Lectures in Climate Change: Volume 1

Our Warming Planet

Topics in Climate Dynamics

Edited by: **Cynthia Rosenzweig** (*NASA Goddard Institute for Space Studies, USA & Columbia University, USA*), **David Rind** (*NASA Goddard Institute for Space Studies, USA & Columbia University, USA*), **Andrew Lacis** (*NASA Goddard Institute for Space Studies, USA*), **Danielle Manley** (*Columbia University, USA*)

CLIMATE LECTURE 20: The Educational Global Climate Model (EdGCM)

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Climate Lecture 20

The Educational Global Climate Model (EdGCM)

Mark A. Chandler

Columbia University, Center for Climate Systems Research, Goddard Institute for Space Studies, New York, NY, USA

Mark Chandler (PhD in Geoscience from Columbia University, 1992) is a paleoclimatologist at Columbia University and works at NASA's Goddard Institute for Space Studies, which is part of Columbia's Morningside Campus in New York. His research involves the study of extreme climate change in Earth's geologic history, with a particular focus on past periods of global warmth. In addition, he has worked for many years to improve educational access to NASA's global climate models (GCMs) through a project he directs called the Educational Global Climate Modeling Project (EdGCM). The EdGCM Project develops software and educational materials that make it possible for teachers and students to operate a GCM on desktop computers. He encourages educational experiences that immerse people in realistic global climate change research and hundreds of universities, schools, and research institutions currently use EdGCM as a means of lowering the barriers to participation in the science of climate modeling.

Introduction

Climate change will profoundly impact Earth's environmental health as well as the world's economic and geopolitical landscape over the coming decades. The impacts of climate change are, in fact, already beginning to be experienced and have the potential to affect every living plant and animal on Earth within decades (IPCC, 2014). Given this reality, every citizen of this planet should have the right to knowledge about the Earth's climate system and have the option to adapt to, or help mitigate the profound changes that are coming. In addition, a portion of the workforce needs to be capable of interpreting and analyzing climate information because, since the impacts of climate change will be widespread, pervasive, and continue to change over time, more professions will be interacting with climate data. We are already at, or past, the point where educators and their students require access to the scientific and technological resources — computer models, data, and visualization tools — that scientists use daily in the study of climate change.

Although scientists use many methods to study Earth's climate system, global climate models (GCMs) have become the primary tools for exploring the complex interactions between components of the entire system: atmosphere, oceans, and land. GCMs are used to make projections of future climate change, to simulate climates of the past, and even to help scientists look for life on other planets (Flato *et al*., 2013; Way *et al*., 2017). Like any model, a

GCM can help people evaluate actions before they are taken. Like Business Intelligence software, they are Climate Intelligence tools. Unfortunately, GCMs are black boxes to most people. A previous chapter in this book by Gary Russell, entitled *Building a Climate Model*, is one example of the growing body of literature aimed at the general public describing the inner workings of GCMs. This literature goes a long way toward explaining climate model fundamentals. However, it will not be enough to alleviate their black-box nature unless people are afforded hands-on, authentic learning experiences as well.

Twenty years ago it was thought that GCMs would become commonplace in schools and perhaps might even be running on the desktops of congressional staffers (Randall, 1996). But today very few schools, including institutions of higher learning, have hands-on access to GCMs. Most GCMs still require supercomputing resources and skilled programmers to operate them. It might surprise many people that this lack of access extends to many research scientists as well, because GCMs are developed primarily at national labs where security and cybersecurity concerns have made such facilities less accessible over the past two decades. In some sense, the limited accessibility of GCMs has been beneficial, since these immensely complex models have been developed and applied almost entirely by highly trained scientists who are positioned to understand the strengths and limitations of the models. Experts who are better able to avoid misuse and misinterpretation of simulation results. Some skeptics have painted this as nefarious, but it is simply a best practice of most professions to have trained professionals operating complex tools — whether that be in engineering, medicine, law, economics, or any other vocation. Nevertheless, the resulting lack of familiarity with climate models and the techniques used to project future climate change has oftentimes engendered public distrust of important scientific findings based on modeling methodologies.

The Educational Global Climate Modeling Project (EdGCM), discussed in this lecture, makes one of NASA's GCMs accessible through a user-friendly interface so educators can run it using desktop or laptop computers, and without the need for scientific programming skills. EdGCM affords students the opportunity to explore the subject of climate change in the same manner as research scientists, and in the process become knowledgeable about a topic that is affecting their lives. It will better prepare them to grapple with the myriad of complex climate issues of the coming decades.

The EdGCM Project: Objectives

The overarching objective of the EdGCM Project is to improve the quality of teaching and learning of climate change science through broader access to GCMs. But, also to provide appropriate technology and materials to help educators use these models effectively. The design of EdGCM encourages students to learn about the scientific process while performing authentic investigations and real research projects that follow this process. The tools also provide a mechanism for linking classrooms with the research at national labs and universities and, ultimately, all of these things will demystify the science of climate change.

Teaching the Scientific Method Via Climate Modeling

Guiding introductory-level students through the scientific process is best accomplished by laying out a pathway where discrete steps are clearly and simply identified (Bush *et al.*, 2017).

With classroom time at a premium, it is most efficient to combine using the tools — in this case climate models — with learning about climate science, and simultaneously conducting authentic research to experience the scientific method in action. The steps presented here engage participants in the fundamentals of the modeling process, emphasizing a simple step-by-step approach, as well as the basic analysis of climate model results through data processing and scientific visualization. Although this simple step-by-step approach is certainly commonplace in climate research, it is also common that climate scientists will iterate through subsets of these steps many times during the course of a typical research project. While EdGCM usage mirrors the scientific process as viewed through the lens of a climate modeler, we are mindful that there is no universal scientific method. With EdGCM projects students participate in five basic steps: (1) experiment design, (2) simulation setup, (3) running experiments, (4) analyzing output using data-processing and scientific visualization methods, and (5) communicating results.

(1) *Experiment Design*: Hundreds of simulations have been conducted using NASA GCMs (and extensively published in scientific journals) so students can explore the typical design of climate modeling research using pre-existing, classic examples. EdGCM employs a variety of classic simulations in its design so teachers and their students can quickly begin working with authentic research topics using the method of 'rediscovery'. Rediscovery being the ability to re-examine previous research using similar methods to the original work. Using EdGCM in this fashion to begin means there is little upfront instruction required in the use of the software. The classic simulations are pre-packaged and can be run with the click of a 'Play' button. These simulations cover a range of topics and are chosen because they are highly cited in the scientific literature and can be used to examine fundamental climate science issues. There are climate simulations that depict simply the modern climate ('modern' here meaning the mid-20th century, before the impacts of anthropogenic warming become substantial). There are 'business-as-usual' greenhouse gas scenarios to examine future climate change, as well as ice age scenarios that contrast the climates of today with those of the last glacial maximum. All of these simulations make it possible for students to apply the actual GCM, and perform analyses, in a nearly identical fashion to those originally published by NASA scientists. This alone can provide many courses with a capstone moment; the ability to compare student-generated results to peer-reviewed scientific publications.

(2) *Simulation Setup:* Once students are familiar with the basic design of classic climate change experiments the next step is to allow them to design and setup their own unique simulations. Within the archetypal climate modeling lab this step would require experience in scientific programming and knowledge of climate modeling jargon. EdGCM reduces this need using a graphical point-and-click interface to accomplish most of GCM setup. The graphical interface is a form, called Setup Simulations, which is sub-divided into several logical sections. When fully expanded the form allows students to modify nearly every feature of the GCM, short of changes that require recompilation of model code, however, each section can be shown or hidden, allowing the teacher to focus students' attention on specific topics. Simulation Setup forms can be duplicated easily, because it is actually quite rare to set up GCM simulations from scratch, with most scientists instead duplicating previous experiments and modify only those inputs that are required to generate a unique experiment.

Completing a General Information section begins the task of setting up a climate simulation. This information is used to uniquely identify each simulation and store it as metadata in a relational database. Supplying a short Run ID and a modest descriptive title are the most basic information, as are the name of an experiment's owner and the start date of the project. But, this is also where users define the length, in calendar years, of the simulation. The existence of the EdGCM database also means that students can manipulate the GCM's input files (initial and boundary conditions) without needing to understand the details of complex file formats, and although pro-users have the option to select, or even create, individual input files, students can easily select directories that contain sets of input files that are compatible with one another. For example, a set of modern boundary condition files may be used for present day or future climate experiments, a set of ice age files could be selected to simulate the climate effects of large ice sheets, or a Cretaceous set could be chosen to simulate climate in the age of the dinosaurs.

After the basic information and input files are selected, students can assign values for a variety of climate forcings, which can be combined in a multitude of ways to create unique climate scenarios. These forcings include the level of greenhouse gases (carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons), the luminosity of the sun, and the physical parameters of the Earth's orbit. Each forcing type may also be assigned a trend, which can take the form of simple or complex functions. Simple functions, like linear or exponential trends and step functions, are easily assigned with a few clicks of a button, while more complex trends, such as those incorporating episodically increasing and decreasing forcings, can be created and loaded as datasets, with only a bit more effort. With Setup Simulations educators can easily explain to students the fundamental details of how climate models are controlled and how, with a few simple commands, nearly limitless experiments are possible. Students can quickly design simulations to examine past, present, and future climates, or a myriad of 'thought experiments'.

(3) *Running Experiments*: In the context of climate modeling studies, a research project may be composed of one, often two, or sometimes several computer simulations. Ordinarily, it would take months to complete such a series of simulations with a cutting-edge GCM, even using a supercomputer. EdGCM uses a coarser resolution GCM (i.e., fewer grid cells define the 3-D geography of the atmosphere, land, and oceans) making it feasible to simulate several hundred years of the Earth's climate on a laptop in less than a day (Hansen *et al*., 1983). Once a new simulation is set up, therefore, a click of the Play button will start the model running and any curriculum that is devoting 1 or 2 weeks to climate topics would easily be able to incorporate some aspect of climate modeling. However, there are clearly many educational settings that would only be able to devote a few days of time to the subject of climate change. Anticipating such situations, EdGCM also makes it possible for teachers to pre-compute GCM simulations and then upload them to lab computers or to a web-based utility, called EzGCM, that can mimic in a matter of minutes, a GCM simulating decades of climate change (The EdGCM Project, 2017). Even with this method, students can still be asked to perform some of the tasks of running the GCM, including the selection of specific simulations, choosing which climate variables to monitor, and using graphical controls to launch the climate model run. While the simulation is underway, text-based information is presented, offering

the student feedback — status messages generated by the GCM. More importantly, animated line plots convey the progression, and change, through time of the state of forcings and climate variables (e.g., CO_2, temperature, cloud cover, and precipitation). There are numerous climate variables to explore, since the number is limited only by the plethora of diagnostics calculated by the GCM itself. These displays of climate forcings and climate variables, along with the ability to simultaneously compare time series from multiple climate change experiments is an immersive experience for students even if schedules limit them to only a class period or two for the subject of climate change.

(4) *Analyzing Model Output — Post-Processing and Scientific Visualization*: Raw computer climate model output, the data of climate simulations, is generally written out in a binary format that must be prepared for direct scientific analysis. This form of data preparation is often described by the generic term 'post-processing' and it is actually the first part of the analysis step in the scientific process. Post-processing involves making scientific decisions as well as a substantial amount of programming, since the raw binary output must be reformatted using computational coding methods.

A graphical user interface can be used to automate a number of the most-used post-processing techniques, such as averaging across temporal and spatial domains and extracting individual variables from larger datasets. We believe that these post-processing steps can and should be run by the students as part of their learning about the scientific method for several reasons: (1) unlike GCM runs, post-processing can be computationally executed in a matter of seconds rather than hours or days; (2) processing the data interactively, and in real time, empowers users to understand that raw computer model output demands a degree of analysis prior to visualization, something that is probably not obvious to students who are used to CGI-laden movies and video gaming; (3) by requiring an interactive step involving post-processing the learner begins to recognize the importance of making analytical choices prior to detailed examination of individual variables; and (4) all of this effort conveys to users the significance of decisions that are made throughout the scientific process. We think that having students perform these steps is also necessary because smartphones and tablets have hidden from average users the crucial steps that lie between a complex computer operation and the visual display of information. In EdGCM, therefore, users make a series of choices that advance them through required post-processing steps, to end up with a resulting data file that is prepared for visual analysis.

After post-processing is complete, the next step is to represent the climate data visually. Scientific visualization involving plotting, mapping, and other 2-D images condenses complex information into a manageable form. It also makes it possible to compare multiple variables to one another, or to compare the same variable across time or geographic locations. A further, very common means of condensing climate model results can be accomplished by differencing 2-D arrays and then graphing the resulting anomaly array. These types of scientific visualization strategies are commonplace for earth science researchers, but students would normally have little access to such capabilities because such software generally involves some level of scripting and programming (or extraordinarily high costs). EdGCM comes with its own visualization software, called Panoply, that is easy for almost any student to use — and it is probably the most fun part of the process since color maps and cross-sections of the GCM output make the simulation results come to life (Schmunk, 2017).

(5) *Communicating Results*: No scientific study is complete without communicating the results to others. Whether the audience is the general public, other scientific specialists, classmates, or the teacher, it is crucial that students understand this is the culmination of their research and a fundamental part of the scientific process. EdGCM's eJournal feature is a tool that makes it simple to create reports that integrate text with in-line figures. This teaches students to prepare a written report of their results in a style similar to a publishable scientific manuscript.

An individual eJournal report can contain up to 20 sections that accommodate either text or images. Sections may be added or rearranged and images are easily inserted as needed. Once inserted into an eJournal an image becomes a figure. A figure in an eJournal manuscript is not just a graphic, but has an associated text field that becomes the figure caption. Figure captions are editable and students learn to use them to emphasize specific information in the image that is pertinent to their analyses. If a figure is moved within the eJournal its figure caption follows.

EdGCM also incorporates a tool called the Image Browser, from which the figures for eJournals are derived. The Image Browser is a window into an image library of photos, graphs, maps, and plots that are stored in the EdGCM folder on the computer's hard drive. Thumbnails of the images, along with other metadata, are stored in the EdGCM database. The image library is fully editable by a teacher (and by students, if they have permission) and can contain images in every major graphics file format. Even images created by the students themselves (possibly using EdGCM's scientific visualization applications) can be saved to the library and displayed for use with eJournal reports.

When an eJournal report is finished it can be converted to html through a single button click and it will automatically be previewed in the user's default web browser. Once the report is finalized (edited, reviewed, and graded) another click generates a unique eJournal directory, which includes the text of the report, the original images and their thumbnails, the associated figure captions, and the html that defines the layout. This eJournal directory can be uploaded to a school web server or emailed to the teacher, at which point the report is considered 'published' and in final form. eJournal reports can even make grading more efficient, since they have the consistent style of an organized scientific manuscript.

Concluding Remarks

Lessons and exercises that guide students through the methods outlined above deliver authentic research experiences, which teach students to follow a multi-step approach that is similar to the scientific research process that climate modelers use. The steps emphasized by EdGCM include: setting up and running simulations, post-processing computer model output, using scientific visualization to analyze simulation output, and communicating results. When students participate fully in this approach, they can quickly and effectively gain experience in (1) the scientific process, (2) climate science content, and (3) the use of computer models. This engages students and can help educators teach this important subject in a 3D fashion. This can excite students about science, make them proud of their own scientific efforts, and get them communicating through their own social avenues.

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Slide 1

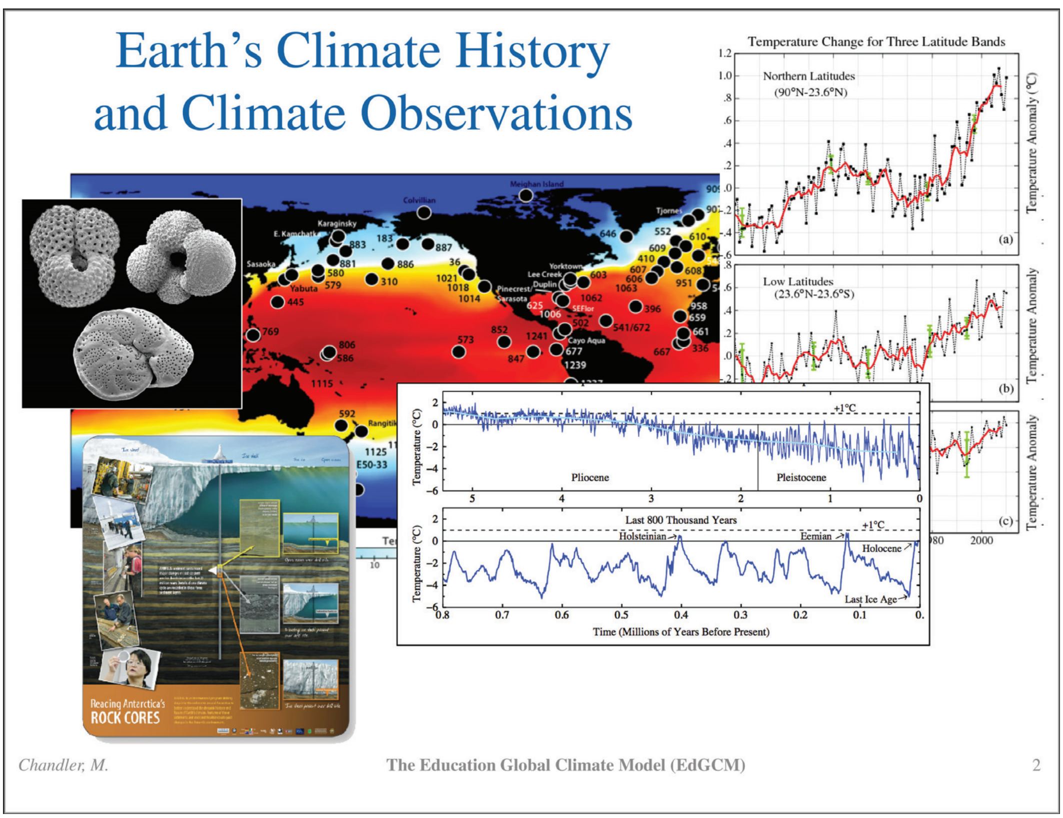
EdGCM: Educational Global Climate Modeling

Tools for Training the Climate Change Generation

Mark A. Chandler
NASA Goddard Institute for Space Studies
Columbia University

Our Warming Planet: Topics in Climate Dynamics
Lectures in Climate Change, Vol. 1
2017

Slide 2



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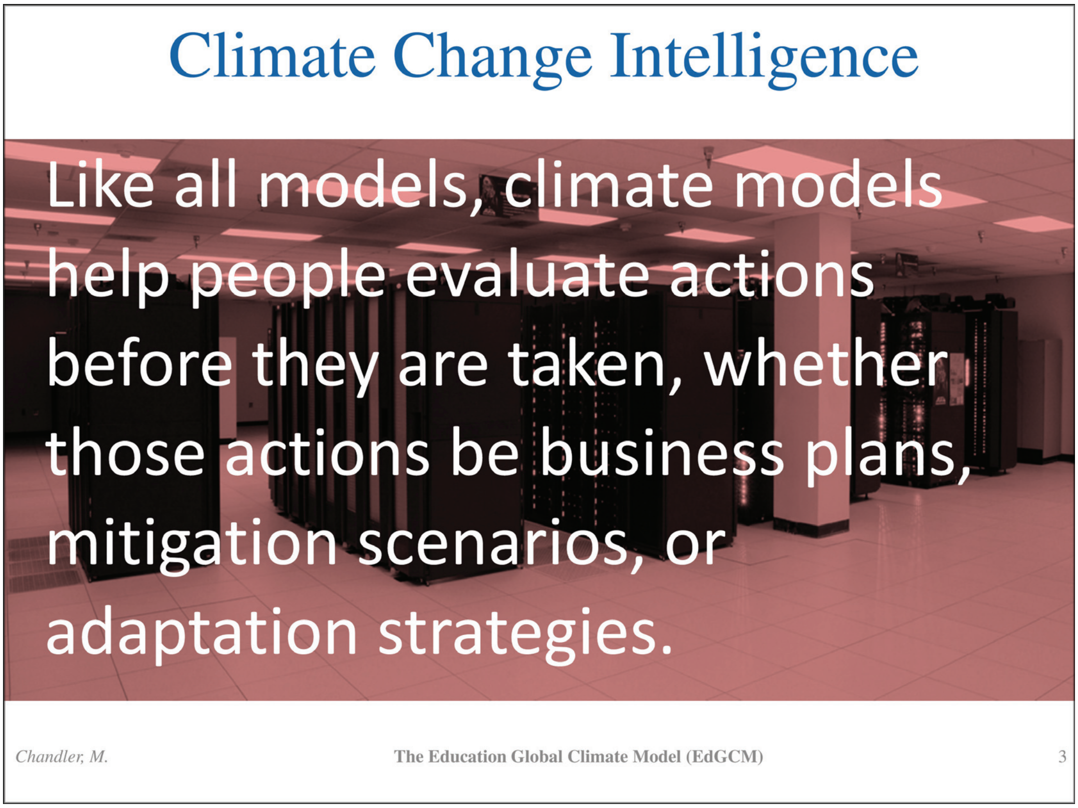

Slide 4

Slide 5

GCMs Were Expected to be in Common Use by Now…

'…Very soon it will be possible to run a GCM on a laptop computer.'

'GCMs will begin running on workstations in high schools, and possibly elementary schools. They may even be running in the offices of congressman.'

Dr. David Randall
Bulletin of the American Meteorological Society, 1996

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Slide 6

What is *Ed*GCM?

- A GLOBAL CLIMATE MODEL
  The NASA/GISS GCM Model II
- A GRAPHICAL USER INTERFACE
  Wrapped around the global climate model

NASA-GISS
www.giss.nasa.gov

Columbia University
edgcm.columbia.edu

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Slide 7

The Educational Global Climate Modeling Project

Project Objectives

- Allow teachers and students to run a full research version of a global climate model on desktop and laptop computers
- Encourage students to participate in the full scientific process
  - Experiment design
  - Running simulations
  - Analyzing data
  - Reporting on results

Chandler, M. **The Education Global Climate Model (EdGCM)**

Slide 8

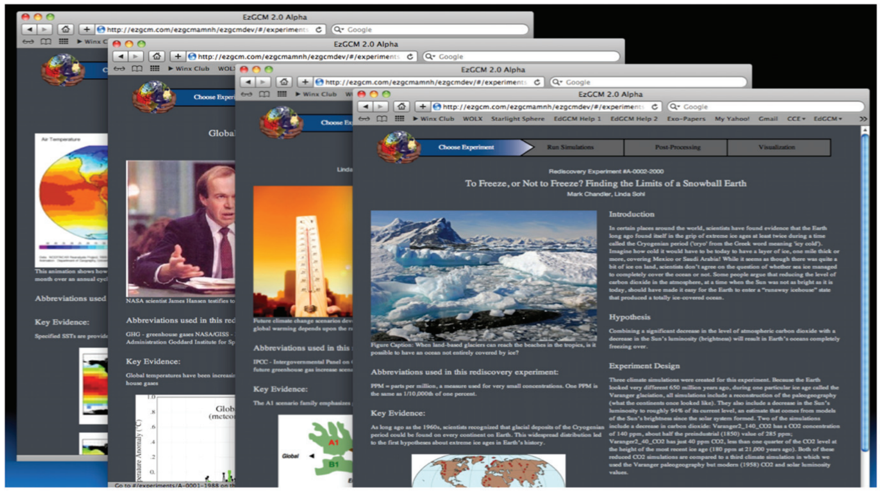
The Educational Global Climate Modeling Project

Project Objectives (continued)

- Enhance collaborations between schools, universities, national labs, and the private sector, so students become familiar with the role of teamwork in scientific research.
- …and by doing the above demystify how scientists forecast climate change.

Chandler, M. **The Education Global Climate Model (EdGCM)** 8

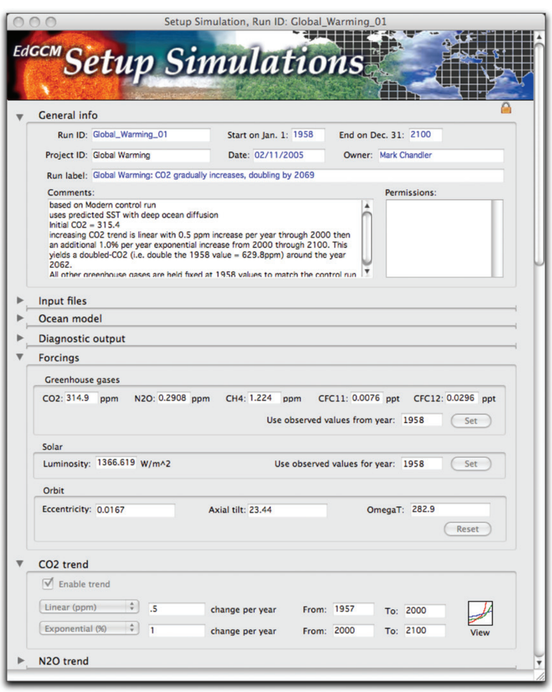
Slide 9



The scientific process often begins with an examination of prior research, in this case exploring how climate scientists have designed classic research projects that used computer models to study climate change. Materials that present the essential background of a climate science topic and present a hypothesis for testing can act as a guide to learning how climate modeling has been employed by other researchers to produce scientific results. The EdGCM Project provides short summaries of a number of such topics, and also supplies a web-based template that allows teachers or students to create summaries of their own research projects, which can then be added to the online collection.

Chandler, M. **The Education Global Climate Model (EdGCM)** 9

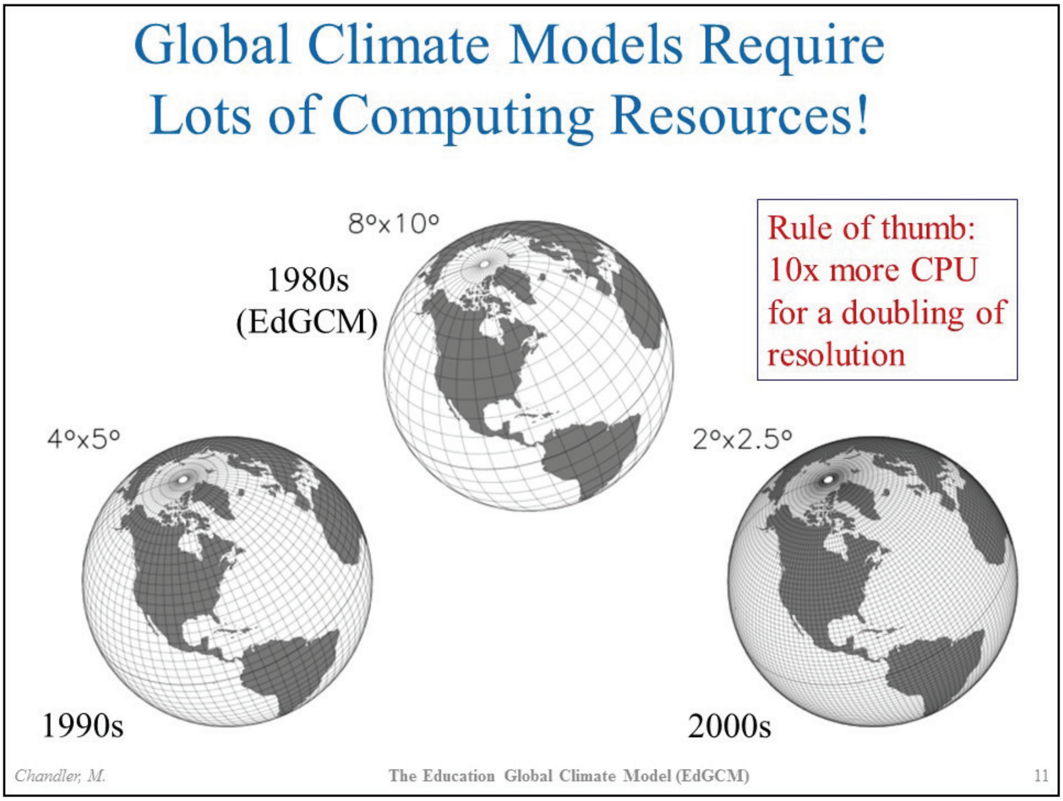
Slide 10



Experiments are designed using the "Setup Simulations" form. This form acts as an interface for manipulating the GCM itself, with well-defined fields for entering the names of input files, such as initial and boundary conditions. The interface is divided into logical sections, each of which the educator can show or hide, depending upon which components of the GCM they want students to focus. Point-and-click controls select model options (e.g., number of simulated years per experiment, levels of greenhouse gases in the atmosphere, orbital parameters, and paleocontinental configurations). With the guidance of the Setup Simulations tool, students can easily run experiments that simulate a wide variety of climates, from future global warming to past ice ages. It is equally possible to run "thought experiments" that allow students to test the sensitivity of the climate model to hypothetical changes in solar luminosity or greenhouse gas levels.

Chandler, M. **The Education Global Climate Model (EdGCM)** 10

Slide 11



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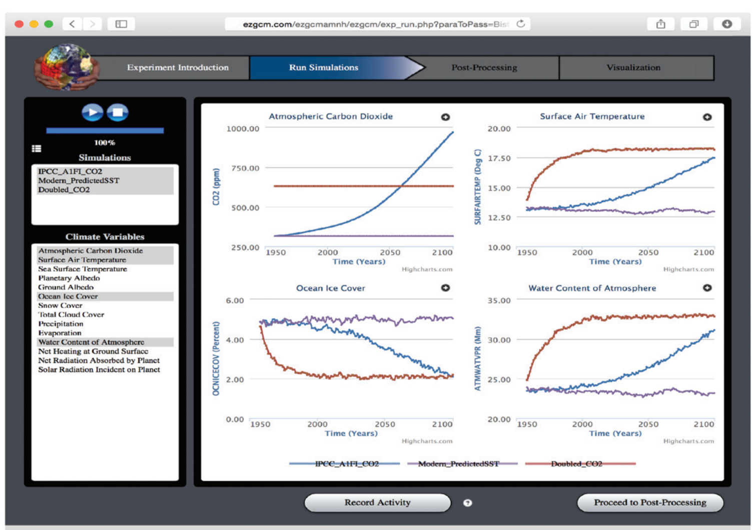
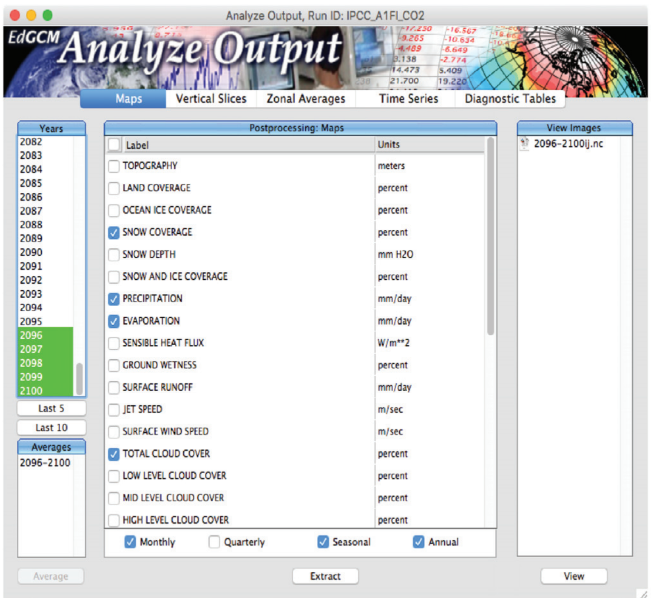


Raw data from pre-computed simulations make it possible to mimic the running of a simulation in a minute or two rather than days. Instead of de-emphasizing this step because actual simulations may take longer than a particular class can devote, we can enhance the learning experience by expecting students to make choices and to give them real-time analytical options. Simple interfaces like this can be nearly self-explanatory and yet offer instant feedback that students can consider and investigate.

Chandler, M. The Education Global Climate Model (EdGCM) 12

Slide 13

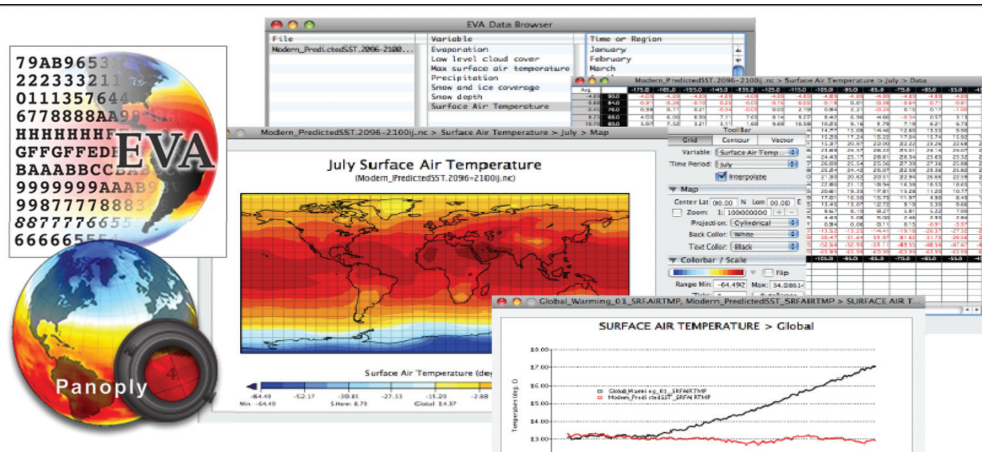


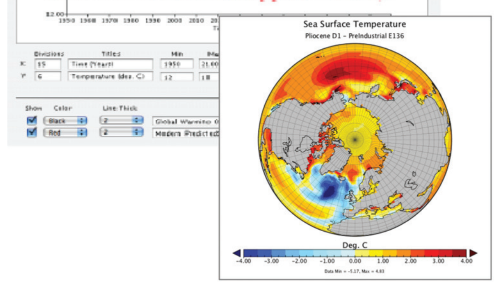
The post-processing of model output is typically performed by dedicated systems analysts or by scientists who are also skilled programmers. This can be a limiting factor on the amount of analysis that can be performed in many research programs. However, it is more akin to an insurmountable obstacle for most schools and educational institutions. To solve this problem EdGCM automates the most-used post-processing operations, including:

- The production of summary tables for all variables produced by the global climate model (over 400), averaged over months, seasons, and years for any subset of the length of a simulation.
- The creation of global maps, vertical atmospheric slices, global time series, and zonal averages for approximately 80 different climate variables.

Chandler, M. **The Education Global Climate Model (EdGCM)** 13

Slide 14

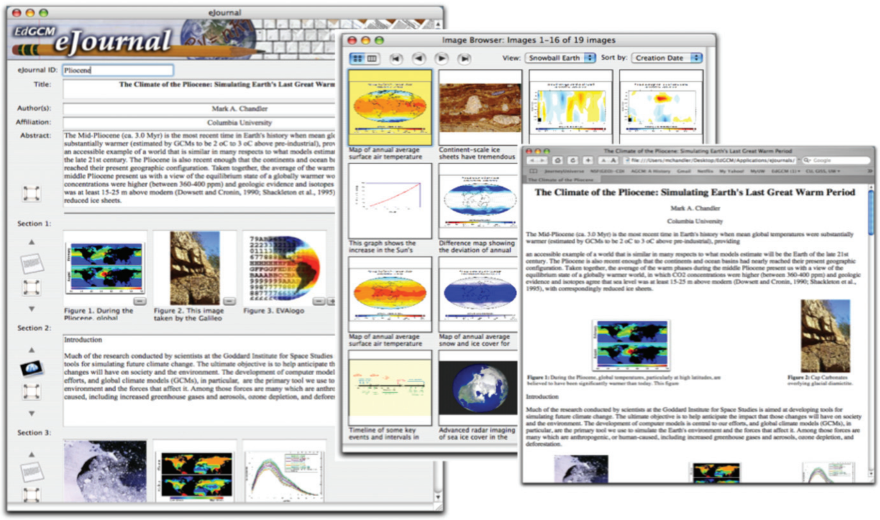




EdGCM comes installed with two scientific visualization applications (EVA and Panoply) for analyzing and interpreting climate model output. Students can create both line plots and global maps from the GCM's 1-D and 2-D output. Continental overlays, latitude by longitude grids, as well as a wide variety of map projections and colorbars can be applied. The scaling of the data is also easily changed, which helps to highlight various features of interest within the data without altering the data values.

Chandler, M. **The Education Global Climate Model (EdGCM)** 14

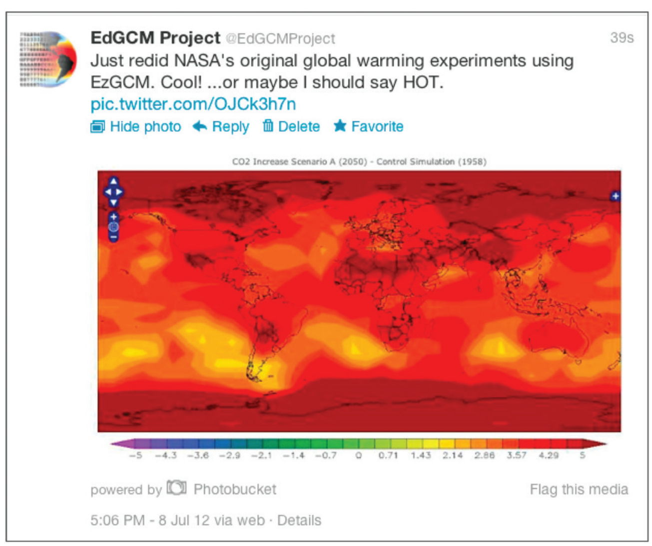
Slide 15



Communicating the results of your climate modeling research project is what we define as the final step of the scientific process. The professional communication of science results generally requires that reports be in the form of a scientific manuscript, containing not only text, but images and figure captions (like this one). EdGCM makes this much simpler for students to accomplish through a tool called eJournal, which encourages report writing in sections, with in-line images and figure captions. EdGCM also creates html code that lays out the manuscript and makes it convenient and efficient to publish student manuscripts to school or personal websites.

Chandler, M. **The Education Global Climate Model (EdGCM)** 15

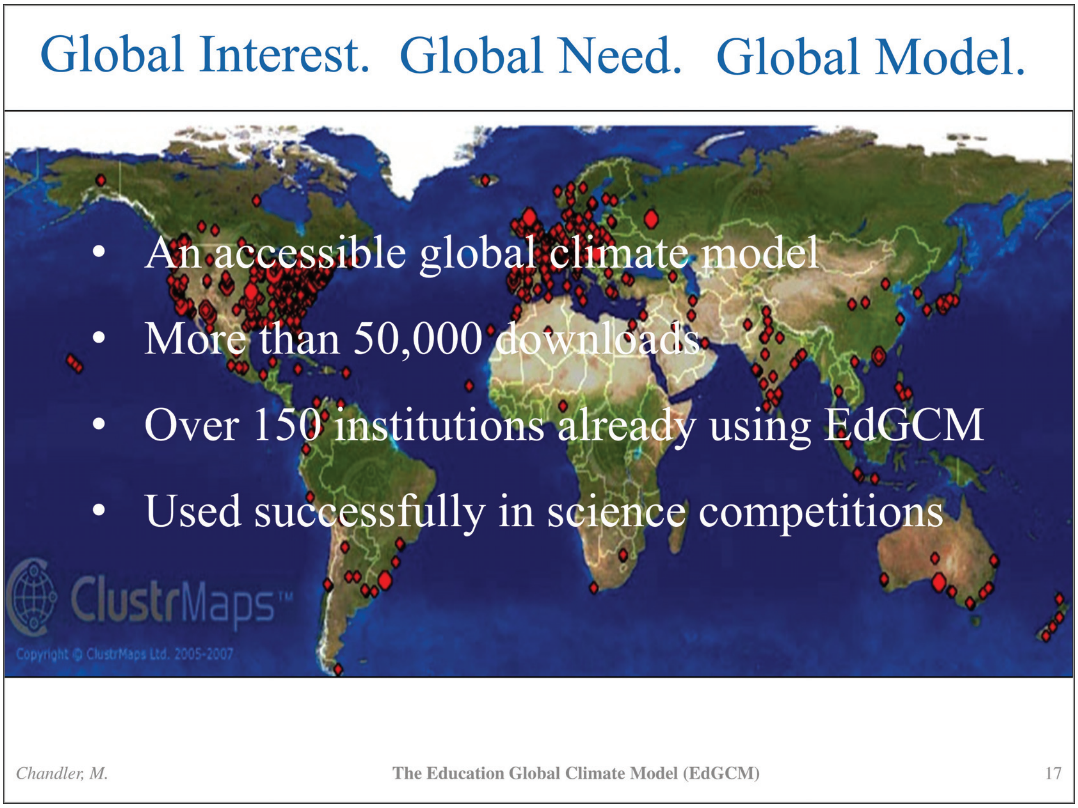
Slide 16



A tweet of an image created using EdGCM showing the results of a rediscovery experiment. The map shows the surface air temperature anomaly as simulated by the GISS GCM in much the same manner that the climate model was used by NASA in its earliest 3-D global warming simulations, The original simulations were published nearly 30 years ago by GISS scientists, including David Rind, and played a significant role in raising the level of concern about the potential planetary-scale side effects of burning fossil fuels.

Chandler, M. **The Education Global Climate Model (EdGCM)** 16

Slide 17



Slide 18

Slide Notes

Slide 1 Global Climate Modeling in the classroom — presentation at AAAS Meeting, 2012

AAAS Meeting, Vancouver, British Columbia, Canada, February 17, 2012
Authors: Mark Chandler and Linda Sohl, NASA Goddard Institute for Space Studies at Columbia University
Jian Zhou and Renee Sieber, McGill University, Department of Geography

Slide 2 Climate scientists use many methods to learn about Earth's climate and Earth's CHANGING climate:

- Paleoclimate data (from Hansen new article)
- Current Observations (from GISTEMP)
- Current Impacts (Svante Scientific Inc. slides)
- GCMs to examine and further inform…but, GCMs really do provide the only tools that can lead us toward detailed projections that can help us prepare for the consequence of continuing climate change and help us assess mitigation proposals.

Slide 3 Computer simulations are the primary tools scientists use and policy-makers rely on to assess the consequences of climate change. Like all models, climate models help people evaluate actions before they are taken, whether those actions be mitigation strategies or adaptation plans…or do nothing.

Slide 4 What is a GCM? The acronym 'GCM' originally stood for general circulation model. These are numerical computer models of the atmosphere (and now the oceans too) — essentially the circulating fluid components of the Earth. However, more recently the acronym 'GCM' has come to refer to a class of 3-D models of the entire Earth climate system known as global climate models. These models include a general circulation model as their core component, but they also simulate many additional components of the Earth's climate system, including ATMOSPHERE, OCEANS, CRYOSHPERE, and the LAND SURFACE. Cryosphere includes snow and sea ice, as well as the ice sheets on Greenland and Antarctica. The land surface component includes simple parameterizations of vegetation, ground hydrology, and river drainage. Some components, such as ice sheets, are not yet fully coupled with the climate system in a two-way fashion. In otherwords, they exist in the GCM and they can impact the atmosphere and oceans, but they are not themselves affected in return by changes in the atmosphere or oceans. This means that the climate change impacts on some features, such as ice sheets, must be calculated separately. As the GCMs become more sophisticated and as climate scientists learn more about how all the components operate, more and more of these 'offline' components are becoming dynamically coupled to the rest of the simulated climate system in GCMs.

Slide 5 GCMs were once predicted to be ubiquitous. This never happened — largely because the IPCC process has dominated the efforts of climate modeling groups who see the need for much higher resolution GCMs with ever more complex physics and chemistry.

Slide 6 EdGCM is a suite of software wrapped around a GCM to make it easier to operate, analyze output, and organize large amounts of data/output.

It is ultimately a joint project between NASA/GISS and Columbia University, CCSR. Funding has also been received from NSF and many individual contributions from our users.

Slide 7 We need to provide access to advanced capabilities (in this case GCMs) for those outside of the large government labs (NASA, NCAR, NOAA, and DOE). But, this brings with it many new requirements that are not so easily met.

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Slide 11 The computing power required by a GCM is an order of magnitude higher each time the resolution is doubled. This occurs about once every decade, based somewhat on available supercomputing technology of at the time. In reality, the computing resources required increase somewhat more rapidly, since scientists have also been adding more complex physics over the decades as well.

Slide 17
- An accessible global climate model
- More than 50,000 downloads
- Over 150 institutions already using EdGCM
- Used successfully in science competitions

Slide 18 Change the world at http://edgcm.columbia.edu (using EdGCM to do climate change experiments).