Lab 12 | EaES 101

Climate: Past, Present, Future

UIC EARTH AND ENVIRONMENTAL SCIENCES

12

EARTH AND ENVIRONMENTAL SCIENCES

Name: ______________________________
Instructor/Section: ___________________

Lab 12 | EaES 101

Climate: Past, Present, Future

OBJECTIVES

- Analyze climate data and evaluate how interactions between climate system components lead to climate variability that impacts human societies.
- Explain the effects short and long term climate change have had on past civilizations.
- Interpret graphs of Greenland ice sheet data and analyze trends in albedo and total ice area.
- Evaluate the predictability of ice loss in Greenland's marine-terminating glaciers.
- Simulate climate systems through the use of models, and evaluate system feedbacks and outputs as a result of variations in forcing mechanisms and climate system components.

MATERIALS

- Computer with Google Earth
- 101_Lab_12.kmz file

I. PAST | Forecasting Climate Variability and Change: A Matter of Survival

Complete this section of the lab BEFORE coming to class.

A. Climate Forecasting and Adaptation through the Ages

By Cindy Shellito, University of Northern Colorado

In the 21st century, it is difficult to avoid news about climate change. Often, news of climate change is reported in the same breath as news about weather: "Greenland ice caps melt and Midwestern crops destroyed by hail storm!" ***Climate*** is the term used to describe the weather conditions that prevail over a long period of time. Most people can describe the climate of their home town without thinking too much about it: it is warm at certain times of the year, cool in others. Sometimes it is wet, sometimes dry. Some places are always dry or wet. But over the course of a lifetime, we might see changes in what we expect from year to year. Ask someone who experienced the dust bowl in the 1930s. They will tell you that the climate of the American Midwest was different back then. Take a look at the Arctic today. The presence of sinkholes left by melting permafrost and retreat of glaciers are indicators that something is different now than it was only a couple of decades ago. Climate is never a constant, but it has such an impact on our lives. Today it not only dictates whether we wish to install air conditioning in our homes, but determines whether crops grow and thrive or shrivel and die. We depend on climate for food, and this is not a new phenomenon; it has always been so for us and for our ancestors.

Climate in a particular region can vary over a short or long period of time. In your lifetime, you might have noticed that some summers are wetter than others, or that some winters are much colder than others. These shorter-term changes in climate, which appear as ***anomalies***—or differences from the average—in our records, are generally referred to as ***climate variability***. When we see a long-term trend in climate, or a change in how frequently we experience anomalies associated with climate variability, we refer to it as ***climate change***.

To better understand the full impact of climate on 21st-century life, we need to take a step back in time. This article surveys the impacts of climate on three past human cultures: the Incas, the Mayans, and the Vikings.

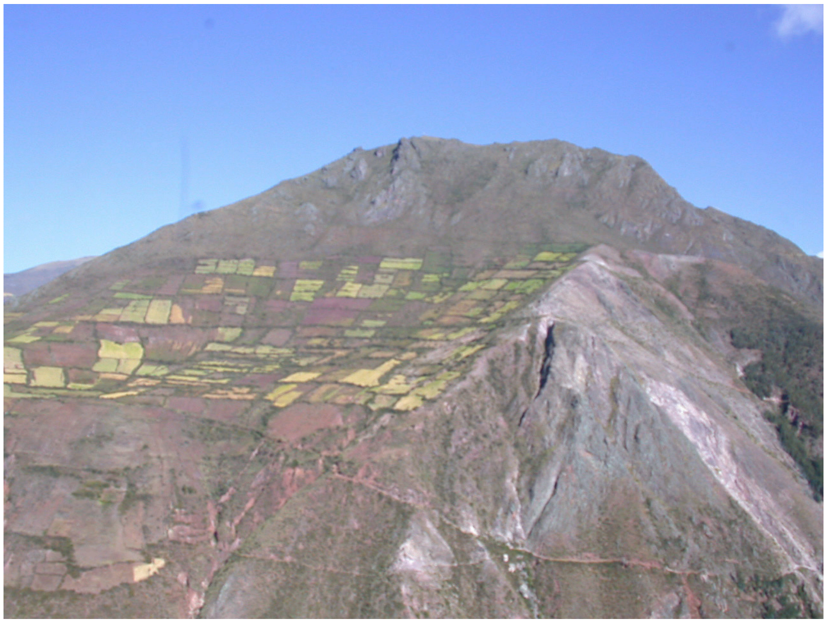
Begin your survey of climate impacts in:

- the snow-capped peaks of the Peruvian and Bolivian Andes
- the steamy jungles of Central America
- the rocky shores of coastal Greenland

1. Peruvian and Bolivian Andes: Forecasting Climate Changes

In the high Andes, it is not unusual to find farms and villages at or above 12,000 feet elevation. Despite the fact that this region is within 15 degrees south of the Equator, the high mountains are a harsh, windswept place. There are few trees, and the natural vegetation consists mostly of scrub. Yet, if you were to drive one of the winding, gravel roads through the mountains, you would find (if you could look away from the precipitous cliff running alongside the road) many of the steep hillsides blanketed by a patchwork of crops (See Figure 1 on page 12-5). These are slopes that are so steep, they would be difficult to walk on, let alone drive a tractor. Corn, quinoa, and potatoes are the staples. Peru is known for having more varieties of potatoes than any other region of the world. Farmers working the land there today follow the same methods that have been in place for centuries, possibly since the time of the Incas, over 800 years ago. The Aymara- and Quechua-speaking people of these high peaks and plains have long depended on their crops for food and trade. Their survival depends on the success of their crops. As they understand it, they are at the whim of their gods. Not enough rain, or too much rain, in any given year could mean a failure of their crops and the end of their way of life. To try to anticipate the whims of their gods, these people, long ago, developed their own means of forecasting the weather.

In mid to late June, often for many consecutive days, farmers observed the constellation Pleiades.



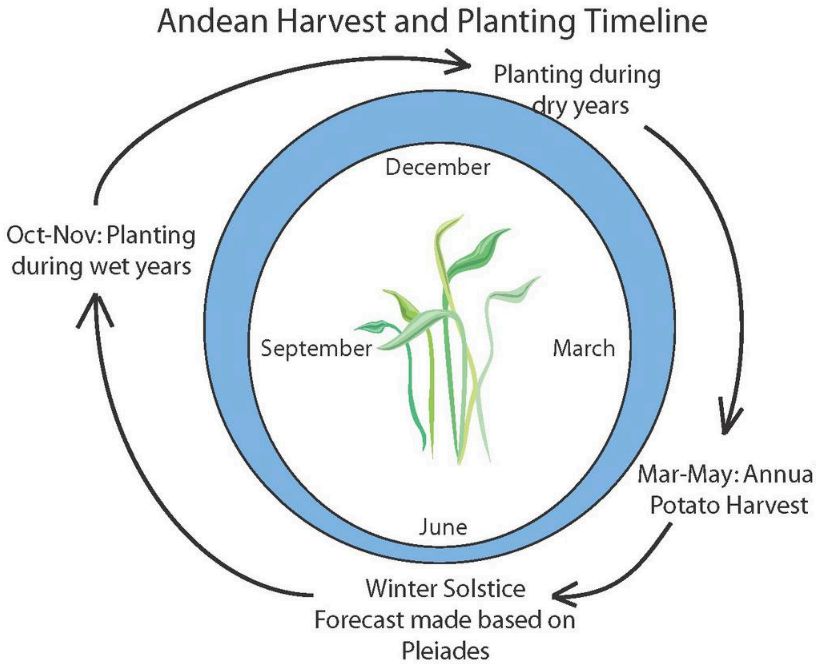
[Figure 1 | Andean Planting on Steep Hillsides]
Source: InTeGrate -The Science Education Resource Center at Carleton College

Around this time of year, the constellation first appears in the eastern sky in the pre-dawn hours. The farmers would take note of several aspects of the Pleiades that relate to the overall brightness of this cluster of stars: the date the cluster first appears on the eastern horizon, the apparent size of the cluster, and the position of the brightest star in the Pleiades. Using these observations, the high mountain villagers would forecast the timing and quantity of precipitation for the upcoming year. This would also allow them to estimate the size of the potato harvest for the following fall (remember: fall occurs in March through June in the Southern Hemisphere).

A clear view of the Pleiades near the winter solstice (June 21) would lead to a forecast of sufficient rainfall and a large harvest the following autumn. If the villagers had an obscured view with less clear skies, they would forecast poor rainfall and delay planting of their potatoes. Potatoes are usually planted in October or November. During low rainfall years, farmers would delay this until December, when they were much more likely to receive rainfall. (See Figure 2 on page 12-6.) Potatoes have shallow roots and require a lot of water soon after planting in order to maximize tuber formation.

It is possible that this forecasting technique dates back several centuries to the Incas. The Incas worshipped the Pleiades, and there are notes about such forecasts soon after their conquest by the Spanish in the 16th century.

So, how well does this ancient forecasting work? Dr. Benjamin Orlove, from the University of California at Davis, and colleagues set out to verify the Incas' technique. They looked at satellite records of Pacific high cloud data archived by the International Satellite Cloud Climatology Project. They used these data



[Figure 2 | The Andean Planting Timeline]
Source: InTeGrate -The Science Education Resource Center at Carleton College

as a substitute for the record of Pleiades visibility (in other words, lots of high clouds in the eastern Pacific means low or no Pleiades visibility), and compared the cloud data each year with crop yields in the Puno district of the high Andes over a period of eight years, from 1983 to 1991. They found that crop yields were well correlated with Pleiades visibility. In other words, the ancient forecasting technique worked quite well! Understanding that climate variability had an impact on their survival, and astute observations of their environment gave the Andean people an enormous advantage.

2. Central America: a Story of Adaptation and Downsizing

The Mayan civilization flourished in Central America from A.D. 250 to 900. They lived in a region that today is occupied by the Yucatan in Mexico, Belize, Honduras, and Guatemala. Their civilization reached a cultural peak around A.D. 800, and today, millions of tourists flock to their pyramids each year to marvel at their ingenuity. The collapse of this productive, successful civilization from A.D. 800 to 1000 has long been shrouded in mystery, although climate change is thought to have played an important role.

The rainforests of Central America provided a gold mine of food and resources for these people. Ample rainfall throughout the year fed the growth of a verdant, lush canopy of incredible diversity. There is little the Mayans would have needed beyond their forest home, if anything. The Mayans had a rather sophisticated system of agriculture, with raised fields and terraces. It is thought that some of these agricultural systems contributed to deforestation as their cities grew and the demand for food increased. The Mayan culture flourished for centuries under this system. Under ample rainfall, this likely would have continued, but the health of the forest and large crops are very sensitive to minute changes in rainfall.

In the early 1990s, a group of scientists from the University of Florida examined lake sediments from Lakes Punta Laguna and Chichancanab on the Yucatan Peninsula of southern Mexico. Lake sediments can provide an excellent record of climate change and may also provide some indicator regarding the events that led to the demise of the Mayans. Over the decades, as sediments settle out of the water column to the lake floor, they preserve a record of the chemistry of the lake, as well as a record of evolution of the life in the lake. Punta Laguna and Chichancanab are even better than most lakes for such studies because of their high sedimentation rate. Punta Laguna also has no streams or rivers branching away from the lake. It loses most of its water via evaporation. The water column is rarely disturbed, and sediments are deposited in smooth layers.

Within the sediments, researchers examined a number of ***climate proxies***, or physical characteristics preserved in the geologic record that can be used to infer past climate. In the sediments of both lakes, researchers examined the chemistry of shells of microscopic fauna that were buried in the sediments after they died. Specifically, they looked at the ratio of heavy oxygen (^{18}O) to light oxygen (^{16}O), as this ratio can provide an indicator of relative evaporation and precipitation over the ages. (You learned/or will learn about this is Lab 15.) At Lake Punta Laguna, they also examined shells and pieces of wood buried in the sediments.

What the researchers found at both of these lakes are records, going back several thousand years, of multiple wet and dry episodes, each lasting, quite possibly, for decades. It is hypothesized that these wet and dry episodes may have had an influence on Mayan history and cultural evolution.

What the proxies show is that for the 1000 years or so prior to about A.D. 280, the region was rather wet over all. Around 280 A.D. things began to dry out, but at the same time, Mayan cultural evolution accelerated. For the next 500 to 600 years, there was a gradual drying, punctuated by more severe droughts. Between A.D. 800 to 900, the Classic Mayan civilization collapsed. This time period also corresponds to what is estimated to be the most severe drought in the past 8000 years. Archaeological evidence points to the movement of people to the northern Yucatan at this time. It has been suggested that these people were dependent on precipitation for water. With reduced precipitation and a drop in the water table, the only way they could adapt was to move somewhere with more water.

Considering that the climate of the Yucatan Peninsula has returned to its previously moist conditions since the collapse of the Mayan civilization, it is likely that the Mayans were victims of long-term climate variability.

[Figure 3 |Map of Greenland]

Source: Coastline data obtained from the Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) of the National Oceanic and Atmospheric Administration National Centers for Environmental Information. Retrieved from: http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html

3. Greenland: When the Going Gets Tough, Pack up and Flee

About 4500 years ago, Inuit tribes from North America crossed over a frozen ocean into Greenland. (At least, that is what we imagine. We have not found any evidence of boats from that time.) First the Saqqaq people, and then the Dorset people, occupied the mostly frozen continent until about 2200 years ago. About 1000 years later, Norse explorers known as the Vikings arrived in Greenland. The Vikings had already settled in Iceland, so Greenland was just one more hop, skip, and step beyond that. Greenland must have been a sort of high-latitude "promised-land" at the time, because the Vikings did not have it to themselves. A couple of hundred years after they arrived, another Inuit group, the Thule people, arrived from North America. Both groups occupied Greenland until the Vikings abandoned their settlements about 600 years ago. The Thule people stayed on, however, and their descendants still live in Greenland today.

How did these different groups manage to make a living in such a harsh land? And why did the Vikings abandon their settlements and leave Greenland entirely to the Thule people? There is little evidence of interaction between the two groups, so it is generally not thought that there were any conflicts between them. Clues lie in the ice and in the lake sediments of Western Greenland.

Dr. William D'Andrea, from Brown University, and colleagues examined sediments deposited over the past 5600 years in two lakes in West Greenland near Kangerlussuaq. (See Figure 3, p. 12-8.) They wanted to create a long-term record of temperature in this region. In the mud samples they collected, they measured "alkenones," or fat deposits made by algae in the lakes (didn't imagine algae could get fat, did you?). The abundance of algae depends on the temperature of the water, which depends on the temperature of the air. So, D'Andrea and his team were able to reconstruct a record of air temperature based on these alkenones.

Chemical analyses of ice cores near the summit of Greenland, specifically, the ratio of heavy oxygen (^{18}O) to light oxygen (^{16}O), also provide a record of temperature changes over the past 5000 years. But the record of temperature inferred from mud samples provides a much clearer picture of what temperatures were like on the coast of Greenland, where people actually lived. (Only scientists are crazy enough to live on the summit of the Greenland ice sheet!) These records show us that at the time the Vikings lived in Greenland, the climate was quite different than what you would experience today. When the Vikings first arrived in Greenland, it was warm enough for birch trees to grow in some of the fjords! The Vikings quickly cut these down to help build their houses, and their goats and sheep grazed on any remaining vegetation. Nevertheless, trees are not something one would associate with Greenland today. The Norse community did quite well for some time, with as many as 600 farms. They traded ivory, sheep, and seals with Iceland and their homeland in Norway for wood, iron, and food they could not grow.

There are no written records explaining why the Vikings left Greenland, but their departure has long been attributed to regional cooling. Both the ice core and the lake sediment records show that the timing of the cooling along the western coast coincides well with the abandonment of Viking settlements. Excavations at settlement sites show that prior to abandonment, there was a change in diet among the Vikings, from sheep, goats, and cattle to seals and fish. It is thought that the Norse, whose lifestyle depended on farming rather than hunting, were unable to adapt to harsher winters, and that they eventually abandoned their settlements. The Thule people, on the other hand, were hunters and fishers, and it seems,they were able to adapt much more easily to harsher conditions.

What was happening in Europe while the Viking outposts were succumbing to those colder, harsher winters? As it turns out, as climate was cooling in Greenland, it was warming in other parts of the North Atlantic! A record of temperature inferred from cave deposits in southwestern Ireland showed that at the same time Greenland was cooling, Ireland experienced warming. Likewise, when Greenland was warming, Ireland experienced cooling. This strongly suggests that there is likely some type of long-term climate oscillation in the North Atlantic, and locations on the opposite ends of this oscillation will experience opposite trends in climate. The Vikings, lulled into Greenland by a relatively long-term warm episode around 1000 A.D., were ultimately victims of these long-term oscillations in the climate of the North Atlantic.

Please answer the following questions BEFORE coming to class:

1. ***What is climate? What variables are used to describe climate?***

2. ***What affects climate in a particular location?***

3. ***What is the difference between short-term and long-term climate variability? For each of the ancient groups (Andean farmers, Mayans, and Vikings), describe whether you think they were responding to short-term or long-term climate variability. Are there differences in the types of climate changes that affected people in low vs. high latitudes?***

4. ***What determines global average climate? In other words, what things are external to the climate system?***

II. PRESENT | Greenland Case Studies

Scientists use a variety of methods to investigate ice sheet changes. In this unit, you will look at graph and map data to think about how, if at all, the Greenland ice sheet is changing. Greenland is the world's largest island and lies east of Canada at the northern margin of the Atlantic Ocean and the southern edge of the Arctic Ocean. (See Figure 4, p. 12-15.) Much of the island (~81%) is covered by the second largest ice sheet in the world. The highest elevations on Greenland are more than 3,700 meters (12,139 feet) above sea level and are underlain by a thick pile of ice more than 3 kilometers (1.9 miles) thick. It is estimated that global sea levels would rise by 7 meters (23 feet) if all of Greenland's ice were to melt. While this is unlikely to occur in the near future, recent investigations have revealed an increased rate of melting for Greenland's glaciers. You are going to analyze some data from the past decade from the Greenland ice sheet, including areas from Greenland's interior and ***marine-terminating outlet glaciers***, to decide for yourself about the potential fate of Greenland's ice.

One of the most important concepts that you will need to consider in thinking about Greenland's ice is ***albedo***, the measure of a surface's reflectivity. As you learned in Lab 2: Earth's Heat Budget, an object's albedo can be estimated based on its color. In general, the darker an object, the more light it absorbs and the less light it reflects. Therefore, darker objects tend to have lower albedos than lighter objects. This is illustrated in Table 1, on p. 12-13. An example of a material with a high albedo (high reflectivity) is fresh snow, which has an albedo of approximately 0.84. In other words, fresh snow reflects approximately 84% of the incoming sunlight that strikes it. In contrast, glacial ice that is not covered with snow exhibits an albedo range of 0.2 to 0.6 (20%-60%). Fresh snow has a relatively high albedo, but once that snow melts, the underlying ice has lower albedo values due to a variety of factors, including:

- The presence of pollutants or other impurities (e.g., dust, soot from wildfires) in the ice.
- Diminished reflection as a result of the rounding of the edges of the ice crystals that make up snowflakes, which is caused by warming.
- Melting of ice creates pools of meltwater with a lower albedo.

It is also interesting to note that, for some objects, like water, albedo is dependent upon the angle of the sun's rays (solar angle). At high solar angles (when the sun is more directly overhead), the albedo of water is lower, whereas, at lower solar angles, the albedo is increased. (See Table 1.) Since water covers approximately 71% of Earth's surface, this means that albedo is also affected by latitude and seasons. (Recall what you learned about the relationship between solar angle, seasons, and latitude in Lab 2: Earth's Heat Budget.)

Scientists use satellite data to measure the albedo on the Greenland ice sheet throughout the year and produce a series of graphical plots of these data that illustrate annual trends. Looking at albedo variations over the course of the year allows scientists to compare how the albedo varies at different elevations within the ice sheet.

Would you expect the entire Greenland ice sheet to exhibit the same albedo values and seasonal/annual/decadal variations? Part of your assignment for this unit will involve assessing annual albedo data for different elevations within the ice sheet to determine if trends are consistent across Greenland.

Surface	Details	Albedo
Soil	Dark-colored and Wet - Light-colored and Dry	*0.05 - 0.40*
Sand		*0.15*
Grass	Long - Short	*0.16 - 0.26*
Agricultural Crops		*0.18 - 0.25*
Tundra		*0.18 - 0.25*
Forest	Deciduous	*0.15 - 0.20*
	Coniferous	*0.05 - 0.15*
Water	Low Solar Angle	*0.03 - 0.10*
	High Solar Angle	*0.10 - 1.00*
Snow	Old - Fresh	*0.40 - 0.95*
Ice	Sea	*0.30 - 0.45*
	Glacier	*0.20 - 0.40*
Clouds	Thick	*0.60 - 0.90*
	Thin	*0.30 - 0.50*

[Table 1 |Albedo ranges of various natural surfaces]
Source: Budikova, D. (2013). Albedo. Retrieved from http://www.eoearth.org/view/article/149954

A. Case Study A: Reflecting on what is happening to Greenland's Ice

1. Data set #1: Reflectivity graphs

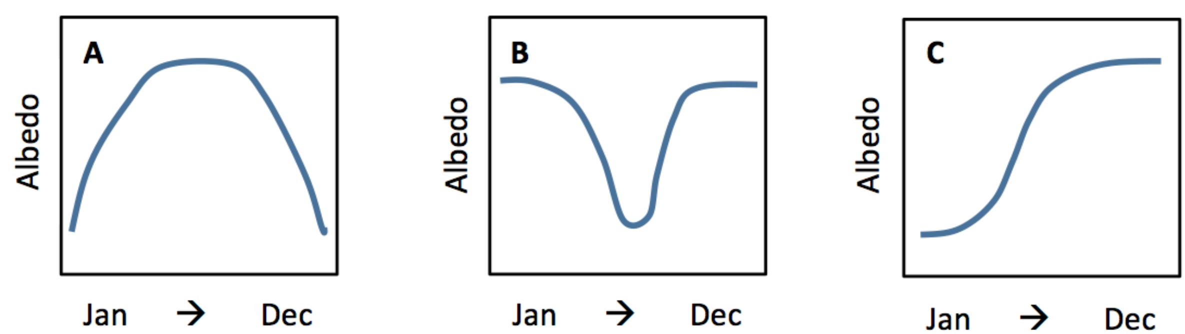
With your lab group, spend a few minutes answering the following questions:

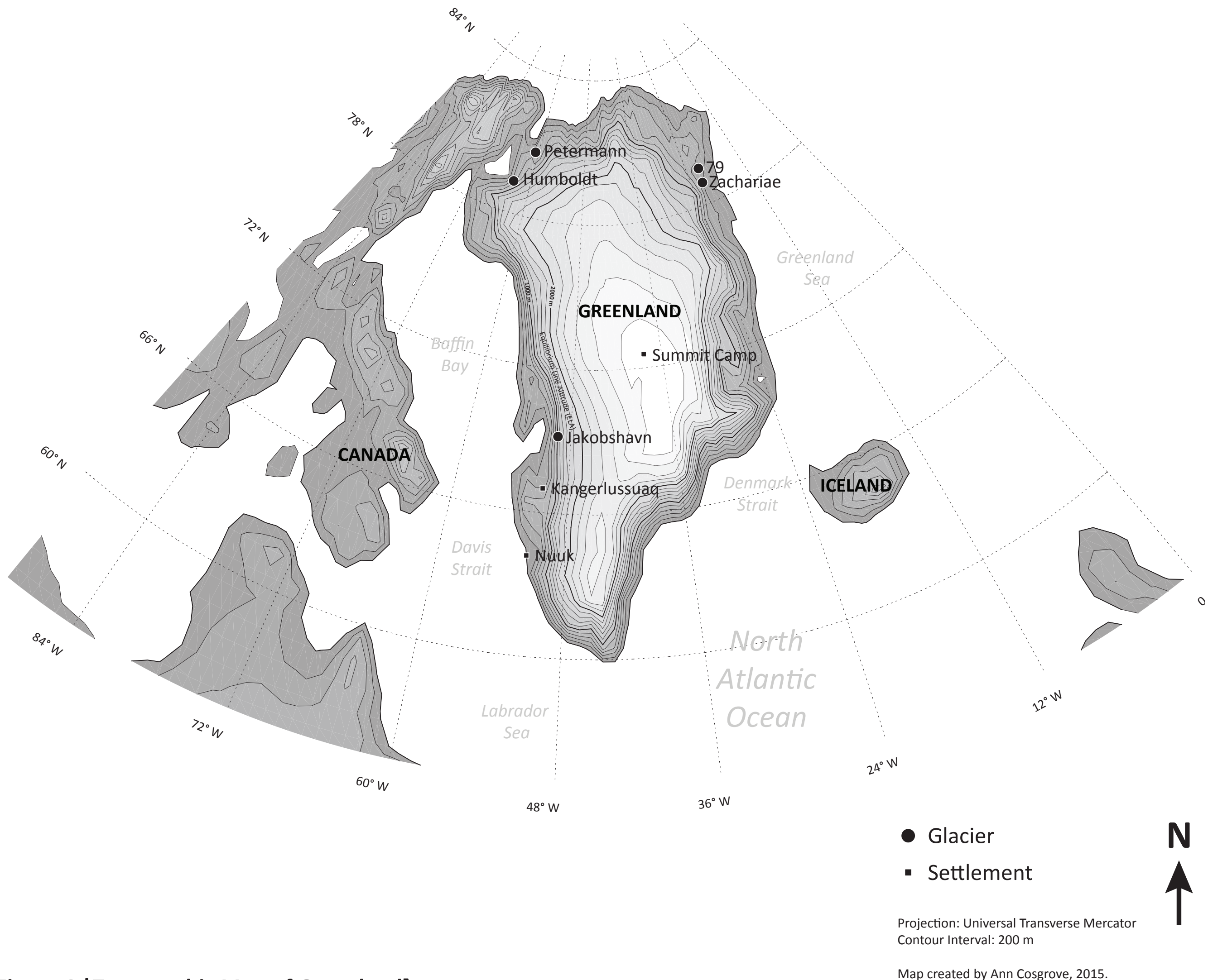
5. ***Brainstorm some reasons why glacial ice can exhibit such a wide albedo range. Record your ideas in the space below.***

6. ***During which parts of the year would you expect the Greenland ice sheet to exhibit the highest and lowest albedo values? Why?***

7. ***During a given month, would you expect all regions of Greenland to exhibit the same albedo (For example, coastal vs. inland areas)? Explain.***

8. ***Satellite observations of Greenland's albedo are available from March 2000 to the present. Before you look at the data, let's make some predictions about how albedo varies annually. Which of the graphs sketched below do you think best represents the variation in albedo over the course of a typical year in Greenland (circle one)?***





[Figure 4 |Topographic Map of Greenland]

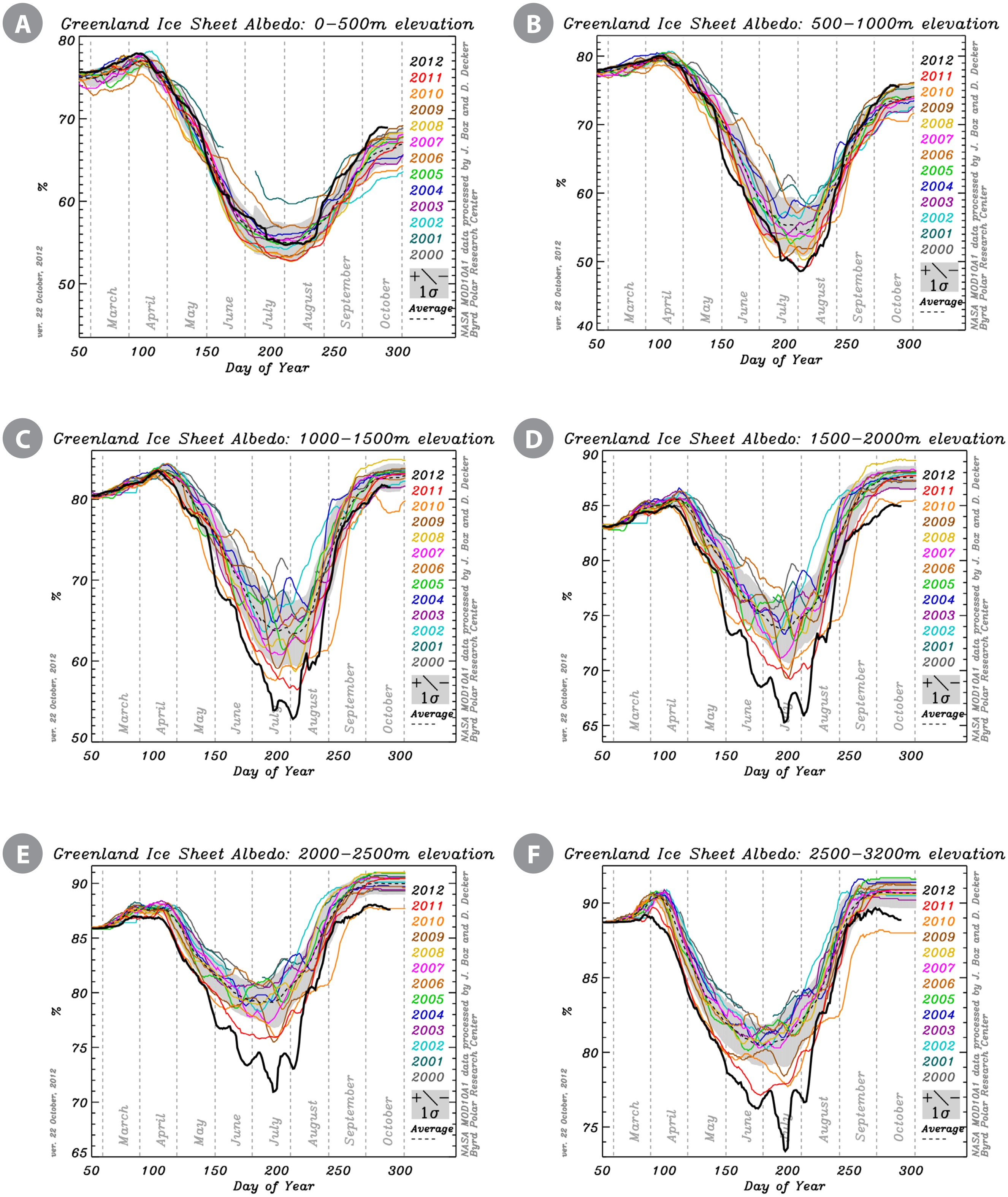
The graphs on the following page (Figure 5 on page 12-16) show real albedo data from Greenland with time on the X axis and albedo on the Y axis. These plots allow you to determine how albedo has varied seasonally in a particular year, as well as how albedo has varied over the past 12 years. Each graph (A-F) shows satellite measurements made at different elevations on the ice sheet. Each color represents albedo values for a different year between 2000 and 2012. Digital versions of the graphs can be found on the following website: http://meltfactor.org/latest-greenland-ice-sheet-reflectivity/.

Pick (1) graph (A-F) to focus on for questions #9 - 11. Each group member should select a different graph. Record the number of the graph you selected on below. You can use the topographic map of Greenland above (Figure 4) as a reference.

Graph selected: _____ (A, B, C, D, E, or F)

Elevation of measurements: _______ m to_______ m

Please note: Make sure you pay attention to the y-axis scale of your graph. Each graph is different.



[Figure 5 |Greenland Ice Sheet Albedo 2000-2012]

Source: Box et al., 2012. Retrieved from: http://meltfactor.org/latest-greenland-ice-sheet-reflectivity/

9. ***Study your graph and write a summary paragraph describing what your graph illustrates. In your description, make sure to include answers to the following questions: What elevation range does your data represent? What do the different colors on the graph indicate? What albedo range is illustrated on your graph? In general, which months have the highest and lowest albedo?***

10. ***Can you discern any trends in albedo values when you compare data from the initial few years with data from the most recent years?***

Compare your albedo graph with the graphs of the other members of your group. First, as a group, make sure that everyone is clear on the questions that you already answered on your own. Share observations about the different graphs and summarize what you interpret the albedo graphs data suggests could be happening to the Greenland ice sheet.

11. ***Based on the overall data, do the higher or lower elevation areas in Greenland have the greatest albedo? Offer an explanation for WHY. Which elevations show the greatest/least contrast in albedo values over the period represented by the data?***

2. Data set #2: Reflectivity anomaly maps

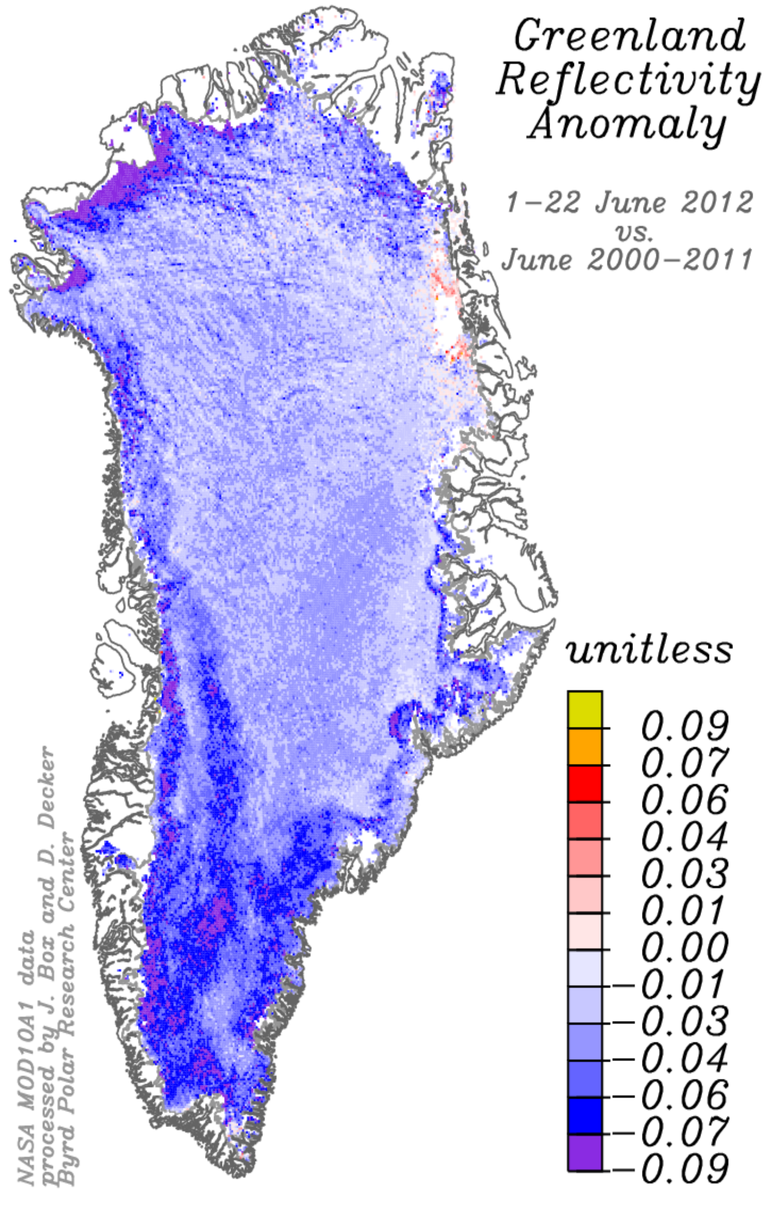
Next, you will work with a partner and look at a Greenland reflectivity anomaly map. Simply, an ***anomaly*** refers to a change from "normal". To obtain a ***reflectivity anomaly***, the long term average reflectivity is subtracted from the current reflectivity. In other words:

Reflectivity anomaly = current reflectivity – long term average reflectivity

The map to the right (Figure 6) illustrates the reflectivity anomaly in Greenland in 2012 vs. 2000-2011.

In this map, the June 2012 reflectivity is being compared with the average June reflectivity from 2000 to 2011. A reflectivity anomaly of 0 means that in a particular place, the albedo in June 2012 was the same as the average June 2000-2011 albedo and is shown using pale pink on the map. A positive reflectivity anomaly, illustrated using pink, red, orange, and yellow, means that for the area in question, the albedo in June 2012 was higher (in other words, more reflective) than the average June 2000–2011 albedo. A negative reflectivity anomaly, illustrated using blue and purple, indicates that the albedo in the area in question was lower (in other words, less reflective) in June 2012 than the average June 2000–2011 albedo.

The measurements on the map are dimensionless but can be converted to albedo percentages (like you looked at on the graphs in data set #1) by multiplying by 100.



[Figure 6 |Greenland reflectivity anomaly 2012 vs. 2000 - 2011]

12. Which colors are used to represent a positive anomaly? What does a positive anomaly mean?

13. Which colors are used to represent a negative anomaly? What does a negative anomaly mean?

14. Why are some areas of the map white? *Hint: If you are having trouble with this question, refer to the Google Earth 101_Lab_12.kmz file provided with this week's lab content. What do you notice about these areas on the map when you look at them on Google Earth?*

Think about all of the Greenland data that you have studied: yearly albedo plots from 2000 - 2012 (Data Set #1) and the reflectivity anomaly map for 2012 compared to 2000 - 2011 (Data Set #2). Based on these data, answer the following questions. **Compare this map to the Google Earth 101_Lab_12.kmz file. The animation included in the file shows Greenland ice sheet surface melt characteristics from 1979 - 2007**.

15. Briefly summarize what the reflectivity anomaly map suggests is happening to the Greenland ice sheet. Use evidence from the map in your answer. What other information would you want to be more certain that you are interpreting the map correctly?

16. Based on what you've learned in Data Set #1 and #2, which of the following sets of conditions should result in the highest ice sheet albedo?

a) summer, low elevation, exposed ice sheet

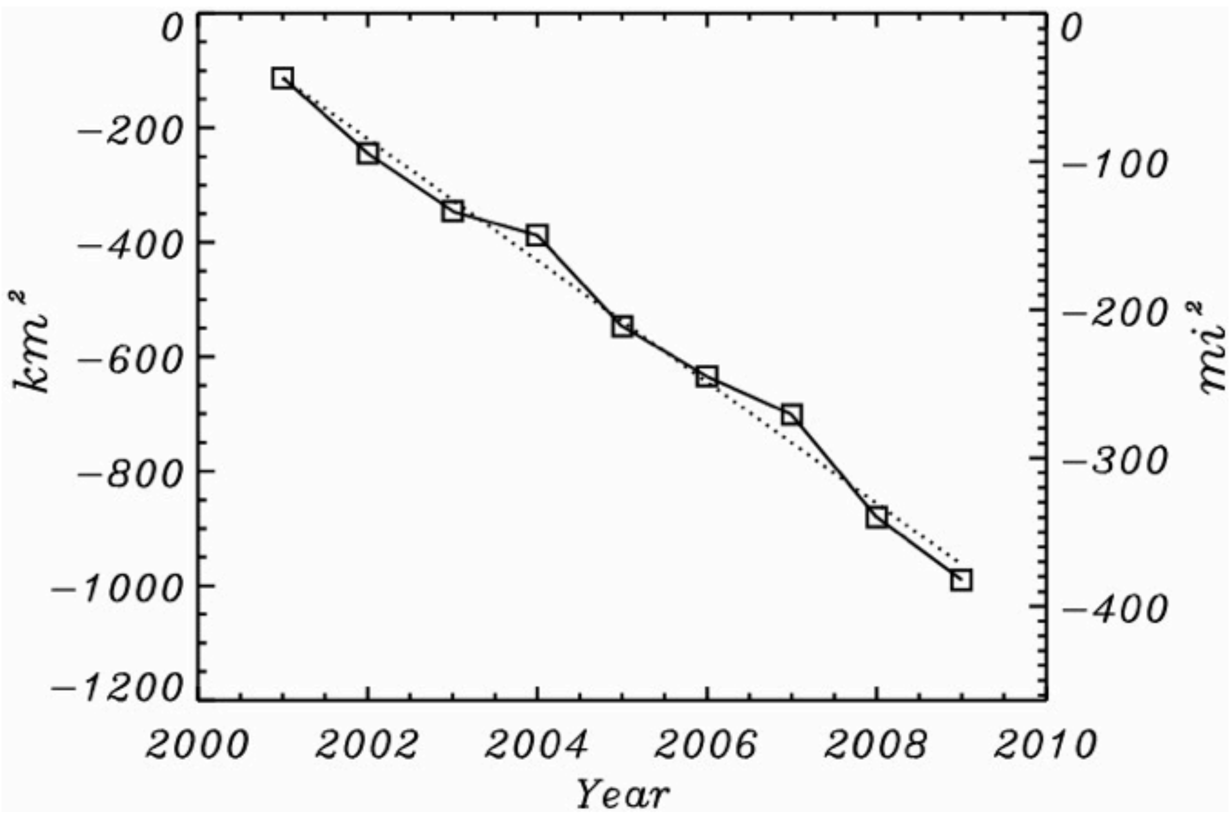
b) winter, high elevation, snow covering the ice sheet

c) summer, high elevation, snow covering the ice sheet

d) winter, low elevation, exposed ice sheet

B. Case Study B: Predicting ranges of change using Greenland outlet glaciers

You have just learned about marine terminating outlet glaciers in Greenland. Figure 7 below illustrates changes in the combined areas of the 34 widest marine terminating outlet glaciers in Greenland from 2001-2009. (The area is expressed in km^2 on the left side of the graph and mi^2 on the right side of the graph.) Satellite technology called MODIS (Moderate Resolution Imaging Spectroradiometer), which is aboard NASA's Terra satellite, was used to obtain the data necessary to generate this graph.



[Figure 7 |Changes in combined areas of 34 marine terminating outlet glaciers from 2001-2009]
Source: NOAA Arctic Report Card 2009

17. Explain why the values on the Y-axis are negative numbers.

18. Approximately how much total area change occurred in these marine terminating outlet glaciers between:

A. 2002 – 2003?

B. 2003 – 2004?

C. 2004 – 2005?

19. Did the area of the marine-terminating outlet glaciers in the study change consistently from 2001 to 2009? Briefly explain your answer, using evidence from the graphed data.

The dashed line in Figure 7 represents the straight line that fits the data best (and consequently is called a best-fit line!) You are going to use the best-fit line to calculate the average rate of area change from 2001 to 2009.

20. If you are looking for the average area change per time for these marine terminating glaciers, in which units should your answer be expressed?

The average area change per time is the same as the slope of the graph, which is expressed as:

$$\frac{|y1 - y2|}{|x1 - x2|}$$

21. Using the graph, calculate the average rate of change of the area of Greenland's marine-terminating glaciers from 2001 to 2009.

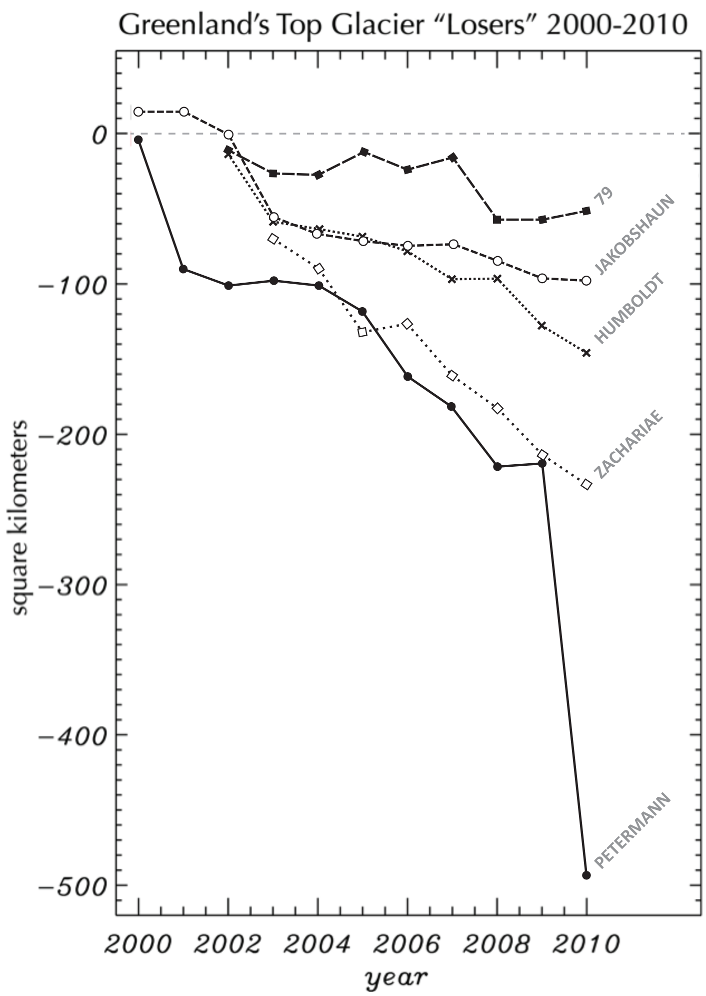
22. Using the rate that you just calculated, predict how much you think the area of Greenland's marine-terminating glaciers changed from 2009 to 2010. In addition, explain how you came up with your answer, and plot your prediction on Figure 7.

A. Predicted change in area of Greenland's marine-terminating glaciers, 2009–10:

B. Explanation of how you came up with your prediction: *(Someone who isn't in this class should be able to read your explanation and understand how to solve a problem like this.)*

(Don't forget to plot your prediction on the Figure 7 on page 12-20.)

Next, let's look at some data for 2010 to evaluate your prediction. Figure 8 below illustrates the five marine-terminating outlet glaciers in Greenland that experienced the greatest cumulative loss in area between 2000 and 2010. **<u>The locations of these five glaciers are indicated on the maps of Greenland (Figures 3 and 4) on page 12-8 and 12-15.</u>**



[Figure 8 |Cumulative area loss for five marine-terminating outlet glaciers from 2001-2009]
Source: MODIS studies of Greenland, Byrd Polar Research Center

23. Name one glacier that did not lose area from 2009 to 2010.

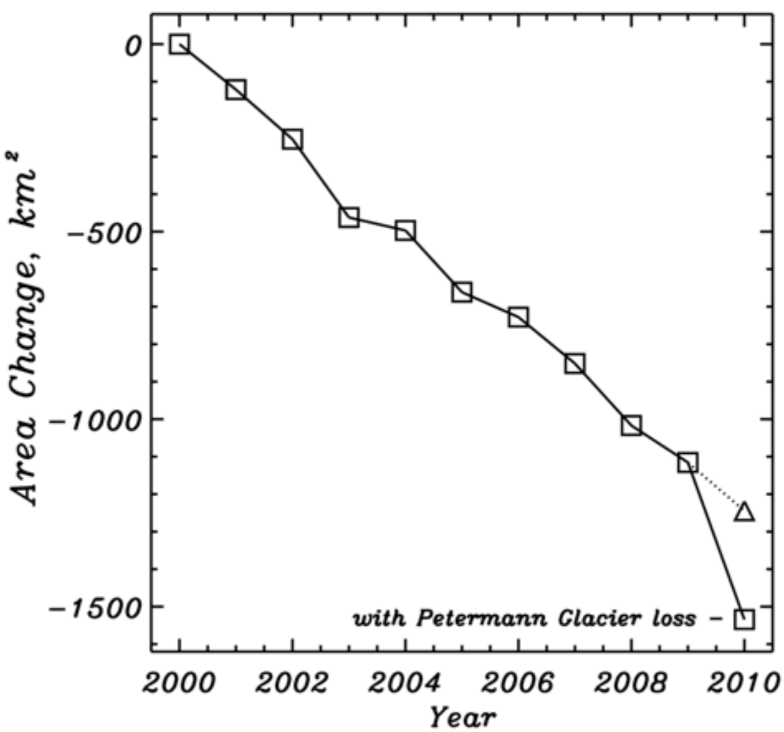
24. Name one glacier that lost area relatively consistently between 2008 and 2010.

25. Which glacier was "the biggest loser" from 2009 to 2010?

26. If asked to predict how the data for these five glaciers looked for 2011, how certain would you be in your predictions? Would you be equally certain (or uncertain) for all five of the glaciers? What additional information would be helpful in making 2011 predictions?

27. Keeping in mind that these are some of the marine-terminating outlet glaciers used to make graphs like Figure 7, discuss how certain you are about the prediction for the total ice area loss that you made in question 22. Are you more confident in your predictions for the individual glaciers or for the total ice area loss? Why?

Finally, let's take a look at Figure 9 below, an area change graph that includes 2010. Notice that two points are plotted for 2010: the triangle represents the change in area in 2010 excluding the Petermann Glacier. The square represents the change in area in 2010 including the Petermann Glacier.



[Figure 9 |Changes in combined areas of 34 marine terminating outlet glaciers from 2001-2010]
Source: NOAA Arctic Report Card 2009

28. Why do you think that the scientists who made this graph provided a "with Petermann" calculation and a "without Petermann" calculation for 2010? If you were conducting a study on climate variability in Greenland, which calculation would you use for 2010, and why?

29. How accurate was your prediction in question 22 if you include the Petermann data?

30. How accurate was your prediction in question 22 if you do not include the Petermann data?

31. Based on what you did in this exercise, what are your thoughts on scientists' ability to predict how the Greenland ice sheet will change in the future? Use evidence from this exercise to support your response.

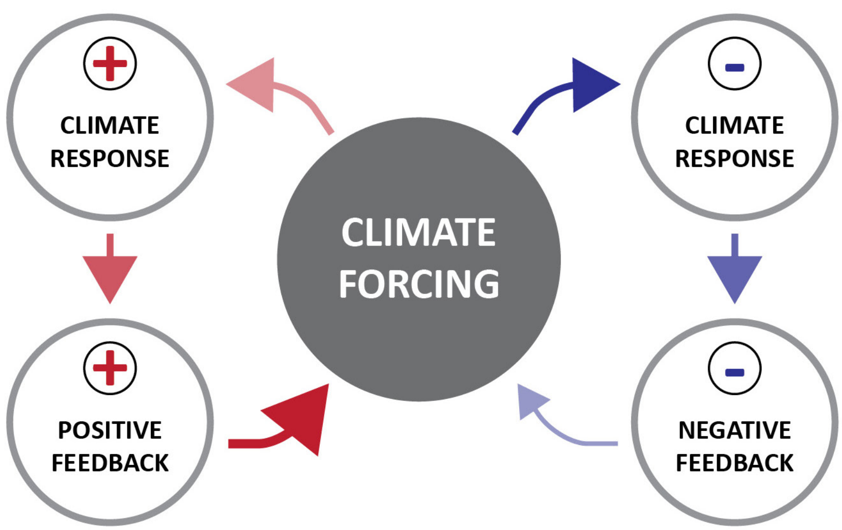
III. Future | Systems at Play

In this unit, you will learn about climate models and consider how climate system components respond to various forcing mechanisms. You will also examine the challenge of making predictions within a system as complex as climate. You will learn how feedbacks and thresholds work and how they create relationships between climate system components which can be straightforward to understand in some cases and more challenging in others. As a human being, you are part of this climate system , along with things like precipitation, plate tectonics, and greenhouse gases.

Some climate system interactions are direct cause-and-effect relationships that are easy to understand. Other relationships are indirect, increasing the system's complexity. Climate scientists work to understand these relationships, and in so doing, help demystify climate function. Our climate system owes much of its complexity to ***thresholds*** and ***feedbacks***.

The terms for cause and effect in the climate system are ***forcing mechanism*** and ***climate change***. Sometimes the relationship between forcing and change is regular: forcing occurs and change occurs. Sometimes, however, forcing must occur multiple times or for an extended period of time before the change occurs, just like how you can continue to squeeze a balloon until it pops. The pressure required to cause popping is a threshold. The point at which enough climate forcing has occurred and climate change begins is a ***climate threshold***.

A ***climate feedback*** is a specific set of interactions, the result of which impacts the initial climate change. If a change in climate sets into motion a series of events that causes the initial change to intensify, this is a ***positive feedback***. A ***negative feedback*** results when a change in climate forces other changes that lessen that initial change. (See Figure 10 below.)

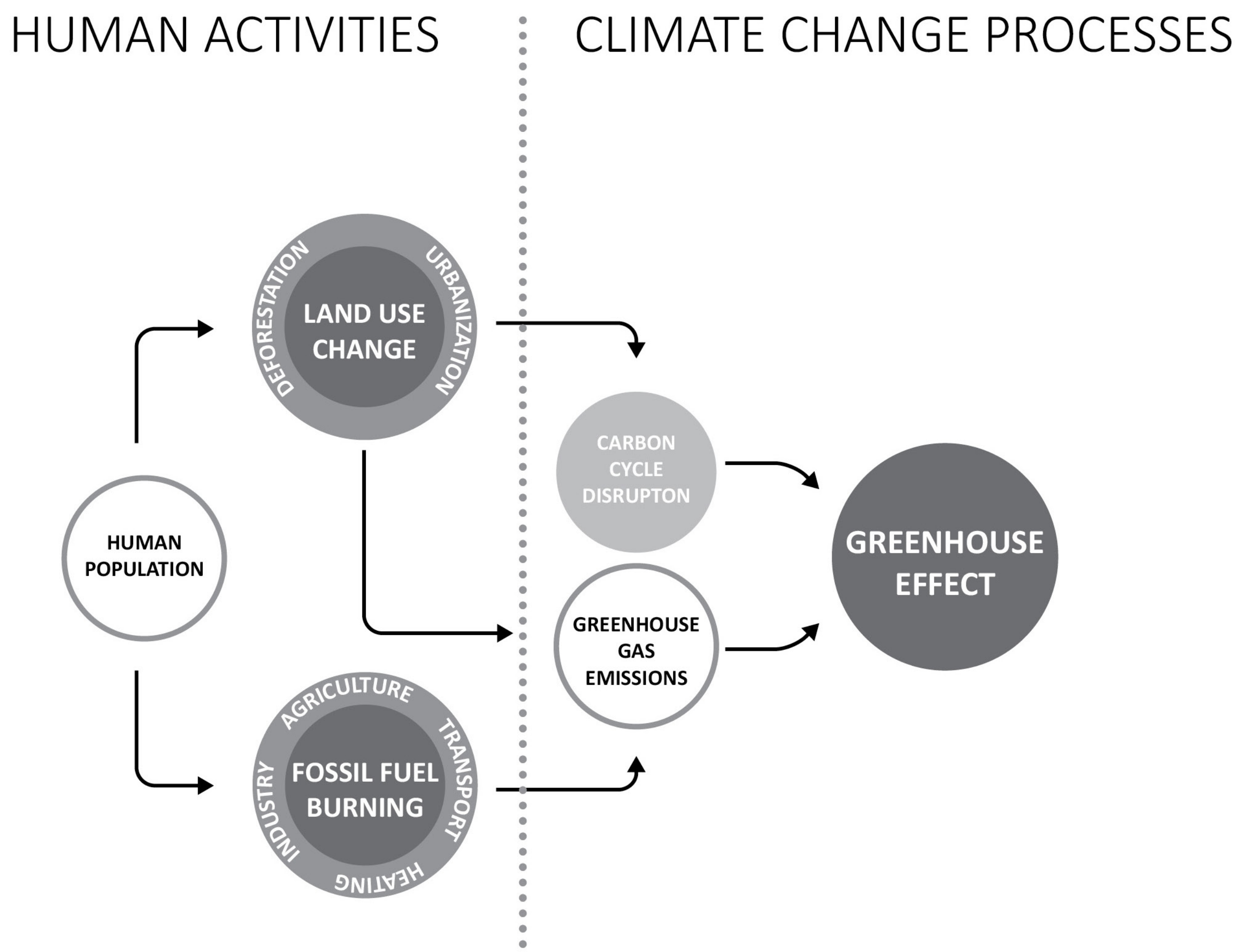


[Figure 10 |Climate Feedbacks]
Source: Adapted from B. Booth, 'Climate feedbacks can be positive and negative.' Retrieved from: http://www.metoffice.gov.uk/climate-change/guide/science/explained/feedbacks

A. Our Climate System

1. Climate Forcing Example

The diagram below shows the relationship between human activities such as land use change and fossil fuel burning and an enhanced greenhouse effect.

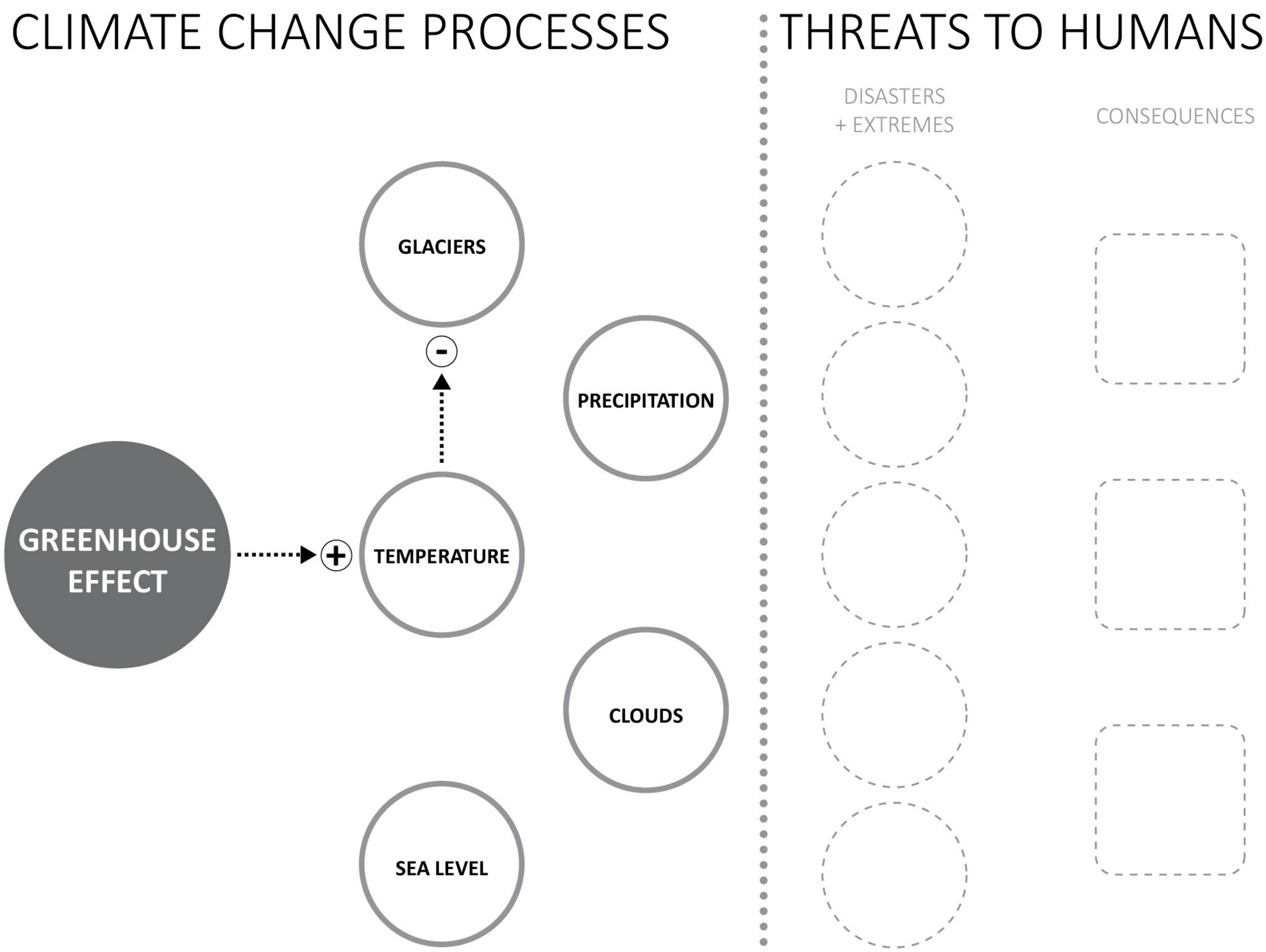


32. Using the diagram above as a guide, explain what would happen to the greenhouse effect should human population increase. Which forcing mechanisms will respond to population growth? <u>Add (+) and (-) signs in front of the arrowheads on the diagram to indicate positive and negative responses.</u>

33. What would happen if human population decreased? List which forcing mechanisms would respond in a positive manner and in a negative manner.

2. Exploring Feedback Mechanisms

Assuming an enhanced greenhouse effect, think about how other climate components will change (e.g. temperature, glaciers, precipitation, clouds and sea level). Discuss these relationships with your lab group. The diagram below shows an example of the positive impact the greenhouse effect will have on temperature, and how increased temperature will cause the melting of glaciers.



On the left side of the diagram above:

[ ] <u>Use arrows to show relationships between the climate components.</u> (Use BLACK colored pencil.)
[ ] <u>Add (+) and (-) signs to indicate positive or negative changes</u>. (Use RED colored pencil for positive and BLUE for negative.)
[ ] <u>Identify positive and negative feedback loops.</u> (Use RED colored pencil for positive and BLUE for negative.)

Note: Our climate system is complex! There are several 'correct' answers to this exercise.

As characteristics of climate processes change, there are several threats to humans that may emerge. On the right side of the diagram on the previous page (12-27):

[ ] Fill in examples of threats to humans that may be a result of the changes in climate processes that you have identified. Categorize these threats into environmental disasters and extremes versus larger consequences that may be a result of these changes. Suggestions for these threats include: DROUGHT, HEAT WAVES, LOSS OF BIODIVERSITY, SPREAD OF DISEASE, FLOODING, ECONOMIC LOSSES, FAMINE, HURRICANES, DISPLACEMENT, CONFLICT. These are only examples. You should also brainstorm other ideas for threats to humans that may develop and include them on your diagram.

[ ] Use arrows to connect these threats (on the right side of the diagram on Page 12-27) to the climate components and processes that they relate to (on the left side of the diagram on page 12-27).

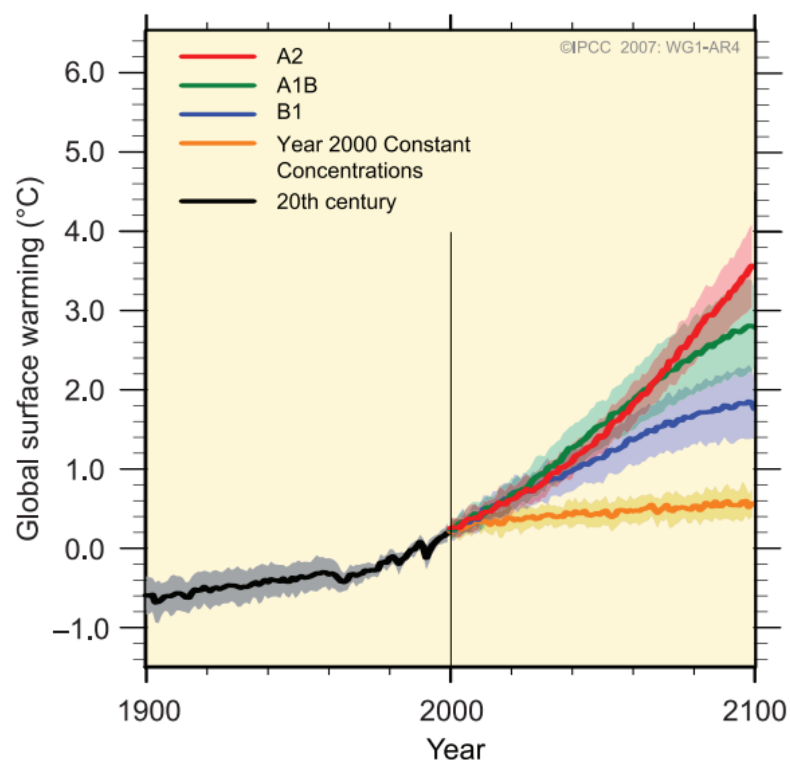
34. Compare your diagram on page 12-27 with the other members of your lab group. Are there any threats that they identified that you did not include? Record any differences here.

35. Can you think of any positive outcomes of the effects of climate change you have identified? Discuss with your lab group and record your thoughts here.

B. Future Climate Scenarios

Climate modeling gives us the ability to watch the climate relationships we currently understand play out in the world of computer simulation. We enter into the model each climate attribute and the way that it interacts with all the others. Then we get to ask the model questions and see what our future would look like depending on changes that occur today or choices the world may make. Climate models involve known climate interactions, thresholds and feedbacks but have many possible outcomes.

The figure below (Figure 11) is from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change released in 2007. It shows projected global average surface warming for three future greenhouse gas emission scenarios. These scenarios are modeled using climate models operating under different future conditions. The black curve shows historic global average surface warming over the last 100 years. Scenario A2 is a high emissions scenario, whereas Scenario A1B and B1 show two different temperature scenarios with less greenhouse gas emissions. For Scenario A2, the climate model assumes continuously increasing global population and a large disparity in renewable and fossil fuel energy use by region. For Scenario A1B, the climate model simulates the peak of population around 2050 and its decline after with globally balanced use of fossil fuels and non-fossil fuels. For Scenario B1, the climate model simulates the peak of population around 2050 and its decline after with the use of predominantly clean energy sources. The yellow curve shows global surface warming that would result if we are able to keep greenhouse gas constant in the atmosphere over the next 100 years.



[Figure 11 | IPCC 2007 Projected global average surface warming]

Source: Adapted from IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

36. According to Figure 11, how much did the global surface temperature change between 1900 and 2000?

37. How many degrees warmer will the average global surface temperature be in 2100 if the future is correctly predicted by Scenario A2, the highest emissions scenario?

38. How many degrees warmer will the average global surface temperature be in 2100 if atmospheric greenhouse gas concentrations stay constant at the year 2000 levels?

39. What is true about the future average global surface temperature predicted by all of the scenarios shown in Figure 11?

40. According to Figure 11, the scenario that produces the lowest projected rise in global average surface temperature is the one in which we are able to keep greenhouse gas concentrations constant in the atmosphere over the next 100 years (the yellow curve).

a. What steps do you think would need to be taken in order to keep greenhouse gas emissions steady? In the space below, list and describe some specific ways in which you think humans could accomplish this.

b. Do you think that keeping greenhouse gas emissions constant is a realistic scenario? Why or why not?

This lab was adapted from: 'Climate of Change: Interactions and Feedbacks between Water, Air and Ice.' InTeGrate - Interdisciplinary Teaching about Earth for a Sustainable Future. The Science Education Resource Center at Carleton College.