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Interactive comment on "What glaciers are telling us about Earth's changing climate" *by* W. Tangborn and M. Mosteller

W. Tangborn and M. Mosteller

wendell@hymet.com

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Author's response to Review of "What glaciers are telling us about Earth's changing climate" by "W. Tangborn and M. Mosteller"

In the present study, W. Tangborn and M. Mosteller, try to model and document the 160000 mountain glaciers worldwide, to demonstrate the link to climate change and to assess impacts of changing glaciers to the society. Documenting and modeling the mass and volume change of mountain glaciers, detecting the climatic drivers of the change and investigating the impacts of melting glaciers e.g. on sea level is a cutting-edge topic in cryospheric science and addressed in several recent publications (e.g. Gardner et al., 2013; Giesen & Oerlemans, 2013; Marzeion et al., 2012; Radić & Hock, 2011; Radić et al., 2013). Unfortunately, the presented study suffers from several

fundamental deficits and therefore cannot be seen as a useful contribution.

Authors Response: I appreciate this referee's thorough review that will definitely improve the paper, but unfortunately, I am also disappointed that he did not understand the scope of the paper and the implications of the PTAA model. The "cutting edge" publications he mentions were not cited because they are not pertinent to the approach we use to relate glaciers and climate change. To cite prior publications they must demonstrate a precedence to the current work that we are doing– these publications do not.

Responses to each section are as follows: He introduces his comments by making the negative connotation that we only try to model and document, implying that we did not succeed in our attempts to model glacier balances. However, the 50-60 years of independent balance results summarized in Table 1 and on the www.ptaagmb.com website for six glaciers, indicate our attempts were successful. Also, the model's balance results shown for the Bering Glacier (Tangborn, 2013) – Section 3.1 Validation, provide irrefutable evidence that the PTAA model balances are reliable and accurate.

Obviously we need to explain the PTAA model much more clearly and better describe the approach we have developed using glaciers to monitor climate change. Accordingly, the paper has been revised and expanded to include several more explanatory figures and tables.

General Comments/Deficits:

1. The indirect question in the title is answered without presenting any novel ideas to the community. I assume that it is clear to every glaciologist that glaciers are sensitive to meteorological parameters like temperature or precipitation (as stated in the conclusions). Furthermore I agree that changing glaciers (as accessible e.g. from historic moraines) can be useful as a proxy for the climate in the past (before meteorological monitoring networks were established) or for regional climate in the few remote areas without data records. If meteorological records are available it makes little sense to try to reconstruct the global climate by observing glaciers – weather stations are way more

precise to track the individual meteorological parameters. So the relevant question for non-paleo work is: “How do glaciers respond to Earth’s changing climate?”

AR: The main gist of the paper is based on the unique relationship between calculated ablation of Wrangell Range glaciers and the observed average global temperature (derived from 7000 temperature stations in the Northern Hemisphere (which might be considered a novel idea by the unprejudiced) .

It is necessary to read this puzzling paragraph several times to understand what the referee is saying. Most glaciologists would disagree that “ it makes little sense to try to reconstruct the global climate by observing glaciers – weather stations are way more precise to track the individual meteorological parameters.” I certainly do not agree that weather stations are more precise monitors of climate change than are glaciers. He ends by saying “ So the relevant question for non-paleo work is: “How do glaciers respond to Earth’s changing climate?”, which is nearly the exact title of our paper?? This is a confusing statement.

2. The introduction (Section 1) misses any information on related scientific work on glacier observations and modeling on a global scale (see citations in the introduction paragraph). You should also precisely explain the advantage of your model approach compared to commonly used temperature based approaches for global scale modeling that require fewer calibration parameters (for examples see literature cited above). You write that your model “does not require manual balances for calibration” which is not clear to me (see also Point 4.b). Beyond that, you definitely need manual balances for model validation.

AR: The advantage of the PTAA model over other glacier balance models is that it does not require manual or geodetic measurements for calibration. It is calibrated by minimizing the error of regressing several calculated balance parameters. In other words it relies on the internal consistency of generated balance variables. Of course it needs manual balances for model validation. How else would it be done? The model uses 15

coefficients to convert observed temperature and precipitation to snow accumulation and snow and ice ablation, but it should be noted that the same coefficients are used regardless of the day, year or elevation. Thus for a glacier with 150 elevation intervals that calculates glacier balances for 60 years, the identical fifteen coefficients are used 2,737,500 times. It cannot be said that we have overdetermined the results using too few equations and too many coefficients.

3. Section 2 (“mass balance measurements”) reads like another introduction but I would expect information on mass balance measurements that are used within the present study.

AR: This section has been incorporated into the introduction in the revised paper.

4. The title of Section 3 is unsuitable. It could for example read: “Mass balance modeling approach” and contain detailed information on the model, the calibration and validation methods. Such information is currently either incomplete or incomprehensible:

AR: he revised paper will have a detailed explanation of the model and how it is calibrated.

a. There is no clear model description in Subsection 3.1 (“Model description”). Even if the model has been published before (e.g. Tangborn, 1999, 2013), the basics of the model used for this study can and need to be presented here. In the present form it is laboriously and confusing to collect together all information required to understand the model.

It will not be necessary to collect information to understand the model – the revised paper will have everything needed to understand it.

b. I do not understand the model calibration method (Subsection 3.2). In the current manuscript, this is because the description is insufficient; but also when considering Tangborn (1999 and 2013), it is nearly impossible for me to understand how and for

which site the 15 values of the mass balance coefficients (Table 2) are initially defined and then optimized. Which measurements from which site(s) are used for optimizing the regression parameters by minimizing the objective function? I might not have understood your approach right, but I also wonder why you minimize 1-R^2 and not the errors between modeled and measured mass balance (as done in Rye et al. 2010, Section 4.3.2). Please also consider the points listed in the short comments of Cameron Rye which have not been fully answered in your first reply.

AR: I do not fully understand this comment. Minimizing the errors generated between modeled and measured balances would not make sense if we are presenting a model that produces balances independently. There appears to be a misunderstanding of how the PTAA model determines glacier balance. Hopefully this will be clarified in the revised paper. Response to Cameron Rye's questions are forthcoming.

c. The manuscript does not benefit from the attempt of a comparison with a Monte Carlo optimization approach (Subsection 3.3) because the comparison is far from complete and off-topic. I would remove this section.

AR: The Monte Carlo section has been removed but the reference to Monte Carlo simulation has not. The model resembles Monte Carlo simulation because it uses repeated random sampling of calculated coefficients that convert weather observations to snow accumulation and snow an ice ablation. Monte Carlo simulation algorithms rely repeated random sampling to obtain numerical results. This seems close enough to be called similar.

d. In Subsection 3.4 you compare modeled and measured annual mass balances for 5 glaciers in Alaska and the Alps. First, why should this be enough for demonstrating that your model yields reliable mass balance results for all 160000 glaciers worldwide? Did the measured mass balances enter the model calibration? Second, some R^2 are very low, suggesting low model skill (e.g. for Kesselwandferner). Third, you need to present further parameters concerning model skill like root mean square error or mean

percentage error (e.g. MacDougall & Flowers, 2011, Section 4) that yield more useful information on uncertainties of modeled mass balance values. Fourth, I appreciate scatter plots between modeled and measured annual mass balances (as shown on your website) but please make sure that the axis are equal and plot the 45° line. Fifth, you need to present much more results of your model evaluation in the present study, not only on your website.

AR: I repeat – the measured mass balances did not enter the model calibration. The R2 from regressing model and measured balances are low but is there another model in existence that independently produces annual balances from weather observations for 50-60 years? Degree-day type models require manual balance measurements and geodetic models do not produce annual balances. Table 1 shows the R2 for manual and independently calculated PTAA balances for over 300 year-pairs, which should be sufficient to give the PTAA model some credibility. We have added scatter plots of measured versus PTAA annual balances for four glaciers, and added a new table of pertinent statistics in the revised paper.

Overall, the descriptions of the model, the calibration and validation need to be understandable for the reader.

4. In Section 4, could you please also calculate and show the correlation between the temperature anomalies from your "model input stations" (McKinley Park and Big Delta) and from the 7000 Northern Hemisphere stations? This may offer an explanation for the high correlation between glacier ablation in the Wrangell Range and Northern Hemisphere temperature anomalies

AR: The correlation between the model input stations (McKinley Park and Big Delta) and global temperatures is zero, as it is for all individual temperature records, signifying that glaciers are significantly more sensitive to the global climate than are temperature observations measured with instruments.

The conclusions in the last paragraph of Section 4 are not meaningful, as ablation is

a function of temperature. It could be interesting if regional temperatures/glaciers are better connected to global (or Northern Hemisphere?) temperature trends than others but this is not shown here. 6. In Section 5 you state: “The main goal of the PTAAGMB project is to analyze glacier mass balance results to understand and predict climate change”. I come back on my first point: I think in general there are better ways to understand the ongoing climate change than by trying to extract climate information from glaciers. Furthermore, glaciers exhibit a certain response time to shifts in climate before they approach a new equilibrium (with the changed climate forcing). So you can partly estimate earlier climate conditions from current mass and volume changes (even though it might be impossible to separate between different meteorological parameters) but how do you want predict climate change from glaciers?

AR: Ablation of the Wrangell Range glaciers is controlled by the area-altitude distributions of the glaciers more than by observed temperatures. Therefore, the ablation and global temperature curves in Figure 3 are derived from independent data and their similarity is significant. Glaciers have long been considered harbingers of climate change. If we had heeded their warnings in the 1980s and taken action then to reduce our dependency on fossil fuels, the threat of a rising sea level, shrinking ice sheets, ocean acidification and the loss of the Arctic sea ice cover would be less worrisome.

At the current state I have no specific comments as too many major details are missing. I hope you can follow my arguments and understand that in my opinion the manuscript in the present form does not fulfill the criterions to be published in a peer-reviewed journal. Sincerely, Wolfgang Gurgiser (wolfgang.gurgiser@uibk.ac.at) Literature Gardner, A. S., Moholdt, G., Cogley, J. G., Wouters, B., Arendt, A. a, Wahr, J., ... Paul, F. (2013). A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. Science (New York, N.Y.), 340(6134), 852–7. doi:10.1126/science.1234532 Giesen, R. H., & Oerlemans, J. (2013). Climate-model induced differences in the 21st century global and regional glacier contributions to sea-level rise. Climate Dynamics, 41(11-12), 3283–3300. doi:10.1007/s00382-013-1743-7 MacDougall, A. H., & Flowers, G. E.

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