Supraglacial lake bathymetry automatically derived from ICESat-2 constraining lake depth estimates from multi-source satellite imagery

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I'm in a hurry, what did you do?

Why?

Where?

Using what data?

ICESat-2

Imagery

Watta? (or simply: How?)

What did we find?

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(external link)

But...what does Watta actually stand for?

I'm in a hurry, what did you do?

Abstract

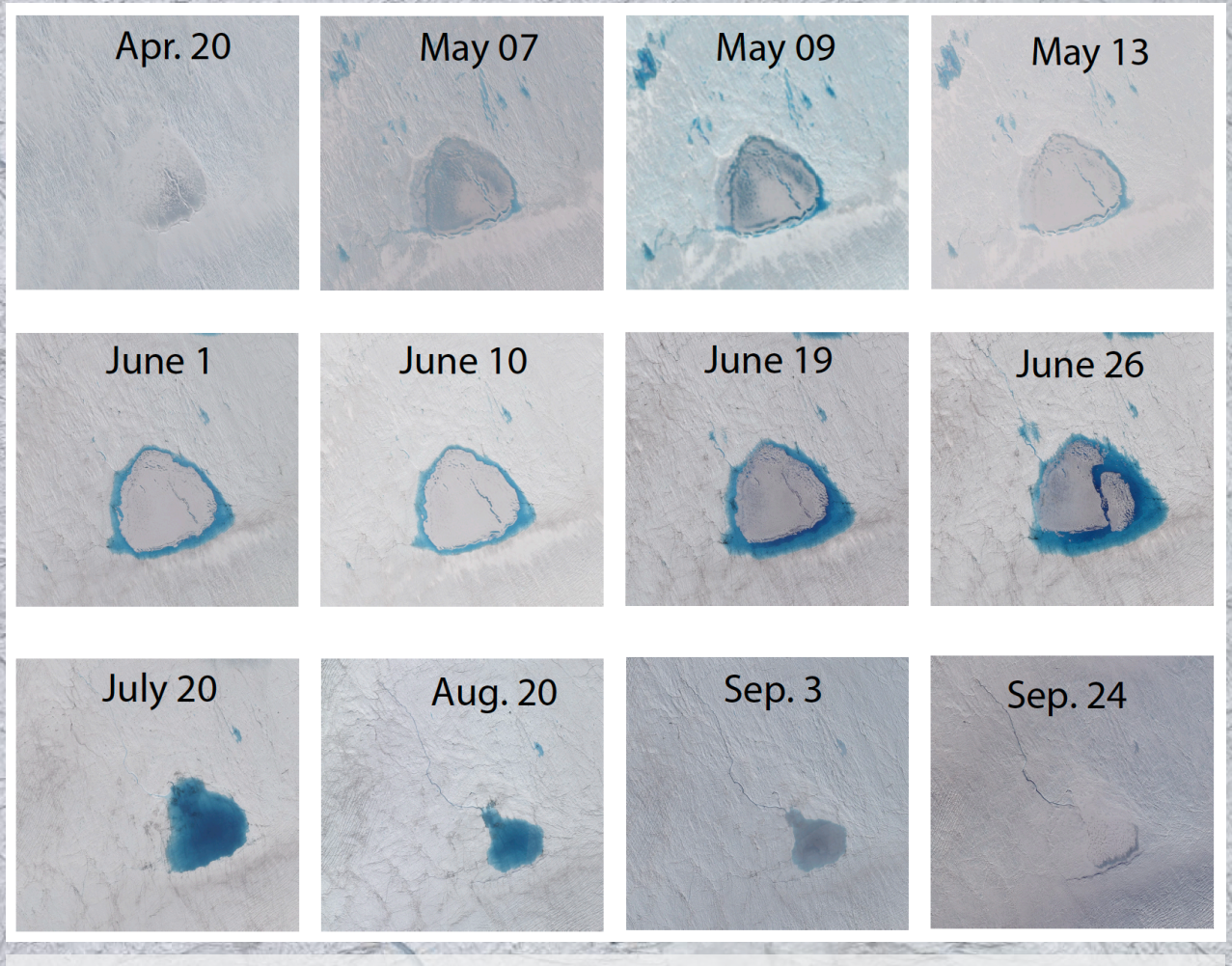
We introduce an algorithm (Watta), which automatically calculates supraglacial lake bathymmetry and potential ice layers along tracks of the ICESat-2 laser altimeter. Watta uses photon heights estimated by the ICESat-2 ATL03 product and extracts supraglacial lake surface, bottom, corrected depth and (sub)surface ice cover in addition to producing surface heights at the native resolution of the ATL03 photon cloud. These measurements are used to constrain empirical estimates of lake depth from satellite imagery, which were thus far dependent on sparse sets of in-situ measurements for calibration. Imagery sources include Landsat OLI, Sentinel-2 and high-resolution Planet Labs PlanetScope and SkySat data, used here for the first time to calculate supraglacial lake depths.

The Watta algorithm was developed and tested using a set of 46 lakes near Sermeq Kujalleq (Jakobshavn) glacier in Western Greenland, and we use multiple imagery sources to assess the use of the red vs green band to extrapolate depths along a profile to full lake volumes. We use Watta-derived estimates in conjunction with high-resolution imagery from both satellite-based sources (tasked over the season) and nearly-simultaneous Operation IceBridge CAMBOT imagery (on a single airborne flight) for a focused study of the drainage of a single lake over the 2019 melt season. Our results suggest that the use of multiple imagery sources (both publicly-available and commercial) in combination with altimetry-based depths, can move towards capturing the evolution of supraglacial hydrology at improved spatial and temporal scales.

Too long; didn't read

There are lakes on ice sheets of Greenland and Antarctica. We used a space laser and space cameras to figure out how much water they store.

Why?

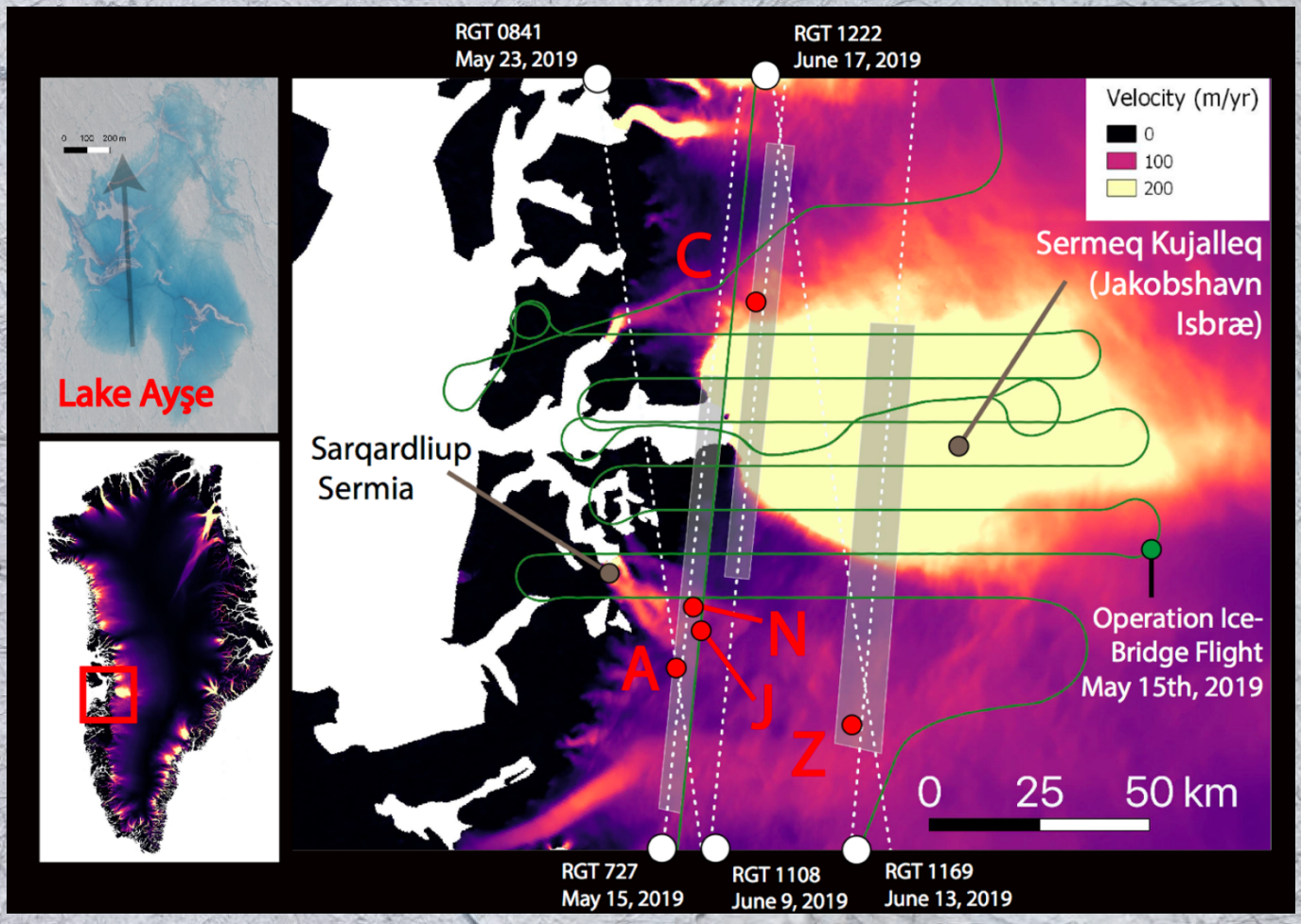


Supraglacial lakes form when meltwater runoff collects in local topographic lows, as illustrated over Lake Niels from April 20th, 2019 through Sep 24, 2019 above. Meltwater production has increased rapidly on the Greenland Ice Sheet (van den Broeke, 2016). As a result, supraglacial lakes are now a common feature on large parts of the ice sheets, have become more extensive and have advanced inland toward higher elevations in the past decades (Gledhill and Williamson, 2018; Leeson, 2015; Howat, 2013).

These meltwater lakes and streams are a key component of the hydrological system of both ice sheets. Meltwater pathways can include surface flow into lakes and then streams, leading to direct loss to the bed from lake drainage or the sudden termination of a stream into a moulin, or near-surface flow where ice slabs can limit vertical motion (MacFerrin, 2019).

Supraglacial lakes have also been observed around the margin of the Antarctic Ice Sheet up to high elevations (Stokes, 2019) and are likely to become more prevalent on firn-depleted ice shelves in future warming scenarios, which could potentially trigger their collapse and consequently lead to accelerated sea level rise (Lai, 2020)

Where?



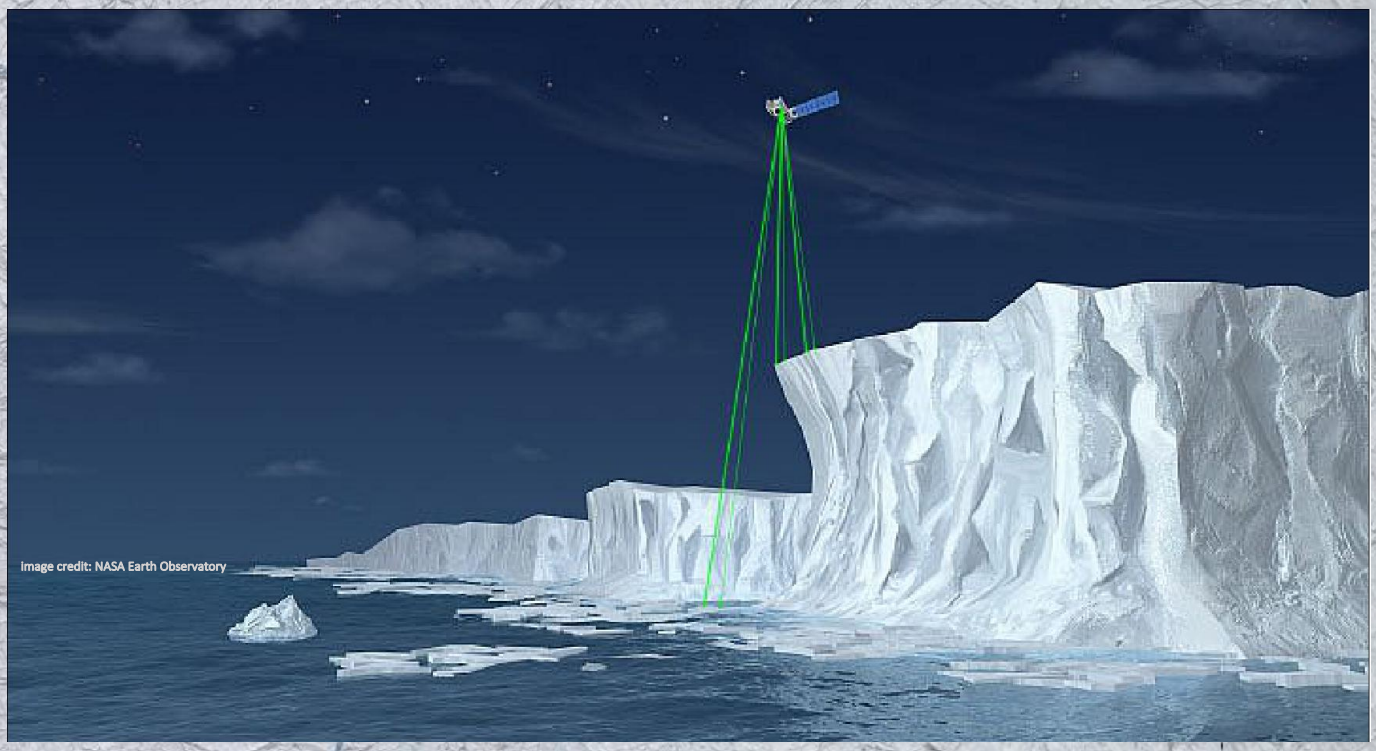
We tested and refined our method using **satellite imagery** and **ICESat-2** data along the flowline of **Sermeq Kujalleq** (Jakobshavn Isbræ), one of the fastest-moving glaciers in Greenland, as well as the slower-flowing Sarqardliup Sermia.

High-resolution Planet SkySat imagery (grey boxes) were acquired along ICESat-2 tracks (dashed white lines), capturing lake depths at various stages of lake development during the unusually intense **2019 melt season**.

The area was also mapped during several **NASA Operation IceBridge (OIB)** flights at the beginning and end of the summer (green lines), providing us with high resolution OIB CAMBOT imagery.

In our study, we focused on **five lakes** indicated in red in the figure above:
C - Lake Cecily, A - Lake Ayşe, J - Lake Julian, N - Lake Niels, Z - Lake Zadie

Using what data?

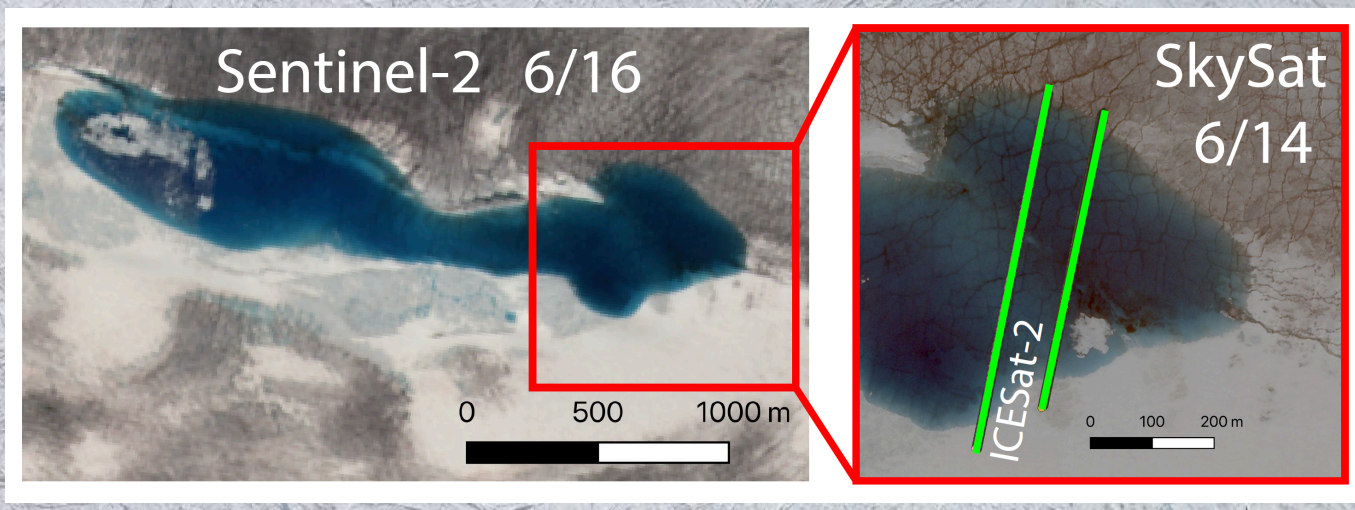


The polar orbiting **ICESat-2** satellite was launched in September, 2018 to continue the mission begun by ICESat (2003-2009) to provide ice sheet mass balance estimates at an unprecedented level.

Our *Watta* method uses **individual photon heights** measured by ICESat-2's ATLAS instrument (ATL03 data, Neumann et al., 2019). ATLAS is a photon-counting 532 nm laser altimeter aboard ICESat-2, split into 6 beams which are divided into 3 pairs (separated by 3.3 km), where beams within each pair are separated by 90m. Each beam pair consists of a strong and weak beam, with the strong beam using 0.6-3.9 signal photons per shot versus 0.6-1.0 signal photons per shot for the weak beam.

Over **water bodies**, ICESat-2 can produce returns both over the **surface** over the lake as well as the **bottom** of the lake (Fair et al., 2020; Fricker et al., 2020; Parrish et al., 2019); these dual returns are used by *Watta* to extract supraglacial lake depths, as well as lake surface characteristics.

Using what data?

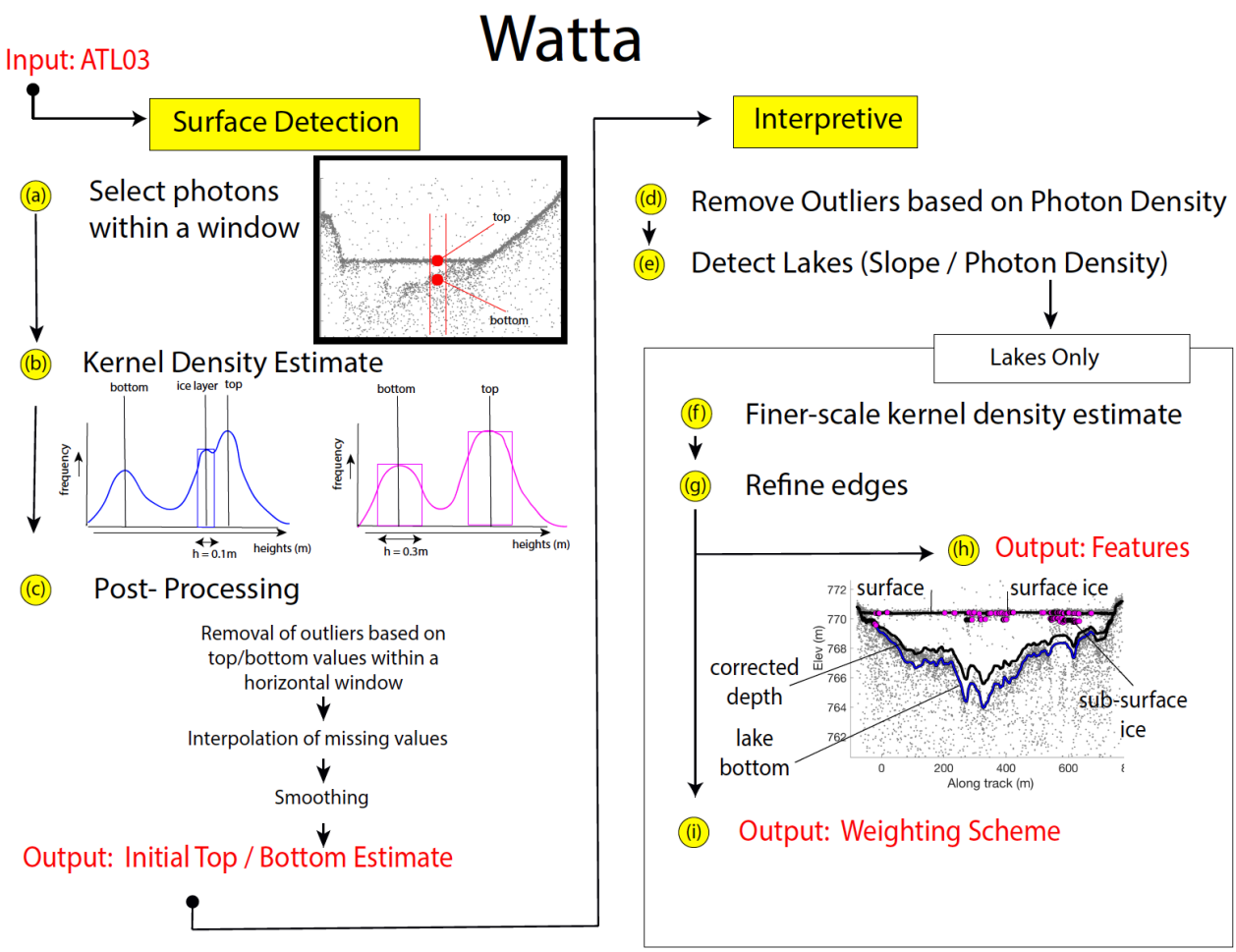


For imagery sources, in addition to freely-available **Landsat OLI** (30m) **and Sentinel-2** (10m) imagery, we incorporate very high resolution imagery **from Planet Labs**, including **Dove-R** (3m) and **SkySat** (~1m). The figure of Lake Cecily above illustrates the added value of the high-resolution imagery.

SkySat imagery is used to **validate** surface types, while all imagery sources are used to derive **spectrally-driven depth estimates** calibrated to ICESat-2-based depths. Additionally, the high-spatial resolution of SkySat allows for the identification of small-scale features on the surface and bottom of supraglacial lakes, which we use to interpret **the temporal evolut**ion of lake characteristics in a number of case studies.

All imagery was coregistered with ICESat-2 using the GIMP-2 digital elevation model (DEM), which is used for the geolocation of both Landsat imagery and ICESat-2.

How?



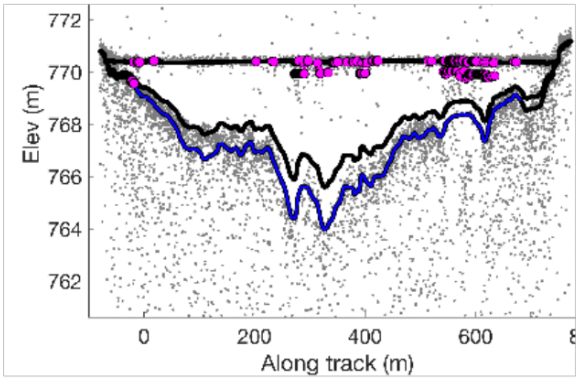
In brief, our *Watta* method looks for **peaks in the density distribution** of the photon returns and automatically assigns these to a surface, lake bottom as well as subsurface ice when present. After detection, a lake depth is calculated and corrected for refraction of the photons. A **lake probability** is assigned to surface segments following the criteria in the table below

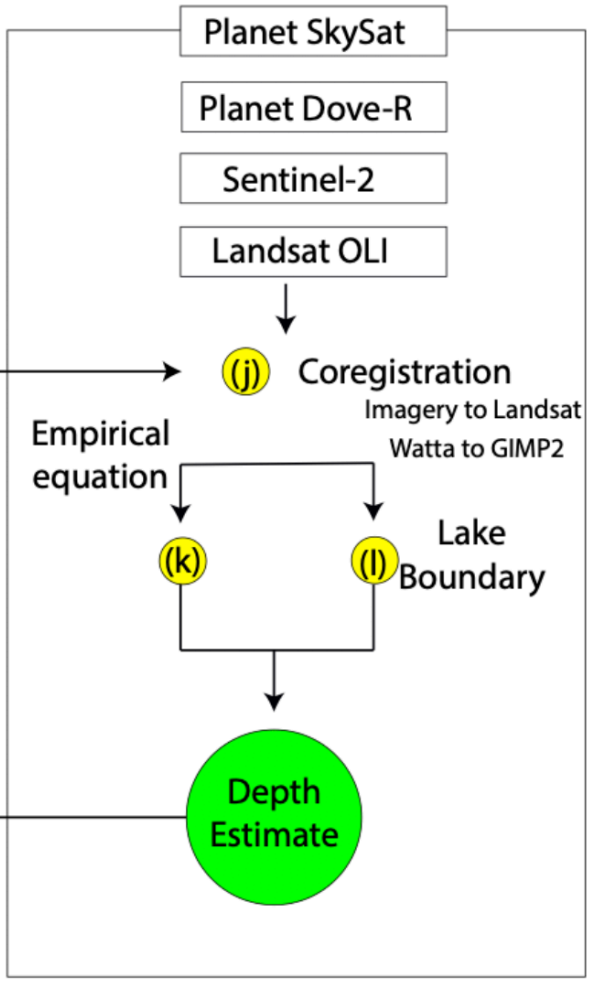
Class	Slope	Bottom reflection*	Lake probability	Lake characteristics
1	< 0.03%	strong	highly likely	very flat open lake, dense bottom photon returns
2	0.3% < slope < 0.3%	strong	very likely	flat, open lake with presence of refrozen ice; dense bottom photon returns
3	> 0.3%	strong	likely	non-flat surface, possibly flowing water channel on sloping surface; dense bottom photon returns
4	< 0.03%	weak	very likely	very flat open lake; weak bottom photon returns
5	0.3% < slope < 0.3%	weak	about as likely as not	flat open lake; weak bottom photon returns
6	> 0.3%	weak	unlikely	Non-flat surface; weak bottom photon returns
7	< 0.03%	none	likely	Very flat refrozen lake; no significant bottom photon returns

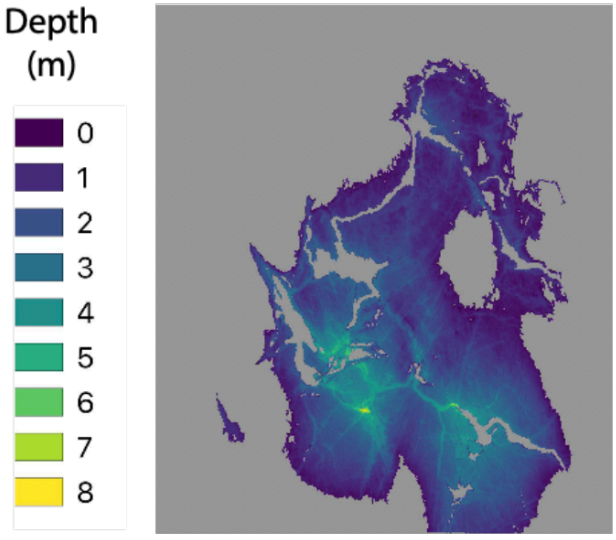
In a next step, the **depth estimates** along the ICESat-2 groundtrack are **combined** with the **imagery** to estimate the total volume of the melt lake

Imagery Processing

How?





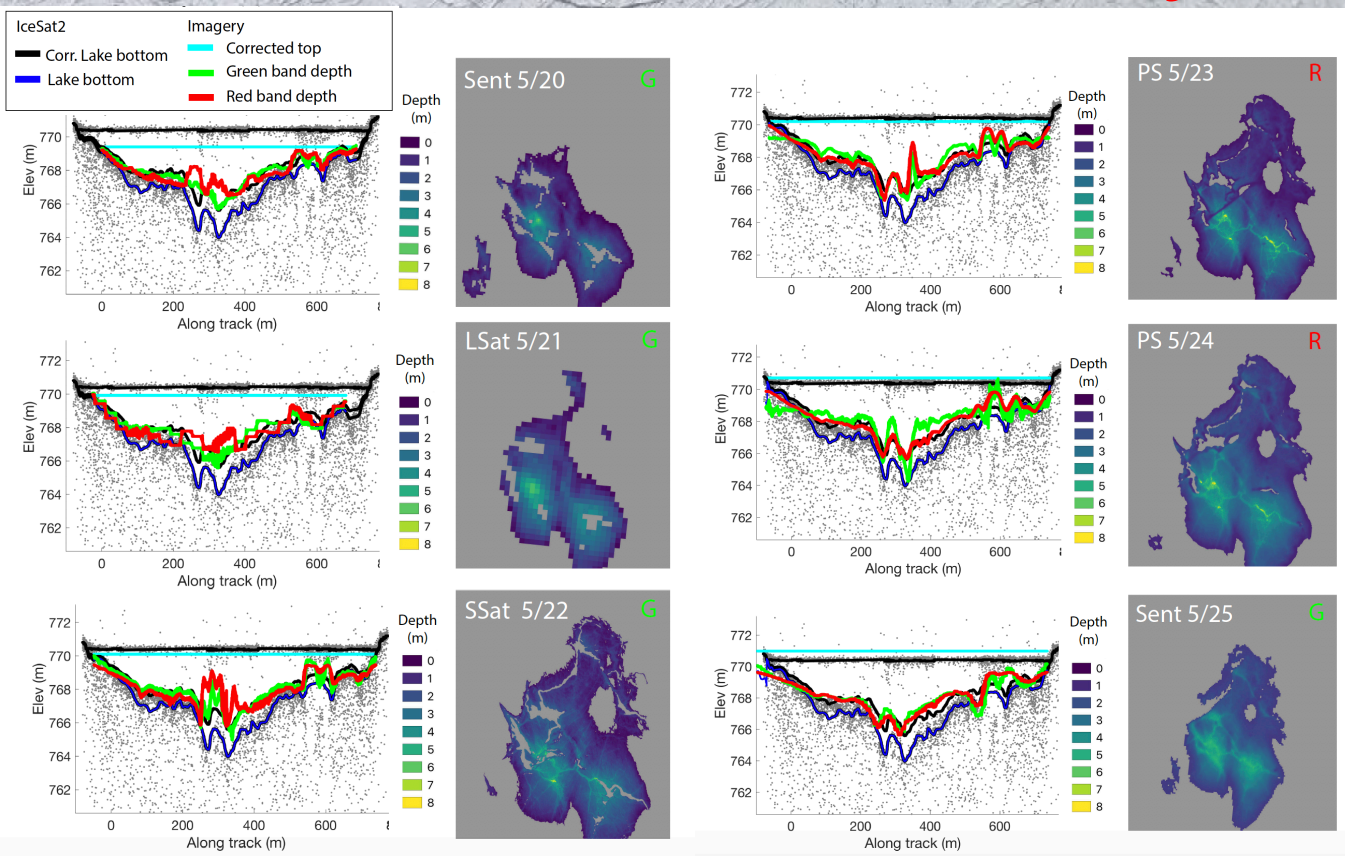


All imagery was coregistered with ICESat-2 using the GIMP-2 digital elevation model and lake boundaries were delineated in the process. To estimate volume, an empirical relationship is used, which was originally presented in Box and Ski, 2007, based on the **exponential decay of reflectance** at water depth.

Originally, in situ depth estimates and reflectance values from imagery (R) were used to estimate the α-coefficients in the equation below, which were then applied to calculate water depth over the full-scale of imagery where lakes are delineated. Such in-situ measurements are scarce, so here we use the **ICESat-2 based depths** to derive the **α-coefficients**. Once we have these, we can estimate the total volume of the lake.

$$D = a_0/(R + a_1) + a_2$$

What did we find?



Sent: Sentinel-2; LSat: Landsat-8; SSat: SkySat; PS: PlanetScope

The sequence above shows **Lake Ayşe**, filling over five days between May 20th and May 25th. ICESat-2 passed over on May 23rd which allowed us to track the **changes in lake depth** using a combination of high and medium resolution imagery.

When comparing results based on the red (R) and green band (G) in the empirical relationship in these different imagery sources,, **the green band** is able to resolve bathymetry at greater depths and emphasize cracks at the bottom of the lakes. The major exception is PlanetScope data where the **red band** consistently showed greater fidelity to Watta-based estimates.

Our work demonstrates the potential of ICESat-2 for automated lake detection and depth estimation, as well as how depths derived from a combination of imagery sources can **complement** each source's strengths and weaknesses. For example, while Landsat is only available at a low resolution, it provides a rich historical record as well as high geolocational accuracy, which we here to better geolocate imagery from Planet Labs. A time series constructed from multiple sources can provide valuable information about the evolution of **ice cover and drainage mechanisms** in addition to **volume estimates.**

What does *Watta* (/ˈwɔː.təʳ/**) mean?**

Watta isn’t an acronym. It’s just **W**outers + D**atta** : the result of working-from-home dullness during a pandemic, late-night/early-morning trans-Atlantic Slack banter, and most of all, one co-author’s lame sense of humor.