Author response to

Interactive comment on "Challenges in predicting Greenland supraglacial lake drainages at the regional scale"

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Anonymous Referee #2

Received and published: 13 November 2020

Authors' replies inline in red December 29, 2020

Summary

Supraglacial lake drainage has crucial impacts on surface-to-bed meltwater connection on the Greenland Ice Sheet but remains challenging to quantify. This study uses remote-sensing velocity datasets to constrain the relationship between strain rates and supraglacial lake drainage and to test the hypothesis that transient strain rates drive fast lake drainage. The results show significantly more-extensional background strain rates at moulins associated with fast-draining lakes than at slow-draining or non-draining lake moulins. This study aims to solve an important science question for the Greenland re-search community. I recommend it for publication with some minor changes.

General Comments

(1) The structure of the paper is basically clear but can be improved. Some suggestions:

Section 3.4, this section is short so it may not be necessary to divide it into two sub-sections.

We agree that the brevity makes it not strictly necessary, but we think that sub-dividing this section is helpful. It also parallels the sub-division of Section 3.5, which is much longer and contains identical sub-sections on "effect of elevation" and "effect of wintertime strain rate".

Section 3.6, some descriptions belong to methods and should be removed.

We have moved the descriptions text to Methods (new Section 2.2.2, "Calculation of principal strain rates from GPS station pairs") and expanded the uncertainty formulas (Equations 6–9) in the Methods to improve their applicability to GPS data (Section 2.2.1, "Calculation of principal strain rates").

Section 3.7, the first paragraph of this section belongs to methods and should be removed.

We have moved this text to Methods (new Section 2.2.3, "Stacking of strain rates across multiple melt seasons").

The discussion section presents very insightful ideas but the discussion should be based on the results of this study. I think sections "4.2 Prediction of future lake-drainage events" and "4.3 Parameterizing moulins in ice-sheet models" should be more closely related to the main findings of this study. In other words, these two sections should highlight how the findings of this study can help us better answer the two crucial science questions (lake drainage and new generation of ice

sheet models) rather than broadly introducing these two science questions. This can be done by slightly modifying some words and expressions.

We have added sentences to Sections 4.2.1 and 4.2.2 to more explicitly tie our extensions to the analysis we performed. We have also added points of discussion to Sections 4.2.3 at the suggestion of the other reviewer. Finally, we inserted more sentences within Section 4.3 to reaffirm how the negative results of our experiments require extensions like the ones we discuss.

(2) Significance test is widely used in the study. It may be useful to briefly explain how the test was conducted at different parts of the results.

We have added a new subsection to Methods (Section 2.5, "Statistical tests") that describes the two statistical tests we used.

(3) The paper concludes that "observational progress in understanding lake drainage initiation will rely on field-based tools such as GPS networks and photogrammetry". I think this should be further discussed. A growing availability of high-resolution satellite imagery (e.g. CubeSat and Landsat-9) provide more frequent observations of supraglacial lakes in future and may mitigate the time gap problem.

We address the Planet.com CubeSat products in Section 4.2.2 (lines ~679 in the differenced document), which will require improved georeferencing if they are to be useful for measuring velocity fields. We added an assessment of the forthcoming Landsat 9, which will operate in tandem with Landsat 8 much as the Sentinel-1 constellation does, improving the temporal coverage from a 16-day repeat to an 8-day repeat cycle 2 (lines ~676 in the differenced document).

(4) The study area of this paper is relatively small (~1600 km^2) and most cover low elevations (<1400 m). Will the results obtained in this study be applicable for larger areas? particularly when including high-elevation areas. It will be useful to briefly discuss this point.

Indeed there is likely to be some ice-thickness dependence on lake drainage, perhaps substantial, and perhaps in a way that would not extrapolate well from our study elevation (s <~1500 m). We added a brief discussion of this to Section 4.3 (lines ~793 in the differenced document).

Specific Comments

line 16, Smith et al (2015) found nearly all surface meltwater drain into moulins in the ablation zone of the southwestern GrIS rather than in the western GrIS. I think it is necessary to distinguish these two study areas. It is not clear if all meltwater drains to moulins, particularly at the high-elevation areas of the western GrIS since few river, lake, or moulin maps have been made for this region.

Here we use "western" as a general term to include the large and widely studied ablation zone on the western flank of the Greenland Ice Sheet. This includes Pâkitsoq (our primary study region) as well as regions north and south of it, including the "southwestern" Greenland Ice Sheet (the Russell Glacier catchment studied by Smith et al. (2015), Doyle et al. (2013), etc.). Both regions have a long history of study, especially Pâkitsoq, whose proximity to Ilulissat allowed extensive study by GEUS in the late 1980s (e.g., the hydrologic map of Thomsen 1988). Indeed it is possible that high-elevation meltwater on the western (or southwestern) Greenland Ice Sheet meets a different fate than lower-elevation meltwater, for

instance refreezing in firn, buried lakes, or ice slabs, but we don't know of any reason this should differ between the Pâkitsoq and Russel Glacier regions.

line 18, on diurnal scale too.

We changed "daily" to "diurnal" for clarity (line 18 in the differenced document).

line 20, add "." before "Our".

Fixed (line 20 in the differenced document).

line 28, "basins of specific supraglacial lakes", do "basins" mean the topographic depressions that host lakes or the upstream contributing catchment area to feed lakes?

We mean the topographic depressions. We replaced "basins" with "topographic depressions" to be clearer (line 29 in the differenced document).

line 42, supraglacial river gauging, streams are narrow and exhibit small contributing areas.

We use "supraglacial streams" throughout the manuscript to refer to water-conveying channels on the ice surface. Some authors distinguish between supraglacial "rivers" (larger fluxes) and "streams" (smaller fluxes), but knowledge of relative water fluxes across channels is outside the focus of our remote-sensing-based study.

line 50, Banwell and Sommers are not appropriate to describe "the next generation of ice sheet models".

We agree they do not describe the next generation of models, but these references do suggest the needed improvements in the representation of the ice-sheet hydrologic systems in forthcoming models. We added text to clarify this (line 41 in the differenced document).

lines 59-61, this sentence is not easy to follow.

We removed a few words and added commas to make this simpler (lines ~63 in the differenced document).

lines 102-103, how to obtain velocity uncertainties?

We use the posted uncertainties associated with each velocity product. To clarify, we added the word "posted" (line 112 in the differenced document).

line 121, panchromatic pixels?

We removed the word "pixels" (line 126 in the differenced document).

line 232, panchromatic band? Multi-spectral bands have lower spatial resolution (2 m).

We have updated this section with the correct band-specific resolutions and to use the words "multispectral" and "panchromatic" to be more precise (line ~281 in the differenced document).

line 258, how is p value calculated?

See our response to the earlier "general comment" on significance testing.

line 266, e3?

Fixed (line 320 in the differenced document).

line 285, are most of these moulins located in topographic depressions that host lakes?

Yes; this is addressed in Section 4.1.2 and illustrated, for a single example lake, in Figure 5. We added text to specify this (lines ~354 in the differenced document).

lines 308-310, how about comparing to Cooley and Christoffersen (2017)?

Comparison added (lines ~372 and ~375 in the differenced document).

lines 320-322, how is p value calculated?

See our response to the earlier "general comment" on significance testing.

line 421, standard deviation 15 days is a very long time because most supraglacial lakes have short lifetime spans. Any implications we can obtain from this long std?

Indeed, the drainage date varies significantly across our dataset of 78 lakes and 19 melt seasons. Lakes in our dataset span elevations from roughly 400–1400 meters, which has a significant effect on drainage date ($p<10^{-9}$, Figure 9), and the date of melt onset spans early April through early June from year to year, which also has a significant effect on drainage date ($p<10^{-9}$, Figure 9). The lifetime of a fast-draining lake on the ice sheet is some dozens of days (see example in Figure 2a), so it does seem that a given lake may well be present or absent on a given calendar day from year to year, or that lakes at lower elevations may drain before higher-elevation lakes fill.

line 428, what does "meaningfully change" mean?

By "the values do not meaningfully change" we mean that they fluctuate within the range of their natural variability and within the calculated errors on these data.

line 591, fix "*Stevens:2015ht".

Fixed (line 663 in the differenced document).

line 723, "meltwater" rather than "melt" delivery to the bed.

Fixed (line 824 in the differenced document).

Figure 4, the moulin elevation colors are not clear for the dots, perhaps change into color ramp? Fix "Bamber:2013 gw" in the figure caption.

We've fixed the black-to-gray-to-white tones, which incorrectly stopped at mid-gray, and fixed the typo in the caption. We've also corrected an error in the data for this figure – the Discussion version of the figure incorrectly showed lake drainage dates from an outdated version of the database.

Figure 8, see the comment for Figure 4.

These black-to-gray-to-white tones display correctly on this figure. We experimented with the suggestion to change these grays to a color ramp, but all color ramps we tried obfuscated the red and blue strain rates or made the figure even busier than it already is. Ultimately, we doubled the marker size to make the elevation data more visible.