Simulating Future Climate Change Using A Global Climate Model

(EzGCM: Web-based Version)

Introduction:

The objective of this abridged EzGCM exercise is for you to become familiar with the steps involved in climate modeling and to understand the basic process that scientists apply when using global climate models (GCMs) to study future climate change. In this assignment, we explore three climate model simulations:

1. A mid-20th century climate simulation (Modern_PredictedSST), which serves as a control experiment
2. A simple global warming simulation (Doubled_CO2)
3. A more realistic future climate change experiment with gradually increasing greenhouse gases (IPCC_A1FI_CO2)

The modern simulation represents the Earth's climate prior to any major effects of greenhouse gas increases and is used as a "control" that the other climate change simulations can be compared to. The doubled CO_2 simulation is one that climate scientists use to gauge model sensitivity for comparison with other models. The third simulation, IPCC_A1FI_CO2, is a scenario that was used for the third and fourth assessment reports of the International Panel for Climate Change (IPCC) in 2001 and 2007.

The model that supplies the simulation results for this exercise was developed at NASA's Goddard Institute for Space Studies, which has been NASA's global climate model development center since 1980.

Overview of Specific Assignment Objectives

- Use a web-based climate simulator to examine the difference between climates in a mid-20th century "modern" climate simulation vs. two global warming simulations, one with double the mid-20th century atmospheric carbon dioxide level and one with gradually increasing atmospheric carbon dioxide.
- Generate and compare time-series plots using data (supplied) from the three simulations and observed surface air temperature data.
- Prepare climate model data for scientific visualization and analysis using basic post-processing operations.
- Use scientific visualization to create surface air temperature maps based on climate model data processed from two simulations: a climate change simulation and a control simulation.
- Generate anomaly maps of surface air temperature and become familiar with the use of anomalies for climate model analyses. Adjust color bars and color scales to emphasize significant results.
- Generate and analyze snow and ice coverage anomaly maps using data from the climate change simulation and its control run and discuss the relationship to the surface air temperature anomaly.

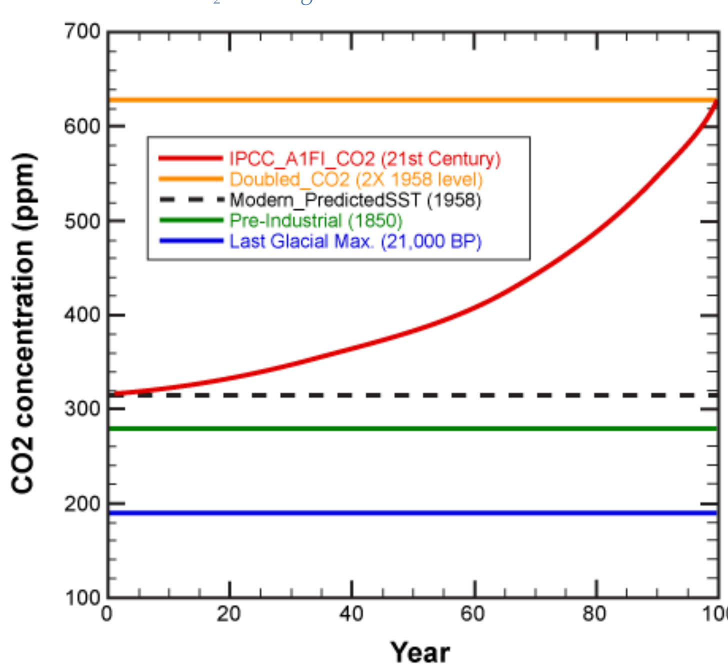
Constant Vs. Transient Greenhouse Gas Forcings

One important distinction in how climate forcings are applied in computer models is whether or not the simulations use constant or transient values of greenhouse gases (transient = changing over time).

Constant Greenhouse Gas Forcings: If a simulation begins with climate conditions that are similar to modern, including a modern level of greenhouse gases (a simulation has to start somewhere, after all) we would expect that simulation would reproduce something like the modern climate. That is, if no other major changes are imposed during a simulation and presuming that the model's equations are accurate, the resulting climate would have no reason to change – except for some natural variation around the mean.
On the other hand, if the same model were run with increased or reduced levels of greenhouse gas the resulting climate would no longer be like the present climate. In most cases the climate would adjust and eventually reach a new equilibrium. In this assignment, these so-called constant forcing simulations are named **Modern_PredictedSST** and **Doubled_CO2.** The latter is also a constant forcing simulation but, as the name implies, it has twice as much CO_2 in the atmosphere.

Transient Greenhouse Gas Forcings: The use of transient greenhouse gases is very important when scientists try to simulate future climate change as accurately as possible. With CO_2 levels rising continuously as a result of fossil fuel burning, the Earth is undergoing a shift in its climate state associated with a transient forcing. In this assignment the climate model run called **IPCC_A1FI_CO2** is one example of a simulation that includes a transient atmospheric CO_2. The trend is actually close to the path we are currently following in the real world. We will examine the climate effects caused by that CO_2 trend later in this assignment but, for now, let's just examine the constant and transient CO_2 forcing trends used in a variety of GCM experiments.

CO_2 Forcings for Various GCM Simulations



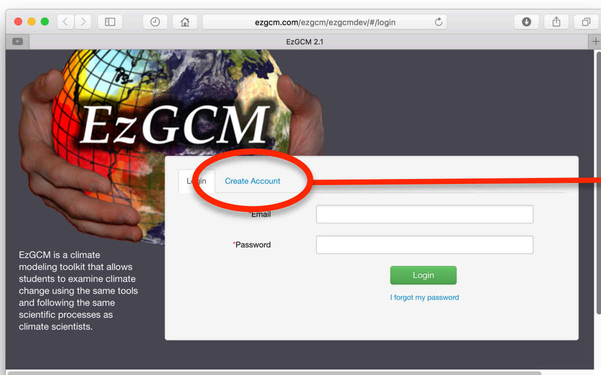
Step1: Getting Started with EzGCM

Welcome to the climate modeling assignments!

The EzGCM website is where you will find the climate modeling tools you will use for the assignments. To get started please visit the EzGCM website (http://ezgcm.com) and create an account (see Figure 1 below). You will need the course activation code from your instructor to create an account.

After filling out the information and clicking on the Create Account button, make sure to activate your account using the link in the email that will be automatically sent to you. Once your account is activated, make sure to read the document "MyGCM in EzGCM" and then download and read over the assignment documents that are available from your MyGCM page.

Happy Modeling,
Mark Chandler



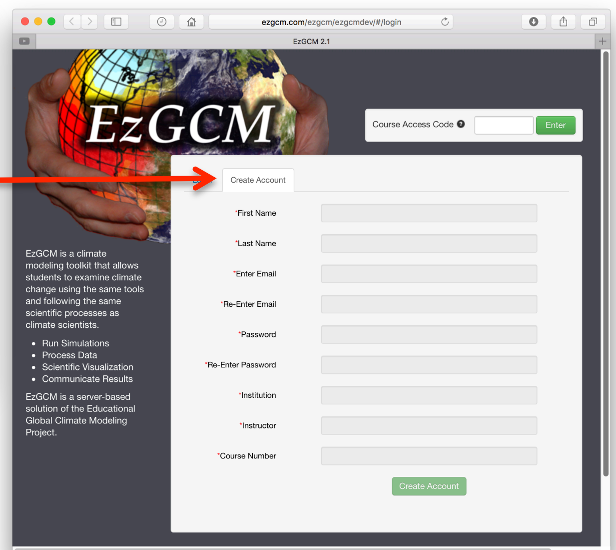
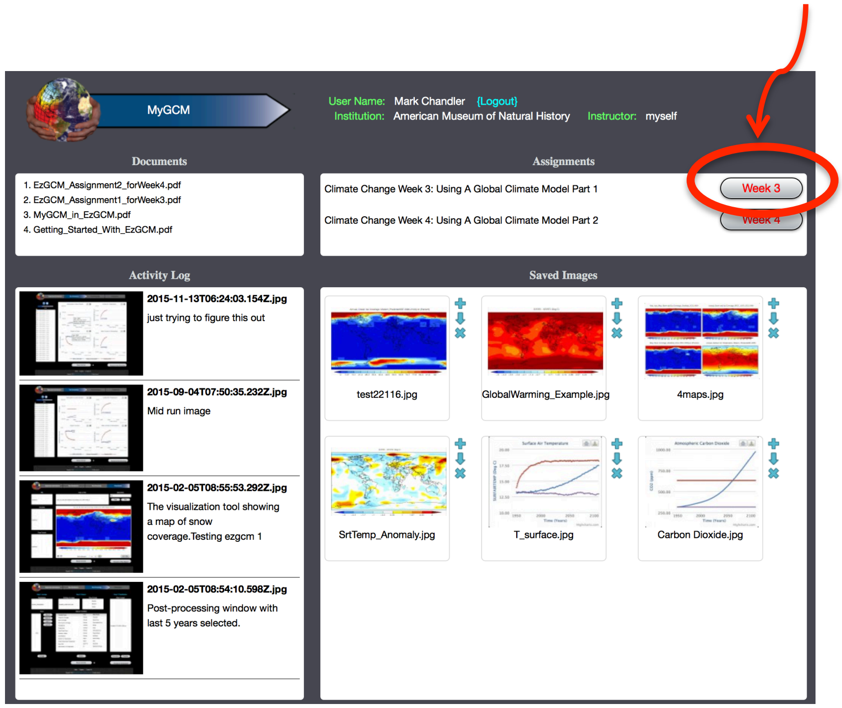
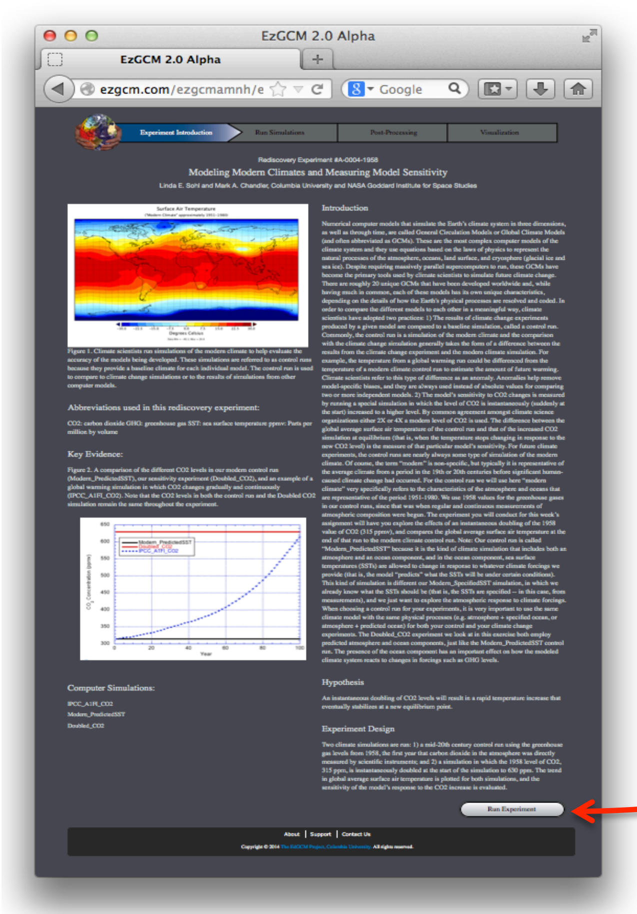


Figure 1. Go to http://ezgcm.com and click on the Create Account tab. Enter the Course Activation Code and the rest of the requested information into the form and make sure to activate your account using the link in the email that will be automatically sent to you.

After you log in you will be on your personal MyGCM page. Click on the **Week 3 button** to go to the assignment.

*Refer to the document **MyGCM_in_EzGCM.pdf**, which you can download from the Documents section of your MyGCM page (click on the document to download it to your computer).*





The Week 3 button will take you to a brief introduction. Read over the introduction and then click the **Run Experiment** button at the bottom of the web page (you may need to scroll down to see it).

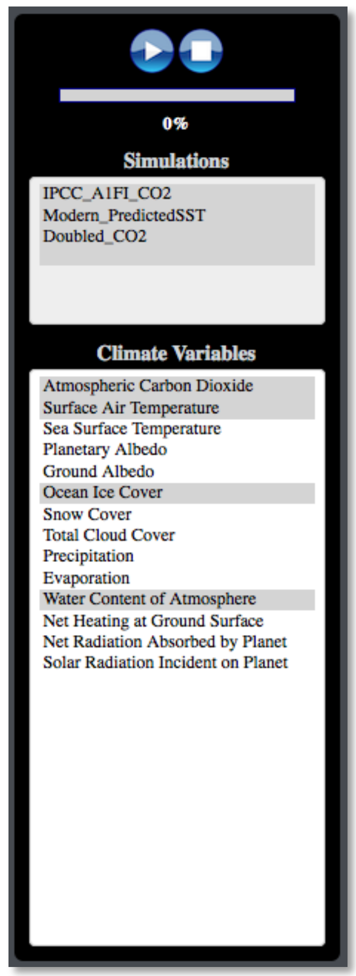
Step 2 – Running Simulations:

Generate Time Series Plots of Important Climate Variables

We will now compare global average climate data from three separate climate model simulations, including: 1) **Modern_PredictedSST**, which is a simulation of the mid-20th century climate, and serves as our "control" experiment, 2) the constant forcing run **Doubled_CO2** and 3) the transient forcing run **IPCC_A1FI_CO2**, both of which are global warming scenarios used by the IPCC (2001, 2007) to evaluate climate models and project future climate change.

The **control run** provides a baseline that represents Earth's climate prior to the effects of anthropogenic greenhouse gases. We use control simulations to compare to altered climate *change* simulations, to evaluate the amount of change that has occurred compared to a known period of time.

2.1 You should now be on the Run Simulations page. Note that there are three simulations available in the **Simulations** field in the upper left hand portion on this page. By default all three simulations are selected. Below the Simulations field is a list of Climate Variables, and the default selections in that list include Atmospheric Carbon Dioxide, Surface Air Temperature, Ocean Ice Cover, and the Water Content of the Atmosphere.



These simulations were created using the NASA/GISS Model II, and GCM developed by NASA and used to help inform the design of the IPCC assessments. Simulations like these can be run by students through a downloadable double-clickable application that can run on Macs or Windows PCs. Typical amounts of time to run such a simulation for 100 years is 5-10 hours on a reasonably modern desktop or laptop computer. Students can design their own simulations with EzGCM's big sister software, EdGCM. The current versions of the NASA/GISS GCM run on supercomputers at NASA and may take as long as a month to run a single 100-year experiment.

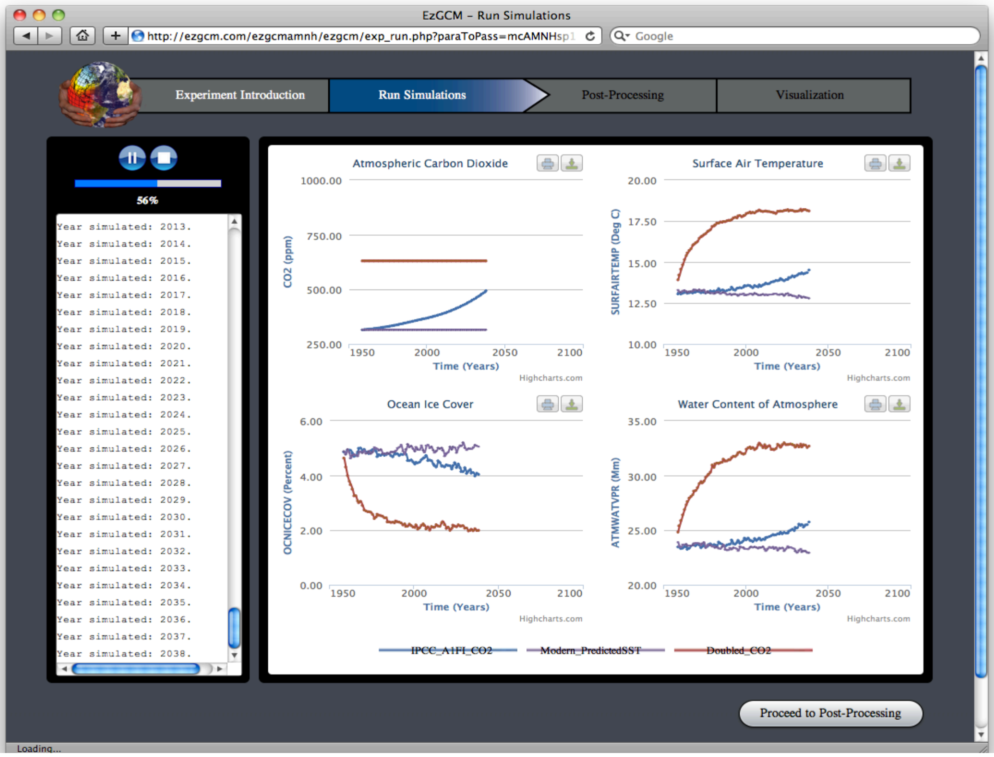
2.2 Begin loading the simulations by clicking the **Play**

button, in the upper left portion of the window. A GCM log window will appear and the time series of the selected climate variables will begin plotting.

As the plotted lines of the selected variables are drawn, examine the legend beneath the plots noting which of the colors represent the three simulations of interest, **Modern_PredictedSST, IPCC_A1FI_CO2,** and **Doubled_CO2.** You can use the add image button in the upper right hand corner of each plot to save the time series plots to your MyGCM page. From the MyGCM page you can always download saved images to your own computer.

2.3 Compare Observed to Simulated Times Series of Climate Variables

The graphs you made in the previous step are called **time series** plots. These are line graphs that show a sequence of data as it changes through time (in this case, time is in units of years and is on the X-axis).



*A **time series** is a sequence of data points across a continuous **time** interval using equal spacing between every two consecutive measurements.*

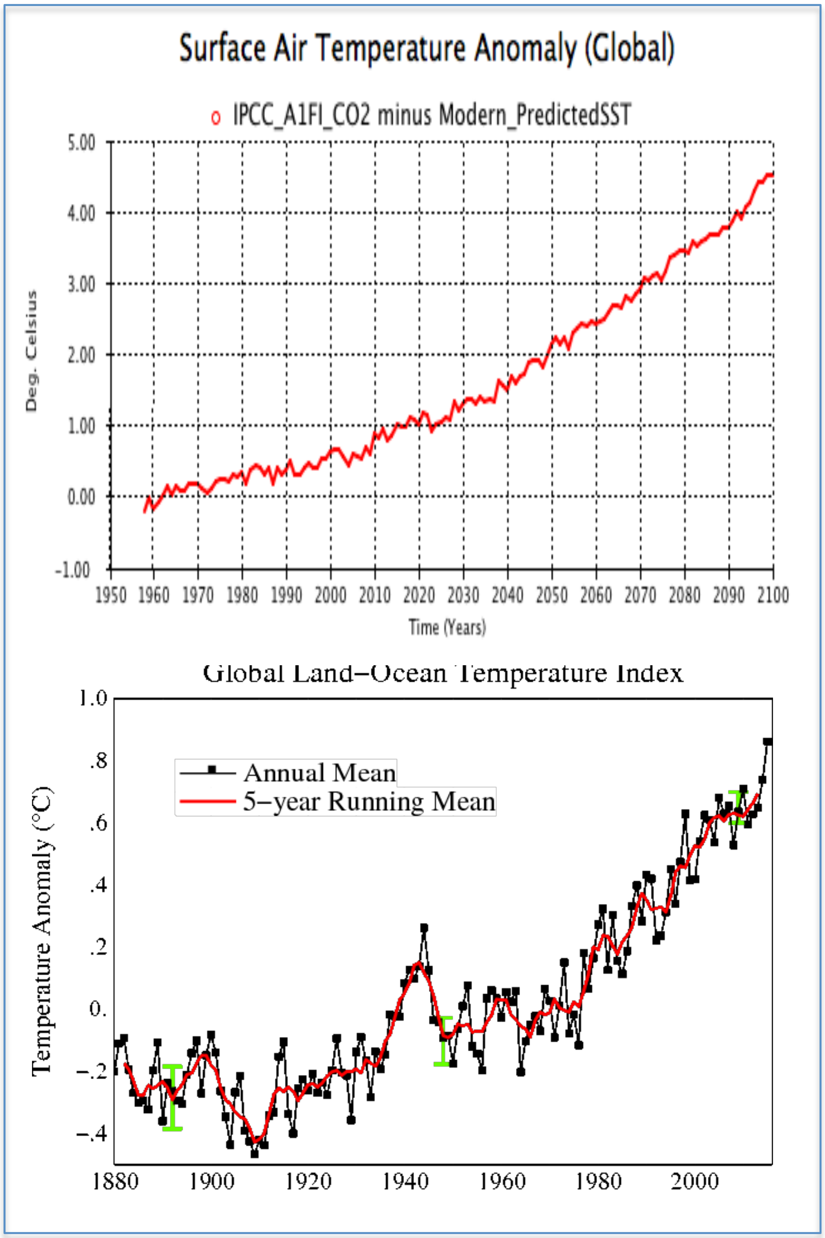
Climate Anomalies

Although these time series show the values of the climate variables as the climate model simulates them, in most cases climate scientists present climate modeling results as anomalies. An **anomaly,** in the jargon of climate science, means the difference between the simulated climate change scenario and the same values from the control run. Note that when examining anomalies between two simulations the control run is nearly always subtracted FROM the climate change run. By doing so a positive anomaly value then represents an increase (i.e. a warming if the value is temperature), whereas a negative value would define a decrease (i.e. cooling). Thus, calculating an anomaly from climate model experiments the equation should generally be:

Climate Anomaly = Climate Change Scenario – Control Run Scenario

2.4 The time series plots on this page represent two common types of anomalies used in climate science. The line in the top plot represents the difference between the annual average temperatures from two global climate model simulations (i.e. a climate change simulation minus a control run).

$$\textbf{Surface Air Temperature}_{(\text{Anomaly})} = \textbf{Tsurface}_{(\text{IPCC\_A1FI\_CO2})} - \textbf{Tsurface}_{(\text{Modern\_PredictedSST})}$$



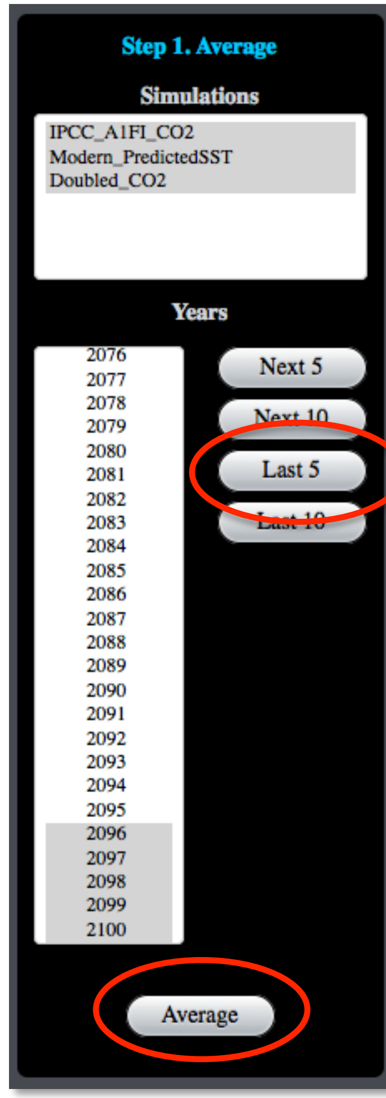
The line plot on the bottom shows a surface air temperature anomaly based on NASA's Global Temperature Index, which is derived from historical observations at thousands of weather stations worldwide. NASA scientists update the data monthly and generate the anomalies by averaging the data across a base time period (e.g. 1951-1980) and then subtracting that average from all other data points.

Compare the observed and simulated data plots, but notice that the axes on the two graphs differ (1880-2011 vs. 1950-2100 and -.4 to 1.0 vs. -1.0 to 5.0).

Step 3 – Post-Processing:

Getting the Climate Model Data You Want to Analyze

3.1 You will now see that the three simulations that you previously examined in Step 2 are listed in the Simulations section of the **Post-Processing** page. In order to conduct more explicit analyses, and eventually create scientific visualizations, we must now make some preliminary decisions about what we want to examine amongst the myriad of data produced by our climate model run. A GCM's standard output consists of enormous (multi-gigabyte) binary files that are of little value scientifically when in their raw form. So, the first "analysis" in any scientific study dealing with **Big Data** is usually to perform some basic computational operations that reduce the volume of information to something the climate scientist can examine. We call these operations "post-processing", since the original processing took place during the running of the climate model and this processing takes place after the simulation is complete. And, we call this the beginning of our analysis, because post-processing forces us to focus our scientific investigation. Only then can we reduce the raw data to a manageable amount and reformat it for viewing with scientific visualization methods.



Note: Using a group of five or more years helps reduce weather-related noise in some variables, smoothing the results and making the climate signal easier to visualize.

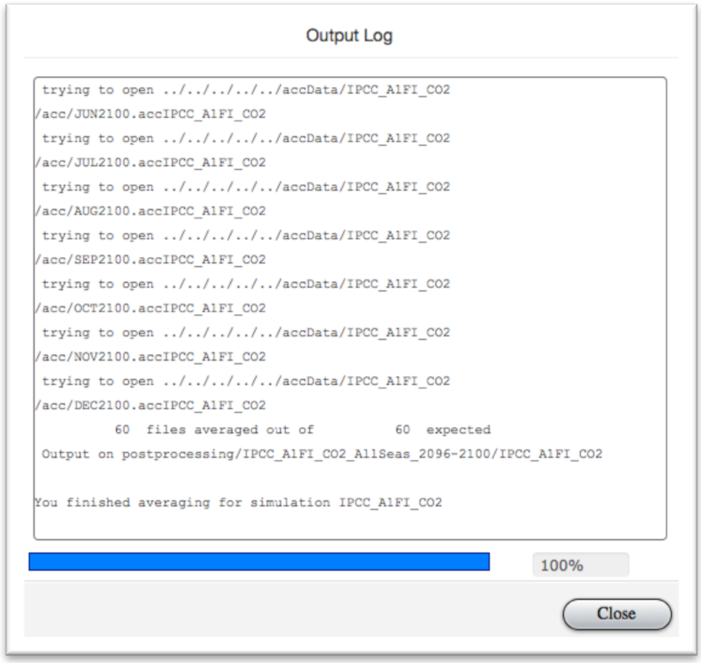
> Analysis (noun): detailed examination of the elements or structure of something, typically as a basis for discussion or interpretation • the process of separating something into its constituent elements.

3.2 Averaging

Probably the most common post-processing operation when analyzing climate model output is to take averages over a subset of the period of the simulations. In most scientific investigations the time period of greatest interest generally begins with the end of the simulations – in other words, the final result of the climate model experiment.

To perform an average of the final five years of two of our simulations, IPCC_A1FI_CO2 and Modern_PredictedSST, select them in the Simulations list, which is the field at the upper left of the window (you can select more than one by holding down the shift, control, or command key). Clicking on the "**Last 5**" button will select the years **2096-2100**. Alternatively, you can manually select the range of years by clicking on the first year (2096), then hold down the shift key and click on the last year of the range (2100).

Once the years have been selected, click on the **Average** button in the bottom left corner of the post-processing control panel. After a brief pause an Output Log window will open showing you that the post-processing program is running the averaging calculations. This post-processing step may take a few minutes depending on how many people are currently running such operations on the EzGCM server at NASA. Please be patient and be sure to let the process finish – it is done only when the progress bar reaches 100% for each simulation (*Note: the progress bar will register 100% for each experiment that is being processed. Twice in this case.*)



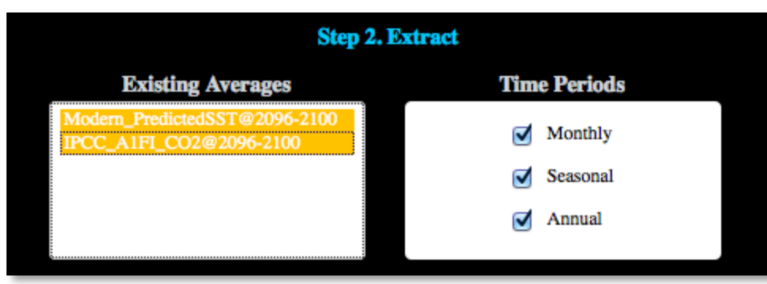
When the averaging process is complete click on the Close button.

Once the log window closes you will notice that **IPCC_A1FI_CO2@2096-2100** and **Modern_PredictedSST@2096-2100** appear in the Existing Averages list in top center of the web page.

3.3 Extracting

Now that we have created averages of the last 5 years of each of our two simulations the second step of our post-processing will be to extract those variables that we want to analyze visually – that is, those variables of which we would like to make global maps.

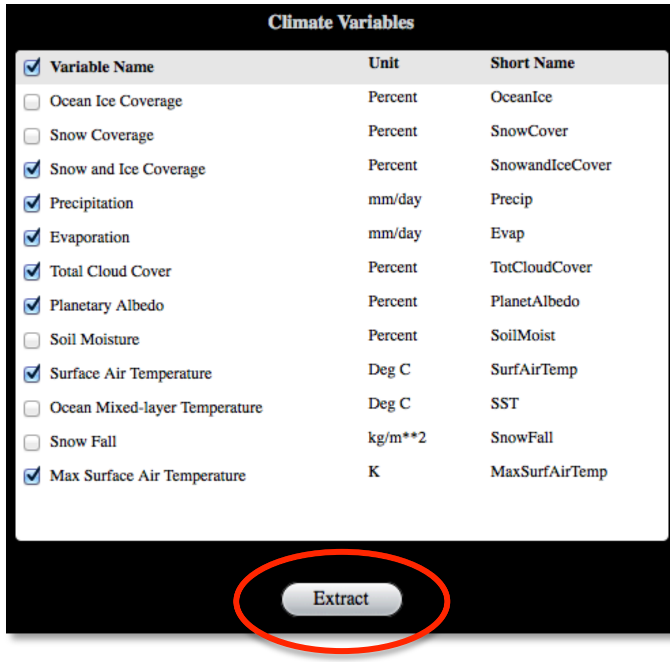
To do this, first select both of the files in the Existing Averages field (once again, **IPCC_A1FI_CO2@2096-2100** and **Modern_PredictedSST@2096-2100**) and also select the **Monthly, Seasonal** and **Annual** check boxes if they are not already selected.



Next, in the center column, labeled **Climate Variables**, select a set of variables that you wish to examine more closely. Do this by clicking on the checkbox next to each (or select them all by selecting the checkbox at the top of the column):

- Snow and ice coverage
- Precipitation
- Evaporation
- Total cloud coverage
- Surface air temperature (in C)
- Max surface air temperature (in K)

Note that the Max Surface Air Temperature variable is in units of Kelvin (K). To convert temperature from K to °C, subtract 273.15 For example 373.15 kelvin (not "degrees kelvin"!) is equal to 100 degrees Celsius.



Finally, click on the **Extract** button at the bottom center of the window. You will see the Output Log window appear again, which shows that another post-processing program is running; let it run to completion and use the Close button when the operation is complete.

3.4 Visualization

Under the **Simulation Files** column in the **Visualization** section you should now see two files listed:

IPCC_A1FI_CO2.2096-2100ij.nc

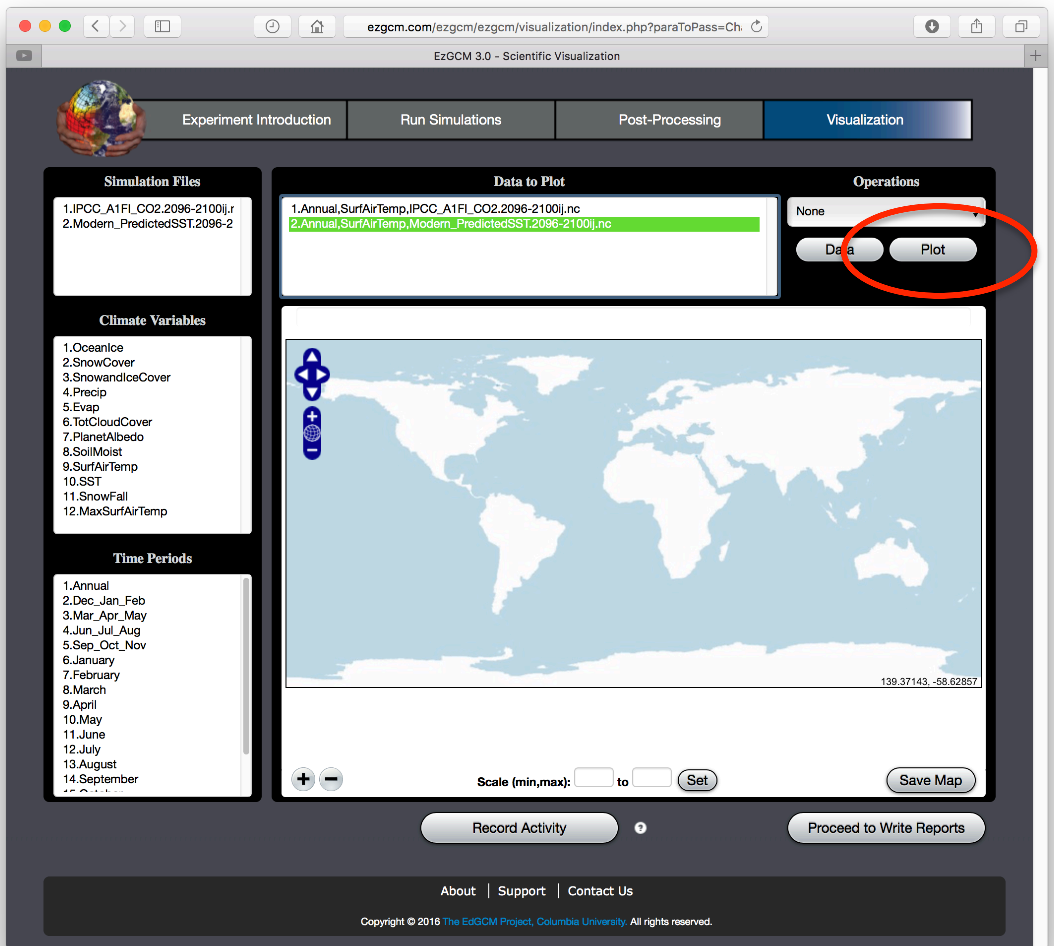
Modern_PredictedSST.2096-2100ij.nc

Once both files are listed in the Files Created column click on the **Visualize** button at the bottom of the column. EzGCM's Visualization Application will open.

You are now finished with the Post-Processing steps and are ready to move on to Scientific Visualization.

Step 4 – Scientific Visualization of Climate Modeling Data

The purpose of scientific visualization is to graphically illustrate scientific data or model output to enable scientists to understand, illustrate, and glean insight from their data (*Source: Wikipedia*). Scientific visualization can be used by the researcher to browse and explore large data sets or it can help focus the viewer on key meanings in the data.



4.1 Use the shift key to select the **Modern_PredictedSST** and the **IPCC_A1F1_CO2** files in the left column under Filename. Then select **SurfAirTemp** (Surface Air Temperature) under Variables and **Annual** from the Time Periods list.

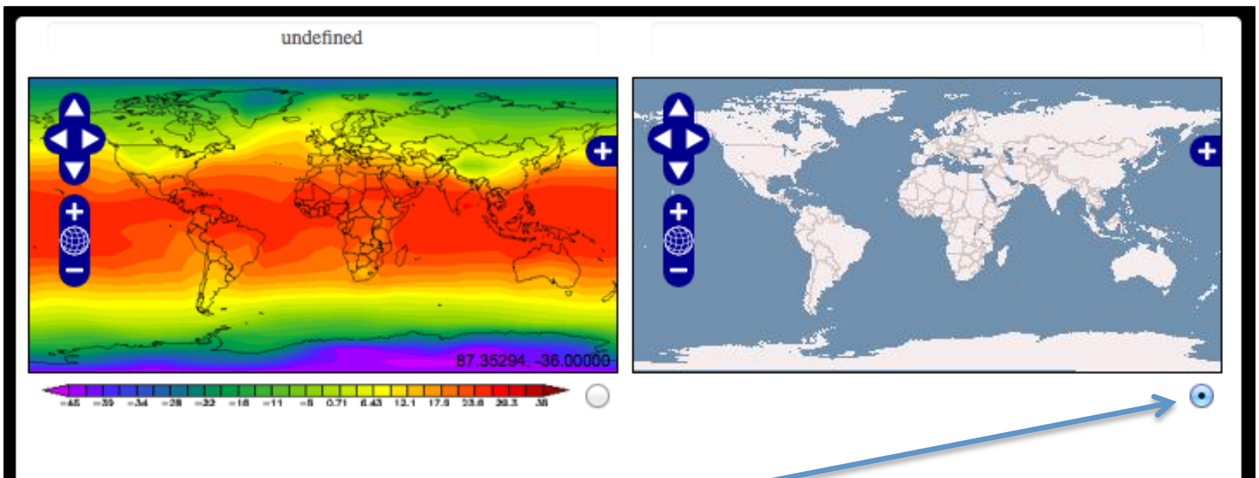
4.2 In the **Data Files to Plot** field in the upper center section of the window select **Annual,SurfAirTemp,Modern_PredictedSST.2096-2100ij.nc** and click the **Plot** button on the right. The map that is produced is the annual average value that was calculated from the last five years of the simulation (see step 3.2) and represents the NASA Global Climate Model's view of the mid-20th Century surface air temperatures.

4.3 Change the scale: To adjust the scale on the color bar use thee controls below the map. Set the Scale (min, max) to -45 to 35 and click the Set button.

Controls below the map area include buttons for adding or removing maps, fields to set the color bar scale, and a button to save the maps to an image file.

4.4 Add another map:

Click on the **+** button below the map on the left side to add another map (or use the **−** button to remove a map)



4.5 The radio buttons  that are directly below the right corner of each map are used to tell the mapping software in which map area to display newly created maps. The controls such as Scale and Save Map also operate on whichever map has its radio button selected.

4.6 Repeat steps 4.2 and 4.3 for **Annual,SurfAirTemp,IPCC_A1FI_CO2.2096-2100ij.nc** plotting the second map in the other blank map area.

Step 5 – Climate Change:
How Will Increasing Greenhouse Gases Effect Temperatures?

5.1 Remove maps using the **–** button until only one large map area remains.

5.2 Select BOTH of the files in the **Data Files to Plot** field:

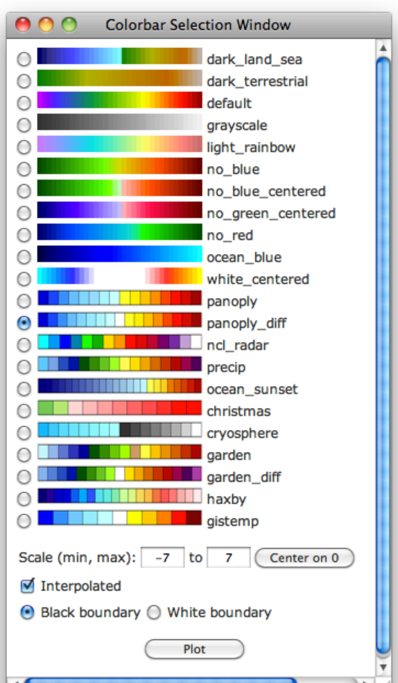
Annual,SurfAirTemp,Modern_PredictedSST.2096-2100ij.nc
Annual,SurfAirTemp,IPCC_A1FI_CO2.2096-2100ij.nc

5.3 Under the Operations menu take a difference of the two variables (red circled menu in below image). Make sure you select both files before differencing and click the Plot button after choosing a difference from the Operations menu.

VERY IMPORTANT: make sure to subtract the Modern from the IPCC simulation. Depending on the order that they are shown in your list you may need to choose

Top - Bottom
or
Bottom - Top

5.4 **Adjust the color bar and scale:** Click on the color bar itself to bring up a palette that allows you to switch color bars and scales. Change the color bar to "panoply_diff" and the scale minimum and maximum to -7.0 and 7.0. Clicking the Plot button at the bottom of the palette will cause the settings to take effect.



Note: For anomaly maps (difference maps), it is often useful to choose a color bar that has white in the middle. White on the map will then represent areas of little or no change. It is also best to use a color bar that is intuitively related to the variable being mapped. For example, red = warm and blue = cold.

5.5 Click on the title of the map to rename it.

For example:

Surface Air Temperature Anomaly (IPCC_A1FI – Mid 20th Century)

5.6 Save the map to MyGCM using the **Save Map** button.

Step 6 – Generate Snow and Ice Coverage Maps

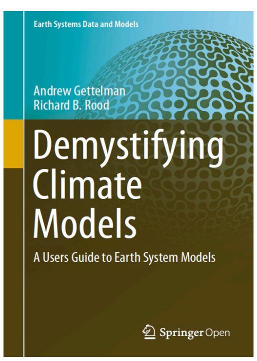
6.1 If you previously quit the EzGCM web tool after completing the Temperature maps portion of this assignment, launch your browser and again go to the EzGCM website at: http://ezgcm.com. Choose Week 4, and then click the Run Experiment button at the bottom of the first page.

It is not necessary to re-run the simulations or to redo the Post-Processing if you ran those previously. Simply go to the top of the EzGCM window and click on the step you would like to jump to, in this case: "Visualization". See the red oval in the following image:

Your data files should still be available under the Simulation Files list.

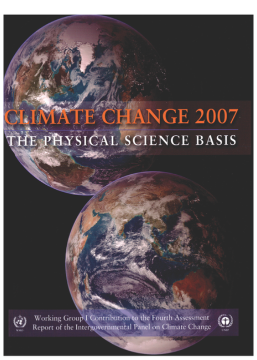
6.2 Repeat Steps 4.1 through 5.6 for the variable **Snow and Ice Coverage.** Use a scale of 0 to 100 for the individual maps and a scale of -20 to 20 for the anomaly maps.

Other Useful Resources:



Demystifying Climate Models
Andrew Gettelman
National Center for Atmospheric Research
Richard B. Rood
Climate and Space Sciences, University of Michigan

http://www.demystifyingclimate.org



Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (FAR, SAR, TAR, AR4, AR5)

http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml