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Future Monsoon Rain over Gangetic West Bengal Simulated by CMIP5 GCMs

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Abstract—*In the present study, future intra-seasonal rainfall change has been assessed over Gangetic West Bengal (GWB) using simulations of the Global Climate Models (GCMs) under RCP 4.5 scenario of CMIP5 experiment. Firstly, the performance of GCMs were assessedfor the period 1951-2000using Taylor Diagram where IMD gridded data (1^0x1^0) is assumed as reference.It is found that none of the models is able to simulate IMD gridded observed rainfall adequately enough in the monsoon season. However, some models show comparatively better performance in the month of July whereas shown worse performance in June. Keeping in view the poor performance of individual models, we developed a Multi-Model Ensemble using 5 best performing models and constructed the future rainfall change time series during two different time periods of 2001-2035 and 2036-2070 for different monthsin monsoon. The model ensemble performs better than most of the individual models. SEM indicates that monsoon rainfall is projected to be increased 2.11% during 2001-2035 with respect to 1961-1990 whereas projections for the period 2036-2070 are showing slightly higher rainfall change 5.58% for monsoon over this region. WEM also indicate similar results.*

Keywords: *CMIP5, GWB, Monsoon Rainfall, Taylor Diagram, SEM, WEM*

1. INTRODUCTION

The General Circulation Models (GCMs) are one of the widely used tools for understanding past climate change and predicting future possible changes. GCMs simulations from the CMIP5 experiment for the fifth assessment report (AR5) of the IPCC have recently become available[1]. Comparing to the IPCC AR4(which uses CMIP3 experiment), the GCMs in AR5 include a more diverse set of model types (i.e., climate/Earth system models with more interactive components such as atmospheric chemistry, aerosols, dynamic vegetation, ice sheets and carbon cycle) [2]. A number of improvements in the physics, numerical algorithms and configurations are implemented in the IPCC AR5 models with a new set of scenarios called representative concentration pathways (RCPs) used in the AR5 simulations[3].

In contrast to SRES scenarios used in AR4 models, RCPs represent pathways of radiative forcing, not detailed socio-economic narratives or scenarios. Central to the process is the concept that any single radiative forcing pathway can result from a diverse range of socio-economic and technological development scenarios. There are four RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These scenarios are formulated such that they represent the full range of stabilization, mitigation and baseline emission scenarios available in the literature.RCP nomenclature reflects socioeconomic pathways that reach a specific radiative forcing by the year 2100. For example RCP4.5 leads to a radiative forcing of 4.5 Wm-2 by 2100[4].

There are many different ways to measure and depict model performance –Using Taylor's diagram[5] is one of the most popular methods. Here three statistics namely correlation, root mean square (RMS) error, and variance ratio are combined in a single diagram, resulting in nice graphical visualizations of model performance.

In the present study we have analysed the performance of CMIP5 models ACCESS1.0, ACCESS1.3, CMCC-CM, CMCC-CMS, CNRM-CM5, INM-CM4, MIROC4h, MPI-ESM-LR, MPI-ESM-MR in simulating observed monsoon rainfall over Gangetic West Bengal (GWB) using Taylor Diagram where IMD (1^0x1^0) gridded data is assumed as reference. This region is a fertile zone for agricultural activities, which are highly dependent on Monsoon Rainfall. Analysis of past rainfall scenario and estimation of the amount of rainfall change in future for in different months (June, July, August and September) of monsoon season will be useful for agricultural planning.

We developed a Multi-Model Ensemble (MME5) from the 5 best performing models in each month and constructed the future rainfall change time series during two different time periods of 2001-2035 and 2036-2070 for different months in monsoon. The use of multi-model ensembles is common practice in weather and short-term climate forecasting [6-7]and it is starting to become important for long-term climate change predictions[8-9]. Here we use both simple ensemble mean (SEM) and weighted ensemble mean(WEM) for constructing multi-model scenario.

The objectives of this study are- i) Assessment of the selected CMIP5 models performance in reproducing the past observed rainfall over GWB for the period 1951-2000 using Taylor Diagram .ii)Development of multi-model ensembles using 5 better performing models in each month of monsoon .iii)Construction of future time series data for 2001-2035 and 2036-2070 time periods using model ensembles. iv)Estimation of the amount of rainfall change in future with respect to climatic baseline 1961-1990.

2. MATERIALS AND METHODS

2.1 Study Area

Gangetic West Bengal (GWB) located in the southern part of the state of West Bengal consisting 10 districts shown in Fig1 and extending from 21.5^0 N to 24.7^0N and 85.8^0E to 88.9^0E. It is one of the agriculturally most productive regions in India. It has 4 distinct seasons, namely pre-monsoon (March to May; MAM), monsoon (June to September; JJAS) and post-monsoon (October and November; ON), winter (December to February; DJF). It is a rain-fed area and agricultural activities highly dependent on rainfall especially on the summer monsoon rainfall.

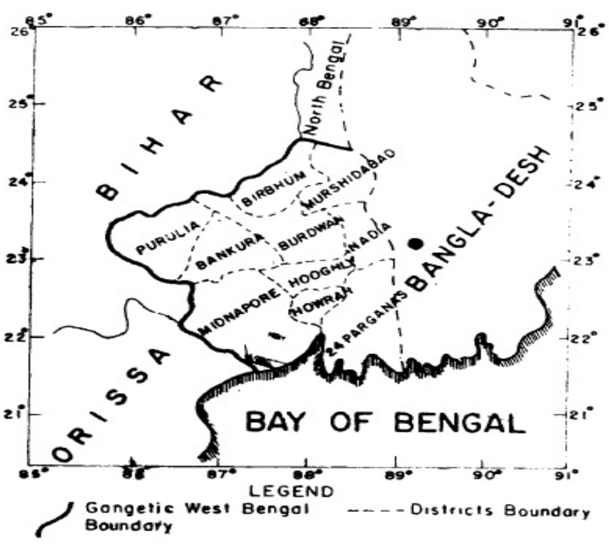


Fig. 1: Map of Gangetic West Bengal(Chanda&Dhar)

2.2 Data

The daily gridded rainfall data at 1°× 1° spatial resolution from India Meteorological Department (IMD) was used [10]as observational data set. This IMD product uses rain gauge data from 1803 stations to estimate accumulated rainfall in the 24 hours ending 08:30 IST (03:00 UTC) during the period 1951–2007. IMD uses the Shepard interpolation technique[11] for gridding data from individual stations over the Indian subcontinent (6.5°N to 37.5°N, 66.5°E to 101.5°E).

Table 1: List of CMIP5 models used in this study with their Institute names and Horizontal resolution

Model Name	Institute	Horizontal Resolution (lat x lon)
ACCESS1.0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	1.25^0x1.875^0
ACCESS1.3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	1.25^0x1.875^0
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	0.75^0x0.75^0
CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	1.875^0x1.875^0
CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	1.4^0x1.4^0
INM-CM4	Institute for Numerical Mathematics,Moscow, Russia	2^0x2.5^0
MIROC-4h	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	0.56^0x0.56^0
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M),Germany	1.875^0x1.875^0
MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M),Germany	1.875^0x1.875^0

The model simulations for both the present-day climate (historical experiments from 1860 to 2005 under changing conditions consistent with observations) and future climate projections (RCP45 experiments from 2005 to 2100 with radiative forcing stabilized at 4.5W m^{-2} after 2100) are analyzed in this study. The RCP45 scenario is selected because its GHG concentrations somewhat intermediate as compared to other RCP scenarios[1].The model data are obtained from the CMIP5 data website (http://pcmdi9.llnl.gov). More details of the selected models are listed in Table 1.

2.3 Methodology

CMIP5 model data are interpolated into a common grid of $1^o \times 1^o$ similar to the observational data set. Bi-linear interpolation technique is adopted where a minimum of 4 points of grid from the domain and nearby areas following the studies of Palutikof et al. (1996)[12], Das &Lohar (2005)[13] and Das et al.,(2012)[14]. To characterize the rainfall variability in GWB, both the observational and model data are averaged over the domain of (21.5^0 N -24.7^0N, 85.8^0E -88.9^0E).

The performance of GCM models are then analyzes using Taylor diagram which is a 2 dimensional plot showing three statistical quantities; the ratio of variances of both simulated and observed fields, the centered root-mean-square error and the correlation coefficient between the two fields for the model variable under consideration in one point.

$$R = \frac{\frac{1}{N}\sum_{n=1}^{N}\left(f_n - \bar{f}\right)\left(r_n - \bar{r}\right)}{\sigma_f \sigma_r}$$

$$E'^2 = \frac{1}{N}\sum_{n=1}^{N}\left[\left(f_n - \bar{f}\right) - \left(r_n - \bar{r}\right)\right]^2$$

$$\sigma_f^2 = \frac{1}{N}\sum_{n=1}^{N}\left(f_n - \bar{f}\right)^2$$

$$\sigma_r^2 = \frac{1}{N}\sum_{n=1}^{N}\left(r_n - \bar{r}\right)^2$$

Given a "test" field (f) and a reference field (r), the formulas for calculating the correlation Co-efficient (R), the centered RMS difference (E'), and the standard deviations of the "test" field (σf,) and the reference field (σr) are given as:

$$E'^2 = \sigma_f^2 + \sigma_r^2 - 2\sigma_f\sigma_r R,$$

The correlation coefficient and the centered RMS difference provide complementary statistical information quantifying the correspondence between the two patterns, but for a more complete characterization of the field the variances(or standard deviations) of the fields must also be given. . All four of the above statistics (R, E',$\sigma_{f,}$ σ_r) can be summarized in a diagram using the relation[5].

The geometric relationship between R, E',$\sigma_{f,}$ $\sigma_r$is shown in Fig. 2.

In Taylor diagram when the distance between the points representing the simulated and observed values is relatively short, good agreement is found between the simulated and observed data. (IPCC Third Assessment Report, Chapter8). On the basis of this argument we have identified five better performing models in monsoon. Multi-model ensemble is made using these better performing models .Two methods are used for constructing ensemble-one is simple ensemble mean (SEM) where equal weights is assigned to each of the GCMs (i.e. a simple mean of all the models).and another is weighted ensemble mean (WEM) weights are assigned according to the performance of each model to generate the observed precipitation in the period 1951-2000, providing greater confidence in the model that records less error as indicated by the centered RMS error.

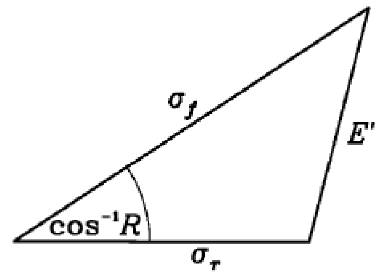


Fig. 2: Geometric relationship between geometric relationship between R, E',$\sigma_{f,}$ σ_r of the test and reference fields, respectively

Simple Ensemble Mean(SEM) - Equal weights is assigned to each of the GCMs (i.e. a simple mean of all the models).

Here rainfall in i[th] year is given by, $\square_{\square} = \frac{\sum_{\square=\square}^{\square}\square_{\square\square}}{\square}$; p: no of models

Weighted Ensemble Mean(WEM)- Weights are assigned according to the performance of each model to generate the observed precipitation providing greater confidence in the model that records less error as indicated by the centered RMS error.

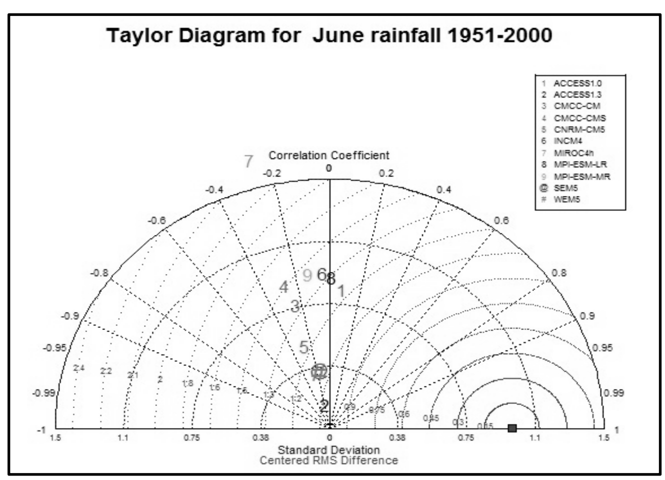
Here rainfall in i[th] year is given by, $\square_{\square} = \frac{\sum_{\square=1}^{\square}\frac{\square_{\square\square}}{\phi_{\square}}}{\sum_{\square=1}^{\square}\frac{1}{\phi_{\square}}}$

Where weight of k[th] model is given by, $\phi_{\square} = \frac{\square\square\square_{\square}}{\square\square\square\square_{\square}} = \frac{\square\square\square_{\square}}{\sum_{\square=1}^{\square}\square\square\square_{\square}}$

Centered RMS error of k[th] model is,

$$\square\square\square_{\square} = \sqrt{\frac{\sum_{\square=1}^{\square}[(\square_{\square} - \bar{\square}) - (\square_{\square} - \bar{\square})]^2}{\square}}$$

M: model data, O: observed data



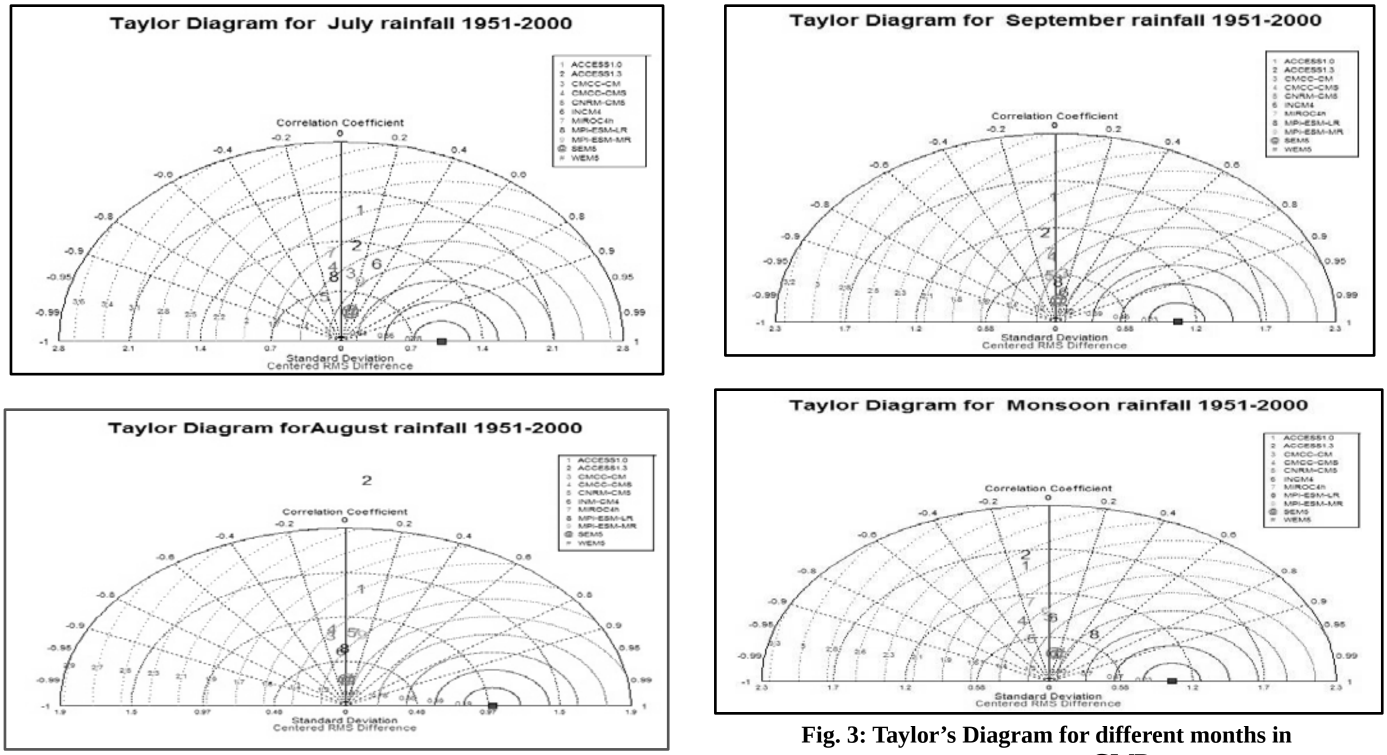


Fig. 3: Taylor's Diagram for different months in monsoon over GWB

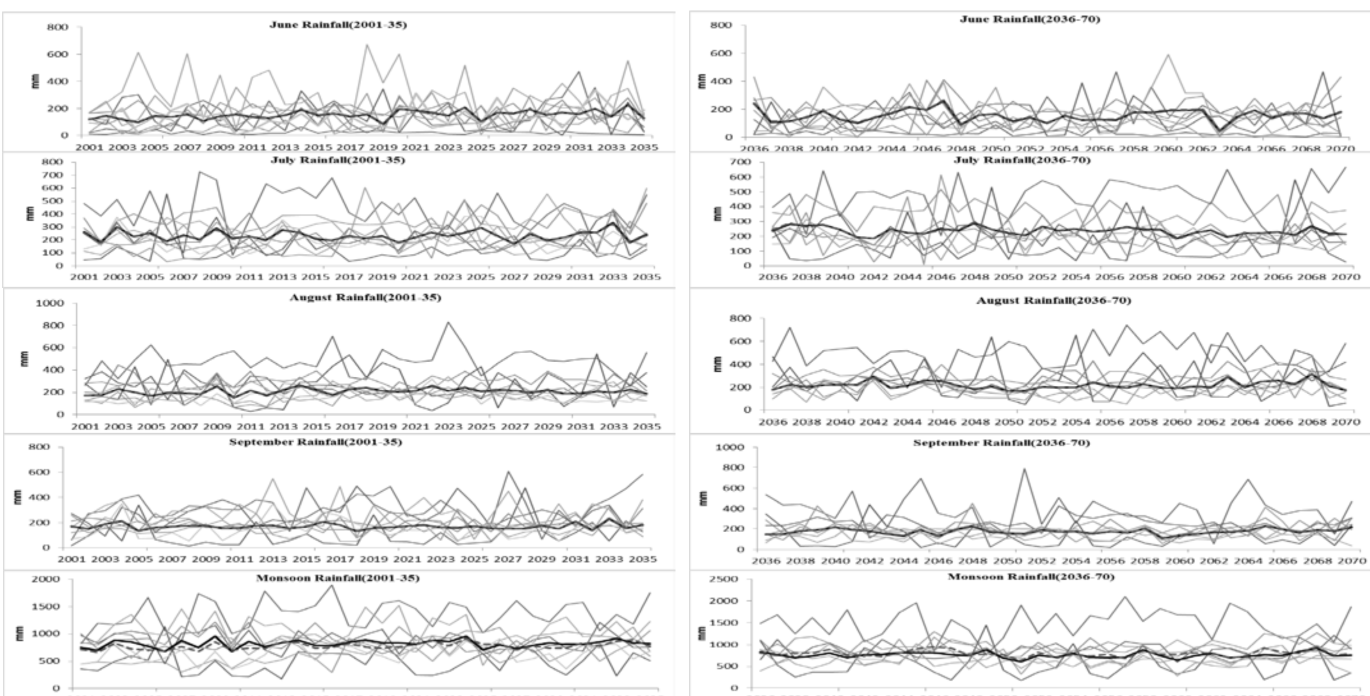


Fig. 4: Future Rainfall for the periods 2001-35 and 2036-70 over GWB for different months in monsoon. Simple lines represent individual models. Solid dark lines represent SEM and dashed dark lines represent WEM

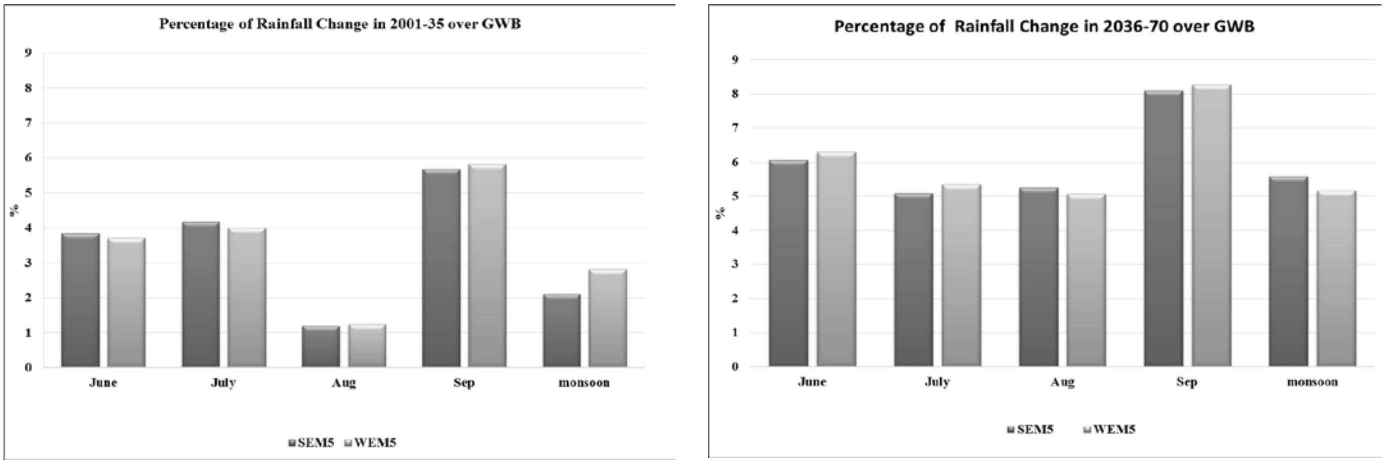


Fig. 5: Percentage change in Rainfall in future for different months in monsoon over GWB

3. RESULTS AND DISCUSSION

3.1 Performance of CMIP5 models in simulating observed Monsoon rainfall

From Taylor's diagram it is found that overall performance of CMIP5 models are poor in compared to IMD gridded data in the period 1951-2000.It is also found SEM and WEM both produces better results in most of the cases than individual models. Performance of the selected models are better in July and worse in June compared to other months in monsoon.

In overall monsoon MPI-ESM-LR, MPI-ESM-MR, CNRM-CM5, INM-CM4, CMCC-CM are five better models in showing closer results to observations in Taylor's diagram. Among them MPI-ESM-LR has shown best performance even it is better than both SEM and WEM.

In September INM-CM4 and in August MPI-ESM-MR is the best performing model. MPI-ESM-MR, CNRM-CM5, CMCC-CM, MPI-ESM-LR are the other better performing models in September and CNRM-CM5, INM-CM4, Miroc-4h, CMCC-CM performs relatively well than others.

In July MPI-ESM-MR, MPI-ESM-LR, CNRM-CM5, INM-CM4, CMCC-CM performs better than others with MPI-ESM-MR the best performer. ACCESS1.0, CMCC-CM, CNRM-CM5, INM-CM4, MPI-ESM-LR are the better performers in June.

3.2 Future projections

Future time series constructed by individual models and SEM and WEM are shown in fig. The constructed SEM and WEM indicate Monsoon rainfall is projected to be increased by 2.11% and 2.82% respectively in the period 2001-2035 with respect to 1961-1990 whereas the projected change during 2036-2070 will be 5.58% and 5.17% respectively. Similar results found by Krishnakumar et al.(2011)[15] using PRECIS simulations which shown around 5% increase in monsoon rainfall for this region in 2050's (i.e. 2041-70).Das and Lohar(2005)[13] found 1%-2% change in monsoon rainfall for 2010-2039 which is nearly consistent with our results.

Rainfall in the months June, July, August and September as projected by SEM will increase by 3.84%, 4.18%, 1.19% and 5.69% respectively during 2001-35 whereasWEM indicates 3.71%, 4%, 1.24% and 5.82% change in June, July, August and September respectively. Projections for the period 2036-2070 are showing slightly higher rainfall change i.e. 6.07%, 5.09%, 5.26%, 8.09% by SEM and 6.3%, 5.35%, 5.1%, 8.29% by WEM for the months of June, July, August and September respectively over GWB region.

4. CONCLUSIONS

From this study it is clear that every month in the monsoon over GWB will experience more or less increase in rainfall and total monsoon rainfall will increase as well. This may happen due to increase of extreme precipitation days in future. Chaturvedi et al (2012)[16] indicates consistent positive trend in frequency of extreme precipitation days (e.g. > 40 mm/day) for decades 2060s and beyond over India and also an increase in all India rainfall from 4 to 5% by 2030s and from 6 to 14% towards the end of the century (2080s) compared to the 1961–1990 baseline. Therefore, rainfall increase catalyzed by extreme precipitation is expected in future.

We also found individual GCMs ability to capture local-scale climate is not satisfactory which lead us to construct multi-model ensembles. Other techniques of developing model ensemble like reliability ensemble averaging (REA) and Bayesian model averaging (BMA) can be used to check whether there is more improvement in performance or not. Statistical/Dynamical downscaling techniques may be applied on GCMs to reduce gap between local and global scale climate.

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