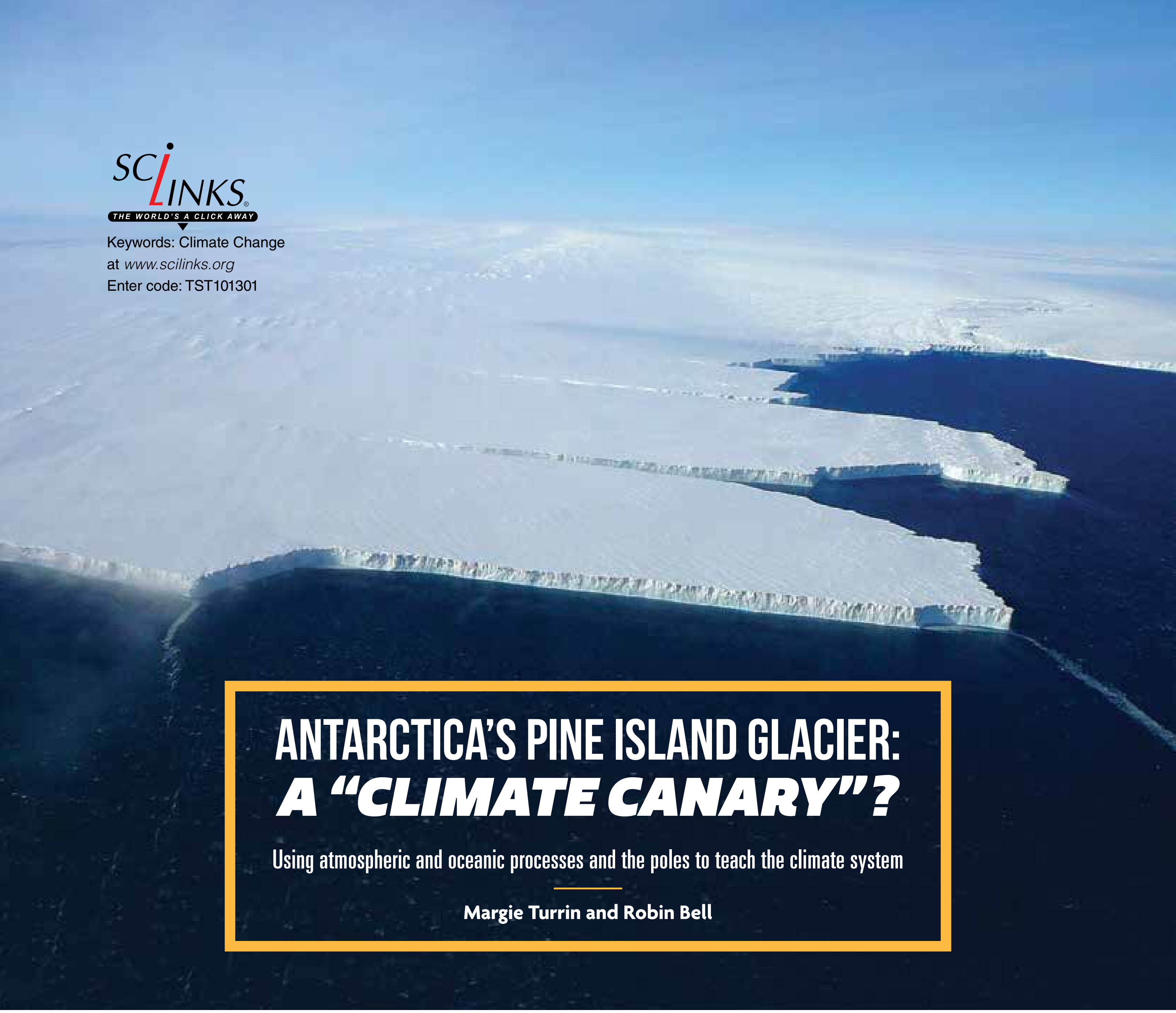

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ANTARCTICA'S PINE ISLAND GLACIER: *A "CLIMATE CANARY"?*

Using atmospheric and oceanic processes and the poles to teach the climate system

Margie Turrin and Robin Bell

Antarctica's Pine Island Glacier (PIG) is large and rapidly changing and flowing into the ocean as a floating ice shelf (above and Figure 1, p. 58). The PIG lies on the edge of the warming Antarctic Peninsula, the handle-shaped section of Antarctica (Figure 2, p. 58). The PIG drains ice from the West Antarctic ice sheet into the ocean—moving more ice than any other glacier in Antarctica. From 1996 to 2006, the PIG accelerated at a rate of 34% (Rignot et al. 2008) and is currently moving ice at speeds of up to 3.5 km/year (9.6 m/day) (Scott 2008; Bindschadler 2009). This accelerating transfer of ice from land to ocean is measured in the drop in ice elevation detected by satellites—one of three sets of evidence scientists use to assess the impact of warming on the ice sheets (others include measuring the acceleration of ice to the ocean and overall loss of ice mass).

Illustrating this process for students, the "Is the PIG a 'Climate Canary'?" activity described in this article links changing Antarctic ice directly with atmospheric and oceanic processes. The important role of these processes in warming the polar regions is an emerging area of scientific study; this activity allows students to study these processes and their effects in a meaningful way.

The data

This activity teaches effectively about Earth's climate system because it places evidence directly into students' hands; students then connect this data to processes occurring in the wider Earth system and the mechanisms triggering change. Learning directly from data is powerful. When students see the connection between the data and the corresponding

FIGURE 1

Pine Island Glacier's floating ice shelf.

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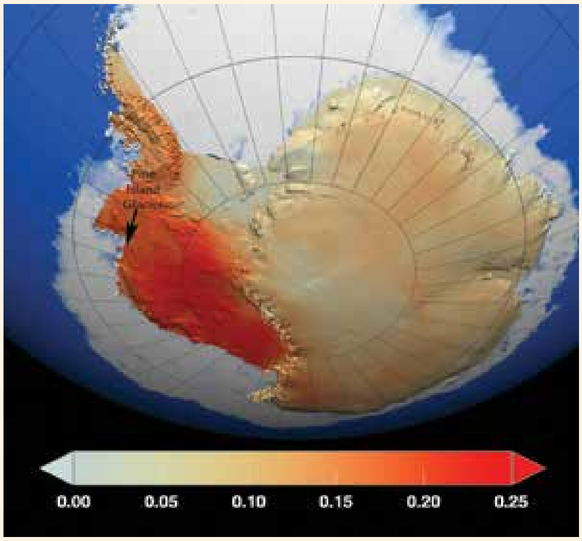
FIGURE 2

A data visualization of the warming Antarctic with temperature changes per decade shown in degrees Celsius. In the image, red represents areas where temperatures have increased the most over the last 50 years. Most of West Antarctica shows as red.



NASA/GSFC SCIENTIFIC VISUALIZATION STUDIO (ANNOTATED BY AUTHOR).

Earth processes, they experience an intrinsic thrill that cements their learning (Kastens and Turrin 2010).

The data for this activity are collected from four of the six years that NASA's Ice, Land, and Cloud Elevation Satellite (ICESat) was in orbit. With each repeat orbit, ICESat's laser measured the ice surface and collected ice-elevation data with an accuracy of within 14 cm (Shuman et al. 2006). Satellites monitoring Earth systems allow scientists—and now students—to measure changes in ice surface elevation through time (dh/dt) along satellite lines.

The activity

The "Is the PIG a 'Climate Canary'?" activity takes place in two 40-minute class periods. The first day's activities are described below; the second day is devoted to hands-on lab experiments, described later. (Full instructions for teachers and more about the science behind the activity are available online [see "On the web"].)

Day 1

Step 1: The question

We begin the activity with a question for students to work through: "Climate scientists report that polar glaciers are shrinking, but what is the evidence for this, and what might be causing these changes?" As students review polar climate science, graph and analyze the ICESat ice surface elevation data, and critically respond to discussion questions, they formulate a response. By the end of the activity, they can answer the driving question: "Do you think Antarctica's PIG is a 'climate canary'?" In other words, could the PIG be an early warning of a larger problem, as canaries dying from poisonous gas were for coal miners?

Step 2: The process

Glaciers are key to Earth's climate system, reflecting the Sun's energy back into space as they cool the air above them. Glaciers are melting, scientists say, and for students to understand how we measure glacial change, they need a basic understanding of the glacier system. Students study the concepts in Figure 3, tracing the snow with their fingers from where it hits the ground to where it returns to the atmosphere. They also consider three simple equations for "glacier accounting" that help reveal the impacts of climate in our polar regions and interpret the ICESat data. These include

- stability in size (a balanced glacier): annual new snow/ice = annual snow / ice loss,
- accumulation (a growing or expanding glacier): annual new snow / ice > annual snow/ice loss, and
- ablation (a shrinking glacier): annual new snow/ice < annual snow/ice loss

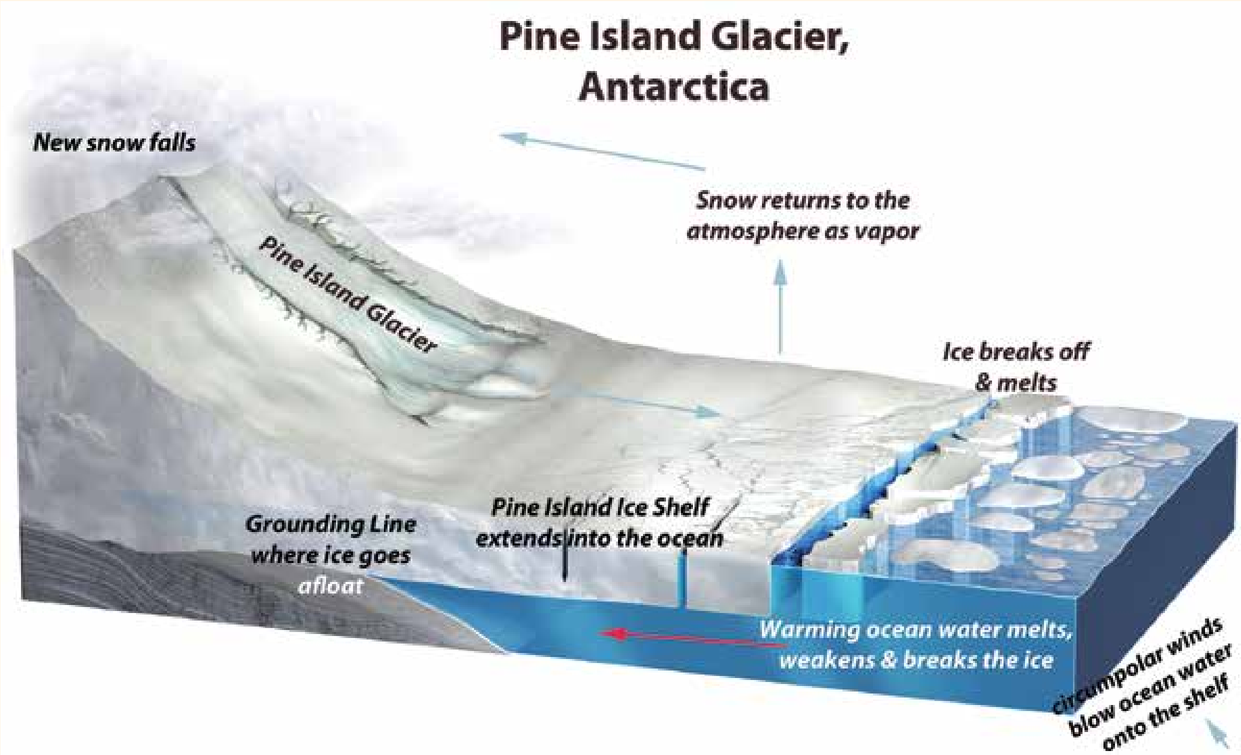
Step 3: Working with ICESat data

Figure 4 is a satellite view showing the PIG's fast-flowing glacier moving ice from land into the ocean—the process illustrated in Figure 3. Students work with data sets collected along a transect line labeled "AB" from repeat satellite orbits in 2003 and 2007, as shown in Figure 5. The activity uses only a subset of the original data sets to focus on the science process rather than the mathematics (the original includes some 600 sample data points). However, the full data sets exhibit the same trend and are available online for teachers seeking a more advanced version of this activity (see "On the web").

FIGURE 3

Pine Island Glacier system.

Students can trace the glacial system using this image of Pine Island Glacier. Moving counterclockwise, they start with "new snow" falling and accumulating and follow as it flows until it reaches the ice shelf. The ice shelf buffers the glacier from warming ocean water. When the ice in the shelf is warmed, it thins and breaks up, allowing the glacier's movement seaward to speed up.



BELL 2008

Students graph the data from Figure 5 (p. 60), plotting location (in km) along the x-axis and the change in elevation along the y-axis. Using the 2003 data as a baseline, students graph the change (Δ) in elevation for the 2007 data. The loss of up to 20 m of ice in the center of this fast-flowing glacier over the four years examined is striking in the resulting data plots (Figure 6, p. 61). Students see the loss as evidence of change but must consider whether this is important.

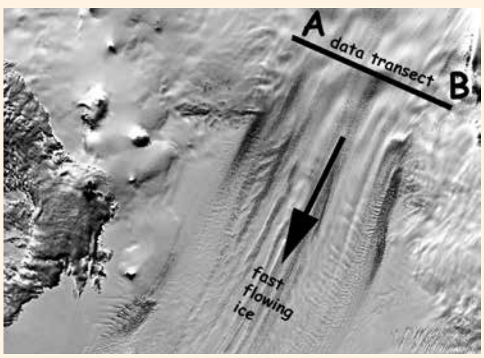
Teachers can ask the following to help put this in context for students:

"The PIG is located in an area of Antarctica where frequent storms dump around 1 m of snow annually. Looking back at the data and considering glacial accounting (e.g., annual new snow/ice vs. annual melting), do you think the

FIGURE 4

Satellite image of Pine Island Glacier.

This image shows the transect line (AB) where data was collected across the glacier's fast-flowing center. Scientists see crevasses, puckering, and flow stripes in the ice as evidence of fast flow.



NASA SATELLITE IMAGE ANNOTATED BY AUTHOR

FIGURE 5

NASA's Ice, Land, and Cloud Elevation Satellite data.

To graph change, 2003 is used as the baseline with 2007 data charted against it. The *x*-axis is the location in kilometers. The change in elevation between the two years is graphed on the *y*-axis. (To bring some context to the amount of ice in a glacier, the actual meters of ice elevation can be discussed.)

Location in kilometers (*x*-axis)	Meters of elevation (Nov. 2003)	Meters of elevation (Oct. 2007)	Change (Nov. 2003 – Oct. 2007)
239	746	746	0
240	512	511	-1
241	392	387	-5
242	343	334	-9
243	279	264	-15
244	245	227	-18
245	293	274	-19
246	332	312	-20
247	389	372	-17
248	480	475	-5
249	507	497	-10
250	557	545	-12
251	573	569	-4
252	604	600	-4
253	690	687	-3

change in elevation plotted on your graph is significant? Why or why not?"

Step 4: The mechanism

Students now have evidence of change (i.e., ice surface elevation loss) and a process that allows for change (i.e., new snow/ice vs. snow/ice loss), but what mechanism causes this change? In step 4, students must focus on the role of ice shelves as a buffer and a barrier between continental ice and warming ocean water. Notably, Antarctica's vast ice sheet produces a unique climate of cold, dense air—creating strong circumpolar winds that move from the continent's interior outward to its icy edges. Earth's Coriolis effect deflects these winds to the right, which establishes a wind pattern circling Antarctica that reinforces the cold temperatures and isolates the continent. Scientific measurements show that since 1950, a warming climate has caused these strong winds to increase (Pritchard et al. 2012, Hogg et al. 2008), shifting the Antarctic circumpolar current inward and driving warming ocean water up onto the continental shelf—thus deflecting it against the PIG and the Antarctic Peninsula.

Ice shelves are critical barriers, blocking this relatively warm 1–4°C water from the glaciers' edges (Pritchard et al. 2012; Dupont and Alley 2005). Reviewing a map of Antarctica's main ice shelves helps students understand their role in protecting the continent's icy perimeter. In this step, students are asked to locate the PIG ice shelf on the map in Figure 7. The following discussion questions focus students on the PIG's vulnerability to warming ocean water—our mechanism for change:

1. *Figure 7 identifies Antarctica's major ice shelves. Locate Antarctica's PIG. Do you see an ice shelf protecting it from warming ocean water?* (Answer: In the image students will not see an ice shelf at the PIG.)
2. *We have seen the PIG's ice shelf in Figures 1 and 3, so why isn't it on this image?* (Answer: The PIG's ice shelf is too small [about 40 × 20 km in size] to be included in this map.)
3. *Calculate the area of the PIG's ice shelf.* (Answer: 800 km^2.)
4. *Compare this to the ice shelves in Figure 7.* (Answer: 17 ice shelves the size of the PIG would fit into Wilkins Ice Shelf, the smallest ice shelf shown on the map.)
5. *Ice shelves form a critical protective barrier between cold continental ice and warmer ocean water. Do you think the size of Antarctica's PIG ice shelf could be related to the ice-elevation changes occurring in the glacier?* (Answer: They should expect a relationship, with the small size of the PIG ice shelf making it unable to provide enough of a barrier to hold the glacier back on land.)
6. *The term* canary in the coal mine *implies that something is sensitive enough to warn early of a problem. Coal miners once used canaries to detect if dangerous gases were present. If a canary brought into the mine died, miners would evacuate. In this activity, we asked if Antarctica's PIG was a "climate canary." What do you think? (Support your answer.)* (Answer: Yes. The PIG has been cited as the fastest moving glacier in Antarctica and is losing ice surface elevation in measurable amounts. Both facts suggest the PIG is being influenced by a warming ocean and atmosphere, early signs of a warming climate.)

Day 2

Step 5: Testing theories using physical models

There are two labs available for day 2 of this activity; each takes up a 40-minute class period and is completed by students working in small groups of three to four students. We recommend all the students complete lab 1. If time allows, teachers may opt to let students complete the experimental phase of lab 2 and complete the math part at home, or teachers may chose to save lab 2 for another day. The labs allow students to develop and test their own hypotheses about glacier processes and mechanisms using physical models, as scientists do, to better understand real-world processes and conditions. Both labs and detailed instructions are available online (see "On the web").

The labs use a simple mixture we call glacier goo—made from warm water, glue, and Borax powder—and other readily available materials to simulate glacier conditions. The first lab is observational, with students testing, exploring, and describing. They establish a "balanced glacier," then one that is losing "ice," and finally they explore the role of an ice shelf in glacier stability. By varying the conditions and testing their own hypotheses, they experiment with processes and mechanisms. Students are encouraged to design their own glacier tests, exploring cause and effect on the glacier as conditions change.

The second lab focuses on collecting measurements that allow students to compare rates of change in their model to the real behavior of Antarctica's PIG, providing a sense of scale. Using their glacier goo model, students collect measurements on glacier velocity and changes in glacier elevation. Antarctica's PIG is moving at a velocity of 9.6 m/day (vs. glacier goo in cm/minute) and lost 20 m of elevation in four years (vs. cm/minute for glacier goo), so a comparison will involve unit conversions. Formulas and

FIGURE 6

Graph of Figure 5, using 2003 ice-elevation data as the baseline.

The *x*-axis represents the AB transect seen in Figure 4.

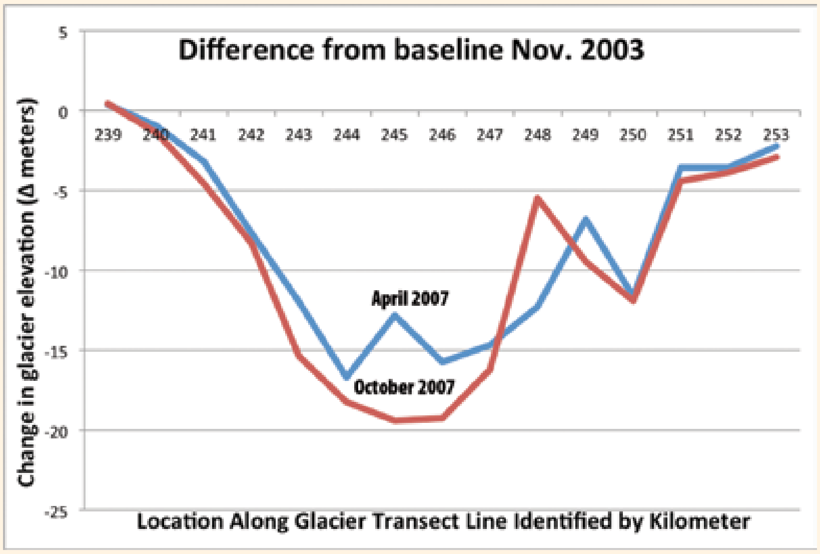
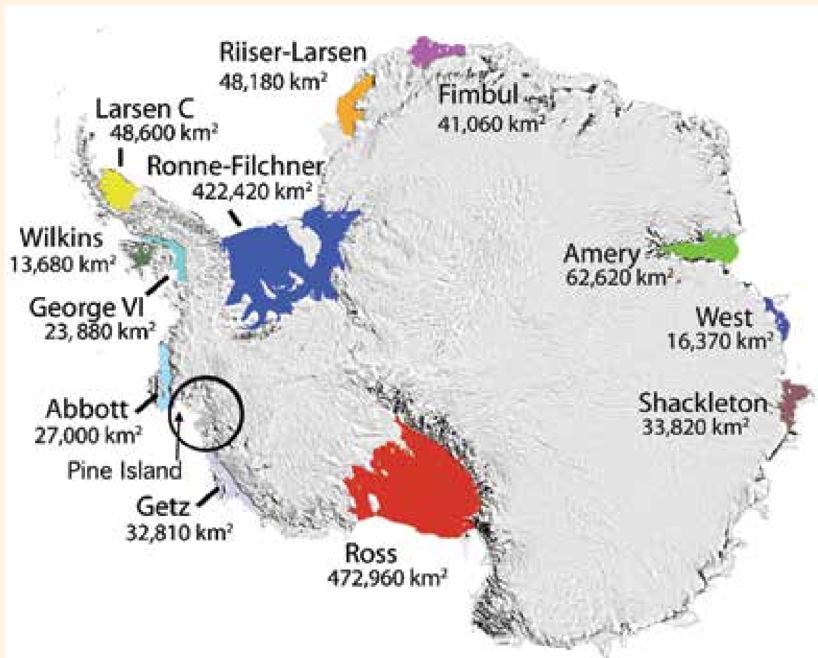


FIGURE 7

A color-enhanced satellite image of Antarctica.

This figure shows each of the larger ice shelves surrounding the continent, noted by name, color, and size. Pine Island Glacier is circled.



NATIONAL SNOW AND ICE DATA CENTER (NSIDC) step-by-step coaching are included in the lab for students, but teachers may want to consider their students' math skills prior to selecting this second lab.

Conclusion

This activity was developed with a team of teachers and tested in several high school Earth and environmental science classrooms. A PowerPoint presentation with teaching notes is available online for use in the classroom (see "On the web"). Students in our test classrooms noted that working with real data was important, allowing them to grasp firsthand the rate of change occurring in the polar regions from our warming climate and reinforcing the important roles of glaciers, ice shelves, and the global ocean in the climate system. (Students were also amazed at the decline in ice elevation over four years!) Teachers in the study noted that linking the evidence of change (i.e., dropping ice elevation), to the process (i.e., snow in vs. snow out) and the mechanism driving the change (i.e., warming ocean water around the small ice shelf) reinforced systems thinking for their students.

The "Is the PIG a 'Climate Canary'?" activity works well alone, but coupling it with experimentation in the labs enables students to model and articulate the changes that are occurring and the cause of these changes, as well as identify potential follow-up data that might be useful to further explore the topic. Additional supporting materials and pedagogical information are available online (see "On the web"). ■

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On the web

About the science behind this activity: *www.nsta.org/highschool/connections.aspx*

Additional materials for this activity including teaching guide, PowerPoint, and labs: *www.ldeo.columbia.edu/polareducation*

An animation of ocean current circulation: *http://1.usa.gov/JATxGk*

NASA's Ice, Land, and Cloud Elevation Satellite data: *http://icesat.gsfc.nasa.gov/icesat*

National Snow and Ice Data Center information: *http://bit.ly/16oWiTs* and *http://bit.ly/1eWTjU3*

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