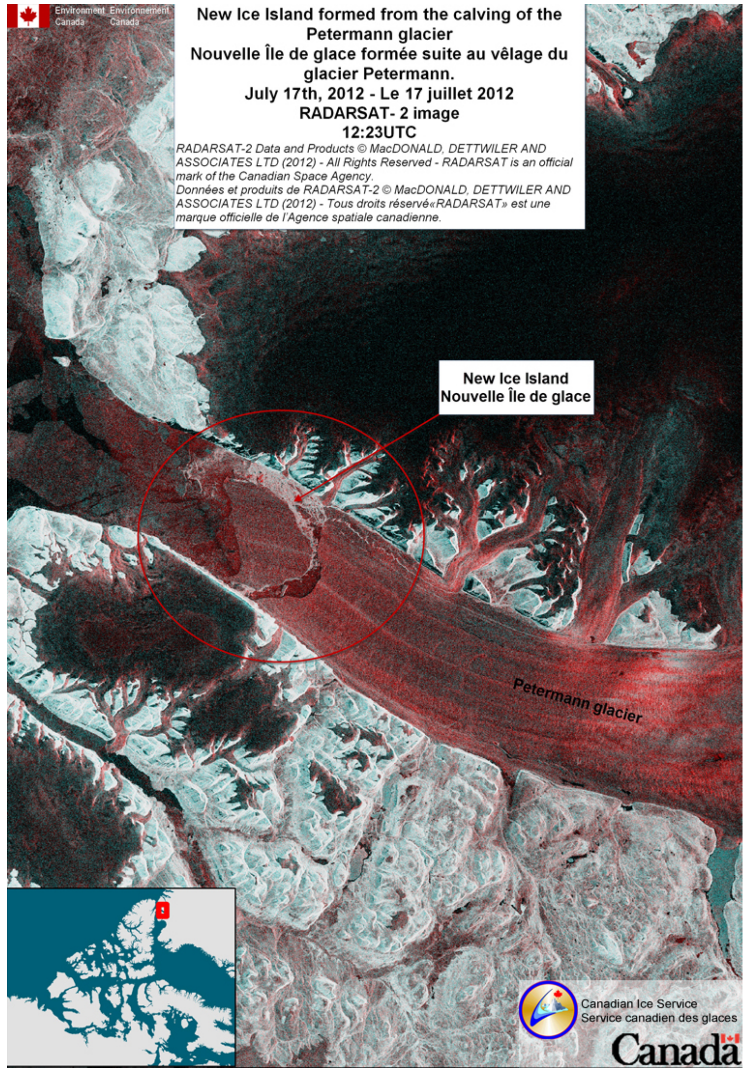
Tasillaq coast, Greenland. ©2009 Christine Zenino

Bellwethers:
Change in climate,
change in glaciers

Name: ________________________________



Glacial monitoring is at the forefront of climate science. We consider these data critical to our ability to understand (and therefore adapt to) climate change. 'Bellwether' refers to the sheep that leads a flock, wearing a bell to sound its movements. Our arctic regions are the most sensitive to global change, making them both excellent laboratories for observing that change and rich sources of data for analyzing it. As bellwethers of warming, sea level rise, and change in oceanic and atmospheric circulation, glaciers teach us to expect the unexpected.

During this activity you will:

- Calculate the average rate of change in area for a set of Greenland's marine terminating outlet glaciers.
- Predict future change for these glaciers.
- Compare your predictions to the measured changes and evaluate the accuracy of your predictions.
- Reflect on our ability to predict future changes in glacial extent.

Figure 1 illustrates changes in the combined areas of the 34 widest marine terminating outlet glaciers in Greenland from 2001-2009. Satellite technology called MODIS is used to obtain the data in this graph.

The dashed line in Figure 1 represents the straight line that fits the data best (a best-fit line). You are going to use the best-fit line to calculate the average rate of change in area from 2001-2009.

1) Why are the values on the Y-axis negative?

2) According to Figure 1, approximately how much change in area occurred between:

a) 2001-2002? __________ km^2

b) 2001-2003? __________ km^2

c) 2001-2005? __________ km

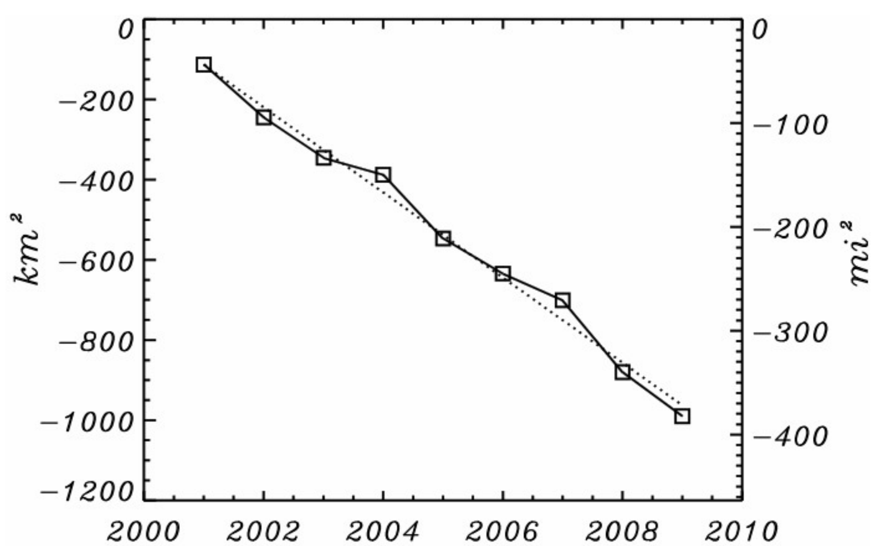
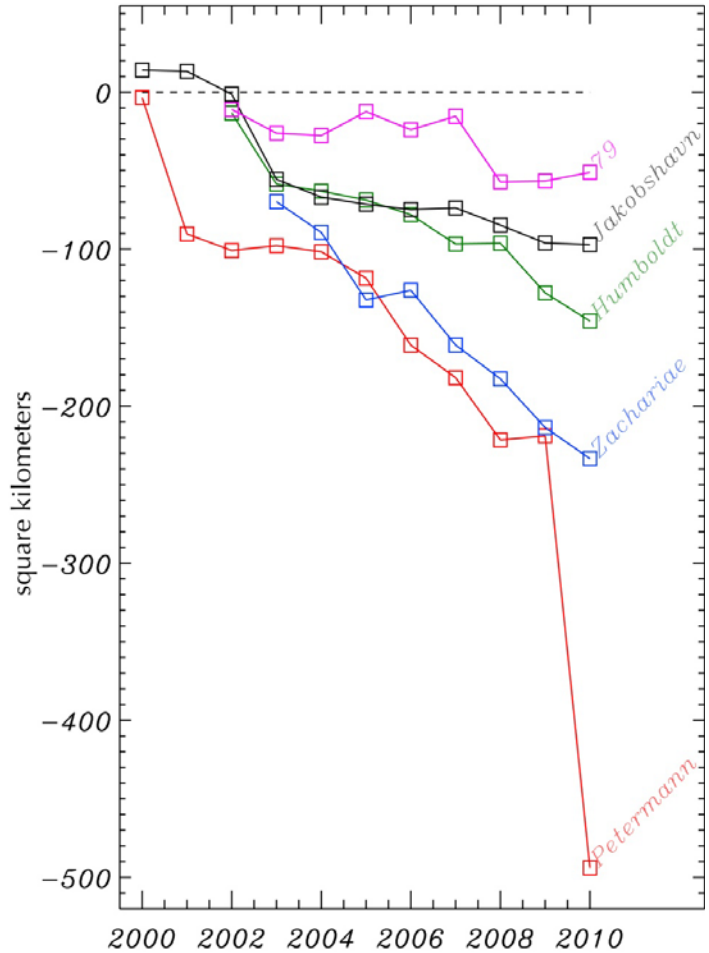


Figure 1. Data from NOAA Arctic Report Card 2009.

Figure 2. Data from MODIS studies of Greenland, Byrd Polar Research Center



3) Did the area of the marine terminating outlet glaciers in the study change consistently from 2001-2009? Explain your answer using the data.

4) If you are looking for the average change in **area per time**, in which units should your answer be expressed?

5) Calculate the average rate at which the areal extent of Greenland's marine terminating glaciers has changed from 2001-2009.

6) Using the rate that you just calculated, predict how much the area of Greenland's marine terminating glaciers will change from 2009-2010.

_______________ km^2

7) Plot your prediction on Figure 1.

Next, let's look at some updated data for 2010 to evaluate your prediction. Figure 2 illustrates the 5 marine terminating outlet glaciers in Greenland that experienced the greatest cumulative loss in area between 2000 and 2010.

8) Which glacier(s) did not lose area from 2009 to 2010? Explain how you know.

9) Which glacier(s) lost area relatively consistently from 2009 to 2010? Explain how you know.

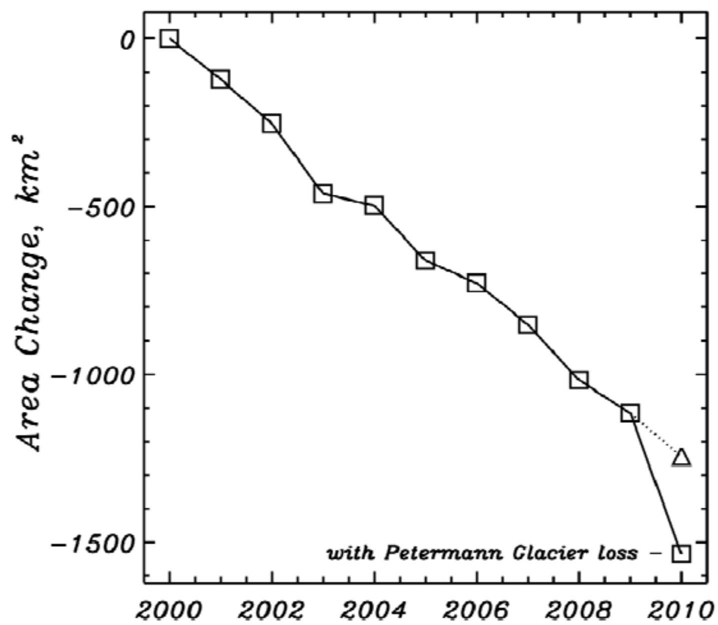
10) Which glacier was 'the biggest loser' from 2009 to 2010? Explain how you know.

11) Use Figure 2 to make a prediction for how the area of each of the glaciers changed in 2011. If you are stuck, refer back to how you made your prediction for Figure 1. Record your predictions in the table.

12) Keeping in mind that these are some of the marine terminating outlet glaciers used to make graphs like Figure 1, how certain are you in your predictions? Are you equally certain (or uncertain) for all five of the glaciers? What additional information would be helpful in making predictions?

Glacier	Predicted areal change for 2011 (km^2)
79	
Jakobshavn	
Humboldt	
Zachariae	
Petermann	

Figure 3. Data from NOAA Arctic Report Card 2010



Finally, let's take a look at Figure 3, a 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.

13) Why do you think that the scientists who made this graph provided a "with Petermann" 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?

14) How accurate was your prediction in question 9 if you include the Petermann data?

15) How accurate was your prediction in question 9 if you do not include the Petermann data?

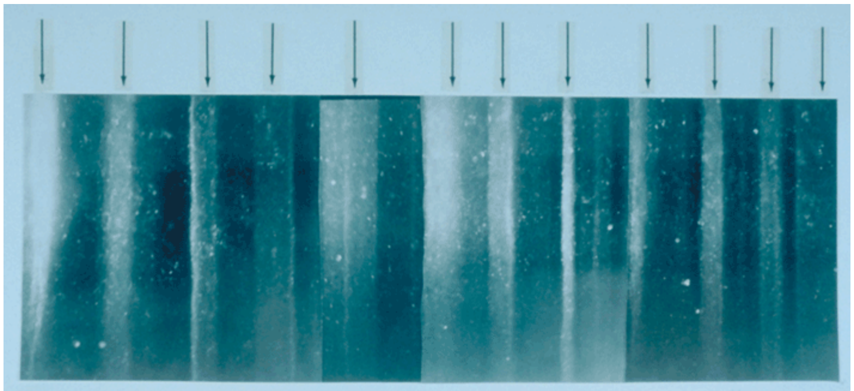
16) On the right are the updated data from 2011 with the area changes for the five glaciers in figure 2. How accurate were the predictions that you made in question 15?

Glacier	**Area change for 2011 (km^2)**
79	+7
Jakobshavn	-9
Humboldt	-20
Zachariae	-19
Petermann	+13

Data from Arctic Report Card 2011

17) 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.

Interpretations:
Reading the Book of Earth



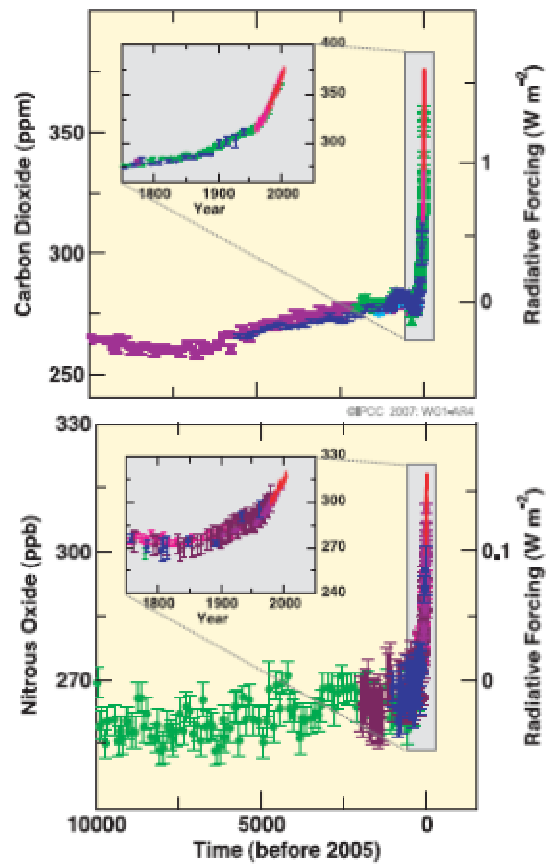
(Above) 19 cm-long section of a GISP2 ice core from 1855 m depth showing annual layers. Summer layers (arrowed) are sandwiched between darker winter layers.
Photo credit: Anthony Gow/USACE/NOAA 2001

To geologists, this planet of ours isn't just a place where wondrous things happen every day. The Earth we study is a dynamic system, constantly producing the environments we all experience while simultaneously writing its autobiography. The layers in sand dunes, glaciers, and lake bottoms are pages of this book.

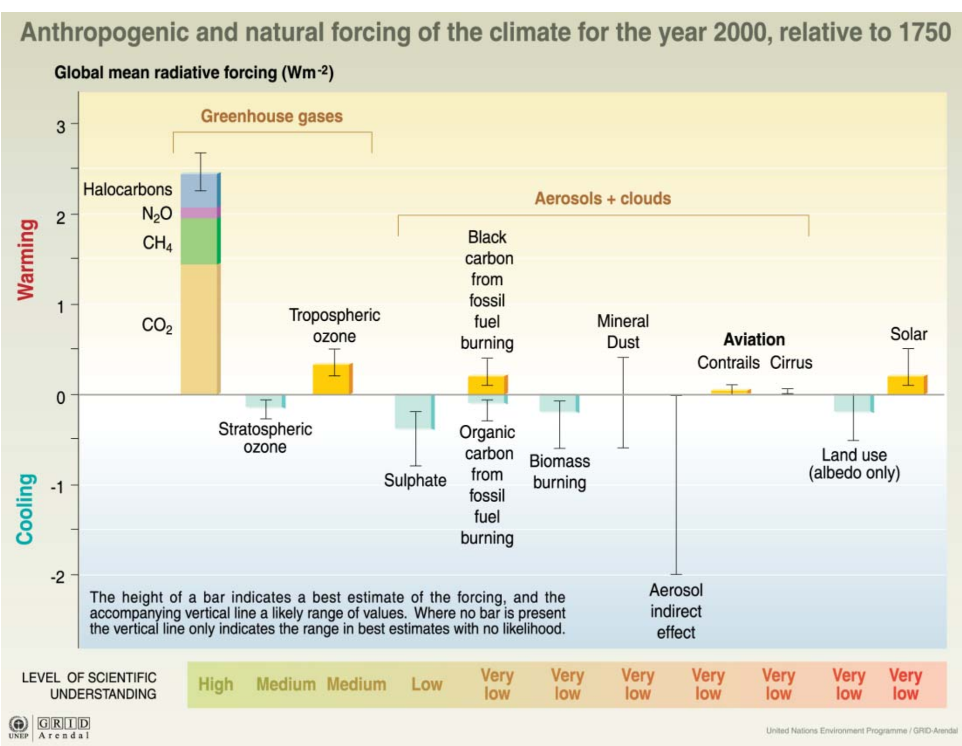
Geologists and climate scientists translate these tomes, so that everyone can learn Earth's story. Just as we read of the world of dinosaurs, the life of the ancient seas, and lush jungles that have turned to deserts, so too do we read of changes in the skies above them. The temperature ranges and precipitation patterns that govern life today were no less important in the past. Glacial ice is a vast repository containing snow that once fell, dust that flew through the air, and bubbles – tiny samples of the ancient atmosphere. The ice core pictured above is just one excerpt from the book, with each layer of ice preserving one year of Earth's story.

Through the course of this activity you will interpret a portion of the book of Earth by

- Graphing and analyzing ice core methane data,
- Calculating the rate of change in modern atmospheric concentration,
- Comparing the radiative forcing of CO_2 and CH_4 quantitatively, and
- Predicting the next chapter in this story and the place of humanity in it.



(Above) Atmospheric concentrations of carbon dioxide and nitrous oxide over the last 10,000 kBP and since 1750 (inset panels). Measurements are shown from ice cores (different colours for different studies) and atmospheric samples (red lines). Corresponding radiative forcings are shown on the right axes.
©IPCC 2007 Summary for Policymakers



(Left) Relative forcing mechanisms of modern climate change.
©UNEP/GRID-Arendal 2005 Vital Climate Change Graphics

1. Open the *case study 5.2 student dataset* using your spreadsheet program.
2. Create a scatterplot (the kind connected with a line) of your data with methane concentration on the y-axis and age on the x-axis. Reverse your x-axis so that 0 years kBP (the present) is on the right.
3. Attach an image or copy of your graph to this assignment.
4. Characterize your graph. What trends do you notice? How does the present differ from the past in terms of atmospheric methane concentration? Be specific.

5. According to your ice core data, when does the most drastic change in atmospheric methane concentration occur? From that date to the present, what is the rate of increase in methane concentration in ppb per year?

6. How does your atmospheric concentration graph for methane compare to those of other greenhouse gases (shown on the first page of the activity)?

7. *Radiative forcing* is a measure of the power that radiation has per unit area of Earth's surface. The greater the radiative power of the atmosphere, the more heat energy it maintains, and the greater the impact (or force) it has on the climate. If CO_2 has a radiative forcing of 1 W/m^2 at 340 ppm and CH_4 has a radiative forcing of 0.1 W/m^2 at 850 ppb, which gas is more powerful? What is the difference in radiative forcing between CO_2 and CH_4 in Wm^{-2}/ppb?

8. How many times greater is the radiative forcing of the more powerful gas?

9. Based on experimental data[*], doubling of the current amount of methane in the atmosphere would result in at least a 0.5°C increase in global average temperature. At the current rate of change, when would the atmosphere reach a doubled concentration? How much hotter would Earth be on average at that time due solely to the doubling of methane in degrees C and F? (1°C = 0.56°F)

10. Given that the current primary sources of atmospheric methane are livestock activity and extraction from natural gas fields and coal seams, do you foresee an increase, decrease, or stability in the rate of change in atmospheric methane? Explain in detail. How will future climate differ according to your prediction?

11. Is it possible to change the future you just predicted? If so, how? If not, how will we have to change to live in this future climate?

[*] Wuebbles, D.J., and Hayhoe, K. (2000). Atmospheric methane: Trends and impacts. In: *Non-CO_2 Greenhouse Gases: Scientific Understanding, Control and Implementation*, J. van Ham et al. (eds.), pp. 425-432. Kluwer Academic Publishers, Netherlands. Available at http://www.atmosresearch.com/NCGG2a%202002.pdf, last accessed 12 Aug 2012.