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The Cryosphere
Discussions

Interactive comment on "*Brief Communication* "Importance of slope-induced error correction in elevation change estimates from radar altimetry"" *by* R. T. W. L. Hurkmans et al.

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Researchers inferring ice sheet changes from satellite radar altimetry (SRA) have long felt that not accounting for the upslope shift of the SRA sampling point induces biases in estimates of integrated volume change. Yet it appears that corrections have not been widely applied, and the amount of the committed bias has been unclear.

This manuscript aims at quantifying and correcting the related error (slope-induced error) in a case study for the fast flowing part of Jakobshavn Isbrae, the prime example for dynamic ice mass losses in Greenland. The case study is based on linear trends from ENVISAT SRA over the period 2003-2006 adjusted at crossover points. Relocation

is performed based on average slopes and aspects over 100 km^2 surrounding areas taken from a digital elevation model. For comparison, airborne (Airborne Topographic Mapper, ATM) and spaceborn (ICESat) laser altimeter data are used. The main conclusion is that for the particular case investigated, the correction for the slope-induced error increases the estimate of ice volume loss by 32%.

Investigations of this kind are highly important and timely, and the presented analysis has the potential of initiating further development in this field. Overall, the presentation is well-structured, clear and sufficient to understand the analysis and its results. Yet, I feel that in its present form, two major issues (A,B) limit, to some extent, the value of the manuscript. There are also a number of minor issues, which I will list in the sequence.

(A)

To say it with some exaggeration, the study investigates SRA errors in observing a signal that is largely unobserved by SRA.

More specifically, most of the volume loss occurs in the fast-flowing part within the 300 m/yr velocity contour. This is exactly the area where virtually no altimetry data are available from the employed SRA crossover analysis. (More precisely: exactly 1 crossover point is available.) The SRA-based elevation rates in the high-velocity area are therefore almost purely the result of an interpolation (or rather extrapolation?) using an approach of kriging with velocity information as an external drift, with reference to a manuscript under review. Thereby, high elevation rates in the fast-flowing part are deduced from much lower elevation rates in the slower parts.

Without doubt, it is an attractive idea to estimate elevation rates in the fast-flowing part by a combination of flow velocity data, assumptions about the relationship between flow velocity and elevation rates, laser altimetry data (used, at least, for validation purposes), and SRA data outside the fast-flowing part. However, for such an estimate the effect of the SRA slope correction is a puzzling interplay between the slope correction (relocation) itself and the effect of the interpolation. The methodology outline and illustration in Section 3 does not cover this interplay but purely refers to the case of an area well-covered by SRA. Without more insight into the interpolation method, the reader has difficulties to assess the general significance of the results. Figure 3b illustrates this dilemma. This figure shows SRA results confined to the area within the 300 m/yr velocity contour, where there is just one single SRA observation, located at the upper end.

I propose that this issue should be discussed, at least. I would also find it helpful to present a separate analysis for the area that is really sampled by SRA, for example the area between the 100 m/yr and the 300 m/yr velocity contours. Roemer et al. (2007) provide one example where the validation of SRA results is confined to the SRA-covered area.

(B)

The quantification of the slope correction effect ("32%") is relative to the uncorrected (biased) estimate. In fact, both SRA-based estimates appear to be biased low. It would be more informative to relate the slope error effect to a best estimate of the true volume change. While the authors have computed such an estimate from the laser altimeter data (p. 164, line 26), they do not quote it. From Fig. 3b and independent sources (Joughin et al. 2008, Khan et al. 2010) I would guess that such an estimate is on the order of -20 km^3/yr. Then, a more objective and more informative quantification of the slope correction effect would be of the following type (with fictive numbers): "Without slope correction, the error of the SRA-based volume rate is -57% of the signal. With the slope correction, the error reduces to -43% of the signal." An analogous (and probably more satisfying) statement could be formulated for the area that is really sampled by SRA.

Minor comments:

(1) Abstract: Revise the statement that the correction “increases elevation change rates

by several metres”. It should read “meters per year” and “up to several meters”, I would suggest. Also, as discussed in (A), it has to be clarified that this is not the effect of the correction on the observation itself, where the slope error cancels out. In the same spirit, one might re-consider the title. I would prefer “volume change estimates” instead of “elevation change estimates”. Then it would be clear that an interpolation is involved.

(2) 160:20 (meaning page 160 line 20): the quoted 14 km displacement depends on the height of the specific satellite, which is not mentioned.

(3) 162:5f: Clarify whether the velocity fields were derived within this study or taken from an external source. Similarly, in 161:9: Are the elevation change rates provided by Li and Davis or derived by yourself?

(4) 162:15f: Clarify the explanation. Currently, only those readers will understand it who already know the three slope correction approaches. For example, R_c is used with different meanings. The formulation "R_c: the closest point to the satellite" seems to suggest that R_c denotes a point, etc.

(5) Fig 1: velocity contours should be marked and annotated more clearly because they are important for the further results.

(6) Fig. 2b,c: Color scale needs units.

(7) 163:2 "sensitivity to slope angle is larger": Clarify, how you compare the sensitivity to satellite height to the sensitivity to the slope error. The chosen numerical example compares the effect of a 10% slope difference with the effect of a 4% height difference.

(8) 163:9: What is meant by crossover location: The nadir location or the relocated one?

(9) 164:5: By what borders is the study area defined?

(10) 164:6f: Fig. 3a illustrates corrections on elevation rates (not elevation) in meters per year (not meters), right? Is it justified to say that these corrections are sometimes

several meters (per year)? That is, does the correction exceed 2 m/yr in any case? From the figure one cannot judge. It might be nice to identify the pairs of red and blue dots that belong together.

(11) Fig. 3b: Explain the dash-dotted line. If this shows the flow velocity, then there might be a problem with the right ordinate axis. I would have expected a value of about 300 m/yr at 80 km from the grounding line, but it is about 1.2 km/yr, instead.

(12) Fig. 3c: explain contour lines again

(13) 164:7: It could be formulated more clearly that reason (i) is a cause for noise in the SRA data while reason (ii) is a cause for noise in the ATM/ICESat values.

(14) 164:17: The text states that the correction effect at 10 km distance from the grounding line is about 4 m/yr. The Figure 3b, in contrast, shows about 1.6 m/yr.

(15) 164:19 and Fig. 3b: This sentence might be confusing, since (i) it states that results close to the grounding line are not used but (ii) it discusses the curves at the extreme left of Fig. 3b in terms of values "close to the grounding line". It might be an option to show the curves in Fig. 3b just starting from 3km on the abscissa.

(16) 164:27 most readers will be interested in the numbers from ATM/ICESat.

(17) 164:26 The sentence suggests that residual errors of the interpolated SRA volume changes after slope correction are (purely?) due to surface mass balance changes not accounted for by the interpolation algorithm. For the moment, the reader has no substantiation for this assertion.

(18) 166:12: reword "ice sheet mass loss from ice sheets".

References:

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