

Interactive comment on “Thermal structure and drainage system of a small valley glacier (Tellbreen, Svalbard), investigated by Ground Penetrating Radar” by K. Bælum and D. I. Benn

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GENERAL COMMENTS

In this paper the authors investigate volume losses, thermal regime and drainage system of Tellbreen, a small valley glacier located in Svalbard. They report interesting results, which can constitute useful reference for future research on this very accessible (20 Km from the main settlement in Svalbard) glacier. Ground penetrating radar data are used to infer a cold based thermal regime at Tellbreen, however, the presence of several englacial-subglacial reflectors interpreted as partially water-filled channels suggest the existence of a diverse drainage system that is capable of storing, trans-

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porting and releasing water all year round. Additionally radar-derived ice-thickness measurements combined to existing maps of the glacier allowed volume calculations and assessment of the recent (post Little Ice Age) volume loss. This study provides new insights into our understanding of the hydrothermal structure of Arctic glaciers and therefore I find it suitable for publication for ‘the Cryosphere’. However there are few weaknesses and there is large space for improvements, especially regarding clarity. A more thorough reference to the appropriate radioglaciological literature is also needed. I will be happy to review the revised version of this nice piece of radioglaciological work. My suggestions are a number of minor points but these all together can represent a major revision.

The only scientific issue I would like to point out is about the conclusion regarding the thermal regime of Tellbreen. The importance of this is highlighted by the title itself of the paper. The thermal structure is only briefly mentioned in section 4.1 (third paragraph). I think it deserves a separate section for itself. In this section would be nice to discuss the thermal structure of the glacier using the Blatter & Hutter, 1991 classification and criteria (thermodynamics, latent heat, strain heating). I believe the authors are familiar with it since it has been recently mentioned in one of Prof. Benn’s recent work. What do you think is the thermal structure like in the accumulation area? Why Tellbreen is cold based? It is similar to Longyearbreen? How does it compare to other polythermal glaciers (e.g. Bakaninbreen or midtre Lovenbreen) in Svalbard? It should also be stated a cautionary note: the absence of scattering-rich ice in the radargram might not preclude the presence of temperate ice at the base (if the ice has very low water-content). Perhaps in an outlook end of the section it could be suggested that a direct comparison between temperature profile and radar [e.g. Pettersson et al., 2003; Gusmeroli et al., 2010] could confirm the cold-based idea for Tellbreen.

The paper is fluently written but, in places, non-intuitively structured. Clarity of presentation can also be improved. A thorough check from the authors on the way of referencing is required before publication. Figures need some modifications. I outlined

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my suggestions for improving structure and clarity in the specific comments. Also few relevant scientific issues are pointed out. References are attached in a separate pdf.

SPECIFIC COMMENTS

I suggest to re-structure the paper as:

1. INTRODUCTION

2. SETTINGS (Figure 1)

3. METHODS

3.1 GROUND PENETRATING RADAR, ACQUISITION AND PROCESSING

3.2 AERIAL PHOTOGRAPHS AND MAPS

4. GPR PROFILES

4.1 ICE THICKNESS ESTIMATES FROM GPR and MAPS (Figure 3)

4.2 THERMAL STATE FROM GPR (Figure 7)

4.3 BASAL REFLECTIVITY (ADD FIGURE with radargram with basal reflector and measured reflectivity; Figure 5; Figure 12)

4.4 WATER IN THE GLACIER (Figure 4; Figure 6; Figure 9; Figure 10; Figure 11)

5. TEMPORAL CHANGES IN GEOMETRY AREA AND VOLUME (Table 1, Figure 2, Figure 8)

6. SUMMARY AND CONCLUSIONS

ABSTRACT: you say that Tellbreen is a cold-based polythermal glacier at line 6. However I understand that this is a result of your investigation using radar. Say it clearly in the abstract. See also my paragraph 2 in the General comment: the fact that Tellbreen is a cold-based polythermal glacier needs to be clearly stated and discussed in the text.

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FIGURE 1. Put (a) and (b) so that we can refer to different thing. Svalbard (Fig. 1 a) and the glacier Tellbreen (Fig. 1b). A scale on the map would be nice. The approximate position of the equilibrium line altitude would help the reader in understanding the glaciological setting of Tellbreen.

PAGE 2171 line 22: medium size does not mean much to me. Change to 3.5 km long (stated in the abstract)

PAGE 2171 line 26: here is where you reference Table 1 for the first time. Table 1 contains results of your calculations. Move it to the results section.

PAGE 2172 Line 2. The whole sentence before Equation (1). Move everything (so from "The volume of the glacier is calculated. . . " to "(Hagen, 1993)" to the methods section. Here you explain how you calculate results showed in Table 1. Is not necessary right here.

PAGE 2172 Line 9. "We have observed open water in front of the glacier even at times when temperatures were below.." photo? Why not provide a photo of this and ad it as a third panel to Figure 1 (e.g. Figure 1 c)?

PAGE 2172 line from 10 to 16. The whole paragraph about geology and pingo is not relevant to the paper. Delete it.

3. METHODS - state them clearly. Here some work is required. You nicely state the three aims of the paper in the Introduction [(1), (2) and (3) in the last introductory paragraph]. Now describe the methods you use to accomplish these three aims

I suggest the following new method section with only

3.1. GROUND PENETRATING RADAR (spell it out in title section). With this you will accomplish aims (1) and (2) - remove section 3.3 and attach it to a bigger section 3.1 which now will include Data collection and processing.

3.2. AERIAL PHOTOGRAPHS AND MAPS These will be used to accomplish aim (3).

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Here you need to introduce the maps you will use. Explain that you will estimate ice thickness and volume variations since the LIA using two different approaches: (a) Equation 1 from Hagen, 1993 and (b) your 3-D model, which comes from a combination of radar-derived ice-thickness and existing maps. You don't really state all these important info which need to be stated clearly.

e.g. 3.1 GPR data were collected during the spring field seasons... in order to determine the thermal regime of the glacier, locate englacial water and measure ice-thickness 3.2 Aerial photographs and maps were analyzed to calculate areal and volume changes since the Little Ice Ages. Explain the calculation and the model here.

PAGE 2174 the whole paragraph between line 4 and line 11 It does not make much sense the fact that you measured 0.16 m/ns at Longyearbreen and then you use 0.17 m/ns. 0.16 m/ns is not close to the theoretical value for clean ice (0.16 is a very low value which indicates very wet ice). This paragraph might benefit a little bit of re-thinking. I suggest don't even mention the CMP at Longyearbreen (is another glacier) and (a) Just simply use the speed of 0.168 m/ns typically applied in time-depth conversion in radio glaciological studies on polythermal glaciers (Pettersson et al., 2003; Gusmeroli et al., 2010). Or (b) use the speed 0.17 m/ns but justify it. This value is typical for cold, dry ice with some little (2-3 %) volumetric percentage of air in it [Gusmeroli et al., 2010], which is pertinent to your case. We measure such a value of 0.17 m/ns with borehole radar at Storglaciaren [Gusmeroli et al., 2010]

PAGE 2175 LINE14-27 and PAGE 2176 LINE1-20 Move to the new section 4.1. These are results.

PAGE 2176 LINE22-29 and PAGE 2177 LINE 1-22 Move to the new section 4.3.

PAGE 2176 EQUATION 2 I think the reference Nielsen, 2001 is not very informative for the reader. Nielsen's thesis is in Danish and the reader might struggle in looking up the equations you use. I suggest change the reference to the classic radioglaciological textbook of Bogorodosky et al., 1985. In the book, chapter 1, page 12, Equations 1.9

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we can see the same equation you quote. Also you need to mention that this equation refers to a wave incident on a planar interface. This could be the case in the middle of the glacier but it may not be true on the side. I think more thoughts on this could be beneficial for the clarity of the paper. Also reference Stuart et al., 2003 in your discussion about dry interfaces etc in LINES 1-11.

PAGE 2177 last paragraph LINES 12-22. It is not clear what you did. The sentence this was done using the surface Attribute in Petrel. The algorithm used was a sum of.. does not give enough info. This is a nice part of the paper and needs further explanation. You need to make the reader aware that bed reflectivity does not come only from the reflection coefficient; there are other factors that need to be taken into account such as dielectric attenuation (e.g. Jacobel et al., 2010). Why don't just show a sample radargram where you suspect there is a wet interface? From this radargram you can simply measure the reflectivity at the bed and you can plot it. You can interpret area of high reflectivity as wet. You also need to reference a little bit the appropriate radioglaciological literature. Have a look at Murray et al., 2008; Pattyn et al, 2009 and Jacobel et al, 2010 to provide to the reader a better idea on how we can infer wet beds from radar surveys. Figure 5 is not very straightforward. Show where is located in comparison to the entire glacier.

FIRST PARAGRAPH OF SECTION 4.1 Here you explain how you did the volume measurements. Move to methods in the new section 3.2.

SECOND PARAGRAPH OF SECTION 4.1 Move to the new section 5 where you present and discuss these changes.

THIRD PARAGRAPH OF SECTION 4.1 Here you discuss the thermal state. MOVE to new section 3.2 and reference to a radargram. E.g. show the lack of scattering-rich ice.

PAGE2179 LINES 6-15. Sentence starting with There are no indications that.. here you switch from thermal state to length changes correlated to surge-non-surge. MOVE

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TO new section 5.

PAGE 2179 LINE 22 whereas canyon-like morphology appears as a series of slightly offset, stacked hyperbolae ADD A REFERENCE TO THIS

PAGE 2179 LINE21 ADD partially filled BEFORE englacial channel, If I interpreted correctly. Also show a schematic of the channel (e.g. Stuart et al., 2003 – Figures 1 and 2). Add a figure to illustrate these travelpaths. E.g. add a panel in Figure 9

PAGE 2180, reference the Radioglaciology book Bogorodsky, 1985 instead of Annan.

PAGE 2180 Paragraph starting at line 25 is Figure 12 similar to Figure 5? Is a repetition? What is the difference between these? Why don't you show them together if there is difference? Explain.

PAGE2180 LINE27 can you indicate the zones you are described in the map?

PAGE2181 LINE4 indicate the water-bearing channel in Figure 5. Where is it?

All the maps. Put a scale on the maps.

PAGE 2182 what is a talik? Do not introduce new words in conclusion.

TABLE 1 – Explain what all the abbreviations are in Table caption. FIGURE 1 – Divide in (a) and (b). Add (c) photo of icings, which is a direct evidence of winter-water release.

FIGURE 2 – Explain all the abbreviations in caption. Check spelling. Indicate upper and lower curve. E.g. Plot of ice thickness, upper curve and mean ice thickness, lower curve of Tellbreen..

FIGURE 4 – Add reference in caption to explain where you take these values

FIGURE 5 – show where is located in respect to the entire glacier Mark areas that you refer in the text with arrows or symbols.

FIGURE 6 – what does <50 from profile means. Explain in Figure caption. <50 what?

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FIGURE 7 – Delete the numbers on the right side of the figure. What are they?

FIGURE 9 – Add (a), (b) to the two Figures. Add a third figure where you show the schematic of the travelpaths you reference in the text. Also why the main arrival from in the radargram is at 170 ns and in the wavelet is at 350 ns? Am I misunderstanding something?

FIGURES 10 AND 11 add (a) and (b)

FIGURE 12 This is a summary map. You reference the thickest bit in the text. Add scale, ice-thickness, flow direction and approximate equilibrium line.

TECHNICAL CORRECTIONS

PAGE 2170 LINE 23 Reference Humlun, 2003 is Humlun et al., 2003 – a thorough check in the way you reference is required. It happens often later on in the paper.

PAGE2171 LINE9 GPR spell it out at its first occurrence e.g. Ground Penetrating Radar (GPR)

PAGE2172 LINE6: LIA spell it out fully as its first occurrence e.g. Little Ice Age (LIA)

PAGE 2174 line 5: Van der Veen reference is not included in the reference list

PAGE 2173 line 18. Add common offset before GPR lines.

PAGE2173 line 21 CHANGE PulsEKKO to PulseEKKO

PAGE 2174 line 21 CHANGE resent to recent

PAGE 2181 LINE16 CHANGE below to beneath.

Reference Hagen et al., 2003 – there are two. Name them with a and b.

Please also note the supplement to this comment:

<http://www.the-cryosphere-discuss.net/4/C1011/2010/tcd-4-C1011-2010-supplement.pdf>

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Interactive comment on The Cryosphere Discuss., 4, 2169, 2010.

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