

## Response to reviewer 1:

### General comments

This manuscript presents a novel winter supraglacial lake drainage detection methodology using a combination of two SAR data sources. This advanced methodology normalizes for differences in acquisition geometry and satellite missions, allowing for a cohesive output with a high temporal resolution. A thorough literature review was conducted and presented in a logical manner, relating the works of other groups effectively to the topic analyzed in this manuscript. The methodology seems well thought-out and incorporates many data sources and processing chains to provide meaningful context to the drainages, in particular the volume estimation using ArcticDEM strips, subglacial water pathways mapping, and the integration of ASCAT data for surface melt estimation. The results are overall well presented and the integration of the summer drainage dataset with their winter dataset provides a novel insight into how the drainage behaviors in each season influence each other. The writing style is elevated yet easy to read; however, some restructuring and concision is needed for the final discussion sections and conclusion. Overall, I find this manuscript to be of a high quality in both methodology and presentation, with some minor work needed to clarify the details of some processes and bring the work to a succinct conclusion.

We thank the viewer for all their very positive comments. We take on board the suggestions of restructuring and concision towards the end of the paper, and of the need to clarify some of the process details. We address these general points within the specific comments below.

### Specific comments

**L16:** "...exhibiting substantial interannual variability, *ranging from* a maximum..."

Will be fixed to include "ranging from".

**L54:** Adjust the phrase "ice layers" to more clearly reference upper ice layers

We will rephrase this so that it is clear that we are referring to upper ice layers.

**L70:** There are several instances of the British spelling of some words being used, while the majority of the manuscript is written with American English spelling. Please adjust the spellings so that they are consistent (specific examples include behaviour, analysed, favourable).

We will review the manuscript so that it is consistent with British spelling.

**L104-109:** An important fact about 79NG is that it has an extensive floating tongue. This fact should be mentioned in this paragraph and related to the study area you define in Fig. 1 (mentioning the fact that lakes that form on the floating tongue are not analyzed). The terminology used to describe your study area must also be changed to reflect the difference between the terminus and the grounding line. There are several instances throughout the manuscript where 79NG's terminus is referenced but the grounding line is meant – these two are not interchangeable for a glacier with a floating tongue and could lead to confusion by the reader.

Thank you for pointing this out. We will add information on 79NG in relation to it having a floating tongue and that lakes on it are not analyzed. We will also review the manuscript to ensure that reference to 79NG's terminus is correctly referred to as its grounding line.

**L109:** I believe where Fig. 2.1 is mentioned, you are actually referring to Fig. 1b.

You are correct. Thanks for catching this typo.

**Figure 2:** I would consider adding a legend to the figure to describe the red and yellow polygons. Additionally, the distance scale could be shortened as it really only needs to be up to 3km long since the image subsets are roughly 4 x 4 km.

We will include a legend for the red and yellow polygons and adjust the size of the scale of Figure 2.

**L214-215:** The flow of this sentence could be improved for ease of understanding. Rephrasing the sentence so that the main clause ("we applied...") starts the sentence with the rest of the information following could help. Putting some of the information into a second sentence would help as well.

Agreed. The flow will be improved in the revised version. We suggest: "We applied a multi-slope normalisation method to account for the influence of surface geophysical changes on regression-modelled incidence angle–backscatter relationships before and after drainage events."

**L231:** You could add some information about how the threshold was defined as four times the monthly median absolute deviation.

We will add some details of how it was defined.

**L278:** This paragraph starts similarly to the last one (place context and provide context). Rephrase one of them to help it sound less repetitive.

To address this, we will rephrase the opening sentences of both the paragraphs to read:

"Subglacial hydraulic potential gradients and associated flow routing were calculated to situate winter lake drainage observations within the framework of potential subglacial meltwater pathways."

And

"Daily ASCAT C-band normalised radar backscatter ( $\sigma^0$ ) data were used to characterise the intensity and spatial extent of surface melt during each melt season across the 79NG and ZI basins."

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**L278:** Make the distinction of surface melt and supraglacial lakes clearer. Describe what exactly is meant by surface melt (i.e., wetness of the entire surface vs. the pooling of meltwater into lakes).

We will clarify this and make the distinction in the revised version.

**L278:** I believe this is the first mention of the ASCAT C-band data. Either give the description of the acronym or briefly summarize what this data is. Also include a citation/website reference for the data.

You are correct that it is the first mention. We agree and will include a brief summary of the data and reference in the revised version. We will expand the definition as “Advanced Scatterometer (ASCAT) aboard the European Space Agency's MetOp-B satellite”.

**L287-289:** Here, it is not extremely clear what the annual melt index consists of. It sounds like you are just adding up the total melt area. Is the melt intensity involved in this index? If it is just the sum of the area, how is that different than what is described in the next sentence?

Thank you for pointing this out. It is confusing. What differentiates melt intensity and index is that intensity is calculated per pixel and displayed in Figure A1, while the melt index is the sum of melt intensity of each grid cell over the study area. In our definition of the melt index, we will clarify how it is calculated and different from melt intensity.

**L298:** I would add “...90 winter lake drainage events” to make it clear this is not including summer drainages. Even though you say “between the 2014/2015 and 2023/2024 winter seasons”, it could be interpreted that the entire years between those two seasons are included.

Agreed. We will include this in the revised version.

**L322:** One of the instances of saying “terminus of 79NG” that is incorrect. These lakes are near the grounding line, whereas the terminus is the edge of the floating tongue. The use of terminus with ZI is correct, since it lost its floating tongue, resulting in the terminus being roughly along the grounding line.

Thank you for pointing this out. We will correct it to specify that it was near the grounding line of 79NG rather than the terminus.

**L322-324:** I would be curious to know if the lakes fully drained both times. Or did they partially drain the first time and then finish the drainage months later? If you're able to tell that from your data, that could be interesting to include.

We were also interested in this behaviour. While we cannot determine this definitively, we suspect that these lakes partially drained and subsequently completed drainage several months later. This interpretation is based on the backscatter time series, which shows an initial increase followed by a prolonged stable period with little to no change, and then a second increase. If the initial increase had been followed by a gradual decrease in backscatter, this might suggest winter refilling mechanism. However, we do not observe this in the backscatter time series and therefore consider winter lake filling to be unlikely.

**L326-327:** Clarify if that means that each pixel depth across all lakes was averaged together or if the maximum or average depth of each lake was calculated and then averaged over all lakes.

We think this is clear as we make no mention of maximum depth and refer only to mean depths. Whether we take the mean of all pixel depths across all lakes, or whether we take the mean depths of each lake and then take the mean of those, the result will be the same.

**L339:** Just wanted to comment that this is a very nice display of a lot data in one figure!

Thank you!

**Figure 5:** Make sure the cube in km<sup>3</sup> is raised instead of using a ^ symbol.

We will fix this.

**Figure 7:** I don't find the second subfigure (b) to be the easiest to draw information from. Consider if there is a better way to display this information. However, if you keep it as is, move the numbers to the side of the circle in cases where the circle is the same size or smaller than the number (i.e., 1, 2 and 3), to improve readability of the numbers.

For the revised version, we will consider other options to display the data. If we decide to keep it as is, numbers will be moved to the side as suggested.

**L405:** I would add "... for individual lakes *over all seven years*" to make the total amount of possible drainages clearer.

We will include this.

**L442:** Perhaps you could add more information about how the lakes are subglacially connected. Are they all along the major meltwater channel? Are some on smaller branched leading to the main channel?

We agree it would be beneficial to include this detail and will include it in the revised version. Information on whether lakes are located along tributaries or the main channel will be described.

**L444-459:** For Events 2-6, there is no mention on the hydrological connections of the lake clusters. Looking at the map, it does not seem that they are always connected on descending channels. Some details to that would be nice to have described here.

We will include mention of the hydrologic connection for these events as was done for the first event.

**L445:** Make it clear that the numbers in brackets for all following events (e.g. (~740-660m)) are referencing elevation. Upon quick glance, it could be mistaken to be the distance between them or the diameter of the lakes.

We will clarify this.

**L550:** I would make this paragraph part of the previous one.

We agree and will change this.

**L551-552:** Expand on this phrase to fully address why this leads to more drainages in the winter of cool years and not in the summer, when the drainage system is presumably also inefficient.

We will expand this point in the revised version to fully address this.

**L572:** "...increasing the probability that meltwater reaches the *grounding line, thus driving basal melting.*"

We will change our text to this.

**L575:** Is the Zheng et al. (2023) study also in Northeast Greenland? If so, there could be a better way to combine this sentence with the previous one more fluidly.

Their study was ice sheet wide; however, the value reported was specifically for Northeast Greenland. We will consider combining the sentences in the revised version.

**L594-569:** This information feels repetitive to the information at the beginning of the previous paragraph. Condense all of the information together in the previous paragraph.

We will condense this information into the previous paragraph.

**L604:** “Instead” does not feel like the right transition word here. Perhaps just saying “These near synchronous drainages...” would help it flow better.

We will incorporate this suggestion to improve flow.

**L615:** “...pathway *and* are...”

This fix will be included.

**L640:** Would it create a better structure for this section to begin the section with this paragraph? This way, the different mechanisms are described clearly first and then can be referenced as you go through the different event descriptions. You could even label each mechanism as Mechanism 1, Mechanism 2, etc. and to make the description within each event description more concise. The way it is now, the event description paragraphs feel a little repetitive and scrambled.

We agree that moving this paragraph to the beginning of Section 5.2 will improve the overall structure. We will consider labelling the mechanisms to reduce repetitiveness throughout the paragraphs.

**L674-684:** The flow feels a little disconnected in these two paragraphs. I would suggest reordering the sentences to something like this: First L679-682, second L674-678, third L682-684. Bringing L679-682 to the beginning gives more context to what will then be described.

We agree and will restructure this accordingly in the revised version.

**Section 5.4:** This section needs significant editing/restructuring. The first and last paragraph of this section do not provide new information; instead, they summarize information already presented in the manuscript. The first paragraph gives a nice overview of the novel method developed and implemented in this manuscript. This, however, does not belong in the discussion, but would be a nice addition at the beginning of the conclusion section. Similarly, the last paragraph addresses challenges in the presented methods. This would be more suitable to include near the end of the conclusion section. The remaining two middle paragraphs discuss the use of  $\sigma^{\circ}\text{HV35}$  in 10-year composite imagery. The title of this section should be renamed to more specifically address the discussion of this particular part of the methodology instead of a general overview of overarching methodology of the manuscript.

**Section 5.5:** This section is also in need of restructuring in order to make the focus more precisely on future work. A majority of the sentences are used to summarize your findings or the findings and downfalls of other researchers. Much of this information has already been stated elsewhere in your manuscript and does not need to be repeated here in order to address gaps for future work. My suggestion would be to take out the few lines which describe actionable future work ideas and bring them together in a short paragraph in the conclusion section, eliminating this section entirely. In the first paragraph, this would be L721-722 about extending winter lake drainage investigations to other regions. In the second paragraph, it is the last sentence about data fusion. In the third paragraph, I do not see a clear future research statement. From the fourth paragraph, you could write a sentence about needing better or more specific data to study how winter lake drainages affect ice dynamics and how that can affect the behavior

of supraglacial lakes in the melt season. In the last paragraph, you could more or less use the final sentence by exchanging “these measurements” in L751 with “SAR observations with high frequency in situ GPS measurements”.

**Conclusions:** As mentioned in the last two comments, I would exchange the first paragraph here with the first paragraph from section 5.4. Then, I would put the last paragraph from section 5.4 as the second to last paragraph, leading in to the future work sentences pulled from section 5.5. The last paragraph in the conclusions section as it is can be condensed to summarize less. The sentence in L780-782 was already said at the beginning of the section and can be removed. Figure A1 caption: Are the first few words in a different font?

We agree that Sections 5.4 and 5.5 contain some repetitive material and would benefit from restructuring. For Section 5.4, we will move the content of the first and last paragraphs to the Conclusions section, as suggested, and revise the section title to more specifically reflect the discussion of the  $\sigma^{\circ}$ HV-based composite methodology. We will eliminate Section 5.5 and move lines on actionable future research directions into the conclusion.

Regarding the Figure A1 caption, there indeed appears to be a different font. We will fix this.