Long-term Autonomous Tidewater Glacier Monitoring Using a Long-Range Terrestrial LiDAR Scanner: Helheim Glacier, Southeast Greenland

C43B-0807

David C. Finnegan[1], Adam L. LeWinter[1], Gordon S. Hamilton[2], Peter J. Gadomski[1], Leigh A. Stearns[3]

david.finnegan@usace.army.mil

[1]Cold Regions Research and Engineering Laboratory, Hanover, NH
[2]Climate Change Institute, University of Maine, Orono, ME, USA
[3]Department of Geology, University of Kansas, Lawrence, KS, USA

Introduction

Tidewater glaciers exhibit dynamic behaviors across a range of spatial and temporal scales, posing a challenge to both in situ (on ice) and remote sensing observational strategies. In situ measurements can capture variability over very short time intervals, but with limited spatial coverage and at significant cost and risk to deploy. Conversely, airborne and satellite remote sensing is capable of measuring changes over large spatial extents but at limited temporal sampling. In recent work, we have shown that long-range Terrestrial LiDAR Scanning (TLS) from fixed near-situ locations is capable of combining the rapid acquisition capabilities of in situ measurements with the broad spatial coverage of traditional remote sensing from fixed standoff locations. LiDAR scanners are typically operated for short-duration campaigns (days to weeks) due to the technical complexity of the instrumentation, which has limited their contribution to our understanding of tidewater glacier studies to "snapshot" processes by incomplete observational d[...]

Fig. 1

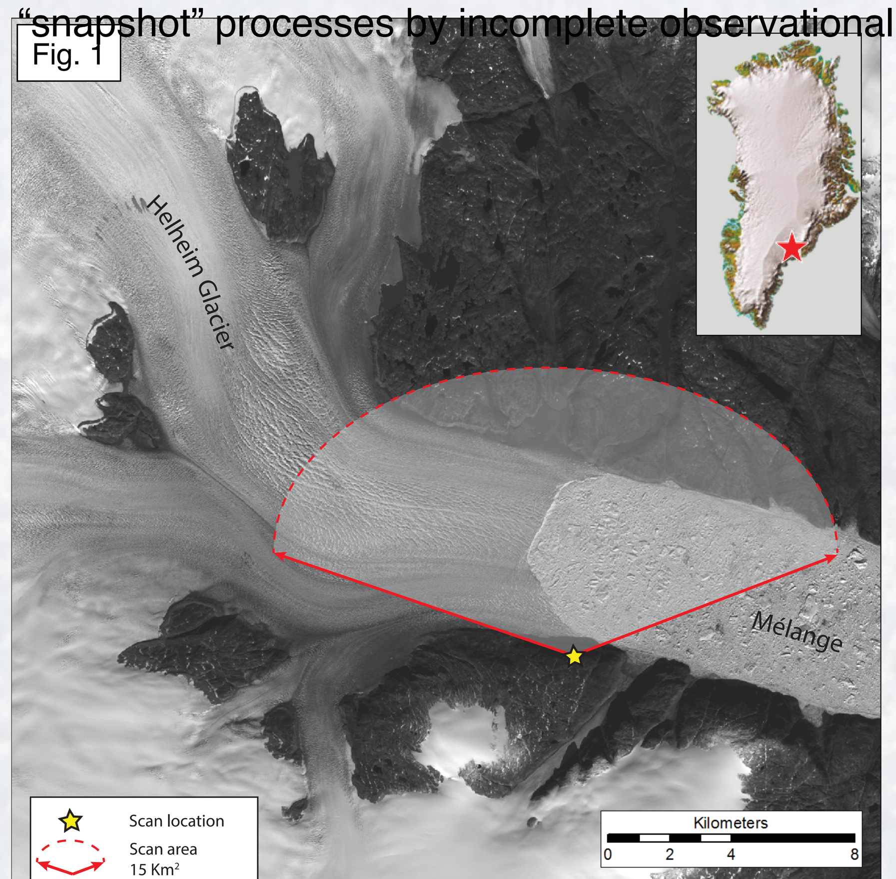


Fig. 2

This paper describes the development and deployment of an autonomous long-range (6-10 km) TLS system for extended operation (> 1 year) in a remote Arctic environment. Called the ATLAS System, the instrument uses a 1064-nm wavelength laser optimized for snow and ice, and allows us to acquire multi-dimensional point-cloud measurements of the lower reaches of the glacier, its terminus and the mélange to distances in excess of 10-km every 6-hours. The system was field deployed at Helheim Glacier in southeast Greenland in July 2015 (See **Fig. 1** and **2** for ATLAS installation location and field-of-view). Helheim Glacier is a large tidewater outlet glacier of the Greenland Ice Sheet and the focus of a coordinated interdisciplinary program to study its dynamics and interaction with the ocean. Results from our year-round scanning instrument will provide new insights into short and long-term ice motion and terminus behavior at temporal and spatial resolutions previously not possible.

System Specifications

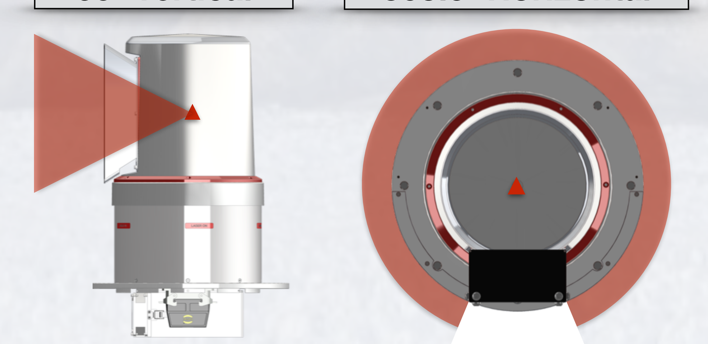
Riegl Arctic Monitoring LiDAR System	
Mode of Operation	Online Waveform Processing or Full Waveform
Wavelength	1064 nm (Class 3B Laser Product, non-eyesafe)
Minimum-Maximum Range	5–6,000 m (CRREL team has measured >10km)
Maximum Pulse Rate	300 kHz (222k measurements/second)
Accuracy/Precision	15 mm/10mm
Field-of-View	Vertical: 60º,Horizontal: 308.5º (due to window shield)
Angular Increment	0.002º—0.280º (vertical), 0.002º—3º (horizontal)
Protection Class	IP64, dust- and splash-proof
Temperature Range	-10º—40ºC (Range increases with heating/cooling unit)
Average Scan for Helheim Site	30-minute duration resulting in ~29 million measurements
Power, Communication, and Climate System	
Solar Panel	327 Watt (x6), 1,962 Watts Total
Wind Turbine	400 Watt (x2), 800 Watts Total
Battery	180 Ah LiFePO4 (x4), 720 Ah Total, 24V
Communications	Iridium SBD and Dial-up Modems
Climate Station Sensors	Temp/RH, Barometric Pressure, Wind Speed

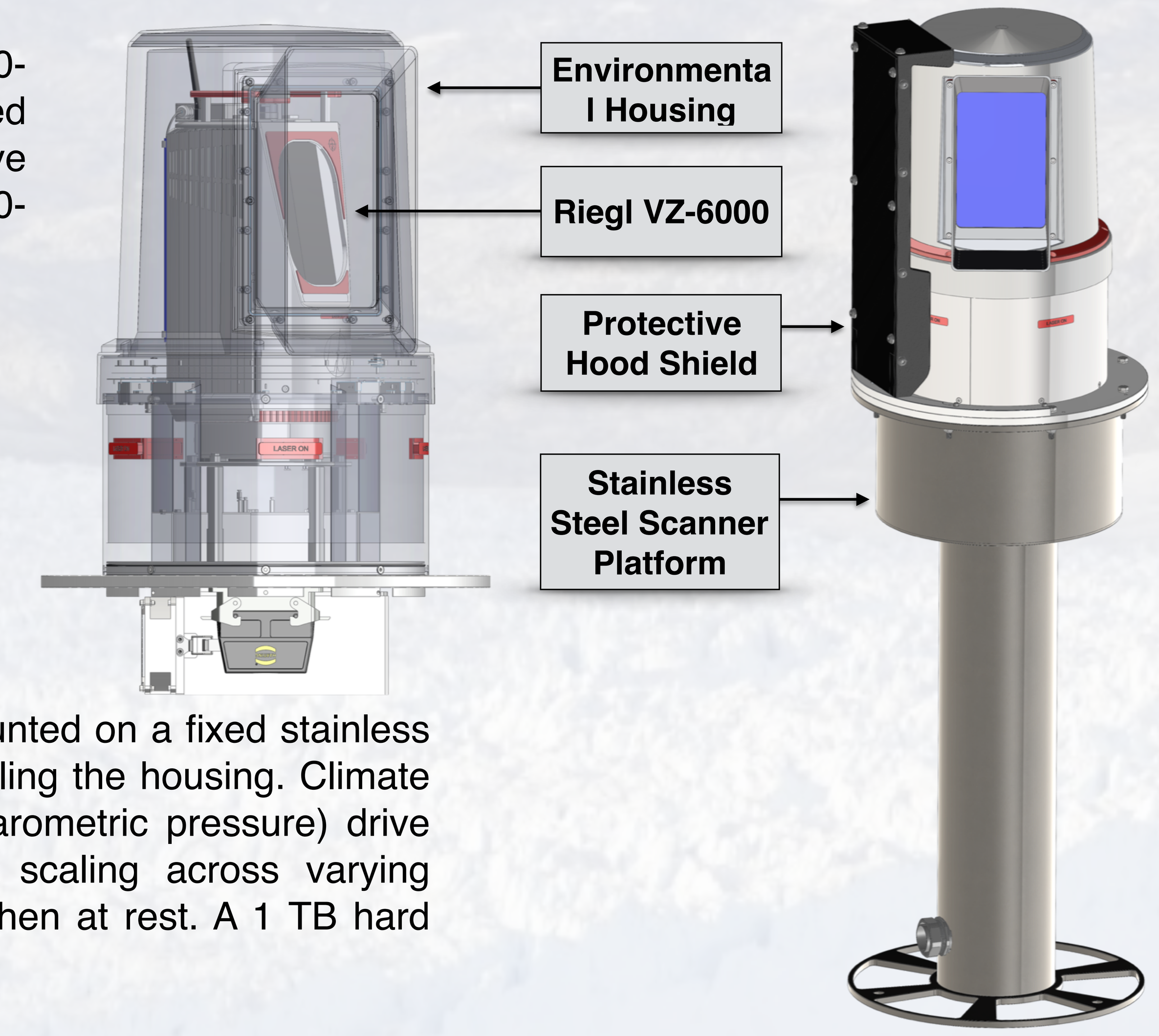
LiDAR Scanner

We utilize a Riegl VZ-6000 long-range TLS capable of measuring up to 10-km in ideal conditions (**Fig. 3**). The 1064-nm wavelength laser is well suited for snow and ice surfaces, but is not eye-safe. The scanner has an effective maximum measurement rate of 222 kHz, capturing 29-million points in 30-minutes. a 1 TB internal hard drive stores the data until revisit.

Fig. 3

Fig. 4

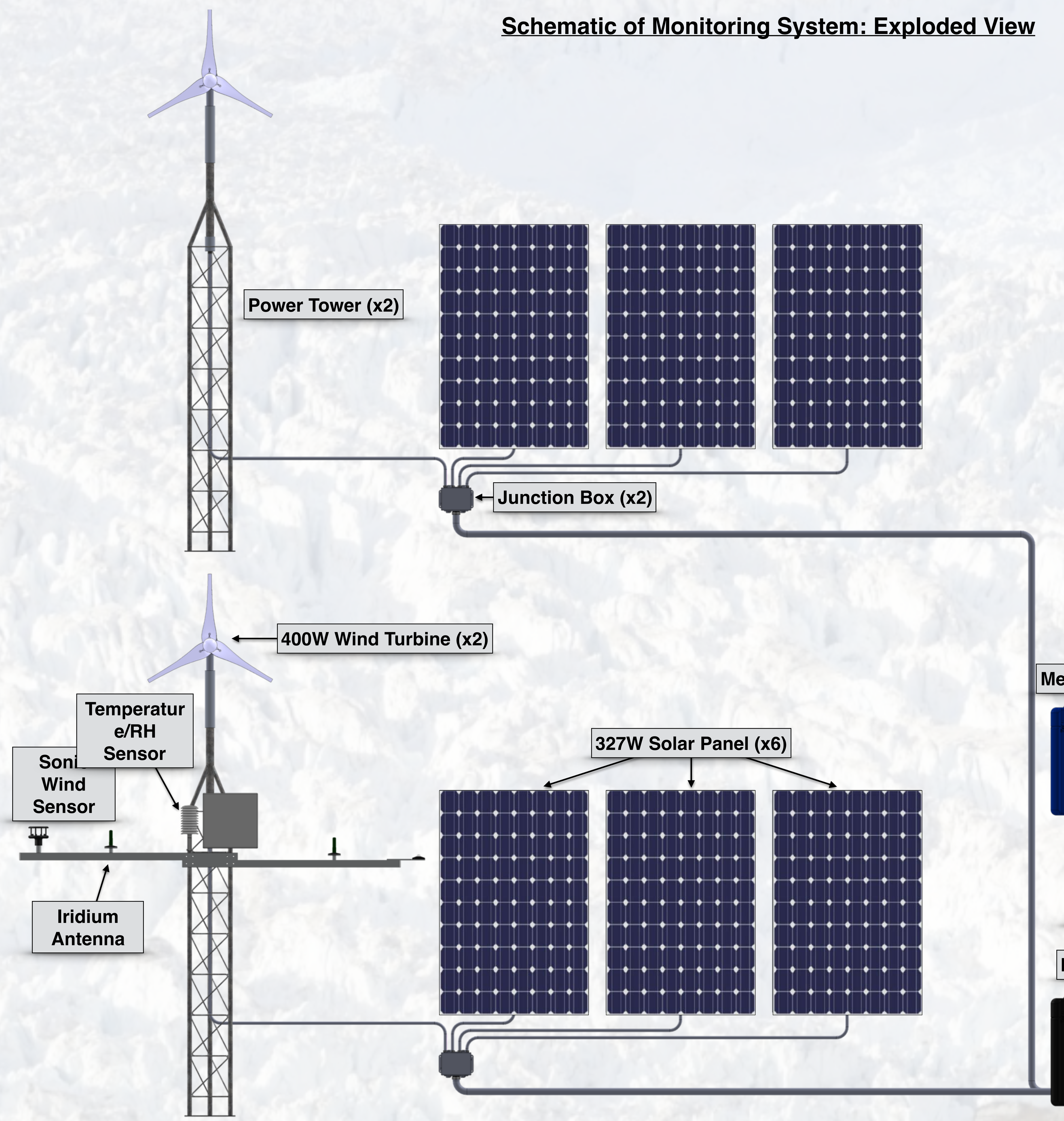




Environmental Housing

The VZ-6000 is installed in a custom environmental housing (**Fig. 4**) mounted on a fixed stainless steel platform that doubles as a volume for air circulation for heating/cooling the housing. Climate station sensors (temperature, wind speed/direction, relative humidity, barometric pressure) drive the heating/cooling unit and are used to adjust the scan data for scaling across varying atmospheric conditions. A window shield protects the enclosure glass when at rest. A 1 TB hard drive provides an onsite back-up of data.

Schematic of Monitoring System: Exploded View



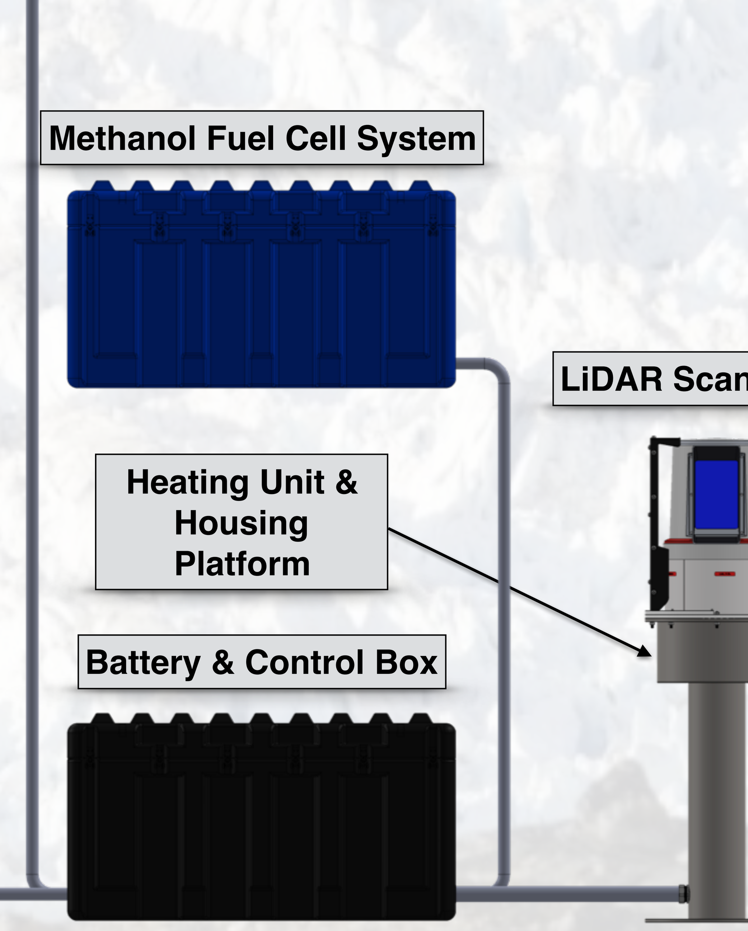


Fig.7

Power System

We have developed a power system incorporating photovoltaic panels (x6 327-Watts), wind turbines (x2 400-Watts), methanol fuel cells (x2 110-Watts), and a custom built 24 VDC $LiFePO_4$ battery array (x4 180 Ah) (See **Fig. 5**, **6**). Two 12-foot aluminum towers hold the solar panels, turbines, climate station sensors, and communication antennas (**Fig. 7**). We use two storage enclosures: the battery and control box houses the battery array, charge controllers, and all control and communication components; the second enclosure houses the methanol fuel cells and fuel cartridges.

Fig. 5: LiFEPO4

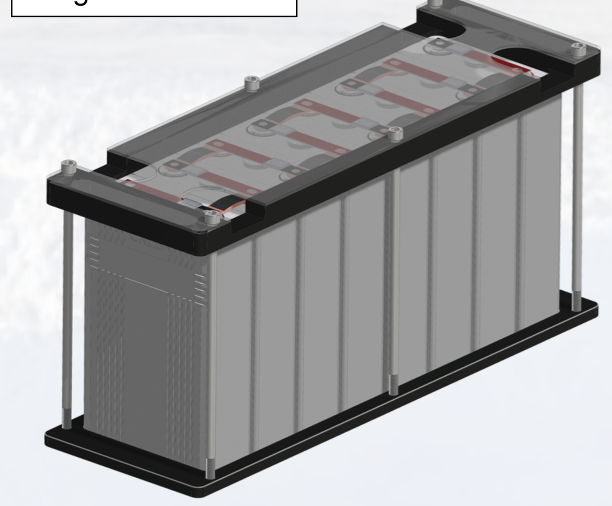


Fig. 6: Methanol fuel cell

Communication and Control System

The ATLAS System is controlled by a Sutron data logger, which collects weather station input, battery health measurements, and status updates from the scanner/housing to schedule scan collections and send heartbeat data via Iridium satellite to our server (**Fig. 8**). In addition, we have installed an Iridium-linked camera, capturing images of the entire installation (with the glacier in the background) every 3-hrs (**Fig. 9**). This provides visual status of the installed hardware.

Fig. 8: Battery & Control

Fig. 9: Iridium webcam

Communication and Control System

The data collected will be processed using coherent point drift (CPD) analysis, which measures displacement between similar surfaces while allowing non-rigid deformation. The resulting displacement vectors will allow for the calculation of ice velocities along and across the ice stream, as well as the mass balance flux.

Fig. 10

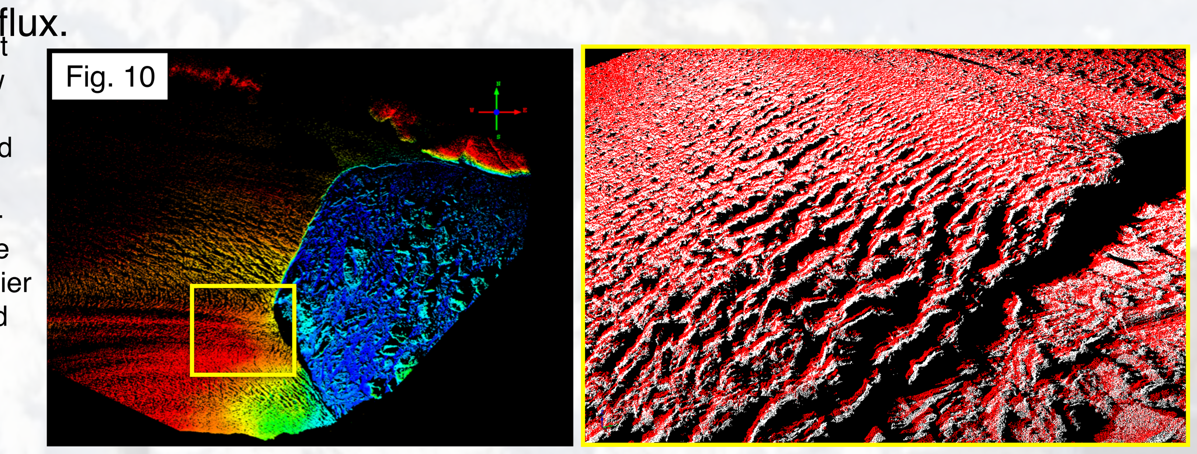


Figure 10: Height colored nadir view of the Helheim Glacier point-cloud (left image). Two scans collected 6-hrs apart show the motion of the glacier and melange. Red points are the earlier scan (right image).

Acknowledgements
This project is funded by a grant to the University of Maine from the Heising-Simons Foundation and development funding from CRREL. Riegl GmbH and Riegl USA have been supportive and active partners in all of our research, and have devoted significant effort to the engineering and design of the LiDAR scanner.

Scan code or visit www.glacierresearch.org to follow this and other projects.