

The Cryosphere Discuss., referee comment RC1  
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## Comment on tc-2021-179

Martin Lüthi (Referee)

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Referee comment on "Generation and Fate of Basal Meltwater During Winter, Western Greenland Ice Sheet" by Joel Harper et al., The Cryosphere Discuss.,  
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### General Comments

This is an interesting attempt to investigate, from in-situ measurements, the basal meltwater generation under the Greenland ice sheet during winter. While there is room for improvement, I think the manuscript can be published after taking into account the comments outlined below.

In Equation (1) the melt rate seems to be volumetric. This should be explicitly stated (units for all quantities). Also state that this is the conservation of energy in a small volume around the glacier bed.

The development in Equations (2) and (3) needs to be improved. Units for the quantities should be given (is  $M_{tot}$  a volume, ice equivalent or water equivalent, or mass?). As it is, it seems that volume (or melted mass) and area are confounded in (3), and there are tacit assumption on ice thickness. Also, it is not clear why all the subscripts are needed. A small sketch of the geometry would help clarify the situation. Figure 8a shows the envisioned geometry, but does not help in that respect since the quantities are labeled with words, without relation to the symbols used in the equations.

Also, the formulas (2) and (3) seem to be unrelated to the results. It seems that some kind of force balance is needed to properly calculate melt rates and cavity size, as larger cavities lead to larger stresses outside the cavities, and increased melt rates there.

The whole process is also likely spatially heterogeneous due to longitudinal and lateral stress transfer (e.g. Ryser et al, 2014 a,b). This might somehow be implied in the equations, but should be made explicit.

One further point to take into account: The melt will be generated not just at the bed (as assumed in Eq. 1), but also within the ice column, especially where vertical shear rates are high. I know that at the

drill site this component is very small, but this might not be the case on upstream or downstream obstacles. As a reference quantity, to which these results could be compared to, it would be interesting to calculate total dissipation of potential energy. This is proportional to  $u_{avg} * H * slope$ . This quantity would also give a good estimate on the percentage of heat generated at the bed with respect to total heat dissipated.

### Specific Comments

40 This was estimated to be an order of magnitude higher in Lüthi et al (2003).

46 What are storage sinks within the ice? Basal crevasses?

Figure 1, Caption: are all used data sets indicated here? Ordering them according to data set would make this clearer (e.g. water pressure at 27N, 27S and 33; GPS at 33 and 46).

Figure 1: dark blue on dark blue (station 46) is hardly visible.

113: The term "fitted" is better expressed as "instrumented with" for an international readership.

116: Why not just use pressure? Then it is absolutely clear what you are comparing.

125: What are the units of  $\dot{M}$ ?

142: You could add some qualifying statements that with longitudinal and lateral stress transfer could change local shear stress by a large percentage below/above average values. But on the km-scale this is likely to be averaged out. But then it is not clear, what the borehole deformation measurements mean.

150: also Ryser (2014a)

151: In light of the above comment, this need not be true, and internal deformation is likely exceptionally low at the drill site (as compared to e.g. Ryser, 2013). It would be interesting doing the same calculations with their results for comparison.

156: there is a stray "we"

184: This seems unintuitive. Melt only happens over  $\lambda - L_s$ ,  $\lambda$  being the wave length, and there is no melt over a cavity as there is no friction. Then also Equation (3) is unclear. This is only true if there if the water in the cavity has unit thickness.

$M_{tot}$  is a volume, and  $C_a$  is an area, so units do not match.

Table 1: It would be useful (and more robust) to show total displacement during the winter period. This displacement times frictional stress gives the total energy released at the base, which is readily transformed to total melt during that period.

240 more precisely: "the heat generated by sliding friction"

Figure 4b: squares are barely visible, consider using a better color

267 (also 397): typeset the number properly, not in computer coding

292: how are these values calculated. Give complete formulas that allow the reader to repeat the calculations. Why is no reference made to Eqs (2) and (3), where this whole development should be carefully made.

297: step length should be named "wave length" as some kind of periodic bed is assumed.

Figure 7, caption: This is not "heat", but "heating rate", "heat production rate", or similar.

310: it seems that 2 cm of water are not hard to store locally in sediment-filled basins or subglacial lakes in depressions. As water pressure is very high everywhere, this is a possibility that should be considered.

317: Here seems to be a confusion between water stored within the ice matrix (Brown) and water stored in discrete cracks, e.g. basal crevasses of some sort or other, sponge-like and large, void space within the compact ice.

325: There are large depressions (100s of meters across) that could easily accommodate large volumes of water.

330: But these might be unrealistic. Looking at the proglacial terrain shows very irregular bed undulations with very large and deep valley, deep and steep valleys etc. This looks very different from Kamb, Iken etc theories, and also from all these model inputs. Such bedrock topographies can, by moderate changes of water pressure, lift the ice and easily accommodate very large volumes of water.

354: "whereas they are small or absent at other locations (Ryser, 2014a).

365: Or lower effective pressure in subglacial sediments leading to liquefaction. A constant pressure and diffuse within the sediments, and increase the vertical extent of "softer" sediments. Such a process would readily explain the observed acceleration.

373: This strongly depends on the time scales of cavity formation and cavity closure. It would be instructive to calculate approximate values to understand their magnitude and their changes under changing pressures and sliding speeds over winter.

Figure 8: step length could also be named wave length of the bed

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