

Interactive comment on “Characterizing supraglacial lake drainage and freezing on the Greenland Ice Sheet” by N. Selmes et al.

Anonymous Referee #2

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This manuscript presents the results of a manual classification of five years of supraglacial lake drainage events on the Greenland Ice Sheet into three categories: fast drainage, slow drainage and refreezing. This manuscript is an incremental improvement over Selmes et al. (2011). In the broader context of other studies, however, this manuscript does not present methodological improvements or substantial novel insight on geophysical implications of lake drainage events.

I have grouped my major comments into four categories listed below. Firstly, there appears to be substantial overlap with Selmes et al. (2011), leaving the reader with the distinct sense that this manuscript is an addendum of sorts. Secondly, this manuscript overlooks several recently published studies on the topic of lake evolution / drainage, some of which already present similar findings that the authors imply are novel. Thirdly,

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the geophysical interpretation presents, but does not interpret, spatial and temporal differences in lake drainage type, and implicitly assumes that end of season fate is independent of lake area. Fourthly, an error analysis is entirely absent.

This manuscript does contain some novelties: (i) entire ice sheet tracking of lake drainage events, (ii) establishing that refreezing is more common than draining at high elevations, and (iii) hinting that synchronous neighboring lake drainages may be linked by a common mechanism or forcing. Overall, however, I would think these highlights are more commiserate with a concise "Brief Communication", than a full length "Research Article" in TC. If these highlights can be bolstered by an improved synthesis with (even some of) the previously overlooked literature, as well as augmented geophysical insights from the presented spatial and temporal variability, then this work has potential as a valuable contribution to the cryospheric community.

Major Comments:

1.) Overlap with Selmes et al. (2011). There appears to be significant overlap with Selmes et al (2011). The key figures of this paper (Figures 1 through 4) seem to be updated/expanded versions of Figures 1 and 2 in Selmes et al. (2011). The new figures essentially divide the previously combined "slow + refreeze" class of Selmes et al. (2011; red colors in their Figure 2), into two separate "slow" and "refreeze" classes (now green and blue in Figure 4). I have attached both these figures to this review. The accompanying text does not provide substantial methodological improvements (the reader is referred to Selmes et al., 2011 numerous times), additional insights on the temporal or spatial distribution of lake area drainage, or novel insights on the implications of lake drainage on ice sheet dynamics in a changing climate.

2.) Other previously published literature. Much has recently been published on the topic of supraglacial lake evolution. The following works are not currently referenced, but contain both results and conclusions that should be properly attributed. These are just the works that quickly come to mind. For example "We conclude that any lake on

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the ice sheet has one of three probable fates. ... [then you revisit 1. sudden drainage, 2. re-freezing and 3. slow drainage] ... The latter two processes have not been reported for lakes in Greenland"... this intends to leave the reader with the impression that the observation of re-freezing and slow draining lakes is a discovery unique to this present study, when in fact it has been previously documented and described.

Box, J., & Ski, K. (2007). Remote sounding of Greenland supraglacial melt lakes: Implications for subglacial hydraulics. *Journal of Glaciology*, 257-265.

Georgiou, S., Shepherd, A., McMillan, M., & Nienow, P. (2009). Seasonal evolution of supraglacial lake volume from ASTER imagery. *Annals of Glaciology*, 95-100.

Johansson, A., Jansson, P., & Brown, I. (2013). Spatial and temporal variations in lakes on the Greenland Ice Sheet. *Journal of Hydrology*. 314-320.

Liang Y., Colgan, W., Lv, Q., Steffen, K., Abdalati, W., Stroeve, J., Gallaher, D., and Bayou, N. (2012). A decadal investigation of supraglacial lakes in West Greenland using a fully automatic detection and tracking algorithm. *Remote Sensing of Environment*, 127-138

McMillan, M., Nienow, P., Shepherd, A., Benham, T., & Sole, A. (2007). Seasonal evolution of supra-glacial lakes on the Greenland Ice Sheet. *Earth and Planetary Science Letters*, 484-492.

Sneed, W., & Hamilton, G. (2007). Evolution of melt pond volume on the surface of the Greenland Ice Sheet. *Geophysical Research Letters*, L03501.

The omission of Liang et al. (2012) seems to be particularly egregious, as that study explicitly assesses the rate at which lakes drain. Granted the Liang et al. (2012) did not study the entire ice sheet, it did span an entire decade, and provided quantified annual distributions of rate of change in lake area (i.e. not qualitative classifications). Overall, I would contend that the authors have an obligation to present their findings in the context of similar previous findings, so that they can highlight important agreements

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or disagreements to the reader, rather than assuming an interested reader will seek out and synthesize these works on their own.

3.) Geophysical implications: A.) Supraglacial lake drainage may indeed have a large potential role in ice dynamics. It matters, however, whether large or small lakes are draining fast. Just looking at Figures 1 through 3, the examples you provide seem to suggest that slow drain lakes are substantially smaller (mean peak area of ~1.8 km² in Figure 3) than fast drain lakes (mean peak area of ~6.5 km² Figure 1). Thus, can the end of season fate really be interpreted as independent of lake area? This is done implicitly when Figure 4 provides the lake area associated with each drainage type, but the abstract (and other text) says "... X % of all lakes", rather than "... X % of maximum lake area". It's subtle nuance, but I think some novelty is associated with assessing end of season fate as a function of lake area.

B.) Multiple years of data are presented, but the results are not interpreted in a temporal context. With the goal of examining slow lake drainage in the context of what role it may play in the hydrological and dynamic systems of the Greenland Ice Sheet, presumably the story would be completed by describing changes in the relative frequency of slow lake drainage in the context of climatic forcing, namely whether slow drainage increases in warmer years. Otherwise, the five years may as well be averaged into a mean climatology of sorts. Liang et al. (2012) showed that the frequency of rapid drainage increased in higher melt years, so I would imagine that the corresponding frequency of slow drainage events would have to decrease to accommodate increase fast drainages? Looking at SW Greenland, in the warmest (?) year (2007), it looks to me like there is 20 % more lake area drainage, comprised almost exclusively of non-refreezing mechanisms. I would think there is also novelty in assessing the absolute volume of water reaching the ice sheet bed as a function of climatic forcing.

C.) Multiple sectors of data are presented, but the results are not interpreted in a spatial context. Why do you think the SW sector has the high proportion of fast drainages? Why is the relative amplitude of inter-annual variability greatest in the NE? With so

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few drainages of any sort, is SE Greenland expected to experience negligible surface meltwater-induced basal sliding? I suppose that fast drainages make up the largest portion of the pie first in the SW sector, but then, curiously, second in the NE sector (rather than say SE if meltwater production was the driving process, or the say NW where ice sheet geometry (i.e. surface slope) is next most similar to SW). I would contend that a bolstered spatial discussion is key to "Characterizing supraglacial lake drainage and freezing on the Greenland Ice Sheet". To highlight the absence of spatial discussion, I note that the word "sector" appears only figure and table captions, and nowhere in the body of the manuscript.

4.) Error analysis: In comparison to automated algorithms, in which sensitivity studies assess error levels relatively easily and reliably, manual classification can be viewed somewhat dubiously these days, given its inherent subjectivity. I think it is therefore obligatory for proponents/users of manual classification to demonstrate the error associated with their output, especially in the context of the error from similar automated algorithms. Simply saying "This process was time consuming but allowed us to observe lake-drainage processes in great detail" does not provide the reader any confidence in the stated frequencies of each drainage class. As far as I can tell, the three drainage classes (fast, slow, refreeze) are essentially qualitative constructions (i.e. quantified drainage rates are never calculated and used for binning events). I would think that it is possible for significant error to arise when subjectively classifying events into three bins, especially when two bins ("fast" and "slow") are, by definition, different parts of the same continuum. Other variables, such as maximum lake area, presumably also carry some more easily quantified error? In any case, these errors need to be propagated in a meaningful fashion and appear in your tables and figures.

Minor Comments:

In terms of detailed comments, I will refrain from adding to the very thoughtful insights of Reviewer 1.

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this manuscript

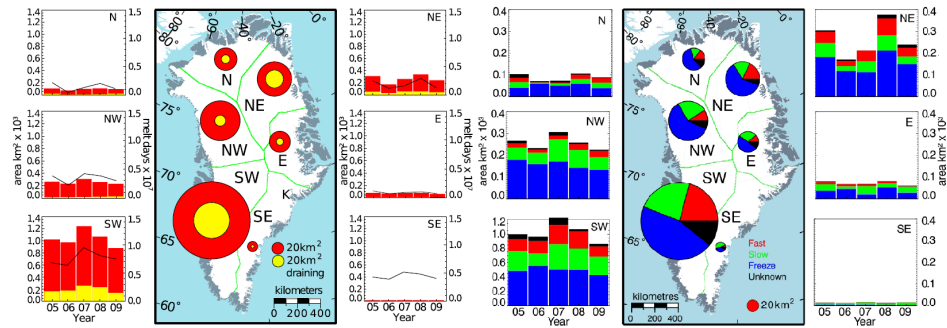


Fig. 1. The non-sudden lake drainages of Selmes et al. (2011; red, left figure) have now been partitioned into slow draining and refreezing (green and blue, right)