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The Cryosphere
Discussions

Interactive comment on "Assessment of ICESat-2 ice surface elevations over the CHINARE route, East Antarctica, based on coordinated multi-sensor observations" *by* Rongxing Li et al.

Anonymous Referee #2

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This manuscript presents the results of a validation of ICESat-2 laser altimetry by kinematic GNSS in East Antarctica. The results of this validation highlight the high quality of both datasets, the satellite data but also the in situ validation data. Together with the validation along the 88°S traverse by Brunt et al., these results provide important insights into the characteristics of the ICESat-2 mission.

The manuscript is well written, the applied methods are appropriate and the results are nicely illustrated. Alone in the structure of the manuscript I would suggest a few changes. It is sometimes difficult to follow a specific method as each section jumps from one dataset to the others. The "Data" section briefly describes the ICESat-2 data

and all the measurements performed during the campaign. Then under "Methods" you describe in detail the GNSS-processing, the height reduction from the antenna to the snow surface, the ICESat-GNSS comparison and the validation with the other measurements. I would suggest to make separate subsections for GNSS, the CCRs, the RTSs and the UAV-DEM and ICESat-2 under "Data" and describe all the details in obtaining the each of these datasets there. Therefore, you could simply move the respective paragraphs from Methods to Data. Then, the "Methods" section could concentrate on the details of the validation between each dataset and ICESat-2.

This little change in the structure would also allow to avoid confusion between the different types of GNSS-processing (which are otherwise easy to be mixed up). If I understand you right, you have 2 types of GNSS observations: a) the GNSS-base stations with permanent observations for ~3 days (more at Zhongshan) and b) GNSS-rovers on the PistenBullys, the CCR stakes and for the ground control points of the RTS and the UAV-DEM. For the processing of the base stations (a) you use PPP. The coordinates of the rovers (b) then are obtained as differential kinematic coordinates with respect to these base stations. These coordinates are obtained in post processing (if I understand it right), so I wouldn't call that real-time kinematic (RTK). I have several remarks to that GNSS-processing:

1. Similar studies used reference stations at the coast (Schröder et al. 2017, doi: 10.5194/tc-11-1111-2017) or directly processed the rover GNSS-data using PPP (Kohler et al. 2013, doi: 10.1109/TGRS.2012.2207963 or Brunt et al. 2019, doi: 10.5194/tc-13-579-2019). Your processing software (RTKLIB) seems to support these types processing modes. Did you try to process your rovers this way? This would overcome the limited availability of your base station data and even provide useful results for your GNSS-measurements near Taishan.

2. It is quite usual that internal accuracy values reported by the GNSS-software are way to optimistic. You results for internal crossovers in your GNSS-profiles demonstrate that nicely. However, in the vertical GNSS accuracy at the CCR of the ground control points,

you simply state values of ∼0.3-0.4 cm without any information about their origin. Is that the accuracy reported by the software? For how long was each point observed? This accuracy is remarkably high for a short observation. Do you have any evidence, that this value is realistic?

3. (this comment refers to l.240) I appreciate that you checked the accuracy of the GNSS-profiles using crossover differences at intersections. However, I would suggest a few more analyses:

- If I understand you correctly, you separate your total profile into shorter sections according to the distance to the base stations and post-process each section with this base station as reference. It would be very interesting to have some overlap in the processing of these the sections. Hence, at the transition from one section to the next one, you could process some measurements with both base station and compare the results.

- Moreover, referring to l.139 you have two antennas. Are they installed on the same PistenBully? If yes, are there any systematic offsets between them and what is the noise? If no, did you check crossovers between the two PistenBullys?

Besides these major point and remarks, I have following detailed comments:

l.21: "...which is important for overcoming the uncertainties in the estimation of mass balance in East Antarctica" is a very general statement. The most important topics in East Antarctic mass balance are probably eliminating mission biases and the conversion from volume to mass. This validation contributes only to the first point.

l.30: remove "As"

l.55-74: I suggest to add brief motivations for each of the methods of validation (kinematic profiles, CCRs, RTSs, UAVs). It would be useful for the reader to know the benefit of each of the methods from the very beginning of the paper.

l.64: Later you describe that you obtain your coordinates in post-processing. So the

survey is not real-time kinematic (RTK). This totally makes sense (as post-processing is much more precise) but please be also precise in describing your method.

Fig.1: In this context, no measurements have been conducted at Great Wall Station. It is fair to mention the original plans in the text but I suggest to remove the inset from Fig.1.

l.95: How is this accuracy obtained? You describe the GNSS-processing and the validation methods later, so such accuracy measures should appear later, when the reader knows how they were obtained. Furthermore, is this really RTK (see comment on l.64)?

l.100: See comments on l.95

l.113: Start a new sentence after "532 nm".

l.134ff: What is the reference frame and the ellipsoid for the GNSS coordinates and the ICESat data? And how about the permanent tide? Many altimetry measurements refer to the Topex ellipsoid and are in the 'mean tide' system while GNSS data generally refer to WGS84 and are 'tide-free'. Please give some details here to show that the different data are comparable.

l.139: Were both antennas mounted on the roof of the same PistenBully?

l.179: The description of the interpolation of h2 fits much better in section 3.1.2.

l.210: I would have expect that the CCR looks like a unique point reflector. Why does it show up as a curve with slightly lower elevations on the sides?

l.226: How was this accuracy obtained? From l.230, I guess that the accuracy of the UAV-DEM is just several meters and you need several ground control points for a more precise absolute orientation. Is this correct? Could you explain this a bit more detailed (or give some references)?

l.264: With regard to the variation between the different ground tracks, the lack of GT2-

results for ATL03 (due to the very strict exclusion conditions) and the precision of ∼9 cm I would be careful concluding that the ATL06 bias is smaller than the ATL03 bias. I don't think that the differences are significant.

l.266ff: You state that the standard deviation of the h2 measurements is ∼3cm and this variation is mainly attributed to the microtopography and firn density changes. However, the effect of microtopography will apply immediately when you move a few meters. Systematic variations in density should be largely accounted for by the IDW interpolation. So in my opinion, these effects alone cannot be responsible for these larger differences when using the full profile. Using only data in a 2km vicinity of the h2 measurements reduces the usable crossovers dramatically. So, before reducing the amount of data so drastically, I suggest to do a few more analysis on these larger difference. Did you do any outlier checks before calculating these standard deviations? A few outliers can have a large effect on stddev. Or is there a specific spatial pattern (maybe in the region around 71°S, which is the largest gap between h2-measurements)?

l.282 Without a precise GNSS-elevation of the CCR, you are comparing ICESat-2 measurements to ICESat-2 measurements of the same orbit. So, all you can do is comparing the offset between photons from the ground and from the CCR to the measured stake height. I would suggest to do this using the ATL03 data only as you cannot be sure, which photons contributed to the mean ATL06 data point.

l.333 As discussed on l.264, I don't believe that the difference in the offset between ALT03 and ATL06 is significant.

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