# Projection of Future Climate Data Using Global Circulation Models

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**ABSTRACT**

The accurate prediction of future climate patterns is of paramount importance in understanding and mitigating the impacts of climate change on various ecosystems and human societies. This study focuses on the utilization of Global Circulation Models (GCMs) to project forthcoming climate data. GCMs are indispensable tools that simulate the Earth's atmospheric and oceanic processes, enabling us to gain insights into the complex interactions driving climatic shifts. Two climate models namely HadGEM2-ES and MIROC-ESM were selected to generate future climate data for the period 2010-2090 from MarkSim daily weather generator and also generated climate data compared with the observed data for the period 2010-2021. By comparing model predictions with observed trends, it helps to validate the performance of GCMs and identify potential areas of improvement. Results reveals that both RCP 4.5 and 8.5 scenarios predicted substantial rise in precipitation and temperature for future years. HadGEM2-ES with RCP 8.5 show very high temperature whereas MIROC-ESM with RCP 4.5 shows very low temperature. There is an increasing trend in prediction of climate data from 2010 to 2090 with highest precipitation and temperature in 2090 and lowest in 2010. From the prediction it is expected to increase in rainfall from 49.75 mm to 1341.66 in the future and maximum and minimum temperature about 32.98-36.84 °C and 24.37-28.58°C. it was also observed that minimum temperature was increasing drastically compared to the maximum temperature. Mean monthly observed and predicted precipitation and temperature was compared for the period 2010-2090. Statistical analysis was done to compare both data. RCP 8.5 scenario is more correlated with observed data. Models had underestimated 1-3°C temperature and 30-49.7 mm rainfall this bias has to be corrected. RCP 8.5 scenario was having highest $R^2$ about 0.88 for precipitation and 0.97 for temperature low correlation was observed for RCP 4.5 scenario compared to 8.5. Statistical analysis results confirms that data obtained from MIROC-ESM with RCP 8.5 scenario are in close agreement with the observed data with low bias in data, hence this model and scenario can be used for future projection of climate data. The findings provide crucial insights for policymakers, researchers, and stakeholders working towards a comprehensive understanding of the Earth's changing climate and the formulation of effective strategies to address its far-reaching consequences.

## I. INTRODUCTION

Climate change (CC) is currently the most pressing environmental concern of the twenty-first century. Its impact on food security is already evident, with changes in precipitation patterns, rising air temperatures, and more recurring extremes [IPCC (2016)., Islam *et al* (2021)]. This issue is compounded by inadequate management of environmental resources and a limited ability to adapt in developing countries [Groitoru *et al* (2016), IPCC (2014)]. India, as a developing country, is highly exposed to climatic shifts. They experienced a substantial rise in air temperature, monsoon and post-monsoon precipitation, while winter precipitation decreased during the late twentieth century due to climate change. Extreme weather events directly attributable to climatic changes have become increasingly common in recent years and have been responsible for substantial financial losses and human casualties. As global warming continues, extreme weather trends are projected to continue throughout the present century [Fahad *et al* (2018), Islam *et al* (2022), Das *et al* (2022)]. Thus, knowing how precipitation and air temperature will alter is vital to develop effective strategies for reducing climatic risk.

Climate projections serve a vital role in climate science and policymaking as they provide valuable insights into how the Earth's climate is likely to change in the future under different scenarios. The primary use of climate projections is to understand and anticipate potential climate trends and impacts over various spatial and temporal scales. Climate projections help assess how human activities, such as greenhouse gas emissions, land-use changes, and industrial activities, may influence the Earth's climate. They provide estimates of future temperature changes, precipitation patterns, sea level rise, and extreme weather events. It's important to recognize that climate projections are not absolute predictions but rather probabilistic estimates based on various emission scenarios and model uncertainties. They serve as valuable tools for informed decision-making in the face of an uncertain future climate. Continuous updates and improvements to climate models and observations enhance the accuracy and reliability of these projections over time.

Research into possible impacts of a climate change requires descriptions of local and regional climate. The Global Climate Models (GCMs) are the fundamental tool for understanding the potential impacts of climate change [Yue *et al* (2002), Eyring *et al* (2016)], and making projections for the future.

Considering the above points, the study was conducted to project future climate data of Bapatla district using two GCMs like, HadGEM2-ES and MIROC-ESM.

## II. MATERIAL AND METHODS

A. Study area

The study was conducted in Bapatla district. Bapatla district is in southern Indian state in Andhra Pradesh. It is situated along the eastern coast of India, Bapatla lies on the Bay of Bengal at approximately $15.9^0$ North latitude and $80.47^0$ East longitude. It is a flat region with a few meters of elevation above sea level and experiences a tropical climate characterized by hot and humid summers, as well as milder winters. The normal maximum and minimum temperatures recorded in the Bapatla district are $32.3^0$C and $18.5^0$C respectively and the normal rainfall of the district is 925.3 mm. The district is agriculturally significant, known for its rice cultivation, as well as the production of crops like pulses, cotton, and tobacco. The soils in general are very fertile and they are broadly classified as Black cotton soil, sandy loamy and red loamy. Black cotton area is in 70%, and sandy loamy in about 30% of the area in the Bapatla district. Bapatla benefits from good transportation links, with the Chennai-Kolkata railway line passing through the town, and National Highway 16 (NH 16) providing road connectivity to nearby cities and states. Location of study area is shown in Fig 1.

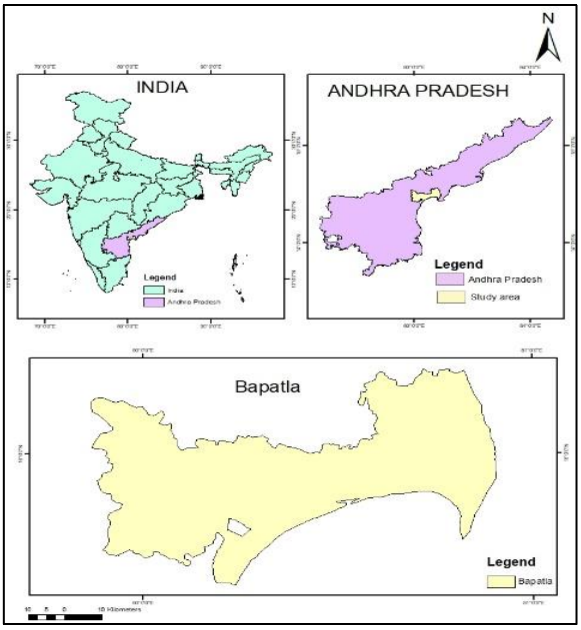


**Fig 1 Location map of Study area**

B. Future Climate data generator

MarkSim is a software package designed to generate daily weather data using a stochastic weather generator. This program utilizes a third-order Markov process to model daily weather data and has been calibrated using a vast dataset from over 9200 weather stations worldwide. These stations were grouped into 664 clusters based on a clustering algorithm, with each group having specific rainfall model parameters predicted from monthly averages of rainfall, air temperature, diurnal temperature range, elevation, and latitude. By interpolating climate surfaces at a resolution of 10 minutes of arc (approximately 18 km), the software can identify the relevant cluster for any specific location and evaluate the model parameters accordingly. In this study, MarkSim was applied to generate daily weather data files for running DSSAT crop models. Out of the 17 available models in MarkSim, two were selected for projecting future climate conditions. (Reference: Jones et al, 2000)

HadGEM2-ES is an advanced coupled Atmosphere-Ocean General Circulation Model (AOGCM) that features high-resolution atmospheric and oceanic components. The atmospheric resolution is N96 (1.875 × 1.25 degrees) with 38 vertical levels, while the oceanic resolution is 10 degrees (increasing to 1/30 degrees at the equator) with 40 vertical levels. Notably, HadGEM2-ES incorporates interactive land and ocean carbon cycles, allowing dynamic vegetation representation. It provides the flexibility to either prescribe atmospheric CO2 concentrations or anthropogenic CO2 emissions and subsequently simulate CO2 concentrations. Additionally, the model includes an interactive tropospheric chemistry scheme to simulate the evolution of atmospheric composition and interactions with atmospheric aerosols. These features make HadGEM2-ES a comprehensive and powerful tool for studying climate processes and the Earth's response to various forcing factors.

ESM, named "MIROC-ESM", is based on a global climate model MIROC (Model for Interdisciplinary Research on Climate). MIROC-ESM (MIROC-ESMCHEM) using a version without the coupled atmospheric chemistry. The importance of chemistry climate interactions on the transient climate system may be estimated.

The climate models project possible future climate shifts under the conditions of the specific scenarios. These models are run multiple times using various scenarios of future conditions, such as population levels and anticipated emissions of carbon dioxide

($CO_2$) or other greenhouse gases. Each GCM is distinct and has a different sensitivity to greenhouse gas emissions. This range, taken as a whole, is important to researchers for providing a sense of the uncertainty surrounding possible future events given a particular scenario and period. To capture this range and make use of the complement of projections, ensembles of multiple global climate model simulations are often used. CMIP5 stands for the Coupled Model Intercomparison Project Phase 5. It is the fifth phase of a collaborative international effort to compare and assess climate models. The project was coordinated by the World Climate Research Programme (WCRP) and involved many climate modelling centres worldwide. The CMIP5 simulations include 4 future scenarios referred to as "Representative Concentration Pathways" or RCPs. These future scenarios have been generated by four integrated assessment models (IAMs) and selected from over 300 published scenarios of future greenhouse gas emissions resulting from socio-economic and energy-system modelling. These RCPs are labelled according to the approximate global radiative forcing level in 2100 for RCP 8.5 during stabilisation after 2150 for RCP 4.5 and RCP 6 or the point of maximal forcing levels in the case RCP 3-PD with PD standing for "Peak and Decline". Out of the four scenarios available, two scenarios were used in this study for climate projection, namely RCP 4.5 and RCP 8.5.

Weather data has been generated from MarkSim DSSAT weather generator. Data from 2010-2090 was generated for future projection and data from 2010-2021 for comparison of projected and observed data. For generation of future weather data, latitude and longitude of Bapatla district has been entered. Screenshot depicting the location, model selection and replication selection for generating future climate data is shown in Fig 2.

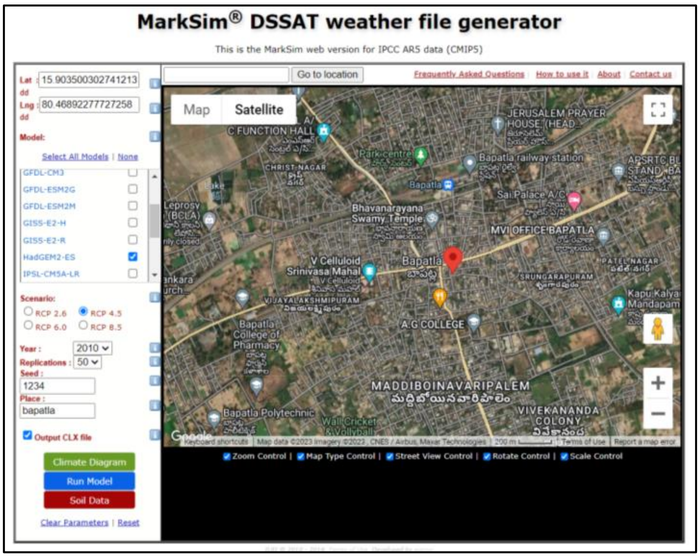


**Fig 2 Entering data in the MarkSim DSSAT weather generator**

As above mentioned, 2 climate forecast models have been selected from the drop window. The input details have to be entered like location, and models. Two models mainly HADGEM2-ES and MIROC-ESM were identified with scenario 4.5 and 8.5 to generate the future climatic data. The model was run with 50 replications to minimise the errors in simulation. After entering the input details run the model and then click on download CXL file.

The future rainfall maximum temperature and minimum temperature and radiation were generated, and the screenshot displaying the data is shown in Fig 3. The future climate data was generated from 2010 to 2090 using the weather generator and from 2010-2021 for comparison of projected and observed data.

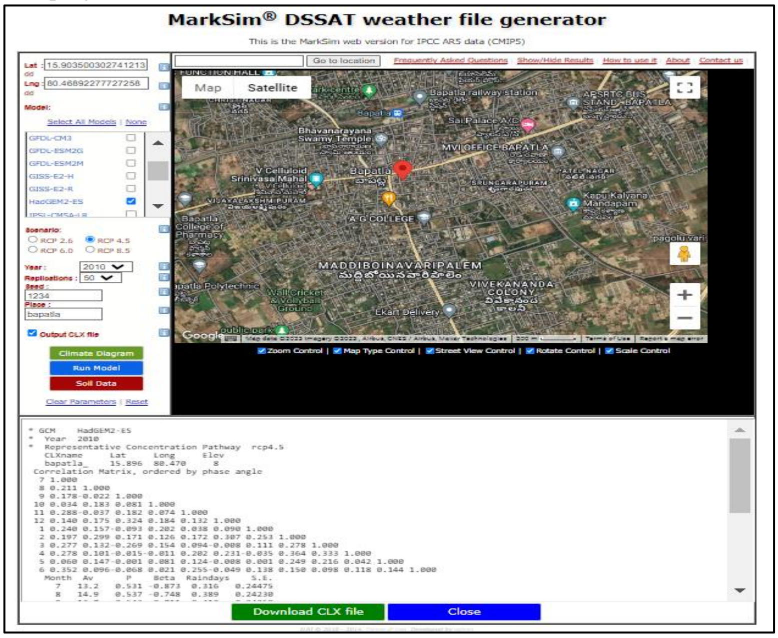


**Fig 3. Generation of weather data in MarkSim DSSAT weather generator**

C. Observed weather data

For the comparison of future projected data and observed data, observed data from 2010-2021 was collected from weather station Dr. NTR College of Agricultural Engineering, Bapatla. Observed data from 2010-2021 is shown in Table 1.

**Table 1. Observed Weather parameters**

| Year | Temperature | | Rainfall(mm) |
|---|---|---|---|
| | Maximum | Minimum | |
| 2010 | 28.90 | 18.90 | 2254.80 |
| 2011 | 30.86 | 18.83 | 838.70 |
| 2012 | 30.20 | 19.17 | 1153.10 |
| 2013 | 29.95 | 17.92 | 1676.20 |
| 2014 | 30.00 | 18.10 | 878.10 |
| 2015 | 30.47 | 18.80 | 1050.20 |
| 2016 | 30.68 | 18.51 | 1200.80 |
| 2017 | 30.52 | 17.65 | 856.20 |
| 2018 | 34.42 | 23.14 | 701.00 |
| 2019 | 34.45 | 23.76 | 716.60 |
| 2020 | 33.93 | 23.49 | 903.70 |
| 2021 | 34.00 | 23.49 | 1035.90 |

## III. RESULTS AND DISCUSSIONS

### A. Generation of future Rainfall data for Bapatla district

MarkSim tool was utilized to project changes in future precipitation data. The climate models, namely HadGEM2-ES and MIROC-ESM with 2 RCP scenarios i.e., RCP 4.5 and RCP 8.5 were used to generate future climate data from 2010-2090.

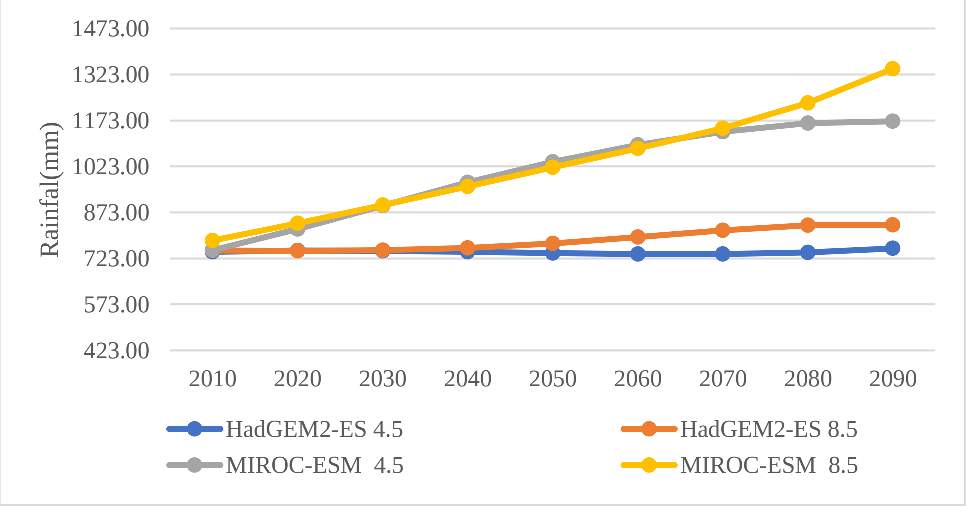


**Fig 4. The variability of projected average annual rainfall from 2010-2090 in HadGEM2-ES and MIROC-ESM in both 4.5 and 8.5 RCP scenarios**

The average annual rainfall projection for the period 2010-2090 from different climate with RCP scenario 4.5 and 8.5. from the graph (Fig 4) it can be observed that the rainfall trend is increasing from 2010-2090 with minimum rainfall in the year 2010 and maximum in the year 2090 for all the scenarios and models. In both HadGEM2-ES and MIROC-ESM models with RCP 8.5 rainfall is increasing drastically compared to 4.5 RCP scenario for the same models where rainfall is gradually increasing and also low rainfall compared to RCP 8.5 scenario.

Similar trend was also observed from previous studies (Thoeun H C 2015, Krishnan *et al* (2020), Tyagi et al (2022), Kamruzzaman *et al* (2023) where at the end of century there is highest rainfall.

### B. Generation of future temperature (Maximum & Minimum) data for Bapatla district

The projected maximum and minimum temperature for future is shown in Fig 5.a &b respectively for all the selected climate models with RCP 4.5 and 8.5. Figures show the temperature for moderate emission scenario (RCP 4.5) and high emission scenario (RCP 8.5) from 2010-2090, as time passes the maximum temperature is projected to rise by 1°C to more than 3°C, whereas the minimum temperature is projected to rise by 1°C to more than 4°C. As per the analysis the minimum temperature is increasing drastically compared to maximum temperature for both models and scenarios the same trend was also reported by Kamruzzaman *et al* (2023). For the period 2010-2090 the maximum warming is projected to be from 32.98°C to 35.58°C for RCP 4.5 and from 33.12°C to 36.84°C for RCP 8.5 in HadGEM2-ES, and from 32.12°C to 34.12°C for RCP 4.5 and minimum warming is projected to be from 24.32°C to 26.53°C for RCP 4.5 and 24.43°C to 28.58°C for RCP 8.5 in HadGEM2-ES model whereas in MIROC-ESM it is projected to be from 24.39°C to 25.75°C for RCP 4.5 and from 24.37°C to 26.89°C for RCP 8.5 scenario. Both maximum and Minimum temperature generated in HadGEM2-ES for RCP 8.5 is in increasing trend, the potential consequences could pose a significant threat to the entire region.

It strongly agrees with the report submitted by Krishnan *et al* (2020). Under the RCP8.5 scenario, it is projected that by the end of the twenty-first century, temperatures will increase by around 4.7°C to 5.5°C compared to the average temperatures during the recent past (1976–2005). Tyagi *et al* (2022) and Krishnan et al (2020) also reported that under RCP 4.5 scenario increase mean temperature is projected to be by 2.1- 4.8°C and under worst case that RCP 8.5 it is projected to be increase by 3.1-5.8°C at the end of 21 century.

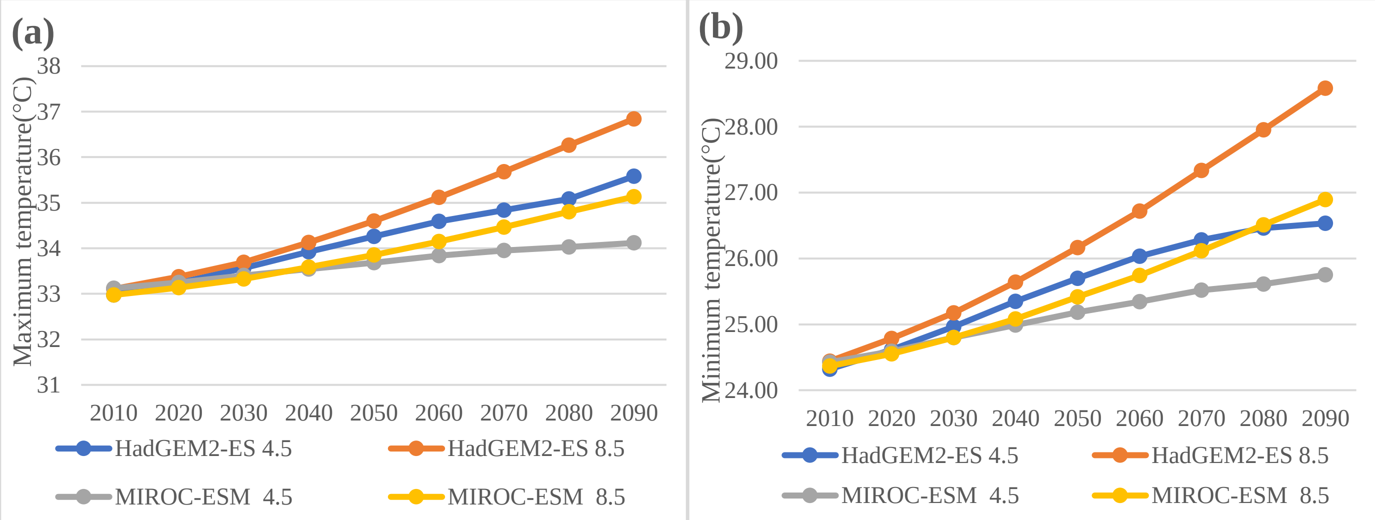


Fig 5. The variability of average annual (a)Maximum and (b)Minimum temperatures from 2010-2090 in HadGEM2-ES and MIROC-ESM for both 4.5 and 8.5 RCP scenarios

### C. Comparison of observed and projected mean monthly climate data

For the validation of data obtained from both the climate models, observed data from 2010-2021 was compared with model data, various statistical analysis was also done. Results obtained from statistical analysis is presented in below (Table 2). Trend analysis and comparison of both data is graphically represented below (Fig 6.a-c).

From the analysis it was observed that there has been an increasing trend in monthly rainfall from January to September and then decreasing trend up to December in both climate models and observed data (Fig 6.a) the results align with earlier research that has similarly forecasted a rise in rainfall during monsoon periods and a decline in winter precipitation (Kwon and Sung, 2019). All the scenarios show increase in precipitation, smallest increase in precipitation is shown by MIROC-ESM 4.5 with lowest $R^2$ about 0.77 and R as 0.88, and the error in prediction was MAE 35.66 mm and RMSE 49.74 mm the highest correlation and lowest error was observed for MIROC-ESM 8.5 (Table 2). All the scenarios underestimated the precipitation during rainy season.

The comparison of mean monthly observed maximum and minimum air temperatures for the period 2010-2021 with the maximum and minimum temperatures from HadGEM2-ES and MIROC-ESM for Bapatla region indicated that maximum and minimum temperature were high in summer for both predicted and observed data. From the analysis it can be revealed that models underestimated the temperature data. The maximum temperature was in the range 30.5-38.13°C (Fig 6.b) and minimum temperature was 18-27.9°C (Fig 6.c) Similar trend and results were observed from the previous findings (Thoeun H C 2015.) that a comparison of observed maximum and minimum air temperatures from 1985 to 2008 with the annual maximum and minimum temperatures projected by climate models showed that the maximum temperature range was between 31.5°C and 36.1°C, while the minimum temperature range was between 21.5°C and 26.3°C.

Observed maximum temperature data was more than the predicted data 2-3°C whereas minimum temperature was 1-1.2 °C higher. Statistical results confirms that the MAE and RMSE are in the range 3-3.3°C for maximum temperature and for minimum temperature they are in the range 1-1.2°C (Table 2).

**Table 2. Statistical results obtained from the comparison of predicted and observed data for the period 2010-2021**

| Statistical Parameters | Maximum temperature °C | | | | Minimum temperature °C | | | | Rainfall (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HadGEM2-ES | | MIROC-ESM | | HadGEM2-ES | | MIROC-ESM | | HadGEM2-ES | | MIROC-ESM | |
| | RCP 4.5 | RCP 8.5 | RCP 4.5 | RCP 8.5 | RCP 4.5 | RCP 8.5 | RCP 4.5 | RCP 8.5 | RCP 4.5 | RCP 8.5 | RCP 4.5 | RCP 8.5 |
| **$R^2$** | 0.97 | 0.96 | 0.97 | 0.97 | 0.96 | 0.96 | 0.97 | 0.97 | 0.84 | 0.84 | 0.77 | 0.88 |
| **R** | 0.98 | 0.98 | 0.99 | 0.99 | 0.98 | 0.98 | 0.98 | 0.99 | 0.91 | 0.92 | 0.88 | 0.94 |
| **MAE** | 3.19 | 3.06 | 3.11 | 3.22 | 1.03 | 0.97 | 1.04 | 1.05 | 32.20 | 32.05 | 35.66 | 29.29 |
| **RMSE** | 3.26 | 3.14 | 3.16 | 3.28 | 1.19 | 1.10 | 1.17 | 1.19 | 47.58 | 47.26 | 49.74 | 41.99 |

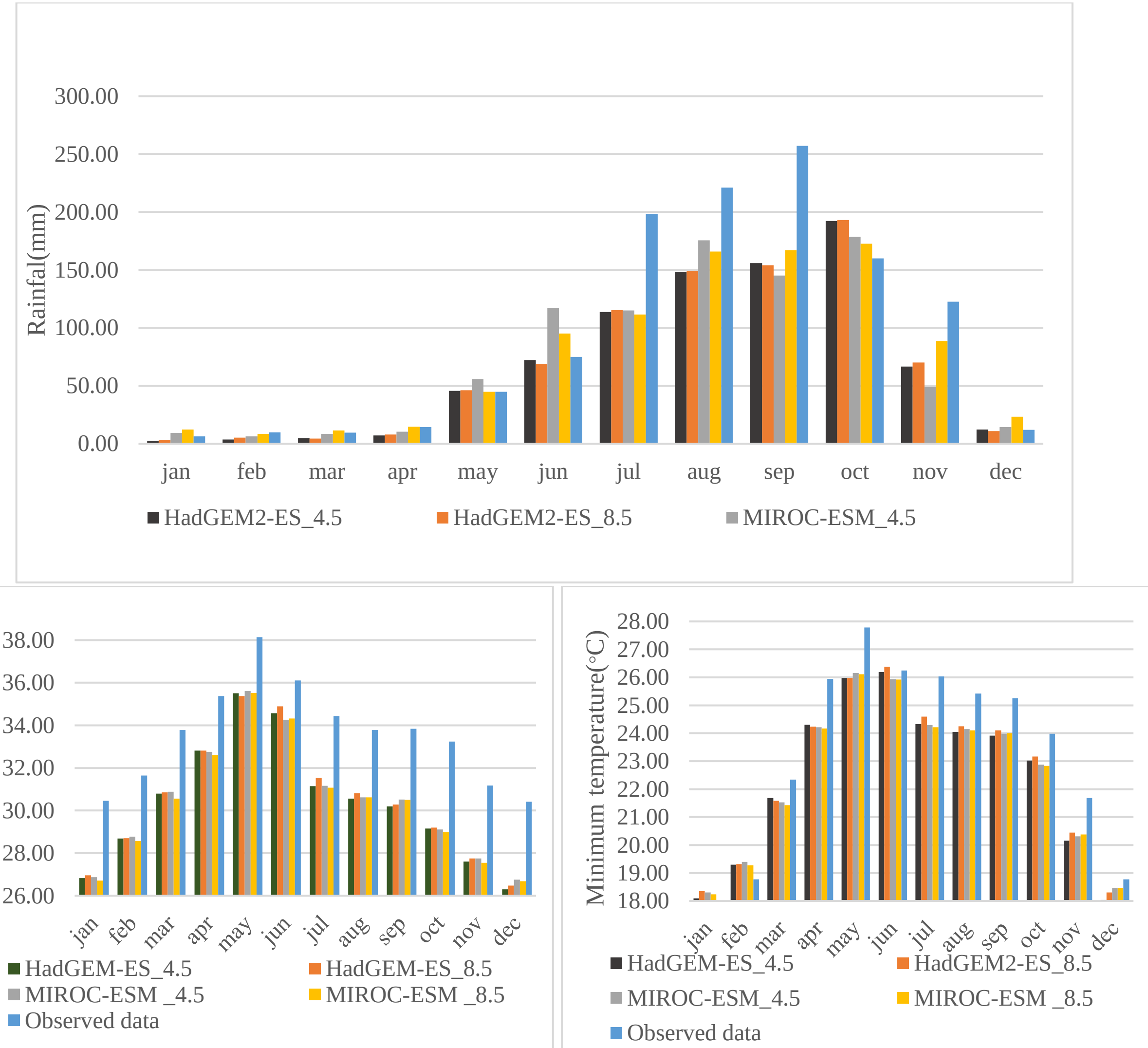


**Fig 6. Mean monthly projected and observed climate data for selected climate models with RCP scenario 4.5 and 8.5 (a)Rainfall, (b)Maximum temperature and (c)Minimum temperature**

## IV. CONCLUSION

Projections of climate data for period 2010 to 2090 from two climate models with selected RCP scenarios showed an increasing trend in average rainfall, maximum temperature and minimum temperature in all the cases. At the end of the twenty-first century i.e., 2090 all the projected climate data reaches the extreme end in RCP 8.5 scenario for both models. The projected results obtained from RCP 8.5 scenario in both GCMs for all the climate parameters agrees with the observed data, this can be considered valid projection models for future. Comparison of observed and predicted data for the period 2010-2021 reveals that RCP 8.5 is having highest correlation lowest error in prediction and there is 2-3°C bias in the model in temperature prediction and also underestimated the precipitation, it should be corrected before prediction.

The ongoing human-induced climate change is projected to persist throughout the twenty-first century. To enhance the precision of future climate projections, especially when considering regional forecasts, it is crucial to adopt strategic methods aimed at advancing our understanding of Earth system processes. Additionally, continuous efforts to improve observation systems and climate models are essential for refining our predictions and addressing the challenges posed by climate change effectively. climate projections from GCMs are indispensable tools for understanding the potential trajectory of earth's climate. They help the society to prepare for a changing climate, foster sustainable development, and inform actions aimed at safeguarding the environment and future generations and also helps in policy making and implementation related to adoption and mitigation in interest of a larger society.

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