

## **Interactive comment on “An estimate of global glacier volume” by A. Grinsted**

Referee #2 Roger J. Braithwaite

### **General Comments:**

The total volume of water contained in the world’s glaciers is important because it sets a limit on the potential sea level rise from glaciers under global warming. Insofar as sea level rise is regularly re-assessed by bodies like the Intergovernmental Panel on Climate Change (IPCC), research on global glacier volume is policy-relevant and, like all policy-relevant research, the emphasis has to be on the best available science at the time of the assessment rather than on the last word.

Estimation of the volume of all the world’s glaciers and ice caps (excluding the great ice sheets of Greenland and Antarctic) is difficult because of lack of data. In a strict sense, there is no single glacier whose volume has been measured directly, although glacier volume can be assessed with greater or lesser accuracy for about 200-300 glaciers, using field data from the glacier in question. We are referring to these (roughly) 200-300 glaciers when we talk of “observed” glacier volume, although there will still be questions of sampling of measuring sites and extrapolations to unmeasured sites.

A number of recent studies use so-called volume-area scaling to estimate glacier volumes from known glacier areas, e.g. from a glacier inventory. Some people may prefer thickness-area scaling but the final global ice volume will be the same whichever way you go. To apply volume-area scaling, a.k.a. thickness-area scaling, you would need (1) the area of each and every glacier in the world, and (2) a tried and tested equation (or equations) to calculate average glacier thickness or total glacier volume for each glacier from its area. We still have some way to go to achieve both (1) and (2) but the paper by Grinsted is a very interesting, challenging and timely contribution to the literature.

With respect to (1), the paper by Grinsted uses the newly compiled Randolph Glacier Inventory v2 together with updates to the WGMS and GLIMS datasets, which must surely be the best available data on glacier areas. With respect to (2), Grinsted uses volume-area scaling carefully and critically although he should look seriously at suggestions made by Referee #1 and by M. Huss. In particular, Grinsted’s comment that the scaling law “remains the only feasible way of estimating the volume of the vast majority of glaciers” may require some modification in the light of the newly published paper by Huss and Farinotti (2012).

Grinsted refers the reader to Cogley (2012) for a review of earlier estimates of global ice volume. As this review constitutes a chapter in a relatively expensive book, excellent as it may be, I think Grinsted should exploit the open-access character of *The Cryosphere* to give a brief review of earlier estimates in this paper, e.g. in the form of a table.

### **“Low and “high” ice volume estimates:**

An earlier estimate of global glacier volume by Raper and Braithwaite (2005a) suffered from the lack of a complete global glacier inventory at that time. These authors could only use available glacier areas, which then excluded local glaciers around the ice sheets of Greenland and Antarctica. The ice volume estimate of Raper and Braithwaite (2005a) was heavily attacked as being too low by Meier et al. (2005) but Raper and Braithwaite (2005b) defended themselves vigorously. A revised version of Grinsted’s paper could usefully reference this discussion for the insights that it may still give and for the fact that the global ice volume of Raper and Braithwaite (2005a) is a relatively “low” estimate ( $0.241 \pm 0.026$  m sea level equivalent SLE) compared with Grinsted’s ( $0.35 \pm 0.07$  m SLE). However, if we adjust the Raper and Braithwaite estimate for their lower glacier area total, it would agree reasonably well with Grinsted’s estimate, which is itself much lower than the  $0.60 \pm$

0.07 m SLE found by Radić and Hock (2011). An ice volume of  $0.43 \pm 0.06$  m SLE from Huss and Farinotti (2012) is between these “low” and “high” extremes.

### Specific comments:

Abstract second sentence reads: ‘I calibrate scaling laws against volume observations of optimized towards the purpose of estimating the total global ice volume’. Perhaps ‘glaciers’ should be inserted after ‘of’.

Page 3650 line 12: ‘GLIMS where.’ Delete ‘where’

Page 3650 line 13: replace ‘does contain’ should be ‘do contain’.

Page 3650 line 18: replace ‘determined ERA40’ by ‘determined from ERA40’.

Page 3650 line 19: other authors have used the annual range (from warmest to coldest month) to express “continentality”

Page 3650/3651: delete ‘This has been...’ and start the sentence with ‘The only practical...’

Page 3651 line 27: ‘weighing’ should be ‘weighting’.

Page 3652 line 7: ‘...that is...’ should be ‘...that it is...’

Page 3653 line 8: I am not sure I know what ‘...imputation models’ means.

Page 3653 line 19: You give the range 0.30 to 0.39 m SLE but Table 3 gives 0.27 to 0.41 m SLE.

Page 3653 line 26: There is something odd about the units given on this line!

Page 3656 line 13-14: ‘...probably hundreds of glaciers and ice caps that have been measured, but which have yet to be included...’.

Page 3663 Table 4: As commented earlier in this note, Raper and Braithwaite (2005a) estimate global glacier volume to be 0.24 m SLE for glaciers and icecaps but they exclude local glaciers in Greenland and Antarctica. Adding the regional values in Table 4, but excluding Greenland and Antarctica, gives an equivalent value of 0.23 m SLE, i.e. Grinsted’s ice volume for the same areas is almost the same as the Raper and Braithwaite (2005a) value. When it comes to applying glacier thicknesses to glacier areas, the two studies are almost identical.

### References:

Cogley, J.G. (2012). The future of the world’s glacier. In *The Future of the World’s Climate*, 2<sup>nd</sup> ed., edited by A. Henderson-Sellers and K. McGuffie, p 197-200, Elsevier, Amsterdam.

Huss, M. and D. Farinotti (2012). Distributed ice thickness and volume of all glaciers around the globe. *Journal of Geophysical Research* 117, F04010, doi:10.1029/2012JF002523

Meier, M.F., D.B. Bahr, M.B. Dyurgerov and W.T. Pfeffer (2005). Comment by M.F. Meier et al.

on “The potential for sea level rise: New estimates from glacier and ice cap area and volume distributions” by S.C.B. Raper and R.J. Braithwaite. . Geophysical Research Letters, 32, L17501, doi: 10.1029/2005GL023319.

Radić, V. and R. Hock (2010). Regional and global volumes of glaciers derived from statistical upscaling of glacier inventory data. Journal of Geophysical Research 115, F01010, doi:10.1029/2009JF001373.

Raper, S.C.B. and R. J. Braithwaite (2005a). The potential for sea level rise: New estimates from glacier and ice cap area and volume distributions. Geophysical Research Letters, 32, L05502, doi: 10.1029/2004GL021981.

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