**The Cryosphere
Discussions**

Interactive comment on "Comparison of direct and geodetic mass balances on a multi-annual time scale" *by* A. Fischer et al.

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First I would thank A. Fisher for addressing the question of agreement/discrepancy between direct (glaciological) and geodetic (volumetric) determination of glacier mass balances.As mass balance data are recognized as sensitive indicator of climate fluctuations, the quality of the data, their control with independent methods in search of systematic errors are important for the glaciological community, especially in the context of climate changes.

As well explained in the paper, each method has its own assumptions, uncertainties and intrinsic biases. Moreover, because they are performed on different time scales, when comparing the 2 methods one should sum the annual mass balances (direct) to obtained a cumulated balance covering the period between the 2 DEM determinations

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used in the geodetic balance. This last point as an important effect, as explained hereafter.

Summing annual balances, any potential systematic error committed annually will increase years after years proportionally to the number N of year, while random errors will just slightly increase proportionally to square root of N. Cox and March (2004, J. Glaciol., 50(170)) have exposed this point clearly and used this property on Gulkana glacier in search of a significant discrepancy. Thibert et al.; 2008, J. Glaciol., 54(186) have later analyzed this when comparing direct/geodetic determination of the balance on Sarennes, French Alps) identifying first and second errors types when making a conclusion about the occurrence of systematic errors.

As typical annual random errors in the direct measurement are about sigma(direct)=0.2 m w.e./yr, one should therefore expect a random error in the cumulated balance of 0.6 m w.e. for a 10 years sum, 1.0 m w.e. for 25 years, and 1.4 m w.e. for 50 years, illustrating the slight increase from year to year. Regarding the geodetic balance, typical random errors due orientation residuals and sighting error, etc..., are sigma(geodetic)=1 m w.e.

Therefore identifying for example a difference of delta.b= -1.5 m w.e. over 11 years (1996-2007) between the 2 methods for HEF glacier (Table3) is reasonably explained with random error in the 2 methods without referring to potential systematic difference in the measurements.

In search of a systematic discrepancy between the direct and geodetic balances, the question is to decipher a bias within the scattering of the results due to their own random errors. Again to give numerical examples, a systematic error of +0.2 m w.e. committed annually in the direct measurement (overestimation) will result in overestimating the cumulated balance of 2 m w.e. over 10 years, or 10 m w.e. over 50 years, which illustrates how fast this kind of error cumulates from year to year. This highlights that identifying delta.b of a few meters w.e., if related to a systematic error, corresponds to

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a very small error in annual value, of the same order of magnitude (or less) than the annual random error.

Because systematic errors grow proportionally with N, in search of a bias committed annually in the direct method, the difference delta.b should be divided by the number of year N over which the comparison extends (as the Figure 7 reports the comparison result for HEF glacier). Once divided by N, delta.b/N should be tested statistically: - is delta.b/N = 0?, delt.b/N being scattered by the variance sigma2(direct)+ sigma2(geodetic) - is delta.b/N different from 0? If this is admitted, there is a bias between the 2 methods.

At Sarennes (1952-2003; 51 years), we found: b(geodetic)$\pm$sigma(geodetic)=-32.30$\pm$1.04 m w.e.

cumulated over 51 years, b(direct)$\pm$(N)$^{\frac{1}{2}}$.sigma(direct)= -34.89$\pm$1.15 m w.e.; sigma (direct)=0.16 m w.e.

Therefore: delta.b=2.59 $\pm$ 1.55 m.w.e. is not significantly different from zero at the 95% confidence level. Or, equivalently, considering annual differences between the 2 methods: delta.b/N=0.051$\pm$0.22 m w.e is not significantly different from zero. If delta.b corresponds to a bias (annual bias of delta.b/N=0.06 m w.e./yr.), it cannot be detected.

Applying this kind of test show that in most of the cases, the 2 methods being scattered by their own random errors, most of the difference delta.b can be explained by random errors and delta.b is not indicating a bias. Systematic errors are very difficult to detect: Again at Sarennes glacier, we found delta.b/N = 0.11 m w.e. as the minimum annual detectable bias, with sigma(direct)=0.16 m w.e./yr, and sigma(geodetic)=1 m w.e. calculated from the data. This corresponds to delta.b= 5.6 m w.e. over 51 years.

Applying the same kind of analysis would certainly lead to more optimistic conclusion in your analysis (hopefully), establishing that delta.b is due to the natural scattering of the data in relation to random error. This requires quantifying errors for each comparison.

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Therefore I would suggest using the delta.b/N parameter when comparing the 2 methods. delta.b/N is more intelligible as it can be used whatever the covered period, and can be compared to annual random error in b(direct), which is typically 0.2 m w.e./yr

Other minor comments follow:

P. 1152 Line 5: you should perhaps give also the average of the absolute value of delta.b

P. 1153Line 15: Also should be highlighted that geodetic balance integrate the overall natural spatial variability of the balance at the glacier surface, which is not accessible from the direct method due to an impossible exhaustive sampling.

Line 23: the combination was proposed because the geodetic method seems less affected by systematic errors, and these ones are very difficult to detect and quantify with a good confidence level Thibert et al. (2008, J. Glaciol., 54(186))

P 1177 and 1178 Table 3-4: 2 additional columns could be included: - 1rst additional column indicating delta.b/N - second column indicating the annual random errors in b(direct) and b(geodetic), this last one being reduced to an annual amount from: sigma(geodetic)/(N)$\frac{1}{2}$.

Please consider these comments and suggestions in the same constructive spirit they are proposed

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Interactive comment on The Cryosphere Discuss., 4, 1151, 2010.