Review report on "Year-Round High-Resolution Sea Ice Freeboard Retrieval Using ICESat-2 ATL03 Photon Data" by Liu et al.,

Sea ice freeboard is a critical parameter not only a proxy for snow depth estimation, but also critical for sea ice thickness extraction. This manuscript introduces the High-Resolution Freeboard Method (HRFM), a novel framework that retrieves sea ice freeboard directly from ICESat-2 ATL03 photon data at 5 m along-track resolution. The approach combines a two-stage denoising strategy (Kernel Density Estimation with adaptive histogram-based filtering) and a machine-learning surface-type classifier trained on 25 coincident Sentinel-2 scenes covering winter and summer conditions across diverse ice types. The authors validate surface heights against ATM (Airborne Topographic Mapper) data, compare their freeboard estimates with the operational ATL20 product, and demonstrate improved performance in preserving ridge heights, mitigating after-pulse effects, handling melt-season complexities, and enabling consistent weak-beam utilisation.

The study is highly relevant to the scope of TC Journal and timely to the cryosphere society, addressing a critical need for year-round, high-resolution sea ice thickness monitoring. The manuscript is well-structured, the methodology is clearly described, and the results represent a substantial advance over existing ICESat2 sea ice products (ATL07/ATL20), which convinced me that this study warrants publication in TC Journal. However, before final acceptance. There are numerical issues that either need further clarification or significant improvement. Please see my major and minor comments below that I hope the authors can consider during the revision.

Major Comments / Required Revisions

1. The authors should specify explicitly what annual cycle was investigated either in the title or in the abstract. Why was this annual cycle selected in this study?

2. The key algorithm parameters are mentioned throughout the text (e.g., horizontal scaling a=25/100, histogram bin size 0.1 m, after-pulse offsets 0.45/0.9 m, 10-km window for sea-level reference, 3σ outlier removal, 10th percentile density threshold for refined denoising), a single table summarising all critical parameters with their values and justifications would greatly enhance reproducibility. Please add such a table (e.g., in Section 3 or as an appendix) in the revised manuscript.

3. In the abstract and results (Sect. 4.1), the authors state that weak-beam retrievals achieve "comparable accuracy" to strong beams. How "comparable" it was? Please provide a concrete assessment. Please consider adding a statistical test to show whether the remaining difference is meaningful or not.

4. Table 2 shows thin-ice recall is only 0.50 (strong beam) and 0.43 (weak beam), with precision ~0.65. The authors merge thin ice into sea ice for two-class validation (Table A1, overall accuracy >0.98). However, thin ice is a distinct surface type with different

radiative, thermodynamic, and mechanical properties. Please discuss:
a: How often does misclassified thin ice affect freeboard retrieval (e.g., when thin ice is wrongly labelled as lead and thus included in the reference sea level)?
b: Should users treat the thin-ice class as “experimental” or apply the two-class version for freeboard estimation? A clear recommendation would be helpful.

5. The reference sea level is computed by aggregating lead segments within a 10-km along-track window. The choice of 10 km is plausible but not justified. Could the optimal window size vary with ice regime (e.g., compact vs. marginal ice zone, winter vs. summer)? A brief sensitivity test (e.g., 5 km, 10 km, 20 km) on a representative track would strengthen the method. If such a test already exists, please cite or summarize it.

6. Figure 10 shows seasonal mean differences between HRFM and ATL20 up to ±0.04 m, with sign reversals between winter and summer. The authors attributed these to differences in surface-height retrieval, lead detection, and reference sea-level construction. A rough quantitative decomposition (e.g., how much of the winter difference is due to after-pulse removal vs. lead sampling density) would greatly strengthen the discussion. Even an approximate breakdown based on the examples in Figs. 8 and 12 would be valuable.

7. The classifier was trained on scenes south of 82°N because of Sentinel-2’s orbital limit. How confident are the authors that the classifier works north of 82°N (e.g., the central Arctic) where no coincident optical imagery is available for validation? Please add a discussion of potential extrapolation risks and whether the physical feature space (photon rate, density, height STD, background rate) is expected to remain valid poleward.

Minor comments

-Line 70: “detector after-pulses” should be introduced earlier (it is defined in Sect. 3.1.2 but referenced here). Consider adding a brief definition at first mention.
-Line 125: Use consistent version notation (e.g., “Version 6” rather than “V06”, or define “V06” at first use).
-Figure 8 caption: “The green dashed lines represent the ATL07 signal selection envelope” :please describe this explicitly in the caption.
-Section 5.1, line 585: “lower transmitted energy level (~ 80% of outer beams)” – please verify and provide a citation for the energy difference between middle and outer beams.
-Figure 5 caption: “It’s a 10-km profile” should read “It is a 10-km profile”
-Language: The manuscript is generally well written, yet there are a few grammatical issues that remain (e.g., “It’s” in figure captions, occasional missing articles). I see you have English co-authors, and please ask them to proofread the language.
- The text fonts in almost all figures are quite small. Please consider enlarging them to

improve the readability of the figures

- The authors provided this data availability statement: The Sentinel-2 imagery was derived from Google Earth Engine at https://developers.google.com/earth-engine/datasets/catalog/sentinel-2. I am not sure if this is adequately enough by TC, or should authors provide the Sentinel-2 imagery data somewhere for readers to explore. I leave this for the TC handling editor to decide.