Reviewer#1

Subglacial lakes are an important component of ice sheet hydrology, particularly in their influence on meltwater transfer between the ice sheet surface and bed. Although previous efforts have documented subglacial lakes over Antarctica, lakes over the Greenland Ice Sheet have received less attention. This manuscript aims to improve our understanding of Greenland subglacial lakes using ICESat-2 altimetry data. A combination of the ICESat-2 ATL11 product and the ArcticDEM is used to infer and validate the location of subglacial lakes. Interannual changes in ice sheet height from ATL11 are used to measure changes in lake area, height, and volume. The authors were able to identify 61 subglacial lakes over Greenland, many of which were not reported in previous literature.

Overall, this paper discusses an interesting and underreported topic in the cryosphere community, and its contents fall within the scope of The Cryosphere. The paper is generally well-written, and it is interesting that to see ATL11 applied to a novel application. Before publication, I do have a few concerns:

We thank the reviewer for the helpful feedback, we are appreciative of his or her help and time.

Main Comments

Previous methods for lake detection have used lower level ICESat-2 products, such as ATL03 or ATL06. Although it is interesting to see ATL11 used for this analysis, and ATL03 is used to identify supraglacial lakes, I would like to see some justification on why ATL11 was selected as the primary dataset over other ICESat-2 products. A reader less familiar with ICESat-2 may wish to know why ATL11 is preferable for this application, or why other ATLAS products may be less effective.

Response:

The ATL06 product is developed from the ATL03 product, and is corrected for

instrument bias (e.g. transmit pulse shape bias correction and first-photon bias correction). ATL11 is then based on the ATL06 product, which employs a technique that builds upon those previously used to measure short-term elevation changes using repeat-track data. This process scheme provides the time series of slope-corrected ice surface heights during each ICESat-2 repeat cycle. Quantifying elevation at different times at the same location is the key to identifying subglacial lakes.

Lake detection in Greenland tends to be complicated by surface lakes. The ATL06 and ATL11 products only capture heights for aggregated photons. If there is a surface lake during data acquisition, the recorded elevation will not be the ice surface but the water surface elevation. This effect can be corrected using the ATL03 data, which provides the depth of shallow water (i.e. reveals the lake bottom ice surface) by its double reflection.

We have added data descriptions in the revised manuscript in the *Data* Section (Page 2, Line 60-61; Page 3, Line 82).

Generally, the results are presented as a range of values across all 51 confirmed lakes. For an ice sheet as large as Greenland, I do not think this is very useful, particularly when the range is across three orders of magnitude (e.g. volume change rates and uncertainties). The lakes are grouped into regions in Figures S5 and S6, so I suggest aggregating the statistics (mean, uncertainties, etc.) by region and discussing how the elevation and volume change rates vary (or do not vary) between regions.

Response:

This is a good idea, thanks. The total lake volume-change rate for each basin has been added as a circle in Figure 2(d), where the circle size is proportional to the magnitude of the absolute rate. We have added the aggregated statistics (mean, uncertainties, etc.) by basin in Figure S5 and S6, and added description in the *Result* Section (Page 8, Line 293-294; Page 8, Line 301-303).

But this can only represent the state of the 61 subglacial lakes that have been detected so far, and it may not be representative of the state of the entire Greenland subglacial system.

I appreciate that the data in the supplementary tables is provided, but I think the spreadsheets would be better placed in an open-sourced repository. The tables in the manuscript could then be used to show aggregate statistics for each region of Greenland assessed.

Response:

We have uploaded the supplementary tables to the National Tibetan Plateau/Third Pole Environment Data Center.

Other Comments

Abstract: Lake area, height, and volume are an important part of the analysis, so I suggest adding a few lines that mention these parameters.

Response:

We have added some descriptions on lake characteristics in the *Abstract* Section (Page 1, Line 21-22).

Line 32: "Subglacial lakes can be identified from various remote sensing *techniques*"

Response: We have changed 'observations' to 'techniques'.

Lines 32-33: What kind of instrument (or instruments) is used to make these inversions?

Response: Seismic and gravity data can be measured by acoustic impedance or amplitude-versus-angle analysis (Livingstone et al., 2022). We have added this statement in the revised manuscript (Page 2, Line 34-35).

Line 48: Minor nitpick, but the documented footprint size is ~13 m.

Response: The footprint size is ~11 m according to Magruder et al. (2020) – see also comment by reviewer 2. We have corrected this in the revised manuscript.

Reference:

Magruder, L. A., Brunt, K. M., Neumann, T., Klotz, B., & Alonzo, M. (2020). Passive ground-based optical techniques for monitoring the on-orbit ICESat-2 altimeter

geolocation and footprint diameter. Earth and Space Science. https://doi.org/10.1002/essoar.10504571.1

Line 68: Are all these reference points co-registered with subglacial lakes? If not, I would mention how many reference points are (if that is not too difficult).

Response: This number is the footprints that covered the entire Greenland Ice Sheet, and we counted how many points were within the identified lakes and added them to the *Result* section (Page 7, Line 250).

Line 68: Replace "entire of Greenland" with "Greenland Ice Sheet"

Response: Accept and revised.

Line 88: "a more conservative threshold *of*…"

Response: Accept and revised.

Lines 103-105: Is this a significant problem? Please provide justification on why or why not.

Response: The percentage of lakes that exhibited elevation anomalies during the ArcticDEM period is not a significant problem because it is a preliminary screening step. The lake identification relies on confidence levels determined by the elevation profiles and the long-term elevation change trends.

Line 106: For clarity, this is referring to ICESat-2 tracks, correct?

Response: We added 'ICESat-2' here for clarity.

Line 112: Consider revising to something like: "Supraglacial lakes seasonally form over much of the GrIS ablation zone. These surface lakes may either refreeze on the surface or drain to the ice bed (Selmes et al., 2011)."

Response: Accept and revised.

Line 114: Elaborate on what ATL06 is (i.e. land ice height).

Response: Accept and revised.

Equations 3+4: “confirmred” à “confirmed”

Response: Accept and revised.

Line 168: 2009 à 2019

Response: We rephrased the sentence as ‘Spatial patterns of elevation and volume changes over the ICESat-2 period (2019-2020) were generated, and the elevation time-series over the combined ArcticDEM and ICESat-2 periods (2009-2020) were used to determine the temporal patterns of lake activity.’

Line 168: Use “ICESat-2” to prevent confusion.

Response: ArcticDEM was corrected by ICESat data rather than ICESat-2 data, with this information provided in the metadata of the ArcticDEM strip data.

Lines 170-171: Nitpick, but a more up-to-date number is from Brunt et al., (2021), which shows an accuracy of ~0.04 m over ice sheets (reference below).

Response: We corrected this in the revised manuscript.

Lines 177-179: “An additional 10 active lakes were detected by ICESat-2 but not the ArcticDEM” can be removed – the first sentence of the paragraph establishes this already. The rest of the sentence could be rephrased as: “Five of the reported active lakes were missed by ICESat-2, indicating that…”

Response: Accept and revised.

Line 179: “bright” and “strong” are redundant in this context.

Response: We removed these words in the context

Lines 184-185: I am not sure if I understand the connection here. If the lakes with the

most sampling are at upper latitudes, then why would it not be associated with the increased density of ICESat-2 tracks?

Response: We have removed this vague statement in the revised manuscript.

Line 207: Where were these lakes located? A depth of >50 m is awfully large…

Response: These lakes are located in northeastern Greenland, including one known lake in the Flade Isbink Ice Cap. The estimated depth of ~ 60 m for this lake is consistent with the published subglacial lake inventory of Livingstone et al. (2022).

Reference:

Livingstone, S. J., Li, Y., Rutishauser, A., Sanderson, R. J., Winter, K., Mikucki, J. A., Björnsson, H., Bowling, J., Chu, W., Dow, C., Fricker, H., McMillan, M., Ng, F., Ross. N., Siegert, M., Siegfried, M., and Sole, A.: Subglacial lakes and their changing role in a warming climate. Nat. Rev. Earth Environ., 19, https://doi.org/10.1038/s43017-021-00246-9, 2022.

Lines 211-212: "Lakes with both positive and negative elevation change rates during the study period were found in each basin with few exceptions." Redundant sentence – consider revising or removing.

Response: We removed the sentence in the revised manuscript.

Line 238: Terms such as "quiescence" and "high stand" are infrequently used jargon. I suggest using other terminology (or define what "high stand" means) to make it more understandable to a general audience.

Response: We defined this pattern in plain language in the revised manuscript (Page 9, Line 332).

Line 241: "The temporal resolution of the ArcticDEM varies[,]…" (add comma)

Response: Accept and revised.

Conclusions: This needs a paragraph on how this paper would benefit future research

studies, or how future studies could build upon the limitations or difficulties discussed in this study.

Response: We added a paragraph about the limitations and difficulties (i.e., the discrimination between surface and subglacial lakes), and how further studies can build on the quantification of surface water on subglacial water systems.

Figure 1: A colorbar label (with units) is needed.

Response: The label and units has been added in Figure 1.

Lines 381-382: "The red-blue lines represent the differences between ICESat-2 tracks…"

Line 382: "…while *the* grayscale colorbar is the ArcticDEM."

Lines 382-383: "Elevation anomaly profiles across the subglacial lake are given for RGT 321 (b) and RGT 162 (c)."

Response: We rephrased the figure caption as follows 'The red-blue line represents the elevation change rate derived from the linear fit of ICESat-2, while the grayscale colourbar represents the elevation change rate derived from the ArcticDEM. Elevation anomaly profiles across the subglacial lake are given for RGT 162 pt3 (b) and RGT 321 pt2 (c).'.

Line 384: "Their spatial locations are also indicated in (a)." Redundant sentence.

Response: We removed the sentence in the revised manuscript.

Figure 2: I suggest adding a label for the colored circle legend in (b), otherwise I am not sure what the colors represent (or what the units are).

Response: We added the legend in this Figure. The colored circles in Figure 2(b) indicates the percentage of lakes that belong to this grade of area.

Figure 3: Please provide a legend for the differently colored dots.

Response: We added this legend in the revised manuscript.