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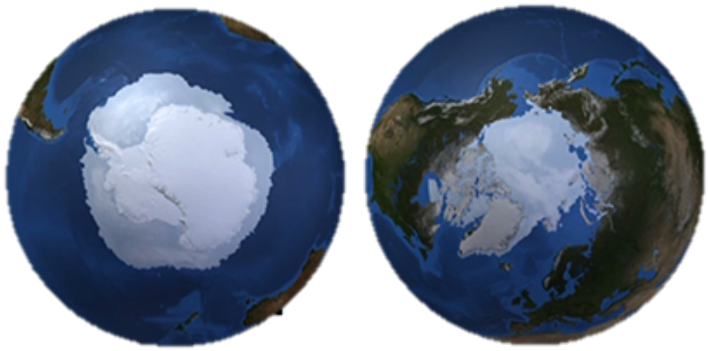
ICE SHELVES ACTIVITY 1: DECODING THE ROLE OF ANTARCTIC ICE IN GLOBAL CLIMATE

Ice Shelves play a critical role in Antarctica, serving as a buffer between the ocean and the continental ice sheet covering the land.



NASA Images of **Antarctica** and the **Arctic** covered in both land and sea ice

OPPOSITES: Antarctica and the Arctic are opposite in many ways.

The Arctic is an ocean covered by a 'cap' of both annual and persistent sea ice, and surrounded by countries like Canada, the U.S. (Alaska), Greenland, Scandinavia and Russia that have seasonal and some year round ice cover, but only Greenland has enough permanent ice to qualify as an ice sheet.

Antarctica is a large block of land 1.5 times the size of the continental U.S., covered by a massive ice sheet 7 times the size of Greenland's. Surrounded by an ocean Antarctica is effectively separated from the rest of the globe.

Both Poles have several kinds of ice that work together to cool temperature around the globe.

ANTARCTIC ICE appears in a range of types and sizes, including the newly formed surface skim of sea ice called grease ice, the older meter thick sea ice, icebergs, ice shelves, and finally the massive land based Antarctic ice sheet. Each part of this ice inventory has a critical role in protecting both the icy climate of Antarctica and cooling the larger climate system.

GOALS:
In this activity you will work as a team to:

1. Learn about the different types of ice in Antarctica
2. Evaluate the importance of the role each type of ice plays in the stability of the Antarctic Climate
3. Evaluate the importance of the role of each type of ice plays in the stability of the Global Climate

ACTIVITY:

1. **Become an Expert**: You will be placed in teams of 4. Each person in the team draws one Ice Card and learns as much as they can about the type of ice on their card and its role in Antarctica, becoming an 'ice specialist'. Consider the following in your information review but note that these questions are not answered directly on the cards. You will need to make inferences from the information provided:

- What role does this type of ice serve for the Antarctic ice system?
- Does it contribute to the stability of the Antarctica climate? If so how?
- Does the ice provide a positive service for the stability of the Global Climate? If so how?
- If your ice were no longer there what would be the effect on Antarctica?
- If your ice were no longer there what would be the effect on Global Climate?

2. **Place Your Ice:** Using the map of Antarctica provided identify where your ice would be found. Label the area.

3. **Represent your ice in a team meeting**: Using the map as a guide take turns explaining:

- Where your ice would be found?
- How does your ice interact or relate to other types of Antarctic ice?
- What its role is in Antarctica's stability?
- What its role is in the larger Global Climate?

4. **Discuss:** Discuss as a team:

- Recall how the different types of ice interact. What if your ice were to disappear tomorrow, what would be the effect on the other types of ice?
- What would be the effect on climate both in Antarctica and Globally?
- Is Antarctic ice a linked system or are certain types of ice more important than other types? If so…what and why?

SEA ICE

- When the atmosphere is really cold, ice begins to form at the salty ocean surface.
- As the water freezes it rejects the salt crystals allowing ice to form at the surface.
- The rejected salt falls, creating dense water below, blocking out warm, less dense Atlantic water, and helping to drive ocean circulation both locally and globally.
- The 1 to 2 meter thick white surface of sea ice is highly reflective (called albedo) and is an important part of global cooling.
- The ice packs up against both the land and ice shelves providing habitat and food for many marine organisms, birds and mammals such as plankton, krill, penguin and seal.
- Unlike sea ice in the Arctic the vast majority of Antarctica sea ice is seasonal, forming next to the continent in the winter when it is colder and melting or drifting away in the open ocean in the summer

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ICE SHELVES

- Ice is not static, it flows like honey under the gravitational pull of its own weight.
- Ice flows from the center of the continent to the edges, moving off the land into the water in thick floating sections called shelves.
- In the ocean ice shelves form thick aprons of attached, but floating ice. The shelves are deep floating blocks of ice ~ a km thick where they first meet the ocean and thinning to several hundred meters at their front edge.
- The shelves are critical for the future stability of the Antarctic ice sheet, a barrier or buttress to hold back the continental ice sheet. Braking the flow from land into the ocean.
- Today ~ 45 ice shelves exist covering almost half the Antarctica coastline representing an area of ~1.5 million km², or almost10 percent of Antarctica's total ice cover. In human history some have thinned and collapsed.

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ICEBERGS

- One major way that Antarctica sheds her ice is through the release of icebergs.
- Sections or slabs of ice collapse from the steep ice shelf fronts, or break off in large tabular slabs of ice like in this photo.
- The shedding of icebergs is a natural part of the ice system of Antarctica, and each section that breaks off is not cause for alarm. However, if more ice is lost through releasing icebergs and surface-melt than is added in new ice formation, the ice total for Antarctica will drop.
- Currently Antarctica is losing more ice than it is gaining, primarily because of ice loss in West Antarctica. The loss is from both iceberg releases and surface ice melt on the shelves, both the result of a warming atmosphere and ocean.

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ICE SHEETS

- The vast majority of Antarctic ice is the large ice sheet that covers 98% of the continent.
- Ice Sheets are large expanses of ice over 50,000 km^2 (about the size of Louisiana). In today's world we have ice sheets only on Greenland and Antarctica. Both are much larger than 50,000 km^2.
- Permanent land ice began to form in Antarctica some 34 million years ago and has collected through time, growing to its current extent and a thickness of up to 3 miles in the deep interior.
- Antarctica's ice sheet is divided by the Transantarctic Mountains. Some call it two ice sheets, the East Antarctica Ice Sheet and the West Antarctic Ice Sheet.
- The high 'albedo' or reflectivity of the massive white expanse of ice reduces heat absorption not only in Antarctica but it contributes to cooling the whole planet.

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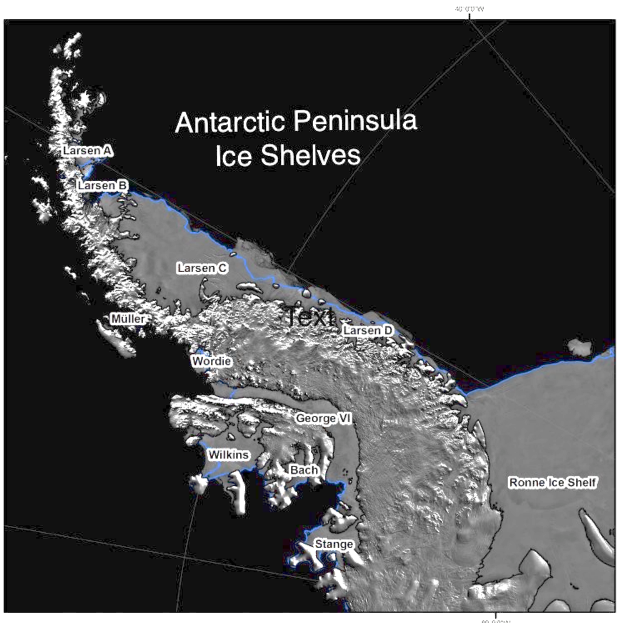
Fimbul Ice Shelf
Riiser Larson Ice Shelf
New Schwabenland
Queen Maud Land
Enderby Land
Graham Land
Larsen Ice Shelf
Biscoe Islands
Palmer Land
Filchner Ice Shelf
Berkner Island
Mac. Robertson Land
Amery Ice Shelf
Alexander Island
Ronne Ice Shelf
American Highland
Ellsworth Land
South Pole
Antarctica
Abbot Ice Shelf
Demas Ice Tongue
Shackleton Ice Shelf
Marie Byrd Land
Ross Ice Shelf
Roosevelt Island
Getz Ice Shelf
Wilkes Land

ACTIVITY II: THE FATE OF THE LARSEN'S, A FAMILY OF ICE SHELVES

Ice Shelves play a critical role in Antarctica, serving as a buffer between the ocean and the continental ice sheet covering the land.



In Activity II we will focus on a specific region of Antarctica, the Peninsula, the exposed handle shaped region of Antarctica that stretches up towards South America. The peninsula edges are currently lined with ice shelves, and historically there were even more.

An Important Point to Consider: Ice moves as gravity pulls on it. The deep stack of ice at the center of the Antarctic ice sheet is constantly flowing towards the edges of the continent. In the center of the ice sheet the movement is slow, a meter or so a year. But around the edges it can move much more quickly, in some areas up to 4000 meters a year! Let's think about this for a minute.

1 meter = 3.28 feet. How many feet is this in a year?____________
If the ice moved at the same rate every day of the year how much would it move each day in meters__________ in feet___________.
This puts a different light on the expression "Moving at glacial speed".

Activity Goals:
In this activity you will:

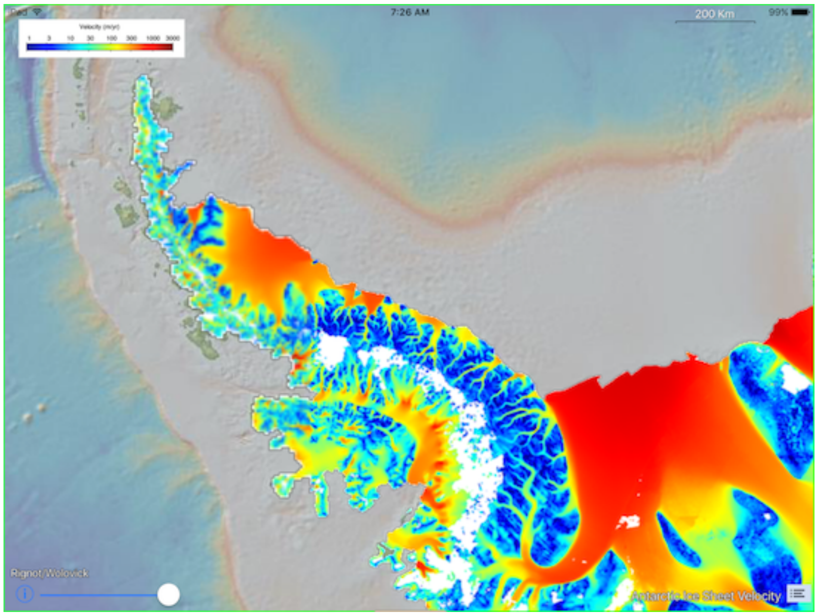
- Examine the role of ice shelves in the Antarctic ice sheet stability.
- Consider the connections between the air (atmosphere), the ocean (hydrosphere) and the ice (cryosphere) in maintaining the ice cover of Antarctica.
- Review the meaning of 'time' in the history of Antarctic ice.

Things to consider as we examine ice shelves:

1. Ice shelves form when ice flows off the land, bridging between the two types of ice, land based and floating ice.

2. The shelves remain attached to the continental ice sheet on the back and sides. At the front they are a thick floating section of ice up to 100 meters thick. The image at the top of the page is a satellite image of the Antarctic Peninsula. There is a visual change in the surface where the ice is no longer attached to the land and starts to float as a shelf; it suddenly looks very flat and smooth. See if you can identify an ice shelf and then **use a yellow highlighter** to draw a line highlighting where it goes afloat from the land. Now locate the large Larsen and Ronne ice shelves and highlight where they transition from being attached to the land and going afloat.

3. Ice accelerates as it moves towards the edges of the land but ice shelves help to slow the flow of ice behind them off the land into the ocean, where it contributes to a rise in global sea level. Working a bit like a dam, the attached edges of the ice shelves are like a brace holding back the ice behind. Below is a velocity map showing the speed the ice is moving on the Peninsula. Consider the role of the ice shelves in protecting the land based ice sheet. Using your experience outlining the ice shelves and pick two ice shelves and calculate how much faster the ice is moving at the unprotected front of the ice shelf and at the attached back of the ice shelf. Label the shelves #1 and #2 on the image.



Velocities:
#1 Front__________
#1 Back___________

#2 Front__________
#2 Back __________

4. Ice shelves have long history covering many thousand years. The Antarctic ice sheet has a much longer history covering millions of years. Our own life history is very short in comparison.

5. Ice shelves are sitting in the ocean, which is several degrees warmer than the ice.

6. In the center of the ice sheet the elevation is high and the air is colder. Ice shelves are at sea level where the air is warmer. Average air temperatures in the Antarctic Peninsula have risen by 2.5 C or 3.8 F over the last 50 years.

Lets examine the story of a set of Ice Shelves…the Larsen's

The Larsen ice shelves are well known in Antarctic science because of how they have changed in human history. How does human history relate to ice history?

Let's start with the history of the Antarctic ice sheet. Ice has covered some portion of Antarctica for at least 34 million years. It is hard to even imagine that far back. The ice shelves are much younger than the ice sheet. Larsen B had a life of 10,000-12,000 years. Larsen A formed, broke apart and reformed about 4,000 years ago. Thousands of years is still a long time but compared to millions it is young. To help us think about this let's create a timeline of these events.

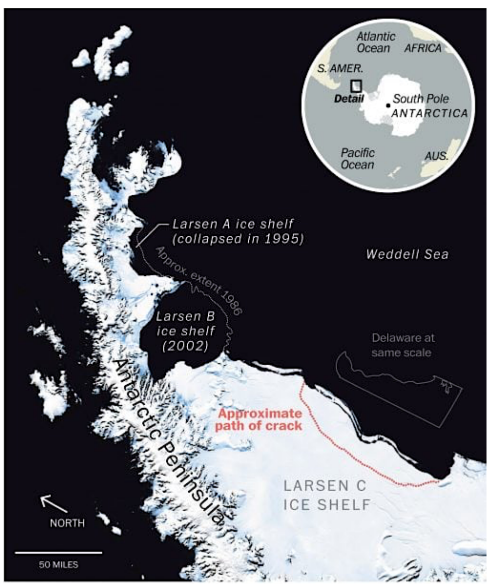
Using the line below place markers and dates to create a timeline showing the temporal (time) relationship between the four following events in Earth's history:

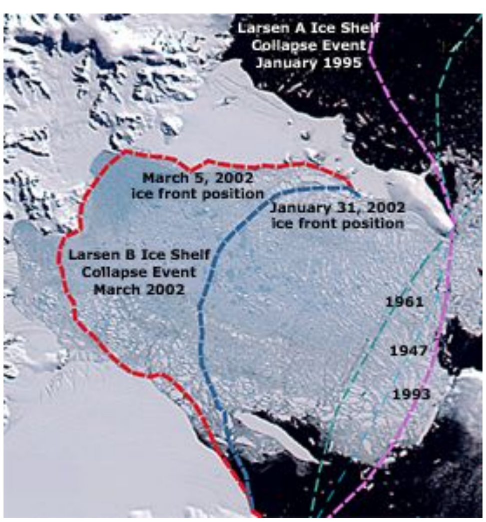
1) Origin of the Antarctic Ice Sheet
2) Formation of Larsen A ice sheet
3) Formation of Larsen B ice sheet
4) Your own origin on planet Earth

You will need to plan your spacing carefully. Think about the relationship between each event in time before you place them on the timeline. Mark and label each of the four events.

TIMELINE ARROW

What does your timeline tell you about human history compared with geologic history?

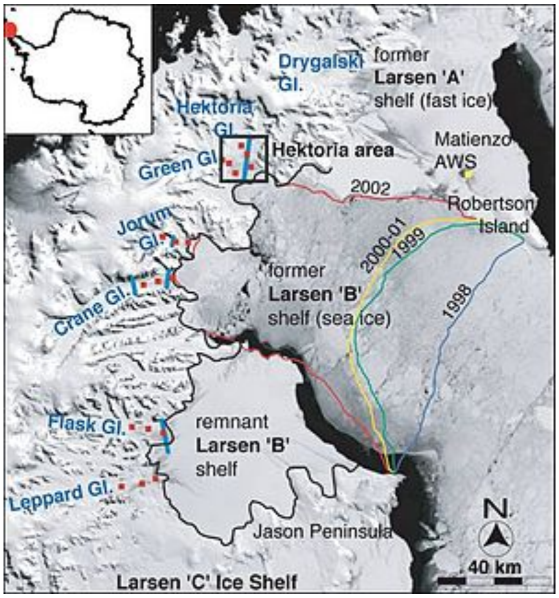




THE LARSEN STORY

Larsen A - It was January 1995, toward the end of the Antarctic summer, when Larsen A, broke apart rather suddenly and was gone. Located the furthest north of the Larsen 'family', this small shelf was located just north of the Larsen B and just outside of the area designated as the Antarctic Circle. Due to its size and location, the 1,500-square-kilometer block of ice was the most vulnerable of the series of Larsen shelves. Warming water that had been moving around the peninsula was expected to be the cause for its collapse.

Larsen B – Without Larsen A, Larsen B became more vulnerable. Although twice the size at 3,250 square kilometers, the shelf was now un-protected from warming ocean waters to the north. This exposure combined with several warm summers and Larsen B weakened and became destabilized. In 1998, satellites captured evidence of the front edge of Larsen B beginning to change, showing large ponds of water on the surface of the shelf, but with ~220 meters of ice thickness, these ponds did not seem to pose a threat. However between early February and early March 2002, the shelf suffered a massive collapse, with section after section all but evaporating before our eyes. There was disbelief among the science community that a section of shelf this size, and one that had been relatively stable for an estimated 10,000-12,000 years, could so swiftly suffer a collapse. Locate the light blue surface melt ponds located on the top of the ice



shelf in this image from the National Snow and Ice Data Center. It is believed that these weakened the thick shelf from the surface and the ocean weakened it from below.

Acceleration & Elevation Change

It had long been hypothesized that the loss of ice shelves led to a speed up of the glacial land ice behind. This results in more ice moving from the land into the ocean where it affects global sea level, and ice thinning as it increases in flow rate. Here we cite data from two studies using two techniques to measure ice velocity from a set of glaciers flowing into Larsen B from before and after the shelf collapse. The glaciers can be located in this Larsen image. Review the data to test this hypothesis and provide your conclusions.

Data Set #1 - Landsat 7 & IceSat Data

Glacier	**Speed m/yr 2000**	**Speed m/yr 2003**	**Calculate Change over 3 years of study**
Crane	~550 m/yr	~1500 m/yr	
Green	~350 m/yr	~1500 m/yr	
Hektoria	~350 m/yr	>1800 m/yr	
Jorum	*increase but not as dramatic		

Data Set #2 INSAR data (Radar Interferometry)

Glacier	**Speed m/yr 2000**	**Speed m/yr 2003**	**Calculate Change over 3 years of study**
Crane	>500 m/yr	> 1500 m/yr	
Green	~275 m/yr	~2200 m/yr	
Hektoria	~275 m/yr	>2200 m/yr	
Evans (next to Green Glacier)	~275 m/yr	>2200 m/yr	

Data Set 1 and 2 are from "Coastal Change & Glaciological Map of Larsen Ice Shelf Area, the Peninsula ***Antarctica: 1940-2005. From Ferrigno et al.***

Elevation: In addition to acceleration these glaciers also showed tens of meters a year of elevation loss demonstrating the thinning of the glacier due to its accelerated flow and movement of ice into the ocean.

Neighboring Glaciers: A small section of Larsen B remained intact after the collapse. Two glaciers, Flask & Leppard, lie behind the remains of Larsen B ice shelf. Neither of these two glaciers showed a velocity change or any noticeable change in ice surface elevation after the collapse of Larsen B.

Conclusions:

- Consider the velocity data from Data Set #1 and Data Set #2.
- Consider the elevation data.
- Consider the data from the neighboring glaciers blocked by the remnants of the Larsen B shelf

Write your hypothesis of the role of ice shelves in ice velocity:

Take this to the next level

You have been asked to give a short presentation to the Parent Teacher Association of your school explaining why your class should be studying the polar regions in science. They are concerned that this topic is not important in our curriculum. They argue that there is so much material to cover in school, the polar regions are so far away, they have no apparent connection to us, and they have been the same for all of human history.

Outline your ideas below for your presentation.

What key ideas will you use to convince them?
Be sure to cite evidence in your presentation outline.

ACTIVITY III: ROSETTA: DECODING THE MYSTERIES OF THE ROSS ICE SHELF

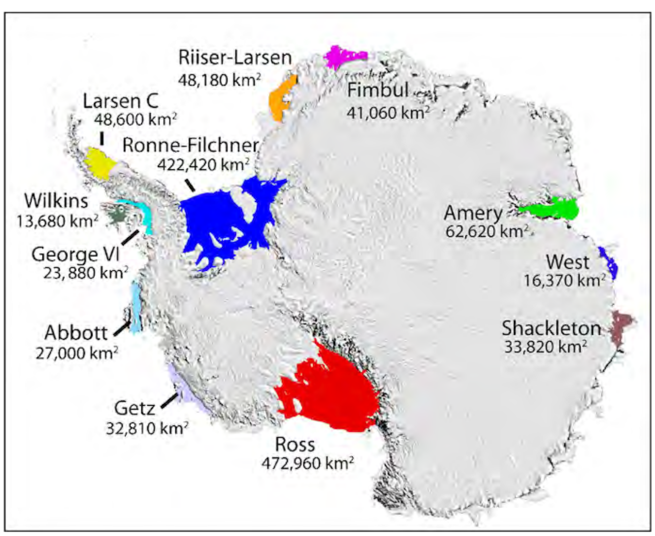
Ice Shelves play a critical role in Antarctica, serving as a buffer between the ocean and the continental ice sheet covering the land.

The Ross Ice Shelf: In this third activity focused on Antarctic Ice Shelves we take a look at the Ross Ice Shelf. The largest of the Antarctic ice shelves the Ross is a massive apron of ice stretching to an area of 487,000 sq. kms (188,000 sq. mi.). You will measure the ice yourself using radar data to see just how thick the ice is at the shelf front.

This incredible block of ice about the size of France is being fed a constant flow of ice from glaciers draining in from both the East and West Antarctic Ice Sheets. You will track some of the ice as it moves across the shelf, calculating its age. The Ross Ice Shelf plays a critical role in stabilizing the Antarctic ice sheet, buttressing the ice that is constantly moving over the land surface. But just how stable is it? We will turn to some models to help answer this question.

Activity Goals:
In this activity you will:

- Consider the importance of the scale of ice shelves in the overall ice cover in Antarctica
- Use data from the Ross Ice Shelf ROSETTA Project to determine ice shelf thickness (http://www.ldeo.columbia.edu/rosetta)
- Ice has a specific signature. You will use data to track packets of ice from Mulock glacier as it enters the ice shelf until it melts away
- Consider two models on the stability of the Ross Ice Shelf under different global conditions

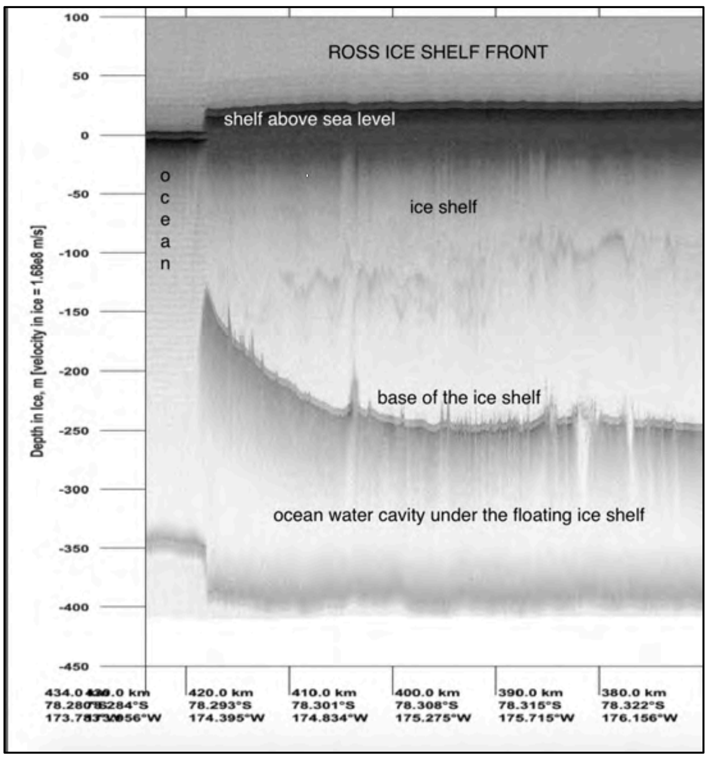


How Big Is Big? There are approximately 45 ice shelves surrounding the Antarctic continent covering almost half the coastline. They represent an area of ~1.5 million km^2. This is close to 10 percent of the total ice that covers Antarctica. Recall from activity #1 that white Ice cover is reflective. The high albedo sends a lot of the sun's energy back into space.

About a dozen of the ice shelves are considered major shelves, with the largest being the California-sized blocks of ice of Ross Ice Shelf and the Filchner-Ronne across from it. These two shelves fill the bays at the intersection of East and West Antarctica.

Circle the largest and the smallest of the dozen largest ice shelves. What is the difference in scale between these two ice shelves? __________

Overall ice shelf size is important and hints at the stability of the shelf. But there can be other factors that influence the life of an ice shelf. We will consider this later in this activity.



Section 1. Measuring Ice Shelf thickness: Ice shelves are weakened by melt at the base from ocean water below and melt at the surface from a warming atmosphere above. A thick ice shelf has more buffering from these processes. The image to the left is from radar looking through the ice at the front of the Ross Ice Shelf. Radar, like an x-ray, is a black and white image that needs to be reviewed and annotated. We added labels to help with orientation.

- The far left and under the ice shelf is the Southern Ocean.
- The dark layer on the top of the image is the surface of the ocean on the left and then steps up to the surface of the ice shelf.
- The base of the ice shelf has been labeled.
- The Y axis is meters of elevation above and below sea level.
- The X axis is kilometers of distance.

A) Start by calculating the elevation of the ice shelf. The part of the ice shelf that is visible to the human eye is that small part sitting above the ocean. Use the scale on the Y axis and estimate approximately how much of the ice shelf sits above the water. _________

B) Ice shelves, like icebergs, are mainly below the waterline. This is a result of the difference in density between ice and ocean water. The density of water is 1.0 g/ml. When water freezes into ice the water molecules spread apart and it becomes lighter with a density of 0.92 g/ml. Because of the salt, ocean water has a little higher density than freshwater (1.03 g/ml). Because the densities of ice and ocean water are so close in value, ice floats very "low" in the water, with a large percent of the ice below water.

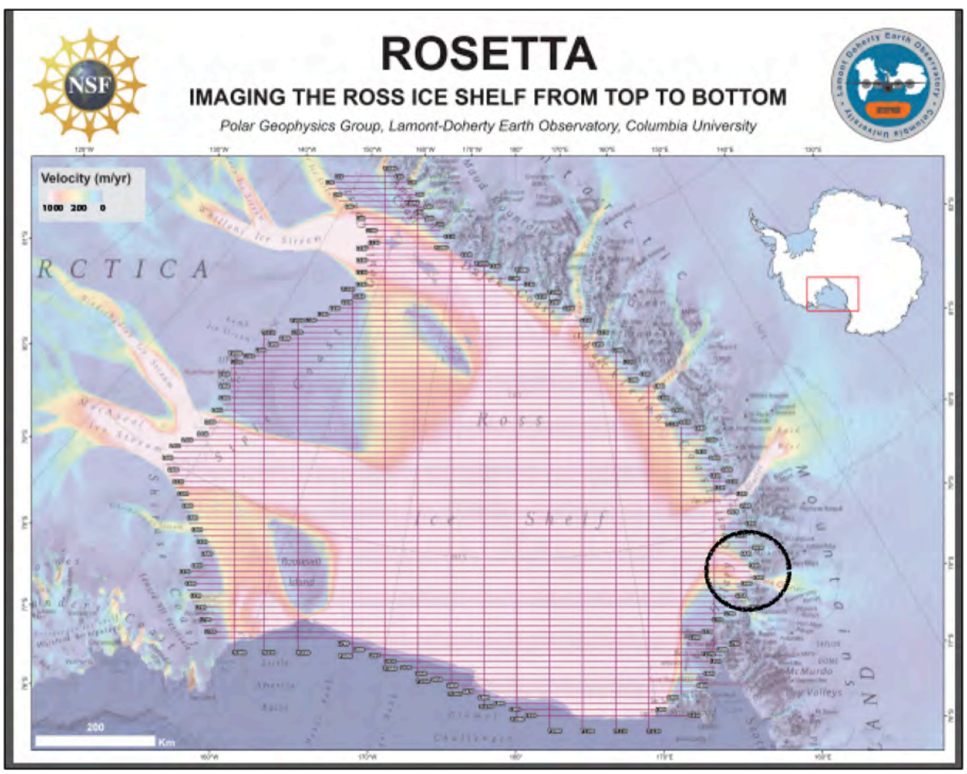
What percent of the ice shelf would we expect to find below the water surface? ________

C) Since the majority of the shelf is only visible using instruments we will use the measurements from our radar to see what percent of the Ross Ice Shelf is below the water. Our radar measurements tell us that the shelf gets thicker as you move further away from the front of the ice shelf where the water has been melting the ice at the base. Estimate the ice shelf thickness at each of the kilometer markings starting at the ocean edge and moving back under the shelf.

Kilometer Reading	Ice Shelf Thickness below the surface in meters	Ice Shelf Thickness above the surface (Question #2)	% Submerged
420 km			
410 km			
400 km			
390 km			
380 km			

Check to see how your calculations match the density principle. What was your average percent submerged?________

Fast Fact: You calculated thicknesses at the front of the ice shelf. You might be surprised to learn that at its thickest, back away from the floating edge where it is frozen to the ground below, the shelf is close to 1200 m (~4000 ft.) thick! That is a lot of ice!



Section 2. The image above is the Ross Ice Shelf. The dense grid of lines is the ROSETTA project planning tool. We focused on collecting a complete series of radar data by flying back and forth both N-S and E-W in order to make a grid of data on ice shelf thickness. This

will help us to better determine areas where thinning may occur. We will be working with some of the data collected during our flights. We are going to look at Mulock glacier, circled above, where ice is streaming along the southeast edge of the ice shelf. Ice is constantly moving into the ice shelf from a series of glaciers all around it. Ice from Mulock glacier flows in and hooks down along the edge of the shelf at ~ 125 meters a year or 1.25 km every 10 years.

A) Using the series of images provided by your teacher you will track this ice over 80 kms as it moves across the shelf. You will be calculating the ice thickness of the glacier input at each of 5 areas, as well as calculating how long the ice has been on the shelf given the rate of flow provided above and distance covered.

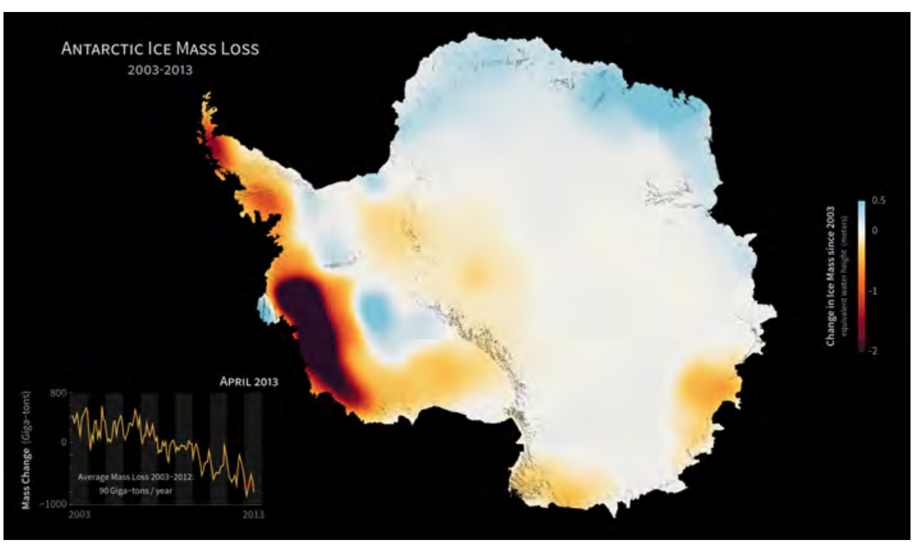
Kilometer of the reading	**Thickness of the ice**	**Time the Ice has been traveling on the shelf**
Kilometer 790		
Kilometer 800		
Kilometer 830		
Kilometer 850		
Kilometer 870		

B) What happens to the ice as it moves?

C) How many years does it take for the ice from Mulock's glacier to be melted away at the base?

Section 3. Stability of the ice shelf: If size equals stability the Ross Ice Shelf should be very stable. However it is important to consider the location of the ice shelf, and the stability of the glaciers feeding it. Ross ice shelf becomes vulnerable because of its neighbors. Ross depends on ice from both the West and the East Antarctic ice sheets and without constant inflow of ice a warming atmosphere and warming ocean will wear away at the ice shelf.

A) Satellite Data: Consider this satellite data collected by NASA showing ice loss in West Antarctica over a 10 year period (2003-2013). The image shows large amounts of ice loss in West Antarctica that extends over to the Ross Ice Shelf.



Why is West Antarctica losing so much ice? West Antarctic is primarily a string of islands that have been frozen into a peninsula. It sits much lower than East Antarctica, and is more exposed to warming ocean water. One hypothesis is that warm water is moving up over the continental shelf along this region and weakening the ice where is it frozen to the ground. Several science journal articles have noted that we have passed the 'tipping point' and we can no longer stop the melt of this area. But have we?

B) Models: Two different sets of models have been developed from a team of scientists (DeConto and Pollard). The models are based on two of the International Panel on Climate Change (IPCC) scenarios, RCP 2.6 and RCP 8.5. Scenario RCP 2.6 presumes the global annual Greenhouse Gas (GHG) emissions peak by 2020 and decline substantially after that. Scenario RCP 8.5 presumes the global annual GHG emissions continue to rise throughout the century.

Run the models.
Changes are necessary if we want to protect the future. If the West Antarctic ice sheet collapses global sea level will rise over 6 meters (~21 ft.)

C) Action Now!
Not everyone sees the need to respond since the big changes don't happen until the end of the century and later. We need the help of people who understand the hat not acting is harming us more. Consider how we can start creating change locally and communicating to others by what we do.

- Work with a group of students and identify changes students your age can make to reduce GHG emissions.
- Identify how you and your friends can share this information with other students.
- Identify opportunities that you have to communicate to businesses, corporations and community leaders about changes that can be made both through your actions and through direct communications.