United States Army Corps of Engineers
Cold Regions Research & Engineering Laboratory
Remote Sensing and GIS Center of Expertise
Hanover, NH

Boise, Idaho Airborne LiDAR Survey at Mores Creek Summit

2023-2024 Snow Season

Overview

Beginning in winter 2020-21, the Cold Regions Research and Engineering Laboratory (CRREL) has collected airborne lidar data around the headwaters of Mores Creek, located in the Boise Mountains of Southwest Idaho (*figure 1)*. These data support several military and civilian snow projects, and collections are designed to allow time series analyses of snowpack properties and sub-seasonal to interannual changes of these properties. Flights occur primarily during winter, and differencing of snow covered and snow free terrain reveals the snowpack distribution. This report details collection efforts through the 2023-24 winter, when 6 flights occurred.

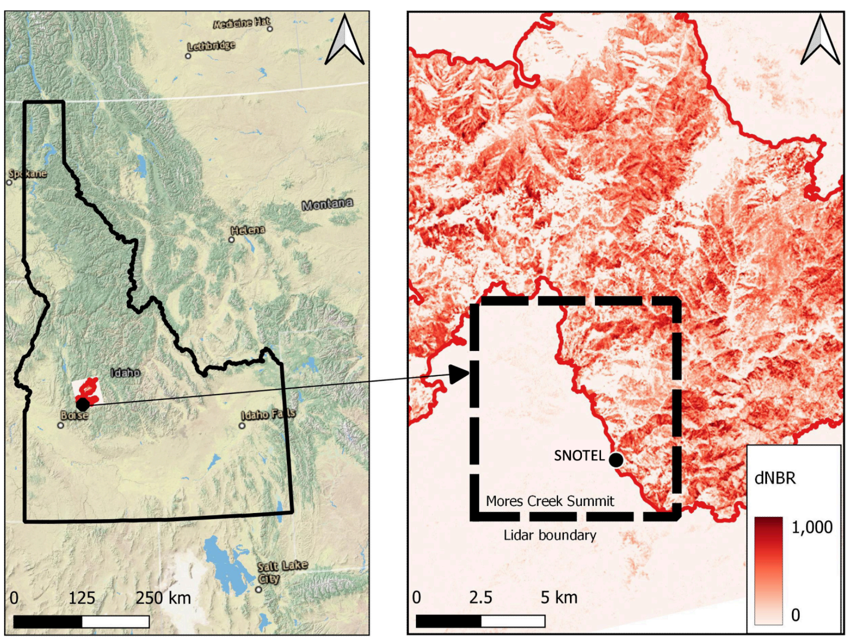

Figure 1- (Left panel) Mores Creek is in the Boise Mountains of central Idaho. (Right panel) The 2016 Pioneer Fire severity (differenced Normalized Burn Ratio, or dNBR) in red, and the lidar collection outline in black. The black dot marks the location of the nearby Mores Creek Summit SNOTEL site.

Topography at the study site is rugged and complex, with approximately 600m of topographic relief. The site is characterized by moderate slopes (20-40 degrees), with deeply incised ravines between opposing slopes. The entire domain is below treeline, and primarily forested or recently burned (≈40% burned in the 2016 Pioneer Fire). The climate is characterized as warm-summer Mediterranean continental and is typically snow covered from November through May.

- Collection dates: November 13, 2023; December 28, 2023; January 15, 2024; February 13, 2024; March 15, 2024; April 28, 2024
- Location: Mores Creek Summit (MCS) in Boise Mountains of central Idaho
- Collection type: Airborne Laser Scanning
- Sensors: CRREL RS/GIS RaLiPod
    - Riegl VQ-580ii Airborne Laser Scanner
    - Applanix AP60 Inertial Measurement Unit
    - Antcom G5ANT-42AT1 Antenna
- Point of contact: Siobhan Ciafone (siobhanciafone@boisestate.edu) & Shad O'Neel (shadoneel@gmail.com)
- Aircraft: Robinson R66 Helicopter (Tail # N166FS)
- Spatial reference system: WGS84 / UTM Zone 11N (EPSG: 32611)
    - Height: WGS84 Ellipsoid
    - Units: meters

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Mission description

As part of a multi-year effort to monitor monthly snow distribution over a 35 km² region of Mores Creek Headwaters in the Boise Mountains of central Idaho, airborne LiDAR was collected throughout the 2023-2024 snow season by the Remote Sensing and Geographic Information Systems Center of Expertise (RSGIS CX) at the Cold Regions Research and Engineering Laboratory (CRREL) and the Boise State University Geological Sciences Department, Cryosphere Geophysics and Remote Sensing Group (Cryogars). The nose-mounted RaLiPod system (*figure 2*), mounted on a Robinson R66 helicopter, consisted of: REIGL VQ580ii laser scanner; Applanix AP60 Inertial Measurement Unit (IMU); Antcom G5ANT-42AT1 antenna, and TopoFlight flight management system (FMS) (Figure 2). The aircraft is owned and operated by Silverhawk Aviation, based out of Caldwell, Idaho.

A nominal mission consists of:

1. 5 minute ground-based initialization period
2. Boresight calibration over built environment, consisting of several passes in different directions over a neighborhood.
3. Main data acquisition over survey domain as weather and fuel allow
4. 5 minute ground-based static-alignment before aircraft shutdown.

Most missions are paired with ground-based calibration/validation data collection consisting of snow-depth probing and/or snow pits.

Figure 2 - CRREL's nose-mounted RaLiPod system installed on a Robinson R66 helicopter. All sensors are located inside the pod, with control systems located within the passenger compartment for in-flight operations.

Deliverables

The following deliverables are available for each survey:

- Point Clouds:
    - LAZ v 1.2, all unclassified returns
        - *MCS_YYYYMMDD_PC_#.laz*
- 0.5-Meter Rasters:
    - Digital terrain model: ground points
        - *MCS_YYYYMMDD_DTM.tif*
    - Digital surface model: surface points
        - *MCS_YYYYMMDD_DSM.tif*
    - Canopy height model: found by subtracting reference map from DSM
        - *MCS_YYYYMMDD_CHM.tif*
    - Snow depth: found by subtracting reference map from DTM
        - *MCS_YYYYMMDD_SNOWDEPTH.tif*
- KML of target survey area
    - *MCS_survey_region.kml*

Raw data files are preserved at CRREL. Anyone interested in accessing raw data can contact POCs listed in Overview.

Base Station Control

Several base stations were used during trajectory processing (*figure 3)*. Pilot Peak and Treeline are semi-permanent stations installed in 2022 that consist of Septentrio PolaRx5 receivers and Trimble Zephyr 3 antennas. These stations are owned and maintained by the Boise State CryoGARS group. The Boise State University station consists of a Trimble NetR9 receiver and Zephyr Geodetic 2 RoHS antenna. This station is owned and maintained by the university.

The Treeline station was unavailable from December through February 2024. The Boise State University station recording interval was adjusted from 10-minutes to 1-second in January of 2024, at which point this station was incorporated into trajectory processing. A temporary base station positioned at Silverhawk Aviation on the morning of flights was included from February 2024 onward. The temporary base station is a portable system consisting of a Septentrio Mosaic-X5 GNSS receiver with an NGS Calibrated Survey GNSS antenna that was set up on a survey tripod and is referred to as “ temporary base station” in flight data tables.

Positions for Pilot and Treenline stations were resolved by processing several 24-hour observation periods using the NOAA Online Positioning User Service (OPUS; https://geodesy.noaa.gov/OPUS/) and averaging solutions to obtain the positions given in Table 1. The standard deviation among daily solutions was less than 5 mm suggesting these mounts are stable enough to be used as reference data for these campaigns.

Table 1 - Permanent base station coordinates EPSG(32611).

Reference System: ITRF2014						
Station ID	**Latitude**	**Longitude**	**Ellipsoid Height (m)**	**Northing (m)**	**Easting (m)**	**Antenna Height (m)**
Pilot Peak	43 57 34.240834	115 41 10.211798	2449.604	4842269.634	659244.7581	3.12
Treeline	43 43 48.8307973	116 8 24.8128245	1601.180273	4868214.451	605408.5431	3.0
Boise State University	43 36 0.43809	116 11 53.92464	830.1916	4827772.613	564706.2855	1.054

Figure 3 - A map of base stations used throughout the collection period. A temporary base station was erected at Silverhawk Aviation when other semi-permanent base stations were unavailable. The red polygon in the northwest corner denotes the target survey area.

Data collection summary

November Survey

Table 2 -MCS airborne laser scanning survey parameters for November flight. This survey served as an opportunity to test systems prior to the snow-on surveys. Roughly 1 inch of snow was observed on the ground at higher elevations in the survey domain, which is within system error.

Collection Dates, # Flights:	November 11, 2023, 2
Start time, end time (UTM):	19:16:57 - 21:03:15
Target flight parameters:	overlap: 50%, flying height: 3,000 ft a.s.l., flying Speed: 40 knots
System Operator:	Karina Zikan and Naheem Adebisi
Pilot:	John Grommet
Base stations used:	Pilot Peak, Treeline
Average Point density:	> 20 points/m^2

December Survey

Table 3 - MCS airborne laser scanning survey parameters for the December snow-on flight.

Collection Dates, # Flights:	December 28, 2023, 1
Start time, end time (UTM):	17:53:42. 20:32:52
Flight parameters:	overlap: 50%, flying height: 3,000 ft a.s.l., flying Speed: 40 knots
System Operator:	Josh Enterkine and Naheem Adebisi
Pilot:	John Grommet
Base stations used:	Pilot Peak
Average Point density:	> 20 points/m^2

January Survey

Table 4 - MCS airborne laser scanning survey parameters for the January snow-on flight. Due to low clouds over the survey domain, only a portion of the intended survey was completed.

Collection Dates, # Flights:	January 15, 2024, 1
Start time, end time (UTM):	19:40:31, 22:37:14
Flight parameters:	overlap: 50%, flying height: 3,000 ft a.s.l., flying Speed: 40 knots
System Operator:	Karina Zikan and Naheem Adebisi
Pilot:	John Grommet
Base stations used:	Pilot Peak, BSU
Average Point density:	> 20 points/m^2

February Survey

Table 5 - MCS airborne laser scanning survey parameters for the February snow-on flight. Low clouds

Collection Dates, # Flights:	February 13, 2024, 1
Start time, end time (UTM):	17:09:03, 19:52:22
Flight parameters:	overlap: 50%, flying height: 3,000 ft a.s.l., flying Speed: 40 kn
System Operator:	Karina Zikan and Naheem Adebisi
Pilot:	John Grommet
Base stations used:	Pilot Peak, BSU, temporary base station
Average Point density:	> 20 points/m^2

March Survey

Table 6 - MCS airborne laser scanning survey parameters for the March snow-on flight.

Collection Dates, # Flights:	March 15, 2024, 1
Start time, end time (UTM):	15:51:46, 18:53:49
Flight parameters:	overlap: 50%, flying height: 3,000 ft a.s.l., flying Speed: 40 kn
System Operator:	Karina Zikan and Rainey Aberle
Pilot:	John Grommet
Base stations used:	Pilot Peak, Treeline, temporary base station
Average Point density:	> 20 points/m^2

April Survey

Table 7- MCS airborne laser scanning survey parameters for the April snow-on flight.

Collection Dates, # Flights:	April 28, 2024, 1
Start time, end time (UTM):	16:03:31,, 18:45:34
Flight parameters:	overlap: 50%, flying height: 3,000 ft a.s.l., flying Speed: 40 kn
System Operator:	Nani Ciafone and Naheem Adebisi
Pilot:	John Grommet
Base stations used:	Pilot Peak, Treeline
Average Point density:	> 20 points/m^2

Reference Map Collection

NV5 Geospatial was contracted by Boise State University to collect LiDAR data as part of NASA's SnowEx Program. Mores Creek Summit study area was surveyed with a Riegl VQ-1560ii sensor on September 17, 2021 as a part of this effort. The resulting 0.5-meter resolution bare-earth map serves as a reference DEM for snow depth mapping. Reference map details are available upon request.

System Parameters

Table 8 - Specifications of the Riegl VQ-580ii laser scanner.

Riegl VQ-580ii Airborne Laser Scanner (serial number H2225798)	
Parameter	**Specification**
Laser Wavelength	1064 nm
Accuracy	20 mm
Precision	20 mm
Pulse Repetition Rate	150 kHz to 2000 kHz
Scan Angle	75°
Beam Divergence	0.25 mrad

Table 9 - Specifications of the Applanix AP60 inertial measurement unit.

Applanix AP60 Inertial Measurement Unit (serial number 19560)	
Parameter	**Specification**
Embedded GNSS	L1/L2, GPS, GLONASS, BeiDou, Galileo, QZSS, SBAS, L-Band
Weight	2.6 kg
Size	179mm x 126mm x 127mm
Output refreshing rate	200 Hz
Time tagging	PPS output
Heading accuracy (PPK)	Up to 0.005°
Roll and pitch accuracy (PPK)	Up to 0.0025°
Horizontal Accuracy (PPK)	Typically <0.05 m
Vertical Accuracy (PPK)	Typically <0.10 m

Processing Workflow

ALS Data

1. Download laser scanner data and GNSS/INS data from the scanning system
2. Download base station data from the GNSS receivers
3. Post-process the GNSS/INS trajectory against the base station receivables to determine a Smoothed Best Estimate of Trajectory (SBET)
    - Software/application: Applanix POSPac software
4. Post-process the laser scanner data against the SBET to create a point cloud
    - Software/application: Riegl RiPROCESS software suite
5. Using planar features in the boresight survey, iteratively adjust sensor orientation parameters (roll, pitch, yaw) to improve the alignment between overlapping data. The orientation solution found during boresight alignment is applied to all AOI records.
    - Software/application: Riegl RiPROCESS software suite
6. Minimize offsets between scan data overlap using a least squares solution
    - Software/application: Riegl RiPROCESS software suite
7. Export the point cloud from the post processing software into a deliverable file format for all collection records
    - Software/application: Riegl RiPROCESS software suite

Post-processing with ice-road-copters

ice-road-copter suite (https://github.com/SnowEx/ice-road-copters) leverages Point Data Abstraction Library (PDAL) and NASA's Ames Stereo Pipeline (ASP) to create four DEM deliverables - (1) digital surface model (all surface points), (2) digital terrain model (all ground points), (3) snow depth model (the difference between the digital terrain model and reference DEM), and (4) a canopy height model (the difference between the digital surface model and reference DEM). A summary of point cloud processing via ice-road-copter can be found at the URL linked above.