

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

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— SUMMARY —

Building upon previous work and an existing glacier model (Marzeion et al., TC, 2012), the authors analyze (1) the equilibrium sensitivity of worlds’ glaciers, and (2) the impact that different scenarios of glacier adjustment have on projected global glacier mass loss. Scenarios for future climate evolution are taken from CIMIP5 experiments, and accounted for in an ensemble-like fashion. Although some of the experiments have very theoretical character, they provide useful insights for quantifying the feedbacks affecting glacier evolution. The study has a very simple set up and a clean methodology, which makes it easy and pleasant to follow. The clarity of the presentation, however, would benefit of a revision of the text: In many cases the reading is hampered by exces-

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sively long and complex sentences. I would recommend acceptance of the manuscript after minor revisions.

— GENERAL COMMENTS —

The only general comment I have concerns the presentation of the manuscript: I would strongly encourage the authors in trying to simplify every single sentence as much as possible. The use of footnotes and rather prominent use of explanations in parenthesis are probably one of the most immediate signs of a text that doesn’t runs as smooth as it could. This often hampers the reading - which is a pity in light of the cleanliness in which the experiments are set up. See the “stylistic comments” section for some example and concrete suggestions for reformulations.

All further comments are of specific nature, and listed hereafter. The most important concern the informative value of P2778 (which in my opinion addresses a very specific question, hardly of practical relevance), and the interpretation of Figure 9 (see “Comments to figures”).

— SPECIFIC COMMENTS —

P2762 L10-12: This is somewhat unclear: What do you mean with “because of geographic distribution” (what is so special about it)?

P2762 L11: “anomalies” with respect to what?

P2762 L17-19: At this stage, it is not possible to understand how “sensitivity” is defined (there is no general definition for it in glaciology, is there one?). Similarly it is unclear with respect to what this sensitivity is “decreased [...] by a factor two to three”.

P2765 L24: Why “area mean monthly solid precipitation”? “Mean” over what? Do you mean “precipitation per unit area”? The confusion arises also because of the sentence at P2767 L8.

P2766 L25: μ looks like a “melt factor” in PDD models. The wording “sensitivity”

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sounds rather artificial to me. . .

P2766 L8: Where is the bias correction coming from? This also brings me to the question if the model parameters are glacier-specific. T^{terminus} definitely is. What's about the other ones?

P2766 L16: Why "linearly adjusting"? What do you mean with "linear"?

P2766 L7: Why "towards"? It sounds like there is a time-lag or something similar. Is there one?

P2766 L20: For consistency you should write $dA(t)$ and $d\tau_A(t)$, isn't it? This is particularly true for τ_A . Moreover, I would suggest placing Eq.(5) directly here, since the question "how is τ_A computed?" immediately comes up.

P2766 L20: Somewhere you need to state something like $dV(t)=B(t)*A(t)$.

P2766 L22: Directly in the text, give the values and units for c_A and γ that you used.

P2767 L23: Give the values and units for c_L and q . Place Eq. (4) at the point where you introduce τ_L .

P2767 L8: Over which period is the "climatological solid precipitation" determined?

P2767 L15-16: State the actual number of glaciers that have "available mass balance measurements in Cogley (2009)"

P2767 L16-18: Not sure to understand correctly: What you do is to "scan" through the past time series and look for a given period that fulfills your condition "Eq. (6)"?

P2768 L2: Ok, but the "t" mentioned here is a particular "t", not "any t" as it was in Eq.(1) to (5), correct? Shouldn't the "t" have a particular symbol then? Like t^* or so?

P2768 L3: Is the number 109 correct? Or should it read 1308 (=12*109)?

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P2768 L5-7: Not sure again: Do you run the glacier model over 109 years for each of the 109 possible μ s?

P2768 L11-15: So the assumption is that the glaciers of a given region are in equilibrium with a climate all at the same time, right? It may be worth stating it explicitly. But isn't there an elevation dependence to be expected? Is the sentence at L20-21 going in that direction?

P2768 L16-17: Interpolating the bias? What is the argument for doing that? And how do you justify it?

P2768 L25: You are certainly aware that there is RGI v3 available by now. Do you stick to v1 for allowing direct use of your previous results? It may be worth stating it.

P2770 L1: What are the "statistics" you need?

P2770 L1-2: Where did you get the information about "year of observation" from? RGI v1 did not include such info!

P2770 L4-7: Wow! In each iteration step you need re-computing all ** variables, don't you? How often do you need to iterate for achieving convergence? And how do you afford iteration at all, with about 170,000 glaciers contained in RGI? (This is rather a curiosity than a question that needs an answer in the paper :-)

P2770 L25: What are "climatologies of the anomalies"? Should the climatology (= mean) of an anomaly not be zero by definition? Is this "climatology of the anomalies" something similar as the "delta" that is used in delta-change methods?

P2771 L16: Please quantify "small": Is it <1%, <5%, <10%?

P2771 L7-8: I don't understand what you mean: Is the error getting larger with increasing length of the modeling period? Or is it the other way round?

P2771 L9: I would state 128 ± 27 mm, instead of "of the order of 130mm". The same comment applies for the other numbers given in the section.

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P2771 L18-21: Oh! This is quite an important statement, isn't it? According to what you state we (= the worlds' climate) are close to a "change point"! You may want to highlight this finding!

P2771 footnote: How did the "upscaling" took place? More information is required! Moreover, why didn't you use another volume estimate, in order to avoid the strange >100% volume loss? And you don't need to take too serious the even more annoying question about why you didn't omit these glaciers from the estimate ;-)

P2772 L4: It seems appropriate to me adding a sentence like "[. . .] since energy input from liquid precipitation was neglected." (or similar) at the end of the line.

P2772 L9-12: Stating that ignoring warming precipitation changes according to 4K warming would do x and y sounds rather awkward to me. Wouldn't it be more appropriate speaking about a given percentual precipitation variation? The same comment applies to Fig. 4.

P2772 L12: At "lower" than what? The 4K mentioned before?

P2773 L5-7: The positive correlation is easily explained, but what's about the "amplification"? Can you give an explanation similar to what you gave for temperature? I found it quite illuminating :-)

P2773 L12-ff: Ok, these scenarios are rather funny, aren't they? The second would imply only reduction of width and thickness, the third implies area expansion at high elevation, and the third one even implies a moving bedrock! It may be worth stating that you are well aware that these scenarios are purely synthetic. No modeler would ever consider using such things – I hope ;-). Moreover, I would suggest giving a "title" to each of the scenarios, since your following subsections refer to these scenarios. Taking your subsection titles, I would suggest "Constant hypsometry, infinite ice volume"; "Constant terminus elevation, variable hypsometry and volume"; "Constant surface area, variable hypsometry and volume"; and "Constant hypsometry, variable volume". The following

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subsections should then be named accordingly, and the same wording used in the caption of the figures. And by the way, you may want to cite Gabbi et al., HESS, 2012, who performed similar sensitivity experiments addressing the ice volume distribution at the catchment scale.

P2774 L4-6: State explicitly that the model by Marzeion et al. (2012), is accounting for all effects simultaneously! At the moment, you are only implying it.

P2774 L15-16: At this stage it is unclear why you need the two different weighting methods. I was wondering if you need the weighted version at all, since the result is the same at this stage. The difference becomes clear only later. You may give a hint here, or introduce the weighting only when you need it.

P2774 L20: Here and after: What "seasons"? Do you mean "melt and rain season"? State it explicitly!

P2774 L26: Ok, 1 mm SLE yr^{-1} is the value of your function for $\Delta T=0$. State it explicitly.

P2775 L11-16: It is really not clear to me how you can make this attribution. . . Clarification is required.

P2775 L20-24: Shouldn't you compare the coefficients of a linear fit first? The numbers would be different than now (actually they would be even higher), wouldn't they?

P2775 L24: Why "variability"? You are using the past climate as such (i.e. same mean temperature etc.), not only the variability, isn't it?

P2776 L1-5: Well, if the "sensitivity" is a function of the glacier state itself, of how much use is the concept at all? In particular, how do you argue for using a constant "sensitivity" in your model, that is run for 300 years or so?

P2776 L14-19: Isn't this rather trivial? Why would someone expect something else?

P2777 L2: Why "negative feedback"? Higher terminus elevation means higher (i.e.

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less negative) mass balance, isn't it? This is probably called a "positive feedback"...

P2777 L6-7: The sentence is unclear: Did the two mentioned references allowed for adjustment of the terminus or not?

P2777 L16: "close to equilibrium": Well, "equilibrium"... that's rather the state when all glaciers are gone!

P2777 L19-23: I do not understand what you want to say. In particular: What does your last sentence imply?

P2778 L3-4: "weaker" and "stronger weakening" compared to what? Shouldn't the next sentence then begin with "In contrary..." in order to illustrate what you mean?

P2778 L5-27: If I'm honest, this is the only part of the paper I didn't liked: The issue you are addressing seems to me a very particular artifact that may occur when a glacier that has reached zero volume is not defined as "gone" in a model. This is a "bug" which is that easily fixed... I don't think there is the need of much discussion for that. By far more important is what happens during the time the glacier has a volume >0. However, this point is hardly addressed at all. I would appreciate more discussion on that.

P2779 L26: Have you an explanation for why the precipitation compensation is smaller in your case?

P2782 L1-2: What do you mean? This is not clear to me.

— STYLISTIC COMMENTS —

P2762 L1: ",," after "the past"

P2762 L6-8: It took me quite a while understanding what you mean. Maybe placing "to a large degree" after "is governed" (instead of vice versa) would help? Or maybe you can reformulate the sentence.

P2762 L1-23: The wording "mass loss" occurs 7 times in about 10 sentences! There

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is certainly a way of avoiding that much repetition :-)

P2762 L15: "it" should read "is" or "will be"

P2762 L16: consider "potential" instead of "projected"

P2763 L4: "probably" can be removed.

P2763 L13: Start a new sentence after the first "total mass".

P2763 L16-17: The construction for the citation looks somewhat involved. Try to simplify the whole sentence.

P2763 L23: Why don't you give only the range (as you did in the previous line)?

P2764 L1: I think you can remove the footnote.

P2764 L5-10: This is a good example for a rather complex sentence. At L5 you can remove "overlap of"; "of the ensemble of climate projections" can be replaced by "in the climate projections"; and L8-10 could almost be omitted. Try to be as concise as you can.

P2764 L11-12: Also this sentence may be removed.

P2764 L17: "However," instead of "But"

P2765 L1: Remove "conditions"

P2765 L6: "To date" instead of "But"

P2765 L11: Remove "- but not all -", or explain which of the "relevant mechanisms" are not "captured".

P2765 L17: Remove "by keeping various aspects of glacier hypsometry fixed in the model" – at this stage it is unclear what you mean.

P2766 L6: "location and elevation of the" can be removed.

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P2766 L25: “through the glacier steepness” can be removed

P2767 L5: Remove “roughly”

P2767 L8: Remove “surface”

P2768 L8-9: reword to “[. . .] the corresponding temperature sensitivity μ yields the smallest difference between modeled and observed mass balances”

P2768 L14: Add “by solving” (or similar) after “i.e.”

P2770 L14: Remove “glacier” in “leave-one-glacier-out”.

P2770 L20: Maybe you can make an introductory sentence before you start with the individual subsections. It would be easier to follow if one knows what you are aiming at.

P2771 L3-8: You can write these sentences without brackets.

P2771 L17-19: I would consider removing the sentence. It opens more questions than it answers: What is a “true equilibrium” (why “true?”) What does it mean that a climate system “is not itself an equilibrium”? The wording doesn’t make much sense to me (of course a climate system is not an equilibrium; it is a climate system ;-)).

P2771 L5: Remove “relative to the same time period”

P2771 L19: 15mm SLE K^{-1} is the “glacier sensitivity”, not the “glacier mass loss”, right?

P2772 L12: Move “(400mm SLE)” at line 10, after “mass loss”

P2774 L14: “easier to understand” than what? What do you mean?

P2774 L24-25: You can remove “mean goodness of fit (measured by)” - and the closing parenthesis of course.

P2774 L27: Insert “as” before “discussed”, and “in” after it.

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P2775 L10: Start a new sentence after “and ablation”.

P2776 L11-12: Reword into “The remaining differences are due to the patterns in precipitation anomaly, and history [. . .]”

P2776 L20-25: Most of this paragraph is repetition. Moreover, the writing style is rather colloquial. I would suggest removing the paragraph (or reformulating and condensing it).

P2777 L9-10: Maybe I don’t understand what you mean, but “higher mass-loss rates” are the only way for getting a higher volume change in the same time frame, isn’t it?

P2777 L11: “presence” (or something else) instead of “availability”

P2777 L17: Check the wording: What does it mean that the “effect” is a “function” of something? How do you measure this “effect”?

P2777 L27: Consider “arguably” instead “presumably”

P2779 L3: Remove “us”

P2779 L7: “large”, not “great”

P2779 L15: State the two “reference times” explicitly.

P2779 L16: Repeat your number when saying “out estimate”

P2780 L19: “Our” instead of “The”

P2780 L16-ff: Split this sentence!

— COMMENTS TO FIGURES —

Fig. 1: Remove the “two sigma”-shading. It is hard to see, and complicates the figure.

Fig. 2: (1) Why are some lines stopping at $\Delta T \approx 4$? Do these model runs go up to a certain period only? (2) Avoid the abbreviation “% w/o AA” in the y-axis.

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Fig. 4: x-axis should read “precipitation anomaly associated with . . .”

Fig 6. Reword the caption into “Global glacier mass balance, expressed in terms of global mean sea level equivalent (SLE), as a function of anomalies in (1) global mean (open circles, dashed lines) and (2) glacier area weighted (filled dots, solid lines) temperature. Results refer to the “constant hypsometry, infinite volume” scenario. Colored lines show [. . .]. Different panels refer to different RCPs” The statement about the different panels should be included in Fig. 8, 9, and 10 as well.

Fig. 8: Add “(fully adjusted geometry)” (or similar) to the x-axis label. Can you put a time frame until when this mass losses are expected to occur?

Fig. 9: Why this different behavior in the different RCPs? In (a), (b), and (d) the different glacier-adjustment scenarios cluster very differently: By 2300, they are more or less equally spread for RCP 26; in RCP45 “terminus & area fixed” is almost the same as “full”; and in RCP85 “full”+“terminus fixed” and “area fixed”+ “terminus & area fixed” cluster at two different levels. Why is that? Doesn't this compromise the generality of the results that you have described in the text? And by the way, what's the “jump” around year 2100 in RCP26?

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