Attachment 3: Lab Handout 2

This lab is adapted in part from materials provided on the EdGCM web site here: *http://edgcm.columbia.edu/documentation/EET_EdGCM_Chapter.pdf*

A. Objectives

- Utilize EdGCM to investigate ice melt globally
- Quantify the amount of ice melt climate change may cause
- Connect melting of the Antarctic and Greenland ice sheets to sea level rise

B. Background

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

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

Over the past several decades, scientists and observers have seen snow and ice coverage decrease across the northern latitudes, melt earlier in the spring, and alter runoff patterns to rivers and streams. Less and earlier snow melt also means less runoff in the summer months, when irrigation water is needed for agriculture. Changes also impact water-based recreation activities on rivers, lakes and reservoirs when they become un-navigable for some groups of boaters and the water, consequently, becomes too warm or shallow for some fish.

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

C. Generate a Time-series Plot of Temperature and Compare it to DoubleCO_2

Step-by-step Instructions

1. Launch EdGCM by double clicking on the icon in the "EdGCM.4db Alias" filer in the folder. The application will load. The tool bar window will appear. As you know by now, it is from this toolbar window that the user controls the software. The buttons in this window will change depending on the active window.

2. On the left side of the Toolbar window, select **Modern_PredictedSST** and, under "Window," click the "Setup Simulations" choice. (*The other way to get here is to click the file folder looking icon above the scenarios on the toolbar.)* **Modern_PredictedSST** is a simulation that demonstrates what future climate would be like with no increase in greenhouse gases or any other variables, such as solar luminosity. This is the baseline, or "control run," for any climate change experiments. Make sure you read its description and look at how it is setup.

3. Since we don't have time in lab today to run the model on this scenario, watch your instructor as he shows you how to move the prepared output file into your model's "Output" folder.

4. Now that you have the output (or a completed model run of **Modern_PredictedSST**), it's time to make a time series graph. In EdGCM, use the dropdown Window menu and select, "Analyze

Output" or, use the "Analyze Output" button at the top of the Toolbar that looks colorful and has numbers on it.

5. In the "Analyze Output" window, click on the "Time Series" tab near the top of the window, and then click the button called "Time Series" in the bottom left hand corner of the window. *(Note: If this step has been done previously, the "Time Series" button may be grayed out (i.e., inactive); if so, progress to the next step. This step runs a program that takes a little while on slower computers.)*

6. In the list of variables in the center section of Analyze Output window, select the check box next to "Surface Air Temperature" and then click the "Extract" button in the center bottom part of window. You may also wish to repeat this step for the "Ocean Ice Cover" or "Snow Cover" variables or any others you are interested in. This step in climate modeling is called post-processing and, by extracting, you are making the data available for visualization. If you are using EVA, please follow steps 7-10; For Panoply, use steps 12-16.

For EVA users, please use steps 7-10

7. In the right-hand column of this window, under view images, select **Snow and Ice Coverage** and click the View button below that column. This will launch EdGCM's scientific visualization application Eva and open the visualizer. The Data Browser will list one simulation in the File column, **Snow and Ice Coverage** in the Variable column, and 5 items in the Time or Region column. Confirm that you have these items and then ignore this window while you import a second data set.

8. Now return to EdGCM and select the **Doubled_CO_2** simulation, by single clicking on the name in the Run List. Extract the data for analysis by repeating the steps numbered 2-8.

9. In the visualizer browser, select the two **Snow and Ice Coverage** files listed in the 1st column, by clicking with the shift key held down. Then select **Snow and Ice Coverage** (2nd column), and select **Globa**l (3rd column).

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

11. In your visualizer browser, use the pull-down differencing menu, located in the lower right-hand corner, and select the two files to compare. Subtract the control run **Modern_PredictedSST** from the experimental run **Doubled_CO_2**. (*NOTE: You can check the order of the graphs by looking at the bottom part of the visualizer window and choosing the appropriate order.)*

12. If needed, click the button on lower right to Plot All. Finalize your second graph using step 18 of these instructions. You may now skip to step 18.

For Panoply, please use steps 12-16

13. Since the built-in Eva data browser for EdGCM does not work with this operating system, the following instructions are for making the time-series plots in Excel. First, go to the "Go" tab and click on the choice "Output" Folder. (*Alternatively, you can open the EdGCM folder on your desktop and navigate to the "Output" folder manually.)*

14. Open the "Diagnostics_Modern_PredictedSST" folder (*Note: For other scenarios this name would change to their name*). Then open "plots_Modern_Predicted_SST" and the time series for which you averaged. If you averaged all of the years, then yours should read "Modern_PredictedSST_1958-2100" Finally, open in Excel the file for the variable you want to work with, in this case **Surface Air Temperature**.

15. From here on out, it's as simple as making a line plot graph in Excel. You'll notice that you have your choice of "Global," "Land," "Ocean," "Open Ocean," and "Ocean Ice" values in each column. For now, we'll work with global. If you do not know how to make a line plot in Excel, please raise your hand and ask your instructor for help.

16. Now return to EdGCM and select the **Doubled_CO_2** simulation by single clicking on the name in the run list. Extract the data for analysis by repeating the steps numbered 2-6 and 13-16.

17. Want to compare different scenarios? Or different output geographic regions? You can copy and paste output from different scenarios into the same Excel file. You can also plot different columns together. Try plotting more than one line on your graph. In our case, we'll first examine what **Doubled_CO_2** and **Modern_PredictedSST** look like in comparison to each other.

18. Finalize your first graph as instructed below.

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

Questions

1. How do the 2 temperature trends differ?

The Doubled_CO_2 run should show a dramatic rise in temperature until it levels off. In contrast, the control line should continue along as a baseline around the same level from where it started.

2. Predict where the **Double_CO_2** graph will be in 50 more years (Explain how you made your prediction).

Since there are no rate-wise increases, it should mimic the control run and level off as a parallel straight line after initially surging upward. You should make the point to students that **Double_CO_2** deals only with absolute amounts or concentration in the atmosphere, and how this is different from rate wise or continual yearly increases.

3. How does the modeled data **Double_CO_2** compare with the observational data? Are there years where they are the same? Different?

This data roughly parallels observed data (which students can use the Internet to search for on a variety of sites listed in "Attachment 6: Data Sites and Resources for Framing a Research Question.") There are differences as not all of the greenhouse gases are included, and the absolute amount of atmospheric concentrations of CO_2 is different than current levels today.

4. By how much does the temperature change in each graph between the years 1960 and 2000?

Approximately 4 degrees Celsius.

5. What other information do graphs of average global temperature leave out?

How temperature changes in specific regions, how it varies across the globe, other variables that could be plotted.

6. Compare your graph of modeled data using EdGCM to other graphs of temperature trends from the NCAR climate model animation

(http://www.vets.ucar.edu/vg/IPCC_CCSM3/index.shtml). What are some of the differences and similarities? Why do you think they are not the same?

This model has a great deal of spatial data and also shows dynamic changes through time. Student answers could be a variety of differences including that the greenhouse gases in this model include more than just CO_2. This model also represents rate-wise increases rather than a doubling of CO_2.

D. Making Temperature Maps and Difference Plots

1. Launch EdGCM by double clicking on the icon in the "EdGCM.4db Alias" filer in the folder. The application will load. The tool bar window will appear. As you know by now, it is from this toolbar window that the user controls the software. The buttons in this window will change depending on the active window.

2. In this window, choose **Modern_PredictedSST** in the toolbar Run List. This is a baseline scenario used with this model. As you know from Part 1, scientists have used this simulation based on our present climatic conditions in order to demonstrate the future climate trends with no change in present greenhouse gases or other variables, such as solar luminosity. It is also the baseline for comparison (we did in Part 1) with the experimental **Doubled_CO_2** simulation in which greenhouse gases and other conditions have been changed according to the **Doubled_CO_2** scenario.

3. Again, launch the "Analyze Output" feature of EdGCM by clicking on the button on the top of the toolbar. Or use the dropdown window menu. This time click on the "Maps" tab.

4. On the left-hand side of the "Analyze Output" window, choose the last five years by clicking on the "Last Five" button. Alternately, manually select the years of your choice. *(Note: Using a group of five or more years helps to smooth out some variables that may differ a lot from year to year. You can average more than this as well, but the buttons below the years provide a guide to what is normal.)*

5. Once the years have been selected, click the "Average" button at the bottom of the list. This creates an average of all variables from the last five years of the simulation. A window opens as the files are being post-processed. This step may take up to a minute to complete. *(Please Note: If this step has already been completed the button may be grayed out (inactive). When complete, the year range* "2096-2100" *will appear in the Averages list in the lower right corner of the window. Make sure this is selected by single clicking on it.)*

6. In the center section of the "Analyze Output" window select from the following variables by clicking on the checkbox next to each. For our purposes, you will want the variable "Snow and Ice Coverage" but you may wish to post-process others that interest you.

7. Check the "Monthly," "Seasonal," and "Annual" check boxes at the bottom of the "Analyze Output" window. This is where you can specify at what time frame you want to see data averaged.

8. Click on "Extract" button. You will see a window open, which shows that another post-processing program is running. Again, this may take a few moments.

9. Under View Images Select the **2096-2100ij.nc** file, then click the View button at the bottom right of the window. Whichever of EdGCM's Visualization Application your instructor has enabled will launch. If you are using EVA, please follow steps 10-14; For Panoply, use steps 15-21.

For EVA users, please use steps 10-

10. Repeat steps numbers 2-9 from above for **Doubled_CO_2** simulation. Now both files are listed in the Eva data browser window under the file header or in the Panoply window that launches in the central panel. Notice that only the variables and time spans you have post-processed in previous steps will appear for selection.

11. If you are using EVA, use the shift key to select the **Modern_PredictedSST** and the **Doubled_CO_2** files in the left column of the data browser. For Panoply, you can launch each map separately or together depending on how you click on them before clicking the "Plot All." button. For either visualizer, you will want to select the "Annual" values for "Snow and Ice Coverage."

12. Click the "Plot All" button. The software will generate two maps:
Modern_PredictedSST Snow and Ice Coverage and **Doubled_CO_2 Snow and Ice Coverage.**

13. Look at your two maps. What differences do you notice? Do you find it hard to compare them visually side-by-side? Now we are going to learn how make difference plots or anomaly maps by subtracting your treatment map, **Double_CO_2**, from your control run, **Modern_PredictedSST**.

14. In EVA's Data Browser, subtract the control run, **Modern_predictedSST**, from the climate change experiment (**Doubled_CO2**) using the differencing drop down menu located at the bottom of the window. Do you find it easier to compare the maps now that they are differenced? What do you notice about the equatorial and polar areas? You may now skip ahead to step 22.

For Panoply, please use steps 15-21

15. Under "View Images," select the "2096-2100ij.nc" file, then click the "View" button at the bottom right of the window. After a few moments, the Panoply data visualizer should launch. The window that open displays the dataset file name as a folder. Double-clicking the folder name opens it to show individual variables listed by their abbreviated name in the file; the long name of each variable (usually more descriptive than the abbreviated name); and the type of variable (whether latitude-longitude or latitude-vertical). By default, only plottable variables are shown initially, but you can opt to see all variables in the dataset by selecting "All Variables" from the drop-down menu at the bottom of the window.

16. Multiple datasets can be opened in the data browser, which is especially useful if you plan to compare the same variable in different datasets. To add more datasets, simply open them in the same way you opened the initial dataset. The new dataset files will appear as new folders within the data browser. To remove an extra dataset at any point, simply select the folder name and click on the "Remove" whiskbroom icon in the upper right corner of the data browser. If you have already made plots and want to delete any unused datasets at that point, click instead on the "Remove All" whiskbroom icon. For more details on using Panoply, see the guide in your "EdGCM Manuals" folder on your desktop.

17. Now we're ready to create a plot! When you are ready, select a single variable from the list. At that point, the "Create Plot" icon in the upper right corner of the data browser becomes available. Click once on this icon, or else double-click the name of the specific variable you want, to create a plot. In our next lab, we will learn about manipulating the types of maps we use as well as the different aspects of visualizing this map. For now, go ahead to step 10.

18. Repeat numbers 2-11 from above for "Doubled_CO_2" simulation. Now both files are listed in the Panoply data browser window under the file header.

19. Next let's practice making an anomaly or difference plot. Use the shift key to select the "Modern_PredictedSST" and the "Doubled_CO_2" files in the left column of the Panoply data browser. Then select "Snow and Ice Coverage" in the center and "Annual" in the right column.

20. There are two different options for comparison you might like to make:
a. *1. Differencing two-time intervals for a single variable within a single dataset:* With one array already open and mapped, go back to the data browser and select the same variable you have already plotted. In the "target" drop-down menu at the top, instead of selecting "new plot," select the option named after the variable. When you do, you will see the icon to the left change to "Combine Plot." Click this icon to add the second array to the plot.

b. Differencing the same variable from two different datasets: With one array already open and mapped, go back to the data browser. Go into the Panoply File menu to open a new dataset. In the data browser, double- click on the dataset folder to display all the variables and select the same variable name you have already plotted. In the drop-down menu at the top, instead of selecting "New Plot" select the option named after the variable already plotted. When you do, you will see the icon to the left change to "Combine Plot." click this icon to add the second array to the plot.

21. Once you have a second array opened, you will see that the comparison drop-down menu has become enabled in the Array(s) tab of the map plot. The menu allows you to examine each array individually as well as difference them (array 1 – array 2 and vice versa), add them, multiply them, and average them.

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

23. Finalize your maps:

- Click on the Projection menu under map heading in on the toolbar. Use the pull-down menu to change the projection to Mollweide.
- Change the range shown on the Color bar /scale so that the minimum is -45C and the maximum is +35C on both maps. This will give you the same end points on the color bars of both plots.
- Add overlay modern with USA for both maps. Optional: Explore other overlay options.
- When you are done, save your maps to use in the next part of the lesson. Or make a screenshot of them.

24. In the last EdGCM lab, we will look at how to alter the maps themselves and many of the different aspects of the visualization including the scale, colors, map projections, etc. For now, you can try playing with each of these options. For a detailed description of what each tab does, make sure that you look at the "EdGCM Manuals" folder on your desktop at the "EdGCM_Panoply.pdf" file.

Questions
1. What areas of both maps are the warmest? Coolest?

Answers will vary based on which maps student choose to analyze and how they finalize their maps. In general, the biggest changes occur near the poles and higher latitudes. Extents of change will vary in relation to which run is being examined and whether areas are located near to coasts and oceans. The **Modern_PredictedSST** will contain the most snow and ice cover and the **Doubled_CO_2** the least.

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

Student answers can vary but the **Doubled_CO_2** run will show more dramatic decreases in snow and ice cover near the poles and the **Modern_PredictedSST** will be roughly the same as today.

3. What projection makes the most sense for an examination of snow and ice cover in the Arctic? Antarctic?
Azimuthal non-perspective and related maps are for mixed uses are best suited to examining changes to snow and ice cover in the polar regions.

4. What do you think these maps imply for winter sports in the United States? In Canada? Are there other impacts you might foresee for winter sports enthusiasts?

Students can use the Internet to help answer this question to watch videos or read news headlines. In general, the news is not good although many ski resorts in the Northeast United States and Canada have begun intensive *adaptation* processes such as making snow and diversifying their summer programs. Please also point students toward some of the materials in the slide deck for this lab.

5. What changes do you think might happen to ecosystems in the United States and Canada?

This is an intentionally broad question to elicit student thinking beyond this specific lab exercise with snow and ice cover (Although students may talk about effects relating to these changes too). Answers might include anything from the migration of species to the earlier springtime greening of plants as winter ends sooner. The point is to get students interested in a specific topic and point them to other resources including those contained in "Attachment 6: Data Sites and Resources for Framing a Research Question."

D. Open Exploration
Now explore making maps of any of the variables below using different time periods, regions of the world, types of maps, and anything else you can think of.

- **Precipitation**
- **Evaporation**
- **Low-level cloud coverage**
- **Surface air temperature (in C)**
- **Max surface air temperature (in K)**

Sources:
Youngman, B., Chandler, M., Sohl, L., Hafen, M., Ledley, T., Ackerman, S., & Kluge, S. Envisioning Climate Change Using a Global Climate Model. Earth Exploration Toolbook. January 25, 2010.