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Hydrology and Earth System Sciences Discussions

Interactive comment on "Future high-mountain hydrology: a new parameterization of glacier retreat" *by* M. Huss et al.

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We would like to thank T. Schuler for his comments that were very helpful to improve the initial manuscript.

Below, all comments of the reviewer are given (in italic), and discussed (normal type style), and, where applicable, we suggest a new version of the text (in quotation marks).

Criticism: As mentioned in the Abstract, the (empirical) Δh-function is site specific, but the authors generalize the observations from 34 glaciers and use three size classes to transfer the function to other glaciers. A couple of questions is related to this approach: 1) The second question raised by B. Schaefli deserves definitely more attention: how

different are the Δh-functions for the 34 glaciers? Are they clustered such that the subdivision into three size classes is evident?

This important point was raised by both reviewers and in the additional interactive comment. In the revised version, we address the issue in detail and provide an additional subfigure (see revised manuscript). The figure shows individually derived parameterizations for the 34 glaciers divided into the three size classes, as well as the empirical functions given by the equations (see Fig. 3b), as solicited particularly by Reviewer #2. Additionally, standard deviations of the different parameterizations within the size classes are displayed in order to show their range of variability and the overlap with the other functions.
In general, the variability of the indivdual Δh-parameterizations within a size class is relatively small for the 'large valley glaciers', but high for the 'small glaciers', as these are more importantly affected by individual characteristics of glacier geometry and small scale effects. The overlap of the three size classes is considerable, but, as discussed as response to the next comment, the use of different parameterizations relative to glacier size instead of only one, is of benefit nevertheless.

"The deviations of individual parameterizations from the mean of the size class is considerable especially for small glaciers, as these are more importantly affected by small scale characteristics of glacier geometry change. The overlap of parameterizations for different size classes decreases towards the ablation area, where the largest changes occur (Fig. 3c)."

Caption of updated Figure 3 (see below):
"(a) Δh-parameterization derived for Rhonegletscher from observed ice thickness changes in the 20th century. The variability in the equilibrium line altitude (ELA) is shown. (b) Empirical Δh-parameterizations for three glacier size classes applicable to unmeasured glaciers derived from digital elevation model comparison for 34 glaciers. The equations refer to a numerical approximation (according to Eq. 1) of the line for each size class. (c) Approximations (see (b) for equations) including individually de-

rived parameterizations for all 34 glaciers (thin lines). The colour indicates the size class. Error bars show the uncertainty of the approximation; they are calculated as the standard deviation of the individual parameterizations within the size class."

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2) The validation against predictions made by full-Stokes modelling is testing the temporal transferability of the Δh-function. How about the spatial transferability? How transferable is the Δh-function to other glaciers? This could have been investigated by dividing the data set of 34 glaciers into a training and a validation subset.

We followed the suggestion of the reviewer and performed a more detailed analysis of the 34 parameterizations for individual glaciers (see Fig. 3c). A paragraph was added to the Discussion section (see below).

"In order to test the spatial transferability of the generalized Δh-parameterizations (see Fig. 3b), we performed two crossvalidation experiments based on the functions derived for the 34 glaciers individually. (1) For calculating an average Δh-function for each size class, one glacier is omitted; the mean rms error of the omitted function and the size class parameterization is evaluated. This is repeated for all items in the size class. (2) As in (1), one glacier is omitted, but the averaged function used for comparison is based on glaciers in arbitrary size classes (same number of functions as in (1), randomly chosen). We find that, overall, the rms errors are significantly higher (T-test at the 95% level) in experiment (2) compared to (1), indicating that the use of the size class specific parameterization is of benefit. For one fifth of the analyzed glaciers, however, the division into size classes is not an advantage."

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3) During retreat of a large or medium sized glacier, it will at some point shrink into a different size class. How is this transition handled? From the MS it seems that each glacier maintains its size class until disappearance, still giving acceptable results. One

may wonder whether the division into three size classes is necessary and one single mean Δh-function would have performed equally well.

In this study, the size class of a glacier is the same throughout the entire modelling period. Possible errors due to this simplification are highlighted in the Discussion. The second part of the reviewers' comment is addressed (see comment above).

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4) Establishing the Δh-function: in Sec 3.1 it is stated that "the quality ... increases with time span covered and the magnitude of changes occuring". This is only true if there is a monotonic trend in the changes. If the period covers an entire cycle of glacier fluctuation, the quality of the corresponding Δh-function would be lower than that derived from a shorter period that covered only advance or retreat.

This important point is added to the text.

"Given a monotonic long-term trend in glacier evolution, the quality of the Δh versus h relation generally increases with the time span covered and the magnitude of changes occurring during this period."

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5) As mentioned on P 363, L 16-25, the approach is used for glacier retreat only, but the argument why it would not work for glacier advance is not very convincing. Of course, the Δh-functions have been derived for periods of persistent retreat, and are therefore not necessarily applicable for advances. However, the main problem seems to me the question of how and where to distribute the ice volume in case of glacier advance. This is not straightforward, and treating the retreat is much simpler (unfortunately this is also the case that mostly applies).

The same approach can also be used to simulate glacier surface elevation change in the case of glacier advance. However, reasonable results are only expected after reaching a new equilibrium geometry (several decades). Our parameterization is ex-

plicitly designed for glacier retreat (see title of the paper). This is the condition that is expected for the next decades. As the transient changes in surface elevation are more complex for glacier advance than for retreat (see e.g. Finsterwalder and Rentsch, 1981), we do not recommend the Δh-parameterization for simulating changes in glacier geometry in the case of advance.
We reformulated our statements (see below).

"The parameterization is applied at the end of every year, assuming an immediate transformation of the local mass change into a distributed surface elevation change over the entire glacier. As the transient changes in surface elevation are more complex for glacier advance than for retreat (see e.g. Finsterwalder and Rentsch, 1981), and the Δh-parameterization is explicitly derived for periods of persistently negative mass balances, the short-term glacier geometry change in the case of advance cannot be simulated accurately. For this task we recommend the use of an ice flow model."

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The technical corrections and suggestions by the reviewer were very helpful and were adopted as proposed. In the following only the more important changes applied to the manuscript are discussed.

P349, L20-22: reword this sentence, it is hard to understand.

"Consequently, the shape of the Δh-parameterization differs from glacier to glacier."

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P359, L6-9: reword this sentence, it is hard to understand.

"Strong ice melt in combination with precipitation events also leads to an increased potential for destructive floods in this period. This is due to the significantly reduced storage capacity of glaciers that have only marginal snow and firn coverage."

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P360, L28: I do not understand how surface elevations are derived using the AAR-method, which only describes the adjustment of the glacier area.

"The 'AAR-method' yields a considerable underestimation of glacier area for the entire modelling period."

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P365, L1-11: this part is very general and should be included in the introduction rather than in the conclusions.

We have now formulated this section more specifically for our study.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 345, 2010.

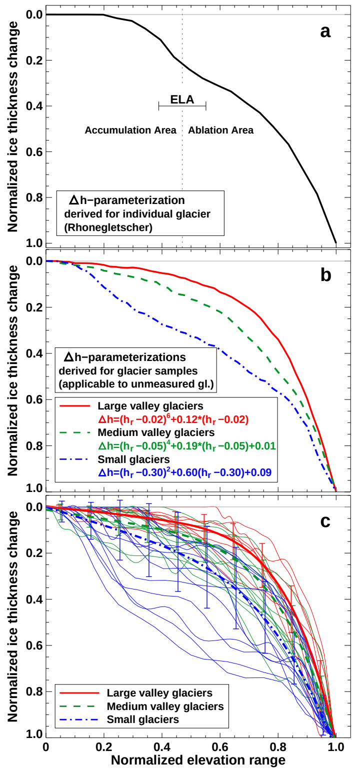

Fig. 1. Updated Figure 3 - see complete Figure Caption in the text