**Response to the review by Graham Cogley**

We very much appreciate the careful review, and you make many important points that we believe will strengthen the paper. As requested, the presentation can been shortened and cleaned by removing repetitive points. All of the stylistic comments can be incorporated as well. Details for the substantive comments are given below, and we appreciate the thought that went into these.

*P737*
*Title The title would be more accurate if it were similar to "Significant contribution to total mass from very small glaciers".*

This works for us, and the title will be changed as suggested.

*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).*

Agreed, and we would add the following text to the second paragraph (giving this point some prominence in the paper).

"It is entirely possible that the smallest glaciers' sea-level contribution could be underestimated, in large part for practical reasons which make a catalog of the smallest glaciers expensive, time consuming, and error prone due to difficulties of separating small glaciers from snow patches (Bolch et al., 2010). As an inventory's size threshold is lowered, relative errors may rise, but with the smallest glaciers rapidly melting and possibly disappearing over the next few decades (Mernild et al, 2011; Radić and Hock, 2011), the potentially rapid sea-level contribution of these smallest glaciers should be considered, or systematic errors due to their exclusion should be estimated."

*In fact, it might be better to replace most instances of "error" with "underestimate".*

The calculation that we do is a standard method for estimating the relative error. We agree that this is the same as an underestimate in this instance, but by calling this a relative error we make clear the origin of our derivation. There are calls to more accurately estimate errors in each sea-level rise component. For example, recent "NSF calls for proposals" ask applicants to more accurately estimate the errors from thermal contributions, melting ice, groundwater, etc. Using the term "error" is consistent with this ongoing effort.

*L15 "104 km2". (There are no glaciers with areas near to 105 km2.)*

Thank you for catching this. This will be fixed.

*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.*

"Large" and "smallest" are defined with numbers in the first sentence of the paragraph, but we agree that this implies more glaciers than actually exist. We plan to change this to "tens of thousands" which reconciles the difference.

(As noted below, this could be presented in terms of mass – e.g., percentage of mass in the largest 5% of the glaciers – but this would necessitate a discussion of the mass calculation in the introductory paragraph. Instead, we intend only to set the stage by giving an intuitive reference point for the numbers of glaciers. Colloquially, we are saying "There are overwhelmingly more numbers of 'small' glaciers than numbers of 'large' glaciers.")

*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*.

In this case, the missing smallest glaciers would make a downscaling necessary. We will clarify by writing

"At the very least, any future upscaling or downscaling of incomplete inventories would benefit from knowledge about the theoretical distribution of glacier mass at the smallest glacier sizes."

*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 km2". 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.*

To avoid repetition (per comment below), this paragraph would be eliminated. There is now no need to refer to the largest percentiles.

*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.*

To avoid this repetition, this paragraph will be deleted. The references will be moved to the next paragraph.

*P741*
*L7 "all glaciers of size 100 km2": 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 – ΔS and S + ΔS …".*

Agreed, the number of glaciers with exactly any specified area will likely be zero. But this is only meant as a verbal description of the upcoming calculation. Equation 3 is necessary to the calculations, and this phrase "all glaciers of size 100km^2" describes the meaning of the distribution in that equation. The next sentence says that integrating (in effect, moving to the cumulative distribution as you suggest) gives the total mass between any range of sizes. We mention a range between orders of magnitude of 1000 to 10,000 km^2.

*P742*
*L21 "making it less likely": say "… but that power-law behavior should then be resumed by snowpatches that …".*

This sentence will be rewritten as "Data also show that snow patches have a power-law distribution (Shook and Gray, 1996), making it unlikely that small glaciers should deviate from a power law but then resume power law behavior for only slightly smaller snow patches."

*L26 Bolch et al., 2010: This inventory adopted 0.05 km2 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.*

Good point, and one with which we wholeheartedly agree. We will add text in the second paragraph of the paper to make this clearer. We can also mention this in the second paragraph of the conclusions. See the note above for P738, ln7.

*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).*

In response to another reviewer's comment, the figures have been reworked. The tick marks have been lengthened. (We used data from the indicated sources.)

*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 km2 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 "inventorer" of all time. In particular, the prescribed WGI minimum threshold, 0.01 km2, 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).*

We can envision many possible detailed analyses that might help distinguish small glaciers from snow patches and test the theoretically derived power law. This is an excellent suggestion, and ideally, just this sort of analysis would be combined with the flowshed algorithm to help delineate causes. This would become tangential to the primary purpose of this paper but we are certain that this analysis would make an excellent candidate for a follow up paper.

*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 lg2 N, as seen in eight of the ten observational curves in Figure 1.*

Agreed, and we will change both the wording and the precision of our statement. As with all data (real or synthetic), deviations are always present at all glacier sizes, large and small. From a paper suggested by another reviewer, we have found a defensible method for exactly estimating the deviations at small glacier sizes. Using this statistical technique, the size of the deviation $S_{deviate}$ remains $1km^2$ for both the real and synthetic data. However, the standard deviation associated with $S_{deviate}$ show that the flowshed algorithm is roughly twice as accurate.

*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.*

Apologies for the unintentional straw man construct. This also was noted by another reviewer and has will be removed from the paper. The changes would combine sections 2.2 and 2.3 to eliminate the discussion of the largest size bin. References to bins would also be eliminated from the introduction (fourth and fifth paragraphs removed) and the conclusion (the second and third sentences would be replaced in the first paragraph). Incidentally, this will also get rid of a notational typo – the variable "*f*" should have been replaced with a "*1-f*".

*L19 Use a symbol other than Smin here; in eqs. 7-9 Smin stood for the smallest glacier of all.*

This is a problem with the wording used in the preceding section. Smin represents the smallest glacier with a relevant contribution to the total volume of all glaciers. (If all glaciers were relevant, then Smin would be the smallest glacier of all.) The sentences before equation 7 would be revised to read

"Let Smin be the smallest size of glaciers that could make a relevant contribution to the total volume of all glaciers Vtotal. (If all glaciers are relevant, then Smin will be the smallest existing glacier.) It follows that…"

*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.*

This will be done.

*P751 3*
*L9 I do not think a conference presentation is eligible to be referenced.*

We hope to reference a paper by Mernild et al if it is submitted in time. Hopefully a reference to the conference proceeding will not be necessary; but while not ideal, The Cryosphere guidelines do currently allow conference proceedings that are available to the public. However, the reference is not key to this paper, so we can remove it if the editors indicate this would be better.

*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.*

The order of magnitudes are important when showing that there is no substantive difference between the lower and upper bound limits (the two methods used to estimate volume errors in this paper). Each limit gives the same order of magnitude results.

*P753*

*Figure 1 The titles of the horizontal axes should read "$Log_{10} S$". (There are base-2 logarithms on the vertical axes.) The caption should mention the bin width on the horizontal axes.*

Both axes are in the same logarithmic base of 10, but we agree that this should be clearer. Revised versions of Figures 1 and 3 will label the axes with $10^0$, $10^1$, $10^2$, $10^3$, etc to make the base clear. We will leave "log" as the traditional notation for base 10. The revised figures will also show the cumulative density functions rather than the probability density functions.

*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.*

These will be changed to match the recently released inventory.