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The Cryosphere Discussions

Interactive comment on "Mass change of Arctic ice caps and glaciers: implications of regionalizing elevation changes" *by* J. Nilsson et al.

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We would first like to thank the anonymous reviewer for his comments and suggested improvements on this manuscript. Further the cited references in this response are available in the main manuscript.

In response to the main comments 1 and 2 on the first page.

1. The reviewer finds the manuscript "very badly written" in response to this we can suggest to send the manuscript in for professional proofreading.

2. The reviewer finds the analysis "sloppy", we do not agree with this but we have

taken the criticism to us and tried to improve our manuscript accordingly. We further think that main focus of the manuscript has been overlooked. If this is due to poor writing, descriptions or misunderstanding of the context of different words we can not say.

1.14: Will be changed accordingly

1.15: The use of the "optimum" selection is used to judge the different inter/extrapolation schemes against the original data set, as this is the main source of error in the mass balance estimation. The word optimum will be changed to "preferred" so not to confuse the reader. It is simply just a way to find the most suitable inter/extrapolation method for the area in question. We have also discussed this in response to Geir Moholdt review. Further we do not claim that external validation can be avoided, validation data should of course always be used if available. The problem lies in that many places in the Arctic have little or no validation data available in the form of in-situ measurement on the scale of an altimetric study. Hence our goal is to estimate the spread due to inter/extrapolation methodology, which will give more realistic error estimates and also guidance for a preferred method for the region. Thus will help us judge the robustness of the derived mass balance for the region. Performing absolute validation of the mass balance using in-situ data is outside the scope of this paper.

1.25: This will be rewritten

2.3: The preferred method is based on subjective robustness, which is based on the spread of the different methods in relation to the original elevation change estimates.

2.5: We have chosen to use a simple volume to density conversion scheme that is similar to other studies. Studies such as (Gardner et al, 2011), (Moholdt et al, 2010a) and (Moholdt, et al, 2012) have used a 900 kg/m3 assumption for their estimations of mass balance. Our approach is somewhat different compared to these studies but still show good agreement for most areas, such as RUS, CAN and CAS. But the main reasons of using a simple density scheme is to minimize the effect that the density conversion has on the spread of the mass balance, and also to make it easier to compare them to other studies, as detailed above.

2.7: This manuscript was submitted in late October 2013 only a couple of weeks after AR5 was published, so for this purposes we did not include it. AR5 and SWIPA will though be referenced in the next iteration. Reference will be bracketed as will the next paragraph.

2.11: Will be changed accordingly

2.12: Yes

2.18: Will be changed accordingly

2.25: Will be changed accordingly

3.4: The intention of the paragraph is to describe how mass changes are estimated from elevation changes in a general manner. A reference to the how elevation changes are estimated from altimetry can of course be included. The word “knowledge” will be removed so not to imply that we actually know them.

3.6 - 3.10: Noted

3.10 – 3.12: Will be changed accordingly

3.15: Will be changed accordingly

3.17: Will be changed, and more information will be added to the methods part!

3.20: See 4.2.

3.23: The wording will be change as the intention is to determine in a relative way the most suitable method when external validation data is lacking or spares.

3.24: The objective is not to critique other people’s methods! The objective as stated before, is to find out how sensitive the mass balance in these regions are to different methods of estimating the inter/extrapolated fields. This is important as we don’t

usually have large amounts of external validation data. Thus some relative criteria (decribed in 4.2) has to be invoked to judge the result.

4.1: Will be changed accordingly

4.2: We agree, and the the reasoning will be changed

4.7: For this study we have chosen to include Alaska and the western part of Canada for a more comprehensive analysis, even though they are not technically part of the Arctic.

4.8-4.10: Will be changed accordingly

4.11-4.12: Will be changed accordingly

4.11: Will be changed accordingly

4.13: “regional elevations for each region” will be replaced with “elevations for each region”.

4.18: Will be changed accordingly

4.22: Will be changed accordingly

4.25: The scope and motivation of the manuscript will be more clearly defined and described in a revised version of the manuscript.

5.2: Will be changed accordingly

5.6: Will be changed accordingly

5.10: Will be changed accordingly

5.12: Samples of elevation change estimates

5.15: Screening for outliers is always difficult as they can be both errors and part of the signal. In this case large/small spurious values not in line with the overall distribution can affect or bias the interpolation or the fitting of the polynomial. We use visual inspection to judge if the screening was successful or not.

5.16: This is subjective and is performed using visual inspection.

5.20: Will be changed accordingly

5.21: Smoothing is performed to remove along-track high-frequency noise that might affect the interpolation or the fitting. Whether it is incorporated into the estimates or not, is a more mathematical discussion of finite impulse response filters and how they work. Our opinion is that removal of high-frequency variations is important for the accuracy of the fitting procedure, even though it might remove some of the signal dynamics.

6.3: Will be changed accordingly

6.4: Will be changed accordingly

6.5: Will be changed accordingly

6.8: 'Regional elevation changes' refers to the area on which the point data has been inter/extrapolated to. 'Regionalized' referees to the model or interpolation surface obtained from the point-data set. This will be clearly explained in the text.

6.11: Will be changed accordingly

6.14: Will be changed accordingly

6.15: Will be changed accordingly

6.16: We do not rule out anything we simply use a fixed density to make our result comparable with other studies, and to minimize the impact of the density conversion on the spread of the mass balance. The manuscript will be improved by including the 900 kg/m3 assumption for easier comparison to the studies made by e.g. (Gardner et al, 2011), (Moholdt et al, 2010a) and (Moholdt, et al, 2012).

7.3: Will be changed accordingly

7.9: The along-track coverage is increased via the fitting of the spatially dependent

polynomial. Thereof areas that have been affected by the outlier screening procedure or the culling of ICESat data are again filled.

7.15: Will be changed accordingly

7.19: Usually linear interpolation does not work well over large gaps or at least it is not trustworthy as the closest points are just too far away. Applying a polynomial based on the location and the relation to elevation would give a more stable estimate, due to it takes into account the overall spatial pattern.

7.29: To reduce interpolation artifacts known as the "bullseye" effect the correlation length is increased until the individual tracks are not longer visible in the error surface. This creates a smooth continuous surface in between the individual tracks, which usually have large cross-track spacing, and reduces interpolation artifacts.

8.4: Will be changed accordingly

8.5: Will be changed accordingly

8.8: In each elevation band the volume change is obtained by multiplying the median value with the number of pixels according to dV_band = h_median_band*A_band, where A_band = N_band*Apix.

8.12-8.15: Will be rewritten

8.16: Will be changed accordingly

8.23: Will be changed accordingly

8.27: Will be changed accordingly

9.5: Will be changed accordingly

9.6: Will be changed accordingly

9.8: The Rˆ2 ratio and this will be changed to Rˆ2.

9.10: Will be changed accordingly

9.12: Will be changed accordingly

9.23: Will be changed accordingly

9.24 Will be changed accordingly, and a more detailed explanation will be included

10.1-10.4: Will be shown by plotting ICESat data against the elevation-area distribution

10.3: Will be changed accordingly

10.6: Will be changed accordingly

10.8: Will be changed accordingly

10.10: Will be changed accordingly

10.11: The error is derived from (Brenner et al, 2007), who found that the ICESat error was less than 0.6 m for terrain with a slope between 0-1.2 degree over areas in Greenland. As we are applying this error to ice caps and glaciers that usually have more rugged topography than ice sheets we have increased this to 1 m to be more conservativ.

10.12: Will be changed accordingly

10.13-10.15: We will rewrite this sentence. The error is induced in the conservative estimate of the ICESat elevation-point error. Though it is important to note that the error exists and if a specific correction has been used to correct for it. This for comparability purposes!

10.17: To the least squares model for estimating elevation changes.

10.19: Will be changed accordingly

10.21: Will be changed accordingly

10.25: Will be changed accordingly

10.25: This means that all (lat,long) track data inside every 50 m elevation band will be binned to one new (lat,long) point in the center of that bin.

11.4: We have used the methodology from (Moholdt et al, 2010a) and (Nuth et al, 2010) which showed that individual ICESat tracks are correlated. They either restricted the correlation length to 50 m in elevation or a 5 km along-track over glaciated areas in Svalbard.

11.8 – 11.10: It is the computation of the error from the least squares collocation interpolation algorithm. The error is then the estimated standard deviation of the data used for the prediction of the grid point. This will be clarified in a revised manuscript

11.11: (Moholdt, et al, 2010a) used a 5 km correlation length on Svalbard and this was assumed to be conservative. This approach uses 10 km instead as this is the size of the sub-rectangles for the estimation of the standard error. This is more conservative than than (Moholdt, et al, 2010a) and in the next iteration we will try to use the actual correlation length from the data if applicable.

11.15: Not using data outside the glacier area boundaries. This will be changed to : "is the individual standard deviation from the collocation prediction of data inside the glaciated area".

11.16: Will be changed accordingly

11.18: Will be changed accordingly

11.23: Will be changed accordingly

12.5: Will be changed accordingly

12.15: As the main objective is not the absolute mass change but the spread of the mass change we have only used a simple conversion scheme for comparability to other studies.

12.16: Will be changed accordingly

12.18: Will be changed accordingly

13.2: Figure layout will be changed to make it easier for the reader.

13.4: Exactly, and this has been changed in the manuscript.

13.5-13.7: We plan to use the suggestion made by Geir Moholdt in (P5902, L7) and also to find more appropriate reference for the patterns observed on ice caps and glaciers.

13.8: Larger variability of elevation change estimates, which are located in clusters in the lower elevations around the coastlines.

13.9: The clustering of the elevation changes are in areas with a larger number of outlets. This can be best seen in CAN just by plotting the data below a specific elevation (500-800 m), which also shows the largest variability (Figure 3.).

13.11: Will be changed accordingly

13.12: Will be changed accordingly

13.13: This is discussed and it is one of the main points of the paper.

13.16: Will be changed accordingly

13.20: Will be changed accordingly

13.22-13.23: Yes

13.23: This will be included in the next iteration

14.2: Will be changed accordingly

14.16: Will be changed accordingly

14.24: Will be changed accordingly

15.1: According to the strategy implemented and described in 4.2, where the method

or methods that gave the smallest shift from the original mean was used. Using this approach the methods that are shown in 15.3-15.4 was used.

15.5: See Response to: “A couple of more general points” (2.).

15.17: “average a lower estimate” refers to the fact that the magnitude of the elevations change is smaller or less negative. The last sentence will be rewritten to

15.20: Will be changed accordingly

15.21: How the optimal values where estimate are listed in the last paragraph of section 4.2.

15.22-15.24: The ICESat sampling will be included in the next iteration and arguments will be included accordingly.

15.26: Will be changed accordingly

15.27: Will be rewritten

16.1: Maybe a more correct description would be ‘less sampled’ as these areas are usually small and are not covered by a large number of observations.

16.3: The assumption that the ICESat sampling resolves the full ice cap geometry.

16.6: Will be changed accordingly

16.8: This will be rewritten to explain better.

16.11: Overestimate in comparison to the data available in the cited paper, thus more negative.

16.13: The sampling according to elevation will be included and commented on in the next version.

16.15: Will be changed accordingly

16.18: This statement will be softened or removed

16.19: Will be changed accordingly

16.24: For (Arendt et al, 2002) its airborne profiles and for (Luthcke et al, 2008) its GRACE so they are independent sources. This information will be included.

16.25: Will be changed accordingly

16.29: Will be changed accordingly

17.3: Will be changed accordingly

17.5: There is spatial variability in the elevation changes as a function of elevation. Though the magnitude and of this variation is less (comparing standard deviations) over the entire region when comparing to for example Svalbard and Alaska.

17.10: Indicator of what method to use.

17.11: Will be changed accordingly

17.17-17.19: There are areas in the higher elevations that show positive elevation changes, indicating snow accumulation. So ice cap and glaciers, depending on altitude, can have mass loss in the lower elevations and gain in the higher elevations. Thus the overall mass loss might still be negative due to an imbalance between these two rates. This pattern is for example seen on Austfonna and Vatnajökull, in Fig. 4, where positive elevation change are seen in the higher elevation and negative elevation changes in the lower elevations.

17.20: of inter/extrapolated elevations changes.

17.22-17.24: This is outside of the scope of the paper and will be left untouched. In this we have stuck with just one density scheme to be able to determine better the spread of values in the mass balance due to different methods.

17.27: With dynamic signals we mean high variability and not ice dynamics itself. This will be changed as this is confusing, depending on the background of the reader.

17.28: Will be changed accordingly

17.29: Will be changed accordingly

18.1: Changed and the sentence will be rewritten.

18.3: Will be changed accordingly

18.4-18.8: Will be rewritten

18.9: Will be changed accordingly

18.10: Will be changed accordingly

18.12-18.13: Will be changed accordingly

18.19: Will be changed accordingly

18.22: with the variability of elevation change. The spatial variability is of course a factor but the variability due to the climate regime, for areas such as Svalbard and Iceland, would be the most important factor. In either case this statement will be softened and “mostly” will exchanged to “probably “.

19.1: Will be changed accordingly

19.2: Will be changed accordingly

19.2-19.4: Will be rewritten

19.7-19.13: This will be revised accordingly using information about the sampling bias from the elevation-area distribution.

19.19: Yes

Response to: “A couple of more general points”

1. This is of course interesting but outside of the scope of this paper. The main focus of this paper is the study off the effect that different inter/extrapolation scheme have on

the estimation of mass balance. By studying the spread of these estimates one will get insight in how robust the estimate actually are in the absence of good in-situ data.

2. This is something that really needs to be clarified! The word “dynamic” is not used to describe ice dynamics, instead it is used to describe signal variability and signal content in the elevation changes. In hindsight, due to the target audience, a more clear distinction should have been made here, this will also be implemented.

3. We think that using all available years (6 years) is more robust than using individual years only. This due to that our method for estimating elevation change takes into account both the seasonal and spatial variability of the data, see (Sørensen et al, 2011) method M3 for more details. This allows us to separate the two components due to the longer time-series.

4. The Russian Arctic was treated as separate regions for the M3-M4 fitting procedure, as it does not take into account spatial variability. In the case of M1-M2 this is not needed, as the interpolation is made locally. For visualization we present the the Russian Arctic as one histogram to make it easier for the reader to judge the mean and spread of the elevation changes in an overall fashion. Unfortunately there seems to have been typesetting problems in the production of the manuscript for discussion. The layout and sizes will be change in response to this.

Interactive comment on The Cryosphere Discuss., 7, 5889, 2013.