Name________________________ Date______________________________

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

WHAT IS HAPPENING TO ANTARCTICA'S PINE ISLAND GLACIER?

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

INTRODUCTION: Scientists tell us that glaciers in the polar-regions are shrinking, but how do they know this and what might be causing this change? You will examine measurements from Antarctica's Pine Island Glacier (P.I.G.) to see if you detect changes over the four-year sample period & develop a physical model to explain what is happening to P.I.G., and how this connects to climate. What do you think, is P.I.G. a climate 'canary'?

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****.*

Name________________________ Date______________________________

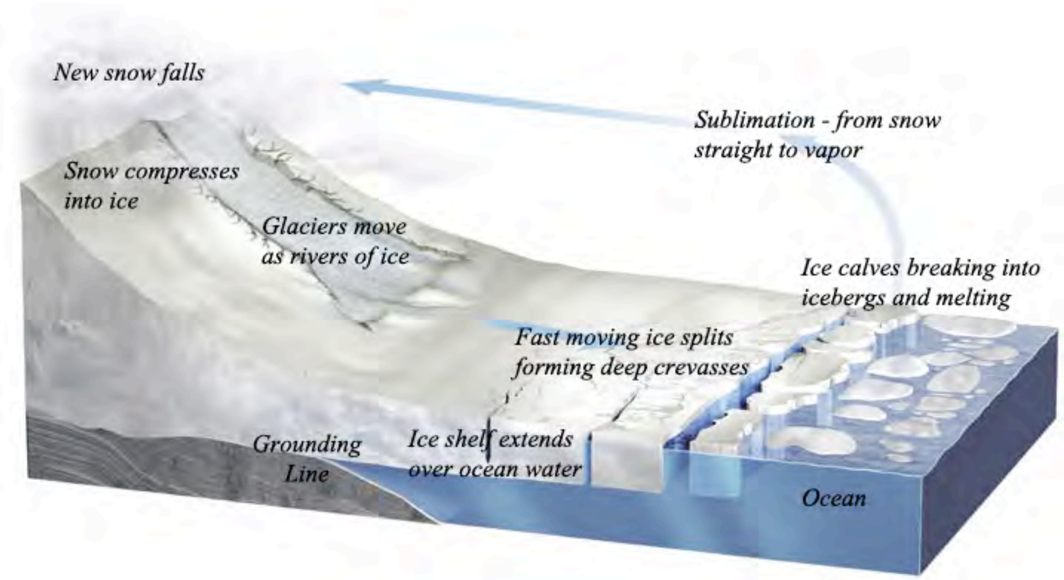


Image 4) A Glacial System. Trace the system counter clockwise starting with 'new snow falls' and accumulates, then compresses into ice and moves to a lower elevation as a river of ice, at the lower elevation it can calve or break off as icebergs, melt into the global ocean, or turn straight to water vapor (edited from R. Bell, The Unquiet Ice, Scientific American, Feb. '08).

'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:*
1) ____

2) ____

3) ____

Name________________________ Date______________________________

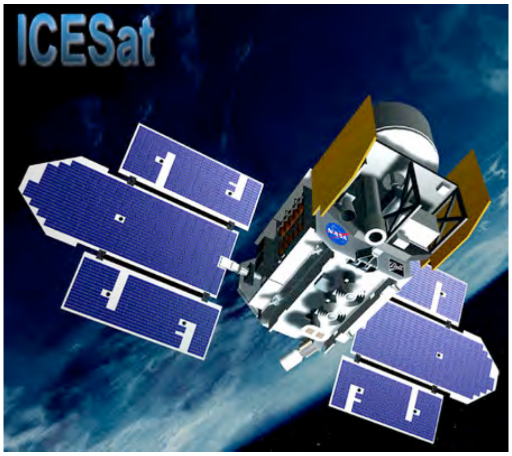


Image 5) NASA ICESat used a laser to measure the ice surface elevation. It's measurements are accurate to ~15 cm (6 inches) of elevation!

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?*

____

____

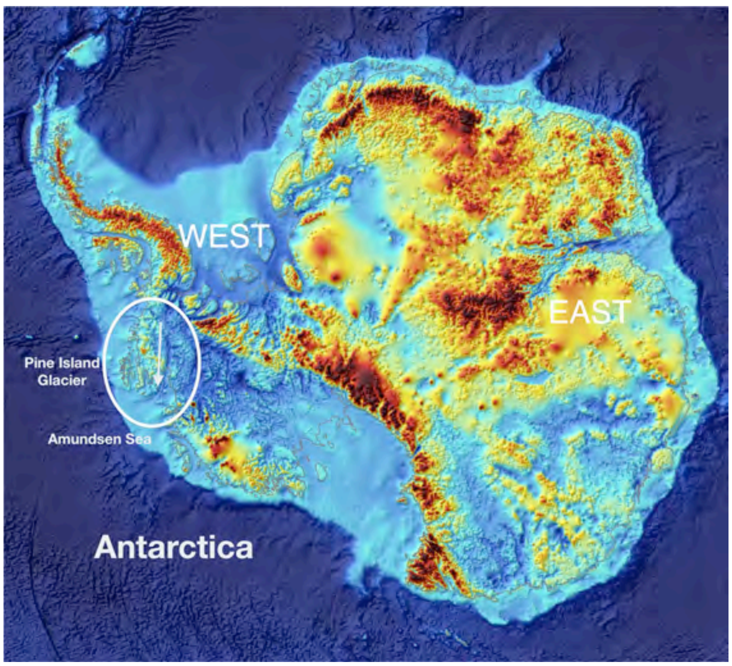


Image 6) Antarctic image showing the land surface with the ice sheet removed. P.I.G. is circled. (Edited from British Antarctic Survey BEDMAP program, 2011)

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.

Name________________________   Date______________________________

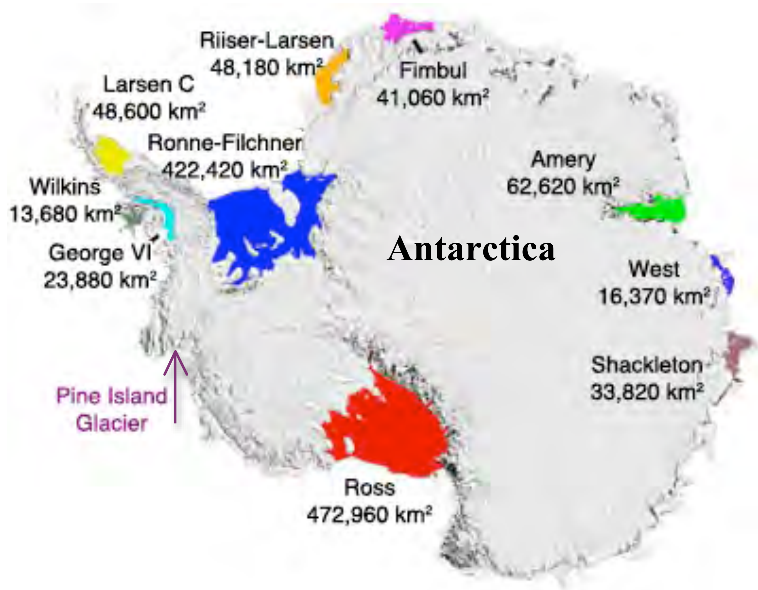


Image 7) Antarctica's Ice Shelves - The large ice shelves in this image are colored and labeled with ice volume (Edited from T. Scambos, National Snow and Ice Data Center)

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.

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* _________.

How does its size compare to the other ice shelves in Image 7?

____

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?

____

____

Name________________________ Date______________________________

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.

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

Name________________________ Date______________________________

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?________

   - **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_____ and lowest____ 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.

   ____

   ____

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 ________.

Name________________________ Date______________________________

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	
242	343	335	334		
243	279	267	264		-15
244	245	229	227	-16	-18
245	293	281	274	-12	
246	332	316	312	-16	
247	389	374	372		-17
248	480	468	475	-12	
249	507	500	497	-7	-10
250	557	545	545	-12	
251	573	569	569	-4	
252	604	600	600		-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.

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______
Which would mean MORE ice, a growing glacier? ______

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_____ and lowest____ (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.

____

____

Name________________________   Date_______________________________

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? _______
Explain your answer____
____

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.?
____
____

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?___________ Explain your answer____
____

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?
____
____

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.

Name________________________ Date_______________________________

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.
____
____

2. What is needed for a glacier to maintain a steady size and surface elevation (height)? Remember the glacier basics equations.
____
____

3. Could a change in ***ablation*** cause a change in the elevation of the glacier? Explain.
____
____

4. Recall the data you graphed for P.I.G. Write a hypothesis to explain the cause of the changes in P.I.G.
____
____

Compare your hypothesis with your class. Now use your model to test this hypothesis.

Name________________________ Date______________________________

ACTIVITY: TEST YOUR HYPOTHESIS

Image 10) Side view of glacier set up

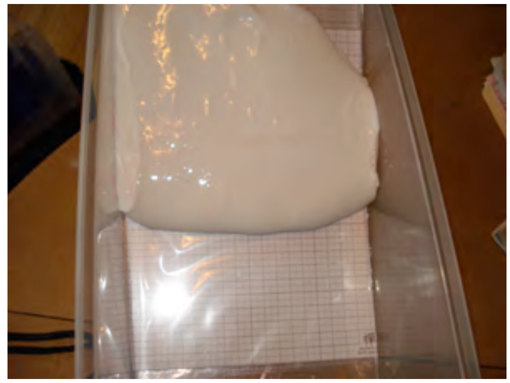


Image 11) Top view of glacier set up

1. **What makes glaciers move in nature?** ____________________
   Mound your glacier (goo) on the top of the ramp. Release and describe your glacier (goo) movement:
   ____

   How is the glacier goo like a real glacier?
   ____

2. **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.

3. **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**?
   ____

4. **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? __________________
   Does this match one of the glacier equations from ***Glacier Basics*** **on page 2**?
   ____

5. **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.
   ____

6. **Compare to Your Hypothesis**. Does the behavior of this model glacier support your hypothesis? Explain.
   ____

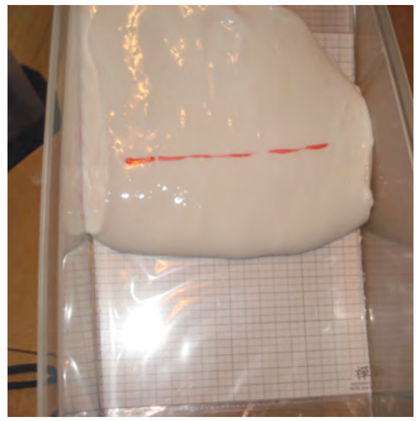
Name________________________ Date______________________________

7. What other data would be useful to further test your original hypothesis, or a new hypothesis?
____

8. **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.
____
____
____

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!)

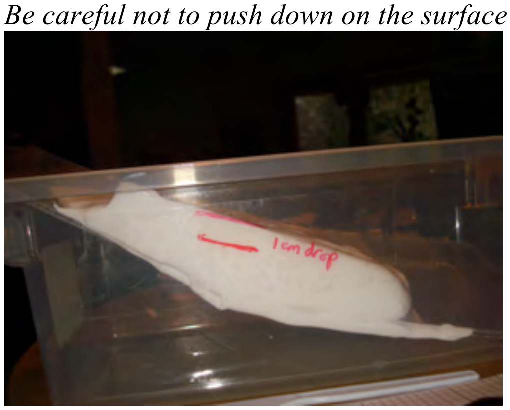


Image 12) Mark up surface and 1 cm drop

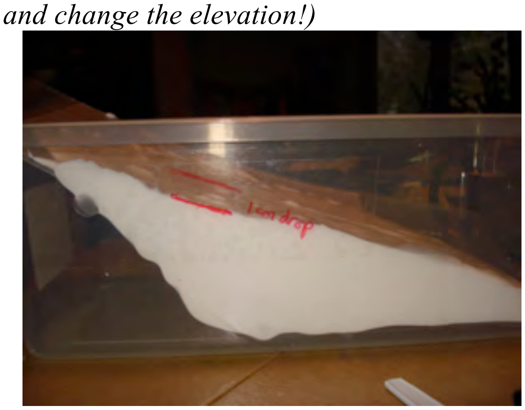


Image 13) Time goo as it drops 1 cm

Name________________________ Date______________________________

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

_______________	_________________	_______________	_________________
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 _____ meters/ 4 years

   Divide for _____ meters/1 year

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

   ____ meters X 100 cm = _____cm/ 1 year

   365 days in a year = ______ 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/_____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.? ____________________
____?
What if P.I.G. was made out of glacier goo, how would that affect 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.

Name________________________   Date______________________________

Record the time below. Repeat twice more, or pool class results to get an average (**round to the nearest minute**).

________________ ________________ ________________ ____________

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.? ___________________

____

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.

   ____

   ____

   ____

PINE ISLAND GLACIER LINE #279

GRAPH #1 Name ________________

GLACIER ELEVATION (HEIGHT) IN METERS (M)

DISTANCE IN KILOMETERS (KM)

PINE ISLAND GLACIER LINE #279

GRAPH #2 Name________________

CHANGE IN ELEVATION - METERS (M)

DISTANCE - KILOMETERS (KM)

10 cms start here

10 cms stop here

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

GLACIER GOO

For Use in Modeling Glaciers

Mix#1:
One 20 oz cup
1 stirring stick
3/4 cup warm water
1 cup Elmers white glue

Mix#2:
one 8 oz cup
1/2 cup warm water
one stirring stick (for the 8 oz cup)
2 tsp. Borax powder
1 qt plastic zip lock bag

****

Mix # 1:
In the large cup, add 3/4 cup warm water and 1 cup glue. Stir until well mixed.
Mix # 2:
In the smaller cup, measure 1/2 cup warm water. Add 2 tsp. of Borax powder.
Stir
until the powder is dissolved.
Pour Mix 2 (the powder mix) into the glue mix. Stir until a glob forms and most of the water is mixed in. This happens quickly! Knead and work the mix for 2 – 3 minutes. Most, if not all, of the water will be incorporated into the mixture.
Place the glacier goo in the zip lock bag.
The mixture will store for a few months.