Determination of the Bedrock and Surface Relationship of Helheim Glacier by Reflection Seismology.

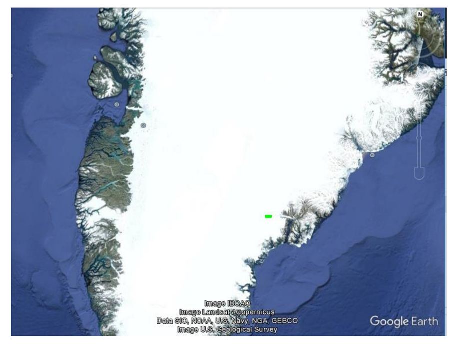
Geol 393

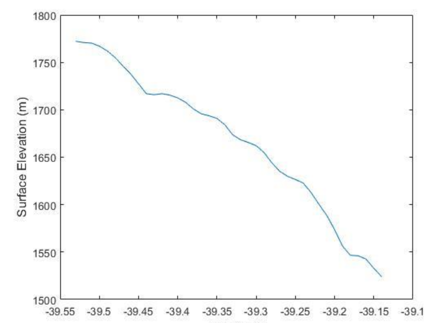
By Benton Williams

Advised by Nicholas Schmerr

Introduction:

- Helheim Glacier is an outwash glacier on the south eastern section of the Greenland ice sheet.
- The glacier also has a series of slope changes that occur down its ice-flow line that is not typical of outwash glaciers (Mathews, 1974).
- Finally the glacier contains a fresh water aquifer known as a firn aquifer.
- Radar reflections are usually the easiest way to measure the depth to the bedrock underneath the glacier, however this method is highly limited when being used for a glacier that contains a firn aquifer.
- Reflection seismology will work in areas with a firn aquifer due to the primary wave of a seismic wave being able to travel through water.





Elevation Profile of glacier in testing area

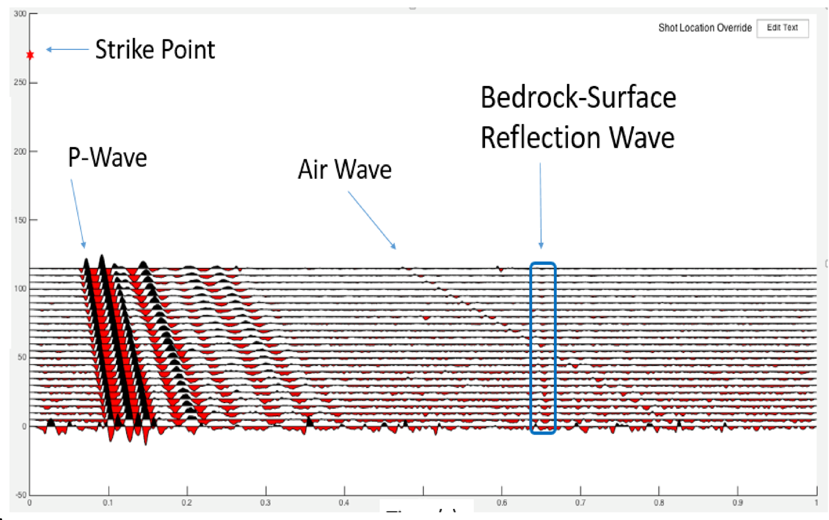
Slope changes on the surface of the glacier from west facing east

Hypothesis:

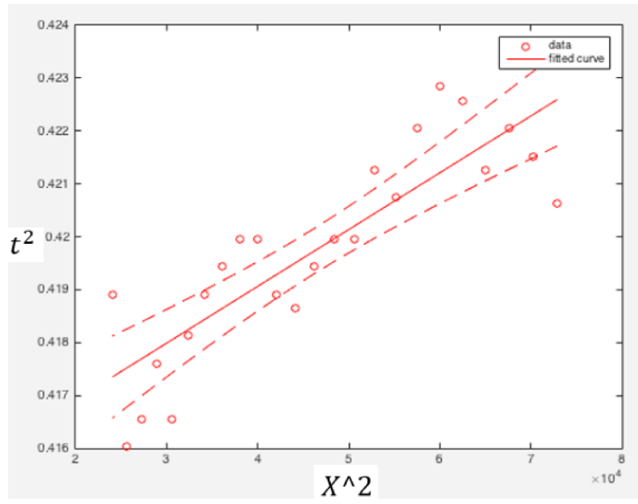
- **<u>Irregular surface topography seen at the surface of the glacier is correlated to the bedrock underneath the glacier.</u>**
- Reflection seismology can be used to determine the bedrock topography through the firn aquifer.
- Slope changes seen on the surface will have a correlated slope change in the bedrock underneath.
- Slope changes may not be 1:1, but instead will most likely be relative in their change, with a drop in slope angle on the surface being correlated to a drop in slope angle in the bedrock.

Methods:

- Geophone lines are set up in areas along the ice-flow line.
- Seismic waves are generated along the geophone lines, where the geophones record all seismic waves that pass them, producing seismograms.
- The reflection wave from the bedrock is picked out from the other waves in the seismogram.



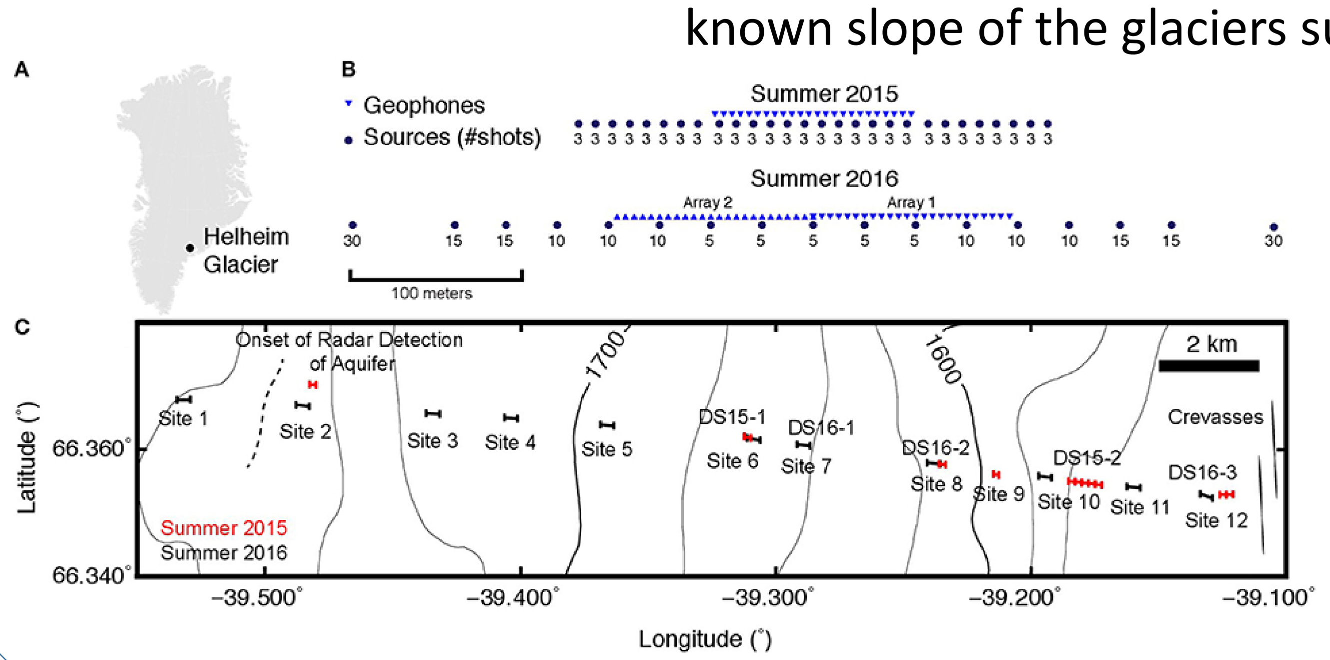
Seismogram produced from a geophone line with different sections labelled. X-axis is time Y-axis is distance in meters.



$$t^2 = \left(\frac{1}{V^2}\right) X^2 + t_o^2$$

Scatter plot of reflection wave time and distance plotted with line of best fit. Equation for line of best fit given as well (Shearer, 2009).

- The picked times of arrival of the reflection wave are placed on a distance^2 by time^2 plot.
- The line of best fit for these plotted points determines the velocity of the wave and the time the wave took to travel(Shearer, 2009).
- Distance of the bedrock from the glacier is determined from velocity and time.
- Distance to bedrock is determined at multiple points along the ice-flow line which then is used to calculate slope of the bedrock.
- Slope of the bedrock is compared to the known slope of the glaciers surface.

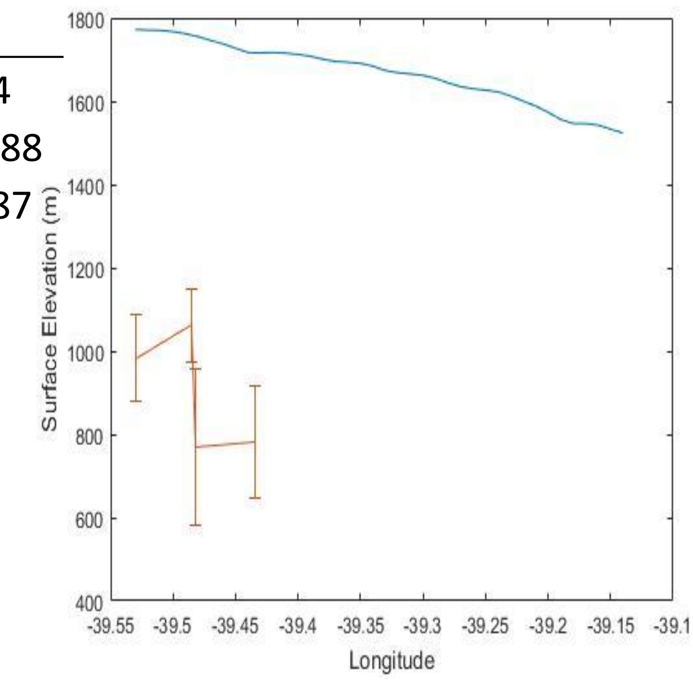


Locations of geophone lines as provided by Montgomery et al, 2017

Results:

Test Site	Velocity (m/s)	Time (s)	Depth (m)
16	2.5*10^03±320	0.643±0.001	8*1002±104
18	2.5*10^03±308	0.555±0.003	6.9*10^02±88
20	2.8*10^03±524	0.706±0.002	1*10^03±187
22	2.5*10^03±369	0.727±0.001	900±136

Test Site	Depth (m)	Elevation of bedrock (m)
16	8*10^02±104	983±104
18	6.9*10^02±88	1062±88
20	1*10^03±187	769±187
22	900±136	782±136



Blue line shows surface elevation profile of the glacier and the red line shows the calculated bedrock depths with error bars.

Site #'s	16-18	18-20	20-22
Distance Between (m)	2080	2280	3050
Change in Depth (m)	110±192	310±275	100±323
Slope (degrees)	3±5	-7±6.8	2±6.1

Site #'s	16-18	18-20	20-22
Distance Between (m)	2080	2280	3050
Change in Depth (m)	17	40	76
Slope (degrees)	0.4683	1.005	1.427

Tentative Conclusions and Future Work:

- Current data suggests that no correlation exists between the bedrock slope changes and the slope changes seen on the surface of the glacier.
- Bedrock slopes appear to have much greater changes in their slope in comparison to the relatively small slope changes seen on the surface.
- Distance to bedrock will be produced for the remainder of the test sites along the ice-flow line.
- Redundant distance to bedrock measurements will be produced for the test sites that a distance has already been produced for in order to confirm data.
- Velocities may be produced instead from known seismic velocities through ice instead of experimentally in order to produce less error in the final calculations (Bentley, 1972).
- Errors are rather large but relative slopes are still able to be determined from my produced data, so the use of reflection seismology is still feasible to test my hypothesis.

Citations:

1. Mathews, W. H. (1974). Surface profiles of the laurentide ice sheet in its marginal areas. Journal of Glaciology,13(67), 37-43. doi:10.1017/s0022143000023352
2. http://sites.uci.edu/morlighem/dataproducts/bedmachine-greenland/
3. Montgomery, L. N., Schmerr, N., Burdick, S., Forster, R. R., Koenig, L., Legchenko, A., . . . Solomon, D. K. (2017). Investigation of Firn Aquifer Structure in Southeastern Greenland Using Active Source Seismology. Frontiers in Earth Science,5. doi:10.3389/feart.2017.00010
4. Bentley, C. R. (1972). Seismic-wave velocities in anisotropic ice: A comparison of measured and calculated values in and around the deep drill hole at Byrd Station, Antarctica. Journal of Geophysical Research,77(23), 4406-4420. doi:10.1029/jb077i023p04406
5. Shearer, P. M. (2009). Introduction to seismology. Cambridge: Cambridge University Press.