Review of 'Modelling regional glacier length changes over the last millennium using the Open Global Glacier Model' by David Parkes and Hugues Goosse
Submitted to 'The Cryosphere Discussion' on November 15 2019

In this manuscript, Parkes and Goosse, use the Open Global Glacier Model (OGGM) to model the temporal evolution of a few hundred glaciers over the past Millennium. For this, they select glaciers from different regions in the world for which glacier length records are known from observations. The simulated glacier lengths under six different climate forcings are compared to 'observed' length records and the authors suggest that a good general agreement is obtained.

The idea put forward by Parkes and Goosse in this study is an interesting and a challenging one. As they rightly state, many of today's glacier evolution models focus on relatively limited time periods for model calibration and/or evaluation (typically present-day period or recent past) that are shorter than the time periods over which these glaciers adapt to climatic conditions (their response time). This raises questions about their applicability over longer time scales. A study on the multi-centennial to millennial evolution of glaciers and its ability to reproduce observed changes is thus of high relevance and directly relevant for the readership of 'The Cryosphere'. At this point, I do however feel that many of the interesting questions that are raised in the introduction are not really elaborately answered, and that this study is in need of additional quantifications and additional experiments before it can really be considered to be of interest for the glacier modelling community. I made a list of suggestions on how this could be tackled and other issues (some rather major, other minor) that should be considered before this manuscript could be considered for publication.

General comments

1. At this point, many statements a bit vague and the analysis presented are not very in-depth. Additional information (mainly quantitative information) and analyses will be required to really make point that the authors are able to use OGGM to closely reproduce past glacier changes. Two main points here:
   a. You chose to mainly focus on relative length changes at regional scales and explain why you present the results in such a fashion. This is definitely fine, but I do not think this should impede you from also giving some results in absolute values and for individually modelled glaciers. This is just a matter of showing the results differently and does not require any additional runs/simulations. More specifically, it would be interesting to see how the model is able to reproduce the present-day glaciers: i.e. are the glaciers that you obtain at the end of your simulation (around 2000) close to the observed ones? So far, you argue that it is important to look at the model for periods when glaciers were more stable (e.g. l.38-40), but this should not stop you from also considering the model performance for the recent past and its capability to closely reproduce the present-day glacier. An example: take a glacier for which the relative length change is well reproduced over the last 300 years, but where your modelled present-day length is 8 km vs. an observed length of 20 km… This means that your glacier was also 2.5 times too long 300 years ago (everywhere between 300 years ago and now): would you argue that the model does a good job at representing the changes here? Would be good to have a figure (e.g. in suppl. Mat.) with on the x-axis the observed glacier length at present-day, on the y-axis the modelled present-day glacier length (after transient run) and having every individual glacier plotted in this (for all regions together; could do this for one climate model)
   b. Role of the SMB. You barely mention the SMB component of the model, which I found surprising, given that this is the main driver for the glacier behavior (the dynamics then translate your SMB forcing – with a lag due to the response time – to a length change). For instance, when considering the role of temperature vs. precipitation forcing, it would be highly relevant to describe how much these components affect the modelled SMB (with quantifiable information). Many studies have provided insights in the role of temperature vs. precipitation forcing for the SMB (e.g. Lefauconnier et al., 1999; Braithwaite & Zhang, 2000; Oerlemans & Reichert, 2000; Sicart et al., 2008; Trachsel & Nesje, 2015), and often found that the temperature is the main driver. Your finding that temperature is the main driver directly results from the calculated SMB, which is far more sensitive to temperature changes than it is to precipitation changes. Would be really nice if you could show some of the calculated SMBs and perform some basic sensitivity tests (e.g. what happens with SMB when forced with +1°C, -1°C, +20% precipitation,…etc.)
2. Title is a bit misleading: when reading 'regional' glacier length changes, I would expect that an entire region is considered. However, glaciers from various regions are selected, which in every case represent only a very small subset of all glaciers in this region. Suggest reformulating this, which could be done

by simply omitting 'regional'. Or should rather mention something like: 'in various regions around the world'

3. Almost all the 'action' occurs in the pre-frontal glacier region (compared to the present-day ice cover): how well is OGGM able to handle this? More information is needed about how the flowlines are defined here, how the cross shape is parameterized,…etc. This information is lacking at the moment.

4. I generally found the manuscript relatively easy to follow and found the figures to be simple, but clear, which is very nice. At several occasions I did however get lost in long sentences (often multiple brackets are being used…) and had to read through these several times before getting the meaning of the sentence. I therefore suggest reducing the use of brackets, and splitting up long sentences where possible. Examples are provided in the 'specific comments' section below.

5. You describe this study as being a kind of first attempt to reproduce past length changes with a flowline model for glaciers in many different regions and suggest that this would open the door to regional scale applications. I agree with the former, but have some doubts about the possibility to fully extend this to regional scales. What about glaciers that are now separate ice bodies but used to be connected? What about glaciers that disappeared by now but may have existed before (whether as separate ice bodies or tributaries to present-day glaciers) – a field in which Parkes himself authored an important study (Parkes & Marzeion, 2018). I think it would be fair to also mention these issues/challenges in your conclusion, were you provide an outlook (last sentence of the manuscript).

Specific comments

Abstract
- l.5: 'in active development'. Well, I guess this can be said about almost every model. OGGM has now reached a certain maturity and will of course further evolve in the future, but think it would be better to drop the 'in active development' part.
- l.8-9: 'modelled glacier changes…more rapid than – modelled retreats': quite vague. Try to be more specific (also in previous sentence).
- l.13-16: statement is again rather qualitative here: could you provide concrete numbers that support this statement?

Introduction:
- l.20: Reference to IPCC AR5. For the 'future glacier part', I suggest adding a reference to recent GlacierMIP effort by Hock et al. (2019).
- l.21: most relevant study from Oerlemans to support this statement is Oerlemans (2005)
- l.22: 'direct observations of glacier geometry': what do you consider being a direct observation?
- l.22-26: very long sentence and difficult to follow: suggest splitting up and omitting some brackets were possible.
- l.25-26: 'though even this is likely a significant underestimate (Parkes and Marzeion, 2018)'. Well, the number of glaciers is simply subjective, as it is related to the threshold that is used to decide whether a glacier is mapped (outlined) in the Randolph Glacier Inventory (RGI Consortium, 2017). We know that the number would be higher if smaller ice bodies would also be considered, so would not refer to this as an 'underestimation' here.
- l.29: '(OGGM) (OGGM e.V., 2019; Maussion et al., 2019)': try to avoid multiple repetitions of brackets. Also a few sentences before, in the sentence with 'WGMS' and 'NSIDC'.
- l.32: 'by default calibrates the glacier sensitivity to local temperatures based on CRU data…': what criterion is used for calibration? You mention that CRU data is used, but what do you (try to) match in the calibration procedure? i.e. what is the target? (e.g. measured SMB, geodetic mass balance,…etc.)
- l. 34: 'already experiencing significant retreat… (Zemp et al., 2015)': here I did intuitively expect a reference to work by Leclercq et al. (2014). Becomes clear later in the story that this is the main dataset you'll be using, but nevertheless good to already mention this important study here.
- l.39: 'we expect that…': strange formulation. You expect smaller and globally less consistent temperature trends? Based on what? Or is this just what the reconstructions suggest? Would rather formulate in lines of 'Studies/Observations suggest that temperature trends were smaller and globally less consistent…'
- l.45: when mentioning the glacier length changes, could make link with observed changes from Leclercq et al. (2014) (which you use later, but reader does not know at this point) and Solomina et al. (2016) in which the literature on glacier geometry changes over the last 2000 years is summarized.
- l.45: 'we cannot compare': you as authors? Or the literature in general?

- l.46-47: focus is on the transition from more stable pre-LIA to retreat. This is a complex matter – and many studies have tried to shed a light on this and came up with several possible mechanisms to explain the timing of this transition (e.g. Painter et al., 2013; Lüthi, 2014; Sigl et al., 2018). Would be surprising that your relatively simple setup (with temperature and precipitation forcing only) is able to simulate the right timing (as it is generally known that retreat starts before a real increase in temperatures is observed). Would be good if you could provide a few words of explanation on this.
- l.48-50: observations → any reference for this?
- l.50-52: agree, European glaciers are indeed not representative for worldwide glacier fluctuations. This is clear from recent Glacier Model Intercomparison Project (GlacierMIP), in which a strong contrasting behavior between the evolution of glaciers in various regions is highlighted (Hock et al., 2019).
- l.57-61: long sentence with many brackets, consider reformulating. Furthermore, given the fact that you focus on proxies for past glacier extent, would be relevant to again refer to work by Solomina et al. (2016) here.
- l.68: '…comparisons of between models and differences between regions': which models are you referring to here? Glacier and/or climate models?

Methods and data:
- l.74-75: strange description for OGGM: model for glacier dynamics that accounts for geometry and ice dynamics. Ok, but is also really a model in which SMB is coupled to glacier dynamics to simulate the temporal evolution of glaciers. Would suggest already mentioning the SMB here, and giving more information about the SMB in general in the following sentences, as this is the main driver for your changes over the past centuries... (see general comment 1b)
- l.81-84: you use an uncalibrated version of the OGGM model. What are the implications for the modelled glacier geometries at present-day (i.e. after several centuries of transient run): do you end up having a realistic glacier shape? Would be surprising that this can be obtained without any calibration and by just taking the model as is: see also general comment 1a: would be good if you could show the modelled present-day geometry (after transient run) vs. observed (and thus not only rely on relative changes).
- l.85-89: long sentence: maybe split up?
- Would need information about pre-frontal area and how you treat glacier changes here. See general comment 3 for more information
- l.112: 'may also still be', suggest replacing by 'are': see comment on l.25-26 for explanation.
- l.112-117: in your explanation, you link the glacier response time to its size. Is however not the case for many cases / regions (Raper & Braithwaite, 2009; Oerlemans, 2012; Zekollari et al., 2020), and quite often the main driving mechanism for the glacier response time is the surface slope. Could simply reformulate this by saying that the glaciers you consider are typically large and relatively gently sloping glaciers and that these may not be representative for all glaciers in the region when it comes to their response time, as this is driven by a combination of glacier-specific factors.
- l.118-132: OK to have regional values and relative changes, but also need to show your results in absolute values and for individual glaciers. Does not require additional simulations, just a different and elucidating way of looking at results. See comment 1a for more info.
- l.139: the area given in the Leclercq dataset: area at which time period? Guess this depends on the region/glacier considered? Would be good if could give indication.
- l.140-144: very long sentence. Suggest formulating the part between brackets as a separate sentence.
- l.144-152: very nice to have such a detailed description. Often missing in papers, here very clear. Could potentially even be a bit more specific?
- l.146: 'time of the Leclercq measurement': when is this?
- l.158: Recinos et al., 2018 (= discussion paper) → Recinos et al., 2019 (= final paper)
- l.162: 'excluded per region': was not entirely clear to me. Suggest omitting 'excluded'.

Results:
- l.166-168: you explain that sometimes not fully equilibrated after 300-yr spin-up: if this is the case, why do you simply not consider a longer spinup (> glacier response time) of e.g. 1000 years? Seems that in any case an initial adjustment will occur, because glaciers are never entirely in steady state, and you use this as a starting point. This is OK, but could reformulate this.
- l.180: 'models underestimate the retreat shown in the observations': how come? Maybe also role for other factors not accounted for in your model: e.g. role of aerosols (global dimming) and other mechanisms?
- l.187: '…use of normalised glacier lengths removes the ability to tell which…': well, you can simply also additionally give your results as non-normalised glacier lengths. Need to do this to increase insights

in your results and capability of OGGM to reproduce the present-day glaciers (after multi-century transient run): see general comment 1a.

- l.213-215: 'This suggests that differences in total post-industrial retreat are more influenced by differences in when the retreat starts than by…': OK, from the modelling perspective. Is this also the case when considering the observations?
- l.223: '…we do not examine the patterns of pre-industrial length change on a per-region basis': why not? Would be interesting to examine this and this aspect would add novelty to the paper. In the end, the manuscript almost solely focuses on post-industrial time period (although not clear if modelled absolute glacier length changes are realistic, see comment 1a) and when the retreat starts here, although the simulations cover a millennial timescale..
- l.226: Results shown only for 1 climate model: definitely ok, but would be good if you could argue / give a reason why IPSL is chosen (without this explanation this seems rather arbitrary).
- l.224-256: in general a lot of rather qualitative statements are made at the end of your result section, which does not leave the reader with real take-away messages: i.e. what should one remember when reading this section? Two suggestions for topics to focus on / include in your discussion:
  - I think it is important to focus more on the SMB here and link this to other studies in which the SMB and its sensitivity to temperature and precipitation changes are described + show this for OGGM's SMB component used in this study (see general comment 1b + comment on l.74-75).
  - What about the response time? This is not really mentioned in your story, but in the end this plays an important role, as the response time will explain the lag between the change in SMB (the effect signal of your climate input) and the change in glacier geometry (the glacier length you consider for model evaluation). Would put more emphasize on response time in this section and e.g. explain inter-region and inter-glacier differences in the timing of the post-industrial retreat and how this can be linked to response time.

Conclusions:
- l.261: 'this observed retreat is within the range of the modelled retreats': difficult to judge as only relative changes are given and over regional scales. See comment 1a and related specific comments.
- l.262: '…at least qualitatively capturing major trends in glacier length in many regions': mainly for post-LIA, as this is what you focus on. With some additional analyses and results, as suggested throughout this review could change the 'at least qualitatively' to 'quantitively' ☺
- l.273: 'in almost all cases temperature is the dominant forcing' and l.276: 'suggests negative feedbacks between…on overall glacier geometry changes': indeed, as known from many other studies in which link SMB and climatic forcing is examined (comment 1b + related specific comments). Would make story stronger if you would also explore the link between climate forcing and SMB.
- l.277: 'using dedicated glacier models': real need to have glacier model (vs. only considering the SMB): is to have the lag between SMB forcing and geometry change due to response time. By linking your story to response time (see last suggestion on the 'results' section): reinforce your story line and gives you an additional argument to support the use of OGGM.
- l.282-284: several challenges when considering all glaciers at regional scale. See general comment 5: would be good to at least mention some of the problems that will arise in such a case.

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