interactive comment on "Comment on "100-year mass changes in the Swiss Alps linked to the Atlantic Multidecadal Oscillation" by Matthias Huss et al. (2010)"

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1 General

In our comment on Huss et al. [2010a], we have argued that they likely overestimated the importance of the Atlantic Multidecadal Oscillation (AMO) on the mass loss of glaciers in Switzerland over the last decade. The reason is that they used the conventional mass balance instead of the reference-surface mass balance. The correct way to make a climatic interpretation of glacier mass balance is by using the reference-surface mass balance. All authors of the three interactive comments agree on this.

Furthermore, the minor importance of the AMO is illustrated by the phase difference between the AMO index and the mass balance anomaly. Huss et al. [2010a] argue that a positive AMO index causes a negative mass balance in the Swiss Alps and a negative AMO index a positive mass balance (superimposed on a linear trend). However, the conventional mass balance anomaly becomes negative (positive) and then, with $\pm\frac{1}{4}$ period delay the AMO index becomes positive (negative). So the phase relation is opposite to what you might expect for a causal relation. This indicates that the influence of the AMO is not very strong, or at least not strong enough to determine the phase of the sinusoid well within 1,5 periods. This point is touched upon in the comment by J.M. Cogley, who asked for a clarification of our formulation, and in the comment of C. Vincent, who thinks the time series used by Huss et al. is too short to draw conclusions.

Our comment was based on a simple method to calculate the effect of glacier area change on the mass balance, as well as on studies that used a mass balance model on a different sample of glaciers, for a different period [Paul, 2010; Nemec et al., 2009]. The results of our simple approach are confirmed in the comment by C. Vincent. M. Huss would like us to mention the uncertainties of such a simple approach and points to some processes that we neglected. M. Huss also pointed out that the proportion of the climate change that is missed by using the conventional mass balance calculated by Paul [2010] and Nemec et al. [2009] is specific for certain periods. It should likely be less than the 50-70% they found, when applied to the period 1908-2008 under discussion here. However, we consider our estimate of 30% as a minimum.

Meanwhile, M. Huss et al. have repeated their mass balance reconstruction making use of a reference-surface mass balance. This detailed reply to our comment [Huss et al., 2010b] is highly appreciated. Huss et al. conclude from their mass balance model that over this period (1908-2008), and averaged over this set of glaciers, the reference-surface mass balance and the conventional mass balance give more or less the same results. They ascribe this to compensation of the decrease in ablation area by surface lowering. This contrasts with Paul [2010], who finds that the surface lowering is approximately compensated for by increased shading. This issue is at the moment unresolved, and could be an interesting topic for future research.

2 Response to specific comments

2.1 J. G. Cogley

- The amplitude of the sinusoidal fit indeed does not change when the reference-surface mass balance is used instead of the conventional mass balance. In the comment on Huss et al. we only argue that the size of the amplitude relative to the size of the trend is overestimated by using the conventional mass balance. (See also comments in 2.3 en Figure 1)
- We acknowledge that we should have used “conventional” instead of “specific” throughout the paper.
- *causal relation (P 2478 L21-24)* The phase difference between the mass balance anomaly and the AMO index is such that first the mass balance become more negative, followed by a positive AMO index several years later. Huss et al. [2010a] argue that a negative phase in the mass balance anomaly is caused by a positive phase in the AMO index because the latter is associated with higher temperatures in Europe. In this causal relation, we would expect the change in AMO before, or simultaneously with, the change in mass balance anomaly.
- To conclude, the reviewer has several lesser points, which are all of textual nature (except for the point discussed above). We thank the reviewer for his thorough reading and will acknowledge all of his suggestions in a final version.

2.2 M. Huss

1. Our calculations given in the supplement are meant as a first order estimate of the difference between the conventional and the reference-surface mass balance. The results are in line with detailed mass-balance model studies of glaciers in the Swiss Alps [Paul, 2010; Nemec et al., 2009]. Based on the crude estimate, it is necessary to include the reference-surface mass balance

(be it in order to show the difference between the conventional and reference-surface mass balance is small). However, detailed calculation of the area changes, surface lowering and increased shading are not included in our first order estimate. We agree we should include a more explicit mention of this in a revised version of this paper.

2. We do not use the equilibrium line altitude (ELA) in our method to make a first order estimate of the mass balance at the glacier tongue. In addition, we want to calculate the melt at the glacier tongue over the last decade, so the average ELA over the last 100 years is not very relevant (it is to low). We used the melt rate at the Morteratsch for two reasons: i) it is measured recently for a number of years in a row, and ii) by using melt at the north facing Morteratsch tongue, we tried to avoid the risk of overestimating the average melt. As some of the glaciers used for the calculations are facing south, we expect that the melt averaged over the sample gives a conservative estimate. We should note that in the calculations giving the 0.36 difference, the clear outlier Pizol ($\Delta b = -3.00$) is left out. We have to add this note to the revised supplement, as it is missing at the moment.

3. Recalculation with half the melt $\dot{b}$ on the three debris-covered glaciers gives a difference between conventional and reference-surface mass balance of -0.30 instead of -0.36 mwe a^{-1}. So, in view of the purpose of the estimate described above, the debris cover is of minor importance to this sample of glaciers.

4. We have taken very conservative estimates of the lost ablation area (see Figure 1 of the Supplement) in order not to overestimate the difference between the two mass balances. In addition, we have calculated the melt from a north sloping glacier, also for those glaciers that face more towards the sun (that is, to the south), at the altitude of the present-day tongue. Therefore, we call our estimate a minimum estimate.

   The difference between the conventional and the reference-surface mass balance relative to the reference-surface mass balance is not only dependend on the changes in glacier geometry, but also in the magnitude of the conventional mass balance. This magnitude is variable, so the relative difference of the two methods in the last decade is likely to be smaller than the 50-70% found by Paul [2010], although the studied period of comparable length to the period of Huss et al. [2010a]. We consider our estimate as a minimum estimate for the reasons given above.

2.3 C. Vincent

1. We appreciate the fact that the reviewer has made the effort to compare conventional mass balance with reference-surface mass balance for another glacier in the Alps, Glacier de Saint Sorlin. His findings support the results of our simple approach to estimate the relevance of the difference between conventional and reference-surface mass balance.

2. In Huss et al. [2010a], the mass balance anomaly w.r.t. to 1908-2008 mean is shown in Fig 3c together with their fit of a combination of a sine function and a linear trend. As the anomaly is just the mass balance plus a constant, the fit will have the same trend and the sine function will have the same period and frequency when it is fitted to the mass balance instead of the mass balance anomaly (see next point). Huss et al. [2010a] probably plotted the mass-balance anomaly to make the comparison with the positive and negative phases of the AMO index (Fig 3d) more clear. However, they conclude that 50% of the mass loss since the year 2000, that is the mass balance - not the mass-balance anomaly, can be attributed to the oscillation related to the AMO. It is this last conclusion we have commented on, so we do not agree we missed a factor $\frac{1}{2}$. The difference between the conventional and reference-surface mass balance anomaly is just distributed differently over the time series, such that about half is at the end and half is at the beginning. This point is schematically shown in Figure 1. For the absolute values of the mass balances, as used in the conclusions of Huss et al. [2010a], the size of the amplitude, indicated with a green bar, is smaller compared to the mass loss given by the mass balance (black bar) than to the reference-surface mass balance (red bar).

3. As the variations in the mass balance are not affected by the transition from mass balance to mass balance anomaly, the fitted sinusoid is the same for the mass balance and the mass balance anomaly. As we have argued in our comment, the difference between the reference-surface mass balance and the conventional mass balance will mainly be in magnitude of the negative trend. This is also visible in the results the reviewer included in his comment: in (his) Figure 2, the fit to the reference-surface mass balance starts higher and ends lower. This brings us to the conclusion that the relative importance of short-scale climate fluctuations is smaller when it is calculated from the reference-surface mass balance than from the conventional mass-balance (see Figure 1). Judging from the phrase "We tentatively fit a sine function", Huss et al. [2010a] are aware that the sinusoid fitted to a data set that has 1.5 times the length of the period is not very robust. So we focused our comment on the conventional vs. reference-surface mass balance issue.

4. We agree with the reviewer that it is also possible to use mass balances at a specific point to derive changes is climate, if corrections are made for changes in elevation.

References

Huss, M., Hock, R., Bauder, A., and Funk, M.: 100-year mass changes in the Swiss Alps linked to the Atlantic Multidecadal Oscillation, Geophysical Research Letters, 37, doi:10.1029/2010GL042616, 2010a.

Huss, M., Hock, R., Bauder, A., and Funk, M.: Reply to the comment of Leclercq et al. on "100-year mass changes in the Swiss Alps linked to the Atlantic Multi-decadal Oscillation, The Cryosphere Discussions, 4, 2587–2592, doi:10.5194/tcd-4-2587-2592, 2010b.

Nemec, J., Huybrechts, P., Rybak, O., and Oerlemans, J.: Reconstruction of the annual balance of Vadret da Morteratsch, Switzerland, since 1865, Annals of Glaciology, 50, 126, 2009.

Paul, F.: The influence of changes in glacier extent and surface elevation on modeled mass balance, The Cryosphere, 4, 569–581, doi:10.5194/tc-4-569-2010, 2010.

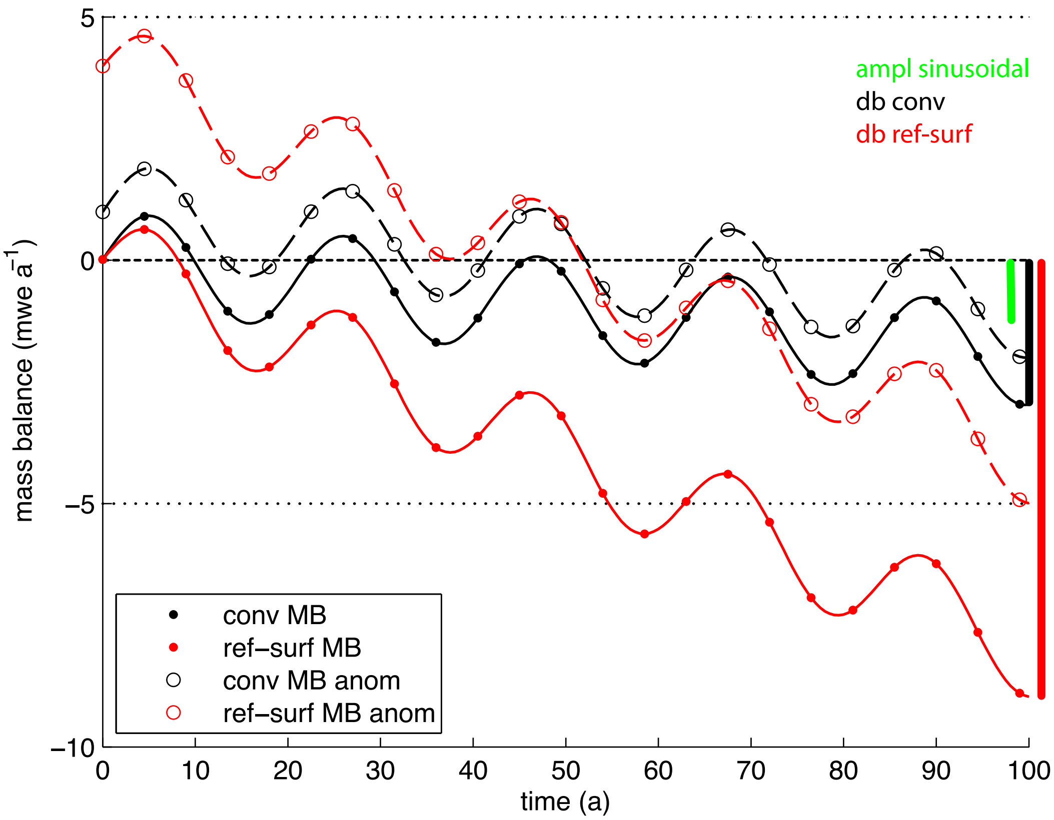

Figure 1: Schematic display of the conventional (black) and reference-surface (red) mass balance (MB). Both are assumed to follow a sinusoid superimposed on a negative linear trend. The linear trend will be more negative for the reference-surface MB, that accounts for the adjustment of the glacier geometry to the changing climate, but the sinusoid is identical for both MBs. In this figure, the difference between the conventional and the reference-surface MB as well as the number of oscillations is exaggerated for visual reasons. The conventional MB anomaly and the reference-surface anomaly are shown with dashed lines. The amplitude, as well as the linear trend of the MB anomaly is the same as for the absolute values, for both the conventional MB and the reference-surface MB anomaly. At the right side of the figure, the amplitude of the sinusoid (green), the conventional imbalance (black) and the imbalance following from the reference-surface MB (red) are indicated with bars. The amplitude of the sinusoid is smaller compared to the reference-surface imbalance than compared to the conventional imbalance.