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Interactive comment on "Feedbacks and mechanisms affecting the global sensitivity of glaciers to climate change" *by* B. Marzeion et al.

P. W. Leclercq (Referee)

p.w.leclercq@uu.nl

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The authors present sensitivity studies of the glacier response to climate change in terms of contribution to sea level change. They combine a simple temperature index mass balance model and a schematic description of the changes in glacier geometry to study the reponse of glaciers to temperature and precipitation changes. The model is forced with the output of a range of climate models for 4 different climate scenarios.

The geometrical adjustment of glaciers to climate change and the relative importance of changes in precipitation and temperature changes have been addressed in previous studies. Nevertheless, the results presented in this study are a welcome additional illustration of the implications for the global mass budget of glaciers in the coming century.

I have two major issues with the methods used and a number of smaller points, which are listed below.

Major comments:

- Calibration and interpolation of mass balance parameters

The mass balance model is very simplistic, which to a certain degree is understandable in a study of global glacier changes. The calibration of this mass balance model on observations (p 2767 ln 14 - p 2768 ln 10) makes a detour by looking for a period in which the present glacier geometry would have been closest to balance. For the glaciers for which no mass balance measurements are available, the time of this period is determined by spatial interpolation and subsequently used to derive the MB parameters for these glaciers. This is a very peculiar procedure: if e.g. for one glacier with MB obsersations the equilibrium period is found to be centered around 1910 and for another glacier with MB observations the period is centered in 1970, then for a third glacier in between these two the period will be centered around 1940, while in reality this could be a period of stong disequilibrium for all three of the glaciers. I do not see a solid ground for this spatial interpolation of the timing of periods. The fact this procedure gives smaller errors in the cross validation than direct interpolation of the parameters is not enough to justify it. With such a simplified approach compensating errors cannot be excluded and the method should be legitimate on a priori grounds. I therefore think the determination of model parameters for glaciers without mass balance observations should be changed.

- Uncertainty/error analysis

The uncerainty in the model parameters is determined using a leave-one-out cross validation. For a proper uncertainty estimate this method requires independent observations. This is problematic as the mass balance records against which the glacier model is tested are often strongly correlated if they are within the same region, and therefore not independent. The problem is amplified by the inverse distance interpolation, which gives nearby measurements larger weight in the model fitting. This probably leads to an underestimate of the uncertainty in the model results. Therefore the uncertainty has to be re-evaluated, for example by using samples of correlated MB records instead of a leave-one-out procedure in the cross validation.

Other points:

p 2762 ln 15: is liquid

p 2765 ln 6-10: these issues have been discussed before, also at a global scale: e.g. Zuo and Oerlemans (1997) have stressed the importance of the imbalance between climate and glaciers at the start of SLR calculations, and Oerlemans et al 1998 also discuss the effect of changing glacier geometry on the response to future warming for a sample of 12 glaciers modelled with dynamical glacier models.

p 2766 ln 11: the gridded climate data sets most likely underestimate the precipitation on glacier as they do not capture the orographic effects. Is this accounted for in some way?

p 2771 ln 3: use the same units throughout the paper: cm SLE or mm SLE

p 2769 ln 19: here and in other parts of the study sensitivity analysis are performed based on runs with different CMIP5 outputs which are then sampled in steps of 1 K temperature change. This results in rather crowded figures (Fig 2, 3, 4, 6) and the combination of the effects of spatially hetereogenous climate change and change in glacier geometry. Firstly, I think that for this sensitivity study not all climate models and not all climate scenarios are needed. Secondly, I would suggest to use a uniform warming, or precipitation change, on all glaciers to study the effects of changes in glacier geometry, a second set of experiments to show the relative importance of

temperature and precipitation changes, and finally perform a seperate experiment to show the effect of spatial differences in the projections of climate change. I think such an approach would simplify the presentation and discussion of the results.

p 2772 l 9: the two do not cancel, they are seperate experiments. Maybe rephrase into something like: "The mass gain calculated by increasing precipitation only is of the same magnitude as the mass loss calculated from changing both temperature and precipitation.

p 2772 p 12-14: To me it is not clear what is meant here. You mean for small climate change the mass loss calculated from the full forcing is larger than the mass gain for forcing the model with only precipitation anomaly and the other way round for large climate change?

p 2772 ln 23: Maybe include a reference to Gregory and Oerlemans (1998) who found the same with exactly the same explanation.

p 2773 ln 20: keeping the area constant while increasing the terminus elevation is a very unphysical experiment. It implies that the surface area at high elevations of the mountain ranges increases with climate warming. Of course this leads to less mass loss (see p 2778), but a change in mountain topography like this is so unrealistic that I suggest you leave this experiment out.

p 2775 ln 17: "ignoring the" suggests that this quadratic approximation derived from eq 1 is a true, or at least better, description of real mass balance sensitivity. Although it is clear that the sensitivity is non-linear due to many feedbacks, I haven't seen any proof that a quadratic approximation is better than a linear one, so I suggest you leave the phrase (i.e ignoring ...) out.

p 2275 ln 18: are you sure this is not the number for the contribution of the Greenland ice Sheet (their page 476, 3rd paragraph, 5 line from below)?

p 2776 ln 24: the fairly constant rate of glacier mass loss in the 20th century is an intriguing issue. The authors also seem think it is important as a large part of the discussion is devoted to the subject. Therefore, I wonder why they do not show an experiment comparing modelled mass change with geometric adaption and with constant geometry for the 20th century. Then maybe the "supporting" could be replaced with a firm answer.

p 2777 ln 6: in the approach of Van de Wal and Wild (2001) and Slangen et al (2011) the mass balance is not dependent on the terminus elevation as in the model used in this study. I therefore wonder if the comparison is that straightforward.

p 2777 ln 11-12: The disappaerance of glaciers is a good explanation for the difference after substantial climatic change. However, also for limited mass loss (150-200 mm SLE, i.e. a range that is reached in both scenarios) the difference between no terminus change and full geometric change seems to be larger for RCP 2.6 than for RCP 8.5. What explanation can be given for this difference?

p 2778 ln 3-4: I think you should skip this experiment (see above) but still the advise to rephrase "weak": "smaller mass loss", "with stronger reduction of mass loss for warmer"

p 2779 ln 1: This experiment could be relevant for several glaciers that loose mass with a lowering of the surface but show limited retreat. However, the model used in this study cannot account for surface lowering as the mass balance is determined by the terminus elevation instead of the surface elevation.

References

Gregory and Oerlemans (1998) Simulated future sea-level rise due to glacier melt based on regionally and seasonally resolved temperature changes, Nature 391, pp 474-476

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