To Referee #3,

Thank you for the constructive comments. We have attempted to address them as follows:

Specific Comments

1. P3783, L1-3 – you need to explain why understanding thermal structure in smaller ice masses is important.

– Added examples relevant to hydrology (Wohlleben et al., 2009; Irvine-Fynn et al., 2011), rheology (Duval, 1977), and climate and mass balance (e.g. Delcourt et al., 2008).

2. P3783, L10 – I struggle to understand this section...i.e. how can a model of polythermal structure 'neglect the presence of temperate ice'? Isn't this pretty fundamental when modelling polythermal glaciers? If it does indeed neglect temperate ice, then surely it's not a polythermal model!

– Here, we mean models of glaciers that are polythermal in the real world, while the model does not represent this. It becomes clearer if we remove the word 'polythermal.'

3. P3783 L15-18 – following on from the comment above, I really struggle to understand how a cold ice model can predict more temperate ice! If it is a cold ice model, how can it predict temperate ice? I accept that it may be my weakness that prevents me from understanding this better, but I would still like to see a fuller explanation. Finally re. this comment, you say that investigating the use of a cold ice model for polythermal glaciers hasn't been thoroughly investigated. Surely, however, it would be wrong to do this.

– We think that it would be useful to change our terminology. Formerly, a "cold-ice model" referred to a model that simply truncated heat content at the melting point with zero water. Many state-of-the-art thermomechanically-coupled models do this (e.g. Elmer, CISM, ISSM). Any area where $T = T_{\mathrm{melt}}$ (and $T > T_{\mathrm{melt}}$ is prohibited) is then "temperate", despite the model not explicitly representing temperate ice as thermally and compositionally distinct. We have switched to calling cold-ice models "temperature-dependent models." Presumably, the alternatives are "temperature- and water content-dependent model" and "enthalpy-dependent model."

4. P3783, L27 – brief mention needed that some heat sources would be entirely unaffected by climate (e.g. geothermal).

– Noted

5. P3784, L5 – Im not sure I really like your definition of thermal structure. You say that it refers to the 'distribution of englacial heat which affects temperature in cold ice and water content in temperate ice'. I find this a little confusing, since surely englacial temperate also affects whether the ice is temperate or cold in the first place! Your definition implies, somewhat, that the distribution of temperate and cold ice is fixed, and that it is the temperature within this that varies, but to me, thermal regime or structure is about the distribution of warm and cold ice (which is defined according to temperature). I think that there needs to be greater clarity here.

– Our definition is slightly different. We have clairfied by elaborating on how temperate and cold zones are not fixed. One point that our definition permits is that a wholly cold glacier may still have "thermal structure," only in this case it excludes temperate ice. From a modelling perspective, it is useful to consider cold and temperate ice along a continuum.

6. Pp3875-3878 and 3790-3792 – I would strongly urge that these equations (and indeed those that also appear later on) are checked thoroughly by someone more qualified to do so than myself. To me, they seem to be okay (no obvious, glaring errors, as far as I can tell), but this needs to be more rigorously checked.

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7. P3790, L21 – as a non-modeller, I am always suspicious of such statements...i.e. that something in a model is not 'physically meaningful'. What are the 'real' implications of such a consideration? I'd like this better explained.

– This is odd – Eq. 13 appears to be different in the published version than in that submitted. T_0 should not be in the denominator. It is not meaningful because H itself is defined relative to a reference temperature not far from the melting temperature so that c_p can be held constant. Presumably, it would be physically defined relative to something like absolute zero, and then $T_0 \equiv 0$.

8. P3792, L11-12 – 'neglecting sliding' here seems to be important, and although this is acknowledged, I think that greater consideration of how this impacts on the outcomes is needed.

– We have added detail regarding the effect including sliding has on the control runs REFT and REFC by adding a sliding test to Experiment 1. See response to referee #2 for details.

9. P3792, L1-4 – I have no understanding of this discussion of 'upwinding'...this needs to be checked by someone else.

– See Tsui (1991) and LeVeque (1992), for example.

10. PP3795-3797 – I think these statements of the purpose of each experiment are very neat and concise!

– Thanks!

11. P3796, L14 – although you state that considering these parameters in isolation is not strictly accurate, since they are not independent, you nevertheless go on to do this. Can you comment on how useful this actually is?

– There are two reasons that this is useful. The first is that considering the variables in isolation simplifies the experiments and makes it much easier to see which changes have which effects, rather than having it be some combination of multiple influences. The second reason is that it is not obvious how these different variables are coupled. In Experiment 3, we assume a particular coupling (Eqs. 20–21), but the individual tests in Experiments 1 and 2 are more robust in this sense.

The text has been modified to state:

> "In reality, the parameters in Table 2 are not independent, but considering them as such yields information about the environmental variables controlling thermal structure without complicating the results with multiple causes. Furthermore, considering independent parameters for now avoids assumptions about how parameters may be coupled."

12. P3796, L18 – you say that the importance of advection as compared to diffusion varies widely from glacier to glacier, yet there is no supporting evidence for this statement (or indeed further explanation). Can you please provide further support and explanation?

– As one possible example, consider two glaciers of similar size, where one is sliding must more quickly then the other. The thermal diffusivities will be comparable, but the faster glacier is advecting heat at a faster rate. We have rephrased this section to make it clear that this is what we refer to.

> "Heat flow within glaciers has been described as advection-dominated (characterized by high Péclet numbers) (Aschwanden and Blatter, 2009), but due to the wide range in worldwide glacier velocities, the relative importance of heat transfer by advection compared to diffusion varies significantly."

13. P3801, L6-10 – I wonder if there just needs to be a very brief mention of subtler changes that might arise in terms of future climate i.e. that changes may be more complex and therefore perhaps more or less pronounced in different seasons, as opposed to just a simple overall climate warming (e.g. the role of changing precipitation patterns).

– This is absolutely relevant. It is not something that we have tried to address here, but it is worth mentioning (placed in Section 2.4.2).

14. P3802, L13-19 – I find this passage a little confusing. I don't understand how there can be a higher fraction of temperate ice if the equilibrium line elevation is increased and the size of the accumulation zone decreases. In this same section, I don't follow the logic that the ablation zone cold layer thins because there is more water that must refreeze...does it refreeze, or are you saying that there is too much to do so? I'm also not clear what your 'starting' thermal structure is here. I feel this section needs further clarification.

– This section has been rearranged (covers too much space to quote effectively here). Comments related to the equilibrium line have been moved to the previous discussion of the accumulation zone, which is a better fit. The starting model is REFT, and we have clarified this point in section 2.4.2. The ablation zone cold layer thinning occurs because a steeper thermal gradient is required to completely refreeze the larger amount of water. In order to steepen the thermal gradient, the CTS must be nearer the cold temperatures at the ice surface. Put the other way, higher water contents in temperate ice cause there to be more temperate ice (because it must lose more energy to freeze).

15. Figure 7 – can enthalpy, as plotted here, at all be recast as temperature (in some way)? If so, it may be more useful.

– Yes, this is a good idea, and has been done. See also referee #1 comments.

Technical Corrections

1. P3782, L6 – I dont really like the use of the term 'flowband' in the abstract. Why not use 'glacier'? You were happy to use this term in the title!

– Since we do not make any attempt to explore lateral heterogeneity, it is probably good to specify the domain for the experiments. If a change is needed, I would be more inclined to place 'flowband' in the title as well, but this probably isn't necessary.

2. P3782, L12/13 – 'volume of temperate ice...' relative to the volume of cold ice presumably?

– fixed: 'volume' → 'fraction'

3. P3783, L6 (and elsewhere) – the referenced paper is Rippin et al., 2011...NOT Rippen.

– Thanks for the correction!

4. P3794, L19 – 'of' is missing from after 'quantity' and before 'meltwater'.

– Fixed

5. P3798, L1 – seems odd to use a here instead of years! Id prefer to see years.

– We have made this change.

Nat Wilson and Gwenn Flowers, Dec 2012

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