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Research Paper

Evaluation of CMIP6 GCMs performance and future projection for the *Boro* and *Kharif* seasons over the new alluvial zones of West Bengal

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ABSTRACT

Present study examined the overall performance of 12 CMIP6 GCMs for rainfall, maximum and minimum temperatures for rice crop-growing seasons i.e., *Boro* (January to May) and *Kharif* (June to October) over the new alluvial zone of West Bengal. A wide range of indices i.e., index of agreement, error indices and bias estimators were utilized to put more confidence on the results. Results indicated that CMIP6 models were able to reproduce observed mean climatology and inter-annual variability of maximum and minimum temperature adequately for both seasons while a smaller number of models (3-4 models) out of a total of 12 GCM-CMIP6 models showed satisfactory performance for rainfall. The ranks assigned to the models revealed that CNRM–ESM2–1 was the best-performing model for *Kharif* and MRI-ESM2-0 showed the highest skill for *Boro*. ACCESS-CM2 and MPI-ESM1-2-LR performed worst for *Kharif* and *Boro* seasons respectively. Further, CNRM–ESM2–1 and MRI-ESM2-0 were used to project the future climate for *Kharif* and *Boro* seasons respectively under both moderate (SSP2-4.5) and extreme scenarios (SSP5-8.5). Higher warming was projected during *Boro* season than *Kharif*. Projections revealed increasing rainfall during *Kharif* season but decreasing rainfall in *Boro* season in both the moderate and extreme future scenarios.

***Keywords**:* Climate model; CMIP6-GCMs; *Boro* rice; Future projection; Model evaluation; Model rankings.

The Coupled Model Intercomparison Project (CMIP) initiated in 1995 provides advanced information on climate change resulting from natural, unforced variability and radiative forcing in a multi-model context. Evaluation of the model responses during historical periods and the ability to project weather under different temporal and spatial scales are performed with the help of idealized experiments (WCRP, 2022). Models are showing their improving skills to reproduce sub-regional scale grossed features starting from SAR to AR4 (Das *et al*., 2012) but still are not adequate to generate climatic features in seasonal and monthly scales on the point location. The sixth phase of the Coupled Model Intercomparison Project (CMIP6) came during 2014 to bridge the gap between the flaws of CMIP5 and successive budding challenges in the current scenario of climate modeling (Eyring *et al*., 2016). Despite, a model that performs well in one region may not necessarily perform as well in another region. Therefore, studies to rank the performance of individual CMIP6 models over specific regions have been initiated (Anil *et al*., 2021). Hence, it is necessary to test the model performance on regional and local scales because of the inherent bias and uncertainty shown by the CMIP6 GCMs. So, evaluation is required to judge the best-performing model for a given site. The complex process of evaluation of the most appropriate model is done based on the observed data of the location of interest for historical period. A ranking is assigned based on the values of various statistical indices. Mukherjee *et al*., (2024) used the 15 CMIP6 models outputs from 2000 to 2014 and compared with observed data set of Kalyani West Bengal. They selected the best model and assessed the future field-pea yield from 2040 to 2099 period using climatic projection data under SSP2-4.5 and SSP5-8.5.

The present study aimed to evaluate CMIP6 models for West Bengal's new alluvial zone, focusing on the *Kharif* and *Boro* rice-growing seasons, which are crucial for the state's agriculture. The objective was to assist users in selecting appropriate models for impact analysis studies and to explore future projections of key variables essential for crop growth, including maximum and minimum temperatures and precipitation.

MATERIAL AND METHODS

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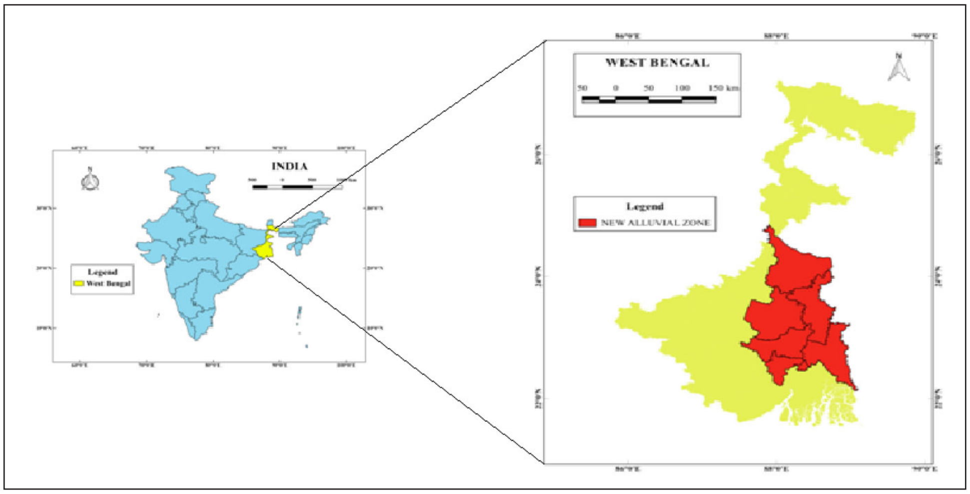

Fig. 1: New alluvial zone of West Bengal

Study area

The study area is the new alluvial zone (NAZ) of West Bengal representing the lower Indo-Gangetic Plain (Fig. 1). The NAZ encompasses districts of Nadia, Murshidabad, North 24 Parganas, Hooghly, Howrah, and Bardhaman. The observed weather data were collected from the Meteorological Observatory at Bidhan Chandra Krishi Viswavidyalaya, located in Mohanpur, Nadia, West Bengal, with coordinates 23.6565 N and 88.2254 E. The region experiences three distinct seasons: summer (March to June), rainy (June to September), and winter (October to February). May typically registers the highest temperatures, ranging from 27.3°C to 33.5°C, while January sees the lowest temperatures, ranging from 14.7°C to 20.5°C. The annual rainfall averages 1467.5 mm, with over 80% occurring during the South-West monsoon. Overall, the climate is warm, humid, with a short winter period.

CMIP6 data

The CMIP6 dataset, accessible via the Earth System Grid Federation (ESGF, available at https://esgf-node.llnl.gov/search/cmip6), has a daily temporal resolution. The criteria for selecting CMIP6 models for analysis included: availability of datasets for both historical and future periods under various SSP scenarios, no missing data from 1998 to 2014, and the provision of daily maximum and minimum temperature and rainfall data for both historical and future periods (Table 1).

Evaluation of GCMs through statistical measures

The performance of general circulation models (GCMs) was assessed by comparing their outputs, interpolated to the specific site, with observed data from 1998 to 2014. Both statistical and graphical model evaluation techniques were utilized in the study. Different statistical indices exhibit sensitivity to different meteorological parameters. So, the entire conventional statistical indices were segregated into three major categories of indices namely Index of agreement (correlation, NSE and d-index), some error indices (NRMSE) and bias (PBIAS). The detailed description is provided in below.

Correlation coefficient (r)

Correlation coefficient (r) describes the degree of co linearity between simulated and measured data ranging from −1 to 1. If r = 0, no linear relationship exists. On the other hand, r = 1 or −1, confirms existence of a perfect positive or negative linear relationship. This index is expressed as below.

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y^2)]}}$$

Index of agreement (d)

The index of agreement (d) was developed as a standardized measure of the degree of model prediction error and varies between 0 and 1. A computed value of 1 indicates a perfect agreement between the measured and predicted values, and 0 shows no agreement at all. This index is calculated as below mentioned formula.

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(|P_i-\bar{O}|+|O_i-\bar{O}|)^2}\ ,\ \ 0 \le d \le 1$$

Error index (NRMSE)

The normalized root mean squared error (NRMSE) is also called scatter *index*. It is a statistical error indicator defined as below.

$$\mathrm{NRMSE} = \frac{\sum(S_i-O_i)^2}{\sum O_i^2}$$

Nash-Sutcliffe efficiency (NSE)

The NSE ranging between − ∞ and 1 is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance. The expression for this index is mentioned below.

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(\mathrm{OBS}_i-\mathrm{SIM}_i)^2}{\sum_{i=1}^{n}(\mathrm{OBS}_i-\overline{\mathrm{OBS}})^2}$$

Table 1: Description of selected CMIP6 GCMs

CMIP6 model	Horizontal resolution (longitude. by latitude) *	Institute	Key references
ACCESS-CM2	1.9° × 1.3°	Commonwealth Scientific and Industrial Research Organization, Australia	Bi *et al.,* (2012)
BCC-ESM1	2.8° × 2.8°	Beijing Climate Center, China	Zhang *et al.,* (2021)
CNRM–CM6–1	1.4° × 1.4°	French National Centre for Meteorological Research, France	Voldoire *et al.,* (2019)
CNRM–ESM2–1	1.4° × 1.4°	French National Centre for Meteorological Research, France	Séférian *et al.,* (2019)
INM–CM4–8	2° × 1.5°	Institute for Numerical Mathematics, Russia	Volodin *et al.,* (2018)
INM–CM5–0	2° × 1.5°	Institute for Numerical Mathematics, Russia	Volodin *et al.,* (2018)
KACE–1–0–G	1.3° × 0.9°	South Korea	
MIROC6	1.4° × 1.4°	Atmosphere and Ocean Research Institute, University of Tokyo, Japan	Tatebe *et al.,* (2019)
MIROC-ES2L	2.8° × 2.8°	National Institute for Environmental Studies and RIKEN Center for Computational Science, Japan	Hajima *et al.,* (2020)
MRI-ESM2-0	1.1° × 1.1°	MRI, Japan	Yukimoto *et al.,* (2019)
MPI-ESM1-2-LR	1.875° × 1.86°	Max Planck Institute for Meteorology (MPI-M), Germany	Mauritsen *et al.,* (2019)
NorESM2–MM	0.9° × 1.3°	Norwegian Meteorological Institute, Norway	Seland *et al.,* (2020)

$*1^0$=111km

Percent bias (PBIAS)

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimate on bias and vice versa. The formula for this index can be expressed as below.

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}$$

Overall ranking

The statistical indices were used to assess the performances of the selected models on seasonal basis (January-May and June-October) individually. The models were assigned their respective rankings based on the values of different indices such as correlation coefficients, d-index, NRMSE, NSE, PBIAS. Different models responded differently to different indices. Hence the sum total of the ranks for all the index for two different seasons (*Kharif* and *Boro*) cumulatively was taken for each model for the final ranking for the respective season**.**

RESULTS AND DISCUSSION

The study pointed out different models to be the best performing ones (rank 1) for different weather parameters for the two seasons so far. It was realized that dealing with separate models for different parameters might not be feasible for the users. So, an overall ranking was assigned to the selected group of models considering their performances for all the three weather parameters. The final rank of the models summed over three mentioned parameters for *Kharif* and *Boro* seasons were displayed in the Table 2 and Table 3 respectively. It can be reported that CNRM-ESM2–1 and MRI-ESM2-0 models among the entire set of CMIP6 models considered for the study may generate decent outputs in portraying future climatic scenario for *Kharif* and *Boro* seasons respectively.

Future projection

The future projections (Fig. 2) are divided into two-time frames, 2030-2060 and 2061-2090, and assessed under two scenarios: SSP2-4.5 and SSP5-8.5, corresponding to moderate and extreme scenarios, to differentiate potential outcomes based on greenhouse gas emissions and socio-economic pathways.

Projection for Kharif season

The CNRM–ESM2–1 model project weather condition for the *Kharif* season from June to October. Average maximum and minimum temperatures may range from 31 to 32 °C and 22 °C, with rainfall between 1900 to 2200 mm. In the moderate scenario, maximum temperatures may reach the highest point between 35 and 37 °C in the years 2030–2060 and 2061–2090. Average values of minimum temperature may exist between 21-22 °C, with upper ranges of 26-28 °C. However, variations may be found in lower minimum temperatures, with SSP2-4.5 and SSP5-8.5 showing 18 °C and 14 °C respectively during 2030–2060. Rainfall projections indicate an average of 1860 mm under a moderate scenario for both periods, while extreme scenarios predict higher rainfall between 2100–2200 mm. SSP2-4.5 anticipates higher rainfall around 4500 mm during 2061–2090. Both scenarios suggest increased rainfall in the later period (2061–2090) of the *Kharif* season.

Projection for Boro season

The MRI-ESM2 model projections for the *Boro* season indicate varying climatic conditions under different scenarios. Maximum temperatures may vary from 33.5 to 37°C under SSP2-4.5 and SSP5-8.5, with extreme conditions potentially reaching 40°C during 2061-2090. Minimum temperature is expected to remain relatively consistent, averaging around 20°C for 2030-2060 and 21°C for 2061-2090. Higher rainfall is projected during the later period (2061-2090) for both scenarios, with averages of 145-190 mm. The highest rainfall values are anticipated around 500 mm during 2030-2060 under both conditions and 2061-2090 under

Table 2: Variation of ranks of each model according to different meteorological parameters but irrespective method of analysis (indices) for *Kharif* season

Models	Tmax	Tmin	Rainfall	Sum	Rank
ACCESS-CM2	10	12	10	32	12
BCC-ESM1	3	9	4	16	4
CNRM-CM6–1	2	1	9	12	2
CNRM-ESM2–1	1	2	3	6	1
INM-CM4–8	12	4	3	19	7
INM-CM5–0	9	6	7	22	9
KACE–1–0–G	8	3	8	19	7
MIROC-6	7	7	11	25	10
MIROC-ES2L	11	5	6	22	9
MPI-ESM1-2-LR	7	11	12	30	11
MRI-ESM2-0	5	8	6	19	7
NORESM2–MM	4	10	1	15	3

Table 3: Variation of ranks of each model according to different meteorological parameters but irrespective method of analysis (indices) for *Boro* season

Models	Tmax	Tmin	Rainfall	Sum	Rank
ACCESS-CM2	7	5	6	18	5
BCC-ESM1	8	10	5	23	7
CNRM-CM6–1	9	2	8	19	6
CNRM-ESM2–1	10	3	11	24	8
INM-CM4–8	7	7	3	17	4
INM-CM5–0	5	8	1	14	3
KACE–1–0–G	11	12	4	27	12
MIROC-6	12	7	7	26	10
MIROC-ES2L	2	1	9	12	2
MPI-ESM1-2-LR	5	10	12	27	12
MRI-ESM2-0	1	4	3	8	1
NORESM2–MM	3	11	11	25	9

moderate scenarios. However, under extreme conditions, lower values of rainfall are projected for 2061-2090. These projections underscore potential changes in temperature and precipitation patterns, with implications for the *Kharif* and *Boro* season and regional agricultural activities.

Change in meteorological parameters from baseline

Future climate trends indicate significant differences in temperature and rainfall patterns affecting the *Kharif* and *Boro* seasons (Table 4). For *Kharif*, temperatures are expected to show minimal change, with a possible decrease of 1°C on an average for both maximum and minimum temperatures late this current century. The *Boro* season, however, is predicted to undergo notable temperature increases, with minimum temperatures rising by 1-2°C and maximum temperatures potentially ascending by 6-8°C in certain years. This dramatic rise in temperatures during *Boro* could adversely affect paddy production, highlighting the need for adaptive strategies such as adjusting planting times and introducing heat-resistant crop varieties.

Rainfall patterns are also projected to vary, with the *Kharif* season seeing increases of 45-65% under moderate scenarios and up to 80% under extreme scenarios, surpassing baseline levels. In contrast, the *Boro* season could face a significant reduction in rainfall, with projections indicating a 30% decrease during 2030-2060 and a 15-18% decrease during 2061-2090, with most years experiencing an 80-90% reduction (Table 4). Addressing these changes requires implementing measures such as developing water harvesting structures, adjusting irrigation practices, and promoting moisture-conservation technologies during the *Boro* season.

CONCLUSION

The study evaluated CMIP6 models to identify the best performers for a specific location, focusing on maximum temperature, minimum temperature, and rainfall for *Kharif* and *Boro* seasons. For the Kharif season, CNRM-ESM2–1 excelled in simulating maximum temperature, CNRM-CM6–1 for minimum temperature, and NORESM2–MM for rainfall. In the Boro season, MRI-ESM2-0, MIROC-ES2L, and INM-CM5–0 were the top models for maximum and minimum temperatures and rainfall, respectively. The study highlighted the varying skills of modeling centers, naming CNRM–ESM2–1 and MRI-ESM2-0 as the best fits

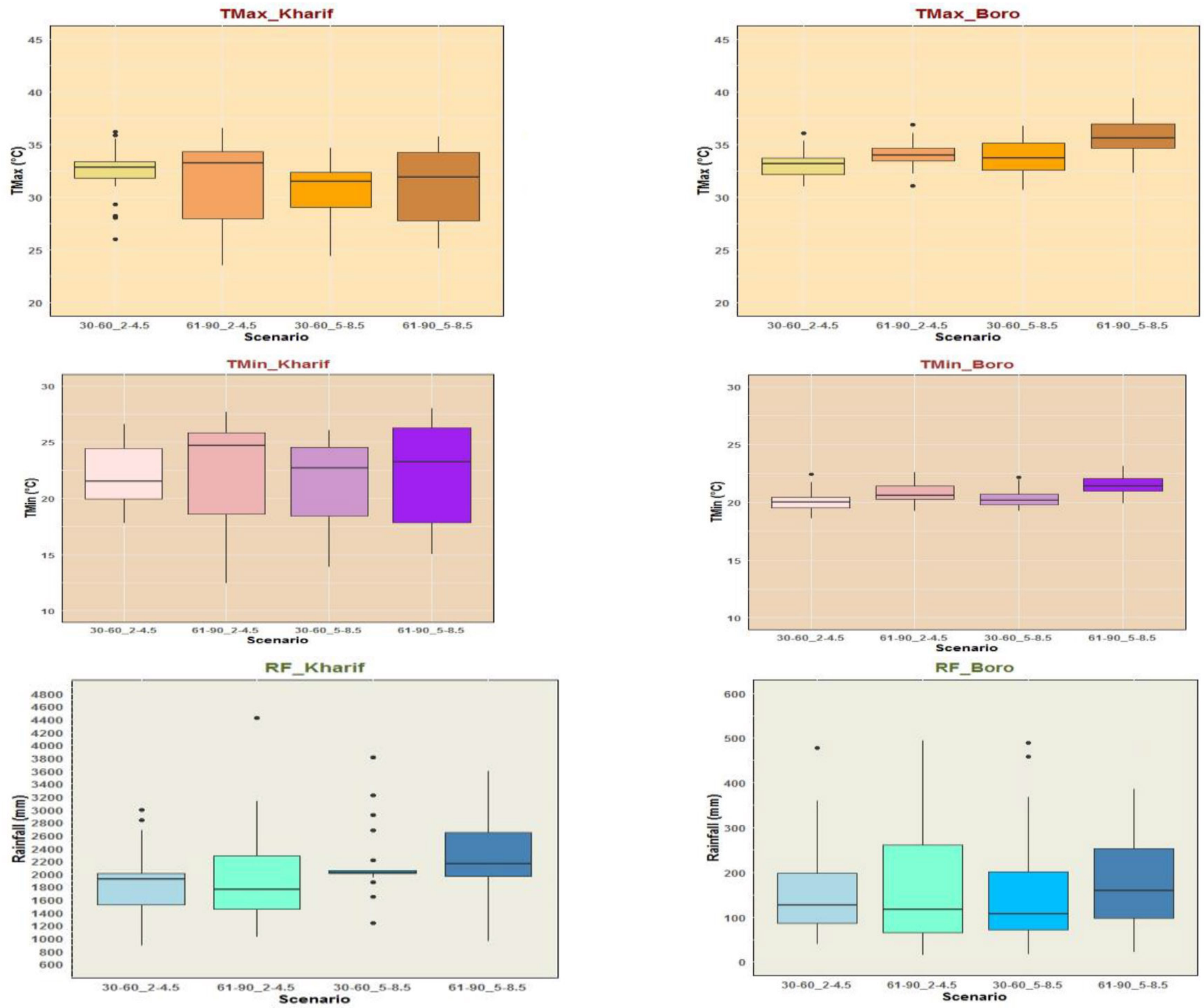

Fig. 2: Future projection of maximum temperature (Tmax), minimum temperature (Tmin) and rainfall (RF) for *Kharif* and *Boro* seasons

Table 4: Change of meteorological parameters from baseline condition during *Kharif* and *Boro* seasons in two time periods and projection scenario

Projection scenario	Time period	Maximum temperature (°C)		Minimum temperature (°C)		Rainfall (mm) & Departure (%)	
		Kharif	*Boro*	*Kharif*	*Boro*	*Kharif*	*Boro*
Base line	1998-2014	32.4	30.8	23.3	19.7	1257.6	211.1
SSP2-4.5	2030-2060	-0.03	2.33	-1.13	0.34	47.75	-28.56
	2061-2090	-0.72	3.19	-0.77	1.04	55.83	-14.63
SSP5-8.5	2030-2060	-1.78	3.09	-2.04	0.60	69.52	-31.02
	2061-2090	-1.30	5.00	-1.07	1.77	81.83	-18.00

for *Kharif* and *Boro* seasons, respectively, while ACCESS-CM2 and MPI-ESM1-2-LR performed poorly. It underscores the importance of evaluating model simulations specific to the study region and temporal scale. Future projections suggest a decrease in temperature and an increase in rainfall for *Kharif,* with opposite trends for *Boro,* providing valuable insights for climate impact studies in West Bengal's New Alluvial Zone.

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