Point-by-point reply to Reviewer 2 – Manuscript entitled: Evaluation of satellite methods for estimating supraglacial lake depth in southwest Greenland, authored: Melling et al.

Manuscript iteration: Revision post review

Editor: Joseph MacGregor

We thank anonymous reviewer #2 for their comments on and suggested edits to our paper. Please find each comment given below in bold type, with our response following in normal text. All line numbers refer to the original manuscript.

1) "The methods section for the RTE method is very difficult to follow. I think it would help to start by explaining that until now, there have been values for various parameters that have been used in the literature, and to state these first. You can then go on to justify why you look to create and use new values."

We agree with the reviewer that this section was difficult to follow. In the revised manuscript we will reorder the section.

2) "The above comment cascades into Figure 6 and the caption for Figure 6 being very hard to follow. Please think about how you can better explain and present the variables tried and tested. It may be that some information from Appendix Section 4 would be better placed in the main text. Following on from this, whilst in Figure 6 you vary each parameter in turn, what happens if you vary all parameters together, is this not something that needs testing?"

In the revised manuscript we will alter the text for the Figure 6 caption to read, "*Figure 6: Sensitivity analysis of the RTE parameters, within plausible ranges identified for each parameter (Appendix A.3). Each panel shows the variability of lake depth, as given by Eq. (1), with measured surface reflectance, (a) when A_d is altered only, (b) when g is altered only, and (c) when R_∞ is altered only. When one parameter is altered, the other tuneable parameters are set to their 'literature value' (see Method section). R_w is varied over its observed range on July 8th 2019, where reflectance values were extracted using a lake inventory not generated explicitly for this study (E Glen 2022, personal communication, 22 July). 'Red standard value' and 'Green standard value' are calculated using our approach to calculating A_d, g, and R_∞ (see Method section). The darker-coloured shading indicates the uncertainty of these values. 'Red range' and 'Green range' correspond to the possible depths achieved when upper and lower bounds are used for the parameter being varied. We note that in (c), the range and uncertainty of the depths are small and so appear as thin lines along the standard value lines.*"

In Figure 2, the parameters are varied together to find the uncertainty and range of the band-specific RTEs. We will add the following text to line 203 to clarify this, "*The uncertainties for each lake's band-specific RTE are calculated by co-varying all permutations of the RTE tuneable parameters*."

3) "More attention should have been paid to the selection of values of Ad in the RTE. Specifically, I would recommend the authors test a wider range of Ad values before this work is published. The author should read and refer to Dell et al. (2020), who use careful selection of Ad values to avoid the impact of slush."

A_d is intended to represent the reflectance of the lake bottom and we agree that it needs to be selected carefully. We have read Dell et al. (2020), to which we have added a citation on line 358, but note that their study focuses on Antarctic lakes, which often have more blurred boundaries, and tend to form on cleaner, flatter ice. For studies of lakes on Greenland it is reasonable to use the ring of pixels directly adjacent to the lake because:

1. Lakes tend to have well-defined boundaries (Figure 1 of the manuscript) and we have high confidence that we have detected the lake edge effectively.
2. Lakes occur in regions where cryoconite coverage is spatially variable. Pixels at the lake shoreline are therefore more likely to have more representative levels of cryoconite than distant pixels.
3. Lakes are surrounded by topographic highs – and so going too far away from the lake risks including A_d values associated with dry snow.

We also note that in our analysis of the plausible ranges for each tuneable parameter, we test A_d values in the range 0.1347–0.7724 (red) and 0.2055–0.7973 (green) which we consider to be comprehensive. Interestingly, this analysis reveals that the RTE is most sensitive to the uncertainty in the value of A_d and we note that refining the method for determining A_d, especially at scale, should be a priority of future work.

We will add the following text to the revised manuscript at line 359, "*Dell et al. (2020) estimated A_d from the sixth concentric ring of pixels around Antarctic lakes to reduce the potential impacts of slush on the RTE. In future work, methods of estimating A_d on both Greenland and Antarctica should be tested due to the importance of A_d in the RTE*."

We will also add the Dell et al. (2020) citation to the reference list of the revised manuscript.

4) "Despite your comments r.e. averaging the red and the green band depths, I would like to see some evidence for this method not being suitable moving forward, particularly given its use in both Pope et al. (2016) and Williamson et al. (2018). I understand what you are saying with regards to the plateauing effect caused using the red band, but it would be more convincing if you could provide evidence for this. You also do not mention the fact that previous studies have averaged these depths until the discussion, I would advise mentioning this much earlier on."

As requested, we will now mention this much earlier on. Specifically, at line 95, we will add the following text, "*Although previous studies have averaged the depths retrieved from the red band RTE and the panchromatic band of Landsat 8 (Pope et al., 2016; Williamson et al., 2018), we do not do so within this study as Sentinel-2 does not have a panchromatic band. Additionally, this study specifically aims to understand the uncertainties associated with applying the physically based RTE to data acquired at a single band, and so an empirical averaging without a clear physical justification does not serve the purposes of this research*."

At the end of section 2.2, we will also add the following text, "*We do not average band-specific depth estimates here, for the reasons outlined previously; however, we do note that this has been done in previous studies (e.g. Pope et al., 2016; Williamson et al., 2018).*"

We will also add/edit the following text at line 366, "*With a larger amount of ArcticDEM and/or ICESat-2 data, we suggest that future research could combine multiple satellite bands (Adegun et al., 2023) and data sources as inputs to a machine learning model and generate a well-constrained depth-*

detection product using a data-driven approach, as opposed to the model-derived approach we use here."

We will also add the Adegun et al. (2023) citation to the reference list.

5) "L74: Does this region only contain active lakes?"

No, it also contains non-active lakes. We will alter line 74 to read, "*This region contains both active (repeatedly filling and draining) and non-active lakes…*"

6) "L134-136: For the section starting 'we manually appraised', please can you better clarify what was done here, I can't make sense of it."

To clarify the method, we will alter lines 131-135 to read, "*To estimate R_∞ we averaged the reflectance of the ten darkest pixels in each substitute image, after manually filtering out pixels obviously associated with sediment traces or sensor-related scanning issues. This is slightly different to the way that R_∞ has been calculated in previous studies but does not produce values that are appreciably different.*" in the revised manuscript.

7) "L160: Whilst I understand that it is more likely for lake bathymetry to change over 11 months for Lake 5, surely the lake bathymetry could feasibly change over any lake and time period?"

Although we agree with the reviewer that lake bathymetry could feasibly change over any lake and any period given the enhanced ablation one would expect at the lake bottom, the shape of the lake basin is dictated by the bedrock topography meaning that large changes through this mechanism are unlikely over the time periods in our study. To reflect this, we will remove the reference to Lake 5 in line 160. In the revised manuscript, the text on lines 159-162 will read, "*As the location and shape of supraglacial lakes are determined by bedrock topography (Echelmeyer et al., 1991), we assume there should be little change in the bathymetry of the lake basins between the data acquisition dates (see Sect. 3.1 for further details).*"

8) "L165: For the paragraph containing line 165 (which details the method used to calculate each lake's depth from the DEM) and the two following paragraphs, much more detail is needed. It is very unclear how you carried out your methodology."

We will add/edit the following text at line 163 to the end of section 2.3, "*In ArcticDEM, full lakes are represented by flat surfaces. To measure their depth, we need to examine the shape of the basin before it has filled or after it has drained. As drained lakes have similar characteristics to perpetually dry surface depressions, we had to first identify which depressions in the DEMs were associated with active lakes. To identify lakes that drain in our study region, we followed the approach outlined in Bowling et al. (2019). This takes all DEMs covering our study area in the ArcticDEM dataset and stacks them, then interrogates the variance of the stack, with areas of high standard deviation indicating potentially active lakes. We filter to identify pixels where the standard deviation lies in the range of 2-7 m; below this threshold, variation in elevation can arise from artefacts in the DEM; and ICESat-2 depth detection is limited to lakes up to 7 m deep (Fair et al., 2020). We then cross-*

referenced these areas with the locations of known supraglacial lakes, and the availability of ICESat-2 data, to generate our sample (Appendix A.1).

We set the lake level in the empty DEM to be consistent with the ICESat-2 data, under the assumption that the ICESat-2 and ArcticDEM data are spatially coregistered; i.e. we identified the DEM elevation value at either end of the ICESat-2 transects where ICESat-2 depths are zero, averaged these values and subtracted the average from the entire DEM.

Due to the sparse temporal sampling of ArcticDEM, and the need to resolve empty basins, the DEMs are not temporally concurrent with the ICESat-2 and Sentinel-2 data. As a result, the smallest period between the ArcticDEM and ICESat-2 acquisition dates was approximately two months (Lake 4), and the largest period was approximately 11 months (Lake 5) (Table A1). As the location and shape of supraglacial lakes are determined by bedrock topography (Echelmeyer et al., 1991), we assume there should be little change in the bathymetry of the lake basins between the data acquisition dates (see Sect. 3.1 for further details)."

9) "L194: lake surface?"

To clarify the manual delineation procedure for ICESat-2, we will alter lines 192-196 to read, "*We invited 10 altimetry experts to manually digitise the lake bathymetry from the refraction-corrected ATLAS ATL03 photon data plots using an online digitisation tool (https://apps.automeris.io/wpd/)*." This section was relevant only for a previous version of the ICESat-2 bathymetry data set and so this comment will not be relevant to the revised manuscript.

10) "L269-L275: You only talk about the red depths in detail here, what about the green depths?"

We will add the following text to the revised manuscript at line 275, "*The green band RTE shows a different pattern to that of the red band RTE. From the location of the cloud in relation to the XY line, we see that the green band RTE typically overestimates depth compared to ArcticDEM. The plateau depths of the green band RTE for these lakes are not visible but the size of the cloud gives an indication of the larger spread of values compared to the red band RTE.*"

Further discussion regarding the green band data in Figure 5 can be found in the Discussion section of the original manuscript at lines 317-323.

11) "L325: I am not sure 'However' is the right word to use here."

We propose altering the manuscript at lines 325-326 to read, "*However, the large variances in volume estimation between the green and red RTE depths and the ArcticDEM DEMs have contrasting implications to both this assertion and to one another.*" to clarify the subject and context of the sentence.

12) "L332-224: This section could do with some re-wording to improve its clarity."

We assume that the reviewer is referring to lines 331-334 and will alter the text accordingly to read, "*With a lower estimate of the water available within the ice dynamics system, our ability to predict ice* *calving rates at marine-terminating glaciers is affected. Specifically, it could cause us to underestimate the contribution of meltwater to localised ice velocities, potentially understating the role of meltwater in ice calving caused by glacier velocity increases*."

13) "L357: The authors should also consider referencing Moussavi et al. (2020) here."

We will cite Moussavi et al. (2020) on line 357.

14) "Figure 1: Caption – where are the background images from? Sentinel-2? North Arrow is hard to see in main map and subset maps."

In the caption for Figure 1 we will add the following text, "*The background images in panels (1)-(5) are the Sentinel-2 tiles detailed in Table A1*." In the revised manuscript we will alter the colour of the northing arrows.

15) "Figure 3: For the Y-axis find a way to space out the text for 'ArcticDEM' and 'ICESat-2'"

In the revised manuscript, we will space out the text for 'ArcticDEM' and 'ICESat-2'.

16) "Figure 4: Please add North labels and scale bars to these plots! You also need to state that you show the ICESat-2 transects on the depth plots."

In the revised manuscript, we will add northing arrows and scale bars to the true colour imagery plots to give context to the figure. In the caption, we will alter the text to read, "*The true colour imagery is from Sentinel-2 (Table A1). ICESat-2 transects are shown in orange on the true colour imagery and the depth difference plots.*"

17) "Appendix A Section 1: The authors should consider moving comments on the quality of ICESat2 into the main text."

We agree that comments on the quality of ICESat-2 would help to develop the main text and will add the following text to line 185, "*After limiting the potential lake inventory by the availability of ArcticDEM (Appendix A.1) we considered the quality of the available ICESat-2 data, where the highest quality translates to the basins which can be most easily delineated from ICESat-2 photon refraction i.e. we can see both the lake surface and bed returns of the photons. In doing so, we limited our lake selection to the five study lakes.*"

18) "Table A1: What date was the imagery downloaded by you? – Apply this comment elsewhere too."

We will add columns to each of the data tables (Table A1 and Table A2) to reflect the dates when the data was downloaded.

References within this response

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