

# Using CReSIS Radar Data to Determine Ice Thickness and Surface Elevation at Pine Island Glacier

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**Abstract**— The Pine Island Glacier region of Antarctica is an area under intense scrutiny because of its sensitivity to climate change. Pine Island Glacier is located in Western Antarctica and drains a large portion of the West Antarctic Ice Sheet. It has shown to be particularly vulnerable to glacial ablation [1]. The 2012 Research Experience for Undergraduates (REU), Ocean Marine Polar Science (OMPS), Penn State Team analyzed CReSIS radar data to identify the ice-surface and ice-bottom features. From this, both elevation and ice thickness at Pine Island Glacier were determined. The team utilized MATLAB along with an add-on picker program; The Penn State Environment for Seismic Processing (PSESP), developed at Pennsylvania State University. MATLAB is a programming environment that analyzes data as well as many other technical processing applications. With the picker program the team selected specific, maximum-strength radar peaks on individual radar traces and applied a formula to compute the distance traveled by the signal. The difference between the distance traveled from the surface and bottom features was calculated to produce an ice thickness map. The team results will provide data that will aid in modeling of the Pine Island Glacier.

**Keywords**—glacier; radar; refractive index; mass balance; calving; Ice-sheet; topography; echogram; picker program;

## I. INTRODUCTION

Glaciers are made up of snow which accumulates over time and, if it does not melt, eventually compresses into large,

thickened ice masses [2]. Repeated snowfall that does not melt, subjects the lower layers to such pressure as to cause the deeper layers of snow to recrystallize into ice. This crystallized ice is much denser than the snow, and air pockets between the crystals are very small.

Glaciers cycle through budget gains and budget losses. Budget gains are referred to as accumulation, which include all processes that add material, usually snow. Budget losses are termed ablation, which may come in the form of melting with run-off, or calving, as two examples. Calving is the process of large portions of ice breaking off at the terminus of a glacier [3]. The change in overall mass of a glacier over a period of time is referred to as “mass balance” [1]. If a glacier has a net balance of zero for a long period of time then the glacier is said to be in a steady state.

In this research project the 2012 Research Experience for Undergraduates (REU), Oceanic Marine and Polar Sciences (OMPS), Penn State Team evaluated Center for Remote Sensing of Ice Sheets (CReSIS), radar data to determine glacial ice thickness. The focus area for this study is the Pine Island Glacier region of Antarctica. See Figure 1. The data collected with CReSIS radars provide glaciologists with information to develop precise simulation models. Ice-sheet models are expected to help provide accurate estimates of the contributions of the Antarctic and Greenland ice sheets to climate change [4], especially sea level rise.

Radar is a device or system consisting usually of a synchronized radio transmitter and receiver that emits radio waves and processes their reflections for display [5]. Radar

waves travel at the speed of light, 186, 226 miles per second in a vacuum. When radar travels through ice the speed is reduced due to the refractive index of water [6]. This fact is taken into account in the ice thickness calculation.

Radar pierces through the thickest ice and measures the shape of the bedrock beneath the ice. The shape and thickness of the glacier once determined can provide comparison model data for future reference. Current measurements of Pine Island Glacier (PIG) provide modelers with real-world data that is necessary for their models. It also provides a snapshot of the glaciers configuration which can be used in the future to identify changes in bed topography or surface features. This reference data may help researchers determine whether the glacier is in a steady state, experiencing net gain or net loss over a specific time period.

The results of the research study will provide numerical elevation data for The Pine Island Glacier study area. In addition the study will clarify whether the CReSIS Accumulation radar data sets, as seen in The Penn State Environment for Seismic Processing (PSESP) program, agree with CReSIS snapshot echograms.

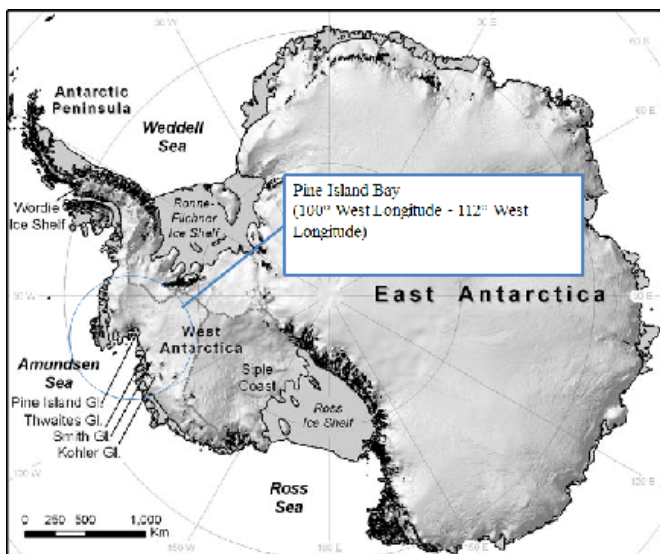


Figure 1 Study Area

## II. METHODOLOGY

CReSIS radar files containing data sets collected from the CReSIS accumulation radar were used to conduct this research, along with CReSIS snapshot echograms. The team downloaded the radar data files and snapshot echograms from Pennsylvania State University. These data files originated at Kansas University, a major repository of CReSIS data.

To analyze and process the data the team utilized MATrix LABORatory (MATLAB) R2012a version 7.14.0.739 with the Penn State Environment for Seismic Processing (PSESP), an add-on picker program developed at Penn State University. Picking refers to the process of manually selecting a specific

point in the data trace. The PSESP was also downloaded at Penn State.

The first step in the data analysis was to load the data set to be analyzed into the PSESP. A PSESP function “Initiate\_Pick\_REU.m” was then called. This displayed the panel to be picked as shown by the example in Figure 2. The first horizon to be analyzed was the lower reflector, or ice-bed interface. The point corresponding to the maximum strength radar signal at the bottom was then manually selected. An example picked point is shown in Figure 3. This procedure was then performed for a complete panel consisting of 400 radar traces. Once a panel was completed a function was called by the shift “m” command that tuned the user selection by assigning the selection point to the maximum point on the selected arc. . An example is shown in Figure 4. Next the panel was saved in a folder student\_picked\_xxx. This process was repeated to complete an entire data flight pass which normally consist of 6 to 7 panels with 400 traces each. An example flight pass is shown in Figure 5.

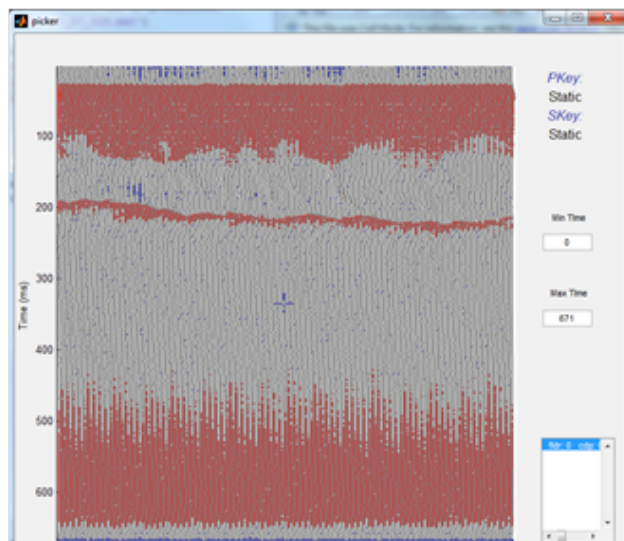


Figure 2 Data Panel

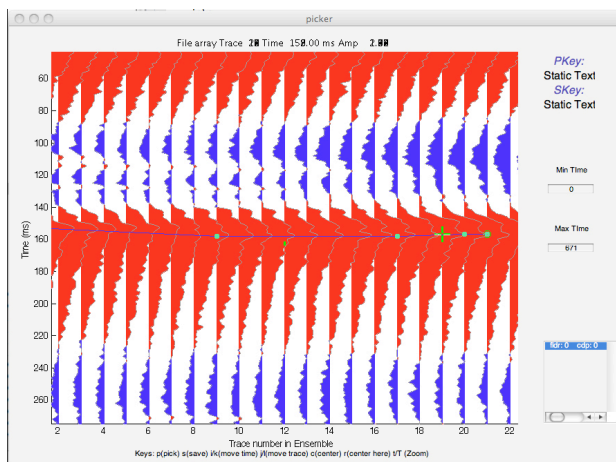


Figure 3 Manual Picked Point

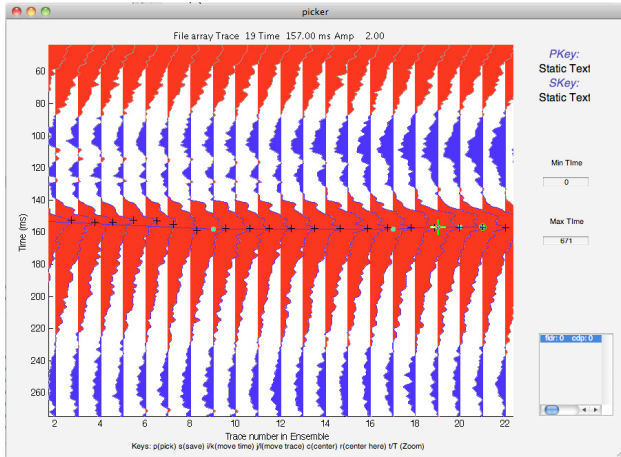


Figure 4 Automatic Program Pick

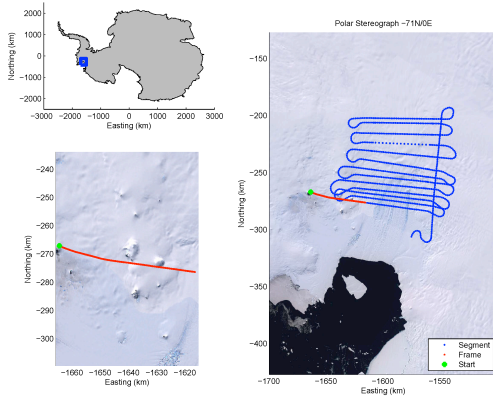


Figure 5 Flight Path with Single Pass Highlighted

Once a complete path was picked the picked data were plotted. An example plot is shown in Figure 6. The plot was then compared to the snapshot echogram to examine for major discrepancies. An example snapshot is shown in Figure 7. One adjustment the team made to better visualize the data line comparison with the snapshot was to flip the data plot so that time increases downward. An example is shown in Figure 8.

The process was repeated to find the upper horizon, the ice-surface line. Calculating ice thickness requires the surface elevation and the ice-bottom depth. An example plot showing the bottom and surface expression is shown in Figure 9.

The next step was to use the picked data to calculate ice thickness. A formula was provided by our mentor Dr. Anandkrishnan that converts the picker time value into a distance in meters. The formula is shown in Figure 10. Calculating the time the radar signal traveled from the source to the bottom surface and then subtracting the time traveled to the top surface, a distance from the top to the bottom is derived. This distance = ice thickness at that point.

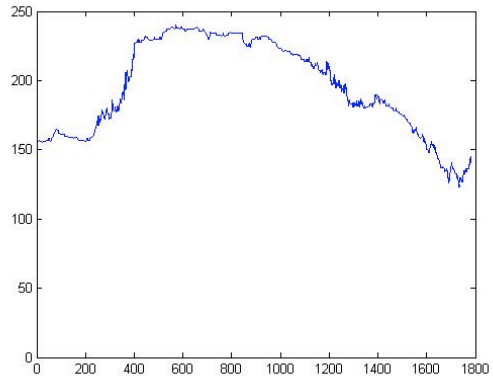


Figure 6 Plotted Data Bottom Surface

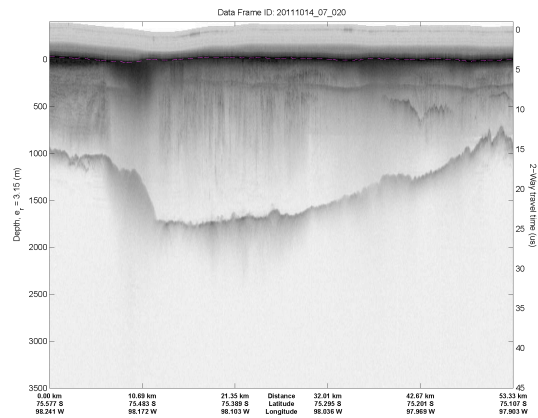


Figure 7 Bottom Surface Snapshot Echogram

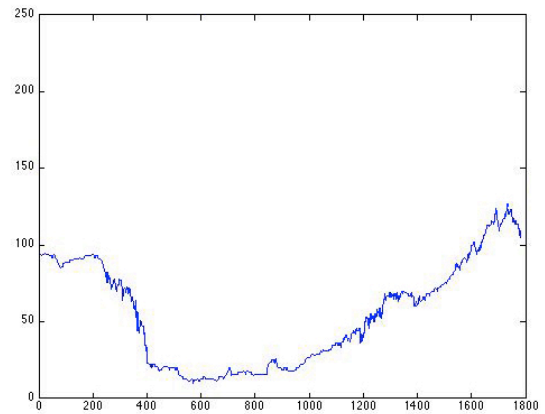


Figure 8 Bottom Surface Snapshot Echogram

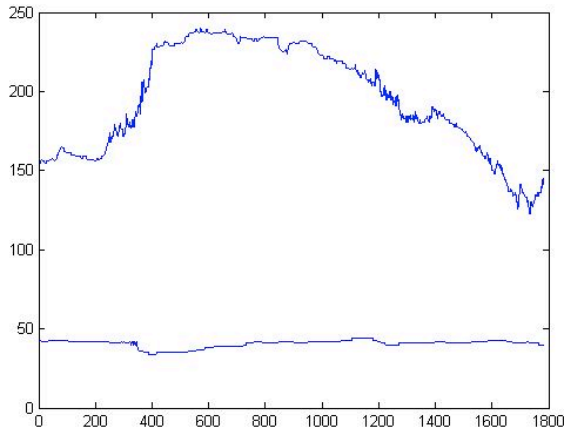


Figure 9 Bottom Surface Snapshot Echogram

### Ice Thickness Calculation :

$$[(((\text{Bottom horizon} - \text{surface horizon}) / 10) / 2) * 170 \text{m/uS}]$$

- Step 1: Take the Picker difference value of time between the bottom and surface horizon.
- Step 2: Divide by 10. This converts it from "samples" to real time (in micro seconds).
- Step 3: Divide that time by 2. This converts the "two way" travel time (going from the plane to the bottom of the ice and back to plane) into a one way travel time (from the plane to the bottom of the ice).
- Step 4: Multiply that number by 170 (which converts time to distance because radar waves travel at 170 meters/uS in ice).

Figure 10 Ice Thickness Calculation

### III. CONCLUSION

The analysis provided numerical elevation data from the CReSIS radar data sets which could be plotted and compared to the CReSIS echogram images. Our analysis found that the automated picking performed by CReSIS matches the hand-picked analysis. There may be difficulty in the human analysis of data sets especially for the less experienced researcher. That difficulty can arise when the data sets are less clear. Problems such as multiple traces peaking roughly along the same elevation force the researcher to make an educated choice as to the correct horizon line.

The team concluded that the data plots did correlate to the echogram snapshot images. Ice thickness calculations were performed and also matched with the echogram snapshots. The data plots provided a reliable source to perform the ice thickness calculations and could be used in future modeling of the study area.

### IV. FUTURE WORKS

There were two main goals of this research. The first was to compare plotted data derived from picked CReSIS data sets to CReSIS echogram snapshots and determine whether they match. The second goal was to calculate ice thickness based on the picked CReSIS data. The team met these goals by providing plotted comparison data and a viable ice thickness calculation. With the completed calculations of Pine Island Glacier ice thickness, a 3D model of the glacier can be created. The 3D model may be used in several different ways to improve upon the study of the glacier. One way the model may be used is to compare present day and future ice sheet thickness.

The team suggested that in the future the PSESP program could be modified to automate part of the process. The manual picking of data sets is very time consuming and the team wondered if the snapshot echogram could be projected onto the data echogram and the intersections between the image and the data be auto picked. The team wondered if some type of optical character recognition software could be used in conjunction with the PSESP to make the system more highly automated.

The team suggested another modification to the program that would aid in visual referencing. Presently the data image is plotted upside down. A modification to the program to plot the image with the ice surface at the top and the bedrock at the bottom would aid visually.

### ACKNOWLEDGMENT

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