## Sea Ice Freeboard Extrapolation from ICESat-2 to Sentinel-1

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## General comments

The authors present a study aimed at extrapolating along-track ICESat-2 sea ice freeboard heights to two-dimensional Sentinel-1 freeboard heights by using cumulative distribution functions (CDFs). The study utilizes 59 Sentinel-1 scenes co-located with ICESat-2 ATL10 data, examining the correlation between freeboard heights (roughness) and Sentinel-1 HH/HV backscatter. Guided by these correlations, the authors employ CDFs to map ICESat-2 data onto Sentinel-1 imagery. The extrapolated freeboard estimates are then compared with the near-coincident validation track over the same scenes.

Overall, the work is promising. As the authors highlight, achieving two-dimensional sea ice freeboard measurements could significantly enhance the capacity to monitor sea ice at spatial scales that were previously difficult to attain. However, before the manuscript can be accepted, the authors should address the following concerns and make the method more convincing:

1. Using CDFs to link radar backscatter (especially HV polarization) to the distribution of sea ice freeboard has a certain degree of validity. However, questions remain about the method's underlying assumptions. CDF matching aligns distributions based solely on the observed data, without necessarily establishing a direct physical link between HV backscatter and freeboard. Consequently, when applying the extrapolation, high HV backscatter is mapped to high freeboard, while low HV backscatter is mapped to low freeboard. Given the complexity of sea ice conditions, such a straightforward relationship may be insufficient. Radar backscatter can be influenced by multiple factors, including salinity, surface roughness, and snow depth. Sea ice with identical freeboard heights might exhibit different backscatter signals, potentially leading to inaccuracies in freeboard

estimation when relying on such a simplified mapping strategy.

2. The manuscript mentions 59 datasets. It appears that a separate CDF mapping is created for each dataset, rather than one universal mapping for all 59 datasets. If this is correct, it implies that the method cannot be directly applied to new Sentinel-1 data for which no coincident ICESat-2 data exist. This limitation would significantly reduce the broader applicability of the technique. Clarifying whether a single CDF mapping was generated or multiple mappings were used—and if the latter, how the authors envision applying the method to future acquisitions—would be helpful.

3. The study uses ICESat-2 data acquired within 24 hours of the corresponding Sentinel-1 data. However, some of the validation data were obtained under near-coincident conditions (e.g., time differences of less than 10 minutes). Given the rapid drift of sea ice, non-coincident ICESat-2 observations may not perfectly align with the Sentinel-1 pixels, thus introducing potential errors in correlations. It would be beneficial to explain why strictly near-coincident data (e.g., with a time difference of less than 10 minutes) were not used to establish the CDF mappings directly.

4. I guess that using both freeboard height from strong beams and weak beams is not a better way to calculate the mean freeboard height in a pixel. Generally, weak beam segments are typically about four times longer than strong beam segments, the resulting freeboard estimates from weak beams may be smoother. It would be more informative to analyze and present the correlations separately for strong and weak beams, thereby highlighting potential differences or biases in the derived freeboard estimates.

## <u>specific comments</u>

line 94: ‘be distinguished’ should be ‘distinguished’;

Line 175: ‘becaise’ should be ‘because’;

Figure 6: suggest that plot the raw Sentinel-1 image as well to compare.