SL'ICE' of Science
USING RADAR TO UNCOVER ICE MYSTERIES

Introduction: Ice penetrating radar is used to measure ice depth and annual snow accumulation; both are critical to studying climate change at the poles. But radar can also capture 'stories' frozen into the ice that tell us about the age of the ice, how it moves over the landscape, and how in some places it melts and refreezes.

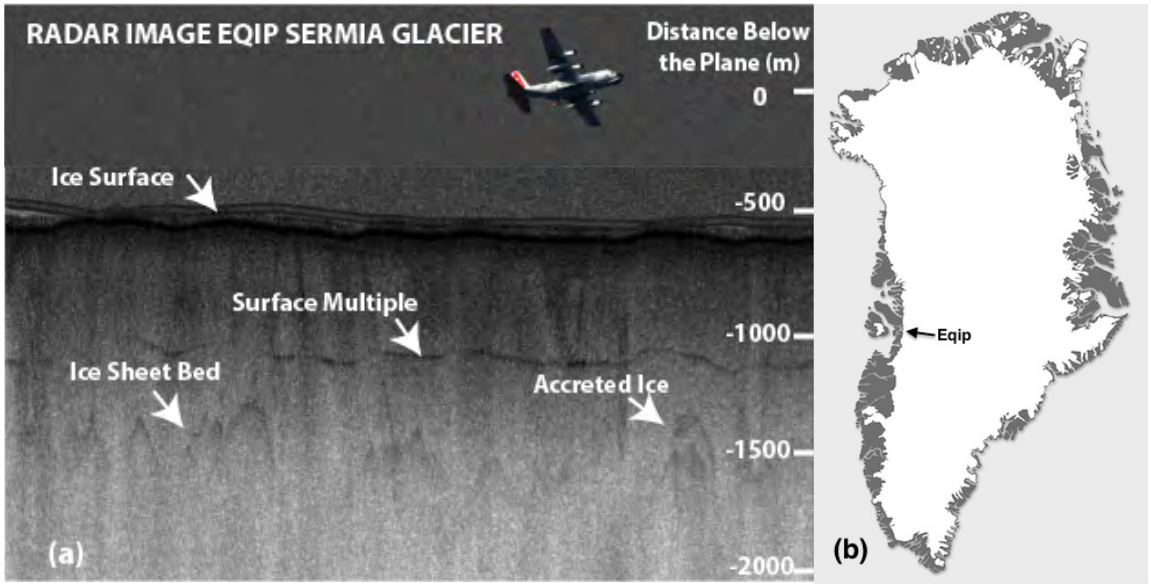

Image (a): IcePod flew over the Eqip Sermia Glacier in Greenland using ice-penetrating radar to collect data. The data were then processed to create this image that looks inside the ice sheet, shown as if the glacier was cut straight across and you are looking up into the ice as it flows towards you on the coastline. Image (b) is a map of Greenland. The arrow locates the glacier and the direction of ice flow.

Part A: HOW RADAR WORKS

Radar uses **time** to compute **distance**. A series of electromagnetic pulses are sent from IcePod down into the ice, and the signal is reflected back and recorded at a receiver. The time that the pulse takes to send, reflect off a surface and return is called ' two-way travel time'. The two–way travel time (in seconds) is multiplied by the speed of light in ice (in meters per second) to get the total distance traveled (in meters). As the reflective layer is only half the total distance traveled the number is divided by two to give the depth of the reflective layer.

IcePod collects two kinds of radar data:

- Deep Ice Radar (DICE) measures down to the bottom of the ice sheet (the rock 'bed') recording ice thickness and internal layers. It is used to track ice movement, history and evidence of melting and refreezing..
- Shallow Ice Radar (SIR) measures the top 100 meters (m) of ice of annual snow accumulation rates and to help in determining overall ice volume. Over time, snow that falls as snowflakes will be compressed into ice crystals. It is very important to understand how this affects the density of the top layers of the ice sheet to understand how the mass and volume of the ice sheets are changing.

Examine the radar image (a) above collected by IcePod flying over Eqip Sermia Glacier. 'Relative elevation' measurements are taken in relation to the aircraft flying 500 (m) above the ice sheet. The ice surface elevation of -500 (m) is measured below the aircraft. The surface of the ice and the ice sheet 'bed' show a top and bottom measure for the ice.

1. In this image locate the ice sheet bed. It extends all the way across the radar image. Use your finger to trace it and estimate the ice sheet bed elevation at its Highest _____ and at its Lowest _____.

2. Use the data to estimate the maximum thickness of the ice in this coastal section of the ice sheet _____?

3. ***Visualize this!*** The Statue of Liberty is 93 meters from the ground to the top of her flame. Stacked top to bottom how many complete 'Statues of Liberty' would fit in the thickest part of the ice sheet? _____

4. A ***'surface multiple'*** is a second radar reflection in the ice. Remember radar measures _____ and interprets that as _____. Think of a radar reflection as a 'V' with the radar waves being sent down and bouncing back up to be recorded. Not all radar waves are collected at the receiver on the first bounce, some reflect off the plane and go back down to the ice surface, returning a second time, like a 'W', where they are recorded as a second reflection. These are classified as 'surface multiples'. They are quite strong and record as deeper than the actual ice surface. Use your understanding of how radar measures the surface to write a hypothesis of why a 'surface multiple' would record deeper than the actual surface? (Hint: consider travel time) _____

PART B: ACCRETED ICE:

Part of doing science is asking questions, it's how we explore new ideas and learn about things that are hard to study, like ice sheets. When you look at the radar image you (a) might ask: Which direction is the ice flowing in this image? Why is the ice flowing this way? Is the ice flowing at the same speed throughout a region or is it moving differently because of the channels or high areas in the land it flows over? What might be causing the odd shape in the ice identified as 'accreted ice'?

Comparing radar data showing the land underneath the ice sheet (Image a), to ice surface (Image c) and velocity (Image d) data can help us answer some of these questions.

Accreted ice forms at the base of the ice sheet from melting and refreezing. Accreted ice was first found in the interior of Antarctica where ice can melt at the base of the ice sheet from Earth's geothermal heat warming the ice from below. The overlying ice acts like a blanket holding in the heat and causing more melt. The melted water flows reaching areas where it refreezes as it moves.

More recently, accreted ice has been identified at the base of the Greenland ice sheet (Image a) in both the interior deeper areas and along the edges of the ice sheet. The process forming accreted ice seems to be different at the edges. Here it may be that meltwater forming at the ice surface in surface lakes and channels, may find it way down to the bed through holes and cracks, where in places it refreezes as accreted ice.

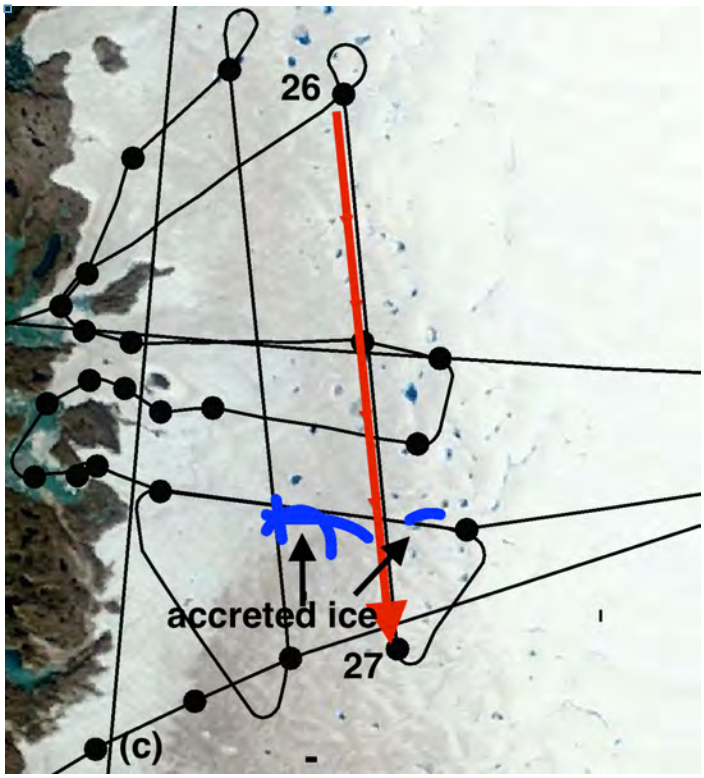

Image (c): **Ice surface of** Eqip Sermia Glacier. Ice is flowing from right (the center of the ice sheet) to left (the coast). The black lines are IcePod flight tracks and the blue shapes are the identified location of the accreted ice. The red arrow show flight direction with points 26 and 27 being the end points of radar image (a).

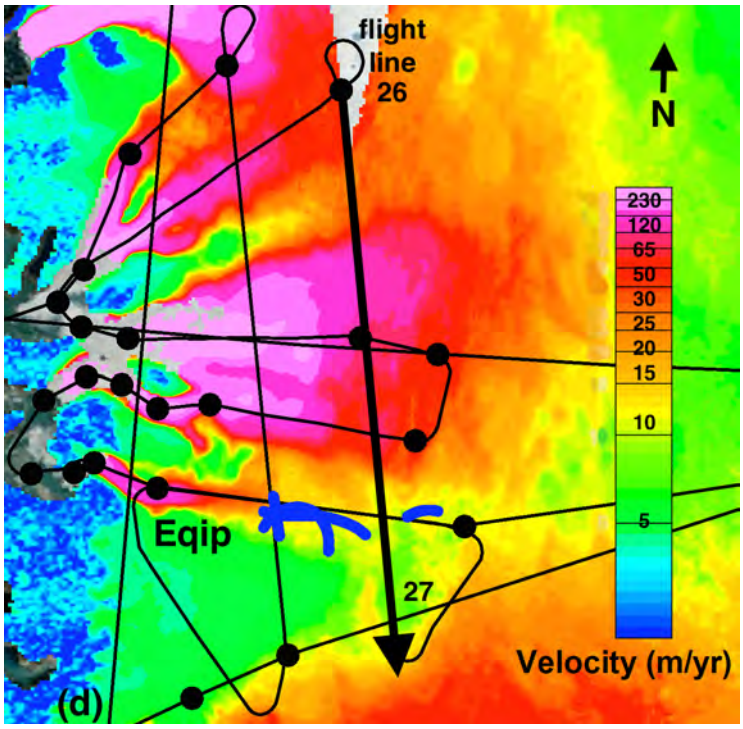

Image (d): **Velocity data** -shows the same flight tracks with ice surface replaced with ice velocity to show how fast the ice is moving in this region recorded as m/yr. The scale shows the fastest ice moving at 230 m/yr. Note the color scale does not related to the accreted ice.

The location of accreted ice in Greenland raises new science questions. Is there surface meltwater in the area of accreted ice? Does the velocity of the ice movement affect the formation of accreted ice? Use the data in the images above to build hypotheses.

5. ***Analyze the environment***. Surface melt ponds look like blue dots on the ice sheet. Recall meltwater is a possible water source for accreted ice. Circle several melt ponds in Image (c). Estimate how many you see. _____

6. Use image (d) and locate the accreted ice on Eqip glacier. How fast is the ice moving in this section of Eqip? _____

7. Compare Eqip to the two glaciers to the north. Is the accreted ice located in the fastest flowing section of ice in this region of the ice sheet? _____

8. Consider your answers to Questions 7 and 8 and build a hypothesis about where you would expect to find accreted ice at the glacier edges.
   _____

9. We don't know the answer to this hypothesis but it could be tested. How would you test it? Describe your science plan including the type of data you would need?_____
   _____

A flight track is a slice of data through the glacier. The more flight lines we collect the more complete our picture of the glacier is. The two sections of accreted ice that are shown in blue in Images(c) and (d) were identified through another science project. IcePod was interested in testing if what appeared in the earlier data as two separate sections of accreted ice at the bottom of the ice sheet might actually be connected.

To see how the radar data in Image (a) matches to the Images (c) and (d) we are going to rotate it in our minds. Imagine you will turn it clockwise 90 degrees so it is standing on end. Now it is aligned with the other 2 images and flight line 26-27.

10. Now consider where the accreted ice shows in the radar. What do you think, is the accreted ice all connected? _____
    What evidence would you cite to support your answer?
    _____

11. For this activity which type of radar data was most useful DICE or SIR? _____
    Why? _____

    Looking for more? See these other resources:
    For more on how radar is helping scientists learn about the past in Greenland:
    http://www.nasa.gov/content/goddard/nasa-data-peers-into-greenlands-ice-sheet/
    For more on the IcePod project visit:
    http://www.ldeo.columbia.edu/icepod
    For more polar science education activities:
    http://www.ldeo.columbia.edu/polareducation