MAUSAM, **72**, 3 (July 2021), 545-552

551.577 : 551.553.21 (540.33)

Assessing pre-monsoon and monsoon rainfall change signal with future projection over Gangetic West Bengal

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(*Received 1 September2020, Accepted 4December 2020*)

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सार – मॉनसून की वर्षा सामान्य रूप से कृषि की सफलता या विफलता के निर्धारण में एक प्रमुख कारक है। गांगेय पश्चिम बंगाल कोई अपवाद नहीं है। इस क्षेत्र में खरीफ चावल के उत्पादन के लिए मॉनसून की वर्षा अत्यधिक महत्वपूर्ण है। चूंकि मॉनसून-पूर्व वर्षा से किसानों को उचित फसल योजना बनाने जैसे प्रजाति का चयन आदि में सहायता मिलती है, इसलिए विभिन्न मॉडलों के साथ इसकी तुलना और भविष्य की योजनाएं बनाने में दीर्घावधि (1901-2005) तथा लघु अवधि (1961-2005 तथा 1991-2005) के वर्षा के आँकड़ों का आकलन अत्यधिक महत्वपूर्ण है। इस उद्देश्य से, भारत मौसम विज्ञान विभाग के नौ चयनित स्टेशनों से वर्षा के आँकड़े एकत्र किए गए तथा प्रवृत्ति विश्लेषण में उनका उपयोग किया गया । प्रेक्षित स्टेशन आँकड़ों से मॉडल आउटपुट की तुलना की गई। परिणामों से 1902-2005 के दौरान मॉनसून-पूर्व वर्षा की समग्र ऋणात्मक प्रवृत्ति देखी गई। हालांकि, इसी अवधि के दौरान मॉनसून की वर्षा में वृद्धि की प्रवृत्ति देखी गई। भविष्य के परिदृश्य में, मॉनसून की वर्षा में मामूली वृद्धि (~ 6%) दिखाई देती है जबकि मॉनसून-पूर्व वर्षा में मध्यम मात्रा में वृद्धि (~ 11%) होती है। अतः अध्ययन से यह कहा जा सकता है कि निकट भविष्य में किसानों और फसल नियोजकों को बेहतर फसल नियोजन और अन्य हितधारक गतिविधियों के लिए मॉनसून-पूर्व वर्षा को अधिक महत्व देना चाहिए।

ABSTRACT. Monsoon rainfall is the dominant factor that determines the success or failure of agriculture in general. Gangetic West Bengal is not any exception. Monsoon rainfall has immense importance for growing *kharif* rice in this region. Whereas pre-monsoon rainfall helps farmers for proper crop planning like choosing variety etc. So assessing a long (1901-2005) and short (1961-2005 and 1991-2005) period rainfall data, its comparison with different models and construction of future scenario have utmost importance. For this purpose, rainfall data from nine selected station of India Meteorological Department were collected and subjected to trend analysis. Model outputs were compared with the observed station data. Results showed an overall negative trend of pre-monsoon rainfall during 1901-2005. However, increasing trend in monsoon rainfall was noticed during the same period. In future scenario, monsoon rainfall indicates a nominal increase (~6%) whereas pre-monsoon rainfall increases in moderate amount (~11%). So, from the study it may be said that in near future farmers and crop planner should give more importance in pre-monsoon rainfall for better crop planning and other stake holder activities.

Key words – Gangetic West Bengal, Monsoon, Pre-monsoon, Projected rainfall.

1. Introduction

Gangetic West Bengal (GWB) region contributes a large amount of the food production of the state West Bengal. The area prevails four distinct seasons, namely winter, pre-monsoon, monsoon and post-monsoon. The pre-monsoon season comprises of the months namely March, April and May and in this season the area experiences thunderstorm activity. This pre-monsoon season is a good contributor for well amount of rainfall. Sadhukhan *et al*. (2000) noted a maximum of 30 mm to more than 100 mm of rainfall over the GWB region in pre-monsoon season. Climatologically the focused area is located in tropical monsoon region. The months June, July, August and September are considered as monsoon season months. The moist end of the monsoon trough not only lies over this area but a number of depressions cross through the area, causing more rainfall in the monsoon season. Farmers of this region mainly grow *Kharif* rice during the monsoon season. It is observed that increased amount of rainfall also increases the biomass production hence it enhances the yield of crop specially *kharif* rice (Samanta *et al*., 2019). However, pre-monsoon rainfall has immense importance for crop planning purpose. From this point of view, a long term analysis of pre-monsoon and monsoonal rainfall change along with a future scenario have utmost important for agro-climatic research. Niyogi *et al*. (2010) observed an increasing trend of monsoon rainfall over the east central region of India and a decreasing trend over north and north west India due to change in land use pattern associated with agricultural intensification. The rainfall pattern of red and laterite zone of West Bengal were studied using the daily rainfall data for the period of 1970-2000 with noting increasing trend in annual rainfall (Mukherjee and Banerjee, 2007). Guhathakurta and Rajeevan (2008), for the period 1901-2003, pointed out increasing trend of monsoon rainfall in this region. Pal *et al*. (2015) reported substantial increasing trend of monsoon rainfall (1.901 mm per year) over GWB region. Chakraborty and Das (2016) have also recorded a positive trend of post-monsoon rainfall over GWB region. Lohar and Pal (1995) examined the modification of climatic variables due to change in land use pattern during the pre-monsoon season over Southern part of West Bengal. Das and Lohar (2005) investigated the climate change information over GWB using General Circulation Models (GCMs) and concluded an increase of rainfall in all the season except for pre-monsoon season. ParthSarathi *et al*. (2015) compared the rainfall pattern in Gangetic Plains of India through different simulation models.

Present study focuses the trend analysis of pre-monsoon and monsoon rainfall along with its future projection. This study will be helpful for farmers of this region for taking decision about suitable crop planning and any mid-agricultural activities during these seasons. Further, the future rainfall scenario will be helpful for the policy makers and stake holders in this region.

2. Data and methodology

The present study has been carried out over Gangetic belt. The state is situated in eastern part of the country between coordinates 21°20′ N to 27°32′ N and 85°50′ E to 89°52′ E. Nine IMD stations are selected, most of which lie in the Gangetic region of West Bengal (Table 1). The study area is considered extending from 20-26° N and 83-89° E where all available GCMs grid points are located. Two types of data are used in this study, observed station data from IMD Kolkata and the Coupled Model Inter-comparison Project - 3 (CMIP3) GCMs outputs downloaded from the Programme for Climate Model Diagnosis and Inter-comparison (PCMDI) archive (www-pcmdi.llnl.gov/ipcc/about_ipcc.php).

Six GCMs namely INGVECHM4, UKMO-HaDCM3, MIROC-Hi, CNRM, GISS and MPI are used for the present study (Table 2). The rainfall data, collected from IMD were scrutinized, five stations have the data set of 1901-2005 and the remaining four stations have the

TABLE 1

Location and time series of the studied station

Latitude	Longitude	Station Name	Data period
22.53	88.33	Alipur	1901-2005
23.4	88.52	Krishnanagar	1901-2005
21.65	88.05	Sagar	1901-2005
22.42	87.32	Midnapur	1901-2005
24.13	88.27	Berhampur	1901-2005
23.23	87.07	Bankura	1961-2005
21.78	87.75	Contai	1961-2005
23.67	87.7	Shantiniketan	1961-2005
22.03	88.06	Haldia	1991-2005

data set from 1961-2005 except Haldia station which have data set from 1991-2005. Nine IMD stations located in the southern districts of West Bengal were selected for the present study.

Among the nine stations, Alipur, Krishnanagar, Sagar, Midnapur and Berhampur have the database for the period 1901-2005; Bankura, Contai and Shantiniketan have the database for the period 1961-2005 and Haldia has the database for 1991-2005 (Table 1).

Two types of simulations namely the 20thcentury run and A1b scenarios (a future world of very rapid economic growth, low population growth and the rapid introduction of new and more efficient technologies, with a balanced emphasis on all energy sources) were used in the present investigation. The characteristics of the model are given in Table 2. Two types of analysis were performed: the long-term analysis using the data for the period of 1901-2005 andshort-term analysis with 30 years period that comprised of 1901-1930, 1931-1960, 1961-1990 and 1991-2005 within the long-term period. To test the accuracy of the model simulation with observations, selected few statistical indices as listed in Table 3 were calculated for the purpose of GCMs validation. For the purpose of constructing future scenarios, the GCM outputs were used and validated with observed station data.

3. Results and discussion

3.1. *Analysis of rainfall trends in pre-monsoon season*

To detect the observed rainfall change signal over GWB, analysis of the linear trends for a long-term and short term period as well as regional trend was carried out for both pre-monsoon and monsoon season. The linear

TABLE 2

Description of GCMs used in the study

Model ID	Modeling Centre	Atmospheric resolution (Lat. × Long.)	Oceanic resolution	Reference
INGV-ECHAM4	Max Plank Institute For Meteorology, Germany	1.125° × 1.125°	2° × 2° L31	Bacher *et al*. (1998); Stendel *et al*. (2002); Min *et al*. (2005)
UKMO-HaDCAM3	Hadley Centre For Climate Prediction and Research, UK	2.5° × 3.75°	1.25° × 1.25° L20	Gordon *et al*. (2000)
MIROC-Hi	JAMSTEC, Japan	T106 L56	0.2° × 0.3° L47	Emori *et al*. (1999); Nozawa *et al*. (2001); K-1 Model Developers (2004)
CNRM	Centre National de Recherches Météorologiques, France	T63 L45	0.5–2° × 2° L31	Madec *et al*. (1998)
GISS	Goddard Institute for Space Studies, USA	4° × 5°	4° × 5° L13	Russel *et al*. (1995)
MPI	Max Plank Institute For Meteorology, Germany	1.9° ×1.9° (T63) L31	1.5° ×1.5°	Marsland *et al*. (2003)

TABLE 3

Description of statistical measures

(where, M = Model output, $\overline{M}$ = Mean of the Model output, $б_M$ = standard deviation of the Model output,

O = observations, $\overline{O}$ = mean of the observations, $б_O$ = standard deviation of the observations and N = number of year)

Name of similarity	Equations	Reference
Mean bias	$\mathrm{MB} = \left[1/N\sum_{n=1}^{N}(M_n - O_n)\right]$	Willmott (1982)
Correlation	$\mathrm{R} = \left[\frac{1/N\sum_{n=1}^{N}(M_n - \overline{M})(O_n - \overline{O})}{\sigma_M \sigma_O}\right]$	Taylor (2001)
Index of agreement (D-Index)	$\mathrm{D\text{-}index} = 1.0 - \left[\frac{\sum_{n=1}^{N}(O_n - M_n)^2}{\sum_{n=1}^{N}\left(\lvert M_n - \overline{O}\rvert + \lvert O_n - \overline{O}\rvert\right)^2}\right]$	Willmott (1981); Lagtes and McCabe (1999)
Normalized total RMSE	$\mathrm{NTRMSE} = \frac{1}{\sigma_O}\left[\frac{1}{N}\sum_{n=1}^{N}(M_n - O_n)^2\right]^{1/2}$	Janseen and Heuberger (1995); Covey *et al*. (2002)

change of rainfall during the pre-monsoon season if inspected carefully it would be observed the rainfall declined during 1901-1930; 1931-1960; and increased during 1961-1990 for all the stations (Table 4). However during 1991-2005 the trend of rainfall recorded an increase at Alipur, Krishnanagar, Shantiniketan and Haldia; remaining stations recorded a negative trend. When 105 years rainfall data were inspected for five IMD stations, Alipur, Krishnanagar and Berhampur recorded the negative trend but Sagar and Midnapur showed the positive trend (Table 4). The long term linear trends of rainfall showed that the rainfall change at Alipur, Krishnanagar, Sagar, Midnapur and Berhampur were -7.86, -96.98, +27.24, +60.07 and -3.13 mm per 105 years respectively. The linear trends for Bankura, Contai and Shantiniketan was positive during 1961-1990 period, however, from 1991-2005 the trend was negative except Shantiniketan. Haldia observed an overall positive trend during pre-monsoon season. Regional averaged rainfall during pre-monsoon season shows overall negative trend for 1901-2005 period (Table 4). However, a positive trend of regional averaged rainfalls was noticed during 1991-2005.

The above analysis showed that the stations located at the new alluvial (Alipur and Krisnanagar) and old

TABLE 4

Linear trends of rainfall change pattern in pre-monsoon

Station	Location		Rainfall change in different time series (mm)				
	Lat.	Long.	1901-2005	1901-30	1931-60	1961-90	1991-2005
Alipur	22.53	88.33	-7.86	-124.06	-103.43	+80.83	+109.83
Krishnanagar	23.4	88.52	-96.98	-103.45	-157.07	+97.67	+375.75
Sagar	21.65	88.05	+27.24	-92.34	-126.45	+114.08	-97.07
Midnapur	22.42	87.32	+60.07	-86.46	-8.36	+119.28	-20.94
Berhampur	24.13	88.27	-3.13	-55.95	-85.99	+74.79	-62.73
Bankura	23.23	87.07	-	-	-	+136.62	-34.11
Contai	21.78	87.95	-	-	-	+130.48	-59.64
Shantiniketan	23.67	87.7	-	-	-	+42.55	+110.89
Haldia	22.03	88.06	-	-	-	-	+88.49
Regional averaged	-	-	-20.60	-462.21	-481.29	+796.32	+409.95

TABLE 5

Linear trends of rainfall change pattern in monsoon

Station	Location		Rainfall change in different time series (mm)				
	Lat.	Long.	1901-2005	1901-30	1931-60	1961-90	1991-2005
Alipur	22.53	88.33	+113.61	+73.89	-197.72	+188.97	-303.72
Krishnanagar	23.4	88.52	-27.56	-66.83	+24.08	+134.14	+211.25
Sagar	21.65	88.05	-3.09	+268.59	-165.32	-149.52	-219.58
Midnapur	22.42	87.32	+106.8	+210.24	+4.71	+179.16	-318.99
Berhampur	24.13	88.27	+113.55	-147.54	-10.54	+187.59	-153.59
Bankura	23.23	87.07	-	-	-	+203.65	-260.65
Contai	21.78	87.95	-	-	-	-253.09	-246.57
Shantiniketan	23.67	87.7	-	-	-	+277.45	-234.64
Haldia	22.03	88.06	-	-	-	-	-102.28
Regional averaged	-	-	+60.65	+67.67	-68.93	+96.04	-128.71

alluvial (Berhampur) zones had received low rainfall as compared to the past rainfall scenario when 105 year rainfall data was considered. Patra *et al*. (2012) reported the rainfall during summer season had an increasing trend in Odhisha. In the present analysis the Sagar and Midnapur had recorded an increasing trend. Midnapur and Sagar Island are adjacent to coastal environment which might be the reason of increasing rainfall trend. The behavior of pre-monsoon rainfall which comes during March to May has an important impact on pre *kharif* crops. The major pre *kharif* crops cultivated in Indo-Gangetic Plains (IGP) or red and laterite zones are sesame, groundnut and mung bean. The productivity of these crops is severely limited due to low soil moisture content during the reproductive phase (March and April). Chakraborty (1990) observed from rainfall probability analysis that jute, upland rice, sesame can be sown within 16-20 meteorological weeks if there is a rainfall of 10 mm per week during pre monsoon season.

3.2. *Analysis of rainfall trends in monsoon season*

The linear trend of monsoon rainfall is reported in Table 5. During 1901-1930 Alipur, Sagar and Midnapur recorded an increasing trend in rainfall (+73 to +268 mm) whereas Krishnanagar and Berhampur recorded a

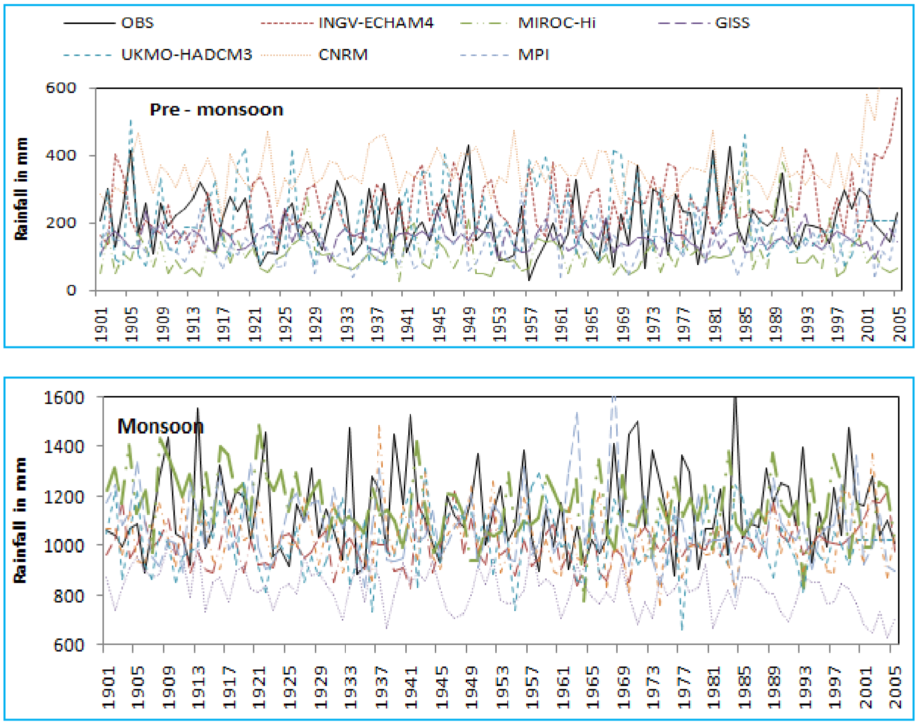

Fig. 1. Comparison of pre-monsoon and monsoon rainfall with different GCMs simulation during time series 1901-2005(OBS stands for Observed rainfall)

declining trend in rainfall (-66 to -147 mm).During 1961-1990 Sagar and Contai recorded a declining trend whereas the remaining 6 stations recorded an increasing trend in rainfall. During 1991-2005 all the stations except Krishnanagar recorded a declining trend in monsoon rainfall. The regional averaged rainfalls during monsoon season showed overall positive trend for 105 years but a negative trend is observed from 1991-2005 period (Table 5).

The declining trend of monsoon rainfall has been reported from the different parts of the country (Prasada Rao *et al*., 2008; Patra *et al*., 2012; Sam and Chakma, 2019). Singh and Sontakke (2002) observed a decreasing trend of monsoon rainfall (50 mm per year) from 1939 onwards over the eastern part of IGP. Productivity of *kharif* rice highly depends on the amount of monsoon rainfall. Delayed onset of monsoon with decreasing trend of rainfall results in decreasing production of *kharif* rice and *vice versa* over this region. Auffhammer *et al*. (2011) reported yield of *kharif* rice might be 1.7% higher in overall India if there is no change in monsoon characteristics. Bhattacharya *et al*. (2013) observed grain yield of rice increased on an average of 0.35 kg ha^{-1} per mm increase of monsoon rainfall in Kharagpur area. Mandal *et al*. (2015) reported early onset of south west monsoon is related with timely transplanting of *kharif* rice in Sagar Island region.

3.3. *GCMs comparison with observation and testing accuracy of rainfall simulation*

Regional averaged seasonal observed rainfall using five meteorological stations (Alipur, Krishnanagar, Sagar, Midnapur and Berhampur) were compared along with regional averaged of each GCMs simulation using available grid points over GWB. The seasonal time series of simulated rainfall by six models along with observation was displayed in Fig. 1. Visual interpretation of Fig. 1 indicates that the trends of rainfall simulation by all GCMs to some extent similar to observation in pre-monsoon and monsoon season. Calculation of the observed as well as model simulated rainfall trends during the period 1901-2005 for pre-monsoon and monsoon season were presented in Table 6. In the pre-monsoon season observed rainfall is also showing a decreasing trend (Table 6) while an increasing trend is noticed in all the GCMs simulations except UKMO-HaDCM3 and GISS. It reveals that in the pre-monsoon season, the models are not able to capture the meso-scale phenomena like thunder storm etc. To test the accuracy of model simulations with observation, some statistical measures (indices) namely D Index value, R (Correlation), Normalized Total Root Mean Square Error (NTRMSE) and Mean Bias (MB) are used. All the parameters were computed using the standards equations (Table 3) for each models and a multimodal ensemble using six models

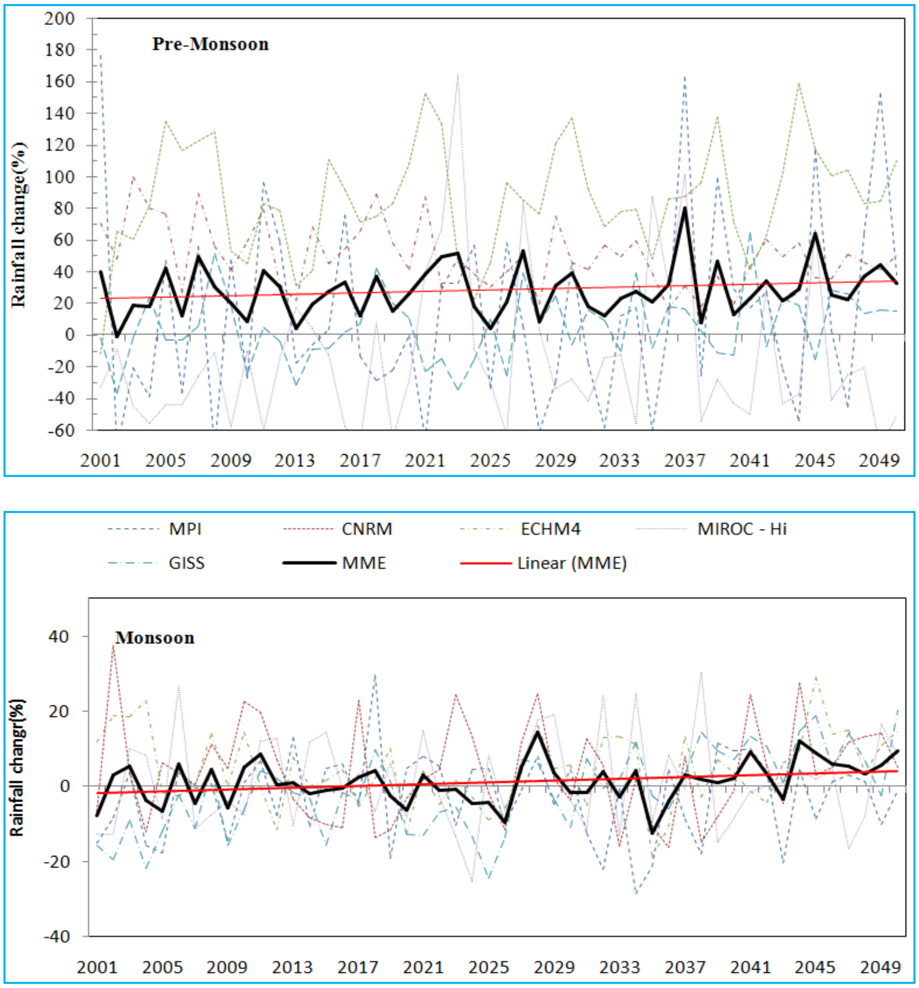

Fig. 2. Projected rainfall change (%) in future during 2001-2050 over Gangetic West Bengal in pre-monsoon and monsoon season

TABLE 6

Comparison of different GCM output with observed total rainfall change (mm) (1901-2005)

Season	Observed total rainfall change (mm)	Different GCM output (mm)					
		INGV-ECHM4	MIROC-Hi	GISS	UKMO-HaDCM3	CNRM	MPI
Pre-monsoon	-4.12	+81.66	+24.53	-14.16	-1.51	+69.02	+31.51
Monsoon	+54.24	+54.43	-127.43	-116.61	-8.47	-38.78	-52.16

(MME) was generated with overall averages. It is to be noted that the model performance was tested on the basis of the values of the computed indices. Higher the values of D Index and R, better is the performance of the model. Similarly, lesser the values of NTRMSE indicate the better performance of the model while the negative value of MB indicates an underestimation of model simulation and *vice versa*. Comparison of model rainfall with observed in pre monsoon season shows poor relationship. R values are very small and are negative for ECHAM4 and GISS models. This shows that models failed to generate the observed rainfall in pre-monsoon season. Similar is for monsoon season (Table 7).

3.4. *Projected rainfall change during 2001-2050*

In this present study, it is assumed that all six GCMs outputs for constructing the future climate change

TABLE 7

Statistical values computed between observed and model simulated pre-monsoon and monsoon rainfall

Name of GCM	Statistical measures							
	Pre-monsoon				Monsoon			
	D Index	R	NTRMSE	MB	D Index	R	NTRMSE	MB
INGV-ECHM4	0.26	-0.13	1.56	40.75	0.42	-0.03	1.36	-136.01
MIROC-Hi	0.43	0.04	1.66	-95.77	0.29	-0.12	1.32	17.43
GISS	0.39	-0.01	1.22	-51.47	0.39	0.02	2.11	-316.55
UKMO-HaDCM3	0.49	0.13	1.45	2.87	0.72	-0.05	1.44	-121.16
CNRM	0.38	0.07	2.21	153.36	0.43	0.04	1.35	-111.62
MPI	0.46	0.13	1.36	-62.83	0.40	-0.01	1.34	-64.83
MME	0.32	0.10	1.02	-2.18	0.42	-0.06	1.26	-122.12

[MME = Multi Model Ensembles of GCMs]

scenarios assuming that models will also perform in the same fashion as they simulate the past climate with a higher confidence. The models INGV-ECHM4, MIROC-Hi, MPI and GISS indicates future rainfall during pre-monsoon season will increase which is not similar with observation whereas the CNRM projects decline trend which is similar for the observed trend (Fig. 2). All models projected a nominal increasing trend of monsoon rainfall during 2001-2050 (Fig. 2). As different models show different amount of rainfall change scenarios, therefore, it is better to make a multimodal ensemble using large number of model's results to adequately represent the real change scenarios of a place. This MME picture will be used by the impact researchers with a more confidence. Therefore, a MME scenario is also calculated and results are plotted in Fig. 2. Overall rainfall change scenario through MME, showed approximately 11 and 6% increase in pre-monsoon and monsoon season respectively over GWB region.

4. Conclusions

The stations like Krishnanagar, Sagar Island, Midnapur and Bankura showed a decreasing trend of pre-monsoon rainfall during 1991-2005 whereas Alipur and Berhampur recorded an increasing trend. Observed rainfall during monsoon shows an increasing trend for the data of Alipur, Berhampur and Midnapur while the data of Krishnanagar and Sagar indicates decreasing trends. It is revealed that all GCMs failed to simulate the observed trend of monsoon rain. No model is able to capture the decreasing trend of pre-monsoon rain. Perhaps it is due to the inability of the GCMs to capture the meso-scale phenomena of thunderstorm activity which is locally known as "*Kalbaishaki*". Multi Model Ensembles show a nominal change in monsoon rain (~6%). However projected increasing trend in pre-monsoon season rainfall (~11%) will enhance soil moisture status which in turns help farmers for growing *kharif* rice along with other vegetables.

Acknowledgment

Authors are grateful to India Meteorological Department (IMD) and the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) for providing data and archiving the model outputs. Special thanks are also extended to Mrs. Monami Dutta and Dr. Jitendra Kumar Meher for their constant support and encouragement for analyzing GCMs simulations for this work. The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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