

## ***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

This paper largely concerns GPR investigations of a small valley glacier in Svalbard, and gives some suggestions as to how GPR can be used to identify and quantify the size of internal-drainage channels and their mechanisms of formation. There is also some consideration given to the changing dimensions of the glacier since the Little Ice Age Maximum.

I feel the paper does contain some interesting elements, in particular the use of GPR signals to identify different aspects of subsurface drainage channels. It also contains

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four seasons' worth of GPR observations from an arctic glacier, which is an impressive record that is worth supporting with a publication. For this reason, the paper is worth following up. However, in its current form I feel it requires major revisions and a further review before becoming acceptable. The major reasons for this concerning the paper in its current form can be summarised as follows (but I will also give more detailed suggestions below): (a) it is not well structured and rather unfocused; (ii) the writing contains a lot of minor errors; and (iii) there is a lack of attention given to wider implications of the study and thus the paper fails to extract the value it could from the impressive dataset. This may sound rather negative but I encourage the authors to persist with a more focussed submission that can address these concerns.

### SPECIFIC COMMENTS

#### Scientific focus

I think the paper in its current form tries to address too many issues at once, whereas it would actually benefit from having a much tighter focus. I would suggest that by far the most interesting element (because it remains little discussed in the literature) is the use of the GPR to locate and investigate the characteristics of drainage structures in this “cold-based” glacier. Indeed, simply showing evidence that water can, under certain circumstances, flow through ice interpreted as cold from radar data is still required; I have been involved in work of this nature at polythermal John Evans Glacier (Bingham et al., 2005); water flow through patches of cold ice was inferred through White Glacier, Arctic Canada, as far back as the early 1970s (Müller and Iken, 1973); and the concept has been reinvigorated with recent hydrology-dynamics work in Greenland (Alley et al., 2005; Bartholomew et al., 2010) - yet it remains physically non-intuitive, so presenting evidence for its existence, and explaining how it can happen in different contexts, is worthwhile. Where the authors have particular potential here is in building on their use of radar data to interpret englacial channel morphology, and considering further why areas of water can persist beneath a small cold-based glacier over winter and contribute to proglacial icings (I expand on these points below).

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By contrast, the element of the paper that concerns 'mapping' of the past (larger) extent of the glacier is rather overwritten, and is mostly an elementary exercise the principles of which would be largely familiar to most readers of this journal. There are data/maps here that are of some interest (without the overlong exposition of their generation) and might better contribute to a differently-focussed paper (perhaps to another journal) and the WGI; but I don't think that they complement the more interesting focus on the radar analysis of thermal structure and englacial channel morphology. That the glacier was larger and thicker in the past is an element can be stated in the discussion of why water persists overwinter in the "cold" ice (cf. Wohlleben et al., 2009) – but this can be stated concisely with brief reference to the old maps and geomorphological evidence without requiring the detailed DEMs.

#### Structure

In its current form the paper contains several deficiencies in its structure: (i) it does not have a distinction between results and discussion; (ii) the conclusion is overlong and contains superfluous summary material (more appropriate, perhaps, for a thesis, but less so for a relatively short journal paper); (iii) the methods section contains too much detail in describing 'standard' methods of DEM analysis (which contrasts with a lack of the detail and discussion of wider implications required in the discussion section); and (iv) there are too many diagrams (some of these can be combined to become more effective) and they are not ordered consistently with their first mention in the text.

I suggest a revised structure and some guidance as follows; the extent to which this is followed is the authors' and editor's prerogative.

Consider a change of title Abstract 1. Introduction – largely OK as written, but suggest removing aim 3. 2. Background 2.1 Water flow through cold ice – Introduce idea that few studies have shown water flow through cold ice, and then use material from last two paragraphs of existing Section 2, but in reverse-order, i.e. so that you discuss hydrofracture first, and then cut-and-fill. You can close the section saying that cut-

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and-fill true for many Svalbard glaciers, including Tellbreen, that you now introduce. 2.2 Field site – Introduce Tellbreen. I would entirely cut out the paragraph on geology unless you can state why it is of relevance for the study. There should also be some explanation in this section for why it is thought that the glacier occupies a low-erosion setting (you allude to this in the current summary section, p13, line7-9, but it should come in at this stage; it's important because it's supporting evidence for the glacier's cold regime). 3. Methods 3.1 Data acquisition – from existing Section 3.1 3.2 Radar data processing – largely from existing Section 3.3 (i.e. I advocate not including lots of detail on the DEM generation / outline mapping)

(At this point my suggested structure diverges a lot from the existing paper...) 4. Results - Present, but at this stage do not explain, results of 4.1 distribution of water under glacier, i.e. current Fig. 12; and 4.2 radargrams showing evidence of channels, e.g. Fig. 9 right panel.

5. Discussion – fundamentally what I think you need to include in this section is more material explaining why the findings from Tellbreen have wider implications for glaciology/radar analysis...

5.1 Basal water distribution. Discussing the results presented in Section 4.1, you can (i) confirm that at this glacier there is water at the bed overwinter, which is likely the source for the proglacial icing, and therefore for other proglacial icings (rather than having to be evidence for polythermal conditions as in e.g. Hagen et al., 2003). A significant point for discussion is then how can you reconcile the existence of subglacial water with what you interpret from the radar to be cold-based ice. One possibility is that ice is warm just at the basal interface (in effect existing in a diffuse layer too thin to be detected by the radar, e.g. Copland and Sharp, 2001). A further possibility (not exclusive of the former) might be that when the glacier was larger it was thick enough to maintain warm basal conditions; now that it is smaller this is no longer the case; but that the annual injection of supraglacial melt just maintains parts of the interface at a sufficient temperature to allow coexistence of water and ice – I draw the authors' attention to Wohlleben et al.

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(2009).

5.2 Radar determination of englacial channel morphology. The data and models currently presented in Figs 9,10 & 11 are very interesting and I think could be presented more usefully in the form of a “conceptual model” of how radar returns bring out different aspects of channel morphology, from open to partly-open to completely closed (water-filled). Can you think about a way of combining Figs 9,10 & 11 into a single diagram, perhaps a series of the wavelet traces in a left-hand column against radar sections in the right-hand column, progressing through channel types with each row. Presenting the data/model in this way would more meaningfully show how the results have implications for other studies using radar to elucidate englacial channel structures.

5.3 Links between basal water distribution and englacial channel locations. Essentially a presentation of Fig 12 and the last two paragraphs of current Section 4 discussing distribution of englacial channels with respect to subglacial water distribution.

6. Conclusions – don’t bother with a summary; simply try to draw together the main conclusions from Section 5. Refer firstly back to why you did the study in the first place, i.e. to elucidate origins of water in proglacial icings at cold-based glaciers. The state in just a few sentences what the radar has now told us, i.e. subglacial water sources shown to exist, likely that they feed icings, associated with channels, radar used to discern channel attributes.

Issues of detail

P5, line 18: You state that Garmin GPS was used to position radar data in 2005, 2009 & 2010 – so what was used in 2004? P6, line 9: You do not state how 2010 radar data were processed (presume using Rad Explorer too, but this needs to be clarified). P7, line 23: While I argue in general for less detail concerning the DEM generation, I would like to see an explicit explanation for why the DEM underestimates the thickest ice. P8, line 8. The Nielsen (2001) reference is inaccessible to most of the readership, and in

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any case the equation is well known and can be found in Bogorodskiy et al. (1985)

Referencing

Throughout the manuscript, multiple-author papers are incorrectly referenced, and this can in some cases lead to confusion. For instance, in the first paragraph, line 10, the reference “(Hagen, 2003)” is given, but in the reference list one finds two Hagen et al. (2003) papers which cannot be distinguished from the in-text reference. At resubmission please ensure that the in-text referencing style is consistent with that expected for *The Cryosphere*.

I also feel that the paper is generally under-referenced with respect to wider bodies of related work, and work conducted outside Svalbard. For example, there has been other work on use of radar to map basal properties, e.g. Copland and Sharp (2001); Jacobel et al. (2009; 2010); Harper et al. (2010), King et al. (2008); and radar to map internal drainage structures, e.g. Navarro et al. (2005a; 2005b), Murray et al. (2000), Moorman and Michel (2000).

Figures

As stated above, one immediate problem is that the figures are not ordered as they are mentioned in the text. However, I think some are unnecessary and some others can be combined so that ultimately a more focussed suite of figures is generated.

Fig. 1 – Essentially this is a location map which could be reduced to an inset in a subsequent figure. In fact, if one were following the suggested structure above, a new Fig. 1 could essentially show a map of the glacier with the radar lines (perhaps also including map of basal conditions inferred from the radar, as in current Fig. 5), and the location map could simply appear as a small inset in this figure.

Fig. 2 and 3 – may not be necessary in revised manuscript, but if DEMs are drawn, they would be better shown with radar lines superimposed.

Fig. 4 – I may be wrong but this looks like it is sourced from another study. If this is the

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case, no need to include this figure, just refer to its source. If this is not the case, the figure needs more explanation as to how it was derived, especially with respect to the derivation of values for different materials.

Fig. 5 – caption is not clearly written, and I suspect the white squares are mislabelled.

I advise combining Figs 9, 10 and 11, but in the existing version: Fig. 9, scale in left panel is twice that of scale in right-panel Fig. 10, right-hand panel needs arrow showing source of trace shown in left-panel.

Fig. 12 – can probably be incorporated into the new Fig. 1 I advise above.

#### Technical corrections

Because I encourage a major revision, I highlight here only consistent errors that appeared throughout the manuscript, and would be happy to review a revision for more detailed technical corrections.

Decimals – all decimal numbers should use “period” separation (used in English language) rather than “comma” separation (correct for Scandinavia, but not for The Cryosphere!), e.g. p21, 0,17 m/ns should become 0.17 m/ns – but there are numerous examples throughout the manuscript including Table 1.

In all cases, where a quantity and a unit is given, e.g. 30 m, the quantity and the unit should be separated by a space. This is not always true in the current manuscript.

I think that in almost all cases used here, the word “areal” should be spelt “aerial” – this is certainly true for all instances of “aerial photographs.”

The plural forms “antennas” and “antennae”, and “hyperbolas” and “hyperbolae” are both used indiscriminately in the current text. Need to decide on a consistent form.

References mentioned above: Alley, R. et al. (2005) *A. Glac.* 40, 8-14.

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Finally, to re-emphasise, I think the manuscript presents some interesting ideas, but would be much more effective with a streamlined structure, more of a focus on the radar analysis of channels wherein lies its main novelty, and more attention paid to the wider implications of the research. I would be happy to review another draft.

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

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