Multi-annual patterns of rapidly draining supraglacial lakes in Northeast Greenland

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Comments by Nina Kirchner, Stockholm University and Tarfala Research Station, 27 December 2024

Summary

This manuscript presents mainly observational data in relation to drainage of supraglacial lakes on two outlet glaciers in north-eastern Greenland. The focus is on rapid, and furthermore, cascading (also known as coupled or, as here referred to: chained) drainage events during the years 2016-2022. Observed drainage patterns are based on analysis of Sentinel-2 L2A imagery. Timing of rapid drainage is reported to be related to elevation at which drainage takes place, confirming similar observations reported in the literature. It is further reported that investigations remain inconclusive regarding the relation between rapid drainage and i/lake volume prior to drainage, ii/ ice flow dynamics (via strain rate, represented by the July 2019 configuration for the 2016-2022 time-interval) around the time of rapid drainage, and iii/ averaged summer (JJA) surface air temperatures for each year for the collective drainages of each year.

Assessment and specific comments:

Detailed datasets on supraglacial lake drainage on glaciers in the northern sector of the Greenland Ice Sheet are few. Therefore, the here described novel dataset is of value and interest for the scientific community. A persistent challenge with observational datasets, especially from rarely studied regions, is that their perhaps largest value is their mere acquisition and open-access publication. This is often overlooked, and there is moreover a risk that works presenting and exploring novel datasets are rejected because they are regarded as lacking clear research questions and/or hypothesis. However, without base data, these are impossible to formulate.

To me, the manuscript by Lutz et al. is a telling example. A rich dataset is presented, and a first attempt is made to attribute rapid drainages to several potential "drivers", but no other conclusions can be established than there is great spatio-temporal variability, and likely not a single driver but multiple ones, acting possibly intertwined with exact mechanisms still to be discovered. Yet this is a solid conclusion. Yes, a statistical analysis of how potential drivers related to rapid drainage is not included in the analysis presented here, but since the dataset presented is – to me – the largest achievement, the author's "first approximation" analysis of attribution is sufficient in my view. As the dataset will be made freely available, it is for the scientific community to pick up on this when need is seen.

However, I think the manuscript would benefit from major revisions. To start with, a stronger motivation should be given why this dataset was created and analysed. Formulations such as "rapid drainages can substantially affect […] aspects of the glacial environment throughout the melt season" are too much of a commonplace and don't match the level expected from a manuscript submitted to TC. In the following, I recommend that a comment on terminology regarding the simultaneous (raid) drainage of supraglacial lakes is included. To my knowledge, these events have first been referred to as "cascading drainage" (Christoffersen et al., 2015, cited in the manuscript), then "coupled drainage (Otto et al., 2022. Supraglacial lake expansion, intensified lake drainage frequency, and first observation of coupled lake drainage, during 1985-2020 at Ryder Glacier, N Greenland. Front Earth

Sci, doi.org/10.3389/feart.2022.978137), and then here as “chain drainages”. It would be beneficial in my view to adopt an already existing terminology (unless “chained” exists already, but in that case I miss a reference to it).

Continuing on this, it needs to be pointed out that the work of Otto et al. (2022), doing a similar study at Ryder Glacier, has apparently been overlooked. As Otto’s work covers the time-span 1985-2020, including first observed coupled drainage at Ryder Glacier, I had expected to read about a comparison of drainage of SGLs at northern Greenland glaciers at least in the Discussion section?

Likewise, I am curious how rapid drainage events contrast to slow drainage events. I assume that to identify “rapid” drainage, all types of drainage need to be detected first? I realize that including a detailed comparison of slow vs rapid drainage is likely beyond the scope of the manuscript, but it would be helpful to know e.g how large the fraction of rapidly draining lakes is compared to slowly draining (or mentioning other similar simple comparative metrics). For southwest Greenland, such info is cited from the literature, but how is it for the region studied here? I think info is available (from e.g Fig 1 which indicates non-rapidly draining lakes), so could be included in a straightforward manner, and even be given some thought and reflection in the discussion section.

Finally, I think it is assumed in the manuscript (unless I misunderstood) that all drained water reaches the bed. But what about englacial storage, that is, if the drained volume vanishes from the surface but if not all of it reaches the bed? Could this impact subsequent drainage in one way or the other? If crevasses in the lake would aid rapid drainage, maybe englacial storage would hinder it? Maybe englacial storage could be reflected on in the discussion, I would be curious to hear the author’s thoughts on it.

Concerning more editorial aspects, the title of the manuscript and the abstract reflects its contents. Overall, the presentation is well-structured and easy to follow, however, major work should be put in making the text more concise (detailed comments are given but may not be exhaustive). Care needs even to be taken concerning the use of time units throughout the manuscript, figures, and figure captions. The figures (main and supplementary) display a wealth of information (where more is desirable this is indicated in the detailed comments) and are still very appealing, great work has been done here!

Detailed comments and questions: Note that rewording suggestions are rendered in orange.

Line 9-10: “Supraglacial lakes are known to undergo rapid drainages in which the contents of the lake are drained through ice hydrofracture to the glacier bed”… -> “Supraglacial lakes are known to undergo rapid drainages in which their watermasses are drained through ice hydrofracture to the glacier bed…”

Line 10-11: “Despite the impact of this sudden loss of meltwater from the glacier, the conditions.. ..” -> “Despite the impact of this sudden englacial transport of meltwater, the conditions…”

Line 13: “Over the 2016 - 2022 summer melt seasons, each supraglacial lake was tracked “--- -> “Over the 2016 - 2022 summer melt seasons, supraglacial lakes on these glaciers were tracked” Question: Over the entire glaciers or with focus on specific regions? This info comes later (l 63) but should be given here.

Lines 17-20, from “Furthermore”: these sentences are unclear/vague and need to be reformulated

Line 20: physical location -> spatial position ?

Line 20: Chain drainage. I think you may be referring to “cascading” or “coupled drainage”, as earlier described by Christoffersen et al., 205, and Otto et al., 2022. If yes, perhaps coupled drainage should be used here, too as terminology. If however chain drainage differs from coupled drainage, it should be explained (later) how.

Line 20: unclear wording in “in which more than one neighboring lake” – neighboring to what? You mena to another lake. You could rewrite as “in which neighboring lakes”

Line 23: “would need to be filled to allow for a rapid drainage to occur, particularly the existence of a crevasse within” -> “would need to be met to allow for a rapid drainage to occur, particularly the existence of fractures or crevasses within”. In any case, I suggest that something in plural form is needed. Not just one crevasse.

Line 27: References are needed re better understood interconnectedness of supra- and subglacial hydrology

Line 29: “where the lakes” -> where a lake”

Line 30: “routed vertically” -> “routed towards the bed”. Note that crevasses may not extend all the way to the bed, and that meltwater may be stored englacial. Note also that neither moulins nor crevasses are vertical.

Line 31*:* “Conduits remain open… until the channel freezes or is closed”. I would rephrase this differently, like “meltwater supplies to bed ceases when channel freezes or is closed”.

Line 35: Why does lake drainage increase tensile stresses? This should be explained. For “cascading drainage” see my comment above (l 20)

Line 37: For which time-period is the number of 26-45% ? And would it be more informative to read that it is ca 35% now but perhaps has increased to this number during a period of xx previous years? I am not sure what to do with this specific, yet not so much saying number of 28-45%.

Line 38: specify “these aspects”.

Line 40: specify “this phenomenon”.

Line 46: “allow us”. I would suggest neutral formulation, as in “large-scale observations allow to “

Line 48: “extended time series” -> “extended time periods”. Also, was Fitzpatrick et. Al 2013 finally accepted or did It stay in TC Discussion? Pls check journal guidelines if refs to TCD are ok or should be avoided.

Line 49: “here, the timing” -> “In these studies, the”

Line 50: “and altitude” -> “and lake altitude”. Consider mentioning that higher surf temps correlate with lake elevation because surface melting occurs at higher elevations. How is drainage timing affected? Earlier drainage? Later?

Caption Fig 1: Add references for Sentinel-2 imagery and ArcticDEM dataset.

Figure 1 and line 64: use consistent terminology. Lambert Land/ Lamberts Land?

Figure 1 and line 68: You speak of both grounding lines, but 79N’s grounding line is not in the map in panel c? And is the grounding line= calving front for Zach? Amend/correct/rephrase

Line 66: “This area” Only Zach or also 79N? In that case: “These areas”

Line 83: “was calculated” -> “was set”

Line 84: “with other researchers” -> “with previous work”

Line 91: Are you saying that the lake volume is identical to the volume of water “lost”? Even if the entire lake drains, it is not known whether all water reaches the base or whether some is stored englacially. Care needs to be exerted when formulating methods. Here lake volume calculation is described. How “accurate” is this volume calculation? What is the resolution of the Sentinel pixel, and how sure is one abut the reflectance, and what is the offset 0.5242 and is this specific for Greenland SGLs or fitted to something else? From where comes depth z?

Line 96: “ice velocity” -> “ice surface velocity”

Line 97/101: “ice sheet velocity” -> “Ice surface velocity”

Line 100: Are velocities from July 2019 used for the entire timeperiod (2016-2020)? And only to calculate strain rates? Clarify.

Line 102 : “rates of the ice was” -> “rates of the ice, epsilon_1/2, were calculated as (formula)”. *So, skip “For this, the first and second invariants of the strain rate tensor was determined in both the x- and y-directions”. Also, give equation a number so you can refer to it later in l 186.*

Line 103: “rate tensor was” -> “rate tensor were” , x and y before “directions” should be in italics

Line 105: “ where ϵ1/2 is the first and second principal strain rates, ϵxx is the strain rate tensor in the x-direction, 105 ϵyy is the strain rate” -> “where , ϵxx, ϵyy and ϵxy are components of the strain rate tensor, and ϵxy is know as the thear strain rate.”

Line 116: “but never rapidly” -> “but did not drain during 2016-2022”

Line 121: “found within each” -> “found for each”. Also, consider adding a ref to Fig 3 after Fig 2 is mentioned, as eg by writing “shown in Fig. 2, and detailed in Fig 3.” This will help address below (l 135)

Line 122: I very much like the visualization with the wheel, but find it hard to distinguish the colors in the segments clearly enough to related them to the gradually changing color scale. Consider using a more contrasting scale.

Line 123-124: Sentence can be shortened to “Additionally, if the lake never filled up in a certain year, it is marked with an ‘x”

Line 135: It is not good practice to skip references to Figures in the main text. Here, Fig. 3f and g are mentioned, but nothing has been said yet about Fig. 3a-e.

Line 135-236: I find this sentence somewhat imprecise. Do you mean: Since the lakes are disperses across slow and fast moving areas, some other mechanism than ice deformation (higher in fast flowing regions, so likely faster channel closing) must be responsible for keeping the drainage pathways open so that lakes don’t refill? Pls be more specific.

Line 142: “temporal variability within each lake” -> “temporal variability of drainage at each lake” ->

Line 147: Imprecise formulation. Last week of June cannot be same week near end of July. Reformulate.

Line 150, 151: extensive chain drainage is here said to happen on the same day. Why is this not called simultaneous drainage (see line 151) or "cascading" (Christoffersen et al., 2015) or "coupled drainage" (see Otto et al., 2022)? Are chain drainage and simultaneous drainage used as synonyms? Also: "with a couple lakes" -> "with a couple of lakes" (OBS check this throughout the text, there is another occasion where this needs to be fixed in **line 173**)

Line 152: Is about Fig 3b. But I see 7 lakes in panel b, but the text is about six lakes? I find panel b quite compact, and it took me a while to match text and what is displayed in panel b. I suggest that lake id's (since you have them anyhow) are added, which would make it easier to refer to the lakes in the describing text (replacing "the lake to the right of the left lakes" etc.) Pls consider adding lake id's and replacing the description in lines 151-155 by clearer, easier to follow text including these lake id's.

Line 154: without triggering drainages in them – isn't that to be expected because they are downstream of the other lakes discussed in connection with Fig 3b? Perhaps this info could be added?

Caption Figure 3d: "subset, except the lake crossed out, is shown" -> "subset, except the lake crossed out and not included because of its distinctly different drainage pattern, is shown"

Line 167-169: Rephrase according to orange, and rephrase non-logic text highlighted in red (an idea cannot be modelled; repetitive use of "idea")

: "drainage after a certain threshold or under certain conditions. An idea that has often been modeled (Alley et al., 2005; Arnold et al., 2014; Banwell et al., 2013; Banwell et al., 2016; Koziol et al., 2017; Tsai and Rice, 2010; van der Veen, 2007) but also recently contradicted by observations (Fitzpatrick et al., 2013; Williamson et al., 2018) is the idea that each lake has" -> "drainage after a certain threshold is passed, or under other certain conditions. An idea that has often been modeled (Alley et al., 2005; Arnold et al., 2014; Banwell et al., 2013; Banwell et al., 2016; Koziol et al., 2017; Tsai and Rice, 2010; van der Veen, 2007) but also recently contradicted by observations (Fitzpatrick et al., 2013; Williamson et al., 2018) is the idea that each lake has"

Line 170: Logic again. In a figure, you cannot investigate. But you can show results of what you investigated in a figure. Reformulate.

Line 171: Clarification needed: If you say "drain" do you always mean complete drainage? If that is the assumption, drained volume and lake volume are the same. Obs "drained" is not equal to "lost" volume, see an earlier comment.

Line 173 ff and Fig 4. I suggest adding a map with the location of these maps. Just by there id's, one has no idea where they are located. Are any of these lakes involved in coupled, chained, or simultaneous drainage? At Ryder Glacier, no coupled lake drainage was observed in 2018 (Otto et al., 2022)

Line 178: Use superscripts such that it becomes km^3 instead of km3

Figure 5: Inconsistent use of units for strain rate, both 1/a and 1/y are used. Check journal requirements re units and correct. Inconsistent use of units continues in **line 209** (and others, check thourghout) where year^-1 is used. Add grounding line for 79N (see comment Fig. 1). Why does legend for strain rate range over a larger interval that shown in panels g and h? High strain regions are not captured currently in panels g and h, unless I am missing something? See also **line 207.**

Line 189,190: Edges cannot be strains. Reformulate.

Line 194-195: Strain rates can be computed everywhere. What you want to do here is characterize them, not say they exist. Reformulate.

Line 179: "found on areas" -> "found in areas"

Lines 2013-205: Unnecessary repetition. Rephrase without repetition, and observe that velocity data was acquired for 2019, and that strain data was computed from it. You formulate this correctly in the caption to Fig 5.

Line 223: Abbreviation AWS has not been introduced. Should be done in line 109.

Figure 6: Average surface temperature, should that be average air temperature at 2 m above ground? What is the elevation of these AWS? What is an expected elevation corrected temperature over the elevation range of the lakes studied? Perhaps this should be added as an interval around both temperature lines in the figure.

Caption Fig 6: Why use "lower" "middle" and "upper" describing categories if you have introduced colors for them? Use "light green", "green" and "blue" instead.

Line 240-244: Switch: Talk about your results first, then about they confirm what has been reported by others.

Figure A3. Check unit (m/y, m/a, m year^1 etc, see earlier comments. Add grounding lines, see earlier comments. Lamberts vs lambert Land, see earlier comment.

Line 275: "lake itself and would thus only drain if" -> lake itself and the lake would thus only drain if"

Line 276: why does nearby drainage affect strain rates?

Line 385: Shouldn't this be the following?

Lutz, K., Bever, L., Sommer, C., Seehaus, T., Humbert, A., Scheinert, M., and Braun, M.: Assessing supraglacial lake depth using ICESat-2, Sentinel-2, TanDEM-X, and in situ sonar measurements over Northeast and Southwest Greenland, The Cryosphere, 18, 5431–5449, https://doi.org/10.5194/tc-18-5431-2024, 2024.