egusphere-2024-2904 Response to Referee #1

Landy et al.

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In this document, we outline our responses to comments from the reviewer, including modifications that we intend to make to the manuscript where necessary. Reviewer comments are shown in black and our responses in blue with intended changes to the revised version of the manuscript given in italics.

This paper explores existing satellite and airborne radar and laser altimetry observations over the Arctic from 2018-2023 to assess potential future observations from dual frequency Ka and Ku radar from CRISTAL. The study is very well organized, and thoroughly explores similarities and differences in current observations with strong ties to understanding the physical basis for differences. The results are highly impactful and will be an extremely useful reference in preparation for CRISTAL and understanding differences in Ku and Ka radar as well as laser altimetry missions.

I did not see any major technical errors and the explanations and figures were very clear. I just noted some questions that arose while reading the manuscript as outlined below. These are all minor and I would otherwise suggest publication subject to some minor revisions.

Thank you to the reviewer for taking the time to read and check our manuscript, providing valuable comments that improve the clarity of the work.

L118: What is meant by calibrated and uncalibrated observations in this sentence?

This was unclear. We meant the calibrations to OIB freeboards based on radar waveform pulse peakiness, that are applied in the DuST method. Intended revision:

The DuST (dual-altimeter snow thickness) methodology has more recently been applied to produce pan-Arctic "KuLa" snow depth estimates from the difference between CryoSat-2 observations, with the same calibration to airborne freeboards applied, and ICESat-2 ATL10 observations as part of the...

L203-204: Can you describe in more detail how the interpolation is done between tie points? Is it linear and over what length scale?

Details on the interpolation method are provided at the end of Section 3.3 and we will now refer to this at the earlier lines, as suggested. The method is linear interpolation then the SSHA profile is smoothed on a 25-km length scale.

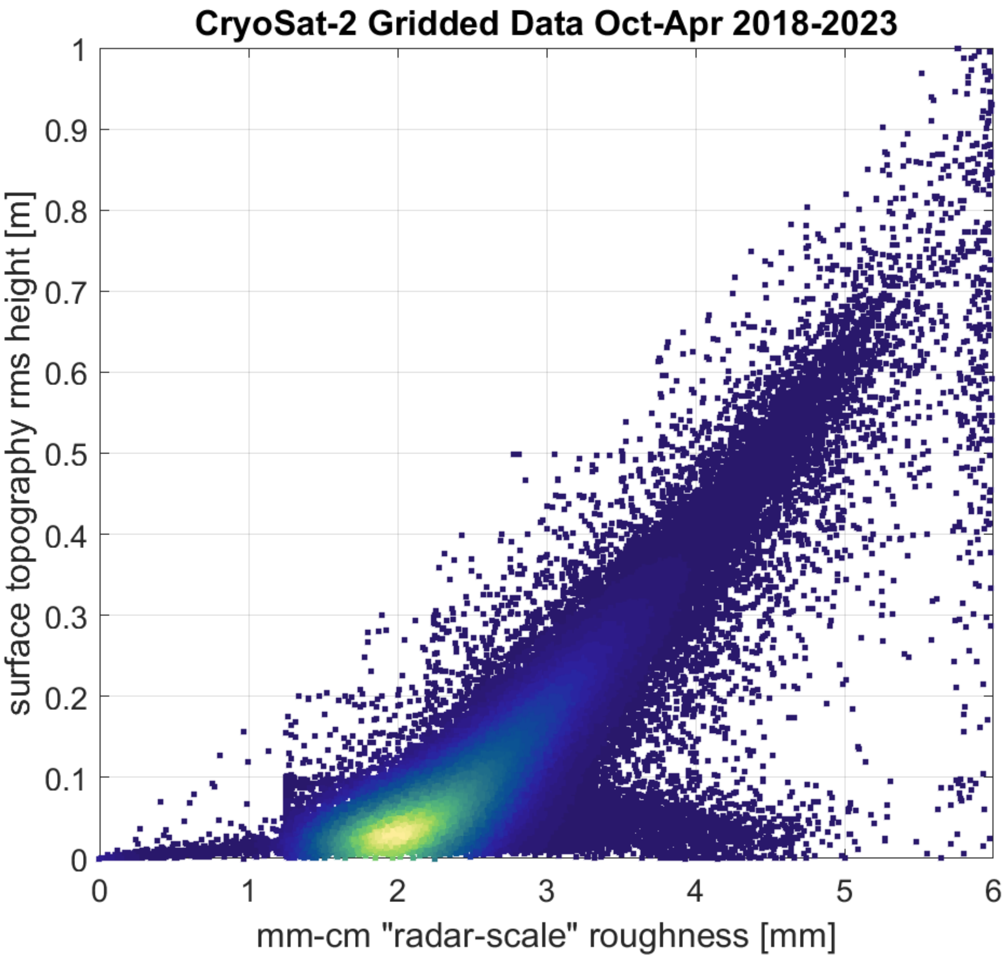

Figure 1: CryoSat-2 gridded surface topography vs radar-scale roughness across the entire dataset.

L225-230: Are these four parameter terms independent or are they linked together in some way e.g. the surface topography root-mean square height and mm-cm 'radar-scale' roughness?

No, they are not independent. For instance, the relative position of the tracking point with respect to the waveform peak is related to the surface topography root-mean square height, and the surface topography is indeed related to the mm-cm roughness. A scatterplot between the gridded CryoSat-2 topography and roughness across the entire dataset is shown in Figure 1. There is a nonlinear relationship between the parameters, but there are a significant number of cases where, for example, a large range of mm-cm roughness can be obtained for relatively low surface topography rms height. For clarity, we choose not to go into details on this aspect within the manuscript.

L259: There looks to be a typo here in 95 8%

Thanks, will be corrected.

L270-275: How are the initial starting point values for the lsqnonlin solver determined?

Good question. We will add the following text to the section:

Initial values for the four free parameters are determined as: t_0 at 70% of the waveform leading-edge power, A at the waveform maximum, and σ and s_{rms} corresponding to the modelled echo from the lookup table with a peakiness value closest to the peakiness of the observed waveform.

Figure 2: Can you describe the methodology for discarding secondary peaks? Does this differ between CryoSat-2 and AltiKA?

We will add the following text to the section:

A filtering routine is applied to exclude samples at major secondary peaks, on the waveform trailing edge, from the model fit (Figure 2). This routine identifies all waveform peaks between the primary peak and noise floor (on the waveform trailing edge) then removes samples if the area of the peak is above a threshold value. The routine is identical between CryoSat-2 and AltiKa, but the thresholds are different.

L331: Is a consistent snow density as outlined here used also in the processing of the snow radar data?

No it is not. A fixed snow density of 300 kg m^{-3} was applied by [Jutila et al., 2022] to estimate snow depths from the IceBird snow radar observations, so we applied the same fixed snow density to estimate snow depths from the OIB data in April 2019. This was to ensure consistency across the reference snow depth datasets. However, the seasonally-varying function of [Mallett, 2025] used for the satellite data gives a snow density of 329 kg m^{-3} in April, so the difference in the ratio of radar wave velocities in snow and free space would be 0.80 vs 0.79, respectively, between these different snow densities.

L396-400: Can you calculate a skewness for the results? They do indeed appear Gaussian visually, but perhaps this metric could show this quantitatively.

The skewness parameters for Dec 2018 and Apr 2019 are 0.99 and 1.36, so the distributions are positively skewed. The text will be amended to reflect this.

L428: I was confused by the reference to the Beaufort Sea and MOSAiC transects here though see these are discussed a bit later in the paper. The MOSAiC measurements could be discussed in more detail in Section 2 as well.

We will add more detail on the MOSAiC measurements in Section 2.4:

(ii) Snow depth collected manually with a magnaprobe along the two loops of the MOSAiC campaign Central Observatory transects, approximately weekly [Itkin et al., 2023], accessible from https://doi.org/10.1594/PANGAEA.937781, for October 2019 to April 2020.

At the line specified by the reviewer, we are referring to the thinnest category of snow depths within the reference data compilation described in Section 2.4. Here, the thin snow primarily comes from IceBird airborne observations in the Beaufort Sea in April 2019, and from the MOSAiC transect data in Nov-Dec 2018 when snow only just started to accumulate. Clarification on this will be added to the manuscript.

L588: I'm not sure the statement about filtering out dark leads applies here. Dark leads are only not considered for sea surface height determination, but their freeboard heights still remain in the product.

Based on [Kwok et al., 2021], removal of dark leads from the sea surface height determination produces generally lower height estimates for the sea surface. This would reduce the prevalence of very thin IS2 freeboards regardless of whether the dark lead freeboard heights are retained.

References

[Itkin et al., 2023] Itkin, P., Hendricks, S., Webster, M., von Albedyll, L., Arndt, S., Divine, D., Jaggi, M., Oggier, M., Raphael, I., Ricker, R., et al. (2023). Sea ice and snow characteristics from year-long transects at the mosaic central observatory. *Elem Sci Anth*, 11(1):00048.

[Jutila et al., 2022] Jutila, A., Hendricks, S., Ricker, R., von Albedyll, L., Krumpen, T., and Haas, C. (2022). Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements. *The Cryosphere*, 16(1):259–275.

[Kwok et al., 2021] Kwok, R., Petty, A. A., Bagnardi, M., Kurtz, N. T., Cunningham, G. F., Ivanoff, A., and Kacimi, S. (2021). Refining the sea surface identification approach for determining freeboards in the icesat-2 sea ice products. *The Cryosphere*, 15(2):821–833.

[Mallett, 2025] Mallett, R. D. (2025). A methodologically robust densification function for snow on multiyear arctic sea ice. *Journal of Glaciology*, 71:e24.