We thank all three reviewers for their constructive comments and suggestions. This manuscript will be much improved by their input. We have made changes to our manuscript. In the following responses, we use "**bold**" text for reviewer's comments, "non-bold" text for our responses, and "*italic*" for changed text in the manuscript.

Referee #3

1 Overview

Li et al. (2020) deliver results from an Antarctic campaign designed to assess elevation measurements from NASA's Ice Cloud and land Elevation Satellite-2 (ICESat-2). For the most part, this was a well-designed and well-thought-out experiment for evaluating the ICESat-2 data. The work presented by the authors falls within the scope of The Cryosphere and could make a good contribution for ICESat-2 calibration and validation (cal/val). Overall, while this is a well-written manuscript, there are a few issues that should be resolved before its publication.

Thanks. The following is our responses. Changes are made accordingly in the manuscript.

2 Broad comments

- **The cal/val data from the CHINARE campaign needs to be publicly accessible to be of use in the ICESat-2 project science office and the scientific community**

The data set is now uploaded to a publicly accessible site Dryad at https://datadryad.org/stash/share/mU52z7OSWAG07tTsGCWXt0Rm0MmT12qwdPORBIUpsnw. They include a) traverse validation data (GNSS data of traverse crossovers, GNSS – ICESat-2 crossovers and ice surface heights), b) CCR and RTS validation data (GNSS CCR positions and GNSS RTS check points), and c) DEM data (DEM and check points).

- **There are other supporting and cal/val efforts that should be mentioned in the text (e.g. NASA Operation IceBridge, Greenland Summit Station (Brunt et al., 2017), salar de Uyuni (Borsa et al., 2019), and the updated Antarctic pole hole campaign (Brunt et al., 2021)**

The suggested work and references are now added to **Introduction**: "*……A comprehensive validation of the surface elevations of the previous ICESat mission using ground GNSS observations was performed on the salar de Uyuni in Bolivia, which also estimated the inter-campaign biases occurred between different campaigns during the mission (Borsa et al., 2019). Prior to ICESat-2 launch, calibration and validation experiments were conducted on both the Greenland and Antarctic ice sheets (Brunt et al., 2017 and 2019b; Magruder and Brunt, 2018). The annual Antarctic campaigns traverse a 300 km stretch of the interior of Antarctica near 88ºS covering 20% of the ICESat-2 reference ground tracks (RGTs) (Brunt et al., 2019b and 2021)……The achieved geolocation accuracy ranges from 2.5 m for laser spot 6 to 4.4 m for laser spot 2 (Luthcke et al., 2021)……*".

- **The L/R designations of the ICESat-2 beams do not correspond with weak/strong full time as it depends on the orientation of the spacecraft. Might also help to include statistics on laser spots (1–6) to help determine any drift or biases in a given beam.**

We discussed this issue and added the correspondence between "left and right" and "laser spot" IDs in the Method section: "*……The left and right correspondence in Fig. 5a may change as the spacecraft changes its orientation. They are also referred to as reference ground tracks (RGTs) with laser spot IDs (1, 2…, 6) corresponding to six beams which are independent of spacecraft orientation. During our study period, the correspondence is (Laser spot 1: 3R), (Laser spot: 3L), (Laser spot 3: 2R), (Laser spot 4: 2L), (Laser spot 5: 1R), and (Laser spot 6: 1L) (Neumann et al., 2019)……*"

The laser spot IDs are also added into Table 2 (also Table B1).

Ground track (Laser spot ID)	**ATL06** **Bias ± Precision (cm)**	**ATL03** **Bias ± Precision (cm)**
GT1L (Laser spot 6)	+2.7 ± 9.6 (N = 64)	+5.9 ± 5.9 (N = 1518)
GT1R (Laser spot 5)	+3.0 ± 7.3 (N = 62)	+1.7 ± 6.7 (N = 2608)
GT2L (Laser spot 4)	+0.7 ± 7.9 (N = 48)	-0.5 ± 6.7 (N = 862)
GT2R (Laser spot 3)	- 2.3 ± 12.0 (N = 42)	+5.8 ± 14.0 (N = 1356)
GT3L (Laser spot 2)	+1.3 ± 8.4 (N = 33)	+4.2 ± 7.7 (N = 800)
GT3R (Laser spot 1)	- 0.7 ± 8.7 (N = 36)	+4.6 ± 10.9 (N = 2695)
ALL	+1.5 ± 9.1 (N = 285)	+4.3 ± 8.5 (N = 9839)

We do not see any apparent drift or biases in a given beam.

- **While ICESat-2 will presumably help improve mass balance and sea level determination efforts with satellite altimetry, these are not in the mission requirements as they require modeling efforts**

We considered your comment here (as well as other two reviewers' comments) and lowered the significance of the results in **Introduction**: "*…… The validation results demonstrate that the estimated ICESat-2 elevations are accurate to 1.5–2.5 cm in this East Antarctic region, which shows the potential of the data products for eliminating mission biases by overcoming the uncertainties in the estimation of mass balance in East Antarctica……*"

- **Links included in the text should have labels for when the website was last date accessed. Some of these links can also be simplified by removing optional URL parameters.**

We added access dates and removing optional URL parameters.

3 Line-by-line comments

Page 1, Lines 9–10: should probably be something like "We present the results of an assessment of ice surface elevation measurements from NASA's Ice Cloud and land Elevation Satellite-2 (ICESat-2) along the CHINARE (CHINese Antarctic Research Expedition) route near the Amery Ice Shelf

in East Antarctica."

We have replaced the sentence with the suggested one "*We present the results of an assessment of ice surface elevation measurements from NASA's Ice Cloud and land Elevation Satellite-2 (ICESat-2) along the CHINARE (CHINese Antarctic Research Expedition) route near the Amery Ice Shelf in East Antarctica……*"

Page 1, Line 13: ". . . the ICESat-2 geolocated photon product (ATL03) and land ice elevation product (ATL06). . . "

We have changed the sentence accordingly.

Page 1, Line 17 replace "in a previous study" with "(Brunt et al., 2021)"

We have replaced the "*in a previous study*" with "*(Brunt et al., 2021)*". It is also updated in **References**.

Page 1, Lines 21–22 While this is an important study, it is limited to a small region of East Antarctica covering a small percentage of ICESat-2 reference ground tracks (RGTs). Need to be careful not to overstate the results here. Not sure how these results help overcome the uncertainties in East Antarctic mass balance.

We considered yours and other two reviewers' comments here to lower the significance of the results: "…… *The validation results demonstrate that the estimated ICESat-2 elevations are accurate to 1.5–2.5 cm in this East Antarctic region, which shows the potential of the data products for eliminating mission biases by overcoming the uncertainties in the estimation of mass balance in East Antarctica......*"

Page 1, Line 23 What do you mean by "especially during the later operation period"? Do you mean that such field capabilities cannot be implemented for a couple of years, or that it is important to calibrate against potential degradation of the satellite measurements?

It is the latter case. We revised the text: "*……especially for calibration against potential degradation of the elevation measurements during the later operation period.*"

Page 1, Lines 25–27 This sentence is awkwardly phrased.

It is rephrased: "*The new photon-counting laser altimetry satellite, Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2), was successfully launched by the National Aeronautics and Space Administration (NASA) on September 15, 2018 (National Research Council, 2007; Markus et al., 2017; Neumann et al., 2019)……*"

Page 2, Line 30 ATLAS is the primary instrument along with the GPS transceivers and the star cameras.

We replaced "*single*" with "*primary*": "*…… The primary instrument onboard ICESat-2, the Advanced Topographic Laser Altimeter System (ATLAS), is a photon-counting laser altimeter using 532 nm wavelength laser pulses ……*"

Page 2, Lines 33-34 ICESat-2 will likely help improve mass balance and sea level contribution estimates from satellite altimetry, but those are not part of the mission requirements.

The sentence is revised to delete that specific part: "*…… which is designed to conduct surface-elevation* *observations at centimeter-level accuracy ~~and is expected to reduce the uncertainty of the estimated sea level rise contribution from Antarctica~~ (Markus et al., 2017; Neumann et al., 2018, 2019).*"

Page 2, Line 34 The 0.4 cm/yr target is a mission requirement, not the current state of knowledge or uncertainty in elevation change.

Thanks for the comment. We decided to delete this sentence and leave this for future papers to prove its realization: "~~*More specifically, ICESat-2 aims to improve the accuracy of the elevation change rate to 0.4 cm a-1 (Markus et al., 2017; Smith et al., 2020)*~~."

Page 2, Lines 34–37 This sentence is awkwardly phrased. Could be something like "We use Release-3 of the ICESat-2 geolocated photon elevation (ATL03) and land ice surface elevation (ATL06) products provided by the US National Snow and Ice Data Center (NSIDC)."

It is revised: "……*We use Release 003 of the ICESat-2 geolocated photon elevation (ATL03) and land ice surface elevation (ATL06) products provided by the US National Snow and Ice Data Center (NSIDC) (NSIDC, 2021; Neumann et al., 2019; Smith et al., 2019)*".

Page 2, Lines 38–39 "The calibration and validation of measurements is important for all satellite missions, particularly for missions with new instruments or technology, such the photon-counting laser altimeter on-board ICESat-2."

The sentence is revised accordingly: "*The calibration and validation of measurements are important for all satellite missions, particularly for missions with new instruments or technology, such as the photon-counting laser altimeter on-board ICESat-2……*"

Page 2, Lines 42–43 "Before launch, the ICESat-2 Project Science Office (PSO) funded calibration and validation experiments to be conducted on both the Greenland and Antarctic ice sheets. The annual Antarctic campaigns traverse a 300km stretch of the interior of Antarctica near 88° S covering 20% of the ICESat-2 reference ground tracks (RGTs) (Brunt et al., 2019)."

They are changed accordingly: "*…… Prior to ICESat-2 launch, calibration and validation experiments were conducted on both the Greenland and Antarctic ice sheets (Brunt et al., 2017 and 2019b; Magruder and Brunt, 2018). The annual Antarctic campaigns traverse a 300 km stretch of the interior of Antarctica near 88°S covering 20% of the ICESat-2 reference ground tracks (RGTs) (Brunt et al., 2019b)……*"

Page 2, Line 45 "the Antarctic Ice Sheet (AIS)"

It is changed accordingly.

Page 2, Lines 47–48 "The NASA-led team also placed and used corner cube retroreflectors (CCRs) to collect ICESat-2 signatures at known points to help determine the horizontal geolocation accuracy of the laser pointing determination."

We changed it to: "……*The NASA-led team also placed and used corner cube retroreflectors (CCRs) to collect ICESat-2 signatures at known points and determined the horizontal geolocation accuracy of the laser pointing* *as 2 - 5 m (Magruder et al., 2020), specifically ranging from 2.5 m for beam 6 to 4.4 m for beam 2 (Luthcke et al., 2021).*"

Page 2, Line 51 Again, while this is an important study, this is not a complete study of the "whole" of Antarctica.

We changed it to "*…… additional coverage containing the lower-latitude interior and coastal regions in AIS should make the validation of ICESat-2 data complete with an ample and comprehensive understanding of elevation of diverse regions of ~~the whole~~ AIS.*"

Page 2, Line 56 Replace "mass" with "volume"

Considering that "mass balance" has a context meaning here, we would like to keep "mass", but add "volume" in parentheses: "*…… mass (volume) balance of AIS……*"

Page 2, Line 70 horizontal or vertical accuracy?

We changed it to: "*…… with centimeter accuracy (vertical)*".

Figure 1 Where is the inset map of Great Wall Station located? Does the inset need to be included if the station was not used as part of the campaign?

We deleted "Great Wall Station" in the inset.

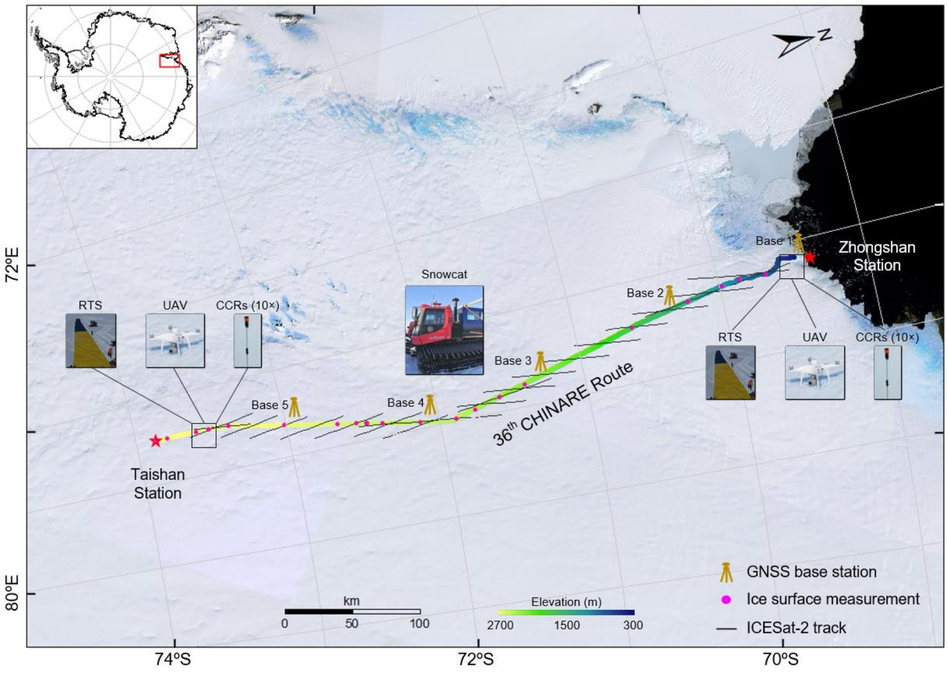

Figure 1. ICESat-2 validation campaign based on coordinated multi-sensor ground observations along the 36th CHINARE route. The Landsat image mosaic of Antarctica (Bindschadler et al., 2008) is used as background.

Table 1 This is less ICESat-2 data than I would have thought. Are these numbers reduced using quality flags?

(Table 1) The numbers of ICESat-2 observations listed in the table depend on the way we select ICESat-2 points (photons) for comparison with the GNSS points. As explained in the **Method** section, each ATL06 point is compared with at least 5 GNSS points within a neighborhood of 20 m, plus the "*satl06_quality_summary*" tag must be 0 (best quality). The total number of ATL 06 points listed in Table 1 are those paired points after reduction using the quality tag. In addition, the ATL 03 photons listed in Table 1 are those within a neighborhood of 20 m of the ICESat-2 – GNSS crossovers after a reduction using "*signal_conf_ph*" = 1, 2, 3 and 4 (buffer - high).

Table 1 What do you mean by "not applicable" for ATL06 geolocation accuracy? That these are simply parameterized in the product?

(Table 1) The elevations of ATL 06 points are representative elevations of 40 m segments and assigned to the segment centers. Therefore, their horizontal location accuracies may not be as meaningful as those for the ATL03 photons. So, we now leave the geolocation accuracy for ATL 06 blank in Table 1.

Page 5, Line 97 Why were 6 cm CCRs chosen for this campaign?

We add the text in the **Data** section to explain why we used 6 cm diameter CCRs: "*Under the time constraints of equipment shipment before expedition and manufacturing cycle of new products we used ten readily available CCRs of 6 cm diameter (Fig. A1a) at each site, which were designed for ground - based laser distance measurement. They were placed linearly at a 10 m interval across a nominal ICESat-2 ground track to reflect photons from ATLAS (Fig. 2a)……*"

We added a paragraph in the **Discussions** section to explain the impact:

"*The use of the readily available CCRs of 6 cm diameter for the 532 nm wave length of ATLAS, which is larger than 8 mm of the CCRs used in Magruder et al. (2020), is subject to velocity aberration caused by a decreased central disc and receiving signals from the outer lobes of the Fraunhofer diffraction pattern (Chang et al., 1971; Born et al., 1999; Sun et al., 2019; Magruder et al., 2020). In addition, the larger aperture of the CCR resulted in a higher level of the total signals received by ATLAS so that signals from both the smaller central disc and outer lobes are detected and used to estimate elevations in ATL03 data. This may have attributed to the creation of the long along-track streaks of ~35 m (Fig. 6a) and ~38 m (Fig. 6b) in comparison to those of ~11 m in Magruder et al. (2020). Thus, photons reflected from the lower neighboring CCR(s) in the cross-track direction (Fig. 6b) were detected for the same reason because of the symmetric Fraunhofer diffraction pattern. Similarly, the one-layer photon streak (green dots in Fig. 6a) may include those reflected from one or both neighboring CCRs because the elevations of all three neighboring CCRs (#4, #5 and #6) are within a 15 cm range (Table C1) due to local ice surface topography and logistic constraints, although the poles were manufactured in different lengths. On the other hand, the received signals in the central disc are generally of a higher level (about 84% of the total energy) than in the outer lobes given atmospheric scattering and other optical losses (Magruder et al., 2020). Correspondingly, we observe that within the window of the nadir CCR (red rectangle in Fig. 6b) the photons are densely aligned along a curve. The same curve trend appears to continue towards both ends, but diverged by potentially blended signals reflected from neighboring CCRs (Figs. 6a and 6b). Therefore, by selecting photons inside the central window of the CCR streak it ensures that* *high quality photons in the central disc of the Fraunhofer diffraction pattern be used to estimate the elevation of the representative photon of the nadir CCR through the fitting curve. The result is also validated by the nadir CCR position surveyed by using the high-precision GNSS RTK technique.*"

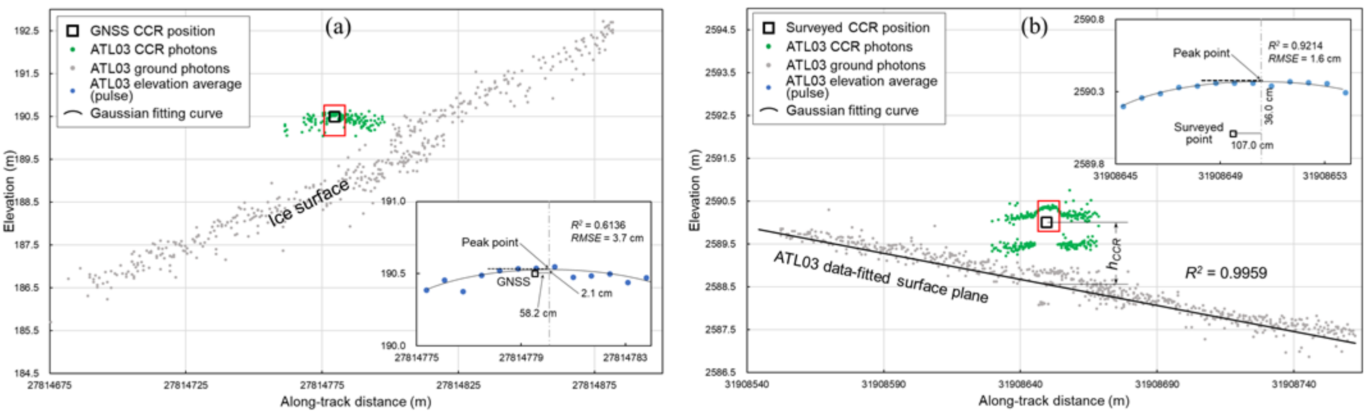

Figure 6 (revised version)

We revised and added the text in the **Results** and **Method** sections to explain how we select the appropriate photons to analyze the data:

In the **Results** section "*……Among the CCRs, CCR #5 near Zhongshan Station and CCR #6 near Taishan Station were closest (~0.3 m and ~1.3 m) to the ground tracks and are called nadir CCRs. Given these CCR shifts from ground tracks, uncertainty of the ground tracks themselves of up to ~6.5 m (Magruder et al., 2020), and the CCR interval of ~10 m, we expected to have one to two CCRs falling into a footprint of ~11 m. Fig. 6b clearly shows returned photons (green dots) of two layers with an elevation difference of ~50 cm. Furthermore, the photons in the upper layer within a window of ~9 m (red rectangle in Fig. 6b) around the nadir CCR (#6) were received by ATLAS, while those of the lower elevation were not present inside the window. Therefore, we only use the returned photons inside a window of ~9 m around the nadir CCR to validate ICESat-2 elevations*".

In the **Method** section "……*where the photons are generally of high quality and have the confidence tag "signal_conf_ph" equal to 3 or 4 to calculate an average elevation in each pulse to reduce noises and potential atmospheric effect (blue dots in inset of Fig. 6a). The average elevations are then further fitted to a Gaussian curve. The peak of the curve is treated as the representative CCR photon position. An offset is then calculated between the positions estimated from the ATL03 photons and the GNSS survey*."

We also answered a similar question asked by Reviewer 1. Please see details in the responses to Reviewer 1's comments with more figures and discussions.

Page 5, Line 102 Possible to use a different positioning technique for these to reduce the impact of the station problems? 1 meter vertical is not going to be beneficial from a cal/val standpoint.

Due to logistic difficulties, GNSS-measurements near Taishan Station were carried out using the single-point positioning technique. The GNSS function is integrated into a field surveying pad system. The data are not appropriate to support a PPP solution. We will look into a potential PPP application for these single point positioning situations in the future.

Page 5, Line 109 "that are separated by 90 meters"

"*…… that is ~90 m apart.*" is changed to "*…… that are separated by 90 meters.*"

Page 5, Line 115 "We selected a silver-gray coating with R = 0.235 as it was the closest to the reportedly highest estimated probability (EP) of photon detection coating with R = 0.28"

We accepted the suggestion and used the sentence in the text.

Page 5, Line 109 Remove "Thus"

It is removed.

Page 8, Line 167 "which are 3 km apart"

We have corrected the sentence: "*…… which are 3 km apart.*"

Page 8, Line 168 Weak/Strong beams can be either left or right depending on the spacecraft orientation.

We discussed this issue and added the correspondence between "left and right" and "laser spot" IDs. The text is revised accordingly: "*……The left and right correspondence in Fig. 5a may change as the spacecraft changes its orientation. They are also referred as reference ground tracks (RGTs) with laser spot IDs (1, 2…, 6) corresponding to six beams which are independent of spacecraft orientation. During our study period, the correspondence is (Laser spot 1: 3R), (Laser spot: 3L), (Laser spot 3: 2R), (Laser spot 4: 2L), (Laser spot 5: 1R), and (Laser spot 6: 1L) (Neumann et al., 2019)......*"

Page 8, Line 171 "We reduce the impact of non-signal and noisy measurements by reducing the ATL06 land ice elevation measurements using the atl06_quality_summary flag and the ATL03 geolocated photon measurements to medium to high confidence photons using the signal_conf_ph flag. We also consider . . . "

We accepted the suggestion and used the sentence in the text.

Page 8, Lines 174–175 What determination did you use to decide if buffer to low classified photons should be included? In some cases, the buffer to low classified photons often can improve comparisons with ground measurements due to the shape of the ATLAS transmit pulse (which can be truncated in the ATL03 classifier if only including high-quality PEs).

The sentence is revised: "*……We also consider the ATL03 photons with "signal_conf_ph" equal to 1 (buffer) and 2 (low) to reduce the effect of the transmit pulse shape bias that may be caused by truncation of the return pulse through exclusion of these lower confidence photons (Smith et al., 2019; Brunt et al., 2019b).*"

Page 8, Line 177 Remove "On the other hand"

The phrase is removed.

Page 9, Lines 187-189 As this campaign includes multiple different terrains, was slope considered when comparing with the ATL06 measurements? i.e. along-track slope is estimated when calculating the

average surface height in ATL06. Would your ground measurements also provide a metric for the along-track and acrosstrack slopes estimated by ATL06?

Thanks for bringing this up. Our data can only provide along - GNSS track slopes. We computed the GNSS slopes at each GNSS – ICESat-2 (ATL06) intersections using GNSS points within a 20 m radius window, so the slope scale matches that of the 40 m ATL06 segments. The GNSS slopes are the result of a least-squares linear fit to the GNSS points. In addition, we also calculated the intersection angle α (Fig. AC3-1)

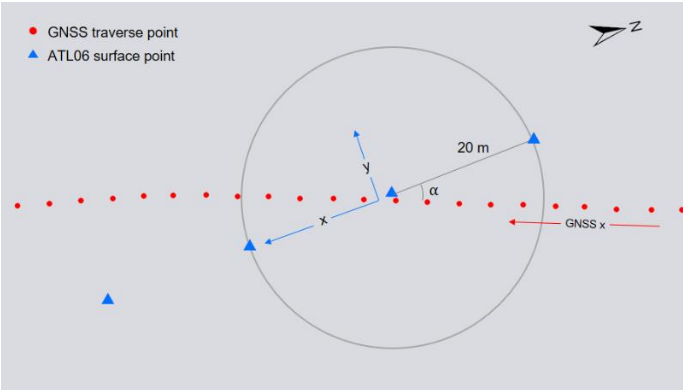

Fig. AC3-1

We generated the following figures to compare the slopes between GNSS (along - GNSS track) and ATL06 (along - and cross – track) results. Fig. AC3-2a shows that the GNSS slopes are relatively consistent with the ATL06 along - track slopes ($R^2 = 0.49$); the RMSE between the two sets of slopes is 0.0062 (0.36°). In contrast, the comparison with the ATL06 across - track slopes resulted in a low R^2 of -0.03 and RMSE of 0.0089 (0.51°) (Fig. AC3-2c). Their histograms are presented in Figs. AC3-2b and AC3-2d. Note that we removed four ATL06 slopes because their error flags dh_fit_dy are too large (in the order of 3.4e+38). Considering that the intersection angles (α) are mostly within 30°, the ATL06 tracks are roughly aligned with the GNSS tracks. Therefore, the GNSS slopes are also closer to the ATL06 along – track slopes.

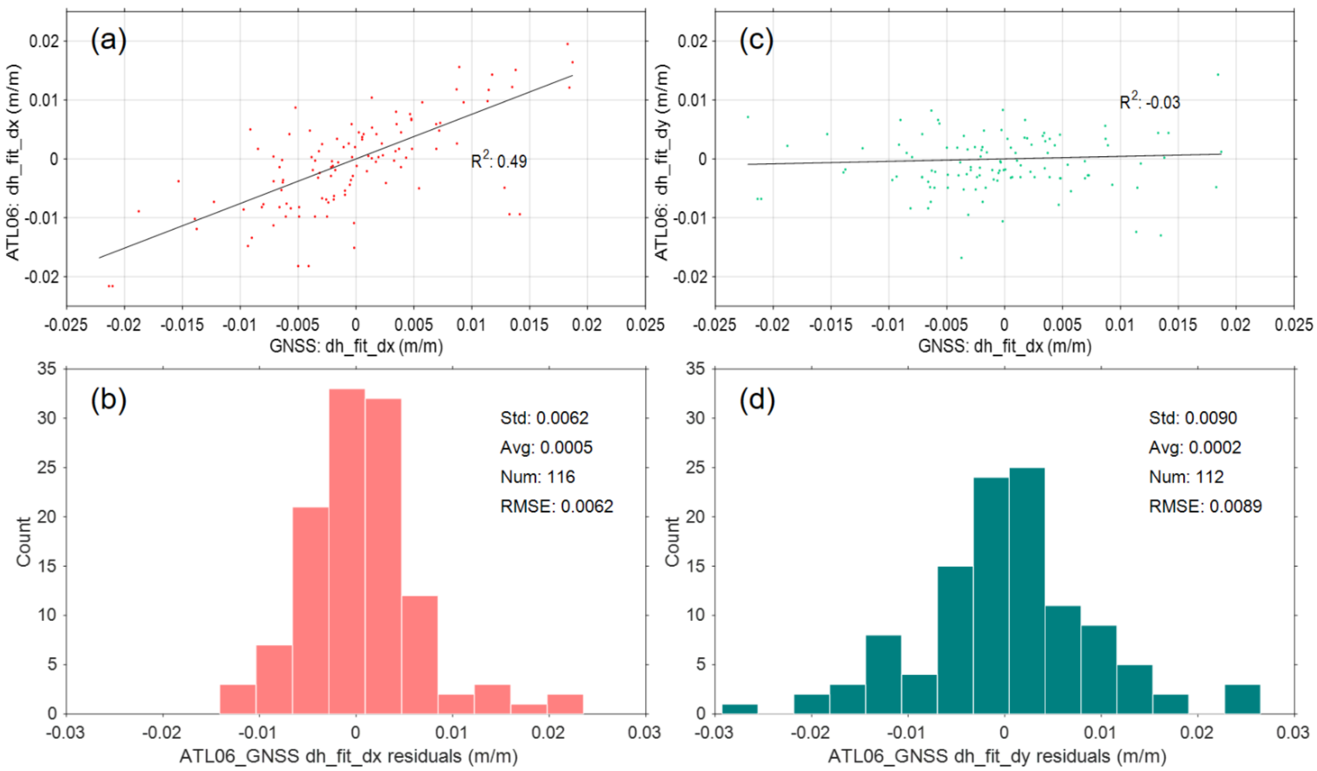

Fig. AC3-2

We performed a preliminary analysis of differences between the GNSS and ICESat-2 elevations vs. the intersection angle α at the crossovers. We did find some large elevation differences associated with increased α. Furthermore, a significant correlation between the elevation differences and along - track or cross – track slopes is not present (very preliminary).

Page 9, Lines 194–196 The early mission pointing issue is a known problem (was due to a reference frame mismatch in the onboard software for the star cameras) (Luthcke et al., 2021).

The sentence is revised: "*Our preliminary analysis of Releases 001 and 002 data indicated that the offsets between the actual and reference ground tracks in the study area were reduced from up to ~3000 m during the initial mission, which is caused by a reference frame mismatch in the onboard software for the star cameras (Luthcke et al., 2021), to 1–6 m before our expedition.*" The paper is also added to **References**.

Page 10, Lines 206–212 These sentences are awkwardly phrased.

The paragraph is now rewritten: "*The photons reflected from a CCR and received by ATLAS are represented as a streak of elevations along a track in the ICESat-2 ATL03 data (green dots in Fig. 6a above); they are distributed on both sides of the GNSS-surveyed location (black square). We select the photons in the central section of the streak, approximately one footprint long (within the red rectangle), as presented in the inset of Fig. 6a to estimate the representative CCR photon position. Then in each pulse the photons are selected using the confidence flag "signal_conf_ph" equal to 3 (good) or 4 (high) and averaged to reduce noises and potential atmospheric effect. The average elevations (blue dots) are further used to fit a Gaussian curve. The peak of the curve is treated as the representative CCR photon position. An offset is then calculated between the CCR positions estimated from the ATL03 photons (peak point) and the GNSS survey (black square).*"

Page 10, Line 207 11 m laser footprint?

We have added "*~11 m*": "*We select the photons in the central section of the streak, approximately one footprint long (~11 m, within the red rectangle) ……*"

Page 10, Line 209 "confidence flag "signal_conf_ph" equal to middle to high confidence in order to calculate an average elevation in each pulse with reduced noise". You're calculating averages over individual pulses? Are there enough return PEs to calculate at this along-track length with significance? This is fitting at approximately 0.7 meters along track correct?

Yes, this gives an average number of photons per pulse, spaced every ~0.7 m. For the two weak beam tracks at Zhongshan and Taishan stations, the CCRs returned a high number of photons: ~4 photons (middle - high confidence) per pulse at CCR, in comparison to ~2 photons (low - high confidence) per pulse on ice surface in the region. Therefore, there is a sufficient number of returned PEs to support the fitted Gaussian curve. The specific counts given are in the **Results** section.

In the 3rd paragraph of Section 4.2: "*From the returned photons near Zhongshan Station (Fig. 6a) we selected 51 photons of 13 pulses, 3.9 photons per pulse, located in the central part of the weak beam streak.*"

In the 4th paragraph of Section 4.2: "*CCR #6 was found to have returned 52 photons in 13 pulses, 4 photons per pulse, from the weak beam track within the ~9 m window in Fig. 6b.*" (Taishan Station)

Page 10, Line 210 replace "further fitted" with simply "fit".

We rewrote the sentence without "further": "*The average elevations (blue dots in inset of Fig. 6a) are used to fit a Gaussian curve.*"

Page 10, Line 210 Are you using "e.g." here because you use different curves besides a Gaussian? What other functionals do you consider? Did you mean to use "i.e." here?

We now directly used "*Gaussian curve*" (see above revised sentence).

Figure 6 Is there a way of combining the plots for the same region to not repeat information? Maybe at some middle level of zoom?

We modified Figure 6 accordingly (see Fig. 6 above).

Page 11, Line 223 1.0 cm horizontal?

It is elevation accuracy. Now both errors of GNSS observations and the reference point are considered. The elevation accuracy is 1.3 cm: "…… *Based on the internal precision given by the GNSS system and accuracy of the known GNSS reference point, the elevation accuracy of three GCPs surveyed by the RTK positioning technique is 1.3 cm.*"

Page 12, Line 250 Can you clarify what is 816 meters apart? As phrased it could be interpreted as the GNSS measurements are over 800 meters from your ICESat-2 measurements.

The sentence is revised to make it more specific: "*The average distance between the h_2 measurements and*

GNSS – ICESat-2 intersections is ~2366 m." This average distance is increased from ~816 m to ~2366 m because the maximum distance is now extended from 2 km to 5 km after a test suggested by Reviewer 2.

Table 2 Would be beneficial to have these statistics for laser spots in addition to the oriented beams (to directly map to individual laser beams).

The laser spot IDs are added into Table 2 above.

Page 12, Line 263 Again need to be careful to clarify that L/R do not necessarily map to weak/strong as it depends on the spacecraft orientation.

Since the data gaps for Laser spots 3 and 4 (GT2L and GT2R) are now filled by using more qualified GNSS – ICESat-2 crossovers (see Table 2 above), these sentences are deleted.

Page 13, Line 273 Replace "orbit" with RGT

We have replaced "*orbit*" with "*RGT*".

Page 13, Line 276 137 medium to high-quality classified photon returns?

The sentence is revised accordingly: "*The ATL03 data showed a streak of 137 medium to high-quality classified photon returns in 50 pulses……*"

Page 13, Line 284 1–2 meters vertical is not going to be accurate enough for cal/val purposes

We agree with you. Thus, we only used the result of the CCR elevation comparison between the centimeter level accuracy GNSS and ICESat-2 observations at Zhongshan Station.

Page 13, Lines 286–289 This seems possibly circular to use ICESat-2 to evaluate ICESat-2. What are the uncertainties in ATL06 here? What about horizontal geolocation errors of ATL06 and the CCR impacting the heights? What are the slopes?

To avoid the impact of the horizontal geolocation errors of ATL06 on the elevation, we used the ATL03 photons to fit the ice surface (see Fig. 6 above), as also suggested by Reviewer 2. Although this may not solve the possibly "circular" issue, it demonstrates the need for precision GNSS survey at CCRs as long as logistics and field conditions can support.

Based on the slope flags in ATL06 segments, slopes in this section (Fig. 6b) range from -0.79° to -0.35°, with a mean and 1σ of -0.54° ± 0.18°. Although not significant, the ice surface slope in Fig. 6b appears steep because of the "squeezed" horizontal scale.

Page 14, Lines 309–310 The weak beam also returns to 1/4th the number of detectors (4 instead of 16) and has different thresholds for saturation in the ATL03 algorithm.

We may not have got your question quite right. Here is our try. The strong beams recorded 9.0 and 7.0 photons per pulse in average at the two sites (see table below): not saturated and no impact of CCR (90 m away). However, the weak beam, for example at Taishan Station, returned 9.7 photons per pulse in average. We further examined all 7 pulses over the 5 m - wide RTS sheet. Their photon counts per pulse are: 10, 12, 10, 9, 8, 9,

10. Correspondingly we can see three layers of returned photons (within the blue rectangle in AC3-3) from a) nadir CCR (top), b) neighboring CCR (middle) and ice surface (bottom), respectively. Since the travel times of these photons from different layers are different, many photons hit the four weak beam detectors at different times and thus, "managed" to be recorded by ATLAS between different dead times of the detectors. We think that it is how the high count-numbers per pulse (9.7 average) came about: saturated, but accepted and recorded by ATLAS.

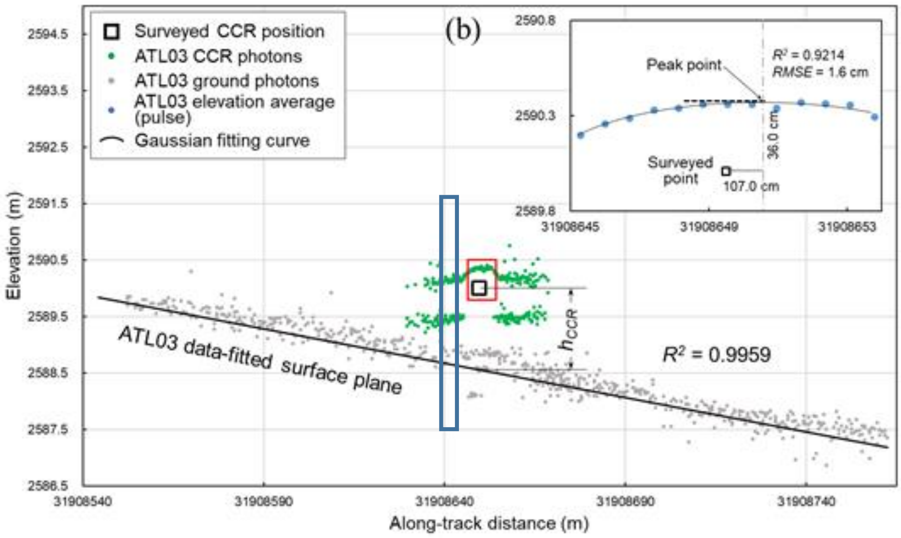

Fig. AC3-3

Page 14, Line 310 This is unfortunate that it was so close to the CCRs.

We will avoid this situation in our potential future field experiments.

Table 3 Should these return photon counts be in count/meter?

We changed it to photon count per pulse averaged over the *5 m* segment of RTS and ice surface (firn).

RTS coating (ICESat-2 beam, site)	**Pre-expedition reflectivity**	**Avg count per pulse (RTS)**	**Full saturation fraction (RTS)**	**Avg count per pulse (firn)**	**Full saturation fraction (firn)**
Yellow (strong beam, Zhongshan)	0.532	9.0	0	6.1	0
Yellow (strong beam, Taishan)	0.532	7.0	0	6.7	0
Silver–gray (weak beam, Zhongshan)	0.235	1.1 (CCR)	0.321 (CCR)	1.7	0
Dark green (weak beam, Taishan)	0.060	9.7 (CCR)	0.429 (CCR)	1.7	0.072

Page 14, Line 321 Replace "orbit" with "RGT"

We have replaced "*orbit*" with "*RGT*".

Page 15, Lines 341–343 Improving the h_2 measurements seems like a good advance for future campaigns.

Thanks. It is on our to-do list.

Page 17, Line 399 The cal/val data needs to be included here in the Data availability section

The data set is now uploaded to a publicly accessible site Dryad at https://datadryad.org/stash/share/mU52z7OSWAG07tTsGCWXt0Rm0MmT12qwdPORBIUpsnw. They include a) traverse validation data (GNSS data of traverse crossovers, GNSS – ICESat-2 crossovers and ice surface heights), b) CCR and RTS validation data (GNSS CCR positions and GNSS RTS check points), and c) DEM data (DEM and check points).

Page 21, Line 491–492 I believe that within a 20 meter ATL03 segment, only one photon event is directly geolocated in an absolute sense. The other PEs are then geolocated with respect to that reference PE.

Thanks for the comment. The text is revised accordingly: "*Within a 20-meter along - track segment, only one photon, referred to as reference photon, is geolocated in an absolute sense. Other photons are then geolocated with respect to that reference photon (Neumann et al., 2019; Luthcke et al., 2021).*"

References

The following 5 suggested references are all cited in appropriate places in the manuscript and added to the reference list.

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