Authors response to the comments of referee #2

We thank referee #2 for the thorough and insightful review of the manuscript. The reviewer criticized a lack of 'well-defined objectives' and 'new insights'. Furthermore, the reviewer argues that the methodology and results should be placed in the context of ice shelf observations of Fricker and Padman (2012) and Paolo et al. (2016), that the discussion of error measures should be included, that besides the kinematic GNSS profiles also IceBridge should be included in the validation and finally, that the volume time series should be converted to mass.

We have put much effort in rewriting the respective sections and think that this contributed to a much clearer presentation of the methodology and the results now. The revised 'Results' section starts with some examples for the surface elevation changes (SEC) at some selected locations, then presents the spatial pattern of the results over different time intervals and finally (after a conversion to mass) provides different time series of basin scale mass changes. The objective of this manuscript is to show which points have to be considered when combining the different satellite altimetry missions, to prove that our approach did successfully deal with these points and to give some examples for the application of the results. As stated in the revised 'Introduction', it is not possible to fully exploit the whole potential of this data set in this paper. Nevertheless, we think that after the revision, the objectives are much clearer now and, also by including significantly more quantitative results, it provides several new insights. The reviewer argues that 'most of the patterns have already been described by other authors'. We think that the point that our measurements see similar patterns and effects as previously reported by other authors (with different data and methods) is not a weakness but, instead, proves the reliability of our results.

To provide further evidence for the successful merging of the data sets, we added the IceBridge data as well as a comparison of the anomalies with a firn model. In order to better discuss this work in the context of previous work, we have completely rewritten the introduction, which now also gives an overview over different previously published approaches to multi-mission altimetry processing.

We totally agree that the inclusion of our uncertainty estimates contains very important information. Hence, we added several maps, error bars and (mainly in the supplement) a detailed description how we obtain these uncertainty estimates.

The reviewer mentions two 'assumptions and simplifications', which might influence the result. The first (1) is the impact of unmodeled effects on our time series. We have added Sect. C.1 to the supplement which discusses our choice of parameters and the impact of these choices. This section, furthermore, contains more detailed information about our outlier detection.
The second (2) is the *stable linear trend* criterion when calibrating Seasat and Geosat. We have revised this criterion. We now introduce additional information about the data gaps between the missions using a firn model. We have shown now that after the offset correction, the anomalies differ by 0.26 ± 0.32 m for Seasat and 0.12 ± 0.31 m for Geosat, which agrees very well within the respective uncertainty.

In the following we will respond to the specific comments one by one.

Comment 1: Throughout the paper the reconstructed changes are described as ice sheet elevation changes. However, changes due to vertical crustal deformations (GIA) have been removed from the reconstructed elevation change rates (page 10, lines 32-34). Therefore, it would be more appropriate to call the parameter ice thickness change.
The mentioned section described how the basin scale ice volume change time series (Fig. 7 and 8 in the TCD manuscript) were generated. Earlier results, which we called 'surface elevation changes (SEC)', were not corrected for GIA. We have changed the structure of the results section, which makes it clearer that the GIA correction was only applied to the 'Ice Sheet mass time series'.

Comment 2: Abbreviations should be spelled out when they appear first, e.g., ESA, SARIn.
We have spelled out SARIn. However, the 'The Cryosphere - English guidelines and house standards' say that abbreviation do not need to be defined when they 'are better known than their written-out form (e.g. NASA, GPS, GIS, MODIS).' In our opinion, this applies to ESA as well.

Comment 3: Page 2, lines 15-16: use release numbers instead of "most recent".

As mentioned at the end of this paragraph, all details, including the release numbers, are located in the supplement. We modified this paragraph, so this information appears directly after the data center listing now.

Comment 4: Page 3, lines 10-11: add beam limited, i.e., approximately 20 km "beam limited" footprint;
Done.

Comment 5: lines 14-18: more details are needed to explain on how to find the POCA
Text edited for easier understanding.

Comment 6: line 24: ICE-1 and ICE-2 methods need to be described;
The description of ICE-1 has been modified for more clarity. A reference for ICE-2 has been added

Comment 7: line 25: remarkably higher precision than what?
Edited.

Comment 8: Page 4, line 22: spell out CFI retracker, include reference.
CFI means 'Customer Furnished Item'. However, the written out form is widely unused. Instead, we added a reference.

Comment 9: Pages 6, 7: it would work better to explain first why the planar surface approximations are different for the different missions, followed by the equations.
Done.

Comment 10: Page 7: outlier detection procedure should be explained in detail.
Explained now in detail in the supplement C.2.

Comment 11: Page 9: explain the use and effect of the moving median filter.
Explained now in detail in the supplement C.3.1.

Comment 12: Page 10, lines 2-4: provide more details on the spatiotemporal smoothing, why was it performed and how effective was it?
Explained now in detail in the supplement C.4.

Comment 13: Line 10: explain the definition of "each month observed". Is there a minimum number of observations or spatial coverage?
Explained in C.4 now as well.

Comment 14: Line 15: how are the surface elevation change rates determined? Are these average rates determined by straight line fitting in temporal domain?
This has been explained in detail now in Sect. 5.1.

Comment 15: Page 16, lines 10-12: the error of the trend (slope of the linear fit) is not the standard deviation from the linear fit and can easily be estimated from the data.
We are not sure how the reviewer defines 'standard deviation from the linear fit'. This was the formal error of the trend parameter obtained by the fit. However, in the revised version we changed the way how we calculate trends. Instead of a fit, we now use the differences between epochs. This is discussed in Sect. 5.1. This also applies to the rates from the time series. The respective uncertainty is discussed in Sect. F.2.

Comment 16: Page 18, line 4-6: the long-term trends over Kamb Ice Stream and Totten Glacier have been detected earlier, for example by Zwally et al., 2015.
For this reason, the sentence continued with 'which was already reported by a range of previous publications (e.g. Wingham et al., 2006; Flament and Rémy, 2012; Helm et al., 2014; Zwally et al., 2015).'

Comment 17: Page 18, lines 29-34: it is not clear what this statement refers to: "Around kilometer 600 where the profile bends into the main flowline of Totten Glacier, we see a significantly rising elevation. The profiles at different epochs reveal that this is not a continuous change but that there is a distinct jump in the early 2000s." Maybe a different representation and a more detailed explanation would help.
The whole paragraph has been completely revised.

Comment 18: Table 1: $\sigma_{constant}$ is a misleading parameter name – σ_{flat} or $\sigma_{noslope}$ might be better.
Changed to σ_{noise}.

Comment 19: Figure caption should include the type of retracker used, i.e., 10%-threshold retracker from this study. Better yet, a comparison of the performance of the different retrackers (from Fig. 2, Fig. S2) could be compared in this table.
Table has been modified accordingly.

Comment 20: Figure 1. The southern extents of the different radar altimetry missions are not clearly presented in the left panel.
Figure + caption modified.

Comment 21: Figure 2. ICE-2 retracker is mentioned in this figure caption only, not in text. Needs more explanation.
Done.

Comment 22: Figure 4. Time axis labels should be fixed. Describe vertical axis. Should show the combined time series.
In the submitted pdf, the time axis was complete. This issue occurred when the journal header was added for the Discussion Paper. The comments concerning the vertical axis and the additional final result have been adapted accordingly.

Comment 23: Figure 5. Define the yearly mean surface elevation change.
This is obsolete as the results have been presented in a entirely different way now.

References

Flament, T. and Rémy, F.: Dynamic thinning of Antarctic glaciers from along-track repeat radar altimetry, J. Glac., 58, 830–840, 2012.

Fricker, H. and Padman, L.: Thirty years of elevation change on Antarctic Peninsula ice shelves from multimission satellite radar altimetry, J. Geophys. Res., 117, https://doi.org/10.1029/2011JC007126, 2012.

Helm, V., Humbert, A., and Miller, H.: Elevation and elevation change of Greenland and Antarctica derived from CryoSat-2, The Cryosphere, 8, 1539–1559, https://doi.org/10.5194/tc-8-1539-2014, 2014.

Paolo, F., Fricker, H., and Padman, L.: Constructing improved decadal records of Antarctic ice shelf height change from multiple satellite radar altimeters, Remote Sens. Environ., 177, 192–205, https://doi.org/10.1016/j.rse.2016.01.026, 2016.

Wingham, D., Shepherd, A., Muir, A., and Marshall, G.: Mass balance of the Antarctic ice sheet, Phil. Trans. R. Soc. Lond. A, 364, 1627–1635, https://doi.org/10.1098/rsta.2006.1792, 2006.

Zwally, H., Li, J., Robbins, J., Saba, J., Yi, D., and Brenner, A.: Mass gains of the Antarctic ice sheet exceed losses, J. Glac., 61, 1019–1936, 2015.