

Review of “Brief communication: Hydrologic connectivity of a tidewater glacier characterized with Sentinel-2 satellite images – a case study of Nordenskiöldbreen, Svalbard”

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Summary

The authors present an analysis of the changes in supraglacial lake area, meltwater plume area, and sea ice concentration during the summer seasons of 2016-2020 at Nordenskiöldbreen, Svalbard. By manually digitizing these features from Sentinel-2 imagery, they demonstrate that simple remote sensing approaches can yield valuable information on the hydrological system of a tidewater glacier. The data presented in the manuscript is indeed important to understanding Nordenskiöldbreen and is, I believe, worthy of publication. However, the details of the methods are sometimes unclear, and the manuscript is currently lacking in originality and impact. I agree with reviewer William Armstrong that “the study could be strengthened by framing their research around a process-based question about glacier hydrology.” There should be more discussion of the significance of this work and new insights; an explanation of what this work contributes to the field of glacial hydrology or our understanding of tidewater glaciers. Addressing this, clarifying details of the methods, and addressing other comments described below would constitute significant revisions that would help increase the impact of this manuscript.

General Comments

- 1) There should be more discussion of the limitations of this method, both technical limitations relating to the remote sensing method and environmental limitations in your ability to detect plumes. There is some discussion of technical limitations (temporal resolution and cloud cover) in lines 161-165 (in the Results and Discussion section on meltwater plumes), but this should be expanded on and moved to a different section as it is also a limitation for detecting sea ice and supraglacial lakes. A mention of spatial resolution limitations could also be added (difficulty of observing very small features, if they exist).
- 2) Regarding the limitation of observing plumes using remote sensing, there needs to be some comment on the possibility of plumes existing without surface expression. The distance a plume rises before reaching neutral buoyancy depends on the discharge volume and rate, fjord stratification, and mélange/sea ice presence/rigidity (Carroll et al., 2015; Slater et al., 2015; De Andrés et al., 2020; Everett et al., 2021). Additionally, the organization of the subglacial hydrologic system determines whether discharging water forms a concentrated plume or not (Melton et al., 2022). A channelized subglacial hydrologic system will result in a discharging plume, whereas a distributed system would result in discharging water to be dispersed along the terminus. Therefore, you cannot conclude that there is no discharge when there is no plume, and you also cannot assume that there is no plume when you do not observe a plume at the surface (in this case there could be a plume at depth that reaches neutral buoyancy before reaching the surface.) You must make it clear that your record of plumes is *conservative* and be careful about

making conclusions about what is happening when a surfacing plume is not visible throughout the manuscript.

3) Details about the methods need to be clarified to ensure that the approach is valid and reproducible. Why was the false-color band combination used? How did you define the edge of sediment plumes? How was sea ice cover fraction calculated? In general, how were all the features (lakes, plumes, and sea ice) defined and identified in the imagery? (This relates to reviewer Armstrong's Major Comment 2.)

4) Throughout the manuscript, and especially in the introduction/background, you should consider including additional key references to recent articles about meltwater plumes (e.g., Slater et al., 2018; De Andrés et al., 2020; Cook et al., 2021; Everett et al., 2021; Melton et al., 2022).

5) This is a comment a reviewer once gave me, which also applies here: "As a reader, every time the importance of another study is mentioned by name, it takes the focus away from the amount of work that has gone into this study... A suggested modification would be to summarize the findings of prior research as they relate to this work (instead of who was the author and what they found) and then citing the authors in parentheses at the end of the sentence." In general, you could aim for more parenthetical citations and less narrative citations.

Specific Comments

Line 7: Is it appropriate to say that Sentinel-2 images have "high temporal coverage?" Perhaps compared to some other satellite imagery, but you would really need time-lapse imagery to get high enough temporal coverage to see when lakes drain and plumes appear/disappear.

Line 13: The first time you mention Adolfbukta, it would be helpful to clarify that this is the name of the fjord.

Lines 20-25: Some of the sentences in the introductory sentences about glacial hydrology need references (the sentences that do not currently have references).

Lines 32-34: "Direct measurements of glacier hydrologic processes are usually restricted to short periods and a limited number of sites due to financial, meteorological, and logistical constraints. In response, the indirect study of glacier hydrology and runoff production through remote sensing has gained traction"

This is almost the exact same wording as in the abstract. Re-write either this or the abstract to fix this repetition.

Line 37: "At the same time, the need for expert knowledge to process this abundance of remotely sensed data has been limited." This is unclear. Do you mean that the expert knowledge is limited or that there is no need for it? I expect you mean the expert knowledge is limited, so I would suggest deleting "the need for."

Lines 40-42: “By quantifying the areal extents of key dynamic features (i.e., evolution of sea ice, supraglacial lakes, meltwater plumes) as proxies of glacier hydrology from Sentinel-2 observations, a simple alternative amidst the outlined constraints is potentially available.”

Again, word-to-word this is almost the exact same sentence that appears in the abstract. Re-write to avoid repetition.

Lines 44-46: This needs a reference: “Marine areas where such glaciers meet the sea are often considered biological hotspots, directly providing the adjacent marine environment with essential nutrients and other mineral materials.”

Line 55: The Nordenskiöldbreen section reads like a review paper on the glacier. Perhaps it could be consolidated/summarized to include only that information which is directly relevant to this study.

Lines 59-62: You talk about where the glacier calved in the past and allude to the fact that it no longer calves along the entire front. Where does calving happen now? A few sentences describing the current calving behavior would help establish the present-day context. The following sentence touches on this, but it could be elaborated further.

Lines 62-63: Move this sentence before the previous sentence to help establish present context before moving on to the future: “Presently, the southern and northern margins and the center of the glacier front (on Retreat Island) are land-based, as derived from satellite imagery through the absence of crevasses.”

Paragraph starting at line 78: This paragraph especially reads like a review of all the studies done on the glacier. Consider consolidating this paragraph and using parenthetical citations (at the end of sentences – see General Comment 5).

Line 90: Describe/define what Petuniabukta is the first time you introduce it.

Line 93: Reference for the mean air temperature during the study period? (Or, if this is part of your results, don't include it in this section.)

Figure 1: When I first saw this figure, it was unclear where Terrier and Ferrier Lakes were (especially because it looks like there is no water in Terrier Lake at this time). Is there some way to label the location of the lakes more clearly, either with arrows or drawn outlines?

Line 97: Why was this false-color band combination chosen? This is a NIR-red-green combination (this should be stated for readers unfamiliar with Sentinel bands), which is commonly used for areas covered in vegetation to visualize plant health. Discuss why this false-color combination was beneficial to your study.

Line 98: How was the “assumed ablation season” determined/decided?

Line 100: How was it decided that only images from the spring season would be used for sea ice extent?

Line 103: How was the boundary of the sediment plume determined? It seems like the visual signature of the plume on the surface of the fjord does not have a clear boundary as the turbid water fades out gradually. Without determining a threshold based on the spectral signature of the turbid water, I'm not sure how a visual estimation of the plume boundary could be standardized.

Line 105: This part of the methods is unclear and needs to be elaborated on: "The area of such delimited shapes was then generated automatically in the QGIS software and used for further analyses." What do you mean by "generated automatically?" Do you mean that the areas of the shapes were calculated in QGIS? (If so, say that instead.)

Methods section: For sea ice, how was the cover fraction defined/calculated? What was the total area used to determine the fraction of this total area that was covered in sea ice? Sea ice cover fraction is not mentioned in the methods, but it is plotted in Figure 3.

Figure 2: The label for sediment plume is not in the location where the plume appears to be coming from. An arrow should be used to indicate where the plume is coming from, or the location of the label could be moved.

Figure 3 caption: Should it read "air temperature observed in Petuniabukta and Adventdalen?"

Lines 128-129: It is suggested that abrupt lake drainage is "probably due to the opening up of subglacial conduits." However, abrupt drainage would be more indicative of opening of a moulin or hydrofracturing through crevasses (e.g., Das et al., 2008; Danielson and Sharp, 2013).

Line 132: Why do you think Ferrier Lake only filled in one year? Do you have a hypothesis for the physical mechanism explaining this?

Line 134: Seconding the comment by reviewer William Armstrong. Why do you propose that the water is from snowmelt?

Lines 141-142: "The filling of two supraglacial lake clusters was shifted towards the peak melt season (July/August), while the third cluster had a similar temporal pattern through its filling during June and draining in late June/July." This level of detail may not be necessary for describing someone else's results from a different glacier.

Line 147: This paper by Shield et al. is focused on Rink Isbræ, West Greenland. While it is good to mention their findings in the background and potentially other parts of the manuscript, I'm not sure it makes sense to mention one result from Greenland so specifically in your results/discussion section. If comparing your results to those of Schild et al., why not compare them to all the other papers studying plumes and supraglacial lake drainage? This could be done more generally, referencing studies together at the end of a sentence (parenthetical citations) instead of within the sentence (narrative citations). (See General Comment 5 and comment above on parenthetical vs. narrative citations.)

Figure 4: Why is Long Lake's extent not included in this figure?

Lines 155-156: “The subglacial transport of suspended sediments ceased during September, indicated by the lack of meltwater plumes and hence runoff.” This inference is too far-reaching. You can’t say it ceased because sediment-laden subglacial water could still be discharging without creating a surface expression visible in satellite imagery. Subglacial water could be discharging in a more dispersed pattern without forming concentrated plumes (indicating distributed rather than channelized subglacial hydrology), or the plume could still exist without rising enough to create a surface expression. (See General Comment 2 and our discussion in Melton et al., 2022.) Even if you did know for sure that there was no discharge of suspended sediment, there could still be *subglacial* transport of suspended sediments beneath the glacier. More analysis would be needed to support this conclusion (e.g., a time-series of meltwater discharge/runoff).

Lines 156-157: “The observed meltwater plumes originated from the southern part of the glacier front and exhibited a stable spatial pattern.” Does this say anything about the spatial network of meltwater drainage through and under the glacier? Simple subglacial flow routing based on hydraulic potential calculations could add significance to the location of the observed plume and even lake locations. If DEMs of the glacier surface and bed are available for your study area, you could consider including this. See Everett et al. (2016), How et al. (2017), and Melton et al. (2022).

Lines 161-165: The limitations of this method should be discussed in a different section because they are limitations for everything (including sea ice concentration and supraglacial lakes), not just the plumes. See General Comment 1.

Line 172: This needs a reference: “A somewhat more prolonged period of meltwater plume activity (beginning of June to the end of September) was observed in Kangerlussuaq Fjord, West Greenland, for non-tidewater glaciers.”

Lines 188-189: “the meltwater plume outlet is situated close to the sea surface.” Isn’t it at the base of the glacier, not close to the sea surface?

Line 192-193: “We argue that spring inflow of meltwater originated probably without contact with the subglacial environment as no visual evidence of sediment inflow was observed.” This does not necessarily mean that the meltwater didn’t have contact with the glacier bed. The sediment plume may not have been visible during this time if it did not reach the fjord surface, or subglacial discharge could be dispersed instead of concentrated as a plume. See General Comment 2.

Lines 194-195: This last sentence of the section seems out of place in the results/discussion section without more discussion of ice velocity and/or including velocity data in your study.

Lines 201-202: “the set of selected Sentinel-2 images was studied to define of a potential short-term statistical relation between air temperature and meltwater plume activity.” This is confusing wording. You can just say what you did (I think a linear regression between temperature and plume area).

Figure 5 caption: Add a short statement of what the “Theil-Sen estimation” is and a reference.

Lines 222-224: “The rather abrupt drainage of the supraglacial lakes at the beginning of the summer season activated the whole hydrologic system of the glacier.” I think this might be too far-reaching. There was likely water present in englacial and subglacial networks before the lake drainage which could have been active, even if it were not discharging. I’m not sure you can say that the lake drainage activated the whole hydrologic system.

Lines 230-231: This last sentence of this manuscript does not belong in the conclusions and is especially out of place as the last sentence of the paper. The manuscript needs another couple of sentences or a paragraph on the broader significance and impact of this work / recommendations for future work.

Technical Corrections

Throughout the manuscript, there are several times when “the latter” is used, and it is unclear what this is referring to. The first time I noticed it is in line 13: “... clearly indicates the latter in Adolfbukta at the glacier terminus.” I would suggest removing “the latter” here and elsewhere and saying specifically what you are referring to. In most cases this can be fixed by simply changing “the latter” to “this.”

Line 42: Unclear use of “the latter”

Line 49: Change “Tidewater glacier is” to “Tidewater glacier termini are” or similar

Line 50: Unclear use of “the latter”

Line 51: Change “Even more so” to “This is even more important” or similar

Line 52: Change “continue” to “continued”

Line 53: Remove “also”

Line 67: Change “has ice” to “with ice”

Lines 83-85: For this sentence, all three references could be at the end of the sentence instead of mixed into the beginning, middle, and end.

Line 101: Written as is, “respectively” is not needed. It could be written: “Respectively, 15, 13, 24, 25, and 24 images were obtained for 2016, 2017, 2018, 2019, and 2020.”

Line 102: “(see list of dated images in Supplementary material)”: This is labeled as Table 1. You can just say “(Table 1)” or, if it is supposed to be in the Supplementary material, “(Table 1 within the supplementary material)”

Lines 103-105: This is repetitive, saying the same thing in different ways: “manually delimiting the areal extent of studied features (supraglacial lakes, sediment plumes, and sea ice extent). Areal extent of each feature was delimited for each image to obtain the timeseries of features studied.” Consolidate these two sentences into one to avoid repetition.

Figure 2 caption: change “showing casing” to “showcasing”

Figure 3: The order of lettering in this figure is a bit confusing. Maybe the letters could increase sequentially down the columns (a,b,c in the first column and d,e,f in the second column) so that the lakes would be d,e,f instead of b,d,f. This would make the caption easier to read.

Figure 3f: The title should indicate both Terrier Lake and Ferrier Lake instead of only Terrier Lake.

Figure 3 caption: There are 2 (e)s in the caption. Delete “(e) Terrier supraglacial lake areal extents”

Line 128: At the beginning of the sentence, change “Probably due to” to “This was probably due to” (or combine the two sentences into one)

Line 139: Change “Other than” to “Different from” or “Unlike”

Line 186: Change “depth’s” to “depth”

Line 191: Change “as well” to “also”

Line 198: Change “freezing point” to “melting point”

Line 204: “It is no surprise that a positive correlation was found.” This is subjective and unnecessary. This sentence can be deleted.

Lines 204-205: Change “The best correlation was found in the case of aggregated five consecutive days’ average air temperature preceding the sediment plumes occurrence” to “The best correlation resulted from averaging the air temperature over the five consecutive days preceding the sediment plumes’ occurrences”

Line 210: I suggest changing “onset of snowmelt on the glacier surface” to “onset of surface melting” or similar.

Line 212: Unclear use of “the latter.” Change to “This”

Line 213: Same comment as above. Change “The latter” to “This”

Line 215: change “with the air temperature getting down to zero” to “while the air temperature drops to zero”

Line 219: change “consecutive seasons” to “consecutive years” or “consecutive summers” or “consecutive melt seasons”

References

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- Danielson, B., and Sharp, M. (2013). Development and application of a time-lapse photograph analysis method to investigate the link between tidewater glacier flow variations and supraglacial lake drainage events. *J. Glaciol.* 59, 287–302. doi:10.3189/2013JoG12J108.
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