We thank the reviewers for taking the time to read through this manuscript and providing constructive feedback, which we believe has improved the quality of our work.

Our replies are written in blue in this document.

Reviewer 1

This manuscript makes an important and timely contribution to the ongoing debate surrounding the validity of the snow-penetration assumption in Ku-band satellite radar altimetry. By analyzing the temporal evolution of spaceborne laser (ICESat-2) and radar (CryoSat-2, Sentinel-3) freeboards over immobile landfast first-year ice (FYI) and multi-year ice (MYI) off the Greenland coast, Taelman et al. provide one of the first empirical, multi-sensor, in situ–supported assessments of when and under what conditions Ku-band freeboards become positively biased. The paper is carefully structured, the literature review is comprehensive, and the combination of field measurements with satellite time series represents a genuinely novel methodological approach. The finding that radar freeboard over FYI generally tracks the snow–ice interface during cold-season conditions; while exhibiting positive biases under saline snow or snowfall events - is both substantive and well-supported by the data. The implications for the Copernicus CRISTAL mission are clearly articulated and add strong relevance to the work.

That said, several methodological choices require additional justification, and a number of analytical gaps need to be addressed before the manuscript is ready for publication in The Cryosphere. The major concerns center on: (1) the treatment of multi-sensor sampling differences in the time series analysis; (2) the basis for the 100 km ATL10 lead tie-point accumulation distance; (3) the representation of snow depth uncertainty from LaKu; and (4) several insufficiently substantiated concluding statements. These are detailed below:

Specific Comments:

- Line 45: It would be very useful to link the citations directly to the specific snow dielectric properties they refer to. Consider placing the relevant citations immediately next to each property listed.
  We have added the relevant references directly after each specific snow property.

- Line 50: Can you cite these studies in this line?
  We have added the citations to this line.

- Introduction: The authors did a fantastic job with a very comprehensive literature review and stated the objectives very clearly. I would suggest re-emphasizing the

methodological uniqueness of this study in a bit more detail towards the end of the introduction.
We have highlighted the novelty of our approach more, just before introducing the goals of the study.

- Line 161: Citing the study that mentioned the ~17 m diameter could be helpful since there have been other studies that claim even finer footprints for ICESat-2.
We have added the relevant citation.

- Line 188: Is there an approximate distance between the in-situ measurements and the ROIs that is used to quantitatively define "proximity"?
We have added the range of distances between in-situ measurements and the ROIs in the description.

- Line 190: It would be worthwhile to provide the uncertainty estimates for these instruments over sea ice.
We have added the accuracy for the Magnaprobe and GEM devices that were used.

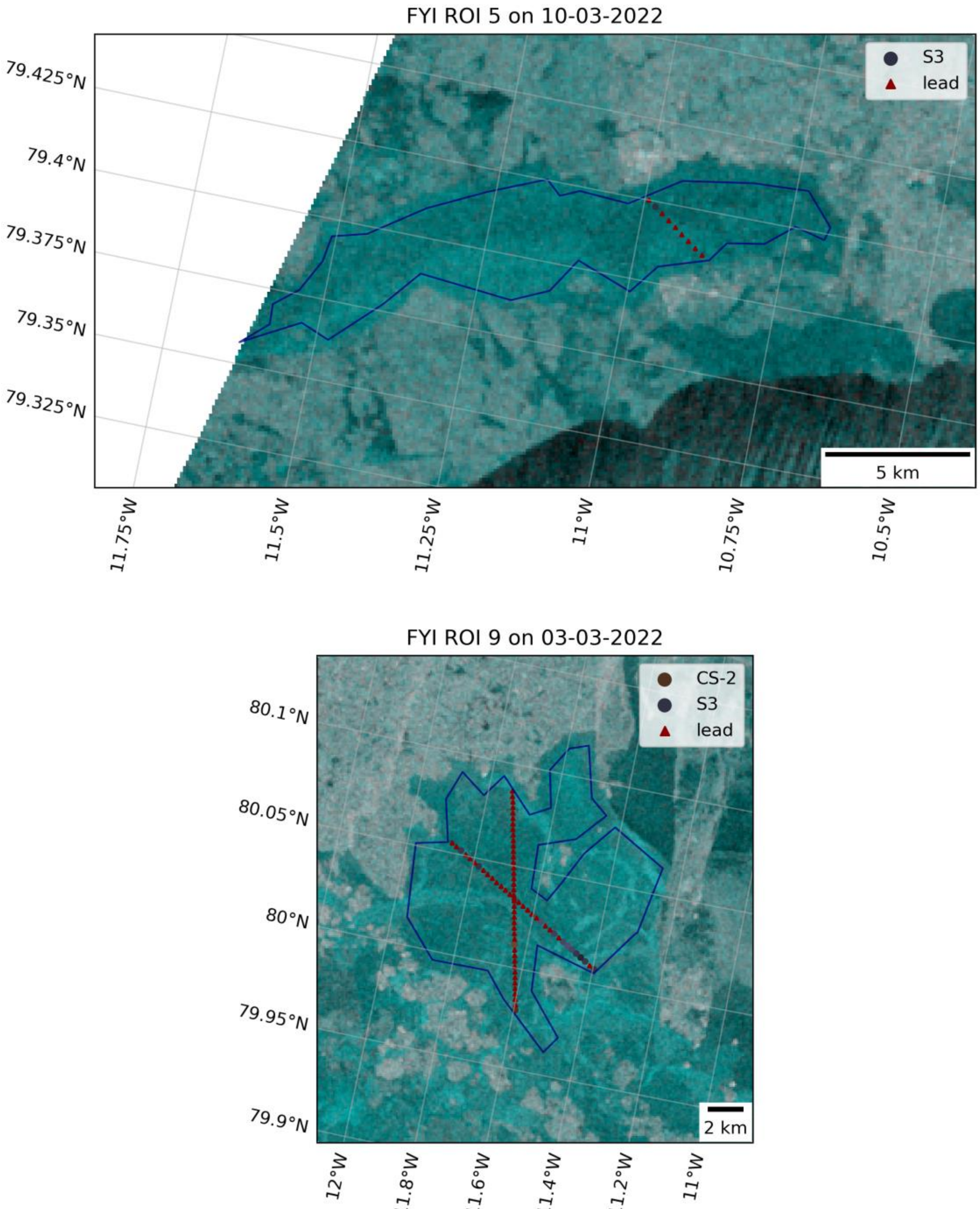
- Line 195: Please clarify the spatial distribution of the snow pits with respect to the FYI and MYI ROIs.
We have added clarification about the spatial distribution of the snow pits in the manuscript.

- Line 295: Is it possible to provide a map illustrating examples of these false leads? Additionally, please provide statistics on the extent of these false leads compared to each dataset, and quantify the impact that excluding them had on the overall measurements.
In the Supplementary Material (Section A2) we now provide examples of altimetry tracks overlaid on SAR imagery over our ROIs to show how we identified that the returns were indeed ice and not actual leads. Additionally, we added an overview map to illustrate the lead returns inside the ROIs and generally inside the fast ice over an entire month, before applying the fast ice mask. The map shows all samples acquired by CS-2 and S-3 for the month of March 2022 over the study region, where returns classified as “lead” are marked with red markers.

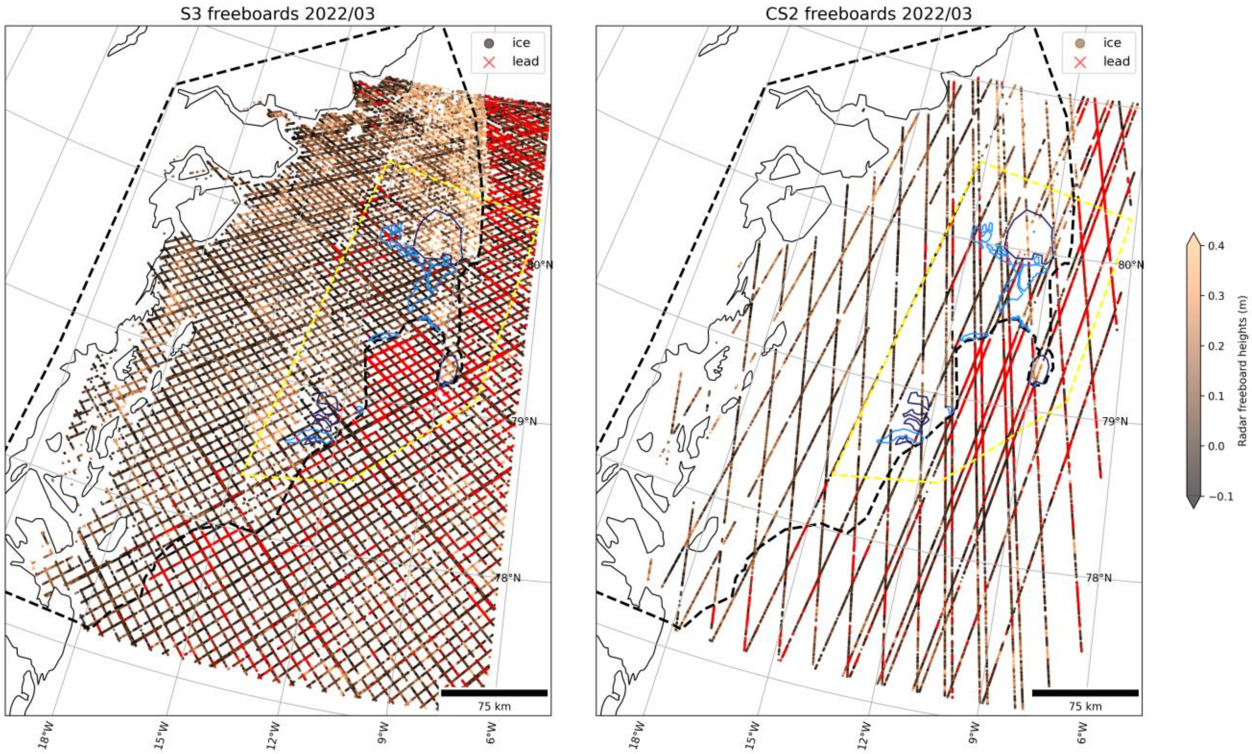
The fast ice mask was applied from February until May 2022 and in that time period 1630 out of 55670 S-3 returns and 811 out of 16999 CS-2 returns were originally classified as “lead” over the fast ice inside the study area (i.e. the intersection between the Belgica Bank study area polygon and fast ice outline, see Fig.1). It is important to note that some of these returns might in fact have been leads, but since we wanted to make sure to not bias the radar freeboards in our study site with incorrect lead tie points, we decided to mask all “lead” returns over the fast ice between February and May and instead only use lead tie points identified in the drift ice. The impact of the masking on the radar freeboard time series is as follows: for FYI the mean absolute error (MAE) is 0.0041 m and the Root Mean Squared Error (RMSE) is 0.0065 m, while for MYI these values are 0.0029 m and 0.0049 m, respectively. The masking effect is larger over the FYI ROIs, as these are the areas that contained many returns classified as “lead” in the original data product, while for MYI the returns were classified correctly as “ice” but subsequent freeboard calculations were affected if false lead tie points were used in the estimation of sea surface height anomaly. We assume the impact is small because the fast ice locations classified as lead are typically very thin, newly-formed ice areas with a freeboard close to sea level.

We have also re-produced Figure 6 of the manuscript (time series of laser and radar freeboards) without applying the fast ice mask. This figure (shown further down) shows that the increases in radar freeboard during periods of warmer temperatures and precipitation are also visible in this time series before applying the fast ice mask. It proofs that the masking of lead tie points over the fast ice does not artificially create these increases.

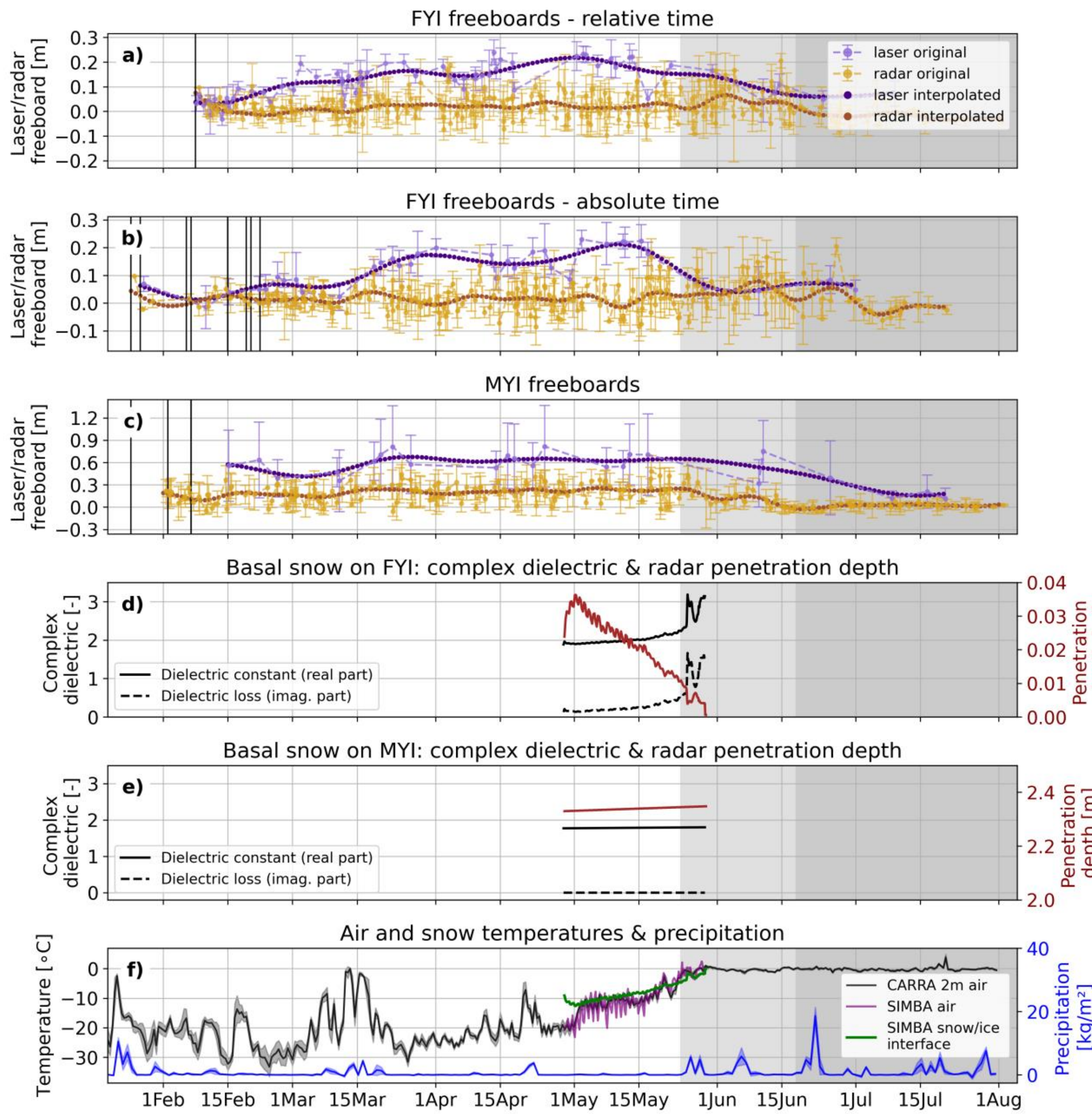
We have rephrased the title of Section 4.4.3 from ‘Removing false lead tie points’ to ‘Removing lead tie points over fast ice’. We have added the statistics about the extent of these leads in the fast ice and the results of the masking (reported MAE and RMSE), and discuss the impact the masking had on the time series.



Examples of the radar altimetry returns classified as 'lead' (red triangular marker) or 'ice' (gray/brown circular marker) in our regions of interest, when the ice has already been growing for ~3-4 weeks. The background image is a false-color RGB composite (HV-HH-HH polarization) of C-band SAR backscatter acquired by Sentinel-1.



Example of the typical monthly coverage by Sentinel-3 (left) and CryoSat-2 (right) over the study area, here shown for March 2022. It shows the radar returns before the fast ice mask is applied, with returns classified as 'lead' marked in red, while returns classified as 'ice' are shown in brown scale. Note the amount of red markers inside the ROIs (blue polygons), and generally inside the fast ice (dashed black polygon).



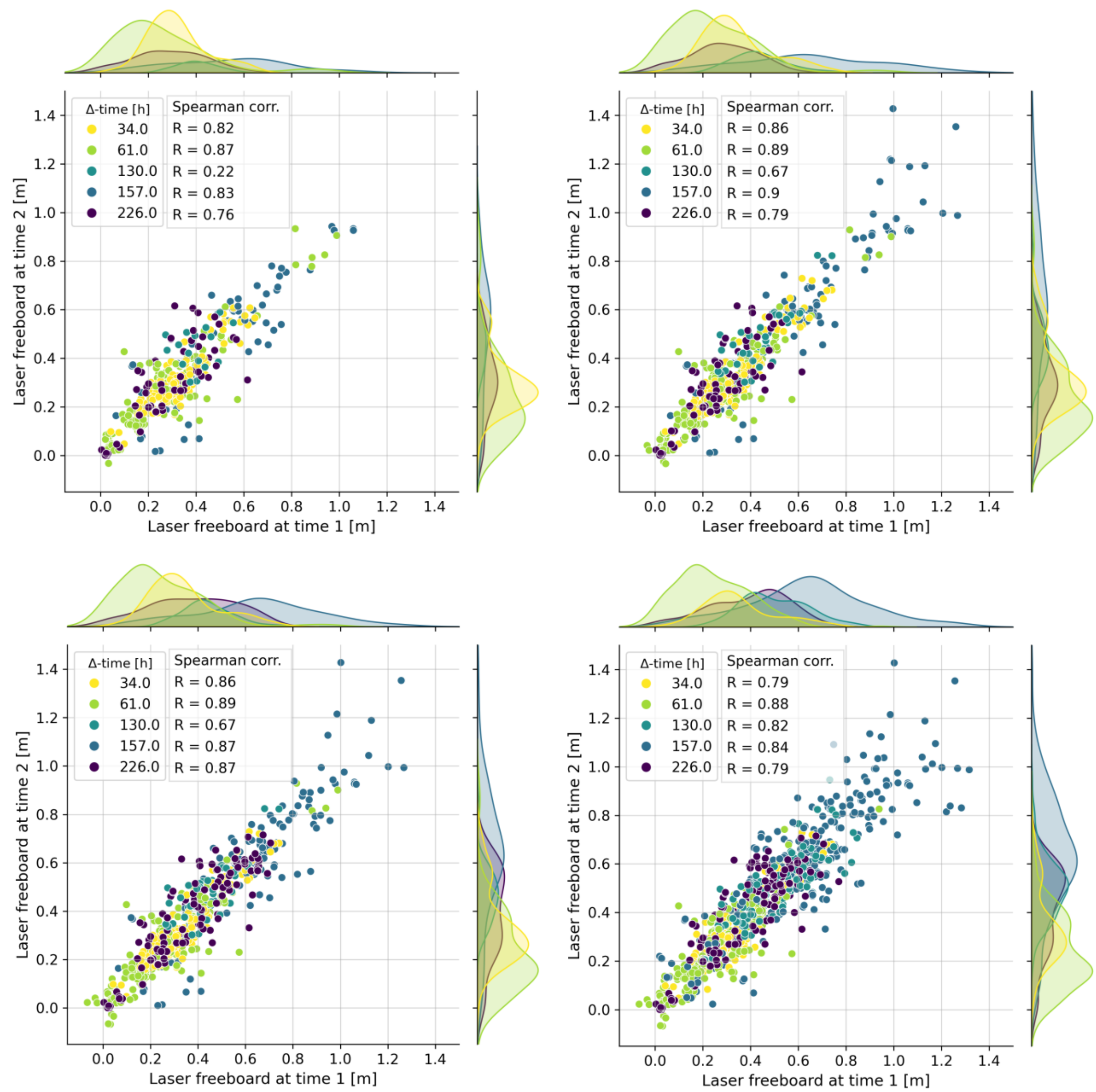
The time series of radar freeboards <u>without</u> applying the fast ice mask when identifying lead tie points. The increases in radar freeboard during periods of warmer temperatures and precipitation are also visible in this time series, confirming that the masking of lead tie points over the fast ice does not artificially create the increases we are observing.

- Section 4.5: The approach used to fill gaps in the ATL10 freeboard is interesting, but the rationale needs further justification. What was the basis for selecting a 100 km radius instead of, for example, 10 km for accumulating lead tie points? Were other distances tested to determine the optimal threshold? Furthermore, the inverse distance squared weighted (IDW) interpolation method might be too simplistic given the complex ice dynamics typical of near-shore environments; this limitation should be discussed.

The choice of a 100 km radius for accumulating lead tie points - contrasting with the stricter 10 km default threshold used in the standard NSIDC ATL10 product - is based on a trade-off between spatial coverage and data quality. While the NSIDC ATL10 product uses a strict 10 km limit to ensure high data quality for downstream monthly aggregates where data density is high, our objective requires maximizing spatial and temporal laser coverage over the ROIs. The ROIs are located around 0-65 km from the fast ice edge, so the standard 10-km ATL10 limit provides no data coverage over a large part of our study sites. We acknowledge that the inverse distance squared weighted (IDW) interpolation method is relatively simplistic and may not fully capture the complex ice dynamics typical of near-shore environments. However, implementing a more complex extrapolation scheme without rigorous, independent validation could introduce greater uncertainties and artifacts than the straightforward IDW approach.

To determine the optimal distance threshold for lead tie points and to validate the interpolation scheme, we performed the IS-2 cross-over analysis using maximum search distances of 50, 80, 100, and 120 km for the lead tie points. This analysis evaluates independent laser altimeter overpasses intersecting over the same ice within a set time window. The 100 km distance was ultimately selected because it was shown to maximize data coverage while ensuring robust sea surface height estimates. This can be seen in the scatterplots showing the cross-over analysis results and correlation coefficients for the distances of 50, 80, 100, and 120 km (shown below). The analysis shows that i) data density increases when increasing the maximal search distance for lead tie points, and ii) laser freeboards generally show good agreement between overpasses, with correlation coefficients in the range 79 - 86 for intersections with a time lag of 34 hours. Some variability is expected due to the nature of the experiment, as we do not look at exact repeat passes, but rather at intersections where track A does not sample the exact same ice surface as track B. The correlation coefficients across the different time lags are stable or even slightly improve for maximal lead tie points distances up to 100 km, but start decreasing for 150 km distance. We concluded that the IDW method with 100 km distance threshold provides reliable sea surface height estimates while maximizing laser altimetry coverage and use this method to obtain a laser freeboard for each ATL07 height sample without corresponding ATL10 freeboard.

We have updated the description of the methodology in Section 4.5.1 of the manuscript to clarify the choice of the 100 km distance for lead tie points, and also updated the corresponding Supplementary Material, Section A4.



Results of the IS-2 cross-over analysis for a maximum lead tie point search distances of 50, 80, 100, and 150 km (top left to bottom right).

- Section 4.6: While constructing this time series for laser and radar freeboards provides a more comprehensive picture, it is difficult to confidently assume that all tracks intersecting the ROIs within the study period are similar enough to reconstruct a single time series. Given the fine spatial resolution of IS2, one can expect varying snow distributions between tracks and differences among beams. Similarly, the spatial distance between the CS2 and S3 tracks could result in observations of different snow distributions. I recommend providing further analysis to account for these spatial and temporal variabilities and to ensure consistency between the instruments.

We agree that representation issues are potentially problematic when building such a time series from along-track freeboard estimates. When originally creating the time series, we investigated where representation issues are present and subsequently adjusted the workflow to construct the time series in a way that minimizes the impact of representation issues. Here is an overview of our reasoning and workflow:

- ICESat-2: We agree that different overpasses might sample different snow distributions within our ROIs. For FYI, we see in Figures 6b, 7, and B1 that the IQR variability of the original IS-2 freeboards (i.e. not interpolated) is very consistent throughout the time series. For each of the 15-day time periods in Figure 7 and B1 the IQR is in the range 0.05-0.1m. The same is visible in the detailed time series of Figure 6b, where most freeboard samples that are acquired close in time have similar IQR values, with only a few exceptions (IQRs are represented by the vertical error bars). This is not unexpected, as the landfast FYI grows in quiescent conditions without strong ice deformation/ridging, and the ice is therefore very level and smooth, which leads to a relatively homogeneous snow accumulation. Still, some variability in median laser freeboards is visible in the time series of original laser freeboards (Fig 6b). For MYI, however, we see that the IQR is generally larger and more variable. This is expected as the MYI surface is much rougher and has accumulated snow over a longer time period, leading to a very heterogenous snow distribution. Representation issues are thus much larger over the MYI ROIs than over the FYI ones. Additionally, laser altimetry coverage is poorer over the MYI ROIs compared to the FYI ROIs.

  A first step towards mitigating these representation issues is taken by calculating the median laser freeboard of all six beams together per overpass instead of considering all six beams individually. This results in a fair amount of spatial averaging as the tracks intersecting ROIs have lengths in the range 1-38 km, and the IS-2 beam pairs are ~90 m apart and are separated ~3 km across track. This strongly reduces the random uncertainty that arises from sampling different snow distributions. Then, remaining day-to-day inter-track variabilities in median laser freeboard are dealt with when we interpolate the original freeboards to daily resolution using the Radial Basis Function with Gaussian kernel (which acts as low-pass filter). We believe the two-step spatio-temporal averaging approach used to construct the laser freeboard time series minimizes the impact of representation issues, but we acknowledge that we are not able to rule them out.

- CS-2/S-3: the first main difference compared to IS-2 is that the combination of these three sensors ensures more detailed spatial and temporal sampling of the study site (see Figure A1 for a visual example of the monthly coverage by S-3 and CS-2). Furthermore, as shown in the histograms of Figures 7 and 8, the radar freeboard distributions of CryoSat-2 and Sentinel-3 are nearly identical across all 15-day intervals, even when the coverage with CryoSat-2 is poor (i.e. a few tracks only). In Figure B1 we see that the IQR for radar freeboards is stable throughout the winter time, for both ice types. This proves that CS-2 and S-3 observations do not suffer from major representation issues over our ROIs, regardless of ice type.

  We apply the same spatio-temporal averaging procedure as for the IS-2 laser freeboards. First, we spatially average over scales ranging from 1- 38 km when calculating the median radar freeboard per track crossing a ROI. This along-track spatial averaging strongly reduces the random uncertainty that is inherently present in the radar altimetry sampling. The few individual overpasses that have a large difference in median freeboard compared to neighboring samples (seen in Fig 6b/c) are dealt with in the subsequent temporal interpolation step. We conclude that representation issues are minimal in the interpolated radar freeboard time series.

We have added these considerations about representation issues when constructing the time series in Section 4.6 of the manuscript, as well as a cautionary statement regarding potential remaining representation issues in the IS-2 time series, especially for MYI.

- Section 4.7.2: Using snow depth from LaKu is a positive step away from relying on climatology or models. However, did the authors consider the uncertainties inherent in these approaches, as noted in recent validation studies (e.g., Fredensborg Hansen et al., 2024; Saha et al., 2025)? Given that these uncertainties are often quite significant even over landfast ice (Saha et al., 2025), I suggest discussing how they might impact the subsequent ice freeboard and sea ice thickness derivations.

We have updated Sections 4.6 and 4.7.2 to include a discussion about the uncertainties in radar and laser freeboard retrievals, and how these uncertainties impact LaKu snow depth retrieval and subsequent ice thickness derivations.

The along-track spatial averaging step used when constructing the time series strongly reduces the random uncertainty that is inherently present in the radar and, to a lesser extent, laser freeboards. It also reduces the random uncertainty that arises from sampling different snow distributions, especially over MYI. The subsequent temporal averaging step further reduces the random errors that affect the median freeboard of individual crossings, mitigating both representation issues and random biases introduced due e.g. errors in the SSHA estimation. With this the two-step spatio-temporal averaging procedure we expect the random uncertainty in our LaKu snow depth time series to be lower compared to the values reported in studies of along-track Laku snow depth such as in Fredensborg Hansen et al. (7 cm) and Saha et al. (2-4 cm). Compared to the study of Saha et al. where LaKu snow depth is obtained over landfast ice from differencing absolute sea ice heights, we have lead tie points available close to our study sites and therefore use the conventional freeboard differencing method which has lower uncertainty. Nevertheless, we are not able to reliably assess the random uncertainty in our time series. Regarding systematic uncertainty, we can only minimize the systematic bias introduced due to the footprint size discrepancy between the laser and radar altimeters (see specific answer further down about the impact of footprint size discrepancies). Quantifying the systematic uncertainty would require more comprehensive in situ validation data covering the entire study area and period, which we do not have. The isolated comparisons between LaKu snow depths and in situ data from our visit in April are very consistent over FYI and MYI ROIs (Fig. 10 panels b and f). Since we do not have a good estimate of the average uncertainty, we report the IQR and use this to visualize the spread in the freeboard retrievals and subsequent snow depth and ice thickness estimates, as can be seen in Fig. 10.

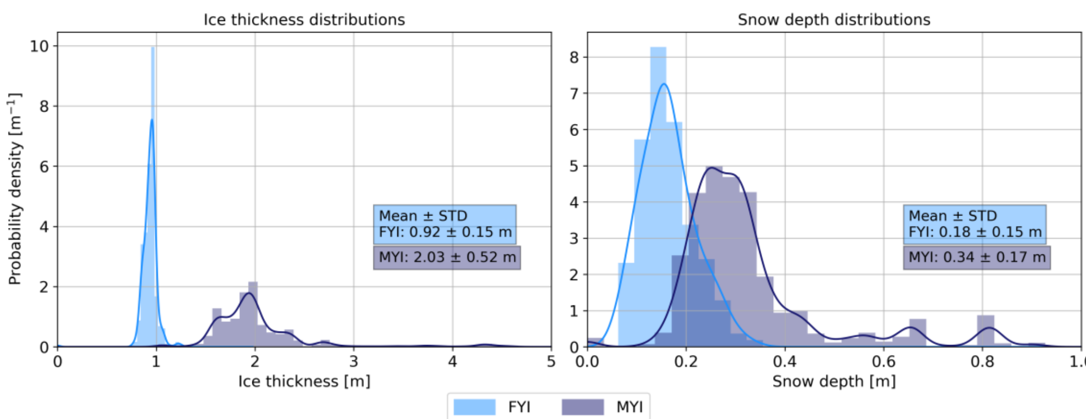
- Figure 4 (Salinity): One snow pit appears to have a significantly different salinity profile (median ~4 PSU). Is there a physical explanation for this discrepancy, and what does it suggest about the snowpack on that specific FYI ROI?

The figure shows median values across all snow pits per ice type, not individual snow pits. The y-axis shows the relative height in the snow pit. So, this figure shows that only the basal layer of the FYI snow pits was saline, with a median salinity of 4 PSU.

- Figure 4 (Hardness): The IQR for one of the FYI snow pits ranges widely between F and K (with a median of 1F). Is there a particular reason why the hardness values varied so significantly in this instance?
  As for the snow salinity, the hardness is also shown as the median + IQR across all snow pits versus relative height inside the pit, so no individual snow pits are represented anywhere.

- Figure 5: This plot could potentially be simplified and made more readable by separating the ice and snow depth data into two distinct panels.

  We have now split this figure into two subplot panels for clarity.



- Line 475: How were the uncertainty values for the snow depth and ice thickness measurements from the MagnaProbe and GEM determined?
  The values reported here are the mean and standard deviation of the snow depth and ice thickness values obtained across all transects, per ice type, which we have now stated in the figure caption.

- Lines 490–495: The dichotomy presented here regarding the laser freeboard time series is interesting and warrants further discussion regarding the physical mechanisms that could potentially explain this phenomenon.
  We present a detailed analysis and potential causes for the contrasting behavior of the laser and radar freeboards in the FYI time series around melt onset in the discussion (Section 6.2.2).

At the start of melt onset (24 May) the laser and radar freeboards start dropping for MYI. Over FYI, however, radar freeboards rise while laser freeboards decline. This uptick in radar freeboards starts before melt onset, with the first elevated freeboards around 17 May, and lasts until 7 June. Radar freeboards rise by ~8 cm in this time period, while air temperatures go from -10 to 0 °C and snow temperatures from -8 to 0°C. Vertical snow temperature gradients from the SIMBA instrument reveal a transition period between mostly positive gradients to negative gradients between 16-22 May (Figure B2 in Supplementary Material). This coincides with the appearance of the first elevated radar freeboards (individual crossings >0.1 m), but no clear changes are seen in the waveform parameters before melt onset. At the start of melt onset, a change in C-band backscatter is observed over both FYI and MYI, implying geophysical changes in the properties of the snowpack across the entire study region (Karlsen et al, 2024). However, we only observe a concurrent change in nadir Ku-band backscatter over FYI, not over MYI which is relatively stable, with the LEW also changing for FYI. So, the changes in the snowpack evident in C-band SAR only seem to manifest as a clear change in waveform parameters over FYI.

We evaluate different physical mechanisms that could be causing the Ku-band radar freeboards over FYI to increase around melt onset while laser freeboards and MYI freeboards show the opposite behavior:
- Saline basal snow layer
- Wet snowpack
- Superimposed ice
- Melt ponds

From this analysis, we conclude that the increase in FYI radar freeboards during melt onset is a bias that is most likely caused by the saline snow, and potentially exacerbated by simultaneous snowfall. This theory is backed-up by the radar modeling results showing an exponential increase in the complex dielectric constant of saline snow when the brine volume fraction exceeds 0.01, i.e. 1%.

- Lines 515–524: When comparing the time series between laser and radar freeboards, the inherent difference in footprint size must be carefully considered. I encourage the authors to include a discussion on how these differing footprint sizes impact the conclusions of the comparative analysis. Specifically, how much of the observed difference is likely due to the footprint size discrepancy rather than differences in snow/ice interaction?

The potential impact of footprint scale discrepancies between the laser (~17 m) and radar (~300 m) sensors is largely mitigated in the spatial averaging step where we compute the median and IQR range for each individual track. Using the median instead of the mean prevents topographic features resolved by the finer laser footprint size, but potentially missed by the larger radar footprint (e.g. ridges), of influencing the result. In a second step, we interpolate these median laser and radar freeboard values to daily resolution using a Radial Basis Function with Gaussian kernel. This kernel effectively acts as a temporal low-pass filter, thus mitigating the random uncertainty that affects freeboards of individual altimetry crossings. This two-step filtering process minimizes the bias introduced by footprint size differences between the sensors, so we believe the differences between the laser and radar freeboard time series can mostly be attributed to the wavelength differences and the respective interaction of these waves with the snow and ice cover, or choices in the retracking process.

We have updated Section 4.6 to clarify the reasoning behind the choices we have made in the construction of the time series, and be more explicit about the impact of the spatio-temporal averaging on the final time series and on the uncertainties related to laser and radar freeboard retrievals.

- Figure 7: Excellent figure; the alignment of CS2 and S3 is impressive. A few suggestions: (i) What is the cause of the bi-modal distribution of the IS2 freeboard in the June plot? (ii) Please include the number of tracks (n) for each sensor within each sub-plot. (iii) For the 15-day periods with limited laser and radar tracks, please discuss how representative those time series are for that period. (iv) Consider using slightly more distinct colors for CS2 and S3 to improve contrast.

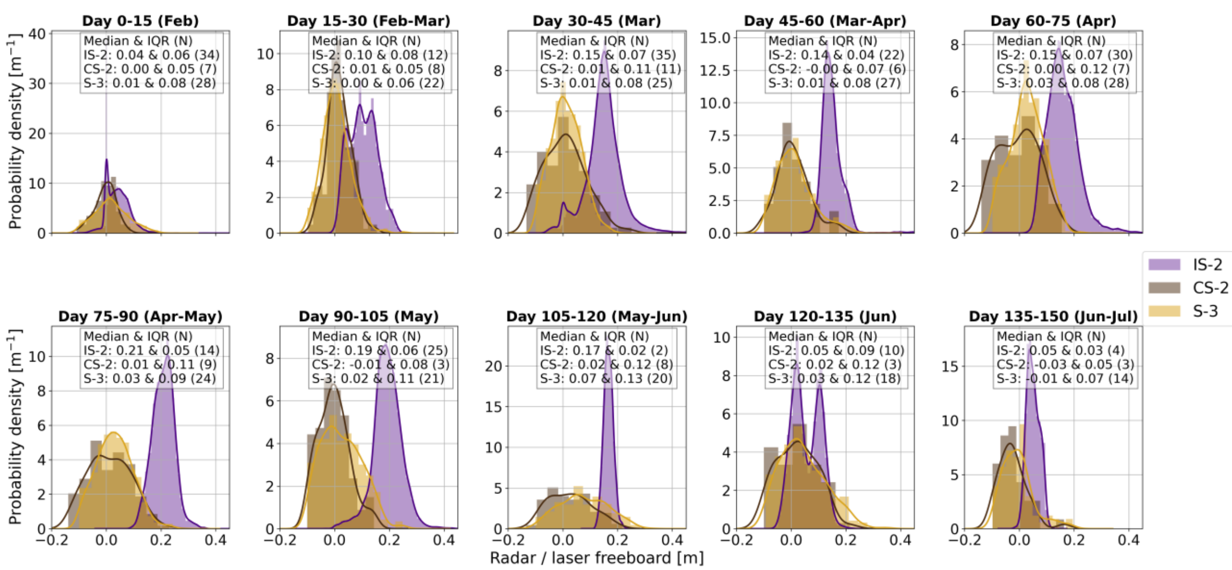
  Thank you for these suggestions to improve the clarity of the figure. We have updated Figure 7 and the text as follows:

  (i) Cause of the bi-modal IS2 distribution in June: we agree that this is an interesting feature. We suspect this 15-day time window captures the period of snow ablation, including 10 IS2 crossings where some crossings capture pre snow melt and others post melt. The right-hand peak represents the higher freeboard returns from ice that is still covered by snow (matching with the distribution of the previous 15-day period), while the left peak represents the lower freeboard returns where the snow has melted (matching with the following 15-day distribution). We have added this explanation to Section 5.2.

(ii) We have updated all sub-plots in Figure 7 to explicitly include the number of unique tracks (N) for each individual sensor within each respective 15-day period.

(iii) Representativeness of sparse 15-day windows: we have expanded the manuscript text to discuss the statistical robustness of periods with lower track density. For the radar altimeters (CS2 and S3): We find that even in periods with sparse data (e.g. when CS2 only has ~3 tracks), the resulting freeboard distributions consistently align very tightly with the independent Sentinel-3 distributions. This excellent cross-sensor agreement indicates that the radar spatial sampling remains highly representative even at low sample sizes. For the laser altimeter (IS2): due to the finer footprint size and the fact that only one sensor is available, it is harder to assess representativeness in time windows with few overpasses. We have added a cautionary note in the text stating that interpretation of the IS2 histograms should be treated with care in windows containing fewer than 5 overpasses.

(iv) Color contrast optimization: we have updated the color scheme of Figure 7, shifting away from the original overlapping tones and implementing a distinct gray tone for one of the radar altimeters to better differentiate CryoSat-2 from Sentinel-3.



Updated Figure 7, here shown for FYI.

- Line 573-575- This uniqueness may potentially be included in the introduction. Just a suggestion.
  Thank you for this great suggestion. We have included this in the last part of the introduction.

- Line 590- I would recommend providing a statistics comparing the impact of including the negative freeboard vs excluding. What percentage of the readings were negative freeboards?
  We have not filtered out any negative freeboards, but rather set negative LaKu snow depths to zero, as it's physically impossible to have a negative snow depth, and this would propagate unrealistic values in the SIT calculations. The snow depth has been set to zero for the period 10-16th february, as can be seen in Figure 10 panel b), so only for a brief part at the start of the time series over FYI. The negative snow depth in this time period is a direct consequence of the interpolated radar freeboards being higher than the interpolated laser freeboards (see panel a) of Fig 10)). This period is the moment is forms in the FYI regions, and radar freeboards are high owing to wave-affected radar returns and/or retracking errors (more details are given in Section 6.2, paragraph about newly-formed ice).

- Line 594- I'm curious the extent of impact using the interpolation scheme had on the overall freeboard time series? Is this leading to any over-generalization in the freeboard values? Also, are the interpolated values being used for the freeboard comparisons e.g. in Figure 7 and 8?
  The histograms in figures 7 and 8 are generated using all original along-track freeboard samples, so they do not include interpolated values. The impact of the interpolation is visible in Figure 6b/c, as this shows both the original and interpolated freeboards in the same plot. The interpolation is most likely over-generalizing the trends in freeboards, as changes in freeboard height related to synoptic weather systems that fall below the kernel size are either entirely smoothed away, or at least underestimated in the interpolated time series. This is more impactful for the laser freeboard time series, with sparser data coverage, than the relatively dense radar freeboard time series. Nevertheless, an interpolation that over-generalizes is preferred over one that under-generalizes, as we need to ensure that trends in the time series are not originating from the variability that is inherent in the altimetry sampling (owing to noise and representation error).

  We have updated Section 4.6 in the manuscript to include this information.

- Figure 10: For the SIT over MYI, there appears to be better correspondence between the modeled results and the in-situ data compared to the altimetry. What factors are driving this difference?

  The modeled SIT for MYI relies heavily on the assumed SIT at the modeling start date, which in our case was set to 0.3 m on 10 October 2021, as described in Section 4.8. We therefore believe the correspondence between modeled SIT and in situ measured SIT for MYI is a coincidence. This is not the case for FYI as we have SIT=0 m at the start of the FYI time series and can therefore more reliably model ice growth throughout our time series and compare the modeling results and the in situ data.

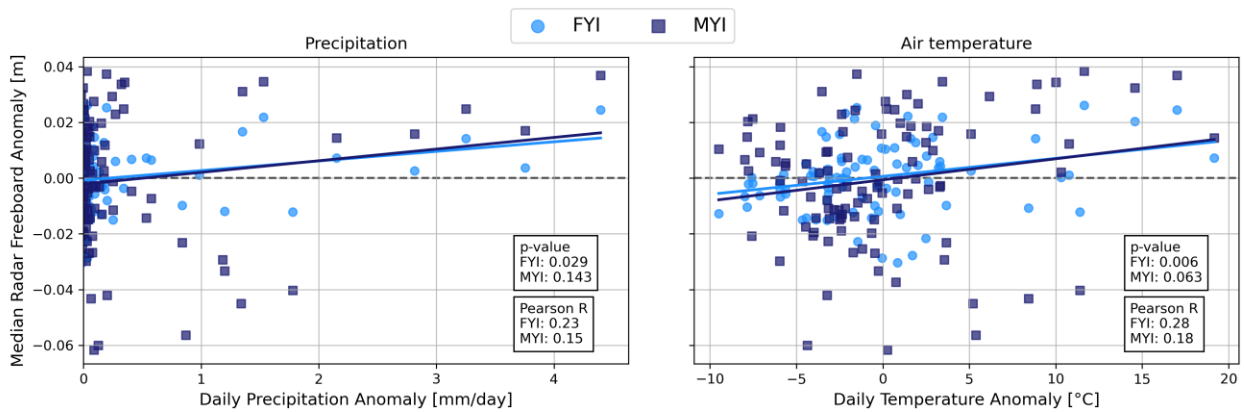
  The variability in IQR between altimetry crossings over MYI ROIs suggests that the thickness of MYI within the fast ice was highly variable. The discrepancy between altimetry and in situ SIT for MYI could therefore be entirely caused by representation issues, given the in situ data was collected over a transect of 1 km versus a total area of 1340 km^2 for the MYI ROIs. The vertical offset between the SIMBA-derived and altimetry-derived laser and radar freeboards also illustrates this.

  We partly touched on this subject in Section 6.1 (thick snow cover), so we have now updated this section to include a discussion about the correspondence between the modeled and in situ MYI SIT, while the altimetry-derived SIT is higher.

- Line 694- I'm not convinced that the time series trends challenging the common understanding that snow loading weighs down the ice down resulting in decrease in radar freeboard are well substantiated. Further analysis needs to be conducted before conclusively making this claim.

  In theory, each cm of snow accumulated should lead to an instantaneous 0.54 cm decrease in radar freeboard, for a snow density of 300 kg/m3 (Nab et al., 2023). During the winter warming event around mid-March there is ~5 cm snow accumulation over the course of seven days (see Figure 10 panel d). So, theoretically, the radar freeboards in our time series should decrease by ~ 2.7 cm during this time. However, we see FYI radar freeboards rising from ~0 to 4 cm and MYI freeboards rise from ~15 to 25 cm (see Figure 6 panels b) and c)), so a ~4 and ~10 cm increase for FYI and MYI, respectively. To better illustrate and quantify the phenomenon we observe, we have made a scatterplot showing precipitation anomaly versus radar freeboard anomaly. The plot confirms our observations from the time series, with a positive correlation between precipitation anomaly and radar freeboard anomaly for both ice types. Also note that this plot is made using the interpolated radar freeboard samples, so it likely underestimates the correlation.

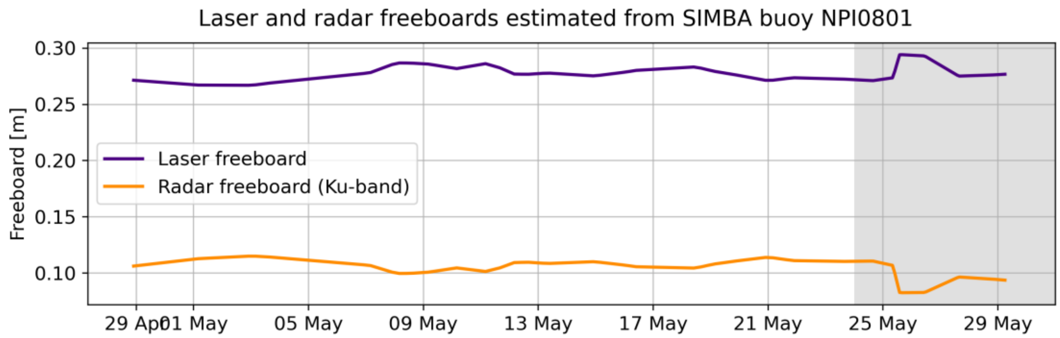
We have added this scatterplot in the Supplementary Material, and updated the text in Section 6.2.1 to be more specific.



Scatterplots of precipitation (left) and temperature (right) anomaly versus radar freeboard anomaly during the winter period of the time series. We fitted a linear regression model through the data and report the p-value and Pearson's correlation coefficient.

- Line 669- Is there a reference to this assumption made?
  We have rephrased this section and added clarification as to why we believe the in situ data over MYI in this study is likely not capturing the snow depth and ice thickness of the most deformed areas.

  The transects of GEM and Magnaprobe used in this study were performed manually and therefore surveying the heavily deformed ice was unfeasible. In addition, we only have one transect of 1 km total that was made over MYI, whereas our polygons cover 1340 km2; well beyond the in situ sampling sites. The variability in IQR of altimetry crossings over MYI ROIs and wider distribution of in situ ice thickness data suggest that the thickness of MYI within the fast ice was highly variable. The discrepancy between altimetry and in situ SIT for MYI could therefore be entirely caused by representation issues. Hence, the thickest ice and snow is likely not well captured in the in situ measurements. The vertical offset between the SIMBA-derived and altimetry-derived laser and radar freeboards (in Supplementary Material, and shown below) also shows that the in situ measurements over MYI suffer from representation issues, as a single SIMBA buoy cannot capture the variability in snow and ice thickness of the highly heterogeneous MYI surface within the ROI polygons.



Laser and radar freeboard estimates obtained from the SIMBA snow and ice thickness time series. The vertical offset between these laser and radar freeboards and the altimetry-derived freeboards is due to representation issues, as a single SIMBA buoy cannot capture the variability in snow and ice thickness of the highly heterogeneous MYI surface within the ROI polygons.

- Line 710: Year missing in the in-text citation.
  We have added the year.

- Figure 11: Excellent Figure!

- Line 719: Was this bias reported in the results section? If not, I would suggest providing a detailed analysis of this bias as high as 400% for FYI.
  We agree that this needs better clarification. The FYI radar freeboards go from ~0 to 4 cm and back to 0 cm over the course of the winter warming event (a period lasting ~7-10 days). This is a 4 cm bias and corresponds to 160% bias in SIT. The 400% bias in radar freeboard that was mentioned in the conclusion might have been misleading, so we took it out. It was so high because the radar freeboard increases from a very small value (close to zero) to 4 cm. Instead, we now report only the absolute bias in radar freeboard and then the resulting relative bias in SIT. We have included a description of how this bias is obtained in the discussion (Section 6.2.1) and reformulated the concluding statements.

- Line 738: While observations do support the conclusions drawn here, I believe the authors need to state more explicitly that the exact percentage of impact of these factors during warming events could not be quantified.

We have included this into a new paragraph in the discussion (see also the reply to Reviewer 2).

In particular:
In summary, we observe short-term periods (~7-10 days) with positively biased radar freeboards, both during winter and melt onset. We believe the bias arises when scattering processes in the snow and ice deviate from the assumed behavior at the Ku-band wavelength, which is that the main radar return originates from surface scattering at the snow/ice interface. However, we do not have the data required to ascertain the exact magnitude of the biases, fully separate the drivers (i.e. warmer temperatures, snow accumulation, saline snow, or a combination of these factors), nor to quantify their relative contributions.

- Line 805: Some quantitative comparisons with these studies would be helpful here.
  Good suggestion, we have added the following comparison in the revised manuscript.

  Landy et al. find that the mean snow depth on new ice in the Atlantic sector is 14.9 cm within five days of formation, suggesting that frequent storms deposit large amounts of snow and new ice is quickly being snow-covered in this region. Over the newly-formed ice in our time series, we observe ~5cm snow cover within a week after formation, and ~15cm snow cover after 1 month.

- Code Availability: According to The Cryosphere (TC) guidelines, the data and code must be published open-source. Please double-check the journal's requirements and ensure that valid links to the available data/code are provided prior to publication.
  We will publish the data set and any code needed on public repositories (Zenodo/Github).

Reviewer 2

[Synopsis and recommendation]

This manuscript presents an empirical analysis of Ku-band radar and laser altimeter freeboards over immobile landfast first-year ice and multi-year ice off northeast Greenland. By exploiting the fast-ice condition, the authors are able to follow approximately the same sea-ice areas from ice formation through winter and into the melt season. This is a valuable and novel observational framework, and the topic is highly relevant for The Cryosphere.

Overall, I find the study interesting and potentially important. However, I think several key interpretations need to be better qualified. In particular, the manuscript often interprets variations in retracked Ku-band freeboard as evidence for changes in the radar scattering horizon, but the retrieved freeboards are also affected by retracker behavior and processing choices. The manuscript would be strengthened by more clearly separating these two effects, or at least by explicitly acknowledging where they cannot be separated. I therefore recommend publication after major revision.

[General comments]

This is a very good and novel idea: obtaining time series of altimeter observations over the same ice floes by taking advantage of non-drifting fast ice. Our community needs more studies of this kind, and the approach is well suited to investigating the temporal behavior of laser and radar freeboards.

My main concern is that the interpretation currently mixes two different sources of variability: first, deviations between the assumed Ku-band radiative process and the actual scattering process in the snow–ice system; and second, limitations or biases of the retracking algorithm itself. Much of the analysis is based on retracked radar freeboard, which is affected by both. A positive bias in retrieved freeboard can arise not only because the relative contributions of air/snow, snow-volume, and snow/ice scattering change, but also because of how the LARM retracker handles fixed or constrained model parameters and the optimization procedure. Please discuss this coupled issue more explicitly throughout the manuscript.

We agree that this coupled issue could be better described and discussed in the manuscript. We have therefore added a section in the Introduction and Discussion to point out that variability in radar freeboards can indeed also originate from choices in the retracking process.

A radar altimetry waveform must be “retracked” to obtain an accurate measurement of the range between the altimeter and the principal radar backscattering height on the snow and ice surface. The LARM algorithm determines the retracking point by fitting the modeled echo to the observed waveform through a least squares optimization of four free parameters: the scaled waveform amplitude (A), the tracking point of the mean radar scattering surface (t_0), the surface topography rms height (σ), and the small-scale roughness (s_{rms}). So, compared to fixed-threshold retrackers, the retracking point chosen by this physical retracker takes into account how the surface roughness within the radar footprint modifies the waveform. In theory, LARM is thus producing the optimal height estimate of the principal backscatter response - assuming there are no biases in the radar model or its assumptions. In this manuscript, we test this concept by applying the LARM retracker to retrieve a time series of radar freeboards over the same ice. Since the retracking point is directly linked to the shape of the waveform, it is challenging to assess whether a temporary positive bias corresponds to a rise of the principal radar backscattering height in the snow and ice, or if it is an artefact introduced purely by the retracker. However, by careful inter-comparison of the time series of radar freeboards, radar waveform parameters, and C-band SAR time series, we find pieces of evidence pointing towards the fact that, during winter, the temporarily biased radar freeboards seem to originate from changes in the scattering processes of the snow and ice, rather than being introduced purely by the LARM retracker.

One of the parameters optimized by LARM is the surface topography root-mean-square (RMS) height, or more explicitly the RMS of the radar scattering distribution if it is not just a sinlge surface contributing to the detected waveform. Figure B5 in the Supplementary Material (shown below) shows the seasonal evolution of this parameter for both FYI and MYI. For MYI we see that the surface roughness closely follows the patterns of atmospheric conditions during the winter: periods with warmer temperatures and heavy snowfall have higher roughness. These are also the periods where we observe heightened radar freeboards over MYI. The MYI has a baseline roughness around ~10 cm during winter, which temporarily rises to ~20 cm during the warming events of mid-March and late April, and even further in May right before melt onset. Remarkably, no concurrent changes in other waveform parameters or Ku-band backscatter are observed for MYI, though there is a temporary decrease in C-band SAR backscatter in the HV-polarization during the mid-March warming event and in the period leading up to melt onset (see Fig. 9). A drop in SAR HV-polarized backscatter indicates a decrease in volume scattering, and an increase in surface roughness means the waveform has broadened; both implying actual changes in the scattering processes on the surface. The fact that two independent sensors observe a change is a strong indicator that the temporary increases in radar freeboard over MYI are caused by changes in the scattering processes on the surface, rather than being a bias introduced by the LARM retracker.

For FYI we also see an increase in surface roughness in periods of higher temperatures and snowfall, but the increase is less pronounced and not of temporary nature. The time series of large-scale surface topography (shown below) shows that the FYI is very level and smooth, with roughness<3 cm at the start when the ice is newly-formed. We see a first slight increase in roughness to ~5cm during the warming event in mid-March, when the newly-formed ice first gets snow-covered. In contrast to the radar freeboards that decrease again after the warming event, the roughness stays ~5cm. We observe a large, concurrent shift across all waveform parameters for FYI, and a decrease in nadir Ku-band and C-band SAR backscatter (see Fig. 9). Again, the fact that we see a simultaneous change in the C-band SAR backscatter indicates that the rise in FYI radar freeboards originates from a change in the scattering processes in the snow and ice. In contrast to the radar freeboards that decrease again to values observed before the warming event, the waveform parameters stabilize at the new values, indicating a lasting change is introduced on the snow and ice surface during the period with warmer temperatures and snowfall. This lasting change could e.g. be a densification of the snow due to wind packing. The fact that the radar freeboard increase is temporary whereas the waveform parameters change irreversibly points to the presence of a second mechanism rising the FYI radar freeboards in periods of warmer temperatures and precipitation. In addition, the relative increase in radar freeboard is larger over FYI than over MYI, even though the surface roughness increase is larger over MYI. We suspect the saline basal snow layer over FYI could be causing this additional increase during periods of warmer temperatures.

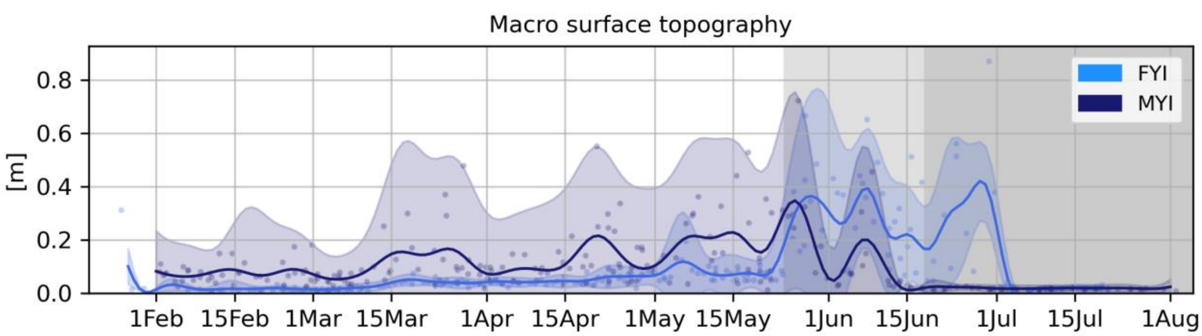


Figure B5 of the Supplementary Material. Time series of surface topography root-mean-square height; one of the four free parameters optimized by LARM.

Thus, for both FYI and MYI, we believe the temporary increases in radar freeboard are likely the result of changes in the scattering processes in the snow and ice, or a physical change in the freeboard height, rather than being artefacts introduced purely by the LARM retracker. This leaves us with the question of whether the temporary increases in radar freeboard correspond to a physical increase of the ice freeboard, or if they are unphysical, i.e. a bias between the retracked ice freeboard and the actual location of the snow/ice interface. Note that in this study, we defined radar freeboard as the height of the principal backscatter response from the snow/sea ice interface relative to the local instantaneous sea surface height. Thus, the derived radar freeboard can be biased (under- or overestimated) if the principal backscatter response does not originate from this interface.

The ice we track is entirely immobile during the entire time series and thus experiences minimal to no dynamic thickening. If the 4 cm increase in radar freeboard seen during the warming event in mid-March was a physical increase in freeboard, this would imply ~0.4 m thermodynamic ice growth in 10 days. Such rapid ice growth would require cold conditions, which is not the case during the warming event. In addition, there is ~5 cm snow accumulation over the time of the event, which should reduce the physical freeboard. Theoretically, each cm of snow accumulated leads to an instantaneous 0.54 cm decrease in radar freeboard, for a snow density of 300 kg/m3 (Nab et al., 2023). In our time series, this would translate to a ~ 2.7 cm decrease in radar freeboards during the warming event in mid-March. The fact that we see a 4 cm increase instead implies the presence of a strong counteracting mechanism. We are not aware of any physical mechanism that could temporarily raise the freeboard as much and therefore suspect this increase to be a radar scattering bias. The same argument holds for the temporary increases in radar freeboard observed over MYI, which also coincide with periods of heavy snowfall.

The in situ snow depth and ice thickness measured with the GEM and Magnaprobe devices are in good agreement with the altimetry-derived snow depth and ice thickness for FYI. Even though this tie point is only available in late April, it indicates that the interpolated median values in the altimetry-derived time series are not far off from the true values. The time series of in situ snow and ice thickness estimated from the SIMBA buoy is only available for one month (May). No changes in the location of the air-snow and snow-ice interfaces are detected during this period. As the ratio of snow depth and ice thickness are constant throughout the SIMBA time series, and if we assume constant densities for the snow, ice, and water, the ice freeboard also remains constant. We have derived the laser and radar freeboard time series corresponding to the snow depth and ice thickness obtained from the SIMBA buoy. This time series confirms that there are no physical increases in MYI freeboard from April 28 until melt onset on May 24. Unfortunately, the SIMBA buoy did not acquire data when we see the increases in altimetry-derived radar freeboards, nor any data over FYI, so we cannot use this in-situ time series to verify whether the increases in radar freeboard are unphysical or represent real changes in the ice freeboard. What we can say, though, is that no superimposed ice is forming around melt onset.

In summary, we observe temporary increases in radar freeboard that cannot be linked to physical increases of the ice freeboard, and we see concurrent changes in C-band SAR backscatter. We thus suspect the temporary increases in radar freeboard to be a bias that arises when the scattering processes in the snow and ice do not correspond with the assumed behavior of Ku-band radar waves, i.e. the main return originates from surface scattering at the snow/ice interface. However, we do not have the data required to ascertain the exact magnitude of the bias, fully separate the drivers of the bias (i.e. warmer temperatures, snow accumulation, saline snow, or a combination of these factors), nor to quantify their relative contributions. The biases we report are based on the interpolated time series and are therefore minimal estimates.

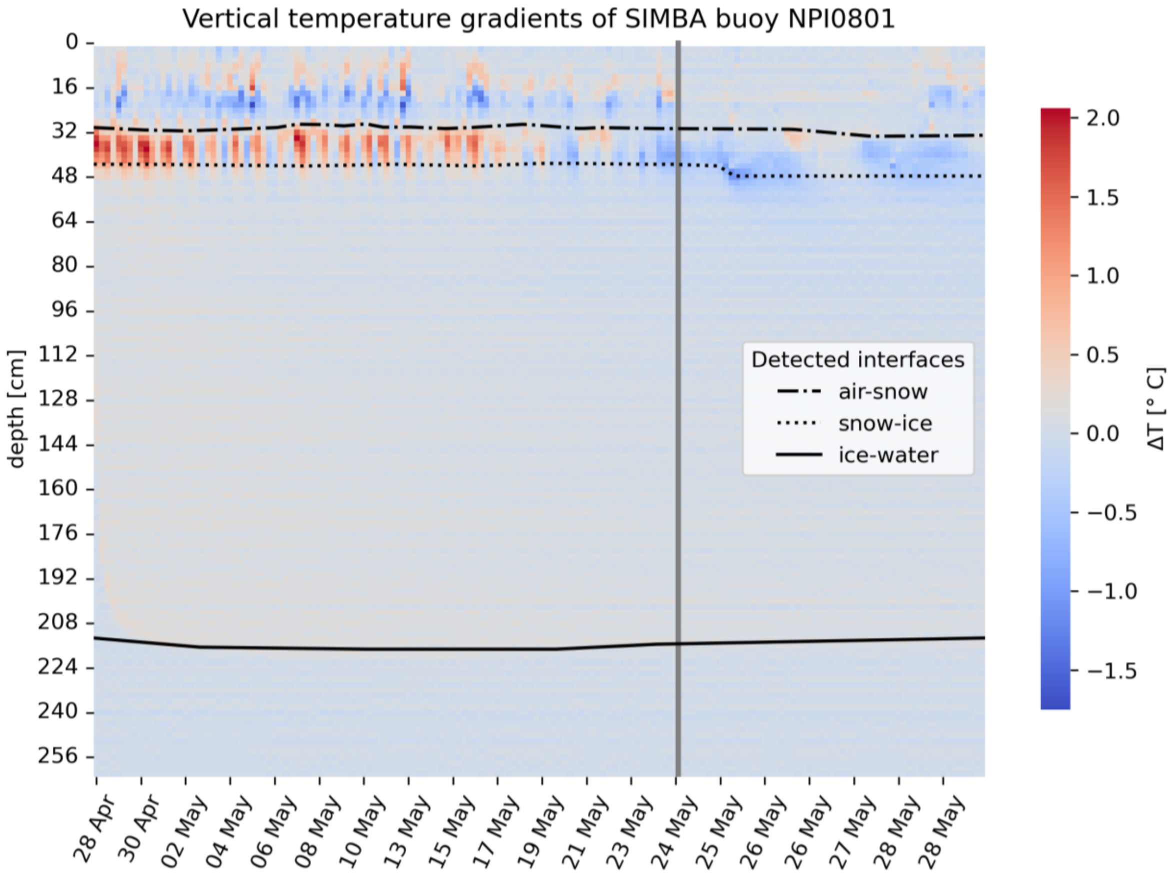
Concerning the variability between retrackers, since height estimates from both physical and empirical retrackers are affected by changes in waveform shape as well as range, we expect the relative variations in our time series to appear similarly for an empirical retracker even if their magnitudes could be different. The retracker is not the only freeboard processing step that could affect the results; the lead classification and SSHA interpolation routines may also. It is therefore beyond the scope of the study to investigate the sensitivity of the results to all possible processing steps. For now, the findings are only proven for radar freeboards retracked with the LARM processing chain. We will publish the time series derived in this work together with a list of altimeter granules used and shapefiles of the ROIs, so that this case study can be used as a starting point to test e.g. different retrackers, classification algorithms, SSHA interpolation routines, snow depth and ice density products.

Related to this point, many previous studies used different retracking algorithms, which makes it difficult to synthesize earlier findings into a single physical interpretation. If possible, I recommend that the authors provide information on the retracker used in the studies cited in the Introduction, for example TFMRA50, TFMRA70, LARM, or other approaches. This would help readers understand whether apparent differences among studies reflect physical snow/radar interactions, retracker dependence, or both.

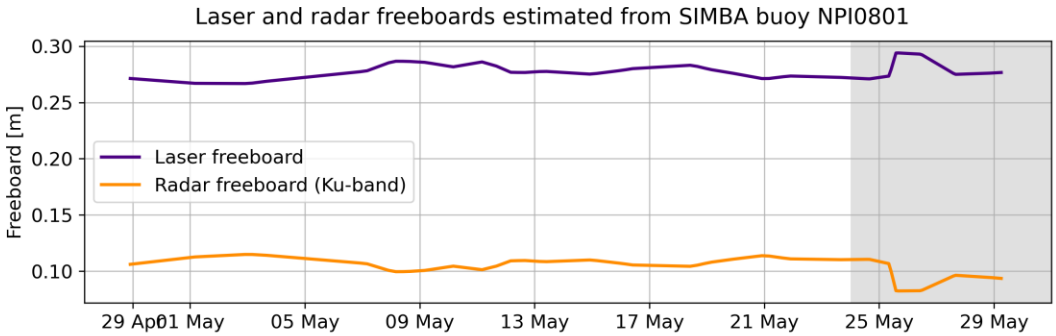
We have added the retrackers used in the studies cited in the introduction, when applicable.

I also wonder whether any time evolution of ice freeboard from in situ observations is available. It would be very helpful to verify whether the suspicious increases in radar freeboard are actually unphysical, rather than real changes in the ice/snow system. A reliable reference is critical when using terms such as “overestimation” and “underestimation.” For example, if SIMBA-derived snow depth and ice thickness are available, they might be converted into freeboard using assumed snow, ice, and seawater densities. Even if such a comparison is limited to MYI or only part of the season, it would provide useful context.

This related back to a few points mentioned earlier, so the answer is incorporated in the text above. However, to reiterate, no reference in situ observations were available for the study prior to the fieldwork campaign in April-May. The measurements from spring, at the seasonal peak of the ice thickness, therefore represent an end member from which we can evaluate the full FYI time series. We know the ice thickness starts at zero, and we know it approximately matches the seasonal peak in April-May, so “overestimation” and “underestimation” are relative to these seasonal end members. The SIMBA-derived laser and radar freeboards are stable before melt onset, confirming there are no physical increases in MYI freeboard during this period. Unfortunately, no similar in situ data is available over FYI, or at other times during the season.



Vertical temperature gradients measured by the SIMBA buoy on MYI between 28 April-29 May 2022, and detected interfaces for air/snow, snow/ice, and ice/water. Depth is measured along the thermistor string, with 0 being the top of the string. The gray vertical line marks the start of melt onset.

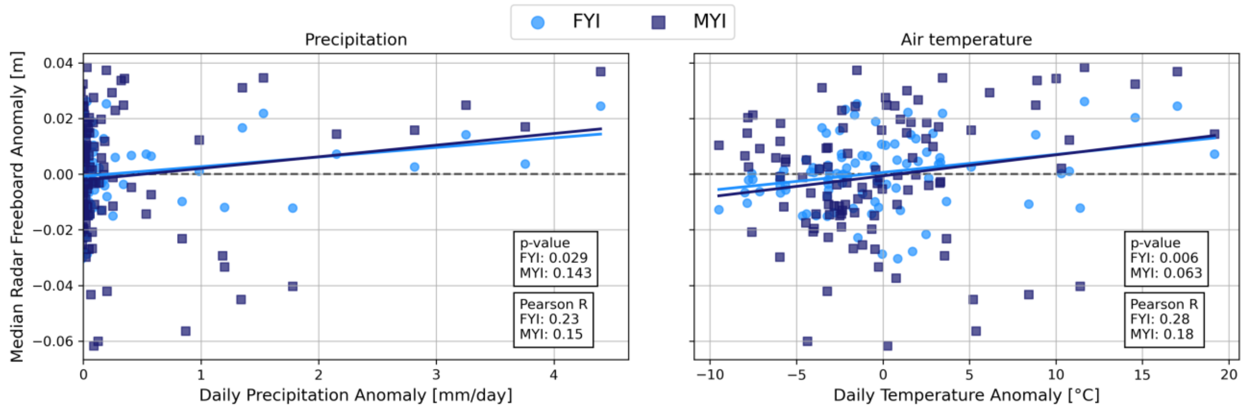


Laser and radar freeboards estimates obtained from the SIMBA snow and ice thickness time series. The vertical offset between these laser and radar freeboards and the altimetry-derived freeboards is due to representation issues, as a single SIMBA buoy cannot capture the variability in snow and ice thickness over the highly heterogeneous MYI surface within the ROI polygons.

Finally, regarding objective 3, I found it difficult to see how the stated hypotheses were directly tested. The analysis is persuasive in places, but it is mostly observational and interpretive rather than a controlled test. Since LARM is based on a physics-based waveform simulator, the authors could consider adding a controlled numerical experiment. For example, they could define a reference snow–ice scene representing the physical conditions that they argue cause positive radar-freeboard bias, simulate the corresponding waveforms, and then retrack those waveforms under the usual cold, non-saline, snow/ice-interface-dominated assumption. Comparing the retracked radar freeboard with the known ideal radar freeboard would provide a more quantitative test of the proposed mechanism.

We agree that such an experiment would add value to the study and interpretation of the results, but it is beyond the scope of this already lengthy and comprehensive paper. The volume scattering model in the facet echo model used for LARM has cannot currently simulate scattering and absorption for a snowpack with a saline basal layer, so we would not be able to accurately perform this experiment without major code updates.

To provide clearer a evaluation of the stated hypotheses, we present scatterplots showing radar freeboard anomaly versus precipitation and temperature anomaly during the winter in the Supplementary Material. These plots confirm a positive correlation between (heavy) snowfall and radar freeboard anomalies, as well as between large positive temperature anomalies and radar freeboard anomalies.



Scatterplots of precipitation (left) and temperature (right) anomaly versus radar freeboard anomaly during the winter period of the time series. We fitted a linear regression model through the data and report the p-value and Pearson's correlation coefficient.

[Specific comments]

Line 66: "Landy et al." appears to be missing the year.

This is now fixed.

Lines 68–70: The manuscript states that only a few studies report satellite-based empirical observations of biases between retracked radar freeboards and the expected snow/ice interface. Armitage and Ridout (2015) and Shi et al. (2024, especially Sect. 5.1) also address closely related issues. Please consider citing these studies.

We have added these references.

Line 381: Similar to Jutila et al. (2022), Shi et al. (2023) reanalyzed the SEVER expedition dataset, which was the basis of the widely used two-density approach of Alexandrov et al. (2010), and found that MYI density may be closer to FYI density than commonly assumed. Please consider citing this study if relevant.

We have added this reference.

Figure 6: It is somewhat difficult to understand the distinction between relative and absolute time. Please clarify this in the caption and/or main text.

We have clarified this in the caption of the figure, and a more detailed explanation is given in the text of Section 4.6.

The new caption to Fig 6: “Panels (a), (b), (c): time series of laser and radar freeboards over FYI (relative and absolute time) and MYI, respectively, showing original samples (median + IQR) as well as daily interpolated values. The FYI time series in relative time is obtained by aligning the data points of individual FYI ROIs such that timestamp t=0 corresponds to the moment of ice formation. The relative timestamp t=0 is mapped to February 8th in this figure, which corresponds to the average date when the FYI ROIs form. The MYI time series is only produced in absolute time. Black vertical lines mark the timestamps when we start tracking individual ROIs. Note the difference in scales between the y-axes of FYI and MYI plots. Panels (d) and (e): modeled complex dielectric constant and radar penetration depth for basal snow on FYI and MYI, respectively. Panel (f): atmospheric conditions. The background colors highlight the different seasons: winter--melt onset--advanced melt.”

Line 623: “For both ice types and during most of the winter, the time series suggests that the retracked heights at Ku-band frequency correspond to locations well below the air/snow interface, and likely close to the snow/ice interface.” What are the clearest pieces of evidence supporting the phrase “likely close to the snow/ice interface”? Please make this reasoning more explicit.

We have added clarification around this statement, explicitly mentioning the different data sources that led us to this conclusion.

The freeboard time series of both ice types suggest that during winter the retracked heights at Ku-band frequency correspond to locations well below the air/snow interface, based on the clear vertical offset between the laser and radar freeboards. The reference in situ observations are only available in late April and May, at the seasonal peak of the ice thickness. For the FYI ROIs in this study, the in situ observations therefore represent an end member from which we can evaluate the full FYI time series. We know the ice and snow thickness start at zero, and we know they approximately match the seasonal peak in April-May, so we assess fluctuations in the time series relative to these seasonal end members. In addition, we use the modeled SIT as reference for ideal thermodynamic growth, and study fluctuations in laser or radar freeboards in relation to the meteorological conditions. In this context, and for the retracking processing chain used here, we find that the FYI radar freeboards trace the snow/ice interface during ~85% of the winter time. This number corresponds to the amount of days the radar freeboards follow the monotonous, slight positive trend corresponding to the thermodynamic ice growth compared to the total amount of days in the winter period. This finding is consistent with the assumption that radar waves penetrate through cold snow and that the dominant return originates from surface scattering at the snow/ice interface. Over MYI we were not able to reliably assess the location of the retracked heights relative to the snow/ice interface, but found that the minimal penetration depth into the snow is 40% (derived in Section B1 in the Supplementary Material).

Line 647: "Zhu et al., 2917" should be "Zhu et al., 2024."?

Correct, we have fixed this.

Lines 649–653: As far as I understand, LARM optimizes an ice-surface roughness parameter during retracking. Does this mean that the roughness effect associated with frost flowers is not fully represented by the LARM waveform model? Please clarify whether such frost-flower-related effects can be absorbed by the LARM roughness optimization, or whether they could still lead to a positive bias in the retracked radar freeboard.

We cannot directly evaluate whether the LARM retracker is able to absorb frost-flower related roughness and dielectric effects without dedicated datasets, which are challenging to obtain. LARM optimizes two surface roughness parameters (large-scale topography and radar wavelength-scale roughness) and, essentially, the broader the radar waveform, the larger both parameters and the lower the predicted waveform retracking threshold. So, if frost flowers (with ~0 large-scale topography) produce a very broad radar waveform then both roughness parameters are likely to be overestimated, the retracked range will be artificially lowered, and the freeboard will be biased high.

We have edited the corresponding paragraph in Section 6.2 to include this information.

Line 701: "Landy et al." is missing the year.

We have fixed this issue.

Line 710: "Khvorostovsky et al." is missing the year.

We have fixed this.

Lines 744–745: The manuscript states that the radar-freeboard increase is temporary. Which specific results support this? Please refer to the relevant time series or quantify the duration more clearly.

The temporary nature of the increases in radar freeboards is visible in the time series of laser and radar freeboards shown in Figure 6 panels b and c (both the original data samples and the interpolated samples). We have articulated the temporary increases in radar freeboards more clearly in the text of Section 5.2 and quantified their duration.

In particular, for FYI: "The absolute time series shows that the radar freeboards exhibit a temporary (~7-10 days) rise of ~4 cm around 15 March, coinciding with the warming event that includes heavy snowfall."

And for MYI: “The periods with higher radar freeboards are short-term (~7-10 days) and coincide with periods of warmer air temperatures (T>-15°C) and snowfall.”

We then re-iterate the temporary nature of the radar freeboard increases in the first paragraph of the Discussion (new paragraph that was added).

Lines 752–753: Is the relevant supporting figure Fig. B2? Please cite it explicitly in the text.

Indeed, we have now added the reference to this figure in the text.

Line 807: “Landy et al.” is missing the year.

This is now fixed.

Conclusions: Where do the values of 85% and 60% come from, and how were they evaluated? Please explain this more clearly in the Results or Discussion before using these numbers in the Conclusions.

We see that these numbers should be explained more clearly. We have added a section in the Supplementary Material explaining the detailed derivation of the minimal penetration depth of Ku-band radar waves in snow on MYI. After revising the derivation, we chose to stick with the most conservative approach to derive the minimal radar penetration depth and therefore allow the laser freeboard to equal the snow depth (meaning 60 cm of snow on the MYI), whereas we previously limited the snow depth to 50 cm. Therefore the minimal penetration depth is now reported as 40% instead of 60%.

The fact that FYI radar freeboards appear unbiased 85% of the winter time was only mentioned at the end of Section 6.2.1: “Generally speaking, periods of biased radar freeboards are short-term during the winter period - making up only ~15% of the time.” We have now stated this more clearly earlier on in the discussion and explain how we get to the value of 85%. The 85% corresponds to the total amount of days the FYI radar freeboards follow the monotonous, slight positive trend corresponding to the thermodynamic ice growth compared to the total amount of days during the winter period.

Line 833: The phrase “short-term periods with heightened radar freeboards” needs clearer definition. Short-term relative to what timescale, and heightened compared to which reference level?

We agree this was not explained in enough detail. We have quantified the length of the periods (7-10 days) during which we observe the temporary increases in radar freeboard in the Results section (Section 5.2). Heightened is in comparison to the trendline we would expect for ice that grows thermodynamically (taking into account snow loading by using reanalysis data). These details have been added in the manuscript.

Line 854: “Kern et al. 2235” should be corrected.

We have fixed this reference.

[References]

Armitage, T. W. K. and Ridout, A. L. (2015), https://doi.org/10.1002/2015GL064823

Shi et al. (2023), https://doi.org/10.1109/TGRS.2023.3265274

Shi et al. (2024), https://doi.org/10.1029/2024EA003715
