

## Author's response to the comments from Reviewer #2

This paper uses a band thresholding approach to map surface meltwater over several ice shelves in Dronning Maud Land between 2014 and 2021. It is the first study to look at inter- and intra- annual variations in ponded water extent across several ice shelves in this region.

Overall, this paper is fairly well written, and adds some detail to our understanding of surface meltwater across Dronning Maud Land. However, in my opinion, the paper requires some major and minor edits prior to being ready for publication, which I have outlined below.

*We would like to thank the reviewer(s) for their work on our manuscript and the encouraging comments. We address each of the suggestions and provide responses to specific comments below.*

***Additionally, we have made some amendments to the sections pertaining to the relationship assessments between Supraglacial lakes and Climate, which is described below.***

*Initially, correlation calculations were performed using 'actual' SGL extents (SGL area and volume) and Mean DJF Temperatures. However, due to the large inherent differences in SGL extents between regions (e.g., Fimbulisen and Roi Baudouin East), the relatively good correlation for individual ice shelves was not reflected for the region as a whole. We have therefore normalized each annual maximum lake area/volume estimate with respect to their maximum for the whole study period. These normalized extents (values between 0 and 1) are now used to calculate correlations between lake extents and temperatures. This doesn't change the regional correlation values but increases the overall Dronning Maud Land correlation, better reflecting the relatively good local correlations. These values have been updated in Table 2 and relevant text has been updated as well (Section 3.7, Section 4.3, and Section 5.4). A figure has also been added to the supplement (Figure S9), showing a scatterplot of normalized areas with respect to mean summer temperatures.*

### **Major Comments**

The authors use relatively new methods from Moussavi et al. (2020) to mask for clouds, rocks, and ocean prior to classifying water pixels. However, Moussavi et al. (2020) also provide a multi- band threshold approach for mapping surface meltwater, but the authors opt to just use an NDWlice approach, with no justification for this decision. This is an odd decision to make, given the success of the methods provided by Moussavi et al. (2020), and given that the methodological approaches are now mixed. I would recommend mapping the meltwater using the methods provided by Moussavi et al. (2020), or giving a strong justification as to why this is not done.

*Clarified the text by rephrasing the methodology (Section 3: 3.1 – 3.4). The mapping of lakes was done using all steps recommended by Moussavi et al. (2020).*

In addition to this, please can I request that the authors provide the exact equations used for all methodological steps in their work. At times I find the methodological descriptions very vague. *To address this, the methodology section has been rephrased entirely and a methodological flowchart has been added as supplementary Figure S8, including band indices and thresholds used. Additionally, the equation of NDSI has been added in the manuscript, and all the equations have been presented in Figure S8.*

Throughout the text, there is a significant lack of references to the relevant papers. Please can the authors comb through their work and make sure any idea that is not their own is referenced. This is particularly true for the discussion.

*Added references at several places in the manuscript. Some examples:*

~ L474 – ‘...the surface meltwater has drained or begins to freeze at the surface to form relict lakes (as observed by Lenaerts et al. (2017))’

~ L480 – ‘...feedback mechanism of exposed blue ice areas that enhances melting of surrounding ice (Bell et al., 2018; Lenaerts et al., 2017).’

~ L484 – 486 – ‘... laterally transported across the grounding zone and over the ice shelves by surface streams and channels, as also observed by (Dell et al., (2020) over Nivlisen Ice Shelf.’

~ L545 – ‘...directly draining into the ocean through surface streams (Bell et al. 2017).’

~ L547 – ‘... partial surficial freezing and subsequent insulation of deeper meltwater (Dunmire et al., 2020)...’

*Please see also the response to reviewer 1 on adding further references in the manuscript.*

At present, there are a lot of interpretative and discursive statements in the results section, which need to be removed and placed into the discussion of the paper. The results should simply state the results presented by the study, and nothing more. Examples of this are parts (or all) of lines 292-293, 321-322, 336, 340-341.

*We agree and have removed several discussion-type statements:*

~ L292-293 Removed – ‘where meltwater production is more efficient due to the exposed blue ice having lower albedo.’

~ L321-322 Removed – ‘This mixed pattern in nearby regions suggests that local processes also influence melting and ponding in the region.’

~ L336 Removed – ‘The reasons for these large variations in surface ponding over different regions (over 2 orders of magnitude) remain unexplained.’

~ L340-341 Removed – ‘This relative consistency in melt extents for different areas indicates that there are common climatic factors that control melting and ponding in Dronning Maud Land at large’.

~ L282 Removed – ‘presumably due to the low supply of meltwater’

~ L284 Removed – ‘likely due to percolation into the unsaturated firn pack that surrounds the meltwater ponds.’

The authors state numerous times that they see the transfer of water across the ice-shelf surface. However, I would argue that they present no evidence for this. The data collected here simply maps surface meltwater extent and does not prove flow or transfer of water in any dimension. It is not implausible that water is flowing across the ice-shelf surface along topographic gradients, but without evidence and analysis showing this, I think these inferences should be removed from the paper.

*Evidence for Lateral transfer of meltwater is presented in Figure 4 and Figure 5 of the manuscript (in addition to Figures S4 and S5 of the supplement), and has been interpreted similarly by earlier studies (e.g., Dell et al., 2020; Kingslake et al., 2017)). We noticed that nothing about lateral transfer was mentioned in the figure caption - this has now been added. Additionally, we have also added Supplementary Animation 1 as supporting evidence of meltwater transfer.*

*Since the transfer of meltwater is also reported by Dell et al. (2020) over Nivlisen Ice Shelf, we have referenced this following the discussion of meltwater transfer. E.g., L377 – 378 : ‘The produced meltwater is laterally transported across the grounding zone and over the ice shelves by surface streams and channels, as also observed by Dell et al. (2020) over Nivlisen Ice Shelf.’*

The discussion currently includes numerous claims that are neither supported by references from the literature nor from evidence in the paper. This discussion should build on phenomenon that the analysis finds and embed this in previously published literature.

*Thanks for pointing this out. We have removed several such statements from the manuscript.*

## **Minor Comments**

L8 (and elsewhere): The phrase ice sheet – ice shelf stability regime is a bit odd, perhaps rephrase to ‘severe impacts on the stability of an ice shelf’ and then weave in the subsequent implications for the ice sheets because of this.

*Modified accordingly at two instances on ~L8 and ~L40.*

L12: Change ‘Antarctic ice sheet’ to ‘Antarctic Ice Sheet’. Check for this elsewhere too & check other nouns.

*Corrected at several instances.*

L27/28: This sentence is vague, try to add detail.

*Replaced the sentence with some details.*

*‘Ice shelves are floating extensions of Antarctic Ice Sheet and play a critical role in regulating the flow of ice from the continent into the ocean. As the climate warms, these ice shelves are becoming increasingly vulnerable to melting and collapse, which can accelerate the discharge of ice from the grounded ice sheet into the ocean and contribute to sea level rise.’*

L30: If the water isn’t being exported as run off, but surface melt is occurring, then tell the reader what the fate of that surface melt is.

*Modified the following sentence to include the fate of meltwater*

*‘Large amount of the meltwater produced due to melting of snow and ice (Echelmeyer et al., 1991) percolates and refreezes in the underlying layer of firn, whereas the remaining water ponds in topographical depressions, typically occurring around grounding zones (Stokes et al., 2019), leading to formation of supraglacial lakes.’*

L37: In this paragraph you start by talking about meltwater on ice shelves, but on this line you say meltwater can drain and cause glacier speed-up, which is something that would occur on grounded ice rather than an ice shelf. Please read through your paper again thoroughly and make sure you clearly separate out ideas pertaining to ice shelves vs. grounded ice.

*Removed the statement.*

L42: There are so many more references you could use here. If you just want to use a couple, then please write this as ‘(e.g., Kingslake et al., 2017; Stokes et al., 2019)’. This concept should be applied elsewhere throughout the paper too.

*Agreed and modified accordingly. See also the response to reviewer 1 on adding further references in the manuscript.*

L46-48: The evolution of supraglacial lakes has also been observed on the Nivlisen Ice Shelf (Dell et al., 2020), and Roi Baudouin Ice Shelf (Dell et al., 2022). Both of these are in Dronning Maud Land.

*Added details of Dell et al., 2020 in the paragraph.*

L59: What do you mean by ‘simple configuration’, perhaps reword.

*Sentence removed.*

L66: The two papers you reference here actually use different methods, so which did you use?

*Removed the incorrect reference (Williamson et al., 2018).*

L72: ‘houses’ is an odd choice of word, perhaps change.

*Changed to ‘has’.*

L73: Change 'kms' to 'km'  
*Corrected.*

L77: The periphery of what? This isn't very clear. Where exactly on the ice shelf are you referring to?  
*Removed the sentence as the context in which it was initially written is lost.*

L80-83: Could you show this in a figure? Which glaciers feed which ice shelves?  
*This sentence has been removed on suggestion of Reviewer # 1. The main glaciers feeding the ice shelves are indicated Figure 1.*

L87: These papers aren't really Antarctic-wide. Find alternatives, depending on how you want to define Antarctic-wide.  
*Changed 'Antarctic-wide studies' to 'Various studies'.*

L88-89: This study by Dell et al. (2020) should have been referenced much earlier on before you justify your study and your work. Also you should reference Dell et al. (2022) and Kinglake et al. (2015).  
*Added references to Dell et al., 2020 in the Introduction.*  
*Added references to Dell et al. (2022) and Kingslake et al. (2015) in the paragraph.*

L92: Change 'Landsat-8' to Landsat 8  
*Changed several instances in the manuscript.*

L104: Here and elsewhere, where did you download all your datasets from?  
*Added links to the websites from where the data was downloaded. Also, the access information to all the data that is used in his work is detailed in 'Code and data availability' section after 'Conclusion'.*

105: What is the common pixel size?  
*Addressed in the rephrased methodology section.*

L104-105: Could this information be weaved into a different paragraph; it seems odd to have it structured in this way.  
*Removed the sentences.*

L109: It might be better to say that you use Collection 2 Landsat data before this point.  
*Addressed in the rephrased methodology section.*

L111: Did you pick these bands because they were the bands used by Moussavi et al. (2020), if so then perhaps say this.  
*Addressed in the rephrased methodology section.*

L114: Did you get a script for the per-pixel corrections from somewhere? If so perhaps reference it.  
*Added: (Williamson et al. (2018); script by Neil Arnold, University of Cambridge).*

L146-147: What are the 'other outliers'?  
*Changed 'other outliers' → 'Outliers (e.g. exposed rock, insignificant water pockets, shadows and clouds)'*

L148: How much manual post processing was required? You could perhaps give an example of an image before and after manual post-processing as a supplementary figure.  
*Added figure (Figure S7) in the supplement showing the occasional need for manual post processing.*

L168: Reference needed.  
*Added reference (Pope et al., 2016).*

L173: And Dell et al. (2020)

*Added reference.*

L182: What do you mean by ice-shelf region?

*Since lakes were not only present on ice shelves but also on grounded ice (e.g., Fimbulisen and Muninisen) we decided to say 'ice-shelf regions', not just 'ice-shelf'.*

L191: What do you mean by 'Larger areas having such pixels were manually removed'? You removed lake edges found in Sentinel but not Landsat? Clarify.

*Since the sentence was misleading and incorrect, we have removed the sentence. The elimination in Sentinel-2 outputs was done only to identify common pixels for Landsat 8 – Sentinel-2 comparison and this is understood in the next sentence '..we first identified common water pixels..'*

L200: change 'temperature' to 'temperatures' (in two places). Change 'was' to 'were'.

*Corrected.*

L206: Change 'seasons' to 'season'.

*Corrected.*

L209: So do you chose to refer to areas or volumes?

*Modified to refer only to correlation values with respect to maximum lake areas.*

L220: Do you have a figure showing what areas were randomly sampled? Did you randomly sample homogeneous features separately to homogenous features? Or did both types of features just get selected in the same random sample?

*We randomly chose areas bearing in mind to contain both homogenous and inhomogeneous lakes. The text has been changed to better reflect this:*

*"...four randomly selected areas that contain water bodies of both homogenous and inhomogeneous character..."*

L225-227: What was the maximum difference, minimum difference etc? Does this justify your selection of a 1% relative uncertainty? Error is a function of lake size.

*Maximum difference is 0.94 km<sup>2</sup> (Area: 4.22 km<sup>2</sup>) and Minimum difference is 0.07 km<sup>2</sup> (Area: 0.055 km<sup>2</sup>). Although there are certain cases where percentage of difference is as high as ~400% (mostly in very small sized lakes), we can say that on average 1% error is justifiable, as these small lakes would have minimal contribution to the cumulative lake area.*

L232: Give the seasons in brackets after 'several seasons'

*Added 2 examples.*

L256: This should probably be made clearer earlier in the text too, but did you look at every ice shelf in DML to start with, and then only find melt on five ice shelves? OR did you only look at these five ice shelves in the first place?

*Agreed. We have added a sub-section to Section 3: Data and Methods:*

### ***'3.1 Identifying areas with SGLs***

*To identify locations with sizeable SGLs in Dronning Maud Land, we closely assessed ~120 Landsat 8 scenes captured in January 2017 and January 2021 (time periods randomly selected), representing the peak austral summer seasons. Careful visual inspection of these scenes was carried out to outline areas with possible SGL occurrence. After identification of these areas, further assessments were restricted to scenes covering these areas only.'*

265: Here and elsewhere: What does 'viz' mean? Rewrite/ reword.  
*Replace 'viz' with 'namely'.*

L272: Give examples of the years of low and high melt.  
*Added one example each.*

L285: remove '(within a particular melt season)'  
*Removed.*

L286: remove '(multiple melt seasons from different years)'  
*Removed.*

L339: I think you mean Fig 7.  
*Corrected.*

L392-395: What are you trying to say here? It doesn't make much sense to me.  
*Rephrased the sentences.*

L396: Again, missing references, if you are just giving some then use (e.g. refs).  
*Added 'e.g.,'.*

L423: Put these refs immediately after the ideas they are relevant for.  
*Moved references accordingly.*

L440: Clarify what you mean by 'Direct surface drainage into the ocean'. I think you mean water flow off the ice shelf edge into the ocean, but this could also mean hydrofracture. Check this elsewhere too.  
*Corrected → Direct Horizontal overflow (runoff over the frontal edge of the shelves)*

L451: Change 'Shackleton ice shelf' to 'Shackleton Ice Shelf'.  
*Corrected.*

## **Figures**

Figure 1: What dataset in Quantarctica did you use? It should have a reference as it would have come from somewhere.  
*Added source: SCAR's Antarctic Digital Database (ADD) through Quantarctica.*

Figure 3: Does the 10 Km scale apply to all the individual ice shelf maps? Give the inset map a scale.  
*Changed 'Scale' → 'Scale for all panels (a-g)*  
*Added Scale for the inset map.*

Figure 6: For the 'b' figures, consider changing the Y axis to %'s, as this is how you present the data in the text. This Y axis also needs a label! X axis labels needed for both a and b!  
*Added labels to all X and Y axes and changed values to percentage in Panel b.*

Figure 7: Add X axis labels.  
*Added X axis labels.*

Table 2: Caption: correct 'ices helves'  
*Corrected.*

## **Supplementary**

Figure S3: Give the actual image information for imagery used. Apply this where appropriate elsewhere too.

*Added the dates on which the images were captured.*

Figure S6: Legend needed. If you are using REMA data it needs to be detailed in the methods of your paper.

*Added Legend to the figure.*

*Added a sentence at the end of Section 3.1 – ‘For topographic assessments we used the 100 m product of Reference Elevation Model of Antarctica (REMA, Howat et al. (2019)).’*

Figure S7: Not referred to in the text? Also this builds heavily on the work of Moussavi et al. (2020), correct? This should be acknowledged. The figure also provides no info on the threshold values used.

*Reference to the figure is added in the rephrased methodology section. Threshold values and legend have been added to the figure. A flow chart of the methodology has also been added as Figure S8.*

A table of the satellite data used and data availability should be included as supplementary info.

*Added ScenesList.csv as additional supplementary document.*

## **References**

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Williamson, A. G., Banwell, A. F., Willis, I. C., and Arnold, N. S.: Dual-satellite (Sentinel-2 and Landsat 8) remote sensing of supraglacial lakes in Greenland, *Cryosphere*, 12, 3045–3065, <https://doi.org/10.5194/tc-12-3045-2018>, 2018.