

## ***Interactive comment on “Dual-satellite (Sentinel-2 and Landsat 8) remote sensing of supraglacial lakes in Greenland” by Andrew G. Williamson et al.***

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Williamson et al. present a new technique which combines two different types of satellite imagery to create a lake geometry time series with an unprecedented combination of spatial and temporal resolution. The methods are rigorous and described in comprehensive detail. Indeed the detailed description of the methods gives the impression that the manuscript is largely a techniques paper despite significant results also being presented. The figures and tables are of a high standard and the referencing is appropriate throughout. The manuscript reads well with very few errors. The finding that a large proportion of surface water drains through small (and often previously undetected) lakes is significant. The paper builds on previous work on supraglacial lakes on the Greenland ice sheet.

## General comments

My main concern stems from L213: “*We treated these Landsat depths and volumes as ground-truth data as in Williamson et al. (2018)*”. This assumption is not discussed in detail at any point in the manuscript, although I guess it may have been described in the author’s previous paper. In my opinion, there should be more discussion in this manuscript of the lack of actual ground truthing and how this might affect the absolute accuracy of the results. That is, how do the authors expect the results to compare with reality? How does this study compare to previous studies which employed ground truthing? To be clear, I’m not expecting ground truthing to be undertaken, but the lack of ground truthing and its potential effects should be discussed.

There is also a lack of discussion of the depth limitation of the techniques used. The techniques presented only retrieve lake depth up until a certain point. Figures 3 and 4 suggest a 6 m limit, when lakes are known to be often deeper than 10 m. If many lakes are deeper than the limit then this would hypothetically create a bias in the results by underestimating the volumes of the deeper lakes, which could affect the reliability of the main conclusion of the paper — that the water drained through small lakes is greater than that through large lakes. Given this, the relatively low maximum lake volumes ( $1.2 \times 10^7 \text{ m}^3$ ) reported on L334/335 compared to those in the literature (e.g. Box and Ski, 2007) are potentially concerning. These limitations should be discussed to make the reader aware of them. The authors could also look to previous studies, which have measured lake depths to understand whether the maximum depth of their technique is potentially too shallow.

These issues aside, the discussion of problems and limitations in Section 4.1 is well-considered and appropriate.

## Specific comments

L24/25 — consider offering an explanation for why small lakes drain such a large proportion of the runoff. Is it because they are more numerous? An explanation for this

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observation is never given in the manuscript.

L29 — the last two references in this sentence are in the wrong place. They currently only relate to there being two main ways the ice sheet loses mass (without specifying what they are), which as a statement does not need a citation. Perhaps move them to later in the sentence/paragraph.

L40 — I'm not sure whether the citations to Doyle et al. (2018) and Hofstede et al. (2018) are appropriate here. Presumably they are given here as evidence for subglacial sediment? In fact the number of citations given here could be significantly reduced to list only the key studies.

L43 — Consider the recent paper by Christoffersen et al. (2018) here.

L44 — It is well established that surface water delivered to the bed of the Greenland ice sheet accelerates ice flow in the short term. Given the evidence for this, the phrase 'potentially explaining' seems a bit weak.

L45 — Consider citing Joughin et al. (2013) and Hoffmann et al. (2011) here.

L75 — I'm not aware of any evidence which suggests lake hydrofracture takes days. All the evidence suggests the process is rapid, taking hours or less.

L111 — May to October is not summer, perhaps use 'melt season' instead, although there is not usually much melt in October.

L124 — Why does the study only cover up to 90 km inland? Perhaps give a reason here.

L187 — stating the increments provides no information on how much it was adjusted in absolute terms, unless only one increment was used? Or is the percentage change given per 0.01 increment? Please clarify.

L230 — Can you (briefly) be a bit more specific here as to how the new technique was validated, even if it requires some repetition.

L260 — Consider discussing the implications of Cooley and Christoffersen (2017) regarding the effects of observation bias on the detection of rapidly draining lakes. The reduced interval of the new technique presented in the manuscript under review should reduce the observation bias associated with the longer intervals of previous studies.

L271 and L418 and L496 and elsewhere — The term ‘interior’ is here used as a synonym for ‘englacial’. This is arguably ambiguous with the frequent use of ‘interior’ to describe the central region of the ice sheet (including the surface) away from the margin. The use of this term here also neglects the important effects of surface water reaching the bed.

L335 - These maximum volumes seem quite low. How do they compare with the literature? Are there any reasons why the volumes are low? Is it due to the depth limitation of the techniques used?

L411 — The two modelling studies cited here were not the first to suggest this. Consider citing other studies and/or adding an e.g. before the citation.

L418 — Why is this? Why does more water drain through small lakes than larger ones? Can it be explained by the greater number of small lakes, or is it a result of drainage basin size, or is it a result of a bias in the technique? Some discussion is warranted.

L503 and other occurrences of this pair of citations — these modelling studies may not be considered as the first or most appropriate for the establishment of drainage through moulins, which has been known for a long time (and was not determined by modelling). Consider listing earlier citations and/or giving an e.g. first to show that these citations are selected examples. Some of the sentences preceding these citations (including that on L503) may not even need a citation.

L511 — ‘runoff’ not ‘meltwater’.

L512 — ‘*the moulins*’.

Fig. 1 — Consider labelling some glaciers to aid the reader. Also, consider showing

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enlarged images of each of the two example lakes as subplots to demonstrate the capability and resolution of the imagery.

Fig. 3 — at this scale, whether the markers are circles or squares is redundant.

Fig. 10 — consider a red/blue transparency with purple overlap (or any other primary colour pair).

### Technical corrections

L20 — ‘identify’ is the wrong word here, suggest ‘estimate’

L25 — strictly speaking its not via *all* moulins but only those identified within ‘small’ and ‘large’ lakes.

L95 — define MSI.

L112 — the last sentence of this aim isn’t written as an aim and there is change of tense from the adjacent sentences.

L114 — define ‘rapidly’ here.

L208 and other occurrences — within the text write out ‘Section’ or ‘Figure’ in full.

L258 — citation should be to Doyle et al. (2013).

L297 — replace ‘more poorly’ with ‘worse’.

L330 — what does the number in brackets refer to?

L376 — Suggest: ‘when the pair of images were only separated by a day’.

L391 — “Large lakes are *defined as* . . . ”

L396 and L405 and L428 — Write out ‘Figure’ within text.

L434 — consider rearranging to avoid double brackets.

L465 — ‘entirely’ is not necessary here.

L490 — ‘offset’ is the wrong word here.

Table 2 — Consistency with precision. Specifically, minimum drainage volume should be given as 0.020 for large lakes for Sentinel 2 (not 0.02). The same applies to the same for Landsat 8.

Section S1 — delete ‘the value of’ in the first sentence.

Table S2 — Write out ‘The asterisk denotes ...’

Fig. S1 — Overlap in X-axis label superscript. Also, consider inserting ‘therefore’ in ‘... between the two sets of lake areas is *therefore* remarkably small’.

### **Additional references (not already cited in the manuscript)**

Christoffersen, P., Bougamont, M., Hubbard, A., Doyle, S.H., Grigsby, S. & Pettersson, P. 2018. Cascading lake drainage on the Greenland ice sheet triggered by tensile shock and fracture, *Nature Comms.*, 9 1064.

Cooley, S. W., & Christoffersen, P. (2017). Observation bias correction reveals more rapidly draining lakes on the Greenland Ice Sheet. *Journal of Geophysical Research: Earth Surface*, 122, 1867—1881

Joughin, I., Das, S., Flowers, G., Behn, M., Alley, R., King, M., Smith, B., Bamber, J., van den Broeke, M. & van Angelen, J. 2013. Influence of ice-sheet geometry and supraglacial lakes on seasonal ice-flow variability, *The Cryosphere*, 7, 1185-1192.

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