

General comments

This manuscript provides a thorough description about retrieving snow grain sizes from airborne LiDAR and investigating their impact on penetration biases in ICESat-2 elevation data. It is very impressive to see the recovery of new information from datasets that were collected in the past (that were not necessarily customized to retrieve this information). The data and methods are dense but described in detail. The authors make this research immediately applicable by linking recovered snow grain sizes with elevation bias corrections for ICESat-2.

Most of my concerns can be addressed by improving the writing style (see specific comments). My major gripe is the use of “Figure X shows” at the start of paragraphs. It’s OK once or twice but it becomes tiresome when every paragraph of the results starts with these words. I recommend that the authors revise some of the first sentences of these paragraphs.

I was also a little underwhelmed by the correlations between ATM/AVIRIS grain sizes with satellite-derived grain sizes. But the authors provide some ideas for the differences which I think this is sufficient for the current scope of the paper.

Response to general comments

Our first submitted version of the manuscript was much rougher than it should have been. Although referee 2 seems to have followed the logic of the study, it can't have been easy, and my (Ben's) writing style was subpar. We thank referee 2 for the kind words, and for the detailed recommendations for revisions. Being a referee is hard and often thankless work, all the more so when the study being reviewed is not presented clearly.

We have done a lot of rewriting in response to the two reviews and made an effort to strengthen the topic sentences in our results section to avoid the “Figure X shows” problem mentioned above.

Like Referee 2, we were also underwhelmed by the comparisons between OLCI and ATM/AVIRIS grain sizes. It seems that measuring grain size from space is not easy, and we hope that better techniques and data might help in the future (as we discuss). Even so, we do show that the OLCI-based correction improves the biases in the expected biases, as calculated from the ATM waveforms. Like many other studies, this one will not necessarily solve the problem it sets out to solve, but it should point in the direction of a solution that future studies may achieve.

Specific comments

Our responses are interpolated below, in blue. All quotes from the revised manuscript will be in italics.

L33: There are a lot of “efficients” in the first paragraph. It would be useful to clarify why these detectors are so “efficient”. Are they sensitive? Low SNR? Energy efficient?

- We now specify that the detectors are “highly sensitive.”

L32-25: Long, wordy sentence, consider splitting.

- Done:
These biases are relevant to interpretations of ICESat-2 altimetry measurements over glaciers because ICESat-2 was designed to make precise measurements of glacier elevation change, and time varying biases in ICESat-2 measurements over glaciers and ice shelves can produce spurious signals that might be interpreted as ice-sheet mass changes. Likewise, spatially varying biases in measurements over sea ice might be interpreted as variability in freeboard and thus ice thickness (Harding et al., 2011; Smith et al., 2018).

L36: Just glaciers? Or ice sheets as well? It seems like these two terms are being used interchangeably which is at odds with the first couple of sentences.

- Added ice sheets.

L41-49: Even though this is a well-known phenomenon, it might be useful to add some references here which describe this in more detail.

- We added citations to the previous papers treating this phenomenon (Harding et al, 2011, and Smith et al, 2018).

L56-59: I would need access to these manuscripts to judge overlap and novelty of this paper.

- Both papers are close to publication, and we will provide the drafts as assets in our resubmission of this manuscript

L84: Define acronym on first use of term “ATM” (L75) rather than here.

- In fact, the acronym is defined in the abstract (L15 or thereabout). We will delete the definition here

L88: Diameter?

- Yes. Now specified.

L103: Instruments? Surely there is only one LiDAR or were LVIS and SIMPL also onboard? It may be useful to name the lidar sensor given that ATM is defined as a suite of instruments (or revise L84).

- We now specify "ATM instruments".

L110-112: Might be useful to clarify the difference in swath widths here or L96 when it is first mentioned. Or are these two different sensors? Either way I think some general tightening of terminology is needed in this section.

- This is now covered by a more extensive description of the two systems early in the ATM section.

L114: "Verify" seems a bit strong. Validate or evaluate might be better.

- We will replace "verify" with "help evaluate whether"

L123: This raises the question about how many data files were excluded from the analysis. Are all 26 data files from the same five-day period in 2019 when ATM was followed by AVIRIS-NG?

- We reviewed the files that we had initially excluded and determined that there was really only one that needed to be removed. We have revised the text to point to a supplemental figure that includes the comparison between the problematic file and the rest of the data.

L134: Consider revising because the way it's written makes it sound like Gallet et al. (2009) validated snow-grain sizes from OLCI which was launched in 2016.

- We deleted the reference to Gallet et al. That reference is contained in the Vandecrux paper, which should be adequate documentation of the comparison.

L143: What was the threshold for removing data points that have not been recently updated?

- We do not compare points separated by more than a day (now stated in the text here)

L213: It would be useful to briefly remind readers how the IRF was measured here.

- Added: *"measured using a calibration target with no significant subsurface scattering on 9 March 2018"*

L280: Is the satellite not named "ICESat-2"?

Fixed.

Fig. 5: AVIRIS is misspelled in Panel E

Fixed

L361: It would be useful to name the two ATM sensors since this is the first sentence of the paragraph

Done

L398: Please could you clarify if this is **all** coincident grain sizes from Summer 2019 or just a sample.

We now specify that this is all available ice-sheet ATM data, but excludes a single AVIRIS-NG transect on sea ice.

L401: "comes about" is clumsy, consider revising.

Replaced with "is."

Fig. 9: What is the justification for the position of the dashed lines? It would be useful to clarify that here.

- We specify this in the caption: *To help illustrate the magnitude of the difference between the datasets, we plot two dashed lines that show the ATM : 3 x AVIRIS-NG (upper) and ATM : 1/3 x AVIRIS-NG (lower) relationships*

Fig. 10: Same comment about the dashed lines as above.

Also clarified.

L411: Which years?

- All of our AVIRIS data are from the 2019 summer survey, which we now specify: *"Figure 10 shows a comparison between AVIRIS-NG-derived grain sizes from the summer-2019 survey and OLCI-derived grain sizes"*

Fig. 11: I think the satellite grain size should be on the y-axis to be consistent with Fig. 10.

We have tried to make our figures so that the less familiar dataset is plotted on the y axis. Since ATM grainsize is the newer, more experimental dataset, we plotted figure 11 that way.

Fig. 12: It took me a minute to figure out what this figure was showing and I think it is because the word "satellite" is being used to refer to both Sentinel-3 grain size and ICESat-2 range bias. Please modify the axes labels to clarify. Also if the black lines show the modeled range bias as a function of grain size then the x-axis label should just be "grain size" and the legend should provide information about where the grain sizes came from.

L440-449: Be specific about which satellite.

We now specify OLCI

L485-489: I think the first half of this paragraph should be removed (or placed later in the discussion) because, as it is written, it seems like the main takeaway is the consistency of the different snow grain size estimates. However, there are substantial biases between the estimates (Figs. 9-11) which the authors are up front about later in the discussion and should be the focus.

L532: Again, which satellite measurements?

We now use "OLCI" instead of satellite

L542-543: This statement seems at odds with L584-585 which states that elevation biases could be decimeter scale. Consider revising.

This may be a misunderstanding. At 542-43, we specify here that there is no problem in the small-grain size regime. The large biases to which we refer in 584-585 are in areas with large grain sizes.

Citation: <https://doi.org/10.5194/tc-2023-147-RC2>