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Long-term temperature analysis and its future projection during post-monsoon and winter season in the alluvial, red laterite and costal region of West Bengal

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ABSTRACT

Nine IMD stations (Alipore, Krishnagar, Sagar Island, Midnapore, Berhampore, Bankura, Contai, Shantiniketan, Haldia), distributed randomly in alluvial, red-laterite and coastal regions of West Bengal, were selected for studying the temperature change. First five stations have database of 105 years, sixth, seventh and eighth stations have database of 45years and the ninth station has the database of 15 years during the period of 1901-2005. Six GCMs simulations wore used for the purpose of model validation and future temperature change for the year 2050. First five stations showed drastic rise of temperature ranging from 1.24-3.67ºC in 105 years in the post-monsoon season whereas the stations in the red laterite zone recorded a nominal change of temperature ranging from 0.26-0.98^{0}C during 1961-1990. The winter seasons showed the similar warming trend (0.75-2.81^{0}C in 105years) alike post monsoon in the first five stations. Abrupt warming (~0.05-3.03ºC) was recorded in last 15 years in the remaining four stations. All GCM models showed a rise of post-monsoon temperature by 0.8-1.8 ºC indicating slightly under estimate the observed warming whereas the winter warming is well simulated by GCMs as 1.4-2.4ºC. Irrespective of these two seasons, future temperature may rise by 1.4-1.8^{0}C with reference to 1961-90 at end of 2050. This temperature may rise have an important effect on growth and productivity of crops sown during October-March.

Keywords: Future projection, global circulation models (GCMs), IMD stations, post-monsoon

In the context of global warming and climate change, assessing the exact amount of temperature change in the centennial scales as well as 30 years periods over a sub-regional or local scale pay more attention to the policy maker as well as Government agencies. Assessing the seasonal temperature change and its future projection over a small scale or in a point location (station level) is very essential for the impact study leading to agricultural crops as well as hydrological planning. Indian agriculture largely depends on the variability of temperature and rainfall pattern. During post monsoon and winter season wheat, oilseeds, pulses and potato are the major crops, grown in the *Gangetic* plains of West Bengal. Besides, summer rice is also grown across the large tract of the state. All these crops show high sensitivity to the temperature change during the post monsoon and winter season. Rise in temperature reduces the duration of phenophases (Parya *et al.*, 2010), increases evapotranspiration (Cuddeford, 2002), thus lead to lower productivity of winter crops (Banerjee *et al.,* 2007; Dash *et al.,* 2007). The temperature change also caused the variation in GDD requirement for growth phases in winter crops (Basu *et al*., 2012). Average temperature of this region has shown an increasing trend. Lal (2001) projected a rise in temperature to the tune of 3.5-5.5ºC by 2080 over the Indian sub-continent. Das and Lohar (2005) also projected an increase in average temperature to the tune of 0.3-0.7ºC per ºC global change over *Gangetic* West Bengal (GWB). All mentioned studies are not adequate to provide suitable pictorial representation with a higher confidence for the exact amount of temperature warming so far occurred over the *Gangetic* West Bengal regions where diverse *kharif* and *rabi* crops are grown and developed throughout the year but have sharp climate variability and change from the extreme hot period in pre-monsoon to extreme cold in the winter. None of these studies assessed the warming trends using the modern tool of the global circulation model outputs over such a small domain of GWB. In this present study an attempt has been made to assess the warning trends at regional scale as well as each station location for the 20th century and it future predictions for the 21st century using the station data of IMD and GCMs simulations from CMIP3. The outputs of this research work will help the farmer and agricultural policy makers to adopt suitable measures for growing winter crops in this region.

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MATERIALS AND METHOD

Present study used two different types of data sources namely observed station data from India

Meteorological Department (IMD) and secondly the Global Circulation Models (GCMs) simulations from the IPCC 4th assessment report (IPCC-AR4). The station data were collected from Regional Meteorological Centre, Kolkata of the IMD. After scrutinizing the data, we finally found nine stations distributed scatterly over the southern districts of West Bengal have adequate data length and quality with some missing values which are carefully replaced by the mean of climatological 30 year period (Table 1). Among the nine stations, Alipore, Krishnagar, Sagar Island, Midnapore and Berhampore have the database of 1901-2005; Bankura, Contai and Shantiniketan have the database of 1961-2005 and Haldia has the databsae of 1991-2005. On the other hand the GCM outputs downloaded from the Programme for Climate Model Diagnosis and Inter comparison archive (PCMDI) in the web link www-pcmdi.llnl.gov/ipcc/about_ipcc.php. Six GCMs, which has simulation available for the period 1901-2000 and prediction for the period 2001-50, were used. The GCMs are namely INGV-ECHM4, UKMO-HaDCM3, MIROC-Hi, CNRM, GISS and MPI from the different modeling centres situated from different geographical location of the world. The details and characteristics of the model are given in table 2. Two types of simulations namely the 20th century (20CM) run during the period 1901-2000 which is commonly known as historical run was used to validate the GCMs simulation whereas constructing future climate change trends for 2001-2050 period we considered only A1b scenarios for each GCMs.

Table 1: Location and distribution of stations with time period

Latitude(^{0}N)	Longitude(^{0}E)	Station Name	Abbre-viation	Data period
22.53	88.33	Alipore	ALI	1901-2005
23.40	88.52	Krishnanagar	KRIS	1901-2005
21.65	88.05	Sagarisland	SAG	1901-2005
22.42	87.32	Midnapur	MID	1901-2005
24.13	88.27	Berhampur	BER	1901-2005
23.23	87.07	Bankura	BAN	1961-2005
21.78	87.75	Contai	CON	1961-2005
23.67	87.70	Shantineketan	SHAN	1961-2005
22.03	88.06	Holdia	HOL	1991-2005

We calculated the statistical measures like mean, standard deviation, coefficient of variation, for each station during the period of 1901-2005 and short-term analysis with a 30 years period that comprises of 1901-1930, 1931-1960, 1961-1990 and 1991-2005 within the long-term period. We also calculated long-term (100 years) and short-term trends using linear regression technique for each station. Regionally averaged (simply averaging all available stations) trends are also calculated for the GWB region. GCMs are validated by two different approaches: firstly through visual comparison of observed data and GCMs simulations through different graphical representation and secondly by testing the accuracy of the model simulation with observation, we computed some conventional statistical indices which is briefly defined as described in table 3. The future projection of temperature changes can be prepared by two different approaches: firstly interpolated the GCMs outputs to each station locations through bi-linear interpolation technique. Then averaging the interpolated values to have a regionally averaged future time series. Secondly averaging the available grid-points over GWB for each GCMs. Time series of each GCM is generated using the second method of grid averaging and calculating the season wise linear temperature trend using regionally averaged time series. Finally we also calculated the multi-model ensemble (MME) through averaging the 6 models results or simulation.

RESULTS AND DISCUSSION

Post monsoon temperature analysis

Among the five major IMD stations, Sagar Island recorded maximum mean temperature (25.7±0.7ºC) and Krishnagar recorded minimum temperature during 1901-1930 (Table-4). During 1931-1960 Alipore, Krishnagar, and Berhampore recorded a rise in temperature by 0.4, 1.4 and 0.3ºC, respectively. However, Midnapore recorded a reduction in temperature by 0.4ºC when compared to the previous cycle. During 1961-1990 among the five major stations Alipore, Sagar Island, Midnapore and Berhampore recorded an increasing trend in post monsoon temperature (Table 4). Bankura and Contai also recorded a very high post monsoon temperature.

It was observed that the Sagar Island recorded a continuous increase in post monsoon temperature during 1961 to 1990. During 1991-2005 Alipore, Krishnagar, Sagar Island, Midnapore, Berhampore, Contai and Shantiniketan recorded an increase in temperature to the tune of 2.2, 2.4, 0.4, 2.2, 2.9, 0.1and 0.4ºC respectively. It was observed that the post monsoon temperature recorded a continuous increase at Alipore, Sagar Island and Berhampore during 1901 to 2005.

During post monsoon season five major IMD stations recorded a rise in temperature in the last century (Table 5). The short-term linear trend if inspected, it would be observed that Bankura, Contai, Shantiniketan and Haldia also recorded a rise in temperature during post monsoon season.

Winter temperature analysis

During 1901-1930 Sagar Island recorded maximum temperature during winter season. Among the five major stations Krishnagar recorded the highest fluctuation during winter season (Table 6). During 1931 to 1960 Alipore, Krishnagar, Sagar Island and Berhampore recorded a rise in mean winter temperatures to an extent of 0.8, 0.5, 0.4 and 0.7ºC respectively. During 1961 to 1990 Alipore, Sagar Island and Berhampore showed an increasing trend of winter temperature in comparison to previous 30-year cycle. Krishnagar recorded the highest fluctuation in the mean winter temperature. During 1991 to 2005 Alipore,Krishnagar, Sagar Island, Midnapore, Bankura and Contai recorded a rise in winter temperature by 1.3, 1.3, 1.1, 1.3, 0.6 and 1.0ºC respectively. During 1901-2005 Alipore, Sagar Island and Berhampore recorded an increasing trend in winter temperature.

The linear trends of temperature change in winter are presented in table-7. During 1901-2005 all the five major IMD stations recorded a positive change. The positive temperature change during winter season at Alipore, Krishnagar, Sagar Island, Midnapore and Berhampore were +2.41, +1.89, +2.04, +0.75 and +2.81ºC per 105 years (Table 7).

Temperature change and model simulation:

Observed temperature change and different model simulation results showed that the simulation models could not predict the post monsoon and winter warming properly (Table 8). The GCMs temperature simulations were tested through several statistical measures. Among the different models the MIROC-Hi has the highest D-Index and R values with lower NTRMSE, suggesting its best performance for winter and post monsoon temperature (Table 9, 10).

Projected future temperature change during 2001-2050

The projected temperature change during 2001-2050 is shown in figure 1 and 2. And the magnitude of projected change for different model is shown in Table

Table 2: Description of models

Model ID	Modeling Centre	Atmospheric resolution (lat×long)	Ocenic resolution	Reference
INGV-ECHAM4	Max Plank Institute For Meteorology,Germany	1.125º× 1.125º	2º × 2º L31	Bacher *et al*. (1998) Stendel *et al*. (2002), Min *et al*. (2005)
UKMO-HADCAM3	Hadley Centre For Climate Prediction and Research,UK	2.5º × 3.75º	1.25º × 1.25º L20	Gordon *et al*.(2002)
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 RecherchesMétéorologiques, 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	1.9º×1.9º(T63) L31	1.5º×1.5º	Marsland *et al*.(2003)

Table 3: Description of statistical measures

Name of similarity	Equations	Reference
Mean bias	$MB = /N\sum_{n=1}^{N}(M_n - O_n)$	Willmott (1982)
Correlation	$R = \left[\frac{\frac{1}{N}\sum_{n=1}^{N}(M_n - \bar{M})(O_n - \bar{O})}{{}^{\sigma}M^{\sigma}O}\right]$	Taylor (2001)
Index of agreement (D-Index)	$d - index = 1.0 - \left[\frac{\sum_{n=1}^{N}(O_n - M_n)^2}{\sum_{n=1}^{N}(\lvert M_n - \bar{O}\rvert + \lvert O_n - \bar{O}\rvert)^2}\right]$	Willmott (1981), Lagates & McCabe (1999)
Normalized total RMSE	$NTRMSE = \frac{1}{\sigma_o}\left[\frac{1}{N}\sum_{n=1}^{N}(M_n - O_n)^2\right]^{1/2}$	Janssen &Heuberger (1995), Covey *et al*. (2002)

Note : Where M = Model output, M= Mean of the Model output, $б_M$ = standard deviation of the Model output, O = observations, O = mean of the observations, $б_O$ = standard deviation of the observations and N = number of year

Table 4: Post monsoon temperature (ºC) statistics for different time series

Stations	1901-1930			1931-1960			1961-1990			1991-2005			1901-2005		
	Mean	SD (±)	CV (%)	Mean	SD (±)	CV (%)	Mean	SD (±)	CV (%)	Mean	SD (±)	CV (%)	Mean	SD (±)	CV (%)
ALI	23.4	1.4	5.9	23.8	1.3	5.4	24.3	1.3	5.4	26.5	1.5	5.6	24.2	2.5	10.3
KRIS	22.3	3.1	13.9	23.7	2.3	9.7	23.5	2.1	8.9	25.9	1.7	6.5	23.7	3.1	13.1
SAG	25.7	0.7	2.7	25.7	0.7	2.7	26.3	1.1	4.1	26.7	0.9	3.3	26.1	1.1	4.2
MID	23.2	1.4	6.1	22.8	1.4	6.1	23.3	1.6	6.9	25.5	1.6	6.2	23.4	2.2	9.4
BER	23.1	1.2	5.2	23.4	1.7	7.2	24.2	2.8	11.5	27.1	2.3	8.4	24.0	3.2	13.3
BAN	-	-	-	-	-	-	25.6	1.5	5.8	25.4	0.9	3.5	-	-	-
CON	-	-	-	-	-	-	25.6	0.8	3.1	25.7	1.9	7.4	-	-	-
SHAN	-	-	-	-	-	-	24.9	1.1	4.4	25.3	1.2	4.7	-	-	-
HOL	-	-	-	-	-	-	-	-	-	26.8	1.1	4.1	-	-	-
Reg.Avg	23.6	3.2	13.5	23.9	2.9	12.1	24.7	3.1	12.5	26.1	4.1	15.7	24.3	5.1	20.9

Table 5: Linear trend of temperature change during post monsoon

Station	Temperature change (ºC)				
	1901-2005	1901-30	1931-60	1961-90	1991-2005
ALI	+2.97	+0.61	+0.16	+0.17	+0.37
KRIS	+2.49	+0.67	+0.81	-0.48	-0.07
SAG	+1.24	-0.54	+0.08	+0.94	-0.37
MID	+1.98	-0.36	+0.13	+1.42	+0.14
BER	+3.67	-0.36	+1.18	+2.98	-1.49
BAN	-	-	-	+0.98	-0.61
CON	-	-	-	+0.26	+2.20
SHAN	-	-	-	+0.68	-0.35
HOL	-	-	-	-	+0.42
Reg.Avg	+2.51	+0.21	+0.44	+0.87	+0.03

Table 6: Winter temperature (ºC) statistics for different time series

Station	1901-1930			1931-1960			1961-1990			1991-2005			1901-2005		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
ALI	18.8	1.9	10.4	19.6	2.4	12.4	19.9	1.8	9.1	21.2	2.8	13.3	19.7	3.1	15.9
KRIS	18.0	2.9	16.2	18.5	2.6	14.5	18.3	6.3	34.5	19.6	2.3	11.6	18.4	4.3	23.4
SAG	19.8	1.9	9.7	20.2	3.9	19.7	20.7	1.9	9.0	21.8	2.5	11.7	20.4	3.3	16.1
MID	19.4	2.2	11.3	19.3	2.5	12.7	19.1	2.7	14.2	20.4	2.2	10.6	19.4	2.7	14.2
BER	17.7	1.9	10.6	18.4	2.7	14.7	18.5	2.6	13.8	20.6	2.2	10.9	18.6	3.6	19.3
BAN	-	-	-	-	-	-	19.1	3.7	19.4	19.7	1.4	7.3	-	-	-
CON	-	-	-	-	-	-	20.1	1.8	9.1	21.1	3.6	17.2	-	-	-
SHAN	-	-	-	-	-	-	19.7	1.7	8.5	19.5	1.2	6.3	-	-	-
HOL	-	-	-	-	-	-	-	-	-	21.6	1.2	5.3	-	-	-
Regavg	18.7	2.8	14.8	19.2	4.1	21.2	19.4	5.3	27.4	20.4	3.9	19.3	19.3	4.7	24.2

Table 7: Linear trend of temperature change during winter

Station	Temperature change (ºC)				
	1901-2005	1901-30	1931-60	1961-90	1991-2005
ALI	+2.41	+0.56	+0.88	+0.38	+1.85
KRIS	+1.89	+1.61	+1.73	+2.49	-1.11
SAG	+2.04	-0.22	+0.99	+0.84	-0.36
MID	+0.75	+0.31	+0.27	+1.36	+1.03
BER	+2.81	+0.28	+1.53	+5.39	-0.96
BAN	-	-	-	+0.71	+0.48
CONTAI	-	-	-	+0.53	+3.03
SHAN	-	-	-	+0.48	+0.05
HOL	-	-	-	-	+0.59
Reg. avg	+1.96	+0.51	+1.08	+0.03	+0.58

Table 8: Validation of different GCM output with observed temperature change (ºC) during 1901-2005

Season	Observed	Different model output (ºc)					
	temp. change (ºc)	INGV-ECHAM4	MIROC-Hi	GISS	UKMO-HaDCM3	CNRM	MPI
Post-monsoon	2.54	0.61	1.04	0.44	0.42	0.78	1.02
Winter	1.96	0.55	0.91	1.07	0.97	0.31	0.91

Table 9: Statistical values computed for observed and model simulated post-monsoon temperature

Statistics	INGV-ECHAM4	MIROC-Hi	HADCM3	GISS	CNRM	MPI	MME
D-Index	0.44	0.53	0.24	0.30	0.29	0.51	0.38
R	0.18	0.44	0.04	0.19	0.23	0.38	0.49
NTRMSE	1.09	1/03	4.23	3.23	3.55	1.30	2.20
MB	-0.3	-0.5	-4.1	-3.2	-3.5	-0.9	-2.1

Table10: Statistical values computed for observed and model simulated winter temperature

Statistics	INGV-ECHAM4	MIROC-Hi	HADCM3	GISS	CNRM	MPI	MME
D-Index	0.44	0.54	0.28	0.42	0.31	0.42	0.45
R	0.17	0.48	0.14	0.34	-0.06	0.18	0.39
NTRMSE	2.03	1.12	3.72	1.99	2.93	1.31	1.55
MB	1.6	-0.7	-3.3	-1.6	-2.5	-0.6	-1.2

Table 11: Projected temperature change (ºC) during 2001-2050 simulated by GCMs in post monsoon and winter season

Season	Temperature change (ºC)						
	INGV-ECHAM4	MIROC-Hi	HADCM3	MPI	CNRM	GISS	MME
Post-monsoon	+1.64	+1.86	+1.63	+1.57	+1.78	+0.86	1.56
Winter	+1.89	+1.94	+1.82	+2.41	+1.39	+1.46	1.81

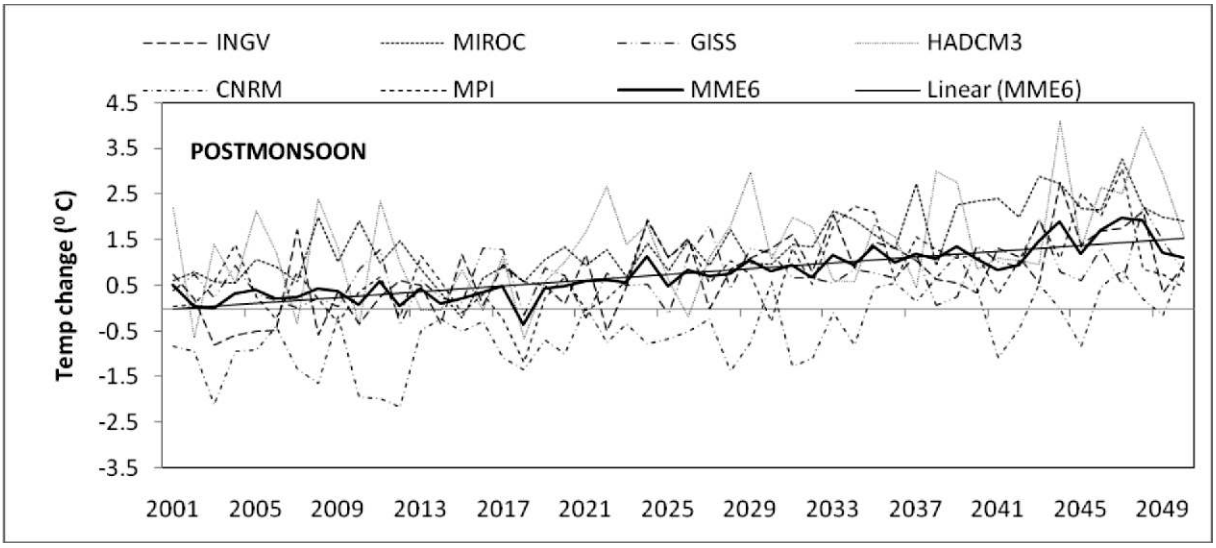

Fig. 1:Projected temperature change in future during 2001-2050 over the study area in post-monsoon season

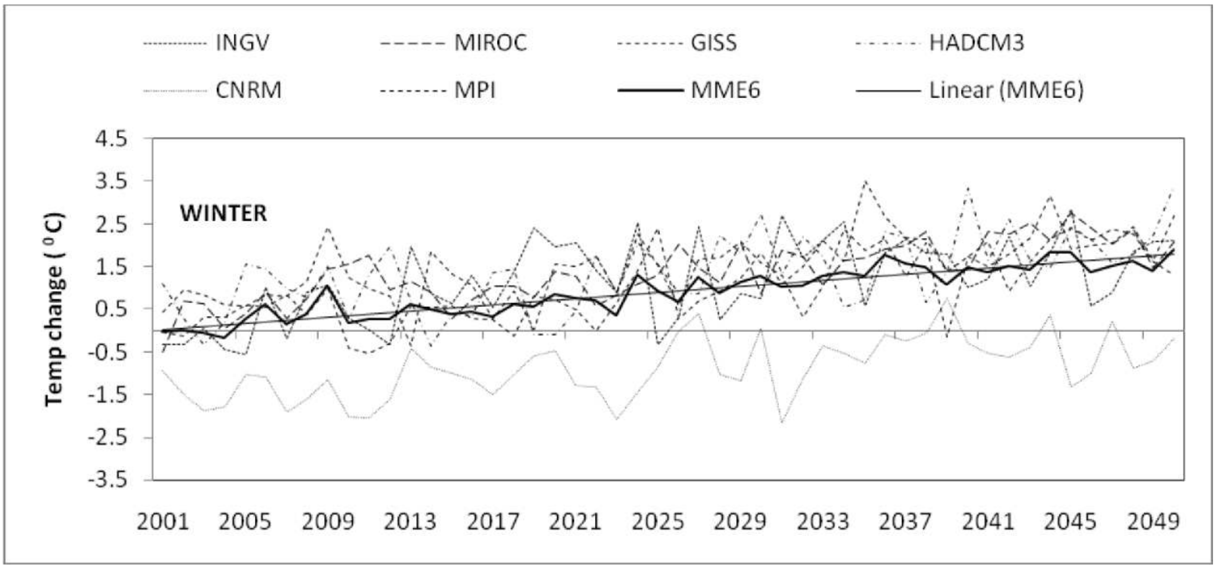

Fig. 2: Projected temperature change during 2001-2050 over the study area in winter season

11. MIROC-Hi predicted a rise of 1.86 and 1.94ºC during post monsoon and winter season whereas; INGV-ECHAM4 projected a rise of 1.64 and 1.89ºC respectively. All the GCMs projected a rise in post monsoon and winter temperature. The multi model ensemble (MME) result showed that the temperature in winter and post monsoon season will rise by 1.81 and 1.56ºC, respectively.

The present study clearly indicated that our post monsoon and winter seasons are experiencing high warming which may be due to different anthropogenic activities by the increased population density over the Gangetic West Bengal region in addition to gradual changing of land-use land cover by the processes of urbanization and industrialization etc. It is revealed that future temperature will rise more rapidly than the past as we considered all A1b scenarios. Among the different GCMs MIROC-Hi showed better acceptability. The information on temperature rise in these two important seasons will be helpful to manipulate the sowing dates of different winter crops and give information to the breeder for developing such short duration varieties whose reproductive stage would not suffer due to high temperature.

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