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Estimating Supraglacial Melt Lake Volume Changes in West Central Greenland Using Multiple Remote Sensing Methods

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Abstract

- The Greenland Ice Sheet (GrIS) is losing ice mass as the climate warms.
- Supraglacial melt lakes (SGLs), which are present in the ablation (melt) zone of the GrIS are found to be responsive - and reinforce - changes in glaciological and climatological dynamics.
- Developing a spatiotemporal model to monitor lake volume change throughout the melt season (late-April through September) can enhance our understanding of subsequent GrIS changes.

Research Questions

Q1: Can we pair Landsat satellite imagery with high resolution digital elevation model data (DEMs) to estimate melt lake depth (per satellite pixel) and derive melt lake volume during the 2021 melt season?

Q2: Coupling DEM data with average daily temperature measurements; can we simulate the amount of melt occurring within an SGL watershed?

Q3: How could the data from Q1 and Q2 complement our current understanding of glaciological and climatological dynamics of the GrIS?

Study Area

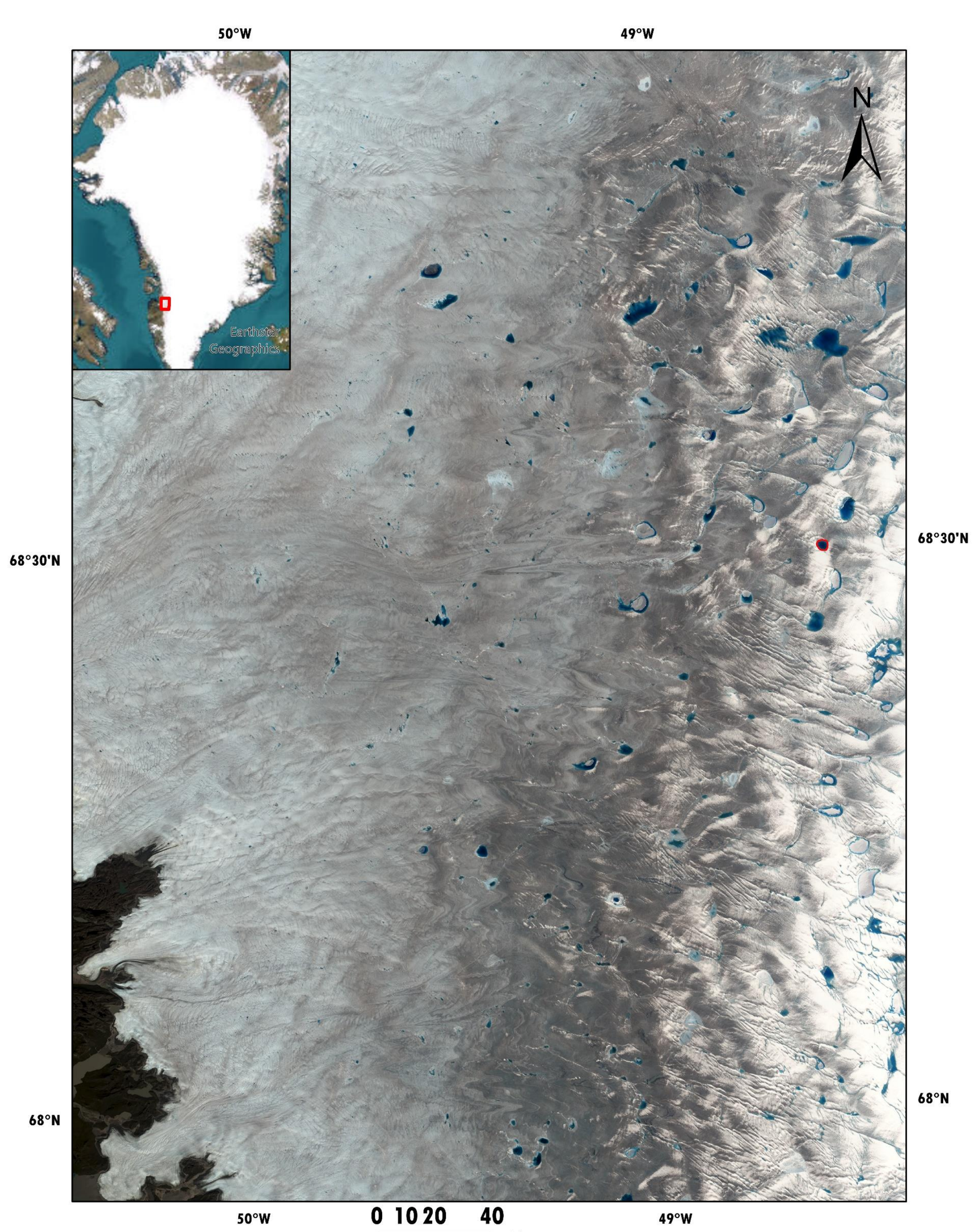

Figure 1: Composite image study area in West Greenland. Imagery acquired from Landsat 8 on 31 July 2021 Path: 8 Row: 12. Using bands 4, 3, and 2 of Landsat 8 we can generate a true color composite displaying information in the red, green, and blue portions of the EM spectrum.

8 July 2021

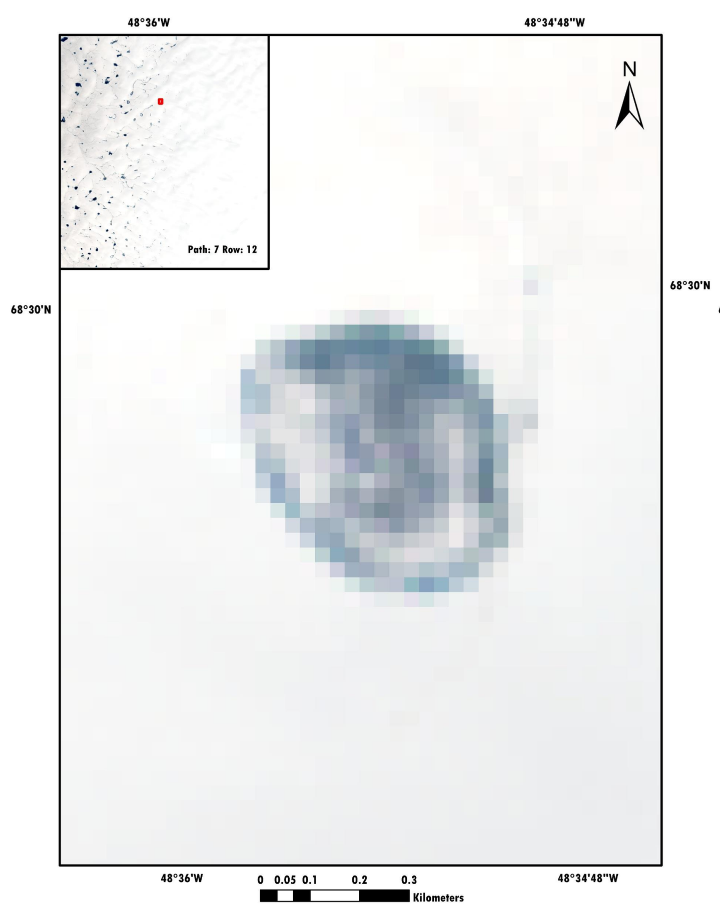

Figure 2: Composite image of study lake in West Greenland. Imagery acquired from Landsat 8 on 8 July 2021 Path: 7 Row: 12.

15 July 2021

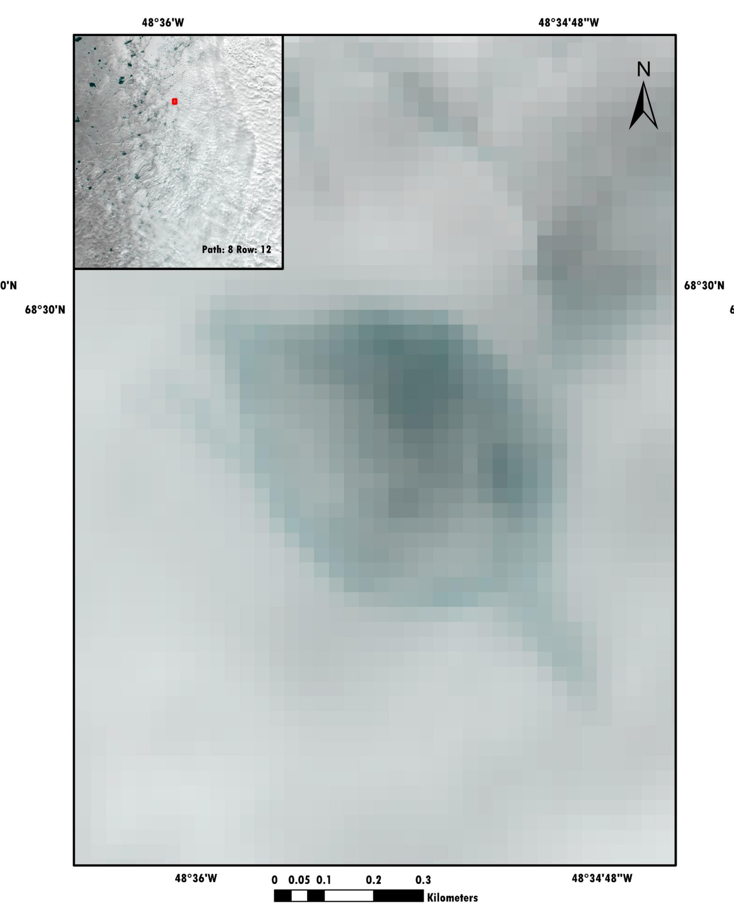

Figure 3: Composite image of study lake in West Greenland. Imagery acquired from Landsat 8 on 15 July 2021 Path: 8 Row: 12.

31 July 2021

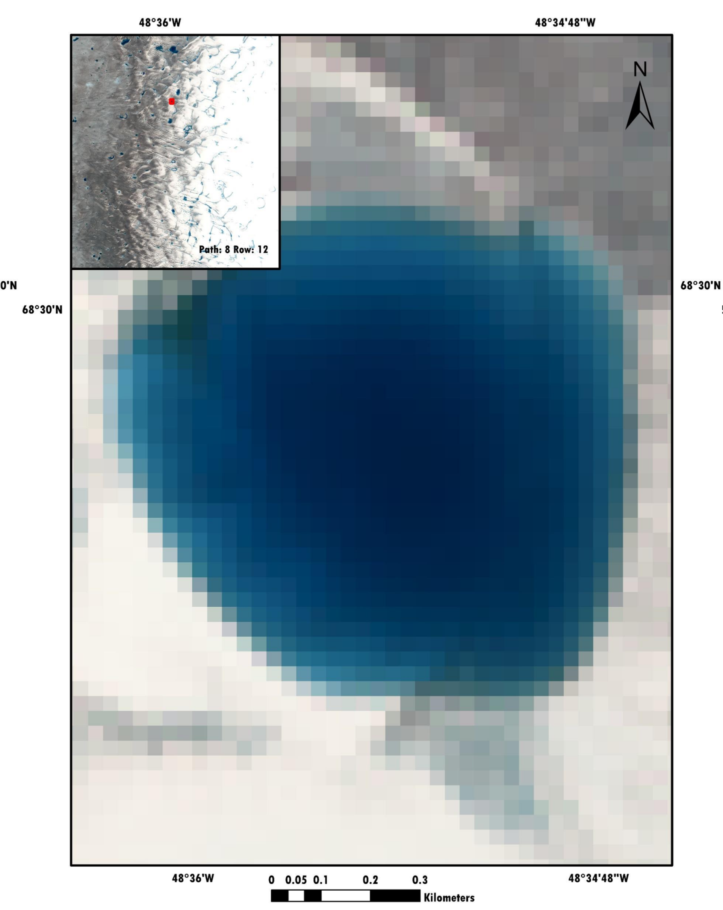

Figure 4: Composite image of study lake in West Greenland. Imagery acquired from Landsat 8 on 31 July 2021 Path: 8 Row: 12.

1 September 2021

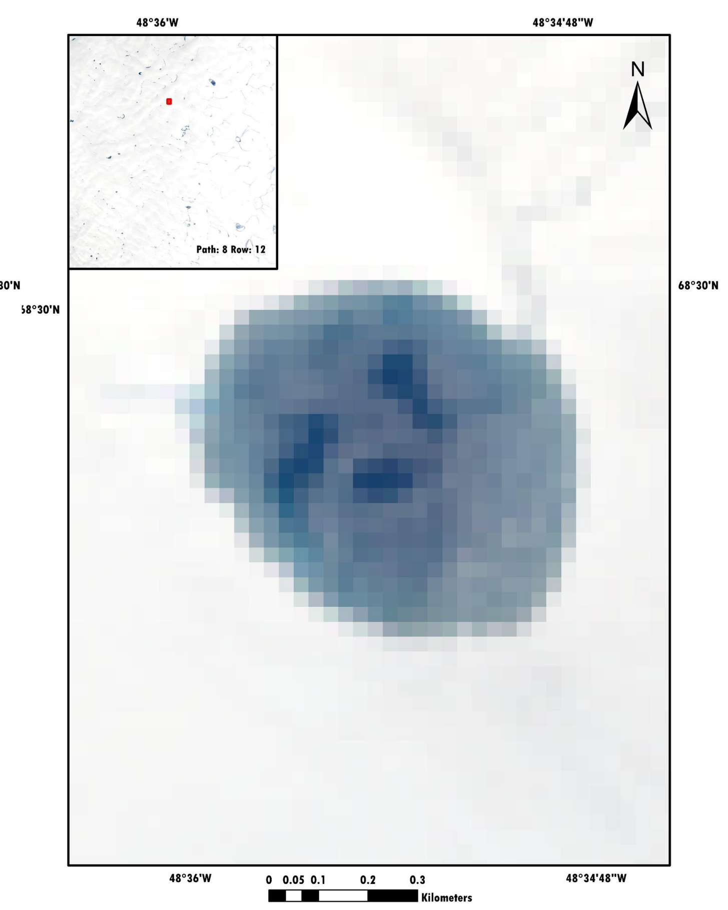

Figure 5: Composite image of study lake in West Greenland. Imagery acquired from Landsat 8 on 1 September 2021 Path: 8 Row: 12.

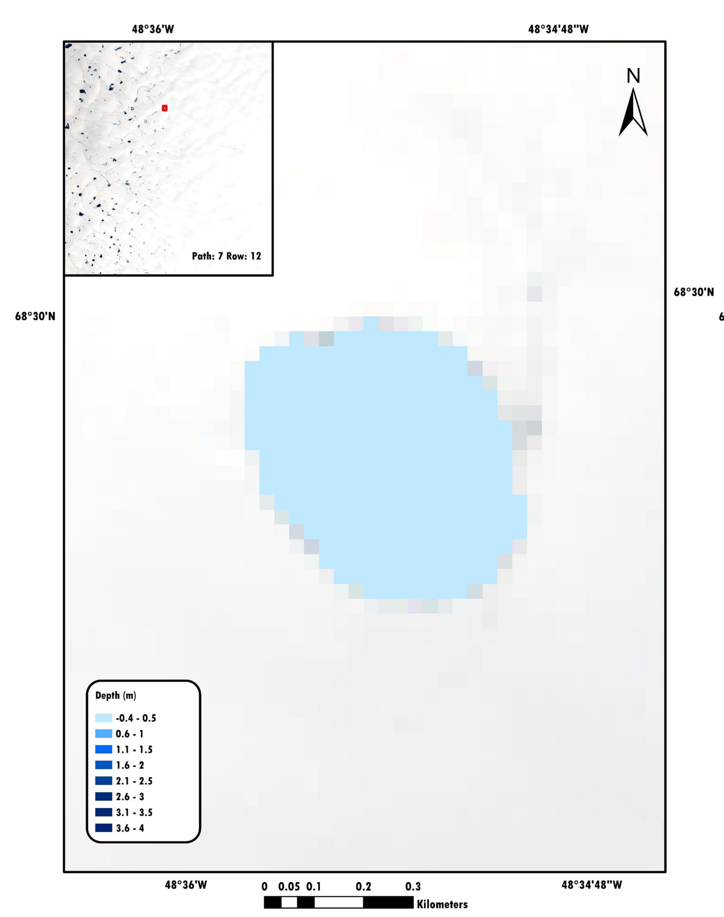

Figure 6: Result from depth reflectance analysis for study lake at first time interval. 8 July 2021 Path: 7 Row: 12. Little to no clear delineation between lake center and edges.

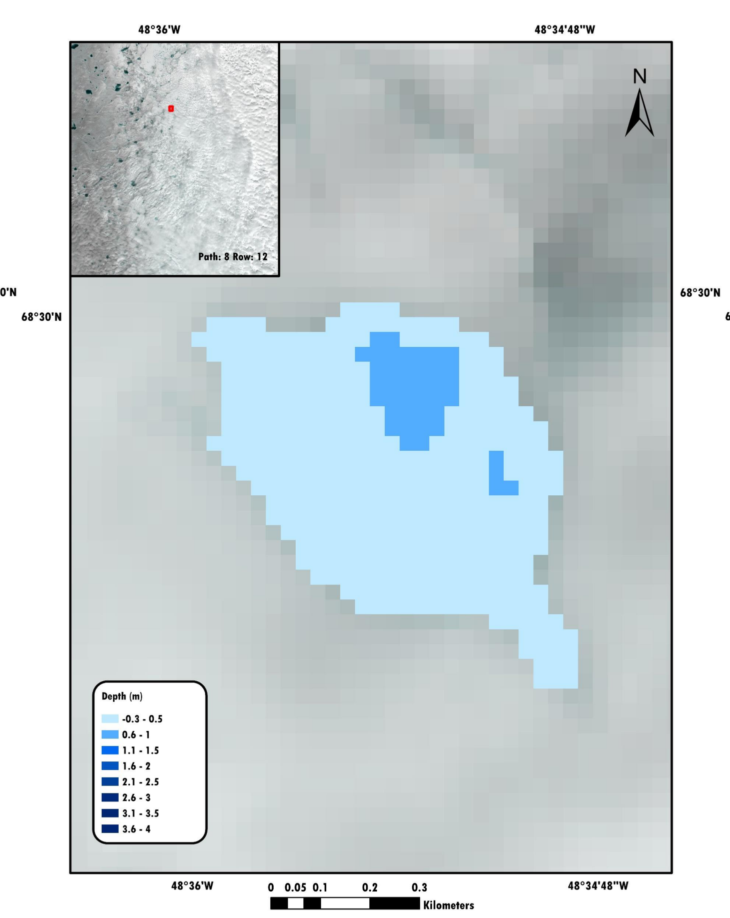

Figure 7: Result from depth reflectance analysis for study lake at second time interval. 15 July 2021 Path: 8 Row: 12. Moderate delineation of depth values within the lake.

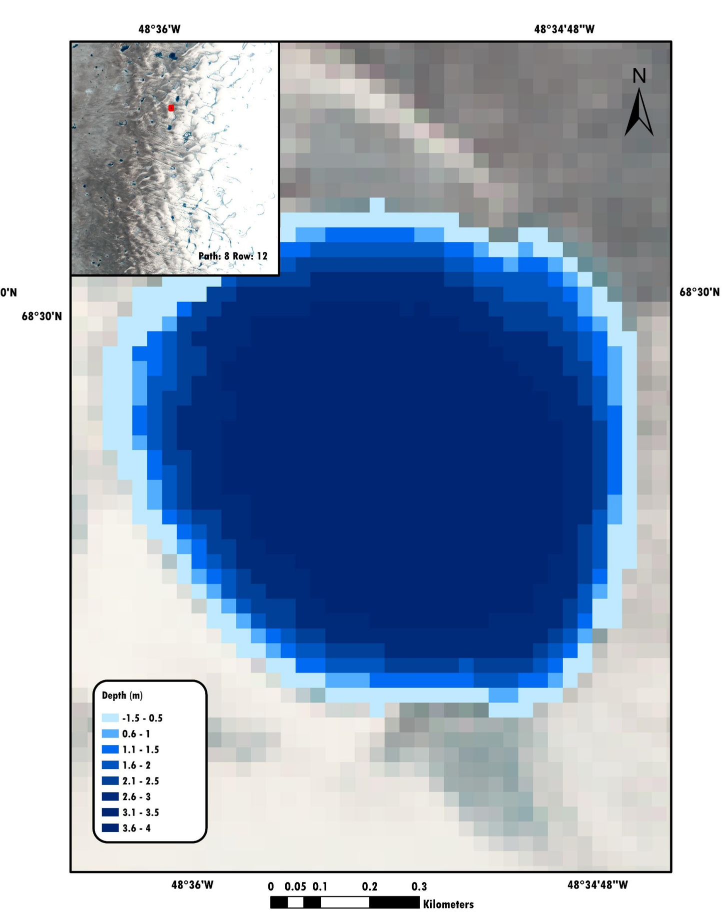

Figure 8: Result from depth reflectance analysis for study lake at third time interval. 31 July 2021 Path: 8 Row: 12. Clear distinction between deep lake center vs shallow edges.

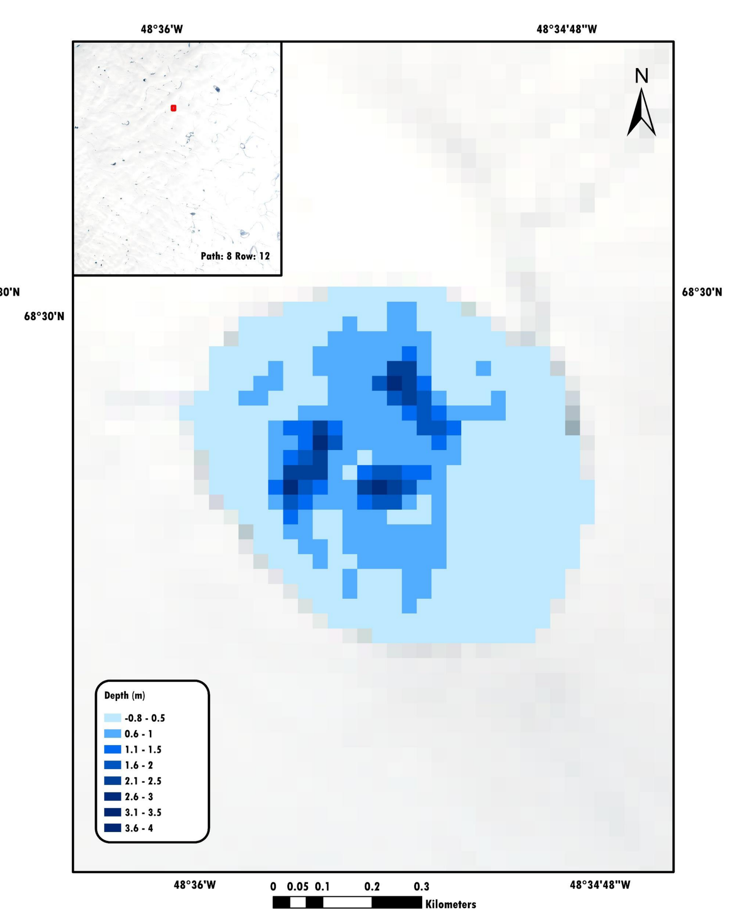

Figure 9: Result from depth reflectance analysis for study lake at fourth time interval. 1 September 2021 Path: 8 Row: 12. Lake begins to decrease in size and depth as the melting season comes to an end.

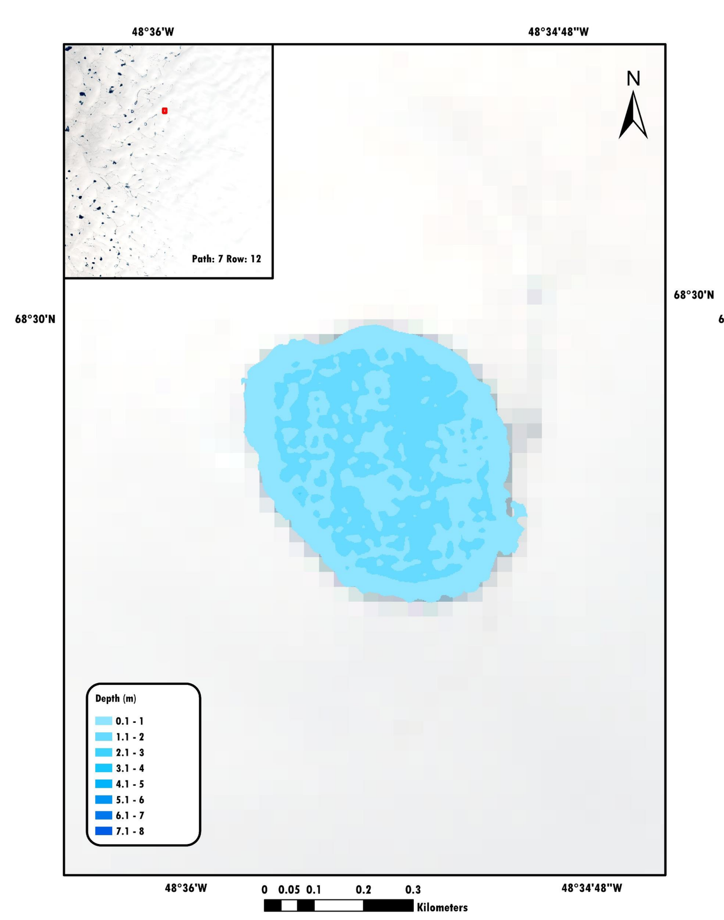

Figure 10: Result from DEM perimeter tracing for study lake at first time interval. 15 July 2021 Path: 7 Row: 12. Distinction between shallow and deep waters. Some anomalies present where could be debris or floating ice.

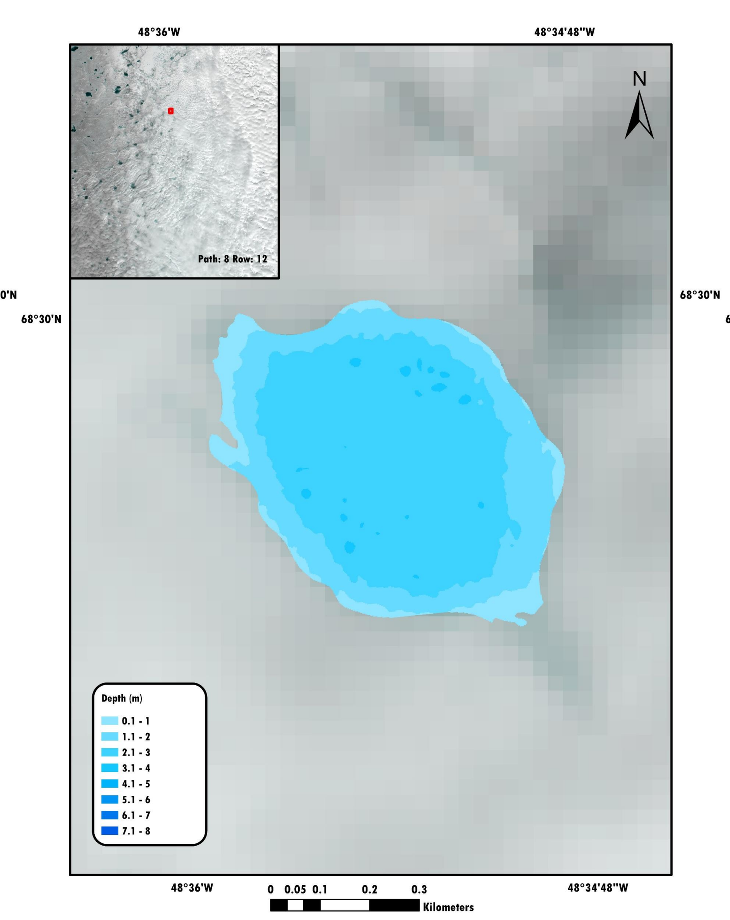

Figure 12: Result from DEM perimeter tracing for study lake at second time interval. 15 July 2021 Path: 8 Row: 12. Lake begins to increase in size and depth increases in the center.

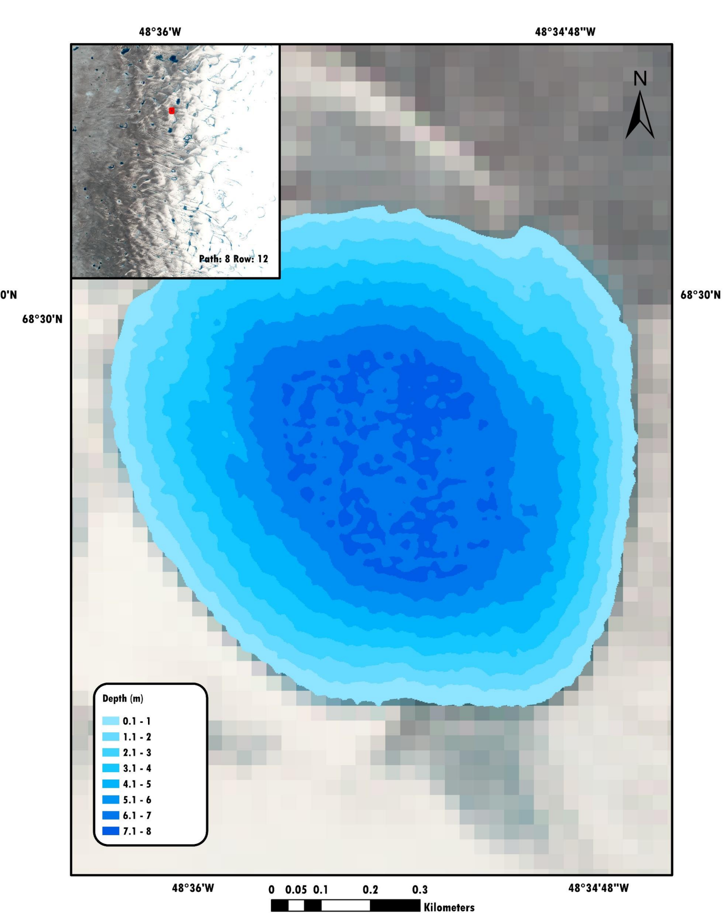

Figure 12: Result from DEM perimeter tracing for study lake at third time interval. 31 July 2021 Path: 8 Row: 12. Very clear distinction between the lake's deeper centermost parts from shallow outer edges.

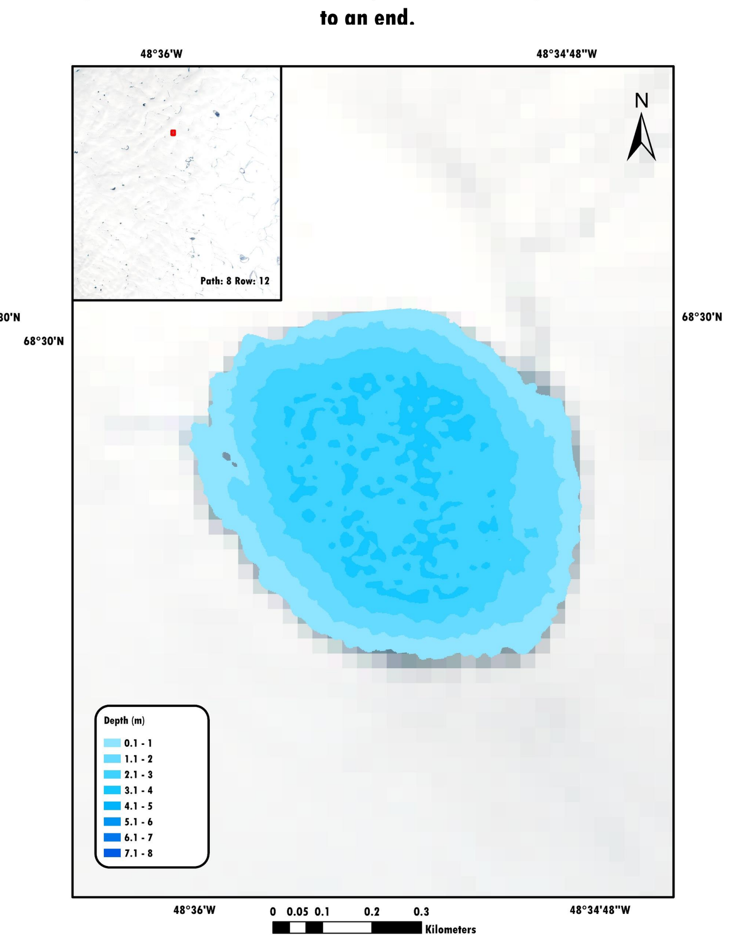

Figure 13: Result from DEM perimeter tracing for study lake at fourth time interval. 1 September 2021 Path: 8 Row: 12. Lake decreases in size and depth but maintains clear delineation from deep center vs shallow edges.

Methods

1. Perimeter tracing of Digital Elevation Model (DEM)
2. Depth−Reflectance[2]:

$$EQ\ 1{:}\ Z = \frac{[Ln(A_{d} - R_{\infty}) - Ln(R_{LAKE} - R_{\infty})]}{g}$$

3. Application of hydrologic functions in ArcGIS Pro to DEM [1]
4. Positive Degree Day Factor[1]:

$$EQ\ 2{:}\ \sum_{i=1}^{n} M = DDF * \sum_{i=1}^{n} (T^{+} * \Delta T)$$

Results

- Obtained depth values following perimeter tracing (Figures 10-13).
- Obtained depth values for each time interval following Equation 1 (Figures 6-9).
- Obtained melt amounts following Equation 2.
- Derived lake volumes following depth results for each method.

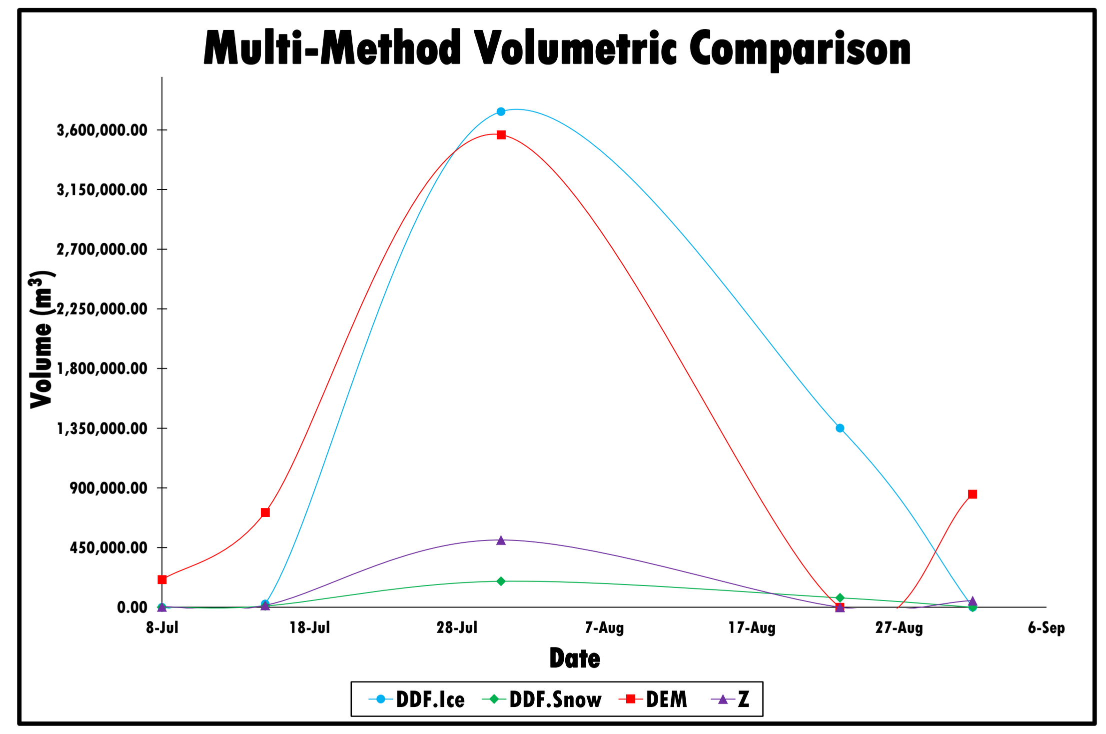

Figure 14: Results comparing DDF simulation of volumetric melt produced within a watershed for ice vs snow. Moreover, lake volume calculations at each time interval for the two methods were included to compare accuracy with DDF simulations.

Conclusions

- Initial results suggest DEM data generates more accurate depth to volume calculations compared to Landsat data.
- Additionally, results from Equation 2 are more aligned with depth calculations derived from perimeter tracing compared to depth reflectance method (Equation 1).
- Going forward we could apply the same methods to more lakes on the GrIS.

References

1. Hock, R. (2003). Temperature index melt modelling in mountain areas. *Journal of Hydrology, 282*(1), 104–115. https://doi.org/10.1016/S0022-1694(03)00257-9

2. Pope, A., Scambos, T. A., Moussavi, M., Tedesco, M., Willis, M., Shean, D., & Grigsby, S. (2016). Estimating supraglacial lake depth in West Greenland using Landsat 8 and comparison with other multispectral methods. *The Cryosphere, 10*(1), 15–27. https://doi.org/10.5194/tc-10-15-2016