Referee #2

We thank the referee for their feedback on our manuscript, and suggestions for improvements.
In the following, we will reply in detail to all issues raised by the referee and explain how we will revise our manuscript accordingly if we are invited to submit a revised version of it.
We show the referee's comments in black and our response in blue italic text.

General Comments

This paper combines multiple satellite missions to improve the temporal resolution of ice surface elevation change measurements over 4 previously identified active subglacial lakes in Greenland to provide new constraints on lake volume and evolution. In addition, they find one potential new active lake that might be hydrologically connected to one of the known lakes (although see specific comments). The study is generally well written with some nice figures, and I found the combination of methods to improve the temporal resolution convincing. I did, however, find quite a few minor errors or places which needed further clarification (see specific comments below), and I agree with the other reviewer that the implications of their findings are currently not clear, and could do with expanding / reworking. For example, could you combine your improved monitoring of recharge rates with your basal melt modelling (expanded to all sites), to make this a more significant component to better explore the role of surface vs basal melt. How do your recharge rates/ drainage rates compare to elsewhere? Can you use your improved timings of drainage to better link to triggers?

As also mentioned in our reply to referee #1 the aim of our study has been to investigate whether CS2 SARIn data and TanDEM-X data can be used to improve monitoring of subglacial lake activity in Greenland. Both referees suggest that the manuscript is reworked to make its aim clearer. We would prefer to keep the focus on this paper on the data and its usefulness in subglacial lake monitoring. We suggest removing the basal melt plot and discussion from a revised manuscript, and instead improve and expand on the data method section and associated discussion.
We will further expand on the discussion and conclusion to focus on possible applications of our findings – e.g., that it can be used to better link to triggers.

Specific Comments

L4 – Antarctic Ice Sheet
Agree. We will revise accordingly.

L6 – I think it would be worth mentioning earlier in the abstract that active lakes are typically identified from ice-surface elevation changes to put this point into context.
Agree. We will add the following sentence to the abstract: "Active lakes may be identified by local changes in ice topography caused by drainage or recharge of the lake beneath the ice."

L14 – It is odd to mention surface hydrology at the end as this is not discussed in the rest of the abstract.
Agree. We will shorten the last sentence to: "These findings show how improving the measurement capabilities of subglacial lakes, improves our current understanding and knowledge of the subglacial water system."

L21 – not sure this reference is appropriate here as it focuses on predicting lake locations. Perhaps refer to the Livingstone et al. (2022) study instead.
Agree. This was a mistake. We will refer to Livingstone et al. (2022) instead of Livingstone et al. (2013).

L24 – "steeper ice surface slopes"
Agree. We will revise accordingly.

L27 – delete "further". Your previous points were around different settings not detection.
Agree. We will revise accordingly.

L30 – the use of e.g. in this sentence does not work that well. Can you combine the first part of this sentence with the second part of the next to provide a more general mechanism for lake drainage?
We suggest revising the sentence to:
"The lake will eventually drain when filled with enough water to resist the pressure exerted by the overlying glacial load (Chandler et al., 2013), hence a subglacial lake drainage events can be triggered by a prolonged addition of surface meltwater (Livingstone et al., 2022)."

L33 – I think Palmer look at vertical displacement, but don't really mention horizontal displacement. It might be better to refer to some of the key velocity studies in Antarctica or Iceland here.
Agree, we will change reference from Palmer et al., (2015) to Magnusson et al, (2007) and Stearns et al., (2008).

L35 – suggest – "Notably, the period of lake recharge following a drainage event provides…"
Agree. We will revise accordingly.

L49 – should this be InSAR not SARIn?
We made an error here. We will rephase to: "synthetic aperture radar interferometric (SARIn) mode mode".

L56 – delete "source of" to avoid repetition of this word.
Agree. We will revise the sentence to : "An additional source of high-resolution ice surface topographic information is provided by two Digital Elevation Models (DEMs);..."

L59 -this makes it sound like there have just been 4 active lakes identified in Greenland. There are actually 7 – see Livingstone et al. (2019). Worth noting this and rephrasing to justify the four you have chosen.
We agree, and will mention the three other subglacial lakes beneath the Isunguata Sermia.
We suggest to add this paragraph to Section 2:
"We have chosen not to include the three subglacial lakes located beneath the highly dynamic Isunnguata Sermia glacier due to the the small size of the collapse basins and their location very close to the ice sheet margin (Livingstone et al. 2019)."

L66 – this makes it sound like Bowling et al. (2019) identified all these lakes. It would be better to cite the original papers for all these lakes.
We agree and we will cite the original papers.

L72 – Figure 2a is cited before Figure 1.
We will include a new figure in a revised manuscript. It will show the location of all of the lakes and will be the first figure we will refer to.

L83 – is this a subsidence event in 2004? Not clear.
Howat et al, 2015 states that "Drainage occurred in two episodes: a smaller event in 2004 and a larger one in 2011."
We will delete the current sentence and revise the current L 76-77 to: "These studies find that Lake 1 has drained both in 2004 (smaller event) and one in 2011 (larger). The 2011 drainage occurred with an unknown rate within two weeks (28 June, 2011 to 12 July, 2011), resulting in the formation of a collapse basin in the ice sheet surface."

L94 – suggest: "… which could indicate some recharge of the subglacial lakes by surface water".
Agree. We will revise accordingly.

L97 – Flade Isblink Ice Cap
Agree. We will revise accordingly.

L105 – clarify whether this was infill of the collapse surface basin or infill of the subglacial lake by surface water causing the ice surface to rise.
We agree that the paragraph needs to be more specific. We suggest changing it to: "The elevation of the collapse basin rapidly increased by 30 meters over the following two years due to inflow of surface water to the subglacial lake, and between August 2012 and April 2013 a topographic bulge appeared in the basin (Willis et al., 2015)."

L107 – can you quantify the elevation change associated with this event?
Liang et al (2022) observed an elevation change of 10 m. We will add this to the text.

Section 3 – it would be useful to provide details on the final resolution and vertical/ horizontal errors of the processed datasets.
As mentioned above, we suggest to rework the manuscript to put more focus on the data, and processing methods. We will elaborate on e.g. resolutions and errors.

L112 – SARIn has already been defined.
Agree. We will revise accordingly.

L124 – It would be helpful to quantify this change in density.
The density of the swath-processed data compared to the POCA varies and depends on e.g. the thresholds used in the swath processor, and the physical properties and topography of the surface, which affects the waveform. We will add the following sentence to the paragraph:

"The swath processing leads to a 10 to 100 folds increase in elevation measurement compared to the POCA approach, as the output depends on e.g. processing thresholds chosen and the physical properties and topography of the area."

L128 – "… thresholds compared to those usually applied …."
Agree. We will revise accordingly.

L134-138 – Maybe this is because I am a visual person, but a figure showing the raw to processed data points would be really helpful here in allowing the reader to judge the effectiveness of the approach.
We agree that such a figure will be good to include. As previously mentioned, we will revise the manuscript to put more focus on the data and processing methods. We propose to include figures to show the data coverage (geographical maps) and quality (2d waveform plots).

L143 – not sure why you need the word "apparent"?
Agree. We will delete it.

L145 – "assumed to be representative"
Agree. We will revise accordingly.

L146 – how close in time? This is rather vague and could do with rephrasing.
Rasmus
Agree. We will rewrite this paragraph to clarify.

148 – would be useful to get a rough estimate – 1%, 10%, 90%? See my comment above, a figure showing the stages in the processing would be helpful here.
Agree. We propose to include new figures to illustrate better (see comment above for L134-138). We will also provide the information (%) in the text.

L160 – "data takes located"? Is there an error here, I didn't follow this part of the sentence?
We will delete "takes".

L181 – "the vertical bias."
Agree. We will revise accordingly.

L192 – given you correct using local ice flow, it would be useful to know here whether this 100 m in 10 years equates to a local ice flow in this region of ~10 m/yr.
We are not sure what the referee is asking for here.

L198 – "One reason for this is that the…" I don't really get the point around the size of the lake as surely it is the lake edge that you are tracking.
Correct. We will revise the sentence to: "One reason for this can be that the subglacial lake drains again in the observational period, which could make the potential ice flow less evident since the collapse basin is re-formed over the stationary location of the subglacial lake."

Section 4.2 – are these calculations still based on the local difference compared to the basin rim? If not, could these not be influenced by the different penetration depths etc? I don't really follow the approach to calculating the deepest depths (why take a mean if looking for deepest point) or the use of standard deviation. Is this not just a measure of roughness of the floor of the basin? This needs clarifying.

These calculations are the absolute elevations of the aligned datasets. Since the datasets all are aligned at the rim (section 4.1) they will not be affected by different penetration depths. We will rephrase to make this more clearly.
We agree that the mean and standard deviation is also a measure of the roughness of the floor of the basin, but these will inherently have an impact on the accuracy of the measurements. We will rewrite this part to clarify.

L226 – In other papers error is calculated by multiplying the internal error of the DEM by the lake area both before and after drainage and adding together in quadrature. What is the basis for your approach, especially as you state that 2 standard deviations is not a true measure of their accuracy?
We address this in the answer to ref. 1:
We will rewrite the paragraph "line 226" to:
"To estimate the error of the DEM volumes, we compute a new set of volumes at each grid point, with the uncertainty from the depth estimation for the used DEM added to the extracted surface elevations. We then subtract the previous set of volumes, and sum the discrepancies, to get the total volume error at each DEM."

L260 – does this actually show uplift? Could you run regression analysis over the two periods to calculate the recharge rates more accurately.
No, not a significant uplift. We will revise the sentence to:
"The subglacial lake recharge can be divided into a fast basin uplift of ~13 m/yr in the period 2011-2015, and a period with no significant uplift from 2015-2019."

L276 – Flade Isblink Ice Cap
Agree. We will revise accordingly.

Section 5.1 – Some of the text in this section would I think be better incorporated into the figure captions e.g., "To maintain a visually clear plot not all data sets are shown in Figure 5b." This would help the flow of this section while making the figures standalone.
We agree and will revise accordingly.

L297 – Although this is the maximum volume measured, it is the minimum possible volume (given you might have missed the period of maximum collapse (i.e. it might have collapsed and then recharged between data points).
Good point. We will revise the sentence to :
"The lake had a measured maximum volume of ~0.0006 km3 +/- 0.00005 km3 in January, 2011, although since the timing of the drainage is poorly constrained, the actual maximum volume is likely larger than the observed."

L310 – can you quantify this – re. number of data points over X years?

Good point. We will provide more precise numbers for the increase in data points by inclusion of the CS2 and TanDEM-X data.

L313-315 – There does seem to be some signal of the final collapse and then beginning of the recharge period though during the winter 2011/2012 period. To better test this it would be better to split these components and calculate the recharge for the upwards tick as a rate vs. the summer after.
What we meant was that we do not see that there is a recharge in late 2011 when taking error bars into account. We will rephrase to make it more clear: "Notably, the addition of CS2 observations during 2011/2012 allows us to conclude that no significant recharge of the subglacial lake occurred in the second half of 2011, while recharge is observed throughout 2012."

L316 – How do you know it is bedrock? Suggest change to "bed"
Agree. We will revise accordingly.

L318 – Ok, but could this not be associated with a decrease in filling over time as the area increases (i.e. for a given melt input the rate will decreases because of the basin shape?). I think it is fairly common for recharge rates to slow over time.
Good point. We will rephrase the sentences to: "We further hypothesize that the infilling of the collapse basin after 2014/2015 is likely primarily caused by snowfall and ice flow, and less recharging of the subglacial lake due to the fact that the center of the collapse basin moves away from the subglacial lake as a result of local ice Flow. The filling rate will however usually slow over time due to the geometry of the lake."

L320 – "model estimates of basal melt rates" – ok, based on what data? Need a supporting reference and to quantify. I don't quite see how this point fits with the idea of ice flow/ snowfall. What is the surface mass balance change?
As previously mentioned we suggest to remove the basal melt estimates (Appendix A) and discussion from the manuscript at part of shifting the focus towards the data and methods.

L321 – Appendix not Append.
Agree. We will revise accordingly.

L322 – capitalise vatnajokull ice cap
Agree. We will revise accordingly.

L330 – A more positive spin would be to give the time span over which the drainage could have happened.
Agree. We will revise accordingly.

L331 – "drains"
Since we are here discussing two lakes we believe that it should be "drain" and not "drains"?

L332 – "spring"
Agree. We will revise accordingly.

L334 – In which case, how do you know whether Lake 2 is actually a supraglacial lake that is filling and draining? It would be useful to confirm whether the 2011 data is associated with surface water or not.
Agree. We will investigate and include this in the analysis.

L347 – please state the infilling rate from this calculation.
Agree. We will revise accordingly.

L352 – It would be useful to incorporate the results of Liang et al. (2022) into this discussion as they look at seasonal recharge (i.e. impact of warmer summers on recharge rate, with rates of up to 49 m/yr).
We will incorporate the Liang et al. (2022) further on our discussion.

L357-358 – "which shortly affected the local horizontal ice velocity" – needs rephrasing.
Agree. We will rephrase the sentence to: "The surface lowering in 2019 is also documented from ICESat-2 data by Liang et al. (2022), who also identified it as a drainage event. They also document that this event caused the ice velocity downstream from the lake to abruptly but shortly increase. "

L368 – "basins are flat"
Agree. We will revise accordingly.

L378 – You use SARIn elsewhere.
Yes, but this is correct. For CryoSat-2 the data is called SARIn.

L386 – Ok, but others have shown this in their data, so should acknowledge this.
Agree. We will revise accordingly to acknowledge.

L387-388 – this needs clarifying? Where is this low pressure region?
We suggest to delete this sentence.

Section 6.5 – this seems rather tagged on and is not explained in the methods, and very briefly here. I would suggest introducing earlier in the method section and showing in the results, or deleting.
We suggest to delete this part to focus more on the data and methods.

L402 – There is also a new paper in TCD by Fan et al. (2022) with lots of new active subglacial lakes. Is this one of the lakes in their inventory? https://tc.copernicus.org/preprints/tc-2022-122/
As stated above we will include Liang et al (2022) further in our discussion.

Section 6.6 – given that this period coincided with a large melt event could these both be responding independently to large volumes of water accessing the bed in this region? More information is needed here to better test this hypothesis.
This is true. Here, we simply want to point to the fact that the timing of the events could imply that they are connected. We do not foresee to do any detailed analysis in this work to

support this hypothesis. But we agree that the section can be improved by expanding on the information and discussion. We will do so.

L422 – Greenland Ice Sheet.
Agree. We will revise accordingly.

L423 – "investigated elevation changes"
Agree. We will revise accordingly.

Figures/ Tables

Given that you correct based on the elevation outside of the collapse basins, I was surprised to see many of the plots with a y-axis of elevation rather than elevation anomaly (relative to the tie points). It would be useful to clarify whether you use similar time periods as cross-over points or how you are able to show these.
We thought that it could be relevant for the reader to know the actual elevation of the lake site. We will revise the figures (see also our reply to referee #1) and will add the explanations of the shaded areas as requested below in the caption.

Figure 1 – what is the blue shaded bar? (also in figures 2 and 3)
This is the area from which we calculate the deepest point. We will add explanation.

Figures 2 and 3 – what are the red bars? (also true for Figure 7)
This highlights those measurements that are likely connected to the occurrence of surface water. We will add explanation.

Figure 6 – what is the grey-blue bar around the points? Need to clarify. Why do only (a) and (d) have red lines?
This is the error bar on the volume calculation based on the scaling factor between volume and depth. Since we do not have CS2 measurements over Lake 2 and 3 it does not apply for those. We will add explanation.

References

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