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Interactive comment on "Using ICESat-2 and Operation IceBridge altimetry for supraglacial lake depth retrievals" *by* Zachary Fair et al.

Anonymous Referee #1

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1 Overview

Fair et al. (2020) use laser altimetry measurements from ICESat-2 and the Airborne Topographic Mapper to map supraglacial lakes on regions of the Greenland and Antarctic ice sheets. This is one of the first of what will likely be many studies incorporating ICESat-2 geolocated photon data to map supraglacial lake depths. The paper provides a method for extracting lake surface and bottom elevations from 532nm laser altimetry data. The work presented by the authors falls within the scope of *The Cryosphere* and could make an interesting contribution to a developing field of measuring supraglacial lakes with remote sensing data. Overall, while this is a promising methods study of supraglacial lakes with laser altimetry measurements, there are a few issues that

should be resolved before its publication.

2 Broad comments

- There are places outlined in the line-by-line comments where it could be more quantitative
- Some of these sections are "in the weeds" concerning HDF5 variable names or classification differences. These sections and figures could probably be excluded
- I would expand on the section of difficulties of making a fully automatic lake depth detection algorithm with laser altimetry
- I would mention the impact of detector saturation on highly flat specular surfaces creating a "false" bottom return. This could be noted in the Algorithm Performance section.

3 Line-by-line comments

Page 1, Lines 2–4: I would split this sentence to be something like:
"Detection of lake extent, depth, and temporal evolution is important for understanding glacier dynamics. Previous remote sensing observations of lake depth are limited due to inherent uncertainties of depth retrievals with passive remote sensing techniques, and the high absorption of infrared laser energy in water from the original ICESat mission."

Page 1, Line 8: I would change this to reliably or statistically detect lake beds as deep as 7m.

Page 1, Line 10: The insufficient classification of photon events when profiling lakes is expected due to how the ATL03 classification algorithms work with a bimodal or multimodal surface, particularly if the lake surface return is not specular.

Page 1, Line 16: You are noting here that the contributions to sea level rise from ice sheets will likely overtake steric sea level effects and not that the contributions will overtake glacier and ice caps correct?

Page 1, Line 17: I would probably use “aggregation“ and not “accumulation“.

Page 1, Line 18: “When unfrozen, these lakes exhibit a lower albedo than the surrounding ice,“

Page 1, Line 21: “which can lead to potentially significant impacts“

Page 2, Lines 2–4: “Meltwater penetration into the ice during catastrophic lake drainage events can also lead to hydrofracture, a mechanism through which meltwater facilitates full ice fracture as a result of the stresses induced by the density contrast between liquid water and ice”

Page 2, Line 5: “thus can impact sliding velocity and ice discharge“

Page 2, Line 12–13: Hopefully we don’t reach a time where supraglacial lakes are present over the entirety of either ice sheet. “sheer size of the ice sheet ablation areas“

Page 3, Line 4: “6 distinct beams named in the products based on the ground track: GT1L/R, GT2L/R, and GT3L/R”.

Page 3, Line 6: “approximately every 0.7 meters“

Page 3, Line 16: GT2R can be either the central strong beam or the central weak beam based on the orientation of the spacecraft. For the both of your dates (2019-01-02 and 2019-06-17) GT2R was the weak beam.

Page 3, Lines 18–20: This is expected due to transmit pulse truncation. The transmit pulse shape is slightly non-Gaussian with a trailing tail. Calculating the average of photon events without that trailing tail biases the results compared to a “true“ surface.

Page 3, Lines 21–22: Versions of ATM have flown in Greenland since 1993. As written it suggests that ATM was designed as a gap filling instrument rather than an existing and verified instrument suite used in this role.

Page 3, Line 25: The ATM1B QFIT elevation product is not a geolocated photon product but a geolocated elevation product

Page 3, Line 26: While ATM does not contain a statistical confidence definition, ATM uses a thresholded centroid model from their digitized waveforms and thus will typically only retrieve higher confidence returns. The data is also processed prior to release for QA/QC purposes.

Page 3, Line 26: Remove “Despite this”

Page 3, Lines 27–28: “Here, the ATM results serve as a proof of concept for the lake detection algorithm”

Page 4, Lines 4–5: The lake surfaces aren’t necessarily “easily” identifiable and potential lake beds can be hard to detect on highly flat surfaces because detector saturation (related to first-photon-bias) can lead to a non-existent false bottom.

Page 4, Lines 5–6: “To simplify the identification of lake features, we separated them into two arrays: one for the surface and one for the bed, which we refer to as "lake surface-bed separation" (LSBS)”

Page 4, Line 8: What is $\sim 10^4$–10^5 photons in terms of distance?

Page 4, Line 11: Are there times when the lake bottom can be the dominant return?

Page 4, Line 12: “We check the flatness of the window by computing the standard deviation”

Page 4, Lines 23–24: Seems somewhat arbitrary that the thresholding needed to be different surface classification. Would it be better to only use the full set of potential signal photons and the second set of thresholds?

Page 4, Line 30: I would say that these were “potential” or “probable” false positives

Page 5, Line 6: “overlapping 40 meter segments”

Page 5, Paragraph 2: The ATL06 algorithm assumes a single returning surface within a segment of photon events. In supraglacial lake instances, the ATL06 algorithm can compute a height for either lake bottom or lake surface depending on their corresponding return strength. These return strengths can be highly variable.

Page 5, Line 18: The ATL06 algorithm uses 3m as the minimum window height.

Page 5, Line 26: I would mention that 3cm is far below the horizontal geolocation uncertainty of ICESat-2

Page 6, Line 10: What do you mean quantitatively by agree well?

Page 6, Lines 12–14: These sentences are awkwardly phrased.

Page 6, Lines 16–18: You list the dates here, in Figure 1 and in Table 1. I would get rid of Table 1 as it seems extraneous.

Page 6, Lines 21–23: Why mention this?

Page 6, Lines 25–26: I would rewrite to be “We detected 12 lakes with sufficient bed returns from the ATM data and 16 potential lake surfaces overall.”

Page 6, Line 27: What do you mean quantitatively by good accuracy?

Page 7, Line 3: “lake bed elevations”

Page 7, Line 4: “perhaps influenced by low signal-to-noise ratios or the conical scanning of the lidar instrument”

Page 7, Lines 8–9: “We examined an additional 12 supraglacial lakes with ICESat-2, eight in Greenland and four highlighted in Magruder et al. (2019) on the Amery Ice Shelf in Antarctica (Fricker et al., in prep.).”

Page 7, Line 10: What do you mean by reasonable success?

Page 7, Line 21: less necessary for ICESat-2 than ATM for the supraglacial lakes studied here

Page 7, Line 34: ICESat-2 returns are also affected by first-photon-bias (particular if complete saturation of the detectors occurs), blowing snow events (which by forward scattering can create sub surface photons or have a multi-modal return by the snow itself), and solar radiation background.

Page 8, Line 7: What do you mean in the attribution sentence?

Page 8, Lines 14–31: I’m not sure if mixing classifications is the best approach for determining the signal classification. You’re right that supraglacial lakes are not quite fit in any default category in the signal classification algorithm of ATL03. I may be mistaked but I think supraglacial lakes being classified higher in “land” than “land ice” makes sense due to the tighter histogram window of “land ice” (and not that supraglacial lakes resemble canopies). Going forward, it might be better to use signal and buffer photons of a single surface class and iterate to remove potential background photons.

Page 9, Line 7: Should add a value for “too deep”

Figure 4: The polynomial fits are pretty poor for complex beds. I get the need to not overfit the beds, but would it be better to use a variable order of polynomial or splines?

Figure 4: Bed detection seems to be a bit off on the lake edges (a, e, g, i, j, k, l)

Figure 5: I don't know if this figure has much meaning.

Table 1: I don't think this table is necessary with Figure 1 and the text.

References

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