Firn densification in the accumulation zone of Kaskawulsh Glacier, Yukon Territory, Canada

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Abstract

As sources of fresh water and critical components of the global climate system, terrestrial glaciers are important features to monitor, particularly in light of anthropogenic climate change. Remote sensing techniques are being increasingly used to gather information on Earth's shrinking complex glacial terrains. However, these methods possess critical challenges, including capturing firn dynamics and the presence of ice lenses. Meltwater percolation and retention, as well as thermodynamic effects on snow and firn density can complicate the relationship between surface height and mass balance changes; lowering of the glacier surface may masquerade as a mass change as detected by remote sensing technologies. The St. Elias Mountains, straddling the border between Yukon Territory, Canada and Alaska, USA, are home to extensive icefields. While numerous mass balance studies have been conducted in this region using remote sensing, there is a significant lack of in situ measurements of accumulation zone processes and firn properties. Our research examines refrozen ice layers and firn densification processes in the accumulation zone of Kaskawulsh Glacier in the St. Elias Mountains. In spring 2018, we extracted two firn cores (20 m and 35 m) from the study area and conducted a snow stratigraphy and ice lens survey on both core sections. After subsampling and melting the cores, we analyzed major ion and isotope chronology to identify extreme meltwater percolation and refreezing events, both of which critically affect firn density. The snow stratigraphy analysis from both of the cores showed numerous refrozen ice layers, indicating surface melt and refreezing processes in the accumulation zone. Preliminary results from isotope chronology analysis reveal a wash-out of the glaciochemical pattern in the 35 m and the 20 m ice core at 15 m depth, thus indicating severe surface warming events and subsequent changes in the density of the firn. This may indicate errors in the assumed density of the accumulation zone snow and firn when using remote sensing technologies to infer mass balance of Kaskawulsh Glacier.

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1. INTRODUCTION

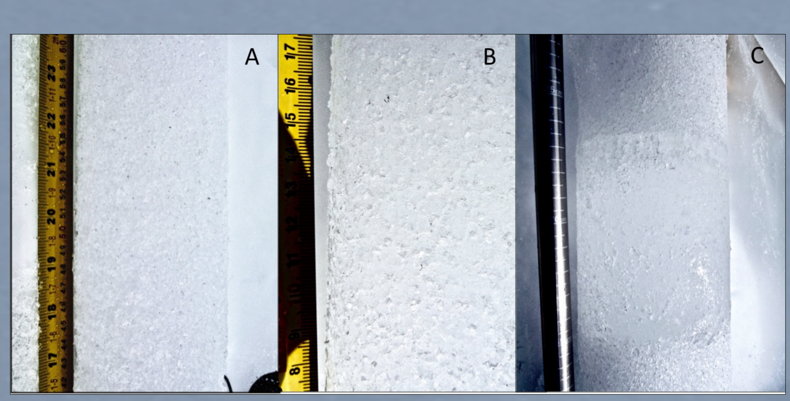
- The St. Elias Mountains in Yukon Territory, Canada and Alaska, USA, are home to extensive icefields and large glaciers, such as the Kaskawulsh Glacier
- Meltwater percolation and retention, as well as thermodynamic effects on snow and firn **density** can complicate the relationship of surface height and mass balance changes.
- **Lowering** of the glacier **surface** through densification may masquerade as a **mass change** as detected by remote sensing technologies.

2. QUESTIONS

- Is there a **greater** amount of meltwater percolation and refreezing in **recent** years compared to the **last decades**?
- How do ice content and firn density **change with depth**?
- What are the characteristics of the ion and isotope stratigraphy in firn at this site, and what are the **effects** of meltwater percolation and **refreezing** on this stratigraphy?

3. METHODS

In May 2018, with a field team of four, we dug one snowpit and drilled two ice cores 60 cm apart (depth of 21 and 36 m), using the Eclipse Ice Core Drill. In the field, we performed stratigraphy analysis and weighed 10 cm section samples for density calculations. Below is an example of A) regular firn, B) melt affected firn, and C) an ice layer.



Back in Alberta, we analyzed the melted 10 cm sections for oxygen-18 and deuterium isotopes, and the major ions.

4. RESULTS: Ice Content and Density

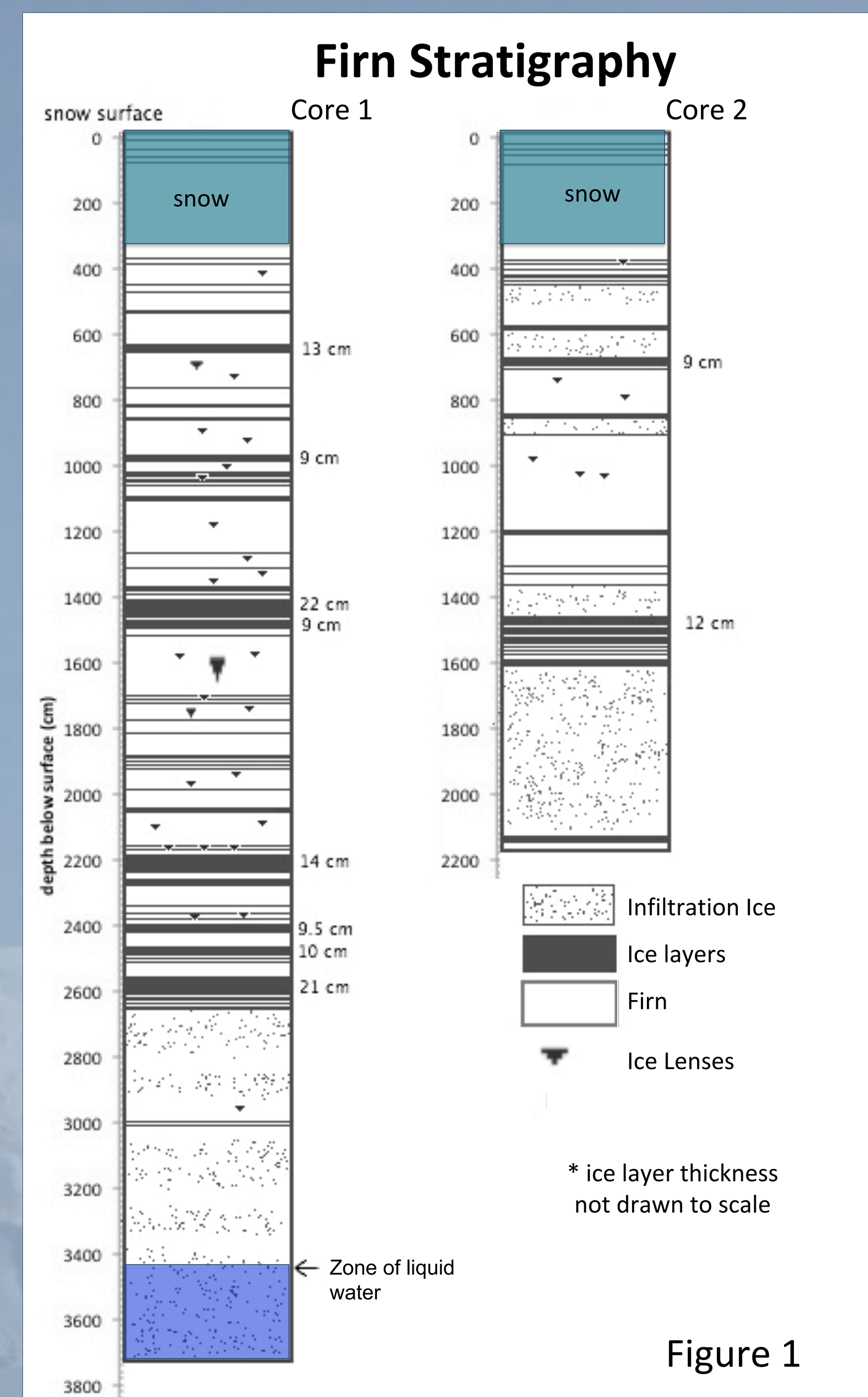


Figure 1

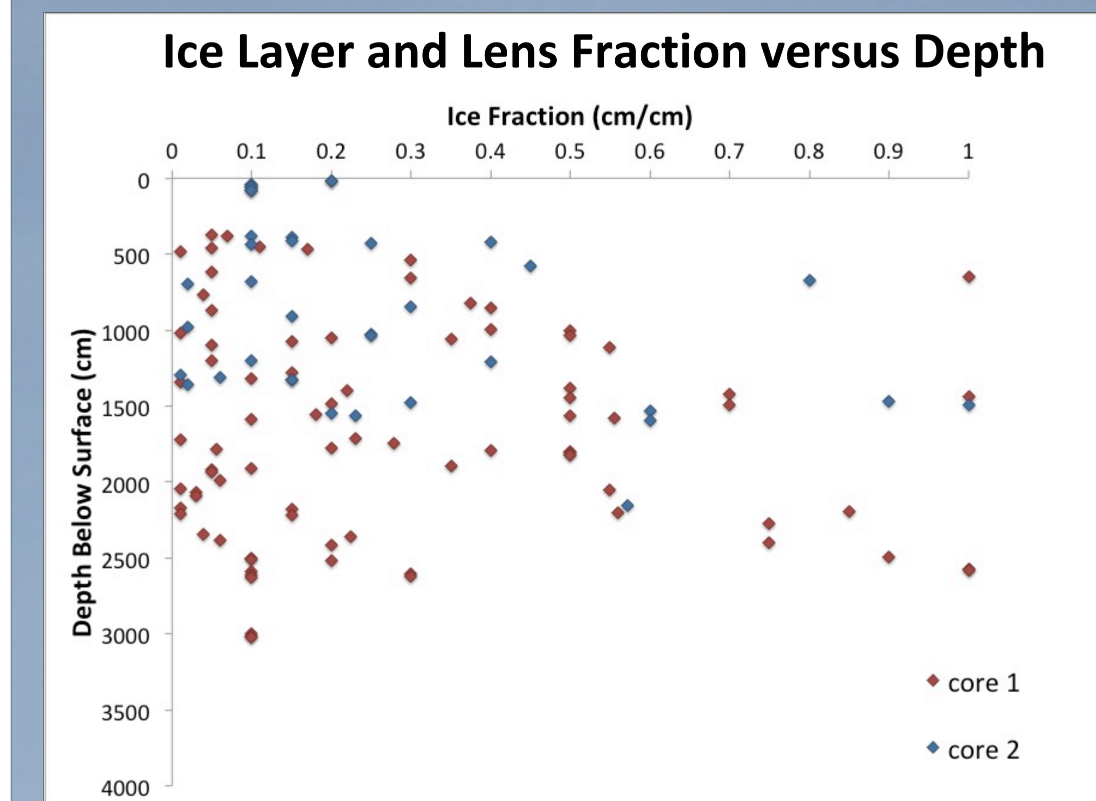


Figure 1 and 2 display the clustering of ice layers in the middle section of the firn. Ice fraction is total ice content per 10 cm sample. There are stratigraphic differences between core 1 and core 2 despite their close proximity, indicating small scale spatial variability. There is a decrease in ice layers when firn crystallography has been reconfigured due to meltwater percolation and refreezing at the greater depths (starting around 2600 cm).

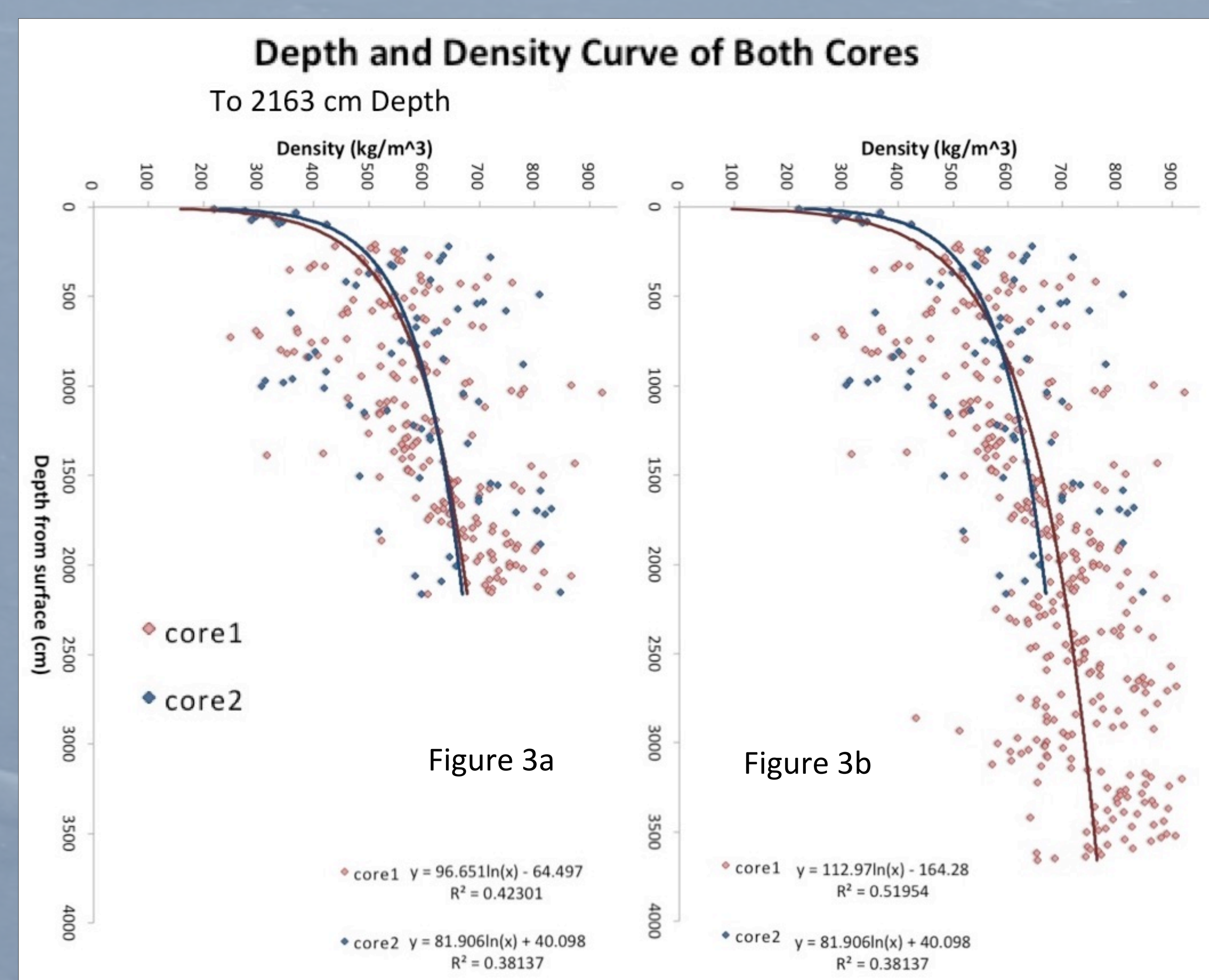


Figure 3a and 3b display the density with depth and the fitted curves. Figure 3a shows that core 1 and core 2 are visually similar down to 21 m despite the variation in ice layer content. Figure 3b shows that the curve shifts when the extra 15 m of core 1 is included, therefore a 21 m core is not sufficient for understanding how the density changes at the greater depths present in core 1.

4. RESULTS: Isotopes

Figure 4's arrows depict possibly six seasonal peaks of the negative winter isotope signal and no positive summer peaks. Only 1/3 of the calculated 18 years of accumulation is identifiable. (calculated from Wake et al., 2002) There are several sections of the firn where there is no distinguishable variation in the isotopic ratio.

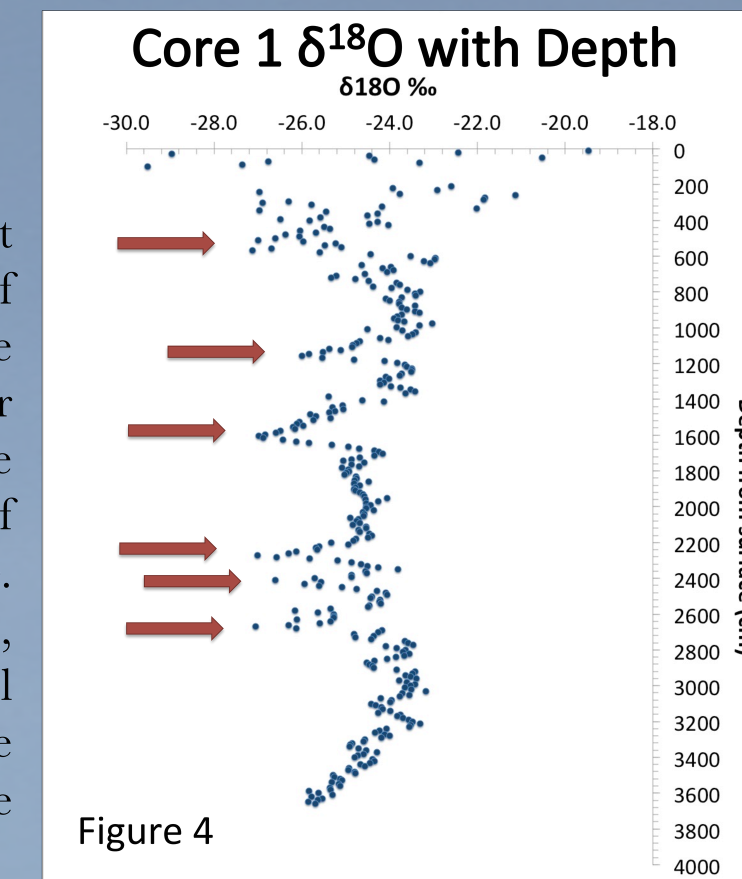


Figure 4

5. CONCLUSIONS

Large scale meltwater percolation and freezing introduces internal accumulation in the firn area of Kaskawulsh Glacier. This lowers the surface of the glacier possibly influencing altimetry measurements that provide pieces to the mass balance puzzle. At least 90 cm of surface lowering occurs and does not take into account the liquid water at the base of the firn ice transition zone, which is potentially a large scale firn aquifer. The presence of a firn aquifer further complicates the future of Kaskawulsh and its melt and run-off regime in the coming years. There may be effects on future coring endeavors for climate information due to the homogenization of the glaciochemical signature and the presence of liquid water. Further research includes greater evaluation on the effects on the glaciochemical time series and more information needs to be gathered on the dimensions and timing of creation of the firn aquifer

- Significant meltwater percolation and refreezing has occurred on Upper Kaskawulsh Glacier in recent years **permanently** altering the **densification** and firn **characteristics**..
- There is a **greater amount** of ice content in the middle portion of the firn layer **between 2000-3200 cm** in addition Core 1 density is only 36% correlated with ice fraction ($p < 0.05$).
- The internal accumulation of ice content is equal to 2.44 m, which can result in at least **90 cm** of **surface lowering**.
- The **ions** were entirely **washed out** and the **isotopes** mostly **altered**.

8. ACKNOWLEDGEMENTS

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Reference: Wake, C. P., Yalcin, K. & Gundestrup, N. The climate signal recorded in the oxygen-isotope, accumulation and major-ion time series from the Eclipse ice core, Yukon Territory, Canada. *Ann. Glaciol.* **35,** (2002).