

POLAR I.C.E. (Interactive Climate Education)

REMOTE SENSING: USING RADAR TO LOOK THROUGH ICE

BUILD A 3D MODEL OF THE LANDSCAPE THAT LIES UNDER THE ICE!

INTRODUCTION: It is hard to believe that melting ice from Greenland or Antarctica could affect sea levels around the world, but with increasing amounts of polar ice sliding from land into the world's oceans, sea level is rising. Knowing what is under the ice is important in predicting how quickly glaciers can move, and what might cause them to accelerate. But how do scientists can 'look through ice' to image hidden landscapes below?



Image 1 Greenland's Ice Sheet (from R. Bell, *The Unquiet Ice*, Scientific American, 2/08)



Image 2 Antarctica's Ice Sheet (edited from R. Bell, *The Unquiet Ice*, Scientific American, 2/08)

HOW CAN WE LEARN WHAT IS BENEATH POLAR ICE?

The Ice Expanse is Large! Greenland and Antarctica are home to the last ice sheets on Earth. An ice sheet is what scientists call glacial ice when it reaches an area larger than 20,000 square miles (50,000 sq. kms), an area twice the size of Massachusetts. Look at the two images above. These two continental size expanses of polar ice easily qualify (*Images 1 and 2*). But just how big are they? If you dropped the **Greenland** ice sheet onto New York City it would reach down the entire east coast from Manhattan to Havana Cuba, and across to the Pennsylvania/Ohio border. The **Antarctic** ice sheet is over eight times larger, at ~5.4 million square miles (~ 14 million km²). It would cover the whole of the United States and extend well into Canada! Imagine ice sheets the size of entire countries! We are interested in what is under the ice, but how can we study something that is completely buried?

The Ice Depth is Thick! The ice sheets are not only large they are deep! At their thickest the Greenland ice sheet measures up to 2 miles thick (3.2 km) and the Antarctica ice sheet measures up to 3 miles thick (4.8 km). These cover entire landforms! Think of an ice sheet covering the United States. The ice would hide deep canyons, towering mountain ranges, flat prairies, miles of streams, pockets of lakes and steep fjord-like cuts in the topography. The land beneath the ice is too large and varied for scientists to gather meaningful data by surveying around the ice edges.

Age of Ice is Old! In the polar regions ice has been covering the land for several million years, long before the first humans were on the Earth. It takes many years, in fact many centuries to build ice sheets. We can't look through old photos of the land from before the ice sheet formed since there were no people around to take pictures or write narratives before the ice formed.

So how old is the ice?

How do scientists determine when the ice sheets first formed? They use various methods called *proxies* to determine the approximate ages of the ice sheets. A *proxy* measures one physical quantity as an indicator of the value of another. There are several different proxies used to determine the age of the polar ice sheets, and there is some variation in the ages each assigns to the ice, however, even with these variations, scientists agree that we are looking at ice that formed millions of years ago. Much of the discussion focuses on when the ice cover became **expansive and permanent**. Let's look at one proxy to see what it tells us.

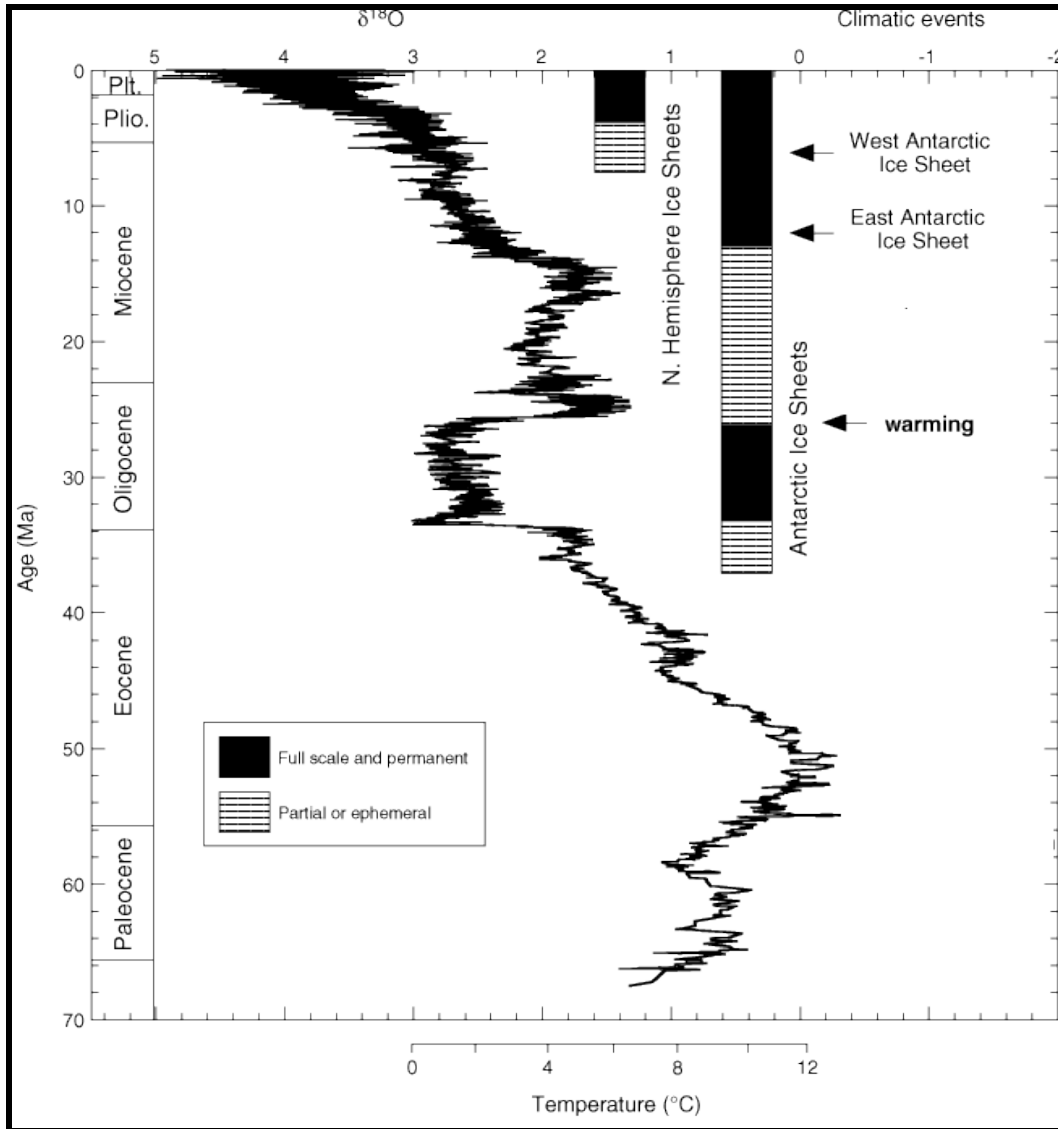


Image 3) Oxygen isotopes of foraminifera are used as a proxy to determine the age of the ice sheets. (image edited from ODP publication after Zachos et al., Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present, 2001, *Science* 292, 686.)

The information in *Image 3* uses one type of proxy to determine ice sheet ages. The proxy examines the ratio of two oxygen isotopes found in the shells of ancient ocean bottom dwelling microorganism called foraminifera, collected in deep-sea mud. We will use the graph in *Image 3* to determine what this record shows as the age of the polar ice sheets.

TASK: First examine the graph. Focus on the main squiggly line on the graph. This squiggle is a graph of polar sea surface temperature data from our proxy (a ratio of oxygen isotopes 16 to 18, shown as $\delta^{18}\text{O}$ on the top of the graph). The polar temperature is shown in $^{\circ}\text{C}$ on the **X axis** below. Now look at the **Y axis**. (Ma) is equal to 'million years ago', and is read from the top down starting at 0 for present day, and reading down as **age before present**. Next locate the two bars along side the oxygen isotope measurements labeled along their side as **N. Hemisphere** (for Greenland) and **Antarctic Ice Sheets**. The **graph key** in the box shows that when these bars are solid a full-scale, permanent ice sheet exists, and when it is striped there is not a permanent ice sheet. Let's see what the graph tells us about climate, and the age of the polar ice sheets.

- 1) Starting at the bottom of the chart, use your finger to trace the squiggle of proxy data, moving from millions of years ago in time up towards the present. See how the movement of the squiggle relates to the polar temperature graph on the bottom of the chart.
- 2) Use a second finger to trace up the bar labeled **Antarctic Ice Sheet**. Start at the bottom and stop where the bar changes to solid. Describe what happens to the squiggle? _____ Look down to the polar temperature data on the bottom of the chart and record the degree change from ____ to _____. Run your finger across to the **Y axis** and record the time when this occurred _____.
- 3) Trace up to where the bar shifts back from solid to striped. Describe what happens to the squiggle? _____ Look down to the polar temperature data on the bottom of the chart and record the degree change from ____ to _____. Run your finger across to the **Y axis** and record the time when this occurred _____.
- 4) Continue up to the next spot where the bar changes to solid. Describe what happens to the squiggle? _____ Look down to the polar temperature data on the bottom of the chart and record the degree change from ____ to _____. Run your finger across to the **Y axis** and record the time when this occurred _____.
- 5) Now look at the bar labeled **Northern Hemisphere**. Starting at the bottom, stop where the bar changes to solid. Describe what happens to the squiggle? _____ Look down to the polar temperature data on the bottom of the chart and record the degree change from ____ to _____. Run your finger across to the **Y axis** and record the time when this occurred _____.
- 6) What relationship do you see between polar temperature and when full-scale ice sheets form?

- 7) What does this graph tell you about the polar climate over the last 65 million years? _____
- 8) According to this proxy when did the ice sheets that exist today at the poles form? West Antarctic Ice Sheet _____ East Antarctic Ice Sheet _____ The Northern Hemisphere? _____
- 9) Scientists have been talking about our climate warming. Looking at the graph how warm would our climate need to be before we lose the full-scale or permanent Antarctic Ice Sheet?

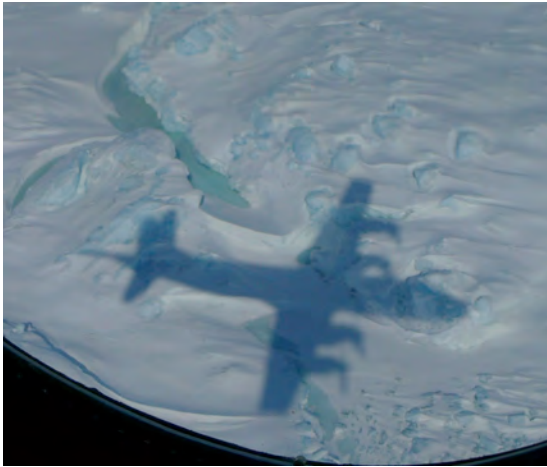
REMOTE SENSING:

Image 4) Shadow image of aircraft flying over Greenland collecting data on the ice sheet and underlying surface (Image by M. Wolovick)

How do scientists study the polar ice sheets, and beneath the ice? You have seen that the ice sheets are large, deep and very old, making it impossible to use some of the methods we might have considered to learn about what is underneath them, but scientists have other tools. Satellites from space, and aircraft flying over the ice sheet carry instruments that can collect information from a distance (*Image 4*). This type of measurement, called ‘remote sensing’, uses the interaction between energy in the electromagnetic spectrum and the object being measured. It can be ‘active’, where the energy being used is transmitted, collected and measured (as in a microwave oven), or passive where naturally occurring radiation is

reflected, collected and measured (as in film photography).

This activity focuses on **radar**, a type of active remote sensing because it sends energy out to collect its measure. Using a radio frequency pulse, it sends and receives a series of microwave signals that travel at the speed of light through the ice. Scientists measure the time delay and the direction of the returning radio frequency pulse to create an image of the land underneath the ice.

You have probably heard of radar before, but what does ‘radar’ stand for? The name was first used by the Navy in 1940 to refer to their **RA**dio **D**etection and **R**anging equipment. The name tells us that radar can be used to both ‘find’ (detect and image) our target, and provide range or distance information. In this activity you will use remote sensing data from **ice penetrating radar** to create an image of our target, the **hidden landscape** underneath the ice sheet.

USING RADAR TO IMAGE THROUGH THE ICE:



Image 5) The Ice Pod project LC130 Aircraft outfitted with radar mounted on an external 'pod' to collect images of the ice layers and the bedrock surface below. (edited image by R. Bell)

HOW DOES RADAR WORK? Just how does Radar tell what is under the ice surface?

Radar works much like an ultrasound that you could receive at the doctor's office. *Image 6a* shows the stomach of an expectant mother just as you would see it without any special instruments to help. Below that is an image created using ultrasound to show the baby inside the stomach. An ultrasound uses high-frequency sound waves sent through the body and reflected back off internal objects to measure distance, size and shape, creating the detailed image you see below (*6a bottom*). This process is similar to a radar pulse sending microwaves through the ice, and receiving them back on an antenna mounted on an aircraft. Information on the depth of the ice sheet, and on the land surface below becomes visible (*Image 7 bottom*).



Image (6 top) Expectant mother and an ultrasound image of the baby (bottom). The ultrasound image of the mother's 'tummy' allows us to see below the surface to the growing baby.



Image (7 top) The East Antarctic ice sheet and a radar image (bottom). Radar allows us to see below the ice surface, through the internal ice layers to these mountains ~2000 m below!

THE ICEPOD PROJECT WILL LOOK THROUGH THE ICE!



Image 8) The New York Air National Guard will fly the LC130 aircraft over the ice sheets collecting data. (Image courtesy of E. Lewis at Airdyne)

As part of the IcePod project we will use an LC130 aircraft outfitted with an equipment pod, called the 'icepod', to hold science instruments and remotely collect information on the ice below. Attached to the pod will be radar antenna. Each instrument will measure a different piece of information about the surface of the ice sheet and the land below it. The LC130 aircraft will fly their regular support missions in the polar regions, while collecting survey lines over the ice sheet as they travel. This activity focuses on the deep ice radar that sends out a series of radio signals that reach all the way to the bottom of the ice sheet and bounces back to the receiver. The length of time for the signal return gives us depth information on the ice sheet. From this we can piece together a picture of what the land underneath looks like.

Using Our Model:

We created a model demonstrating how the LC130 aircraft will collect radar data while flying over the polar ice sheets (*Image 9*). An instrument mounted beneath the small model plane (*Image 10*) sends, collects and records energy pulses measuring the depth to the 'ice sheet' below as the plane moves across the ice surface. At the end of each 'flight path' a set of depth measures is posted to the monitor as individual points that can then be displayed as a flight line (*Image 11*). The plane path can be moved to fly over different areas of the ice sheet collecting multiple lines of depth data. You will plot the depths on a graph to build an image of the underlying land surface, or topography.

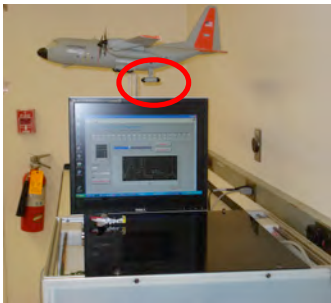


Image 9) Model (back to front) an LC130 aircraft (pod circled below); flight recording monitor; small plane on simulated ice sheet.



Image 10) A small plane (circled) travels across the ice sending down a pulse, measuring depth to the land beneath.

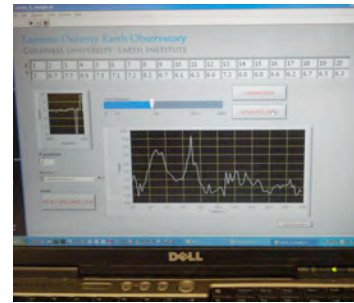


Image 11) The data is transmitted back as numbers along the flight path (top of screen), which are used to create a graph of the surface.

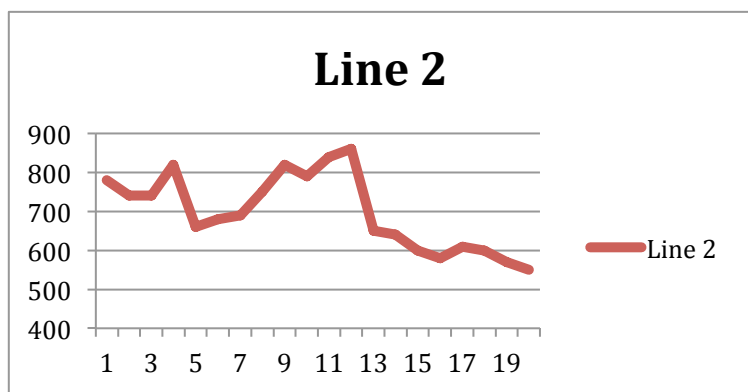
FOR PART I: CHARTING THE DATA

ICE POD MODEL DATA

-Data Points 1 to 20-

Number of flight lines collected		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	9	740	710	630	640	640	600	600	600	610	670	750	660	690	580	570	610	750	640	630	630
	8	710	750	720	640	640	640	610	600	610	600	680	760	660	660	600	580	650	720	600	660
	7	610	630	700	620	590	620	610	600	630	610	670	610	600	620	590	620	610	600	590	600
	6	760	750	690	650	820	650	620	590	590	560	560	540	550	560	550	550	540	520	500	530
	5	760	630	600	580	580	580	550	540	560	550	550	540	540	540	520	530	540	530	540	540
	4	600	610	610	620	580	690	790	640	800	640	570	600	600	600	600	610	570	530	520	530
	3	660	650	620	580	570	570	640	740	810	760	620	610	570	570	570	650	610	540	510	530
	2	780	740	740	820	660	680	690	750	820	790	840	860	650	640	600	580	610	600	570	550
	1	560	670	780	850	640	570	580	550	570	550	550	540	550	540	520	540	530	530	530	540

Chart 1. Nine flight lines of data (shown as lines 1 through 9 on the left column) were collected from our model LC130. Each line shows 20 measurements of elevation for the land surface below the ice sheet. Think of the plane flying 9 separate survey lines across the ice sheet and recording elevation measurements of the land surface below as it flies. Elevations are recorded in meters.



Each flight line 1 through 9 contains numerous data points but the plane was set to report at intervals, posting only a total of 20 points per line. The program was set up to collect each reading as a distance from the plane to the land surface, it then inverted (reversed) the reading so the that the number at each point in the chart above is actually showing land surface elevation. The larger the number reported in the box, the higher the elevation. Line 2 is drawn for you to demonstrate that data point #12, shown as 860 meters of elevation on the chart, is the highest point on the graph.

PART I: GRAPHING THE DATA

Let's work with Ice Pod model data! On page 7 is a table of the flight lines of land elevation data collected from the model. Look through the data for the flight line that recorded the greatest difference in elevation. This line shows the 'maximum relief' in the topography. Highlight this line with a highlighter. Do the same for the single line of data that recorded the smallest difference in elevation. This is the 'minimum relief' in the topography. The chart below can be used to help locate the two lines.

Line #	Highest Measure	Lowest Measure	Difference
9			
8			
7			
6			
5			
4			
3			
2			
1			

Once you have selected the two flight lines, plot them on the graph paper provided. In your graph the cells labeled '1' to '20' on the data table will be the 'x' axis, while the range of values in the flight line (elevation) will be the 'y' axis. See the sample graphed on page 7. Select a different color pen for the two flight lines. Be sure to create a color key for the graph and label each line.

1) What range did you select for your 'y' axis? _____

2) Describe each line and what it tells you about the topography. Be sure to include the line number in your description.

Line # _____

Line # _____

3) Compare the two lines. Could the range you use in the 'y' axis affect the comparison?

4) In radar surveys the flight lines are often flown in grids 10 kms apart. A lot can change in 10 kms. As the area increases in size the differences in topography can also increase. Assuming our lines were flown at 10 km distance, how far apart were the two data lines you graphed. _____

5) How do you think the model would differ if the lines were flown at 5 kms apart?

6) Do you feel these two lines give you a good understanding of the full survey area? Explain your answer.

PART II: WORKING IN EXCEL TO CHART THE DATA SET:

Looking at the whole data set can help us fill in some of the missing pieces in the topography. Use the attached excel file (either .xls or .xlsx) to graph the full set of collected data for a 3-D image of the topography.

Working with the data in Excel! The data has been saved in two excel formats (A) .xlsx file and

(B) .xls file. Both file formats will allow you to create 3D images, but the process and final image will differ slightly so select the write up that matches your files.

A) DIRECTIONS WORKING WITH .xlsx:

Select the full range of data points excluding line 1 (the header for the 20 points) and column A (the identification of the lines of data 1-9) as these are not part of the data.

Select the “**Charts**” heading and then “**Other**”

1) Select **3-D Surface** and you should see a 3-D surface appear.

The image you see is a reflection of the actual data measurements. You will see numbers 1-19 or 20 on the X axis. These numbers match to each of the measurement points recorded by the model plane. The Y elevation (series 1- series 9) matches each of the flight lines flown. You will probably see numbers 0-1000 on the Z axis. These numbers were selected by the computer to include the top elevation measurements the model plane collected. You can change this by clicking on the scale and adjusting the range.

2) You can change the image and rotate it to get a different view. Click on the image and you will get a pop up box offering to “**Format Chart Area**” with an assortment of options.

3) If you click on **3-D Rotation** you can **Free Rotate** the image. You can try rotating or tilting the image. Rotating the X coordinate moves the image so that you can view it face on and see down the low areas in the topography. Rotating the Y coordinates tips it down and up.

Experiment a bit to get what you feel shows the land shape under the ice sheet. You can even shortening your Y axis.

When you have the image the way you like it save it. Check it against the image we created, and the actual land surface that was under the ice sheet by checking the link below. Remember there will be differences!

B) DIRECTIONS WORKING WITH .xls:

Select the full range of data points excluding line 1 (the header for the 20 points) and column A (the identification of the lines of data 1-9) as these are not part of the data.

Select **Insert** and then “**Charts**”.

1) Step #1 of 4 under Chart Wizard - Under “**Standard type**” select “**Surface**” and “**3-D surface**”

2) Step #2 of 4 under Chart Wizard – Under **Data Range** select series in “**Rows**”

3) Step #3 of 4 under Chart Wizard - Enter A Chart Title. Your X axis will be **measured data points**. Your Y axis will be **lines flown**. Your Z axis will be **surface elevation**.

4) Step #4 of 4 under Chart Wizard – Select show as object in Sheet 1 and then click **Finish**.

You should see a 3-D surface appear. The image you see is a reflection of the actual data measurements. You will see numbers 1-20 on the X axis. These numbers match to each of the measurement points recorded by the model plane. The Y elevation (1-9) matches each of the flight lines flown. You will see numbers 0-900 on the Z axis. These numbers were selected by the computer to include the elevation measurements the model plane collected. You can change this by clicking on the scale and adjusting the range.

You can change the image and rotate it to get a different view. Drag the bottom corner and you can rotate and move it around. You can tip the front down to better see the elevation in your 3-D image. Experiment a bit to get what you feel shows the land shape under the ice sheet. You can shorten your Y axis. When you have the image the way you like it save it. You can check it against the image we created, and the actual land surface that was under the ice sheet by checking the link below. Remember there will be difference

Name _____

Date _____

To see how your 3D image matches with the actual landscape go to:

<http://www.ldeo.columbia.edu/edu/polareducation/underimagecomparison.pdf>

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Resources & References

Ice Sheet Information: National Snow and Ice Data Center (NSIDC)

<http://nsidc.org/quickfacts/icesheets.html>

RADAR: <http://southport.jpl.nasa.gov/desc/imagingradarv3.htm>

Ice Sheet Ages: Zachos et al., Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present, 2001, Science 292, 686.)

ODP website for graph: http://www-odp.tamu.edu/publications/202_SR/204/204_fl.htm

Remote sensing: http://wapi.isu.edu/Geo_Pgt/Mod07_RemoteSensing/mod7.htm

Electromagnetic Energy: http://missionscience.nasa.gov/ems/01_intro.html