

The authors present ground-based GPS data from a series of traverses on the East Antarctic Ice Sheet, in an attempt to: a) assess the errors associated with satellite-based altimetry data (Envisat, ICESat, CryoSat-2); b) provide a set of ICESat intercampaign biases; and c) make assessments of various DEMs from satellite-based data.

**General Comments:**

In general, I am fine with the authors' a) assessment the errors associated with satellite-based altimetry data. With one caveat: the authors state the accuracy of the traverse-based GPS data by comparing the DGPS results of the various baselines, which is an assessment of the spread of the result, or the repeatability of the measurement, or the PRECISION; but not the accuracy. The wording here must be changed, but this edit should not have a significant impact on this particular result.

However, I have significant reservations associated with b) providing a set of ICESat intercampaign biases and c) making assessments of various DEMs from satellite-based data.

***ICESat intercampaign biases:***

I am very concerned about the presentation of these ICESat intercampaign biases, which are a tricky thing to determine. My concern lies here:

- 1) the intercampaign biases presented here (Table 3) are determined based on kinematic, traverse-based GPS data, which generally has decimeter-scale accuracy;
- 2) the GPS traverse data are processed via DGPS methods, using 5 different base-station sites (Vostok, Mirny, Progress, Casey, and Davis), with baselines that can exceed 800 km, and therefore, I question the accuracy of these DGPS results, especially when considering that the troposphere (and ionospheric) corrections have to span that spatial scale;
- 3) the authors claim to assess the accuracy of the traverse data by comparing the DGPS results of the various baselines; while comparing various baselines is a good strategy for beating down the noise in the solution, this strategy represents an assessment of the spread of the result, or the PRECISION, not the accuracy, thus, the authors have no assessment of accuracy, or ground 'truth';
- 4) to develop intercampaign biases, you have to make an assessment of ICESat vs 'truth', and given the comments I have made about accuracy/precision, I do not believe that the authors have done this adequately;
- 5) to develop intercampaign biases, you also need to do this using relatively coincident (with respect to time) data, or you have to show that the surface is not changing; from Figure 2a, the surface being used as ground 'truth' (which is a substantial percentage of the East Antarctic Ice Sheet) is changing at decimeter scales, yet the authors obtain cm-level bias corrections. Given that they are using GPS data from a changing surface, with a gap in time associated with the first half of the ICESat campaign (2003 – 2006), I again do not believe that the authors have adequately defended their set of intercampaign biases.

Therefore, overall, this method does not represent the rigorous attention to detail needed to determine cm-level intercampaign biases. Yet casual users of ICESat data will take Table 3 as 'truth'.

### **DEM assessments:**

A DEM represents a snapshot of the ice surface at some specific time. The DEMS that the authors are assessing are from about 2006 and 2009, while the validation data (from the traverses) generally spans the subsequent 6 to 8 years (Table 1). The result they find is that near the coast, where the surface is steeper, the DEM elevations deviate from the GPS data. However, steep-slope areas around the coast of Antarctica are also where the ice sheet is changing the most (Pritchard, et al 2009); their result is probably at least partially associated with real surface change. The DEM comparison, in my mind, is pointless.

I suggest that the authors remove the intercampaign bias and DEM assessment sections of this manuscript.

### **Specific Comments:**

- line numbers are needed.
- abstract lists accuracy of in situ data, but not precision. What is accuracy based on?
- “A crossover analysis with three different Envisat...” this sentence is so specific and doesn’t allow the abstract to stand-alone. Consider edit.
- Baseline B, to the best of my knowledge, is no longer available, thus, these results are not reproducible.
- give example(s) for ‘systematic effects’
- “One crucial step in the processing of surface elevations from satellite radar altimetry... is the slope correction”: this is not unique to radar; this was a big problem for ICESat, which had smaller, 70-m footprints. I believe what the authors are getting at is the large error in the radar. But this error is not negligible in the laser altimetry, when significant mass change in east Antarctica is associated with cm-level surface change. An edit is needed here.
- Author needs to verify proper mission naming conventions throughout (e.g., CryoSat-2, NOT Cryosat-2; Ice, Cloud, and land Elevation Satellite, NOT Ice Cloud and Land Elevation Satellite)
- “...[ICESat] mission these effects do not arise...” be more specific here. The slope issue does arise in steeper terrain. I believe you mean volume scattering, which is NOT necessarily mitigated by the use of laser altimetry (as opposed to radar altimetry); certain wavelengths of light could potentially volume scatter.
- write out GPS and GLONASS here in the last paragraph of the Intro. You write them out in section 2.2, but THIS is the first instance...

- "This set of surface-elevation profiles..." Processed? Raw data?
- "The profiles acquired on snowmobiles provide accuracies of only a few centimeters..." Based on what? Are you comparing the snowmobile data to the static site?
- "...and are thus well suited for precise studies on local elevation and elevation changes..." Only if their precision (again, compared to what) is also small/good. Given that you don't use these data, I'm inclined to tell you to remove this text (and the accuracy text).
- regional peculiarities: like what? Slope? Surface compaction? What else?
- Figure 1: a colorbar is not useful for capturing the date detail. Make a legend or label them in the figure.
- Processing: 800 km baselines are long. Did you try looking at PPP solutions? Kohler et al 2013 used PPP specifically for this reason. You could use the DGPS method when close to the stations and compare your results.
- IGS08: is this appropriate for comparison with both ICESat and CryoSat-2? What frame are those data in?
- Perhaps Table 1 could capture which kinematic traverses that included GLONASS
- "Therefore, in this case we used the Melbourne-Wübbena and the Quasi-Ionosphere-Free Linear Combination only" this needs more description or references
- The last part of this paragraph needs more elaboration/clarity. This is important, given my previous statement about PPP. Your troposphere and ionosphere corrections won't hold up over these length scales. So what does this technique (with which I am not familiar) do to address this critical issue?
- "Altimetric elevations, in contrast, refer to the "mean tide" system..." I believe that ICESat has tide-free (WGS-84/ITRF) height as well as TPX 'mean-tide' heights. If so, this statement is not entirely accurate. How does your conversion compare to what's on the ICESat data product?
- "A more realistic measure is found by comparing multiple baseline solutions." What about comparing to PPP solutions?
- Further, comparing GPS solutions from multiple baselines does not compare these GPS data to 'truth'. Without 'truth', you cannot get at an overall bias/accuracy assessment of your GPS data. Instead, your RMS\_BL informs you about the reproducibility, or spread, of the results; this is the precision of the solution, not the accuracy/bias, which is the difference between the measurement and truth. RMS\_BL may be a meaningful error assessment, but not as described.

- Same of RMS\_S
- Same for RMS\_X. These are all spreads of the data.
- For RMS\_X, a useful value would be the number of crossovers per traverse. How large is the dataset 'N'?
- "While crossover differences within one expedition are used for accuracy estimates, the elevation differences in crossovers between profiles of different years allow to assess temporal rates of surface elevation changes ( $h_{dot}$ )."  
The first part of this statement is not accurate: again, RMS\_X is an assessment of precision, not accuracy. The second part of this statement is true, as a differential assessment ( $h_{dot}$ ) does not require absolute 'truth'.
- "are found on the traverse to Mirny. In the lower parts..." lower = elevation?
- "Our profiles shall be used nevertheless for the validation of SRA, which is..." You will be comparing this to ICESat as well, yes? Then perhaps SRA is not the best term to use. Perhaps 'SA'?
- From section 2.4 to section 3, these are really results. And then other datasets are introduced in section 3... It might be good to reorganize the paper a bit to have all of the data introduced early (then perhaps questions associated with, e.g., IGS/WGS84 are answered immediately).
- "Above steeper terrain, the altimeter is switched to SARIn Mode..." 'Above'?
- Fricker et al., 2005, Shuman et al., 2006, Kohler et al., 2013, Siegfried et al., 2011 should all be cited in the ICESat accuracy assessment section. Most of these were 'on-ice' or 'ice-like' surface assessments. Schutz et al, 2005 is an ICESat overview paper, not an assessment based on in situ data.
- "Our validation approach is the following: We assess how accurately the altimetry data reflects the actual surface elevation at the nominal positions of the altimetry data."  
This assumes that the in situ data are 'truth' and error-free, which is probably never the case. It's reasonable to make that assumption, it just has to be stated, with the caveats.
- "On the other hand, in this zone typically the largest elevation can be expected" this is not clear to me.
- "ICESat surface elevations are less sensitive..." 'Relatively' less sensitive. This is still an issue. For cm-level surface change, the effect of slope on ICESat data is still significant, especially in your 'zone 1'.
- "Including the unbiased GNSS profiles..." The authors are trying to present a new set of ICESat intercampaign biases. The community may cite these widely. My concern is that the

authors haven't truly provided and accuracy to their kinematic data (they instead provide precision). I am strongly against presenting a new set of bias corrections this way. See my comments above.

- "For the ICESat elevations, in contrast, we assume a homogeneous accuracy and adopt a standard deviation of 10 cm..." also not a good idea. The spread (standard deviation) of ICESat data increased (got worse) with extended laser life. It was not static.

- Figure 4: "4 ... 9" must mean 4 – 9?

- Table 2: Are statistics with an 'N' of 2 (or 3 or 6) really meaningful? I know you acknowledge this in the text, but it jumps out at you in the table.

- Fig 5: What are the 'N's associated with each assessment?

- Prior to the validation of ICESat elevation data, we first determine the ICESat laser campaign biases as described in Sect. 3.2.2." Again, I express my concern on how this is being presented, given that a more rigorous accuracy assessment needs to be made for the ground-based data. Note that for many of the other assessments of the intercampaign bias, the timing of the in situ data and the ICESat data was taken into consideration (e.g., Fricker et al., 2005, Borsa et al., 2014, Siegfried et al., 2011). These GPS data have very little overlap with ICESat overpasses.

- "...not surprising that our biases are very similar to the set presented by Richter et al. (2014) for R33 including the Gaussian-Centroid (G-C) correction" What does this mean? Did you remove the G-C correction from the R33 data to make the comparison?

- "we perform an absolute calibration..." I don't believe this to be true, given what I have said about the RMS method of determining 'accuracy'.

- Fig 7b: what are the 'N's? Also, right-most panel shows that slope has an impact on ICESat (comments above)

- Section 4: Why are we validating the 2007 and 2009 DEMs (which are snapshots of the ice surface at some specific time) with these GPS datasets, which generally (from Table 1) span the subsequent 6 to 8 years? This is not meaningful.

- "However, with increasing slope the standard deviation of this DEM grows..." High slope areas around the coast of Antarctica are also where the ice sheet is changing the most (Pritchard, et al 2009). Thus, some of these differences are probably associated with real surface change. I ask again why are the authors validating a 2007 and 2009 DEMs with these GPS datasets, which generally span the subsequent 6 to 8 years?

- "The comparison of the CryoSat-DEM with the ICESat-based models proves that SRA with advanced instrument design provides excellent elevation information over all zones" Note that the traverses are more coincident with the CS-2 time period. Again, this comparison is

pointless.

- "We resolved the challenges of the GNSS processing, such as the very long baselines and ..."  
"I do not think that you have characterized the accuracy, therefore, I do not feel that this statement is valid.