Investigating a firn aquifer on the Juneau Icefield

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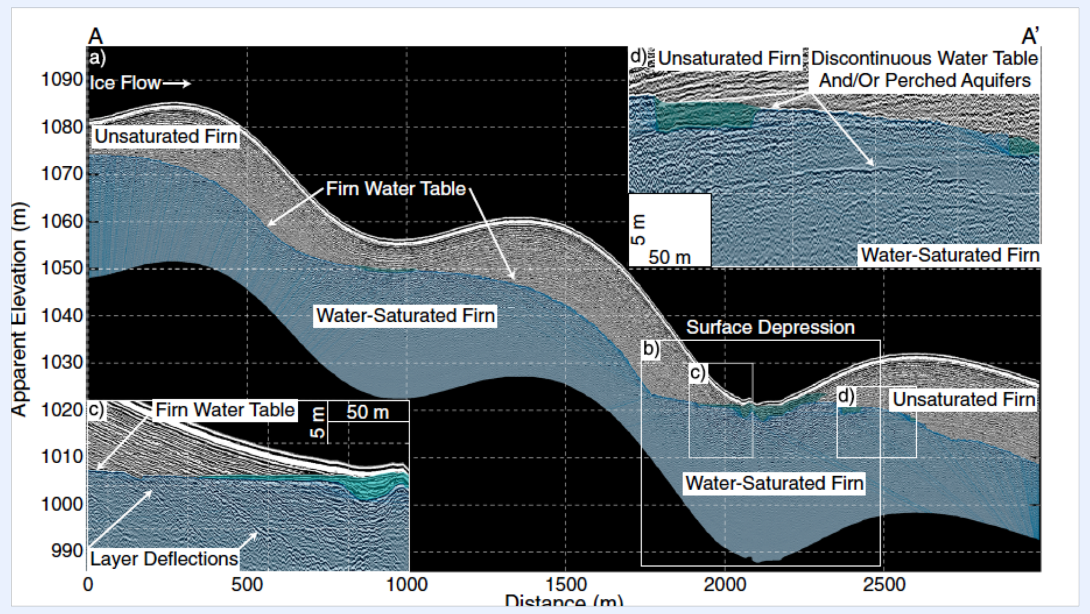
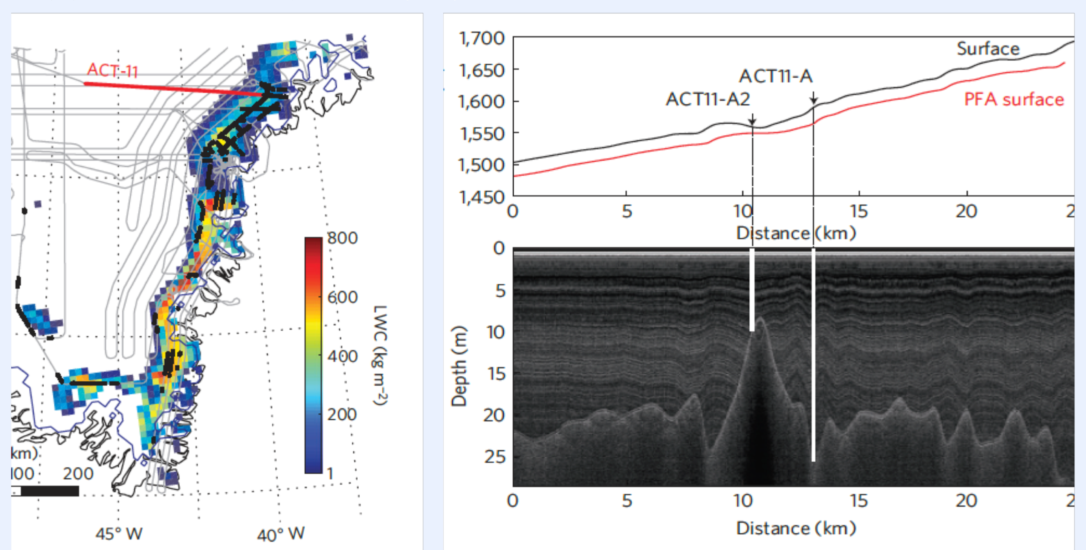
Motivation

- Firn aquifers **modulate glacial sea level contributions** by storing meltwater and the latent heat of that meltwater.
- Firn aquifers can change how ice flows by adding heat to the system, softening the ice.
- As climate change increases surface melt runoff from glaciers, the extent and storage of firn aquifers may increase.



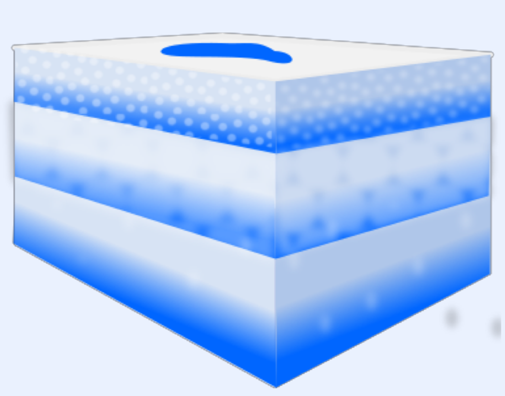
Christianson, K., Kohler, J., Alley, R. B., Nuth, C. & Pelt, W. J. J. van. Dynamic perennial firn aquifer on an Arctic glacier. *Geophysical Research Letters* **42**, 1418–1426 (2015).



Forster, R. R. *et al.* Extensive liquid meltwater storage in firn within the Greenland ice sheet. *Nature Geoscience* **7**, 95–98 (2014).

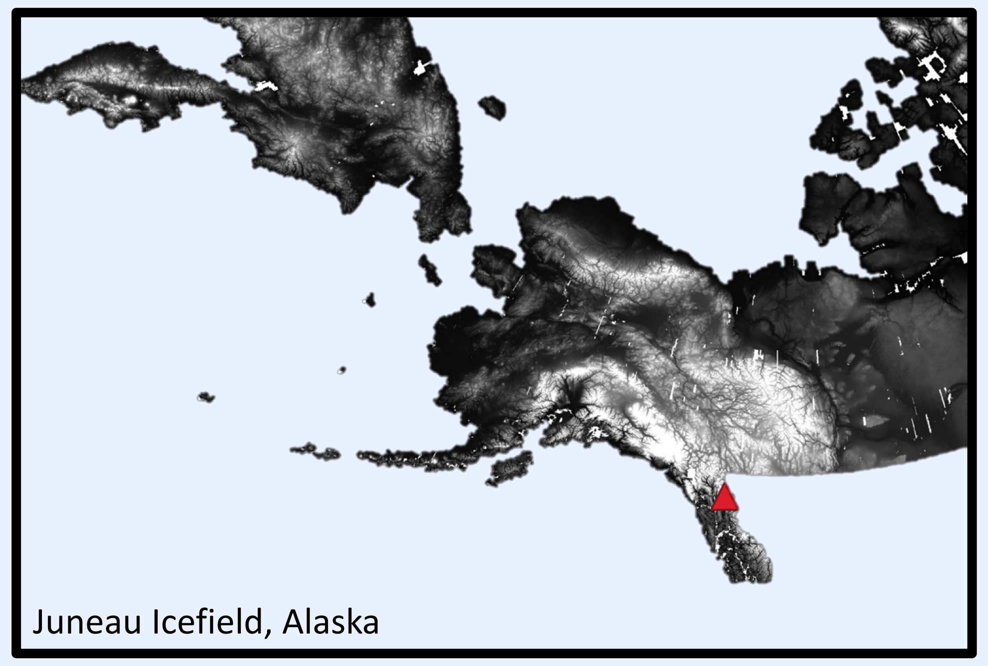
The top figure is a diagram of a firn aquifer on an arctic glacier, with unsaturated firn/snow at the top and an aquifer that extends to where firn achieves ice density.
The bottom two figures show the modelled liquid water content on Southeastern Greenland in a large perennial aquifer; the radargram shows the top of that aquifer.

Expected Results

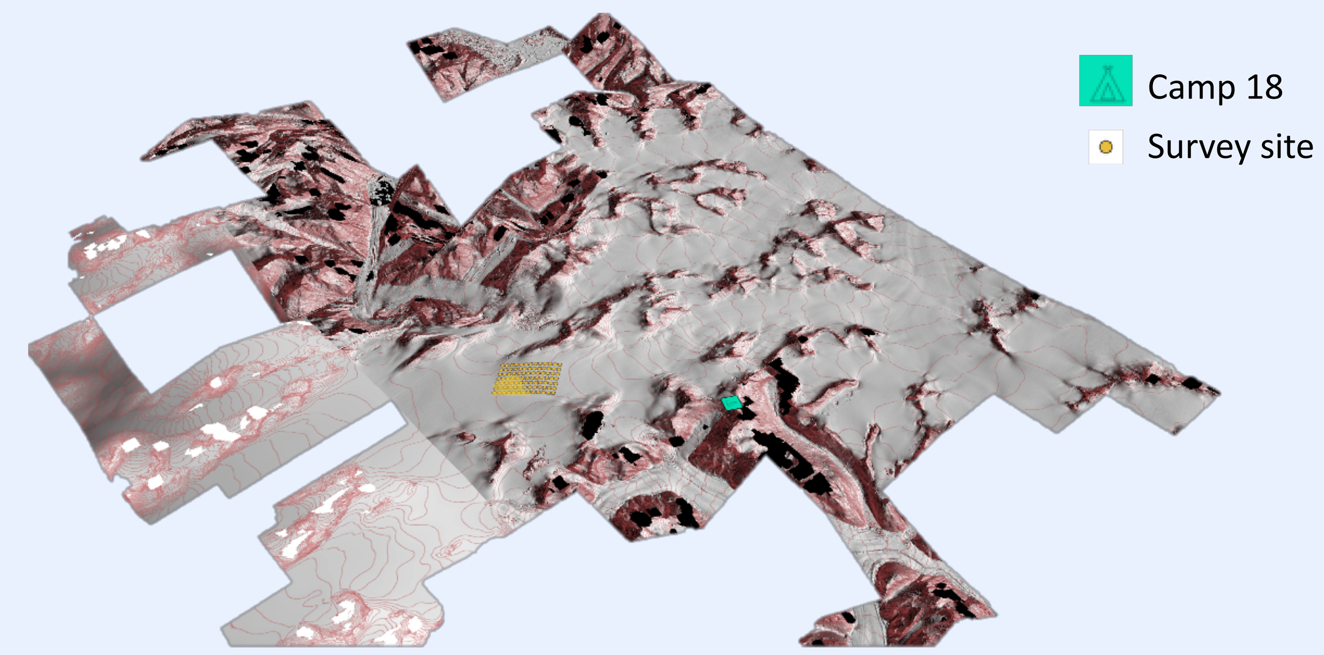


- We expect to **identify diurnal cycles of meltwater flow** through the firn by comparing the cumulative attenuation of the radar signal through the firn over the course of each day.
- We don't know if we will see more water where we have an aquifer (storage) or more water where we don't have one (indicates the meltwater leaves the divide)

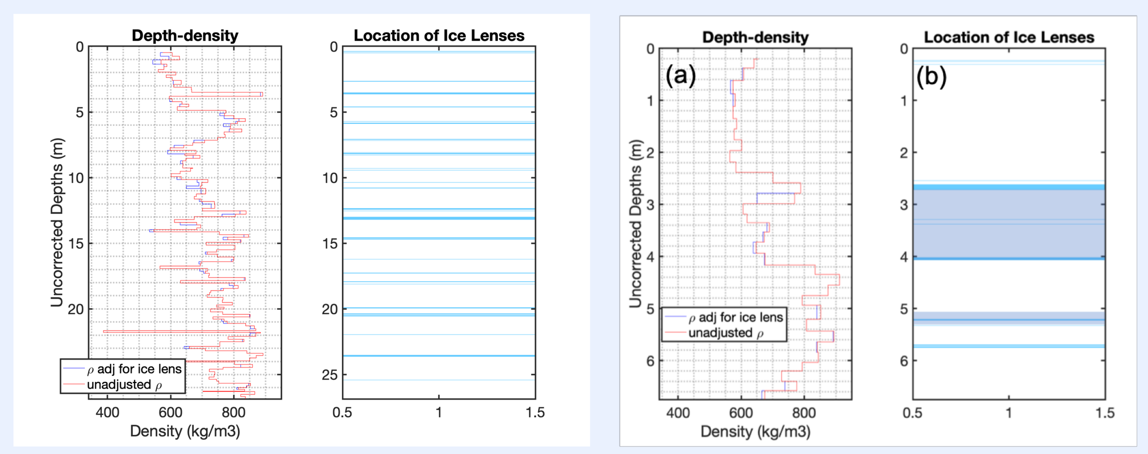
Previous Fieldwork: finding the aquifer



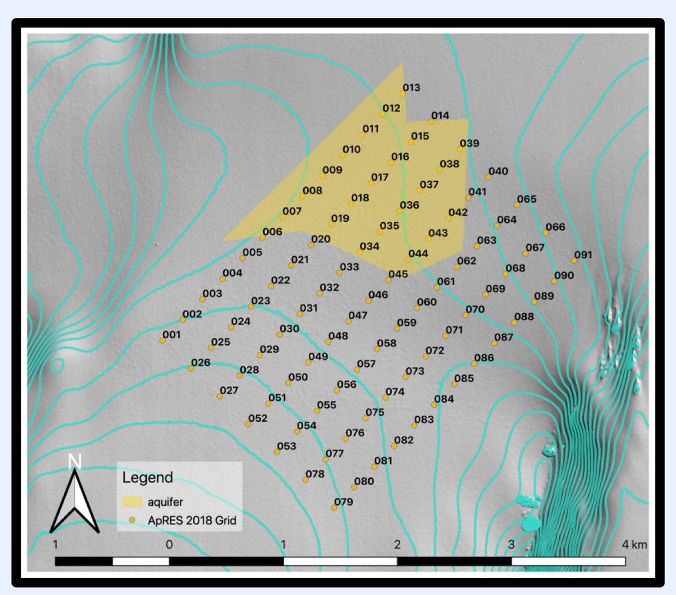
The Juneau Icefield, located east and north of Alaska's capital, is a mass of ice about the same size as Rhode Island and more than 2000 feet thick at its deepest. The Juneau Icefield Research Program has been monitoring its outlet glaciers for 70 years.

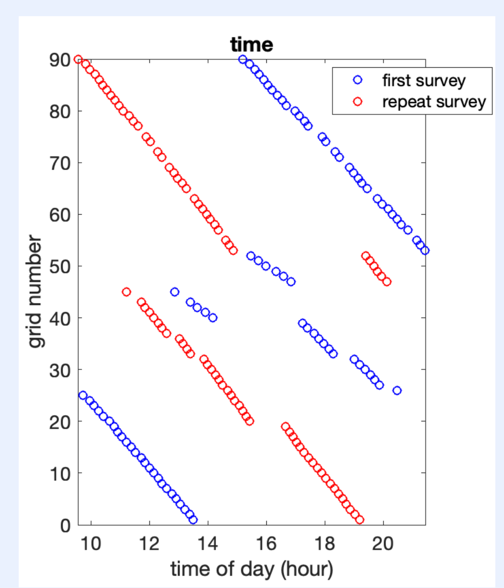


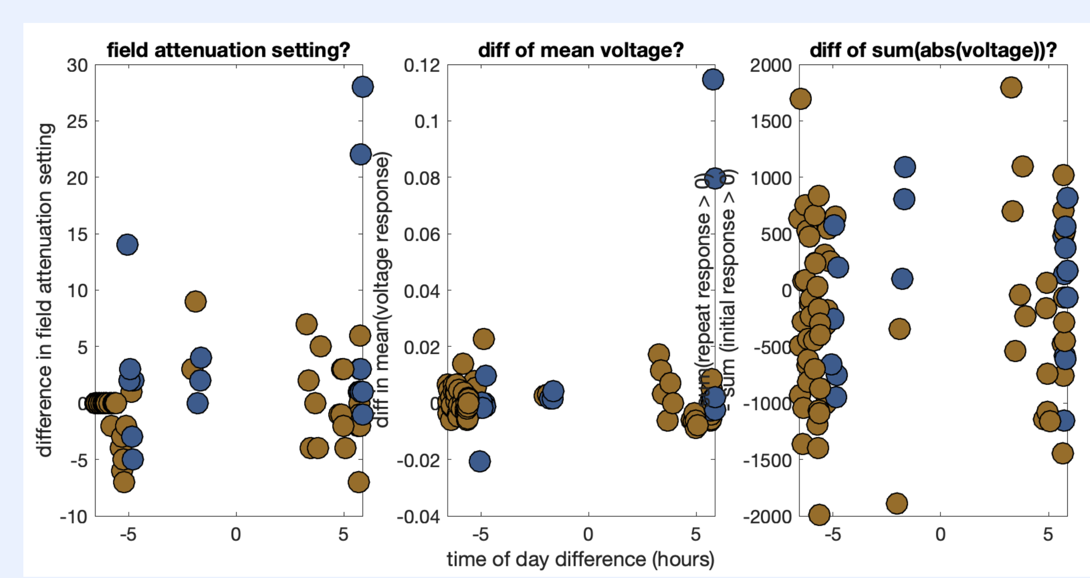
Our field site is on the ice divide of the Juneau Icefield – the glaciers on the northeastern side flow into Canada, and the glaciers on the south western side flow into the U.S. toward the coast. Our basecamp is Camp 18, a set of five wooden structures maintained by the Juneau Icefield Research Program and a six mile ski from the survey site.



We drilled more than 80m of **firn cores**, some of which we found dripped with water (indicative of a **firn aquifer**) and some of which were relatively dry (e.g. still frozen – as dry as water can be!). The leftmost core profile (density of the old snow on the left) shows one of the dry cores, with evidence of melt and refreezing from ice lenses (thick blue lines and left photograph). The right core profile shows a shallow core drilled near point 13, where we found evidence of the thickest **firn aquifer**. Between 3 and 4m, we found soaking wet snow.



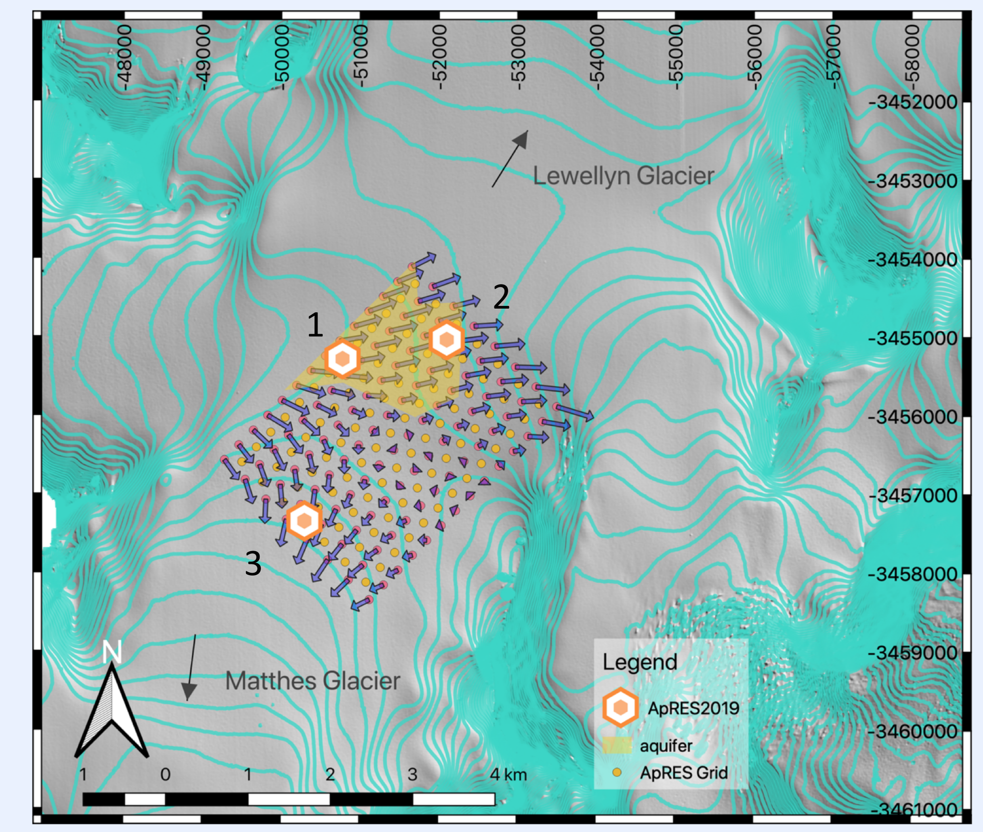




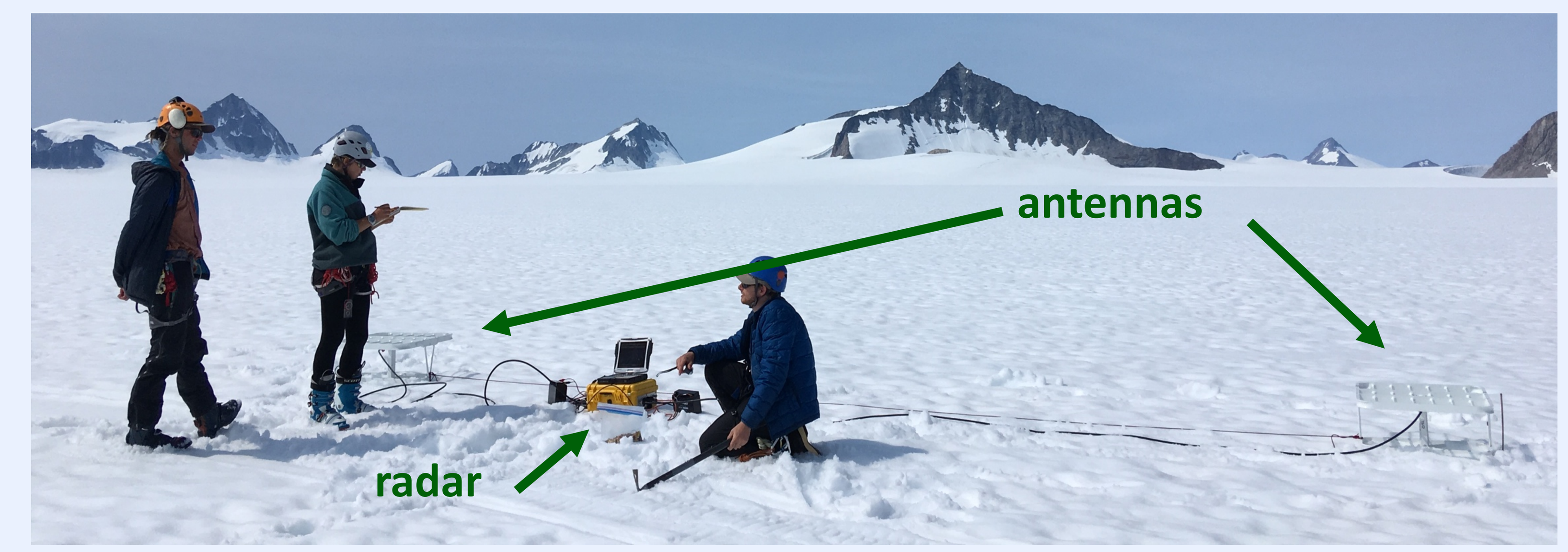
- We set up a 3 km^2 grid across the **ice divide** and took **phase-sensitive radar** measurements at 91 points, once at the beginning of our field season (first survey) and once at the end (repeat survey).
- Our survey was designed to investigate the vertical strain rate within the column, which tells us about how ice flows.
- Because ice is incompressible, any horizontal stretching will result in vertical compression. By comparing the relative downward movement of **isochrones**, which are layers in the ice we can see with the radar, we can understand how ice is flowing off the divide.

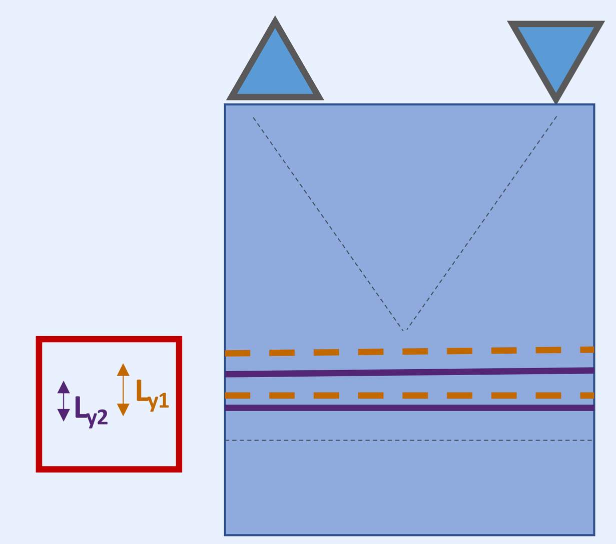
- Could our data also tell us something about the **firn aquifer** we found in our cores? Water slows down and scatters the radar signal, so we can expect a weaker signal with more water present.
- I compared first and repeat survey radar data to see if we saw any patterns related to the time of day we measured a point.
- The **blue circles** are survey points overlying the aquifer; the **brown circles** do not, but are not necessarily dry. We do not see any patterns in our 2018 data that might indicate we measured water content – which means I get to head back to Juneau in July 2019.

Methods: monitoring water flow



- This summer, I will return to the Juneau Icefield with three **phase-sensitive radars**. Two radars (1, 2) will be placed on the firn aquifer along glacial flowlines, while a third will monitor the southside of the grid (3). The radars will record continuously for 14 days.
- In addition, we will map the ice divide for **crevasses** with a drone and record the **surface energy balance** with an automated weather station.
- We can estimate the amount of water we ought to see through by modelling ice melt with our weather station data.





- Phase-sensitive radars send a signal of increasing frequency into the ice. Layers within the ice reflect the signal, which is then recorded by the radar.
- Between the first and repeat measurements, the ice layers can move relative to the radar because they flow with the ice (they are the ice!).
- We can see this movement by comparing the shape of the signal from each survey.
- Water in the firn or ice will 1) slow the signal, making it look like layers are deeper, and 2) scatter the signal, reducing the power of the signal return.

Broader Impacts

- The **Juneau Icefield Research Program** brings students age 17-28 onto the icefield to learn mountaineering and glaciology over 8 weeks.
- I will teach two weeks of the geophysics curriculum, and design a creative writing course geared toward scientists for the students Students will be actively involved in the radar campaign on the ice divide.
- I will develop techniques and a codebase for using phase-sensitive radars to monitor meltwater flow through firn.