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The Cryosphere Discussions

Interactive comment on “*Brief Communication* “Expansion of meltwater lakes on the Greenland ice sheet”” *by* I. M. Howat et al.

Anonymous Referee #1

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Overview: The notion that there is no physical limit on the recent upwards migration of supraglacial lakes to higher elevations in Greenland is important. The authors have assembled a dataset to demonstrate this fairly convincingly. The manuscript would benefit from improving the discussion of their algorithm sensitivity and other sources of uncertainty. This would more unequivocally demonstrate their hypothesis is not influenced by biases, such as a decrease in their effective threshold size over time due to a growth in lake area over time.

P4448 L13: An order of magnitude guess of the total number of supraglacial lakes in Greenland is probably well beyond 10ˆ4 and closer to 10ˆ5, rather than "thousands".

P4448 L15: It is not immediately apparent to me the elevation "where seasonal meltwater runoff is less than annual snow accumulation" on the ice sheet. Perhaps you

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could use the zone facie vocabulary of Benson (1961)? It almost sounds like you are describing the equilibrium line, which is of course far below the upper elevation limit of lakes in Greenland.

P4448 L20: If I recall correctly, Zwally et al. (2002) do not really discuss the warming effect of meltwater on velocity, perhaps you need an additional citation.

P4449 L4: You are blending the meltwater mechanisms of increased deformational and basal sliding velocities together. Meltwater increases deformational velocity by warming ice and lowering "effective viscosity" (not a true "viscosity" because ice has a non-linear fluid rheology). Meltwater increases basal sliding velocity by reducing effective basal pressure, by "floating" part of the overburden pressure of the ice, and hence reducing basal friction. You need to clearly articulate that these are two different processes.

P4449 L7: So you are indeed calling the "elevation at which meltwater runoff equals the snow accumulation" the equilibrium line altitude (ELA)? At first glance that almost sounds correct, but upon reflection I suppose there are the additional surface mass balance (SMB) mass loss sinks of evaporation and sublimation that need to be considered. So technically, the ELA would be equivalent to the location where all mass loss (runoff, sublimation, evaporation) is equivalent to accumulation on an annual basis. Also, how does this square with your usage of the phrase to denote the upper elevation limit?

P4449 L10: Actually, the Liang et al. (2012) population of lakes in West Greenland that was shown to shift to higher elevations in warmer years extended quite high into the wet snow (possibly percolation?) zone. They actually found that lakes formed every year in the bare ice zone, so there was no significant relation between temperature and the lowest fraction of their population's elevation.

P4449 L15: How many images total?

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P4450 L6: Perhaps it would be more accurate to say "similar to the methodology of..." as you are introducing a novel aspect of inverting pixel values and then applying an exponential stretch. It is not immediately clear to me what this preconditioning does to the sensitivity of an algorithm that depends on the slope of a distribution tail. Presumably the algorithm is already quite sensitive to tail slope, and applying an exponential stretch might make it more so? In any case, it might be good to state what the inversion aims to accomplish, and what the exponential stretch aims to accomplish.

P4450 L15: When you state "this area threshold" it is not explicitly clear what parameter you are talking about. Presumably it's the 0.1 kmˆ2 state in the preceding sentence? In any case, I think you need to demonstrate to the reader that the uncertainty in area returned by your algorithm is significantly less than this arbitrarily chosen threshold. I suppose that means quantifying the uncertainty associated with identifying lake pictures from the histogram tail. And maybe it would be good to state the absolute total elevation sensitivity of your algorithm and include it as vertical error bars in your Figure 2?

P4450 L27: "In East Greenland and above Humboldt Glacier (area I) in the far northwest, however, lake elevations have not kept pace with the rise in the ELA, suggesting a physical limit." – Looking at Figure 2, I would disagree with this statement. It appears that all the time series from East Greenland do exhibit positive slopes post-2000, which supports the notion that maximum lake elevation is increasing with ELA. Study region I does seem to have a bit of a post-2005 "plateau", but that is hardly conclusive. Given that you have 11 of 12 study areas exhibiting broad trends over the observational period, I think your big finding is that there appears to be no upper limit on lake elevation across most of the ice sheet. To make a statistically robust claim, however, I think you would need to perform a regression between maximum lake elevation and ELA in each study area. Then you could say maximum lake elevation is related to ELA with a chosen degree of confidence.

Other Thoughts: Is RACMO2 known to over-estimate ELA? In Figure 2 the maximum

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lake elevations appear to be very close to the modelled ELA, when in fact anyone who has worked in Greenland knows that lakes are found well above the ELA. The pre-2000 ELA of 1650 m shown in Figure 2 for Southwest Greenland seems exceptionally high. I think a bias in RACMO2 output is fine, as long as it is acknowledged, since the task at hand is comparing trends in observed maximum lake elevation to trends in modelled ELA.

Presumably there is some intra-annual variability in maximum lake elevation at each site. For example, is the highest lake in an early June image at the same elevation as the highest lake in a late August image? Please assess and discuss this source of uncertainty in maximum lake elevation.

Another sticky thought: Is there some way to control for (presumably?) more lake pixels during warmer years? Given that you are using a maximum area threshold (0.1 kmˆ2), I would imagine that the apparent maximum elevation is higher in a year with say 100 kmˆ2 of lake pixels, than a year with say 50 kmˆ2 lake pixels, simply because 0.1 kmˆ2 represents a smaller fraction of the former case. Would perhaps using a proportional threshold (i.e. 1 % of lake pixels) address an underlying increasing trend in the absolute number of lake pixels?

Figures: 1 – "above" in caption. Should their perhaps be dates of image acquisition shown? If the aim is to show an upward progression in lake extent, it would probably help if the images were more evenly spaced in time, rather than having two pairs of years together.

2 – If the ELA is a five-year average, should the average be "lagged", rather than (presumably?) "centered" on each year? For example, the year 2000 maximum lake elevation is more likely to better reflect the 1996-2000 mean ELA, rather than the 1998-2002 mean ELA (something to keep in mind if you do indeed do regressions, but then the smoothing affects the degrees of freedom).

Interactive comment on The Cryosphere Discuss., 6, 4447, 2012.