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The Cryosphere Discussions

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)" *by* P. W. Leclercq et al.

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The point raised by Leclercq et al. is important and deserves attention. In our detailed reply which is published in TCD (Huss et al., 2010b) we show that when using the same model as in Huss et al. (2010a) the differences between conventional and reference-surface mass balances are much smaller than found by Leclercq et al.

In this interactive comment I would like to address some details of the methodology adopted by Leclercq et al. for estimating the difference between conventional and reference-surface mean mass balance of the last decade. Part of the disagreement between their results and the values published in my Reply (Huss et al., 2010b) might thus be explained.

Below I list four important points that might be addressed by Leclercq et al. in a revised version of their paper:

1. The simple model presented by Leclercq et al. is easily applicable and allows a first order estimate of the effect of glacier terminus retreat on glacier-wide mass balance. However, the model is a highly simplified representation of reality, and I miss a discussion of uncertainties in the estimates arising from this model. As elaborated in my reply, the lowering of the glacier surface compensates for part of the positive effect of glacier retreat on the glacier-wide mass balance. It would be of benefit for the reader to see the limitation of the simple model if the impact of neglecting glacier surface lowering is shortly discussed by Leclercq et al.

2. I do not agree with the assumption that the Equilibrium Line Altitude (ELA) of Morteratsch Glacier is representative for the entire Swiss Alps. The mean ELA obtained from the data set of Huss et al. (2010a) varies by almost 600 m over the 12 glaciers chosen by Leclercq et al. In Table 1, I have compiled mean ELAs, and their difference from the ELA of Morteratsch for the 12 glaciers with length change data used by Leclercq et al. In order to obtain a more realistic estimate using their method, Leclercq et al. could use these ELA values. Very large differences between conventional and reference-surface mass balances, particularly for small glaciers, would thus be significantly reduced.

3. Furthermore, three of the analyzed glaciers have a strongly debris-covered tongue (Table 1). Thus, the estimated mass balance b_{t} at the glacier tongue is too negative. This leads to an overestimation of the differences between conventional and reference-surface mass balance as well. Debris coverage can reduce ice melt by 50% or more (see e.g. Jackson and Fountain, 2007). This effect should also be included in the model proposed by Leclercq et al.

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4. Leclercq et al. compare their results with the study by Paul (2010), who finds significantly higher differences between conventional and reference-surface mass balance. Therefore, Leclercq et al. refer to the number obtained with their model as a "simplified *minimum* estimate", although the effect of surface lowering is not accounted for. According to Paul (2010), "50-70% of the climate change is "hidden" in the geometrical change of the glacier surface" (page 2478, line 6-7). However, this result is not generally applicable as explained in detail below. The estimate by Paul (2010) was derived by static calculations over two different glacier geometries (1850, 1973/1985). It is therefore only valid for the considered glaciers and the period 1850-1980. Furthermore, it is not possible to apply this number to a fluctuating signal (i.e. annual or decadal mean mass balances). This is done however by Leclercq et al. (page 2478, line 15-17).
   Figures 1 and 2 visualize why the percentage numbers obtained by Paul (2010) for the period 1850-1980 ("50-70% "hidden" in the geometrical change") are not generally applicable to short periods (e.g. one decade) or individual years. Percentages of mass balance due to geometric adjustment rather than climate variability for both decadal periods and individual years were evaluated by comparing the mass balance calculated over the concurrent glacier surface (i.e. conventional mass balance) and the mass balance calculated over the first available glacier digital elevation model (reference-surface mass balance, see also Huss et al., 2010b). In the latter case, surface geometry refers to a year in the time interval of about 1920-1940 (depending on the glacier). Results are thus not directly comparable to Paul (2010). The percentage R of mass balance due to geometric adjustment rather than climate variability (equivalent to mass balance "hidden" in the geometric change following Paul, 2010) is obtained by dividing the difference between decadal means of conventional $\overline{b_{\text{conv.}}}$ and reference-surface mass balance $\overline{b_{\text{ref.}}}$ by the reference-surface balance, i.e. $R = (\overline{b_{\text{ref.}}} - \overline{b_{\text{conv.}}})/\overline{b_{\text{ref.}}}$ (see Figure 1). The same procedure is adopted for individual years instead of decadal means using annual conventional and reference-surface mass balances

(see Figure 2).
Figure 1 shows that the percentage R strongly varied over the last six decades: Values range between 12% and $>$100%. Generally, high percentages prevail for decades with a quasi balanced mass budget, and low percentages for decades with mean mass balance strongly below the long-term average. This indicates that the 50-70% found by Paul (2010) can not be applied as a general number to individual decades as by Leclercq et al. (page 2478, line 15-17). Moreover, decades with very negative mass balance (as the period 2000-2008, the focus of the comment by Leclercq et al.) exhibit the smallest portions of mass balance that are not revealed in the conventional balance (Fig. 1).
This is even more evident when performing the same analysis for individual years since 2000 (Fig. 2): The extreme year of 2003 only shows a percentage of mass balance due to geometric adjustment rather than climate variability of about 5%. Years with mass balances closer to the long-term average balance mostly yield percentages of 10-20%. This is far below the 50-70% assumed by Leclercq et al. based on Paul (2010).
Percentage numbers as derived by Paul (2010), or as interpreted by Leclercq et al. based on Fig. 7b of Nemec et al. (2009), are only applicable to long-term mean mass balances, and not to annual balances or means of short periods (see Figs 1 and 2). Compared to the 100-year mean mass balance, the conventional balance of the last decade is more than three times more negative (according to Huss et al., 2010a). Thus, the magnitude of the effect of glacier geometry change derived by Paul (2010) without considering year-to-year mass balance variability is not valid for the last decade's mean mass balance.

References

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Huss, M., Hock, R., Bauder, A., and Funk, M. (2010b). Reply to the Comment of Leclercq et al. on ”100-year mass changes in the Swiss Alps linked to the Atlantic Multidecadal Oscillation”, *The Cryosphere Discuss.*, 4, 2587-2592.

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Table 1. Comparison of assumptions on the Equilibrium Line Altitude (ELA) by Leclerq et al. and detailed 100-year mean ELAs for the 12 glaciers with length changes (see also Table 1 in the Online Supplement of Leclerq et al.). The mean ELA for the period 1908-2008 was evaluated form the 30-glacier data set presented in Huss et al. (2010a). $\Delta\overline{ELA}$ is the difference to the mean ELA of Morteratsch Glacier over the same period derived using the same method. The condition of the ice surface on the glacier tongue is given.

Glacier	$\overline{ELA}$ (m a.s.l.)	$\Delta\overline{ELA}$ (m)	Surface
Morteratsch	2990	0	bare ice
Grosser Aletsch	3010	+20	bare ice
Gorner	3240	+250	bare ice
Unteraar	2740	–250	debris
U. Grindelwald	2720	–270	debris
Allalin	3230	+240	bare ice
Rhone	2930	–60	bare ice
Gries	2950	–40	bare ice
Trient	2980	–10	bare ice
Zinal	3100	+110	debris
Basodino	2860	–130	bare ice
Pizol	2680	–310	bare ice
Verstancla	2700	–290	bare ice

Figure caption 1:
Time series of 30-glacier average conventional mass balance of the last six decades (1948-2008). Annual balances are shown with blue symbols and decadal means with solid red lines. The righthand-side axis and the bars refer to the percentage R of the mass balance of each *decade* that is due to geometric adjustment rather than climate variability (following Paul, 2010). The percentage is calculated for decadal means as $R = (\overline{b_{\text{ref.}}} - \overline{b_{\text{conv.}}})/\overline{b_{\text{ref.}}}$. If the decadal mass balance is close to zero, the percentage

tends towards infinity, and can no longer be interpreted.

Figure caption 2:
Time series of 30-glacier average conventional (blue) and reference-surface (red) annual mass balances for 2000-2008. The righthand-side axis and the bars refer to the percentage of the mass balance of each *year* that is due to geometric adjustment rather than climate variability (following Paul, 2010).

Interactive comment on The Cryosphere Discuss., 4, 2475, 2010.

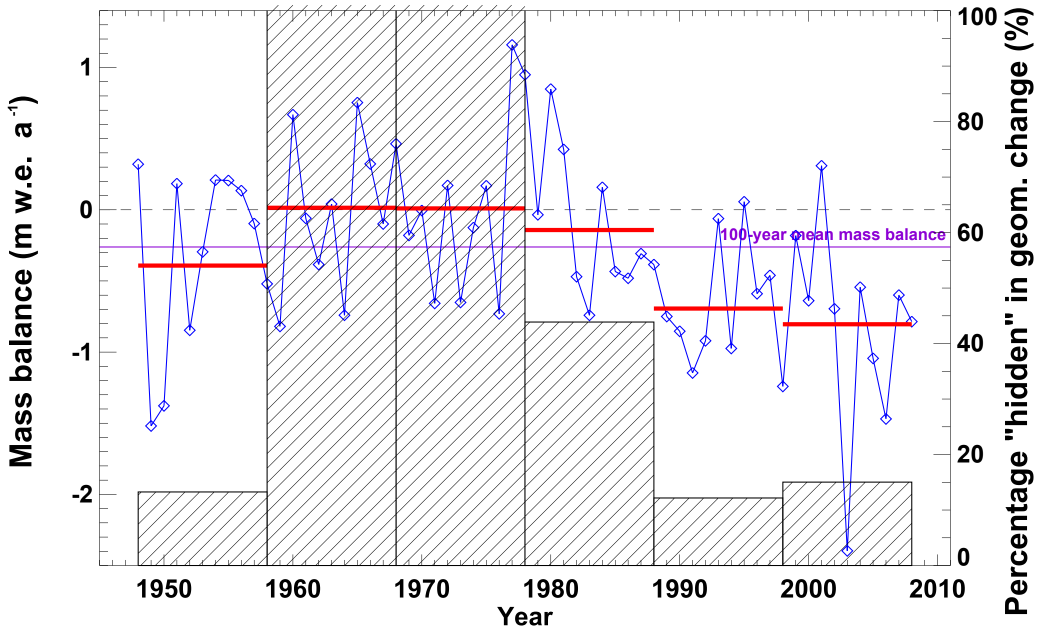

Fig. 1. Time series of 30-glacier average conventional mass balance of the last six decades and percentages of decadal mass balance ”hidden” in geometric change (see entire caption above).

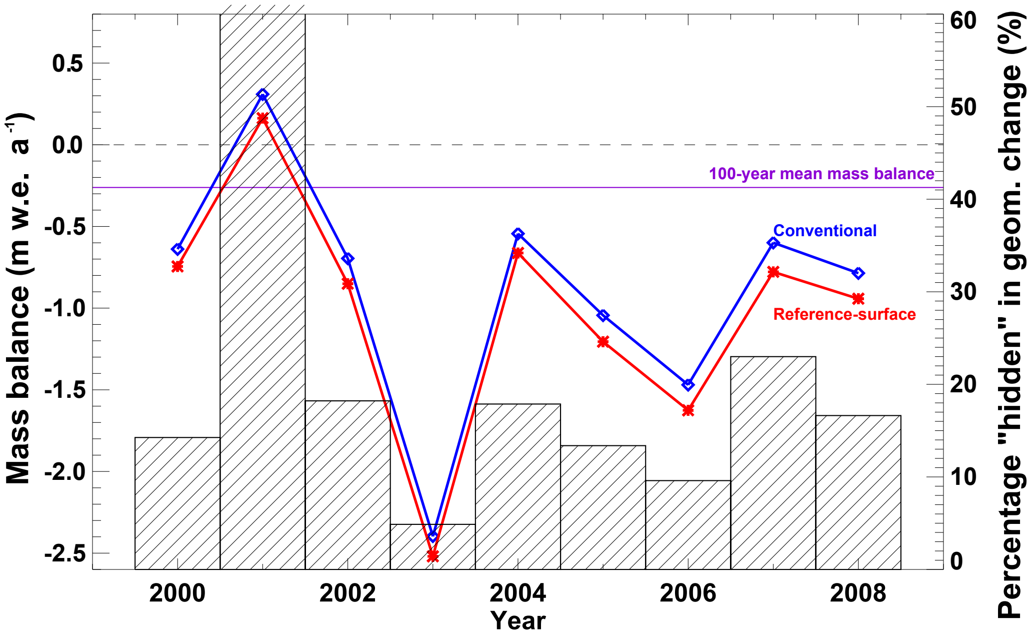

Fig. 2. Time series of 30-glacier average conventional (blue) and reference-surface (red) annual mass balances for 2000-2008 and percentages of "hidden" annual balance (see entire caption above).