

Review: Elevation change of the Antarctic Ice Sheet: 1985 to 2020

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Summary

The authors present an integrated satellite altimetry record for the Antarctic ice sheet for the period 1985 through 2020, combining altimetry measurements from seven missions including Geosat, ERS-1, ERS-2, Envisat, ICESat-1, Cryosat-2 and ICESat-2. The authors develop a series of processing steps to correct for various errors and differences between sensors, including spatial coverage and instrument characteristics.

General Comments

The manuscript is generally well written and the authors have described in extensive detail the methods used to generate the dataset. The suggestions below are mainly related to improving clarity of the manuscript.

Specific Comments

1. **Line 16:** Could the authors briefly mention what is novel about the approach?
2. **Figure 1:** The meaning of the concentric circles and mission labels on the map is not entirely clear from the figure. Please clarify in the text that the circles indicate that there is missing data south of the specified circle for each mission. The meaning of the basins and basin numbers should be mentioned in the caption. Labels of different regions of Antarctica would be helpful for interpreting the text later in the manuscript. Also it would be best to include a small colorbar indicating the velocity scale.
3. **Lines 130-131:** Could the authors briefly mention what the 2 m threshold is applied to?
4. **Lines 139-140:** How does this compare to the LRM resolution?
5. **Line 155:** Please elaborate briefly on how the “relocation method” works.
6. **Lines 156-158:** Bedmap2 would give more recent estimates of surface slope. Could this bias estimates from earlier periods and what might be the magnitude of this error?
7. **Lines 160-168:** It would be useful to have a simple schematic diagram summarizing the processing steps, as they are quite extensive and it is easy to lose sight of the bigger picture.
8. **Lines 176-180:** While the authors stated earlier that this was done separately for each mission and mode, it would be helpful to clarify here as well that (1) is done for each mission separately, and to clarify that the purpose of (1) is to establish a different “correction grid” that is suitable for each mission.
9. **Line 183:** By “center date” do the authors mean the center date of the mission? After establishing the mean topography for ascending and descending orbits separately, do the authors also then remove the mean for

each orbit type within each mission separately? Please provide some additional details for clarity.

10. **Line 185:** Clarify that the “mathematical model” is a model of the surface topography. Also clarify that the differing number of coefficients is allowed to vary spatially.
11. **Lines 192-193:** Clarify that this is done for each mission and mode separately.
12. **Line 195:** Clarify that this selection of the best correction occurs when there are multiple centroids per data point.
13. **Line 205:** I don’t think this point about a linear temporal trend was not mentioned earlier. Can the authors mention this earlier in this section and briefly elaborate?
14. **Line 220:** Can the authors briefly explain why variability in the waveform shape can be used to remove these errors?
15. **Line 231:** Are the standard deviations here the standard deviations for the residuals of the Bs, LeW and TeS terms? If so I think the authors should use “dBs”, etc. for the subscript of σ to be consistent with “dh”.
16. **Line 264-265:** Can the authors provide additional explanation as to which features are related to surface slope and meteorological signals?
17. **Line 288:** Here $n_f = 2$ is specified, but earlier a “four-term” Fourier series is mentioned. Should $n_f = 4$?
18. **Lines 292-293:** How does it work for the 2 km grid cell to have a 1 km search radius in some instances – could some data be ignored in this case?
19. **Lines 292-301:** The 10 MAD correction is mentioned twice in this paragraph. Are these two different steps? Please clarify.
20. **Line 306:** Are Envisat and ICESat somehow combined here, or do the authors mean that a coefficient is created for ERS-2 to Envisat and ERS-2 to ICESat. In general, it is not entirely clear how Envisat and ICESat are combined in the final product. This should be discussed in further detail.
21. **Line 342:** Are these produced after the first calibration step? Please clarify.
22. **Line 343:** Again, how has Envisat been grouped with ICESat?
23. **Line 353:** For someone unfamiliar with these regions, it is difficult to know where they are on the map. Perhaps additional labels can be added to Figure 1, as noted above.
24. **Line 356:** The authors have mentioned the offsets associated with the initial least squares adjustment, but have not provided any discussion of what happens after the final cross-calibration steps, which could be provided briefly here.
25. **Line 368-369:** Suggest revising to read “After removal of the long-term trend, the amplitude normalization was computed for each mission, except for ICESat and CryoSat-2, according to:” so it is clear the formula is for the amplitude normalization.
26. **Line 372:** It appears that a , α_s and α_c are not defined. Please add definitions for these.

27. **Lines 381-386:** This discussion of the figure would be more appropriate in the main text.
28. **Line 395:** Is this the REMA DEM? Please clarify.
29. **Lines 406-407:** Clarify how the local surface roughness is determined. From the REMA DEM?
30. **Lines 426-428:** The description here is a bit confusing. Which model is added back? Is it a surface extrapolated from ERS1/2 and Envisat?
31. **Lines 441-442:** Can the authors add a brief explanation as to why this procedure was appropriate for the analysis in the paper but not for the data product?
32. **Lines 464-479:** I don't believe Table 1, or the description of the computed errors in Table 1, are mentioned in the text. Additionally, is there a column missing from Table 1 which provides the computed "sensor and mode error" for each sensor? How do these calculated errors fit in to the rest of the error analysis? Please clarify and revise the text appropriately.
33. **Line 496:** Mention here that the validation is discussed further in Section 5.
34. **Line 506:** Make clear that "JPL" is referring to the product described in this paper. Also, I would suggest referring to the authors' product as the "ITS_LIVE" product throughout if the authors think that is reasonable.
35. **Line 541:** I believe the reference to Figure 7c should be changed to "Figure 7e".
36. **Line 542:** The reference to Figures 7d-e should be changed to "7f-g".
37. **Line 544:** "Figure 7b" should be changed to "Figure 7c"
38. **Lines 542-545:** Figure 7b (the comparison between JPL and ATM products) is not mentioned in the text. This should also be mentioned here.
39. **Line 545:** I believe "the synthesis" refers to the JPL/ITS_LIVE product, but this is unclear from the text. Please clarify.
40. **Lines 545-548:** Here Figure 7a can be referenced.
41. **Line 555:** Are the bias and error shown in Fig. 7f-g the bias and error for the JPL product? Please clarify.
42. **Lines 568-573:** Could the authors mention briefly which source data were used for the TUD and CPOM products?
43. **Line 599:** Can the authors note the general location of basin 3?
44. **Line 601:** Change "we find for the 1992-2017..." to "we find the following volume change estimates for the 1992-2017..."
45. **Line 607:** I believe "extrapolation" refers to the hypsometric extrapolation. Please clarify.
46. **Lines 607-608:** The statement that the products agree well but are biased low seems contradictory. Please clarify. Also clarify that "low" refers to lower in magnitude.
47. **Line 611:** Again, clarify that "low" refers to lower in magnitude.
48. **Line 642 (Figure 9):** I believe that the upper-right figure should read "JPL: 1992-2016" rather than "FDM: 1992-2016".
49. **Lines 652-660:** Somewhere in here the authors should reference Figures 10 and 11.

50. **Line 659:** Specify the year rang for the “last decade” and the period for “EAIS has reverted back...”.
51. **Lines 667-670:** The trends over the other periods in the EA2 region should be discussed so that the 1985-1989 period can be understood in context.
52. **Lines 682 and 683:** Both Figures 10 and 11 could be referred to here, as it helps to look at these figures when interpreting the text below.
53. **Line 690:** Figure 11 could also be referred to here.
54. **Line 701:** The “earlier timing” is not apparent from the figure, but it is clear that there is a large increase in precipitation during 2006. Please clarify.
55. **Lines 704-706:** Figure 10 could be referred to here.
56. **Lines 717-718:** The strong negative trend for WAIS over the full timeseries should be mentioned here.
57. **Line 732:** Are the authors referring to improvements over previous work? Please clarify.
58. **Line 772:** It is not entirely clear what is done in Figure 12. Is there a processing step additional to what was discussed in the methods section? Please clarify.
59. **Line 791:** What method is being referred to here. Does the correction discussed in the methods section bias the amplitude in the interior of the ice sheet, or is this what would happen if ICESat-2 were to be used?
60. **Line 811:** Should this read “south of 81.5°S” rather than “north”?
61. **Line 815:** What is the bias referred to here relative to?
62. **Line 845:** Could the closer agreement with laser-altimetry validation data be affected by the inclusion of the laser-altimetry data in the development of the ITS_LIVE dataset?
63. **Lines 852-853:** But the authors do mention above this point that there can be errors in the altimetry data in this region. Could this affect the comparison with the firn densification models. Please clarify.
64. **Line 877:** Suggest adding “Our dataset indicates that...” before the beginning of this sentence.

Technical Corrections

1. **Line 9:** Change “losses” to “loses”.
2. **Line 11:** Change “sea levels rise” to “sea level rise”
3. **Line 53:** Change “inter mission” to “inter-mission”
4. **Line 100:** I believe these are two different flags. If so, then revised to read “quality flags” and “were used”. Also, is it “chirp” rather than “chip”?
5. **Line 123:** Change “that uses 532 nm laser” to “that uses a 532 nm laser”.
6. **Line 125:** Change “arrange” to “arranged”
7. **Lines 170-190:** To improve readability I would suggest creating a new paragraph for each correction (1,2, and 3), or add italics in the text, e.g. “*Issue (1):* To account for differences in orbital geometry when applying the correction...”
8. **Line 259:** Figure 5 is mentioned before Figure 4. Suggest switching the two.

9. **Line 267 (Figure 3):** Change “CS-2 LRM” and “CS-2 SIN” to “Cryosat-2 LRM” and “Cryosat-2 SarIn” for clarity.
10. **Line 281:** Correct “Bevis etl al.”
11. **Line 436:** Suggest revising to “To estimate volume changes at the basin scale (Figure 1)” so that it is clear that “Figure 1” provides the basin outlines and not the volume changes.
12. **Line 450:** I believe Fig. 6 should be referred to here, rather than Fig. 2.
13. **Line 565:** Change “where ICESat-2 shows” to “with ICESat-2 showing”.
14. **Line 584:** Change “(as CPOM only provides rates in five-year intervals of all products...” to “(as CPOM only provides rates in five-year intervals) for all products”
15. **Line 599:** Change to read “Larger differences between JPL and CPOM compared to JPL versus TUD...”
16. **Lines 603-604:** Change to read “The regional estimates agree well among products, with the largest discrepancies found in the Antarctic Peninsula.”
17. **Line 621:** Change “average surface temperature, 10 m windspeed...” to “average surface temperature, and 10 m windspeed...”.
18. **Line 635:** Change “-25 km³ a¹” to “-25 km³ a⁻¹”.
19. **Lines 649-650:** Change “East Antarctic Ice Sheet (...) that experienced” to “East Antarctic Ice Sheet (...), which experienced”
20. **Lines 651:** Change “measure elevation change is” to “measure elevation change of is”.
21. **Line 666:** Change “the precipitation event” to “a precipitation event”.
22. **Line 672:** Change “panning1985 to 2020” to “spanning 1985 to 2020”.
23. **Line 688:** Change “Basin 18, that contains...” to “Basin 18, which contains...”
24. **Line 719:** Change “landfalls” to “landfall”.
25. **Line 743:** Change “importance of this correction that can” to “importance of this correction, which can”
26. **Line 756:** Change “that large ice sheet wide changes occur” to “the large ice sheet-wide changes that occur”
27. **Line 769:** Change “long-time separation” to “long time separation”.
28. **Line 777:** Change “applied to the data align” to “applied to the data to align”.
29. **Line 792:** Change “than than” to “than that”
30. **Line 796:** Change the comma after “maximum orbital coverage” to a semicolon.
31. **Line 827:** Change “contribution significantly” to “contribute significantly”.
32. **Line 830:** Change “overall uncertainty estimates” to “overall uncertainty estimate”.
33. **Line 831:** Change “ice sheet but rapidly increase closer” to “ice sheet, which rapidly increases closer”.
34. **Line 841:** Change “with difference within” to “with differences within”
35. **Line 848:** Change “across mission” to “across missions”.
36. **Line 866:** Change “captoolkit - Cryosphere Altimetry Processing Toolkit” to “Cryosphere Altimetry Processing Toolkit (captoolkit)”.