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Introducing Educational Global Climate Model (EdGCM) for improving education and research in climate change: Bangladesh perspective

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Abstract

Bangladesh is one of the most vulnerable countries to climate change and a basic knowledge of Earth's climate system is critical for making informed judgments in climate related issues. General Circulation Models are the primary climate research tool used today but only a few researchers of Bangladesh have access to them, which typically requires high-computing facilities and skilled programmers to run. This often breeds a distrust of important scientific findings and graduate geo-environmental sciences students, who are the primary users of such modeled outputs, end up academic life without having any practical knowledge about them. The current study aims at improving this scenario by introducing an academic purpose climate model called EdGCM (Educational Global Climate Model) that can be operated on existing desktop computers and laptops. A simulation has been programmed under IPCC A1Fl emission scenario which has been simulated on two different computers before it is analyzed by using two scientific visualization tool named EVA and Panoply. It has been found that, global scale, regional scale as well as time series analysis plots can be produced successfully by using EdGCM. Though the model has a very coarse resolution (8°×10°) to study local scale climatic variation, it is highly anticipated that with all these facilities packed in a single place to experience the details of climate model setup, model operation, post-processing, interpretation and scientific visualization, EdGCM will contribute significantly in improving climate research and education in Bangladesh.

Keywords: Climate Change, Climate Model, GCM, EdGCM, Bangladesh, modeling, climate research

Introduction

Bangladesh is a low-lying South-East Asian country which is globally known as one of the most vulnerable countries to climate change. A very high population density with poor institutional capability to deal with extreme climate events put Bangladesh on a highly vulnerable state. Moreover, high prevalence of poverty and biophysical resources, particularly water, which is highly sensitive to climate variability and change, makes it even worse (Ahmed, 2004). As these impacts have the potential to affect everyone, a basic knowledge of Earth's climate system is critical for making informed judgments about climate-related issues.

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To achieve that goal, educators and general people who are not necessarily climate specialists need accessibility to scientific and technological tools that are used to forecast climate change. General Circulation Models (GCMs) are the primary climate research tool used today by the technologically advanced countries. But it is a matter of great unfortunate for the educators and researchers of Bangladesh that the development of such promising tool is still at its initial stage due to our inaccessibility to supercomputers, electricity problem and absence of specialist climate modelers. This is one of the main reasons why most of the existing researches about climate change in Bangladesh are focused on mitigation measures and social science based adaptation practices (Rawlani & Sovacool, 2011; Rahman & Dutt, 2011; Shahid, 2011, Shahid, 2012; Saroar & Routray, 2012; Saha, 2012).

Recently Government of Bangladesh (GoB) has undertaken a giant project to initiate climate modeling in Bangladesh using PRECIS (Providing Regional Climates for Impact Studies), a regional climate modeling system that can be used anywhere in the world (BCCSAP: MoEF, 2009). This project primarily aimed at building in-country capacity to apply regional climate change models, interpret the outputs from those models and, therefore, providing policymakers with the data they need to plan for climate change. But still after all these efforts, the access to the model has not been made easy for the general educators and researchers who use this model based theoretical academic knowledge. As a result, these students and young researchers have to complete their academic life without having any kind of practical experience about how these models work or how to make a climate prediction.

The Educational Global Climate Model (EdGCM) addresses this problem by providing a research-grade GCM within a user-friendly interactive framework that can be operated on traditional desktop computers and laptops. It has been developed by NASA and Columbia University to give its users access to a real-time global climate model and provided them with the opportunity to experience the details of climate model setup, model operation, post-processing and scientific visualization. With this capability in place we can begin training the skilled workforce that is necessary to deal with the multitude of climate impacts that will occur over the coming decades (Chandler *et al*., 2011).

Climate Model

Climate Models are mathematical representation of the climate system based on physical, biological and chemical principles (Goosse *et al.*, 2010). According to National Snow and Ice Data Center, USA, climate models are the representation of the Earth's climate system based on the mathematical equations governing the behavior of the various components of the system and including treatment of key physical processes and interactions, cast in a form suitable for numerical approximation making use of computers.

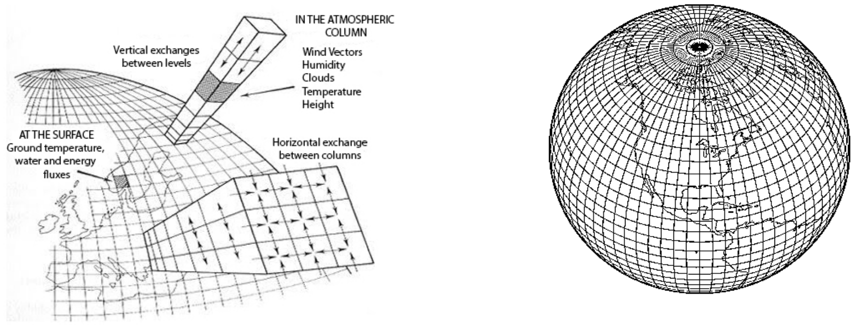


Figure 1: Division of the Earth into 3-dimentional boxes or Grids (After Henderson-Sellers, 1985)

In almost every climate models, scientists divide each of the Earth's components spatially into a set of boxes or blocks. Simple models may have only a few boxes. The most complex models may have more than a hundred thousand. The more the number of grids in a climate model, the more precise it is and it will be able to represent the actual scenario.

Models attempt to capture the very complex interactions between Earth's components. The movement of energy, air, and water are represented as horizontal and vertical exchanges between the boxes which are expressed as mathematical equations, averaged over time and grid volumes. These equations describe the evolution of many variables (e.g. temperature, wind speed, humidity and pressure) and together define the state of the atmosphere.

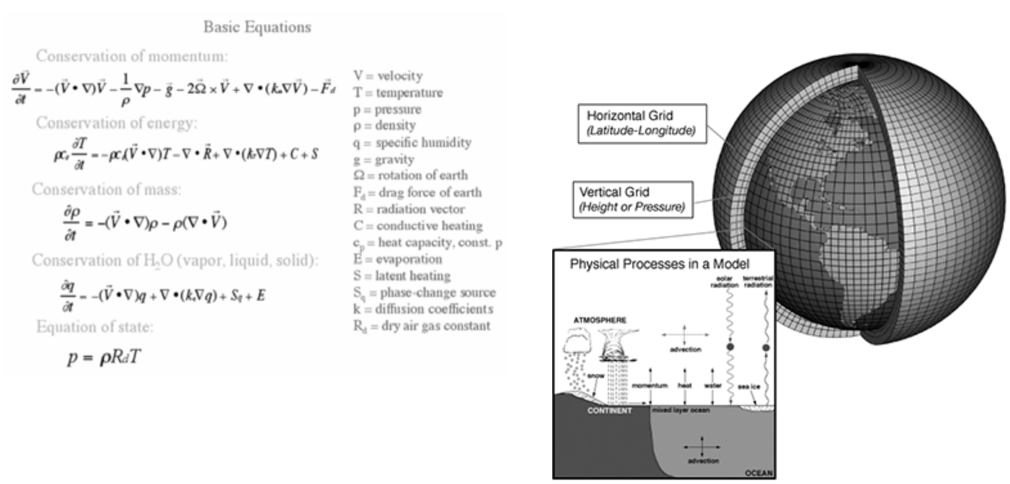


Figure 2: Physical Processes within different Grid boxes and Basic Equations that mathematically represent them

These equations are then converted to a programming language, defining among other things (e.g. cloud, dust, atmospheric gases etc.) their possible interacting with other formulations, so that they can be solved on a computer and integrated forward in discrete time steps. To let all these things happen, most of the traditional GCMs require supercomputing facilities to run the model and skilled programmers to perform the complete operation. As a result, there are only few lucky researchers and scientists who get the chance to work with these GCMs.

Educational Global Climate Model (EdGCM)

Educational Global Climate Model (EdGCM) provides a research-quality global climate model (GCM) that runs on a desktop computer, unlike GCM which runs on a supercomputer or workstation. The climate model used by the EdGCM software was developed at the Goddard Institute for Space Studies (GISS), NASA. This type of 3D computer model is known as a grid-point GCM. The EdGCM model has 7776 grid cells in the atmosphere, with each horizontal column corresponding to 8° latitude by 10° longitude, and containing nine vertical layers. The EdGCM software allows designing of the experiment, running simulations, post-processing and analyzing data using scientific visualization for data display. The coarser resolution of the climate model in EdGCM (8°×10°, latitude x longitude) makes it computationally inexpensive to run. So, EdGCM can be readily used in classrooms for interactive class projects and assignments. A graphical interface has been added to the program to make it suitable for less technical users, and to allow it to run on a PC or Mac operating system. However, the underlying code is the same.

Table 1: Technical specification of EdGCM

Code Name	EdGCM
Full Name	Educational Global Climate Model
Developer	Goddard Institute for Space Studies, NASA and Columbia University
Spatial Resolution	8°×10°
Layers	Vertical Atmospheric Layers = 9; Ground Layers = 2; Ocean Layers = 2
First Released	January 2005
Recent Version	3.2 (build 926)
Operating Platform	Microsoft windows and Apple MAC OS
System Requirements	Windows 2000 / XP / Vista /Windows 7 Any PC with an Intel or AMD processor running at 300 MHz or faster 1 GB of free disk space 512 MB RAM minimum recommended Internet connection is helpful but not required The 64-bit CPUs in machines allow the GCM to run faster than 32-bit

Methodology

Major objectives of the study was to evaluate the suitability of EdGCM climate model in improving climate education and research in Bangladesh. An extensive literature review has been performed from different peer-reviewed journals to understand the basic principles of climate models. A simulation has been programmed under IPCC A1Fl emission scenario for the time 1958 to 2100 which was later simulated on two different computers. The obtained results were scientifically visualized by using EVA (EdGCM Visualization Application) and Panoply for scientific analysis. Major steps involved in the present study are illustrated in figure 3.

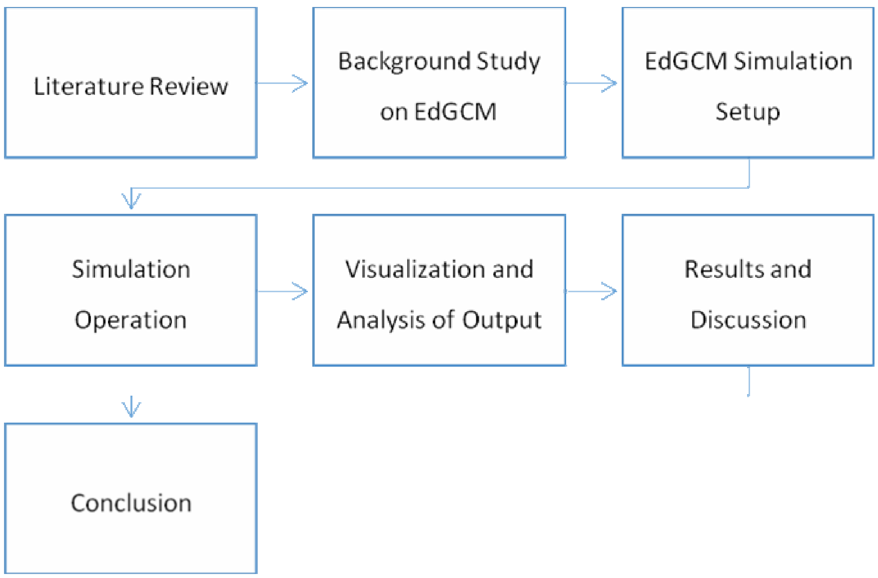


Figure 3: Conceptual framework of the present study

Results and Discussion

In the present study, two different computers have been used to operate EdGCM climate model simulation under IPCC A1Fl emission scenario separately. Once the simulation has been completed successfully, the model outputs were post-processed and analyzed using 'EVA' and 'Panoply' to study climatic parameters at global, regional as well as time series level in order to evaluate their effectiveness in improving climate educations and research in Bangladesh.

Simulation Performance

The EdGCM simulation has been configured considering the IPCC A1Fl emission scenario which was later simulated on two different computers having significant difference in configuration. The laptop computer shows relatively longer time to complete the simulation (Table 2) as the hardware configuration of the desktop is significantly better than the laptop.

Table 2: Simulation time of EdGCM model in two different computer

Parameter	Laptop	Desktop
Processor	Second Generation Intel core i3 2.2 GHz	Third Generation Intel core i7 3.2 GHz
System Memory (RAM)	2 GB	8 GB
Simulation Range	1958 - 2100	1958 - 2100
Time required to complete one year simulation	6 minutes	3 minutes
Total simulation time	About 13 hours	About 6.5 Hours

Global Scale Analysis

It has been found in the current study that EdGCM suite can be successfully used to produce global scale plots, maps and charts for studying climatic parameters like planetary albedo, surface air temperature and sea surface temperature at global scale.

1. Planetary Albedo

By studying planetary albedo using EdGCM climate model, it has been found that the upper and lower portion i.e., the Northern and Southern regions of the Earth are the major contributors of planetary albedo where polar ice caps act as a mirror and reflects back the incoming solar radiation figure 4 (left) . The variability of annual average planetary albedo with latitude is illustrated in figure 4 (right) that indicates that there is a steady increasing trend for planetary albedo with increasing latitude.

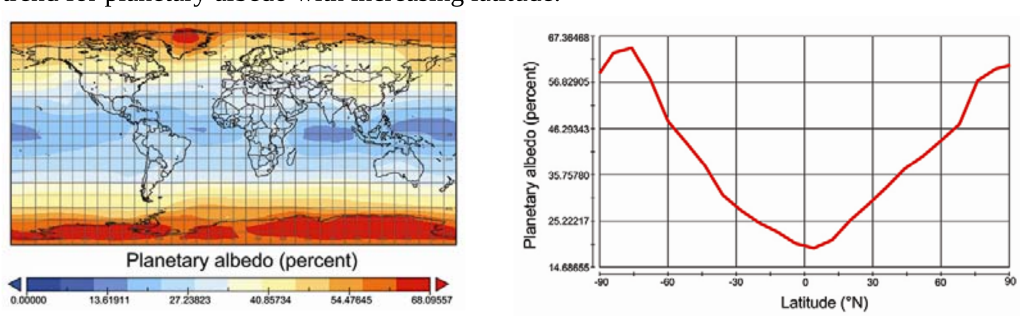


Figure 4: Global Scale distribution of planetary albedo (Left) and variability of albedo with latitude (right)

2. Surface Air Temperature (SAT)

The variation of global surface air temperature is represented visually in figure 5 (left). The attached colored bar represents the scale of the map. During 1958 to 2100, the predicted lowest and highest average annual surface air temperature are respectively -44.55°C and 28.56°C. The variability of surface air temperature with latitude is denoted in figure 5 (right) that shows that there is a steady decreasing trend for surface air temperature with increasing latitude.

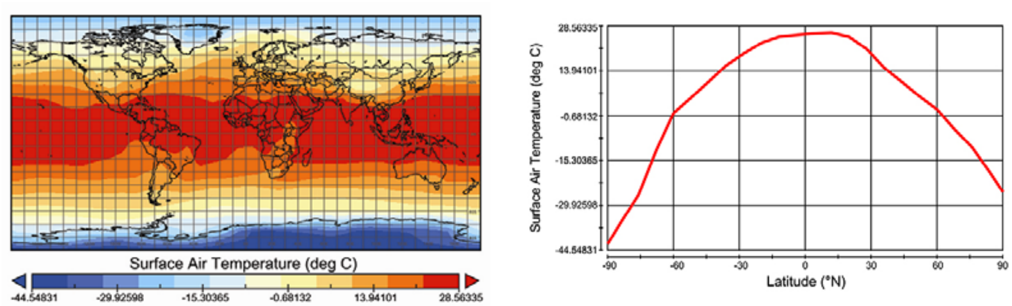
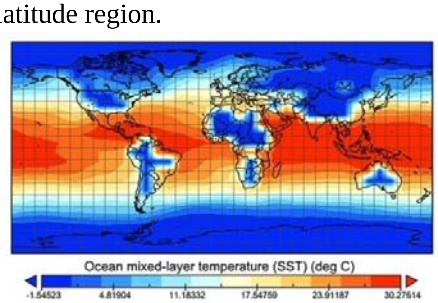


Figure 5: Global Scale distribution of Surface Air Temperature (SAT)

3. Sea Surface Temperature (SST)

Global annual average sea surface temperature distribution can be found in figure 6 (left). According to this map, lowest and highest values of sea surface temperature are -1.55°C and 30.28°C, respectively. The variability of sea surface temperature with latitude is illustrated in figure 6 (right). According to this figure, annual average sea surface temperature shows a sharp decreasing trend with increasing latitude and the low latitude tropical regions of the world possess the maximum SST values while the Polar Regions of high latitude possess very small SST values. Maximum sea surface temperature value ranges within the -30°N and 30°N latitude region.



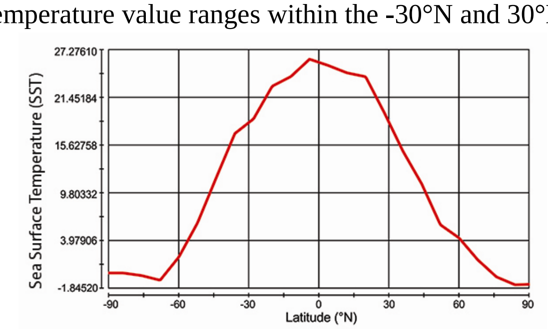


Figure 6: Global Scale distribution of Sea Surface Temperature (SST)

Regional Scale Analysis

Two important climatic parameters (surface air temperature and sea surface temperature) have been studied for regional scale variation within the Indian Subcontinent region. These following sections will briefly describe the found results with corresponding discussions.

1. Surface Air Temperature (SAT)

The variation of global surface air temperature is represented visually in figure 7 (left). As we can see from the figure, annual average surface air temperature changes significantly with latitude. The northern regions i.e., the Himalayan Regions possess the minimum surface air temperature while the Southern regions including Bangladesh, India, Myanmar and Bay of Bengal region have relatively higher surface air temperature. During 1958 to 2100, the predicted lowest and highest average annual surface air temperature are respectively -44.55°C and 28.56°C.

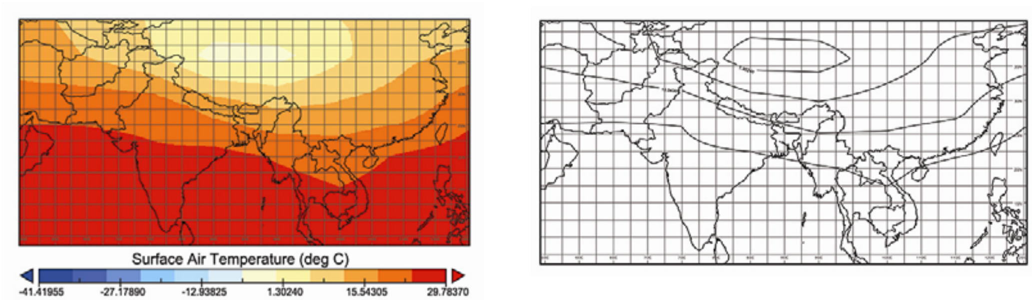


Figure 7: Regional Scale distribution of Surface air Temperature

The difference in surface air temperature is discussed in figure 7 (right) where variability of surface air temperature is represented by contour lines.

2. Sea Surface Temperature (SST)

Figure 8 (left) illustrates the distribution of annual average sea surface temperature (SST) for the Indian Subcontinent. SST is also high in the southern part of the Indian Subcontinent and low in northern regions. Figure 8 (right) provides a contour map showing the variability of SST with latitude in the Indian Subcontinent region.

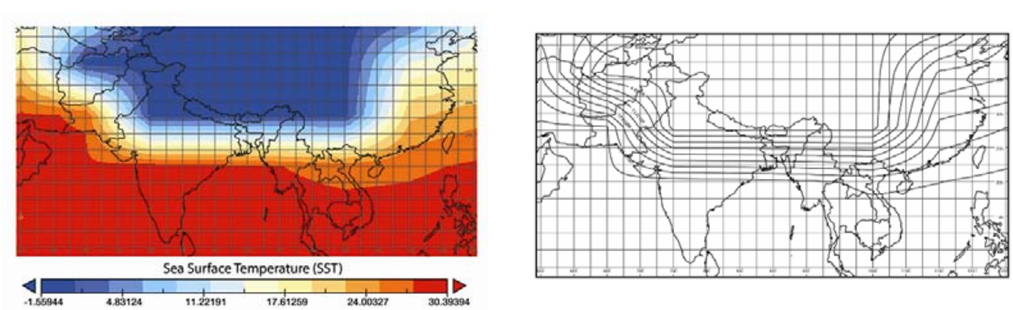


Figure 8: Regional Scale distribution of Sea Surface Temperature

Time Series Analysis

Time series analysis of global sea surface temperature is discussed in figure 9. Here, a steady increasing trend for sea surface temperature is observed. According to this figure, global sea surface temperature in 1958 was 12.74°C while it will be around 14.95°C by the year 2100. According to the most commonly accepted concept on global warming, the high prevalence of fossil fuel burning is considered as one of the leading causes responsible for the increase of global temperature (Hansen *et al.*, 1981; Wuebbles and Jain 2001). This result shows similarity with the findings of IPCC's third assessment report that global temperature is going to increase up to 2.5°C in the next centuries.

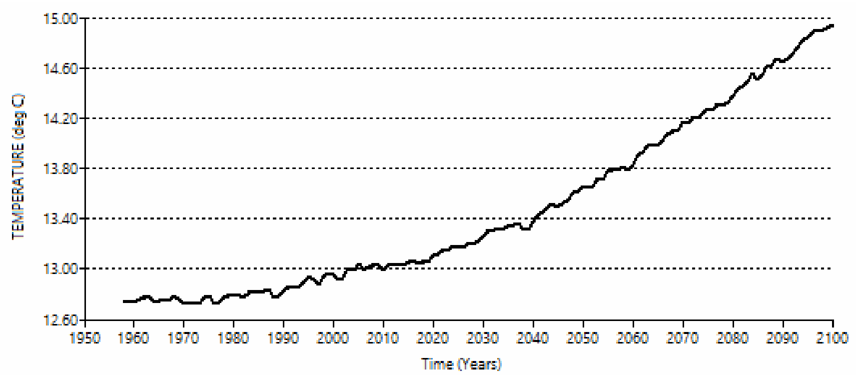


Figure 9: Time series analysis of Sea Surface Temperature

The variation of global surface air temperature with time is illustrated in figure 10. With time, surface air temperature provides a steady increasing trend. According to this figure, global surface air temperature was about 13°C in 1960's while it is projected that the average global surface air temperature will be increased to 17.25°C by the year 2100.

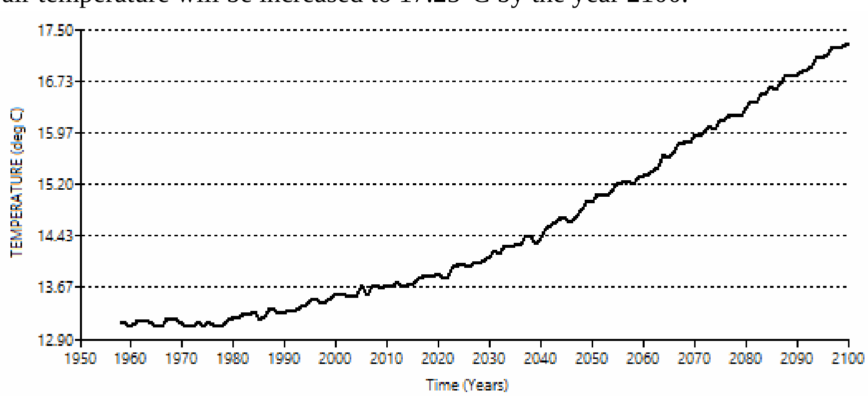


Figure 10: Time series analysis of Surface Air Temperature

Rajib *et al.*, (2011) studied the surface air temperature of this region during 2011 to 2100 under IPCC A1B emission scenario. Table 3 represents a comparison about the results found in our EdGCM simulation with the results of Rajib *et al*., (2011). In this comparison, we can find a little bit difference after 2040. This is mainly because of the difference in primary assumptions and model characteristics.

Table 3: Comparison of average surface air temperature in five different GCMs

	CGCM3.1 (A1B)	CCSM3 (A1B)	HADGEM1 (A1B)	MIROC3.2 (A1B)	EdGCM (A1Fl) Current Study
2011-2040	1.09	0.98	0.72	0.52	0.73
2041-2070	1.95	2.10	2.38	2.16	1.55
2071-2100	2.78	2.72	3.58	3.34	1.51

Source: Rajib *et al*., (2011)

A1Fl assumes that, the future will be fossil fuel dominating and after depletion of fossil fuels, relatively cleaner alternative energy will be used, which will play contributing role in controlling the increasing trend of temperature. On the other hands, A1B doesn't provide any of such assumptions and therefore the rate of change of temperature remains steady with increasing time.

Limitations of Edgcm

A key limitation of EdGCM is the fairly coarse horizontal resolution. The resolution of EdGCM is 8° latitude by 10° longitude. For the practical planning of water resources, flood defenses etc., countries require information on a much more local scale than EdGCM provides.

There are three possible solutions to this problem:

1. Run the full simulation using a GCM with finer resolution
2. Use statistical techniques to 'downscale' the coarse GCM results to local detail
3. Embed a Regional Climate Model (RCM) in the GCM:

Conclusion

The current study investigates the possibilities of Educational Global Climate model (EdGCM) in improving climate research in Bangladesh by using traditional desktop computers and laptops. It has been found that, the EdGCM climate model has a relatively coarse grid resolution (8°×10°) which makes it computationally inexpensive to be operated in a traditional computer without making any further change. The highly customizable graphical user interface makes it perfectly suitable for less technical users to use it without having any technical knowledge however, the underlying code that works behind the graphical user interface is the same. High quality global scale as well as regional scale and time series plots can be produced by using EdGCM suite. It has been found that the performance of the model simulation increases significantly with increasing processor speed. So, the more powerful the computer is, the less time it will take to complete simulation. Only problem is, the resolution of EdGCM is too coarse (8°×10°) to study local scale climatic variability. But still, it may be of great help in improving our conceptions about the Earth's climate and climate dynamics. With all the facilities that EdGCM may provide in a single place, it is highly anticipated that, EdGCM will contribute significantly in improving climate research and education in Bangladesh in the upcoming decades.

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