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The Cryosphere Discussions

Interactive comment on "Multi decadal glacier area fluctuations in Pan-Arctic" *by* S. H. Mernild and J. K. Malmros

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We thank the anonymous referee (#1) for taking his time to review our paper.

Anonymous Referee #1 Received and published: 23 November 2012 General Comment I found this paper to be poorly written, scientifically problematic, and displaying a remarkable lack of awareness of prior literature that addresses the same issues as it does but in a much more comprehensive manner. This literature is comprehensively summarized in chapter 7 of the 2011 SWIPA (Snow, Water, Ice and Permafrost in the Arctic) report published by AMAP and available for free download from the AMAP website.

AUTHORS: Thanks for mention the SWIPA report, which we will dig into, and add

relevant references. We will improve the language (before the paper was submitted it was reviewed and edited by someone who is fluent in scientific English, but we will make sure it happens again before resubmission) and look into the scientific issues raised by the anonymous reviewer.

For a number of regions discussed in this paper (Yukon, Canada's Queen Elizabeth Islands, Axel Heiberg Island, Bylot Island, parts of the Russian Arctic for instance) there are published analyses of recent rates of glacier area change that are based on analysis of every glacier in the regional population (not a small sub-sample as is the case here). Although there are some differences in the time periods covered, there are a number of cases where the regional rates of area change derived from analysis of the full ice cover differ radically from those reported here. I think this is pretty clear evidence that the subsample of glaciers used in this study is not regionally representative, despite the authors' claim to the contrary. This likely reflects fundamental flaws in the argument that they use to justify the representativeness of their sample.

AUTHORS: We do understand the concern for the reviewer: We will look dig into the present literature, and compare published numbers with our satellite-derived area change values. However, since the period is not exactly the same it might be problematic for a direct comparison.

Specific Comments 1. The whole analysis presented here is predicated upon the assumption that air temperature is the only climatic parameter that affects glacier surface mass balance and area change (which is manifestly untrue for a number of the areas considered (Kamchatka, western North America, southern Alaska, southern Greenland for instance, for which available mass balance measurements clearly show a sensitivity of mass balance to variations in winter precipitation) – or on an implicit, but unstated, assumption that, if precipitation is important, it is directly correlated with mean annual air temperature and does not therefore need discussion (an assumption that, at the very least needs to be demonstrated to be true).

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AUTHORS: The idea by only adding temperature time series to the discussion was to follow the example published in Bjork et al (2012), Nature Geoscience, where temperature time series were used for SE Greenland to explain changes in land-terminating and marine-terminating glaciers. No problem, we will add summer temperature and winter precipitation to Figure 10 to expand the discussion.

Reference: Bjørk, AA , Kjær, KH , Korsgaard, NJ , Khan, SA , Kjeldsen, KK , Andresen, CS, Box, J, Larsen, NK & Funder, SV 2012, ' An aerial view of 80 years of climate-related glacier fluctuations in southeast Greenland ' Nature Geoscience , vol 5, pp. 427.

2. Since the authors only ever discuss changes in mean annual air temperature, they need to demonstrate that this parameter is well correlated with mean summer air temperature, which is what most directly affects the summer and annual mass balance across the drier parts of the Arctic (northern Canadian and eastern Russian Arctic, for instance). AUTHORS: See above.

3. Many of the sub-regions considered are extremely large, and there are noticeable regional variations in the degree and even timing of recent warming across these regions. Where complete analyses of glacier area change have been conducted, these variations are apparent in the record of glacier area change. Unless the selection of the sub-sample of glaciers chosen to be “representative” of glacier area changes in a given region respects these patterns, it will inevitably be biased relative to the population as a whole. AUTHORS: The reviewer is right - we will discuss these issues in the reviewed upload of the manuscript.

4. In a number of these areas, a not insignificant number of glaciers have actually disappeared completely within the past few decades. Only one such glacier is incorporated in the analysis presented here – so this is another uncorrected bias. AUTHORS: In Mernild et al. (2012) this issue about the disappearing GIC was illustrated and discussed for SE Greenland. Also in this study we will add a discussion about the in-

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significant number of disappearing GIC. It is incorrect stated by the reviewer, that only one disappearing GIC is included in the data set, actually it is minimum seven GIC.

5. The authors state that the number/size distribution of glaciers included in their study for the whole pan-Arctic matches that for glaciers in the same overall geographic area in the Randolph Glacier Inventory. In fact, Figure 4 clearly shows that the largest ice masses in the region are totally omitted from the analysis and that the size distributions of the population and the sample deviate quite significantly. Regardless, the more important point is that the number/size distributions of glaciers in the different sub-regions may differ significantly from that in the population as a whole, and the authors have failed to demonstrate that their sub-regional samples have number/size distributions that are concordant with those of the sub-regional populations. Given the enormous climatic and mass balance regime differences between some of the sub-regions, this issue simply cannot be ignored. AUTHORS: No problem, we will include a GIC size distribution on regional scale. On overall scale the size distribution for our sample (n=321) is significant with the size distribution in the Randolph Glacier Inventory: This is also stated in the manuscript. The largest GIC (> 400 km2) are omitted from the data set simply because the Landsat SLI failure would have impacted on the area estimation. One of the criteria for the data set was (see point 6; page 4), that the SLI failure should not influence the GIC area estimations. This is the reason for not including the largest GIC. By not including the largest GIC will have an insignificant impact on the results, since the number of large GIC are small compare to the total number of GIC in the dataset.

6. Whilst glacier surface mass balance responds to climate change on an annual time scale, the same is not true of glacier area change, which responds to climate trends integrated over significantly longer periods of time. There is no obvious reason to assume that recent rates of area change are directly (or solely) linked to climate trends over the period for which area changes were measured. AUTHORS: A discussion about this will be added to the manuscript.

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7. Factors like glacier elevation, hypsometry, slope, and shape will also influence how glacier area responds to climate forcing. The authors fail to show that their sample glaciers are representative of their regional populations with respect to any of these parameters. AUTHORS: The aspect and type will be added to the data set and possibly also the elevation of the glaciers. Analysis and results will be added to the manuscript.

8. The discussion of why small glaciers lose a greater proportion of their area in a given time period than large ones misses the obvious point that small glaciers likely formed in locations that were climatically marginal for glacier growth, while large ones formed in more favorable locations. If so, it is hardly surprising that small ones shrink more rapidly if climate cause the mass balance to become more negative. AUTHORS: Thanks for the comment.

9. On page 10, the majority of the regions that have a relatively high proportion of glaciers that grew over the measurement period are found in regions of high precipitation. To me this strongly suggests that factors other than air temperature are driving glacier area change in these regions. AUTHORS: The high proportion of glaciers that grew over the observation period was found in regions with glacier surge activity: This is why we added the discussion about the surging glaciers. We will look into the precipitation data as well and add time series to Fig 10, and the precipitation data will be discussed, also related to the comment raised by the reviewer.

10. On page 10, the authors refer to the pentadal regional mass balance estimates of Cogley (2012). Bear in mind that since these estimates are based on interpolation of measured mass balances to all glaciers in a region using an inverse distance weighted method, they can be extremely unreliable in regions where there are no local measurements. This would be true of the Russian Arctic, for instance, where the regional balance signal derived by Cogley carries the signal of mean summer air temperature change in northern Scandinavia and Svalbard, even though this signal is not apparent in air temperature records from the Russian Arctic. This issue is also discussed in the SWIPA report. AUTHORS: Thanks for the comment. We will dig into the SWIPA report,

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and discuss the comment raised by the reviewer.

Technical Corrections 57: Why not refer to the geodetically-based regional mass loss estimates of Jacob et al. (2012)? The Radic and Hock paper referred to provides a modeled estimate, not a measured one. AUTHORS: Is added. 59 and elsewhere: the name is Bolch, not Bloch. AUTHORS: Is changed. 78: are grows or increases, it does not advance! AUTHORS: Is changed. 158: How do you know the errors were underestimated? AUTHORS: The model was underperforming not picking up glacier because of shadows and debris, as stated in the manuscript. 164-166: sentence makes no sense as written. AUTHORS: The sentence is rewritten. 231: Not convinced Figure 8 serves any useful purpose. AUTHORS: We will keep Fig 8, since Fig 8 illustrates what all this is about: GIC area change over time, and here Fig 8 is a good example of this. 244-245: whilst it seems only logical that glacier advance is a response to positive mass balance and (cooling/wetting?) climate, it isn't clear to me that you can actually prove this for any of these cases. AUTHORS: This will be discussed in the text.

Interactive comment on The Cryosphere Discuss., 6, 4417, 2012.