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The Cryosphere Discussions

Interactive comment on "Improving estimation of glacier volume change: a GLIMS case study of Bering Glacier System, Alaska" *by* M. J. Beedle et al.

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This paper examines the extent to which errors in a glacier's outline affect calculations of its volume change. This is a problem that is often overlooked in glaciological studies of glacier mass changes, which tend to focus on errors in the vertical measurement of change. Here the authors take a careful look at the Bering Glacier in southern Alaska, and compare several published surface areas and hypsometries. Their findings, that this glacier's volume contribution to rising sea level varies by a factor of two based on the outline/hypsometry chosen, illustrates the need for continued efforts to accurately map Earth's glaciers, especially those in regions where mass variations are most pro-

nounced. This paper shows that great care needs to be taken when defining the extent of a glacier basin, and highlights the need for a consistent outlining methodology.

The introduction describes a relatively straightforward problem: glacier surface elevation or mass balance can be measured or modeled, but errors occur when these changes are integrated across a poorly-defined surface. I suggest the best way to approach this problem is to choose a mass balance parameterization and define a fixed glacier surface, and test the net mass balance sensitivity to a variety of glacier outline definitions. Here the authors choose a more complex approach, testing 3 different mass balance parameterizations and 3 different glacier surface elevation distributions to test the effect of 4 different glacier outlines on the predicted net mass balance. In order to navigate through these added complexities it is necessary to include more detail in the introduction, and to clarify several key sections of the paper. I recommend the following general clarifications:

- make the distinction between the terms “outline” and “hypsometry” more clear. An outline is a minimum amount of information and is sufficient for many studies that extrapolate net mass balances as a function of total area. Describe how the surface area distribution is crucial when measurements or models provide vertical changes as a function of elevation. Bring out the point that in this paper you are investigating the more complex issue of hypsometry rather than just the area outlines.
- be clear on the dates and sources of your hypsometries, in particular the underlying DEMs used to obtain the surface elevations.
- be explicit as to why the modeling is introduced as the only method for generating the vertical component of mass change. Justify why, for example, differencing of DEMs or surface elevation profiles were not used instead.
- highlight the dynamic nature of surface area and hypsometry. Your model sim-

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ulations cover a 54 year period but make no mention of the feedback effects of changing hypsometry on the predicted balance.

Specific Comments

p.170, line 7: change “ice streams” to “tributaries” or “ice valleys”. BGS is not an ice stream.

p.170, line 11: list also the source of the elevation information used to construct the hypsometry (ie: the ASTER DEM)

p.170, line 12: here and throughout, the term “outline” is used when really you are testing different hypsometries. This is because not only the outline but the DEMs to construct the elevation distribution are different for the different tests.

p.170, line 15: your net balances vary due to different hypsometries, but you need to indicate what mass balance parameterization was used to obtain these numbers. Begin the sentence with something like: “Using a simple elevation-dependent mass balance simulation model,...”

p. 170, line 16: list also whether the volume changes are in water or ice equivalent units.

p.170,line 21: Change “While current inaccuracies...” to “Current inaccuracies in glacier outlines hinder our ability to correctly quantify glacier changes.”

p.170, line 23: “..there is no reason why our understanding...” Remove this statement, because there are reasons, namely a lack of resources dedicated to this effort. Change the tone to say that the datasets and technical tools are available, and all that remains is for resources to be dedicated to accomplishing this important activity.

p.171, introduction: reference the work of Dyurgerov (Arctic Alpine Res., 1997) and Cogley (J.Glac.,1998) who have investigated the representativeness of benchmark glaciers.

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p.171, line 12: Just state that new technologies are responsible for providing new techniques. The “complications” and “efforts” have always been there.

p.171, line 16: Laser altimetry methods difference point measurements, not surfaces.

p.171, line 23: Change “area versus elevation distribution...” to “distribution of area with elevation”.

p.172: I suggest a more complete introduction here, before beginning to describe the BGS (Section 1.1). The material in Section 1.2 should come first, in which you detail what methods will be used to investigate the research questions. Here include more information on the modeling effort as recommended above.

p.175, Section 2.1, Hypsometries: this section is incomplete because it only describes the glacier’s surface area and elevation ranges. The distribution of area with elevation (hypsometry) depends both on the glacier outline and the map or DEM used to describe the surface at a given time. Therefore it is important that this section include information on the date at which the surface elevation distribution was obtained, as well as the source providing the elevations for each hypsometry. The AH elevations come from 1972 USGS topographic maps, the T1H and T2H elevation dates/sources are not known, and the BH elevations come from a composite ASTER DEM (described later on page 179), with an unknown date (but sometime after 2000). This range of dates needs to be highlighted because it means that comparisons later in the paper are investigating the effects of different outlines as well as different area distributions on the calculated mass balance. Can you say something about how that will affect your comparisons?

p.176, Section 2.2, Mass Balance Models: I suggest putting a complete description of the models here, rather than splitting between a “Data” and “Methods” section. The current layout is not consistent with your headings. For example, Section 3.4.1 in the Methods section describes data used to drive the PTAA model, which should appear under “Data”

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p176, line 17: what percent reduction due to debris cover do you use in the model? Is there an energy balance study you can reference to justify the choice of values?

p.176, line 20: Why generate the ELA from the PTAA model? This should at least be confirmed by examining the location of the ELA on your Landsat images.

p177, line 3: change “dependent” to “depending”

p.177, line 16: change “attributable” to “flowing into”

p.177 line 25 to p.178 line 2: The verbatim quote of the GLIMS glacier definition should be replaced by a reference to Raup and Khalsa (2006). Descriptions of GLIMS glacier IDs and special cases like tropical glaciers detract from the focus of the paper. The next paragraph is much better because it discuss GLIMS guidelines in the context of outlining issues on the BGS.

p.178, line 17: The wording “...necessitates a decision as to the inclusion...” is awkward

p.178, Debris cover: I thought it was a GLIMS standard to outline debris cover separately from clean ice. Then the user can choose an outline based on their particular needs. Is this correct?

p.179, line 3: What specific aspects of the image indicate mature versus other types of karst?

p.179, line 3-6: “Doing so is subjective...” This sentence is very unclear.

p.179, line 10-12: “Previous work...” What is the reason for mentioning automated techniques? Did you test these on BGS?

p.179, line 28: Description of ASTER DEM: include details on DEM resolution, vertical accuracy, and dates. As stated above, this information should appear in the hypsometry section.

p.180, line 5: DCH: do debris-covered areas include karst as defined in the previous

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section?

p.180, line 17: OK, here are the references I was suggesting previously, regarding reduction in ablation due to debris cover. Does you value of 1/4 reduction come from these references?

p.181, line 4-6: Remove this sentence and just reference Tangborn (1999) in the first sentence.

p.181, PTAA model: If I understand this model correctly, nearby weather station data are used to drive a regression-based mass balance model for a specific glacier hypsometry. Which hypsometry did you use (date/outline/DEM)? Discuss how changing surface geometry during 54 years would affect the model results.

p.181, line 7: Your use of the term "mass balance gradient" is confusing. The model produces an estimate of the balance as a function of elevation. The derivative of this function is the mass balance gradient. Figure 8, right chart, is a plot of balance versus elevation, not the balance gradient. If you wish to use this terminology, be sure to define it clearly.

p.181, line 14-16: This sentence does not make sense to me. Be specific with your use of the term "mass balance". Hypsometry determines a glacier's net mass balance, but mass balance at a point depends only on the climate. One could easily say mass balance (climate) exerts a control on the hypsometry.

p.182, line 18: remove "(qualitatively)"

p.182, Section 3.5: Remove this section, and just reference these results in the discussion when comparing to other measurements. I do not see how it is possible to compare an SLE value with a mass balance gradient?

p.187, line 24: The lack of information on these outlines begs the question as to whether they should be included at all in the analysis.

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p 188, line 9-15: List the dates of surges occurring within the period of your measurements. The 1993-95 surge occurs between the 1972 AH and the > 2000 BH and could explain differences.

p.189, line 12: "average" b_n, in what sense? Following standard mass balance terminology (see Mayo et al, J.Glac. 1972), b_n means area-averaged net balance. By "average b_n" do you mean time-averaged?

p.193-194: Implications Section: Your models are calibrated to climate data from 1950-2004. You use this to obtain a time-averaged balance versus elevation curve. You then apply that rate to the 1972-2000 period to compare with laser altimetry. This is not a very robust comparison. It would be much better to calibrate the model to 1972-2000 data. One compelling reason is that 2004 had record high summer temperatures across Alaska and could be biasing your model results toward negative values. Also, you integrate the PTAA "balance gradient" against the BH hypsometry, representing a glacier surface that is considerably lower than the AH 1972 elevations. Thus BH samples a more negative climate and your comparison is not entirely valid. It should be reasonably easy to quantify the effects of changing surface geometry on your estimates, while being clear that your models do not account for the feedbacks between climate and glacier dynamics.

Your models do not produce estimates that are precise to 3 or 4 significant figures.

Recent results using GRACE agree closely with 1995-2000 estimates derived from aircraft laser altimetry. Be clear that your results suggest the "early period" laser altimetry assessment underestimated Alaska glacier mass losses.

If the authors wish to publish a new mass balance value for this glacier, one that would potentially be included in future mass balance inventories, then I would like to see a more rigorous treatment of the modeling effort. At a minimum, it would be necessary to at least mention the potential effects of changes in glacier hypsometry, and surge dynamics, on the model results. In addition to the comparisons with the laser altimetry

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measurements on this glacier, the model results should be validated against measurements by Muskett and others (GRL, 2003, Vol 30), who have calculated geodetic balances for BGS by differencing a series of DEMs.

p.211, Fig.8: Label the y-axis of both plots.

p.212, Fig.9: Remove one of the two first sentences repeated in the caption.

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