Summary and comments on the manuscript entitled

Impact of frontal ablation on the ice thickness estimation of marine-terminating glaciers in Alaska

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by

B. Recinos et al.

Summary

In this manuscript, the authors forward a refinement of the thickness-estimation module of the Open Global Glacier Model (OGGM v.1.0.1.). The refinement concerns the difficulty to close the overall mass budget of glaciers if they show a calving front. In these cases, frontal ablation has to be considered. Yet this quantity is typically badly constrained because it depends on many oceanographic and atmospheric conditions as well as on the unknown frontal ice thickness, being the target quantity of the module. As a solution, the authors present an iterative procedure that can dynamically infer frontal ice thickness by adapting a melt sensitivity parameter. The method is then applied to all marine-terminating glaciers in Alaska. There, the iterative procedure is calibrated to reproduce observation-based estimates of frontal ablations acquired for many of the prominent Alaskan outlet glaciers. The ice volume estimate is put into perspective by a sensitivity analysis varying several model parameters. The refinement suggests an upward correction of the ice volume stored in the marine terminating glaciers of Alaska, from 9.0 to 10.4 mm sea level equivalent.

The study is well written and clearly motivated. Initially, I was very enthusiastic about the methodology and the results. Therefore, it saddens my heart to report that I might have identified a severe issue in the central iterative procedure. The issue boils down to an under-determination of the mass budget problem when frontal ablation is introduced as a free parameter. Consequently, I have many questions on the performance, stability and convergence behaviour of the presented approach. The answers will certainly require an additional section. Moreover, the sequence in which results are presented gives rise to confusion. I therefore suggest some re-organisation. On this basis, I have to recommend that the manuscript undergoes a major revision and I leave it to the discretion of the editor if he wants to continue to consider this submission for publication in *The Cryosphere*.

General comments

Convergence of iterative procedure
Looking at your iterative calibration procedure from the perspective of an optimisation, I wonder what target quantity is minimised. In other words, what is the reason for this procedure to converge or reach the stopping criterion. Starting from an initial thickness guess, you infer F_{calv} and update the temperature sensitivity μ^* in the surface mass balance equation (5). Then, you re-run the reconstruction and get an updated frontal thickness value. From all involved equations, I cannot see a good reason why the following updates should produce values with a gradually reducing relative differences. A reason for non-divergence is that the thickness update involves a polynomial relation with an exponent smaller than one. Yet even if convergence is reached, I wonder about the physical meaning of this specific solution. Please do not misunderstand me here, but I really think that this is an important point with serious implications for the expedience of your approach. I unfortunately do not have a good suggestion for a useful target quantity or another potential quick fix.

To convince the reader about the functionality of this calibration procedure, I think you have to expand the article by another section, which will elaborate on the stability and the convergence behaviour for a few test cases. I am particularly interested in figures showing the iterative changes in the frontal thickness. Is it monotonous or are the over-shootings. The latter seems unlikely considering the underlying equations. An interesting test would be to check what happens if you started from a too large thickness value (for a well-studied glacier). I would expect an even higher calving flux and thus a further increase in ice thickness. I ultimately miss a relation which counter-balances a steady increase during the iterations. In general, you should assure that the final thickness profile does not depend on the initial thickness guess. Another informative analysis would be to see what happens if the stopping criterion is ignored and you continue the iterations for 100 or even 1000 steps. Do the relative differences in the frontal thickness decrease further? This would be a requirement for the introduction of the suggested stopping criterion.

To put my whole concern in simple words: by introducing a calving flux in the mass budget, you have to reduce the amount of necessary melt (for a balanced situation) This reduction further increase the necessary calving flux in each iteration. To break this run-away cycle, you need another physically motivated relation that penalises either low melt values, high calving fluxes or high frontal thicknesses. Such a counter-balance effect might already be at work by the underlying functional dependencies but without a clear physical motivation.

Manuscript structure
The structure of the manuscript is not very clear and only after reading all of the results, I finally got my head around the overall strategy to set up the method. A

major drawback is that the calibration of the proportionality factor k in the calving relation with respect to available regional estimates of the frontal ablation is presented rather late in the text. I think that a calibration section will be very useful at the end of the methodology (P9). This section can also serve to explain that you will use two variants of the model: one with sliding and another without.

Specific comments

Suggestions for the iterative calibration procedure

A *Initial thickness*

Concerning the first two steps in your iterative process (P8L19-22), you determine an initial guess for the calving flux, by assuming a frontal ice thickness which is 1m higher than the surface elevation. I think that it will be beneficial to use the flotation criterion here, making an assumption on the ocean water density. This criterion is simple to implement, it will give a larger first guess and it will therefore speed up your convergence.

B *A-priori limits*

The flotation criterion for the frontal ice thickness also provides a lower bound $H_{\text{min}}$to the ‘real’ frontal thickness value. The reason is that most tidewater glacier will likely be thicker and firmly grounded. An upper bound for the frontal thickness (H_{max}) is given by integrating the accumulation field. This will provide the maximum ice flux possible along the glacier. Alternatively, you could integrate the SMB above the ELA. This will give smaller maximum flux values (these will however dependent on μ^*). The maximum flux can then be translated into an upper bound for the frontal thickness value (H_{max}) via Eqs. (8-10). A conflict between the upper and lower bound ($H_{\text{min}} > H_{\text{max}}$), will indicate inconsistencies in the climatology and thereby give useful information.

C *Stopping criterion*

The stopping criterion is chosen to be an absolute flux value. In this way, the stopping criterion is easier to be reached for small glaciers with overall lower flux values. I do not think that this is a desirable behaviour and it was not communicated as a deliberate decision. I would therefore suggest that you define the threshold as a fraction of the annually received precipitation volume. If this should not be feasible, you could use a constant values that scales either with glacier area or the terminus width.

Technical corrections

At this stage, I refrain from providing a list of detailed comments.