Review of "*Initialization of a global glacier model based on present-day glacier geometry and past climate information*"

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In this manuscript, Eis et al. use a numerical approach to assess how well past glacier geometries can be reconstructed by relying on the present-day glacier geometry. For this purpose, they utilize the Open Global Glacier Model (OGGM), which is a state-of-the art glacier evolution model that has the capacity to model a large ensemble of glaciers (Maussion et al., 2019). The OGGM is used to simulate the transient evolution of >2000 glaciers in the European Alps between 1850 and present-day, after which they are compared to observed geometries (or rather synthetic geometries close to these). In many cases, different initial geometries lead to an almost identical present-day state (i.e. various initial states lead to unique present-day geometry). The authors also show that when using the entire information about the present-day geometry, the uncertainty on past conditions reduces compared to more simplified approaches in which only the present-day length is considered.

I must say that I was very enthusiastic when starting to read this manuscript, but that in the end I have several questions - some more substantial than others. On the hand, I think the idea is very interesting, the model is the correct one to tackle this particular problem, and the presentation of the results is neat: the text is generally easy to follow, and so are the figures. On the other hand, I have some reservations concerning the experimental setup (with a largely theoretical focus, but no incorporation of real data/observations) and the conclusions drawn from this. I have detailed on this in the next section, and hope that the authors will be able to address (some of) the issues raised. There may be some elements/passages that I may have misunderstood, and on which I would gladly be corrected, but in that case I am afraid they may also be problematic to understand for some other readers.

General comments

- When going through this manuscript, the first thing that popped up in my mind is: 'these experiments are all about glacier response time'. Also when reading the entire manuscript, this idea persisted: this is a response time story! I was therefore rather surprised to not see any discussion on this, or not even having it mentioned anywhere. In the end - to me - it boils down to: you can say something about the past glacier geometry (when considering the present-day geometry) over time periods that are close to or shorter than the glacier response time (depending on which definition is used for the response time). Or formulated differently: the present-day geometry does not depend on the past glacier geometry when considering time periods that exceed the glacier response time. As the response time of Alpine glaciers is typically in the order of years to decades (e.g. Haeberli and Hoelzle, 1995; Oerlemans, 2007; Zekollari and Huybrechts, 2015) it is difficult to picture how the present-day geometry (or a simulated geometry resembling this) can be used to say something about the glacier geometry in 1850.
- Continuing on the above point, do you think that what you derive as the past geometry in 1850 is realistic and that for cases where a non-unique answer (i.e. a non-unique glacier geometry) arises for the present-day: that the 'best' 1850 geometry that you obtain is really an indication of the past geometry? Are there not other model uncertainties that play a bigger role?
- You mention that you cannot perform tests with real present-day geometries. When reading the manuscript, it does not entirely become clear to me why that is. Could you elaborate on this? It would have made it

really interesting if you could have worked with real present-day geometries and performed your simulations based on this, which I was in fact what I was expecting... e.g. (1) reproduce geometries at the end of the LIA and compare these to real geometries at that time or (2) for instance compare the length changes modelled between 1850 and the present-day with observed length changes over this time period (e.g. from Leclercq et al., 2014). Such a validation would really have been of great value here, and would probably be the best way to increase our confidence in the applicability of the method you propose.

- The ideas put forward in this manuscript are really interesting, but it would be good to have a different light shining on this. I leave it up to the editor whether it is necessary to rethink/redo some of the experiments or not, but at this point, I am left with many questions and cannot help myself thinking there are some missed opportunities. Based on the above discussion, some points that could be included are for instance:
  1. Why not invert the setup? Could potentially be very interesting: for every individual glacier the question could be asked 'how far can you can back in time to have an initial geometry that still determines the present-day glacier geometry?': this is a kind of response time for every glacier. This information could be used to infer something about the response time of Alpine glaciers, even in the rather theoretical framework that you are using so far (with little to no observational data).. Again, I understand that this would be a considerable amount of work at this stage, so I am not saying that this has to be included, but I think it would be a nice addition, which would be more valuable for the reader (vs. the so-far used rather technical setup..)
  2. In whichever way the manuscript/experiments are reorganised: a discussion on the role of the response time seems crucial!
  3. Would really be rewarding to have the whole story a bit less theoretical and more applied to the real world. You model the glaciers in the European Alps, for which there is an amazing dataset on past changes...

Specific and technical comments

Abstract

- p.1, l.7: 'alpine'. Is the term 'alpine' not referring to the type of glacier (i.e. a mountain glacier) instead of the region ('Alpine')? See e.g. nsidc.org/cryosphere/glossary/term/alpine-glacier . From my understanding, here, and throughout the manuscript, you want to refer to 'Alpine' glaciers?

- p.1, l.13-15: the problem does indeed turn out to be 'non-unique' in many cases. As said earlier, even for the cases where a small difference exists in the modelled present-day glacier, I am not really convinced if this can really be seen as an indicator for how the glacier was in 1850... Could be valuable when considering shorter time periods between model initialization and present-day (e.g. multidecadal timescale), but not convinced over time periods >100 years... See also suggestion 1 at the end of the 'General comments' section.

1 Introduction

- very nice introduction overall. Summarizes the problem really well.

- p.1, l.18-19 and/or p.2, l.2-3: could consider adding some new references here: Zemp et al. (2019) and Wouters et al. (2019)

- p.2, l.12-13: from this: sounds like in most numerical experiments the starting point is an observed geometry, which is typically not the case (e.g. due to problems related to model drift,...etc) (e.g. Goelzer et al., 2018, which you mention later). Could consider reformulating this.

- p.2, l.21-23: do not know the details about this study, but I am surprised that unique glacier area in the past can be used to have correct glacier area at present over such long time periods. Is this an artefact of using the V-A scaling method? Can imagine that in reality, can build up same glacier when starting from two very different states in 1850 (e.g. from zero ice thickness in 1850 and when using the present-day geometry as the 1850 state). Could you comment on this here?

- p.2, l.30-31: starting in 1990 for all simulations is indeed somewhat arbitrary. Your setup could potentially be used to suggest a good starting point for every individual glacier, which could be a few decades in the past (suggestion 1 in 'General Comments' section). But again, not convinced you can go back to >100 years when it comes to deriving past glacier information from the present.
- p.2, l.32: 'most work focuses on estimating the present-day state of ice sheets'. Is a bit strangely formulated, as you make it sound like the main goal of ice sheet modellers is to correctly represent the present-day geometry of an ice sheet. Would rather say that their work is focused on making accurate projections of future ice sheet change, for which accurate reconstructions of the present-day state are crucial.
- p.2-3, l.34-35 - l.1: odd sentence. Consider splitting up / reformulating?

2.1 The Open Global Glacier Model

- p.3, l.25: resolution varying from 10 to 200 meters. Which criterion is used to decide which horizontal resolution to use for a given glacier?
- p.4, l.9: 'realistic climate settings': what do you mean with 'realistic' here?

2.2 Problem description

- p.5, l.1-2: 'such that the forward modelled state is as close as possible to the observation': OK. Here I get a bit lost however. If I understand it correctly from reading the text further, in the end you try to model a present-day state that is as close as possible to the observation, but for this purpose, as a reference/observed state, you do not use the observed present-day glacier, but a state resembling this ('observed state' of the synthetic experiments). Correct? If so, can you explain why that is? I seem to have missed this piece of information, and find it quite confusing. If not, I am still afraid that it will not be easy to understand for other reader. Potentially consider reworking this..
- p.5, l.11-12: 'non-unique': of course → related to the fact that the time period (1850 - present-day) considered exceeds the response time of this individual glacier. By here, would have expected to have the response time mentioned somewhere...

2.3 Synthetic experiments

- I get somewhat lost here (in general in section 2.3 and 2.4).. See first comment on previous section: is the real present-day geometry used as the 'observed state': why (not)?
- p.6, l.1-2: temperature bias of -1 K: seems rather arbitrary. For which other values was it tested? What is influence if other value would have been chosen?
- p.6, l.4: Guslarferner. Please state where this glacier is located. Why are these two Austrian glaciers (together with Hintereisferner) considered and not others? As no data is used for evaluation/calibration, it seems that any glacier could have chosen (i.e. also glaciers that are not monitored / glaciers that are less well known).

2.4 Reconstruction of initial glacier states

- Figure 2: from panel a, the temperature bias seems to be varying between -3.0 and 1.95 K. But in the legends a range from -2.65 to 2.95 K is mentioned. Should this be the same or am I misunderstanding this?
- p.7, l.11: 'where all trajectories have reached this stagnation period': could you be more specific? How do you define stagnation?
- p.7, l.11-12: linking the 'stagnation period' (somehow related to glacier response time) to glacier size → questionable. Not always the case that 'longer/larger glacier has got a longer response time' (e.g. Leysinger Vieli and Gudmundsson, 2004; Bahr et al., 1998; Pfeffer et al., 1998; Raper and Braithwaite, 2009; Oerlemans, 2012). It is OK to take the largest glacier to determine the stagnation period, but would be careful with the statement linking the response time to the glacier size/thickness (Jóhannesson et al., 1989)

- p.8, l.1: smoothing. Over which time period?
- p.8, l.3-4: 'equilibrium with the climate around 1850': questionable, as many Alpine glacier were still advancing and reached a maximum extent later, while others were already retreating by then (Leclercq et al., 2014). Not a major issue, but would be good if could shortly discuss this assumption.
- p.8, l.10: 'same model parameters set': could you provide a bit more details here. For instance, how is the ice rheology described (deformation/rate factor) for every glacier. How is this determined/tuned? Is this the same for every glacier? And what is the effect of this on your results?
- p.8, l.15: 'sorted by their fitness value': what do you mean by this?

3 Test site and Input Data

- p8, l.20: 90 m resolution DEM: this seems to be relatively low, especially given the fact that you consider glaciers as small as 0.01 km^2 (1 grid cell at this resolution).
- p.8, l.22: RGI date: 2003. Is the case for most glaciers in RGI6.0 (those derived by Paul et al., 2011), but not for all.
- p.8, l.24: '5 minutes resolution'. What is this approx. in meters here?
- p.8, l.27: 'threshold for the RGI': for this region? Not sure, but thought this was region-dependent?

4 Results

- p.9, l.7: non-uniqueness for Guslarferner: as expected, given the fact that response time of this glacier is likely much shorter than the period between 1850 and present day... Do not think you can really say anything about glacier state in 1850 from these experiments, as you also point out. But also for Hintereisferner (p.9, l.25-...): not convinced that the narrower set of 1850 sets having a lower 'fitness value' are indicative for how the glacier was in 1850..Intuitively, expect that you can say something about past Hintereisferner state (from present-day state) for max. a few decades back in time (1950 maybe?)
- To be more convincing, would really be rewarding to compare these 'best' estimates for the 1850 state with observations. And this ideally for a large set of glaciers. Think this could work, also for the length changes between 1850 and present-day, even when considering the fact both states (1850 and present-day) are synthetic → are the length changes close to observations for your 'best' results (i.e. closer when considering the 1850 states that are not being considered as 'good')?
- p.9, l.10: '...200 candidates has a...' → '...have a...'
- p.9, l.16-17: 'in close proximity to the synthetic experiments': OK. Because do not compare to the real observation. Is it not possible to work with real observation? To get match here, would probably have to tune some model parameters. Is this the problematic aspect of working with observed present-day geometry? (seems to be the case when reading the 'Discussion and conclusions' section)
- p.9, l.18: 'the observation': which is also modelled, right?
- p.9, l.25: results are different: quite trivial. Would reformulate this or simply omit this
- p.9, l.26: only few with small fitness value: see first comment on this section
- p.9, l.27-28: 'need more time to adapt' → response time!
- p.10, l.1: '11.7 to 12.4 km': from this: deduce a retreat of ca. 5 km. Is this the case? Would be really interesting to compare. For this glacier and for many others. Would make story much stronger.
- p.10, l.6: 'we were able to show': personally not really convinced at this point unfortunately. See suggestion about incorporating 'real' data (observed past states and observed (length) changes)
- p.10, l.7-8: combining with climatic information. How big is the role of the past climatic information on your results? Does the choice of past conditions (the conditions that you impose) affect the 'best' past states?

- second part of section 4.1 and section 4.2: well presented!
- Figure 9+10: number of glaciers mentioned in figure title = 2619 vs. 2621 before. How come?
- p.15, l.1: 'This holds also true': strange formulation. Consider reformulating

5 Hardware requirements and performance

- Very nice to have such a section. Very useful to get an insight into this!
- p.15, l.12: 'influence strongly' → 'strongly influences'

6 Discussion and conclusions

- p.16, l.3-4: 'identify errors...introduced by model approximation': OK, but this is not very satisfying for the reader and makes the paper almost purely theoretical...
- p.8-10: synthetic glacier state in 2000. Due to this cannot say something about real glacier state in 1850. Is it not possible to say something about the (length) change during this period and compare this to observations (for the 'best solutions')?
- p.13: 'which we don't address here' → 'which we do not address here'. A pity...I understand that this is difficult, as explained by the authors (p.16, l.4-7), but question may arise at this point how relevant this story is for the community? Seems to be a good starting point for further research by the group and users of OGGM (p.17, l.26-27: 'framework will be useful'), but more limited for outsiders. Feels more like a 'technical' note/paper now. Here again, I am convinced that by incorporating some 'real data' and/or rethinking of some experiments (see e.g. also suggestion 1 in 'general comments' section): the story would become far more relevant for the glacier (modelling) community.
- p.16, l.15: 'observed state': really the observed state or a synthetic one?
- p.16, l.16: 'depends on the situation' → 'depends on the specific glacier setting'?
- p.17, l.8: 'performs equally good' → 'performs equally well'?
- p.17, l.9: 'In Sect 4.2...': find it strange to have this formulated in such a manner in the conclusion
- p.17, l.12: 'could differ strongly in volume and area': would expect the differences to be relatively small with a trapezium/parabola cross-section, no?
- p.17, l.13: 'lead more variability' → 'lead to more variability'
- p.17, l.18: 'for some glaciers': indeed, for the ones with a short response time

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