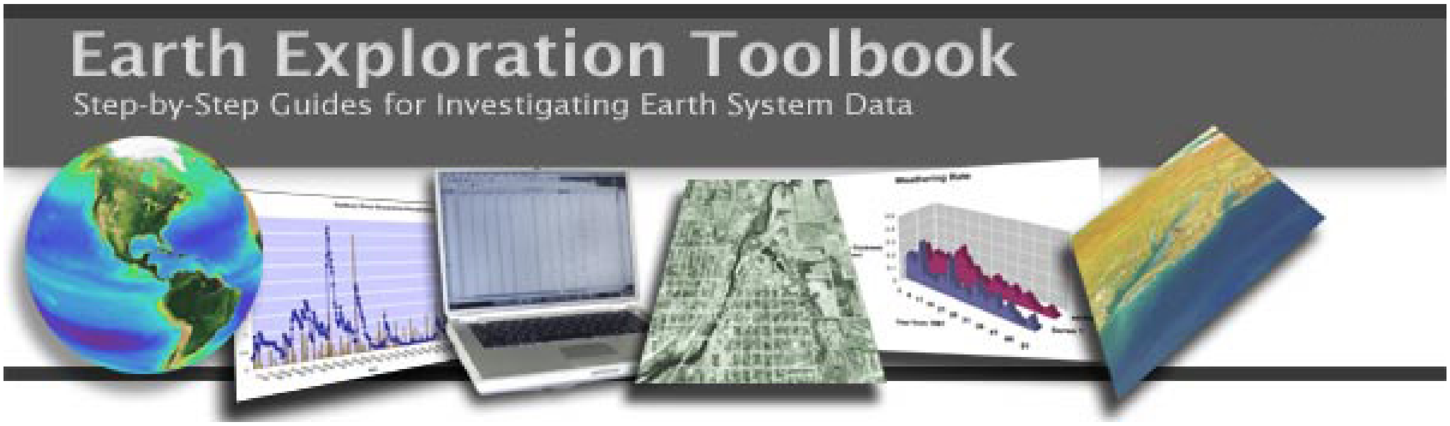

Envisioning Climate Change Using a Global Climate Model

Betsy Youngman, Mark Chandler, Linda Sohl,
Mark Hafen, Tamara Ledley, Steve Ackerman, and Steve Kluge

The Earth Exploration Toolbook is a collection in the National Science Digital Library (http://nsdl.org) and the Digital Library for Earth System Education (http://www.dlese.org). The National Science Foundation provides funding for the development of the collection under NSF Award #0226199.

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The EdGCM Project acknowledges the support of the National Science Foundation, Division of Atmospheric Science—Paleoclimate Program (NSF Award #0231400), and by NASA's Climate Programs (NASA Award #NNG04GP65G).

Contents

Envisioning Climate Change Using a Global Climate Model

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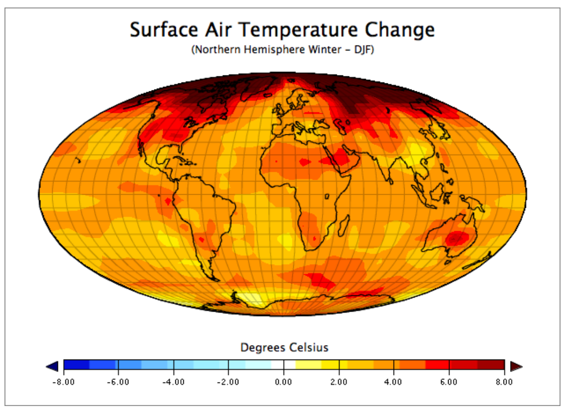
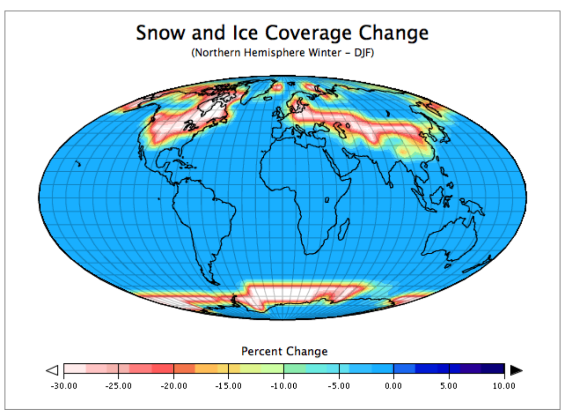
Published January 25, 2010

Description

In this chapter, users run the climate modeling software, Educational Global Climate Modeling Suite (EdGCM), to visualize how temperature and snow coverage might change over the next 100 years. They begin by running a "control" climate simulation to establish a baseline for comparison. After this first simulation, they run a second "experimental" simulation. Then they compare and contrast the changes in temperature and snow and ice coverage that could occur due to increased atmospheric greenhouse gases. Next, users choose a region of their own interest to explore. They compare their modeling results with those documented in the Intergovernmental Panel on Climate Change (IPCC) impact reports. Through working with EdGCM, users gain a greater understanding and appreciation of the process and power of climate modeling.

This chapter is part of the Earth Exploration Toolbook (http://serc.carleton.edu/eet/index.html). Each chapter provides teachers and/or students with direct practice for using scientific tools to analyze Earth science data. Students should begin on the Case Study page.





Examples of output from EdGCM. Maps of Temperature and Snow and Ice Coverage Differences, generated with EdGCM software. The maps show the change in temperature and snow coverage conditions predicted for the year 2100, based on the IPCC scenario A1FI.

Teaching Notes

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Grade Level

This activity is appropriate for students in grades 9-12. With modifications, the lesson could be used at a younger grade level (6-8).

Lesson Objectives

What are the big ideas and enduring understandings of this unit?

- Energy transfers control the weather and climate.
- Scientists use the laws of physics to predict future events.
- Science is collaborative – teams of individuals work together to design experiments, present and understand outcomes.
- Science and mathematical processes are used to understand the earth system and to prevent harm to all elements of the ecosystem.
- Scientific understanding is iterative; it evolves with experimentation and dialogue.

What are the essential questions needed to lead to this understanding?

- How is climate modeling a form of experimentation that leads to an increased understanding of the earth system?
- What are the important parts of a climate model?
- How do scientists "program" a model? What variables are significant when designing an experiment to test climate change hypotheses?
- What does the GCM predict about future impacts of climate change on water resources?

Students who complete this activity will:

- Gain insight into how Global Climate Models (GCM) are used to investigate global warming.
- Analyze climate simulation data.
- Compare and contrast the results of their global warming experiments with the actual observations compiled by climate scientists.
- Use EdGCM to visualize climate change's impact on a region and system of their own choosing.
- Have the opportunity to present their visualization results to the class via PowerPoint or with the EdGCM journal feature.

Rationale

Global climate models are one of the primary tools used today in climate research. Because of the computer computational requirements these models were originally developed and housed at national laboratories run by the government science agencies. NASA's climate modeling lab, the Goddard Institute for Space Studies (GISS), is located at Columbia University in New York City

(this is also where EdGCM was developed). NOAA's lab, the Geophysical Fluid Dynamics Laboratory, is located in Princeton, New Jersey, while NSF funds the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. As a result of their complexity, these models are not well understood by the general public. This EET chapter strives to give teachers and students the opportunity to more fully understand the process and potential of climate modeling through a hands-on interaction with an educational version of climate modeling software. This educational version of the software differs from the original climate modeling software only in that it is designed to run on school computers, which are generally smaller and have less computing power than the supercomputers used by national labs.

More About the U.S. Global Climate Model Development Labs

NASA Goddard Institute for Space Studies (NASA/GISS)
- http://www.giss.nasa.gov/

National Center for Atmospheric Research (NCAR)
- http://www.ncar.ucar.edu/

NOAA Geophysical Fluid Dynamics Laboratory (NOAA/GFDL)
- http://www.gfdl.noaa.gov/

Background Information and Resources

Basic information about the climate modeling and EdGCM written for teachers by the EdGCM team is available at the EdGCM web site (http://edgcm.columbia.edu). Part 1 of this chapter includes an introduction to climate modeling.

Some additional science articles on climate modeling that may also be of interest are listed below. Keep in mind these articles range in depth and difficulty. Please keep the age and ability of your students in mind when assigning reading. These resources may also be used for classroom presentation.

References

- United States Global Change Research Program has excellent up to date report on global climate change impacts on the United States. It also includes a summary of global climate change. (http://www.globalchange.gov/)
- Complete IPCC reports are available online. (http://www.ipcc.ch/index.htm)
- Wikipedia climate modeling webpage. (http://en.wikipedia.org/wiki/Climate_model)
- Introduction to climate prediction. (http://www.climateprediction.net/content/basic-climate-science)
- Earth Portal article on global temperature distribution. (http://www.earthportal.org/?p=1411)

- Background PowerPoint on EdGCM for use in presentations (http://serc.carleton.edu/files/eet/envisioningclimatechange/edgcm_introduction_ppt.ppt) (PowerPoint 6.8MB Aug23 09)

- IPCC WG1 AR4 report chapter 4, Observations: Changes in Snow, Ice and Frozen Ground. (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html)

- IPCC WG1 AR4 report Frequently Asked Questions. (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html)

- Manual for EdGCM. (http://edgcm.columbia.edu/documentation/EdGCM_Manual_v3.2.pdf) (PDF 7.2MB Aug15 09)

- Arctic Report Card 2009 NOAA - Terrestrial Snow. (http://www.arctic.noaa.gov/reportcard/snow.html)

Key Terms and Prerequisite Knowledge

Glossary of Terms

- Climate forcing: a variable that impacts climate, usually the focus of the climate experiment. Sets into motion the change.
- Climate feedback: a postive feedback amplifies, and a negative feedback dampens, the effects of climate forcings; positive feedbacks are often more powerful than the original forcing.
- Global climate model (GCM): computer model that simulates Earth's climate system in 3-D.
- Grid cells: 3-D boundaries of set around the atmosphere. Expressed in degrees of latitude and longitude and height.
- EdGCM: educational global climate model
- EVA: EdGCM Visualization Application
- Experiment: Several simulation runs using the variables from the scenario.
- Parameterizations: additional equations used by the GCM to calculate variables based on relationships derived from observations, experiments or theoretical analysis.
- Resolution: the number of grid cells per unit area.
- Scenario: a storyline, or set of conditions, that incorporates the social, economic and population growth predictions as well as fuel sources and advances in technology. Used in the set up of the model simulation.
- Simulation or Run: Once a scenario has been described these are the forcing factors incorporated in the model experiment. Include concentrations of greenhouse gases and solar luminosity.

Prerequisite Knowledge

Students will gain more from this exercise if they already have a basic working knowledge of climate and the factors that control it such as: elevation, latitude, the Earth's orbit, seasons, temperature and precipitation. This unit can be used as a stand-alone unit or embedded in a larger unit on climate change. Ideally, students should also know basic information on greenhouse gases, the IPCC reports and scenarios, and the issues surrounding climate change impacts. This background information can be found online at IPCC home or in most environmental science texts. A helpful, although somewhat technical, summary document from the ARWG 4 report is the frequently asked questions page (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html). Other helpful background documents on climate modeling can be found in the reference links above. Listed below are four excellent sources of information on climate change.

- Weather and Climate Basics
 (http://www.eo.ucar.edu/basics/index.html)
- About Climate Research
 (http://www.ncar.ucar.edu/research/climate/)
- Global Warming Facts and Our Future
 (http://www.koshland-science-museum.org/exhibitgcc/index.jsp)
- Short webcasts about climate change from UCAR
 (http://www.ucar.edu/webcasts/voices/)

Instructional Strategies

Learning Contexts

Students begin this lesson by examining decreasing snow and ice coverage. Using this case study as the initial introduction to the technical skills needed to use EdGCM, students can use EdGCM to investigate other subjects and questions of their own design. Students can use EdGCM to investigate the impacts of climate change on temperature, precipitation, snow and ice coverage. Students will relate global processes to changes that affect them at a local level. The contexts or subject areas that this lesson is suited for are broad. The outcome of the discussions will be guided by the parameters set by the individual instructor. The outcome could be, social, environmental or economic. This lesson is suitable for environmental science, world politics, geography, or earth science classes.

Groupings

As this lesson is outlined, students begin as a large class for part 1, move to individual or paired grouping for parts 2-5 and then form small "research" teams for part 6. The final class period should be a large group discussion of the research team findings and a comparison of the students' observations with those of the IPCC global impact reports (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm).

Teaching Strategy

1. Begin lesson with a recent news article or video clip. Suggestions:

    - The Heat of the Moment website has numerous short documentaries from around the world. (http://pulitzergateway.org/heat-of-the-moment/)

    - The opening scene of Heat Frontline (http://www.pbs.org/wgbh/pages/frontline/heat/)

    - World Glacier's declining On Thin Ice (http://www.pbs.org/now/shows/516/index.html)

    - Share a selection from Thoreau's Legacy: American Stories about Global Warming American Stories (http://www.ucsusa.org/americanstories/)

2. Use a world map to discuss the concept of the regionalism of climate impacts. Suggestions:

    - Climate Hot Map (http://www.climatehotmap.org/)

    - IPCC reports (http://www.ipcc.ch/index.htm)

    - Heat of the Moment (http://pulitzergateway.org/heat-of-the-moment/)

    - Arctic Report Card (http://www.arctic.noaa.gov/reportcard/index.html)

3. Explain climate change and climate modeling by showing the introductory EdGCM powerpoint. (http://serc.carleton.edu/files/eet/envisioningclimatechange/edgcm_introduction_ppt.ppt) (PowerPoint 6.8MB Aug23 09).

4. Review the background information and Case Study as a class. Alternately, begin the lesson with the information and suggested activity described in *Part 6 – Design Your Own Investigation* for a more global perspective.

5. Optional – give students an introductory worksheet with the EdGCM buttons and toolbars defined. Give them time to explore the software before beginning the lesson.

6. Complete the lesson parts 1-6.

7. Wrap-up the lesson with impacts presentations and group activity from part 6. A possible alternative lesson plan to use with this section:

    group decision-making activity (http://www.koshland-science-museum.org/teachers/wq-gw-gdt002.jsp)

8. Show the America's Choice video (http://americasclimatechoices.org/). Discuss what is being done by the United States and what can individuals do? Use resources such as the carbon footprint calculator (http://www.koshland-science-museum.org/exhibitgcc/responses01.jsp) and heat of the moment (http://pulitzergateway.org/heat-of-the-moment/); see the share your story section.

Assessment of Student Learning

Teachers can adapt these assessment suggestions to their own classroom situation.

- Student work can be collected.
- Students can create e-portfolios of their work including answers to questions, maps and graphs.
- ***Part 6 - Design Your Own Investigation*** could stand alone as an assessment of student work.

Time Required

Estimated times for completing the ***Case Study*** and each Part of the chapter. Total time 3-6, 45-minute periods will be needed to complete the case study and exercises. Running the climate model is a time consuming step, taking anywhere from 12 to 24 hours per simulation. It is suggested that teachers begin the program well (several days) in advance of using it with classes.

Step-by-Step; Outline and Descriptions

Preview -Introduction and Case Study (45 minutes-can be done as homework)

Part 1-(1-24 hours, depending on connection) Download software, run simulation or download the output files for the 2 model runs, IPCC_A1FI_CO2 and Modern_PredictedSST.

Part 2-(30 minutes) Prepare - Read background materials and discuss the theory of climate modeling.

Part 3-(45-90 minutes) Engage – Generate and analyze a time series graph of temperature.

How dramatically will the Earth's surface temperature rise in the next century? What exactly is a model? How do climate change models work? What goes into the programming of a climate model?

Part 4-(50 minutes) Explore – Generate maps of surface air temperature using EVA.

Use Analyze Output in EdGCM to generate data sets that can be mapped. Then use EVA to create several maps of temperature and snow and ice coverage under both global warming and non-global warming scenarios. Discuss why averaging is important.

Part 5-(50 minutes) Examine – How will climate change impact winter snow and ice in the northern hemisphere?

Use EVA to create a difference (anomaly) map of Snow and Ice Coverage.

Part 6-(30-60 minutes) Elaborate (and Assess) – Learn about climate changes impacts on another region, present findings to class.

Use EdGCM and EVA to investigate another region and impact of your choice. Present your findings to the class. Why is climate change a truly global problem?

Standards

Science Standards

The following National Science Education Standards are supported by this chapter. Additional Standards are referenced in the EdGCM Manual: (http://edgcm.columbia.edu/documentation/EdGCM_Manual_v3.2.pdf) (PDF 7.2MB Aug15 09)

Grades 5-8

- Use appropriate tools and techniques to gather, analyze, and interpret data. [8ASI1.3]

> The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design. The use of computers for the collection, summary, and display of evidence is part of this standard. Students should be able to access, gather, store, retrieve, and organize data, using hardware and software designed for these purposes.

- Think critically and logically to make the relationships between evidence and explanations. [8ASI1.5]

> Thinking critically about evidence includes deciding what evidence should be used and accounting for anomalous data. Specifically, students should be able to review data from a simple experiment, summarize the data, and form a logical argument about the cause-and-effect relationships in the experiment. Students should begin to state some explanations in terms of the relationship between two or more variables.

- Communicate scientific procedures and explanations. [8ASI1.7]

> With practice, students should become competent at communicating experimental methods, following instructions, describing observations, summarizing the results of other groups, and telling other students about investigations and explanations.

- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations. [8ASI2.4]

- Women and men of various social and ethnic backgrounds - and with diverse interests, talents, qualities, and motivations - engage in the activities of science, engineering, and related fields such as the health professions. [8GHNS1.1]

  Some scientists work in teams, and some work alone, but all communicate extensively with others.

Grades 9-12

- Formulate and revise scientific explanations and models using logic and evidence. [12ASI1.4]

  Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation.

- Use technology and mathematics to improve investigations and communications. [12ASI1.3]

  A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results.

- Scientists rely on technology to enhance the gathering and manipulation of data. [12ASI2.3]

  New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

Geography Standards

Standard 1. How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective.

Standard 5. That people create regions to interpret Earth's complexity.

Standard 7. The physical processes that shape the patterns of Earth’s surface.

Standard 13. How the forces of cooperation and conflict among people influence the division and control of Earth’s surface.

Standard 14. How human actions modify the physical environment.

Standard 15. How physical systems affect human systems.

Standard 18. How to apply geography to interpret the present and plan for the future.

Case Study

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Climate Change and Recreation

Winter ski trails in Idaho. Photo credit: Betsy Youngman.

While climate change may seem distant and far away for many people, winter sports enthusiasts in the Northern Hemisphere are already aware of climate change's impacts on their winter recreation opportunities. People who love the winter sports skiing, snowshoeing, snowmobiling and ice-skating are reporting shorter sporting seasons that start later and end earlier each year.

What will the future bring for these outdoor sports? Should you invest in skiing or skating lessons for your children or grand children? Does it make sense to develop new trails for Nordic skiing and snowmobiling? How can the ski resorts adapt so that they can stay in business beyond 2050?

Changing seasonal patterns involve more than just winter. Over the past several decades, scientists and observers have noted that even as snow and ice coverage is decreasing across the northern latitudes, it is also melting earlier in the spring, affecting runoff to local rivers and streams. Less snow that also melts earlier means less runoff in the summer months, when irrigation water is needed for agriculture. These impacts are also changing water-based recreation activities as rivers, lakes and reservoirs become unnavigable for some groups of boaters and the water becomes too warm or too shallow for some fish habitats.

Since much of the world's fresh water supply for drinking and farming depends on this frozen storage system, it is a significant topic to explore and understand. In this chapter, you will use a Global Climate Model (GCM) specifically adapted for Education, EdGCM, to discover the impact of climate change and increasing surface temperatures on the Northern Hemisphere's snow and ice cover.

Rafting the Grand Canyon of the Colorado. Photo credit: Betsy Youngman.

The full reports on climate change science including impacts and mitigation can be downloaded from the IPCC reports page. The United States Impacts report is available at United States Global Change Research Program. This report also includes a summary of global impacts. The recent trends in Terrestrial Snow are described in this Arctic Report Card.

Run-off from Grinell Glacier summer 2004. Glaciologists predict that there will be no remaining glaciers in Glacier National Park by the year 2030. Photo credit: Betsy Youngman.

Step-by-Step Instructions

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Part 1—Download Climate Modeling Software and Data

Download the software, run the simulation or download the output files for Modern Predicted SST and IPCC A1FI CO2.

Part 2—Understand Climate Models

Read background information about climate modeling and understand the theory behind the Educational Global Climate Model or EdGCM software. Answer the following questions: What exactly is a model? How do climate change models work? What goes into the programming of a climate model? Why do they demand so much computer time and power?

Part 3—Generate a Time Series Plot of Temperature

How dramatically is the Earth's surface temperature predicted to rise in the next century? Generate a temperature graph using model data to see the increase in the Earth's temperature that will result from the continued increase of CO2 in the atmosphere. Compare the graph of the simulation with a graph of Earth's temperature given no change in our present amount of CO2 in the atmosphere.

Part 4—Generate Temperature Maps Using EVA

Use Analyze Output in EdGCM to generate data sets that can be mapped. Then use EdGCM visualization software, EVA, to create several maps of temperature under both global warming and non-global warming scenarios. Discuss the advantages and disadvantages of maps versus graphs of data.

Part 5—Generate Snow and Ice Coverage Maps

How will climate change impact winter snow and ice coverage? Use EVA to create a difference (anomaly) map of Surface Air Temperature and of Snow and Ice Coverage.

Part 6—Explore Climate Change Impacts on Another Region

Use EdGCM and EVA to investigate another region and impact of your choice. Present your findings to the class. Why is climate change a truly global problem?

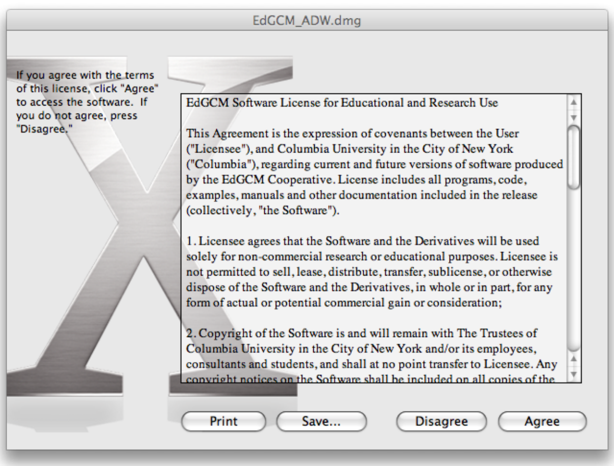
Part 1—Download Software and Data

Step 1 - Download the Tool and Data

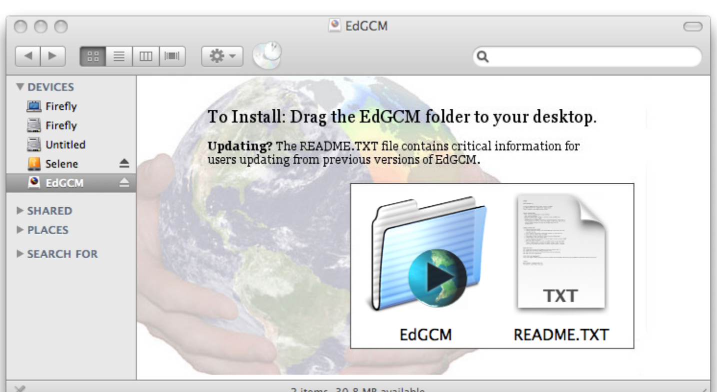
Go to the EdGCM website, download the climate modeling software and install it on your computer. You will need to enter a valid email address. The system will then send an email reply with download links for the Mac and Windows versions of the software. The demo version of the software runs in fully operational mode for 30 days. Link to download EdGCM: http://edgcm.columbia.edu/download-edgcm/. Additional instructions for installation are included in the read me text file included in the download package.

Step 2 - Install EdGCM Software - Mac

1. Download the latest disk image (e.g., EdGCM.dmg) from the Link to download EdGCM (http://edgcm.columbia.edu/download-edgcm/). When the license agreement appears, click "Agree" to continue mounting the disk image on your desktop.



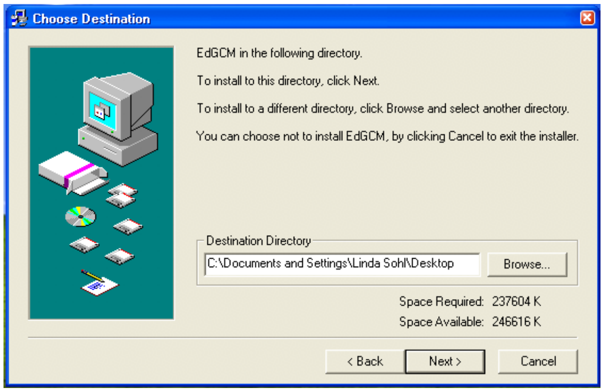
2. Once the disk image is mounted, simply drag the EdGCM folder to the desktop, or to any other desired location where you (or other users) will have write access. Launch EdGCM by double-clicking on the shortcut inside the EdGCM folder.



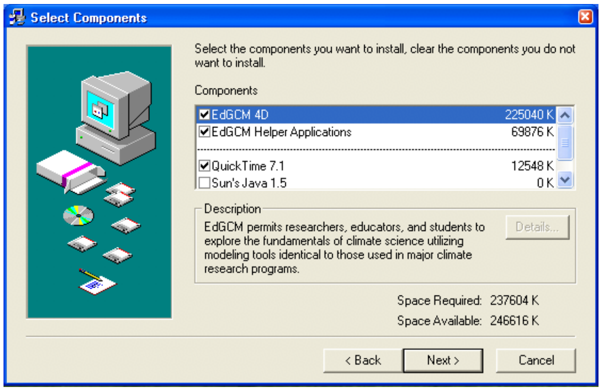
Step 2 - Install EdGCM software - Windows XP / Vista

1. Download the latest installer (e.g., EdGCM.exe) from the Link to download EdGCM (http://edgcm.columbia.edu/download-edgcm/) to your desktop, and double-click on the file name to begin the installation process. When the license agreement appears, click "Agree" to continue the installation process. Please note that you may need an administrator's password to complete the installation; if you do, you will need to ask your IT administrator for assistance.

2. The default installation location for EdGCM is your desktop. You may choose another location, but you (or other users) must have write access for that directory (e.g., C:\Program Files won't work).



3. Select the components of the EdGCM package that you wish to install. We recommend that you leave all choices checked since QuickTime and Java are required to use EdGCM. The QuickTime installer will only run if you do not already have QuickTime installed. The Java installer will replace any existing copy of Java with the latest version from Sun.



4. If you do not already have QuickTime and Java on your PC, installation of these components will begin now. Simply accept the license agreements and opt for a typical setup rather than a custom installation. The installation process for these programs may take several minutes each.

5. Launch EdGCM from either the Start Menu or from the shortcut on your desktop.

Step 3 - Register Your Copy of EdGCM

1. When you launch EdGCM for the first time, a dialog box will appear, asking you to register. If you have already purchased your copy of EdGCM, type in the license key exactly as given in your confirmation email, and click on the "Enter" button to complete your registration.

2. If you wish to use EdGCM in demo mode, leave the license field blank and click on the "Demo" button. You will then have 30 days to try out the software; the demo is fully functional during that time. While running in demo mode, the registration box will appear each time you launch EdGCM, reminding you of the number of days remaining in your free trial.

3. If you have been using EdGCM in demo mode and decide to make a purchase, leave the license field blank and click on the "Purchase" button. You will be directed first to the EdGCM web site to provide some basic user information, and then to the EdGCM online store (hosted by Kagi) to complete your credit card or PayPal purchase. Once you have received your license key, follow step 1 above to complete registration.

Optional: Learn More about EdGCM Performance

The complete EdGCM Manual (http://edgcm.columbia.edu/documentation/EdGCM_Manual_v3.2.pdf) (PDF 7.2MB Aug15 09) is available. The manual has detailed instructions for users of the software, including information on how fast the software will run on various computers. Climate models are complex and take large amounts of computing time to complete. Teachers who are unsure of their computer's technical capability should check with their IT department for information.

Step 4 - Run the Simulations

1. Launch EdGCM by double clicking on the icon (alias pictured to the right) in the EdGCM folder. The application will load. The tool bar window will appear. It is from this toolbar window that the user controls the software. The buttons in this window will change depending on the active window.

2. Once EdGCM has started up, run the simulations. To run one of the provided simulations and generate the 2 raw model output (data files) you will need for Part 2 of this exercise, click on a simulation name in the ToolBar's Run List to select it, and then click on the "Play" button at the top of the ToolBar to launch the GCM component of

EdGCM and start the simulation. The first simulation to run is the Modern_PredictedSST. The second is called IPCC A1FI CO2. These simulations can take 12-24 hours to run.

> ***Why do the simulations take so long to run?*** These calculations are done, for a model with the resolution (8x10) used in EdGCM, in every grid cell once every 15 minutes of each simulated hour, of each simulated day, of each simulated year of a run... and remember, the grid cells are not isolated from each other, but have to pass information across grid boundaries for the every subsequent set of calculations. Each hour of an entire simulation has to be accounted for in the model. That's an awful lot of calculating and bookkeeping to do, so even with faster desktop computers, it takes a while to finish a 142-year run.

3. When a simulation is completed, the GCM window will give you a message that the run has finished successfully, and in the EdGCM ToolBar run list, you will see a solid blue circle next to the simulation name. Note that the GCM will generate a large amount of output - roughly 2.6 GB for a simulation running ~140 years - so you should make sure you have adequate disk space before starting your simulations. Once the simulation is complete, you will be able to remove about two-thirds of the raw files to free up space on your hard disk.

4. The GCM component of EdGCM - the actual climate model created by NASA - is an independent program that will launch in a new window, with its own controls for pausing and continuing the simulation. When you first start a simulation, the GCM will run for about one hour and then stop with the message: "First hour completed successfully! STOP 13: The GCM is no longer running." Click on the "Play" button at the bottom of the GCM window to continue the simulation.

> ***Why does the GCM stop after one hour?*** When the GCM was first developed by NASA, it needed to run on a supercomputer, a precious shared resource. The scientists could not afford to let the GCM run without first checking to ensure that the model was set up with all the appropriately matched input files, and that the model computer code itself didn't contain any major errors that would produce bad results. Their solution was to allow the GCM to run for the first simulated hour, and then check the results to see if they were reasonable before allowing the simulation to continue. EdGCM retains this feature, partly for historical reasons, but also as an aid for EdGCM users designing their own simulations and experiments.

5. To free up system resources, you may quit the EdGCM 4D interface (i.e., the ToolBar) at this point. The GCM window itself can be minimized, but do NOT close the window (on Macs) or quit the application (on Windows), or you will stop the model inadvertently. If you need to stop the model temporarily (for user logoff/computer shutdown), click on the "Pause" button at the bottom of the GCM window; this step will allow the model to collect the information it needs to successfully start up again at a later time. You can then quit the GCM from the File menu, or by clicking on the "Stop" button at the bottom of the GCM window. To restart a simulation, simply repeat step 1 above, and the GCM will continue the simulation from

the previous stopping point. It is possible to work on other programs with the simulation running in the background.

How can I move run output from one computer to another? If necessary, the Modern_PredictedSST and IPCC_A1FI_CO2 simulations can be run on one computer, and the raw output files later transferred to another computer. The transfer process is simple: just copy the specific run output folders in their entirety (e.g., \EdGCM\Output\Modern_PredictedSST) from the first computer into the \EdGCM\Output folder of the second computer. To verify that the transferred output files are recognized by EdGCM on the second computer, launch EdGCM and check the run list in the ToolBar. There should be a solid blue circle next to the specific run names in the list, indicating that the transferred output files are available for analysis and visualization.

A video tutorial explaining the full export/import process, including the transfer of custom simulation setups, is available on the EdGCM web site at: http://edgcm.columbia.edu/downloads/tutorials/importexport.htm

What can I do if I cannot run the simulation? The output files can be downloaded from the NASA/GISS ftp site:

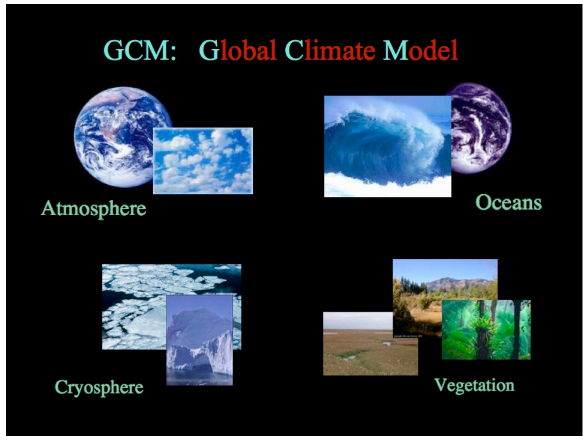
ftp://ftp.giss.nasa.gov/pub/edgcm/EET_EdGCMoutput.zip

As this is a large download, on the order of 2 GB, it will still take quite a while to complete. Patience is in order.

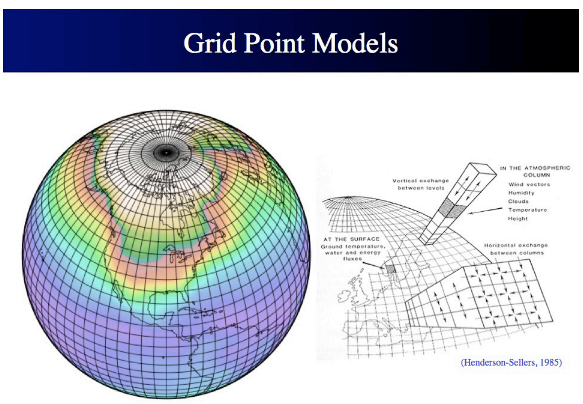
Once the files are downloaded, move the files to the right location within the EdGCM folder, as described above for transferred output files.

Part 2—Climate Models

Introduction to Global Climate Modeling

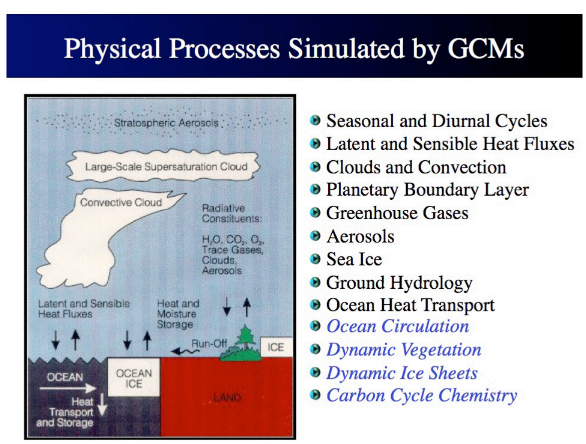


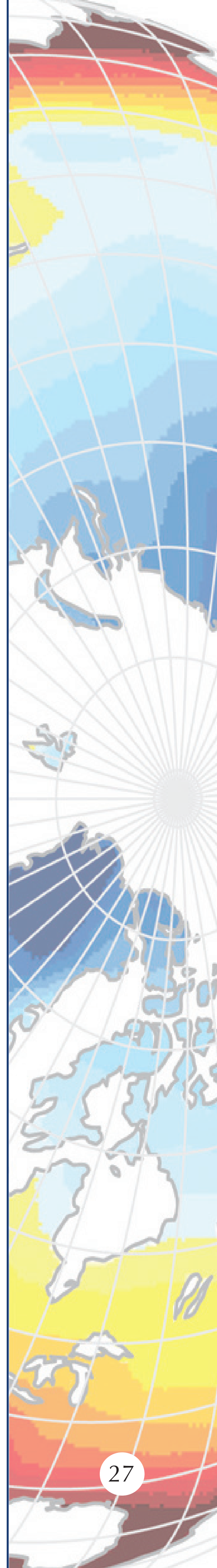
Modeling involves using preset differential mathematical equations to represent the forces that control a situation. By changing variables in the equation, one can envision a future outcome. The primary earth system components that are simulated by a global climate model (GCM) include the atmosphere, oceans, land surface – including vegetation, and the cryosphere (ice and snow). An interactive diagram of GCM components from UCAR (http://www.ucar.edu/news/features/climatechange/ccsm-illus.jsp) gives a detailed description about the roles each component plays in the system.



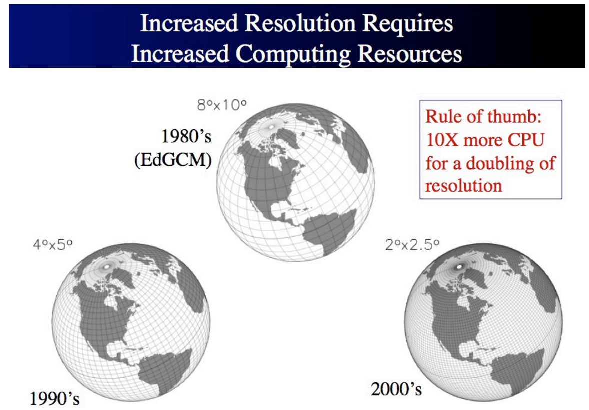
GCMs divide the atmosphere, oceans and land into a 3-dimensional grid system. The physics equations and parameterizations are then calculated for each cell in the grid over and over again, representing the march forward in time, throughout the simulation. On the left below is a schematic diagram of the physical processes simulated by GCMs. Many calculations beyond the fundamental physics equations use "parameterizations". Parameterizations are formulas based on empirical evidence, meaning they are based on observations or the results of experiments.

The fundamental physical quantities calculated by the GCM include Temperature (T), Pressure (P), Winds (East-West = U, North-South = V), and the Specific Humidity (Q). Differential equations are used to relate these fundamental quantities to each other. Though these equations may look quite complex and difficult to understand, they are common math that scientists learn during college.

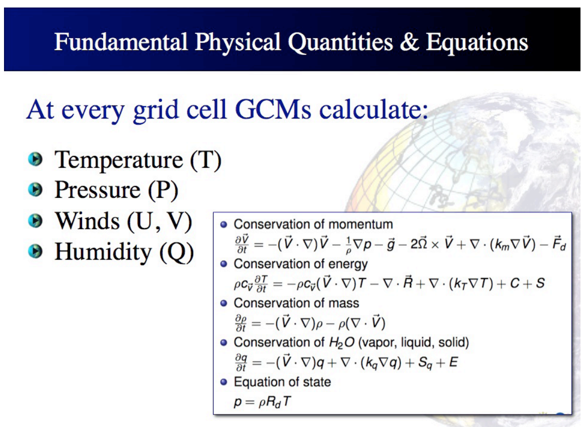


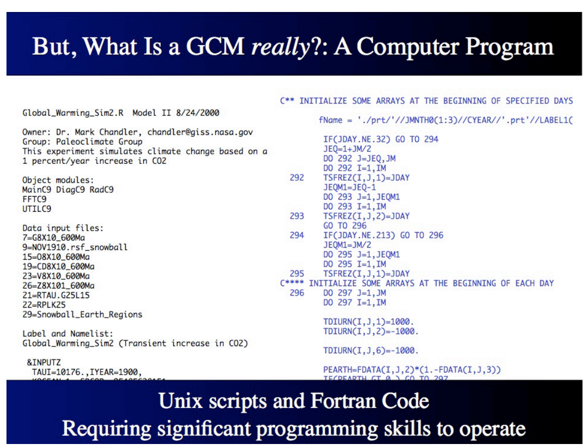


The number of cells in the grid system is known as the "resolution." The more grid cells, the higher the resolution, and the more calculations that must be computed. In general, GCMs are able to represent processes more realistically as they become higher resolution, but the computing time required to do the calculations goes up roughly 10X for every doubling of the resolution. EdGCM uses a GCM with a coarse grid resolution (8° X 10° latitude by longitude) in order to reduce the numbers of calculations and make it possible for the GCM to run on desktop and laptop computers. Pictured are some common grid resolutions for the NASA climate models and the decade during which supercomputers could run GCMs with that resolution.



GCMs are computer programs, often hundreds of thousands of lines of code, mostly written in Fortran and strung together by Unix scripts. They generally require a high level of programming skills to operate. However, EdGCM adds a graphical user interface, a database, and some simple structures that allow non-programmers to do many of the experiments with a GCM that programmers and scientists do in their research.





How are the Variables Chosen for Climate Models?

Climate simulations are based on a set of variables that are the result of complex predictions known as scenarios. In this exercise we are using the greenhouse gas predictions from the IPCC emissions scenario A1 - Fossil Fuel Intensive (FI). This scenario, explained below, was chosen for this exercise because it is the most realistic course for the development of world economies and populations.

From the IPCC special report on emissions scenarios:

> The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

For more information about emissions scenarios, see the IPCC's description at http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=25.

How is Climate Modeling Implemented?

Modeling is using preset differential mathematical equations to represent the forces that control a situation, in this case climate. By changing variables in the equation one can envision a future outcome. As in other scientific investigations, climate experiments, or model runs, are generally compared to control runs. Control runs use known conditions for the oceans and atmosphere. These are characteristic conditions from the years 1951 -1980. This time period is chosen because 1958 was the first year that greenhouse gases were measured. At that point, in 1958, the greenhouse gas CO2 were at a concentration of 315 parts per million (ppm) already 10% above pre-industrial values. The Modern Predicted Sea Surface Temperature (SST) run serves as a control run for this unit. This simulation has constant forcings, which make it easiest to predict. If the run results of this simulation were to exhibit large changes over time it would indicate problems with the model's output.

Optional: Learn More about EdGCM Performance

The complete EdGCM Manual (http://edgcm.columbia.edu/documentation/EdGCM_Manual_v3.2.pdf) (PDF 7.2MB Aug15 09) is available. The manual has detailed instructions for users of the software, including information on how fast the software will run on various computers. Climate models are complex and take large amounts of computing time to complete. Teachers who are unsure of their computer's technical capability should check with their IT department for information.

Part 3 — Generate a Time Series Plot of Temperature

Step 1 – Launch EdGCM

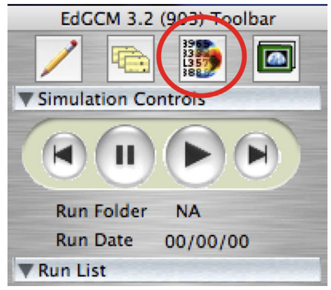
1. Launch EdGCM by double clicking on the icon (alias pictured to the right) in the EdGCM folder. The application will load. The tool bar window will appear. It is from this toolbar window that the user controls the software. The buttons in this window will change depending on the active window.

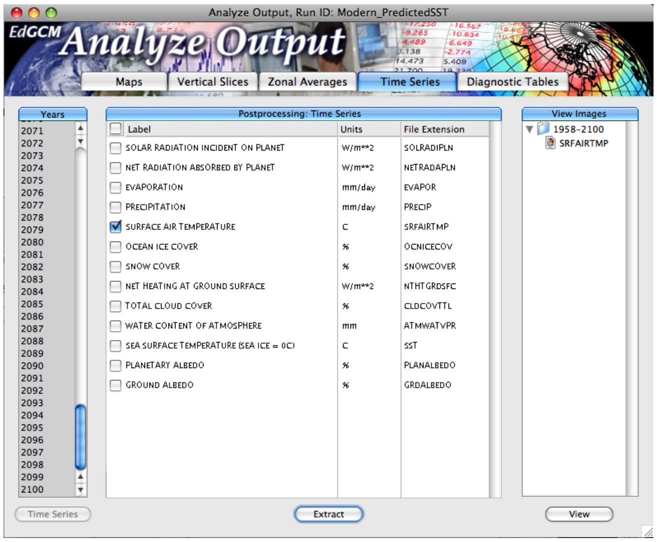
2. On the left side of the Toolbar window, select **Modern_PredictedSST** in the toolbar **Run List**. To "select" a file in EdGCM, single click on the name.

> Modern_PredictedSST is a simulation that demonstrates what future climate would be like with no increase in greenhouse gases or any other variables, such as solar luminosity. This is the baseline, or "control run", for any climate change experiments.

3. In EdGCM, use the drop down Window menu and select, Analyze Output or, use the Analyze Output button at the top of the Toolbar (pictured right).

4. In the Analyze Output window, click on the Time Series tab near the top of the window, then click the button called Time Series in the bottom left hand corner of the window.





Note: If this step has been done previously, the Time Series button may be grayed out (i.e., inactive); if so, progress to the next step.

This step runs a program that takes a little while on slower computers. To save time the teacher might do this step before class.

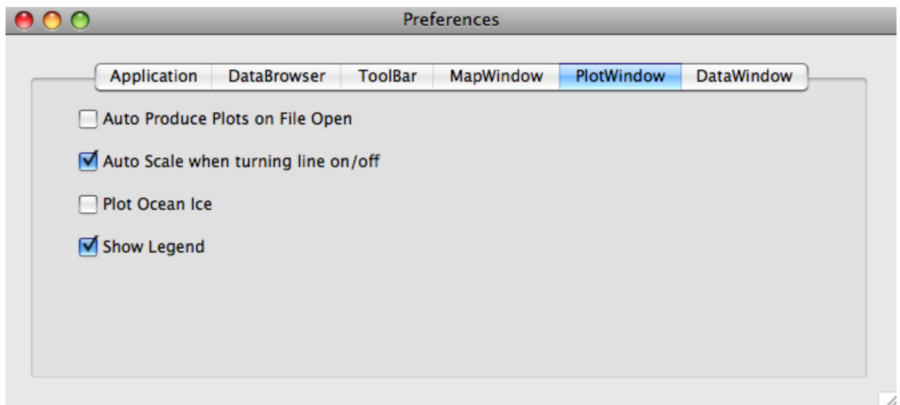
Once this button is clicked a new window will open, showing you that the program is running a Time Series.

5. In the list of variables in the center section of Analyze Output window, select the check box next to **Surface Air Temperature** then click the **Extract** button in the center bottom part of window.

Note: If the extract button is grayed out you have not yet computed the Time Series; it is described in the previous step.

6. In the right hand column of this window, under **view images**, select SRFAIRTMP (Surface Air Temperature) and click the **View** button below that column. This will launch EdGCM's scientific visualization application or EVA, and open EVA's Data Browser window. The Data Browser will list one simulation in the File column, Surface Air Temperature in the Variable column, and 5 items in the Time or Region column. Confirm that you have these items and then ignore this window while you import a second data set.

7. In EVA data browser open the **preference** window. Under the **Plot Window** menu de-select (turn off) the **auto produce plots on file open**. Close the preference window.



Step 2 - Select the IPCC_A1FI_CO2 Simulation for Comparison

1. Return to EdGCM and select the **IPCC_A1FI_CO2** simulation, by single clicking on the name in the Run List.

> IPCC_A1FI_CO2 is the climate change experiment where the greenhouse gas quantities increase gradually as the model runs. These greenhouse gas "trends" have been predicted by scientists and economists working for the Intergovernmental Panel on Climate Change (IPCC) and are based on projections of how much energy humans will use in the future.

2. Extract the data for analysis by repeating the steps numbered 4-6 from Step 1 with IPCC_A1FI_CO2 simulation.

   a. On the left side of the Toolbar window, select **IPCC_A1FI_CO2** in the toolbar **Run List**. Note: to "select" a file in EdGCM, single click on the name.

   b. In EdGCM use the drop down Window menu and select, **Analyze Output** or, use the Analyse Output button at the top of the Toolbar.

   c. In the Analyze Output window, click on the **Time Series** tab near the top of the window, then click the button called **Time Series** in the bottom left hand corner of the window.

Note: If this step has been done previously, the Time Series button may be grayed out (i.e inactive), if so progress to the next step.

This step runs a program that takes a little while on slower computers. To save time the teacher might do this step before class.

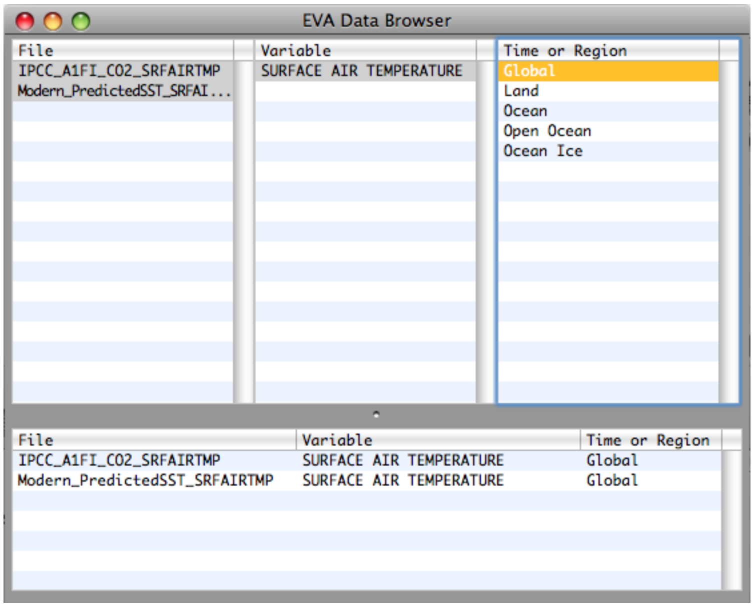
Once this button is clicked a new window will open showing you that the program is running a Time Series.

d. In the list of variables in the center section of Analyze Output window, select the check box next to **Surface Air Temperature** then click the **Extract** button in the center bottom part of window. *Note: If the extract button is grayed out you have not yet computed the Time Series, it is described in the previous step.*

e. In the right hand column of this window, under view images, select **SRFAIRTMP** (Surface Air Temperature) and click the **View** button below that column. This will launch EdGCM's scientific visualization application or EVA, and open EVA's Data Browser window. The Data Browser will list two simulations in the File column, Surface Air Temperature in the Variable column, and 5 items in the Time or Region column. Confirm that you have these items and then ignore this window while you import a second data set.

Step 3 - Plot your Selections

1. In EVA data browser, select the **two SRFAIRTMP** files listed in the 1st column, by clicking with the shift key held down. Then select **Surface Air Temperature** (2nd column), and select **Global** (3rd column).

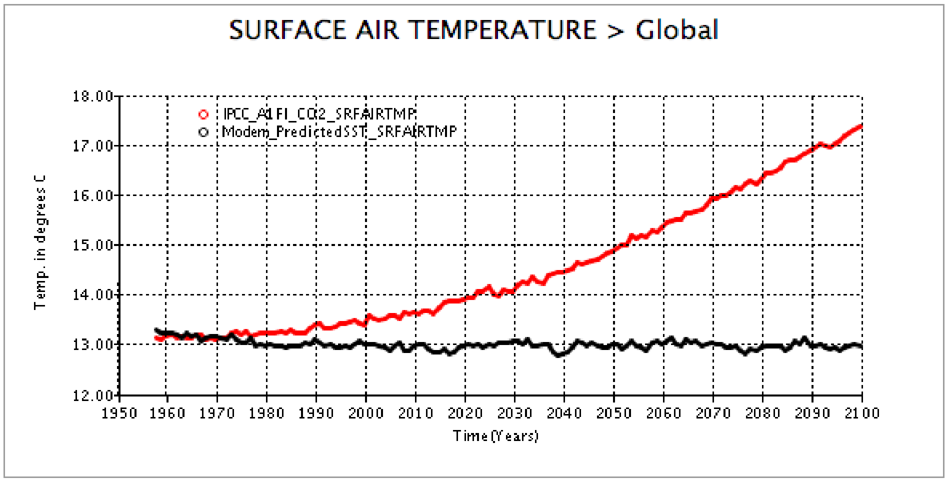


2. Click the button on lower right to **Plot All**. The program may hesitate briefly as it prepares an image (graph), then it will plot the two temperature trends on the same graph.

Step 4 - Finalize your Graph

1. Finalize your first graph as instructed below.

    - Click and drag the legend to relocate it to the upper left hand corner.
    - Click to turn on horizontal and vertical grids.
    - Clean up the legend by changing the colors.
    - Add a title "temperature in degrees C" to the Y axis.



2. Answer the following questions about the graph:

    - How do the 2 temperature trends differ?
    - Predict where the IPCC graph will be in 50 more years - explain your prediction.

The IPCC trend is dramatically steeper than the control run. The IPCC graph will continue to rise for the next 50 -100 years as more CO_2 is added to the atmosphere and other feedbacks kick in.

3. Save your graph for future reference.

Step 5 - Use EdGCM to Calculate the Difference Between Simulations

1. In EVA data browser, use the pull down **differencing** menu, located in the lower right hand corner, and select the two files to compare. Subtract the control run (**Modern_PredictedSST**) from the experimental run (**IPCC_A1FI_CO2**).

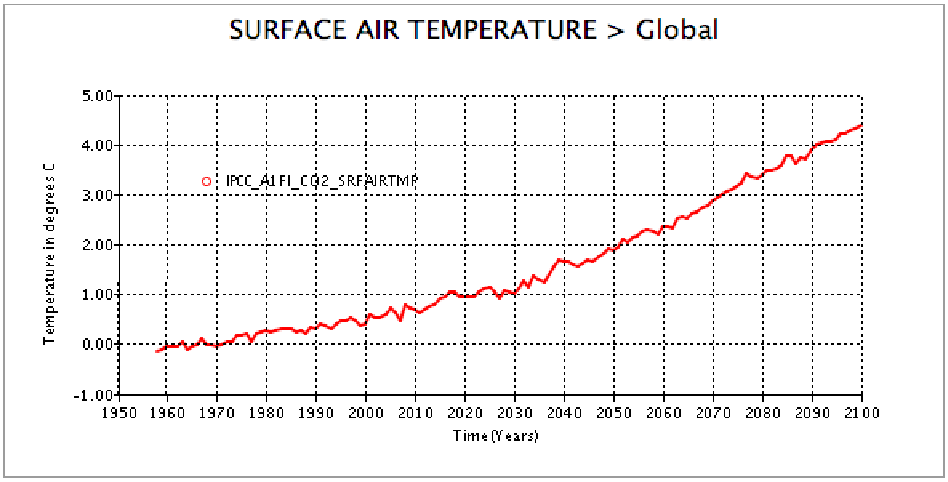
How to subtract: Data 1 is the first graph generated and Data 2 is the second. The order of the list itself is determined by the order the data was added to the browser. In this example the equation will be (data 2-data 1) or (IPCC_A1FI_CO2) - (Modern_PredictedSST).

2. If needed, click the **Plot All** button. Note: In most cases the plot will automatically be generated.

3. Finalize your graph Click and drag the legend to relocate it to the upper left hand corner.

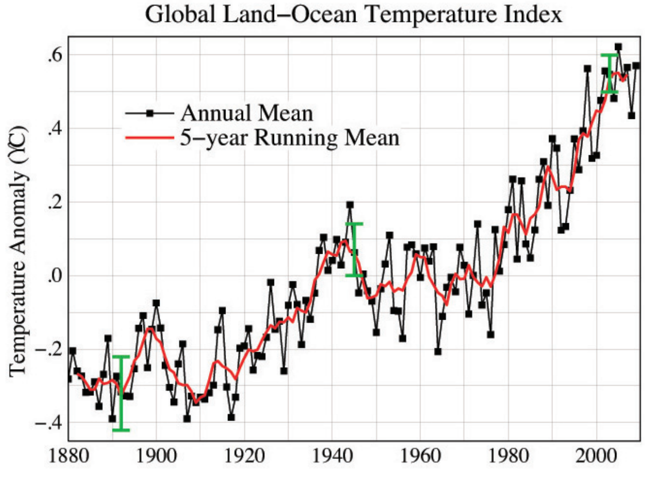
    - Click to turn on horizontal and vertical grids.
    - Clean up the legend, by changing the colors and font size.
    - Add a title "difference in temperature in degrees C" to the Y axis.

    Note the units on the difference graph are not the same as on the original graph. They are degrees of difference between the first simulation and the second. This "difference" is also known as an anomaly.



4. Save the new graph.

5. Compare your graph of modeled data with the one from NASA observed data. Note: the axes on the two graphs differ (1880-2010 vs. 1950-2100 on X axes) because the observational record is different from the years simulated with the model. On the Y axes the scale is much larger on the modeled data than the observed data. Make sure you are comparing data where the two overlap. *Optional: read more about this graph of Global Annual Mean Surface Air Temperature Change at* http://data.giss.nasa.gov/gistemp/graphs/



Line plot of global mean land-ocean temperature index, 1880 to present. The dotted black line is the annual mean and the solid red line is the five-year mean. The green bars show uncertainty estimates. [This is an update of Fig. 1A in Hansen et al. (2006)]

Answer the following questions:

- How does the modeled data IPCC_A1FI_CO2 compare with the observational data? Are there years where they are the same? different?
- By how much does the temperature change in each graph between the years 1960 and 2000?
- What other information do graphs of average global temperature leave out?

> The two graphs, observed and modeled, show the same results in the years 1960-2000. The amount of change is slight, less than 1 degree Celsius. A graph of global temperature average does not show what is happening in any one particular location. In some areas, such as the Arctic these changes are much more extreme, hence the importance of local monitoring efforts.

6. *Optional*: Compare your graph of modeled data using EdGCM to other graphs of temperature trends from the NCAR climate model animation, http://www.vets.ucar.edu/vg/IPCC_CCSM3/index.shtml. Note the similarities and differences in the 4 trends. These 4 trends are based on separate scenarios. Read more about scenarios in Part 1.

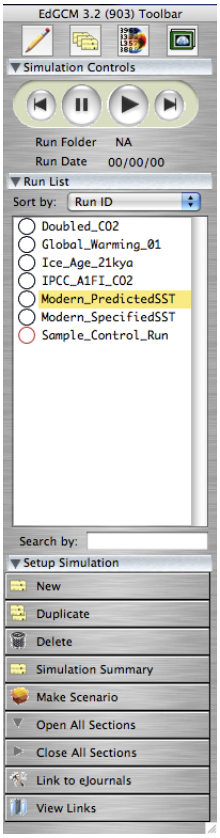
7. If this is the end of your first session, quit EdGCM as instructed by your teacher.

Part 4—Generate Temperature Maps Using EVA

Step 1 - Launch EdGCM

1. Launch EdGCM by double clicking on the icon in the EdGCM folder; the application will load and the **toolbar** window will appear. This toolbar window is the controller for the software. The buttons will change depending on your active window.

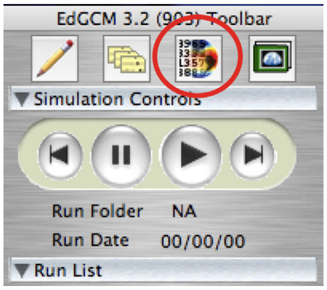
2. In this window, choose **Modern_PredictedSST** in the toolbar **Run List**. This is the baseline for the model. In this simulation scientists have used our present climatic conditions in order to demonstrate the future climate trends with no change in present greenhouse gases or other variables, such as solar luminosity. This is the baseline for comparison with the experimental IPCC_A1FI_CO2 simulation in which greenhouse gases and other conditions have been changed according to the IPCC_A1FI_CO2 scenario. These scenarios are described in detail in Part 1.

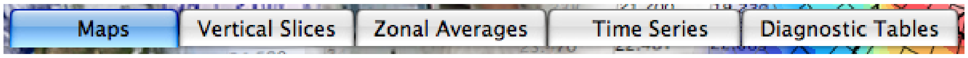


Step 2 - Generate a Map

1. Launch the **Analyze Output** feature of the EdGCM, by clicking on the button on the top of the toolbar. Or use the drop down **window** menu.

2. Click on the **maps** tab.



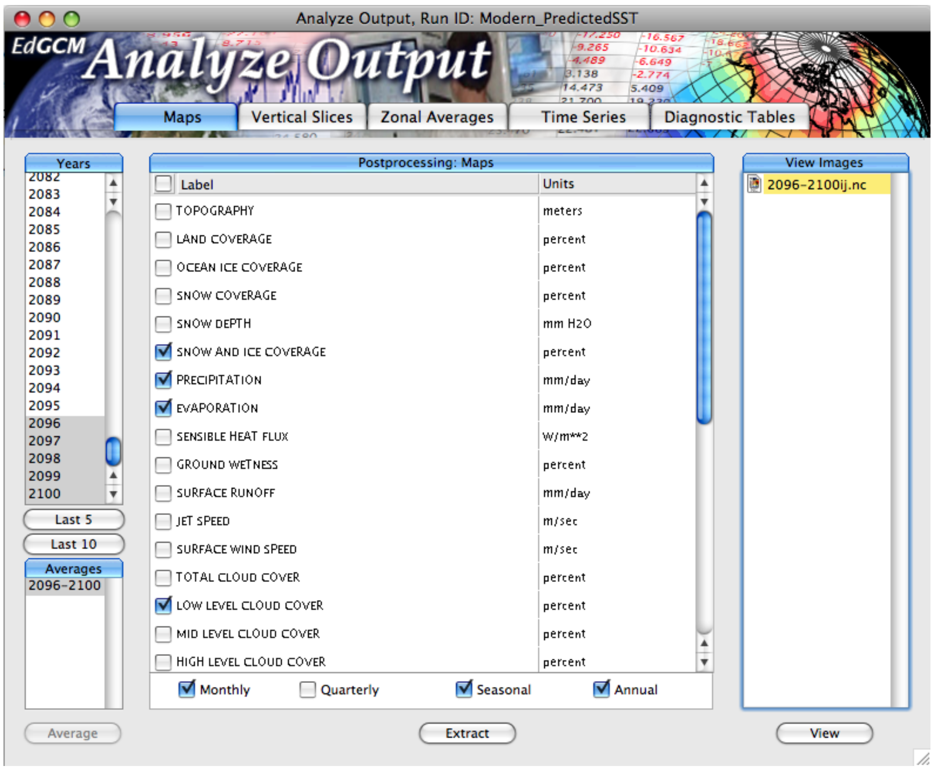


Step 3 - Prepare Output for Analysis

1. On the left hand side of the Analyze Output window, choose the last five years by clicking on the **Last 5** button. Alternately, manually select the years of your choice. Note: Using a group of five or more years helps to smooth out some variables that may differ a lot from year to year.

2. Once the years have been selected, click the **Average** button at the bottom of the list. This creates an average of all variables from the last 5 years of the simulation. A window opens as the files are “post-processed”. This step may take up to a minute to complete. Note: if this step has already been completed the button may be grayed out (inactive).

   When complete, the year range 2096-2100 will appear in the Averages list in the lower right corner of the window. Make sure this is selected by single clicking on it.



3. In the center section of the Analyze Output window select from the following variables by clicking on the checkbox next to each:

   - snow and ice coverage
   - precipitation
   - evaporation
   - low level cloud coverage
   - surface air temperature (in C)
   - max surface air temperature (in K)

   > ***To convert temperature from K to C:*** Subtract 273 from K to get value in C. 373 degrees Kelvin is equal to 100 Celsius.

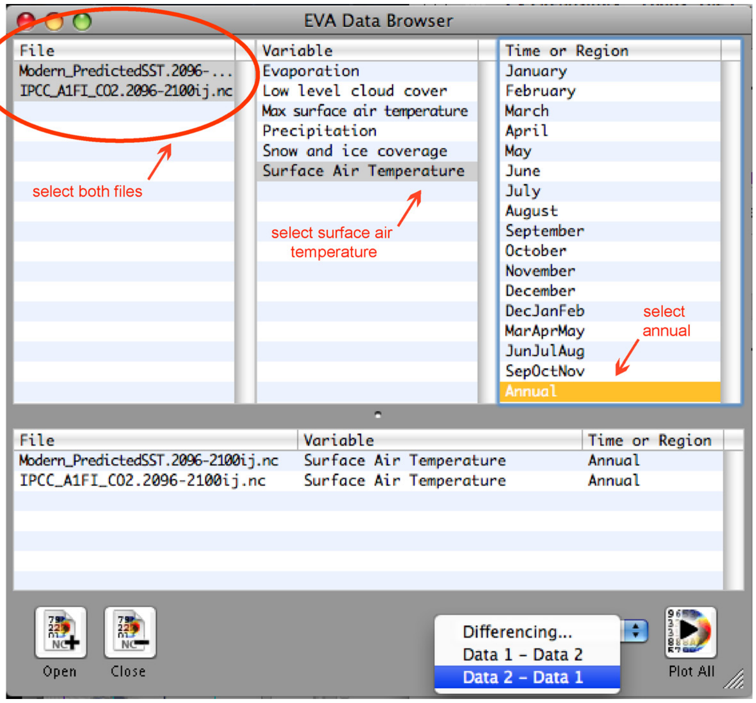
4. Check the **Monthly, Seasonal** and **Annual** check boxes at the bottom of the Analyze Output window.

5. Click on **Extract** button; you will see a window open, which shows that another post-processing program is running.

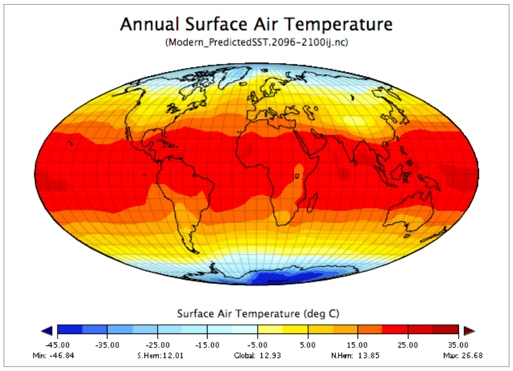
6. Under **View Images** Select the **2096-2100ij.nc** file, then click the **View** button at the bottom right of the window. EdGCM's Visualization Application, EVA, will launch. Ignore it for the moment.
7. Repeat numbers 1-6 from above for IPCC_A1FI_CO2 simulation. Now both files are listed in the EVA data browser window under the file header.

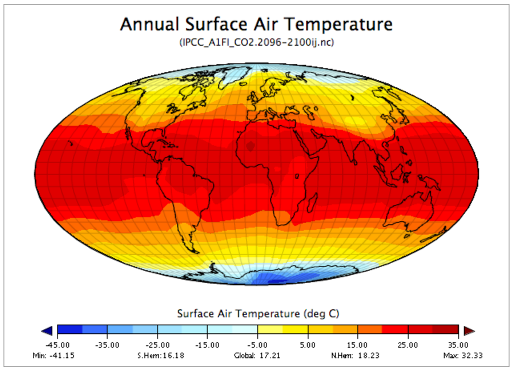
Step 4 - Generate Temperature Maps

1. Use the shift key to select the **Modern_PredictedSST** and the **IPCC_A1FI_CO2** files in the left column of the EVA data browser. Then select **Surface Air Temperature** in the center and **Annual** in the right column.



2. Click the **Plot All** button. The software will generate two maps: **Modern_PredictedSST** Surface Air Temperature and **IPCC_A1FI_CO2** Surface Air Temperature.





3. The maps need to be interpolated, or smoothed. To do this click the "interpolate" check box in the toolbar next to each map (it is near the top of the toolbar).

> Interpolation is a method of smoothing data points. According to the Merriam Webster Dictionary, "It allows one to estimate values of (data or a function) between two known values."

Step 5 - Finalize the Maps

1. Click on the **Projection** menu under map heading in on the toolbar. Use the pulldown menu to change the projection to **Mollweide**.

2. Change the range shown on the **Color bar /scale** so that the minimum is -45C and the maximum is +35C on both maps. This will give you the same end points on the color bars of both plots.

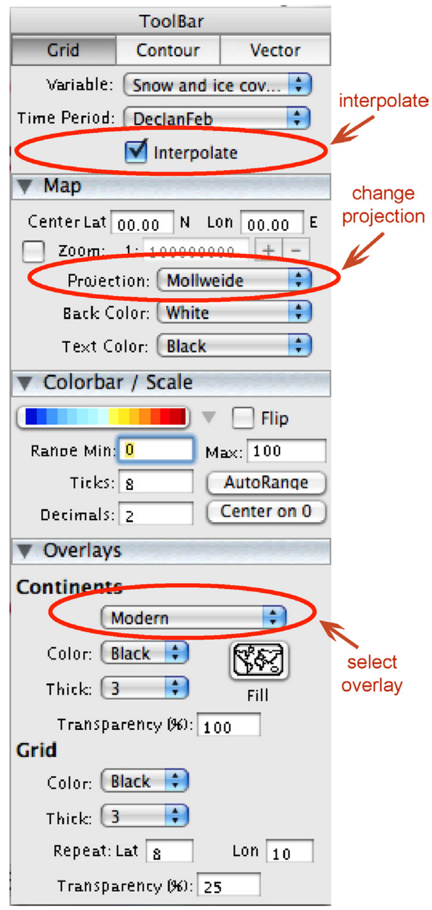
3. Add overlay **modern with USA** for both maps. Optional: Explore other overlay options.

4. When you are done, save your maps to use in the next part of the lesson.

5. Answer the following questions about your maps:

   - What areas of both maps are the warmest? coolest?

   - Describe how the two maps are alike and different. In particular, focus on the polar and equatorial regions.



> The equatorial regions are the warmest, polar regions coolest. In the IPCC_A1FI map the equatorial regions are several degrees warmer than in the control map. The polar regions have also warmed more in the IPCC_A1FI map. The change between the maps is subtle, but significant.

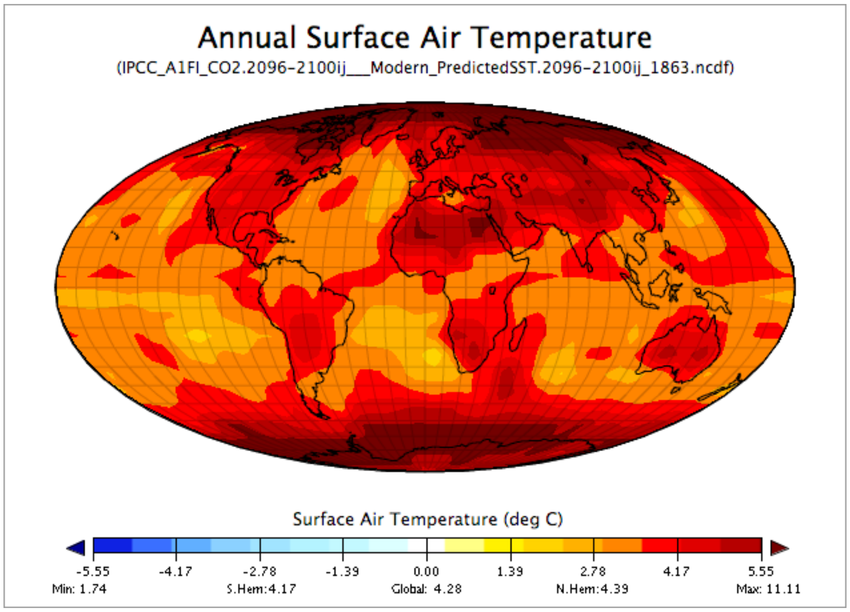
Step 6 - How will Global Warming gases Effect Temperatures?

1. In EVA's Data Browser, subtract the control run, **Modern_PredictedSST**, from the climate change experiment (**IPCC_A1FI_CO2**) using the differencing drop down menu (as in Step 4.1 above).

Another method to do differencing is to right-click (PC) or control-click (Mac) on the IPCC_A1FI_CO2 map that you just generated. In the menu that appears, choose differencing and me - X (IPCC_A1FI_CO2 – Modern PredictedSST).

2. Adjust the Color Scale Use the map toolbar and click on the colorbar to choose a new color scale, such as **panoply_diff.pa1**, click **center on zero**. If necessary “flip” the color scale using a checkbox in the map’s toolbar to make the hottest temperatures appear in red.

It is best to use a colorbar with 1) white in the center (to represent no change), 2) a strong contrast from left side to right side, and 3) a color-variable connection that to most people would be logical (e.g. red = warm, blue = cold). In the case of the temperature difference map, set it up so that people can quickly see the main qualitative point. This difference map shows the Earth in 2100 where the temperature differences in all area show warming everywhere, with no areas cooling.



3. Answer the following questions about your map:

- What regions show the greatest increase in temperature?
- Do any regions show a decrease in temperature?
- Why do you suppose the greatest temperature increases are over the continents rather than the oceans?

The greatest increases in temperature are over the land masses and the Polar regions. No regions show a decrease in temperature. The oceans are able to absorb heat and act as cooling system.

Part 5—Generate Snow and Ice Coverage Maps

Note: If this is a new session with EdGCM, you will need to complete Steps 1-3 below. If you already have the program running you can move directly to step 4.

Step 1 - Launch EdGCM

1. Launch EdGCM by double clicking on the icon in the EdGCM folder, the application will load. The **toolbar** window will appear. This toolbar window is the controller for the software. The buttons will change depending on your active window.

2. In this window, choose **Modern Predicted SST** in the toolbar **Run List**. This is the baseline for the model. In this simulation scientists have used climatic conditions from 1958 in order to demonstrate the future climate trends with no increase in greenhouse gases or other variables such as solar luminosity. This is the baseline, or control, for comparison to the climate change runs.

Step 2 - Generate a Map

1. Launch the **Analyze Output** feature of the EdGCM, by clicking on the button on the top of the toolbar. Or use the drop down **window** menu.

2. Click on the **maps** tab.

Step 3 - Prepare Output for Analysis

1. On the left hand side of the Analyze Output window, choose the last five years by clicking on the **Last 5** button. Alternately, manually select the years of your choice. Note: Using a group of five or more years helps to smooth out some variables that may differ a lot from year to year.

2. Once the years have been selected, click the **Average** button at the bottom of the list. This creates an average of all variables from the last 5 years of the simulation. A window opens as the files are "post-processed". This step may take up to a minute to complete. Note: if this step has already been completed the button may be grayed out (inactive).

   When complete, the year range 2096-2100 will appear in the Averages list in the lower right corner of the window. Make sure this is selected by single clicking on it.

3. In the center section of the Analyze Output window select from the following variables by clicking on the checkbox next to each:

   - snow and ice coverage
   - precipitation
   - evaporation
   - low level cloud coverage

- surface air temperature (in C)
- max surface air temperature (in K)

> To convert K to C, subtract 273 from K to get value in C. In other words, 373 degrees Kelvin is equal to 100 degrees Celsius.

4. Check the **Monthly Seasonal** and **Annual** check boxes at the bottom of the Analyze Output window.

5. Click on **Extract** button, you will see a window open, which shows that another postprocessing program is running.

6. Under **View Images** Select the **2096-2100ij.nc** file, then click the **View** button at the bottom right of the window. EdGCM's Visualization Application, EVA, will launch. Ignore it for the moment.

7. Repeat numbers 2-6 from above for **IPCC_A1FI_CO2** simulation. Now both files are listed in the EVA data browser window under the **file** header.

Step 4 - Generate Snow and Ice Coverage Maps.

1. In EVA Data Browser window, hold down the shift key and select both the **Modern Predicted SST** and the **IPCC_A1FI_CO2** scenarios in the upper left file window. Then select Snow and Ice Coverage in the center and Dec,Jan,Feb in the right column. Both files will appear in the lower bottom file pane in the order that you generated them.
2. Click the **Plot All** button. The software will generate two maps: **Modern_ PredictedSST** Snow and Ice Coverage and **IPCC_A1FI_CO2** Snow and Ice Coverage.
3. The maps need to be interpolated, or smoothed. To do this click the "interpolate" check box in the toolbar next to each map (it is near the top of the toolbar).

> Interpolation is a method of smoothing data points. According to the Merriam Webster Dictionary, "It allows one to estimate values of (data or a function) between two known values."

Step 5 - Finalize the Maps

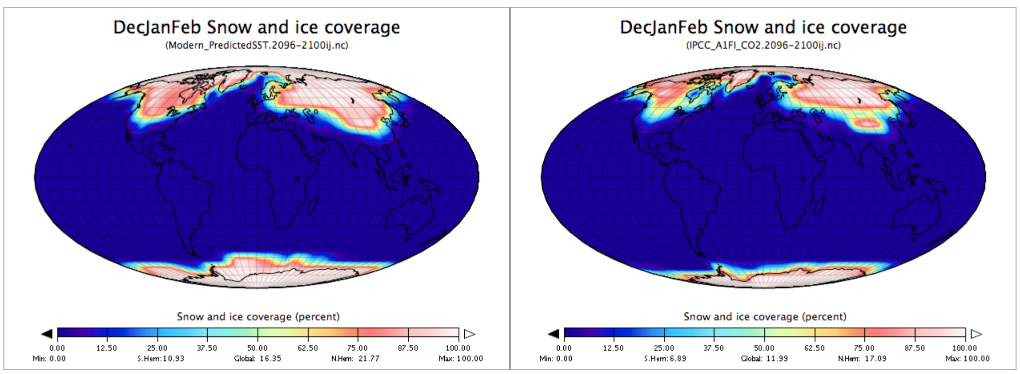
1. Click on the **Projection** menu under map heading in on the toolbar. Use the pulldown menu to change the projection to **Mollweide**.

> Mollweide map projections are a type of equal-area map where the central meridian and latitude lines are straight. They are generally used for global maps. The advantage of this type of projection is that it accurately portrays area while distorting shape and direction. Each type of map projection distorts one or more of these variables, and no projection accurately portrays them all.

2. Note the range shown on the **Colorbar / scale** is now in percentage coverage, with 100% coverage the most complete and 0% the least.
3. Change the **Colorbar / scale** to **haxby.pa1**.
4. Add overlay **modern with USA** for both maps. Explore other overlay options.
5. Save your maps for future reference.
6. Answer the following questions about your maps:
    - In your mind, what is 100% snow coverage?

    > 100% snow coverage is where the snow is continuous without any gaps or open patches. The greatest changes in snow coverage is in Russia (Siberia), the Himalayan Mountain Region and Western North America.

    - Compare the two maps; in what regions of the Earth do you see the greatest change in snow coverage?



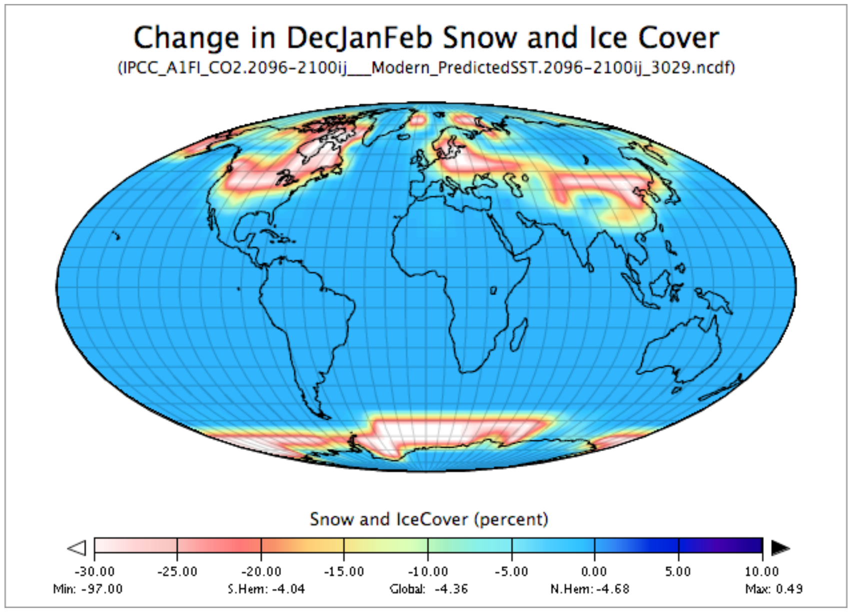
Step 6 - What Effect will Climate Change have on Snow and Ice Coverage?

1. Repeat the steps you used in Part 3 to generate a differencing map, only this time use the snow ice coverage maps.

    > In EVA's Data Browser, subtract the control run, **Modern_ PredictedSST**, from the climate change experiment (**IPCC_A1FI_CO2**) using the differencing drop down menu.
    >
    > Another method to do differencing is to right click (PC) or control click (Mac) on the IPCC_A1FI_CO2 map that you just generated. In the menu that appears, choose differencing and me-X (IPCC_A1FI_CO2 – Modern_ PredictedSST).

2. Edit the map **Colorbar / scale** to emphasize the change of snow and ice coverage.
    - Check the flip checkbox
    - Adjust the range of the colorbar / scale to a maximum of 10 and a minimum of -30

3. Save your map for further reference. When you save the map rename it with a name that describes the map, such as "snow coverage map".



4. Once you have completed the maps answer the following questions.

- How much will the snow coverage decrease by 2100 according to the model?

  The range will be between 10 and 30 percent, depending on the area you are looking at.

- How does this trend compare to the trends seen in satellite observations of changes in North American snow coverage? See NSIDC State of the Cryosphere (http://nsidc.org/sotc/snow_extent.html) for more information, maps and graphs.

- Snow is an important part of nature's water storage system. How will climate change impact water resources in the United State? Read the full report, Water Resources (http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/climate-change-impacts-by-sector/water-resources).

- The snow and ice covered regions of the Earth are known as the cryosphere. These regions are important to the entire world's population. Not only do they supply recreation and fresh water, they also help to moderate the temperature of the planet. To learn more about the cryosphere consult the National Snow and Ice Data Center (http://nsidc.org/cryosphere/allaboutcryosphere.html).

Part 6—Explore Climate Change Impacts on Another Region

Step 1 - Observe Regions Affected by Global Temperature Anomaly

The anomaly maps from the EdGCM reveal that some regions of the world may experience a greater temperature anomaly, and/or a greater loss of ice and snow cover, than others, including regions in which students completing this exercise may reside. The map grid cells overlying these regions provide the actual data for comparison. In this part of the exercise students will choose to analyze the data from the grid cells nearest the region in which their city resides, as well as from another region of the world to which they can compare their "home" data.

Global regions for comparison are outlined below. The IPCC has identified countries and regions with the greatest risk of impact from climate change. These impacts are not always due just to temperature, so it will be necessary to make the connection between temperature and other results of climate change, allowing students to speculate on how each country or region may be impacted and why some countries or regions may have greater concerns than others regarding projected climate change data.

When deciding on a region, think in terms of impacts to:

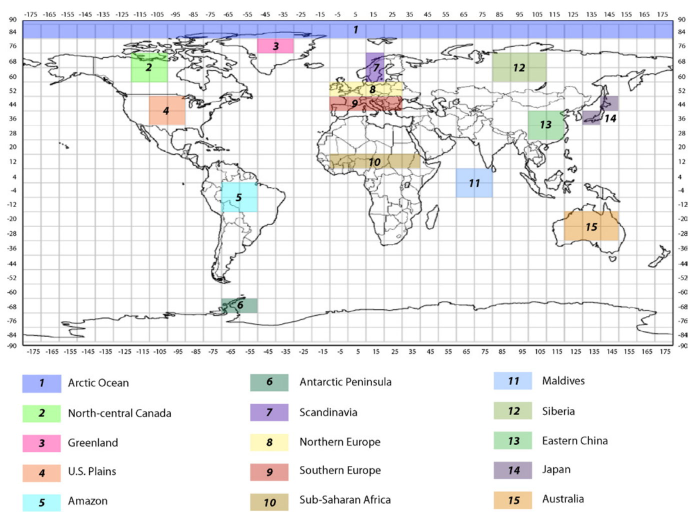
- the environment – loss of biodiversity, loss of habitat, changes to ecosystem components
- economic activities – primary sector (such as agriculture, mining, forestry), secondary sector (such as construction or manufacturing), and tertiary sector (recreation and tourism, retail, financial)
- human populations – such as increased incidence of diseases or natural hazards, migration and resettlement, or cultural adaptations to a changing environment (clothing, housing, food, etc.)

Step 2 - Choose a Grid Cell for your "Home Region"

Download the regions map like the one below. (http://serc.carleton.edu/files/eet/envisioningclimatechange/regions_map_grid_cells.pdf) (PDF 369kB Aug19 09)

Choose a "grid cell" from your region of interest.

Note the latitude and longitude of the highlighted area on the map. Use these numbers when zooming into your region of interest with EdGCM.



Step 3 - Choose a Region of Interest and Impact from the list below

I. Europe: particularly Western and Southern Europe (Portugal, Spain, France, Italy, Switzerland, Germany, Luxembourg, Belgium, Netherlands), and the Scandinavian countries (Norway, Sweden, Finland)

- The 2003 European heat wave, which is estimated to have killed 70,000 people mostly in Western and Southern Europe, is attributed to climate change and particularly to increased maximum temperatures. More frequent and intense heat waves are projected, impacting health in Europe's densely populated urban areas.
- Increased temperatures and changes to rainfall patterns will impact agriculture.
- Mountainous areas will face glacial retreat and reduced snow cover, which will impact biodiversity as well as recreation and tourism.
- In southern Europe, climate change is projected to increase the frequency and magnitude of heat waves and drought, potentially impacting water availability, and the ability to generate hydroelectric power.
- Summer and winter tourism could be affected by these changes.

II. Russian Region: particularly Siberian Russia

- Though sparsely populated, Siberia is home to the largest coniferous forest in the world (the Taiga), an ecosystem that is adapted to cold, relatively dry climates with a short, distinct summer season.
- Increased temperatures will alter the Taiga ecosystem, impacting peat-forming wetlands (important to the global carbon cycle) as well as the fauna unique to the Taiga.
- Climate change potentially impacts logging and other forest-related economic activities, as well as dairy farming (esp. in the Vologda region) and crop production.

III. East Asia: particularly China

- Western China, mostly high desert and steppe, is likely to see drier conditions, impacting agriculture and water availability.
- Snow melt in the mountains may increase stream levels and increase flooding at lower elevations further east.

IV. South Asia: particularly India and Bangladesh

- Snow melt in the Himalayas is a significant source for the largest rivers in this region (Indus, Ganges, and Brahmaputra).
- Increased temperatures will increase snow melt, increasing flood hazards, which is already a problem in Bangladesh. Impacts on monsoonal rainfall patterns are uncertain, but could increase the length and intensity of seasonal droughts and flooding.

- Impacts on human health from flooding and drought, particularly waterborne diseases in the most densely population regions.
- Impacts on agriculture, which is a significant part of the economies of both India and Bangladesh.

V. Southeast Asia: Impacts are not as discernible in this region

- The IPCC cites potential downstream flooding, combined with sea level rise, as the major impact in this region, so the impacts are more indirect.
- Coastal urban areas (sea level rise) and agriculture will experience the main impacts.

VI. South Pacific and Oceania: particularly Australia

- Australia’s drought-prone interior is expected to get hotter and experience longer and more intense droughts.
- Loss of biodiversity in the Great Barrier Reef and Queensland tropics due to increased temperatures.
- Impacts on agriculture and on the availability of water resources in both Australia (southern and eastern) and New Zealand.
- In small Pacific Island nations, higher temperatures will result in increased invasion by non-native species, which is already a problem. Indirectly, sea level rise will impact fresh water and cause deterioration of coastal conditions, forcing evacuation and migration (e.g. the island nation of Tuvalu).

VII. North Africa and Middle East: particularly northern African nations (Morocco, Algeria, Tunisia, Libya, Egypt)

- Hotter, drier, greater competition for already-limited water resources.
- Human health impacts from increased temperatures, lack of water resources.

VIII. Sub-Saharan Africa: particularly countries in two sub-regions (probably best to look at the entire sub-region rather than the individual nations)

- The Sahel (Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger, Senegal)
- The Sahel is the transition between the Sahara desert in the north and the tropical savannah (grasslands) to the south, an area already prone to prolonged droughts. An increase of 5 to 8% of arid and semi-arid land throughout Africa is projected by the IPCC, impacting this region in particular.
- Affects agriculture of all kinds: crops, grazing and animal husbandry. Yields from rain-fed agriculture could be reduced by up to 50% according to the IPCC report.
- Competition for scarce water resources will increase.
- Human health impacts from increased temperatures, lack of water resources, could result in large migrations of people from this subregion.

IX. Southern Africa (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe)

- Seasonal wet/dry periods may intensify.
- Impacts agriculture and other primary sector economic activities.
- Alters seasonal migration patterns of wildlife.
- Alters biodiversity, as some plants and animals will be unable to adapt to higher temperatures or changes in precipitation patterns.

X. Latin America: particularly Ecuador, Brazil, Paraguay, Uruguay, Chile, Argentina

- Increases in temperature and associated decreases in soil water (due to increased evaporation) are projected to lead to gradual replacement of tropical rainforest by savanna (grasslands) in eastern Amazonia; steppe lands will revert to desert.
- There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America.
- Changes to South America's altitudinal zonation climate pattern along the Andes will alter where, when, and what types of agriculture can be practiced.
- Productivity of some important crops is projected to decrease, and livestock productivity is expected to decline, with adverse consequences for food security.
- On the plus side, in temperate zones, soybean yields are projected to increase (Brazil, for example, is one of the world's leading producers and exporters of soybeans).
- Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.

XI. North America: particularly eastern US, northern Canada, Greenland

- Warming in western mountains of the U.S. and Canada is projected to cause decreased snowpack, more winter flooding and reduced summer flows, increasing competition for scarce water resources, and impacting recreation and tourism.
- Warming in polar Canada leads to reductions in thickness and extent ice sheets and sea ice, and changes in natural ecosystems, with detrimental effects on many organisms including migratory birds, mammals (such as polar bears), and higher predators.
- For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. Detrimental impacts could include infrastructure ("Ice Road Truckers") and indigenous ways of life.
- Moderate climate change is projected to increase overall yields of rain-fed agriculture by 5 to 20%, but with important variability among regions.

- Major challenges are projected for crops that are already near the warm end of their suitable range or which depend on irrigation.
- Cities that currently experience heat waves are expected to experience an increased number, intensity, and duration of heat waves, with potential for adverse health impacts (impoverished communities being the most vulnerable).
- Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.
- Coastal communities may become more vulnerable to natural hazards, such as the impact of hurricanes along the Eastern Seaboard and Gulf Coast, due to sea level rise.

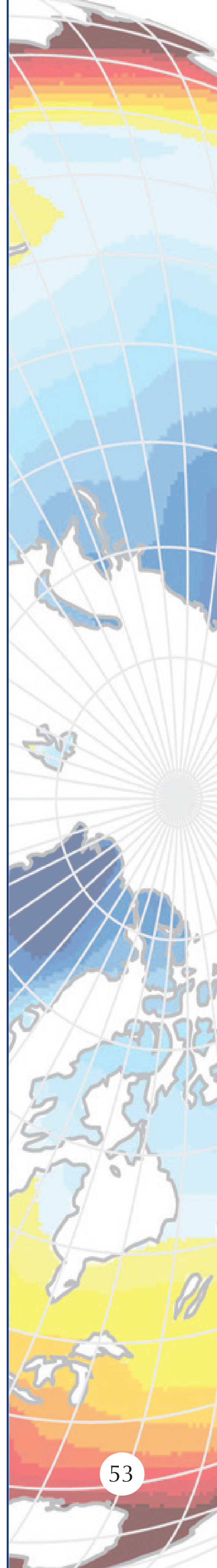
Step 4 - Use EdGCM and EVA to Investigate Further

Choose another region and the climate change impact of your choice. Present your findings to the class.

Why is climate change a truly global problem?

As a class discuss this issue and compare your findings to that in the IPCC impacts report.

Tools and Data



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The EdGCM software suite was developed under the auspices of the EdGCM Project of Columbia University and NASA's Goddard Institute for Space Studies.
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Tool Name

The Educational Global Climate Modeling Suite - EdGCM

EdGCM website: http://edgcm.columbia.edu

Tool Description

EdGCM is a suite of software that allows users to create, run, analyze, visualize and report on global climate model simulations via a user-friendly interface. Users can run pre-created simulations (i.e. "canned") or create their own. All simulation meta-data that is generated during an EdGCM project is stored in a local, searchable data base. EdGCM uses the NASA/GISS Model II Global Climate Model (Hansen et al., 1983, Monthly Weather Review). The full publication is included in the EdGCM Documentation folder.

System Requirements

- Mac OS X 10.3.9 or higher for Mac Intel, including Mac OS X 10.4 for PowerPC; Windows 2000/XP/Vista (XP Pro or Vista Home Premium editions recommended)
- Any Mac with a G3, G4 or G5 or Intel processor running at 500 MHz or faster; any PC with an Intel or AMD processor running at 300 MHz or faster
- 1 GB of free disk space (for installation only; simulation results may require as much as an additional 10-15 GB)
- 512 MB of RAM
- Internet connection is helpful but not required

Tool Builder

Mark Chandler, Michael Shopsin, Ken Mankoff, Linda Sohl and Robert Schmunk

EdGCM website: http://edgcm.columbia.edu

Tool Cost

EdGCM software is sold for non-commercial educational use only by Columbia University. Entering a valid email address sends an email to the user with download links for the Mac and Windows versions of the software. Software runs in fully operational mode for 30 days. Download EdGCM: http://edgcm.columbia.edu/download-edgcm/

Educational Discounts

Quantity	1	5+	10+	20+	50+	Student copy w/ site license*	Student copy / individual
Price per seat	$249	$129	$99	$69	$49	$39*	$69

Tool Help

Mark Chandler and Linda Sohl

EdGCM support forums: http://forums.edgcm.columbia.edu/

Video tutorials: http://edgcm.columbia.edu/support2/multimedia/

Documentation: http://edgcm.columbia.edu/support2/documentation/

Data Name

Input data for the Global Climate Model is included in the EdGCM software suite. Output data is generated by the Global Climate Model itself.

Data Description

Unlike other lessons in the EET the data for this exercise is generated during the running of the global climate model. EdGCM and EVA software allows students to post-process the raw output themselves and generate their own tables, plots and maps for analysis and reporting.

1. Modern_PredictedSST: modern climate control run with sea surface temperatures computed during experiment

2. IPCC_A1FI_CO2: global warming simulation based on transient increase in CO2 (see CO2 trend section of EdGCM Simulation Setup)

The SSTs in the Modern_PredictedSST run are calculated using a simple "mixed-layer" ocean model that derives temperatures based on the balance of vertical energy fluxes at the atmosphere/ocean interface. This ocean model also uses a simple method (we call "Qflux") that further adjusts the SSTs based on an assumption of horizontal heat transfer (this would be accomplished by ocean currents in the real world). Note: Even in the Modern_SpecifiedSST run the SSTs are not held constant. They are "specified" to change at each grid cell through a 12 month seasonal cycle based on an observed climatological data set. But, unlike the predicted SST run, the specified SSTs cannot respond to additional forcing (e.g. added CO2).

For more information about this data set, see Exploring Temperature Change Caused by Greenhouse Gas Increases Using the EdGCM Modeling Suite:

http://serc.carleton.edu/usingdata/datasheets/EnvisioningClimateChange.html

Geospatial Coverage

Global

Temporal Coverage

Modeled data from 1870 to 2099

Data Provider

The EdGCM software comes with the global warming and modern "control" experiments pre-set for immediate running. Running the experiments then creates the raw data and EdGCM facilitates post-processing and visualization. Raw and post-processed GCM output is available also from the EdGCM Project. Contact Linda Sohl or Mark Chandler for more information.

Data Help

Mark Chandler and Linda Sohl, http://forums.edgcm.columbia.edu

Going Further

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Variations

- Design and run your own climate change scenario using the skills learned in this lesson.
- Use the reports tool to write up the lab report describing your experiment.
- Explore other ways to visually explain climate change
- Explore other climate models to learn how they are similar and different.
- Discuss the question, "what is being done about climate change, locally, nationally and regionally?"
- Discuss the question, "what can you, the individual do? and what are our alternatives?"

Other Resources for users of EdGCM:

EdGCM Video Tutorials

- Setup Simulations
  http://edgcm.columbia.edu/downloads/tutorials/setupsimulations.htm
- Analyze Output
  http://edgcm.columbia.edu/downloads/tutorials/analyzeoutput.htm
- Visualization with EVA
  http://edgcm.columbia.edu/downloads/tutorials/evadiff.htm

Other Data

With some knowledge of the parameters of climate change, students can generate other experiments using EdGCM's Setup Simulations feature.

Other Techniques

Teachers could create the visualizations and use them as demonstrations instead of having the students work through the lesson. This could be very helpful for teachers with limited time or resources or for teachers of younger students.

Other Tools

Other GCMs are available for free download but all require significant programming skills and substantial computing resources to operate. Some examples:

Hadley Centre for Climate Prediction and Research (general info on their models and climate change)

http://www.metoffice.gov.uk/climatechange/science/projections/

NCAR/UCAR Community Climate System Model (CCSM)

http://www.ccsm.ucar.edu/

Do it yourself climate prediction

http://www.climateprediction.net/

NASA Goddard Institute for Space Studies' primary research GCM

http://www.giss.nasa.gov/tools/modelE/

The original NASA/GISS global climate model (GCM)

http://edgcm.columbia.edu/modelII/

Canadian Centre for Climate Modelling and Analysis (CCCma) (model info and interface to retrieve model data)

http://www.cccma.bc.ec.gc.ca/

NOAA / Geophysical Fluid Dynamics Laboratory CM2 (global climate model info and model output data files)

http://nomads.gfdl.noaa.gov/CM2.X/

University of Victoria Global climate model free for download (lead researcher was a contributing author to the recent IPCC report on climate change)

http://www.climate.uvic.ca/

Related Case Studies

Within the EET there are several related case studies that explore the the causes and / or impacts of climate change. These lessons could be used to develop a complete unit on the topic.

Is Greenland Melting?

http://serc.carleton.edu/eet/greenlandmelt/index.html

Visualizing Carbon Pathways

http://serc.carleton.edu/eet/carbon/index.html

Understanding Carbon Storage in Forests

http://serc.carleton.edu/eet/globecarbon/index.html

Exploring Regional Differences in Climate Change

http://serc.carleton.edu/eet/climate/index.html

Whither Arctic Sea Ice?

http://serc.carleton.edu/eet/seaice/index.html

Exploring NCAR Climate Change Data Using GIS

http://serc.carleton.edu/eet/ncardatagis/exploring_ncar_climate_change.htm