Global Warming in Bangladesh Perspective: Temperature Projections upto 2100

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Abstract — Some of the major dimensions of climate change for Bangladesh include increase in surface temperatures, associated lowering of ground water table for higher evapotranspiration rates, longer spells of droughts in significant parts of the country and so on. It is therefore, essential to comprehend the future possible scenario of climate change, in terms of global warming. Climate models are the main tools available for developing projections of climate change in the future. There are a number of mathematical models of global circulation that indicate expectations of future climate scenarios. Needless to say, no model will give a perfect projection of future climatology or observations as the inherent physics and associated underlying assumptions of the components like atmospheric, ocean, sea-ice and land-surface might be different for different climate models. As such, it is best to validate two or more climate models to enable a choice to produce the most appropriate projection to be used in climate-scenario generation for a small country like Bangladesh. This paper features the development of Multi-Model combination of future surface temperature projections for Bangladesh on monthly basis, for each of the year from 2011 to 2100, using both global and regional climate models. Four selected IPCC ensemble Global Climate Models (GCMs), namely CGCM3.1, CCSM3, MIROC3.2 and HadGEM1 as well as a Regional Climate Model (RCM) called PRECIS have been applied in this regard. In this paper, evidence of increasing temperature levels in Bangladesh has been found from the climate model projections, as evident from observed meteorological data. The long term historical trend in temperature matches fairly well the future possible temperature trends predicted by the GCMs for a scenario of emissions arising from a future world of rapid economic growth, balanced across energy sources. Again, by developing the projections of a particular climate models under different emission scenarios, the extent of increase of temperature in Bangladesh is found to be highly sensitive to the extent of emissions to the atmosphere. From the multi-model combination (RCM and GCM projections) of future average temperature change with respect to 1971-2000, it can be observed that the winter months in Bangladesh might show relatively more warming in future, than the monsoon and pre-monsoon months. However, the trend of temperature increase might continue to increase invariably in every month.

Keywords — annual, climate change, Global Climate Model, Regional Climate Model, temperature

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1 Introduction

Climate change has been escalating over the centuries, causing a complete upturned impact of the ecosystem of the earth surface. The historical climate change along with the present rate of change has influenced the engineers to project the future climate change, to aid the policy makers in making decisions. Bangladesh is located between 20° to 26° North and 88° to 92° East. Currently, the average temperature of Bangladesh ranges from 17 °C to 20.6 °C during winter and 26.9 °C to 31.1 °C during summer [1]. The average annual temperature of Bangladesh is expected to increase by 1.4 to 0.6 °C by 2050 [2], [3] and the average monthly temperature might continue to rise invariably in every month. Increase in temperature during the months with less precipitation as a result of climate change, will increase Evapotranspiration and create situations like water loss from soil and resultant reduced crop yield, lower level of water both in surface and ground water systems, higher microbial concentration and growth rate in the surface waters and so on. If not checked in time, the exacerbating aridity and accompanying desertification processes as a consequence of increased surface temperature is destined to cause severe environmental degradation in different parts of the country.

2 CURRENTTEMPERATURE CONDITIONS

Average temperature data in each of the year from 1948 to 2009 are available on monthly basis from the Bangladesh Meteorological Department (BMD). These 'average' temperature values are nothing but the average of the observations from all the available stations at any certain period, representing the overall temperature condition of Bangladesh at that period. As summarized in Table 1, the differences between the annual average temperatures of the past 20 years (1953 – 1972) of record and the recent 20 years (1985 – 2004) show an increase of 0.68 °C. A lesser increase of 0.59 °C is apparent in the dry season month of January, with a higher increase of 0.90 °C in the monsoon season month of August.

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Table 1. Temperature increase through years (°C)

	Year	Annual	August	January
10 Year Avg.	1995 - 2004	25.9	29.0	18.1
	1953 - 1962	25.1	28.2	17.9
	Difference	**+ 0.72**	**+ 0.78**	**+ 0.25**
20 Year Avg.	1985 - 2004	25.9	29.0	18.5
	1953 - 1972	25.2	28.1	17.9
	Difference	**+ 0.68**	**+ 0.90**	**+ 0.59**

The plotted data in Fig. 1 shows the average annual observed temperatures of Bangladesh since 1948 upto 2009 indicating an overall increase in temperature is prominent over the past years, with greater warming (as indicated by the slopes of the fitted linear trend lines) in recent 20 years. Clearly, the rate of temperature increase is relatively high in recent years since 1990 to 2009. But if the average annual temperature only in the last 10 years (2000-2009) is segregated and therefore analyzed, it can be revealed that the rate of temperature increment is even higher. Year 2006 and 2009 were the two warmest years in terms of temperature in the recorded meteorological history of Bangladesh, having average annual temperature 26.35 and 26.23 °C respectively.

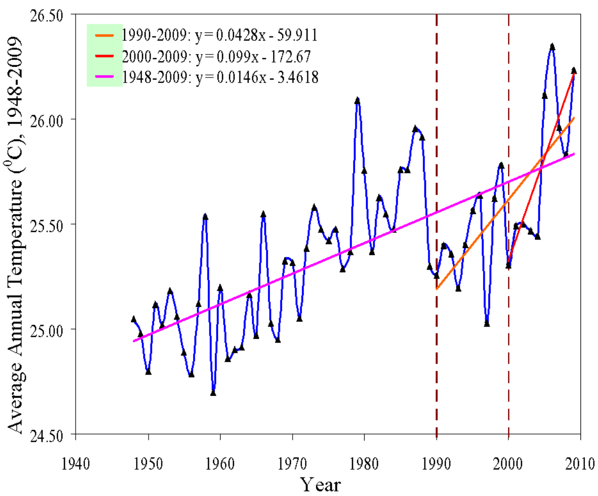

Fig. 1. Observed average annual temperature trends in Bangladesh in three segments: (1948-2009), (1990-2009) and (2000-2009).

3 Applying Climate Models on Bangladesh

3.1 Selection of GCMs and RCM

Climate models are the main tools available for developing projections of climate change in the future [5]. There are a number of mathematical models of global circulation that indicate expectations of future climate scenarios. Four different IPCC (Inter-Governmental Panel on Climate Change) ensemble Global Climate Models are selected herein for developing future temperature scenarios of Bangladesh. They are CGCM3.1-T63 (Canada- T63 (2.81° X 2.81°) L31), CCSM3 (USA-T85 (1.9° X 1.9°) L31), MIROC3.2-hires (Japan-T106 (1.1° X 1.1°) L56) and HadGEM1 (UK- 1.3° X 1.9°, L38). The details in the parentheses show the origin of the modeling center and the designated atmospheric resolution under which the models run. Details of the four GCMs selected herein are listed in [6]. The predictions of coupled AOGCMs might be adequate for areas where the terrain is reasonably flat, uniform, and away from coasts. However, in areas where coasts and mountains have significant effects on weather, scenarios based on global models are unable to capture the local level details needed for assessing impacts at national and regional scales. Also, at such coarse resolutions, extreme events such as cyclones or heavy rainfall episodes are either not captured or their intensities are unrealistically [12]. A regional climate model (RCM), therefore, is the best tool for dynamic downscaling of climate features in case of obtaining detailed information for a particular region [8]. A regional model, also known as limited-area model generally covers a limited area of the globe at a higher resolution (typically around 50 km) for which conditions at its boundary are specified from an AOGCM [4], [8]. The RCM is better able to resolve mesoscale forcings associated with coastlines, mountains, lakes, and vegetation characteristics that exert a strong influence on the local climate [12]. The RCM that has been applied in this paper in conjunction with GCMs is called PRECIS (Providing Regional Climates for Impacts Studies), which is a hydrostatic, primitive equation grid point model containing 19 levels described by a hybrid vertical coordinate [13], [14]. The present version of PRECIS (PRECIS 1.7.1) has a resolution of 50 km horizontal grid with the option of downscaling to 25 km horizontal grid having 0.44 X 0.44 degree resolution (latitude X longitude) and it can generate outputs for more than 150 parameters [12]. The PRECIS RCM is based on the atmospheric component of HadCM3Q [8], [15] with substantial modifications to the model physics.

3.2 Development of 'Change Field'

To examine possible future climatic conditions, one prospect is to develop projections from observed meteorological data [10]. In this paper, the past three decade period in Bangladesh (1971-2000) has been used as a climatological baseline period from which the model output data are referenced. Once climate model outputs have been developed for use in an impact study, there are numerous procedures available for processing and applying the data (i.e. constructing the scenarios). There are often significant biases in the model control simulations [7], [8]. A scenario of future climate is obtained by adjusting the baseline observations by the difference (or ratio) between period-averaged results for the model experiment (usually 10 or 30 year periods are used) and the corresponding averages for the GCM control simulation for future. Differences are usually applied for temperature changes (e.g. 2041-2070 minus 1971-2000). Therefore, this approach of model-bias correction features the use of climate model data for both periods (recent and future) and then the difference or ratio between the two responses will represent the change with respect to the baseline data of particular climatic parameter [8]. A pattern of such differences or ratios of particular climate output variables are known as a *Change Field* [7]. With improvements in control simulations, which are now being realized with improved models and the use of higher resolution, this approach of model-bias correction and construction of 'change field' is becoming increasingly attractive. It is conceptually simpler and allows direct application of the changes in all climate change projections [8].

4 Future GCM Projections of Annual Temperature at Different Emission Scenarios

For the purpose of numerical assessment of future climate change in Bangladesh, all the four GCM projected 'Change Field' and 'Applied Change Field' of average annual values of temperature, with respect to the climatological baseline of 1971-2000, are assembled in Table 2 for the three 30 year future time periods (2011 - 2040, 2041 - 2070 and 2071 – 2100) and in different emission scenarios.

To provide guidance as to future meteorological conditions, the IPCC developed a number of long-term scenarios of global warming gases. The result was a set of worldwide emission scenarios published in 2000 in a Special Report on Emissions Scenarios (SRES), depending upon how society develops. The SRES scenarios have been subdivided into a set of greenhouse gas and aerosol emissions, predicted for the 21st century as follows:. A1: A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. A1F1 – fossil intensive, A1T – predominantly non-fossil, A1B – balanced across energy sources; A2: A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines; B1: A convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reduction in materials intensity, and the introduction of clean and resource-efficient technologies; and B2: A world in which the emphasis is on local solutions to economic; social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development [7]. The COMMIT scenario reflects the scenario wherein the emission commitments made by the developing countries are actually obtained.

In Fig. 2, best-fit linear regressions of the observed annual temperature (T) and Precipitation (P) in past recent years in Bangladesh are plotted, along with average annual projections by the four GCMs, specifically using SRES A1B. Also, to validate the effect of different possible scenario assumptions on the future climatic conditions of Bangladesh, projections of one particular GCM, that is, CGCM3.1, are developed and plotted in Fig. 3 under four scenarios - A1B, A2, B1 and COMMIT. The trends of the GCM-projected climate conditions are assessed by applying a 2nd order polynomial regression curve to each dataset using Microsoft Excel.

Apparent from Fig. 2 is that there are similar slopes, indicated by the projections from historical data, to the predictions from all four GCMs in a particular scenario A1B. Also apparent from Fig. 2 is minimal divergence between temperature projections derived from alternative GCMs for Bangladesh (until 2070). The temperature projections of HadGEM1 and MIROC3.2 indicate higher temperature rates than those of the CGCM3.1 and CCSM3 models and for the period of 2071 - 2100, these GCMs reach mean annual temperatures of 29.3°C and 29.0°C, respectively. For the same period, the CGCM3.1 and CCSM3 models project mean annual temperatures to reach 28.5 and 28.4 °C, respectively. For all GCMs, the mean temperature increase projected for the period 2071 - 2100 was 2.95 °C above the reference period (1971 - 2000) mean of 25.7 oC. Table 4.3 displays for Bangladesh, the projected changes of T, P and E for each model and scenario. In Fig. 3, the temperature projections of the SRES A2 scenario shows increases at the highest rate of the SRES scenarios considered, reaching a mean annual temperature of 29.3 °C for the period of 2071 - 2100, as indicated in Table 4.3. For the same period, the A1B scenario projects the mean annual temperature to reach 28.5 °C and the B1 scenario 27.7 °C. For the GCMs evaluated, the average of A2, A1B, and B1 mean annual temperature increase for the period 2071 – 2100 were 3.63 °C, 3.11 °C and 2.06 °C, respectively, above the observed period mean of 25.7 °C. With greenhouse gas emissions fixed at year 2000 conditions, the COMMIT scenario projects the mean annual temperature to be 26.25 °C for the period of 2071 - 2100, a 0.15 °C reduction from the 2041 - 2070 mean. Noteworthy that, all the GCM projections being developed herein are for Dhaka which is basically the centre of Bangladesh and therefore, representative of the overall average temperature conditions in consideration of the very small geographical area of the country.

According to the Multi-Model Data set (MMD) of IPCC AR4 [11], annual temperatures are expected to increase in the range of 3.3°C across south Asia along with Bangladesh. These projections are, according to the MMD-A1B simulations, averaged over 21 models and represent the change between 1980 – 1999 and 2080 – 2099. The GCM data assembled for this research reflects almost similar, results with A1B simulations projecting annual increases approximately 3.1°C (average of four GCMs) in Bangladesh for the period 2071 – 2100.

5 Monthly Temperature Projections Using GCMs and RCM

Table 3 below shows the monthly projections of temperature, in terms of the average of three future decades, both from the four GCMs and one RCM, giving way to 'Multi-Model Average'. It is observed that the temperature in Bangladesh will continue to increase in all the months with winter months showing relatively more warming in future. However, such combination of monthly temperature projections are derived considering only A1B emission scenario.

6 Conclusions

There is evidence of increasing temperature levels in Bangladesh from the Global and Regional Climate Model predictions, as evident from historical meteorological records. The long term historical trend in temperature matches fairly well the temperature trends predicted by the climate models for a scenario of emissions arising from a future world of rapid economic growth, balanced across energy sources. However, GCM projections show that the temperature increase in Bangladesh is supposed to be highly sensitive to the extent of emissions to the atmosphere. Also, temperature rise in individual months can be observed from the multi-model average projections.

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Table 2. GCM multi-scenario annual temperature projection summary for Bangladesh

			Scenario: A1B			
		Observed	**CGCM3.1**	**CCSM3**	**HADGEM1**	**MIROC3.2**
Mean Annual Temperature, Change Fields (°C)	2011 - 2040		1.09	0.98	0.72	0.52
	2041 - 2070		1.95	2.10	2.38	2.16
	2071 - 2100		2.78	2.72	3.58	3.34
Mean Annual Temperature, Applied Change Fields (°C)	1971 - 2000	25.7				
	2011 - 2040		26.8	26.4	26.4	26.2
	2041 - 2070		27.6	27.8	28.0	27.8
	2071 - 2100		28.5	28.4	29.3	29.0
			Scenario: A2			
		Observed	**CGCM3.1**	**CCSM3**	**HADGEM1**	**MIROC3.2**
Mean Annual Temperature, Change Fields (°C)	2011 - 2040		1.14	0.93	0.52	-
	2041 - 2070		2.07	1.88	1.78	-
	2071 - 2100		3.65	3.33	3.92	-
Mean Annual Temperature, Applied Change Fields (°C)	1971 - 2000	25.7				
	2011 - 2040		26.8	26.6	26.2	-
	2041 - 2070		27.7	27.5	27.5	-
	2071 - 2100		29.3	29.0	29.6	-
			Scenario: B1			
		Observed	**CGCM3.1**	**CCSM3**	**HADGEM1**	**MIROC3.2**
Mean Annual Temperature, Change Fields (°C)	2011 - 2040		1.00	0.88	1.04	-
	2041 - 2070		1.44	1.31	2.02	-
	2071 - 2100		1.98	1.59	2.61	-
Mean Annual Temperature, Applied Change Fields (°C)	1971 - 2000	25.7				
	2011 - 2040		26.7	26.5	26.7	-
	2041 - 2070		27.1	27.0	27.7	-
	2071 - 2100		27.7	27.3	28.3	-
			Scenario: COMMIT			
		Observed	**CGCM3.1**	**CCSM3**	**HADGEM1**	**MIROC3.2**
Mean Annual Temperature, Change Fields (°C)	2011 - 2040		0.52	-	-	-
	2041 - 2070		0.73	-	-	-
	2071 - 2100		0.58	-	-	-
Mean Annual Temperature, Applied Change Fields (°C)	1971 - 2000	25.7				
	2011 - 2040		26.2	-	-	-
	2041 - 2070		26.4	-	-	-
	2071 - 2100		26.2	-	-	-

Table 3. Multi-model temperature increase (^{0}C) for Bangladesh with respect to 1971-2000

Month	Observed	Multi-Model Average (4 GCM and 1 RCM) Temperature Change (^{0}C) at A1B scenario		
	1971-2000	2011-2040	2041-2070	2071-2100
January	18.62	1.16	2.65	3.90
February	21.32	1.24	3.02	4.11
March	25.58	1.03	2.43	3.54
April	28.04	0.80	2.01	2.89
May	28.56	0.69	1.76	2.84
June	28.50	0.76	1.76	2.95
July	28.10	0.77	1.76	2.72
August	28.25	0.78	1.87	2.78
September	28.14	0.85	1.97	2.84
October	27.23	0.87	2.37	3.36
November	23.95	0.96	2.72	3.85
December	19.78	1.03	2.58	3.64

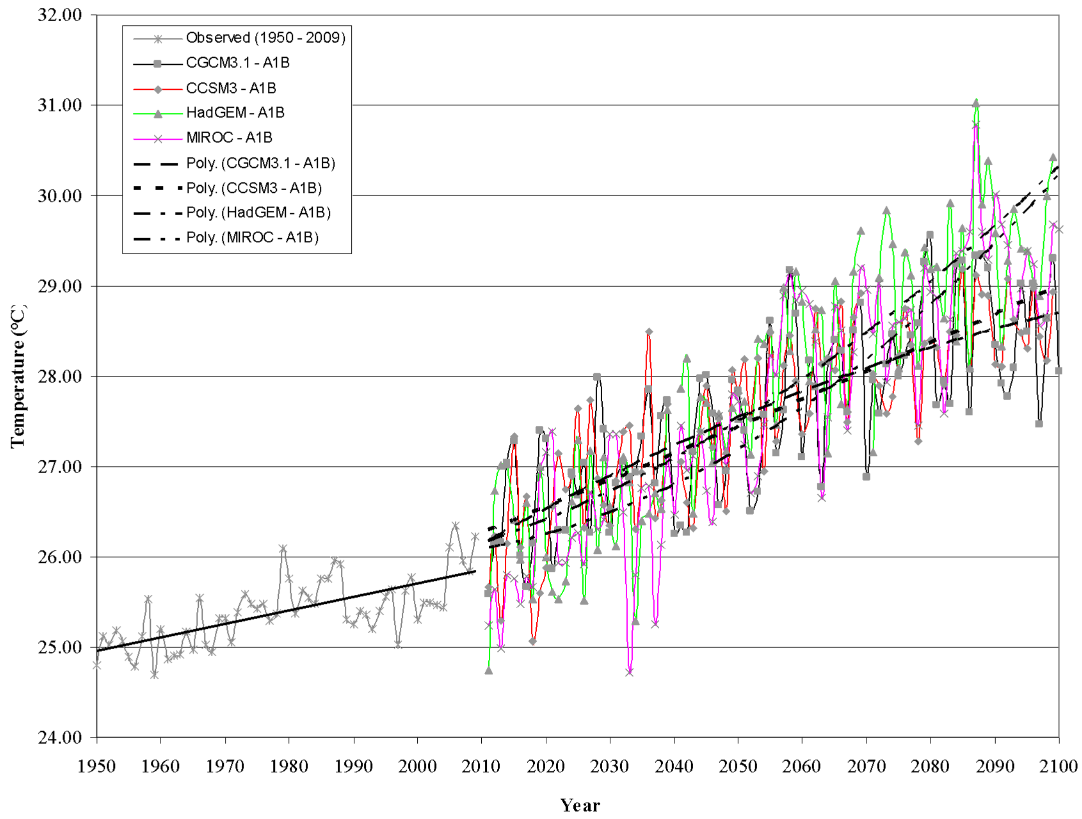

Fig. 2. GCM comparision of average annual temperature projections for Bangladesh at A1B scenario (2011-2100)

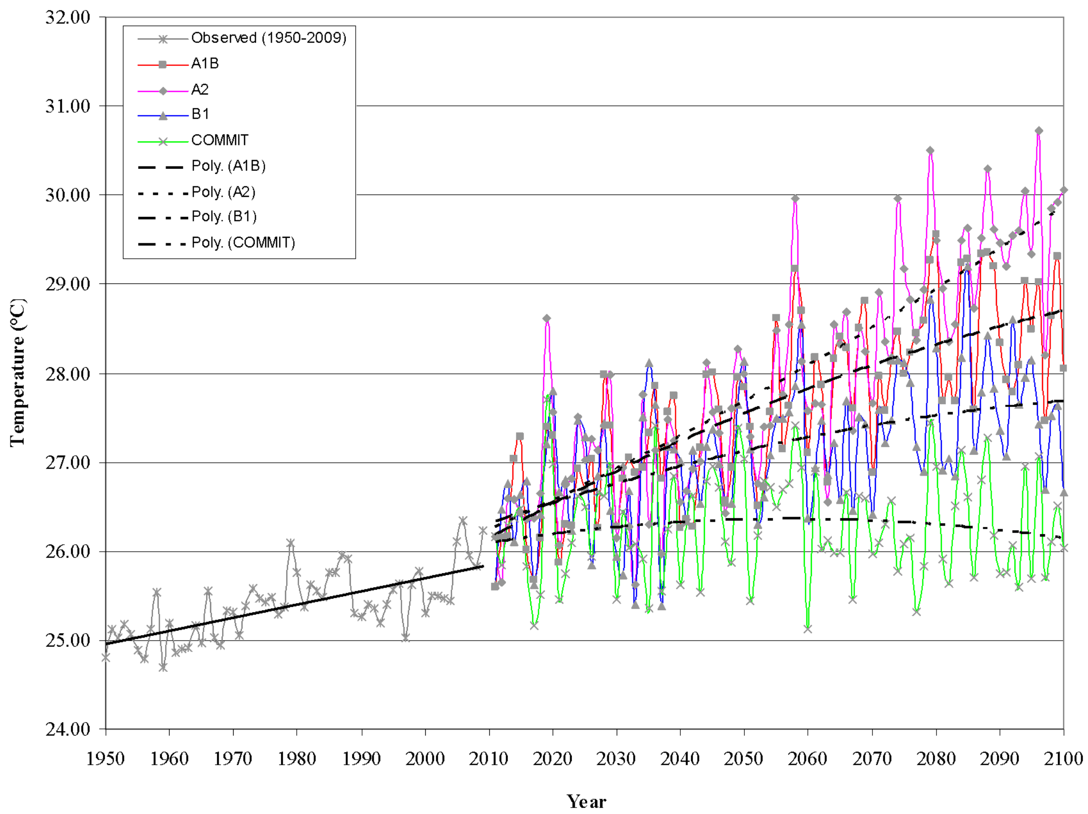

Fig. 3. Comparision of average annual temperature projections at different scenarios by CGCM3.1 model (2011-2100)