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The Cryosphere Discussions

Interactive comment on "Glacier volume response time and its links to climate and topography based on a conceptual model of glacier hypsometry" *by* S. C. B. Raper and R. J. Braithwaite

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General comments

The authors (RB) present a new volume response time of glaciers to climate forcing which in several aspects is similar to the response time of Jóhannesson, Raymond and Waddington (JRW) but takes a different approach to the problem. It is mostly based on scaling relations, which gives it a somewhat statistical nature. The total number of more than 6.000 glaciers used in this study is reason enough to trust this statistical approach.

The volume response time of BR does not use maximum thickness of a glacier as

JWR but mean thickness, and, being based on scaling, it needs simple, characteristic variables to scale to. R&B chose area, volume (and thus mean thickness) and altitudinal extent, all of which are available from glacier inventories, as prime variables and assume that the area distribution with altitude is triangular and symmetric to the median altitude. Assuming a linear increase with altitude of specific balance b(z) the equilibrium line altitude becomes identical with the median altitude.

This concept goes back to Kurowski who used exactly these assumptions in the 1890s, a short, explosive period of the establishment of glaciology as a quantitative science (Kuhn 1996). I appreciate very much the careful study and citation of several early, fundamental articles that the two present authors have undertaken and whose results they have incorporated in their paper.

In several places of the original manuscript and in the comments by Pelto it is suggested that the response time or the steps leading to it should be verified on real glaciers. I believe that is not easy, maybe not possible at all. A response time by definition involves a step change in the forcing and the approach to a new equilibrium. R&B are referring to equilibrium dimensions which are not available in the 20^{th} century data sets.

Even though real verification is lacking, we should still accept R&B's abstract triangle as a very meaningful and useful tool for glaciological perception and thinking. There have been other, well established abstractions:

- The plane parallel slab to demonstrate the most important implications of the flow law.

- The longitudinal cross section along the central flow line to establish the first numerical models of glacier flow

- Finsterwalder (1897) used the central flow line of a wedge-shaped glacier to demonstrate equilibrium line and flow lines under stationary conditions.

- The triangular, symmetric glacier was used by Kurowski (1893) to determine equilib-

rium line altitudes. It was again used by Meier in 1962 and by Braithwaite and Müller in 1980, so R&B are in very good company when they use this concept to derive a new volume response time.

Personally I like working with Area Median Altitudes (AMA, Kuhn et al 2009); I do not find constant k realistic (Kuhn 1984), but I accept it for the present good purpose; and I find that a triangular area-altitude distribution is a good approximation to the Austrian glaciers 1969 and 1998 (Lambrecht and Kuhn 2007); two of our study objects in Austria, Hintereisferner and Kesselwandferner were keeping their firn areas at remarkably constant altitude while their tongues melted away (Span and Kuhn 2003) which speaks against the symmetry of changes. I have seen that many alpine glaciers did not keep their upper ends stationary but lost area from top to bottom. Frequently they lost the steep ice above their bergschrunds, Mischbachferner in the Tirolean Alps being a good example (Google Earth, 47˚02'43"N, 11˚17'22"E) – again, some abstraction and generosity is asked for.

I do not believe that the two short advance periods of 1920 and 1980 imply equally short response times and shall enlarge on that with my comment to 246-10.

In summary I strongly recommend that this manuscript be published with the proper reaction to three positive reviews and comments.

Specific comments

244-3

"It is currently believed..." I am afraid this is an undue generalization. I suggest "It was previously proposed..."

246-10

In the two advance periods ending around 1920 and 1980 alpine glaciers remained far from stationary state and their advance was not a reaction to a stepwise change in forcing. A number of years with intermittently positive mass balances following the

year 1965 started the advance, which across the size spectrum of glaciers proceeded at different rates. The fraction of more than 75% of glaciers advancing in 1980 demonstrates that they were far from equilibrium in 1982 when the mass balance forcing was reversed to strongly negative values with the majority of the glaciers retreating. While we can safely state that the positive forcing was of short duration we cannot infer much about the response time of glaciers from this advance period.

253-3

...involves an extra numerical factor (Gamma /Eta).

Does this agree with equ. 27 where you have only Eta?

254-13

...vs altitude range scaling...

255-1

I suggest you use „area median altitude"

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