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Rainfall and temperature scenario for Bangladesh using 20 km mesh AGCM

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Abstract

Purpose – The purpose of this paper is to demonstrate the use of the Meteorological Research Institute (MRI) global 20-km mesh Atmospheric General Circulation Model (AGCM), called MRI-AGCM, to simulate rainfall and mean surface air temperature. Through calibration and validation the MRI-AGCM was adapted for Bangladesh for generating rainfall and temperature scenarios.

Design/methodology/approach – The model generated rainfall was calibrated with ground-based observed data in Bangladesh during the period of 1979-2006. The Climate Research Unit (CRU) data are also used for understanding of the model performance. Better performance of MRI-AGCM obtained through validation process increased confidence in utilizing it in the future rainfall projection for Bangladesh.

Findings – Rainfall and mean surface air temperature projection for Bangladesh is experimentally obtained for the period of 2075-2099. This work finds that the MRI-AGCM simulated rainfall and temperature are not directly useful in application purpose. However, after validation and calibration, acceptable performance is obtained in estimating annual rainfall and mean surface air temperature in Bangladesh.

Originality/value – Change of rainfall is projected about 0.64 percent in monsoon season (JJAS), 1.90 percent in post-monsoon season (ON) and 13.46 percent in Winter season (DJF) during the period of 2075-2099. Similarly, change of mean surface air temperature is projected about 2.5 degrees Celsius for the same period.

Keywords Bangladesh, Rainfall, Temperature, Monsoon, Climate change, Simulation

Paper type Research paper

1. Introductions

Global warming is an important issue, with a variety of influences on agriculture, water, health and economy. It is now recognized that climate variability and extreme events affect society more than changes in the mean climate (Intergovernmental Panel on Climate Change (IPCC), 2001). Human induced changes in the global climate and associated sea-level rise are widely accepted by policy makers and scientists. The IPCC concluded

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that the balance of evidence suggests a discernible human influence on global climate (IPCC-AR4, 2007). The exact magnitude of the changes in the global climate is still uncertain and subject to worldwide scientific studies. It is broadly recognized that Bangladesh is more vulnerable to these changes. Indeed, it has internationally been argued that Bangladesh, as a country, may suffer the most severe impacts of climate change. Bangladesh is highly vulnerable because it is a low-lying country located in the deltaic plain of the Ganges, the Brahmaputra and the Meghna and densely populated. Its national economy strongly depends on agriculture and natural resources that are sensitive to climate change and sea-level rise. The impact of higher temperature and more extreme weather events such as floods, cyclone, severe drought and sea-level rise are already being felt in South Asia and will continue to intensify (Huq *et al.*, 1999; Ali, 1999). In this connection proper planning and sensible management of water resources are essential for this region. Long-term planning is not possible without any idea of the change of climate that may happen in future. Climate models are the main tools available for developing projections of climate change in the future (Houghton *et al.*, 2001). A little work is done on climate change scenarios for Bangladesh using regional climate model (Islam, 2009). Despite continuous model development, atmospheric general circulation models (AGCMs) still have systematic biases in simulating the East Asian summer monsoon such as an underestimate of precipitation amount over the Western Pacific (Kang *et al.*, 2002) and inappropriate temporal characteristics between precipitation and underlying sea surface temperature (SST) (Wang and Ho, 2002). Recently, a very high resolution AGCM with the horizontal grid size of about 20 km has been developed by the Meteorological Research Institute (MRI)/Japan Meteorological Agency (JMA) use in climate change studies (Mizuta *et al.*, 2006) and which has also been used for climate change projection under increases in atmospheric concentrations of greenhouse gases and aerosols (Kusunoki *et al.*, 2006; Oouchi *et al.*, 2006). The grid size of this model is several times smaller than that previously used in climate model simulations. The global 20 km model is a unique one in terms of the horizontal resolution as well as its application to long-term integration for global change studies. Owing to the very high horizontal resolution, the model has more realistic representation of land-sea distribution and topography with elevated orography than other GCMs have ever had, so it is expected to have an ability to simulate rainfall and temperature more adequately over this region. This opportunity is employed for the first time in climate change scenario development for Bangladesh.

In this paper, rainfall and temperature climatology in Bangladesh derived from 20 km mesh MRI-AGCM was calibrated with reference to the observed data during the period of 1979-2006. Then, projections for rainfall and temperature are made for 2075-2099 in Bangladesh.

2. Model, experimental design and methodology

2.1 Model description

The AGCM used in the present study is a global hydrostatic AGCM developed by the MRI and JMA as a part of next generation climate model for long-term climate simulation. The simulations were performed at a triangular truncation 959 with linear Gaussian grid (T_L 959) in the horizontal in which the transform grid uses $1,920 \times 960$ grid cells, corresponding to a grid size of about 20 km. The model has 60 layers in the vertical with the model top at 0.1 hPa. For the cumulus parameterization, the Arakawa-Schubert scheme with prognostic closure is used (Randall and Pan, 1993).

2.2 Experimental design

High horizontal resolution AGCM experiments are conducted using the time-slice method (Bengtsson *et al.*, 1996; IPCC, 2001), which is a two-tier global warming projection using an atmosphere-ocean general circulation model (AOGCM) and an AGCM with horizontal resolution higher than that of the atmospheric part of the AOGCM. For present-day climate simulation, observed historical SST by HadISST1 (Rayner *et al.*, 2003) are prescribed for the model from 1979 to 2006 (29 years). For the near future climate simulation from 2015 to 2039 (25 years) and the end of twenty-first century climate simulation from 2075 to 2099 (25 years), changes in the multi-model ensemble (MME) of SSTs projected by AOGCMs of Coupled Model Intercomparison Project 3 are superposed to the detrended observed historical SST. Changes in MME of SSTs are evaluated by the difference between the twentieth century simulations and future simulation of IPCC A1B emission scenario. Linear trend for future climate by AOGCMs are taken into account. These settings are applied to each grid point and to each month. Details are found in Mizuta *et al.* (2006).

The IPCC (2000), Special Report on Emission Scenarios and A1B emission scenario was assumed for future climate simulations. The A1B scenario is an intermediate emission scenario characterized by a future world of very rapid economic growth, global population that peaks in the middle of the twenty-first century and declines thereafter, and by a balanced introduction of new and more efficient technologies of all energy supply (IPCC, 2000, 2001). From around 2080 to 2099, with the concentration of CO_2 nearly doubled relative to that at the end of twentieth century, the global mean surface air temperature increases by about 2.2°C.

2.3 Methodology

Observational data of Bangladesh Meteorological Department (BMD) has been utilized for validation of MRI-AGCM generated rainfall and temperature. The BMD observation network density is low, in some cases observation sites are located about 25 km apart, whereas these are about 145 km apart in some others areas (Figure 1). A number of grids are found which do not contain any observation site when the whole Bangladesh is gridded at 20 km by 20 km in the model resolution. Since, it is important to find out the appropriate calibration method for the application of MRI-AGCM for climate change impact studies in Bangladesh, analyses have been performed on point-to-point basis. In this procedure, observed data at a particular site are considered as being the representative for that location (Islam and Uyeda, 2007). Grid value of the model data is compared with the observed data representing that grid. If more than one observation site exist within a grid, the average value of all the observational sites is considered as representative value for that grid. Daily rain-gauge rainfall and temperature data collected by BMD are processed to obtain monthly, seasonal and annual values. The model simulated data of rainfall and temperature are extracted through GRADS for 28 sites of BMD (point value) and then are converted into monthly, seasonal and annual values which are then averaged to obtain country average. The regression equation, slopes and constants are assigned from model and observed rainfall for the base line period. Estimated rainfall is obtained from model generated scenarios with the help of slopes and constants. This estimated rainfall is useful for validation of MRI-AGCM in Bangladesh. Similarly, calibration and validation is completed for mean temperature in Bangladesh.

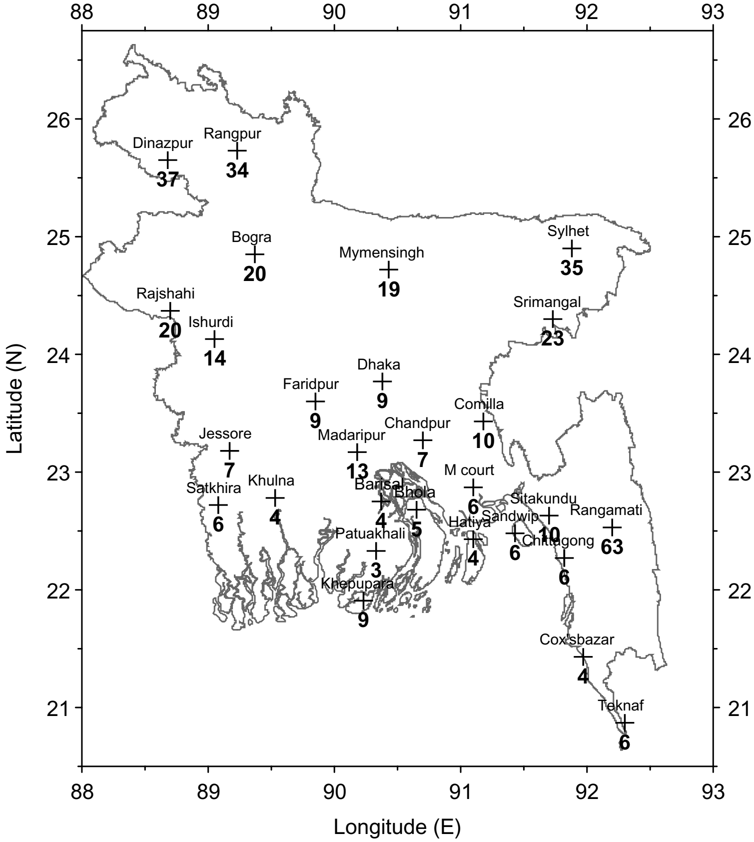


Figure 1.
Plus marks represent BMD rain-gauge station and below plus marks elevation in meters

3. Results and discussion

3.1 Simulation of rainfall in Bangladesh

Figure 2 shows observed annual rainfall (mm/d) averaged from 1979 to 2006. High resolution (20 km) MRI-AGCM generated present climate during the period of 1979-2006 over Bangladesh is shown in Figure 3. It is clear that heavy rainfall belt observed along northeastern part of Bangladesh which is located in the slope of Shillong Hill of India while less rainfall is observed along Western part of Bangladesh. Heavy rainfall is also observed in the northeastern part of the Bay of Bengal. These features are very common and seem to be quite reasonable with rainfall climatology over Bangladesh.

3.2 Monthly rainfall simulation over Bangladesh

Surface area average rainfall data collected by BMD have been used for the comparison with model simulated rainfall. Rainfall obtained from observation and model simulation is shown in Figure 4. The model overestimated rainfall for the dry month from December to April. During the month of May-September rainfall is underestimated by the model. This result is consistent with the Tropical Rainfall

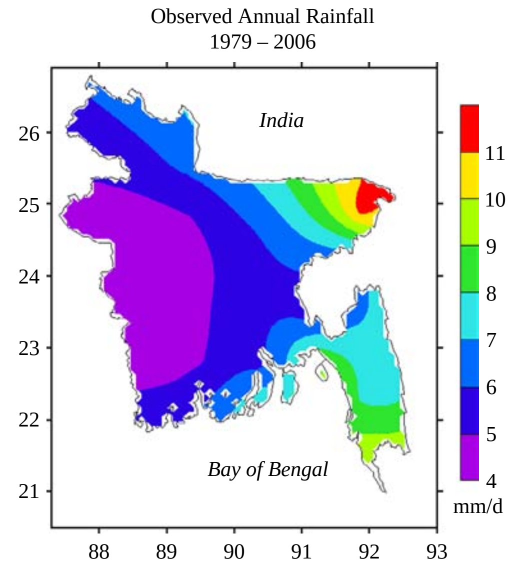


Figure 2.
Observed annual rainfall (mm/d) averaged from 1979 to 2006

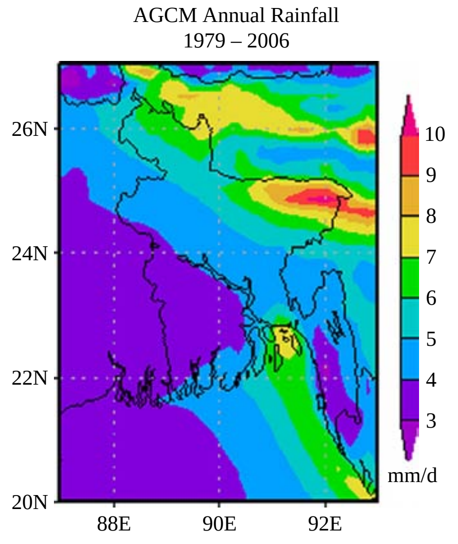


Figure 3.
MRI-AGCM generated annual rainfall (mm/d) averaged from 1979 to 2006

Measuring Mission reported by Islam and Uyeda (2005). In the post-monsoon months of October and November, the model also underestimated than observed rainfall. In fact, the characteristics of precipitation systems, especially the vertical height and precipitation strength in this region are different in different rainy periods.

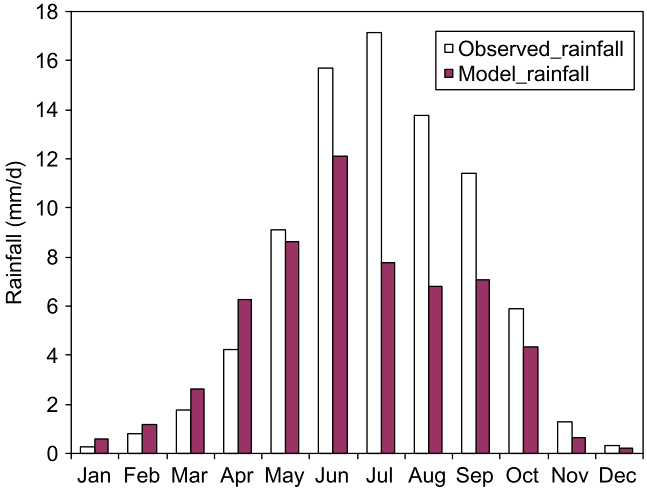


Figure 4.
Comparison of monthly average rainfall obtained from observation and model simulation during the period of 1979-2006

3.3 Seasonal rainfall simulation over Bangladesh

The high resolution MRI-AGCM simulations rainfall has been studied to evaluate the model skills in representing the climatological features, especially summer monsoon characteristics. The monsoon rainfall for the baseline (1961-2006) simulated by MRI-AGCM is 1,026 mm with standard deviation of 72 mm while the pre-monsoon, post-monsoon and winter rainfall simulated by the model is 538, 154 and 58 mm with standard deviation of 94, 72 and 14 mm, respectively (Table I). Bangladesh summer monsoon rainfall based on 28 stations averaged during the period of 1979-2006 has been reported to be 1,771 mm with standard deviation of 80 mm (Table I). This indicates that the model underestimated monsoon rainfall over Bangladesh.

	MAM	JJAS	ON	DJF	Annual
Rainfall (mm) un-calibrated					
Observed	464	1,771	222	41	2,498
Baseline	538	1,026	154	58	1,775
A1B (scenario)	471	1,126	141	59	1,797
Standard deviations					
Observed	116.4	79.7	101.9	7.8	194.8
Baseline	93.6	72.2	80.7	13.8	116.7
A1B (scenario)	67.7	92.8	75.4	7.6	124.8
Rainfall (mm) calibrated					
Observed	464	1,771	222	41	2,498
Baseline	467	1,728	211	52	2,457
A1B (scenario)	466	1,739	215	59	2,479
Standard deviations					
Observed	116.4	79.7	101.9	7.8	194.8
Baseline	111.5	84.8	90.7	13.8	189.6
A1B (scenario)	111.9	85.7	92.5	7.6	190.5

Table I.
Characteristics of observed and model simulated (un-calibrated and calibrated A1B scenario) seasonal and annual rainfall (mm) in Bangladesh

3.4 Calibration process of rainfall over Bangladesh

MRI-AGCM simulated rainfall may have systematic errors and thus needs to be calibrated with the observed data; otherwise model performance may not be well understood. In this paper, 28 stations averaged rainfall (rain-gauge) data of Bangladesh are used for calibration. Model simulated rainfall is compared with rain-gauge rainfall on seasonal and annual scales (Figure 5). Model has reproduced rainfall reasonably well in pre-monsoon, post-monsoon and dry period (winter), but underestimated in monsoon season. On an average the model calculate 27 percent less rainfall in annual scale. To find out the estimated rainfall the following regression equation is used:

$$RF_{\text{estimated}} = \text{constant} + \text{slope} \times RF_{\text{scenario}} \quad (1)$$

where $RF_{\text{estimated}}$ is the rainfall that will be projected for future and RF_{scenario} is the AGCM simulated rainfall scenario. The regression coefficients are obtained with the help of both model and observed rainfall for different months and at different observational sites. The slopes and constant values varied from month to month and from place to place.

3.5 Validation of rainfall over Bangladesh

Monsoon rainfall is very much important for agriculture and water management purposes in Bangladesh. The model simulated rainfall over the SAARC region are compared with the Climate Research Unit (CRU) rainfall as shown in Figures 6 and 7. MRI-AGCM rainfall averaged from June to September (JJAS) during the period of 1979-2006 and CRU rainfall averaged from June to September during the period of 1979-2002 are shown in Figures 6 and 7. Monsoon rainfall simulated by AGCM is much more consistent with CRU observed rainfall as it is seen in Figures 6 and 7. It is indicated that northeastern part of Bangladesh received much more rainfall as observed by CRU, which is well simulated by the model. The model also simulated rainfall patterns in southeastern and Western part of Bangladesh and Western Ghat of India very well; even the lack of rainfall along the Western parts of Pakistan are also well captured by

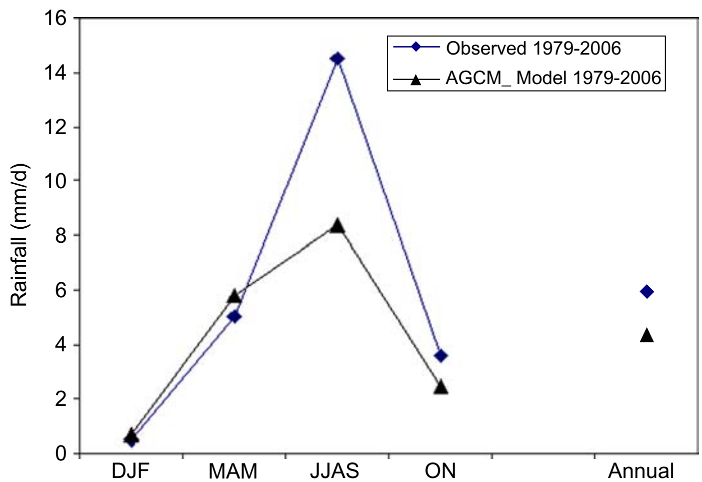


Figure 5.
Seasonal and annual distribution of rainfall as obtained from AGCM model and observed data

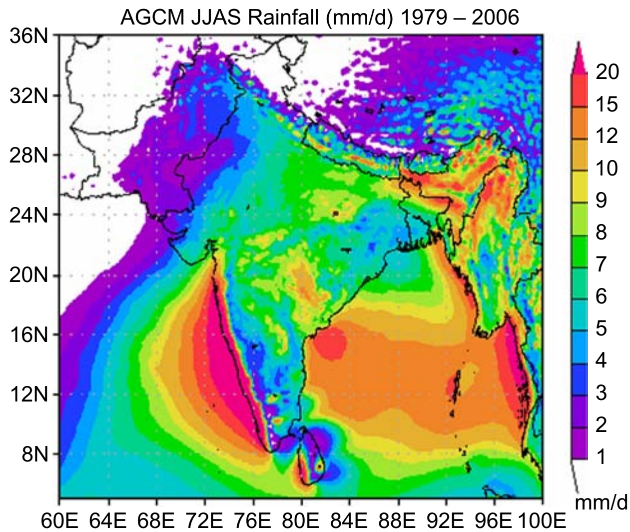


Figure 6.
The monsoon rainfall (JJAS) obtained from MRI-AGCM from 1979 to 2006

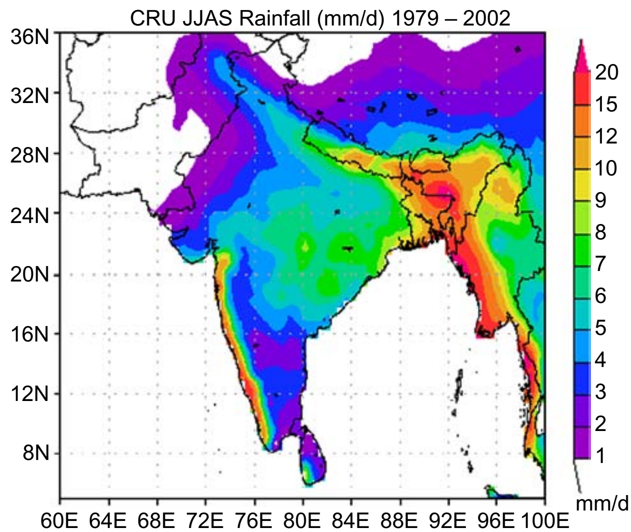


Figure 7.
The monsoon rainfall (JJAS) obtained from CRU data from 1979 to 2002

the model. It is also indicated that AGCM can simulate the seasonal rainfall with a better spatial distribution. Model validation is performed against rain-gauge rainfall. AGCM outputs are calibrated with observed rainfall for Bangladesh with the help of regression slopes and constants. For an example, model simulated scenario (without calibration), estimated (with calibration), observed and normal rainfall (during the period of 1979-2006) are shown in Table I. Without calibration, model generated scenario directly does not match with the observed rainfall whereas use of regression coefficients improved estimated value and made it to be very close to observed rainfall, showing good agreement with the historical pattern. It is indicated that AGCM model captured rainfall on annual scale quite well.

3.6 Calibration of rainfall over Bangladesh

MRI-AGCM model simulated outputs need to be calibrated and validated with ground-based observed data in Bangladesh. When regression constants and slopes are utilized with model outputs, the validated rainfall is closer to observed value. In this connection, regression coefficients of equation (1) are calculated at each station for different months and at different observational sites in Bangladesh. It is found that after calibration, model estimated rainfall is reasonably consistent with observed data on an annual scale as shown in Table I. This is encouraged the use of model results for forecasting annual rainfall in Bangladesh.

3.7 Projection of rainfall over Bangladesh

MRI-AGCM generated daily rainfall was extracted for each month at each observational site in Bangladesh. The model generated monthly rainfall at all stations in Bangladesh from January to December is shown in Figure 8. The average rainfall for all stations over Bangladesh is considered as a country average rainfall. The normal rainfall average from 1979 to 2006 are also incorporated to understand the surplus and deficit of rainfall in different months in Bangladesh. The model simulated rainfall (Table I) is inconsistent with the normal rainfall over Bangladesh. Model simulated rainfall is low with respect to normal rainfall.

After calibration the projected rainfall is very close to the normal rainfall (Table I). The question arises what is the necessity of calibration? The necessity of calibration is well understood through this research work and is also very essential for application purposes. The calibrated model output will definitely be helpful for planners and end-users for sustainable development in the country.

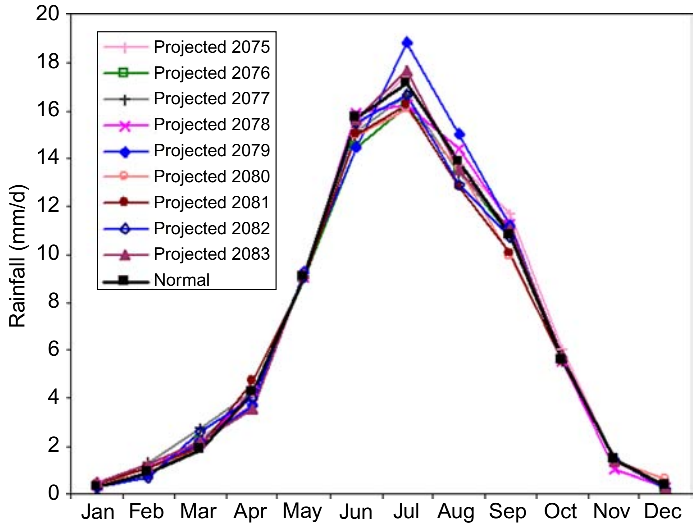


Figure 8.
Annual cycle of projected rainfall with normal over Bangladesh during the period of 2075-2083

3.8 Annual to seasonal projection of rainfall over Bangladesh

Annual projected rainfall over Bangladesh during the period of 2075-2083 is shown in Figure 8 with the normal rainfall averaged from 1979-2006. Projected rainfall follows historical trend with some variations in some months in different years. It appears that in most of the years, rainfall will deficit in April, June-August, November and December and surplus in February, March, September and October.

Monthly to seasonal and annual scale rainfall projections over Bangladesh are shown in Figures 9 and 10 for 2075 and 2083, respectively, for calibration purposes. The historical trend of normal rainfall is also plotted in order to understand the change of rainfall in the future. It is very obvious that the rainfall over Bangladesh in 2075 follows historical trend with deficit in April (0.4 mm/d or 10.65 percent) and surplus in September (0.9 mm/d or 8.31 percent). On seasonal scale, rainfall in 2075 will surplus in MAM (0.2 mm/d or 4 percent), JJAS (0.2 mm/d or 1.39 percent), ON (0.2 mm/d or 5.71 percent) and it will surplus about 0.10 mm/d or 1.47 percent in annual scale.

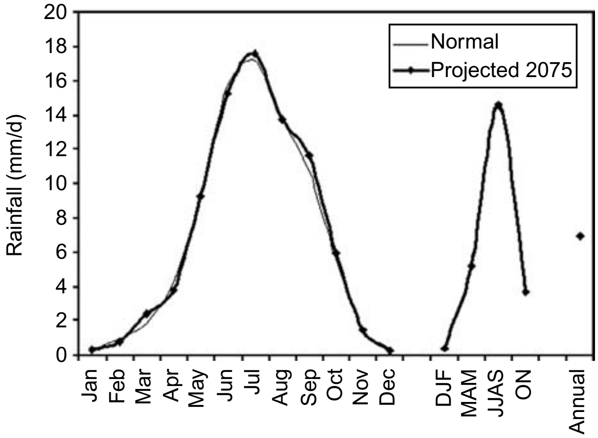


Figure 9.
Rainfall projection with normal over Bangladesh for the year 2075

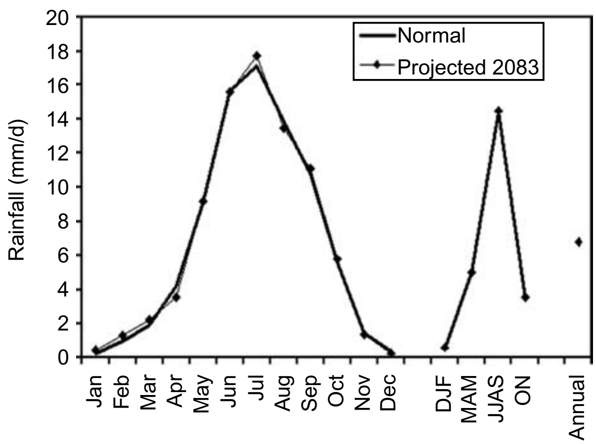


Figure 10.
Rainfall projection with normal over Bangladesh for the year 2083

Rainfall in 2083 also follows historical trend with surpluses of 20.00, 0.69, 2.86 percent during winter (dry period), monsoon and post-monsoon, respectively, while pre-monsoon rainfall remain, unchanged.

4. Simulation of mean surface air temperature over Bangladesh

4.1 Monthly and seasonal mean surface air temperature

Mean surface air temperature data collected by BMD have been compared with model simulated mean surface air temperature. MRI-AGCM simulated monthly mean surface air temperature is compared with the observed mean surface air temperature during the period of 1979-2006 as shown in Figure 11 in which temperature exhibits a systematic cold bias during the year of 1979-2006 while model mean surface air temperature is underestimated throughout the period. The mean surface air temperature in different seasons and at different regions over Bangladesh obtained by MRI-AGCM simulated mean surface air temperature is compared with the observed mean surface air temperature as shown in Table II in which MAM. JJAS, ON, DJF temperatures are underestimated by 0.9°C, 1.4°C, 1.9°C and 2.5°C, respectively, by the model. After calibration, it is seen that the model mean surface air temperature is almost similar with observed mean surface air temperature as shown in Table II.

4.2 Projection of mean surface air temperature over Bangladesh

Nowadays, temperature is an important parameter in understanding global warming. Generally, the change of rainfall and temperature are considered as the measure of climate change in tropical regions. The normal temperature (1979-2006) with projected temperature during the period of 2075-2099 in Bangladesh is shown in Figure 12.

Projected mean surface air temperature follows the historical trend with some variations. The mean surface air temperature is estimated to change by the amounts 1.4, 3.5, 3.5, 2.7, 2.7, 2.1, 2.7, 2.5, 2.5, 2.8, 1.9, 0.9°C for January, February, March, April, May, June, July, August, September, October, November, December, respectively. The historical trend of normal temperature is also plotted in order to understand the change of mean surface air temperature in future years. On an average the mean surface air temperature is estimated to be increased by 2.5°C during the period of 2075-2099.

Projected mean surface air temperature during the period of 2075-2099 over Bangladesh is shown in Figure 13. The dashed line indicates the historical normal.

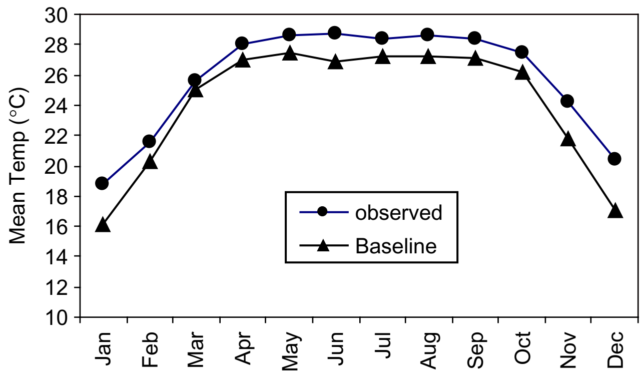
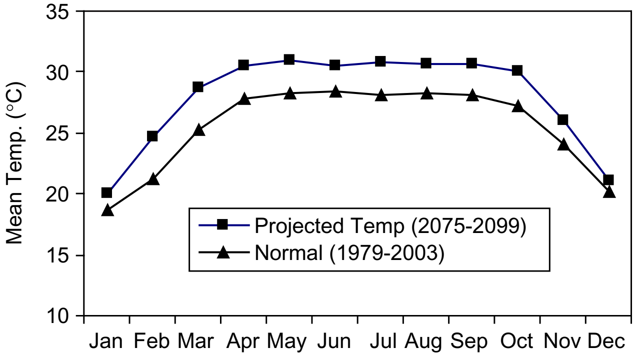


Figure 11. Comparison of MRI-AGCM simulated monthly mean temperature with observed mean temperature during the period 1979-2006

	MAM	JJAS	ON	DJF	Annual
Un-calibrated mean temp.					
Observed	27.4	28.5	25.9	20.3	25.5
Baseline	26.5	27.1	24.0	17.8	23.9
A1B (scenario)	28.7	29.3	26.6	20.5	26.3
Standard deviations					
Observed	1.6	0.2	2.3	1.4	3.6
Baseline	1.3	0.1	3.0	2.2	4.2
A1B (scenario)	1.2	0.1	2.9	2.5	4.0
Calibrated mean temp.					
Observed	27.4	28.5	25.9	20.3	25.5
Baseline	27.1	28.2	25.6	20.0	25.2
A1B (scenario)	30.1	30.7	28.0	21.9	27.7
Standard deviations					
Observed	1.6	0.2	2.3	1.4	3.6
Baseline	1.6	0.1	2.2	1.3	3.6
A1B (scenario)	1.2	0.1	2.9	2.5	4.0

Table II. Characteristics of observed and model simulated (un-calibrated and calibrated A1B scenario) seasonal and annual mean surface air temperature in Bangladesh



Note: The normal temperature is also plotted

Figure 12. Projected mean surface air temperature during the period of 2075-2099

Mean surface air temperature is estimated to be increased at the rate of about 0.0308°C per year during the above period over Bangladesh.

5. Conclusions

The study has brought out the following results:

- The change of rainfall was predicted for Bangladesh to be 0.64 percent in monsoon season (JJAS), 1.90 percent in post-monsoon (ON) and 13.46 percent in winter (DJF) during the period of 2075-2099. Similarly, the change of mean surface air temperature was predicted to be about 2.5°C for the same period.
- The model outputs are very risky for long-term prediction without calibration. However, after calibration with observed data, more acceptable results were obtained for estimated rainfall over Bangladesh with correlation coefficient 0.99.

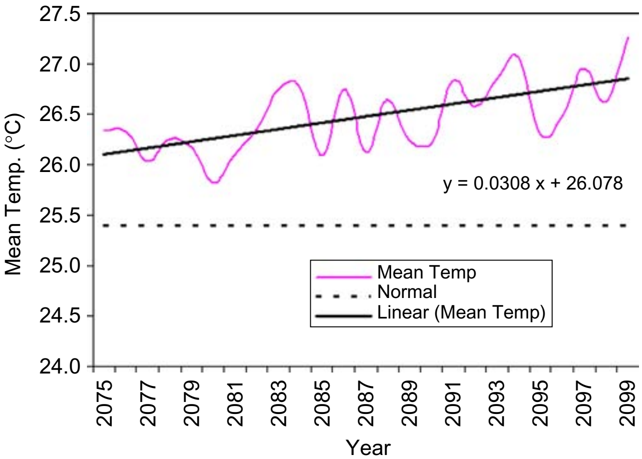


Figure 13.
Mean surface air temperature projected by MRI-AGCM over Bangladesh

These findings will be very much helpful for policy markers and planners of the country in mitigating any kind of disaster like food crisis and water scarcity in Bangladesh in future.

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