Overview

Schröder et al. (2018) use a suite of radar and laser altimetry measurements to calculate the volume and mass change of the Antarctic ice sheet. The paper works to improve our understanding of changes over multi-decadal time-scales that puts in context measurements from other missions, such as the GRACE mass change time series. The work presented by the authors falls within the scope of *The Cryosphere* and could make an interesting contribution to Antarctic volume and mass balance studies. The changes made to the manuscript are substantial and greatly improve the presentation of the results. However, there are a number of issues that should be resolved before I can recommend the publication of this manuscript.

General comments

- Combining laser altimetry estimates with radar altimetry estimates is a non-trivial task (e.g. Fricker and Padman, 2012). Not simply due to the differences in footprint diameter but by potentially measuring different surfaces. The comparisons with NASA Operation IceBridge in West Antarctica and the Peninsula are helpful for this but it was difficult to discern the local discrepancies between the measurements as presented.
- The paper can be still be difficult to follow at times. The manuscript could be reorganized and restructured to not repeat information between sections.
- The data and methods sections could also still be more detailed. Are the GRACE basin time series results simply an available product? If so, it could include a citation for the data repository. If not, should detail the GRACE processing scheme as you start to diagnose specific uncertainties in time-variable gravity measurements.

Line-by-line comments

Abstract This is much improved from the previous versions.

P1, L14–15 I would cite Shepherd et al. (2012) as a reference the time-variability of Antarctic surface elevation change.

P12, L9 Remove “Also” from the start of this sentence.

P2, L18 “Finally, we merge all time series from both radar and laser altimetry”

P2, L22 What do you mean by “three-month temporal averages sampled every month”? A moving average of the elevation data with a three month sliding window?

P2, L24 “independent in-situ and airborne datasets, satellite gravimetry estimates, and regional climate model outputs”.

P2, L25 I wouldn’t use SEC as an acronym here and elsewhere

P2, L26–27 I would phrase it something ilke “The recent elevation changes of Pine Island Glacier in West Antarctica, Totten Glacier in East Antarctica, and Shirase Glacier of Dronning Maud Land in East Antarctica are put in context with the extended time series from radar altimetry”

P2, L30–31 I would remove these two sentences (“While this paper. . . ”).

P3, L3–4 I would place the release numbers of each dataset in the main text.

P3, L8 Should at least include citations for the pre-processing steps used to remove corrupted ICESat returns within this section.

P3, L14–20 Were the ocean and ice modes both used everywhere or was the ocean mode used only in the interior plateau? If different regions were used, a map would be beneficial.

P4, L4–6 Could include detail on the advantages and disadvantages of the “relocation” and “direct” methods. Is the “relocation” method valid over the entire timespan of measurements? The ice sheet has changed surface shape over this time period and a single DEM, particularly one from the latter period of observations, may not be accurate.

P4, L11–12 Is this sentence about optimization necessary? Could simply state the differences from prior work.

P4, L12–13 Will there always be a unique determination of the POCA location with this methodology?

P5, L1–8 This is a good review of the effects of spatial aliasing. However, the penetration of the radar signal into the surface is another bias term that would potentially affect rate estimates. Could add a caveat.

P7, L9–11 At least for laser altimetry, 1km may be too coarse of resolution for the assumption of planar surfaces in coastal regions (Markus et al., 2017). Could include additional higher order surface shape terms.

P9, L1–2 Rewrite to something similar to “Over regions of flat topography, such as the interior of East Antarctica, the weights between PLRA and ICESat are comparable”.

P10, L6 The use of FDM is an interesting approach. I would add the caveat that changes in ice dynamics would not be captured by this metric.

P11, L5–10 Is applying a uniform single bias just forcing the linearity condition to regions where it might not be viable? The distributions of biases in the supplementary material appears to be not random but fairly spatially correlated.

P11, L24 These instruments could be detecting different surfaces beyond the topographic sampling discrepancy.

P12, L1–2 Could possibly use an interpolation scheme with tension or inherent smoothing.

Figure 7 Difficult to discerns the differences from GNSS and Operation IceBridge with these maps. Lots of dots area overlapping. Is the color scale in a) and d) the same as in b) and e)?

P14, L2–3 Could add possible explanations of the difference between the airborne altimetry measurements and the combined estimate.

P14, L4–8 Could expand to note the potential error sources between GNSS and altimetry. This seems like a fairly large amount of variability for East Antarctica. Could potentially use other datasets for validation as well.

P14, L10 Remove “we have to stress that”

P14, L12 I would change it to “publicly available” versus “available to us”.

P14, L15–17 Remove “Before we can compare this model to our SEC results, however, it is important to mention that”

Figure 8 The RMS with the FDM seems surprisingly high.

P16, L3 In terms of spatial resolution?

P17, L15 “rates within uncertainties and very close to zero”

L17, L17–22 The discrepancy with Zwally et al. (2015) is an important finding.

Figure 10 Would the early mission data over the Antarctic Peninsula be at all viable? The Peninsula is particularly difficult to measure with radar altimetry (Shepherd et al., 2012).

P17, L31–P18, L4 This paragraph repeats a lot of information provided previously about individual glaciers. Could be merged.

P17, L 34 Remove "too"

P19, L7 "The surface elevation time series is converted into ice mass changes in order to determine their effect on global sea level."

P19, L7–8 "The elevation time series are corrected for uplift rates related to glacial isostatic adjustment (GIA) using coefficients from the IJ05_R2 model (Ivins et al., 2013)."

P19, L9–10 The elastic effects would likely be much more localized than the outputs from a GIA model, and would be related to the modern-day change rather than the unloading since the LGM.

Figure 11,12 As the area of observation changes with time, would it be more appropriate to calculate the average surface mass density (kg/m^2) change rather than the total mass change of these sectors (i.e. divide the resultant mass by the total area)?

P21, L7–8 "We integrate our measurements over larger regions to calculate the cumulative mass anomalies for individual drainage basins and major Antarctic sectors (AIS, WAIS, EAIS, APIS). Our basin delineations are from Rignot et al. (2011a), which have been updated for the second Ice Sheet Mass Balance Inter-comparison Exercise (IMBIE-2, Shepherd et al., 2018)."

Table 2 Is the area of observation constant for these volume rates?

P22, L7–9 Same GIA model outputs used to correct the GRACE data?

P11, L4 What is the reference period used to calculate SMB anomalies? 1979–2017?

P22, L17 Variations and attribution of Cp-D mass change shown here are supported by Velicogna et al. (2014) and Li et al. (2016).

P22, L18–19 "There is less agreement in regions where surface mass balance change may not be dominant, such as of the Getz and Abbot regions (F-G) in West Antarctica."

P22, L20–21 I'd suggest something like "In some regions, there are also significant discrepancies between the different atlimetry and GRACE data sets. These differences can be due to inadequate sampling by radar altimetry, such as in the northern tip of the Antarctic Peninsula where steep regional topography and small outlet glacier size limits the recovery, leakage in the GRACE estimate between different sectors, and uncertainties in the individual measurements and geophysical corrections."

P22, L34–35 Could add that some of the disagreement with Shepherd et al. (2018) is due to differences in the estimates for the Antarctic Peninsula where retrieving reliable radar altimetry estimates is non-trivial

P23, L17 "better than a centimeter per year in some regions". This wouldn't be expected in some coastal and mountainous regions as you explain in the following sentences.

P24, L8 "Over 25% of the ice sheet, largely in the coastal regions of East Antarctica, the time series can be extended back 40 years."

P24, L8–9 Could reference **?** to indicate that the period of observation for single instruments is short compared to climatic oscillations. Having the extended time series helps separate elevation change due to climate variations, with potential accelerating volume losses.

P24, L13–14 Remove "e.g. at point A in Fig.9c of 0.55±0.50 m with the change modeled using the FDM (0.48 m between 2008 and 2012)". It makes the sentence hard to read.

P25, L8–9 Alternatively it means the altimetry measurements are sensitive to variations in low density material, such as changes in accumulation.

P26, L1–9 This section about radar altimetry in the Peninsula is important as it provides context for the results.

P26, L22–23 “Part of the discrepancy with the GRACE results could be due to uncertainties in the geophysical corrections applied, such as the effects of glacial isostatic adjustment. More work, similar to the Ice Sheet Mass Balance Inter-comparison Exercises, could help identify the key processes leading to the disagreement.”

P26, L27–29 “We showed that the methods used here improved the overall precision by 50% over the standard datasets available from ESA and NASA.”

P26, L29–31 Mention the comparison with airborne altimetry.

P27, L1 “Observations from the Seasat and Geosat missions extend the time series in the coastal regions of East Antarctica back to 1978.”

P27, L13 “might be explained by the density mask used or uncertainties in the GRACE processing”

P27, L16–18 I would use something like “We believe that our multi-mission combination approach can provide an important tool for including and providing context for the ICESat-2 data with observations spanning the past few decades.”

Supplement What is the reference frame of each of these datasets? What ITRF was used for the final combined product?

References

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