

Review of “Supraglacial lake bathymetry from high-resolution airborne imagery using stereophotogrammetry and structure from motion” by Studinger, Wright and Alexandrov submitted to *The Cryosphere*

In this study, the authors use three different techniques to determine the bathymetry of two supraglacial lakes on the western margin of the Greenland Ice Sheet. They use two optical methods, including structure-from-motion (SFM, processed using Agisoft) and stereophotogrammetry (processed with the NASA Ames Stereo Pipeline). The resulting DEMs from these methods are compared with DEMs generated from LiDAR. The LiDAR is a green laser, operating at a frequency of 532 nm, thus allowing for penetration through water with reflection off the ice-water interface, and thereby allowing for a unique opportunity to compare optically-derived bathymetry with lidar-derived bathymetry. To generate solutions for the optical techniques, the authors implement a series of previously developed processing steps to correct for light refraction through lake water. The authors also use a series of pre-processing steps to mask out glacier and lake ice cover.

By taking advantage of the high accuracy GPS timing of the optical acquisitions systems, along with a rigorous calibration of internal and external camera calibrations generated by the SFM algorithm, the authors are able to match the lidar-derived bathymetry with high accuracy using both optical techniques. Furthermore, the authors show that both optical techniques can generate higher spatial resolution in bathymetry than LiDAR. The stereophotogrammetry appears to generate more noisy DEMs than the SFM technique, but the authors suggest that the stereophotogrammetry is more capable of detecting small-scale surface roughness. The limitations of the optical techniques appear to be the caustics (noise generated from surface waves), and the challenge in developing a pipeline to automate the process. However, in the process of analyzing the LiDAR returns, the authors also find a limitation in the LiDAR, in that green LiDAR waves can penetrate below the ice-water interface, leading to a bias in elevation.

In my comments below I address a few minor changes and suggest a few brief discussion points to elaborate on. Otherwise, I would summarize this work as a meaningful contribution in its ability to bring together a series of previously developed tools to provide a useful comparison of three different techniques to map the bathymetry of supraglacial lakes.

Minor comments

In my line-specific comments I suggest a few places where discussion points can be moved to introduction and to methods, so a minor restructuring of the text could improve the manuscript. Two other things that could potentially add minor improvements to the manuscript are:

- 1) A discussion of the relevance of the error. For example, the authors show the absolute error in the difference of DEM depths, but how much does that correspond to an error in the measured hypsometry or lake volume for the two lakes that investigated here? The authors state that there are large errors associated with the caustics, but how much of an error in volume does this correspond to for the given lake?

- 2) At what depth do the authors think that this technique will no longer work for conditions on the surface of the GRIS?

Line-specific comments

Line 43: While melt affects mass balance, the fact that meltwater exceeds basal melt does not “therefore” indicate that meltwater affects stability. The term stability also usually implies a dynamic ice-flow related process, such as meltwater affecting basal sliding.

Line 44: instead of “The lakes”, generally describe the characteristics of the lakes that you’re investigating, like, “We study two lakes along the western margin of GRIS. A large portion of supraglacial lakes along the western portion of GRIS are situated between X and X m. a.s.l., are within X km of the terminus, and have a characteristics size of roughly 100m”.

Line 49: “Crystal clear” is not a scientific term (the milky ice is made of crystals)

Line 90: Describe how the topobathymetric data was acquired and generated....”with topobathymetric data <acquired from a 532nm LiDAR scanner> (ref)”.

Line 95: describe how it affected the flow. I think that it’s important to state that, not only is the volume of the supraglacial basin important, but the hypsometry also matters for controlling pressure vs elevation as the lake drains (if it drains).

Line 118: consider changing “ice surface elevation and change and determining ice thickness” to “ice surface elevation, elevation change and ice thickness”.

Line 120: change to “ice-penetrating radar” penetration depth.

Line 123: Figure X?

Line 124: describe these conditions....did they favour melt, refreezing, etc.

Line 125: in this section you describe general limitations to SFM, but you don’t explicitly describe why the data collections methods lead to these limitations. For example, was there only one flight direction, and does OIB sensors provide the accurate “position and attitude” needed?

Line 180: This line is repeated verbatim from line 22

Line 220: “For situations like this”. Not clear on whether there is manual/human intervention required to distinguish this feature or whether this can be automated

Line 220: be more specific about “connected pixels”. What pixels are being connected and how?

Line 225: Is there a metric here for “performing well”?

Line 231: in this paragraph you use gray scale and grayscale. Choose one and be consistent (preferably grayscale). At line 282 you use gray-scale, though I think you’re referring to luminescence on the green channel

Line 299: Might be helpful to briefly describe the alignment process used in pc_align, since it features in the analysis here.

In this section it might also be good to note how many different image pairs exist for each scene and if image pairs overlap in certain regions, and if so, how the DEMs are averaged.

It might also be good to provide a more thorough description of how the DEMs from the various datasets are gridded and averaged to provide gridded differences between the various products.

Line 384: remove “though” if “however” is also used.

Figure 7. list the frequency of the lidar

Figure 8: make it more clear to the reader that the peaks shown by the red line are the same returns as each other (both from tarmac), and are just spliced and superimposed under the returns shown in blue.

Line 405: Figure X?

Line 420: I was looking for this information in the methods section in section 3.4. perhaps these methods can be moved to 3.4?

Line 431: hill shading -> hillshading (since it's applied to the DEM and not referring to the natural process)

Line 434: the subtle <spatial> changes

Line 434: unclear on what is meant by “resolves”. The roughness in the ASP method might be more noise rather than a true representation of the surface roughness

Line 437: is this the S.D./difference between the average of the two optical vs lidar methods, or the average difference of the three different techniques?

Line 438: From my interpretation, the elevation pattern in 6e and 6f do not appear to be random over the multiple ice layers, and appear to have some structure in the difference.

Line 450: Are differences distributed symmetrically for either of the optical methods or is there a systematic bias across the scene?

Line 458: the use of the shoreline from plain DEM as water surface elevation (Dietrich) could be explained in the methods

Line 459: Put the (a) and (b) lettering in front of the thing that you are describing, unless referring to the figure, in which case add the figure number there too

Line 525: within the (what?) area

Line 526/525: what are the mean difference values?

Line 573: as a possible suggestion, it could be useful for the authors to suggest what other missions could yield data amenable to this processing workflow.

Line 575: do we really need data with better resolution than lidar for process-based studies, or is it more simply that we can derive bathymetry from optical without lidar?

Line 577: you use topobathymetric throughout, here you use topo bathymetry.

Line 590: This seems like good material for the introduction, and based on a brief description of the limitations of these alternative methods, this section could be used to motivate the methods that you use here.

Line 602: we are not aware <that> the depth...

Line 612: I'm a bit confused. Wouldn't you still need SFM or some other technique to derive bathymetry even if the water elevations are the same across lakes?

Line 613: Discuss these limitations, why is this process difficult to automate? What human intervention is required?

Line 646: You have shown that well-defined camera parameters can yield a good model, but you have not shown that the model is a good substitute for having orthogonal flight lines because that data does not exist for your scenes. Consider alternate wording.