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Fairbanks, Alaska USGS 3DEP LiDAR Technical Data Report

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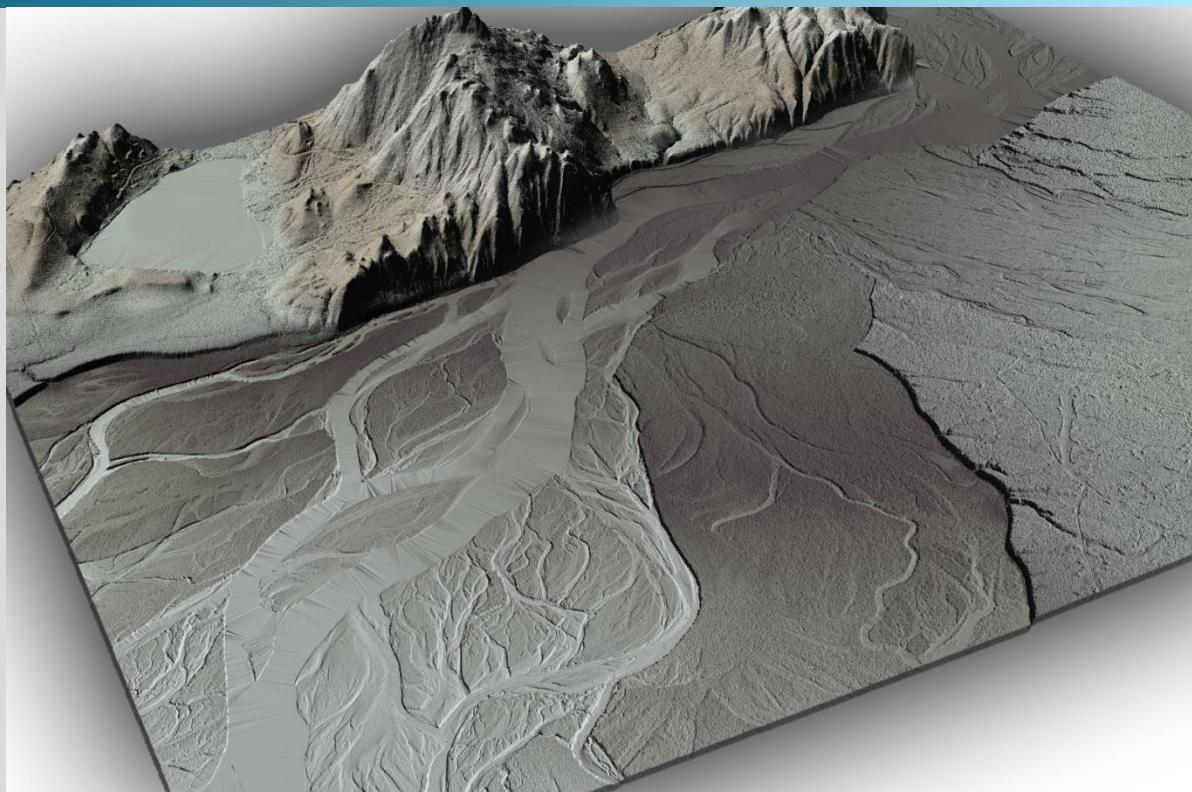
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Cover Photo: A view looking at the meandering channels of the Tanana River, created from the bare earth model and above-ground LiDAR point cloud, colored by elevation.

INTRODUCTION

This image shows a view of the confluence of the Tanana and Little Delta Rivers, created from the bare earth model colored by elevation.



In May 2017, Quantum Spatial (QSI) was contracted by the United States Geological Survey (USGS) to collect QL1 and QL2 Light Detection and Ranging (LiDAR) data over approximately 1.8 million acres of land for the Fairbanks 3DEP mapping site in Alaska (Task Order G17PD00606). Data were collected to aid USGS in assessing the topographic and geophysical properties of the study area to support the 3DEP mapping initiative.

QSI delivered the QL1 portion of the Fairbanks project area to USGS on March 16th, 2018. This report accompanies the delivered QL2 LiDAR data, and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final cumulative dataset including LiDAR accuracy and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to USGS is shown in Table 2, and the project extent is shown in Figure 1.

Table 1: Acquisition dates, acreage, and data types collected on the Fairbanks, Alaska sites

Project Site	Total Acres	Acquisition Dates	Data Type
Fairbanks QL1 Project Area	248,555	06/13/17 – 06/15/17, 06/19/17, 06/21/17, 06/22/17, 06/24/17, 06/26/17, 06/29/17, 07/01/17	QL1 LiDAR
Fairbanks QL2 Project Area	1,186,822	05/28/17 – 05/29/17, 05/31/17, 06/01/17, 06/03/17 – 06/10/17, 06/13/17 – 06/15/17, 06/22/17, 06/24/17, 06/26/17, 06/27/17, 09/03/17	QL2 LiDAR

Deliverable Products

Table 2: Products delivered to USGS for the Fairbanks, Alaska sites

Fairbanks, Alaska 3DEP LiDAR Products	
Projection: Alaska State Plane Zone 3	
Horizontal Datum: NAD83 (2011)	
Vertical Datum: NAVD88 (GEOID12B)	
Units: US Survey Feet	
Points	LAS v 1.2 <ul style="list-style-type: none">• All Classified Returns• Raw Unclassified Flightline Swaths
Rasters	1.5 Foot (QL1) & 3.0 Foot (QL2) GeoTiffs, Delineated in 3000 x 3000 foot tiles <ul style="list-style-type: none">• Hydroflattened Bare Earth Digital Elevation Model (DEM)• Highest Hit Digital Surface Model (DSM)• Intensity Images
Vectors	Shapefiles (*.shp) <ul style="list-style-type: none">• QL1 and QL2 Project Boundary• QL1 and QL2 LiDAR Tile Indices• 3D Water's Edge & Bridge Breaklines• 1.0 Foot Contours (QL1) and 2.0 Foot Contours (QL2)• Flightline Trajectories Ground Survey Shapefiles (*.shp) <ul style="list-style-type: none">• Non-Vegetated Quality Assurance Points• Vegetated Quality Assurance Points• Supplemental Ground Control Points• Ground Control Monuments

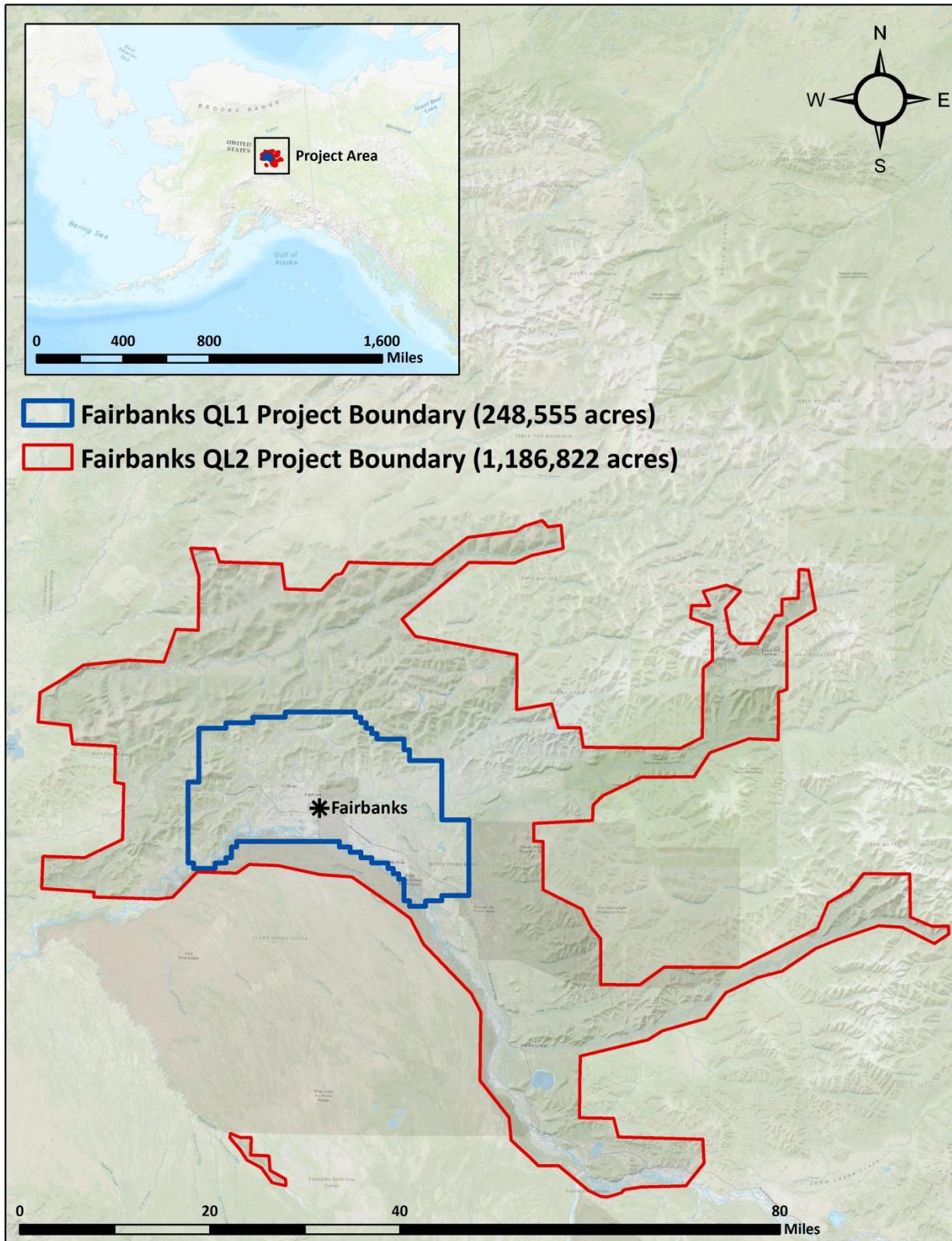


Figure 1: Location map of the Fairbanks, Alaska project sites

ACQUISITION

QSI's Cessna Caravan



Planning

In preparation for data collection, QSI reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Fairbanks, Alaska LiDAR study area at the target point density of ≥ 8.0 points/ m^2 (0.74 points/ ft^2) for QL1 areas, and 2.0 points/ m^2 (0.19 points/ ft^2) for QL2 areas. Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flights were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access and potential air space restrictions were reviewed.

Airborne LiDAR Survey

The LiDAR survey was accomplished using a Leica ALS70 system mounted in a Piper PA-31-350 aircraft. Table 3 summarizes the settings used to yield an average pulse density of $\geq 2-8$ pulses/m² over the Fairbanks, Alaska project area. The Leica ALS70 laser system can record unlimited range measurements (returns) per pulse. It is not uncommon for some types of surfaces (e.g., dense vegetation or water) to return fewer pulses to the LiDAR sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset.

Table 3: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications		
Project Area	Fairbanks QL1	Fairbanks QL2
Acquisition Dates	February 23 - 25, 2016	February 23 - 25, 2016
Aircraft Used	Piper PA-31-350	Piper PA-31-350
Sensor	Leica	Leica
Laser	ALS70	ALS70
Maximum Returns	Unlimited	Unlimited
Resolution/Density	Average 8 pulses/m ²	Average 2 pulses/m ²
Nominal Pulse Spacing	0.35 m	0.71 m
Survey Altitude (AGL)	1600 m	1600 m
Survey speed	150 knots	145 knots
Field of View	30°	30°
Mirror Scan Rate	44 Hz	50.2 Hz
Target Pulse Rate	350 kHz	175 kHz
Pulse Length	4 ns	9 ns
Laser Pulse Footprint Diameter	35 cm	35 cm
Central Wavelength	1064 nm	1064 nm
Pulse Mode	Multi Pulse in Air (2PiA)	Single Pulse in Air (SPiA)
Beam Divergence	22 mrad	22 mrad
Swath Width	850 m	850 m
Swath Overlap	60 %	28 %
Intensity	8-bit, scaled to 16-bit	8-bit, scaled to 16-bit
Accuracy	RMSE _Z (Non-Vegetated) \leq 10 cm	RMSE _Z (Non-Vegetated) \leq 10 cm
	NVA (95% Confidence Level) \leq 19.6 cm	NVA (95% Confidence Level) \leq 19.6 cm
	VVA (95 th Percentile) \leq 29.4 cm	VVA (95 th Percentile) \leq 29.4 cm

All areas were surveyed with an opposing flight line side-lap of $\geq 28\%$ ($\geq 52\%$ overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Position of the

aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

Ground Control

Ground control surveys, including monumentation and ground survey points (GSPs) were conducted by DOWL of Anchorage, Alaska, to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.



*DOWL Established
Monument*

Monumentation

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK) and post processed kinematic (PPK) survey techniques.

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI utilized nine existing monuments and nineteen newly established monuments for the Fairbanks, Alaska LiDAR project, with all coordinates and establishment provided by DOWL (Table 4, Figure 2).

Table 4: Monuments utilized for the Fairbanks, Alaska acquisition. Coordinates are on the NAD83 (2011) datum, epoch 2010.00

Monument ID	Latitude	Longitude	Ellipsoid (meters)
FNSB-1	64° 45' 28.11555"	-148° 22' 17.33039"	302.333
FNSB-2	64° 49' 00.21544"	-148° 02' 36.78724"	256.521
FNSB-3	64° 56' 44.32069"	-148° 19' 18.81493"	702.952
FNSB-4	64° 58' 38.10570"	-147° 32' 37.51023"	284.831
FNSB-5	64° 59' 01.75611"	-147° 51' 05.02068"	537.789
FNSB-6	65° 04' 58.87922"	-147° 42' 52.87523"	177.133
FNSB-7	65° 09' 39.14576"	-147° 56' 26.40890"	394.391
FNSB-8	65° 06' 59.67097"	-147° 30' 11.48115"	207.331
FNSB-9	65° 09' 57.09579"	-147° 18' 20.47569"	235.840
FNSB-10	65° 13' 31.69210"	-147° 07' 31.41685"	290.609
FNSB-11	64° 53' 18.91420"	-147° 37' 13.51393"	239.139
FNSB-13	64° 53' 39.85693"	-146° 40' 19.71035"	205.290
FNSB-15	64° 42' 08.80014"	-147° 08' 30.30564"	172.938
FNSB-16	64° 34' 13.52129"	-147° 02' 33.42564"	190.675
FNSB-17	64° 32' 41.33510"	-146° 48' 51.09965"	339.233
FNSB-18	64° 17' 15.75582"	-146° 28' 48.04940"	268.402
FNSB-19	64° 54' 09.85252"	-146° 21' 39.53274"	241.564

Monument ID	Latitude	Longitude	Ellipsoid (meters)
FNSB-20	64° 19' 52.64774"	-146° 46' 15.67016"	313.994
FNSB-24	65° 02' 48.56178"	-147° 26' 12.21539"	691.712
BADGER R 3.7	64° 49' 58.14467"	-147° 29' 17.62768"	150.235
BALLAINE	64° 55' 39.43611"	-147° 51' 56.57998"	253.785
CHENA 1990	65° 03' 26.15266"	-146° 03' 39.15766"	369.553
CHENA WEST BASE	64° 51' 20.78752"	-147° 51' 52.12714"	152.364
CLGO	64° 52' 25.58664"	-147° 51' 37.64959"	195.798
FAI1	64° 48' 34.67310"	-147° 50' 50.31850"	149.591
FAIR	64° 58' 40.79452"	-147° 29' 57.15692"	318.724
GV 69A	64° 28' 10.98715"	-146° 55' 42.38180"	209.324
TRYPHS	64° 24' 24.00713"	-146° 55' 02.80906"	260.898

During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS¹) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Ground Survey Points (GSPs)

Ground survey points were collected by DOWL, using real time kinematic (RTK) and post-processed kinematic (PPK) survey techniques. Relative errors for any GSP position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. See Appendix B for a full Survey Report provided by DOWL.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however the distribution of GSPs depended on ground access constraints and monument locations and may not be equitably distributed throughout the study area (Figure 2).

Land Cover Class

In addition to ground survey points, DOWL collected land cover class check points throughout the study area to evaluate non-vegetated and vegetated vertical accuracy. Vertical accuracy statistics were calculated for non-vegetated and vegetated land cover types to assess confidence in the LiDAR derived ground models (Table 5, see LiDAR Accuracy Assessments, page 23).

¹ OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions.
<http://www.ngs.noaa.gov/OPUS>.

Table 5: Land Cover Types and Descriptions

Land cover type	Description	Photo	Accuracy Assessment Type
Forested	Forested, fully covered by trees (e.g. deciduous, evergreens, mixed forests)	 A surveyor wearing a yellow vest and cap stands in a forest, holding a tripod-mounted GNSS receiver. The ground is covered with moss and low-lying vegetation.	VVA
Grass and Weeds	High grass, weeds, and crops (e.g. hay fields, sea grass, tundra)	 A surveyor in a yellow vest stands in a tall grassy field, holding a GNSS receiver. A dirt path leads through the grass towards a treeline.	VVA
Brush	Brush lands and low trees (e.g. willow brush, alder brush, berry brush)	 A surveyor in a yellow vest stands in a dense area of low shrubs and small trees, holding a GNSS receiver.	VVA
Bare Earth	Bare earth and low grass (e.g. plowed fields, lawns, golf courses)	 A surveyor in a yellow vest stands on a large, flat, brown expanse of bare earth, holding a GNSS receiver.	NVA
Urban	Urban areas (e.g. high, dense manmade structures)	 A surveyor in a yellow vest stands on a paved asphalt road, holding a GNSS receiver. Residential buildings are visible in the background.	NVA

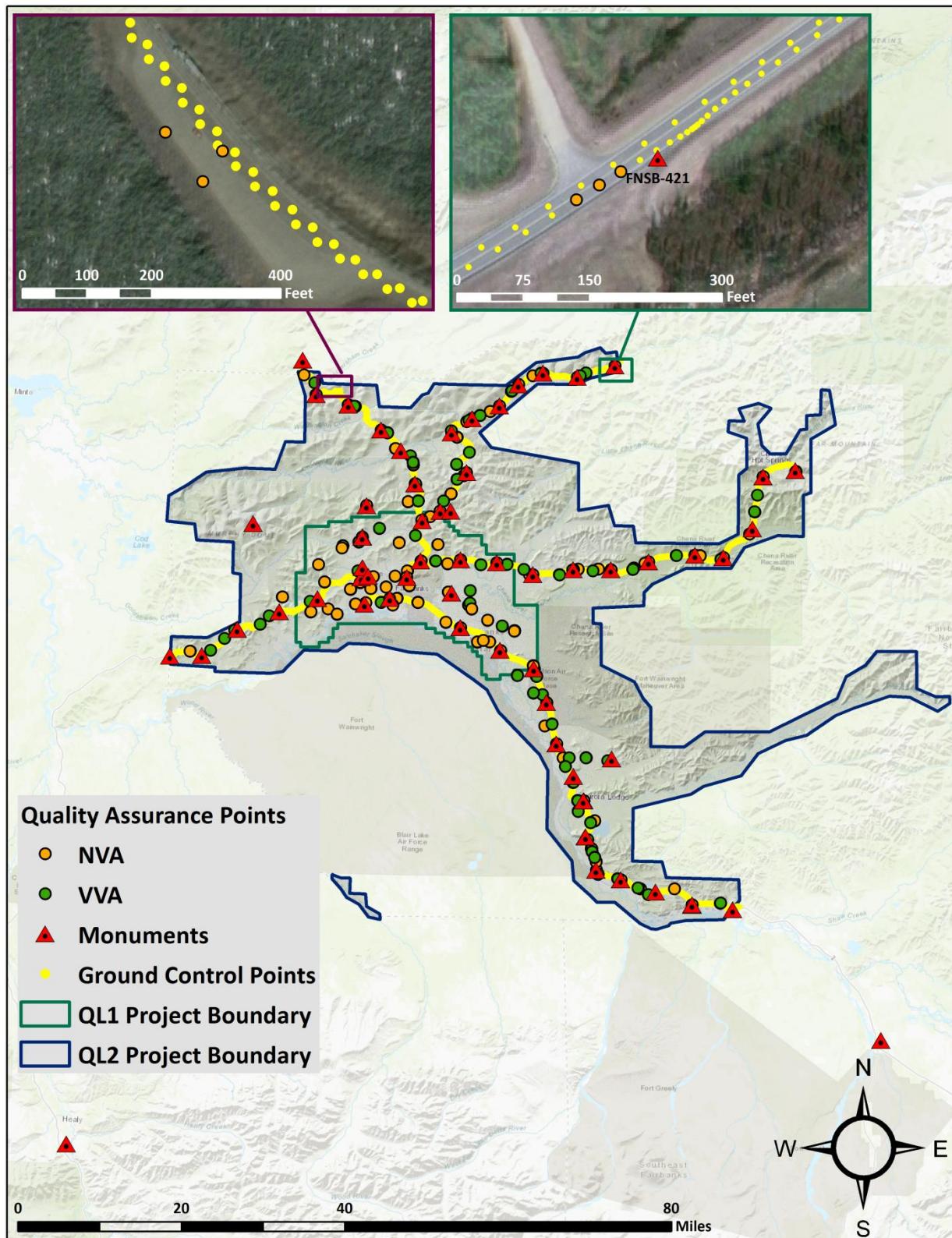
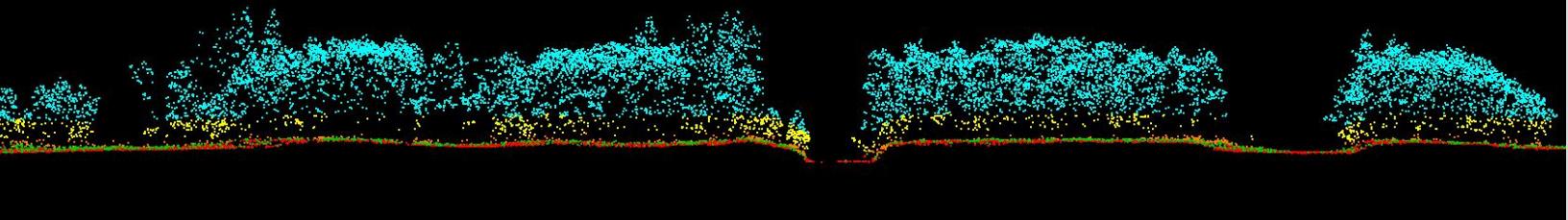


Figure 2: Ground survey location map

PROCESSING

Default	
Ground	
Low Veg	
Medium Veg	
High Veg	

This LiDAR cross section shows a view of the Fairbanks QL2 project area, colored by point classification.



LiDAR Data

Upon completion of data acquisition, QSI processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, sensor and data calibration for optimal relative and absolute accuracy, and LiDAR point classification (Table 6). Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 7.

Table 6: ASPRS LAS classification standards applied to the Fairbanks, Alaska dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
1WO	Default/Unclassified – Withheld Overlap	Laser returns that are deemed not necessary to form a complete single, non-overlapped, gap free coverage with respect to adjacent swaths
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
3	Low Vegetation	Any vegetation within 0.5 – 2.0 meters of the ground surface
4	Medium Vegetation	Any vegetation within 2.0 – 6.0 meters of the ground surface
5	High Vegetation	Any vegetation greater than 6.0 meters above the ground surface
7W	Noise - Withheld	Laser returns that are often associated with birds, scattering from reflective surfaces, or artificial points below the ground surface

Classification Number	Classification Name	Classification Description
9	Water	Laser returns that are determined to be water using automated and manual cleaning algorithms
10	Ignored Ground	Ground points proximate to water's edge breaklines; ignored for correct model creation
17	Bridge	Bridge decks

Table 7: LiDAR processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	Waypoint Inertial Explorer v.8.6
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Convert data to orthometric elevations by applying a geoid correction.	Waypoint Inertial Explorer v.8.6 Leica Cloudpro v. 1.2.2
Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.17
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	TerraMatch v.17
Classify resulting data to ground and other client designated ASPRS classifications (Table 6). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.17 TerraModeler v.17
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface models as GeoTIFFs at a 1.5 foot (QL1) or 3.0 foot (QL2) pixel resolution pixel resolution.	TerraScan v.17 TerraModeler v.17 ArcMap v. 10.2.2
Export intensity images as GeoTIFFs at a 1.5 foot (QL1) or 3.0 foot (QL2) pixel resolution pixel resolution.	Las Monkey 2.2.2 (QSI proprietary) LAS Product Creator 1.5 (QSI proprietary) ArcMap v. 10.2.2

Feature Extraction

Hydroflattening and Water's Edge Breaklines

The Tanana River and other water bodies within the project area were flattened to a consistent water level. Bodies of water that were flattened include lakes and other closed water bodies with a surface area greater than 2 acres, all streams and rivers that are nominally wider than 30 meters, all non-tidal waters bordering the project, and select smaller bodies of water as feasible. The hydroflattening process eliminates artifacts in the digital terrain model caused by both increased variability in ranges or dropouts in laser returns due to the low reflectivity of water.

Hydroflattening of closed water bodies was performed through a combination of automated and manual detection and adjustment techniques designed to identify water boundaries and water levels. Boundary polygons were developed using an algorithm which weights LiDAR-derived slopes, intensities, and return densities to detect the water's edge. The water edges were then manually reviewed and edited as necessary.

Once polygons were developed the initial ground classified points falling within water polygons were reclassified as water points to omit them from the final ground model. Elevations were then obtained from the filtered LiDAR returns to create the final breaklines. Lakes were assigned a consistent elevation for an entire polygon while rivers were assigned consistent elevations on opposing banks and smoothed to ensure downstream flow through the entire river channel.

Water boundary breaklines were then incorporated into the hydroflattened DEM by enforcing triangle edges (adjacent to the breakline) to the elevation values of the breakline. This implementation corrected interpolation along the hard edge. Water surfaces were obtained from a TIN of the 3D water edge breaklines resulting in the final hydroflattened model (Figure 3).

Contours

Contour generation from LiDAR point data required a thinning operation in order to reduce contour sinuosity. The thinning operation reduced point density where topographic change is minimal (i.e., flat surfaces) while preserving resolution where topographic change was present. Contour key points were selected from the ground model every 20 feet with the spacing decreased in regions with high surface curvature. Generation of contour key points eliminated redundant detail in terrain representation, particularly in areas of low relief, and provided for a more manageable dataset. Contours were produced through TerraModeler by interpolating between the contour key points at even elevation increments.

Elevation contour lines were then intersected with ground point density rasters and a confidence field was added to each contour line. Contours which crossed areas of high point density have high confidence levels, while contours which crossed areas of low point density have low confidence levels. Areas with low ground point density are commonly beneath buildings and bridges, in locations with dense vegetation, over water, and in other areas where laser penetration to the ground surface was impeded.

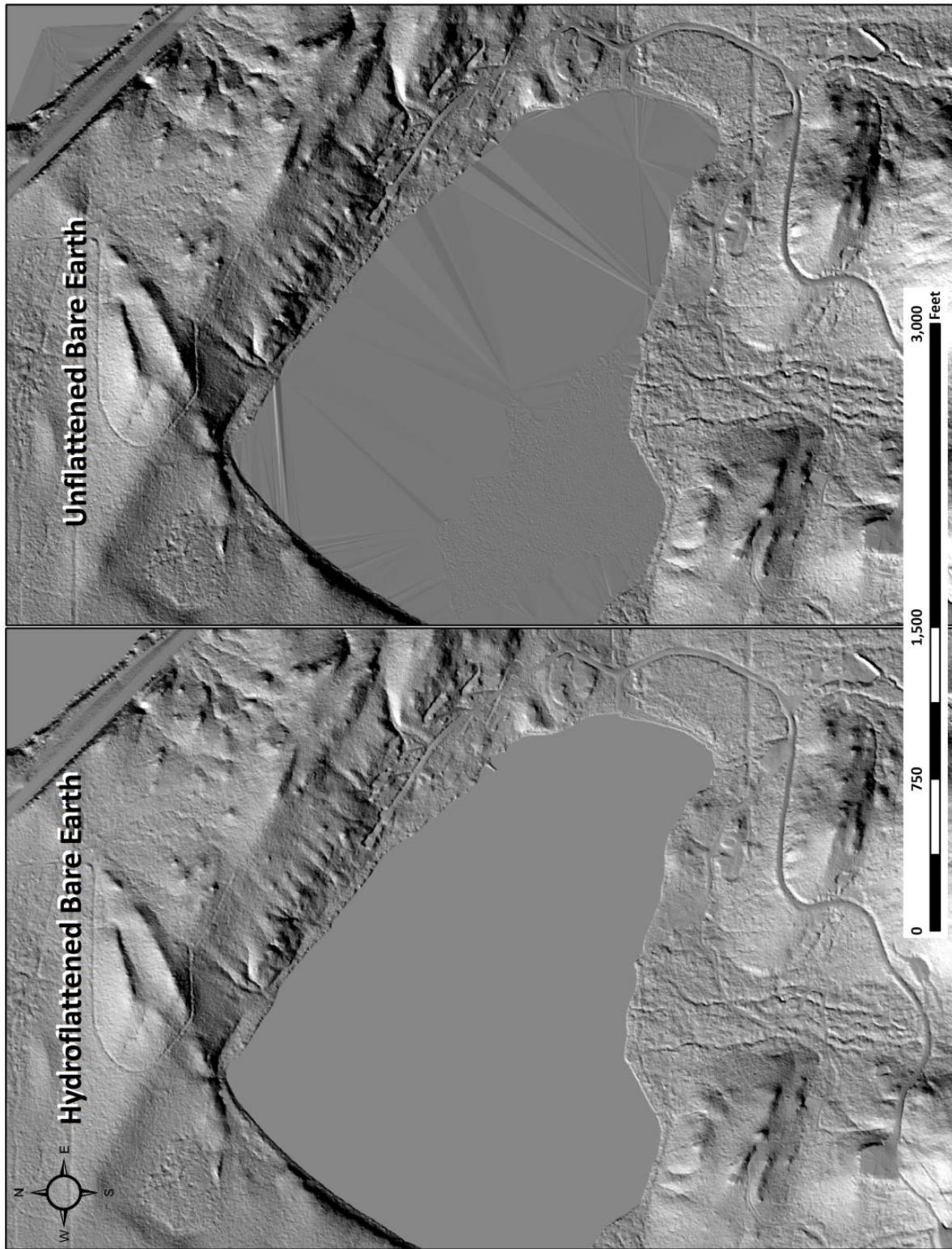
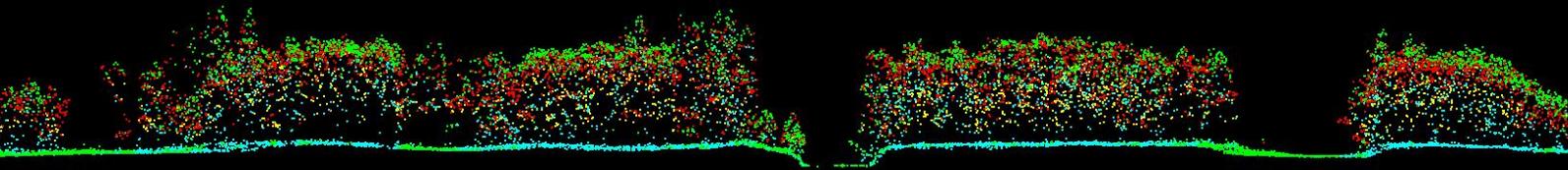


Figure 3: Example of hydroflattening in the Fairbanks, Alaska LiDAR dataset

RESULTS & DISCUSSION

Only Echo	
First of Many	
Intermediate	
Last of Many	

This same LiDAR cross section as above, showing the Fairbanks QL2 landscape in the point cloud, colored by laser point echo.



LiDAR Density

The acquisition parameters were designed to acquire an average first-return density of ≥ 8.0 points/ m^2 (0.74 points/ ft^2) for QL1 areas, and 2.0 points/ m^2 (0.19 points/ ft^2) for QL2 areas. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water and steep slopes) may have returned fewer pulses than originally emitted by the laser. First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The density of ground-classified LiDAR returns was also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may penetrate the canopy, resulting in lower ground density.

The average first-return density of LiDAR data for the Fairbanks, Alaska QL1 project area was 1.38 points/ ft^2 (14.83 points/ m^2) while the average ground classified density was 0.17 points/ ft^2 (1.79 points/ m^2). The average first-return density of LiDAR data for the Fairbanks, Alaska QL2 project area was 0.24 points/ ft^2 (2.59 points/ m^2) while the average ground classified density was 0.09 points/ ft^2 (0.93 points/ m^2) (Table 8). The statistical and spatial distributions of first return densities and classified ground return densities per $100\text{ m} \times 100\text{ m}$ cell are portrayed in Figure 4 through Figure 9.

Table 8: Average LiDAR point densities

Project Site	Point Density Type	
	First Return	Ground Classified
QL1 AOI	1.38 points/ ft^2 14.83 points/ m^2	0.17 points/ ft^2 1.79 points/ m^2
QL2 AOI	0.24 points/ ft^2 2.59 points/ m^2	0.09 points/ ft^2 0.93 points/ m^2

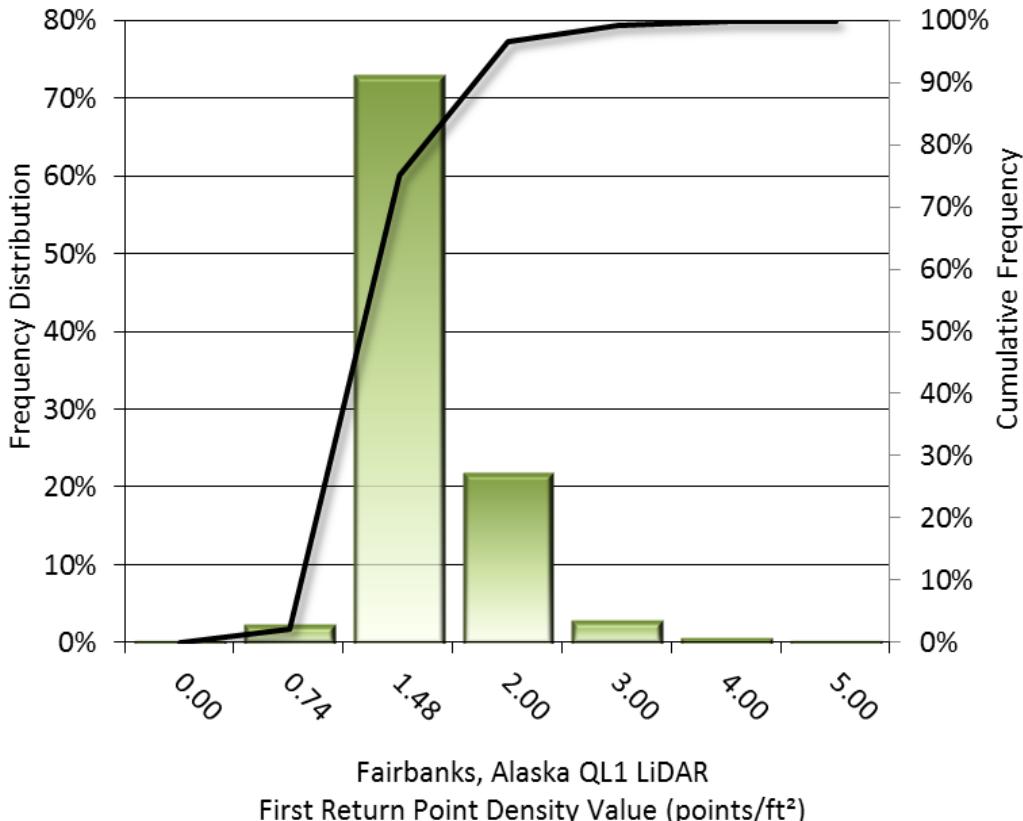


Figure 4: Frequency distribution of Fairbanks QL1 first return point density values per 100 x 100 m cell

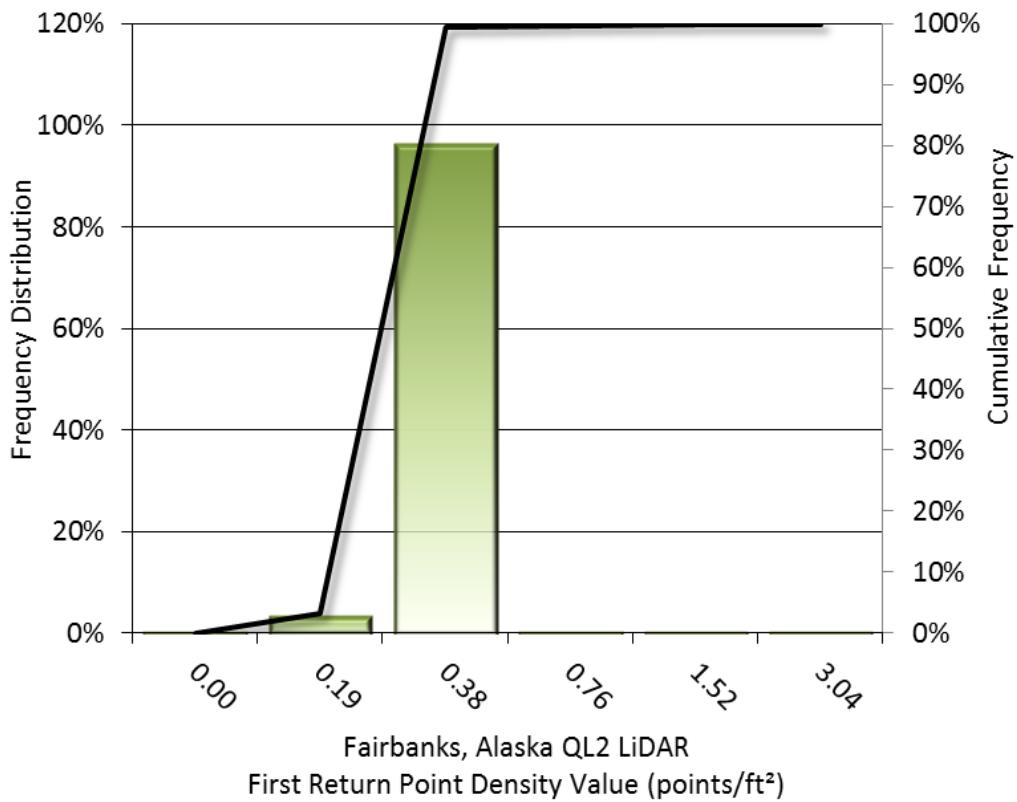


Figure 5: Frequency distribution of Fairbanks QL2 first return point density values per 100 x 100 m cell

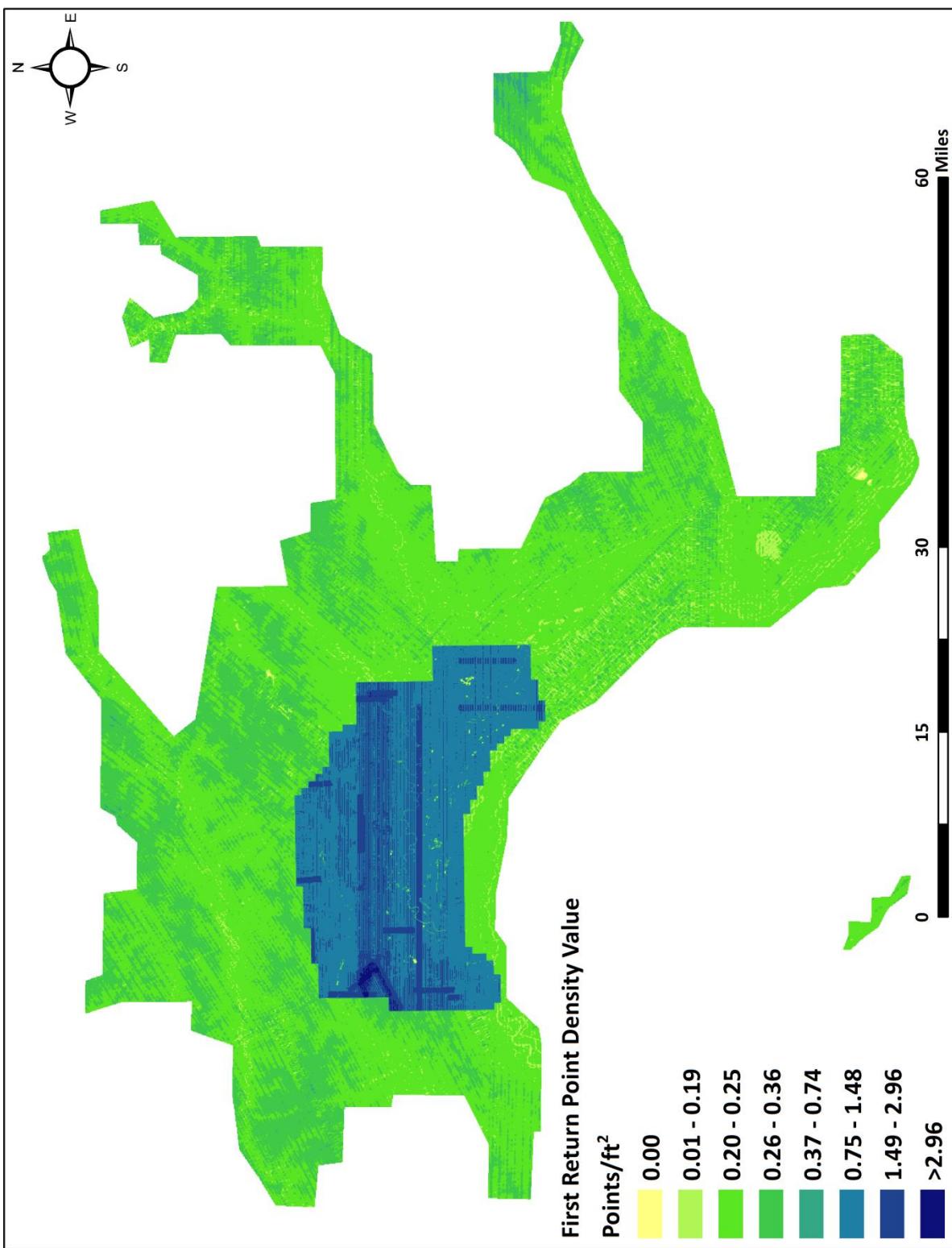


Figure 6: First return point density map for the Fairbanks, Alaska sites (100 m x 100 m cells)

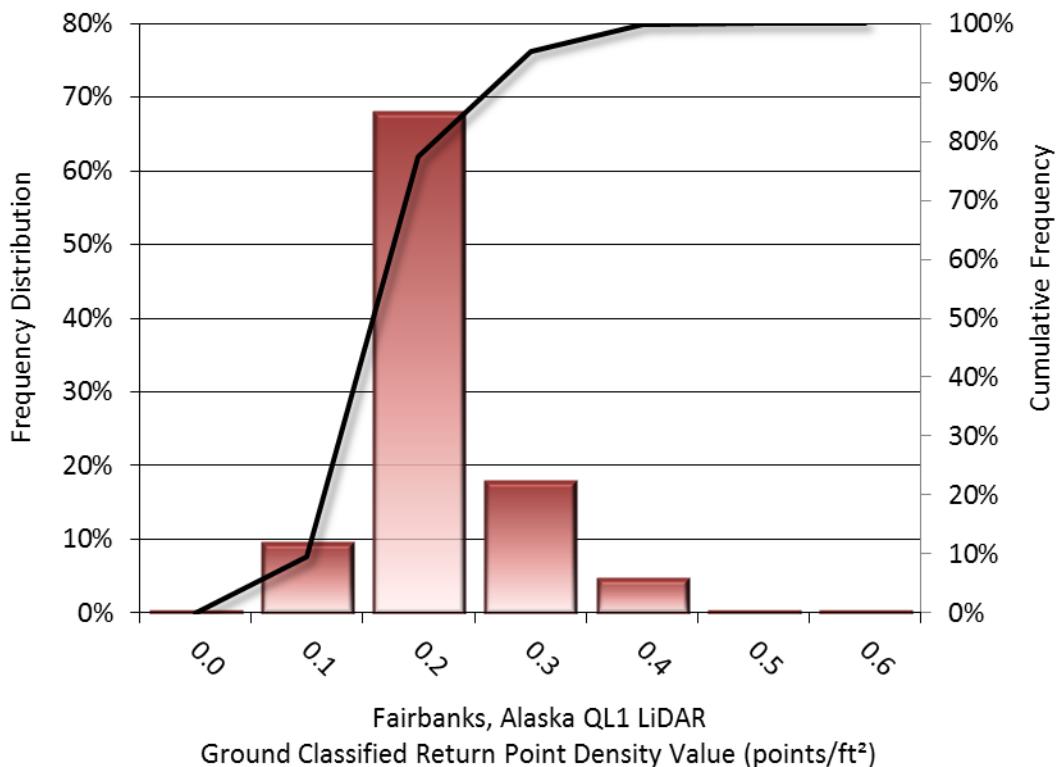


Figure 7: Frequency distribution of Fairbanks QL1 ground-classified return point density values per 100 x 100 m cell

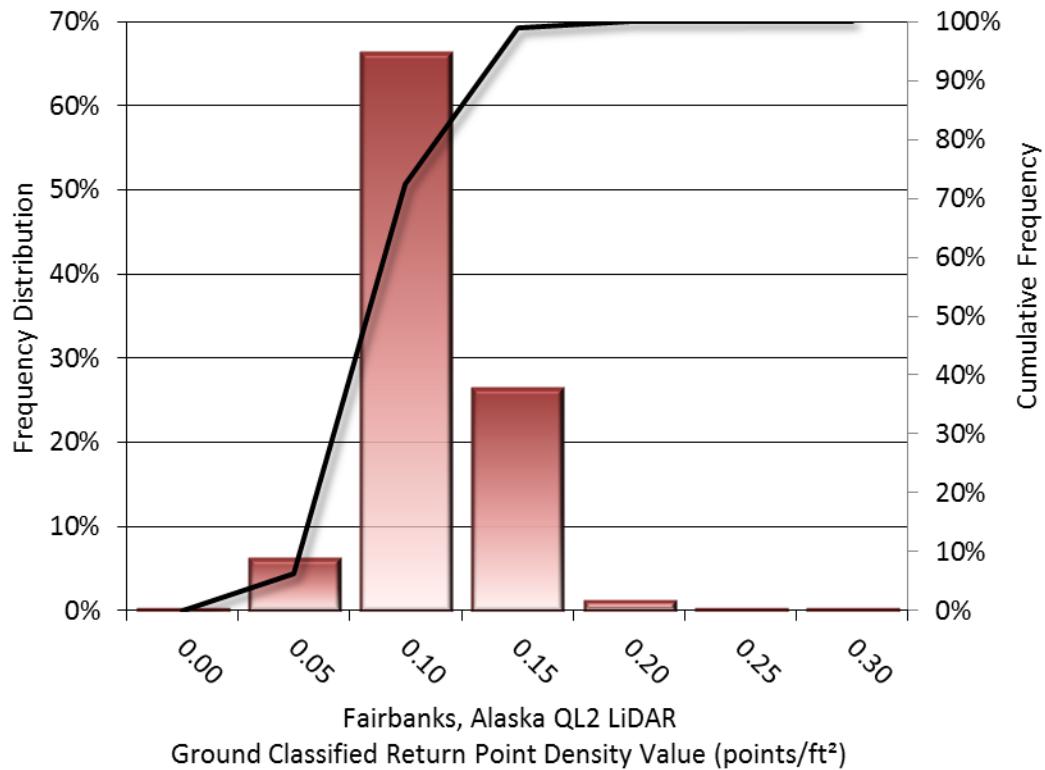


Figure 8: Frequency distribution of Fairbanks QL2 ground-classified return point density values per 100 x 100 m cell

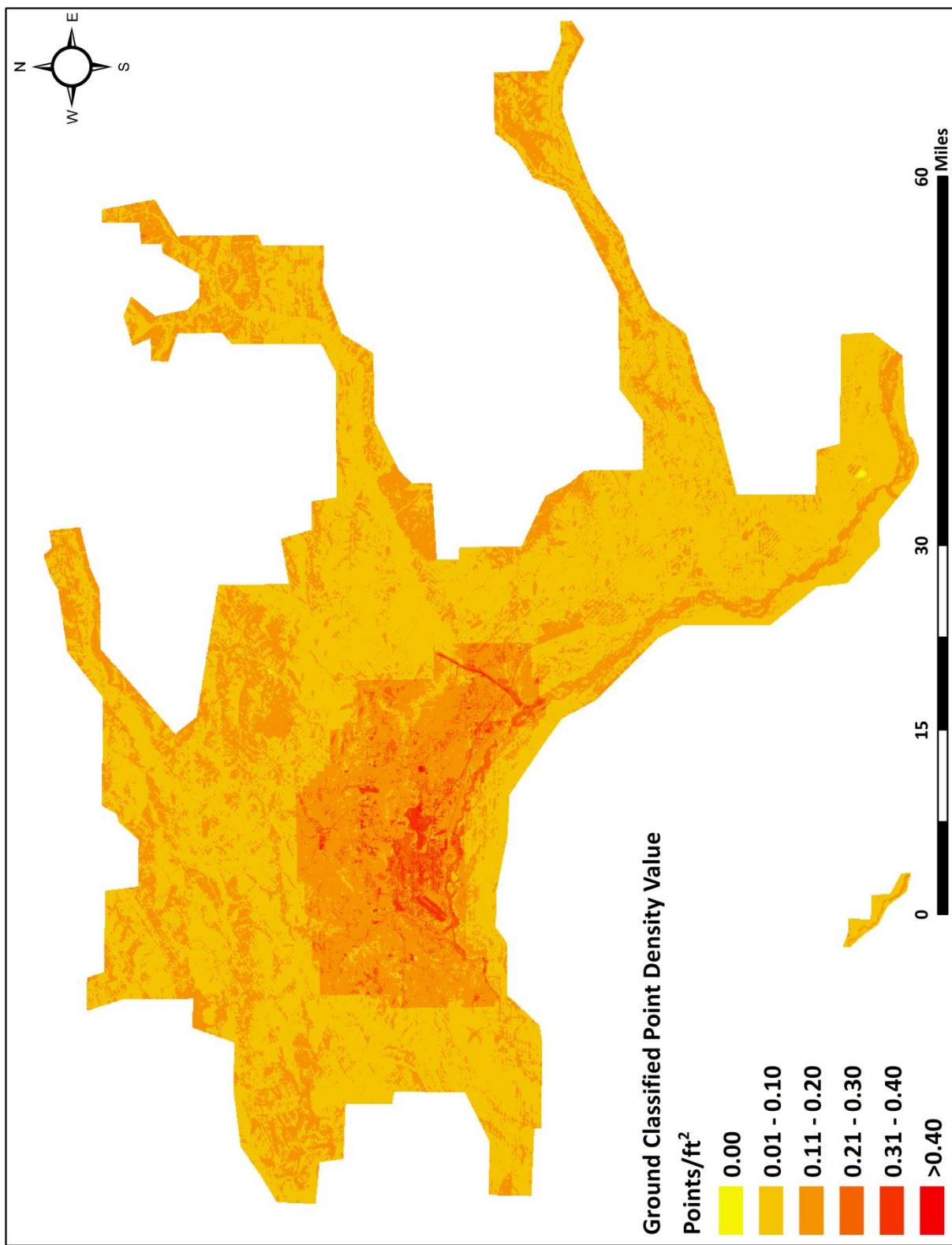


Figure 9: Ground point density map for the Fairbanks, Alaska sites (100 m x 100 m cells)

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

LiDAR Non-Vegetated Vertical Accuracy

Absolute accuracy was assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy². NVA compares known ground quality assurance point data collected on open, bare earth surfaces with level slope (<20°) to the triangulated surface generated by the LiDAR points. NVA is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 9.

The mean and standard deviation (sigma σ) of divergence of the ground surface model from quality assurance point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics.

For the Fairbanks, Alaska QL1 survey, 125 quality assurance points were collected by DOWL, resulting in a non-vegetated vertical accuracy of 0.305 feet (0.093 meters), as compared to the bare earth DEM, and 0.404 feet (0.123 meters) as compared to the unclassified point cloud, with 95% confidence. For the QL2 survey, 196 quality assurance points were collected by DOWL, resulting in a non-vegetated vertical accuracy of 0.311 feet (0.095 meters), as compared to the bare earth DEM, and 0.357 feet (0.109 meters) as compared to the unclassified point cloud, with 95% confidence.

In total, 321 quality assurance points were collected over non-vegetated surfaces for the Fairbanks, Alaska project, with resulting cumulative non-vegetated vertical accuracy of 0.309 feet (0.094 meters), as compared to the bare earth DEM (Figure 10), and 0.376 feet (0.115 meters) as compared to the unclassified point cloud (Figure 11), with 95% confidence (Table 9).

² Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. <http://www.asprs.org/PAD-Division/ASPRS-POSITIONAL-ACCURACY-STANDARDS-FOR-DIGITAL-GEOSPATIAL-DATA.html>.

Table 9: Final Non-Vegetated Vertical Accuracy Results

Non-Vegetated Vertical Accuracy (NVA) Results						
	QL1 NVA (compared to Bare Earth DEM)	QL1 NVA (compared to Unclassified LAS)	QL2 NVA (compared to Bare Earth DEM)	QL2 NVA (compared to Unclassified LAS)	Cumulative NVA (DEM)	Cumulative NVA (LAS)
Sample	125 points	125 points	196 points	196 points	321 points	321 points
95% Confidence (1.96*RMSE)	0.305 ft 0.093 m	0.404 ft 0.123 m	0.311 ft 0.095m	0.357 ft 0.109 m	0.309 ft 0.094 m	0.376 ft 0.115 m
Average	0.002 ft 0.001 m	0.119 ft 0.036 m	0.031 ft 0.009 m	0.084 ft 0.026 m	0.020 ft 0.006 m	0.098 ft 0.030 m
Median	0.003 ft 0.001 m	0.122 ft 0.037 m	0.039 ft 0.012 m	0.086 ft 0.026 m	0.027 ft 0.008 m	0.097 ft 0.030 m
RMSE	0.156 ft 0.047 m	0.206 ft 0.063 m	0.159 ft 0.048 m	0.182 ft 0.056 m	0.158 ft 0.048 m	0.192 ft 0.058 m
Standard Deviation (1σ)	0.156 ft 0.048 m	0.169 ft 0.052 m	0.156 ft 0.048 m	0.162 ft 0.049 m	0.157 ft 0.048 m	0.165 ft 0.050 m

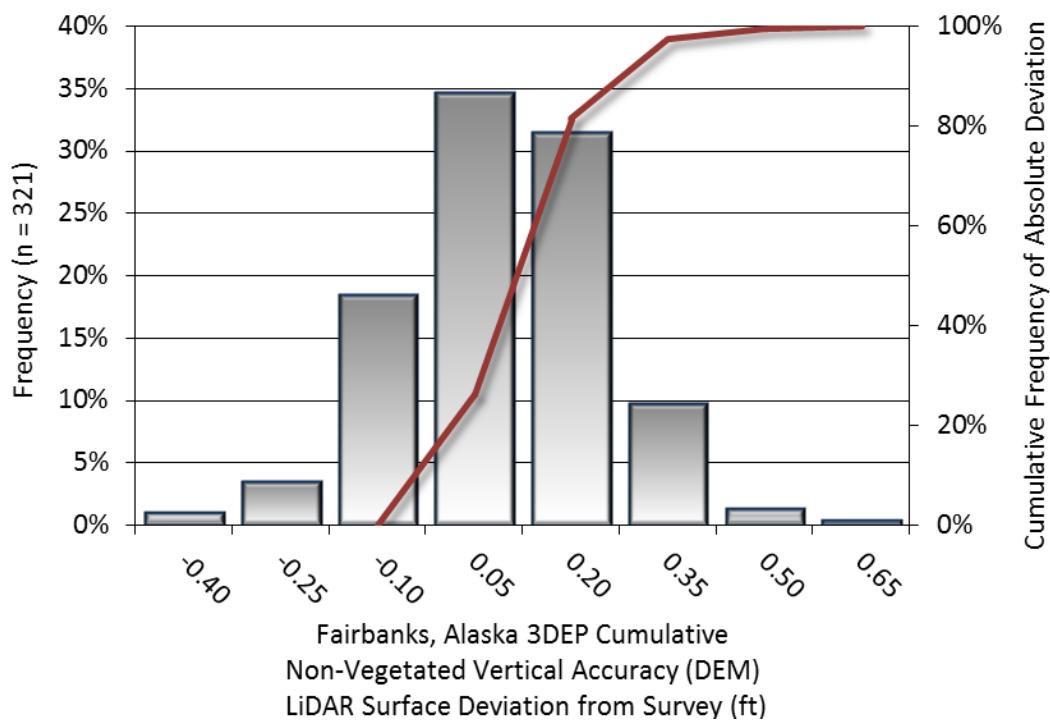


Figure 10: Frequency histogram for LiDAR bare earth surface deviation from quality assurance points (NVA)

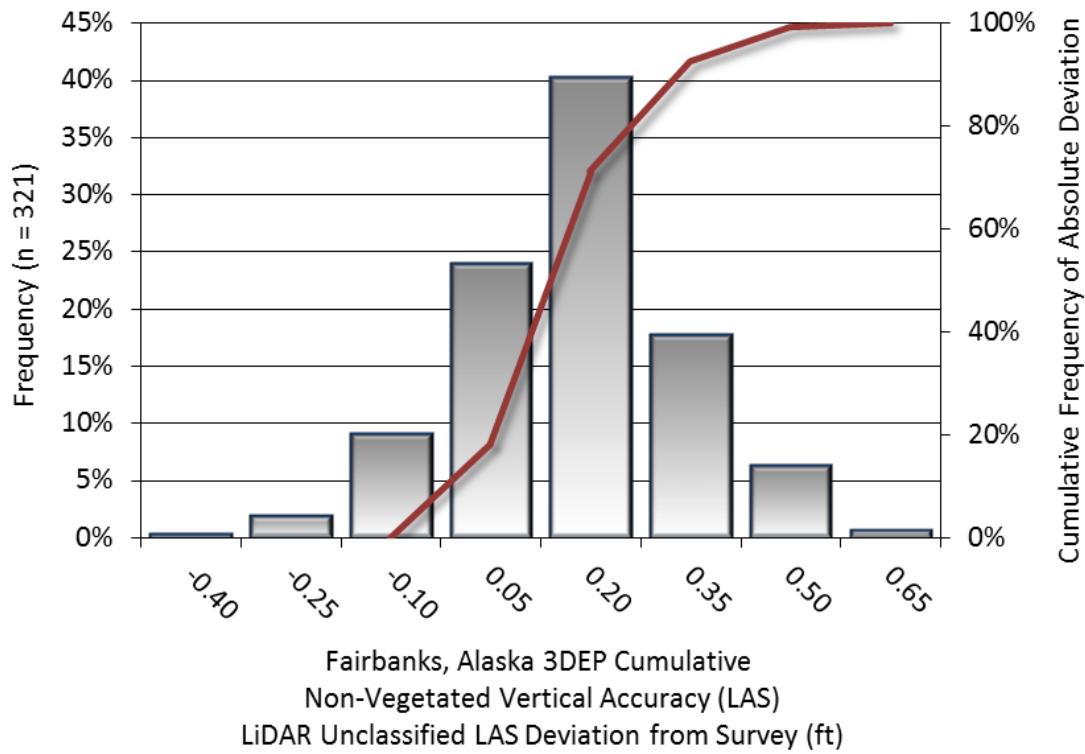


Figure 11: Frequency histogram for unclassified LAS from quality assurance point values (NVA)

LiDAR Vegetated Vertical Accuracies

Vertical accuracy was also evaluated using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground check point data collected over vegetated surfaces using land class descriptions to the triangulated ground surface generated by the ground classified LiDAR points. VVA is evaluated at the 95th percentile (Table 10).

For the Fairbanks, Alaska QL1 survey, 56 vegetated check points were collected by DOWL, with resulting vegetated vertical accuracy of 0.611 feet (0.186 meters), evaluated at the 95th percentile. For the QL2 survey, 163 vegetated check points were collected by DOWL, with resulting vegetated vertical accuracy of 0.724 feet (0.221 meters), evaluated at the 95th percentile.

In total, 321 quality assurance points were collected over vegetated surfaces for the Fairbanks, Alaska project, with resulting cumulative vegetated vertical accuracy of 0.687 feet (0.209 meters), evaluated at the 95th percentile (Table 10, Figure 12).

QSI also assessed absolute accuracy using 51,344 ground control points. Although these points were used in the calibration and post-processing of the LiDAR point cloud, they still provide a good indication of the overall accuracy of the LiDAR dataset, and therefore have been provided in Table 10 and Figure 13.

Table 10: Final Vegetated Vertical Accuracy Results

Vegetated Vertical Accuracy (VVA) Results				
	QL1 VVA	QL2 VVA	Cumulative VVA	Ground Control Points
Sample	56 points	163 points	219 points	51,344 points
95th Percentile	0.611 ft 0.186 m	0.724 ft 0.221 m	0.687 ft 0.209 m	N/A
Average	0.213 ft 0.065 m	0.257 ft 0.078 m	0.246 ft 0.075 m	-0.016 ft -0.020 m
Median	0.257 ft 0.078 m	0.281 ft 0.086 m	0.280 ft 0.085 m	-0.010 ft -0.055 m
RMSE	0.343 ft 0.105 m	0.380 ft 0.116 m	0.371 ft 0.113 m	0.130 ft 0.068 m
Standard Deviation (1σ)	0.271 ft 0.083 m	0.281 ft 0.086 m	0.279 ft 0.085 m	0.129 ft 0.065 m

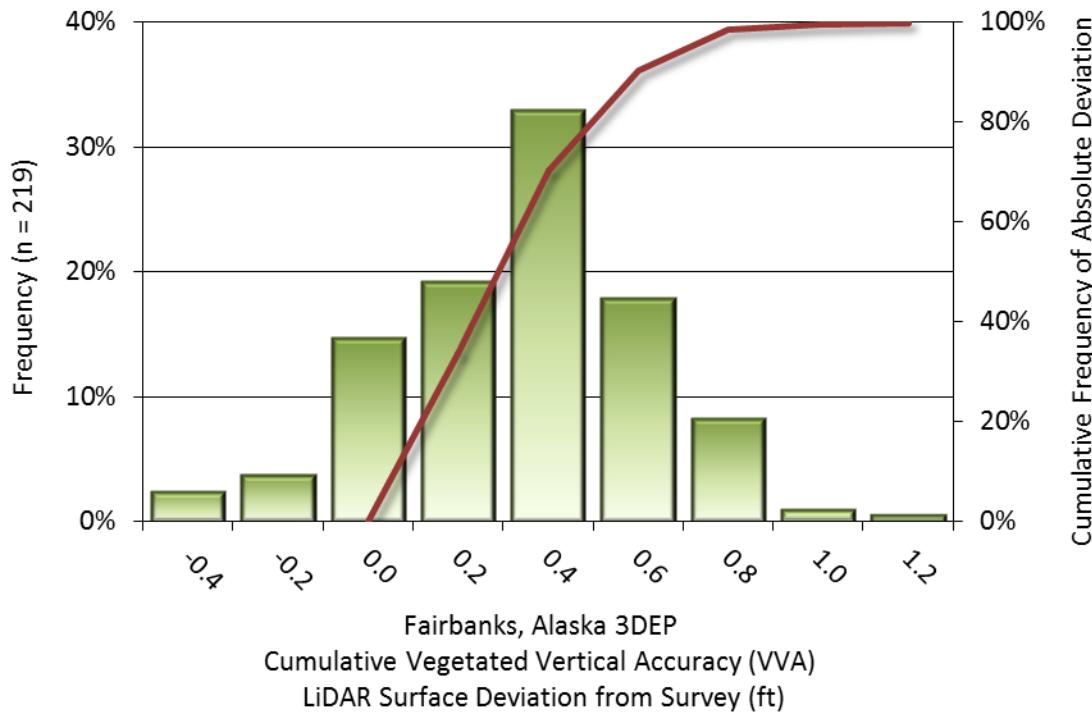


Figure 12: Frequency histogram for cumulative LiDAR surface deviation from all land cover class point values (VVA)

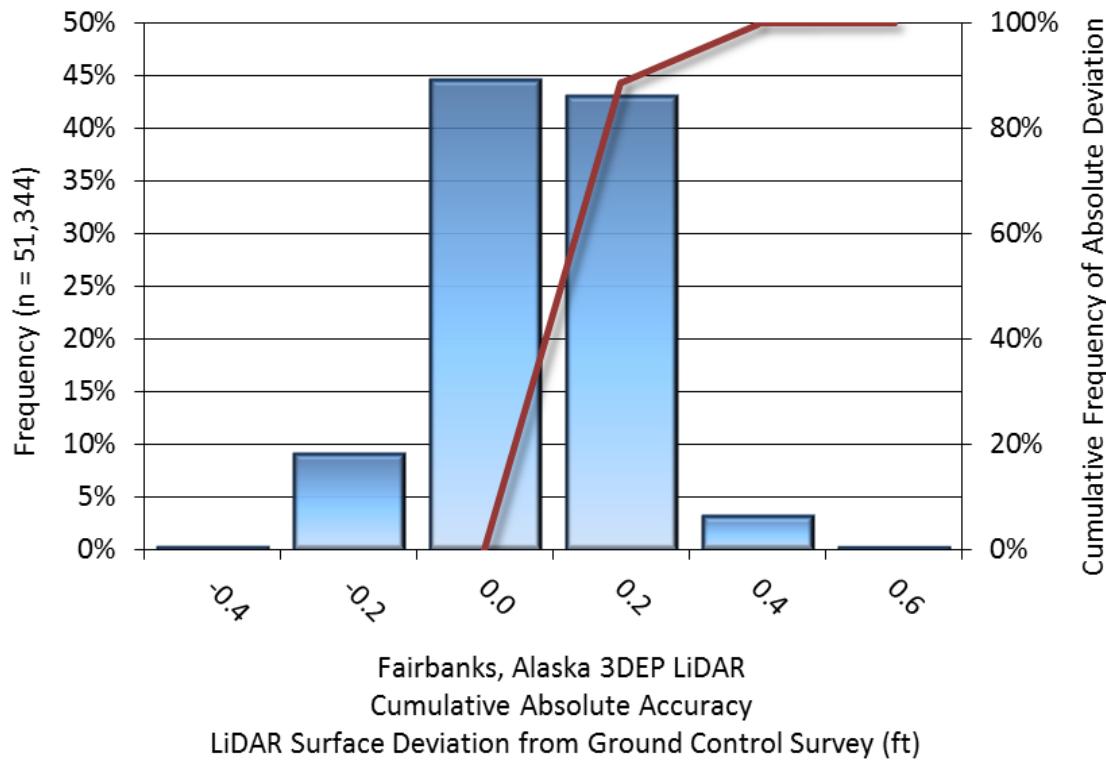


Figure 13: Frequency histogram for LiDAR surface deviation from ground control point values

LiDAR Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the LiDAR system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line cumulative relative vertical accuracy for the Fairbanks, Alaska LiDAR project was 0.160 feet (0.049 meters) (Table 11, Figure 14).

Table 11: Relative accuracy results

Relative Accuracy			
	QL1	QL2	Cumulative
Sample	164 surfaces	771 surfaces	935 surfaces
Average	0.151 ft 0.045 m	0.178 ft 0.054 m	0.160 ft 0.049 m
Median	0.152 ft 0.046 m	0.180 ft 0.055 m	0.177 ft 0.054 m
RMSE	0.155 ft 0.047 m	0.180 ft 0.055 m	0.176 ft 0.054 m
Standard Deviation (1σ)	0.026 ft 0.007 m	0.024 ft 0.007 m	0.026 ft 0.008 m
1.96σ	0.051 ft 0.014 m	0.048 ft 0.015 m	0.051 ft 0.016 m

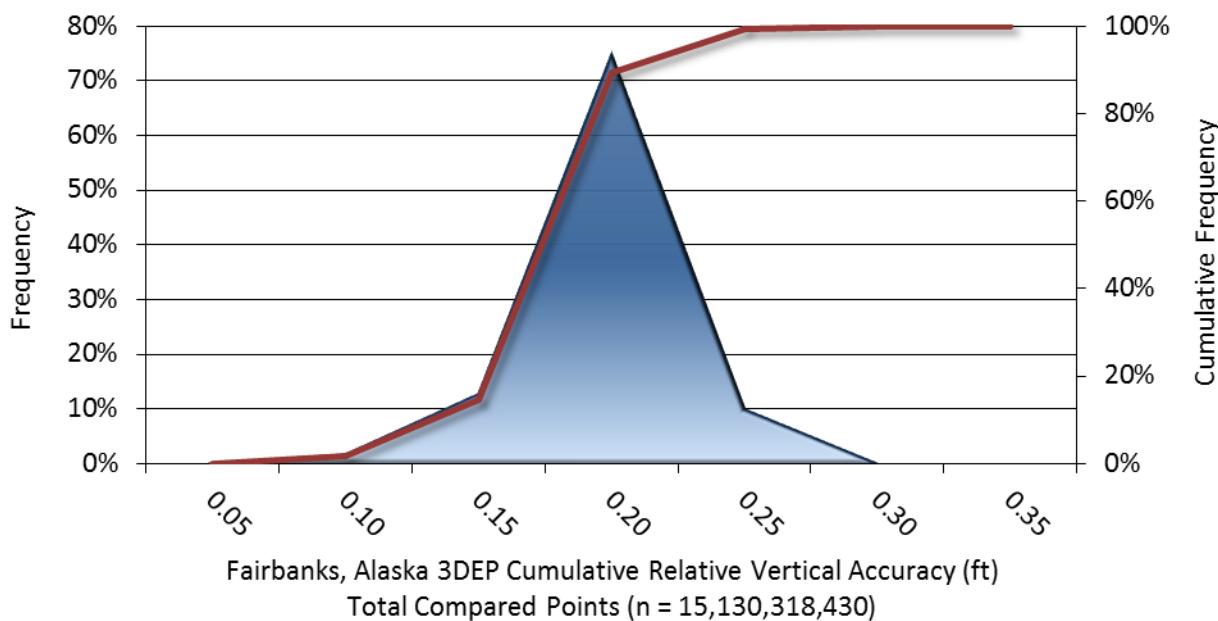


Figure 14: Frequency plot for relative vertical accuracy between flight lines

SELECTED IMAGES

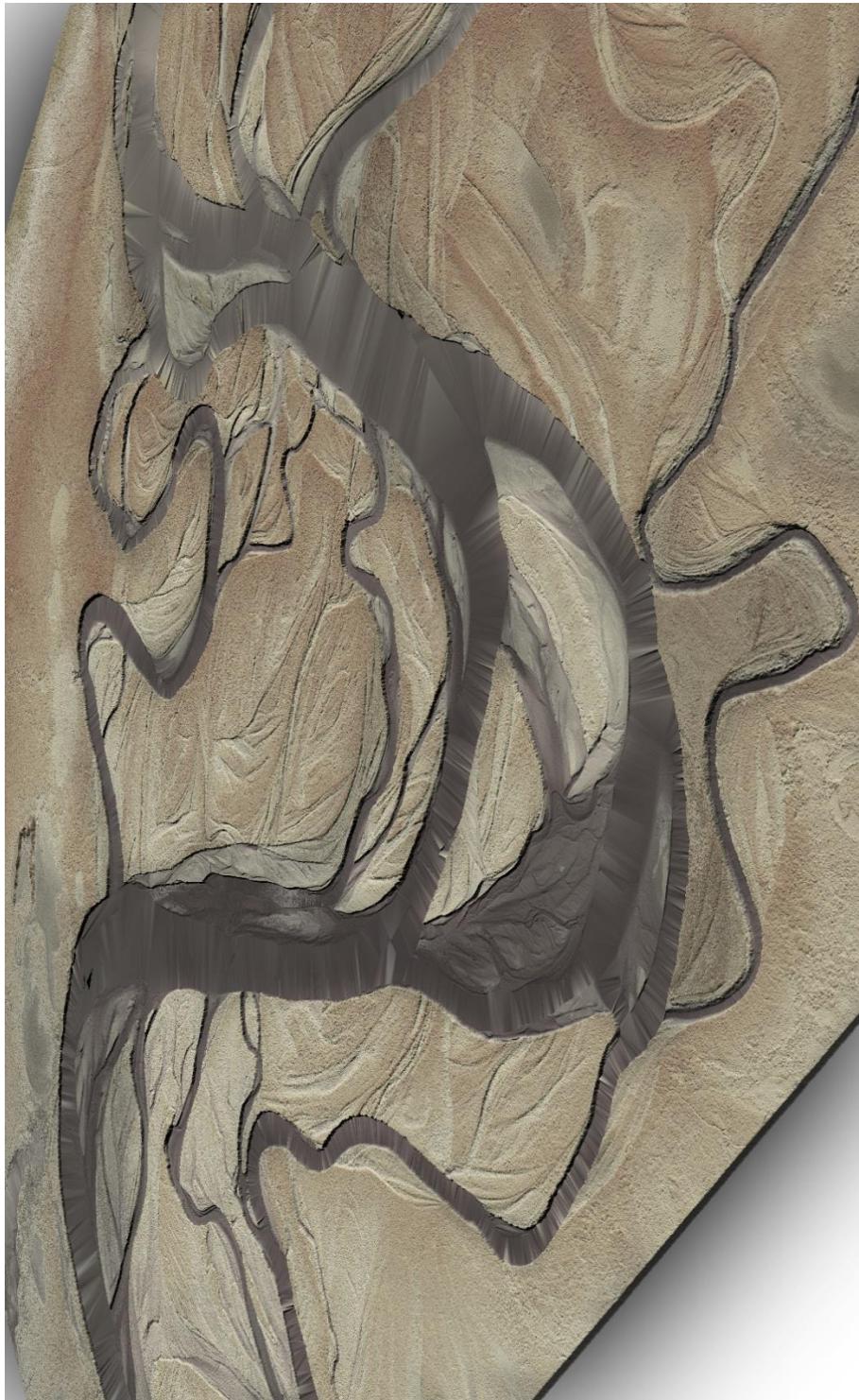


Figure 15: Another view of the meandering Tanana River channel, created from the bare earth point cloud colored by elevation.

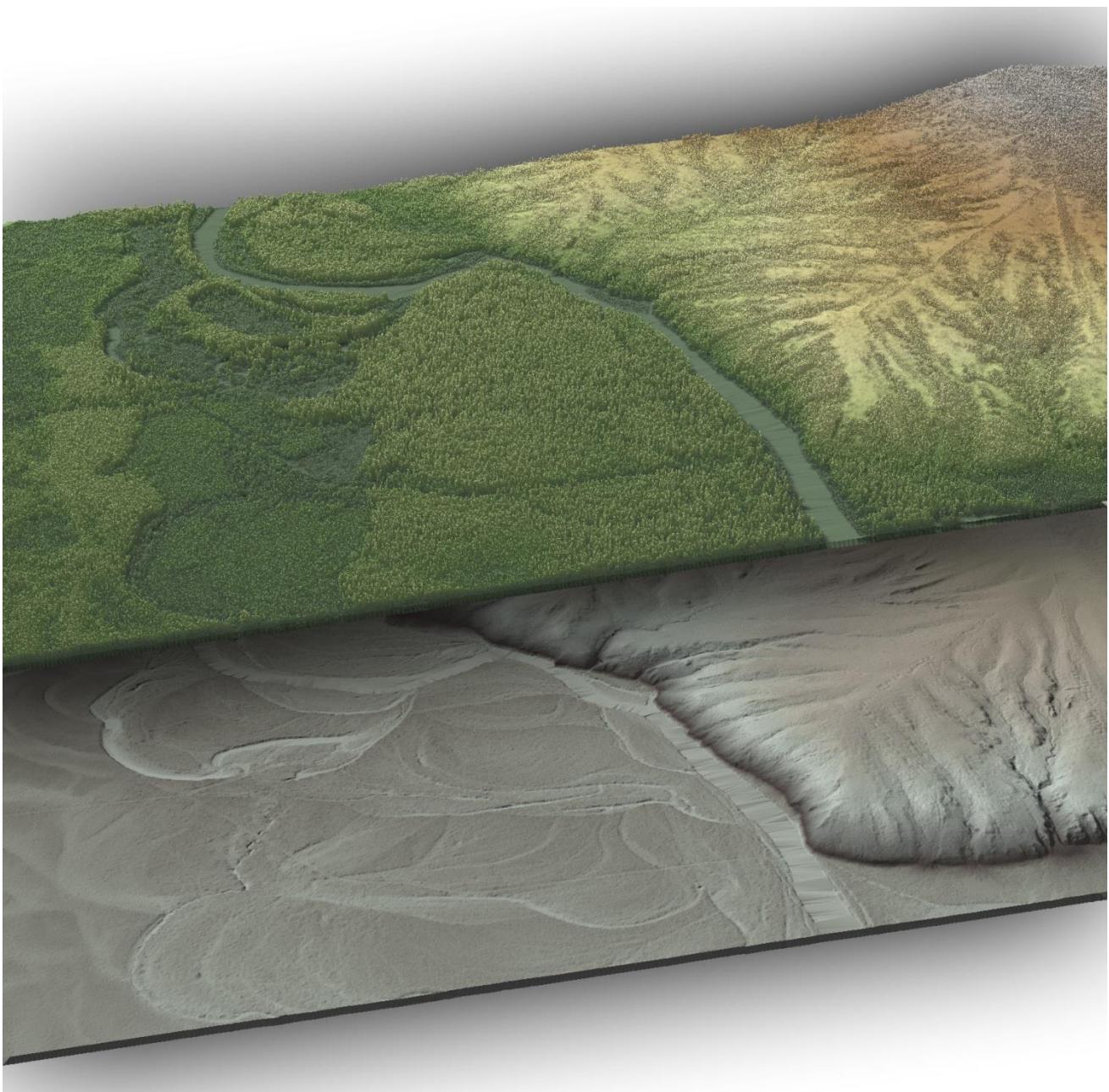


Figure 16: A view of the Chena River: the top layer is the LiDAR highest hit model colored by elevation, while the bottom layer is the bare earth model only also colored by elevation.



Figure 17: This image shows a view of the Chathanika River, created from the bare earth model colored by elevation.

GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Non-vegetated Vertical Accuracy (NVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

Absolute Accuracy: The vertical accuracy of LiDAR data is described as the mean and standard deviation (sigma σ) of divergence of LiDAR point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.

Relative Accuracy: Relative accuracy refers to the internal consistency of the data set; i.e., the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. Affected by system attitude offsets, scale and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm).

Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echoes) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native LiDAR Density: The number of pulses emitted by the LiDAR system, commonly expressed as pulses per square meter.

APPENDIX A - ACCURACY CONTROLS

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 15^\circ$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

APPENDIX B - DOWL SURVEY

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**G17PD00606: ALASKA FAIRBANKS
NORTH STAR BOROUGH LIDAR 2017 B17
LIDAR ACQUISTION SUPPORT
FAIRBANKS, ALASKA
SURVEYING AND MAPPING REPORT**

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August 2017

FAIRBANKS AERIAL MAPPING SUPPORT G17PD00606

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LIST OF ACRONYMS

AOI	Areas of Interest
FNSB.....	Fairbanks North Star Borough
GNSS	Global Navigation Satellite System
GCP.....	Ground Control Point
LGO	Leica Geo Office
NAD83.....	North American Datum 1983
NAVD88.....	National American Vertical Datum 1988
NGS.....	National Geodetic Survey
NVA.....	Non-Vegetated Vertical Accuracy
OPUS	Online Positioning User Service
PPK	Post-Processed Kinematic
QA.....	Quality Assurance
QC.....	Quality Control
QSI	Quantum Spatial Incorporated
RTK.....	Real Time Kinematic GNSS
USGS	United States Geological Survey
VVA.....	Vegetated Vertical Accuracy

HORIZONTAL & VERTICAL CONTROL SUMMARY

1.0 INTRODUCTION

This project consists of providing Terrestrial based Lidar surveying, to support the Lidar acquisition and processing of nearly the whole of the Fairbanks North Star Borough (FNSB) surrounding Fairbanks, Alaska. DOWL is working as a sub consultant to Quantum Spatial, Inc. (QSI), with the client being the United States Geological Survey (USGS). For this project we were requested to collect Ground Control Points (GCPs) for the Lidar processing and Quality Control (QC) points for withholding from the processing of the Lidar data to verify the quality of the data classification.

2.0 CONTROL SUMMARY

Based on conversations between the USGS, QSI, and DOWL; it was decided to provide the data for this project in Alaska State Plane NAD83(2011), and NAVD88 as determined by Geoid 12B both based on an OPUS derived solutions. An OPUS solution was calculated at NGS Station "Chena West Base" (PID TT2833). This station was chosen because it has a published NAD83(1986) and NAVD88 Elevation; however for this survey those values were decided to be not held and a new position was established using OPUS.

There was an expressed interest by the USGS to ensure that this newly collected data matched the historical data that they have. That data is of unknown origin and unclarified coordinate systems both horizontally and vertically. Efforts were made to make a connection between the two datasets. The USGS was asked to provide control points from that other survey. A data set of survey quality "Quick Bird" Points were provided; however, these are not physical monuments to survey to and there is not a method to verify the horizontal positions of this survey. The "Quick Bird" points I believe these points to be the GCPs from the previous survey. These points were staked out and within our control data spreadsheet there is a comparison of our RTK derived height values and the provided values. At this time, it is unknown if the "Quick Bird" points are in the same horizontal coordinate system, and a comparison of the two datasets does provide a vertical translation.

75 Control points were established and processed for this survey effort using dual frequency Static GNSS receivers. The static survey was performed utilizing Leica dual frequency GNSS receivers. GNSS observations were processed in Leica Geo Office (LGO) version 8.3.

3.0 HORIZONTAL CONTROL STATEMENT

Coordinates are Alaska State Plane Zone 3 NAD83(2011) as determined by the National Geodetic Survey (NGS) Online Postioning User Service (OPUS) at NGS station "Chena West Base" PID TT2833. Station "Chena West Base" is the Basis of Coordinates and has Alaska State Plane Zone 3 coordinates of 3971529.433 N., 1350348.452 E. as expressed in U.S. Survey Feet.

4.0 VERTICAL CONTROL SUMMARY & STATEMENT

Elevations are NAVD88 as determined by Geoid 12B holding the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) solution at NGS station "Chena West Base" PID TT2833. Station "Chena West Base" has an NAVD88 elevation of 468.756 U.S. Survey Feet.

5.0 SURVEY PROCEDURES

Real Time Kinematic GNSS (RTK) surveying techniques were used to collect the GCP data, and the QC data. A RTK base was established on static GNSS controlled survey monuments, checkshots were performed on known control points, and the data was processed using both Trimble Business Center as well as Leica Geo Office. Two different sets of equipment were used for this project to get independent RTK vectors to GCP and QC data points. We collected over 120 duplicated GCP and QC points using the two different types of equipment from separate bases. The comparison of that data has a confidence level at 95% of 0.02', and a standard deviation of 0.11'. The conclusion of this is that the GCP and QC data is thoroughly vetted.

Post Processed Kinematic (PPK) GNSS surveying techniques were used to collect the Normalization data. We collected over 52000 PPK Kinematic profile points on Asphalt road surfaces throughout the FNSB Area of Interest (AOI). PPK profile loops were performed to where the end points of the performed loop overlapped with the next session providing a clear connection of the data. Because those data sets are collected from a moving vehicle, it is impossible to stake out individual points. However, as happenstance points would overlap closely, a visual inspection of the overlapping data was performed and it was decided that most often those two data sets matched within 0.04'. The PPK data was also staked out using RTK Surveying techniques and 100 data checkpoints points were collected. The comparison of that data has a confidence level at 95% of 0.02', and a standard deviation of 0.08'.

The redundancy procedures put in place for this project ensure that all the data sets are tied together and that the Normalization data, QC data and control points are all of an accuracy level that will support the American Society for Photogrammetry and Remote Sensing (ASPRS), 2014 standards for mapping.

56 Non-Vegetated Vertical Accuracy (NVA) points and another 131 Vegetated Vertical Accuracy (VVA) points were collected from predetermined QSI locations. There were more locations provided by QSI, but because many of those points were in locations that did not conform or were otherwise unable to be reached, another 106 NVA points and 255 VVA points were collected in similar locations in replacement of the points not collected. In total 162 NVA points and 386 VVA points were collected. They were coded as shown in Attachment "A"

6.0 QUALITY ASSURANCE

Quality Assurance (QA) methods and procedures outlined in the statement of services were reviewed with our staff and adhered to. Some examples of QA methods include the following:

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- All equipment utilized during this project was checked for accuracy, and adjusted when necessary, prior to commencing any work.
- Redundant distance measurements were made in feet and meters.
- Tripods with optical plummet tribrachs or laser plummet tribrachs were used to set up over the points while measuring all control.

7.0 SURVEYOR'S CERTIFICATION

I, A, William Stoll, Alaska Land Surveyor #12041, do hereby certify that the information contained herein is the result of work performed by me or by others working under my direct supervision.



LIDAR MAPPING DESCRIPTOR SCHEME

DESCRIPTOR EXPANDED DESCRIPTION

CHK/### **CHECK SHOT ex. "CHK/403" - 403 IS "Quick Bird" Point**
CONC/ **CONCRETE SURFACE SHOTS**
GCP-01 **GROUND CONTROL POINT FOR LIDAR NORMALIZATION ON ASPHALT WITH SESSION #**
GS/XXXXX **GROUND SHOT WITH SHOT SPECIFIC CONDITIONS *SEE BELOW**

SHOT SPECIFIC CODING FOR VEGETATIVE AND SURFACE CONDITIONS

- 1- Urban areas (e.g. high, dense manmade structures)
- 2- Bare Earth and low grass (e.g. plowed fields, lawns, golf courses)
- 3- High grass, weeds, and crops (e.g. hay fields, sea grass, tundra)
- 4- Brush lands and low trees (e.g. willow brush, alder brush, berry brush)
- 5- Forested, fully covered by trees (e.g. deciduous, evergreens, mixed forests)

Table of Cover Codes	Cover Category					
	Code	1 Urban	2 Bare Earth	3 Grass & weeds	4 Brush	5 Forested
	0	not applicable	not applicable	not applicable	not applicable	not applicable
	1	light density	smooth surface	knee high grass, low tundra	light density	light density
	2	medium density	rough surface	knee high to waist high grass	medium density	medium density
	3	high density	bumpy surface	more than waist high	high density	high density

Circle or check mark each condition before assigning Cover Code

Example 1: Paved parking lot = GS/11000

Example 2: Low grass with light density brush and medium density trees = GS/01112

Example 3: Heavy alders in dense Spruce forest without undergrowth= GS/01022