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The Cryosphere Discussions

Interactive comment on "Environmental controls on the thermal structure of alpine glaciers" *by* N. J. Wilson and G. E. Flowers

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Environmental controls on the thermal structure of alpine glaciers.

by N.J. Wilson and G.E. Flowers

The thermal regime of a glacier is controlled by heat sources including latent heat, strain heating, frictional heat and geothermal heat. The paper by Wilson and Flowers explores the sensitivity of glacier thermal structure to environmental controls by means of a 2-dimensional flow band model. Using an enthalpy method allows the authors to deal with latent heat in an enegery-conserving framework while being able to simulate topological changes in thermal structure. The role of heat sources are studied and a parameter sensitivity study of selected variables is conducted. The paper identifies water entrapped in the accumulation area as the main heat source. Water entrapment is controlled by the supra-glacial hydrology of the accumulation area. Consequently, results may depend on the choice of how water entrapment is represented in the model. Whether a warming climate leads to a decrease or increase in temperate ice volume depends on the competing effects of higher meltwater production, lowering of the ELA, and reduction of firn.

This is the first paper to model topological changes in thermal structure (aside from an early attempt in my PhD thesis). I'm really excited about it as it is a paper I always meant to write but never got to it.

The manuscript provides basic sensitivity studies to better understand how environmental forcings control glacier thermal structure. This is certainly needed, and already deserves publication. The further analysis on how a changing climate might effect thermal structure is based on a lot of assumptions, sometimes insufficiently backed up by literature, especially regarding aquifer thickness and mass balance gradient (see below). Maybe there isn't enough literature on the topic, but that is acceptable. As a modeler, I think it's fine to start with a hypothesis, and explore the potential consequences if this hypothesis is true. I suggest to you either better back up your choices with literature, or clearly formulate it as hypotheses.

In general, this manuscript is well written and structured, with clearly formulated goals. The figures are excellent, of high quality, very readable and help to understand the findings better. I have a few comments I ask the authors to address, see below.

Major comments:

What is the justification of the assumption that the aquifer thickness is related to the net balance (Eq. 21)? This assumption is later used in Sec. 3.2.2, and conclusions are drawn based on this assumption. I think this is needed, otherwise Sec. 3.2.2 would be weak.

The role of basal sliding is only briefly touched, and not very well discussed. I understand that, for simplicity, basal sliding is ignored in the model. On p. 3787, l. 2 the authors promise to justify their decision later on, however, I cannot find it in the manuscript; especially since basal heat flux is part of the sensitivity study, but it's not well addressed in the results section.

Minor comments:

p 3783, l. 12: change "polythermal ice" to "polythermal conditions" (a glacier can be polythermal, but ice can't).

p 3783, l. 14 (and p. 3800, l. 13-14): It was actually Greve (1997), using a polythermal ice sheet model based on a front-tracking method, who first observed a thinner temperate ice layer compared to using a cold-ice method. Using an enthalpy method, Aschwanden et al. (2012) just confirmed Greve's findings.

p. 3785, Eq. 4 and 5: why do you switch from k to k_{eff}, is there a difference. For ice, you switch to talking about diffusivity directly; I find this a bit confusing. I don't think Eq. 4 is really needed, maybe you could write Eq. 5 in terms of diffusivity, e.g.

$$\kappa = \left(0.138 - 1.01 \times 10^{-1}\rho + 3.233 \times 10^{-6}\rho^{2}\right) c_p^{-1} \qquad (1)$$

, where ρ and c_p are density and heat capacity, respectively.

p. 3787, Eq. 9: A is used here for the first time, but not introduced.

p. 3787, Eq. 10: Since Eq. 10 has a term $1/h_{aq}$ I assume that Q_m is calculated over the whole aquifer thickness?

p. 3798, l. 19-22: You state an equivalent difference of up to 1.8 K if Eq. 13 is used. First, you refer to Fig. 3a. Do you mean 3c? Second, I think the figure reference should be at the end of the previous sentence: "by an equivalent difference of up to 1.8 K (Fig. 3c)". Third, looking at Fig. 3c, I see dark blue colors corresponding to equivalent temperature differences greater than 1.8 K. Please clarify.

p. 3799, l. 2 and 15: "Cooler temperatures" sounds odd to me, I'd prefer "lower temperatures" (but that's just a suggestion).

p. 3800-3803, Sec. 3.2.1 Basal heat flux Q_b and run off fraction r are listed in Table 2 as part of the sensitivity tests, but are not discussed in Sec. 3.2.1. Maybe you could also add the two corresponding graphs to Fig. 5?

Fig. 1: Structured grids with stretched vertical coordinates are standard enough so that this figure could easily be removed, I don't think it adds to the understanding of the paper. But this is probably a matter of taste, and I don't mind if the figure stays.

References: Please clean up references. What are the numbers (like 3782 in Robin, G. 1955) after the year?

Review by Andy Aschwanden

References:

Greve, R (2012): Application of a Polythermal Three-Dimensional Ice Sheet Model to the Greenland Ice Sheet: Response to Steady-State and Transient Climate Scenarios. J. Climate.

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