Summary

Ice shelf thickness is often derived from surface elevation data by assuming hydrostatic equilibrium for a given depth-averaged ice column density. Then basal melt rates and other quantities can be derived from repeat mappings of ice-shelf elevation and velocity. The accuracy of these methods suffers from the assumption of hydrostatic equilibrium and assumed densities.

In this paper, the authors aim to address the validity of these assumptions by mapping depth-density profiles of from ice-penetrating radar data. The authors develop a method to infer the vertical density profile of ice shelves from wide-angle radar data using an inverse technique that fits reflector travel times assuming that the depth-density profile has a simple functional form. This new method is based on standard inverse techniques, but has not been applied to wide-angle radar data before in a glaciological setting. The authors develop of robust test of the method using both synthetic models and independent density profiles measured using optical televiewing of profiles on the same ice shelf.

I found this study well-developed and the paper is well written. Most of my comments are minor and can be addressed without significant reanalysis of the data. This paper is both interesting an important. As estimates of basal melt rates from surface elevation data becomes more common due to the proliferation of satellite techniques that can accurately map surface elevation, studies like this are needed to qualify the satellite-based estimates of basal melt. Many groups use radars similar to those of the author, so the techniques they describe could be employed by a variety of groups in a variety of glaciological settings.

Scientific Points

1) This study assumes a uniform snow density at the surface? How valid is this assumption?

2) The reasons for spatial variability in firn densification are not that well developed. What factors might lead to denser snow in the channel? Is it just the drift accumulation that would be scoured off ridges and deposited in channels? Or are there strain feedbacks from this loading that also matter?

3) Although most of the profiles the authors present seem simple, channel basal topography is generally complex. What modifications of the method are feasible to allow it to be adapted to profiles conducted over areas of more complex ice-shelf bottom topography?

Data/Code Access

Do the authors plan to release their data (as an example) and/or code to the community? This could be beneficial to multiple groups who use similar radars. Does *the Cryosphere* have a similar data police to AGU journals?

Grammar/Style:

1) Some would object to using inverting as you do. You are inferring a quantity via an inversion, whereas inverting means taking x to 1/x. However, using inverting as you do as common practice, so I'm happy to leave the choice to the authors.

2) Subordinate clauses and appositive phrases are often lacking proper punctuation. For example, several times commas are missing preceding subordinate clauses (e.g., "…, which…".

Specific Comments

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5: Densification can have a strong a strain-rate dependence too.

6: Infer depth-averaged density? Or density over some depth interval?

9-10: This sentence is awkward. Maybe something along the lines of "We reconstruct depth to internal reflectors, local ice thickness and depth-averaged density using a novel algorithm that includes traveltime inversion and raytracing with a prescribed shape of the depth-density relationship."

15: Is this consistent with theoretical calculations of firn densification?

17: Awkward wording. Maybe "…which reveals that the firn inside the channel is 10% denser than the surrounding firn outside the channel"?

18-19: Awkward wording. Maybe "Hydrostatic ice thickness calculations used for determining basal-melt rates should account for the denser firn in ice-shelf channels."?

19-21: One critical weakness I see is practical. Many radar systems do not permit wide-angle acquisition.

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11-12: This is a more complex process than compaction as dynamic recrystallization may also occur affecting the density profile and that process depends on more than just overburden pressure (temperature and longitudinal and lateral strain are also important as are many other factors).

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1-10: Spatial scale of measurements might be important to mention here. This isn't a point measurement but it is still spatially limited and there are issues of matching the raypath samples

with that of the surface illuminated. So there must be an assumption of uniform density and flat reflectors over some area. Hopefully some of this is mentioned in the methods section to follow.

18-19: Discuss that some studies say they are destabilizing and others say stabilizing? Evidence for the effect on ice-shelf stability is conflicting.

25: Not sure imprint is the right word here, maybe “impact”?

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2: Change “monotonous to monotonic”? Not sure what mathematical connotation is attached to monotonous.

2: Some would object to using inverting as you do. You are inferring a quantity via an inversion, whereas inverting means taking x to 1/x. However, using inverting as you do as common practice, so I’m happy to leave the choice to the authors.

18-20: Might be worthwhile to note that triggering via this method would become unreliable due to missed air-wave arrivals at larger distance than you used (~ 1 km separation or more), which is an important consideration for surveys over thicker ice. Alternate triggering methods via fiber-optic cable or radio link should be considered.

25: Why was it necessary to handpick internal reflectors? They look quite bright in your data and easily pickable. What power criteria was used to pick reflectors, if first break or change in concavity in the Ricker-like wavelet common for these types of radars, an autopicker seems likely to be more dependable than handpicks.

25-26: What was your rationale for choosing reflectors? How many and why?

26: Could the reflection at Site 6 be associated with a basal terrace?

5656

15-20: How do you select v(z) configurations?

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2: Change objection function to “objective” or “cost” function?

Eq 11: Shouldn’t the C matrices be inverses?

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18: “inverstion” to “inversion”

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20: Any idea of how much A actually varies?

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11-14: There is a discussion between local and shelf-wide hydrostatic assumptions. Locally, the hydrostatic assumption does not hold, but over a large scale the entire shelf is in hydrostatic equilibrium. This method would allow estimation of the appropriate spatial scales for the hydrostatic assumption, which would be a useful application worth mentioning.

Figures

Figure 1: Perhaps just use gray color scale instead of red-green color scale. Or some other color scale, just to avoid colorblindness issues.

Figure 2: Make dot on Antarctic inset a bit larger.