

Reviewer 2 Comments:

Using optical satellite imagery, analysed alongside modeled temperature and surface melt data, this paper presents a detailed study of surface lake evolution over the last two decades on the Shackleton Ice Shelf, East Antarctica. The authors observe extensive ponding in the region, and from their analysis find that katabatic winds and an albedo feedback play a key role in the formation of lakes, and the timing of variations in extent and volume. The method used to analyse changes in lake characteristics is scientifically sound, and the analysis of this data alongside climatic factors is of a high quality and interesting. The paper is also clear in stating its limitations. This detailed and comprehensive analysis of lake evolution, both through and between seasons, at a particular region, will be valuable to the scientific community as we strive to improve our understanding of surface hydrology in the Antarctic and elsewhere. A detailed temporal study of this nature is particularly welcome. The results and discussion will especially be of value to those studying the nature of lake evolution and the factors associated with that evolution, including modelers.

I do think the clarity of the paper in sections needs to be improved before final publication. In particular, I think there are instances where lack of consistency and specificity of language can hinder clear understanding. I attach an annotated PDF with all my comments and suggestions.

We would like to thank the Reviewer for their work on our manuscript and their constructive comments. We respond to their specific concerns below.

-Section 3.3 needs substantial change in terms of structure and the use of terms. See the PDF.

We have addressed the specific comments relating to this Section below.

-I think the references to 'englacial' drainage, and what is meant by that, need to be made clearer. See the PDF.

We have addressed this in Lines 275, 289 and 412, please see specific responses to comments below.

- The information in the paragraph from L45 to L56 seems as though it should be in the study site section. Currently 'study site' seems spread out over two sections in a way that disrupts the flow.

We have included this information in this paragraph as a justification for our selection of this particular ice shelf, and in particular to highlight its vulnerability to hydrofracturing, which is of key importance in the context of surface hydrology and ice shelf stability. The purpose of this paragraph is also to introduce the ice shelf to the reader who may not be familiar with our study area. Our reasoning for including a separate Study Site section is to provide more specific glaciological context.

- It would be interesting if the authors, in their discussion, assessed the modeled findings of Banwell and MacAyeal (2015) about lakes deepening inter-annually on ice shelves. I only suggest that they briefly assess Banwell/MacAyeal's finding against this paper's analysis.

We have addressed this in Line 373, please see specific responses to comments below.

-I think figure 4 needs work to be more useful to readers. I find that the attempt to include data from every year in the long study period makes it almost impossible to tell which color corresponds to which year. I leave it to the authors to decide how best to overcome this – perhaps they need to be selective about which data from this series is most important to demonstrate the findings and move some to a supplementary figure. I appreciate this is a difficult challenge. I also have a small suggestion for figure 1 and a tiny cosmetic suggestion for figure 10. All suggestions are included in the same pdf. Thank you very much to the authors for an interesting read and for contributing this valuable research.

We considered these suggestions regarding Figure 4, but decided not to modify the data shown in this Figure. This is because we feel it is important to show the long-term (2000-2020) time series of total lake area, depth and volume, and so feel it would be inappropriate to selectively remove certain years into another Figure in the Supplementary Information. We feel the particular strength of this Figure is that it summarises both the long term and the seasonal evolution of supraglacial lakes. By plotting these data on a common seasonal timescale, it is easier to see the relationship between lake area, depth and volume.

Although individual years could potentially be made more distinguishable by using discrete contrasting colours, we think a graduated colour scale highlights data in later years, and in particular anomalously high years of lake meltwater storage (e.g. 2014, 2015, 2020). Full lake area, depth and volume data for individual years is contained in Table 1, and we have highlighted this in the figure caption. We have made the small suggestions to Figures 1 and 10, and thank the Reviewer again for their encouraging comments.

Responses to specific comments (on PDF):

-Because 'melt' and 'pond' can both be used as nouns and verbs I think you have to be careful with their usage. In particular I think the first sentence needs to be revised, I had to read it several times and I am not sure it is necessary at all.

L26: We agree the use of 'pond' as a verb in this first sentence is potentially confusing, and have decided to remove the sentence.

This sentence sets up the expectation that you will outline the *direct* and *indirect* influences, but then you do not do that. I suggest explicitly doing that, now you don't mention an indirect one, or else you set it up differently.

L27: We have added two sentences to explain how SGLs influences ice shelves both directly and indirectly – this relates to the comment on L34, please see below.

-This sentence is one example of what was presented in the previous sentence – I don't think 'specifically' is appropriate.

L28: Amended: deleted 'Specifically'.

I suggest mentioning in addition to flexure, that lakes can also influence ice shelf stability by being a source of water to fill/propagate crevasses (e.g. Scambos et al., 2003). You do mention hydrofracture, but in passing elaboration of the flexure mechanism. I also suggest mentioning they influence the albedo of the surface.

L34: We have added the following two sentences: 'SGLs can indirectly influence ice shelf dynamics by lowering surface albedo, which can intensify surface melt and induce a warming effect on the adjacent ice column (Lüthje et al., 2006; Tedesco et al., 2012; Hubbard et al., 2016). SGLs can also act as reservoirs by storing meltwater for crevasse penetration and hydrofracture (Scambos et al., 2000; 2003; 2009).'

I suggest 'importance for'.

L43: Amended: changed to 'importance for SGL evolution'.

I find the placement of this paragraph a bit odd and disruptive to the flow given that the study site section comes up shortly after. I suggest moving this info into the study site section and only very briefly introducing the Shackleton in the following paragraph.

L45: We have included this information in this paragraph as a justification for our selection of this particular ice shelf, and in particular to highlight its vulnerability to hydrofracturing which is of key importance in the context of surface hydrology and ice shelf stability. Our reasoning for including a separate Study Site section is to provide more specific glaciological context.

I think over/above/below/under is more appropriate when discussing a threshold.

L83: Amended: changed 'within' to 'below'.

Would it not be advantageous and little work to use both Sentinel and Landsat in this period? i.e. use L8 when there is no S2?

L89: We agree that it is advantageous to use a combination of Sentinel-2 and Landsat 8 imagery, and confirm that we used Landsat-8 where no suitable Sentinel-2 was available. We have clarified this in the text, which now reads: 'Sentinel-2A/B imagery was used in preference to Landsat 8 or another sensor, such

as the Moderate Resolution Imaging Spectroradiometer (MODIS) or Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), owing to its high spatial resolution (10 m) and revisit period of 5 days, though Landsat 8 imagery was used where no Sentinel-2 imagery was available with suitable ($\leq 20\%$) cloud cover.'

It is not important, but the convention is to hyphenate Sentinel-2.

L91: We have now hyphenated 'Sentinel-2' throughout the manuscript.

I think it would be helpful for many readers to very briefly explain what a 'mixed pixel' is.

L116: Amended to include a definition of 'mixed pixels', now reads: '(i.e. pixels containing a combination of water, slush and/or snow or ice [...]).'

Was shadowing an issue on any images?

L119: Shadowing was largely not an issue in our lake classification. In some cases, small shadows associated with crevasses or individual rock outcrops were classified as water, and we removed these false positives following NDWI classification during final post-processing of the lakes dataset.

Shouldn't the title be volumes and depths, not area?

L127: Amended Section Heading to 'Extracting lake depths and volumes'.

I assume you converted to TOA before carrying out the NDWI calculation – the flow of the text seems to suggest otherwise. You should mention this before the NDWI.

L133: Agreed, we have moved this paragraph to Section 3.1 to improve the logical flow of the text.

It is odd to mention that R_z uses the red band, but not A_d . Also, later you mention that you also use the pan band. I think this is quite confusing. I suggest not mentioning which band yet, just explaining the method.

L140: Amended: removed 'red band', so sentence now reads: ' R_z is the reflectance value of a water-coloured pixel [...].'

Banwell et al. (2019) takes a one-pixel ring around the water feature. Two pixels is fine, it just doesn't need to reference Banwell. In contrast, Sneed and Hamilton (2007) used the same A_d for the whole region, which could be mentioned. Again, don't mention the red band here – as its choice has not yet been explained, and also you use the pan band too.

L149: Removed Banwell et al. (2019) citation and deleted 'red band'. We have also added the following sentence: 'This is an improvement on previous approaches which used static A_d values across a region (e.g. Sneed and Hamilton, 2007).'

I find this paragraph to flit between topics a bit. A_d -> Band choice -> R_{inf} , then back to band choice in the following paragraph. Remove mention of band choice here and make it its own paragraph.

L153: We have edited the structure of this paragraph by moving the sentence 'Red light attenuates more strongly in water than blue light, meaning that there are larger measurable changes in red reflectance over water than for other wavelengths (Box and Ski 2007; Pope et al., 2016)' to the beginning of the final paragraph in this section, to improve the logical flow from discussion of A_d , to R_{inf} , to choice of bands.

Switch 'exposed to the atmosphere' to 'exposed at the surface'

L154: Amended to: 'exposed at the surface'

This is not the case in Banwell et al. (2014).

L157: Removed Banwell et al. (2014) citation.

Be consistent between Landsat and Sentinel in how you refer to bands – as colour, or number, or both. I suggest as in the following sentence – colour with band number in brackets in the first instance, then just colour.

L159: Amended to: 'red (Band 4)'.

Again – what is colour is Landsat 7 band 3?

L162: Amended to: 'red (Band 3) reflectances'.

I think it is good to say above/below to be explicit about which side of the grounding line.

L241: Amended 'beyond' to 'above'.

Be more specific, offer a range?

L249: Added: '(~100-1000)' so that sentence now reads as below.

I think this 7.45×10^6 value is for mean total (at any one time) meltwater volume? I don't think that it's clear enough that 'on average' is coupled with this part of the sentence.

L250: Amended: added 'an average', so that sentence now reads: 'In a typical melt season, we observed hundreds (~100-1000) of SGLs that were, on average, 0.02 km² in area, 0.96 m deep, and held an average total meltwater volume of 7.45×10^6 m³.'

You later refer to this as englacial drainage, use the word englacial here.

L275: Amended: added 'englacial' to 'drainage into the firn'.

From optical imagery you can only be sure that the surface freezes over. Mention that it's the surface that freezes.

L276: Amended to 'surface refreezing and/or snow burial'.

I find the sentence from 'as indicated..' unclear, please rephrase.

L277: Sentence re-worded to: 'Lakes commonly refreeze at the end of a melt season, indicated by relict frozen lake scars which are similar to refrozen lakes in previous studies'.

Do you mean that the firn becomes saturated? 'portions of the ice shelf become saturated and pond into large lakes' – I think this is unclear.

L282: Reworded to: 'During the peak of the melt season in some years, large portions of the ice shelf firn layer become saturated, causing meltwater to accumulate and coalesce in large lakes on portions of the ice shelf, such as on the tongue of Scott Glacier.'

Explain exactly what you mean by englacially and how you can tell.

L289: Added 'into the firn', sentence now reads: 'We also recorded several instances of lakes apparently draining englacially into the firn over a \leq 7-day period during January 2018 and 2020'. We explain this interpretation in the subsequent two sentences.

I think you are saying that if the chain of lakes had lost area due to refreezing rather than drainage, the surrounding lakes would also have lost area due to refreezing. However, I don't think this is clearly stated. Also be careful with the subject 'they' here and which set of lakes it is referring to.

L291: Amended to: 'If this chain of lakes had refrozen, we would have expected to record a reduction in area of the surrounding lakes. However, the surrounding lakes did not change in area over this period, suggesting they also did not refreeze.'

'Therefore, we interpret these lakes to have drained englacially into the firn'.

L293: Sentence added: 'Therefore, we interpret these lakes to have drained englacially into the firn'.

Katabatic winds are fundamental here so I suggest that you mention them in this first index sentence of the paragraph.

L330: Amended: changed 'albedo-lowering' to 'katabatic wind-driven'.

Could this also be related to inter-annual deepening as per Banwell and MacAyeal (2015)? I suggest that you assess the modelled finding in that paper about inter-annual deepening on floating ice against your results.

L373: We agree that this could be related to inter-annual lake deepening, and have added the following sentence: 'Inter-annual lake deepening amplified by lake bottom ablation could also mean lakes on the ice shelf evolve to be deeper than those on ice upstream of the grounding line (Banwell and MacAyeal, 2015). We do not observe any inter-annual deepening of individual lakes in our study.'

By lakes that drain vertically I think you are referring to the same group of lakes you earlier referred to as draining englacially – I don't think that is clear, please be careful and consistent with terms such as these. Otherwise it can seem as if you are introducing a different set/mechanism.

L412: Amended: changed 'vertically' to 'englacially'.

See above about this term/sentence construction. Part of the issue is the phrase 'that were, on average held a total meltwater volume' would not be grammatically correct. Unless I've misunderstood what that number represents, that phrase should work for the overall sentence to work properly.

L447: Added 'mean', so that sentence now reads: 'Between the melt seasons of 1999-2000 and 2019-2020, melt seasons were characterised by hundreds of SGLs that were, on average, 0.02 km² in area, 0.96 m deep, and held a mean total meltwater volume of 7.45 x10⁶ m³.'

I think the figure makes it appear as if the Denman Glacier is the boundary of the Shackleton and the area E of it is not part of the ice shelf, I suggest clarifying this in the figure. I would also appreciate a N arrow.

L505: We agree that the label for Shackleton Ice Shelf could be construed as referring only to the part of the ice shelf west of Denman Glacier, and have added a second label to avoid confusion, as well as a north arrow.

I suggest total 'lake' area to be consistent with 'lake depth'.

I appreciate that presenting 20 years of data is a challenge. Unfortunately, I think that it is virtually impossible to distinguish between some of these colours, and therefore I cannot interpret much of this graph. I will leave it to the authors to determine the best solution, but I do not think it works as it is. Consider picking out some of the most useful demonstrative data for a main fig and putting some in a supplementary figure.

L570: We have amended the y axis title on Panel A as suggested, and amended the y axis title on Panel C to 'Total meltwater volume'. Regarding the Reviewer's suggestion for data display on this Figure, we have responded in the general comments above.

In other instances the secondary y axis text is flipped the other way – it would be nice to flip this to be consistent.

L730: Amended: rotated secondary y-axis label.