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: Glaciers are key to Earth's climate system, reflecting the Sun's energy back into space as they cool the air above them. Scientists tell us that glaciers are shrinking. What is the evidence for this and what might be causing these changes? Examine measurements from Antarctica's Pine Island Glacier (P.I.G.) to detect any change over a four-year sample period. What is happening to P.I.G.? How might this connect to climate? What do you think, is this an early warning of a larger problem? 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)

AN EARTH PROCESS - GLACIER 'BASICS':

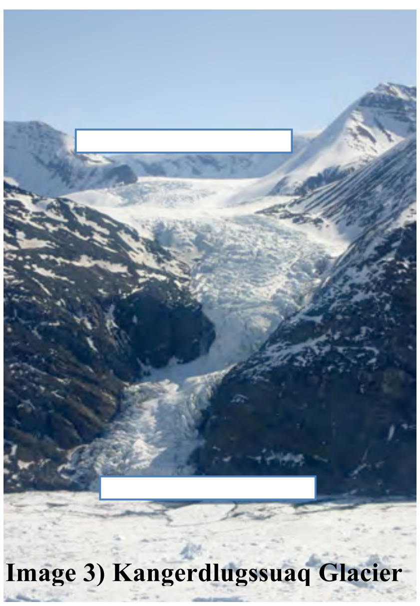

Image 3) Kangerdlugssuaq Glacier

HOW DO GLACIERS 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 GLACIERS GROW? When more snow is added than is removed each year glaciers grow. Adding snow is called ***accumulation*** and occurs from new snowfall or redistributing snow blown from other areas.

HOW DO GLACIERS MOVE? As they 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 GLACIERS SHRINK (OR RETREAT)? Glaciers lose mass, called ***ablation***, several ways. *Wind* - wind blowing over the glacier erodes the surface; *sublimation* - ice can turn directly to vapor without moving through the liquid stage; *melting* - as they flow from a higher colder elevation to a lower warmer elevation they can warm and melt surface ice; *calving* – the breaking off of chunks of at the glacier edges (*Image 2)*. They will shrink or 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****.*

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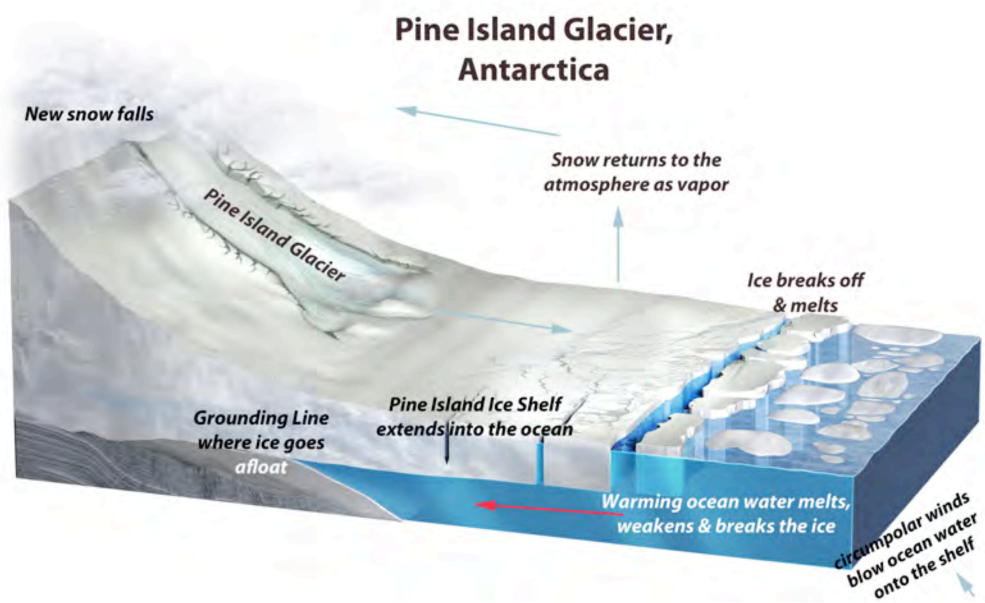

Image 4) A Glacial System. Trace the system counter clockwise starting with 'new snow falls' and accumulates, then compresses into ice and moves to a lower elevation as a river of ice, at the lower elevation it can calve or break off as icebergs, melt into the global ocean, or turn straight to water 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

HOW DO SCIENTISTS MEASURE POLAR ICE?

Scientists use these glacial equations when they measure the polar ice sheets to determine if they are changing. They have been measuring both ***how fast*** and ***how much*** (total amount) they have changed for many 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: *Give three reasons why remote sensing measurements are used in the polar regions:*
1) ____

2) ____

3) ____

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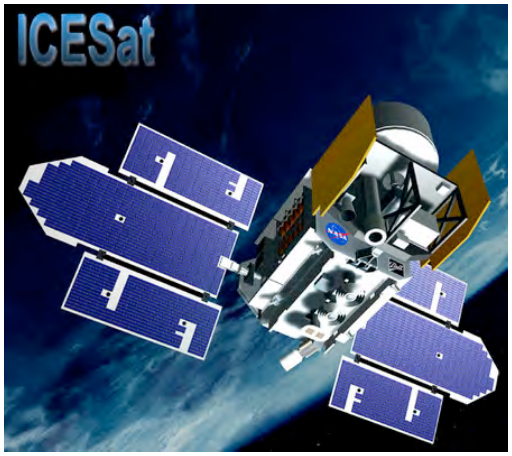

Image 5) NASA ICESat used a laser to measure the ice surface elevation. It's measurements are accurate to ~14 cm (6 inches) of elevation!

Scientists use satellites to collect information about the Earth. Since the 1990s satellites have been key contributors to our science information. In 2003 NASA launched 'Ice, Cloud and Land Elevation Satellite' (ICESat) to collect ice measurements in the polar-regions (*Image 4*). Measurements included ice surface elevation (height) since a glacier dropping in elevation is losing ice. ICESat used a laser to measure ice surface elevation. Sending a light beam to the ice surface lasers use the constant speed of light multiplied by the travel time to measure distance. You will work with ICESat data to measure if the ice surface is changing.

TASK: *Why do scientists measure ice surface?*

____

____

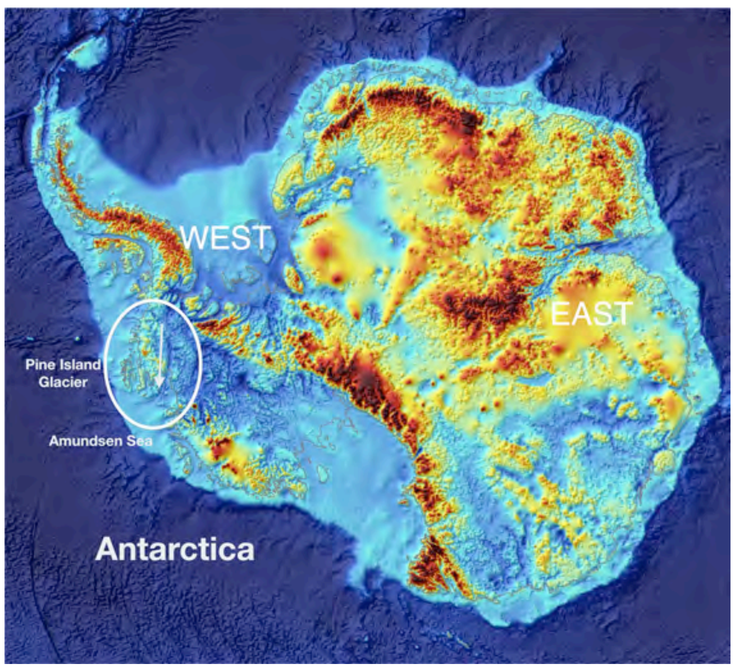

Image 6) Antarctic image showing the land surface with the ice sheet removed. P.I.G. is circled. (Edited from British Antarctic Survey BEDMAP program, 2011)

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 'ice-stream' of fast moving ice. Examine the Antarctic map in *Image 6* locating 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.

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CONSIDER THE EVIDENCE: ICESat DATA FROM P.I.G.

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 the glacier is growing. What is happening to P.I.G.?

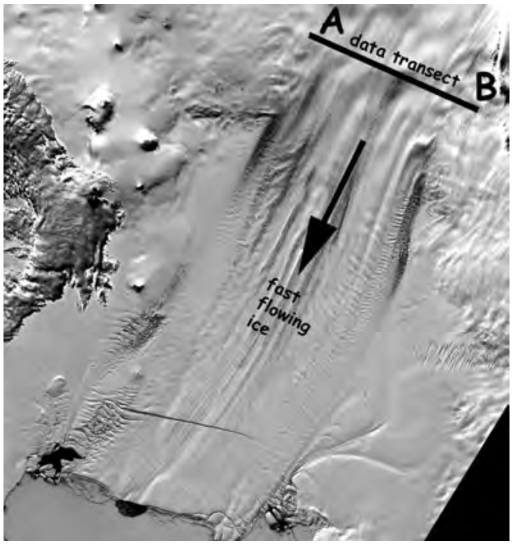

Image 7) A Satellite image of Pine Island Glacier Flow. The top line shows where the data was collected for this activity. The arrow matches the location arrow on image 6.

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 any elevation change in the glacier over this four year time period.

Image 7 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 data you will work with was collected along a transect, or line, crossing P.I.G. like the solid line A-B on the top of *Image 7* cuts across the glacier front.

What was measured: 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 7* with km # 239 and the other with km # 253.

P.I.G. 279 – Examine the Data Part I

The full P.I.G. #279 dataset contains over 600 data points! Below is a small representative section of the data.

Table # 1: 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

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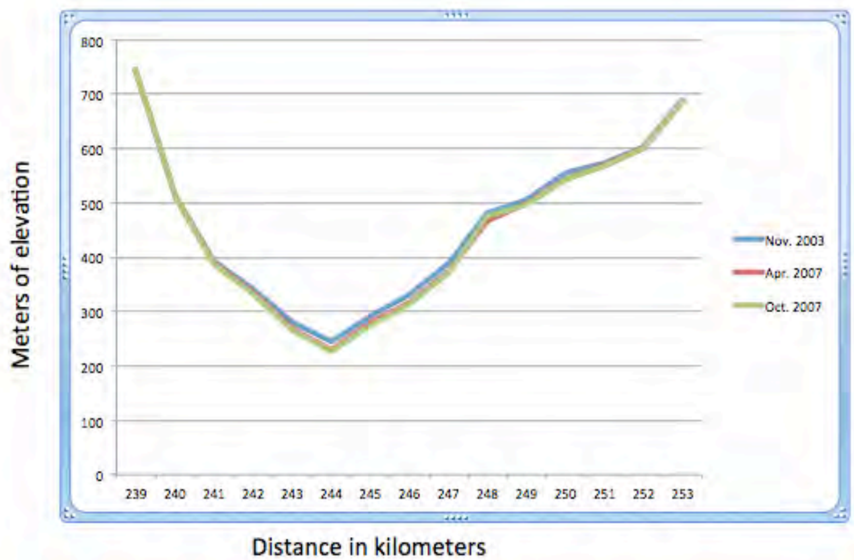
1. **Understanding the Data Chart:**
   - **Column 1 - Location in KM** - Each data point is located by km from a starting point we will call km 0. We are looking at only one section of the data so we have only data points km #239 through km #253. What is the total distance represented in this transect?________

   - **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**.

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 we can plot it on a graph using the X axis for distance and the Y axis for elevations.

Graph 1: Data graph of the three P.I.G. transects



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

____

____

Is this the full story? We are interested in ***change over time*** in the height of the snow over large distances. 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.

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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 comparing the 2007 data sets for changes in elevation focused on the 'difference' from 2003. This shows P.I.G.'s elevation change over time.

3. **Delta means change**. Look at Table #2. The newly added columns outlined with dashes 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. 2007 numbers ***below*** 2003 will be negative. The first two rows are done for you. Complete the graph, paying attention to negative versus positive numbers.

4. **What will the numbers mean?** Visualize the glacier before you start charting. 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? ______

5. **Chart the change (Δ) on the sheet marked Graph #1, OR use the website excel file.** Work with the new columns to show change (Δ) from 2003 to 2007. Your 'X' axis is kms. 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.

6. **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.
   ____
   ____

7. **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____
   ____

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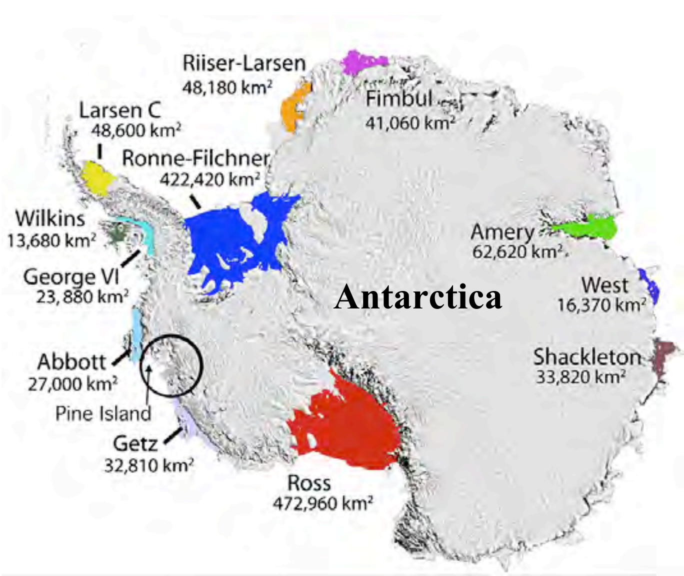

THE MECHANISM DRIVING CHANGE: You have learned the process that builds glaciers and you looked at evidence of change. But what is the ***mechanism*** driving the change? Large ice shelves, like dams, surround much of Antarctica isolating the ice surface from an ocean that is warming. These shelves are like construction barricades or dams, blocking the ice and holding it on the land; the larger the ice shelf, the larger the barricade. If the ice shelves begin to weaken and shrink the ice behind accelerates, pushing ice off the land into the ocean.

Image 8) 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 edges of the ice shelves so they break apart, opening the 'barricades' that hold back the ice. The accelerated ice flow causes the ice surface elevation to drop.

8. Look closely at *Image 8.* Do you see an ice shelf protecting P.I.G.? 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 other ice shelves included in Image 8?

   ____

9. Ice shelves form a critical protective barrier between cold continental ice and warmer ocean water. Do you think the size of the P.I.G. ice shelf could be related to the ice elevation changes occurring in the glacier?

   ____

10. The term "Canary in the coal mine" implies that something is sensitive enough to be an early warning of a problem. Early miners used canaries to show if there were dangerous gases in the mines. If they brought a canary into the coal mine and it died they knew the mine was unsafe and would evacuate. In this activity we ask if P.I.G. is a 'climate' canary. What do you think? (Support your answer)____________________________________

    ____

11. **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?

    ____

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.

PINE ISLAND GLACIER LINE #279

GRAPH #1 Name _________________

GLACIER ELEVATION (HEIGHT) IN METERS (M)

DISTANCE IN KILOMETERS (KM)