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Interactive comment on "Water Content of Greenland Ice Estimated from Ground Radar and Borehole Measurements" *by* Joel Brown et al.

Joel Brown et al.

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Response to: Interactive comment on "Water Content of Greenland Ice Estimated from Ground Radar and Borehole Measurements" by Joel Brown et al.

Anonymous Referee 4

Received and published: 5 December 2016

Author responses are in italics.

Summary

In this study, the water content of the Greenland ice sheet near the margin is estimated.

This is achieved by combining ice sheet borehole and radar surveys from a 1km long transect in southwest Greenland. The reflected travel times from the radar data are inverted to calculate the electromagnetic propagation velocity of the ice body. The borehole data are used to constrain the inversion by providing data for ice sheet depth and the boundary between temperate and cold ice. Their results points toward, higher than previously thought, water content in the ice sheet, specifically in a thick temperate ice layer right above the glacier bed. These findings are an important contribution to the study of Greenland ice sheet as it will results in improved ice viscosity estimates and modeling of ice sheet velocity fields and ice thickness.

I can't speak to the details in the radar surveys and inversion methodology, but the overall methods are well designed. The paper is for the most part easy to read and follow. I don't have any major comments. I only provide some suggestion below for the authors to consider that may clarify the manuscript to readers. In particular those readers who are interested in the topic, but does not have a foundation working with radar data would benefit from some clarification of terms.

Author note: We understand that 'The Cryosphere' is intended for a scientific audience with a broad range of specialties in the cryospheric sciences and that some technical jargon used in this paper may be unfamiliar to part of the audience of the journal. However, this is true for every scientific paper published in this journal. In these comments from referee 4 there are many requests to explain basic geophysical terms, specifically comments 7, 10, 11, 14, 15, 16, 19, and 20 (below). We agree with the referee that a 'foundation working with radar data' greatly improves the potential for understanding the exact methods used in this study and appreciate the suggestions of the referee for increasing the understanding of the manuscript for a broader audience. However, we do not believe that the main text of the manuscript is a proper place for defining geophysical terminology. With this in mind, we have added a short glossary

of selected terminology to the Supplementary Information with the knowledge that in-depth understanding of the geophysical terminology will require further study by the reader lacking a foundation working with radar.

Minor comments:

1. Abstract:Mention the study period (2011 to 2012?)

We have added this information to the Abstract.

2. Page 2:L28-29: Add standard deviation to the mean values

We have added the standard deviation to the mean values

3. Page 2:L26-27: Clarify how the data were retrieved (e.g. datalogger) and the timespan of the study

We have added how the data were retrieved.

4. Page 3: L1: Add the depth of the reported temperatures and also over what time period the estimates are representative (e.g. a year?).

We have added the depth of the temperatures and that the temperatures are representative of the time over which they were recorded.

5. Provide the temperature of the temperate ice.

Temperate ice is, by definition, at the pressure melting point of ice, which changes with depth. This approximated relationship is given in figure 3c. We have made no changes in response to this comment.

6. Also rephrase sentence, change “boundary with temperature ice” to something like “boundary that separates cold and temperature ice”.

We have changed the sentence as suggested by the reviewer.

7. Page 3:L5. The meaning of “common offset” and “common source point” GPR needs to be explained for the reader. You kind of do this later, but consider briefly explaining it the first time you mention these two methods. Also, explain why it is important to use both methods.

“Common offset” is very descriptive and precise terminology for GPR surveys; “Common source point” is less common terminology for GPR surveys in glaciology, however, it is out of the scope of this paper to define basic GPR terminology. Further, as the reviewer states, we describe the acquisition setup for each method in the third and final paragraph in this section (2.2). To avoid repetition, we did not add to this section. Please refer to the ‘Author note’ above.

8. Page 3:L9: MATLAB

We have changed the case of the lettering as the reviewer suggests.

9. Page 3:L10: Check manuscript for tense, here present tense is used “ the wave is adjusted”, the previous sentence used past tenste “oscilloscope was triggered”. Make sure that the tense in the paper is consistent in each section.

The tense in the manuscript is consistent. All sentences that deal with data processing are in present tense. All sentences that deal with data acquisition are in past tense. This is the proper way of presenting each.

10. Page 3:L24: Add reference for Ormsby bandpass filter

This is a commonly used filter in geophysics. Please refer to the 'Author note' above.

11. Page 3:L28: Explain "spatial aliasing", and "stacking" and why it matters

Please refer to the 'Author note' above.

12. Page 4: L18-19: Explain "survey geometry".

We have replaced "This survey geometry is. . . " with "Common-source point multi-offset surveys are. . . " in this sentence.

13. Page 4: L20: Confusing. It is not clear what survey method are you using in this study, or why it matters.

This section describes why the survey that we use is more appropriate for our field site than CMP surveys. We have rewritten the section for clarity of which survey we are using.

14. Page 4: L24: Explain "dip magnitude"

Dip angle is a basic, common geological term. Please refer to the 'Author note' above. We have changed "dip magnitude" to "the magnitude of the dip angle" for clarity.

15. Page 4: L29 Explain "Dix inversion"

The Dix inversion is a common calculation used in geophysics to solve for the

layer by layer properties of the subsurface. Please refer to the 'Author note' above. We have added a reference to the dix inversion for clarity.

16. Page 7: L 24: Explain "RMS misfit". Is it the same as "RMSE"?

This is not the same as RMSE (RMS error). The RMS misfit is not a measurement of error, it is a measurement of how closely the forward model traveltime results match the multi-offset data. Please refer to the 'Author note' above.

Comments on tables and figures:

17. Table 1: The units are sometime provided in the header and always in the table (except for gain). Provide units in header or in the body of the table, but not both.

Gain does not have a unit, it is a coefficient. Please refer to the 'Author note' above. We have moved all units to the header.

18. Table 2: Provide a header for the column between S3 and S4 (upper layer, lower layer etc). Rephrase "clear that the radar data" to "clear that the radar transect". Add text to explain that the inset Greenland map shows the study area. Add text to explain that the rectangle in panel a is the outlines of the WV-2 image in b.

We have made the changes that the reviewer suggests.

19. Figure 2 caption: Is "reflection picks" a scientific term? Can you use another word than "picks". Also mention the geographic direction of the glacial flow in the last sentences.

Reflection 'picks' is a scientific (and descriptive) term; thus, it is the appropriate term to use here. Please refer to the 'Author note' above. We have added the

geographic flow direction to the caption.

20. Figure 3 caption: Explain “moveout”, “interfacial”.

These are basic geophysical terms and therefore out of the scope of description of this paper. Please refer to the ‘Author note’ above.

21. Clarify what “Dashed lines are the velocity model boundaries” refer to by adding the color of the dashed line in question.

We have clarified that the dashed lines that represent the model boundary are in panel (b).

22. Explain that the temperature profiles are collected at site S3 and S4 respectively.

We have labeled the temperature profiles with their respective locations.

23. Figure 3 other: Revise the black dashed line with another color, they are very difficult to find in panel a.

We have changed the color of the dashed lines in panel a to red.

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