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The Cryosphere Discussions

Interactive comment on "Density assumptions for converting geodetic glacier volume change to mass change" *by* M. Huss

Anonymous Referee #1

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This manuscript by Huss is a very nice study on the influence of firn layer variability on ice geodetic measurements of glacier mass balance. The mean density and the thickness of the firn layer constantly adjusts as a function of climate variability, which in turn complicates the direct calculation of glacier mass changes from volume change measurements. Using a simplified firn compaction model including the influence of refreezing, the author shows that the typical density that needs to be used for this volume – mass conversion is not constant, and especially variable for short time intervals.

My main comments are related to the details of the firn compaction model that is used in this analysis. Basically, the model that was first proposed by Herron and Langway (1980) is used as the firn model, but adjusted for the effect of refreezing, following Reeh (2008). There are a few issues that I'd like to see addressed.

1. The HL-model distinguishes two phases of firn compaction: an initial 'rapid' compaction phase, where steady-state firn compaction is not a function of accumulation, and where compaction is believed to be primarily controlled by grain settling and packing. Below a density of 550 kg m^{-3} this is followed by a second stage of compaction, where grain growth and sintering are the dominant processes, until pore close-off. These different phases are not described in the manuscript, which can be improved for the sake of completeness. Equation 6 describes the second stage of firn compaction in the HL-model, which means that the first stage of compaction is essentially neglected. However, since firn density at the surface is set to 520 kg m^{-3} (a high value, see below), the initial fast compaction phase would only occur in a very thin layer, so the difference with the HL-model is only minor. Nevertheless, a comment on this issue would be welcome.

2. Figure 2 illustrates that the original HL-model does not result in a good match between observations and simulated density. To solve this, the compaction rate has been increased, to a tuned value of 0.11 0 m$^{-0.5}$ a$^{-0.5}$. Though effective, this adjustment seems not physically realistic: using $k_1 = 575exp(-21400/(RT))$ this means that the accompanying temperature is ~300 K, i.e. not possible in a firn layer. As the HL-model has been widely recognized to result in a quite good agreement on dry compaction, it is more likely that instead of the dry compaction, it is the refreezing component that should be adjusted to make the model in line with the observations. How the amount of refreezing is calculated is not extensively addressed. It seems more reasonable to increase the influence of refreezing, to get an improved match between simulated and observed density profiles.

3. A total of 12 measured firn density profiles, probably from very different climatic settings, are lumped together to provide a mean density profile including variability. Although the author argues that a good comparison with the calibrated firnmodel indicates that this empirical method can be applied to describe firn compaction for a wide range of mountain glaciers, this merely seems a matter of choosing the right

locations. A table with precipitation and mean annual temperature values for these locations would support this claim.

4. The value of the density of fresh snow (520 kg/m3) is very high, also with respect to the composite of observations (12 firn density curves). It is also strange that the calibrated model results in a firn density of ∼600 kg m^{-3} at the surface. Why is this not 520 kg m^{-3}?

Despite these issues on the description of firn compaction, the implications for the main results are probably minor, certainly regarding the quite small effect that is obtained using the uncalibrated HL-model (discussion). Using a lower value for the density of fresh snow will probably further decrease the value of $f_{\Delta V}$.

Firn compaction rate is largely determined by temperature. In this study, only experiments with a change in surface mass balance forcing are carried out. It would be a valuable addition if firn compaction effects induced by temperature changes would also be addressed.

Minor comments

Page 222, line 17: Helsen et al. (2008) showed that Antarctic accumulation variability is the main driver behind observed elevation changes, not necessarily density changes.

Page 228, line 22: "It is remarkable that already with a minor change. . ." Why is it so remarkable that *even* short-term variability causes volume changes that occur with a near-surface density of the firn? In fact, this is one of the major points of this paper: especially when perturbations are short, these are accompanied with values of $f_{\Delta V}$ that strongly deviate from the ice density. Consider revising this sentence.

Fig. 4: it is unclear what the different grey lines exactly represent. In the text this is only briefly described, it has to do with different elevation ranges, but the details are not clearly presented.

Page 230, line 25: values between -550 and 6500 kg m^{-3}? I can't find this value in the

figure.

Discussion

A number of sensitivity experiments are mentioned. It is not clear which of these are also illustrated in the results, and how they can be recognized (Figure 4, 5). For example, it is mentioned that alternative values for the slopes along the elevation range are used, but I could not find this back in the figures. This can be improved.

The sensitivity to choices in the parameters in the firn compaction model was tested. However, the choice for a value of 520 kg m^{-3} for the surface density is not tested, while this is a very high value. Accumulating fresh snow can have values below 300 kg m^{-3}. This generally will result in much larger deviations of $f_{\Delta V}$ from the ice density.

Page 233, line 13: Here it is suggested that a linear fit in calibrated with the observations, but this cannot be seen in Figure 2.

Conclusion

In the conclusions it might be worthwhile to repeat the explanation of how values of $f_{\Delta V}$ can be higher than the ice density.

Interactive comment on The Cryosphere Discuss., 7, 219, 2013.