Interactive comment on "Sensitivity of geodetic glacier mass balance estimation to DEM void interpolation" *by* Robert McNabb et al.

Anonymous Referee #3

Received and published: 19 October 2018

In this paper, McNabb et al. investigate the effect of missing data (called "voids" in the article) on the glacier volume change that can be obtained from digital elevation models (DEMs) differencing. The methodology is rather straightforward, they differentiate two DEMs acquired over Southeast Alaska that (almost) cover the entire glacierized area. These data are used as reference data. Then, they artificially generate voids in the data and evaluate the impact of different void-filling/interpolation methods on the on the regional glacier volume change estimate, but also for each individual glacier. They investigate 11 different void-filling/interpolation methods that are often used in the literature, providing a unique and comprehensive assessment. They conclude that most interpolation methods introduce very little bias (<1%) on the regional glacier volume change. However, individual glacier volume change estimates can be severely

affected by the choice of the interpolation strategy.

This paper is rather narrow-focused, but its scope fits very well within The Cryosphere, where it will certainly reach an adequate audience. The topic is timely and very relevant, as the geodetic method is more and more widespread in glaciology. To my opinion, this paper has the potential to become a classic paper in the field of geodetic mass balance. However, and while I appreciate the concision of the paper, I have the feeling that the authors could discuss some aspects more in depth. Moreover, I sometimes had a hard time following the paper and found that it lacks clarity in its current form. These are my two major comments.

Major comments:

1-Volume change vs. geodetic mass balance

The title of the paper mention the sensitivity of "geodetic glacier mass balance", but actually discuss only glacier volume changes. This decision is somehow understandable, because it is the quantity that is directly affected by the void-filling strategy. However, the impact of void-filling strategies on the individual glacier volume change expressed in km3 is not very intuitive, and not as informative as it could be. First of all, the IfSAR DEM was acquired over two years and it would be better to present the annual mean instead of the totals, in order to get rid of this temporal inconsistency. Second, the results are largely dependent on the glacier area considered, larger glaciers being more sensitive to the interpolation (P8L12-13), mostly because for a similar elevation change they have larger volume change, due to their larger area. For example, for figures 7 and 8 (and 5?), I suggest to present the results in kg m^{-2} a^{-1} or in m a^{-1} (if the authors do not want to make any density assumption).

If the authors want their study to be reproduced and the conclusions of this article to be applied elsewhere, they need to analyze the influence of the void-filling strategy more in depth. I feel like the paper misses some basic, yet interesting analysis. For instance, what is the influence of the percentage of voids for individual glaciers? Of the glacier-wide mass balance/mean rate of elevation change? Of the glacier area? The authors probably analyzed these influences already and found that they were limited/not interesting, but I think it is probably worth mentioning them, in order to apply their conclusions to a different setting.

2-Some clarifications needed

The objective of the study is quite straightforward, but a number of confusions and unclear statements prevent from an easy understanding of the paper. I had to go back and forth a number of time reading the paper, and I have the feeling that the clarity of the paper could be much improved if the authors address the three comments below.

First, the author mimic the voids of a standard DEM difference, based on ASTER correlation map patterns. Consequently, I expected that they would investigate the influence of the void-filling strategy for this purpose. However, they also investigate such methods as the "global" ones, which are generally used for regionalization of Lidar surveys. They should make a clear distinction between these two applications when relevant. In other words, I do not think that the "global" methods are relevant for DEM differences void filling at the scale of individual glaciers. Correct me if I'm wrong, but I do not know any paper which studied individual glacier mass balances obtained with such "global" methods to fill in the holes of a DEM difference.

Second, the different methods described are relatively basic, however their description should be clearer. For instance, adding equations to the description of each method would be beneficial. Alternatively, you could share the code you wrote, which would also support your conclusion in which you encourage others to test different methods when dealing with voided data.

Third, I found the example about Taku Glacier extremely confusing. If I understand correctly figure 2, the tongue of Taku Glacier is mostly free of voids. However, the global methods (panels e to g) totally change the pattern of areas where data are available! Consequently, the methods should be described as "Interpolation" and not "Void-filling" (for instance the title of section 3.2 should be changed), because they also apply to areas without voids (and it is technically a non-exact interpolation method). If I did not understand correctly figure 2, you can ignore this comment, but you should consider changing figure 2.

Specific comments:
Fig. 2: confusion between the glacier and voids outlines. You should draw the glacier outlines in a different color/line thickness, such as the panel 3 is easier to understand.

Fig. 5: add a scale/grid on the inset.

Fig. 6: this figure is extremely confusing to me. First of all, I'm missing the location of the voids on panel a, and I had to go back on the previous figures to understand where the voids where. Then the figure shows the strong impact of the void-filling procedure on the tongue of Taku Glacier, but from what I understood of figure 2, there were no voids on the tongue. This comment is in line with my major comment 2.

Fig. 7: I think here the reader loses the information about the difference to truth relative to the total glacier volume change. I guess the larger the volume, the larger the error.

P1L3 and P1L17: I do not fully agree with your definition of the glaciological method, which does not really monitor changes in surface height (that would actually be the geodetic method). The glaciological method directly measures the surface accumulation and melt.

P1L8-9: add a word about the artificially generated voids

P1L11: define ASTER

P2L6: "Digital Elevation Models"-> DEMs

P2L33-P3L6: this paragraph is not really well structured in my opinion. You should describe more clearly the philosophy of your study. I suggest to move completely your warning statement about the radar DEM difference (P3L1-2) to the other place where it is mentioned (P4L19-24). You need to add something about the artificially generated voids and to better justify the choice of ASTER, among a large choice of (optical) sensors.

P3L9-14: what is the glacierized area?

P3L19-20: provide references about studies that used SRTM to estimate geodetic glacier mass balance

P3L29: what proportion of the glacierized are if affected by these "small" voids?

P4L2-6: more references and details are needed in this paragraph. What is the precision of the IfSAR DEM? What is the proportion of voids? Has it been used in other glaciological studies?

P4L5-6: is this sentence useful?

P4L12: can you justify the exclusion of glaciers smaller than 1 km^2 from your analysis? Method section: at some point you need to explain how you calculate the regional estimate. Is it the sum of the individual glaciers, or do you consider all the glaciers as a single body of ice? Do you include the glaciers smaller than 1 km^2 in this estimate?

If not you might bias it.

P5L9: see my major comment 2 -> you might want to rename this paragraph "Interpolation" instead of "Void Filling"

Void-filling section: how do you deal with the temporal inconsistency between your two IfSAR DEMs? I guess for most method you interpolate the rate of elevation change and not the elevation change? This should be written clearly. However, this is not possible for the method based on the interpolation of elevation.

P6L4-6: here the reader wonders why using ASTER voids for regionalization applications (i.e., Lidar based studies)? In order to test the influence of regionalization, one could extract elevation changes in your DEM difference along Lidar flight lines... but this would be another paper!

P7L6: define "normalized glacier elevation"

P7L14: consider switching the order between the sections 4.2 and 4.3.

P7L15-23: this paragraph is rather disconnected from the rest of the analysis.

P7L16: "the pattern of elevation change is negative" -> the phrasing is not clear to me

P7L26-27: the average geometric volume change has probably little influence, contrary to the mean elevation difference.

P8L3-10: can you say a word about the constant methods? And about the 1km neighborhood method?

P8L4: define RMS. This sentence is not completely clear to me.

P8L13-14: the larger glaciers are more sensitive than the others, because they have larger volume change for a similar elevation change, due to their larger area. This is one on the limitations of your analysis, because you look at volume changes only (see my major comment 1). You should consider extending your analysis to glacier mass

balance, or rate of elevation change.

P9L6-8: this paragraph is very short, while Fig. 8 is probably a key figure! Could you elaborate a bit? I found an unbalance with the previous paragraph (P8L30-P9L5), which is less important and much longer than this one.

P9L20: the 1km neighborhood is never mentioned earlier in the section 4.2.

Section 4.3: consider adding a column to Table 1, which summarizes the regional totals for each method. It might also be interesting to discuss the difference between the regional estimates obtained by summing the individual glaciers versus the regional totals obtained by applying each method to the glacierized area considered as a single body of ice.

Section 4.4: why don't you use the percentage of voids of individual glaciers to study the influence of the percentage of voids on the distance to truth?

P10L12: give the total percentage of voids for each threshold.

P10L28: again I got confused because you look at 91 individual glaciers and then you mention the "global mean hypsometric" as one of the best performing method... Please clarify.

P10L31: you can mention in the text that outliers are more often located near the voids, which increases their influence in a linear interpolation.

P11L5-7: the order (regional volume change then individual glacier volume) is the opposite from section 4.2 and 4.3.

P11L25-26: you actually did not demonstrate this in your analysis...

———————————————