

**Comments on “Significant total mass contained in small glaciers”, by D.B. Bahr and V. Radić,
The Cryosphere Discussions, 6, 737-757 (2012):**

J. Graham Cogley, February 2012

General Comments

This paper argues persuasively that glacier inventories need to include very small glaciers if they are to meet specified standards of accuracy for the estimation of total mass by the well-established volume-area scaling method. The argument is an elegant extension of that applied to good effect by Bahr et al. (2009, *Geophysical Research Letters*, **36**, L03501), who deduced that present-day glaciers are far from equilibrium with today’s climate. In the present paper it is noted that the frequency distributions $N(S)$ and $V(S)$, number of glaciers and glacier volume as a function of area S , obey power laws with exponents of about -1.9 and 1.36 respectively. The frequency distribution of total mass $\rho N V$ (ρ being a suitable mean density) is found and turns out to follow the 4.26 power of area. It is then possible to calculate the underestimate of mass due to omission of glaciers smaller than any given threshold. For example a global inventory would need to include all glaciers of 1 km^2 or larger if it were to yield an underestimate of total mass no greater than 1% , while the same relative underestimate for the European Alps would require all glaciers down to a threshold of 0.004 km^2 .

I think this paper needs to be published. It makes an important conceptual point that has not been made explicitly before, and the numerical examples of the bias implied by choices of minimum threshold will be valuable for practitioners and for users of existing inventories (for the latter, only if they can find out what thresholds were adopted). However there are some problems of presentation. The basic argument is made repetitively, and it would come across to readers more effectively if the repetitions were eliminated. I have also suggested below that the presentation could be improved and shortened by framing it in terms of the relevant cumulative frequency distributions.

Substantive Comments

P737

Title The title would be more accurate if it were similar to “Significant contribution to total mass from very small glaciers”.

P738

L7 “Such accuracy ...”: somewhere in the paper it is necessary to make the point that omission of very small glaciers introduces a bias. That is, it is not a random but a systematic error (due to incompleteness). In fact, it might be better to replace most instances of “error” with “underestimate”.

L15 “ 10^4 km^2 ”. (There are no glaciers with areas near to 10^5 km^2 .)

L19-20 “for each single large glacier”: this sentence suffers from the vagueness of “large” and “smaller”. How many “large” glaciers are being referred to? If the number is 10, say, then the sentence implies that there are millions of “smaller” ones, leading to a total glacier count much greater than most students would accept.

P739

L19-20 Delete this sentence, or clarify. As it stands, it says that upscaling would benefit from knowledge that would make the upscaling unnecessary.

L21-22 “the mass of the very largest glaciers is indeed almost ...”. But again, “very largest” is vague. Looking ahead, it seems likely that “the very largest glaciers” are those in the largest area bin, but the concept of a bin has yet to be introduced.

The exposition would be clearer if the ideas were framed in terms of the *cumulative* frequency distributions of glacier numbers and extent as a function of size. The vagueness here and at P738 L19-20 could then be eliminated by specifying percentiles, as in “The largest 5% of glaciers contain $X\%$ of the mass” or “The tenth decile of the area distribution consists of glaciers larger than $Y \text{ km}^2$ ”.

This framework would also help with another problem, that of repetitiveness. The paper’s main message is that the lower $Z\%$ of the area distribution may contribute significantly to the mass distribution. The message follows immediately from the observation that the power-law exponents introduced in section 2.1 are greater than

unity. Nevertheless it is valuable and worthwhile to have the message illustrated as in this paper, but the illustration would have greater impact if the message were stated just twice, once in the introduction and once in the conclusion.

P740

L9

I cannot work out what the “If we abandon ...” sentence is trying to say, but it seems probable that it is just repeating a point that has already been made. In fact, the entire remainder of the paragraph is repetitive. The three citations to inventory sources can be placed elsewhere.

P741

L7

“all glaciers of size 100 km^2 ”: the number of such glaciers is very likely to be zero. Eq.1 tells us that *if* there were a glacier of that area its volume would be such-and-such. Here again the exposition would be clearer in terms of the cumulative distribution: “the total volume of all glaciers with sizes between $S - \Delta S$ and $S + \Delta S$...”.

P742

L21

“making it less likely”: say “... but that power-law behavior should then be resumed by snowpatches that ...”.

L26

Bolch et al., 2010: This inventory adopted 0.05 km^2 as a minimum threshold, noting that “We could not justify the costs in terms of effort and high relative error to map glaciers at a larger scale”, and also that “a smaller threshold would include many features that were most likely snow patches”. The present manuscript should acknowledge both of these practical points somewhere. Relative error, cost and time do indeed rise steeply as the threshold is lowered, and thresholds vary between inventories. And the smaller the glacier, the greater the likelihood that it is “really” a snowpatch – although that is not pertinent if the two kinds of object obey power laws with indistinguishable exponents.

Some of the symbols in Figure 3 appear to represent sizes below the Bolch et al. threshold, although the graphs are difficult to read (the axis tick marks being very short).

Something might be learned from giving special consideration to selected parts of WGI-XF (the WGI version of Cogley 2009). For example in Svalbard (glaciers with IdCodes beginning with ‘NO4W’) the smallest glaciers are “nominal glaciers” in the sense defined by Cogley, because the regional source inventory listed only the number and total area of glaciers smaller than 1 km^2 in each of a substantial number of subregions. Three regions that may repay detailed analysis are Axel Heiberg Island (‘CD2R’), Vancouver Island (‘CD2M001’) and the Stikine basin in British Columbia (‘CD2N001’). Records from these regions were generated either by or under the supervision of C.S.L. Ommanney, possibly the most careful “inventor” of all time. In particular, the prescribed WGI minimum threshold, 0.01 km^2 , was observed and candidate objects were screened for evidence of their status as glacierets or snowpatches. For example WGI-XF has 217 glaciers on Vancouver Island (1953-1957), as against Bolch et al.’s 61 (1987) or 65 (2005).

L29

“no deviation from the power law”: eight or nine of the ten observational “curves” in Figure 3 deviate visibly from the power law at small sizes. What they do not exhibit is a relative maximum of $\lg_2 N$, as seen in eight of the ten observational curves in Figure 1.

P745

L8

“only the largest glaciers contain relevant mass”: I know of no instance of this assumption having been made. It seems to be a “straw man”, set up for the sake of argument. See the comment at P742 L26 for reasons why some inventories omit some smaller glaciers.

L19

Use a symbol other than S_{\min} here; in eqs. 7-9 S_{\min} stood for the smallest glacier of all.

P746

L15-22

Omit this paragraph, which seems to labour a point that has been made enough times. The relative error can be read easily off a suitable graph of the cumulative frequency distribution, including by anyone who might wish to represent the entire size distribution by only its largest bin.

P751

L9 I do not think a conference presentation is eligible to be referenced.

Stylistic Comments

P738

L6 “to reduce errors to below 1% requires the inclusion of glaciers ... than those recorded in some inventories.”

L8 “At the global scale, such ... larger than 1 km²,” (or “of area 1 km² or larger”).

L10 Delete “conceivable”.

L11-12 Overstated; say “should not omit the world’s smallest glaciers.”

L17 “ratio”, not “volume”.

P739

L4-5 Delete the repetitive “It is entirely ...” sentence.

L17 Change “a predominance” to “improved recognition”.

L18 Delete “overall”.

L21 Comma needed after “that”.

L23 Delete the repetitive “This matches ...” sentence (and so also “For example,” at the start of the next sentence).

P740

L6 Insert “global” before “total”.

L18 Omit the repetitive “if there is a size ... we can ask”.

P742

L7 “are limited” rather than “would be limited”.

L15 Delete “by the strict power law”.

L19 “distinction”, not “division”.

P743

L10 “While it is natural”.

Eq 5 I read on, expecting an explanation of why it makes sense to keep the space-consuming symbol $\gamma - \beta + 1$ instead of defining a new one, but no explanation ever appeared. The text would be more accessible to readers without this circumlocutory algebra.

P744

L17 “contain”.

L745

L12-14 Delete “-sized”, and clarify, perhaps by saying “In other words, this section identifies the size below which glaciers make no significant contribution to total volume”.

L17 “glacier”.

P746

L8-9 I would omit this sentence, and similar text at L11-13 and later. The order-of-magnitude equivalents add little if any value to the argument.

P747

L5 “, ... the regional S_{\min} must diminish in proportion with the regional S_{\max} .”

L21-22 Delete this sentence. The point has been made in different ways already.

P749

L3 Insert “than the largest” after “numerous”.

L18 “when the context calls for small errors”.

L24 Change “scales” to “object”.

P753

Figure 1 The titles of the horizontal axes should read “Log₁₀ S”. (There are base-2 logarithms on the vertical axes.) The caption should mention the bin width on the horizontal axes.

P754

Figure 2 I believe that the names of regions 3, 4 and 5 in the source (the “Randolph Glacier Inventory”, newly released on Cryolist) are now “Central Asia”, “South Asia (East)” and “South Asia (West)” respectively. This also affects Table 1 and Figure 1.