TEACHER PAGE – *Trial Version*

** After completion of the lesson, please take a moment to fill out the feedback form on our web site (https://www.cresis.ku.edu/education/k-12/online-data-portal)**

Lesson Title: Data Series – Calculating Ice Thickness
Grade: 9-12

Question: How do scientists determine ice thickness and understand

Time:
45 – 60 minutes (plus additional time for instruction of echogram interpretation)

Scope of the Lesson:
This lesson explores the use of radar technology for the purposes of analyzing ice sheet and glacier thickness over time. Students will label, interpret and understand snow surface and ice thickness changes over time. This lesson will likely be an introduction to radar and glaciers, as well as the interpretation of the 2D graphics produced (echograms). Basic physics principles of the electromagnetic spectrum will be explored and put into the context of polar science and glaciology.

Objectives:
Given a set of data students will be able to:

- Understand the basics of CReSIS radar
- Determine ice thickness changes over time using echograms
- Interpret changes in ice thickness within an echogram

Standards:

- National – A1, 2, 3, 4, 5; B1; C2; F1, 2; G6

Vocabulary:

- <u>dielectric constant:</u> electric property of a material which helps describe how an electromagnetic wave travels through the material
- <u>echogram:</u> 2D image created from radar signals detected from the return signal after of the snow surface and bedrock
- <u>frequency:</u> the number of times a wave/vibration repeats itself in a specified time (usually one second), measured in hertz
- <u>glacier:</u> an accumulation of ice, snow, water, rock, and sediment that moves under the influence of gravity
- <u>ice sheet:</u> large sheet of ice and snow that covers an entire region of land (50,000 km^2, 20,000 mi^2) and spreads out under its own weight
- <u>mass balance:</u> the mass that enters a system must, by conservation of mass, either leave the system or accumulate within the system (i.e. a glacier that has a positive mass balance has more snow/ice accumulation than snow/ice melting or otherwise leaving the system)
- <u>Multichannel Coherent Radar Depth Sounder (MCoRDS):</u> radar with frequencies specific for detection of the snow surface and travel through the ice to the bedrock
- <u>Radio Detection and Ranging (Radar):</u> a portion of the electromagnetic spectrum with low frequencies and long wavelengths
- <u>remote sensing:</u> acquisition of information about an object or substance without direct physical contact

- *Active* sensors emit radiation which is directed toward a target. The signal reflected from that target is detected and measured by the sensor.
- *Passive* sensors are used to measure energy that is naturally available.

Background:

Ice sheets, such as those found in Greenland and Antarctica play an important role in a number of Earth systems. CReSIS is especially interested in their role of changing sea levels. An **ice sheet** is formed when large amounts of snow accumulate over time, and under its own weight begins to compress into ice and spread out over the land. In some cases this ice is trapped by come geologic features such as a mountain range. In other cases, this ice is able to flow through breaks in these mountains, flowing through valleys as **glaciers**, and eventually reaching the open water. Through information about ice thickness and where the ice begins to float as it approaches the ocean (the **grounding line**), it is possible gain knowledge about the amount of water displaced from the ice and its role in sea level changes. CReSIS is generally interested in the ice thickness and location of the grounding line for the purposes modeling sea level rise. Depending on how much ice exists and how quickly it is reaching the ocean, it is possible to estimate how much sea level may change in the future.

CReSIS measures ice sheet thickness by flying **radar** sensors mostly over regions of Antarctica and Greenland with the purpose of using the information to better model the amount of ice on Earth and how it changes over time. This is important in the study of glaciers, sea level rise, and climate change. CReSIS radar data are collected via airborne platforms with the radar attached to the wings and/or belly of an aircraft. Radar is an **active sensor** in which signals are sent out (transmitted) and returned by reflection off an object. These return signals are detected (absorbed) and processed to produce a two-dimensional image (**echogram**). Echograms contain data about locations and depths of bedrock or water under the surface of the ice sheets. There are many types of radar that can be attached to an aircraft depending on the science interests. The **Multi-channel Coherent Radar Depth Sounder** (MCoRDS) is a type of radar that is best used for collecting information about the bedrock.

Ice thickness is determined by calculating the difference in two-way travel times of the surface echo and the bedrock echo. Using the equation below and the two-way travel times for the surface echo and bedrock echo, it is possible to calculate ice thickness at any location on the echogram:

$$T = \frac{(t_{bed} - t_{surface})}{2} \times \frac{c}{\eta_{ice}}$$

Where *T* is ice thickness (meters), *t* is the two-way travel time (microseconds, μs) from the radar transmitter to the boundary (snow surface or bedrock surface), *c* is the speed of light (meters per second), and μ is the average **dielectric constant**.

Ice thickness combined with surface measurements allows the ice bed (bottom of the ice, same as top of the bedrock) to be determined. The ice bed is a critical boundary in ice flow modeling. Rough patches (or sticky spots) in the bedrock can help to slow glaciers down by increasing friction, or even causing the glacier to get 'stuck.' Smooth bedrock surfaces may allow for reduced friction and faster glacier speeds. Ice flow modeling is being studied so that we can predict what might happen to ice sheets in the future and how they contribute to future changes in sea level. These measurements are also used in **mass balance** calculations.

Mass balance is generally the measure of whether an ice sheet or glacier is gaining more snow and ice that it is losing (positive mass balance), or if more snow and ice is melting than is being replaced with accumulation (negative mass balance). If an ice sheet has a positive mass balance the ice sheet is growing, leading to possible reductions in sea level as more water is locked up in ice. A negative mass balance is an indication if the ice sheet is shrinking, leading to possible increases in sea level. Along with ice thickness, satellite measurements of surface ice velocity are used to estimate the amount of ice leaving the ice sheet.

Ice thickness measurements are also used to select future ice cores sites. Ice cores provide one of the best paleoclimate records by measuring the chemistry of the ice layers. Knowing the ice thickness is very important in the selection process since this helps scientists determine how the ice may have flowed at this site over the desired paleoclimate time period. In some cases, scientists can predict that a site will not be good because the ice layers may have been disturbed due to ice flow changes in the past.

Materials:

- Computer with Internet and Google Earth
- Echogram Background
- Antarctica echograms (IceThickness_Teacher.pdf – this document contains all the imagery discussed in this lesson along with answer keys and examples)
- Ruler or straight edge
- Student Worksheet (optional)

Engage:

Images and videos of CReSIS researchers and equipment can be found at https://www.cresis.ku.edu/gallery. This media, along with a quick Internet search on weather and living conditions in Antarctica or Greenland will help facilitate discussion questions related to the challenges encountered when conducting research in such extreme environments. Make some notes on what topics are discussed and come back to them at the end of the activity to tie up any loose ends.

- Browse through images and video of CReSIS field work at https://www.cresis.ku.edu/gallery.
- Take some notes from an Internet search on some of the challenges of performing research in Antarctica or Greenland.

Q1) What are some methods used by CReSIS researchers in the field?

Q2) What factors (other than the cold) would make Antarctica or Greenland a challenging place to conduct research?

Explain:

Explore the 'Echogram Background' document. Make sure you are familiar with all the necessary information. As a class, determine the ice depth at lines A and B (Figure 1). Table 1 shows the work for solving ice depth at line A.

- Discuss different characteristics and features of the echogram and how to interpret.
- Calculate ice depth at lines A and B on Figure 1.

This particular echogram is from the 2010 Antarctica field campaign flown near Pine Island Glacier.

Explore:

After walking through the ice depth calculation, students can use additional echograms (Figures 2 and 3) to calculate ice thicknesses at the locations labeled.

- Using Figures 2 and 3, calculate additional ice depths at the locations labeled. You should have six total ice thicknesses values.

Q3) What was the advantage of calculating ice depth at different locations on the echogram?

Q4) Based on where the ice is the thickest, identify the portion of this echogram that might be closest to the coastline.

Q5) Why is the snow surface echo so similar at all test points?

Q6) Why is the difference in the snow surface and bedrock echo's divided by two?

Step 1: *Ice Thickness Formula*	$T = \frac{(t_{bed} - t_{surface})}{2} \times \frac{c}{\eta_{ice}} \approx Ice\ thickness$
Step 2: *Approximated data inserted in formula*	$T = \frac{(20\,E^{-6} - 3\,E^{-6})}{2} \times \left(\frac{3E8}{\sqrt{3.15}}\right) \approx Ice\ thickness$
Step 3: *Reduced data in ice thickness formula*	$T = \frac{(17\,E^{-6})}{2} \times \left(\frac{3E8}{\sqrt{3.15}}\right) \approx ice\ thickness$
Step 4: *Approximated answer for line A*	Ice thickness ≈ 1436 m

Table 1 - Work and solution for the ice thickness at Line A in Figure 1.

Elaborate:

To check whether the interpretation of moving closer to the coast is in fact true, plot the given coordinates on a map or using Google Earth. This should also help to illustrate the direction the plane is flying. In Figure 4, the plane is in fact flying from the inland part of the ice sheet towards the coast. Keep in mind, each of these echograms is only a snapshot along a very long flight path and may not be 100% accurate is explaining all aspects of what is happening below the snow surface.

- Plot the coordinates from the x-axis of the echograms (Figures 2 and 3) using Google Earth and determine the direction the plane was flying in each.

Q7) Does the direction the plane is flying correspond with the interpretation from question 4 in determining where the ice sheet is the thickest? Thinnest?

Extend:

Students should create a depth scale for the echograms (Figure 2 and 3) based on their ice thickness calculations. Increments should correspond to the two-way travel time and should be in meters. The correct scale can be compared with data selections made by CReSIS researchers (Figures 5 and 6).

- Using the two-way travel time as a reference, create a depth scale for each echogram (Figures 2 and 3).
- The scale should correspond to the two-way travel time increments.

Evaluate:

Students should be given a copy of an echogram (Figure 7). Students may draw on the echogram if necessary to illustrate their responses.

- Using a blank echogram (Figure 7), determine the ice thickness at Lines 1 and 2. You may draw on the echogram to answer the following questions.

Q8) Where are the surface and bedrock echo's located on the echogram? How do you know?

Q9) What is the thickness at Line 1?

Q10) What is the thickness at Line 2?

Q11) Do the thicknesses in this image give any indication to the inland part of the ice sheet versus the part that might be located closer to the coastline? Explain.

Q12) Compare Figure 7 with Figure 8. Does Figure 8 give any indication to the inland part of the ice sheet versus the part that might be located closer to the coastline? Explain.

NOTE If there are large differences in the ice thickness answers the students come up with and those in the answer key, it might be worth discussing possible sources of error. Since these images have 5µs increments, it should be clear there will be errors in estimating the actual two-way travel time of a particular echo return. Also, since the microsecond (µs) is such a small unit, any significant figure estimation will play a role in your final answer.

Related Activities:

- Data Series – Grounding Line Location (https://www.cresis.ku.edu/education/k-12/online-data-portal)

Resources:

Center for Remote Sensing of Ice Sheets. 2011. Data Products. https://data.cresis.ku.edu/data/rds/.

STUDENT PAGE

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Objectives:
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- Interpret changes in ice thickness within an echogram

Vocabulary:

- dielectric constant: ____
- echogram: ____
- frequency: ____
- glacier: ____
- ice sheet: ____
- mass balance: ____ ____
- Multichannel Coherent Radar Depth Sounder (MCoRDS): ____
- Radio Detection and Ranging (Radar): ____
- remote sensing: ____
  - *Active* sensors ____
  - *Passive* sensors ____

Background:

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Explain:

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Extend:

- Using the two-way travel time as a reference, create a depth scale for each echogram (Figures 2 and 3).
- The scale should correspond to the two-way travel time increments.

Evaluate:

- Using a blank echogram (Figure 7), determine the ice thickness at Lines 1 and 2. You may draw on the echogram to answer the following questions.

Q8) Where are the surface and bedrock echo's located on the echogram? How do you know?

Q9) What is the thickness at Line 1?

Q10) What is the thickness at Line 2?

Q11) Do the thicknesses in this image give any indication to the inland part of the ice sheet versus the part that might be located closer to the coastline? Explain.

Q12) Compare Figure 7 with Figure 8. Does Figure 8 give any indication to the inland part of the ice sheet versus the part that might be located closer to the coastline? Explain.

ANSWER KEY

Q1) Answers will vary. CReSIS researchers use a variety of techniques in the field to measure a number of aspects of glaciers and ice sheets. Several different frequencies of radar are used depending on whether researchers are interested in ice depth and grounding lines or snow accumulation. Some researchers also use such instruments as GPS units to measure surface velocity of a glacier. Satellite remote sensing is also an important tool.

Q2) Both Greenland and Antarctica are fairly inaccessible by current standards. The travel to Antarctica for research, most people typically have to travel through the United States Antarctic Program. Greenland travel requires a lot of independent connections in order to travel to certain parts of the island. Resources are limited, and yes, it's cold! Most science is also conducted during the long daylight hours during the field season (April – September in Greenland; October – February in Antarctica).

Q3) In general, ice is thickest the farther inland you travel. In this case, by calculating ice thickness in multiple locations, as well as simply looking at the echogram, it should be clear that as the ice is thinning, you are traveling towards the coastline.

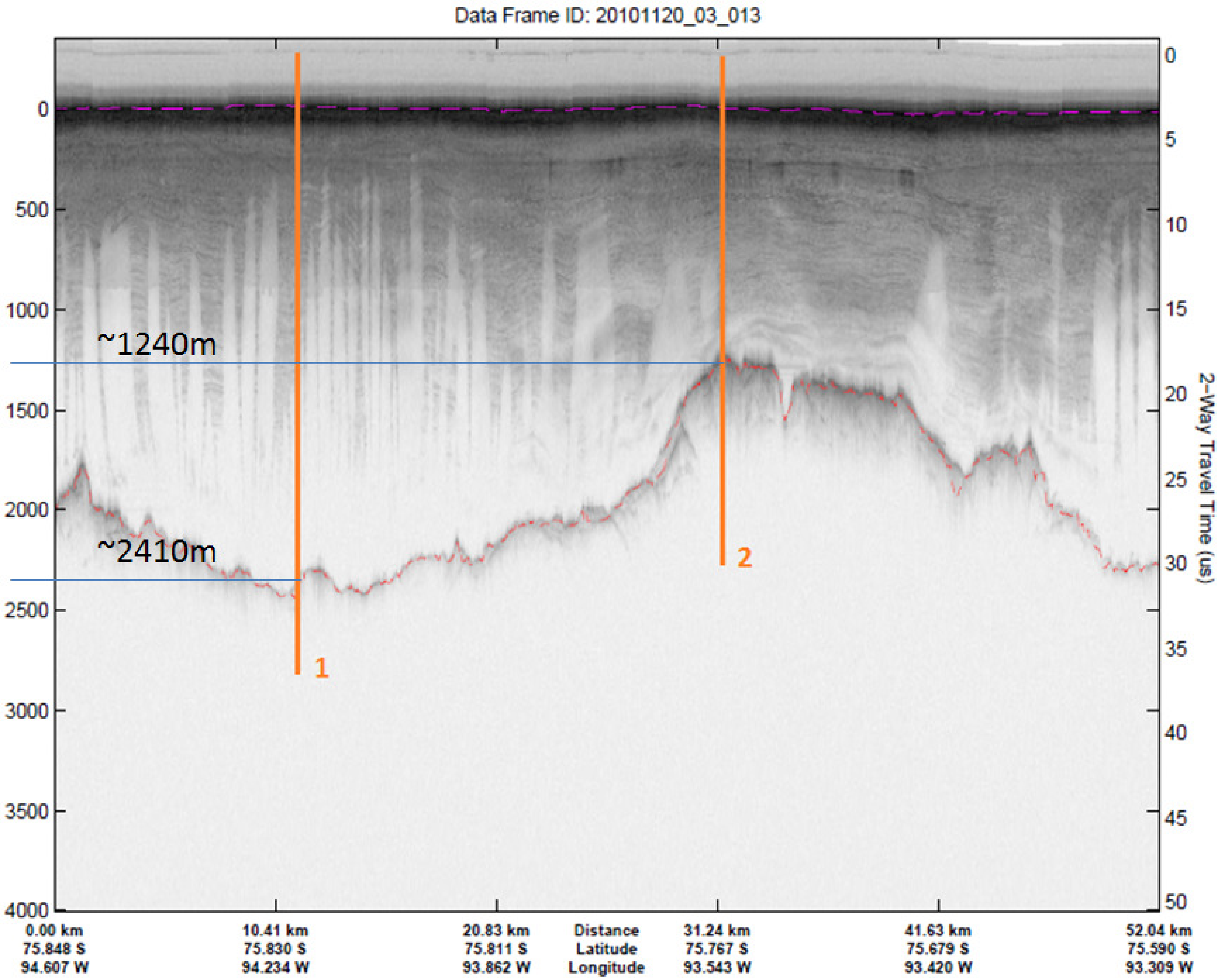
Q4) In Figure 2, the thickest part of the ice sheet is to the left, with it thinning as you move to the right across the echogram. This would indicate that the right-hand portion of the image may be closer to the coastline. Figure 3 shows the opposite, with the thickest part of the ice being located on the right, indicating that may be more distant from the coastline.

Q5) The snow surface stay relatively flat if there are not mountains or other topography to cause changes in the surface. It is possible to notice a small slope towards one side of the image corresponding to a negative slope as you approach the coast.

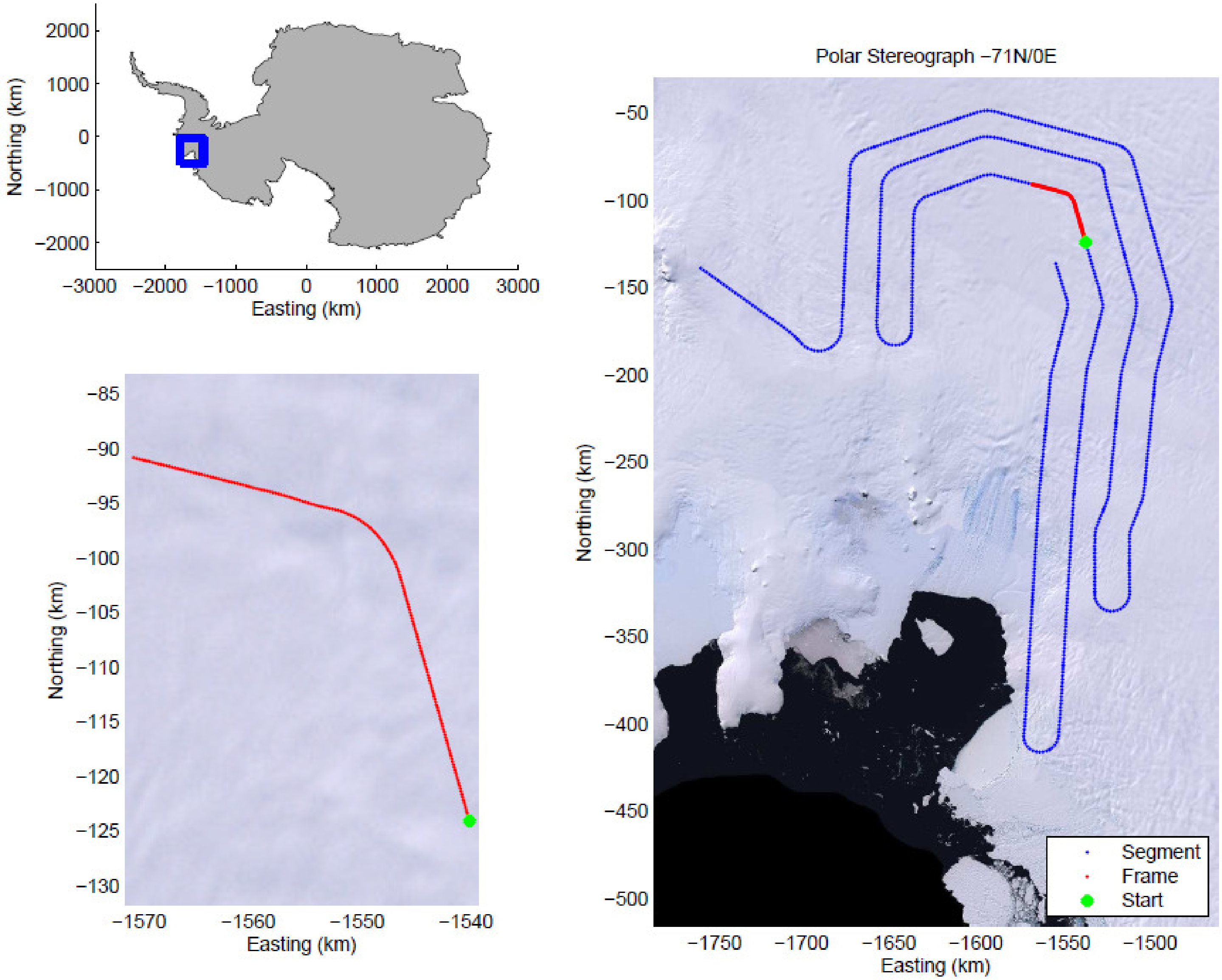
Q6) The ice thickness calculation divides the two-way travel time between the surface and bedrock echo's because you are only concerned with how long it takes the radar signal to interact with these boundaries, not the time it takes for the signal to return.

Q7) After plotting the coordinates in Figure 2, the plane is in fact flying from the interior of the ice sheet towards the coast. This corresponds with the echogram where the thickest part of the ice is on the left-hand side where the plane started recording the signal. In Figure 3, the plane has turned around and is flying from the coast to the interior of the ice sheet. This again corresponds with the thickest ice being located on the right-hand side of the echogram towards the end of the flight segment.

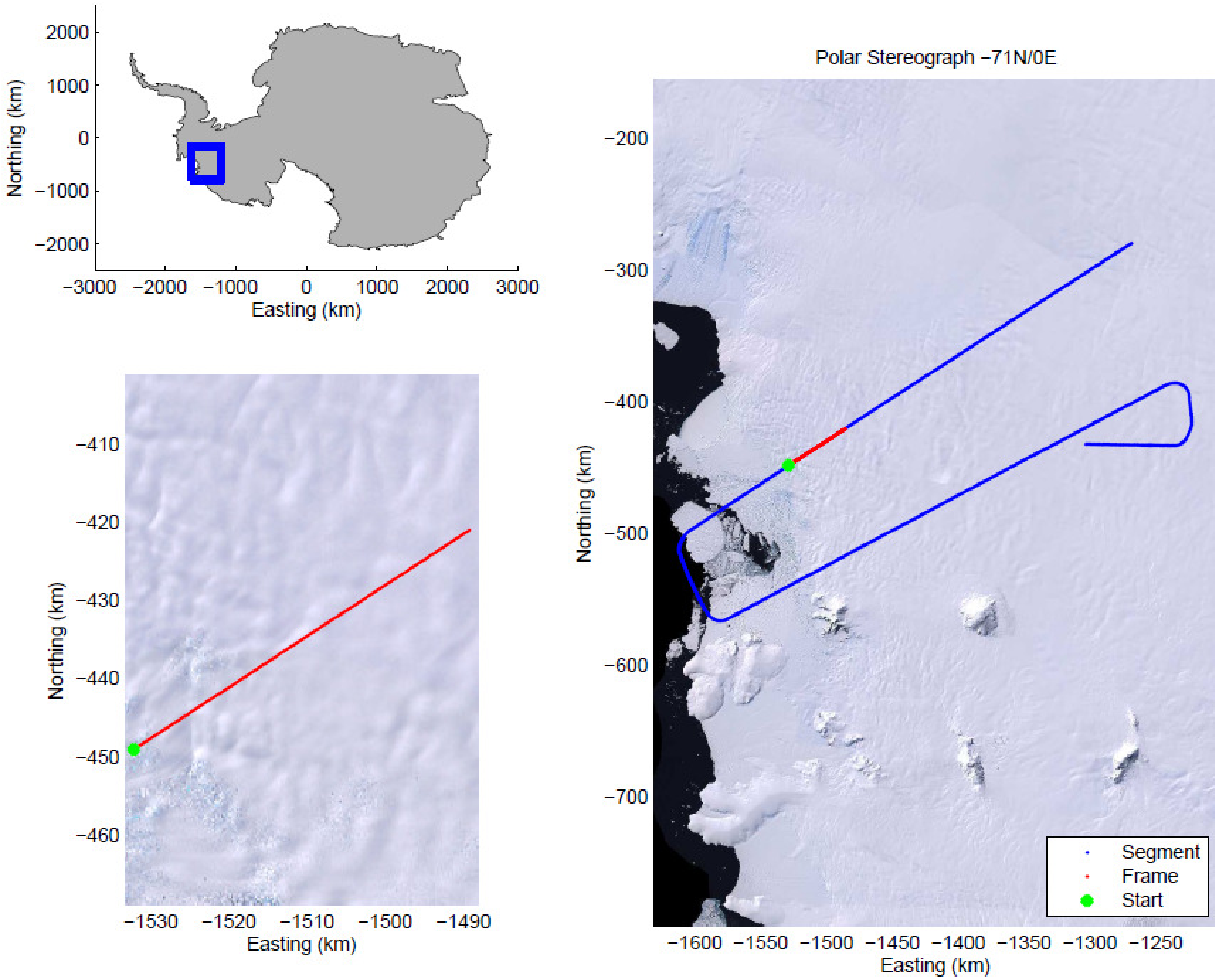
Q8 – 10) The dotted purple line near the top of the echogram represent the snow surface echo. The dotted red line near the middle of the echogram represents the bedrock echo. The calculated ice thickness values are shown and indicated by the blue lines.



Q11) It is not uncommon to see thicker ice the farther from the coast you travel. In Figure 7, it is difficult to tell which direction the coast might be. The echogram starts out with thick ice on the left-hand side, then it shallows, and gets thicker again as you move to the right. From the image below, it becomes clear why this is the case. The flight path is not over any specific glacial feature that could provide some indication to the direction of the coast or inland. The flight path is illustrated with the green dot indicating the starting location as the plane travels along the red line.



Q12) When comparing Figure 7 with Figure 8, it is much more clear where the coast is located. In Figure 8, the thinnest part of the ice is located on the left-hand side with thickening as you move to the right. This indicates that the plane is flying from an area close to the coast towards the interior of the ice sheet. This can be confirmed in the image below, with the green dot indicating the starting location while the plane travels along the red line, away from the coast.



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