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# Simulation performance of selected global and regional climate models for temperature and rainfall in some locations in India

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## ABSTRACT

Global and regional climate models are reported to have inherent bias in simulating the observed climatology of a region. This bias of climate models is the major source of uncertainties in climate change impact assessments. Therefore, use of bias corrected simulated climate data is important. In this study, the bias corrected climate data for 30 years' period (1976-2005) from selected common four GCMs and RCMs for six Indian locations are compared with the respective observed data of India Meteorological Department. The analysis indicated that the RCMs performance is much better than GCMs after bias correction for minimum and maximum temperatures. Also, RCMs performance is better than GCMs in simulating extreme temperatures. However, the selected RCMs and GCMs are found to either over estimate or under estimate the rainfall despite bias correction and also overestimated the rainfall extremes for selected Indian locations. Based on the overall performance of four models for the six locations, it was found that the GFDL_ESM2M and NORESM1-M RCMs performed comparatively better than CSIRO and IPSL models. After bias correction, the RCMs could represent the observed climatology better than the GCMs. And these RCMs *viz.,* GFDL_ESM2M and NORESM1-M can be used individually after bias correction in the climate change assessment studies for the selected regions.

***Keywords:*** Global climate models (GCMs), Regional climate models (RCMs), Rainfall, Temperature.

Climate model (global or regional) outputs are used in climate change impact assessment studies in different sectors (Teklesadik *et al.,*2017; Naresh Kumar *et al.,* 2015). But the climate projections derived by these climate models have significant uncertainties (IPCC, 2012; Woldemeskel *et al.* ,2016; Mandal *et al.,* 2017; Shen *et al.,* 2018). The uncertainties exist in climate change projections as well as the impact models may lead to uncertain projections of climate change impacts in agriculture (Asseng *et al.,* 2013). Hence, they are not usable as such by modellers and policy makers. So, the climate model outputs are recommended to be bias corrected before application.

The climate models are reported to have significant bias for observed climate and extreme events over Indian region (Shweta *et al.,* 2019, 2020). So, it is advised that the bias corrected data should be used as input for respective climate change studies (Maraun *et al.,* 2016). Even the Regional Climate Models (RCMs) outputs also are reported to have bias for Indian locations (Zhacharias *et al.,* 2015).

Globally, several studies are performed to compare bias corrected GCMs or RCMs temperature/precipitation data i.e.GCM-RCM precipitation data over Costa Rica (Mendez *et al.,*2020), RCMs precipitation for extreme events over South Korea (Shin *et al.,*2019). For Indian Ocean, selected GCMs and RCMs wind data are compared withtheir respective ensemble data (Chowdhury *et al.,*2019). Also, GCMs and RCMs rainfall are compared with NEX-GDDP data for India (Singh *et al.,* 2019). Earlier, the outputs of PRECIS model were compared with the observed data for a few selected locations, and were found to have significant bias (Zhacharias *et al.,* 2015). But, these studies are based on CMIP 4 or earlier climate models and were compared using bias-uncorrected data. This study compares the CMIP 5 data from GCMs and RCMs, more over the individual bias corrected GCM and RCM data are compared with the observed data. So, this study aims to compare the bias corrected GCMs and RCMs temperature and precipitation with the observed data for a few locations of Indian region to evaluate individual models performance.

## MATERIALS AND METHODS

The daily data on temperatures (minimum and

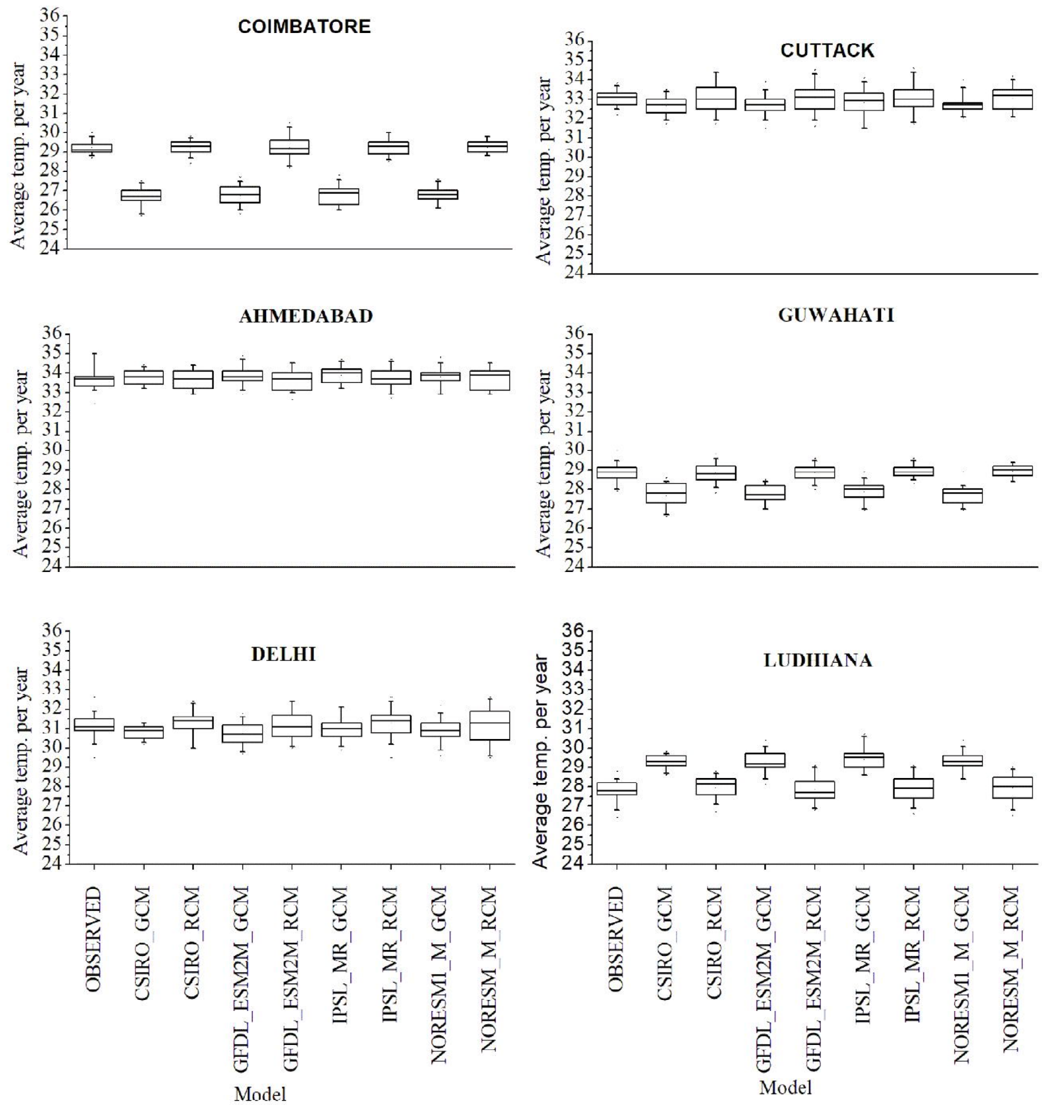


**Fig. 1:** Comparison of average bias corrected maximum temperature per year for four GCMs and RCMs using scaling method.

maximum) and rainfall of the 4 GCMs (NEX-GDDP-NASA Earth Exchange Global Daily Downscaled Projections) and 4RCMs (CORDEX-Coordinated Regional Downscaling Experiment) are bias corrected against the observed IMD (India Meteorological Department) data using scaling method in Rprogramme. Scaling method consists on scaling the simulation with correction factor (Santander *et al.,* 2005).

***RCMs and GCMs used***

Climate models used for this study are CSIRO, GFDL_ESM2M, IPSL_CM5A_LR and NORESM1_Mfor 30-year period (1976-2005).

***Locations for comparison***

This study has been performed for some of the Indian locations i.e. Coimbatore (11.015°N 76.95°E), Cuttack (20.46°N 85.88°E), Ahmedabad (23.02°N 72.57°E), Guwahati (26.14°N 91.73°E), Delhi (28.70°N 77.10°E) and Ludhiana (30.90°N 75.85°E).

The GCMs and RCMs data are compared with the observed data based on annual mean maximum and minimum temperatures and annual total rainfall for six locations during 1976-2005. This study methodology includes the following:

1. Annual temperatures (maximum and minimum) and rainfall calculated for each GCM and RCM individually
2. Number of extreme events of temperatures (maximum and minimum) and rainfall for GCMs and RCMs with respect to the observed data
3. Location-wise statistics i.e. Root Mean Square Error

**Table 1:** Number of extremes events over 30-year period (1976-2005) for rainfall (e”100 and 150 mm) of GCMs and RCMs with respect to the observed data

| | GCM | | | | | RCM | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Obs | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1-M | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1-M |
| | | | | | **≥ 100mm** | | | | |
| Ludhiana | 0 | 0-2 | 0-2 | 0-3 | 0-1 | 0-2 | 0-2 | 0-3 | 0-2 |
| Coimbatore | 0 | 0-2 | 0-2 | 0-3 | 0-1 | 0-2 | 0-2 | 0-2 | 0-1 |
| Cuttack | 0 | 0-3 | 0-3 | 0-4 | 0-8 | 0-2 | 0-3 | 0-3 | 0-3 |
| Ahmedabad | 0 | 0-2 | 0-2 | 0-2 | 0-8 | 0-4 | 0-2 | 0-2 | 0-2 |
| Guwahati | 0 | 0-1 | 0-2 | 0-2 | 0-1 | 0-4 | 0-5 | 0-4 | 0-3 |
| Delhi | 0 | 0-3 | 0-1 | 0-1 | 0-1 | 0-4 | 0-2 | 0-2 | 0-1 |
| | | | | | **≥ 150mm** | | | | |
| Ludhiana | 0 | 0-1 | 0-1 | 0-2 | 0-1 | 0-4 | 0-1 | 0-2 | 0-2 |
| Coimbatore | 0 | 0-1 | 0-1 | 0-1 | 0-1 | 0-1 | 0-1 | 0-1 | 0 |
| Cuttack | 0 | 0-2 | 0-3 | 0-3 | 0-6 | 0-1 | 0-1 | 0-1 | 0-1 |
| Ahmedabad | 0 | 0-2 | 0-3 | 0-2 | 0-3 | 0-2 | 0-2 | 0-1 | 0-1 |
| Guwahati | 0 | 0-1 | 0 | 0-1 | 0 | 0-2 | 0-3 | 0-3 | 0-2 |
| Delhi | 0 | 0 | 0-2 | 0 | 0 | 0 | 0-1 | 0 | 0 |

(RMSE) based on the number of extreme events for 30 years' period.

Annual mean maximum and minimum temperatures and annual total rainfall are calculated for each GCM, RCM individually and also for observed data by taking yearly average of daily data for 30-year period (1976-2005). Annual total rainfall is done by calculating yearly total of daily rainfall data for each and every climate model.

Location wise number of extreme events are calculated for temperatures and rainfall for four GCMs and RCMs using different threshold values. For maximum temperature, two indicators are defined i.e. days with temperatures ≥ 40°C and ≥ 45°C. For minimum temperatures, days with minimum temperatures ≤0°C, ≤5° C and ≤10° C are used as indicators. Similarly, days with rainfall 0.1-2.5mm, ≥50mm, ≥100mm and ≥150mm. Every year, location-wise and model-wise number of days are calculated for every indicator for 30-year period.

Location-wise performance statistics *viz.,* RMSE (Wallach *et al.,* 1989) are calculated to identify performance of models in capturing extreme events over 30-year period. Location wise RMSE of temperatures (maximum and minimum) and rainfall extremes are calculated for each GCM and RCM with respect to the corresponding observed data. These statistics are calculated based on the number of extreme events in 30-year period.

## RESULTS AND DISCUSSION

The temperatures and rainfall data of fourselected GCMs and RCMs are bias corrected for six locations for 30 years' period (1976-2005). These bias corrected data of all GCMs and RCMs for temperatures and rainfall are compared based on

(1) Location wise annual data with respect to the observed data.

(2) Location wise number of extreme days per year and its performance statistics

***Location wise annual temperatures and rainfall with respect to the observed data***

Performance evaluation of GCMs and RCMs are done based for the annual mean maximum and minimum temperatures,and for total annual rainfall for 30-year period (1976-2005) for six locations.

***Maximum temperature***

For Coimbatore location, the RCMs' simulated data on annual average maximum temperatures ranged from 28.2 to 30°C over 30 years period and is much similar to the observed data (28.7-30°C). But the GCMs' simulated annual average maximum temperature is in the range of 25-27.9°C, which are significantly lower than the observed values (Fig. 1). Similarly, for Guwahati, GCMs simulated annual average

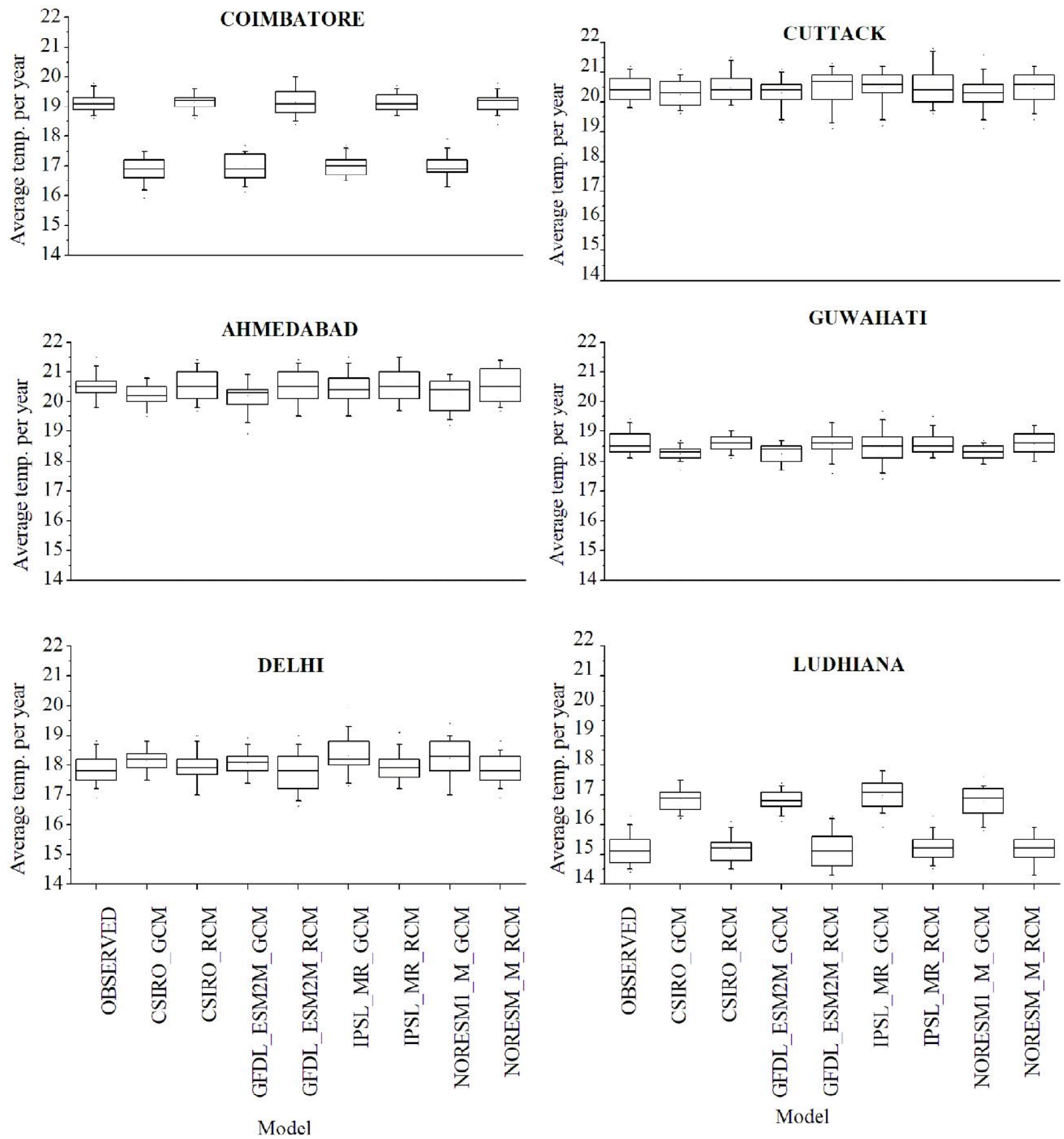


**Fig. 2:** Comparison of average bias corrected minimum temperature per year for four GCMs and RCMs using scaling method.

maximum temperature ranged from 26.6 to 28.9°C which is lesser than the RCMs simulated data (27.8-29.8°C) and observed data (27.9-30°C). But, reverse trend is observed for Ludhiana location. Here, annual average temperaturein GCMs simulated data (28.1-30.7°C) are more than that simulated by the RCMs (26.7-29°C) and observed data (26.4-28.8°C). This indicates that the performance of all RCMs is better than that of GCMs for these locations.

The annual average maximum temperatures simulated by all GCMs (31.7-34°C) and RCMs (31.7-33.9°C) are close to the observed range (32.2-33.8°C) for Cuttack location, but NORESM1-M (32-33.7°C) performed better than other models (Fig. 1). Similar trends were observed for Delhi location also and the simulated values of NORESM1-M (29.5-32.6°C) RCM have similar range as that of observed data (29.5-32.6°C). However, for Ahmadabad location, the GFDL_ESM2M (32.6-34.8°C) RCM performed better than other models in simulating the annual average maximum temperature and the range is close to the observed (32.4-35°C) temperature.

***Minimum temperature***

Similarly, the performance of RCMs' is better than GCMs' in simulating the annual average minimum temperature over 30-year period for Coimbatore and Ludhiana locations. The annual average minimum

**Table 2:** Summary statistics for the performance (RMSE) of GCMs and RCMs in reproducing the number of extreme events in minimum temperatures ( ≤ 5 and 10 °C) with respect to observed events

| | GCM | | | | RCM | | | |
|---|---|---|---|---|---|---|---|---|
| | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1_M | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1_M |
| | | | | **≤ 5°C** | | | | |
| Ludhiana | 22.55 | 25.56 | 22.58 | 23.71 | 14.65 | 16.39 | 14.6 | 15.07 |
| Coimbatore | - | - | - | - | - | - | - | - |
| Cuttack | - | - | - | - | - | - | - | - |
| Ahmedabad | - | - | - | - | - | - | - | - |
| Guwahati | 0.45 | 1.13 | 1.97 | 0.26 | 0.48 | 0.26 | 0.26 | 0.26 |
| Delhi | 11.18 | 9.29 | 10.92 | 12.14 | 10.61 | 9.98 | 10.18 | 8.94 |
| | | | | **≤10°C** | | | | |
| Ludhiana | 18.28 | 16.87 | 14.18 | 15.36 | 15.77 | 18.03 | 16.75 | 11.52 |
| Coimbatore | - | - | - | - | - | - | - | - |
| Cuttack | 7.64 | 8.7 | 7.2 | 9.55 | 7.75 | 10.22 | 8.43 | 8.6 |
| Ahmedabad | 9.16 | 10.57 | 16.18 | 11.72 | 6.65 | 7.46 | 6.07 | 6.9 |
| Guwahati | 13.86 | 13.15 | 19.6 | 14.73 | 12.77 | 12.62 | 14.93 | 11.61 |
| Delhi | 15.97 | 12.25 | 19.14 | 16.5 | 14.42 | 13.87 | 12.56 | 14.08 |

**Table 3:** Summary statistics for the performance (RMSE) of GCMs and RCMs in reproducing the number of extreme events in maximum temperatures (≥ 45 and 40-44.9°C) with respect to observed events

| | GCM | | | | RCM | | | |
|---|---|---|---|---|---|---|---|---|
| | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1_M | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1_M |
| | | | | **40-44.9°C** | | | | |
| Ludhiana | 9.11 | 7.17 | 7.17 | 6.83 | 5.65 | 5.06 | 5.06 | 5.06 |
| Coimbatore | - | - | - | - | - | - | - | - |
| Cuttack | 13.95 | 15.9 | 19.1 | 16.31 | 13.36 | 15.99 | 20.04 | 19.84 |
| Ahmedabad | 18.11 | 19.19 | 19.05 | 18.73 | 11.65 | 8.35 | 11.74 | 13.99 |
| Guwahati | - | - | - | - | - | - | - | - |
| Delhi | 16.5 | 16.5 | 17.72 | 14.12 | 11.4 | 11.4 | 16.06 | 14.59 |
| | | | | **≥ 45°C** | | | | |
| Ludhiana | - | - | - | - | - | - | - | - |
| Coimbatore | - | - | - | - | - | - | - | - |
| Cuttack | 3.38 | 3.22 | 2.79 | 3.24 | 3.28 | 3.12 | 3.58 | 3.87 |
| Ahmedabad | - | - | - | - | - | - | - | - |
| Guwahati | - | - | - | - | - | - | - | - |
| Delhi | 1.82 | 1.82 | 1.77 | 1.96 | 2.44 | 2.44 | 1.99 | 1.74 |

temperature range (18.4-19.8°C) in the data simulated by NORESM1-M is closer to that of observed range (18.6-19.8°C) for Coimbatore location. For Ludhiana, the GFDL_ESM2M RCM performed better in simulating the minimum temperature (Fig. 2). For Cuttack, all RCMs performed much better than the GCMs. However, the performance of GCMs and RCMs are moderate for Guwahati but for Delhi, the NORESM1-M (16.9-18.8°C) RCM has

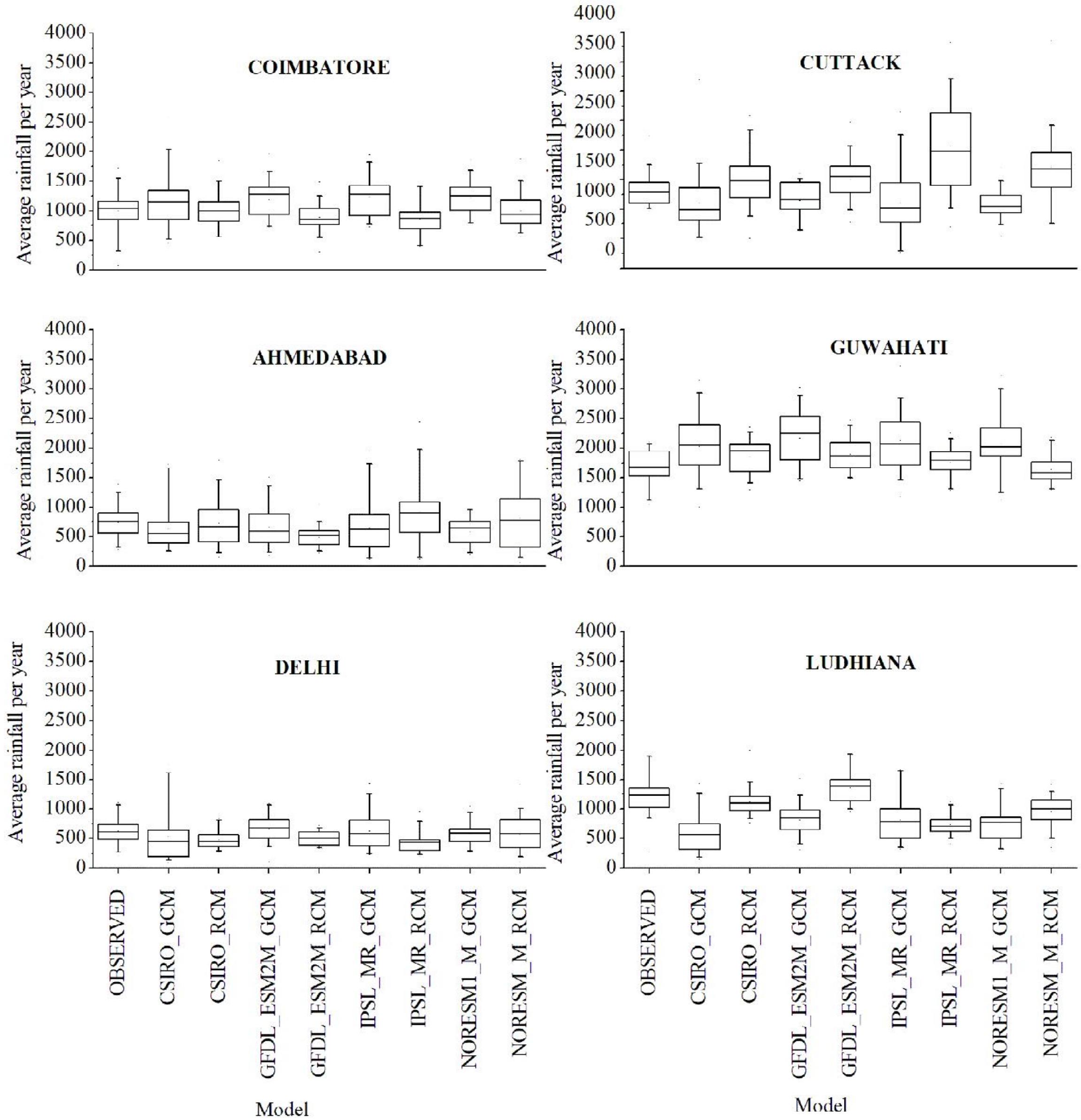


**Fig. 3:** Comparison of total bias corrected rainfall per year for four GCMs and RCMs using Scaling method.

performed better as this model has simulated the annual temperature in the range similar to that of observed (16.9-18.8°C) data. The GCMs CSIRO and GFDL_ESM2M simulated rage of annual mean minimum temperature for 30-year period showed significant difference from observed values for Ahmedabad location (Fig. 2).

***Rainfall***

When the performance of the models was tested for simulation values of annual total rainfall during 1976-2005 period, it was noted that the RCMs and GCMs simulation efficiency was relatively poor for Ahmedabad location. In this location, the observed values ranged between 294-1385 mm over 30-year period, while the simulated values ranged between 65-2400 mm during the corresponding period. Same trend of annual rainfall of GCMs and RCMs is also observed for Coimbatore and Cuttack. Although, RCMs performance is better than GCMs in case of Guwahati. The simulation performance of NORESM1-M (1200-2180 mm) is found to be better than other RCMs with respect to observed annual rainfall (1100-2090 mm) at this location. Ranges of annual rainfall as simulated by IPSL_MR (210-962 mm) and NORESM1-M (118-1067 mm) RCMs are close to the observed ones (217-1109 mm) for Delhi location (Fig. 3) also.

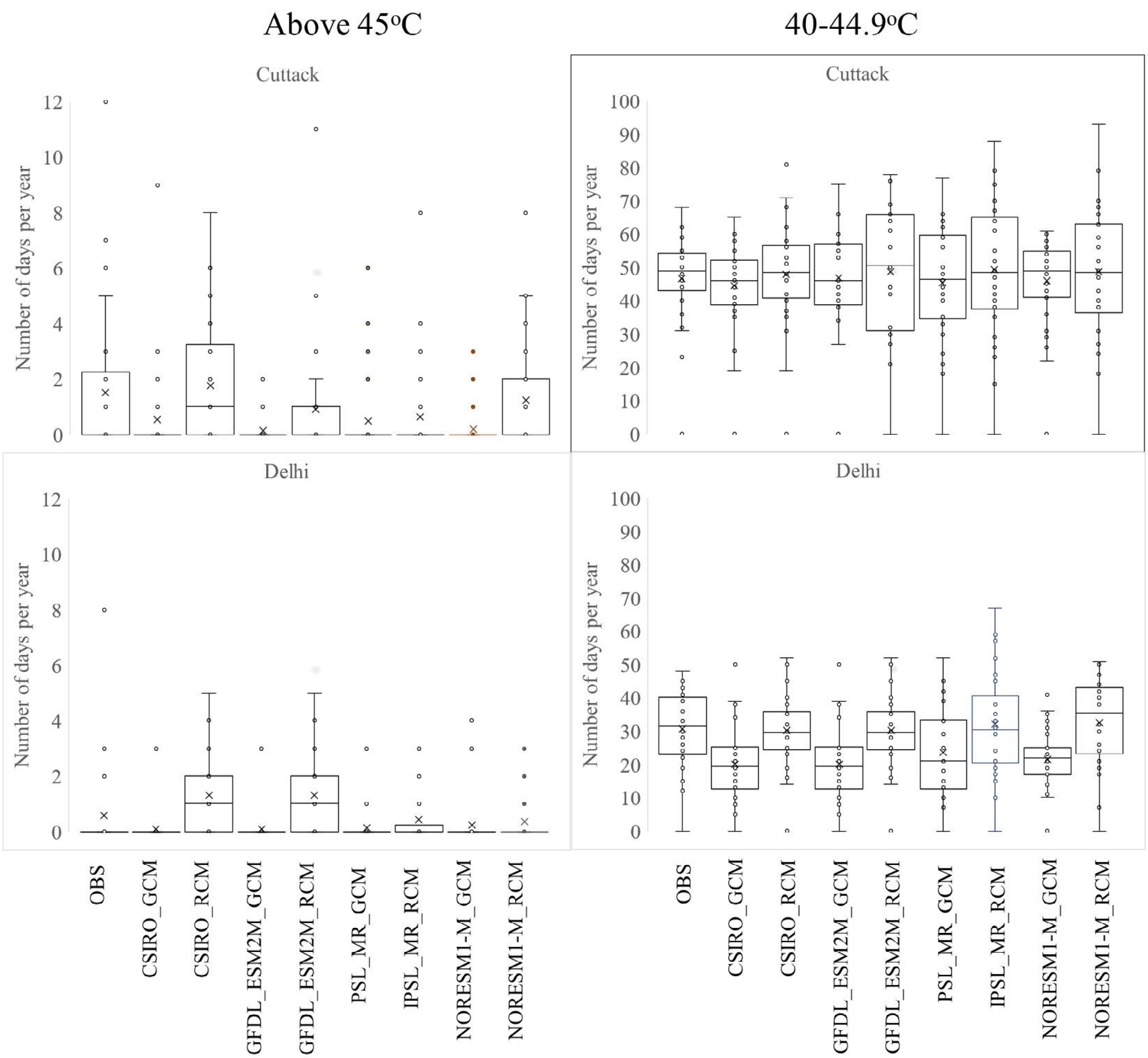


**Fig. 4:** Number of extremes events over 30-year period (1976-2005) for maximum temperatures (≥ 45 and 40°C) of GCMs and RCMs with respect to the observed data.

***Location wise number of extreme days per year and its performance statistics***

Location wise performances of GCMs and RCMs are evaluated based on the number of extreme temperature and rainfall days for 30-year period (1976-2005). Based on the number of temperature and rainfall extreme events per year as simulated by the RCMS and GCMs, the RMSE for each model wascalculated by using the IMD data as observed values for each parameter and for location.

***Maximum temperature extreme events***

For Ludhiana, RMSE values for the RCM simulated datasets are lower than that of GCMs for extreme high temperature days (≥ 40<44.9 °C) per year, indicating that the RCMs are able to capture the extreme events close to the observed data (Table 3). For Cuttack, performance of RCMs in capturing the number of extreme hot days (≥ 45°C) is better (0-11) in 30-year period than that of GCMs (0-9) with respect to observed number of extreme hot days (0-12) days per year (Fig. 4). Based on the low RMSE values for extreme events, the GFDL-ESM2M RCM has performed better than the other RCMs (Table 3) for Cuttack. Similarly, for Ahmedabad also the GFDL-ESM2M RCM is able to capture the extreme days (e”40<44.9 °C) with low RMSE value 8.35 than other RCMs (11.6-13.9) (Table 3). For Delhi, performance of all GCMs and RCMs are moderate in

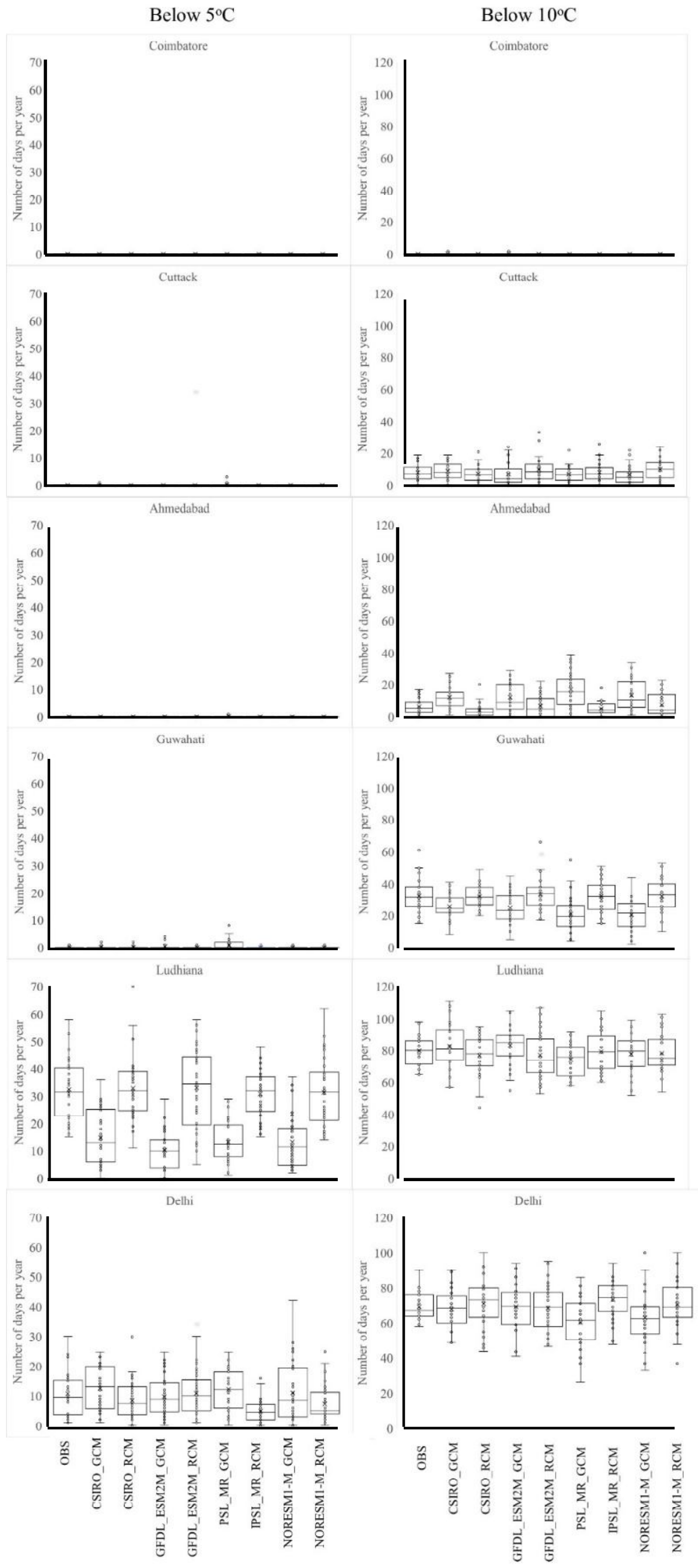


**Fig. 5:** Number of extremes events over 30-year period (1976-2005) for minimum temperatures (≤ 5 and 10°C). of GCMs and RCMs with respect to the observed data

**Table 4:** Summary statistics for the performance (RMSE) of GCMs and RCMs in reproducing the number of extreme events in maximum temperatures (0.1-2.5 & ≥ 50 mm) with respect to observed events

| | GCM | | | | RCM | | | |
|---|---|---|---|---|---|---|---|---|
| | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1_M | CSIRO | GFDL_ESM2M | IPSL_MR | NORESM1_M |
| **0.1-2.5 mm** | | | | | | | | |
| Ludhiana | 54.05 | 32.09 | 24.05 | 23.49 | 33.47 | 34.48 | 248.77 | 22.37 |
| Coimbatore | 99.96 | 71.64 | 108.31 | 112.57 | 26.46 | 33.11 | 28.35 | 28.45 |
| Cuttack | 23.15 | 29.31 | 30.16 | 31.54 | 41.97 | 39.1 | 40.68 | 39.25 |
| Ahmedabad | 25.4 | 36.08 | 26.48 | 32.45 | 21.43 | 21.71 | 19.06 | 31.28 |
| Guwahati | 25.43 | 19.47 | 22.09 | 34.18 | 27.66 | 24.17 | 159.19 | 159.19 |
| Delhi | 44.13 | 34.89 | 19.44 | 25.54 | 36.46 | 36.17 | 28.23 | 39.26 |
| **≥ 50mm** | | | | | | | | |
| Ludhiana | 3.72 | 3.7 | 3.79 | 3.7 | 3.24 | 2.95 | 4.15 | 3.32 |
| Coimbatore | 3.62 | 2.48 | 2.31 | 2.7 | 2.58 | 2.72 | 2.81 | 2.79 |
| Cuttack | 4.12 | 2.87 | 3.89 | 2.44 | 3.09 | 2.62 | 6.13 | 5.16 |
| Ahmedabad | 2.59 | 2.92 | 2.76 | 2.59 | 2.76 | 2.5 | 3.61 | 4.62 |
| Guwahati | 5.74 | 5.94 | 5.3 | 5.59 | 3.53 | 3.43 | 1.9 | 2.29 |
| Delhi | 2.35 | 2.32 | 2.76 | 1.85 | 2.17 | 2.2 | 2.24 | 2.36 |

capturing the number of extreme hot days (≥ 40<44.9 & 45°C) over 30 years' period (Fig 4), as indicated by high RMSE values. But RMSE value for the data simulated by GFDL-ESM2M and NORESM1-M is lower for extreme hot days ≥40<44.9& ≥45°C, respectively for this location (Table 3).

***Minimum temperature extreme events***

For Ludhiana, RCMs could capture the range of extreme number of cold days (≤ 5°C) varied between 11-58 which is near to observed range of number of extreme cold days (15-58) but the performance of all GCMs and RCMs is moderate for the number of days with minimum temperatures ≤ 10°C (Fig. 5). For this location, the RMSE values for NORESM1-M RCM simulated number of days with minimum temperatures ≤ 5°C and ≤ 10°C are lower than other RCMs (Table 2). For Cuttack, performance of GCMs and RCMs is moderate in capturing the extreme cold days (Fig. 5 & Table 2) as indicated by high RMSE. For Ahmedabad, GCMs had simulated more range (2-32) of cold days in a 30-year period than that simulated by the RCMs(0-20) while the observed number of days with temperatures below 10°C varied between 0-17 in 30-year period (Fig. 5). The RMSE values for number of days with temperatures below 10°C are less for RCMs than the GCMs at Ahmedabad location (Table 2). For Guwahati, the number of cold days (≤ 10°C) is under-estimated by the GCMs (2-50) as compared to the observed range of 15-61 in 30 year period (Fig. 2). The RMSE values for number of cold events (≤ 5 & 10°C) are lower for all RCMs than the GCMs. Among the RCMs, the performance of NORESM1-M RCM is better in capturing extreme cold events (≤ 5 & 10°C) than other RCMs for Guwahati (Table 2). For Delhi location, GFDL-ESM2M (1-30) RCM could simulate the number of extreme cold days (≤ 5°C) similar to the observed range of 1-30 days in 30-year period (Fig. 5). However, all GCMs and RCMs have shown wider variation in simulating the extreme number of cold days (≤ 10°C) for Delhi (Fig. 5 & Table 2). In this location in general, the GCMs and RCMs have simulated more number of extreme cold days.

***Number of rainy days***

The range of number of rainy days (0.1-2.5mm) simulated by RCMs (200-255) was in the range of observed values (211-270) except in the datasets of IPSL_MR RCM simulations for Ludhiana location (Fig. 6). The RMSE value of IPSL_MR RCM is higher than that of other RCMs for this parameter (Table 4). The GFDL-ESM2M (0-9) RCM is able to capture the number of rain days with ≥50 mm near to observed values (0-10) for Ludhiana and the RMSE value was low (Fig. 6 & Table 4). For Coimbatore, RCMs are able to simulate the rainfall (0.1-2.5 mm) better than the GCMs

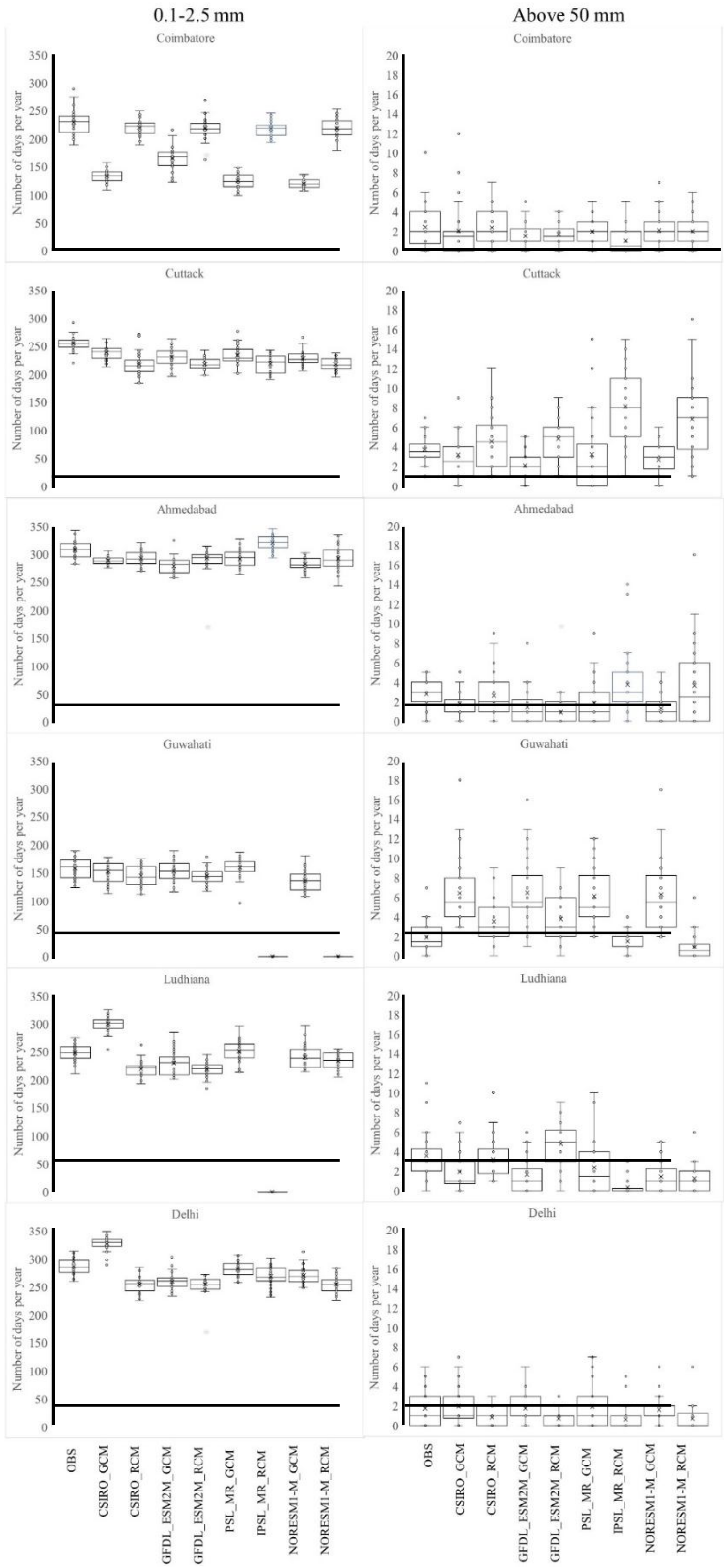


**Fig. 6:** Number of extremes events over 30-year period (1976-2005) for rainfall (0.1-2.5 and ≥ 50 mm) of GCMs and RCMs with respect to the observed data

but performance of GCMs and RCMs is moderate in simulating number of days with rainfall ≥50 mm.For Cuttack and Ahmedabad, range for number of rainy days (0.1-2.5 & ≥ 50 mm) simulated by GCMs and RCMs significantly differed from the observed data and also their RMSE values are high (Fig 6 & Table 4). In these locations climate models are underestimated the rainfall (0-2.5 & ≥ 50 mm) events. For Guwahati, number of rainy days (0.1-2.5 mm) simulated by CSIRO RCM (112-175) and GFDL_ESM2M RCM (117-179) are near to the observed (120-180) values (Fig. 6).Further, NORESM1-MRCM is able to capture the number (0-6) of rainy days (≥ 50 mm) close to the observed (0-7) data with low RMSE value (Fig. 6). For Delhi, performances of all RCMs and GCMs are moderate in simulating rainy days (0.1-2.5& ≥ 50 mm) over 30 years' period (Fig. 6). In all the six locations, there were no events of rainy day with rainfall more than 100 mm and 150 mm. But the simulated data by the GCMs and RCMs indicated the number of events varied between 0-3 in capturing the extreme number of days (≥ 100 & 150 mm) for all six locations over 30 years' period. This indicates that GCMs and RCMs are overestimating extreme rainfall events than observed data for all locations.

Globally, various studies are performed to compare GCMs and/or RCMs for their performance in simulating temperature and precipitation.The GCM-RCM pair performed better for Costa Rica after bias correction using different techniques (Mendez *et al.,* 2020). For China, very fine resolution GCMs captured better trend of air temperature as well as precipitation than RCM dynamical downscaled data (Guo *et al.,* 2016). For Indian locations, this study indicates that RCMs performance is much better than GCMs after bias correction for temperature at least for the selected locations. All RCMs and GCMs varied significantly for rainfall for these selected locations. However, the RCMs *viz.,* GFDL_ESM2M and NORESM1-M performed comparatively better than CSIRO and IPSL_MR in simulating the temperature and rainfall at least for the selected locations.

Performance of GCMs and/or RCMs are also evaluated based on the temperature and rainfall extreme events. Bias corrected RCMs precipitation found to be much better in capturing extreme events using distribution approach over South Korea (Shin *et al.,* 2019). RCM downscaled data showed less significant change in extreme temperatures than the GCM driven data for China (Guo *et al.,* 2020). Global climate model (GCM) forced regional climate model (RCM) simulations are able to capture the observed climatological spatial patterns of the extreme precipitation (Pinto *et al.,* 2016). For Indian locations, RCMs performance is better than GCMs in simulating extreme temperatures. However, both GCMs and RCMs have overestimated the rainfall extremes for selected Indian locations, indicating the need to i) expand this study for all India level comparison for all grid pints and ii) create ensemble data of climate models for impact assessment to capture the climatology better.

## CONCLUSION

Climate change impact assessment studies use bias corrected GCMs and RCMs data to reduce the uncertainties. In this study, the performance of GCMs and RCMs data on mean annual maximum and minimum temperatures as well as annual rainfall over 30-year period, after bias correction using scaling method, was tested against the IMD observed datafor some Indian locations. Extreme events for temperatures per year and number of rainy days per year for GCMs and RCMs were also compared for selected locations. Based on the study, it can be concluded that performance of RCMs are be much better than that of GCMs after bias correction using Scaling method. The GFDL_ESM2M and NORESM1-M RCM simulated temperature and rainfall data can be usedafter bias correctionfor assessment studies at least for the selected locations. Further, as the performance of most of the individual models remains inconsistent, it may be better to generate ensemble datafrom selected climate models.

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