The Basic Guide to *Ed*GCM

http://edgcm.columbia.edu

Version 3.2

About the *Ed*GCM Manual

*Ed*GCM is actually a suite of software containing numerous individual applications all working together as a cohesive unit. The *Ed*GCM applications contain hundreds of features in total, not all of which are described in this manual. The NASA/GISS Global Climate Model (GISS GCM) is one of the applications.

The *Ed*GCM Manual includes:

1) Installation instructions for PCs and Macs
2) A description of the key components of *Ed*GCM and of the file system structure
3) A basic *Ed*GCM tutorial
4) Correlations between *Ed*GCM activities and several national education standards and science benchmarks

Please visit our web site for information about software updates and other news about the *Ed*GCM Project.

http://edgcm.columbia.edu

Thanks,
Dr. Linda E. Sohl
Science Editor, The EdGCM Project

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Dear soon-to-be climate modelers,

In bringing users into direct contact with complex computer models such as a Global Climate Model (GCM), *Ed*GCM exposes the strengths and weaknesses of computer models in a way that scientific papers and newspaper articles frequently obscure. The danger in creating a point-and-click interface for a GCM is that users might be tempted to treat the model as a black box, and then we would not be achieving ***our overarching goal***: ***to encourage more people to learn about and use global climate models***. *Ed*GCM allows people to become familiar with both the scientific process and the tools of the trade that are an integral component of state-of-the-art climate research and climate change forecasting. We hope that courses employing *Ed*GCM will encourage more students to pursue Earth science careers, and that the experience will allow them to participate in climate research at an earlier stage in their education. However, we also hope that all who use *Ed*GCM in any fashion will become better informed about climate change issues that affect everyone on the planet. If *Ed*GCM helps to demystify this complex but crucial subject matter, then it is fulfilling a key objective.

*Ed*GCM does not require a sophisticated understanding of climate to use, but climate science is an exceptionally multi-disciplinary field and an understanding of one or more of the associated disciplines (atmosphere, oceans, geology, physics, mathematics, biology, chemistry) will definitely enrich the experience. During the past few years, we have been heartened to see *Ed*GCM used at levels of education from middle school to graduate level, as well as in museums, science centers, and even in professional research projects. *Ed*GCM is now in use in many countries, and on all seven continents. We welcome you to this growing community of climate modelers, and hope that your experience with *Ed*GCM encourages you to appreciate even more our amazing home planet.

Happy Modeling!

Dr. Mark Chandler
Director, The *Ed*GCM Project

Overview of the *Ed*GCM Project

Climate change will profoundly impact our planet's environment and the world's economy in the coming decades. The general public needs to have a fundamental grasp of the workings of the Earth's climate system, so that informed judgments may be shaped at all levels of society with regard to critical issues. In order to achieve this goal, teachers need to be provided with the resources that will engage students in the scientific and technological processes used by scientists to forecast climate change. In so doing, students will become knowledgeable about a topic that will surely affect their lives, and the next generation of scientists grappling with a myriad of complex climate issues will be better prepared.

Computer-driven global climate models (GCMs) are one of the primary tools used today in climate research. Unfortunately, few secondary school or undergraduate educators have access to GCMs, which have generally required supercomputing facilities and skilled programmers to operate. In addition, the lack of familiarity with climate modeling techniques often engenders public distrust of important scientific findings based on such methodology. As a result, graduate-level programs end up teaching fundamental techniques that could have been taught much sooner, and younger students miss out on excellent opportunities to participate in real-world research projects.

Our goal is to improve the quality of climate-change science teaching and learning through broader access to GCMs, and to assist teachers by providing the appropriate support, technology and materials to use these models effectively. With research-quality resources in place, linking classrooms to actual research projects becomes possible, to the benefit of both educators and scientists. In order to fulfill our goal we have created *Ed*GCM, a software suite that allows teachers and students to run a 3-D climate model on desktop computers. The GCM at the core of *Ed*GCM was developed at NASA and is currently used by researchers to study climates of the past, present and future. *Ed*GCM itself has a user-friendly interface that simplifies the management of climate simulations. Experiments are automatically archived in a searchable database, and easy-to-use utilities for mapping, plotting, and data analysis are fully integrated.

*Ed*GCM permits teachers and students to explore the fundamentals of climate science with unparalleled ease, utilizing tools identical to those used in major climate research programs. Many simple climate experiments are possible (e.g., how does the sun warm the planet?). However, it is also possible to conduct in-depth investigations of current, future and past climates on time frame similar to those used in ongoing climate research. *Ed*GCM comes with some pre-prepared scenarios for investigating a variety of interesting climate issues (global warming, Last Glacial Maximum), but teachers can easily construct their own scenarios to satisfy curricular requirements. The model interface can also be configured for different levels or topics to produce customized instructional materials (text, charts, images), and gives both teachers and students the ability to easily export research reports to the web. *Ed*GCM readily scales for use at grade levels from high school to graduate school, making it a unique tool for linking research to a broad spectrum of classroom settings.

Introduction to *Ed*GCM

Welcome to *Ed*GCM, an integrated software suite designed to simplify the process of setting up, running, analyzing and reporting on global climate model simulations. The software package includes a full copy of 4th Dimension® database software (4D, Inc.) and the NASA/Goddard Institute for Space Studies' Global Climate Model II (i.e., GISS GCM II). The GISS GCM II is currently in used for climate research at NASA labs and several universities. For a complete description of the GISS GCM II see Hansen *et al.,* 1983, included inside *Ed*GCM's **Documentation** folder.

*Ed*GCM includes everything you need to begin exploring climate science using a research quality computer climate model. Despite the complexity of the underlying GCM, the *Ed*GCM interface and associated utilities will allow the model to be operated and managed by teachers, students, and researchers with minimal training. Please note, however, that there is limited documentation, so if you have not already attended one of our training workshops you may have difficulty utilizing some of the many functions available in this package. You are welcome to contact us for help in getting started, but we are currently only offering significant support to institutions that are collaborating with us for evaluation purposes. If you would be interested in attending a training session please DO contact us. Contact information is available at: http://edgcm.columbia.edu .

System Requirements

  • Mac OS X 10.3.9 or higher, including Mac OS X 10.5 (Leopard); Windows 2000/XP/Vista (XP Pro or Vista Home Premium editions recommended)

  • Any Mac with an Intel processor, or a G3 or better PowerPC CPU; 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 an additional 4-5 GB)

  • 512 MB RAM minimum recommended

  • Internet connection is helpful but not required

1.1. Installation Guides: Macs and Windows

1.1.1. For Mac OS X

1. Download the latest disk image (e.g., EdGCM.dmg) from the *Ed*GCM web site. When the license agreement appears, click "Agree" to continue mounting the disk image on your desktop (Figure 1).
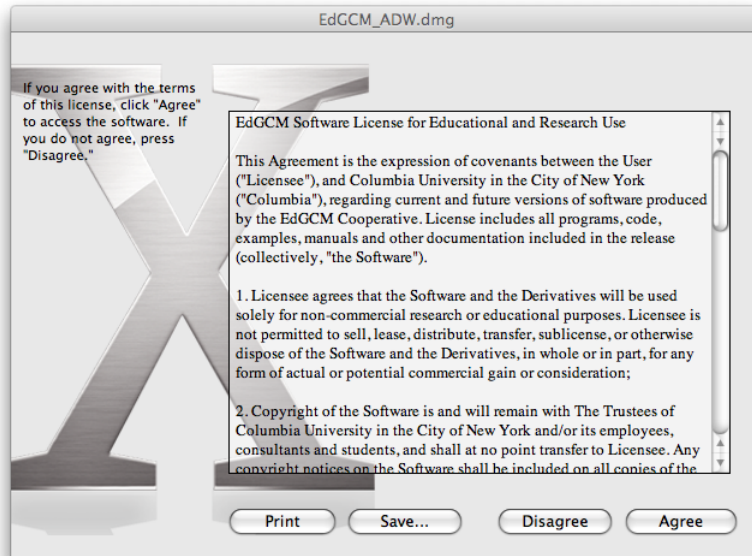
Figure 1. Please note that EdGCM's license agreement is for academic use only.

2. Once the disk image is mounted (Figure 2), simply drag the EdGCM folder to the desktop, or to any other desired location where you (or other users) will have write access. Launch *Ed*GCM by double-clicking on the shortcut inside the *Ed*GCM folder.
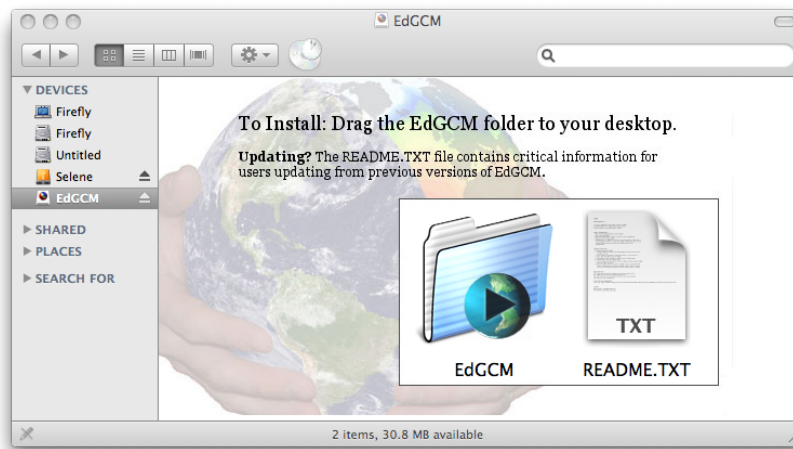
Figure 2. Installation of EdGCM on a Mac is a simple drag-and-drop process.

Note on cross-platform compatibility

All output files produced by the Mac OS X version of *Ed*GCM 3.2 are compatible for use with the Windows 2000/XP/Vista version, with the exception of files used by SuSpect, as this program currently has no Windows equivalent.

1.1.2. For Windows 2000/XP/Vista

1. Download the latest installer (e.g., EdGCM.exe) from the *Ed*GCM web site 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 *Ed*GCM is your desktop (Figure 3). 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).

Figure 3. The Windows installer for EdGCM.
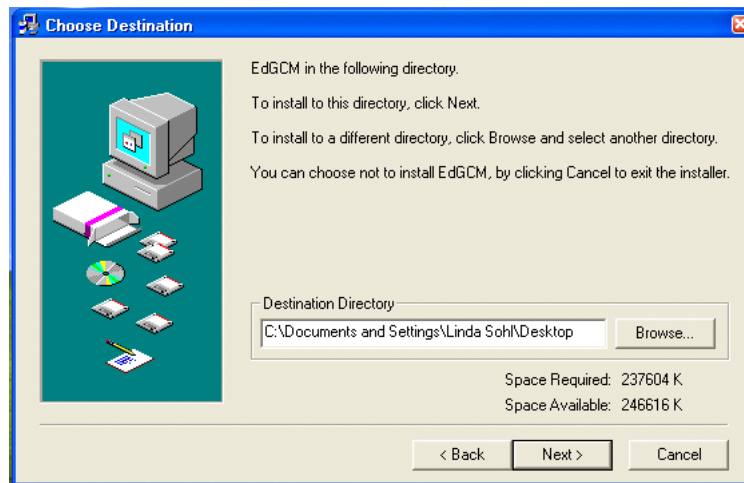
3. Select the components of the *Ed*GCM package that you wish to install (Figure 4). We recommend that you leave all choices checked since QuickTime and Java are required to use *Ed*GCM. The QuickTime installer will only run if you do not already have QuickTime installed. The Java installer will replace any existing copy of Java with the latest version from Sun.

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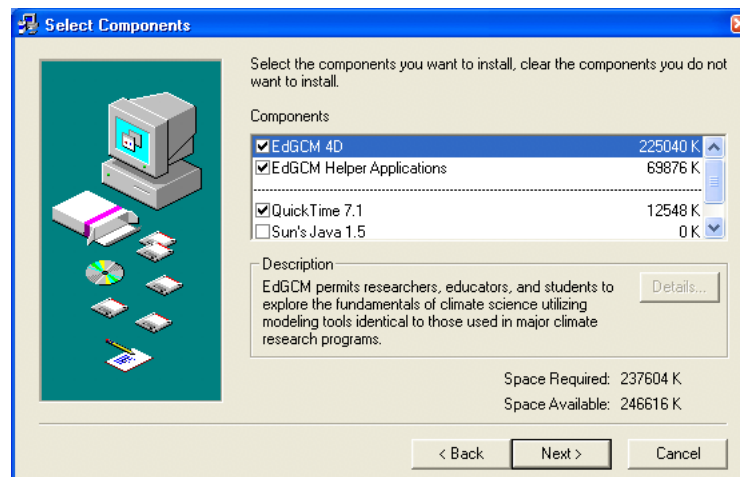
4. If you do not already have QuickTime and Java on your PC, installation of these components will begin now. Simply accept the license agreements and opt for a typical setup rather than a custom installation. The installation process for these programs may take several minutes each.

5. Launch *Ed*GCM from either the Start Menu or from the shortcut on your desktop.

Note on cross-platform compatibility

All output files produced by the Windows version of *Ed*GCM are compatible for use with the Mac version.

1.1.3. Registering Your Copy of EdGCM

1.When you launch *Ed*GCM for the first time, a dialog box will appear, asking you to register (Figure 5). If you have already purchased your copy of *Ed*GCM, 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 *Ed*GCM 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 *Ed*GCM, reminding you of the number of days remaining in your free trial.

3. If you have been using *Ed*GCM 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 *Ed*GCM web site to provide some basic user information, and then to the *Ed*GCM 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.
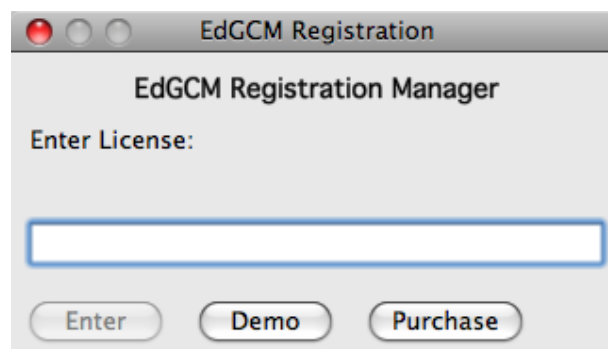
Figure 5.

1.2. Some Notes Before You Begin

1.2.1. Performance: How Fast Will It Run?

The speed at which the GISS GCM runs is based primarily upon the speed of the computer's CPU. Other factors that play a role include the number of applications running at the same time, compiler optimizations, and whether or not your system is dual- or single-processor. The 64-bit CPUs in machines such as the PowerMac G5 allow the GCM to run significantly faster, since twice as many calculations are possible during one clock cycle than in the typical 32-bit systems used by most desktop computers.

The GISS GCM divides the atmosphere into a three-dimensional grid system. The version incorporated into *Ed*GCM uses an 8° X 10° latitude by longitude grid system, and has nine vertical layers in the atmosphere and two ground layers. Running the climate model entails the solving of a series of complex physics equations for every cell in the grid, and a single simulated year involves many billions of calculations. Real-world performance has always been essential for the GISS GCM for research purposes, so the model was originally coded to be highly efficient. It has been further optimized to run at acceptable speeds on desktop computers without sacrificing any accuracy, but newer desktop computers will run the model the fastest.

Over the past four years, the number of simulated years per day (syears/day) for the GCM has increased more than twenty-fold on desktop Macs (see the table below). As a general guideline, most simulations that would be of interest (either in the classroom or for research) need to run at least 10 simulated years. Simulations with altered forcings, such as increased greenhouse gases, must run using the predicted ocean option and require a minimum of 50 simulated years to reach equilibrium.

Table of simulated model years per day. The speed at which the GISS GCM runs on a desktop computer scales closely with CPU speed. However, changes to the microchip architecture, L2 cache levels, and compilation optimizations may also have a significant impact.

Computer (OS)	CPU/CPU Speed	Simulated Years / Day
eMac (OS X 10.3)	PPC G4, 800 MHz	35
PowerMac (OS X 10.4)	PPC dual-G4, 1.42 GHz	66*
PowerMac (OS X 10.4)	PPC dual-G5, 2.0 GHz	120*
Dell OptiPlex (Win XP)	Pentium-4, 2.8 GHz	130
MacBook Pro (Vista)	Intel Core Duo, 1.8 GHz	131*
iMac (Win XP)	Intel Core Duo, 1.8 GHz	152*
MacBook Pro (OS X 10.5)	Intel Core Duo, 1.8 GHz	160*
PowerMac (OS X 10.4)	PPC quad-G5, 2.5 GHz	160*
Dell Dimension (Win XP)	Intel Core 2 Duo, 2.4 GHz	180*
Mac Pro (OS X 10.5)	Quad Core Intel Xeon, 2.8 GHz	373*

*Per processor.

1.2.2. Power Settings On Your Machine

It is also important that you not let the computer "sleep" when the GCM is running. Sleep mode will cause the run to stop and can corrupt the files required to complete the simulation. To prevent the computer from going into sleep mode, the Energy Saver settings for your Mac (Figure 6) should be set to "never sleep the computer." (Setting the display to sleep is fine, and will not affect your simulations). In addition, do not check the box that allows the hard disk to sleep, as this may also damage simulation output files.

You can run *Ed*GCM on newer laptops as well as desktops, but you should always do so with the laptop plugged in, not while running on battery power. Note that some laptops get very hot while the model is running; you should make sure that the laptop gets ample ventilation to avoid shutdown due to overheating.
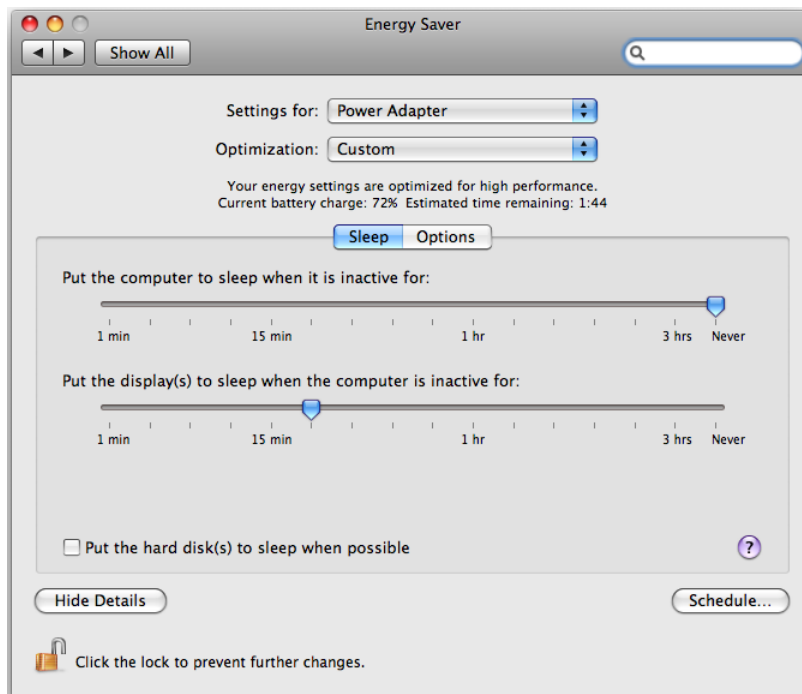
Figure 6. For Macs, the Energy Saver settings (within System Preferences) should be set such that the computer never sleeps.

For PCs, the appropriate power settings are set through the Control Panel, which is accessible from the Start Menu. In the Control Panel, double-click on "Performance and Maintenance" and then select "Power Options" to bring up a dialog box to display Power Option Properties (Figure 7). Select the Power Schemes tab, and from the drop down menu select the "Always On" option. As with Macs, allowing the monitor to go to sleep will not affect the running of the GCM.
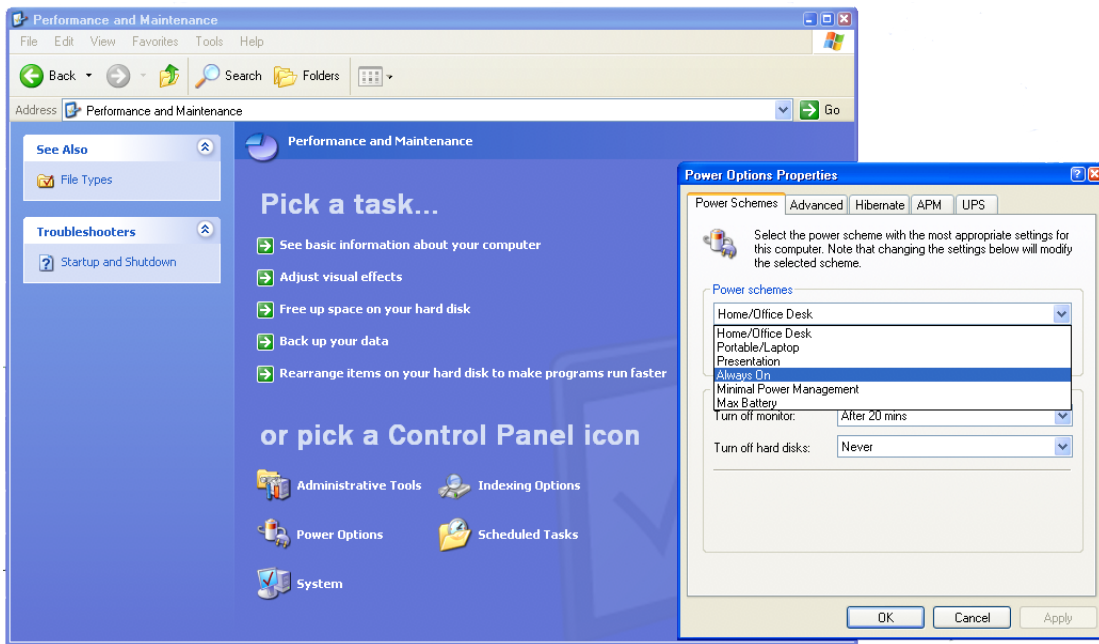
Figure 7. For PCs, the Power Scheme should be set to "Always On" to prevent the system from going into sleep mode while the GCM is running.

Under both Mac OS X and Windows 2000/XP/Vista you may run additional applications, such as Microsoft Word or Excel, while the GCM is running. You may even start more than one simulation at a time, although the simulations will then have to share processor time. On single-processor systems any additional applications will slow the GCM dramatically, but will not harm the simulation in any way. On dual-processor computers the impact on the speed of the run will be minimal unless you run many applications at once.

Finally, you can quit the *Ed*GCM 4D interface once a simulation is running, because the GCM runs as a separate application in the background. However, you will need to restart the *Ed*GCM 4D interface to analyze the output once the run has finished.

1.2.3. Known Software Problems and Issues

· We recommend that you NOT leave the GCM running on a Windows laptop unattended. We have found that some Pentium laptops have difficulty dissipating heat and may shutdown (hibernate) without warning causing the climate model to crash. This does not appear to harm the laptop, but it can corrupt GCM output files.

· *Ed*GCM will work as described on MacOS X using the default HFS+ disk format. We do not recommend using *Ed*GCM on UFS or case sensitive HFS formatted disks as some bugs may appear.

• A few PCs have exhibited strange behavior when running long simulations. The behavior has been traced to faulty cooling of CPUs, and substituting another computer has fixed the problem. Macs appear to have sufficient cooling to avoid similar problems with long simulations.

• *Ed*GCM is not available for the Linux platform, as our 4D database software (the foundation for both file organization and the user interface) is available for Mac and Windows only. It is possible however to run *Ed*GCM on a remote Windows machine using an rdesktop client on a Linux box. *Ed*GCM also runs well on Windows XP and Windows Vista under Parallels on a Mac Intel machine.

• *Ed*GCM running in native Intel mode on Macs has a serious bug that causes the GCM to stop at the end of each calendar year in simulations that use greenhouse gas trends. This requires the user to restart the GCM at the end of each simulated year. *Ed*GCM versions running on PowerPC Macs or on Windows computers are unaffected.

CHAPTER 2

*Ed*GCM on Your Hard Disk

There are four main components to the *Ed*GCM software suite: the *Ed*GCM 4D folder hierarchy, which provised the organizational framework for the suite; the 4th Dimension® database, which provides the structure for the *Ed*GCM 4D interface and database, and integrates the two; the GISS GCM Model II, the GCM at the heart of this software package; and the visualization software - EVA, SuSpect, and Panoply - that permit the simulation data to be displayed and more easily understood.

2.1 The *Ed*GCM 4D Folder Hierarchy

*Ed*GCM incorporates a large folder hierarchy to integrate the graphical user interface with the GCM, the database, the visualization programs, and a host of other utility programs. This hierarchical structure is absolutely necessary to the proper function of *Ed*GCM and its components, so users should not rename, delete, or move any of the folders within the *Ed*GCM 4D folder. However, the *Ed*GCM 4D folder itself can be moved as long as no programs are running and the internal organization of the folder is not altered.

The **Applications** folder contains all the Fortran programs to analyze output and many other support files. It also contains copies of parts of the *Ed*GCM Suite, but may not contain the most up-to-date versions. Users should not change the contents of this folder unless specifically informed to do so by an update message.

The **Database** folder contains the *Ed*GCM interface and ALL of the information about the simulations. *Never replace the contents of this folder with those from another computer since this will overwrite all of your simulations!* Similarly, if you delete this file you will lose all information about your simulations.
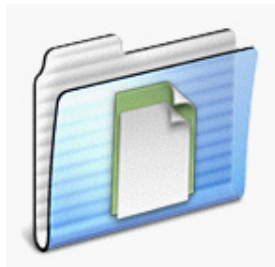
The **Data** folder contains several files of climate-related data, including greenhouse gas (GHG) concentrations (measured) for 1850-2004, and values for the solar constant for 1500-2009. There is also a link to additional datasets for a variety of observations available from the GISS web site (http://data.giss.nasa.gov).

The **Documentation** folder contains several important documents, most in Adobe Acrobat format, including: 1) an EdGCM quick start guide; 2) this manual; 3) manual for EVA and Panoply, our visualization software; and 4) the paper describing the GISS GCM Model II (Hansen *et al.*, 1983 first appeared in the American Meteorological Society's *Monthly Weather Review* journal).

The **Images** folder contains any images you wish to make available through *Ed*GCM's Image Browser utility. If folders containing images are removed or added to the Images folder, it is necessary to click on the "Update" button inside *Ed*GCM (see the toolbar when the Image Browser is open). The Image Browser will accept any images that are stored in a QuickTime compatible format. This does NOT, however, include images in the "gif" format.

The **Input, Input Forcings, Input Oceans and Input Special Regions** folders contain boundary conditions and initial condition files that are used by the GISS GCM. Since these files are necessary for initializing runs, deleting files from either of these folders is not recommended because it may destroy your ability to set up and run simulations. Adding files to these folders, while not damaging to simulations, will cause clutter in various menus within the *Ed*GCM interface. It is best to add files to these folders only when instructed to do by an update message.

The **Multimedia** folder contains a weblink to a series of tutorial videos about using *Ed*GCM's features. See our web site for the latest updates and information: http://edgcm.columbia.edu/support/multimedia/

The ***Output*** folder contains output from any simulations that have been run using *Ed*GCM. Each time a new simulation is started, a "run folder" is created inside the Output folder. Run folders are named after the "run ID" in the Setup Simulation window. Any run folder is basically a stand-alone simulation that could theoretically be moved, intact, to another computer and started. However, we recommend that you leave the run folders within the *Ed*GCM folder so that you may use *Ed*GCM's analysis and visualization programs to post-process and view the output.

2.2 The 4th Dimension® Database

4th Dimension® is the tie that binds the *Ed*GCM 4D graphical user interface together with the databases generated by simulations. A powerful relational database that runs on both Mac and Windows platforms, 4th Dimension® organizes the huge quantity of output generated so that users can focus upon analyzing the results of their simulations rather than having to search for the information of interest.

2.3 The GISS GCM Model II

The heart of *Ed*GCM is the GISS GCM Model II (described in detail in *Hansen et al.* [1983]), a three-dimensional model which solves numerically the physical conservation equations for energy, mass, momentum and moisture, as well as the equation of state. GISS Model II has a horizontal resolution of 8° latitude by 10° longitude, nine layers in the atmosphere extending to 10 mb, and two ground hydrology layers. The model accounts for both seasonal and diurnal solar cycles in its temperature calculations. Cloud particles, aerosols, and radiatively important gases (e.g., carbon dioxide, methane, nitrous oxides) are explicitly incorporated into the radiation scheme. Large-scale and convective cloud cover are predicted, and precipitation is generated whenever supersaturated conditions occur. Snow depth is based on a balance between snowfall, melting and sublimation. Sea surface temperatures (SSTs) are calculated using model-derived surface energy fluxes and specified ocean heat convergences. The ocean heat convergences vary both seasonally and regionally, but are otherwise fixed. This is the primary mixed-layer ocean model developed for use with the GISS GCM (described in detail in *Russell et al.* [1985] and in appendix A of *Hansen et al.* [1988]).

Certain boundary conditions necessary for simulations (e.g., levels of various atmospheric gases, solar luminosity) can easily be adjusted for customized simulations. Other boundary conditions, generally those that are geography-dependent (e.g., alternate land mass distributions for paleoclimate simulations; topography; vegetation) are not customizable for the purposes of most *Ed*GCM users. Development of geography-dependent boundary conditions is a highly labor-intensive task, so new alternatives are not likely to be released in the short term. However, if *Ed*GCM users express a strong interest in a particular paleoclimate or future climate scenario that requires a set of alternative boundary conditions, we will make an effort to incorporate that scenario in a future release.

2.4 Visualization Programs

EVA (EdGCM Visualization Application) is a mapping tool that allows users to plot latitude-longitude and vertical gridded data contained within datasets in the popular netCDF format (generated in this case by *Ed*GCM in the course of data processing). The user may select from a large menu of global map projections and slice specific latitude-longitude arrays from larger multidimensional arrays, which might also have dimensions in altitude or time. EVA was written using the powerful IDL language for scientific visualizaton, and REALBasic. It will run in both Mac (OS X 10.3.2 and higher) and Windows (2000/XP/Vista) environments.

SuSpect is a Mac-only data viewer designed for searching and exploring large text-formatted data sets. It was specifically designed for viewing the standard climate diagnostic tables generated by the GISS GCM. It gives the user an efficient means of comparing data tables that reside within one text file, but its real power lies in its capabilities for comparing multiple data files.

Panoply is another mapping tool that allows users to plot latitude-longitude and vertical gridded data contained within datasets in netCDF format. Since Panoply is as Java application, it will run in both Mac and Windows environments. Panoply is best used for large datasets, or with generic netCDF files created by programs other than *Ed*GCM.

Panoply is now being developed separately from the *Ed*GCM Project. For additional information, please see http://www.giss.nasa.gov/tools/panoply/

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CHAPTER 3
Inside *Ed*GCM

3.1 The Toolbar

The typical global climate model is controlled and started (initialized) through a combination of computer programs and Unix shell scripts. *Ed*GCM removes this layer of complexity by placing overall control of the climate model into a single toolbar palette that manipulates the various components of the software suite.

The toolbar contains controls, similar to those on a DVD or CD player, which allow the user to start, stop, pause, rewind, and extend simulations. Shortcuts to four commonly used sections (Assignments, Setup Simulations, Analyze Output, and eJournal Reports) are always available at the top of the toolbar. The toolbar also contains a "run list" showing the names of all experiments that have been previously set-up and are available for running. Selecting a simulation in the run list in effect accesses the *Ed*GCM database, and opening any of the four main sections will then show data relevant to that simulation.

With a simulation in the run list selected, double-clicking on the Run Folder icon takes the user to where the output for a completed run is stored. The Run Date indicates the last date of a completed run, or the current date of a run in progress.

Figure 3-1. The toolbar in EdGCM is the key to controlling the basic functions of the user interface.

As installed, *Ed*GCM comes with several pre-set simulations that can be run, duplicated, or modified. Additional controls appear in the toolbar depending upon which *Ed*GCM components and features are currently open. This way the toolbar is kept uncluttered, yet useful controls are always available.

3.2 Getting Started: Setup Simulations

Experiments are designed within a feature called "Setup Simulations." This window is an interface for manipulating the GCM itself, with well-defined fields for entering the names of input files and setting initial boundary conditions for each experiment. The interface is divided into several logical sections, each of which the educator can show or hide depending
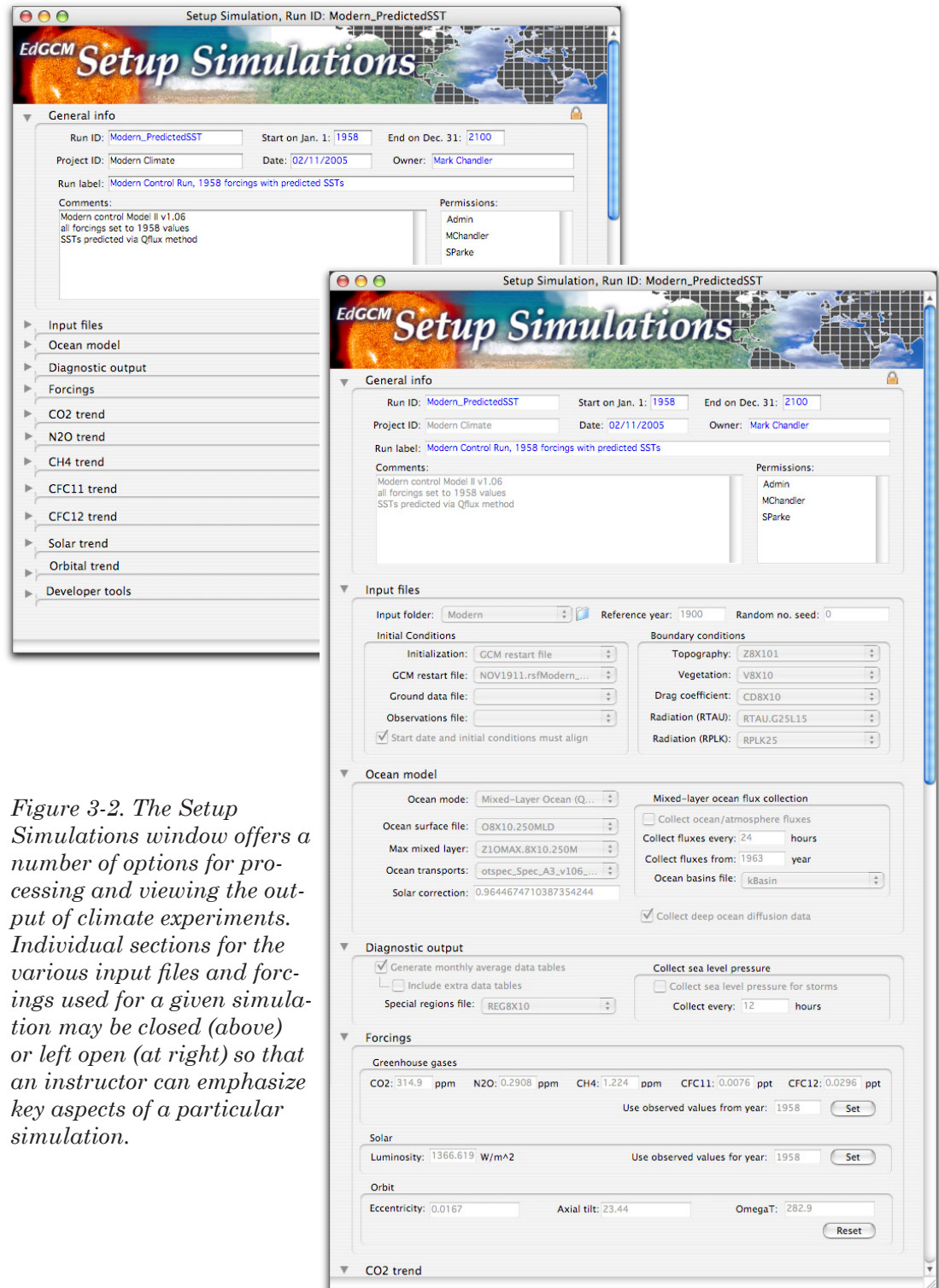

Figure 3-2. The Setup Simulations window offers a number of options for processing and viewing the output of climate experiments. Individual sections for the various input files and forcings used for a given simulation may be closed (above) or left open (at right) so that an instructor can emphasize key aspects of a particular simulation.

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upon which components of the GCM they want to be the focus of study. "Point and click" controls for choosing a variety of modeling options (e.g., number of simulated years per experiment, levels of greenhouse gases in the atmosphere, orbital parameters, and paleocontinental configurations) are available within each section.

The selection of the Setup Simulations window introduces a set of controls at the base of the toolbar. These controls make it simple to create new simulations, copy existing simulations for modification, or delete unwanted simulations. The Simulation Summary button in the toolbar creates a detailed listing of all files and forcings used for a selected simulation, which can be saved as a text file and printed if desired.
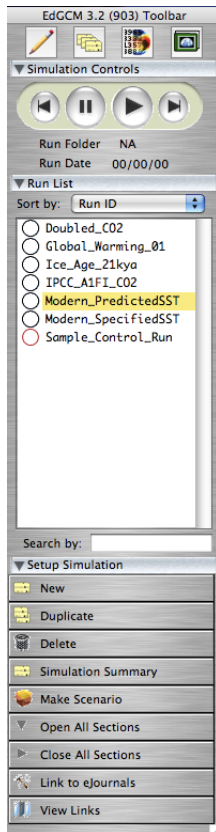
Figure 3-3. Setup Simulations toolbar.
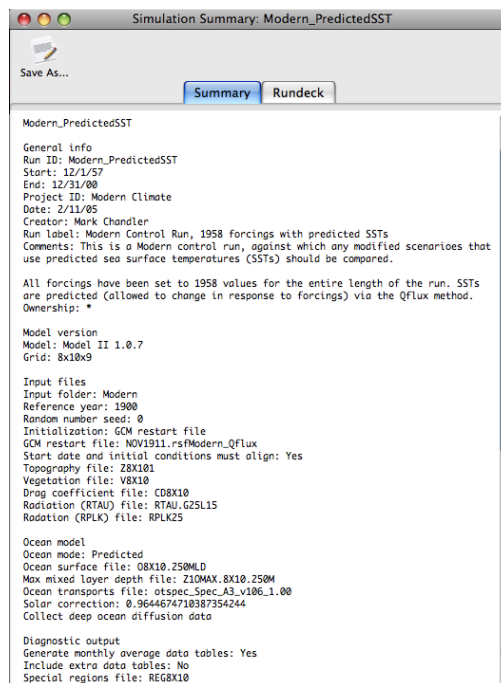
Figure 3-4. The Simulation Summary provides a convenient reference for offline comparison of simulation parameters.

The Make Scenario button in the toolbar is a special feature for designing a specific simulation "template" for classroom assignments. Once a simulation has been created, clicking the Make Scenario button locks the various sections of the Setup Simulation window either open (for further modification by the students) or closed (to prevent unwanted changes to input files or certain forcings). When students run the scenario by hitting the play button, a duplicate is created and they are asked to assign a unique name to their simulation. They may then edit sections as allowed by the template. This feature is most useful in the case where the teacher wants groups of students to run simulations that are variations on a given topic, e.g., global warming experiments using various levels of carbon dioxide.

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The last two buttons on the toolbar in Setup Simulations – Link to eJournals and View Links – allow the user to associate a given simulation with one or more eJournal reports in the database, or to view existing eJournal reports in the eJournal Library.

With the guidance of the Setup Simulations window, educators and students can easily run experiments that simulate a wide variety of climates, from future global warming to past ice ages. Endless "thought" experiments are also possible, to test the sensitivity of the climate to hypothetical changes in solar luminosity or greenhouse gas levels. Examples of past, present and future climate simulations are provided with *Ed*GCM, and may either be run directly, or copied and modified within Setup Simulations to produce an array of related experiments. The new interface allows such detailed control over model functions that *Ed*GCM arguably has more user-definable capabilities than does the original GCM.

3.3 Assignments and Information
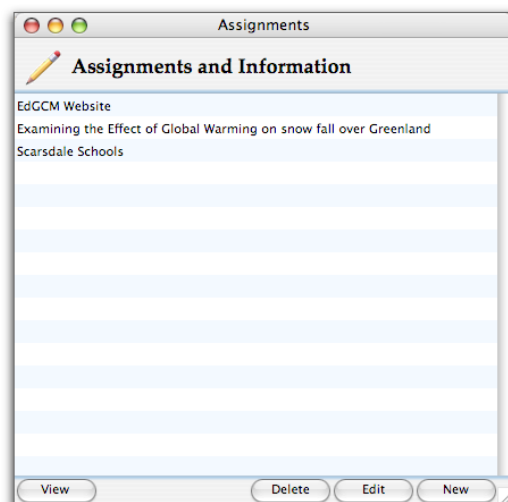
At times it may be necessary to provide more extensive background information for a simulation than can practically fit into the Comments section of the Setup Simulations window. Alternatively, an educator might want to have assignment instructions readily available for students. The Assignments and Information window provides an easy way to link to local text documents or to web pages.

Figure 3-5. The Assignments and Information window is always available by clicking on the Assignments button on the top of the toolbar.

3.4 Running Simulations

Once a simulation has been set up, getting a run started is quite simple: just click the Play icon at the top of the toolbar (see, e.g., Figure 3-1). At this point, a new window will open, displaying some information that may appear a bit arcane (Figure 3-6). This window is actually the GCM itself, running under Fortran and separate from the *Ed*GCM 4D interface. The first time a simulation is run, the model goes through one simulated hour and then stops. This "first-hour check" is designed to make certain that the correct input files have been selected. If successful, the window displays a success message and stops.
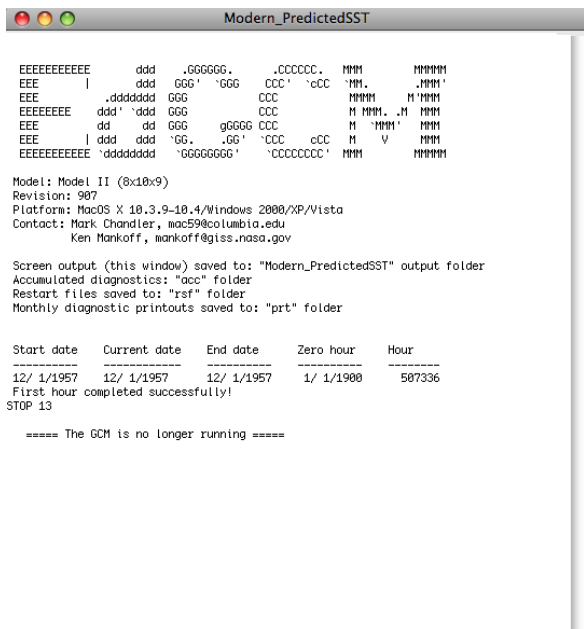
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```
EEEEEEEEEEE     ddd   .GGGGGG.     .CCCCCC.   MMM       MMMMM
EEE        |    ddd  GGG'  `GGG   CCC'  `cCC  `MM.     .MMM'
EEE         .dddddddd GGG          CCC         MMMM    M'MMM
EEEEEEEE    ddd' `ddd GGG          CCC         M MMM. .M MMM
EEE         dd    dd  GGG   gGGGG CCC          M  `MMM'  MMM
EEE        | ddd  ddd `GG.   .GG' `CCC    cCC  M    V    MMM
EEEEEEEEEEE `dddddddd  `GGGGGGGG'  `CCCCCCCC'  MMM       MMMMM

Model: Model II (8x10x9)
Revision: 907
Platform: MacOS X 10.3.9-10.4/Windows 2000/XP/Vista
Contact: Mark Chandler, mac59@columbia.edu
        Ken Mankoff, mankoff@giss.nasa.gov

Screen output (this window) saved to: "Modern_PredictedSST" output folder
Accumulated diagnostics: "acc" folder
Restart files saved to: "rsf" folder
Monthly diagnostic printouts saved to: "prt" folder


Start date     Current date    End date     Zero hour    Hour
----------     ------------    ----------   ----------   --------
12/ 1/1957     12/ 1/1957      12/ 1/1957    1/ 1/1900     507336
First hour completed successfully!
STOP 13

    ===== The GCM is no longer running =====
```

Figure 3-6. The GCM window, with one simulated hour successfully completed.

To continue the run at this point, click on the play button at the bottom of the GCM window, or in the toolbar. The model will pick up where it left off (Figure 3-7) and then run to completion (If a simulation crashes, which is a possibility when testing extreme combinations of forcings, error messages will be displayed in this window).

The model may be paused or stopped at any point by clicking on the buttons at the bottom of the GCM window or in the toolbar. Hitting Pause suspends the run temporarily, whereas the Stop button will end the run and close the GCM window.
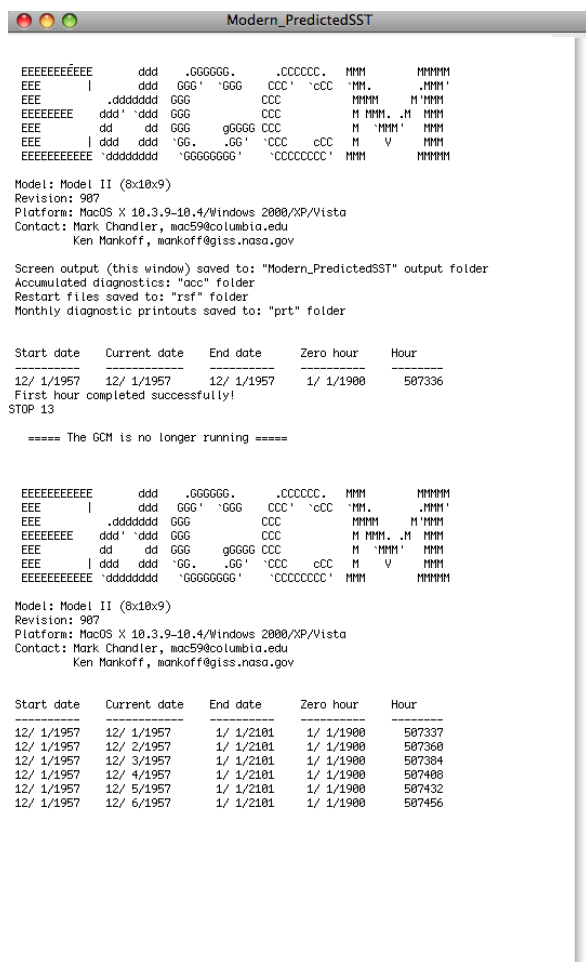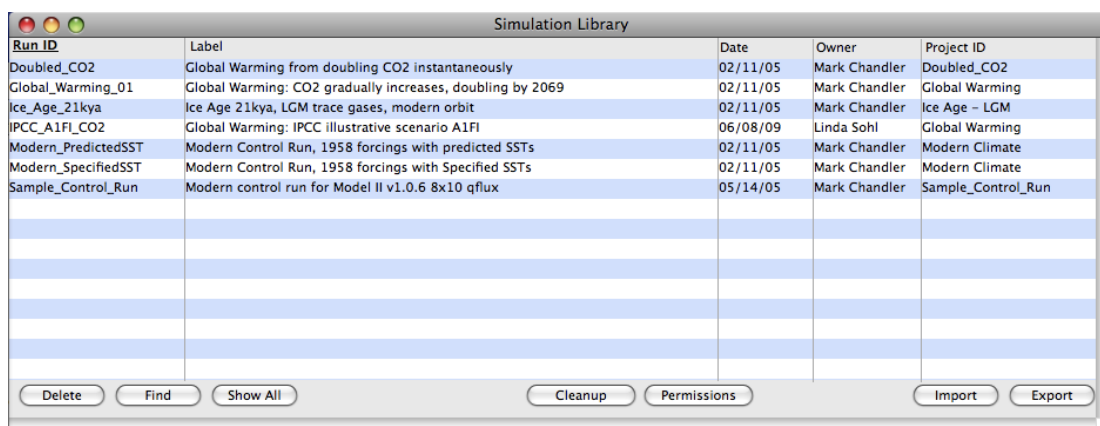
Other run controls that appear only in the toolbar (Figure 3-1) resemble "rewind" and "fast forward" buttons. The Rewind button does not simply step backwards within a run, but instead erases all previous output generated by a run and restarts the simulation from the beginning.

The Fast Forward button comes into play if the user wants to extend a run that has already successfully completed. (Runs that have crashed cannot be encouraged to restart with this button!) A popup window will ask for a new end date; once the new date is entered, pressing the play button again will start the model.


```
EEEEEEEEEEE     ddd   .GGGGGG.     .CCCCCC.   MMM       MMMMM
EEE        |    ddd  GGG'  `GGG   CCC'  `cCC  `MM.     .MMM'
EEE         .dddddddd GGG          CCC         MMMM    M'MMM
EEEEEEEE    ddd' `ddd GGG          CCC         M MMM. .M MMM
EEE         dd    dd  GGG   gGGGG CCC          M  `MMM'  MMM
EEE        | ddd  ddd `GG.   .GG' `CCC    cCC  M    V    MMM
EEEEEEEEEEE `dddddddd  `GGGGGGGG'  `CCCCCCCC'  MMM       MMMMM

Model: Model II (8x10x9)
Revision: 907
Platform: MacOS X 10.3.9-10.4/Windows 2000/XP/Vista
Contact: Mark Chandler, mac59@columbia.edu
        Ken Mankoff, mankoff@giss.nasa.gov

Screen output (this window) saved to: "Modern_PredictedSST" output folder
Accumulated diagnostics: "acc" folder
Restart files saved to: "rsf" folder
Monthly diagnostic printouts saved to: "prt" folder


Start date     Current date    End date     Zero hour    Hour
----------     ------------    ----------   ----------   --------
12/ 1/1957     12/ 1/1957      12/ 1/1957    1/ 1/1900     507336
First hour completed successfully!
STOP 13


    ===== The GCM is no longer running =====


EEEEEEEEEEE     ddd   .GGGGGG.     .CCCCCC.   MMM       MMMMM
EEE        |    ddd  GGG'  `GGG   CCC'  `cCC  `MM.     .MMM'
EEE         .dddddddd GGG          CCC         MMMM    M'MMM
EEEEEEEE    ddd' `ddd GGG          CCC         M MMM. .M MMM
EEE         dd    dd  GGG   gGGGG CCC          M  `MMM'  MMM
EEE        | ddd  ddd `GG.   .GG' `CCC    cCC  M    V    MMM
EEEEEEEEEEE `dddddddd  `GGGGGGGG'  `CCCCCCCC'  MMM       MMMMM

Model: Model II (8x10x9)
Revision: 907
Platform: MacOS X 10.3.9-10.4/Windows 2000/XP/Vista
Contact: Mark Chandler, mac59@columbia.edu
        Ken Mankoff, mankoff@giss.nasa.gov

Start date     Current date    End date     Zero hour    Hour
----------     ------------    ----------   ----------   --------
12/ 1/1957     12/ 1/1957      1/ 1/2101    1/ 1/1900     507337
12/ 1/1957     12/ 2/1957      1/ 1/2101    1/ 1/1900     507360
12/ 1/1957     12/ 3/1957      1/ 1/2101    1/ 1/1900     507384
12/ 1/1957     12/ 4/1957      1/ 1/2101    1/ 1/1900     507408
12/ 1/1957     12/ 5/1957      1/ 1/2101    1/ 1/1900     507432
12/ 1/1957     12/ 6/1957      1/ 1/2101    1/ 1/1900     507456
```

Figure 3-7. The GCM window tracking the simulation in progress.

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Since the model runs independently of the *Ed*GCM interface, *Ed*GCM can be quit to free up resources for the model, and later restarted to analyze output.

3.5 The Simulation Library

The large volume of information produced by any global climate model can easily exceed the manageable level. For this reason, *Ed*GCM is built upon a database, so that all input data, model ouput and supplemental information relating to simulations is automatically organized in a readily searchable format. The database we use is called 4th Dimension, a popular cross-platform program from 4D, Inc. that we have licensed and distribute with *Ed*GCM.

The simulation library provides a number of database management features that are only accessible to users with administrative permissions. (See the next section for an explanation of the permissions structure within *Ed*GCM.) Within the simulation library, experiments may be listed in order by run or project ID, simulation label, date, or owner/creator of the simulation, making it simple to search, sort and access information from several different classes or from one semester. The Find function also allows more specific searches based upon character strings or particular key words.

Run ID	Label	Date	Owner	Project ID
Doubled_CO2	Global Warming from doubling CO2 instantaneously	02/11/05	Mark Chandler	Doubled_CO2
Global_Warming_01	Global Warming: CO2 gradually increases, doubling by 2069	02/11/05	Mark Chandler	Global Warming
Ice_Age_21kya	Ice Age 21kya, LGM trace gases, modern orbit	02/11/05	Mark Chandler	Ice Age – LGM
IPCC_A1FI_CO2	Global Warming: IPCC illustrative scenario A1FI	06/08/09	Linda Sohl	Global Warming
Modern_PredictedSST	Modern Control Run, 1958 forcings with predicted SSTs	02/11/05	Mark Chandler	Modern Climate
Modern_SpecifiedSST	Modern Control Run, 1958 forcings with Specified SSTs	02/11/05	Mark Chandler	Modern Climate
Sample_Control_Run	Modern control run for Model II v1.0.6 8x10 qflux	05/14/05	Mark Chandler	Sample_Control_Run

Figure 3-8. The Simulation Library is a searchable database of previously run experiments that allows users to find experiments with similar themes, as well as export experiments to exchange with other members of the EdGCM Project.

An especially useful feature of the simulation library is the ability to import and export essential database information about single or multiple runs (not including raw model output because of the large size of those files). In this way, students and educators can share the simulations they create with colleagues at other schools or with research scientists, making it easy to collaborate on projects – a key goal of the *Ed*GCM Project. Exported simulations are small enough to be directly emailed to collaborators.

3.5.1 Setting Permissions

Because any alteration of the information within the Simulation Library is potentially catastrophic, access to the Simulation Library as well as individual simulations is restricted to users with the appropriate permissions. Permissions are set at two levels within *Ed*GCM.

At the top level, user login names are added to a list of those with authorized access to *Ed*GCM itself. To reach this window, select the User Editor from the File menu or press ctrl (or cmd) + 9. Users may be added or deleted by clicking on the + or - buttons at the bottom of the list field. An Admin user is listed by default, but does not have a password until you add one. We highly recommend that you do so, to prevent unauthorized access, but take care to keep note of the password in a secure place.
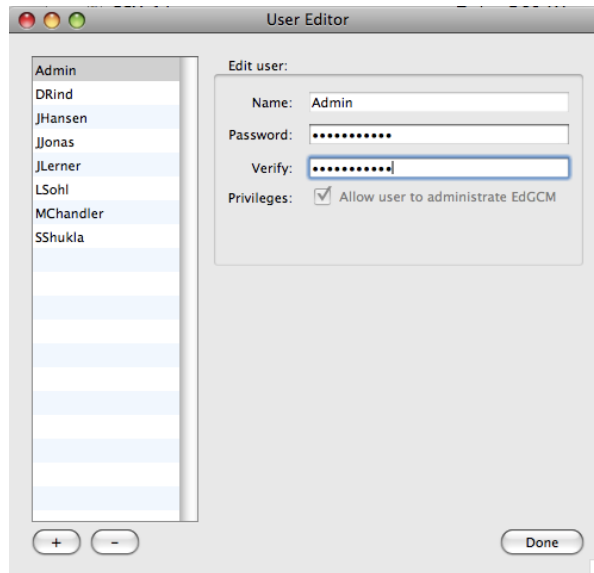
Figure 3-9. The User Editor allows login names to be assigned to authorized users, as well as to set a given user's level of permission.

WARNING: Passwords are stored in encrypted form on the hard disk, for added security.

LOST OR FORGOTTEN PASSWORDS CANNOT BE RECOVERED.

If the Admin password is lost or forgotten and no other usernames with administrative permissions have been created, *there is no way to access the information in the Simulation Library*. Avoid this potential disaster by creating at least one additional username with administrative permissions. Administrative permissions are assigned to a user by checking the Privileges box before saving the username and password.

Multiple users can be added through the User Editor at any time, by any user who already has administrative permissions; simply click on the Save button as each user is added, and then click Done once all desired usernames have been entered. We suggest assigning unique passwords to each user, and restricting administrative permissions to as few users as possible for security reasons. After usernames have been added to the list, quitting and restarting *Ed*GCM will bring up a login window that appears for all subsequent launches of the interface. Users will need to enter the username and password that have been assigned to them in order to use *Ed*GCM.

By default, all users with administrative permissions have access to all areas and functions within the database. It is also possible to assign full access permissions for one or more simulations to a particular user who otherwise does not have administrative access, from within the Simulation Library itself. Having full access to a simulation means that that user could then see the simulation in the toolbar's run list, and add/modify/ delete information associated with that run in the Simulation Library.
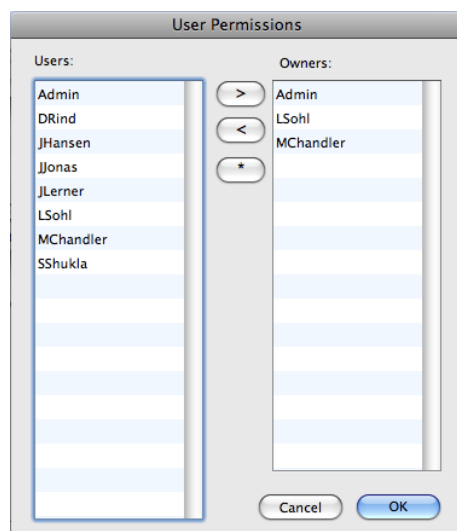
Figure 3-10. The User Permissions feature in the Simulation Library can be used to grant access to simulations on a case-by-case basis.

To assign permissions to a non-administrative user, select the run(s) of interest, and then click the Permissions button at the bottom of the library window. A new window will appear (Figure 3-10) displaying the names of all authorized *Ed*GCM users, whether they have administrative permissions or not. Select a name from the user list and click the > button to add them as owners of the selected simulation(s). Existing owners may also have access removed by selecting their name in the owner list and clicking on the < button. Clicking on the asterisk button grants full access for all simulations to all users, which may occasionally be desirable but is not recommended.

3.5.2 Disk Maintenance: The Cleanup Utility

GCMs are good at two things: simulating global climate, and consuming huge amounts of hard disk space with output. Most research institutions use large arrays of disk drives to store these massive amounts of data, but that is a luxury few schools will have. As a solution, *Ed*GCM contains a "smart" Cleanup utility. The Cleanup utility allows users to keep track of total disk space as well as the amount of space occupied by GCM simulation output. If storage space becomes limited, the Cleanup utility allows users to intelligently clean up the disk (i.e., without damaging the ability to later revisit simulation results) by removing the least important files first. Because running the Cleanup utility involves the deletion of files, it can only be accessed from within the Simulation Library by a user with administrative permissions for the run(s) to be maintenanced.

The Cleanup utility can be run at two levels. Basic Cleanup (Figure 3-11) will show the run(s) to be cleaned, the amount of disk space taken by the run(s), the size of the hard disk and the current used and available space.

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Clicking on the Basic Cleanup button will automatically remove those files that are most likely not needed for further analysis. This level of clean up is appropriate for most users.
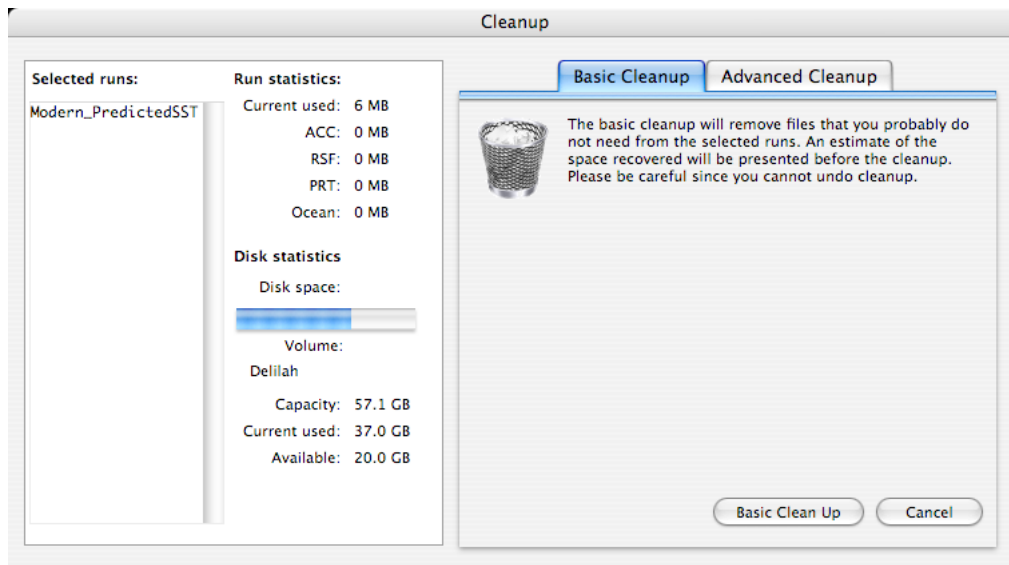

Figure 3-11. The Basic Cleanup utility automates the disk space maintenance process within EdGCM.

Advanced Cleanup (Figure 3-12) shows the same information as Basic Cleanup, but gives added control over the specific types of files to save and delete. We highly recommend that only advanced users take advantage of this level of utility, as it is entirely possible to erase all of your data if you are not careful!
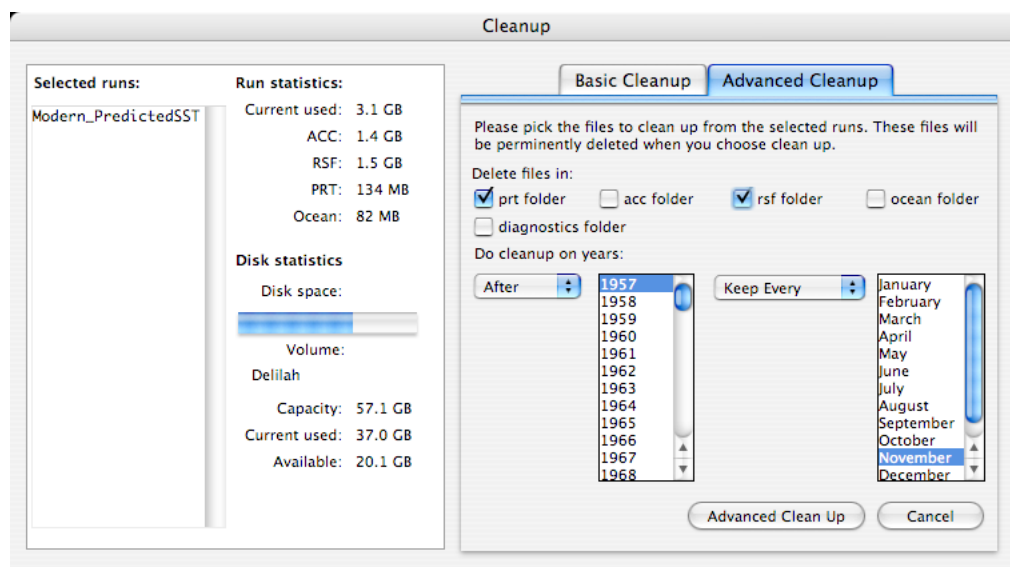
Figure 3-12. The Advanced Cleanup utility allows the user greater control in choosing which files to keep and which to delete.

3.6 Interpreting Results, Part 1: Analyze Output

The most important aspect of any climate modeling project is the analysis of simulation results. For most global climate models, preparing model output for analysis can be as involved as the initial simulation setup. This preparation of model output for analysis is referred to as "post-processing," and it involves several steps. Variables of interest must first be extracted from the large binary files that are a GCM's raw output, and then averaged over meaningful time intervals or geographic areas (e.g., "summer temperature" or "precipitation over land areas"). Finally, the values are scaled to standard meteorological units (e.g., degrees Celsius) and converted to formats that can be read by desktop software programs.

Since post-processing tasks can be so time-consuming, they are typically performed by professional programmers. Thus, while post-processing may be a "resource limitation" for research labs, it is probably more of an "insurmountable obstacle" for middle schools, high schools and many undergraduate institutions faced with the same needs.

In order to tackle this problem, *Ed*GCM automates a number of the most-used post-processing programs, and contains a user-friendly interface – the Analyze Output window – to perform any steps that can't be entirely hidden. Tasks handled by Analyze Output include:

- The creation of global map files for approximately 80 different climate variables, which can be used to analyze geographic patterns of climate change
- The creation of zonal average and vertical atmospheric slices for approximately 80 climate variables.
- The production of time series plots for approximately 80 climate variables, which can be used to track climate changes that occur during the course of a simulation
- The production of summary tables for all diagnostic variables produced by the global climate model (over 400 variables in all!), averaged over months, seasons, and years for any portion of a simulation, as specified by the user

For each of the tasks available within the Analyze Output window, there are three basic steps to selecting the data to be analyzed and viewed. On the left side of the window, the output years available for a simulation selected from the toolbar are visible in the upper section. Since it is common practice for all tasks except time series analysis to average the last five or ten years of run output, the 5 and 10 buttons beneath the year listing will automatically select those years for processing. (Other year ranges can be selected manually from the year list by holding the shift key while clicking on the first and last years desired.) Year ranges that have already been averaged for analysis are then shown at the bottom left corner of the Analyze Output window.
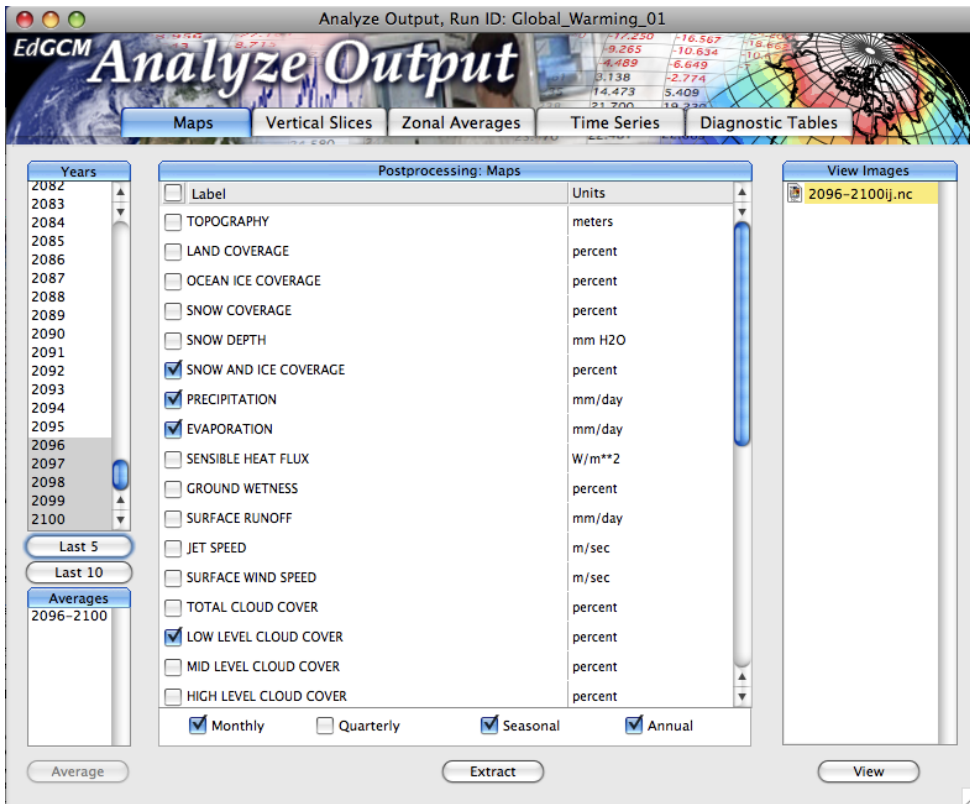
Figure 3-13. The Analyze Output window provides access to all the post-processing functions within EdGCM.

The center portion of the Analyze Output window displays a list of variables available for analysis, and the time intervals at which the data can be compiled (monthly through annually). Simply check the boxes for those variables you wish to analyze, and then click on the Average button at the base of the window. This action will launch a Fortran program in a new window (Figure 3-14) which displays the averaging function in progress for the range of years selected.
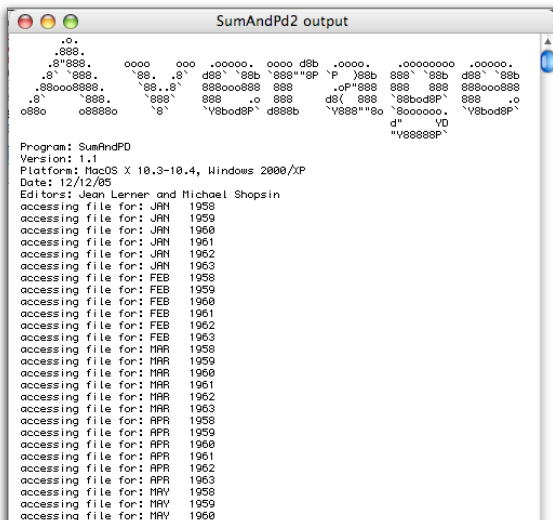
Figure 3-14.

Since it is likely that a user will want to examine only selected climate variables and not the full list available, the Analyze Output toolbar has a special feature that allows the creation of "sets." When a Variable Set is created only those variables in the set are shown in the interface, which vastly reduces interface complexity when it is not desired. The sets are fully customizable, and multiple sets can be created to emphasize different aspects of

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a simulation's results (e.g. Hydrological Variables, Energy Balance Variables, etc.).

Once the Average program has run to completion for a given range of years, the Extract button will become available. Clicking on this button literally extracts only those variables checked in the center list, and generates a new file in netCDF format (a popular file format for spatial data). This file name then appears on the right side of the Analyze Output window, and is ready for the next step in post-processing – visualization. Clicking on the View button in the lower right corner of the Analyze Output window launches that next step.

3.7 Interpreting Results, Part 2: Scientific Visualization

The simplest way to analyze and interpret climate model output is to display it. The Analyze Output feature of *Ed*GCM makes this step simple by putting a simulation's geospatial data into the widely used netCDF file format, with a variety of summary tables, time series sets and latitude-altitude (vertical) data sets saved as tab-delimited text files. The common file formats used for the post-processed data ensure that the user has great flexibility in their choice of visualization options.

The *Ed*GCM suite offers a specially designed companion program called EVA (*Ed*GCM Visualization Application) as the first option in the display and graphical analysis of model output. The engine that drives EVA is IDL, a powerful visualization tool commonly used in the scientific community. Depending on the type of data available, EVA can be used to display and analyze data in a variety of ways (see, e.g., Figure 3-15):

- Plot longitude-latitude data as global maps
- Overlay continent outlines or masks on longitude-latitude maps (including custom overlays of continental reconstructions for the paleoclimate simulations included with *Ed*GCM)
- Display specific latitude-longitude arrays (zonal averages) or latitude-altitude arrays (vertical profiles) as slices from larger multidimensional variables
- Produce line plots of time series data (e.g., change in average global temperature through time)
- Function as a tool for graphical data analysis by allowing the user to combine two arrays in one map plot by differencing (i.e., displaying anomalies)

EVA supports many map projections, colorbars, and overlays that may be further customized as needed. Please visit the EVA website for updates and complete documentation.
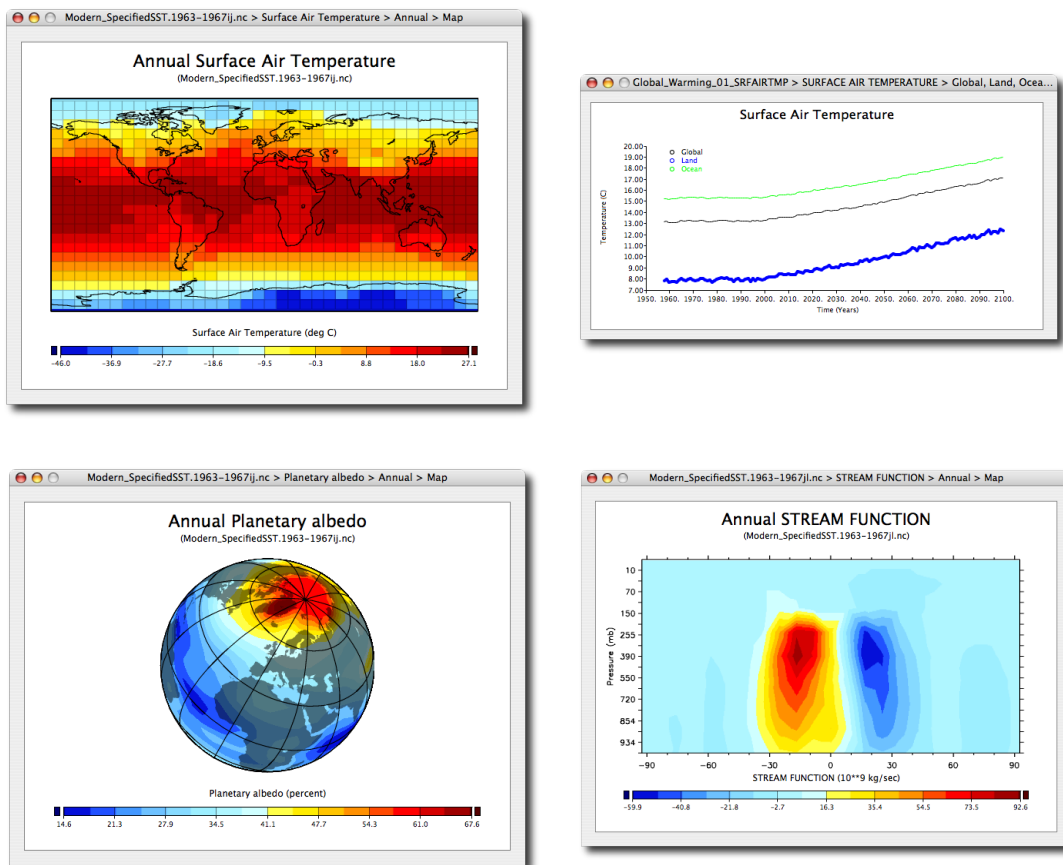
Figure 3-15. Examples of some of the many ways EVA can be used to visualize EdGCM output. Clockwise from upper left: rectilinear map of latitude-longitude data; times series data plot; orthographic global map projection from a selected perspective; vertical atmospheric profile along a longitudinal slice.

Earlier users of *Ed*GCM will be familiar with Panoply, a Java-based cross-platform imaging program that can also be used to visualize data as maps or line plots. Users may continue to use that program with post-processed files generated by *Ed*GCM if they wish. Please visit the Panoply website for updates and documentation.

Since the files for time series, altitude-latitude data sets and summary tables are formatted as tab-delimited text, the data within them can be viewed and plotted with any spreadsheet program (such as Microsoft Excel) available to the user. The tables may also be viewed as an HTML file, which is perhaps easier to understand as it starts with a series of links to the tables for each variable (Figure 3-16).

Mac users have the additional option of viewing their data in SuSpect (Figure 3-17), which also allows the sync'ed viewing of multiple data files simultaneously.

Figure 3-16. The HTML display of tables data begins with a series of links to tables for the individual variables selected for analysis.
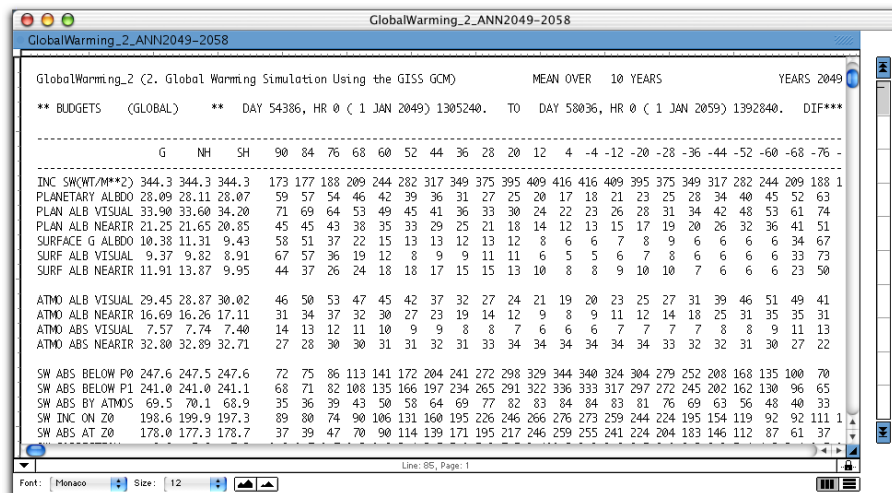
Figure 3-17. Mac users can employ SuSpect to view their data.

3.8 Reporting Results: The *Ed*GCM eJournal

A unique feature of *Ed*GCM is eJournal, a tool that allows students to create reports discussing the results of their experiments. eJournals can incorporate both text and images, and provides a format that encourages students to construct "manuscripts" in a style similar to that of researchers publishing their findings in scientific journals or on the web.

An individual eJournal report may contain up to 20 text and image sections. Sections may be added or rearranged at any time while the report

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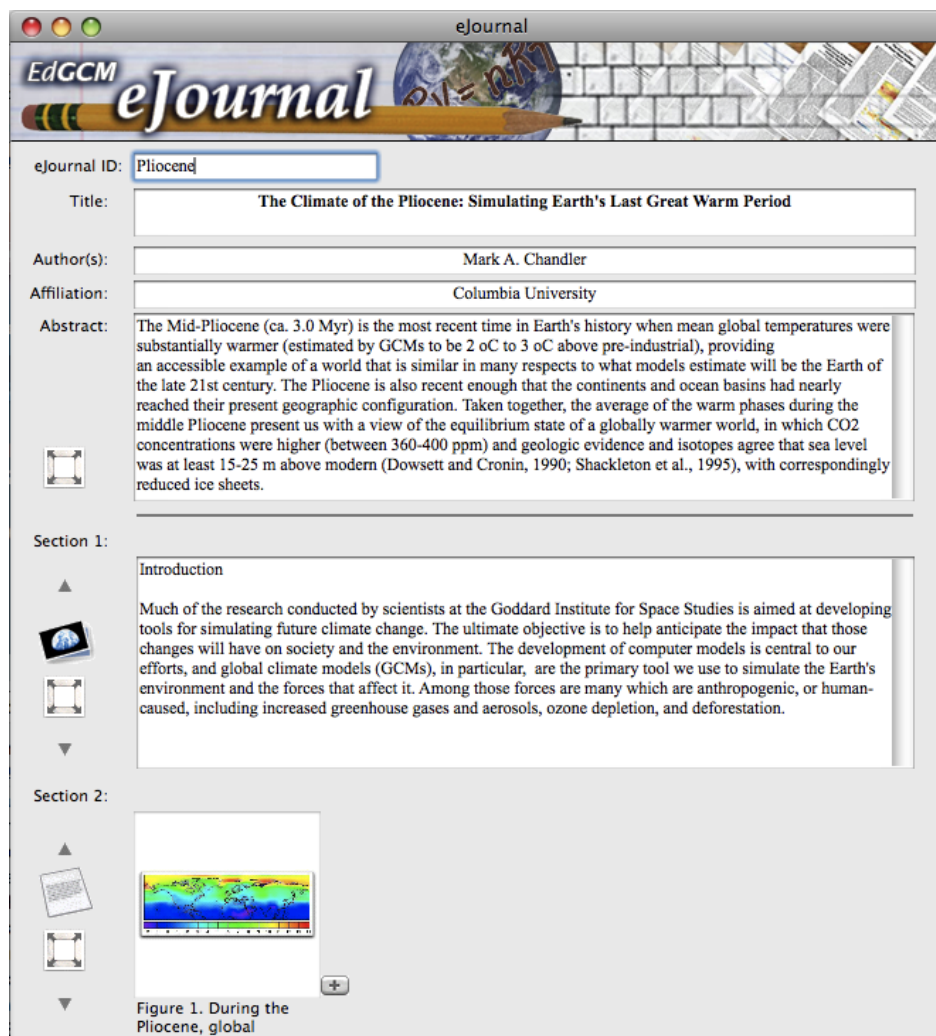
Figure 3-18. The eJournal feature in EdGCM provides a simple way to create a report about simulation results and then publish to the web.

is being written. Converting between text and image sections is simple; just click on one of the buttons to the left of the section (clicking on a photo button sets up the section for figures; clicking on a text button sets up the section for text).

Images can be inserted by cutting and pasting (or dragging and dropping) from the associated *Ed*GCM Image Browser into an eJournal image section. Three additional figures may be added to a given section (for a total of four figures) by clicking the "+" button at the lower right corner of the figure window. Text information about the image is transferred to the report as a figure caption, but figure captions are also editable so that students can point out specific information pertinent to their analyses.

The Image Browser is a library of photos, graphs, and maps that can be used to illustrate key points for discussion in a student's eJournal report. The images may be sorted by name, date created or modified, or by theme (e.g., global warming images), and can be set to display images in gallery

or list form. To page through multiple pages of the Image Browser, click on the "forward" and "reverse" buttons at the top of the Image Browser window. Any user may add images to the Image Browser.
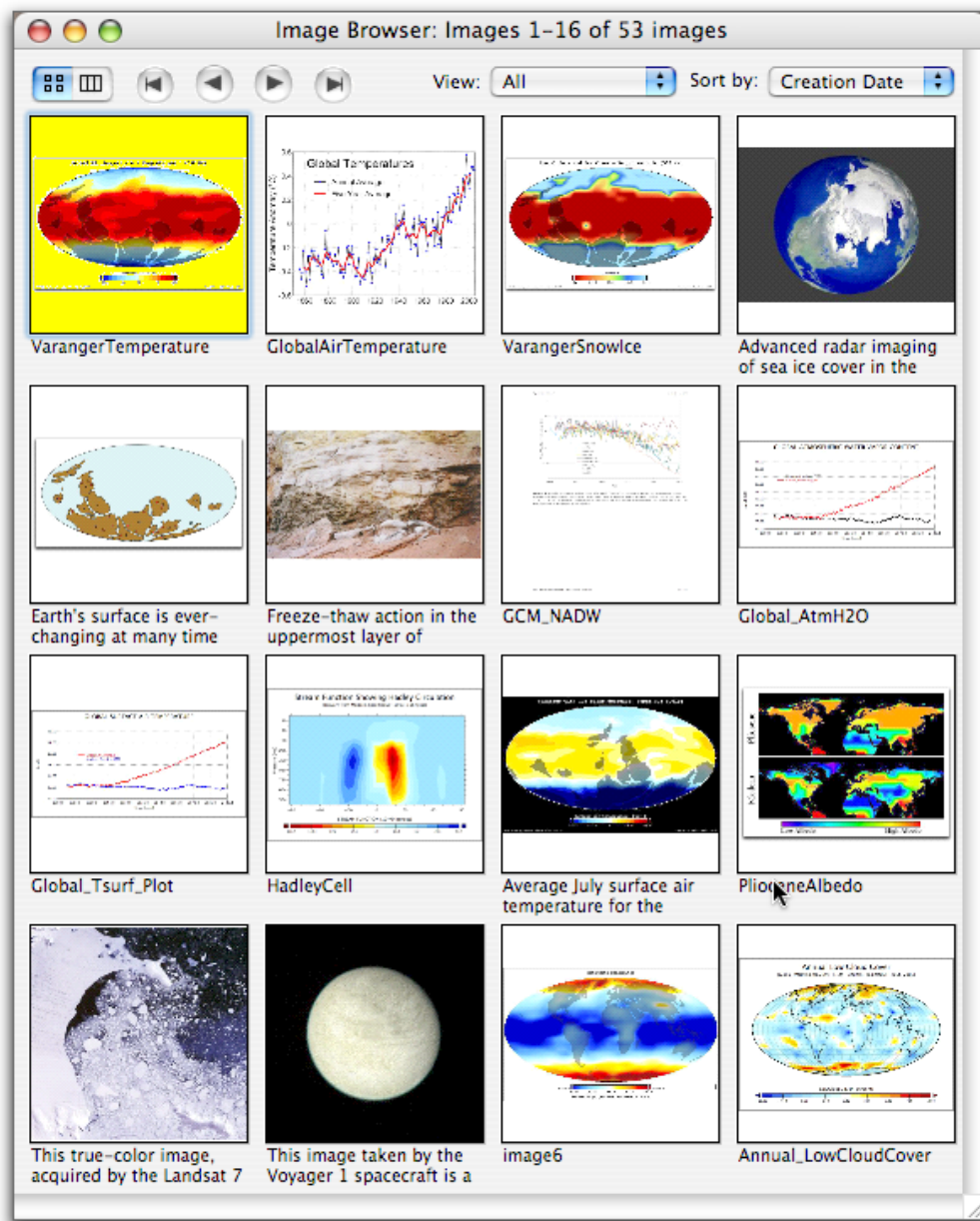
Figure 3-19. The Image Browser is a library of photos, graphs, and maps that can be used to illustrate an eJournal report.

eJournal reports are stored in the eJournal Library (Figure 3-20). They can also be linked to individual experiments in the Simulation Library database, to establish a relationship between simulations and their analyses. The database then keeps track of situations where many students are analyzing and reporting on one experiment, as well as one student analyzing and reporting on many experiments. As with the Simulation Library, permissions can be set for access to individual eJournals.

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Figure 3-20. The eJournal Library is similar to the Simulations Library in form and function.
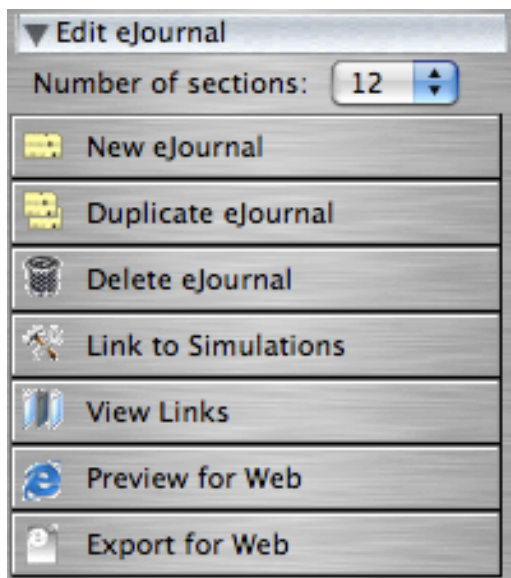
Figure 3-21. Toolbar buttons for the eJournal feature in EdGCM.

When an eJournal report is complete, it is easily converted to HTML format through controls in the toolbar (Figure 3-21). The Preview for Web button generates an HTML file (Figure 3-22) that opens automatically in a new window within your default web browser. After the report is checked for accuracy and completeness, clicking on the Export for Web button opens a window so that the HTML file can be saved directly to a web site directory. The report can easily be published to a school web site or to the student's own web space for public access.
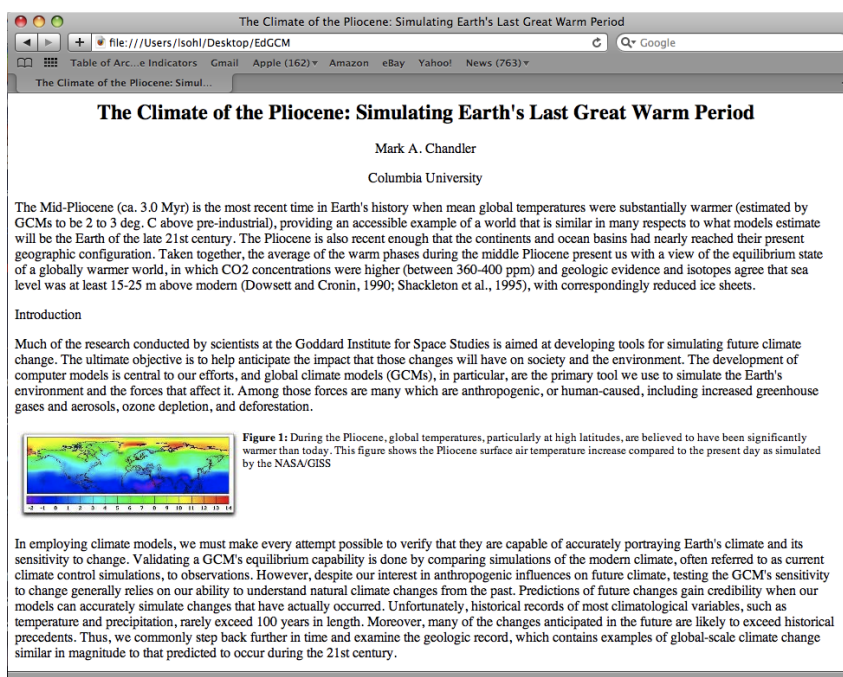
Figure 3-22. The finished eJournal displayed as an HTML file.

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CHAPTER 4
*Ed*GCM Tutorial

The purpose of the following tutorial is to familiarize you with the setup, running, and post-processing of a global climate model simulation. This example is based upon one of the global warming scenarios included on your *Ed*GCM CD-ROM. Although you will see the fields and options that can be changed for customized simulations, we will mainly demonstrate the use of the pre-programmed values in the global warming scenario for this tutorial. Unless otherwise indicated, each step will be the same in both the Mac and Windows versions.

There are also video tutorials for *Ed*GCM version 3.2 available on our web site (http://edgcm.columbia.edu/support/multimedia/).

4.1. Launching *Ed*GCM and Setting Up a Simulation

1. **Mac:** In the *Ed*GCM folder, double-click on the *Ed*GCM shortcut to launch the application.

Windows: Double-click on the *Ed*GCM shortcut on the desktop, or select EdGCM from the Start Menu to launch the application.

The first window that will appear will be the basic *Ed*GCM Toolbar. The set of icons across the top are shortcuts to some of the key functions in the software (e.g., Setup Simulations, Analyze Output). Below these are a set of controls for starting and pausing simulations, as well as restarting and extending them.

The Toolbar also includes a list of simulations already available (the run list). The buttons in the Toolbar will automatically change to provide new options as various *Ed*GCM functions are selected, but the run list will always be present. The run list may also be used to search for a particular run ID, or to sort through a long list of run IDs.

Figure 1. The basic EdGCM Toolbar.

2. In the menu at the top of the screen, click once on "Window" to display the various function windows within *Ed*GCM 4D, and select "Setup Simulations" (or press cmd + 1 for Macs, ctrl + 1 for Windows). To see the initial conditions for the Global_Warming_01 scenario, make sure it is selected in the run list. Note the changes to the Toolbar relevant to the Setup Simulations window (Figure 2).
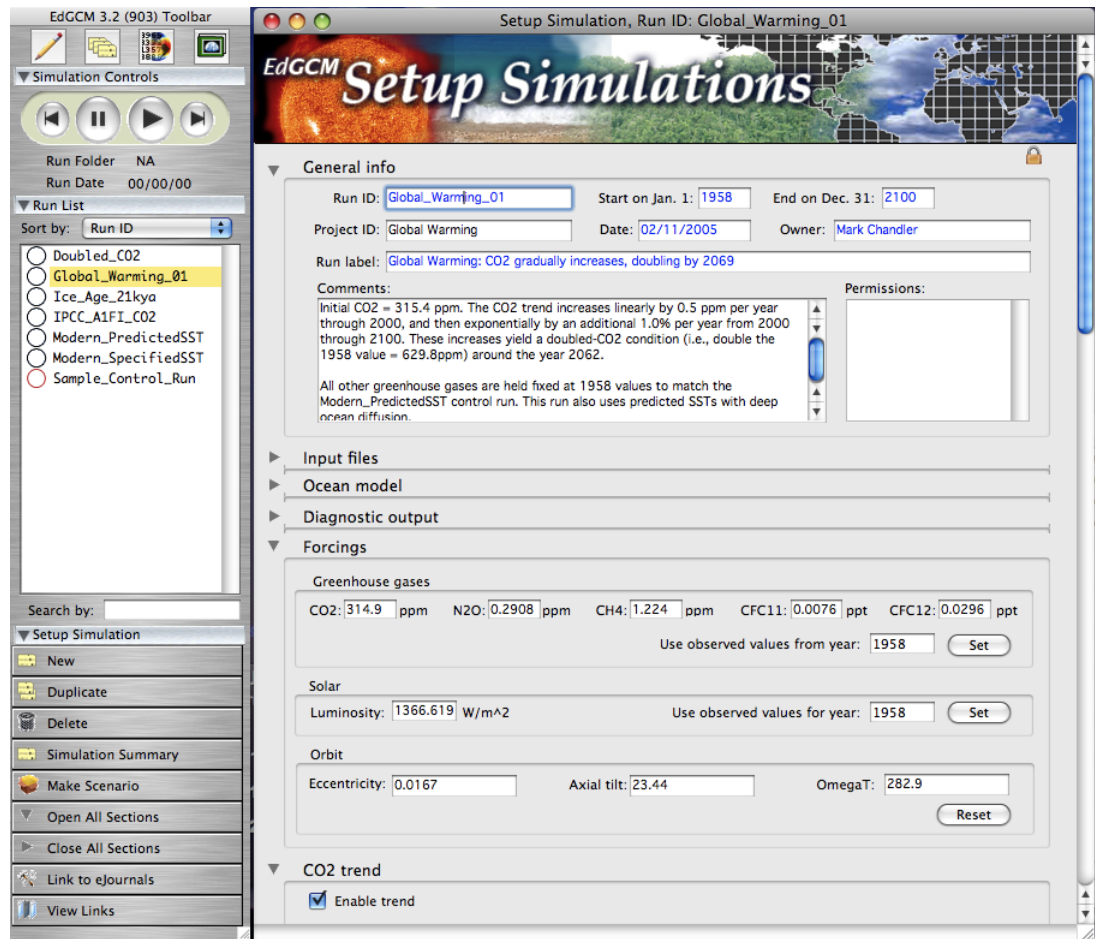

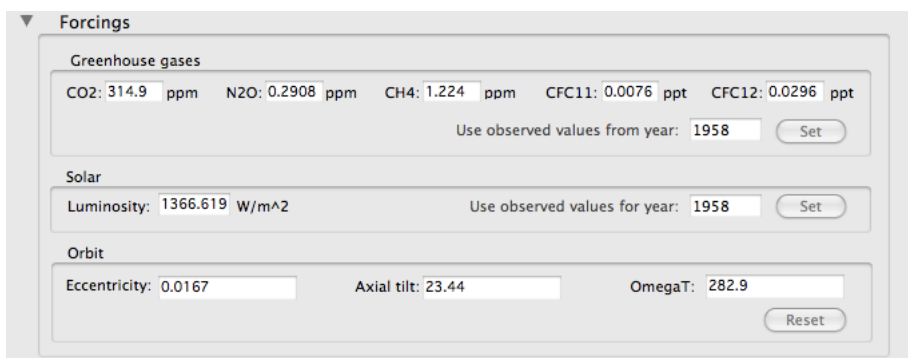*Figure 2. The Setup Simulations window and its associated Toolbar.*

The comments section in the **General info** section of the Setup Simulation window provides the simulation description. This scenario was designed to induce global warming by increasing carbon dioxide in the atmosphere at the linear increasing rate of 0.3 ppm for the first 70 years of the experiment, followed by an exponential increase rate of 0.75% per year over a 130-year interval, starting with the observed value of 295.5 ppm in 1900.

The scenario included is locked, which means that none of the parameters can be changed (note the small lock icon in the upper right corner of the Setup Simulations window, below the banner). In order to create a copy of this scenario that can be modified, click the Duplicate button under "Setup Simulation" in the Toolbar. You have now created a copy of the simulation (Global_Warming_1_copy in the run list) that can be modified to your specifications.

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If you were to continue setting up a new scenario, the remaining sections of the Setup Simulations window would be used to input your modifications. The **Input files** section sets the geographic boundary conditions (i.e., land mass distribution, topography, vegetation distribution) at the appropriate grid resolution for the model, according to the files selected. For the modern control runs, future climate simulations and Pleistocene ice age experiments distributed with *Ed*GCM, the choice of files need not be modified from the default selections. Users wanting to do paleoclimate simulations must take care that all the boundary condition files here are set appropriately for the time period of interest, or else the GCM will crash.

The **Ocean model** and **Diagnostic output** sections are intended for advanced users, and need not be modified for most simulations.

The **Forcings** section (Figure 3) allows you to set the value of solar luminosity and various greenhouse gases, the levels of which would remain uniform through the entire experiment. The values entered into this section are independent of each other and can be set to whatever values you wish. However, the GCM is not guaranteed to behave properly if the values entered are too far beyond modern values (e.g., solar luminosity set to more than 10% above or below modern; more than 20X modern carbon dioxide).

Figure 3. The Forcings section allows basic manipulation of the GCM boundary conditions.

More complex variations of the solar luminosity and various greenhouse gases are also possible by adjusting individual **Trends**. As previously noted, the simulation used for this tutorial sets a linear increase followed by an exponential increase per year for carbon dioxide. It is also possible to include a transient increase in carbon dioxide. Just to illustrate this option, open the CO2 Trend section of the Setup Simulation window, click once on the second drop-down menu bar and select "Step (ppm)" as the second trend (Figure 4). Then fill in a value of 500 for the step function for the years 1970-2010.
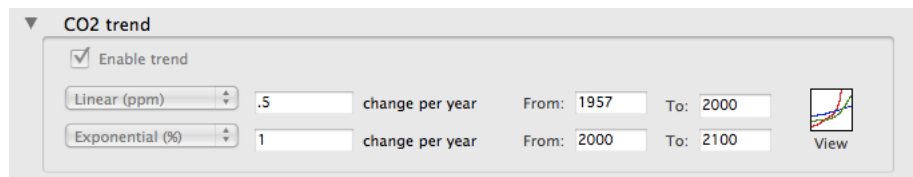
Figure 4. The CO2 trend section, like the other trend sections, permits the levels of greenhouse gases to change during the course of a simulation.

To see a graphic representation of how the level of CO2 would change through time, click on the "View" icon on the right side of the CO2 Trend section to launch the *Ed*GCM Visualization Application, or EVA, and display the trends (Figure 5). More information on how to use EVA can be found in the EVA manual included in the *Ed*GCM Documentation folder.
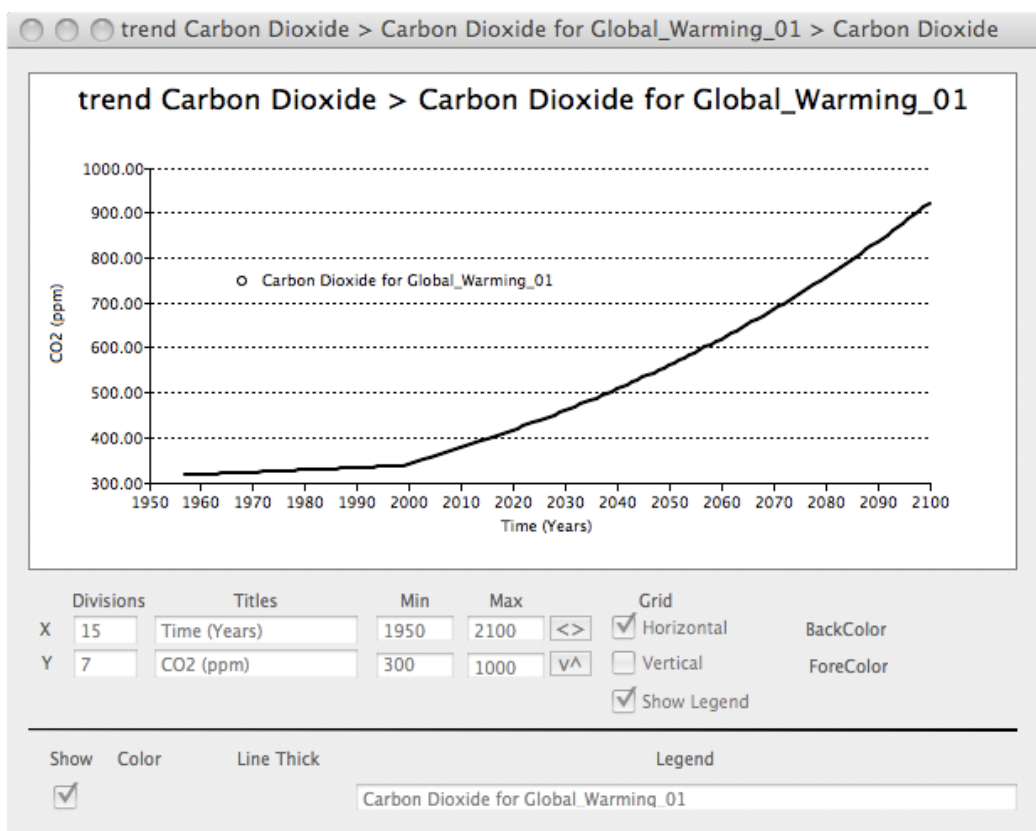

Figure 5. EVA display of changing CO2 trends as selected in Figure 4.

The **Power tools** and **Developer tools** sections are intended for advanced users, and should not be modified without special direction.

NOTE: For the purposes of this tutorial, we have already run the simulation and provided you with the output files. ***Do NOT begin a new simulation run, otherwise you will overwrite the tutorial's data files.***

If you are later running your own simulation, you need to take the following steps to get the experiment under way:

3. With the boundary conditions now set for this simulation, press the "play" button under "Simulation Controls" at the top of the toolbar. A new window will pop up to show you the progress of the model simulation in Fortran. The model will initially run through the first hour of the simulation and then stop (Figure 6), to ensure that no major error have been made in the selection of boundary conditions (e.g., a Snowball Earth land mass distribution with modern vegetation).
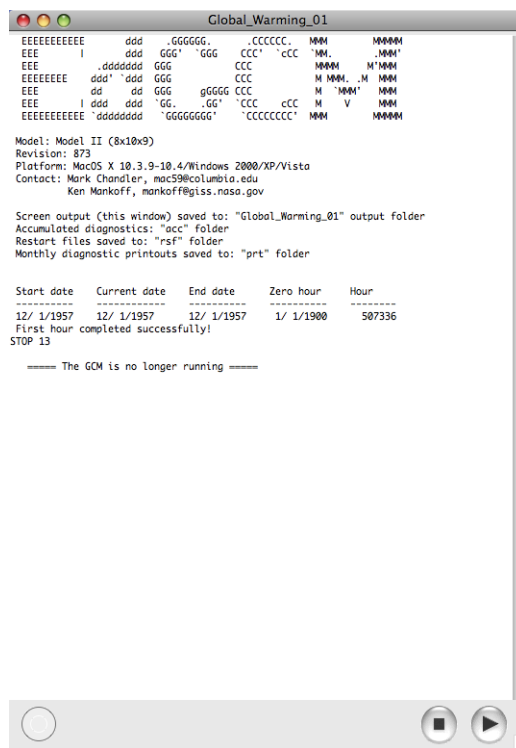
Figure 6. The first hour of a simulation was successfully completed.

4. At this point, the GCM must be restarted. Click on the "play" button at the bottom of the Fortran window in step 5, or at the top of the toolbar again, in order to restart the simulation.

Since Fortran runs independently of *Ed*GCM 4D, the interface can be closed down until the run is finished and you are ready to analyze the results.

4.2. Analyzing Output

After the simulation has been completed, re-launch *Ed*GCM 4D. Now select "Analyze Output" (cmd + 4 for Macs, ctrl + 4 for Windows) from the menu at the top of the screen. A window titled Analyze Output will appear (Figure 7).

The Analyze Output window is used to process four types of data: Maps, Zonal Averages, Time Series, and Vertical Slices. Each of these data types is represented as a tab in the center of the window; clicking on the tab brings you to that given data type and the list of variables available for that type. The fifth tab in this window, called Diagnostic Tables, generates tables of data like those used by NASA scientists to review their results.

On the left side of the Analyze Output window, the years run for a given simulation are displayed twice so that you may select the starting and ending dates for the interval you want to analyze. On the right side, a list of data files will appear as you process the results of the simulation.
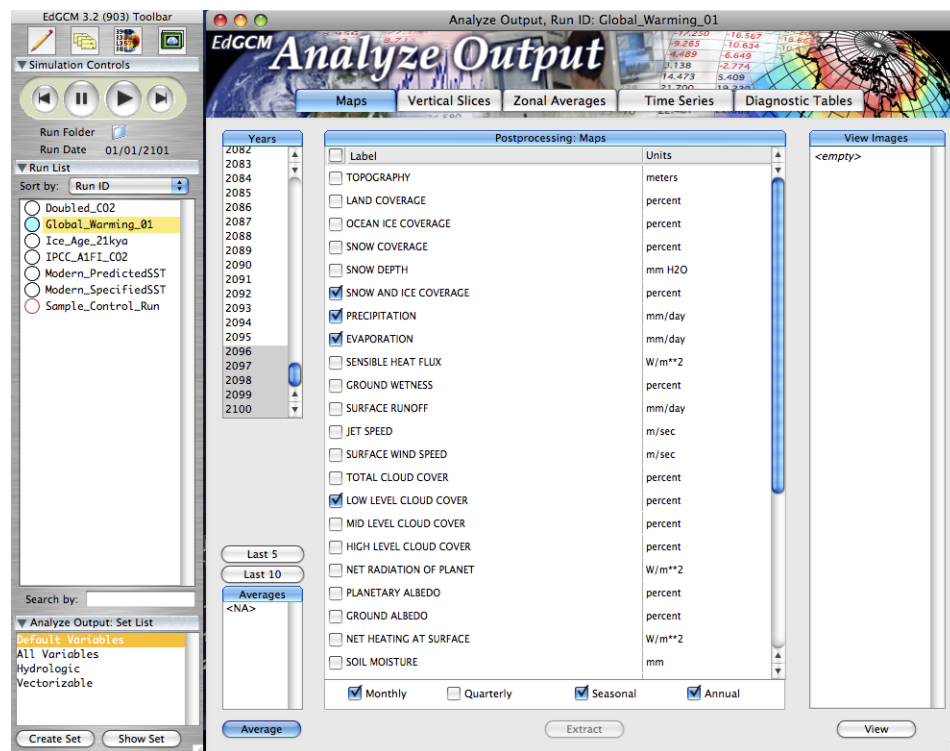
*Figure 7. The Analyze Output window and associated toolbar.*

NOTE: *The first time you execute any of the Analyze Output functions that involves launching a Fortran program, you may receive a warning from your system asking if you want to run the program. Always say "Yes" to these particular warnings to ensure that EdGCM continues to function smoothly.*

Maps

To generate maps displaying annual, seasonal or monthly averages, click on the Maps tab (Figure 8), and then select the first and last year of the time interval over which you would like the results averaged. Typically the last five to ten years of the run are selected for averaging, a practice which helps reduce the amount of noise in the data, so these options are available as buttons just below the list of years. For this tutorial, click on the "Last 5" button, so that the last five years of the run are highlighted on the list. Then click on the "Average" button in the lower left corner of the window to run the Fortan program that averages the years selected. When the averaging program is finished, a range of years will appear under the Averages section in the lower left portion of the window. Select the range you want to work with to continue your analysis.

Next, select the variables which you would like to map in the center portion of the window, then click once on the "Extract" button located at the bottom center of the window. Another Fortran window will appear briefly while the data for the maps are being extracted, and then a file will appear in the upper right portion of the window. To view the map diagnostics, either select the file name and click the "View" button on the lower right, or else double-click on the file name itself; both actions will launch EdGCM's visualization application, EVA.

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Figure 8. The Maps tab in the Analyze Output window, highlighting (in yellow) the file of extracted variables that can be viewed in map form (upper right). The icon next to the file name represents the netCDF format, a popular cross-platform format for spatial data.
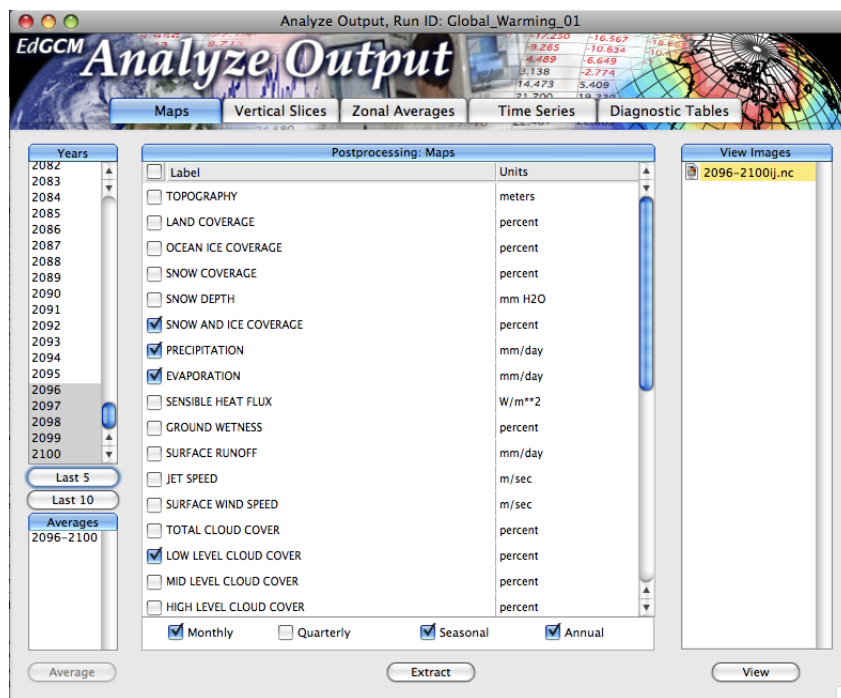
Time Series

To generate a time series that can be plotted linearly, click on the Time Series tab (Figure 9), and click on the "Time Series" button in the lower left corner of the window. This will launch another Fortran program, which may take a few minutes to run. Note that all the years available for processing are selected in the Year list by default; if you wish to view only a subsection of years, you can select them later in EVA or Excel.

Figure 9. The Time Series tab in the Analyze Output window, showing the list of files generated by post-processing. These files are given in Excel format for easy plotting with either EVA or Excel.
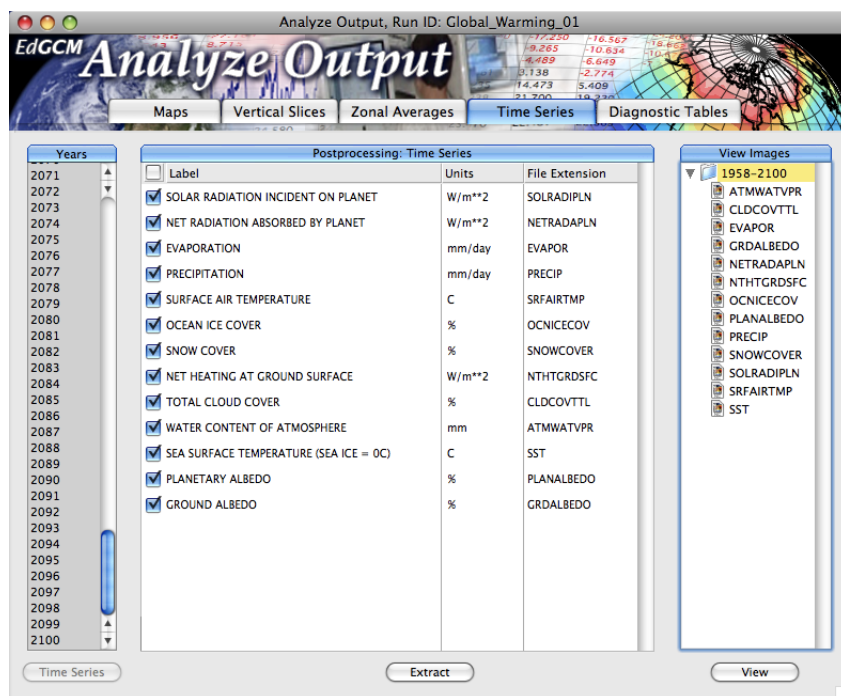
Once the Fortran program ends, select your variables of interest in the center portion of the window, and click on the "Extract" button below the variable list. A number of files - one for each variable you selected for extraction - will appear in the upper right portion of the window. To view any of the time series, either select the file name and click the "View" button on the lower right, or else double-click on the file name itself; both actions will launch EdGCM's visualization application, EVA.

For many users, map variables and time series data are sufficient for a great deal of analysis in a classroom setting. For advanced users, there are additional variables and data formats accessible in the other tabs of the Analyze Output window:

Vertical Slices

To generate vertical slices displaying spatial data along pole-to-pole transects, click on the Vertical Slices tab (Figure 10). If you have already averaged the last 5 years for any tab other than Time Series, you will already have a range of years available in the lower left portion of the window, and need not run the averaging program again; otherwise, follow the steps for averaging years described for the Maps tab above.

Next, select the variables you would like to extract in the center portion of the window, and click on the "Extract" button below the variables list, and a file of the extracted variables will appear in the upper right corner of the window. To view these variables, either select the file name and click the "View" button on the lower right, or else double-click on the file name itself; both actions will launch EdGCM's visualization application, EVA.
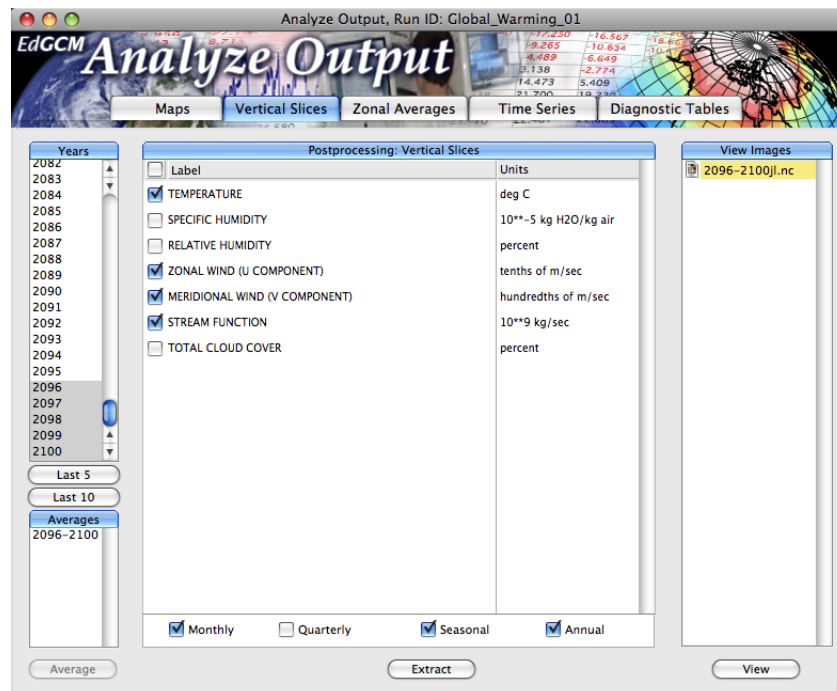

Figure 10. The Vertical Slices tab in the Analyze Output window, highlighting the file generated by post-processing. Vertical slice data files are also in netCDF format.

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Zonal Averages

To generate average values of certain variables along lines of latitude, click on the Zonal Averages tab (Figure 11). If you have already averaged the last 5 years for any tab other than Time Series, you will already have a range of years available in the lower left portion of the window, and need not run the averaging program again; otherwise, follow the steps for averaging years described for the Maps tab above.

Next, select the variables you would like to extract in the center portion of the window, and click on the "Extract" button below the variables list, and a file of the extracted variables will appear in the upper right corner of the window. To view these variables, either select the file name and click the "View" button on the lower right, or else double-click on the file name itself; both actions will launch EdGCM's visualization application, EVA, by default, but these data can also be plotted in Excel if you choose.

Figure 11. The Zonal Averages tab in the Analyze Output window, highlighting the files generated by post-processing. Zonal average data files provided in Excel format.
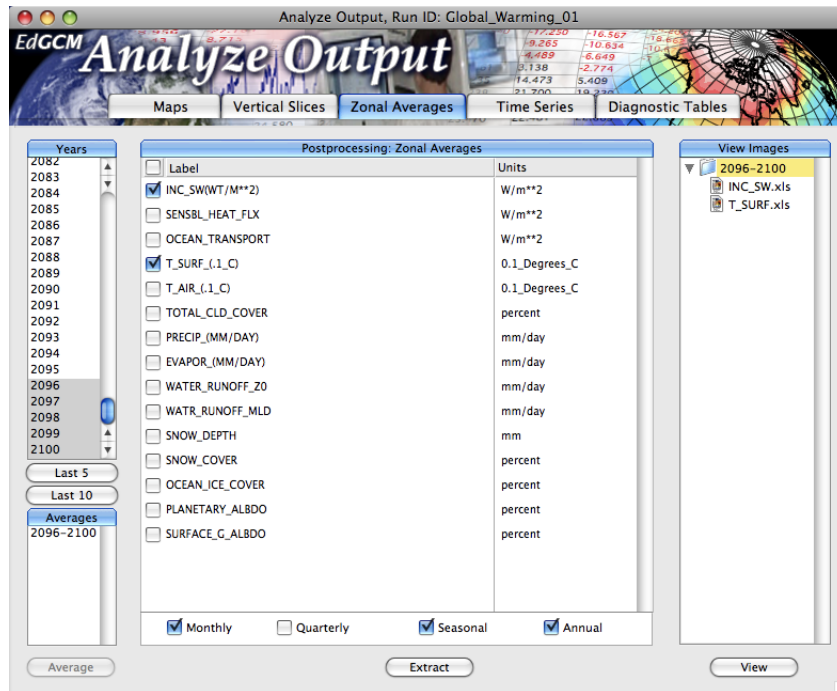
Diagnostic Tables

To generate tables of data showing annual, seasonal or monthly averages, click on the Diagnostic Tables tab (Figure 12). If you have already averaged the last 5 years for any tab other than Time Series, you will already have a range of years available in the lower left portion of the window, and need not run the averaging program again; otherwise, follow the steps for averaging years described for the Maps tab above.

Since the purpose of this tab is to create tables of standard set of diagnostic variables averaged over particular time periods of interest, the center portion of this tab lists options for those time periods. Typical averages selected are the January and July monthly averages (for warm/cold climate
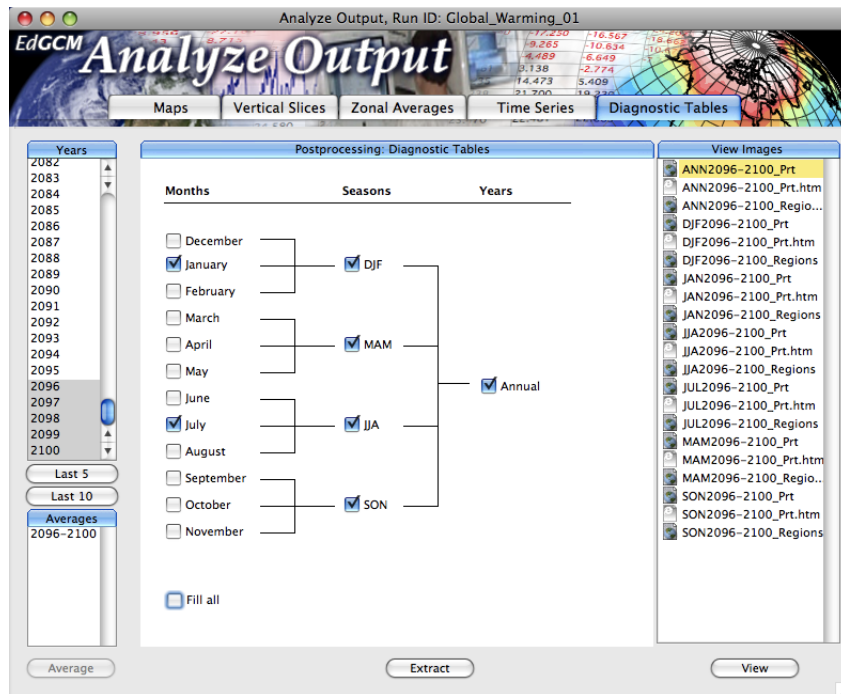
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Figure 12. The Diagnostic Tables tab in the Analyze Output window, showing the list of files generated by post-processing. The icons next to the file names indicate the format of the file: Excel, HTML, and SuSpect (the latter for Macs only).

contrasts); seasonal averages; and annual averages. Select the time periods you want to review, and click on the "Extract" button at the bottom center of the window. A list of the processed data files for each time period will appear on the right side of the window (Figure 12).

4.3. Viewing Climate Model Results

The data generated by the averaging and extraction steps in Analyze Output are displayed in the right-most column of the Analyze Output window. They can be viewed by selecting an item in that column and clicking on the "View" button directly below the column. An appropriate program for viewing the data will open automatically.

4.3.1. Viewing Maps and Plots of Data

*Ed*GCM is distributed with two scientific visualization applications: EVA (*Ed*GCM Visualization Application), and Panoply (from NASA/GISS). EVA is specifically designed for viewing EdGCM's maps and time series results, and allows users to visualize and perform basic analyses (such as differencing) of the global climate model output. Panoply is a powerful, and more generic, Java-based viewer of netCDF earth science data files. It is particularly useful if you plan to compare your *Ed*GCM results to those of other models or to observations, which must also be stored in the netCDF format. Both EVA and Panoply are quite user-friendly and are included with the standard *Ed*GCM installation. Each comes with its own reference guide, so please consult those manuals for detailed information on the uses of these powerful scientific visualization tools.

4.3.2. Viewing the Raw Data Tables

The "Diagnostic Tables" tab in *Ed*GCM's Analyze Output window produces a detailed summary of the climate model output. The format is consistent with that used by the climate model development team at NASA/GISS. Although it is a handy (and voluminous) summary of the data, the abbreviated annotations and presentation requires users to be familiar with many atmospheric science terms and, commonly, with the unique vernacular used by climate model developers. Access to these tables are primarily provided for those who have previously worked with the NASA/GISS Global Climate Models or for those who will be work on project collaborations with NASA/GISS scientists.

Windows users may choose to view Diagnostic Tables using Microsoft Excel® or, by choosing the files ending in .html, using a web browser. These are very large tables containing information on nearly all the climate variables produced by the GCM, and the html view is perhaps the most efficient way to scan the information because there are links to the specific table for each variable at the top of these files (Figure 13). Mac users have the additional option of viewing the data tables with another prorgram we provide called SuSpect (Figure 14). SuSpect allows users to sychronize the viewing of multiple files for quicker comparison of the results from more than one simulation.

Figure 13. The HTML display of tables data begins with a series of links to tables for the individual variables selected for analysis.
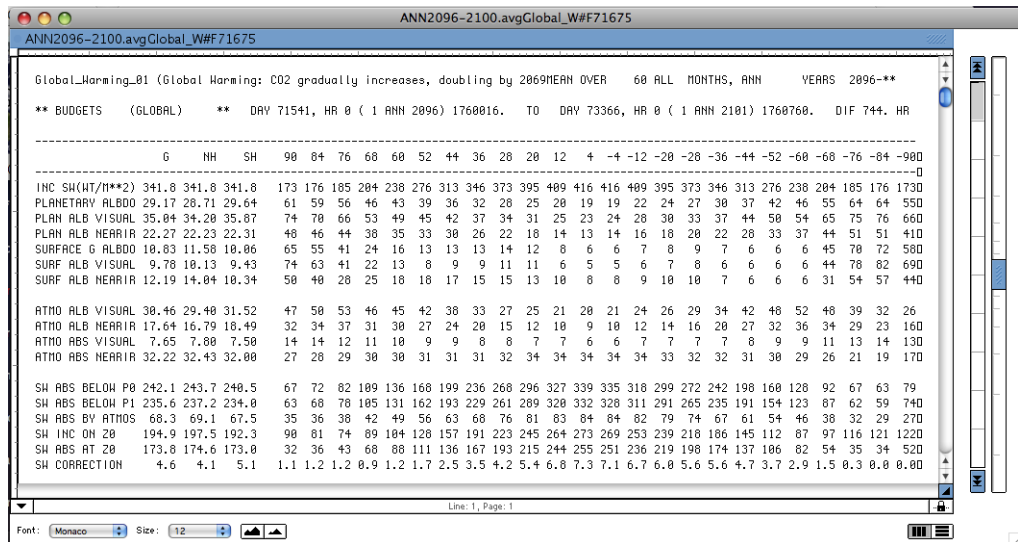

Figure 14. Mac users can employ SuSpect to view their data.

4.4. Reporting Your Results

An important feature of *Ed*GCM is the ability to share simulation results and interpretations by publishing to a web site easily accessible to others. The entire process is greatly simplified through *Ed*GCM's eJournal function.

To report results:

1. Return to *Ed*GCM, and select "eJournal" from the Window menu at the top. The eJournal toolbar and window will appear (Figure 15).
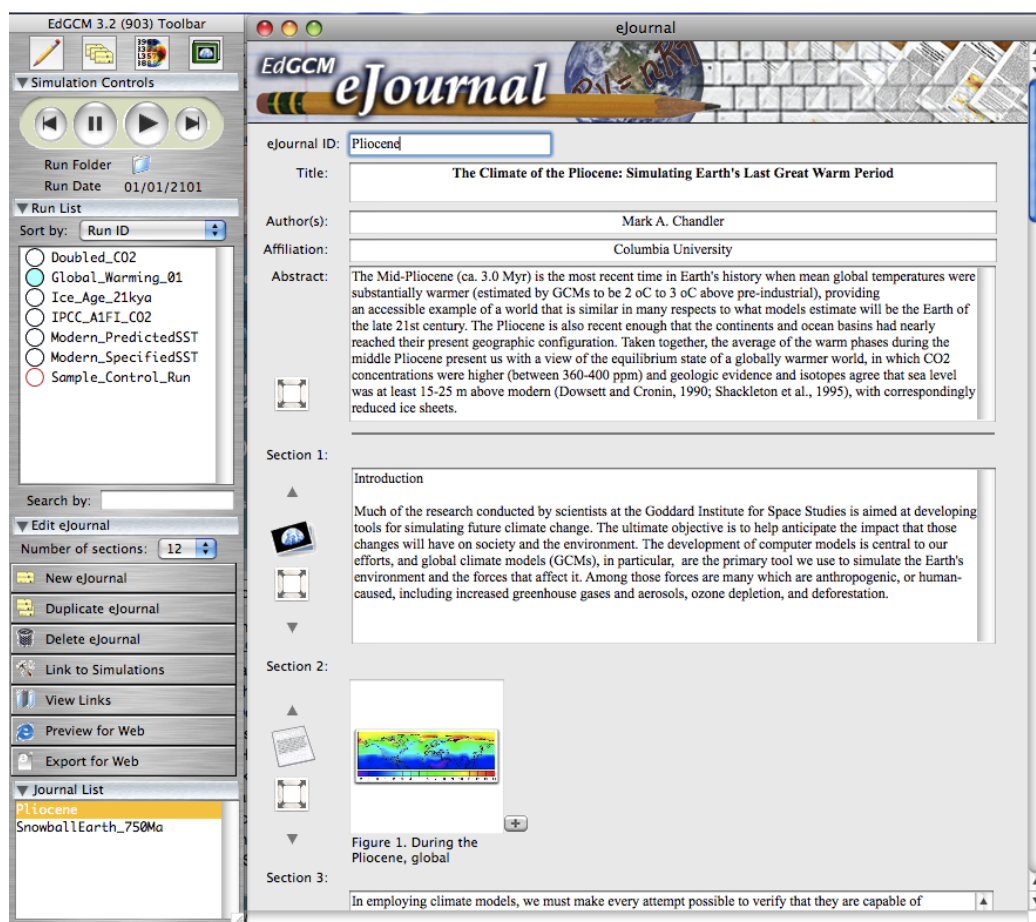

Figure 15. The eJournal setup window and its associated toolbar.

2. Note that the eJournal window is divided into sections. Each section of the eJournal (up to a maximum of 20 sections) can be used for either text descriptions or figures. To convert between one type of section to the other, simply click on the button to the left of the section (clicking on a photo button sets up the section for figures; clicking on a text button sets up the section for text).

3. Three additional figures may be added to a given section (for a total of four figures) by clicking the "+" button at the lower right corner of the figure

window. Up to two lines of figure caption text, if available, will be visible for each figure in the eJournal setup window, although longer captions will be displayed in their entirety when the eJournal is published to HTML.

4. Images of any size or format can be imported from the Image Browser (Figure 16), which is accessible from the Window menu. Images from the Image Browser may be inserted into an eJournal section by simply dragging and dropping the image into a figure box, such as the one seen in section 2 of the eJournal page in Figure 15.
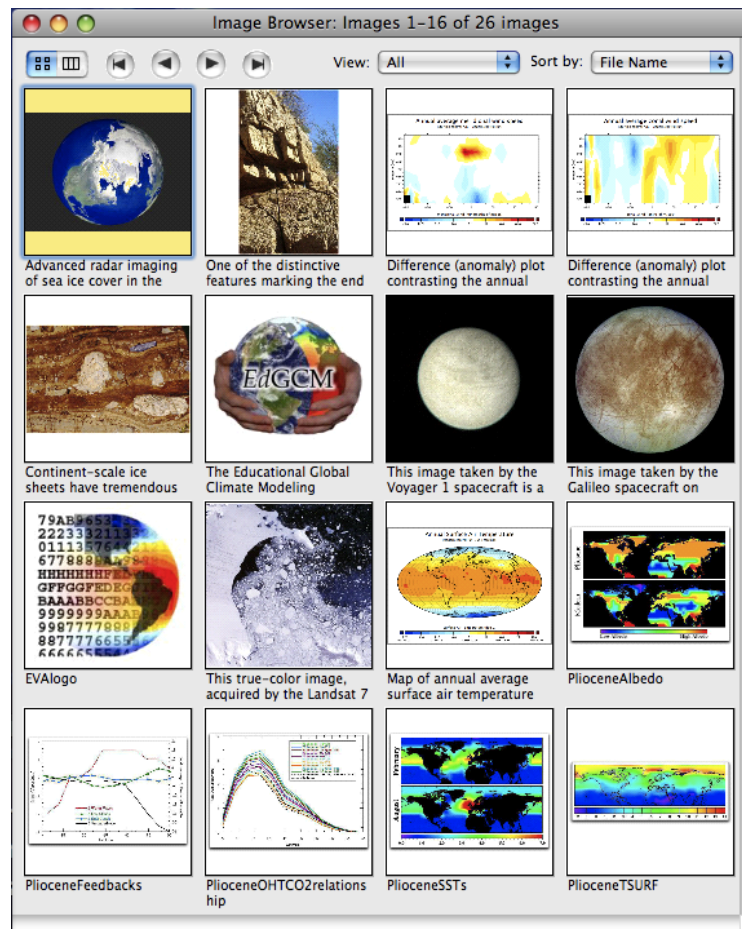

Figure 16. The Image Browser is a library of photos, graphs, and maps that can be used to illustrate key points for discussion in a student's eJournal report. The images can be sorted by name, date created or modified, or by theme (e.g., Pliocene images, global warming images). The Image Browser may be added to at any point by students or teachers.

5. To page through multiple pages of the Image Browser, click on the "forward" and "reverse" buttons in the Image Browser toolbar. It is also possible to search for images by name, or sort images by name, creation date, etc.

6. When an eJournal is ready for web publication, return to the filled-out eJournal page and click on the "eJournal to Web" button in the toolbar (see Figure 15). The eJournal page will be converted to an HTML file, which will open automatically in a new window within your default web browser (Figure 17).

Figure 17. A published eJournal report.

These files can then be published to a school web site or to the student's own web space for public access. A copy may also be added to the school's eJournal library, a searchable offline database for the reports.

APPENDIX A

*Ed*GCM: In Step With National Education Standards

From its inception, the *Ed*GCM project has been proactive in ensuring that its educational goals, objectives and science-research activities are in concert with a large number of national educational standards that have been developed by organizations such as the National Research Council (National Science Education Standards); the American Association for the Advancement of Science (AAAS Project 2061 Benchmarks); the International Society for Technology in Education (National Educational Technology Standards for Students); and the National Council for Geographic Education (National Geography Standards for Students).

A series of correlations of national standards to *Ed*GCM research activities, which follows, illustrates the wide-ranging congruity of the *Ed*GCM program to these standards.

A.1 *Ed*GCM Correlations to National Science Education Standards – Science Content Standards (High School)

CONTENT STANDARD A:

As a result of activities in grades 9-12, all students should develop understanding of

· Abilities necessary to do scientific inquiry

· Understandings about scientific inquiry

EdGCM ACTIVITIES IN SUPPORT OF CONTENT STANDARD A:

· Students actively participate in scientific investigations, and use the cognitive and manipulative skills associated with the formulation of scientific explanations.

· EdGCM investigations are meaningful to students. They are derived from current questions and issues that impact the lives of all people around the globe.

· Students use computers for the analysis and display of data in a variety of formats.

· Students formulate and revise scientific explanations and models using logic and evidence

CONTENT STANDARD B:

As a result of their activities in grades 9-12, all students should develop understanding of

· Structure and properties of matter

· Motions and forces

· Chemical reactions

· Conservation of energy and increase in disorder

· Interactions of energy and matter

AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD B:

· Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.

· In some chemical reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.

As a result of their activities in grades 9-12, all students should develop understanding characteristics of

· The cell

· Matter, energy, and organization in living systems

· Behavior of organisms

· Plant cells contain chloroplasts, the site of photo-synthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.

· As matter and energy flows through different levels of organization of living systems—cells, organs, organisms, communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

· Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often live in unpredictable environments, and so their behavior must be flexible enough to deal with uncertainty and change. Plants also respond to stimuli.

As a result of their activities in grades 9-12, all students should develop understanding of

· Energy in the earth system

· Geochemical cycles

· Origin and evolution of the earth system

In conducting climate research, students develop a deeper understanding of the evidence of earth's past and unravel the interconnected story of earth's fluctuating climate. The students' studies develop the concept of the earth system existing in a state of dynamic equilibrium. They discover that while certain properties of the earth system may vary on short or long time scales, the earth system will generally stay within a certain narrow range for millions of years. This long-term stability can be understood through the working of planetary geochemical cycles and the feedback processes that help to maintain or modify those cycles.

As an example of this long-term stability, students find that the geologic record suggests that the global temperature has fluctuated within a relatively narrow range, one that has been narrow enough to enable life to survive and evolve for over three billion years. They come to understand that some of the small temperature fluctuations have produced what we perceive as dramatic effects in the earth system, such as the ice ages and the extinction of entire species. They explore the regulation of earth's global temperature by the water and carbon cycles. Using this background, students can examine environmental changes occurring today and make predictions about future temperature fluctuations in the earth system.

AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD D:

Energy in the earth system
· Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.

· Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.

· Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.

Geochemical cycles
· The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.

·Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

The origin and evolution of the earth system
· Geologic time can be estimated by observing rock sequences and using fossils

to correlate the sequences at various locations. Current methods include using the known decay rates.

As a result of activities in grades 9-12 , all students should develop understanding of

• Science as a human endeavor

• Nature of scientific knowledge

• Historical perspectives

AS A RESULT OF EdGCM ACTIVITIES STUDENTS SHOULD DEVELOP THESE UNDERSTANDINGS OUTLINED IN CONTENT STANDARD G:

• Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and obser-vational evidence about nature, and must make accurate predictions, when appro-priate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.

• Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirma-tions and are therefore unlikely to change in the areas in which they have been tested. In areas where data or under-standing are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incom-plete, but this is also where the opportunity for making advances may be greatest.

• The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

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A.2 *Ed*GCM Correlations to National Science Education Standards – Science Teaching Standards (High School)

TEACHING STANDARD B:

· Teachers of science guide and facilitate learning. In doing this, teachers

· Focus and support inquiries while interacting with students.

· Orchestrate discourse among students about scientific ideas.

· Challenge students to accept and share responsibility for their own learning.

· Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

EdGCM ACTIVITIES IN SUPPORT OF STANDARD B:

· *Ed*GCM research activities are inquiry-based. Students are encouraged to interact and exchange ideas with each other, their teacher, and with research scientists during the course of their investigations.

· Teachers introduce the functions of the *Ed*GCM application; explain the use of climate models in climate research; and describe the process by which scientists evaluate their conclusions and submit their research to peer review.

TEACHING STANDARD D:

· Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers

· Structure the time available so that students are able to engage in extended investigations.

· Make the available science tools, materials, media, and technological resources accessible to students.

· Identify and use resources outside the school.

EdGCM ACTIVITIES IN SUPPORT OF STANDARD D:

· *Ed*GCM activities can be conducted for various periods of time, including extended research.

· The *Ed*GCM software application, a fully operational desktop version of a global climate model, is a unique resource that enables students to conduct genuine research activities in collaboration with research scientists and educators in colleges and universities.

• Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

• In doing this, teachers and their colleagues

• Nurture collaboration among students.

• Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.

• Model and emphasize the skills, attitudes, and values of scientific inquiry.

EdGCM ACTIVITIES IN SUPPORT OF STANDARD E:

• The research activities of EdGCM may be carried out by groups of students in a collaborative effort, with each pupil assigned specific tasks within the research framework.

• Research tasks assigned to groups of students require that a continuing exchange of ideas and results be communicated in a scientifically appropriate manner.

• In order to ensure that EdGCM student research is properly planned and conducted, teachers stress the skills, attitudes and values of scientific inquiry.

LESS EMPHASIS ON

Treating all students alike and responding to the group as a whole.

Rigidly following curriculum

Focusing on student acquisition of information

Presenting scientific knowledge through lecture, text, and demonstration

Asking for recitation of acquired knowledge

Testing students for factual information at the
end of the unit or chapter

Maintaining responsibility and authority

Supporting competition

Working alone

MORE EMPHASIS ON

Understanding and responding to individual student's interests, strengths, experiences, and needs

Selecting and adapting curriculum

Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes

Guiding students in active and extended scientific inquiry

Providing opportunities for scientific discussion and debate among students

Continuously assessing student understanding

Sharing responsibility for learning with students

Supporting a classroom community with cooperation, shared responsibility, and respect

Working with other teachers to enhance the science program

A.3 *Ed*GCM Correlations to AAAS Project 2061 Benchmarks – Science Content Standards (High School)

Aspects of the scientific world view can be illustrated in the upper grades both by the study of historical episodes in science and by reflecting on developments in current science. Case studies provide opportunities to examine such matters as the theoretical and practical limitations of science, the differences in the character of the knowledge the different sciences generate, and the tension between the certainty of accepted science and the breakthroughs that upset this certainty.

· From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior know-ledge. Change and continuity are persistent features of science.

· No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better under-standing of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

· Students actively participate in scientific inquiry, and use the cognitive and manipulative skills associated with the formulation of scientific explanations.

· *Ed*GCM research investigations are meaningful to students. They are derived from current questions and issues that impact the lives of all people around the globe.

· Students formulate and revise scientific explanations and models using logic and evidence derived from *Ed*GCM climate model data and analysis.

Students' ability to deal with abstractions and hypothetical cases improves in high school. Now the unfinished and tentative nature of science may make some sense to them. Students should not be allowed to conclude, however, that the mutability of

The *Ed*GCM research experience involves students in the following science inquiry activities:

· Formulating a hypothesis

· Selecting variables to be tested

science permits any belief about the world to be considered as good as any other belief. Theories compete for acceptance, but the only serious competitors are those theories that are backed by valid evidence and logical arguments.

The nature and importance of prediction in science can also be taken up at this level. Coverage of this topic should emphasize the use of statistics, probability, and modeling in making scientific predictions about complex phenomena often found in biological, meteorological, and social systems. Care also should be taken to dissociate the study of scientific prediction from the general public's notions about astrology and guessing the outcomes of sports events.

By the end of the 12th grade, students should know that:

· Investigations are conducted for different reasons, including exploring new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.

· Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of the data (both new and previously available).

· Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.

· There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments.

· And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.

· Running authentic climate simulations

· Revising and reformulating a hypothesis

· Running a revised climate simulation, when required

· Analyzing climate simulation data

· Drawing conclusions from these data

· Developing explanations for past climates

· Predicting future climate trends

· Collaborating with classmates, students from other schools and universities, and research scientists

· Publishing and sharing the results of research via the Internet

• Scientists in any one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective about their methods and findings. For that reason, scientific teams are expected to seek out the possible sources of bias in the design of their investigations and in their data analysis. Checking each other's results and explanations helps, but that is no guarantee against bias.

• In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.

• New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators.

1. THE NATURE OF SCIENCE
C. The Scientific Enterprise

No matter how the curriculum is organized, it should provide students with opportunities to become aware of the great range of scientific disciplines that exist. There is no sense, however, in having students memorize definitions of anthropology, astrophysics, biochemistry, paleobacteriology, and the rest of the family. Individual students or small groups of students can study different disciplines in some detail—most scientific societies are happy to help out—and then share their findings with one another. The focus of such studies should be substantive (what are typical studies like in the discipline) and sociological (how is the field organized and who is in it), and they should probably involve, over an extended time, interviews, field trips, readings, data analysis, and, if possible, the conduct of

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK C:

• The *Ed*GCM research experience may often involve students in projects that could require appropriate simultaneous studies within the Earth System, biological, environmental, and chemical sciences in collaboration with groups of students in other schools, university faculty, and research scientists.

• As a result of their experiences, students will become knowledgeable about the inter-disciplinary nature of climate research.

small-scale experiments or field studies. Such activities will contribute to science literacy goals, and they should also help students realize how many different career possibilities exist in science.

• Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy, and all are part of the same scientific enterprise. Although each discipline provides a conceptual structure for organizing and pursuing knowledge, many problems are studied by scientists using information and skills from many disciplines. Disciplines do not have fixed boundaries, and it happens that new scientific disciplines are being formed where existing ones meet and that some subdisciplines spin off to become new disciplines in their own right.

4. THE PHYSICAL SETTING
B. The Earth

By the end of the 12th grade, students should know that

• Life is adapted to conditions on the earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the sun that allows water to cycle between liquid and vapor.

• Weather (in the short run) and climate (in the long run) involve the transfer of energy in and out of the atmosphere. Solar radiation heats the land masses, oceans, and air. Transfer of heat energy at the boundaries between the atmosphere, the land masses, and the oceans results in layers of different temperatures and densities in both the ocean and atmosphere.

• The action of gravitational force on regions of different densities causes them to rise or fall—and such circulation, influenced by the rotation of the earth, produces winds and ocean currents.

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK B:

EdGCM research activities enable students to acquire a thorough knowledge of:

• the hydrologic cycle

• the transfer of solar radiation at and near the earth's surface

• the influence of dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans on the transfer of solar energy

• the heating of earth's surface and atmo-sphere by the sun in driving convection within the atmosphere and oceans, producing winds and ocean currents

• the interactions among the solid earth, the oceans, the atmosphere, and organisms that have resulted in the ongoing evolution of the earth system

E. Energy Transformations

Two major ideas merit introduction during these years, but without resort to mathematics. One of these is that the total amount of energy available for useful transformation is almost always decreasing; the other is that energy changes on the atomic scale occur only in discrete jumps. The first of those is not too difficult or implausible for students because they can experience in many ways a wide variety of actions that give off heat. The emphasis should probably be on the practical consequences of the loss of useful energy through heat dissipation.

By the end of the 12th grade, students should know that

· Whenever the amount of energy in one place or form diminishes, the amount in other places or forms increases by the same amount.

· Heat energy in a material consists of the disordered motions of its atoms or molecules. In any inter-actions of atoms or molecules, the statistical odds are that they will end up with less order than they began—that is, with the heat energy spread out more evenly. With huge numbers of atoms and molecules, the greater disorder is almost certain.

· Transformations of energy usually produce some energy in the form of heat, which spreads around by radiation or conduction into cooler places. Although just as much total energy remains, its being spread out more evenly means less can be done with it.

12. HABITS OF MIND
B. Computation & Estimation

Where do calculators and computers come into the picture? The answer is, nearly everywhere. And computers, with their easy-to-use spreadsheet, graphing, and database capabili-ties, have become tools that everyone can use, at home and at work, to carry out extensive quantitative tasks.

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EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK E:

· Science often advances with the intro-duction of new technologies. Solving technological problems often results in new scientific knowledge. New tech-nologies often extend the current levels of scientific understanding and introduce new areas of research.

· Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations.

· Many scientific investigations require the contributions of individuals from different disciplines, including engineering.

· New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK B:

*Ed*GCM research activities enable students to:

· create computer spreadsheets, graphs, and tables to assist in quantitative data analysis

By the end of the 12th grade, students should be able to

· Use computer spreadsheet, graphing, and database programs to assist in quantitative analysis.

· Compare data for two groups by representing their averages and spreads graphically.

D. Communication Skills

Good communication is a two-way street. It is as important to receive information as to disseminate it, to understand other's ideas as to have one's own understood. In the scientific professions, tradition places a high priority on accurate communication, and there are mechanisms, such as refereed journals and scientific meetings, to facilitate the sharing of new information and ideas within various disciplines and subdisciplines. Science-literate adults share this respect for clear, accurate communication, and they possess many of the communication skills characteristic of the scientific enterprise.

By the end of the 12th grade, students should be able to

· Write clear, step-by-step instructions for conducting investigations, operating something, or following a procedure.

· Choose appropriate summary statistics to describe group differences, always indicating the spread of the data as well as the data's central tendencies.

· Use and correctly interpret relational terms such as if . . . then . . . , and, or, sufficient, necessary, some, every, not, correlates with, and causes.

· Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.

· Use tables, charts, and graphs in making arguments and claims in oral and written presentations

· graphically compare data and analyses of data

EdGCM ACTIVITIES IN SUPPORT OF BENCHMARK D:

*Ed*GCM encourages students to:

· join in on-line group discussions about their research activities with other students, undergraduate faculty/students, and research scientists

· create and publish Internet-based research papers and reports either independently or in collaboration with students in other schools, undergraduate faculty/students and/or research scientists

*Ed*GCM activities require that students:

· Use tables, charts, and/or graphs in making arguments and claims in oral and written presentations regarding their research findings

A.4 *Ed*GCM Correlations to International Society for Technology in Education (ISTE) National Educational Technology Standards for Students (High School)

ISTE Standards for High School Students	*EdGCM Activities in Support of ISTE Standards:*
Routinely and efficiently use online information resources to meet needs for collaboration, research, publications, communications, and productivity. (4, 5, 6)	Students routinely use the on-line Forum, eJournal, SimExchange (simulation exchange) and web publishing components for communications, collaborative research, and publishing of results.
Select and apply technology tools for research, information analysis, problem solving, and decision-making in content learning. (4, 5)	The *Ed*GCM global climate model (GCM) provides students with an opportunity to be engaged in genuine scientific research that requires hypothesis development, experiment design, running simulations, visualization, analysis and interpretation of data, and reporting results. These processes assist students in solving real scientific problems.
Investigate and apply expert systems, intelligent agents, and simulations in real-world situations. (3, 5, 6)	*Ed*GCM allows students to simulate past, present, and future climates using an actual NASA/GISS GCM.
Collaborate with peers, experts, and others to contribute to a content-related knowledge base by using technology to compile, synthesize, produce, and disseminate information, models, and other creative works. (4, 5, 6)	*Ed*GCM fosters collaborations between precollege educators, students, university faculty, and the research community. These partnerships are accomplished through the ongoing utilization of the on-line components cited above.

Numbers in parentheses following each performance indicator refer to the standards category to which the performance is linked. The categories are:

3.   Technology productivity tools
4.   Technology communications tools
5.   Technology research tools
6.   Technology problem-solving and decision-making tools

A.5 *Ed*GCM Correlations to the National Council for Geographic Education (NCGE) – National Geography Standards for Students (Grades 9 - 12)

NCGE Standards for Students Grades 9-12	EdGCM Activities in Support of NCGE Standards:
STANDARD 1: How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information. STANDARD 4: The physical and human characteristics of places. 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 8: The characteristics and spatial distribution of ecosystems on Earth's surface. STANDARD 9: The characteristics, distribution, and migration of human populations on Earth's surface. STANDARD 12: The process, patterns, and functions of human settlement. STANDARD 14: How human actions modify the physical environment. STANDARD 16: The changes that occur in the meaning, use, distribution, and importance of resources. STANDARD 17: How to apply geography to interpret the past. STANDARD 18: To apply geography to interpret the present and plan for the future.	• *Ed*GCM provides students with the tools to create computer-generated maps of atmospheric and oceanic variables, plotted in a variety of projections and regions, which they analyze and interpret in order to draw conclusions regarding their research studies. • During the course of their research, *Ed*GCM student-participants are often required to compare and contrast numerous characteristics of the Earth's surface and its environment. • Student research can also be required to draw conclusions regarding human actions, processes, population characteristics, patterns, and migrations as they relate to specific investigation topics and results. • During the course of numerous climate research studies, students will define the interactions between climate, continental distribution, and topography in the past and present.

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> Chandler, M.A., S.J. Richards, and M. Shopsin, 2005: EdGCM: Enhancing climate science education through climate modeling research projects. In Proceedings of the 85th Annual Meeting of the American Meteorological Society, 14th Symposium on Education, Jan. 8-14, 2005, San Diego, CA, pp. P1.5;

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