

**Comments on “Past and future sea-level change from the surface mass balance of glaciers”, by B. Marzeion et al., *The Cryosphere Discussions*, 6, 3177-3241 (2012):**

*J. Graham Cogley, September 2012*

*General Comments*

This paper describes in detail a highly generalized model of single-glacier mass balance. The model relies on a newly-available and globally complete glacier inventory, and requires input information on temperature and precipitation at monthly resolution. Taking these inputs from datasets from the Climatic Research Unit, University of East Anglia, the model is calibrated against measured glaciological and geodetic mass balances and is used to estimate global average glacier mass balance from 1902 to the present. Mass-balance projections are made to 2100 with input from 15 general circulation models participating in the CMIP5 intercomparison, and to 2300 with five to seven of those GCMs. Each GCM was run for either two or three of the Representative Concentration Pathways.

The mass-balance model resembles other such models in a number of respects, notably its reliance on volume-area scaling to simulate the coupling between mass change and dynamics, but it has a number of intriguing new features of which the most interesting, to me, is the estimation of temperature sensitivity (section 2.1.9). The paper provides a wealth of results that will be extremely valuable for improving our understanding of the history of mass balance before the era of relatively abundant measurements (roughly, before 1960) and for assessing the evolution of mass balance during the next one to three centuries. Highlights include surprisingly large rates of mass loss for 1920 to 1940; confirmation of accelerating loss since the 1960s, as found in previous observational assessments; and confirmation of a previous finding (Radić and Hock 2011) that peak yield of meltwater is likely to come in the mid- to late 21st century. The present study advances beyond Radić and Hock by using the more recent CMIP5 simulations, results from more GCMs, and results from three concentration pathways. A climatologically significant finding is that variation within model ensembles is the main contributor to projection uncertainty in the 21st century, while after 2100 variation between scenarios dominates.

This is an important paper and deserves to be published. It is well written and describes work that has clearly been done thoughtfully and well. It is not free of shortcomings, but as detailed below these are rather minor.

*Substantive Comments*

P3180

L10-12 It would be appropriate to cite Pfeffer et al. 2008 here (*Science*, **321**, 1340-1343).

P3182

L19-21 It would be helpful to give the resolutions of the CRU datasets.

P3184

L16-17 “Since dates of the glacier outlines are not given ...”. Dates or date ranges are given for about half of the outlines in RGI version 2.0, and if it were possible to update this paper to the newer RGI version this information could be exploited to reduce the uncertainty in glacier area.

L25 A brief explanation of the “motivation” of eq.5 would make it more accessible to readers unfamiliar with volume-area scaling. The first term in the parenthesis on the right is simply  $A(t+1)$ .

P3188

L5 “all overlapping 31-yr periods”. But I am not sure what is being done here. I understand a “climatological value” to be a multi-annual average for a fixed reference period, and I therefore infer that  $P(t)$  and  $T(t)$  are 31-yr running means. What I do not understand is why the sensitivity in year  $t$  should be a function of  $P$  and  $T$  in 30 other years. More explanation is needed.

P3190

- L3 “glacier’s”. I have been wondering why the symbol MB was adopted for mass balance in eq.1, and it now appears that *B* (presumably the first letter of *Breite*) represents the width. The development would be more accessible to more readers if mass balance were *B* and width were *W*.
- L15 Eq. 15 assumes that the glacier is a rectangle, which may be harmless but seems odd.  
L20 Define “skill score” briefly.  
P3193
- L7-8 Name the four worst-performing regions of Figure 10. In three, there are only one or two measured glaciers, but some discussion of the worst performer of all (with eight measured glaciers [Low Latitudes?]) might be warranted. It may also be useful to discuss in this paragraph some of the individual outliers in Figure 8. There are too few extreme observed balances (left and right centre) to judge the model’s ability to reproduce them, but all of the really bad instances of mis-modelling (top and bottom centre) seem to be in the Low Latitudes or Southern Andes. (In passing, it is not very easy in some figures to distinguish the regions by their colours, although on the whole the colour coding is a good idea.)
- L22-23 Does “sampled” mean “measured” here?  
L25 “artificially reduces the number of close-by sampled glaciers”: this is obscure to me. I think it may mean that the remote glaciers have a disproportionate impact on the dependency. If so, I am not sure of the correctness of the remark, but as noted in the next sentence it relates to a weak relationship.
- P3195  
L8 This remark about interannual variability is correct, but it is also true, and perhaps more interesting, that climatic *change* (a trend in *n*) will lead to a trend in  $\epsilon$ .
- L18-22 See comment at P3184 L16-17. 5% is likely to be a generous but not unreasonable estimate of the uncertainty in area.
- P3196  
L20-21 It would be more direct to say “the regional density of mass-balance observations is well correlated with the density of weather observations”.
- P3197  
L21 I think this should read “for one series of geodetic volume change measurements”.
- P3198  
L27 Modelled area changes less reliable than modelled volume changes: I do not follow this argument. Surely the two are tightly coupled through eqs. 5-7.
- P3200  
L4-6 Antarctic balances assumed equal to the mean for the rest of the world: Analysis of ICESat data by G. Moholdt suggests that this is a poor assumption. The analysis is not yet published, but I understand that the present authors are aware of it.
- P3202  
L21 “characterized by big glaciers” (see also L15, L18): this concept needs to be better focussed, perhaps in terms of the regional mean or median glacier area. Western Canada and US, in particular, may be inappropriately classified at L17.
- P3206  
L15 “Since our model ...”: I am struck by the apparent absence of any allowance in the model for internal accumulation (sometimes called refreezing). The omission of frontal ablation from a model of surface mass balance is understandable, but the omission of internal accumulation needs to be justified, or at any rate discussed. Generalized as the model necessarily is, it appears that its various thermal parameterizations (e.g. as described in sections 2.1.8, 2.1.9 and 2.2.5) will not capture the tendency for some surface meltwater to be retained with the glacier.
- P3207  
L5-6 “Depending on the scenario”: My reading of the lower panel of Figure 24 is that the broad peak comes in the fourth quarter of the century in RCP 8.5, the middle of the century in RCP 4.5 and the second quarter of the century (say 2030-2050) in RCP 2.6.

Perhaps “Depending on the scenario” should be expanded somewhat. (See also P3178 L18.)

*Stylistic Comments*

P3178

L9-10 “lose”. “either ... or” rather than “between ... to”.

L13-15 “from” rather than “between”.

P3179

Footnote Delete “forms of”.

L10 “Improving knowledge of how”.

L12 Delete “achieve”.

L20 “dynamics leads”. Dynamics is usually considered a singular noun (cf. physics).

L25 “for short and recent periods”.

P3180

L7 “imposes”. “number” rather than “amount”.

L11 “circumvented”.

L14 “degree”.

L20 Change “approx.” to “only about”, and add the apostrophe to “world’s”.

L20-21 “half ... was modelled”. Surely “shields” should be “sheets”.

L28 “more strongly”.

L29 “the”, not “these”. “have projected”.

P3181

L4 “paramount for”.

L8-13 Break up sentence; it is too long.

L15 I would change “following” to “in response to climatically forced”.

L3182

L2-5 “area-mean” is redundant.

L11 “available”.

P3183

L4 Delete “area”.

P3184

Footnote “minimum”.

L7 It would be as well to mention in the text that version 1.0 of the inventory is being used.

L9 “over version 2 of the ASTER global ...”. This is usually referred to with the acronym “GDEM”.

L13 “9 km<sup>2</sup> in size”.

L22 “in”, not “on”.

P3185

L6 To avoid repetition, change “, but” to “; instead it”.

L23 Delete “Afterwards,”.

P3186

L1 Would it not be more natural to say “at the start of the mass balance year”? (See also L19.)

L2 “area mean” is redundant here, as elsewhere.

L3 Change “estimated as” to “assumed to be”.

L11 Change “calculated as” to “taken as”.

P3187

L2 Change “calculating” to “finding”.

L5-6 Delete “, even though ...”.

L18 I believe “metadata” is usually spelled as one word.

L20 Change “2” to “two annual”.

P3188

L9 “consequently”, not “subsequently”.

L11 The quantity  $t^*$  is introduced in an odd way. The reader would have less trouble if the text read "... the year  $t^*$  in which <eq.12> is minimal. Here ...".

L15 " $\beta$ " (not " $b$ ").

P3190

L8-9 "The scaling parameters for ... of a glacier at equilibrium are taken".

P3191

L2-7 Break this convoluted sentence into two or three sentences. Remind the reader that the quantity being discussed is the  $a$  of eq. 2.

L14 Change "increasing" to "increase of".

L20 "and show the results".

P3192

L14 Change "does not melt" to "fails to melt in".

L24 "balances being derived independently of".

P3193

L4 "scale".

L10-11 Delete comma, and say "does a Kolmogorov-Smirnov ... reject".

L28 Delete "model".

P3194

L3 "in the network".

L18 "for reconstructions with CRU data and >200 yr for projections with the GCMs."

L19-22 I think this sentence would benefit from recasting, along the lines of "Changes ..., which affect the temperature that it experiences, act on longer time scales, so model uncertainty related to uncertainty in terminus elevation is ...".

P3195

L6 "time both before and after the date of measurement of".

L13-14 "estimated to be 40%. Before and after ...". If "prior" is used, it must be followed by "to", but "before" is probably better.

L16 Mention the figure in which the results of the cross validation are shown.

L22 "Before".

L24 Insert "(sec. 4.2)" after "as above".

P3196

L5-6 "volume-length scaling, estimated to be". "Before".

L7 Insert "(sec. 4.2)" after "as above".

L9 Change "associated with" to "of".

L12-13 Change "Note that still" to something like "Even so".

L19 "uncertainty due to sampling". The text is wordy in many places, and this is a good example.

P3197

L2 Change "associated with" to "in".

L6-7 "it is not practicable to quantify".

P3198

L5 "losing".

L11 "an indication of".

L26 "percentile".

P3199

L3 Delete second comma.

L11-12 "and" should be "or" and "with" should be "and".

L13 Delete second "the".

L21 "an overview of".

P3200

L8-9 "because i) there are data gaps ...".

L12 Delete "a".

L14 I would hyphenate "regional-mean" and delete "specific".

P3201

L2 “reconstructed to be” or “reconstructed as”.

L4 Add spaces before and after “SLE”.

L10 “consequently”.

P3202

L7-8 “to lose glacier mass continuously”.

L12 “as opposed”.

L15 “during” rather than “within”.

L20 I would delete the parenthesis.

L22 End the sentence at “as well”, and clarify the “However” clause in a new sentence.

P3203

L1 “ensembles”.

L3 Insert “onwards” after “century”.

L10 “at altitudes”.

L15 “principle”.

L22 “information about one glacier”.

P3204

L1 “automate”.

L5 “because of the cumulative”.

L5-6 “deem a negligible bias to be most important”.

L18 “Our model has only one glacier-specific parameter,  $t^*$ , that is not ...”. Delete  $t^*$  at the end of the sentence.

L22 “relatively”.

L24 “more than one parameter”.

L25-26 “data-to-parameter ratio”.

L27 “comparatively well”.

P3205

L18 Insert a comma after “data”.

L29 Delete second “of”, and change “as” to “to that”.

P3206

L6 “prevailed in 1932–1933”.

L10 “explain why, in comparison, our reconstructed ... rise is higher”.

L13 “Much of the mass loss ... comes”.

L17 “very possible”.

L21 “considerably”.

L27 “climate data, climate-model based reconstructions of past climate, and projections ...”.

P3207

L12 Change the first comma to a semicolon or a period.

P3225

Fig8 “interval”.

P3230

Fig13 L6 “forecast”.

P3233

Fig16 L6 “indicate”.

P3239

Fig22 L3 “solid lines”: these, conveying the main message of the graph, need to be thicker than they are at present. They stand out fairly well in black and white, but only poorly in colour. The same remark applies to Figure 24.