study was conducted on 34 meteorological stations in Bangladesh. These 34 stations are shown in Figure 1.



**Fig. 1:** Map of the study area showing BMD stations (Data source: Bangladesh Meteorological Department)

Initially, the model was validated by comparing it to BMD observations. The model's temperature and rainfall biases are computed for this purpose. Monthly, seasonal, and yearly model averages and trends are compared to observed averages and trends for temperature and rainfall for the same period of 1981-2005. The analysis period was divided into two time slices as follows: The era 1950-2005 is P1 and the period 1981-2005 is P2.

Then the bias of previous GCM outputs is computed and corrected for future GCM outputs. The absolute fit of the model to the data is determined by the RMSE of historical GCM outputs. Less RMSE means better match. Bias and RMSE are calculated in R, while bias correction is done in Python. The equations-

$$Bias = \frac{\sum_{i=1}^n (O_i - P_i)}{n} \dots\dots\dots (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \dots\dots\dots (2)$$

Where, P<sub>i</sub> and O<sub>i</sub> are the simulation and observed data, respectively, and n is the length of the distribution of the data point being analyzed.

Furthermore, based on the baseline period (1981–2005), both area to area and grid to grid bias correction is attempted for the future period (2006-2099). From the different methods of bias correction, the common Simple Quantile Mapping (SQM) method is used for both rainfall and temperature. The differences between the observed and simulated cumulative distribution functions (CDFs) for the historical period were quantified and then applied to the future simulations for a given percentile. The following equation [8] is used for bias-correction-

$$X'_p(t) = Xp(t) + F_{obs}^{-1} \left( F_{p.sim} \left( X_p(t) \right) \right) - F_{r.sim}^{-1} \left( F_{p.sim} \left( X_p(t) \right) \right) \dots\dots (3)$$

Where  $X'_p(t)$  and  $Xp(t)$  denote the bias-corrected and raw future projections on month t, and F(θ) and  $F^{-1}(\theta)$  are a CDF of the monthly data θ and its inverse, respectively. The subscripts p.sim, r.sim, and obs indicate the future projection, retrospective simulation, and observed monthly data, respectively.

The future data of temperature and rainfall are analyzed over three distinct time periods with respect to the baseline period (1981-2005) which are: (i) the near-future period: 2025–2049; (ii) the mid-future period: 2050–2074 and (iii) the far-future period: 2075–2099.

### 3. RESULTS AND DISCUSSION

#### 3.1 Rainfall and Temperature Pattern of Bangladesh Throughout History

##### 3.1.1 Bias of Rainfall for the MPI-ESM-MR Model

During the period 1950-2005 (designated as P1), the average annual rainfall in the model across Bangladesh was 2252.8 mm, with a trend of +11.08 mm/10yr. In contrast, it averaged 2235.7 mm during the period 1981-2005 (designated as P2), with a trend of +109.17 mm/10yr, which was lower than the station average over the same time. During P2, the station average was 2489.7 mm, and the trend was a negative 1.85 mm/10yr. According to the MPI-ESM-MR climate model, the monthly and seasonal fluctuation of rainfall is represented in Fig. 2.

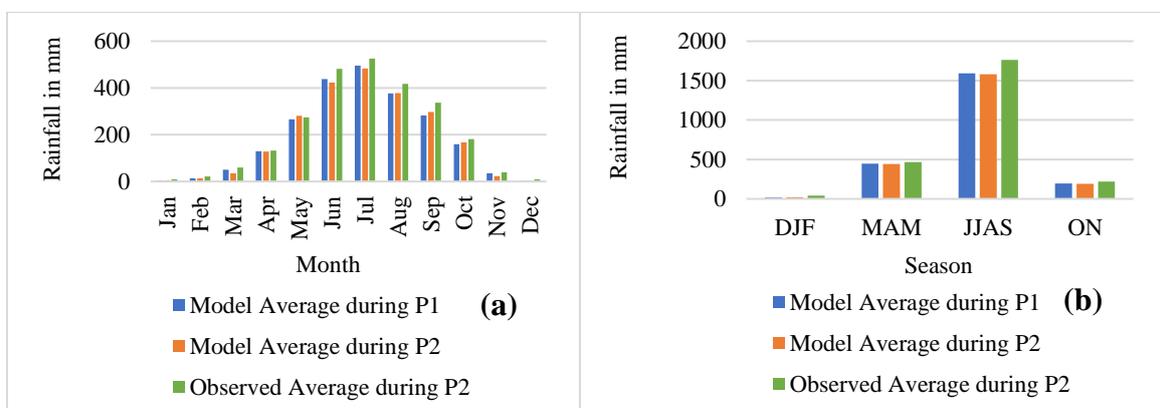
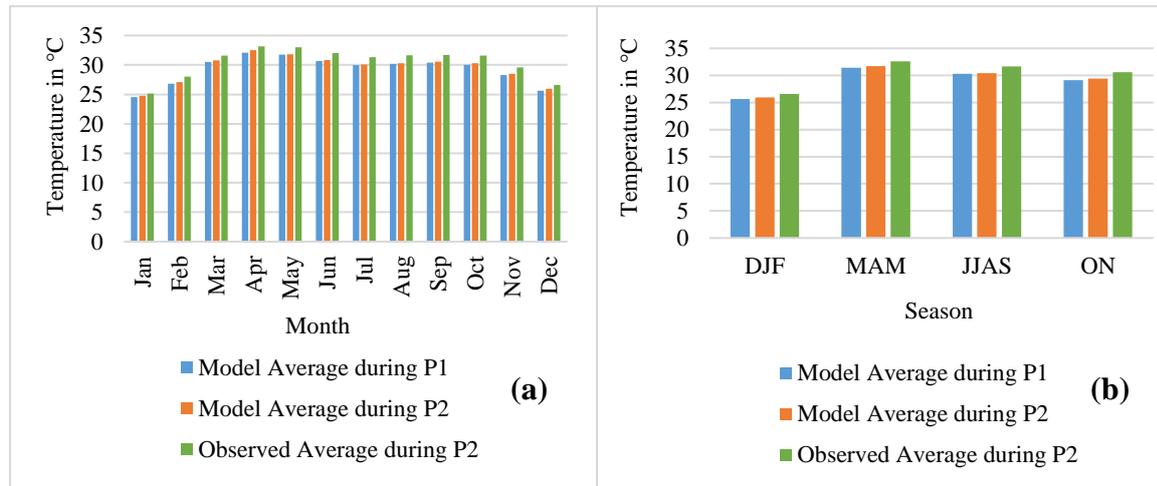


Fig. 2: Variation of (a) monthly average and (b) seasonal average rainfall over Bangladesh for MPI-ESM-MR.

##### 3.1.2 Bias of Maximum Temperatures for the MPI-ESM-MR Model

During the period 1950-2005, the average annual maximum temperature predicted by the model (designated as P1) over Bangladesh was 29.2 degrees Celsius, with a trend of +0.12 degrees Celsius each year. However, for

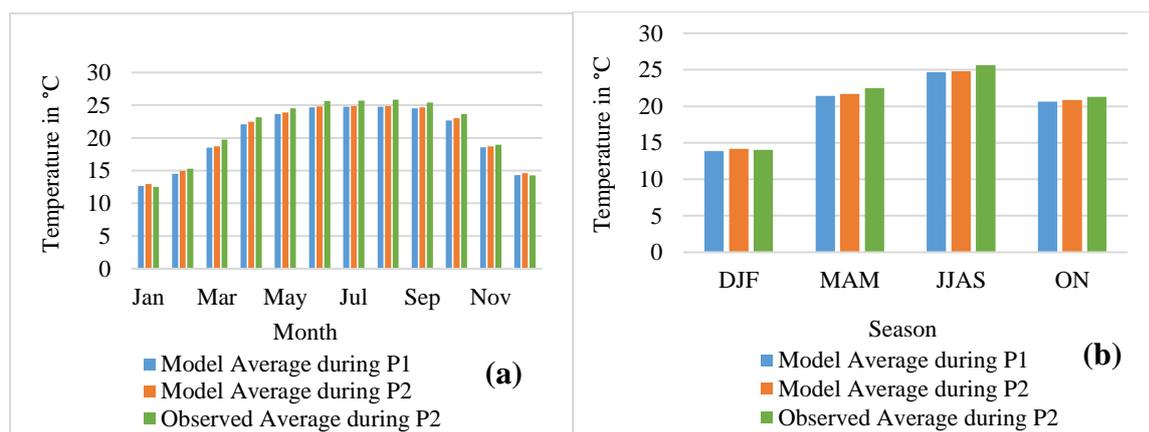
the period 1981-2005 (designated as P2), the temperature averaged 29.4 degrees Celsius, with a trend of +0.15 degrees Celsius per year, which was lower than the station average during the same time. During P2, the station average temperature was 30.5 degrees Celsius, with a trend of 0.25 degrees Celsius each year. According to the MPI-ESM-MR climate model, the monthly and seasonal fluctuation of maximum temperature is represented in Fig.3.



**Fig. 3:** Variation of (a) monthly average and (b) seasonal average maximum temperature over Bangladesh for MPI-ESM-MR.

### 3.1.3 Bias of Minimum Temperatures for the MPI-ESM-MR Model

Between 1950 and 2005, the average annual minimum temperature over Bangladesh (designated as P1) was 20.5 degrees Celsius, with a trend of +0.14 degrees Celsius each decade. However, it was 20.7 degrees Celsius throughout the period 1981-2005 (designated as P2), and its trend was +0.26 degrees Celsius per year, which was lower than the station average during the same period. The station average temperature during P2 was 21.2 degrees Celsius, with a trend of +0.18 degrees Celsius per decade. According to the model MPI-ESM-MR, monthly and seasonal variations in minimum temperature are shown in the figure. (Fig.4.)



**Fig. 4:** Variation of (a) monthly average and (b) seasonal average minimum temperature over Bangladesh for PI-ESM-MR.

### 3.2 Bias-Correction

Before starting the bias-correction process the bias and RMSE of the model data are calculated to estimate the model accuracy. The values are depicted in Table 1.

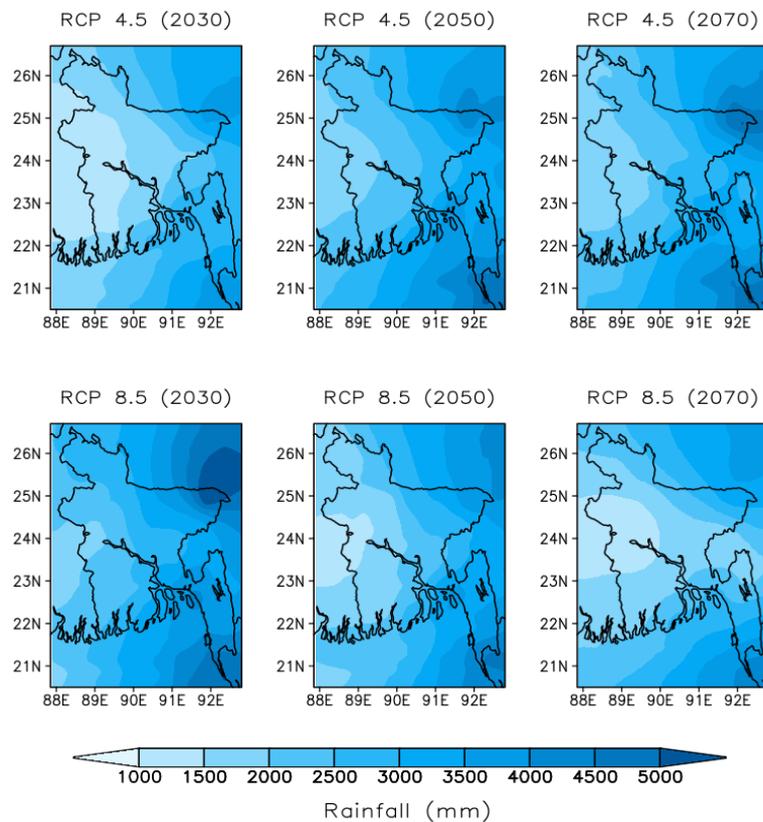
**Table 1:** Monthly Bias and RMSE for MPI-ESM-MR Model.

Variable	RMSE	Bias
Rainfall (pr)	144.23 mm	21.17 mm
Maximum Temperature (tasmax)	1.50 °C	0.99 °C
Minimum Temperature (tasmin)	1.13 °C	0.51 °C

Table 1 reveals considerable data biases and RMSE values imply poor fit. Similarly, to the previous section on historical period analysis, this study discovered large disparities between observed and model data in some circumstances. For these reasons, future data was biased-corrected. This study uses Empirical Quantile Mapping, a simple Quantile Mapping approach. Based on the baseline era (1981–2005), future period bias adjustment was implemented (2006–2099). Quantile Mapping decreases temperature and rainfall model biases.

### 3.3 Future Climate Scenarios for Bangladesh

#### 3.3.1 Projection of Annual Rainfall



**Fig. 5:** Spatial distribution of MPI-ESM-MR model projected annual rainfall of 2030, 2050 and 2070 under the two RCP scenarios over Bangladesh.

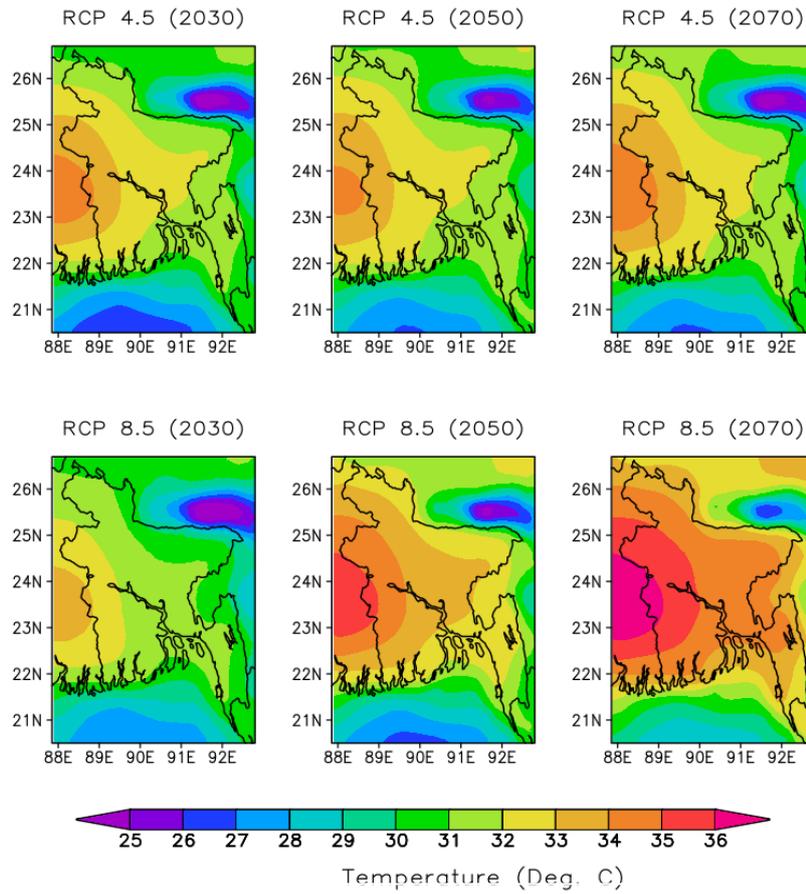
A comparison of MPI-ESM-MR projected annual mean rainfall of Bangladesh in 2030, 2050 and 2070 for the two RCPs is shown in fig.5 In 2030, the annual mean rainfall of Bangladesh will be 2208 mm under RCP 4.5 and 3042 mm under 8.5 (Figure 5, left panels). In the northeast and southeast, rain is expected to be heavier than in the west. In 2050, the annual rainfall will be 2767 mm and 2611 mm under RCP 4.5 and RCP 8.5 respectively (Figure 5, middle panels). In 2070, the annual mean rainfall of Bangladesh will be 2778 mm and 2343 mm under RCP 4.5 and RCP 8.5 respectively (Fig.5, right panels) The west-central part of Bangladesh will be the driest and average rainfall is expected to fall by 2070.

#### 3.3.2 Projection of Annual Maximum Temperature

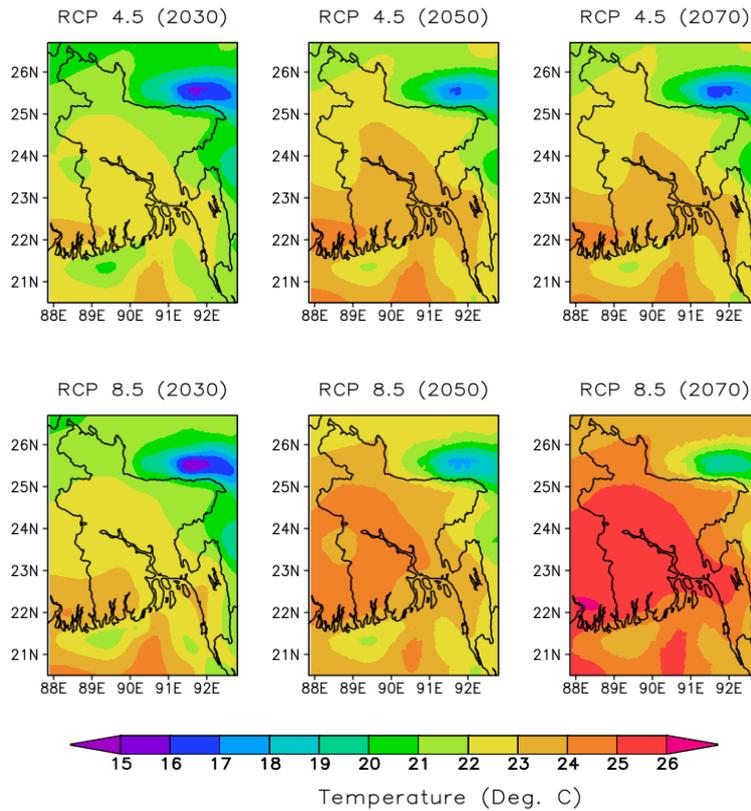
A comparison of MPI-ESM-MR projected annual mean maximum temperature of Bangladesh in 2030, 2050 and 2070 for the two RCPs is shown in fig.6. In 2030, the annual mean maximum temperature of Bangladesh will be 30.5°C under RCP 4.5 and 30.2°C under 8.5 (Fig.6. left panels). The spatial pattern of projected temperature shows a larger increase in the western part of Bangladesh under all future scenarios. In 2050, the annual maximum temperature will be 30.8°C and 31.5°C under RCP 4.5 and RCP 8.5 respectively (Fig.6. middle panels). In 2070, the annual mean maximum temperature of Bangladesh will be 30.9°C and 32.8°C under RCP 4.5 and RCP 8.5 respectively (Fig.6. right panels). The projected temperature is highest over the west-central part and lowest over the northeastern part of Bangladesh

#### 3.3.3 Projection of Annual Minimum Temperature

A comparison of MPI-ESM-MR projected annual mean minimum temperature of Bangladesh in 2030, 2050 and 2070 for the two RCPs is shown in figure 5.29. In 2030, the annual mean minimum temperature of Bangladesh



**Fig. 6:** Spatial distribution of MPI-ESM-MR model projected annual maximum temperature of 2030, 2050 and 2070 under the two RCP scenarios over Bangladesh.



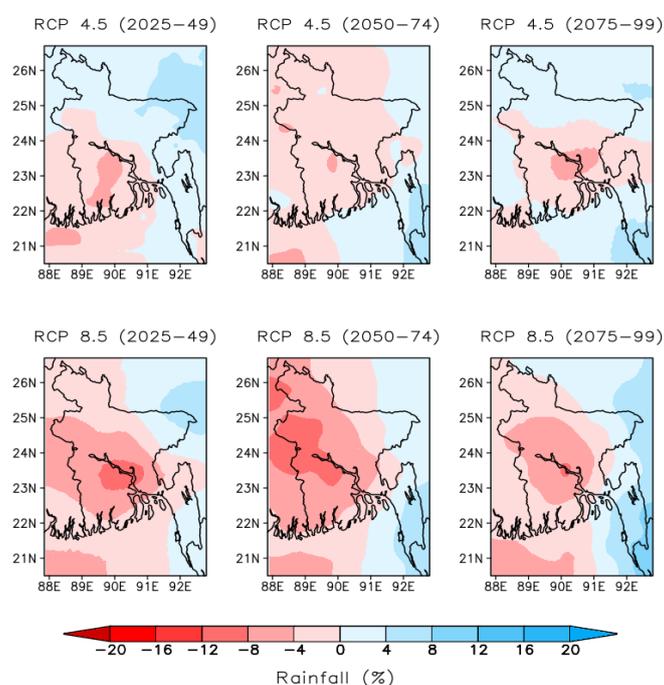
**Fig. 7:** Spatial distribution of MPI-ESM-MR model projected annual minimum temperature of 2030, 2050 and 2070 under the two RCP scenarios over Bangladesh

will be 21.4°C under RCP 4.5 and 21.8°C under 8.5 (Fig 7, left panels). The spatial pattern of projected temperature shows a larger increase in the southern and central part of Bangladesh under all future scenarios. In 2050, the annual minimum temperature will be 22.4°C and 22.8°C under RCP 4.5 and RCP 8.5 respectively (Fig. 7, middle panels). In 2070, the annual mean =maximum temperature of Bangladesh will be 22.3°C and 24.1°C under RCP 4.5 and RCP 8.5 respectively (Fig. 7, right panels).

### 3.4 Changes in Future Rainfall and Temperature on an Annual Basis

#### 3.4.1 Changes in Rainfall

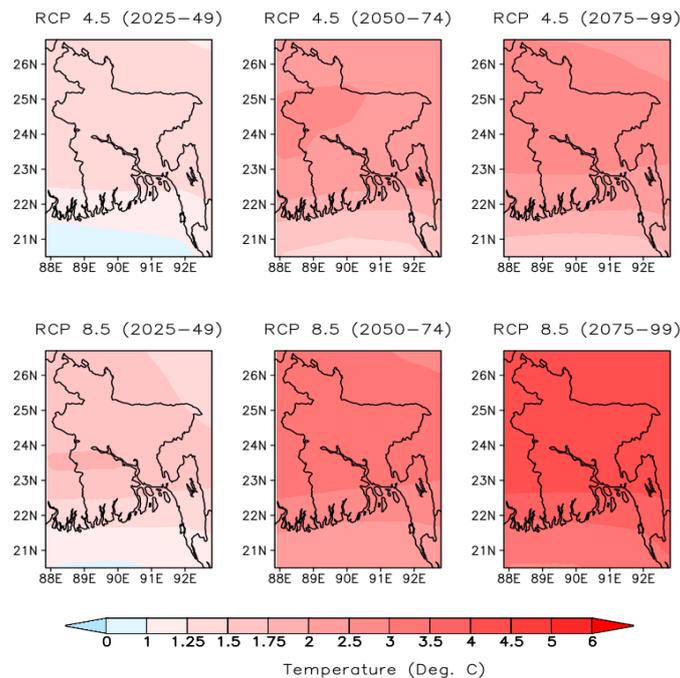
The spatial distribution of projected changes in annual mean rainfall for three future time slices under two RCP scenarios for MPI-ESM-MR model is shown in fig.8. For the near-future period, the projected annual mean rainfall over Bangladesh shows changes between -10% to 8% and -11% to 7% under RCP 4.5 and RCP 8.5 respectively (Fig.8, left panels). The projected rainfall decreases mostly over the west-central and southwestern part of Bangladesh and increases over the northeastern part of Bangladesh. For the mid-future period, the projected annual mean rainfall shows changes between -7% to 8% and -10% to 10% over Bangladesh under RCP 4.5 and RCP 8.5 respectively (Fig 8., middle panels). Almost all the regions show a consistent change in the mid-future period under all the two scenarios though highest amount of decrease is visible in the west-central part during this period under RCP 8.5. On the other hand, during the far-future period, the annual mean rainfall shows changes between -8% to 5% and -11% to 10% under RCP 4.5 and RCP 8.5 respectively (Fig.8, right panels). The projected rainfall decreases mostly over the central part and increases over the northern part of Bangladesh.



**Fig. 8:** Spatial distribution of future changes in rainfall (%) in relation to the reference period (1981–2005) for three future periods (2025–49), (2050–74) and (2075–99) under the two RCP scenarios over Bangladesh for MPI-ESM-MR.

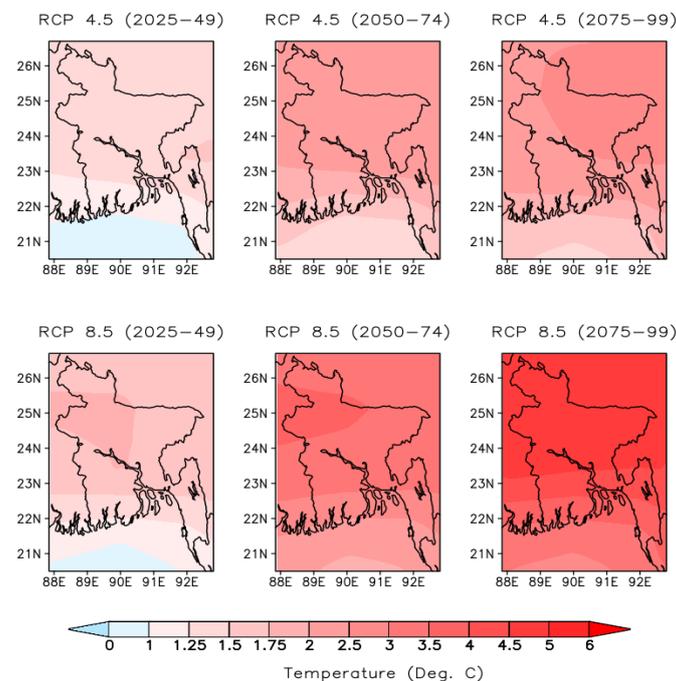
#### 3.4.2 Changes in Maximum Temperature

The spatial distribution of the projected changes in annual mean maximum temperature over Bangladesh under two different RCPs for MPI-ESM-MR model is shown in fig.9. For the near-future period, the annual mean maximum temperature averaged over Bangladesh is projected to increase by 1.3 °C and 1.5 °C under RCP 4.5 and RCP 8.5 respectively (Fig.9, left panels). For the mid-future period, the annual mean maximum temperature is projected to increase by 2.1 °C and 2.9 °C under RCP 4.5 and RCP 8.5 respectively (Fig.9, middle panels). The projected temperature changes are largest over the northwestern part of Bangladesh under RCP 4.5. The rest of the regions shows a consistent change in the mid-future period under all the two scenarios. In the case of the far-future period, the annual mean maximum temperature over Bangladesh is projected to increase by 2.4 °C and 4 °C under RCP 4.5 and RCP 8.5 respectively (Fig.9, right panels).



**Fig. 9:** Spatial distribution of future changes in maximum temperature(°C) in relation to the reference period (1981–2005) for three future periods (2025–49), (2050–74) and (2075-99) under the two RCP scenarios over Bangladesh for MPI-ESM-MR.

### 3.4.3 Changes in Minimum Temperature



**Fig. 10:** MPI-ESM-MR projected changes in minimum temperature (°C) in relation to the reference period (1981–2005) for three future periods (2025–49), (2050–74) and (2075-99) under the two RCP scenarios (RCP 4.5 and RCP 8.5) over Bangladesh.

The spatial distribution of the projected changes in annual mean minimum temperature over Bangladesh under two different RCPs for MPI-ESM-MR model is shown in fig.10. The spatial pattern of projected temperature shows a larger increase in the northern and central parts of Bangladesh under all future scenarios. For the near-future period, the annual mean minimum temperature averaged over Bangladesh is projected to increase by 1.3 °C and 1.5 °C under RCP 4.5 and RCP 8.5 respectively (Fig.10, left panels). The projected annual mean temperature over the region increases as the time progresses. For the mid-future period, the annual mean minimum temperature is projected to increase by 2 °C and 3 °C under RCP 4.5 and RCP 8.5 respectively.

(Fig.10, middle panels). In the case of the far-future period, the annual mean minimum temperature over Bangladesh is projected to increase by 2.2 °C and 4.2 °C under RCP 4.5 and RCP 8.5 respectively (Figure 5.40, right panels). The projected temperature changes are largest over the northwestern part of Bangladesh for all the three periods under both the scenarios.

#### 4. Conclusion

Based on multiple RCP scenarios for Bangladesh, this study evaluated the performance of a CMIP5 GCM to reproduce present temperatures and rainfall.

In terms of rainfall, the findings of historical analysis reveal underestimate with actual data, notably during the monsoon months, while for temperature, the results are practically same. The quantile mapping method was used to rectify future data for past era disparities. The annual rainfall in Bangladesh would change by -15 to 15%, according to this study. In all scenarios, rainfall is anticipated to increase from 2075 through 2099. The model annual mean rainfall averaged over Bangladesh is anticipated to change between -6 and 8% by the end of the century under RCP 4.5 and -15 to 14% under RCP 8.5. The changes in yearly rainfall patterns show a decrease in the southwest and central parts of the country and an increase in the northeast.

Under two RCP scenarios, the model shows an increase in annual mean temperature over Bangladesh (i.e., RCP 4.5 and RCP 8.5). The northwestern and west central parts of Bangladesh are expected to see the most warming (around 5°C) by the end of the century under RCP 8.5 compared to the reference period (1981–2005). The annual mean maximum temperature in Bangladesh is expected to rise by 2.2°C and 4.3°C by the end of the century under RCP 4.5 and RCP 8.5 scenarios, respectively. Similarly, the annual mean minimum temperature over Bangladesh is anticipated to rise by 1.9°C and 4.1°C by the end of the century, respectively. All emission scenarios show a significant rise in annual mean temperatures relative to the reference climate.

The results of this study show that the northwestern area of Bangladesh is very vulnerable to climate change. Extreme summer flash floods may occur in the future due to increased future warming and erratic rainfall. The findings of this study should help develop climate adaptation plans for Bangladesh's various areas. The study's findings can also be used to undertake climatological research and estimate the impact of climate change on Bangladesh.

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