POLAR I.C.E. (Interactive Climate Education)

WHAT IS HAPPENING TO ANTARCTICA'S PINE ISLAND GLACIER?

Teacher Supporting Information

Use your understanding of glacier science to figure out what is happening to this Glacier!

Teacher Background:

This activity is part of a set of curriculum pieces developed as part of the ICEPod project (http://www.ldeo.columbia.edu/icepod/). ICEPod uses geophysical instruments to collect data on the changing glaciers in the polar regions. Each activity includes science graphics and imagery from published climate science research, data for graphing and interpretation and physical models for further learning and exploration (http://www.ldeo.columbia.edu/polareducation/).

Standards: Students develop an understanding of:

NS.9-12.1 Science as Inquiry

- **Abilities necessary to do scientific inquiry**
- **Understandings about scientific inquiry**

NS.9-12.2 Physical Science

- **Motions and forces**
- **Interactions of energy and matter**

NS.9-12.4 Earth & Space Science

- **Energy in the Earth system**

NS.9-12.5 Science & Technology

- **Science & Technology**

NS.9-12.6 Personal & Social Perspectives

- **Natural and human-induced hazards**
- **Science & technology in local, national and global challenges**

Goal: Students will work with real data from Antarctica's Pine Island Glacier to determine if the glacier is shrinking as a result of a changing climate. Students can then work with 'glacier goo' to develop and test their hypotheses.

Usage: "What is happening to Antarctica's Pine Island Glacier" can be used in its entirety or in sections with each piece standing alone. The powerpoint presentation provides background information for pages 1-8 with teacher notes provided in the 'presenter view'.

- **Student Pages 1-4 - A stand-alone summary of glacial concepts and processes and an introduction to the impact of warming oceans on ocean terminating glaciers;**
- **Student Pages 5-8 - Introduction to satellite laser elevation data for a fast changing glacier in West Antarctica for students to graph and analyze. These two sections can be done as classroom activities or homework.**
- **Student Pages 9-13 - The balance of the activities are labs (materials list included): Pages 9-11 is observation based analysis of glacial processes; Pages 11- 13 focuses on measurement and comparison of the student model to data from Pine Island Glacier.**

Teacher Version: Teacher information is added in red font throughout the attached version.

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Image 1) Glaciers are large expanses of ice, often covering the landscape - Kangerdlugssuaq Glacier, Greenland (Image 1&3 -P. Spector)

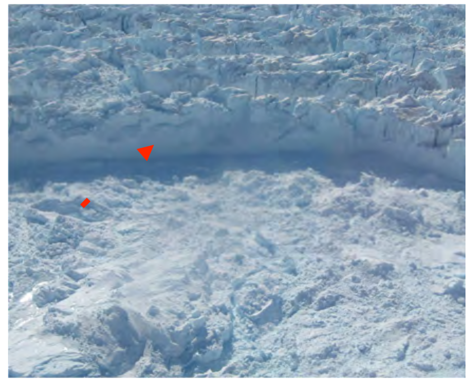


Image 2) Glaciers lose size by calving, breaking off chunks of ice - Jacobshavn Glacier, Greenland (Image - I. Das)

REVIEW OF GLACIER 'BASICS':

Image 3) Kangerdlugssuaq Glacier

HOW DO THEY FORM? Glaciers form in areas where snow stays on the ground all year. Newly fallen snowflakes cover older snowflakes compressing them smaller and denser. Air between is pressed out and over time the snow deepens, crystallizing into large areas of ice (*Image 1*).

HOW DO THEY GROW? When more snow is added (***accumulation***) than is removed (***ablation***) each year glaciers grow. Snow can be added through new snowfall or redistributed snow blown from other areas.

HOW DO THEY MOVE? As glaciers grow from snow *accumulation* they stack higher and higher causing ***gravity*** to tug, pulling them down. Glaciers are called 'rivers of ice' since they move constantly flowing from higher to lower elevation.

HOW DO THEY SHRINK (OR RETREAT)? Glaciers can lose mass *(ablation)* several ways. As they flow from a higher, colder elevation, to a lower, warmer elevation they can experience: *melting* - lower areas are generally warmer; *wind* - wind blowing over the glacier erodes the surface; *sublimation* - ice can turn directly to vapor without moving through the liquid stage; *calving* - chunks of ice break off at the glacier edges (*Image 2)*. They will retreat if there is less snow *accumulation* than *ablation.*

TASK: *Scientists are studying glaciers in the polar regions to see how they are changing. If you were studying the glacier in Image #3, where would you expect* ***accumulation*** *and* ***ablation*** *to occur? Using these words* ***label Image 3 to show your choice****. (labeled in red)*

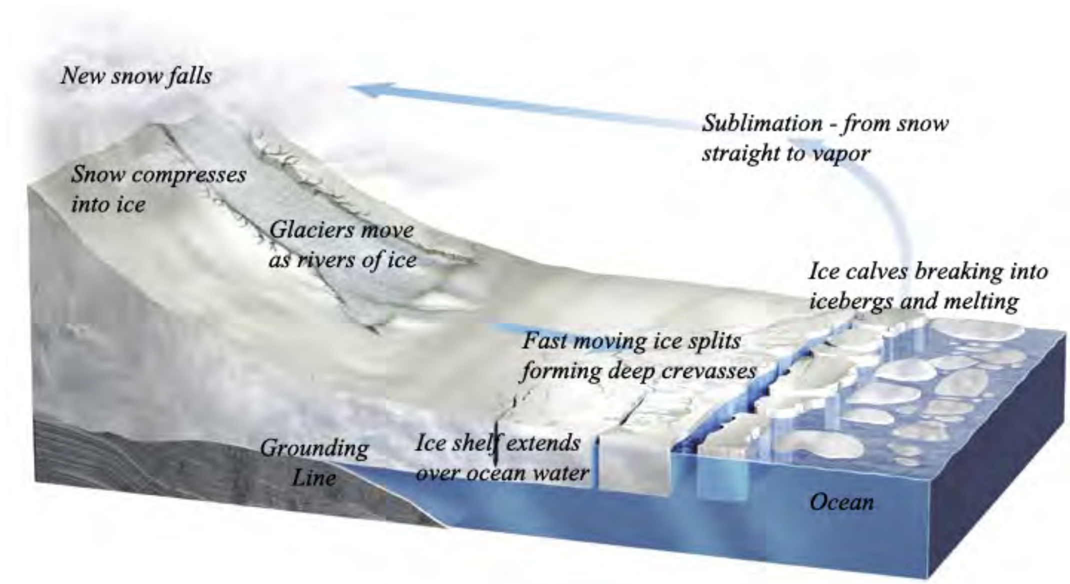


Image 4) A Glacial System. Trace the system counter clockwise starting with 'new snow falls' and accumulates, then compresses into ice and moves to a lower elevation as a river of ice, at the lower elevation it can calve or break off as icebergs, melt into the global ocean, or turn straight to water vapor (edited from R. Bell, The Unquiet Ice, Scientific American, Feb. '08).
(Encourage students to think of what other Earth system this reminds them of. The water cycle should come up. Point out that in the water cycle the largest reservoir is the ocean while in the glacial system it is the glacier holding water on land.)

'Glacier Math' with simple Glacier 'Basic' Equations!

A Balanced Glacier holding steady in size*:* Annual new snow =Annual snow melt (loss)
A Growing or Expanding Glacier*:* Annual new snow > Annual snow melt (loss)
A Glacier Shrinking or Losing Elevation: Annual new snow < Annual snow melt/loss

MEASURING POLAR ICE:

Scientists are measuring the polar ice sheets to determine both ***how fast*** and ***how much*** (total amount) they have changed over the last few years but it isn't easy! Why?

The polar regions are **large**, the **weather is extreme** and there are **few roads** for travel. Much of the ice is not smooth, and huge **crevasses** or deep breaks in the ice (*Image 4*), can appear suddenly in the snow adding to the travel difficulties! One of the most efficient ways scientists have found to collect measurements is from above the Earth's surface using **satellites and aircraft**. These types of measurements are called **'remote sensing'**, which simply means the instruments are not physically touching the objects they are measuring. Much of our understanding of the Earth has come from remote sensing.

TASK: *List three reasons why remote sensing measurements is used in the polar regions:*
Three of the following:

1) The area is very large and hard to reach; 2) *The weather is difficult;* 3) *There are not many roads; 4) The ice surface is hard to travel on with crevasses*

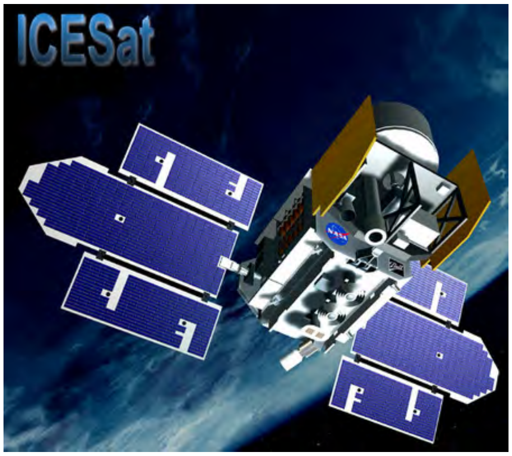


Image 5) NASA ICESat used a laser to measure the ice surface elevation. It's measurements are accurate to ~15 cm (6 inches) of elevation!

Since the 1990s satellites have been collecting information about the Earth. In 2003 NASA launched a satellite to collect ice measurements in the polar-regions (*Image 4*). "Ice, Cloud and Land Elevation Satellite" (ICESat) collected ice surface elevation (height) since a glacier that is dropping in elevation is losing ice. You will be working with ICESat data to determine if the ice surface is changing. ICESat used a laser to measure ice surface elevation. Lasers use the constant speed of light. By sending a light beam to the ice surface travel time is measured and converted to distance.

***TASK:** Why did ICESat measure ice surface?*
If the ice surface drops it tells us the glacier is losing mass.

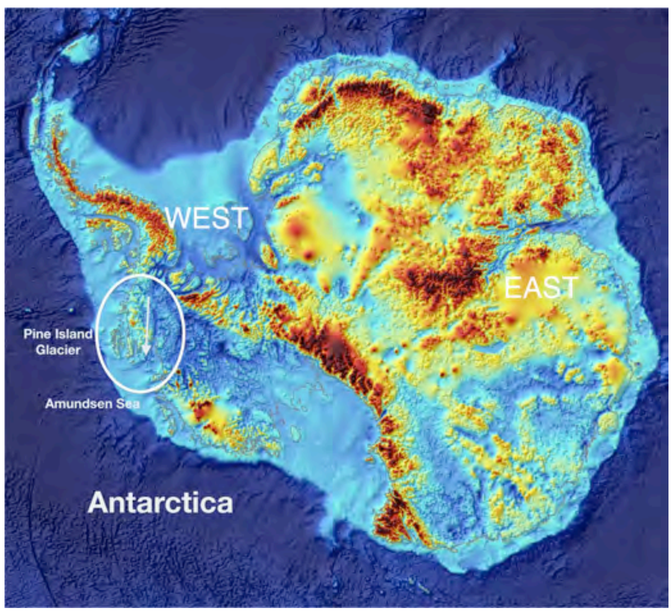
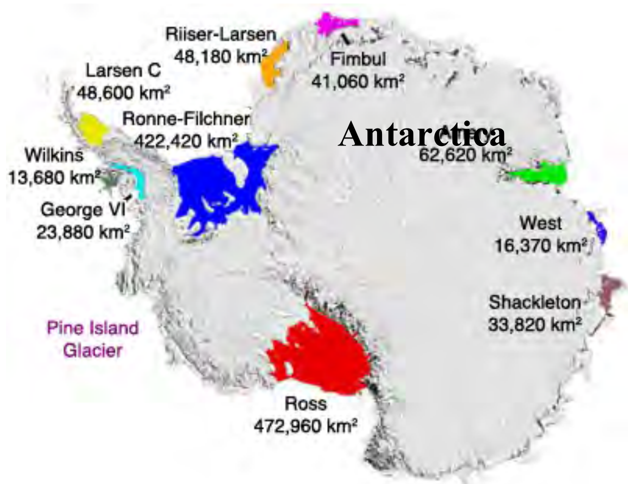


Image 6) Antarctic image showing the land surface with the ice sheet removed. P.I.G. is circled. (Edited from British Antarctic Survey BEDMAP program, 2011)

MEET PINE ISLAND GLACIER (P.I.G.) – ONE OF ANTARCTICA'S FASTEST CHANGING GLACIER!

When ICESat was launched scientists were already interested in P.I.G.**,** and its 'stream' of fast moving ice. Examine the Antarctic map in *Image 6*, locate the circle outlining P.I.G. and the arrow showing the direction of P.I.G.'s ice flow. P.I.G. is considered the largest of 3 major pathways draining ice from the West Antarctic Ice Sheet directly into the Amundsen Sea. Satellite measurements show **it is accelerating**, moving ice at speeds measured at 3.5 km/yr, pushing more ice into the ocean than any other glacier in Antarctica! As more ice from P.I.G. moves into the ocean the glacier surface will lose elevation.



Large ice shelves, like dams, surround much of Antarctica isolating them from the warming ocean. The shelves work like 'construction barricades', blocking the ice and holding it on the land. The larger the ice shelf, the larger the barricade. Once the ice shelves or dams are removed the ice stream behind accelerates, pouring out.

Image 7) Antarctica's Ice Shelves - The large ice shelves in this image are colored and labeled with ice volume (Edited from T. Scambos, National Snow and Ice Data Center)

How are the ice shelves removed? Scientists see evidence that warming ocean water is being forced up around the edges of Antarctica by shifting ocean currents, causing melting and weakening the ends of the ice shelves so they break apart, opening the 'barricades' holding back the ice. The accelerated ice flow causes the ice surface elevation to drop.

Look closely at *Image 7.* Do you see a large ice shelf protecting P.I.G.? That is because P.I.G.'s ice shelf is small, ~ 40 X 20 kms in size, too small to be included in this map.

Task: *Calculate the area of P.I.G.'s ice shelf _800 km^2_.*
How does its size compare to the other ice shelves in Image 7? 20 P.I.G.s would fit into the smallest ice shelf shown on the map – the West Shelf.

Think about what you read above regarding the relationship between ice shelves and glaciers. How do you think the size of the P.I.G. ice shelf might relate to the speed of its glacier? This could be answered a number of ways – a sample answer would be: Yes the size is related. The small PIG ice shelf is unable to provide enough of a barricade or gate to hold the glacier back on the land.

The point of this question is to be sure they understand the role of the ice shelves in stabilizing the glacier. Successful answers should include some mention of this.
Note: a misconception *with some students is that the fastest moving glaciers don't allow ice shelves to form, pushing the ice away. This is the reverse of the actual process.*

PART 1: WORKING WITH ICESat DATA

Activity: Are changes occurring in the elevation (height) of P.I.G.? Scientists have been reviewing satellite data on the surface elevation (height) of the P.I.G. glacier over several years to see if there is a loss of ice. Remember if the height of a glacier drops it shows a loss of ice and a shrinking glacier. If the height increases it means the glacier is growing. Help the scientists determine what is happening!

Image 8) A Satellite image of Pine Island Glacier Flow. The top line shows where the data was collected for this activity. The arrow matches the location arrow on image 6.

Image 8 shows a close up satellite image of P.I.G. The arrow runs along the fast moving ice stream in the center of P.I.G. acting like a conveyor belt to move the ice. The line on the top shows where the data for this activity was collected.

The data: You are working with real data collected over P.I.G. survey line # 279 on three separate dates: **Nov. 2003, April 2007 and Oct. 2007**. We will examine these three sets of data looking for elevation change occurring in the glacier over this four year time period.

What was measured: The data you will work with was collected along a transect, or line, crossing the front of P.I.G. like the solid line on the top of *Image 8* cuts across the glacier front. The elevation (height) is measured for each data point, collected in the same location in different months and years. This will allow us to see if there is a change in elevation. **Orient yourself by labeling** one end of the line on *Image 8* with km # 239 and the other with km # 253.

Students will label each end of the solid line across the top of the glacier with #239 on one end and #253 on the other. It doesn't matter which label is on each end. The goal is to encourage the students to think about where the data in the activity was collected.

P.I.G. 279 – Graphing the Data Part I

The full P.I.G. #279 dataset contains over 600 data points! You will work with a small representative section of the data.

Table # 1: GRAPHING P.I.G. DATA FOR LINE #279

LOCATION RECORDED BY KM	ELEVATION IN METERS NOV. 2003	ELEVATION IN METERS APRIL 2007	ELEVATION IN METERS OCT. 2007
239	746	746	746
240	512	511	511
241	392	389	387
242	343	335	334
243	279	267	264
244	245	229	227
245	293	281	274
246	332	316	312
247	389	374	372
248	480	468	475
249	507	500	497
250	557	545	545
251	573	569	569
252	604	600	600
253	690	687	687

1. **Understanding the Data Chart:**

   - **Column 1 - Location in KM** - Each data point is located by km from a central starting point we will call km 0. We are looking at only a section of the data so we have only data points km #239 through km #253. What is the total distance represented in this transect? 14 km

   - **Columns 2-4 – Dates & Elevation in Meters** – There are 3 columns of elevation data for **P.I.G. 279,** labeled by month and year of collection **11/2003, 4/2007** and **10/2007.** Each of these series of data points measures the ice elevation at the same set of locations for the different time periods. Elevation measurements are listed as meters of ice depth.

2. **Is there a relationship?** When scientists collect more than one 'data series' they look at them together by plotting or graphing them to see if there is a relationship. Plots and graphs can help us to 'see' the data, recognizing patterns and trends. For this data we have the locations by km and the elevation by date so you can plot it on a graph.

3. **Use Graph Paper labeled Graph #1** - Create a graph from **Table #1** that includes **all three sets of data**. First set up the 'X' and 'Y' axes. The 'X' axis will be the distance in km. For your 'Y' axis, locate the highest_746_and lowest_227 elevations over the three years and set up your axis to cover the range you need. To work with the data in excel, you can use the excel files posted at http://www.ldeo.columbia.edu/edu/polareducation/ .

4. **Plot the data** - Select a different color pencil or symbol to plot each of the three sets of data so that they will be easily recognized as a separate line with their own label and color. Be sure to make a graph key. Plot each of the three sets of data connecting the data points within each year with a line.

5. **Examine your chart –** Look to see if there is a story in the data displayed. Do you see differences between the three years of elevation data or does it appear that the ice surface has been fairly stable? Describe.

   From the charted data it seems as if the ice surface has been fairly stable over the 4 years of collection – all the years seem almost the same. Some students might note that the data shows a loss of ice at most data points, and especially at km #244. This doesn't answer the question, instead it describes the overall dip in the data for all 4 years, not a difference between years.

   This is an opportunity to bring up the challenge of displaying what might be a few meters of elevation change over a 14 km distance. Discuss vertical exaggeration in data display.

6. **Look at change -** We are interested in ***change*** in the height of the snow that occurred **for each data point** from 2003-2007. Let's try a new approach to looking at the data, focusing on how much change has occurred at each data point from the first collection date of __October 2003.

P.I.G. 279 – Graphing the data Part II

Table #2: GRAPHING CHANGES IN P.I.G. DATA FOR LINE #279

LOCATION RECORDED BY KM	ELEVATION IN METERS NOV. 2003	ELEVATION IN METERS APRIL 2007	ELEVATION IN METERS OCT. 2007	DELTA (Δ) IN METERS NOV. 2003 TO APRIL 2007	DELTA (Δ) IN METERS NOV. 2003 TO OCT. 2007
239	746	746	746	0	0
240	512	511	511	-1	-1
241	392	389	387	-3	-5
242	343	335	334	-8	-9
243	279	267	264	-12	-15
244	245	229	227	-16	-18
245	293	281	274	-12	-19
246	332	316	312	-16	-20
247	389	374	372	-15	-17
248	480	468	475	-12	-5
249	507	500	497	-7	-10
250	557	545	545	-12	-12
251	573	569	569	-4	-4
252	604	600	600	-4	-4
253	690	687	687	-3	-3

Use Nov. 2003 as a baseline and compare against the 2007 data sets for changes in elevation. Comparing the data sets focuses on the 'difference' from 2003, showing how P.I.G.'s elevation changed over time. **Look at Table #2** and the newly added columns outlined with dashes to see what each one represents.

7. **Delta means change**. The two new columns show **change in elevation from the 2003** for each of the 2007 measurements. For example at km 240 the April 07 reading of 511 is 1 ***below*** the Nov. 2003 reading of 512 so the amount listed is -1. If the 2007 number is ***below*** 2003 it will be a negative number. The first two rows are completed for you. Complete the rest of the graph, paying attention to negative versus positive numbers.
(see completed graph above)

8. **What will the numbers mean?** Before you start charting, visualize the glacier. Think about what a positive 'Delta' number or a negative 'Delta' number would mean.
Which would mean LESS ice, a shrinking glacier negative #
Which would mean MORE ice, a growing glacier? positive #

9. **Chart the change (Δ) on the sheet marked Graph #2, OR use the attached excel file.** Work with the new columns to show change (Δ) from 2003 to 2007. Your 'X' axis has not changed. The 'Y' axis will be "Change (Δ) in Elevation" from 2003.
What is the highest 0 and lowest -20 (Δ) listed?

Set up your axis to cover this range. Consider the negative numbers. Starting high up on the graph draw a line across for Zero and label it 2003 to represent your baseline. Use the same graph key you used in Part I, and remember each set of data will be a separate line with its own label and color/symbol.

10. **Examine your graph. What can you see in the data**? Comparing the elevation data from Nov. 03 to the data from April 2007 and then to Oct. 2007, explain what is happening to P.I.G.? Be sure to note dates and elevations in your answer.

Students should compare the graphs for the April and October 2007 to Nov. 2003 and note that at almost each data point there has been a loss of ice in many meters. Students may note the specific km where the most significant elevation changes occur.

Note: Students might mention that April is a different season than October and November so you would expect differences. (In Antarctica April is considered winter and Oct/Nov are considered the very beginning of summer warming). Looking at the data you will see that snow elevation levels do go down between April and Oct. 2007 and some of this could be due to the changing season. However the take home point is that there are losses in snow elevation between the Oct. 2007 early summer period and the April 2007 deep winter period. Likewise there are losses in elevation between the October 2003 period and the comparable seasonal readings in November 2007, both show a trend of loss over time.

Again this is a good opportunity to revisit how to display 0-20 meters of data variance over a 14 km distance, and to debrief in general on the strategy to graph the delta.

11. **Just how much change is this?** P.I.G. is located in an area of West Antarctica where frequent storms result in ~ 1 meter of snowfall annually. Look back at the data, do you feel it shows a significant change in elevation? _yes_
Explain your answer__Over a 4 year period the data shows the glacier lost up to 20 meters of ice, this is an average of 5 meters a year. Compared to a gain of 1 meter annually, this is significant.

12. **What does this data tell us about the P.I.G. glacier?** Think back to what was discussed as causes for changing elevation in in glaciers. List at least one thing you think could be contributing to change in P.I.G.?
Any of these: warming ocean water around the PIG ice shelf is melting the edges and causing accelerated ice flow, less accumulation of snow annually, more ablation annually.

13. The term "Canary in the coal mine" means to be sensitive enough to serve as an early warning by showing evidence of impact before other areas might see the effects. Early miners used canaries to show if there were ventilation problems in the mines. If the canary died they knew the mine was unsafe, and they would evacuate. In our activity we questioned if P.I.G. was the 'climate' canary. What do you think is P.I.G. a 'climate' canary? Expect students will say 'yes' Explain your answer P.I.G. was noted as one of the fastest moving glaciers in West Antarctica suggesting that it is showing early impacts of climate warming; the ice shelf is a small; it is losing ice elevation at a significant rate – all these suggest it is a climate canary.

A misconception some students might have is that 20 meters of loss is insignificant compared to the 746 meters of ice elevation. This is an issue of temporal scale – the 746 meters of ice is an accumulation of millions of years of snow compared to the loss of 20 meters in just 4 years.

14. **We have looked at one transect of P.I.G. data**, representing one small segment of the glacier, however scientists would want to look at more than one data set. Why would this be important?
It is important to verify your data by collecting information from several locations or several different sets of instruments to be sure that the trends the data are showing are represented beyond just this set of data, or specific area.

15. **Line 362 is posted at** http://www.ldeo.columbia.edu/edu/polareducation/. This is a second set of P.I.G. data that you can work with if you would like to do a further comparison.

Lab Part III

In Part III you will work with a physical model to explore what causes glacier elevation to change. Using the scientific method you will:

1. **Construct a hypothesis**
2. **Test it by doing an experiment**
3. **Analyze your data**
4. **Draw a conclusion**
5. **Communicate your results**

Lab Part IV

In Part IV you will collect and compare measurements on elevation and velocity on your glacier and compare these to measurements from P.I.G.

PART III: HANDS ON LAB -
USE GLACIER GOO TO DEVELOP A MODEL TO SUPPORT THE DATA

(For this section students work in a team of 2-4. Each student needs a work sheet)


Image 9) Supplies used in lab

SUPPLIES: Set up needed for each team:

- Batch of Glacier Goo (recipe attached)
- Small Rectangular container (we used plastic box ~13" x 7-1/2" x 4-1/4" h)
- Section of matboard cut to fit **snuggly** in container to form a ‘ramp’ for glacier goo
- Attached graph measuring paper with 10cm line – cut to fit & laminate/plastic sleeve
- Dry erase marker
- Stop watch
- Calculator
- 6 inch ruler with centimeter measurements

Optional Supplies - Tape, Plastic knife

LAB ACTIVITY:

SET UP: done in advance by the teacher or by the students with supervision.

- Tape a copy of the laminated gridded graph paper to the ramp surface
- Set the matboard ramp in your container with one end resting on the upper rim and one end resting in the bottom creating a ramp for glacier (goo)
- Make sure the team has the full list of supplies

Start with A Glacier Review: You will be using glacier goo as a model for polar glaciers. Before you start let’s review, answering the following questions in full sentences:

1. Thinking back to the ‘Glacier Basics’, are glaciers rigid blocks of ice? Explain.
   No, glaciers are rivers of ice, flowing under their own weight
2. What is needed for a glacier to maintain a steady size and surface elevation (height)? Remember the glacier basics equations.
   annual snow = annual melt.

3. Could a change in ***ablation*** cause a change in the elevation of the glacier? Explain.
   Yes, if there is more ablation the elevation of the glacier will drop, but if there is less ablation the glacier elevation will increase.

4. Recall the data you graphed for P.I.G. Write a hypothesis to explain the cause of the changes in P.I.G.
   Hypotheses will vary but should include a reference to either less snow, or more melt occurring in P.I.G. in 2007 than 2003, or P.I.G.’s small ice shelf allowing the glacier speed to increase.

   Compare your hypothesis with your class then work with your lab team, using your model to test this hypothesis.

ACTIVITY: TEST YOUR HYPOTHESIS

Image 10) Side view of glacier set up

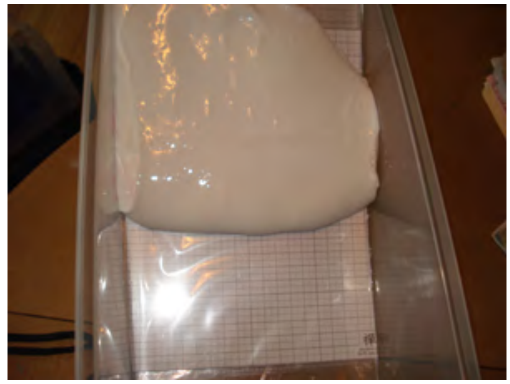


Image 11) Top view of glacier set up

1. **What makes glaciers move in nature?** ___gravity______
Mound your glacier (goo) on the top of the ramp. Release and describe your glacier (goo) movement: _____The glacier flows under its own weight/gravity_______

   How is the glacier goo like a real glacier? both flow under their own weight/gravity

   Establishing Baseline: Set aside 1/3 of your glacier goo. Place the remaining goo at the top of the ramp so that the bottom edge ('toe') lines up with the top 10 cm line on your graph paper. Insert your ruler into the glacier just above the toe to measure elevation (height). Record elevation_______. Now you have 'baseline'. Start each of the following '***Runs #1, 2, 3'*** from this baseline to test elevation changes with changing conditions.

2. **Ablation Run #1:** Begin at baseline. Release your glacier (goo). Time and observe for 2 minutes. Measure your glacier using your ruler as a 'glacial ablation stake' to check for ablation (elevation loss) at the 10 cm start line. Were there elevation changes?___
Does this match one of the glacier equations on ***Glacier Basics* on page 2**?
Glacier retreat/shrinking_- Annual new snow < Annual snow melt _

3. **Steady Run #2:** Begin at baseline. As the glacier flows add small bits of your remaining glacier (goo) to the glacier surface as 'new snow' every 20 seconds. Compare elevations in run #2 to run #1? Run # 2 should maintain its elevation with the regular addition of snow
Does this match one of the glacier equations from ***Glacier Basics* on page 2**? ____
Balanced/Steady State Glacier: Annual new snow =Annual snow melt

4. **Ice Shelf Run #3.** What if the ice shelf in front of our glacier were to melt from warming ocean water? Begin at baseline and place your ruler in front of the glacier as a shelf to hold it in place for 1 minute. Ice will continue to flow over it. Remove your ice shelf (ruler) and observe. Does the glacier behavior change once the ice shelf is removed? Describe what happened, and if it relates to what you know about a real glacier.
The glacier may flow over the ruler (ice shelf) when it is holding back the glacier and as soon as it is released the glacier surges forward down the ramp.

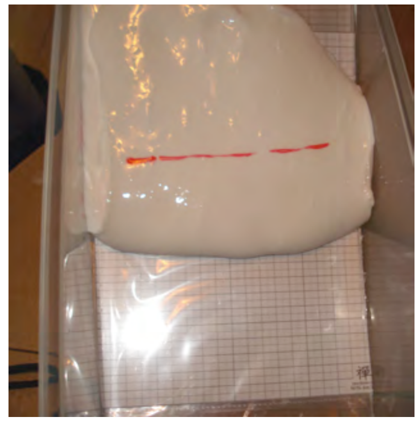
5. **Compare to Your Hypothesis**. Does the behavior of this model glacier support your hypothesis? Explain. Answers will vary

6. What other data would be useful to further test your original hypothesis, or a new hypothesis? Answers will vary

7. **Design your own run**. Design your own experiment using glacier goo. Describe the conditions and the results. Be sure to note how it relates to a real glacier. _ Answers will vary. Teacher may wish to make additional materials available to the students such as the ability to heat or cool the goo, oil to lubricate under the glacier surface etc.

PART IV: COLLECTING MEASUREMENTS & COMPARING TO P.I.G.

P.I.G.



GLACIER GOO

How does your glacier match up to P.I.G.? You will collect measurements on the **elevation** and **velocity** of your glacier, and see how your glacier compares to P.I.G.!

Elevation Change:

1. Let's collect some measurements to see how your glacier elevation matches up to the P.I.G. glacier. You will use your stopwatch to measure how long it takes the glacier to lose 1 cm of elevation. Return to baseline, and mark a line on the outside of the container both at surface level and 1 cm below the surface *(Images 12 and 13)*. Release the goo and start your stopwatch! Stop the watch when the glacier has dropped to the 1 cm line marked on the container. (Report in seconds)
   (Note – glacier goo can stick to the container wall if it spreads to the edge – use your knife to carefully clear this so you get an accurate time for your 1 cm elevation change. Be careful not to push down on the surface and change the elevation!)

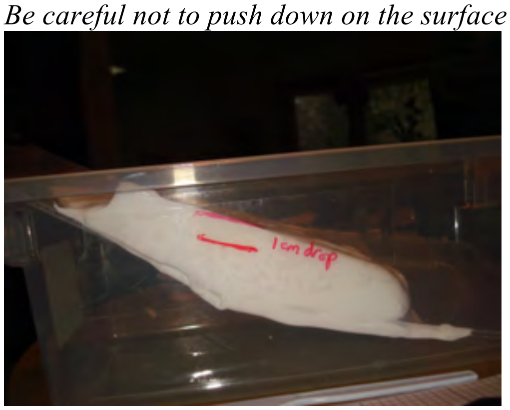


Image 12) Mark up surface and 1 cm drop

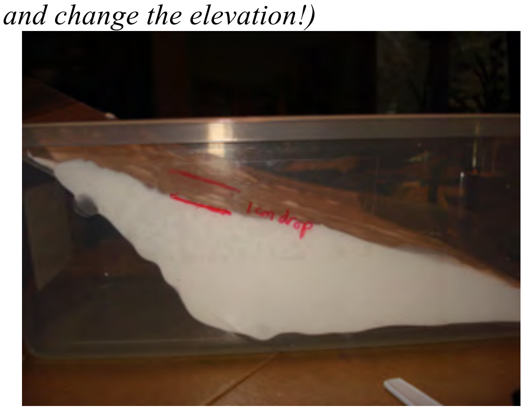


Image 13) Time goo as it drops 1 cm

Repeat 2 other times, or pool class results for an average.

Times will vary ______ ___________ ___________ __________

Time 1 Time 2 Time 3 Average

The average elevation change you calculated is:
1cm/_____secs

Round this to the nearest minute before comparing to P.I.G.
1 cm/_____ mins.
Place your answer in the Glacier Goo results box below.

2. **Compare your glacier elevation changes to P.I.G.** How long did it take P.I.G. to lose 1 cm in elevation? Use the timeframe of 2003-2007 rounding to 4 years. Use two '**DELTA (** Δ)' columns on the chart on **page 7** for elevation change. Find the row that shows the largest drop in meters and write it in the blank below (you don't need the negative sign).

P.I.G. dropped _20_ meters/ 4 years

Divide for __5__ meters/1 year

To better compare the two sets of measures convert the meters to cm

_5_ meters X 100 cm = _500_cm/ 1 year

365 days in a year = _500_ cm/_365 days

To determine how long it takes P.I.G. to drop 1 cm divide 365 days by the number of cms. Place you answer in the results box.

RESULTS

P.I.G. 1 cms/ 0.73 days	Glacier Goo 1cm/____ mins.

Think Scale - P.I.G. is dropping by cms/day while your glacier is dropping by cms/mins.
How does your changing elevation compare to that of P.I.G.?
Thinking of the sizes of the two systems (P.I.G. versus our experiment in a box) the two are much different in size and scope – but the student model is a representation that mimics what is going on with the glacier. The processes students explored are the same.

What if P.I.G. was made out of glacier goo, how would that affect its elevation loss?__
Assuming the glacier goo is flowing faster than P.I.G. it would increase its elevation loss

Velocity:

3. Now examine the velocity (rate of flow). Using a stopwatch you are going to measure the velocity of your glacier & then compare it to the velocity of P.I.G.
In its fastest flowing sections P.I.G. has been measured at **~3.5 km/yr or 9.6 m/day** (this is ~31ft/day!) Let's see what your glacier goo can do!

What is your Velocity? **Velocity = Distance/Time**

Your graph paper is marked to show 10 cms of distance. This will be your distance (D). Return to baseline. Use your stopwatch to time the glacier flow on the 10 cm section on your grid. Start the stopwatch as soon as the toe of the glacier touches the top of the marked square and stop timing as soon as it touches the bottom of the marked square. Record the time below. Repeat twice more, or pool class results to get an average (**round to the nearest minute**).
Answers will vary____ __________________ __________________ ____________

Time #1	Time #2	Time #3	Average Time

Velocity (V = D/T) **V** = 10cm/_____min

4. **How does that compare to P.I.G.'s velocity**? We know how many meters P.I.G. can travel in a day so convert your glacier velocity into meters. This is easy to do since you measured 10cms so multiplying both sides of your equation by 10.

   V = 1meter/(#___ mins. X 10) OR _____minutes* (* insert this number wherever you see this symbol below)

   Your glacier needs * ____minutes to travel 1m

   So how far will it go in a day? There are 1440 minutes in a **day**. Divide by your minutes 1440mins/*_______(your minutes starred above) to get ______m/day

   RESULTS

Glacier Goo V =____m/days	P.I.G. V = 9.6 m/day

   How does the velocity of your glacier goo compare to P.I.G.? ___________________ __________ Each student glacier will vary ____________________________

5. Glacier goo is not the same as a real glacier but it can help us learn about real glaciers. What are three things you have learned about P.I.G. working with your own glacier model, be sure at least one mentions a connection to climate.
   Answers will vary but could include things like:
   - A loss in elevation of a glacier means it is losing mass
   - Antarctica has many ice shelves
   - Ice Shelves help protect the glaciers from the warming ocean water
   - As sections of the ice shelf of a glacier melt or break off the glacier accelerates
   - Any of the glacier equations