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# Helicopter-based Airborne Laser Scanning for Quantifying Vertical and Volumetric Change of a Glacier: Wolverine Glacier, Alaska


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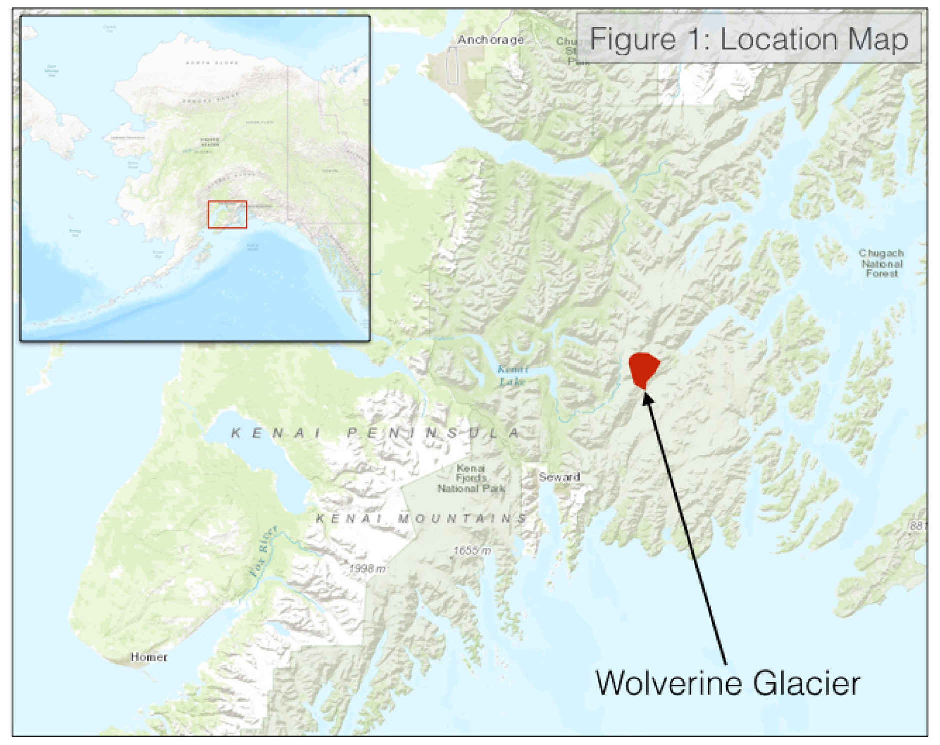

Figure 1: Location Map

## Introduction

Airborne LiDAR data acquisition of small mountain glaciers in high-relief areas poses a unique challenge for the quantification of both volumetric and vertical change over time. This is due to high vertical variations over short horizontal distances, making flight-line planning and execution a challenge. While high-cost airborne laser scanners exist that are capable of collecting data from high above-ground-level (AGL) altitudes, the cost to purchase and operate these sensors is limiting. We describe the development and use of a lower-cost airborne laser scanning (ALS) system designed for terrain-following data acquisition of small mountain glaciers. Through the integration of a compact LiDAR scanner, IMU, and GPS in a helicopter-mounted external cargo pod, and the efficient installation and calibration process, it is possible to collect high quality, multi-temporal data of glacier surfaces.

In collaboration with a USGS-led comprehensive study, we conducted ALS surveys of the Wolverine Glacier basin in south-central Alaska on May 7th and September 10th, 2016, bracketing the summer melt season (**Figure 1**). With these data, we quantify both surface height and volumetric change between the surveys, contributing to the estimation of glacier mass balance and knowledge of snow distribution in the basin.

## System Design

In order to access and map small mountain glaciers in high-relief locations from low AGL altitudes, it was necessary to create a helicopter-based ALS system to exploit the maneuverability of the aircraft (**Figure 2**). We chose the Robinson R44 Raven II helicopter for the following reasons:

1. Availability of both an externally mounted cargo pod capable of being modified for sensor payloads and a tail-mounted GPS antenna mount, both with FAA-STC certification.
2. Lower cost of operation compared to larger aircraft: ~$700/hr vs. ~$1,800/hr for the Eurocopter AS350.
3. Popularity of the helicopter worldwide, increasing the chartering options for future surveys.

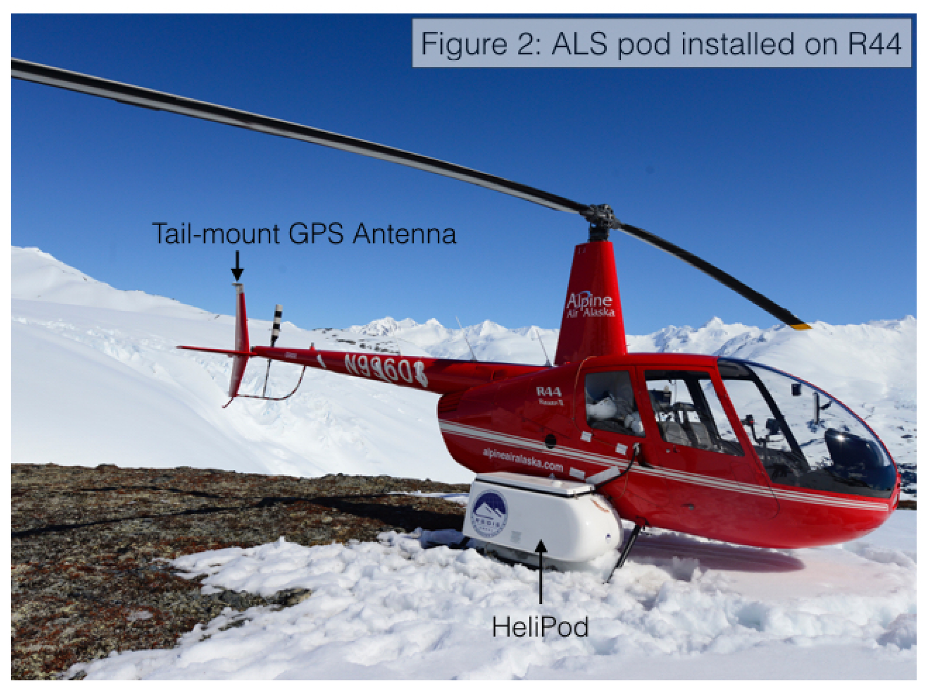

Figure 2: ALS pod installed on R44

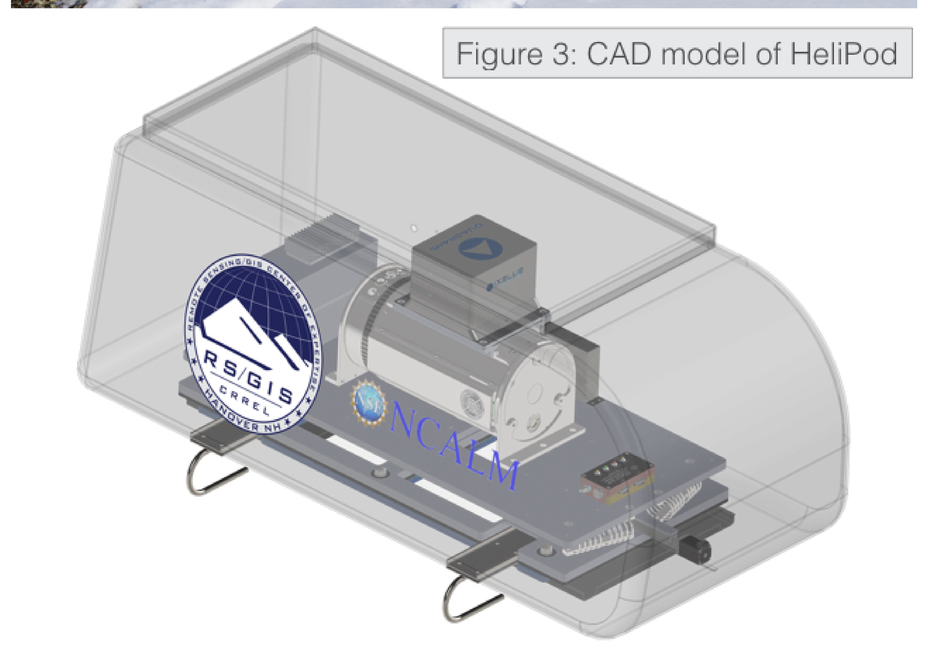
Figure 3: CAD model of HeliPod

We integrated a Riegl VQ-480i laser scanner, iXBlue ATLANS-C inertial measurement unit (IMU), a tail-mounted GPS antenna and the NexTrack 2 Flight Management System for the main system components. We custom designed a mounting system in the pod to isolate the sensors from aircraft vibration (**Figure 3**). Power was supplied directly from the aircraft battery, passing through a voltage conditioner before being distributed to the system components. A single operator runs the ALS system, while the FMS provides flight line guidance to the pilot via a tablet display.

## Data Acquisition & Processing

Data was collected at Wolverine Glacier on 7 May and 10 September 2016, based out of Girdwood, AK. A temporary base station was installed at the USGS Hut at Wolverine Glacier for trajectory post-processing. Flight AGL was 400m, with flight lines planned to provide 50% overlap of target surfaces. Surface reflectance greatly drops with increased surface water saturation and exposed, dense ice, therefore the quality of point returns was monitored by the operator in real-time and AGL was lowered (to approximately 300m) where reduced reflectance was observed. Additionally, the operator called out AGL, as measured with the laser scanner, so the pilot could adjust height with changing terrain.

Trajectory solutions were calculated and applied to the flight lines using the IMU/GPS files from the ALS system and base station file from the temporary setup onsite, with the following results (**Figure 4**):

-Vertical σ ranging from 5 - 15mm
-Horizontal σ ranging from 12 - 28mm
-Heading σ: 0.01 - 0.03°
-Roll and Pitch σ: 0.00 - 0.01°

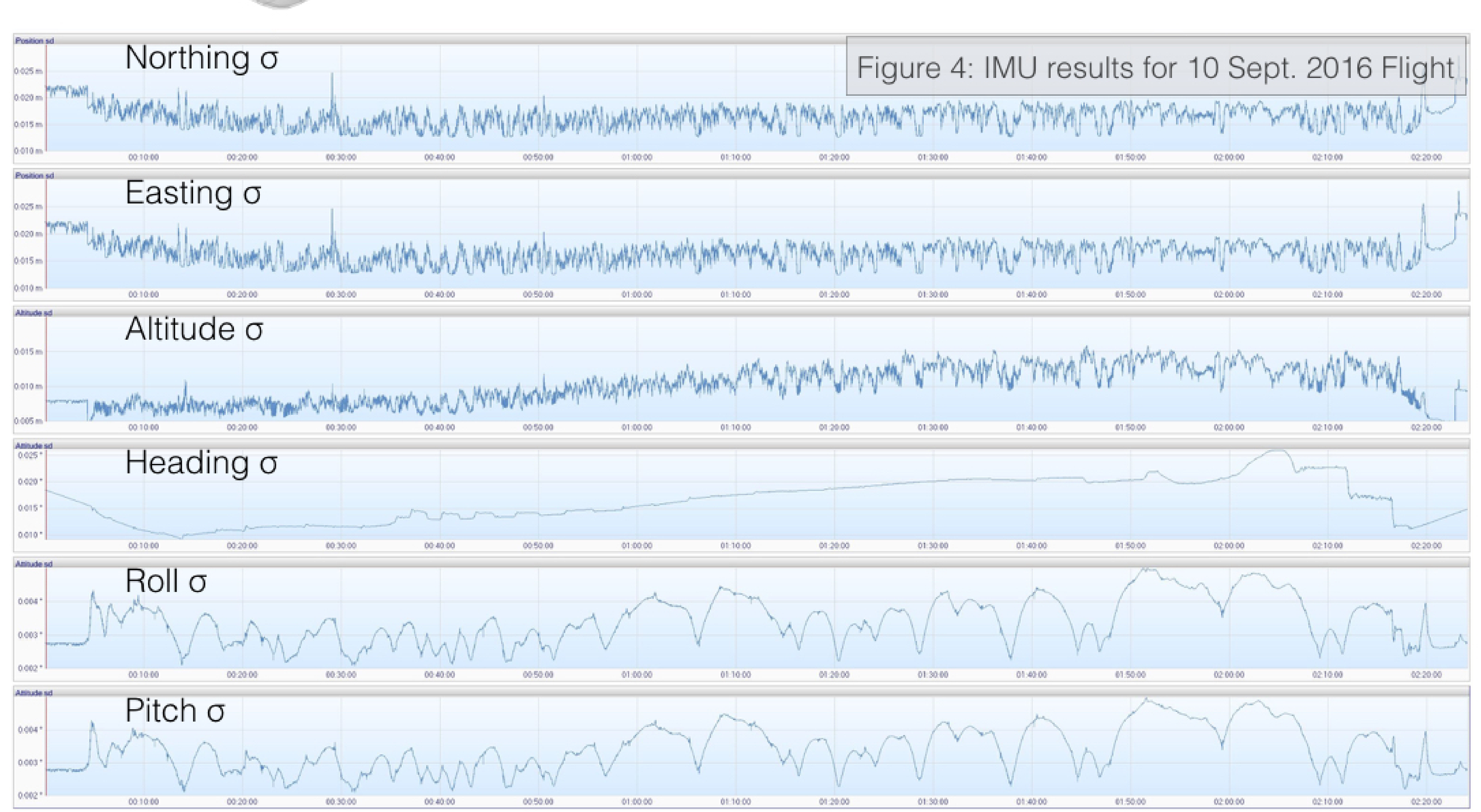

Figure 4: IMU results for 10 Sept. 2016 Flight

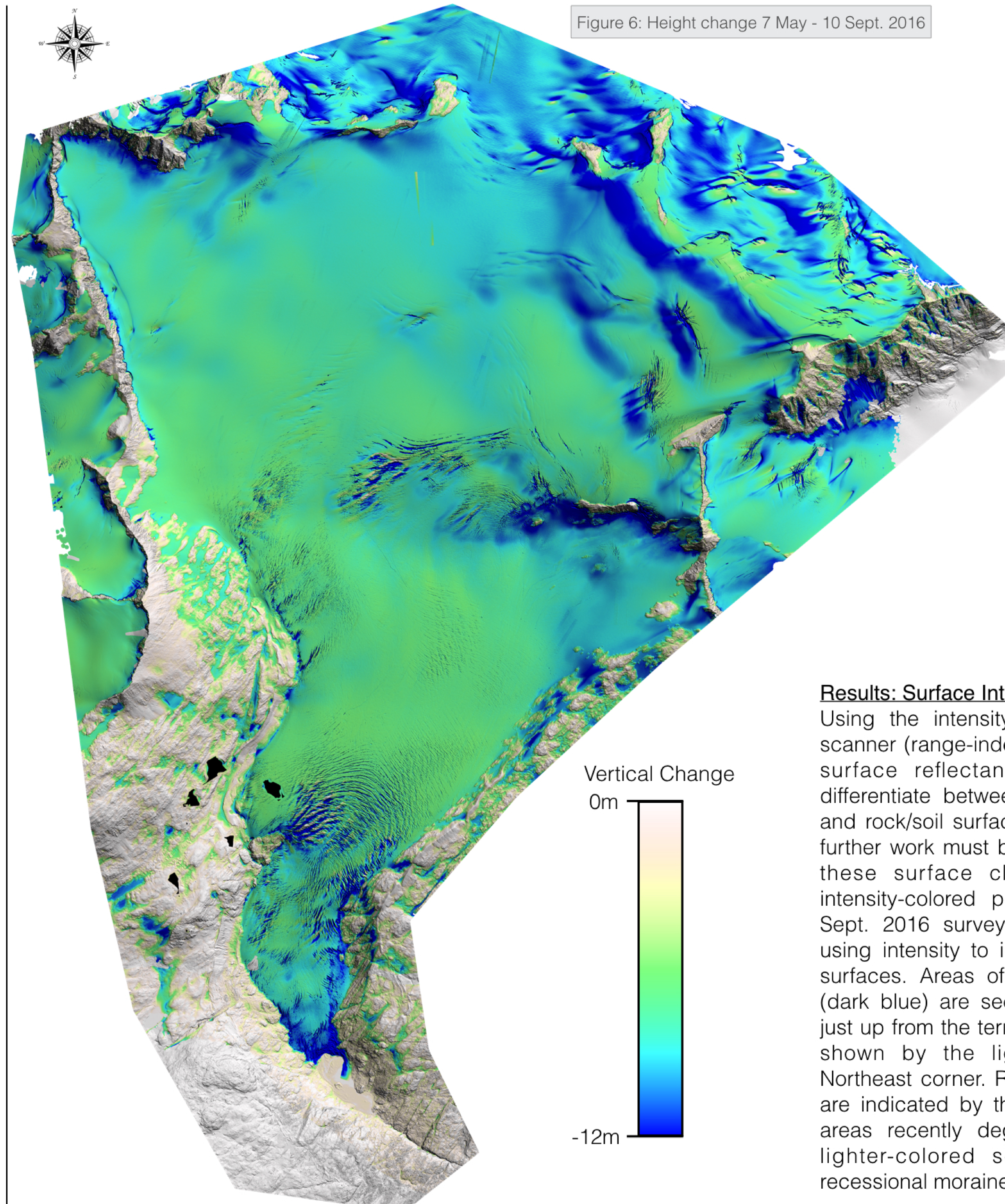

Figure 6: Height change 7 May - 10 Sept. 2016

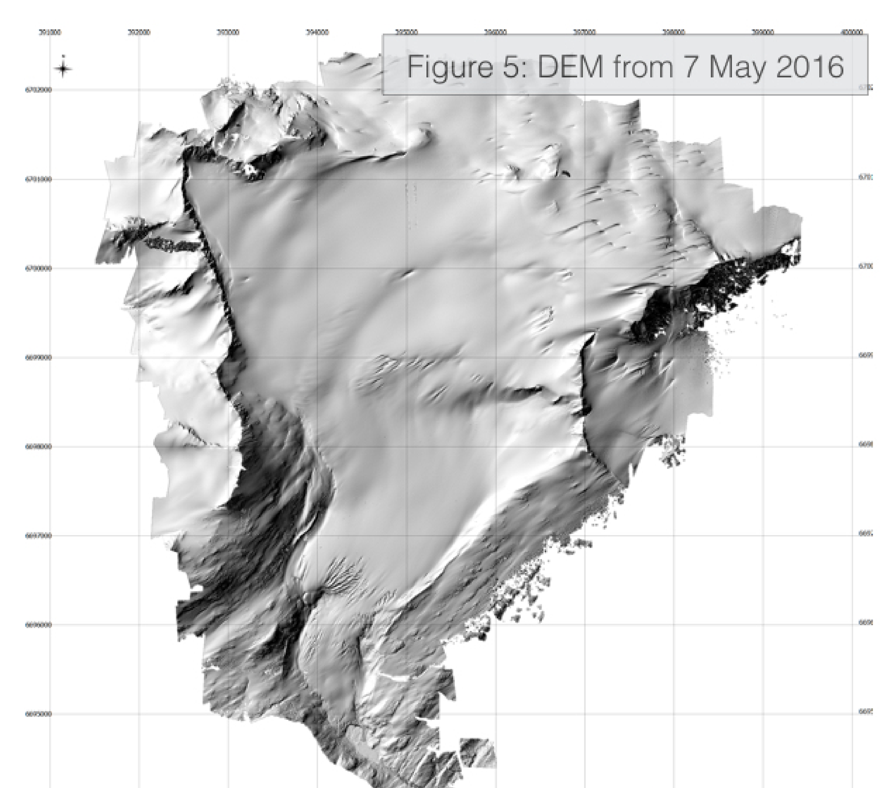
Figure 5: DEM from 7 May 2016

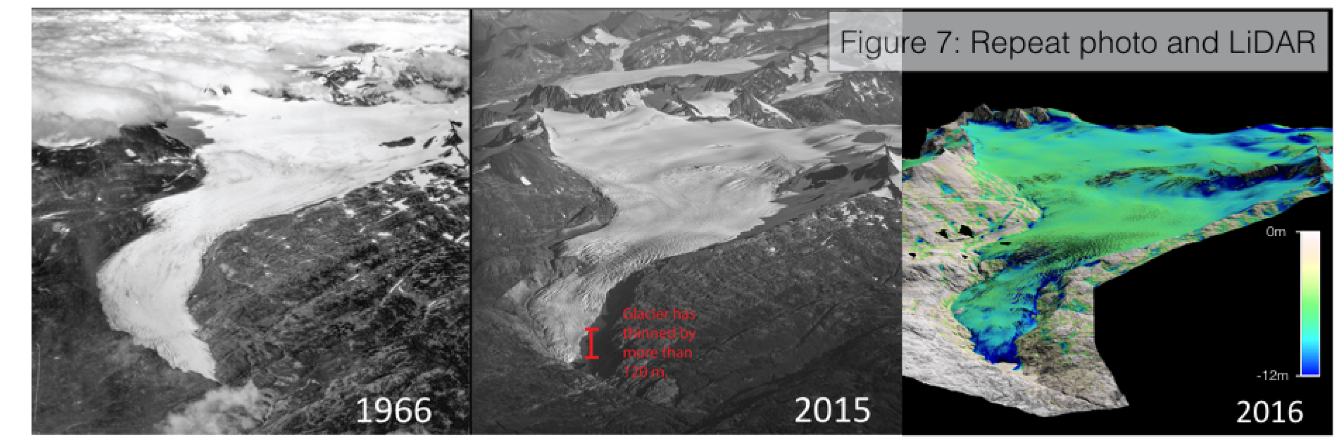

Figure 7: Repeat photo and LiDAR

## Results: Change Detection

From the point clouds collected for both survey dates, 50cm DEMs were produced to use for both surface height change detection and volume change calculation (**Figure 5**). **Figure 6** shows the height change results between the two surveys overlaid on the 10 Sept. 2016 DEM. We measured an average height change ranging from **0 to -12m**, with smaller areas of larger snow/ice loss. Areas of drifting, filled crevasses, snow and ice ablation, and significant melt/retreat at the glacier terminus are apparent.

## Results: Volume Calculation

By differencing the DEM surfaces between the surveys, we calculated a volumetric change of **-219,056,253 m³** for the Wolverine Glacier using a signed delta volume calculation, which calculates the net change in volume for a defined AOI bounded by the X-Y plane.

## Results: Surface Intensity

Using the intensity values from the laser scanner (range-independent, scalar value of surface reflectance), it is possible to differentiate between snow, ice, vegetation and rock/soil surfaces within the AOI. While further work must be done to better classify these surface changes, **Figure 8**, an intensity-colored point cloud from the 10 Sept. 2016 survey, illustrates the utility of using intensity to identify areas of differing surfaces. Areas of exposed, saturated ice (dark blue) are seen in the crevasse zone just up from the terminus. Fresh, dry snow is shown by the light-green area in the Northeast corner. Rock, soil, and vegetation are indicated by the warm colors, with the areas recently deglaciated visible by the lighter-colored sections in the lateral recessional moraines.

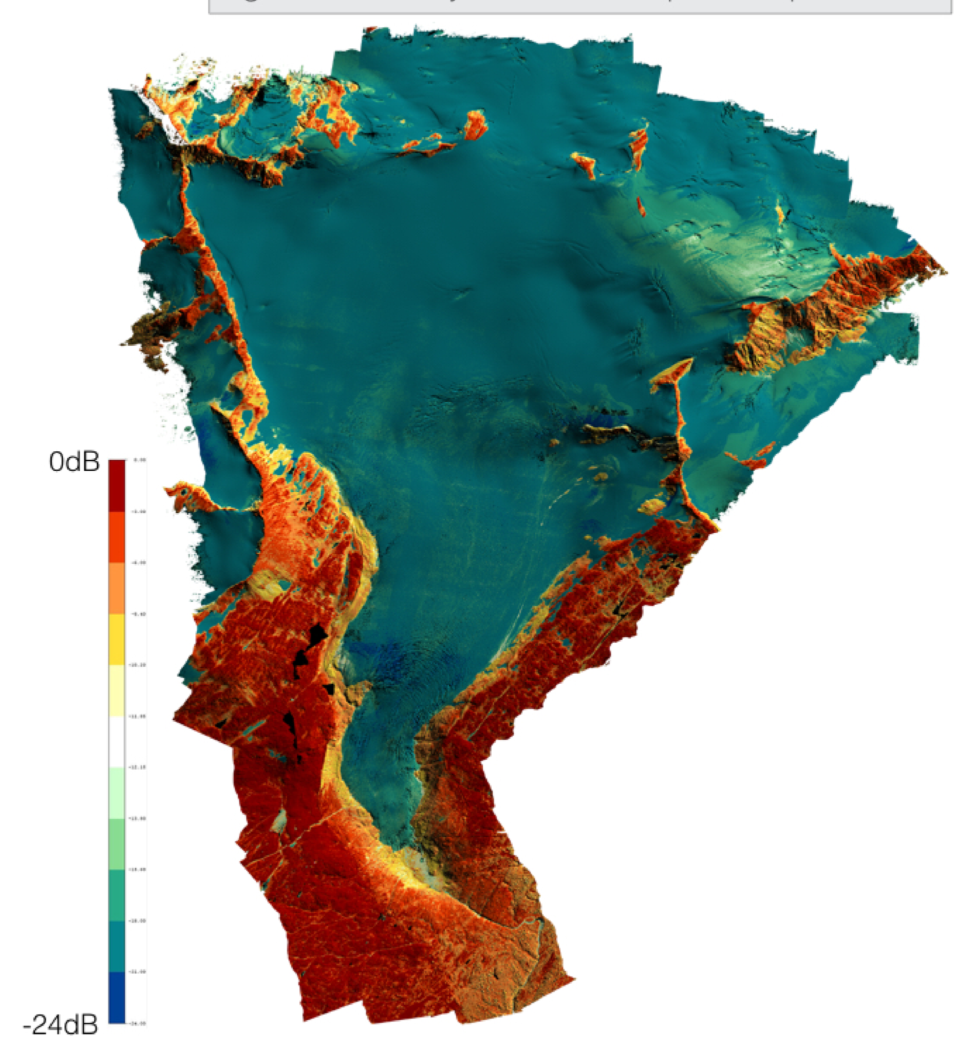

Figure 8: Intensity-colored 10 Sept. 2016 point cloud

## Conclusion & Future Work

With the developed sensor package, aircraft platform, and acquisition/processing techniques, we are able to capture multi-temporal, high-resolution, precise topographic measurements of small mountain glaciers for the quantification of surface height and volumetric change. These results may be utilized for comparing in-situ measurements and as input for glacier mass balance modeling. In addition to full glacier mapping, the system may be used for measuring glacier centerlines of very small, difficult to access glaciers, complimenting ongoing data acquisition of glacier centerline measurements in Alaska through the use of a fixed-wing aircraft. Future work will include validation of the results against in-situ measurements, and the comparison of these results to Structure-from-Motion (SfM) products of Wolverine Glacier.


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