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Interactive comment on "Modelling the transfer of supraglacial meltwater to the bed of Leverett Glacier, southwest Greenland" *by* C. C. Clason et al.

Anonymous Referee #2

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This paper describes the application of a numerical model for routing meltwater over an ice-sheet surface, collecting water in lakes and crevasses, and for the opening of the crevasses by hydrofracturing and the subsequent routing of water to the glacier bed. The application is to a specific catchment basin in western Greenland, using two years of estimated surface melt data. The model behaviour is compared qualitatively to satellite observations of lake drainage and to patterns of ice speed up, which are thought to be linked to surface melt penetration to the bed.

The paper is well written. I do not find the conclusions hugely groundbreaking, and I am not totally convinced that the model is fully predictive in the sense that the lake locations are prescribed. However, such model progression is necessary for linking

surface mass balance and subglacial hydrological models, and this model retains a degree of simplicity which may be advantageous. I think the following points should be considered.

1. The distinction between 'moulins' and 'lakes' needs clarification. It seems to me that the mechanism for opening the pathway to the bed is the same in each case; i.e. through hydrofracture. The main difference is that the position of the lakes is determined from mapping, whereas the position of the moulins is determined from where tensile stress exceeds tensile strength. The condition for draining can effectively be rewritten as a condition that a critical volume of water (proportional to the ice depth, and weakly dependent on tensile stress) has accumulated on that node. In the case of the moulin, that volume builds up in the crevasse itself, and in the case of the lake it is sitting on the surface.

   Given this, the observations concerning the proportion of water draining through lakes / moulins, and how this depends on elevation, do not seem to be results of the model per se - they just reflect the inputs. Since the positions of the lakes are predetermined, and they are concentrated around certain elevation bands, more water drains through lakes at those elevations, and more through moulins at lower elevations.

   Related to this, I think the description of the crevasse calculations in appendix C could be made clearer. All the more so, if the impression they gave me above is incorrect. For instance, (C2) should only be true if Q is constant (which it presumably isn't) and would be much better written as a differential equation, also explaining exactly what Q is and how the surface area of the crevasse comes into this calculation. The solution for the crevasse depth also requires some care, since the stress intensity factor (C1) is a non-monotonic function of d. In particular, for small enough d, $K_I < K_{IC}$, and it is apparently not possible to start propagating the crack. This difficulty may be circumvented by supposing

that there are pre-existing flaws which initiate the crack, but particularly in compressive regions (i.e. beneath a lake), such flaws may need to be large to initiate the crack in the first place. See Krawczynski et al (2009) for some discussion of this.

2. Consideration should be given to other types of lake drainage than under-lake hydrofracture, e.g. Tedesco et al (2013). Many lakes drain through overspill into a downstream lake, or through overspill into a nearby moulin or crevasse, which this model may be missing out on. Even if such processes are not included in the model, they should be discussed.

3. It would be preferable to see a more direct comparison of lake drainages with satellite observations; in section 5, the 'qualitative agreement' seems quite sweeping. Given that the lake locations were imposed from satellite imagery, couldn't you compare the timing of the individual lake drainages? Even if such a comparison is not included it would be good to describe roughly how well it does (for instance, do the correct lakes of the original 93 drain in the end?).

4. The restriction to use pre-determined lakes seems unnecessarily limiting. Given the level of detail in DEMs now available, I would have thought it possible to simply determine lake locations automatically from the low points of a DEM rather than having to see a currently existing lake in satellite imagery (this is in reference to the concern about 'missing' lakes when the ablation area extends to higher elevations).

5. The dependence on model resolution seems a bit concerning. Perhaps the number of moulins is not really the appropriate measure to consider; the rough spatial location of pathways to the bed is probably more important, and this may be relatively robust with changing grid resolution. Indeed the total quantity of water transferred to the bed seems to change little, which is more reassuring. However, I think there should be some comment about this - *i.e.* about what are the results

you think should be the trusted outputs of the model. Why were supraglacial lakes excluded from the grid sensitivity tests? - it makes the comparison rather awkward.

Minor comments

1. Many places throughout the text - percentages are often quoted to 3 significant figures, which seems to place a lot of trust in the quantitative behaviour of the model. I think 2 would be more than enough.

2. Sec 3.2 - how do you determine the maximum volume for a lake (above which it is allowed to overspill)? This seems to require knowledge of the bathymetry, or otherwise to involve an assumption that the satellite observations happened to catch all of the lakes at their largest?

3. Sec 4.2 - the width of the crevasse has a strong control on how much water is needed to change the water depth and drive it to the bed. It should be explained how the value of 1m was arrived at.

4. Sec 4.3 - typo in heading.

5. Sec 4.4 - explain exactly what is meant by the 'revised' meteorological data - do you just add the temperature difference uniformly to the observed 2009 temperatures?

6. As a general point, note that it can be confusing to talk about percentage increases of percentage quantities (for the surface-derived meltwater in section 4.4, line 12, for example), as it is very easy to misread these as percentage *point* changes. Any confusion might be lessened by saying, for instance, a '9% change in the proportion of meltwater reaching the bed.'

7. Page 4256, line 22 - as previously noted by some of the authors, the concept of 'winter background level' for ice velocity may be confusing, and it may be best not to use it.

8. Table 1 - clarify what 'supraglacial storage' includes. Lakes? 'Water' refrozen in snowpack? Water in crevasses?

9. Appendix A - how is the prescribed spring snow depth chosen?

10. Appendix B - why -5°C ice temperature?

11. Page 4265, line 15 - what is Eq (9)?

References

Tedesco, M. et al. 2013 Ice dynamic response to two modes of surface lake drainage on the Greenland ice sheet. *Environ. Res.* Lett. **8**. doi:10.1088/1748-9326/8/3/034007.

Krawczynski, M.J. et al,. 2009 Constraints on the lake volume required for hydro-fracture through ice sheets. *Geophys. Res. Lett.* **36**, doi:10.1029/2008GL036765

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