Global Climate Models in the Classroom to Explore the Complexities of Climate Dynamics

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Bridging the gap between theory and models

Climate modeling results can be an excellent tool for promoting inquiry into the dynamics of past, present, and future climates. Exposing students to global climate model (GCM) output early on in their exploration of the climate system offers them the potential to apply new knowledge to a growing understanding of climate theory in the context of model results. While there have been thousands of climate modeling experiments, very little model output is available in an easily accessible format for review by the general public. Much data is in a format that is difficult to access and requires sufficient technical skill for processing. There are a few sources of GCM output available online that may be directly utilized in the classroom. Effectively using this output in the classroom can require some preparation, however, as students need direction and context that is generally not provided on these websites. Ultimately, with some modification in presentation format and accessibility, GCM output could become an effective educational resource at all educational levels. Making GCM output more accessible to the general public offers the potential to increase awareness of global climate and environmental change, as well as enhance cross-disciplinary collaboration between the physical and social sciences.

Key Content Areas

GCMs offer great potential for teaching theoretical concepts in climate dynamics from an inquiry perspective. I have used models and model output in undergraduate Climatology and Paleoclimatology courses at the University of Northern Colorado to promote inquiry and learning in four key content areas related to climatology:

(1) Physical climate system (e.g., general global circulation; heat, momentum, and moisture transports in the atmosphere)

(2) Climate sensitivity to greenhouse gases

(3) Feedbacks and interactions between components of the climate system

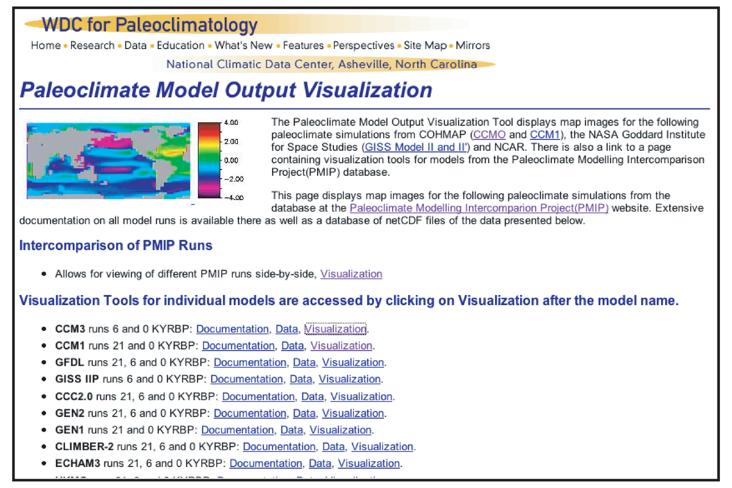
(4) An understanding of model utility and model differences, including advantages and disadvantages of specific model types

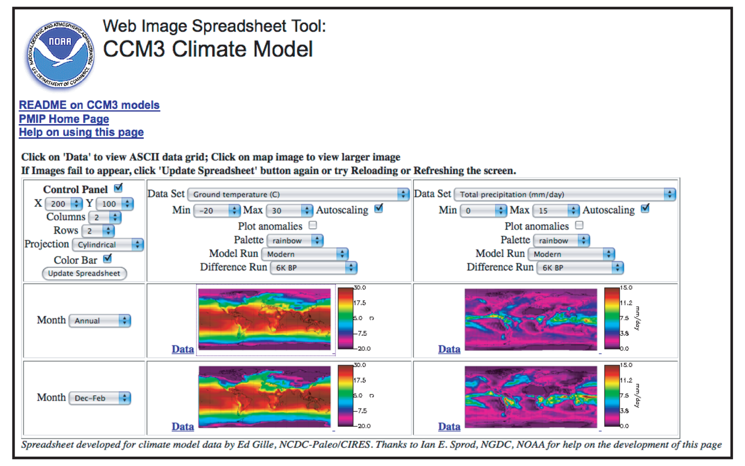
Here, I review some climate model resources presently available online, and offer examples for incorporating these into classroom lessons at the college undergraduate level.

World Data Center (WDC) for Paleoclimatology Model Output Visualization page:

http://www.ncdc.noaa.gov/paleo/modelvis.html

The WDC for Paleoclimatology at NOAA provides access to output from a variety of models. Students can compare modeled climates for the present, 6000 years ago, and 21,000 years ago using an interactive web spreadsheet tool, developed by Ian E. Sprod (NOAA-NGDC-GLOBE) and modified by Ed Gille (NOAA-NGDC Paleoclimatology) (sample depicted BELOW).



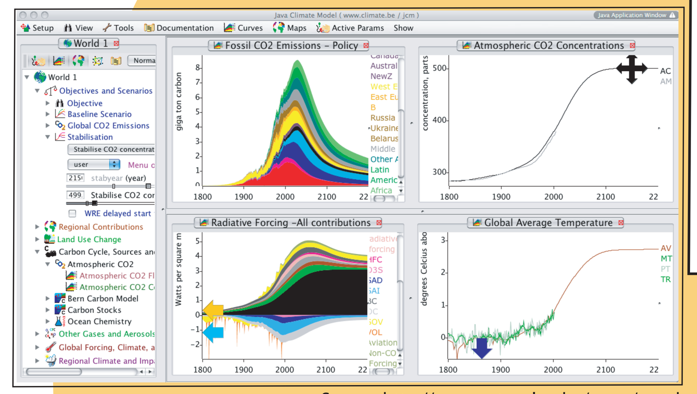


A unique aspect of this site is that it enables a side-by-side comparison of output from different models. This is especially useful in helping students comprehend model differences, and prompts discussion of model sources of error. However, because of the tremendous amount of data available at this site, it is important to focus students on only one or two models, and only a few output fields. I have found it helpful to place students in teams, with each team assigned a different model. After students have had time to examine the output, we compare differences between models as a class.

IPCC Java Climate Model at the UNEP Climate Change website:

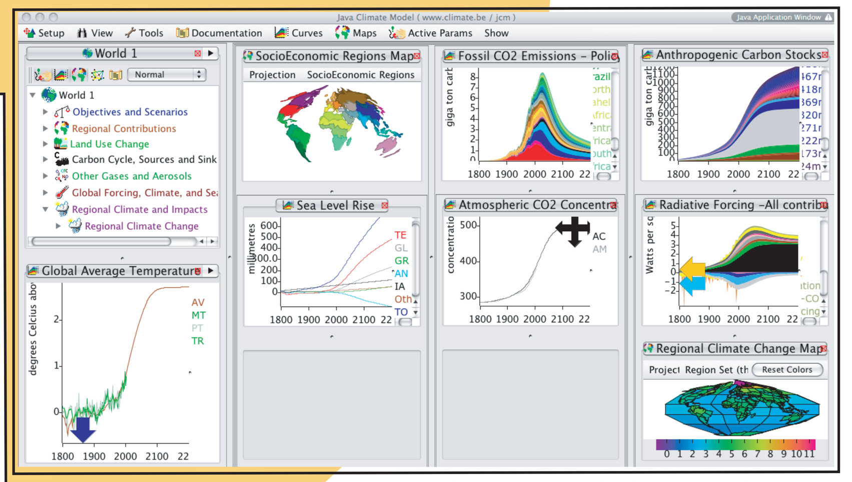
http://www.astr.ucl.ac.be/users/matthews/jcm/

Less time consuming than EdGCM (but with a steeper learning curve), UNEP's java-based climate model allows students to experiment with cause-effect relationships, and examine connections between greenhouse gas levels, temperature, and radiative forcing. The module (developed by Ben Matthews (with KUP Bern, and the Danish Energy Agency) uses simple carbon and climate models based on those in the IPCC. The module allows for easy comparison of IPCC emission scenarios.



Source: http://www.astr.ucl.ac.be/users/matthews/jcm/

I have required students to do a 'mini-modeling' homework assignment using this model. Students were asked to design a short experiment around a question. (For example: "What happens to global temperature and sea level if I raise CO2 by 150 ppm?"). Various model output fields can be conveniently viewed on a single page (RIGHT). To keep students from becoming overwhelmed, it's best to provide very specific directions for use.

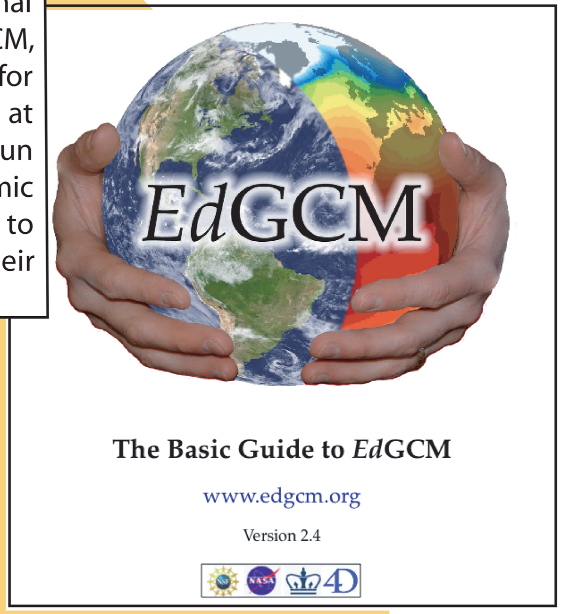


Source: http://www.astr.ucl.ac.be/users/matthews/jcm/

EdGCM: Offering students experience with a GCM

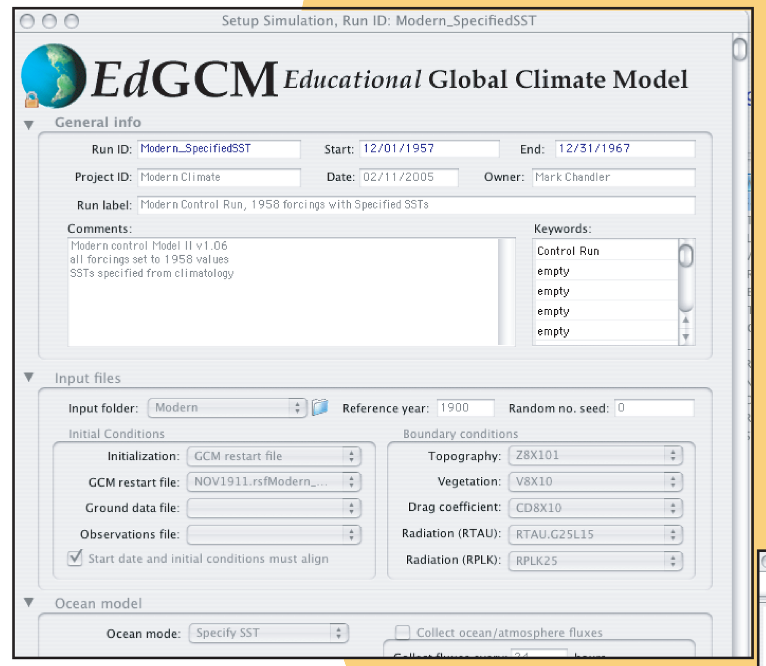
http://edgcm.columbia.edu/

Most models have a very steep learning curve, and require extensive computational resources. Thus, it is generally not feasible to use them in the classroom. EdGCM, developed by M. Chandler (http://edgcm.coumbia.edu), is the first GCM adapted for educational use. This is a low-resolution model first developed over 20 years ago at NASA, and still used for research. It has a user-friendly interface and can be run locally on a laptop or desktop. The model can be tailored for use at many academic levels. Students in the senior-level climatology course at UNC were asked to develop a project using this model, which required them to integrate their understanding of climate theory and models.

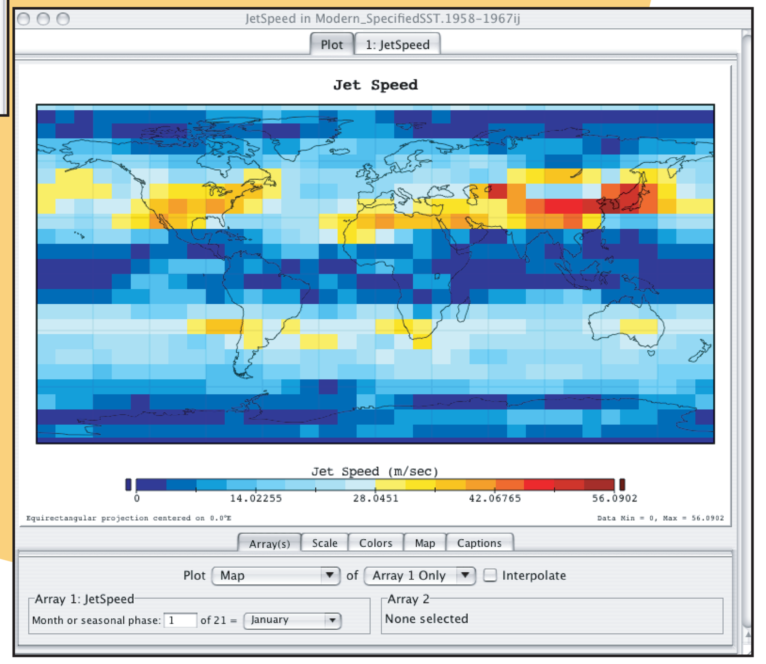


(from 'EdGCM Manual', Mark Chandler, EdGCM Cooperative, Columbia University)

Includes convenient GUI interface for setting up experiments

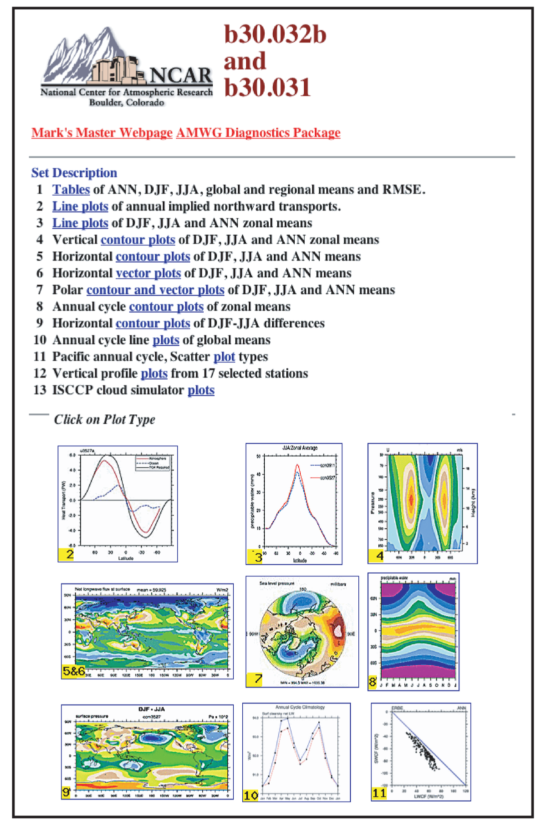


The software package, Panoply, (developed at NASA-GISS), included with the EdGCM v.2.4 download, allows students to easily, and quickly, plot data in netCDF (network Common Data Form) files, a commonly used output file format for GCMs.



CCSM (Community Climate System Model) output available at the National Center for Atmospheric Research (NCAR):

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

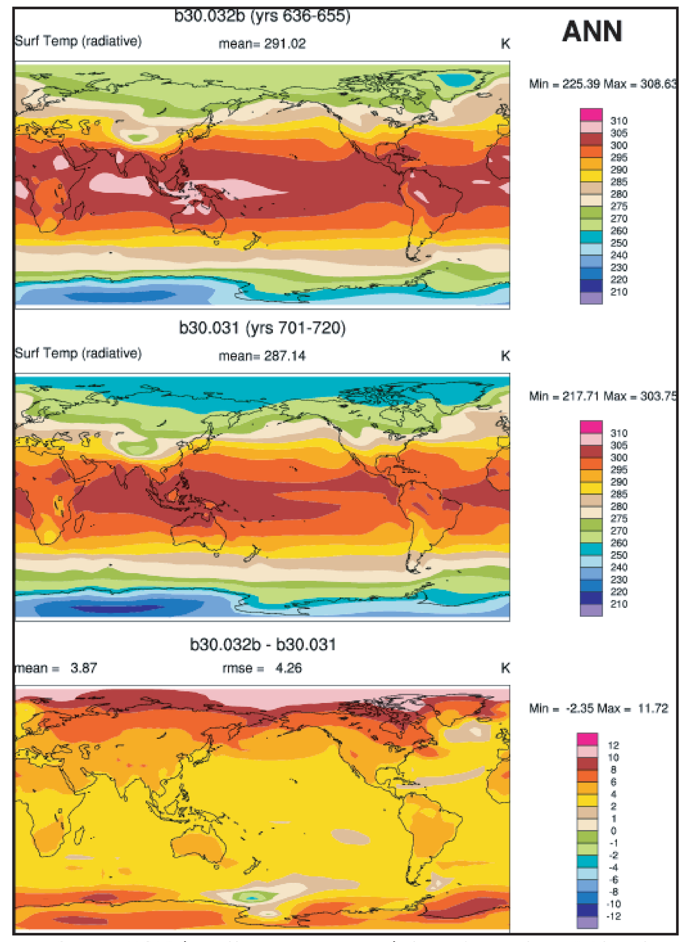


Source: NCAR: http://www.ccsm.ucar.edu/experiments/ccsm3.0/atm/b30.025b.ES01-b30.004/ (A comparison of a control and a 4xCO2 experiment).

Model results can be an excellent tool to facilitate understanding of climate dynamics. Students can view and analyze output from models in connection with theory. At the NCAR Community Climate System Model web page, students can view model output from various control experiments that examine climate sensitivity to CO2. A web page for each experimental comparison (LEFT) allows students to choose which types of plots they will view. Plots (BELOW) show model output fields for each experiment, and the difference between them. Web pages and plots are produced with a diagnostics package developed by Mark Stevens at NCAR. Model output can easily be incorporated into in-class or take-home assignments (see example below).

Classroom Example: After a lesson on the role of ice-albedo feedbacks on climate, students would be presented with model output depicting the effects of such feedbacks. These figures depict modeled surface temperatures and temperature differences in high and low CO2 modeling experiments.

Students would then be asked to compare surface temperatures with other model output: cloud distributions, zonal wind-speeds, and radiation fluxes, and draw conclusions about the effect of Arctic sea ice on these features of climate.



Source: NCAR: http://www.ccsm.ucar.edu/experiments/ccsm3.0/atm/b30.025b.ES01-b30.004/set5_6/set5_ANN_TS_c.png

Student response to models

=> Students seem to enjoy viewing model output and asking questions: "What happens to the Earth if we do this….?" (View it as a game).

=> Students seem to appreciate the immediate application of theory and (in the case of the Climatology students working with EdGCM) can begin to see the creative aspects of developing and carrying out a research project.

=> Students most easily make connections between various model output fields when they can view side-by-side comparisons of various fields in the same window.

Key Challenges

=> Considerable prep time is necessary before students are ready to view data (or to use models) as websites are not always self-explanatory. Time spent preparing students to use models or to look at model output is usually gained at the expense of covering other topics.

=> Students can become overwhelmed by model details. GCMs have a high level of complexity. Models are still mostly 'black-boxes' for students, as there is insufficient time to introduce numerical schemes or coding along with theory and application in one semester.

Reference Cited

Chandler, M., M. Shopsin, S. Richards, L. Sohl, and K. Mankoff, 2005. The Basic Guide to EdGCM.Columbia University

Improving data accessibility for effective classroom integration

Big Questions:

=> How can research and education communities cooperate to develop effective tools for accessing processed model output?

=> How can we continue to develop the use of model output to promote scientific learning through inquiry?

Suggestions:

=> RESEARCHERS: Make more processed model output available online, in an easily accessible format. At NCAR, the Atmosphere Model Working Group diagnostics package, developed by Mark Stevens, is an excellent example of a diagnostics tool that enables individual researchers to easily post model output online in a well-structured, readable format. Allocation of resources to support the development of such packages can ultimately promote greater interaction between research institutions, educators, and the general public.

=> EDUCATORS: Construction of online inquiry modules that utilize model output will ultimately reduce classroom preparation time and allow students to grasp key concepts more quickly. Cooperation between researchers and educators at all levels is necessary to develop effective formats for model output. Tools that allow students to make immediate side-by-side comparisons between models, and between various fields in the model output (such as the WDC Paleoclimate Model Visualization tool) facilitate understanding of connections and feedbacks within the climate system.