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Interactive comment on "Validation of satellite altimetry by kinematic GNSS in central East Antarctica" *by* Ludwig Schröder et al.

Anonymous Referee #3

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This work validates the heights measured by multi-mission satellite-based radar and laser altimeter instruments (Envisat, ICESat and CryoSat-2) spanning 2002-present over a large region (from 65 E to 120 E) of the East Antarctic Ice Sheet (EAIS). This region is important for whole ice sheet mass balance studies, because results have differed dramatically depending on the corrections applied to the data. It is useful, therefore, to validate these measurements using ground observations (GNSS) over the same region. This paper is the first to present ground measurements over this important region and compare them to satellite altimeter measurements. However, there are some significant shortcomings with the way the results are presented, and the manuscript can use tighter writing.

There are major issues with the paper, and I recommend this paper for publication only

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Discussion paper

after these issues are addressed:

1. **Presentation**: A major component of this paper is the derivation of inter-campaign biases in the ICESat data. The authors present a series of histograms showing the residuals between the ICESat-derived heights and those derived by kinematic GNSS in Figure 7b. It would be useful to also have a third panel in the figure showing residuals between ICESat and kinematic GNSS prior to the inter-campaign bias correction, so the reader can see the effect of the correction in improving the height residuals.

   Figure 7a needs to be presented with error bars.

   All histograms shown in this paper should be presented with the number of measurements that go into it (this could be added to all the legends along with the mean and standard deviations).

2. **Stability of reference surface**: There can be issues with height changes in the reference surface between the time of acquisition of the GNSS data and the time of the altimetry-derived height measurement (i.e. the reference surface is not always stable). Toward this, the authors should include a time series of GNSS data over Lake Vostok to demonstrate the variability in the observed height over the reference surface and provide statistics on the time difference between GNSS and altimetry datasets at crossovers.

3. **Precision of GNSS estimates**: The mean baseline differences presented here are only one potential source of error in the GNSS estimate. In this paper, however, there is no mention of the precision of GPS measurements. To estimate

this, the authors could look at GPS data collected by a tractor/trailer in a single place for an extended period (~hours) and present the noise in the determined height (see Borsa et al, 2007 *Modeling long-period noise in kinematic GPS applications*). This is important if the authors include Table 3 in the final version, since this can be a major source of uncertainty. If this cannot be included, the authors should add a note about this in the discussion.

4. **Residuals through time**: The authors show residuals through time between ICESat and GNSS (Figure 7a). It is not clear if the trend in the residuals is unique to the ICESat period. Since the authors already have the data for Envisat and CryoSat-2, I suggest that the authors also plot residuals between each those missions and the GNSS, with time on the x-axis. One way of doing this would be to bin the GNSS-altimeter residuals into yearly (or other) intervals and plot them over the whole time period.

   Furthermore, there is an offset (5 cm) in the residuals between ICESat and GNSS. Through the caption over Table 3, the authors imply that the ICESat elevations need to be corrected for that offset. However, there is no evidence that ICESat-derived heights are biased by 5 cm (this would be a major finding if this is real), and this is likely a bias in GNSS-derived heights. The authors need to discuss potential causes of this discrepancy.

5. **DEM analysis**: The section on DEM validation detracts from the major substance of the paper, i.e., validation of L2 heights derived using various altimeters. The comparison of the ICESat and CryoSat-2 DEM's could be useful in terms of the assessment of their accuracies, but I suggest the authors consider removing the comparisons with the Bamber-DEM and the Bedmap2-DEM.

6. **Crossover analysis**: Section 3.2.1 (Paragraph 4) This paragraph mentions that the crossover method is outlined in Section 2.4, but there is no mention of

how altimeter-GNSS crossovers are defined (which is a major aspect of the manuscript). Does the altimeter footprint need to overlap with the GNSS track, or are the authors interpolating the altimeter track crossing the GNSS traverse to obtain a measurement on the traverse? A further technique one could use would be to fit a line to a few altimeter measurements in the along track direction around the crossover point - the prediction of the line fit at the crossover location would be the altimeter-derived height. The technique the authors use should be discussed and justified.

As the manuscript needs extensive edits to enhance clarity, I have included a non-exhuastive list of minor comments below:

1. Section 3.1.3 - Include reference for the saturation correction.
2. Section 3.2.1 (Paragraph 3) This whole paragraph is confusing, with no citations or anything of substance. Maybe the entire paragraph can be rephrased as *"some studies that used GNSS data for satellite altimeter calibration/validation use a 2-D gridded reference DEM (cite studies), but we do not adopt this here due to observational limitations"*. If not, this paragraph can be deleted, since it does not add too much to the discussion.
3. Section 3.2.1 (Paragraph 4) I think the along track sampling is around 290 m for CryoSat-2. Check (Wingham 2006) or the CryoSat-2 product handbook for details.
4. Section 3.2.2 (Paragraph 1) Consider replacing *"Between the campaigns systematic biases exist. If not corrected carefully, these biases corrupt the inference of temporal surface-elevation changes and estimates of height change"* with *"If not accounted for carefully, any systematic biases between campaigns can corrupt the inference of temporal surface-elevation changes and estimates of height change"*.

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5. Section 3.2.2 (Last Sentence) Provide reference for or justify using this value (10 cm).

6. Section 3.3.1 (Paragraph 2) Replace *"For the GSFC product those errors are even significantly larger."* with *"For the GSFC product those errors are significantly larger."*

7. The conventions used are inconsistent (CryoSat vs. CryoSat-2 vs. Cryosat-2; SARIn mode vs. SARIn Mode vs. SARIN; 18.000 vs 18,000.

8. There is no punctuation in the caption for Figure 1.

9. Units are inconsistent (sometimes m sometimes cm).

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