Summary and comments on the manuscript entitled
Modelling regional glacier length changes over the last millennium using the Open Global Glacier Model

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by

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Summary

In this manuscript, the authors shed light on glacier evolution in the past millennium using the Open Global Glacier Model (OGGM v1.1; Maussion et al. (2019). The authors focus on 339 land-terminating glaciers with multi-centennial length records covering most glacierised regions in the world. The ensemble is driven by temperature and precipitation from six general circulation models (GCM). Prior to the forward simulations, glacier units in the length-record data set are matched with the entries in the Randolph Glacier Inventory (RGI). Comparing the millennial simulations with the length records, the authors conclude that modelled length changes are consistent with the observations. Keeping either the temperature or the precipitation forcing fixed, the simulations show that temperature explains the larger share of the variance in the glacier-length observations.

I was very excited about this study because the authors evoke that they will shed light on the consequences of either calibrating glacier system models during the last century of general retreat or during multiple centuries showing phases both of advance and retreat. Unfortunately, the manuscripts leaves this interesting question unanswered. It seems symptomatic that, although the authors raise high expectations, they are not able to draw strong conclusions. I was all the more disappointed about the technical implementation of the experiments. Important details of the climatic forcing are unclear, the model calibration appears insufficient and the computation of relative regional glacier length changes seems inappropriate. All this precludes a meaningful interpretation of the results. Therefore, I cannot recommend this article for publications in *The Cryosphere*. I fear that the necessary revision of the manuscript will involve fundamental changes in the experimental details, in the analysis and the manuscript content that will justify a new submission. Nonetheless, I leave it to the discretion of the editor if he wants to continue to consider this submission for publication.

General comments

Climatic forcing & calibration

The authors explain that they use 6 general circulation models (GCM) to drive

OGGM with temperature and precipitation. I suppose that they used monthly fields of surface air temperature and precipitation. Yet no details are given. Is the OGGM-inherent interpolation scheme used for these variables. I think that it is worth to specify the assumed lapse rates. However, my primary concern is the casual description of the climatic forcing. In lack of details, I assume that, after the model calibration, the GCM forcing is directly given to OGGM. Yet the GCM performance will differ around the globe making them more or less suitable for explaining length changes in various regions. In my view, the general practice is to define a common reference period with a climatologically meaningful length and apply the climatic forcing in anomaly mode. In this way, GCM biases in the recent period can be accommodated. This aspect is even more relevant in terms of the OGGM calibration. As the authors only refer to the original OGGM publication (Maussion et al., 2019), I assume that the temperature sensitivity parameter (μ^*) is automatically calibrated based on the interpolated CRU data set. Correct me if I am wrong. Please specify the calibration time period in OGGM. The automated OGGM calibration implies that when you change to the GCM forcing, the model is not expected to perform well in the recent past, reverting the benefit from the *CRU* calibration. Changing to anomaly modes will help. The other option is to calibrate μ^* to each GCM. As it stands now, I fear that it is almost impossible to interpret the results.

Representativeness
Please specify how representative the glacier sample that has length observations is for each RGI region. An idea could be to present numbers of hypsometric and glacier-area distribution of the glacier sample as compared to the entire region.

Regional length changes
You compute the regional relative glacier length changes as the mean of normalised length variations of all glaciers with length observations per RGI region. First, this normalisation overrates the importance of small glaciers. You can see this for Alaska in Fig.1: at several points in time, regional relative length changes exceed 0.5 in less than 10 years which should not reflect the response of the large glaciers. Second, the formation of a mean value is highly susceptible to outliers. Outliers in terms of normalised length changes are expected from the small glaciers in the region because large glacier systems will only show moderate relative length fluctuations. Is it possible to use a more robust measure. I do not think that the median will help, let alone that it will be more informative. Yet a weighting by glacier area might help. In addition, you compute the regional mean on an annual basis only considering glaciers with measurements in that year. In many regions you see abrupt step changes in this regional value, which are likely a relict of this strategy. It is therefore very difficult to interpret the regional length change record because they can either arise from the model response or the changing number of considered glaciers from year to year. It would be highly informative to include a plot with the regional length records in addition to the sample size variations through

time. An idea for removing the ‘spike’ behaviour is to assume a linear length change between sparse length observations. In other words, would it make sense to linearly interpolate the observed length record to a yearly timeline for glaciers with irregular sampling of length information. Admittedly, my suggestion is not ideal but it removes the sample-size dependence from the regional length values.

Glacier complexes
In the past, many of the nowadays separated glacier units in the RGI were part of large complexes comprising several glacier branches. As OGGM treats each RGI unit independently, larger glacier complexes in the past are not allowed to form. How important is this fact for the glaciers you are focussing on. The influence of tributaries might well have been important for past length changes even during the period with length observations. Is it possible to consider this effect in OGGM? If not please discuss.

Calibration strategy
Recently, Eis et al. (2019) presented an alternative for the standard initialisation technique in OGGM. They show that it is important to not only consider present glacier length in the calibration but also the full geometry. In this way, the uncertainties in hindcast simulations can substantially be reduced. As I understand it, you use the standard OGGM spin-up which is not intended to reproduce length changes even in the last century. If there is no length change calibration in this period, why would you expect reliable performance over an entire millennium? Please justify. From my perspective, it is a prerequisite that the approach is calibrated against the length change record (Leclercq et al., 2014) to guarantee a certain reliability over multiple centuries.

Manuscript structure
The ‘Methods & Data’ section and the ‘Results’ sections appear as single entities and they lack some structure. For the ‘Methods’ section, you could present OGGM with some more details on the inherent calibration. For the ‘Data’ part, you can specify the RGI and the length record with the pre-processing details. Moreover, the climatic forcing could be described in detail. The ‘Results’ section is a *mélange* with a discussion. I would mention that in the section title. Also try to introduce some sub-divisions.

Objectives
As already mentioned above, you raise high expectations in your introduction but the conclusions appear rather vague (e.g. abstract, L35, L44, etc.). Therefore, I suggest that you better streamline the manuscript on the conclusions that you are able to draw.

Open Data set
From your description, I appreciate the effort to link the RGI to the length change

record from Leclercq et al. (2014). I therefore suggest that you provide a look-up table between the RGI-ID and the ID numbers of the length record, specifying 'positive' and 'best-effort' matches as well as not retrievable entries.

Detailed comments

L35 To what challenges do you refer here? You emphasise this point already in the introduction but you leave it vague here. Please substantiate.
L107-108 From this sentence, I would have expected that Table 1 comprises number of glacier units and glacierised area per RGI-region. Please add.

References

Eis, J., Maussion, F., and Marzeion, B.: Initialization of a global glacier model based on present-day glacier geometry and past climate information: an ensemble approach, The Cryosphere, 13, 3317–3335, doi:10.5194/tc-13-3317-2019, 2019.

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Maussion, F., Butenko, A., Champollion, N., Dusch, M., Eis, J., Fourteau, K., Gregor, P., Jarosch, A., Landmann, J., Oesterle, F., Recinos, B., Rothenpieler, T., Vlug, A., Wild, C., and Marzeion, B.: The Open Global Glacier Model (OGGM) v1.1, Geoscientific Model Development, 12, 909?931, doi: 10.5194/gmd-12-909-2019, 2019.