Author’s response to anonymous Reviewer #1

Summary:

In this study the authors combine observations from SAR (Sentinel 1) and optical (Sentinel 2) satellite imagery to generate a record of Antarctic supra-glacial lake coverage with high spatial and temporal resolution. The record covers six Antarctic ice shelves between 2015 and 2021. Three of the ice shelves are located on the Antarctic Peninsula (George VI, Wilkins, Bach) and three are located in East Antarctica (Amery, Nivilsen, Riiser-Larsen). The authors use machine learning to identify lakes from imagery, with the machine learning methods described in two previous papers (Dirscherl et al., 2020 & 2021). The authors investigate the coverage and reoccurrence of the lakes and perform a statistical analysis of the correlations between lake coverage and atmospheric conditions and global climate indicators.

For the Antarctic Peninsula ice shelves, they find peak lake coverage in January, with the largest lake coverage in the 2018-2019 and 2019-2020 seasons. The most significant correlation is found for George VI Ice Shelf where lake coverage is positively correlated with air temperature, with a lag of approximately 14 days. There appears to be a negative correlation of lake coverage with the Southern Annual Mode for the Antarctic Peninsula ice shelves.

For the East Antarctic ice shelves, there is a less prominent peak in lake coverage, with coverage extending from late December to early February. Furthermore 2020-2021, saw the smallest lake coverage for these East Antarctic ice shelves. Positive correlations are observed for temperature and solar radiation with a range of lag times.

The manuscript is a natural progression from the two previous papers describing the machine learning methods. Here these methods are applied to 6 years’ worth of data from 6 Antarctic ice shelves, thereby providing one of the most (if not the most) comprehensive records of recent Antarctic supra-glacial lake coverage. The analysis is thorough and generates a set of noteworthy/interesting conclusions. However, my one major criticism is that the results and discussion sections are a bit of a jumble, this is mainly due to the volume of information the author tries to convey. This could be addressed by adding more structure to the text, possibly by splitting it into six sections for each ice shelf and limiting the text to reporting the significant results with the figures contain extra details.

This work makes a worthwhile contribution to the field and I feel it will be of interest to many in the glaciology community.

I have included a commented PDF as part of my review. Here I include some more detailed points that require addressing:

We thank the reviewer for the time and efforts spent in reviewing our manuscript in so much detail. The additional comments are very much appreciated and will be of great help to provide an improved version of the manuscript. We will address all points raised in the supplementary pdf as part of our revisions. Moreover, we will improve the structuring of the results and discussion section and limit the text to the most important information and key conclusions. Please find our responses to the individual comments below.

Comments:

- Use of term average:
    - At times I was confused by the use of average, which in some contexts refers to: the mean of the data included in the bi-weekly value; the spatial average over the ice shelf; or the mean of multi-year data. It would be good to clarify what is mean each time average is used.

Many thanks for this helpful comment. We will clarify on the meaning of the term “average” in the main text each time it is referred to.

    - Secondly average is used in the abstract and conclusion with reference to the mean values from the 6 years of data. However, on first reading this gives the impression that it is a long-term record. Saying something is above or below the average, when that is only based on 6 years of data lacks the long-term context. For instance, it may be the case that 2015-2016 was a high lake year in comparison to the 20 years beforehand, but not in comparison to the following 5 years. This point needs to be considered throughout the text when reporting differences between annual results.

Thank you for this suggestion. We agree that the short observational period provided by Sentinel-1 and Sentinel-2 does not capture long-term trends. To clarify on this, we will improve the corresponding wording in the abstract and main text.

- If I am interested in an ice shelf not included in this investigation what can I learn from this paper? Are there any general statements that can be applied to all lakes following the evidence generated here?

Despite some minor variations in lake coverage resulting from varying local control factors (e.g., albedo feedbacks, ice surface topography or local microclimatic conditions), our study revealed similar lake evolution over all three Antarctic Peninsula (API) ice shelves. In fact, lake coverage over all three ice shelves was highest during the past two melting seasons compared to the previous four melting seasons. Likewise, also the detected driving factors agreed well among the three regions (Table 2) making it likely that other Antarctic Peninsula ice shelves in the vicinity of the Bellingshausen Sea Sector responded similar to the present regional environmental conditions particularly during the 2019/2020 and 2020/2021 summers with high meltwater coverage.

For East Antarctic ice shelves, lake evolution was far more variable due to the larger distance among them and thus, the different environmental conditions. At the same time, it has to be noted that over all three East Antarctic ice shelves, temperature conditions and the amount of incoming solar radiation showed strong positive correlations with lake extents making it likely that these are primary control factors also for other East Antarctic regions. Furthermore, the past melting season 2020/2021 revealed very low lake extents over all three ice shelves in agreement with the timing of an atypical Amundsen Sea Low (ASL) leading to low temperature conditions. This highlights the significant influence of large-scale atmospheric modes on entire ice sheet sections where similar trends in lake evolution can be expected, e.g., in terms of low lake extents over other East Antarctic ice shelves during the 2020/2021 summer. In fact, the atypical ASL was also found to cause comparatively low lake extents during the late 2020/2021 melting season over the API suggesting that Southern Hemisphere atmospheric modes can exert continent-wide influence. Likewise, also the influence of SAM and IOD was shown to influence entire ice sheet sections (Table 2) over the API and East Antarctica in a similar manner.

Considering all six investigated ice shelves, the summary in Table 2 highlights that also local control factors show good agreement with respect to the direction of detected relationships. Therefore, similar relationships can likely be observed over other Antarctic ice shelves. Moreover, also temperature conditions show consistent positive correlations over all ice shelves highlighting the strong influence of temperature on lake evolution (most other factors varied for at least 1-2 ice shelves). To provide more general statements in the main text, we will address the described patterns in the discussion and conclusion sections.

- How are datasets (Sentinel 1 & 2) combined? What is the time resolution of the pre-aggregated data? Is this consistent for each bi-weekly value? How does the performance with each dataset compare? i.e. are same lake features identified? Are there any differences? How does this impact your results?

Sentinel-1 and Sentinel-2 classifications were combined through decision-level fusion, i.e., the mosaicking of all obtained Sentinel-1 and Sentinel-2 classification products. Mosaicking was performed to obtain the maximum lake extent during a given time interval thus, considering all classified lake pixels in each single classification map as valid.

The time resolution of the pre-aggregated data thus, of the single classification maps corresponds to the repeat interval of the individual satellite sensors reaching up to daily revisit frequencies over Antarctica due to overlapping orbit tracks in polar regions (the general revisit time at the equator is 5 and 6 days for Sentinel-2 and Sentinel-1, respectively). The data availability for each bi-weekly interval fluctuated only slightly over an ice shelf whereat the number of available acquisitions varied with respect to the timing within the melting season (sometimes more acquisitions were available during the peak of the melting season (January) than in months before and after, particularly for Sentinel-2). At the same time, data availability was restricted during few months over Riiser-Larsen and Nivlisen Ice Shelf requiring interpolation with the bi-weekly long-term mean of 2016-2021 (see Supplementary Figure S1, lines 252-253 in the manuscript).

Comparing classifications from Sentinel-1 and Sentinel-2, the same lake features can generally be identified. However, due to sensor-specific characteristics, lake sizes and lake visibility may vary. For example, lakes in SAR data oftentimes appear larger than in optical imagery due to the penetration capability of microwave sensors through thin ice and snow. Hence, even buried and slightly/partly frozen lakes can be detected with SAR. On the other hand, lakes that are subject to particularly strong refreezing or wind roughening cannot be detected with our deep learning classification method. Regarding optical data, buried lakes cannot be detected while wind roughening does not affect lake visibility. Further, cloud cover hinders lake visibility in optical imagery while SAR data are unaffected by meteorological and illumination conditions. Therefore, the combination of optical and SAR data was particularly beneficial allowing to obtain a more complete mapping record than with single-sensor classifications. At the same time, these differences in mapping capabilities may lead to some variability in intra-annual and inter-annual lake extent mappings particularly when only one sensor type delivers information. For example, data availability during cloud cover or at the onset of Antarctic winter purely results from Sentinel-1 SAR. This could lead to a slight underestimation of the total lake area in case of lakes being subject to strong wind roughening. Likewise, when only optical data are available, lakes covered in snow are not detected and may lead to slightly smaller lake outlines. Overall, the described effects are not believed to bias the overall detected temporal signature of lake evolution since wintertime lake extents are generally small and since a conjoint occurrence of severe wind roughening in SAR data and cloud cover in optical imagery is unlikely.

In order to provide a better understanding of the abovementioned points, we will add relevant information to the corresponding sections in the manuscript.

- This new combined dataset is a great contribution to the field and this is not emphasized enough in the main text. It would be great if the usefulness of the new dataset could be highlighted more, i.e. 2D dynamics of lakes, lake geometries, etc. But maybe this is the focus for future papers?

Many thanks for this positive feedback and helpful suggestion. We will insert a corresponding paragraph on the usefulness as well as on potential future applications of the combined dataset in the discussion section. Since all data will be made publicly available via DLR's GeoService (the link will be added as part of the revisions), future studies on 2D lake dynamics etc. can be easily performed.

- It would good to add details about how machine learning training data was generated and how classification was tested. Are there any feature that might be missed?

Due to the lack of a pan-Antarctic mapping record and an operational monitoring service providing supraglacial lake extent classifications for Sentinel-1 and Sentinel-2 data, the machine learning training data consisted of the original satellite acquisitions as well as manually created labels. For Sentinel-1, only classes “water” and “non-water” were labeled while Sentinel-2 data were labeled for classes “water”, “rock”, “shadow” and “snow/ice”. Regarding Sentinel-2, the availability of multi-spectral data allowed to obtain rock classification maps as side-product, e.g., for further geo-scientific analyses as well as an improved discrimination between shadow and lakes being one of the biggest challenges to overcome. Classification was tested by means of the prediction of independent test scenes distributed across the entire Antarctic continent and not presented to the machine learning models before. For evaluation, an accuracy assessment was performed on basis of randomly sampled and manually labeled points in the test data that were evaluated as part of a confusion matrix. For both classification methods, the main remaining limitations were related to false positive lake classifications (line 235, 244-246). False negative lake classifications occurred less frequently but mostly over mixed pixels at lake edges for Sentinel-2 (line 244) and over particularly large lakes for Sentinel-1. This information can also be found in our preceding papers describing the methods for Sentinel-1 and Sentinel-2 in more detail. To indicate how the stated training data and accuracy values (line 232, line 243) were obtained, we will slightly expand the corresponding paragraphs.

Transport of meltwater:

- You say that water is transported across the ice shelf (and I believe you) but what evidence do you have of actual water movement? It would be really interesting to see the flow of meltwater and subsequent growth of lakes in a time series.

Many thanks for this comment. While we did not provide any direct evidence of water movement across the ice shelves in the manuscript itself, this process is partly reflected in the maps providing details on temporal lags thus, the temporally delayed response of meltwater accumulation to climate drivers in regions that are most distant from initial meltwater accumulation in the early melting season, e.g., near the grounding line (Figure 7b,d; Figure 8b,d,j,l,r,t). Further, also Figure 3 reflects the temporal growth of the surface hydrological network over time and Figure 2 and Figure 5 show the existence of inter-connected surface hydrological networks. Since the manuscript already contains a comparatively large number of figures, we decided not to include an additional figure on time series over individual lake features in the manuscript itself. However, we will add an exemplary Figure showing a time series of the January maximum lake extent over central

Nivlisen Ice Shelf in 2017-2021 to the Supplement (see below). Here, the progressive expansion of the surface hydrological network towards the north-east can be observed. Moreover, the bi-monthly data will be made publicly available online and can be easily used for further time series analyses.

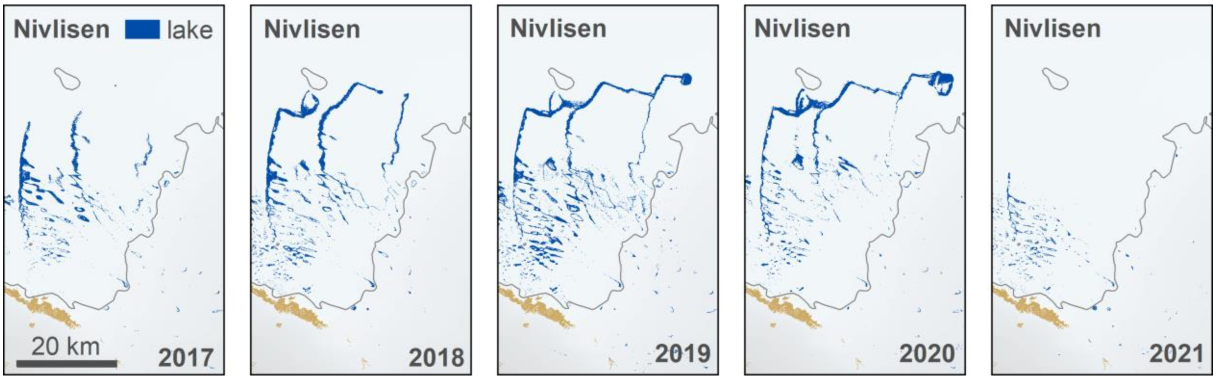

Figure 1 January maximum lake extent mapping products for years 2017-2021 over Nivlisen Ice Shelf. The grounding line data (grey) are from Mouginot et al. (2017) and Rignot et al. (2013) and Sentinel-2 bedrock data are from Dirscherl et al. (2020).

- You say that there is a lag between melt and lake growth where water has been transported across the shelf. How far has meltwater been transported? Can you investigate the lag between ERA5 data where the melt is formed and the formation of the lake?

As can be seen in Figure 2 and Figure 5, the surface hydrological networks extend over long distances particularly on Nivlisen, Riiser-Larsen, George VI and Amery ice shelves. For example, the elongated meltwater features stretching from west to east on Nivlisen Ice Shelf (see Figure 1 above) reach up to >30 km in length in 2020 until they reach the furthest meltwater pond in the north-east. Moreover, Figure 7 and Figure 8 provide details on the location and strength of temporal lags where meltwater has been transported.

- Figure 5: It’s difficult to make out colours representing over 2 or 3 years of reoccurrence. This is possibly due to the small areas where lakes are frequently present. It would be good if bigger map plots were available, possibly in a supplement? There’s so much great data here, it’s a shame not to be able to see it more clearly.

Thank you for this helpful comment. It is correct that supraglacial lakes on the Antarctic Peninsula rarely reached recurrence frequencies >2 years in 2015-2021. Here, supraglacial lakes were mainly present during the past two melting seasons. In East Antarctica, lakes tend to reoccupy the same surface depressions during multiple years even though the overall area with recurrence frequencies >3 years remains comparatively small. We will follow your suggestion and improve the choice of colours in Figure 5 in our revised manuscript version. Moreover, we will include bigger map plots for each ice shelf in the Supplement.

- Results section: As mentioned earlier, the results section can be difficult to read in places because there is so much information about 6 different ice shelves. One way to make this easier to read would be to have a small section dedicated to each one, and then use the discussion to summarise similarities and differences between them. It would also be helpful to only report the statistical significant results and point the reader to the figures for more details.

Many thanks for this important suggestion. We will improve the structuring of the results section and limit it to the most relevant information. Moreover, we will improve the discussion section by highlighting similarities and differences among the ice shelves more clearly.

- Correlation analysis sections: Again these two sections are difficult to read because there is so much information. I like figure 6 – maybe it would be good to use this figure to guide the reader through the results. Similarly with Figures 7 and 8, but possibly here you can be more selective about what plots you choose to show, leaving the others to the supplement.

We will follow your suggestion and shorten the text in Section 4.2. Further, we will move parts of Figure 7 and Figure 8 to the Supplement and focus on the most informative results.

- Similarly, the discussion section includes a lot of repetition of the results section and frequently jumps from one ice shelf to another and back again – this could be trimmed down.

Many thanks for this important comment. We will limit the discussion to the most relevant information and key messages and improve its general structuring with respect to similarities and differences among the ice shelves.

Comparison with large-scale climate indicators such as:

- DMI: Lines 589-591: I don't understand what is meant by this sentence.

With this sentence, we wanted to state that - in contrast to the 2019/2020 melting season - the 2020/2021 melt event was not caused by a strong positive Indian Ocean Dipole event. In fact, the IOD returned to neutral values during 2020 (shown in Figure 10) suggesting other driving factors for increased meltwater accumulation during 2020/2021. We will improve the wording of the corresponding sentence in the manuscript.

- SAM: Line 429: "correlation with annual SAM (Table 1) indicates a significant negative linear relationship (r=-0.82*) over George VI Ice Shelf." This is the only significant correlation identified. Can you draw any API-wide conclusions from this?

Many thanks for this comment. Returning correlation values of -0.78 and -0.74, Bach and Wilkins Ice Shelf similarly showed strong negative correlations. Here, the low number of observations (n=6) used for correlation might have caused unreliable values of p resulting in statistically insignificant values. Hence, rather the r-value should be considered. This is also stated in lines 464-465: "Due to the low number of observations used for correlation, the p-value might not be representative and rather r should be used for interpretation". To summarize, the influence of SAM can likely be observed across most of the API despite some minor variations due to local factors. We will improve the corresponding wording in the manuscript and highlight potential implications for other API regions in the discussion.

I found it difficult to discern the take away conclusions about the interaction with these climate indicators. Lines 642-652 do discuss this, but the explanation is very vague, with few references to other studies that have thoroughly investigated these dynamics.

We will improve the discussion on large-scale climate drivers and highlight their potential implications for other Antarctic regions. We will also add relevant literature where appropriate.

- Melt-albedo feedbacks (Line 678): not sure whether you have mentioned any particular examples of this from your results. It would be great to see some examples.

To highlight the influence of low-albedo surfaces on lake formation, we included our Sentinel-2 rock classification product in Figure 5. As can be seen, lakes on George VI, Wilkins, Nivlisen and Amery Ice Shelf are clustered close to rock. Even though this only provides indirect evidence of melt-albedo feedbacks, it highlights the spatial proximity of lakes to low-albedo surfaces. The same applies to lakes appearing near blue ice regions over Riiser-Larsen, Nivlisen and Amery Ice Shelf (comparison of Figure 5 to Figure 1d,e,f; Figure 2d). This is also reflected in Figure 7 and Figure 8 showing a shorter response time of lake formation in regions close to low-albedo features. As a more detailed analysis of melt-albedo feedbacks would go beyond the scope of this study and require detailed investigation of the spatial proximity of lakes to blue ice or rock over time, we decided not to expand this section. However, we performed similar analyses as part of our preceding paper and will point towards it in the manuscript.

- Table 2: “Local controls” how have you determined these correlations? It’s easy to miss this in the text, so it would be good to have a dedicated results section on this (similar to point above).

As mentioned, local controls were mainly analysed for completeness through the visual comparison of supraglacial lake extent classification maps to rock classification maps, blue ice occurrence (in optical imagery) as well as DEM data (Figure 2, Figure 5). For analysis of the influence of the firn air content, we used previous year precipitation data, as shown in Table 1 and Figure 9 (also see lines 263-265). We will improve the description of corresponding results in Section 4.1 (lines 297-298, 370-374) and Section 4.2 (lines 432-734, 459-462). In particular, we will provide more detail on topographic and morphological controls.

- Buried lakes: This is mentioned in the conclusion and abstract, but not in the main text. How important/common are they? Where are they found? Is this one difference between sentinel 1 & 2? Are you missing them in Sentinel 2? How does this impact your results?

While information on the distribution of Antarctic buried lakes is so far limited with only few confirmed observations over Larsen C Ice Shelf on the Antarctic Peninsula (Hubbard et al., 2016) as well as over Roi Baudouin and Fimbul ice shelves in East Antarctica (Dunmire et al., 2020; Lenaerts et al., 2017; Liston et al., 1999), they likely exist over other parts of the ice sheet as well, similar as expected for firn aquifers (van Wessem et al., 2021, 2016). In addition, it has to be noted that we also refer to buried lakes when only parts of lake surfaces are covered by thin ice and/or snow, as visible in Figure 12 of our preceding paper (Dirscherl et al., 2021).

Considering the penetration of radar sensors into snow and ice, buried lakes can only be mapped in SAR data. In fact, this represents one of the major advantages of Sentinel-1 allowing to obtain a more complete mapping record than with single-sensor Sentinel-2 mappings. In the latter, buried lakes cannot be detected. To improve the understanding of advantages of SAR sensors for supraglacial lake extent mapping in Antarctica, we will insert corresponding information in the introduction.

- ERA5-Land climate reanalysis – you haven’t included any discussion on the potential shortfalls of using this data. For instance, are small scale effects around blue ice or exposed bedrock included? How does this impact your results?

Please find information on the general quality of the ERA5-Land climate variables in Section 3.1.2 (lines 170-197). Even though small-scale effects were not investigated as part of this study, it is not likely that small-scale effects are visible in gridded data at a spatial resolution of 9 km. In order to highlight the main advantages and drawbacks of ERA5-Land data, we will briefly address them in the discussion section. One of the major advantages certainly is that ERA5-Land data are the only publicly available dataset providing climate reanalysis data at large-scale.

Minor Comments:

Line 101-102: Use of space when quoting numerical values to separate thousands from hundreds, i.e. 10 000. (i) I'd usually choose to use a comma; 10,000. (ii) I'd apply this to 1,000 and 10,000. I'm not sure what the formatting choices of the journal are.

Many thanks for noticing that. We will change numerical values to the suggested format.

Line 287-288: "We observe a rapid onset of supraglacial lake formation in late January" Fig 3 shows that the peak lake coverage is in late January not the onset of lake formation.

Thank you for this important comment. We will improve the wording in the corresponding sentence.

Line 292-293: "More specifically, lake extents during the 2019-2020 and 2020-2021 melting season were above average during their peak and slightly below average in parts of early 2019-2020 and late 2020-2021" Does this imply faster than usual lake formation? Do you think this is a result of shallower lakes?

Due to the comparatively short length of the time series it is difficult to say whether lake formation was faster than usual. This particularly applies, as lake formation during preceding years was comparatively low overall thus, values above average simply reflect lake extents that were higher than in the preceding four low-melt years. As stated in the manuscript, specific atmospheric drivers were responsible, e.g., for the early end of melting season 2020-2021 and not a generally shifted melting season. Similarly, to evaluate whether the overall pattern of lake evolution is a result of shallower lakes, longer time series would be required. Another requirement would be to accurately discriminate between frozen lakes and open water lakes in optical data in order to retrieve lake volumes (see line 246-248).

Line 371: "lakes spreading across Nivlisen Ice Shelf": Can you detect whether this spreading is occurring in time? i.e. lakes spread during melt season or lakes spread year on year?

In fact, lakes were spreading across Nivlisen Ice Shelf both, within melting seasons as well as from year to year (see Figure 1 above). Within melting seasons, lakes first developed close to the grounding line and progressively expanded in north-easterly direction towards the late melting season. Similarly, the maximum January lake extent mapping products (Figure 1 above) show a progressive advance of the surface hydrological network towards the north-east over the years with exception of the 2020-2021 melting season where lake coverage was generally low. We will add a brief sentence on this in the manuscript. Furthermore, we will also include the Figure shown above in the Supplement.

Line 377: "average and maximum air temperature" What average is this? The spatial average across the whole shelf? The average of the aggregated data? The multi-year average?

In this context, “average” refers to the bi-weekly average air temperature and “maximum” to the maximum air temperature during a bi-weekly interval (see lines 257-258). In Figure 6, these pixel-based average and maximum values are summarized as spatial averages. In order to clarify on the respective quantities, we will improve the corresponding wording.

Lines 429-434: It might be easier for the reader if you only report the significant results in the text, as otherwise there is too much information to take in.

While we generally agree with this comment, the correlations for SAM and previous year precipitation result from only few observations potentially leading to unreliable values of p. Therefore, also correlations above the determined significance level should be considered and the r-value should be used. This is also stated in line 460 and line 464. For all other correlations results, we will shorten the corresponding sections.

Line 613: I don’ understand what you mean by “north(-easterly)”

Please excuse this ambiguous wording. Here, we wanted to state that winds were blowing predominantly from north-easterly direction with the corresponding directional value being inclined more towards northerly direction. We will improve the corresponding wording also for all following directional indications.

Line 638 -639: “firn air depletion potentially contributing to facilitated melt in 2020-2021” do you mean lakes rather than melt?

Many thanks for this important comment. That is correct, with this statement we actually wanted to refer to facilitated “lake accumulation”. We will correct the sentence accordingly.

Line 665: “latitudinal flow stripes” I don’t think latitudinal is the best word to use here as the structure of the flow stripes is so complex. I suggest just removing latitudinal.

Thank you for this suggestion. We will reword the sentence accordingly.

Line 667: “surface slopes” do you mean low surface slopes?

Many thanks for noticing that. That is correct, this should be “low surface slopes”. We will correct the sentence accordingly.

Line 781: Include reference to: Gilbert, E., & Kittel, C. (2021). Surface Melt and Runoff on Antarctic Ice Shelves at 1.5°C, 2°C, and 4°C of Future Warming. Geophysical Research Letters, 48(8), 1–9. https://doi.org/10.1029/2020GL091733

Thank you for this suggestion. We will insert the reference in the corresponding sentence.

Lines 803-804: Example of how you are using your short record to talk about anomalous years, without any context of long-term values.

We will improve the wording and refer to the corresponding reference period 2015-2021.

Line 807: “record low lake coverage” same as point above.

Many thanks for noticing that. We will improve the wording accordingly.

Line 808: “Lateral meltwater transport” where is the evidence for water flow/movement?

As mentioned earlier, we will include an exemplary Figure in the Supplement showing lateral meltwater transport across Nivlisen Ice Shelf. Moreover, all bi-weekly mappings will be made publicly available.

Line 829: “Reduced firn air content” How is this measured? Are you inferring this from the records of low snow accumulation?

As stated in line 263-265, we use previous year precipitation as indirect indicator for the FAC of snow thus, for analysis of relationships between supraglacial lake formation and the state of the snowpack.

Figure 1: “the large lake feature at the western grounding line was excluded from analyses”

I’m not sure what is meant here. (i) This is not mentioned anywhere else in the text. (ii) It is not clear what feature/lake you are referring to. (iii) What impact does excluding this area have on you results?

Please excuse the lack of information in Figure 1. The large lake feature referred to is Beaver Lake at the western edge of Amery Ice Shelf. Since Beaver Lake is a permanent lake feature that is frequently covered by smooth, see-through ice, it might cause misclassifications in Sentinel-2 data. In fact, the similar spectral characteristics of clear ice and shallow lake area can easily lead to misclassifications. To avoid this, we decided to exclude this permanent lake feature from our analysis. We will clarify on this in the description of Figure 1.

Figure 2: Looking at Figure 2e I wonder how much of this region is classified as a lake? There seems to be a high bright patch of open water and then an elongated drainage pathway. In the main text there is no discussion about meltwater volumes and how this might affect correlations with temperature and radiation, etc.

For a region as shown in Figure 2e, the round lake feature in the middle would be classified as lake area while the drainage structure would only partly be classified as lake. In particular, only the small streams visible in the middle of the drainage structure would be classified as lake while the rest would be masked. This mostly occurs due to the similarity to slush being masked as part of our slush elimination strategy (see line 242). As stated in lines 246-248, lake volumes were not derived due to the difficulties in differentiating between open water and slightly frozen lakes in optical satellite imagery, as also stated in other studies (e.g.,Moussavi et al., 2020). On the other hand, lake depth retrieval in SAR data is not possible.

Figure 5: As mentioned above, visibility of plots could be improved.

Many thanks for this suggestion. We will improve the color scheme in Figure 5 and include larger maps for each ice shelf in the Supplement.

Additional references cited:

Dirscherl, M., Dietz, A. J., Kneisel, C., and Kuenzer, C.: Automated Mapping of Antarctic Supraglacial Lakes Using a Machine Learning Approach, Remote Sens., 12, https://doi.org/10.3390/rs12071203, 2020.

Dirscherl, M., Dietz, A. J., Kneisel, C., and Kuenzer, C.: A Novel Method for Automated Supraglacial Lake Mapping in Antarctica Using Sentinel-1 SAR Imagery and Deep Learning, Remote Sens., 13, 197, https://doi.org/10.3390/rs13020197, 2021.

Dunmire, D., Lenaerts, J. T. M., Banwell, A. F., Wever, N., Shragge, J., Lhermitte, S., Drews, R., Pattyn, F., Hansen, J. S. S., Willis, I. C., Miller, J., and Keenan, E.: Observations of Buried Lake Drainage on the Antarctic Ice Sheet, Geophys. Res. Lett., 47, e2020GL087970, https://doi.org/10.1029/2020GL087970, 2020.

Hubbard, B., Luckman, A., Ashmore, D. W., Bevan, S., Kulessa, B., Munneke, P. K., Philippe, M., Jansen, D., Booth, A., Sevestre, H., Tison, J.-L., O'Leary, M., and Rutt, I.: Massive subsurface ice formed by refreezing of ice-shelf melt ponds, Nat Commun, 7, 1–6, https://doi.org/10.1038/ncomms11897, 2016.

Lenaerts, J. T. M., Lhermitte, S., Drews, R., Ligtenberg, S. R. M., Berger, S., Helm, V., Smeets, C. J. P. P., Broeke, M. R. van den, van de Berg, W. J., van Meijgaard, E., Eijkelboom, M., Eisen, O., and Pattyn, F.: Meltwater produced by wind–albedo interaction stored in an East Antarctic ice shelf, Nat. Clim. Change, 7, 58–62, https://doi.org/10.1038/nclimate3180, 2017.

Liston, G. E., Winther, J.-G., Bruland, O., Elvehøy, H., and Sand, K.: Below-surface ice melt on the coastal Antarctic ice sheet, 45, 273–285, https://doi.org/10.3189/S0022143000001775, 1999.

Mouginot, J., Scheuchl, B., and Rignot, E.: MEaSUREs Antarctic Boundaries for IPY 2007-2009 from Satellite Radar, Version 2. [Coastline, grounding line data]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/AXE4121732AD, last accessed: 27 May 2021, 2017.

Moussavi, M., Pope, A., Halberstadt, A. R. W., Trusel, L. D., Cioffi, L., and Abdalati, W.: Antarctic Supraglacial Lake Detection Using Landsat 8 and Sentinel-2 Imagery: Towards Continental Generation of Lake Volumes, Remote Sens., 12, 134, https://doi.org/10.3390/rs12010134, 2020.

Rignot, E., Jacobs, S., Mouginot, J., and Scheuchl, B.: Ice-Shelf Melting Around Antarctica, Science, 341, 266–270, https://doi.org/10.1126/science.1235798, 2013.

van Wessem, J. M., Ligtenberg, S. R. M., Reijmer, C. H., van de Berg, W. J., van den Broeke, M. R., Barrand, N. E., Thomas, E. R., Turner, J., Wuite, J., Scambos, T. A., and van Meijgaard, E.: The modelled surface mass balance of the Antarctic Peninsula at 5.5 km horizontal resolution, 10, 271–285, https://doi.org/10.5194/tc-10-271-2016, 2016.

van Wessem, J. M., Steger, C. R., Wever, N., and van den Broeke, M. R.: An exploratory modelling study of perennial firn aquifers in the Antarctic Peninsula for the period 1979–2016, 15, 695–714, https://doi.org/10.5194/tc-15-695-2021, 2021.