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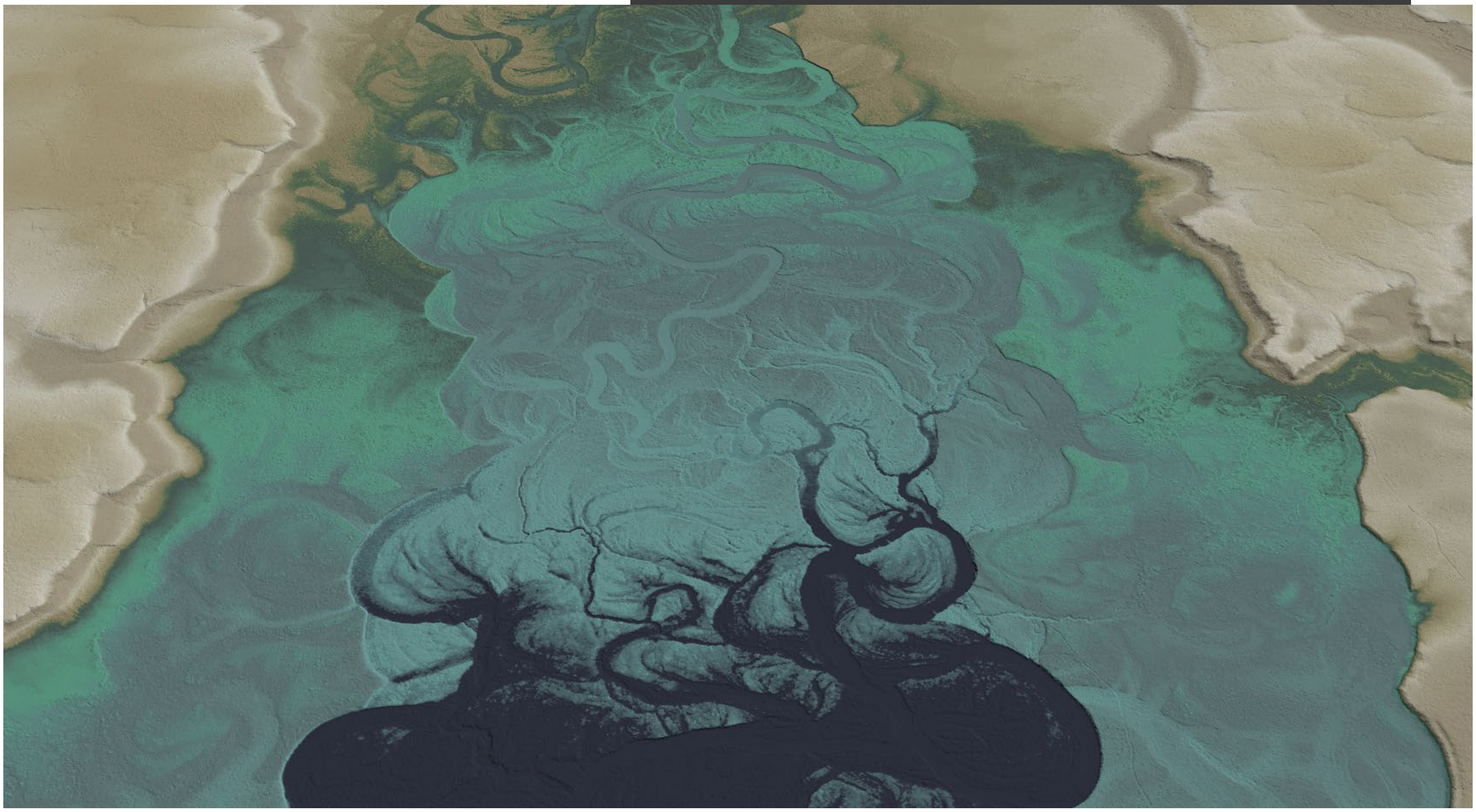

Alaskan Communities, Alaska

2023 Lidar Technical Data Report

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Prepared For:

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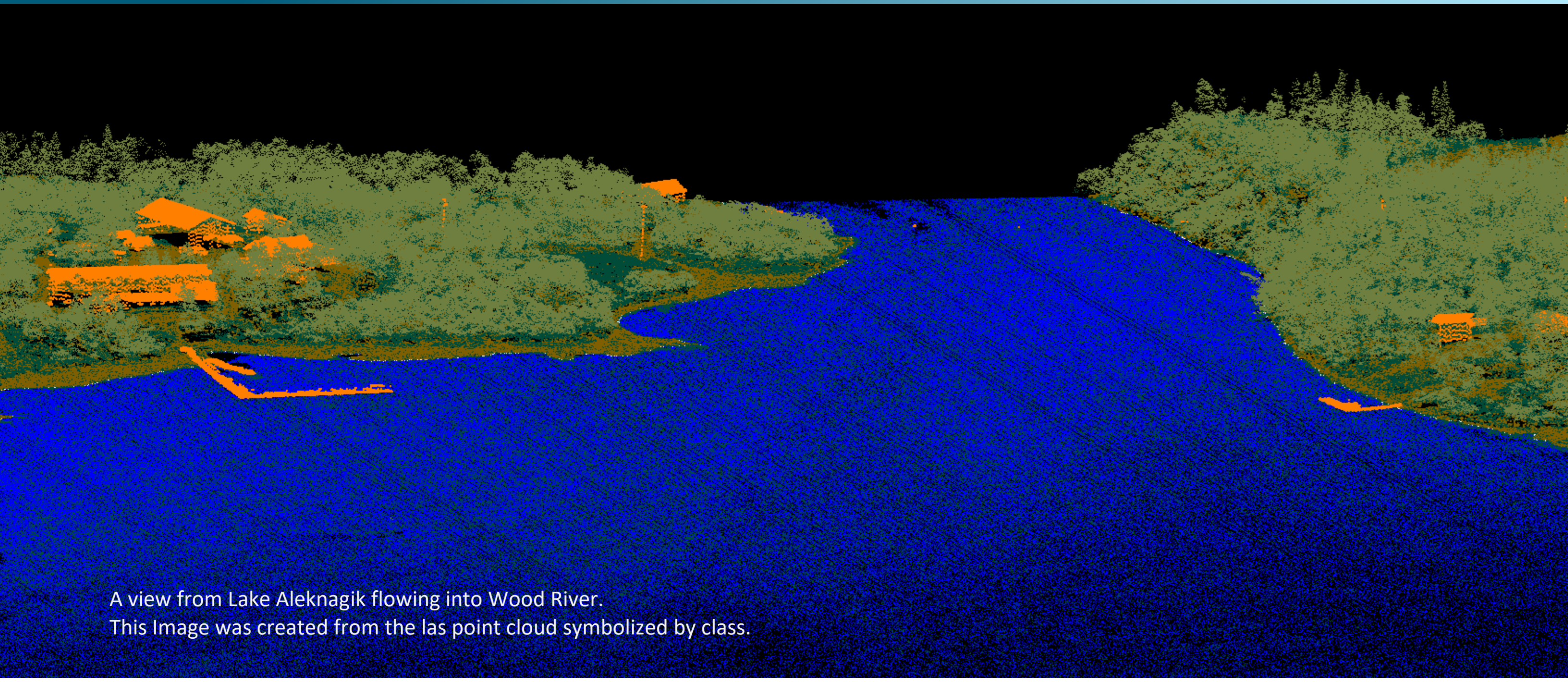
INTRODUCTION



A view from Lake Aleknagik flowing into Wood River.
This Image was created from the las point cloud symbolized by class.

In July 2023, NV5 Geospatial (NV5) was contracted by the National Oceanic and Atmospheric Administration Office for Coastal Management (NOAA) to collect light detection and ranging (lidar) data in the fall of 2023 for the Alaskan Communities sites in Alaska. The 2023 lidar collection includes the communities of Manokotak, Dillingham/Aleknagik, Ekuk, Ekwok, New Stuyahok, and Koliganek. Data were collected to aid NOAA in assessing the topographic and geophysical properties of the study area to support coastal resource managers, watershed managers, and various stakeholders in their decision-making processes.

This report accompanies the delivered lidar data and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final delivered 2023 dataset including lidar accuracy and density. Acquisition dates and acreage are shown in Table 1, deliverable projection information is shown in Table 2, a complete list of contracted deliverables provided to NOAA is shown in Table 3, and the project extent is shown in Figure 1.

Table 1: Acquisition dates and acreage of NIR lidar data collected on the Alaskan Communities sites

Project Site	Originally Contracted Acres	Buffered and Add-on Acres	Aerial Acquisition Dates
Manokotak	37,659	38,937	8/22/2023, 9/4/2023
Dillingham/Aleknagik	106,434	112,671	9/4/2023, 9/17/2023, 9/18/2023
Ekuk	11,204	13,914	9/17/2023
Ekwok	6,768	7,337	9/6/2023
New Stuyahok	4,424	4,855	9/6/2023
Koliganek	5,541	6,023	8/22/2023
Alaskan Communities, Alaska 2023 Totals	172,031	183,738	8/22/2023, 9/4/2023, 9/6/2023, 9/17/2023, 9/18/2023

Deliverable Products

Table 2: Deliverable product projection information

Projections	Horizontal Datum	Vertical Datum	Units
UTM Zone 4 North	NAD83 (2011)	NAVD88 (GEOID12B)	Meters

Table 3: Products delivered to NOAA for the Alaskan Communities 2023 project

Product Type	File Type	Product Details
Points	LAS v.1.4 (*.las)	• All Classified Returns
Rasters	0.5 meter GeoTiffs (*tif)	• Hydroflattened Bare Earth Model (DEM) • Swath Separation • Intensity Images
Rasters	1 meter GeoTiffs (*tif)	• Maximum Surface Height Raster (MSHR)
Vectors	ESRI File Geodatabase (*.gdb)	• Defined Project Area (DPA) • Master Tile Index • Flightline Index • Flightline Swaths • 3D Water's Edge Breaklines • 3D Bridge Breaklines • Ground Survey Data
Metadata	Extensible Markup Language (*.xml)	• Metadata
Reports	Adobe Acrobat (*.pdf)	• Lidar Technical Data Report

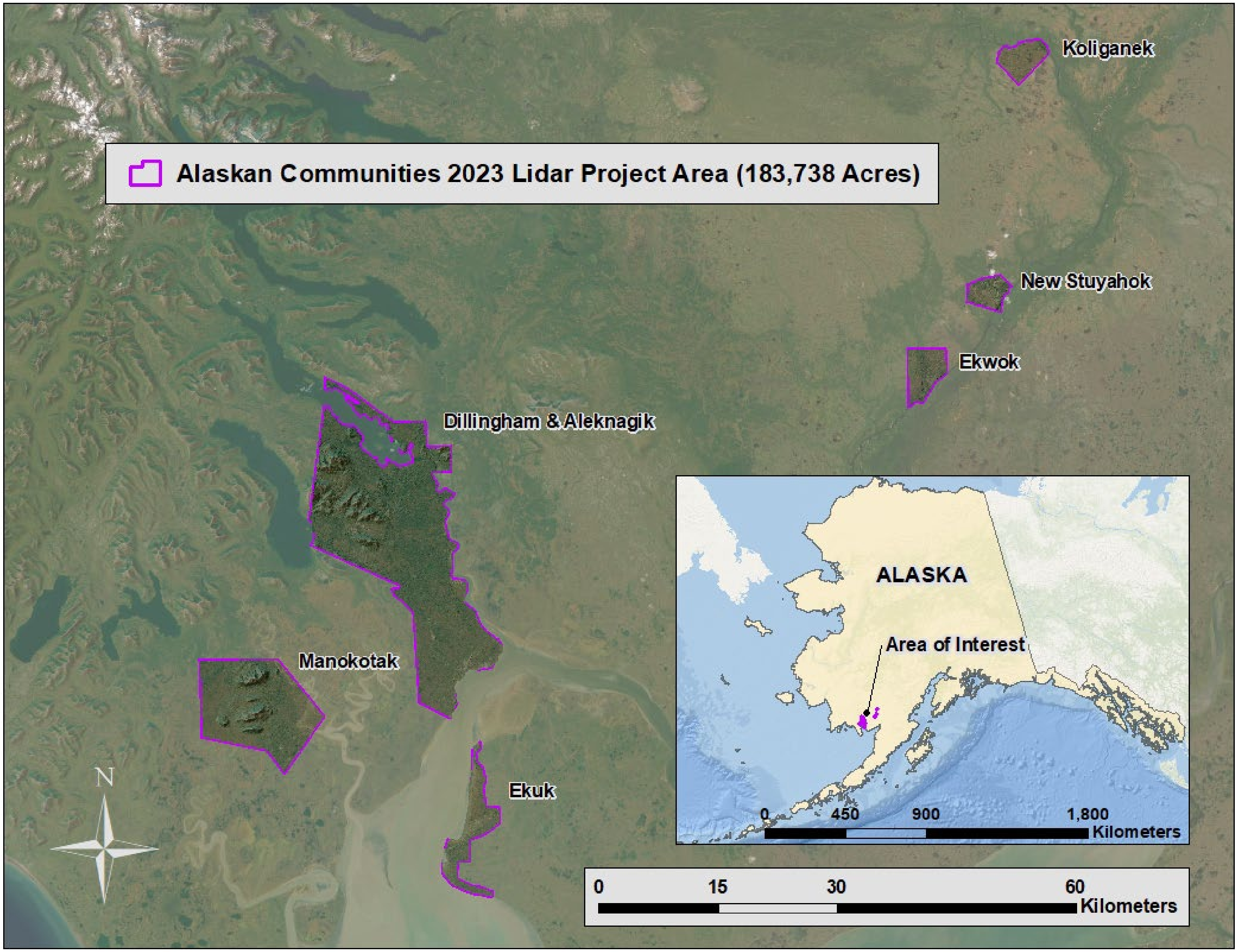


Figure 1: Location map of the Alaskan Communities site in Alaska

NV5 Geospatial's Cessna Grand Caravan

Planning

In preparation for data collection, NV5 Geospatial reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Alaskan Communities lidar study area at the target point density of ≥ 8.0 points/m^2. 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. Figure 2 shows these optimized flight paths and dates.

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.

Table 4: Flight date table

Date	Flight Line Number	Start Time (Adjusted GPS)	End Time (Adjusted GPS)
8/22/2023	500 - 510	376767332	376772322
9/4/2023	700 - 726	377877943	377891469
9/6/2023	600 - 607	378058050	378061402
9/17/2023	1000 - 1025	379007703	379026477
9/18/2023	800 - 803	379103770	379105791

Airborne Lidar Survey

The lidar survey was accomplished using a Riegl VQ-780ii-S system mounted in a Cessna Grand Caravan. Table 5 summarizes the settings used to yield an average pulse density of $\geq$ 8 pulses/m^2 over the Alaskan Communities project area. The Riegl VQ-780ii-S laser system can record unlimited range measurements (returns) per pulse, however a maximum of 15 returns can be stored due to LAS v1.4 file limitations. The typical number of returns digitized from a single pulse range from 1 to 7 for the Alaskan Communities project area. 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. Figure 2 shows the flightlines acquired using these lidar specifications.

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% 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 orientation of the aircraft to the horizon (attitude) were recorded continuously throughout the lidar data collection mission. The 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.

Table 5: Lidar specifications and aerial survey settings

Parameter	NIR Laser
Acquisition Dates	8/22/2023, 9/4/2023, 9/6/2023, 9/17/2023, 9/18/2023
Aircraft Used	Cessna Grand Caravan
Sensor	Riegl
Laser Channel	VQ-780ii-S
Maximum Returns	14
Resolution/Density	Average 8 pulses/m^2
Nominal Pulse Spacing	0.35 m
Survey Altitude (AGL)	2058 m
Survey speed	145 knots
Field of View	58.5°
Mirror Scan Rate	Uniform Point Spacing
Target Pulse Rate	1285 kHz
Pulse Length	3 ns
Laser Pulse Footprint Diameter	47.3 cm
Central Wavelength	1064 nm
Pulse Mode	Multiple Times Around (MTA)
Beam Divergence	0.23 mrad
Swath Width	2305 m
Swath Overlap	57%
Intensity	16-bit
Vertical Accuracy	$RMSE_Z$ (Non-Vegetated) ≤ 10 cm
NVA Accuracy	NVA (95% Confidence Level) ≤ 19.6 cm
VVA Accuracy	VVA (95^{th} Percentile) ≤ 30 cm

Riegl VQ-780ii-S

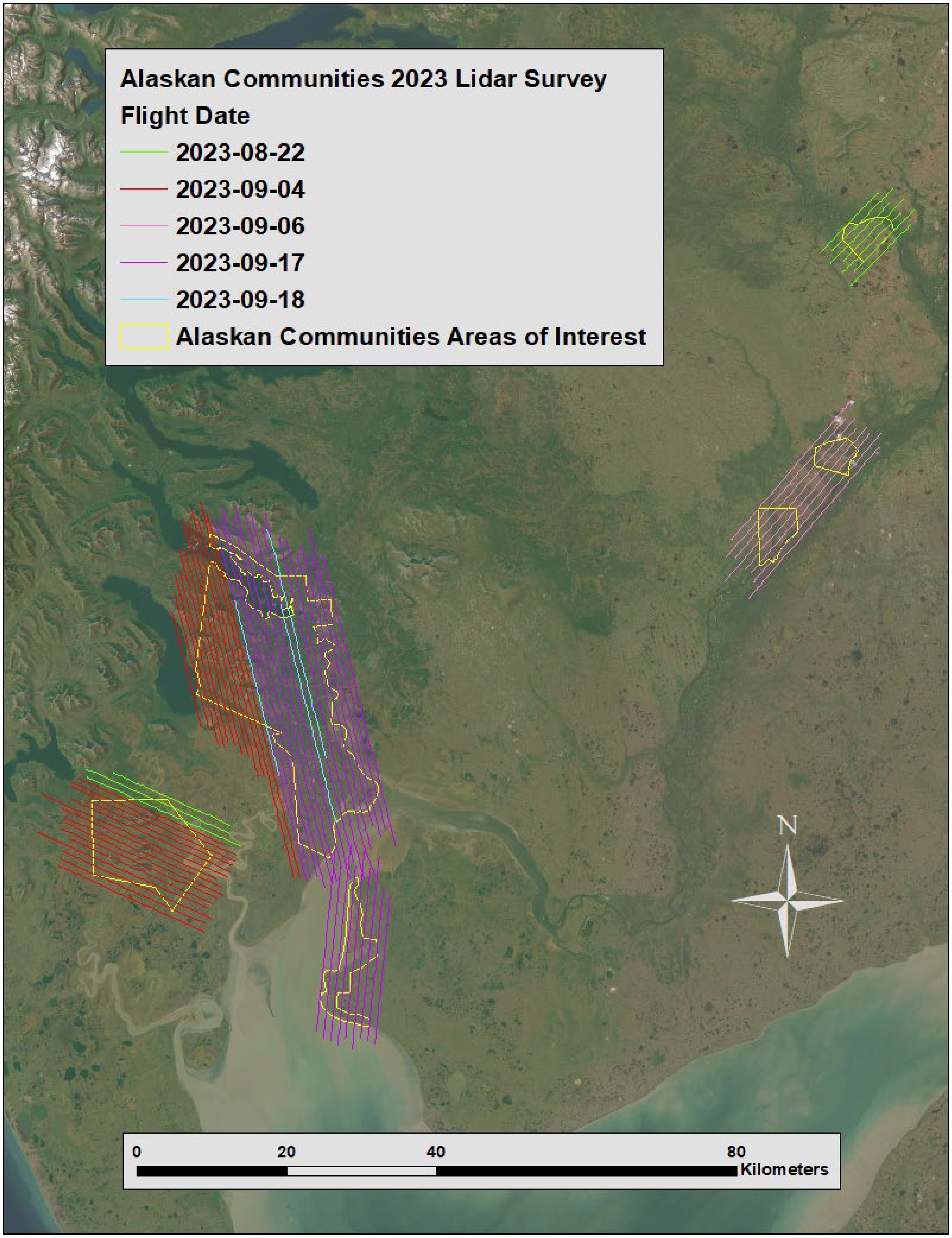


Figure 2: Flightlines map

Ground Survey

Ground control surveys, including monumentation and ground survey points (GSPs), were conducted by DOWL to support the airborne acquisition. DOWL provided the survey data, including base station coordinates to NV5 to perform quality assurance checks on final lidar data. The base stations used for this project are shown in Table 6 below. This section is intended as a summary of the ground survey; the detailed Ground Survey Report with detailed NOAA requirements will be separate from this data report.

Photo provided from DOWL ground survey

Table 6: Base station positions for the Alaskan Communities acquisition.

Base Station ID	Latitude	Longitude	Ellipsoid (meters)	Type
Dillingham-411	59° 14' 10.03021"	-158° 39' 58.15282"	59.562	Mag Spike
Aleknagik-412	59° 04' 41.32448"	-158° 35' 10.58851"	62.599	Mag Spike
Ekwok-413	59° 21' 08.82551"	-157° 28' 25.44266"	49.077	Mag Spike
Koliganek-414	59° 43' 34.00243"	-157° 16' 00.30985"	83.722	Mag Spike
Manokotak-415	58° 58' 30.85932"	-159° 03' 03.34850"	26.923	Mag Spike
Clark's Point-416	58° 50' 11.55197"	-158° 31' 45.60747"	31.111	Mag Spike
New Stuyakok-417	59° 27' 23.51430"	-157° 22' 32.91190"	126.885	Mag Spike
KEK A (PID DK2876)	59° 21' 07.10402"	-157° 28' 38.78147"	48.053	Drive Rod
JZZ A (PID DP6584)	59° 43' 34.65294"	-157° 15' 47.71846"	85.174	Drive Rod
MBA B (PID DL7269)	58° 56' 01.88055"	-158° 53' 45.75903"	44.090	Drive Rod
CLARK AZ (PID UV7281)	58° 50' 35.46064"	-158° 33' 16.11370"	19.389	Brass Cap
1277-3-84 (PID BBBJ80)	59° 02' 14.75487"	-158° 28' 31.26293"	20.543	Brass Cap

Ground Survey Points (GSPs)

Ground survey points were collected 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 equably distributed throughout the study area. GSPs and land cover checkpoints used by NV5 for lidar processing and accuracy checks are depicted in the ground survey location map (Figure 3).

Land Cover Class

In addition to ground survey points, DOWL collected land cover class checkpoints throughout the study area to facilitate vertical accuracy evaluations. Vertical accuracy statistics were calculated for all land cover types to assess confidence in the lidar derived ground models across land cover classes (Table 7, see Lidar Accuracy Assessments, page 29).

Table 7: Land cover types and descriptions

Land cover type	Land cover code	Description	Accuracy Assessment Type
Shrub	SH	Low growth shrubs	VVA
Tall Grass	TG	Herbaceous grasslands in advanced stages of growth	VVA
Forest	FR	Forested areas	VVA
Bare Earth	BE	Areas of bare earth surface; gravel, packed sand or dirt, concrete or pavement	NVA

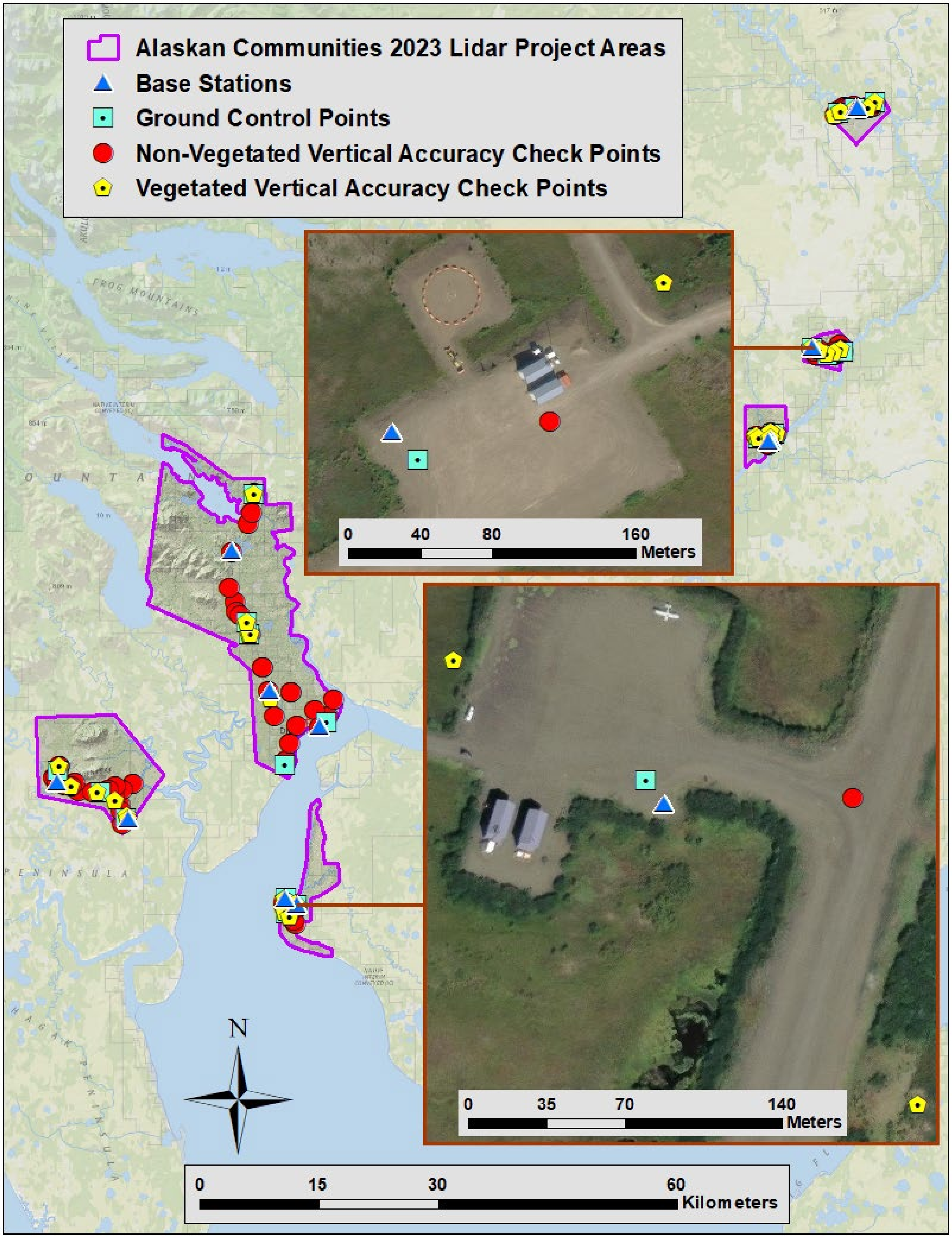
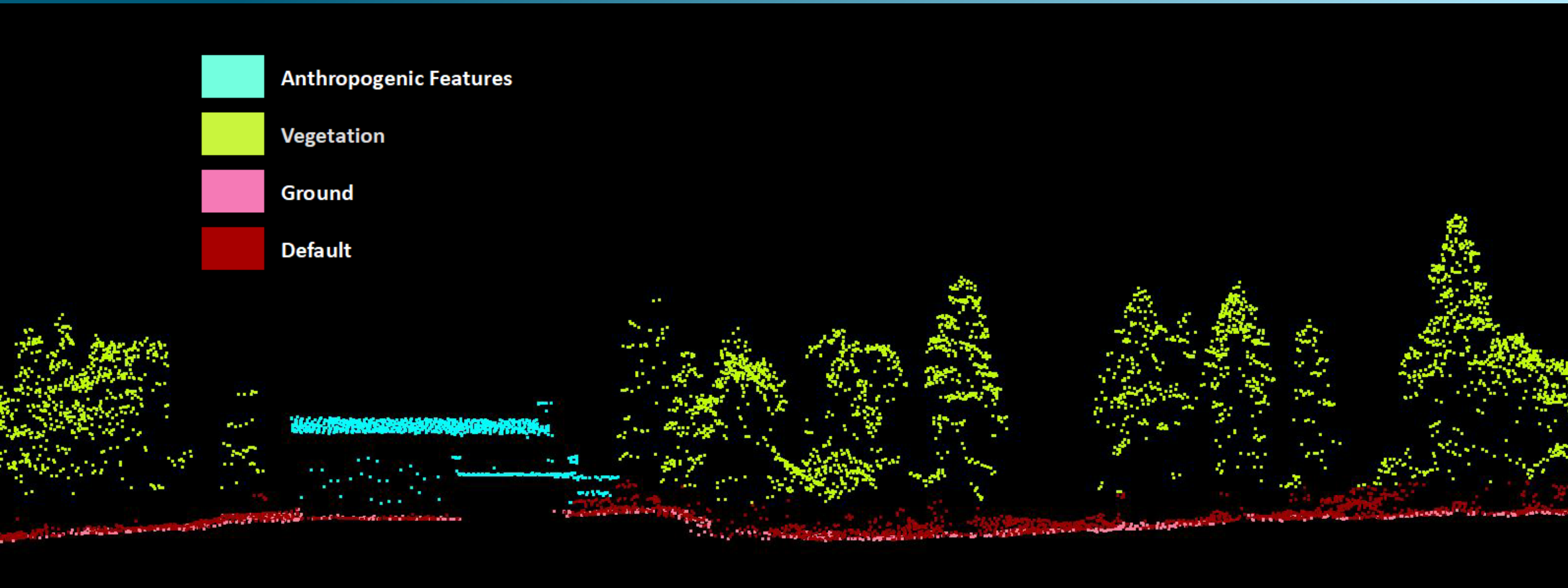


Figure 3: Ground survey location map



This 2-meter lidar cross section shows a view of the Alaskan Communities landscape, symbolized by point classification.

NIR Lidar Data

Upon completion of data acquisition, NV5 Geospatial 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 9). Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in (Table 10).

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis includes maximum horizontal and vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

Point clouds were created using the RiPROCESS software. The generated point cloud is the mathematical three-dimensional composite of all returns from all laser pulses as determined from the aerial mission. The point cloud is imported into GeoCue distributive processing software. Imported data is tiled and then calibrated using StripAlign and proprietary software. Using TerraScan, the vertical accuracy of the surveyed ground control is tested, and any bias is removed from the data. TerraScan and TerraModeler software packages are then used for automated data classification and manual cleanup. The data are manually reviewed, and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler.

DEMs and Intensity Images are then generated using NV5 Geospatial proprietary software. In the bare earth surface model, above-ground features are excluded from the data set. ESRI ArcMap is used as a check of the bare earth dataset. NV5 Geospatial uses a proprietary tool called FOCUS on Delivery to check all formatting requirements of the images against what is required before final delivery. Finally, proprietary software is used to perform statistical analysis of the LAS files (Table 8).

Table 8: Software used for statistical analysis

Statistical Software	Version
Applanix + POSPac	8.7
Las Monkey	2.6.7
RiPROCESS	1.8.6
GeoCue	2020.1.22.1
StripAlign	2.21
ESRI Arc Map	10.8
TerraModeler	21.008
TerraScan	21.016

Table 9: ASPRS LAS classification standards applied to the Alaskan Communities dataset

Classification Number	Classification Name	Point Count	Classification Description
1	Default/Unclassified	12,306,969,743	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
1W	Edge Clip/Withheld	1,606,317,971	Laser returns at the outer edges of flightlines that are geometrically unreliable
2	Ground	4,621,298,013	Laser returns that are determined to be ground using automated and manual cleaning algorithms
5	High Vegetation	4,514,577,983	Laser returns that are determined to be vegetation and greater than 2 meters above ground
6	Buildings	9,426,612	Permanent roofed structures greater than 100 square feet
7W	Noise / Withheld	35,171,962	Laser returns that are often associated with birds, scattering from reflective surfaces, and sensor anomalies
9	Water	196,744,200	Laser returns that are determined to be water using automated and manual cleaning algorithms
17	Bridge	20,765	Bridge decks
18W	High Noise	20,077,713	Laser returns that are often associated with birds or scattering from reflective surfaces
20	Ignored Ground	811,394	Ground points proximate to water's edge breaklines; ignored for correct model creation
22	Temporal Exclusion	186,136	Laser returns that are determined to be due to temporal differences in flightlines and are excluded from model creation (typically non-favored data in intertidal zones)

Table 10: 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.	POSPac MMS v.8.9
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. 1.4) format. Convert data to orthometric elevations by applying a geoid correction.	RiUnite v.1.0.5
Import raw laser points into manageable blocks to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.19.005
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.	StripAlign v.2.24
Classify resulting data to ground and other client designated ASPRS classifications (Table 9). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.19.005 Terra Match v. 19.002 TerraModeler v.19.003 Las Monkey 2.6.8 (NV5 Geospatial proprietary)
Generate water's edge breaklines by creating slopes, elevation, intensities, and return density model inputs and running algorithm software. Review shapefile polygon output and manually digitize any needed edits.	TerraScan v.19.005 LAS Product Creator 4.0 (NV5 Geospatial proprietary) ArcMap v. 10.8.1
Generate hydroflattened bare earth models as triangulated surfaces. Generate maximum surface height models. Export all surface models as Cloud Optimized GeoTIFFs.	LAS Product Creator 4.0 (NV5 Geospatial proprietary) ArcMap v. 10.8.1
Export intensity images as Cloud Optimized GeoTIFFs at 0.5 meter pixel resolution.	Las Monkey 2.6.8 (NV5 Geospatial proprietary) LAS Product Creator 4.0 (NV5 Geospatial proprietary)

Feature Extraction

Hydroflattening and Water's Edge Breaklines

The shores of the Nushagak Bay, Aleknagik Lake, Clark Slough, Weary River, Wood River, Nushagak River, and other water bodies within the Alaskan Communities areas of interest were each 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 and 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. Specific care was taken to not hydroflatten wetland and marsh habitat found throughout the study site.

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 3-D water edge breaklines resulting in the final hydroflattened model (Figure 4).

Hydro-Flattened Raster DEM Processing

Hydro-flattened DEMs (topographic) represent a lidar-derived product illustrating the grounded terrain and associated breaklines (as described above) in raster format. NV5 Geospatial's proprietary software was used to take all the ground point sources (class 2) and create a Triangulated Irregular Network (TIN) on a tile-by-tile basis. Data extending past the tile edge is incorporated in this process so that triangulation can occur without creating edge artifacts. From the TIN, linear interpolation is used to calculate the cell values for the raster product. The raster product is then clipped along the tile edge to remove areas that overlap with adjacent tiles. A 32-bit floating point GeoTIFF DEM was generated for each tile with a pixel size of 0.5 meter. NV5 Geospatial's proprietary software was used to write appropriate horizontal and vertical coordinate reference system (CRS) information as well as applicable header values into the file during product generation. Each DEM is reviewed in ESRI ArcMap to check for any surface anomalies and to ensure a seamless dataset. NV5 Geospatial ensures there are no void or no-data values (-999999) in each derived DEM. This is achieved by using propriety software checking all cell values that fall within the project boundary.

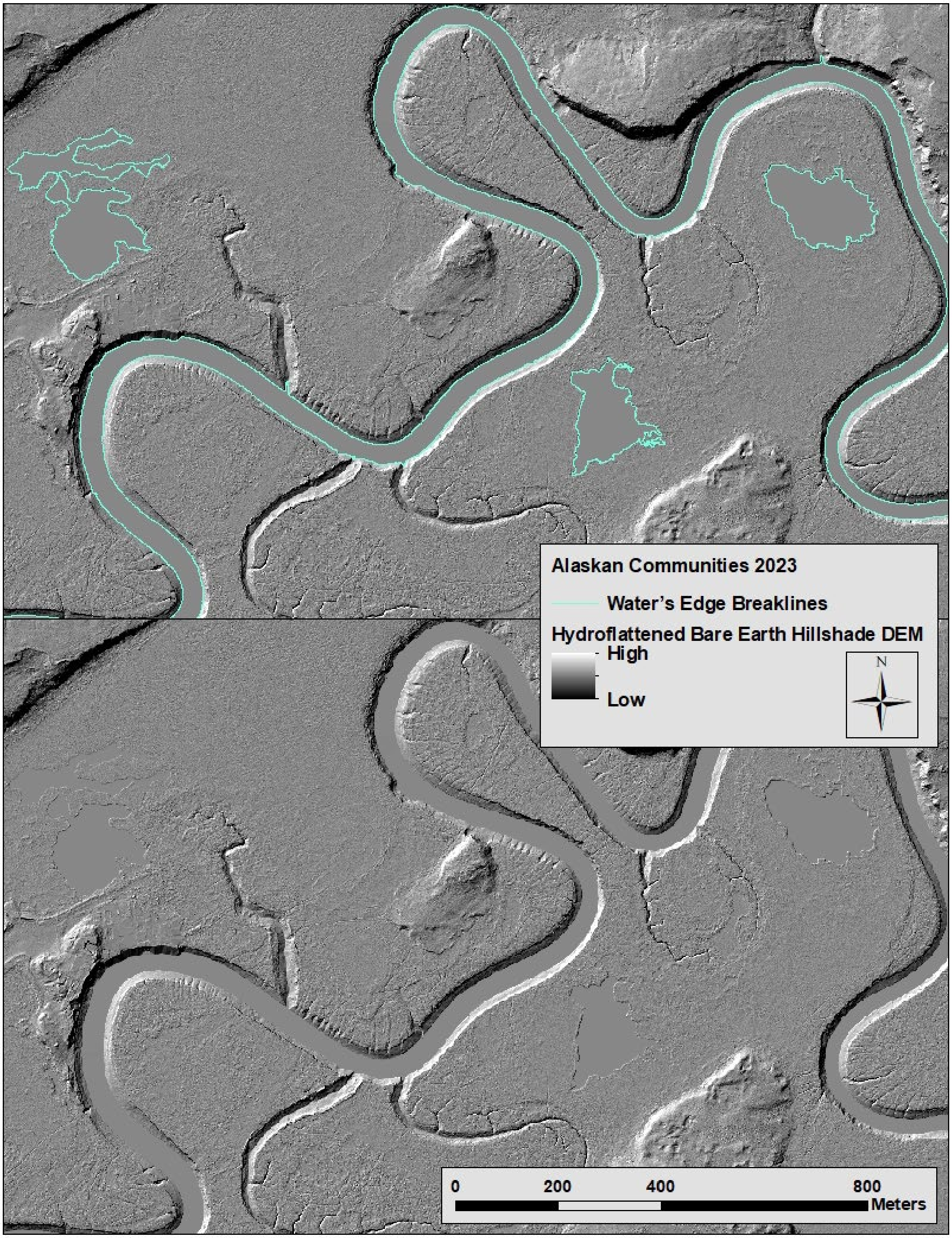


Figure 4: Example of hydroflattening in the Alaskan Communities lidar dataset. The top image displays the water's edge breaklines over the hydroflattened bare Earth hillshade DEM; the bottom image displays the same view without the breaklines.

Intensity Image Processing

Intensity images represent reflectivity values collected by the lidar sensor during acquisition. NV5 Geospatial proprietary software generates intensity images using all valid first returns and excluding those flagged with a withheld bit. Intensity images are linearly scaled to a value range specific to the project area and sensor to standardize the images and reduce differences between individual flightlines. Appropriate horizontal projection information as well as applicable header values are written during product generation.

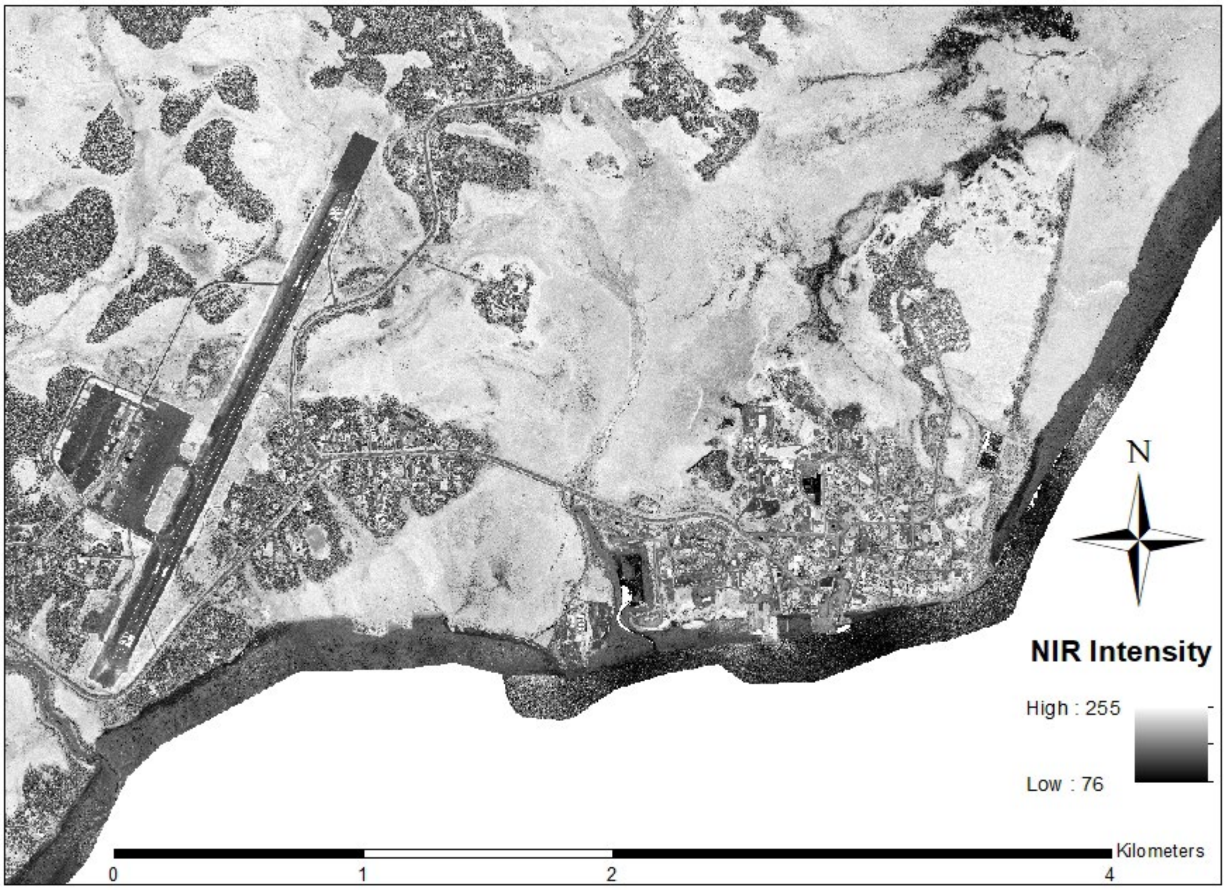


Figure 5: Example of intensity image viewing the Dillingham community

Swath Separation Raster Processing

Swath Separation Images are rasters that represent the interswath alignment between flight lines and provide a qualitative evaluation of the positional quality of the point cloud. NV5 Geospatial proprietary software generated 1 meter raster images in GeoTIFF format using all returns from all the classes (Table 9), excluding points flagged with the withheld bit, and using a grid based average algorithm. Images are generated with 50% intensity opacity and four absolute 8 cm intervals (see Figure 6 below for interval coloring). Intensity images are linearly scaled to a value range specific to the project area and sensor to standardize the images and reduce differences between individual flightlines. Appropriate horizontal projection information as well as applicable header values are written to the file during product generation.

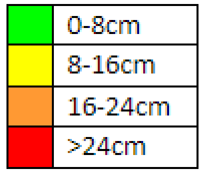


Figure 6: Swath separation raster color ramp values used in the Alaskan Communities project

Maximum Surface Height Raster (MSHR) Processing

MSHRs (topographic) represent a lidar-derived product illustrating natural and built-up features. NV5 Geospatial's proprietary software was used to take all valid classified lidar points, excluding those flagged with a withheld bit, and create a raster on a tile-by-tile basis. A 32-bit floating point GeoTIFF was generated for each tile with a pixel size of 1 meter, which meets the requirements set by USGS that states that the resolution of the MSRH be twice that of the bare earth DEM. NV5 Geospatial's proprietary software was used to write appropriate horizontal and vertical projection information as well as applicable header values into the file during product generation. Each maximum surface height raster is reviewed in ESRI ArcMap to check for any anomalies and to ensure a seamless dataset.

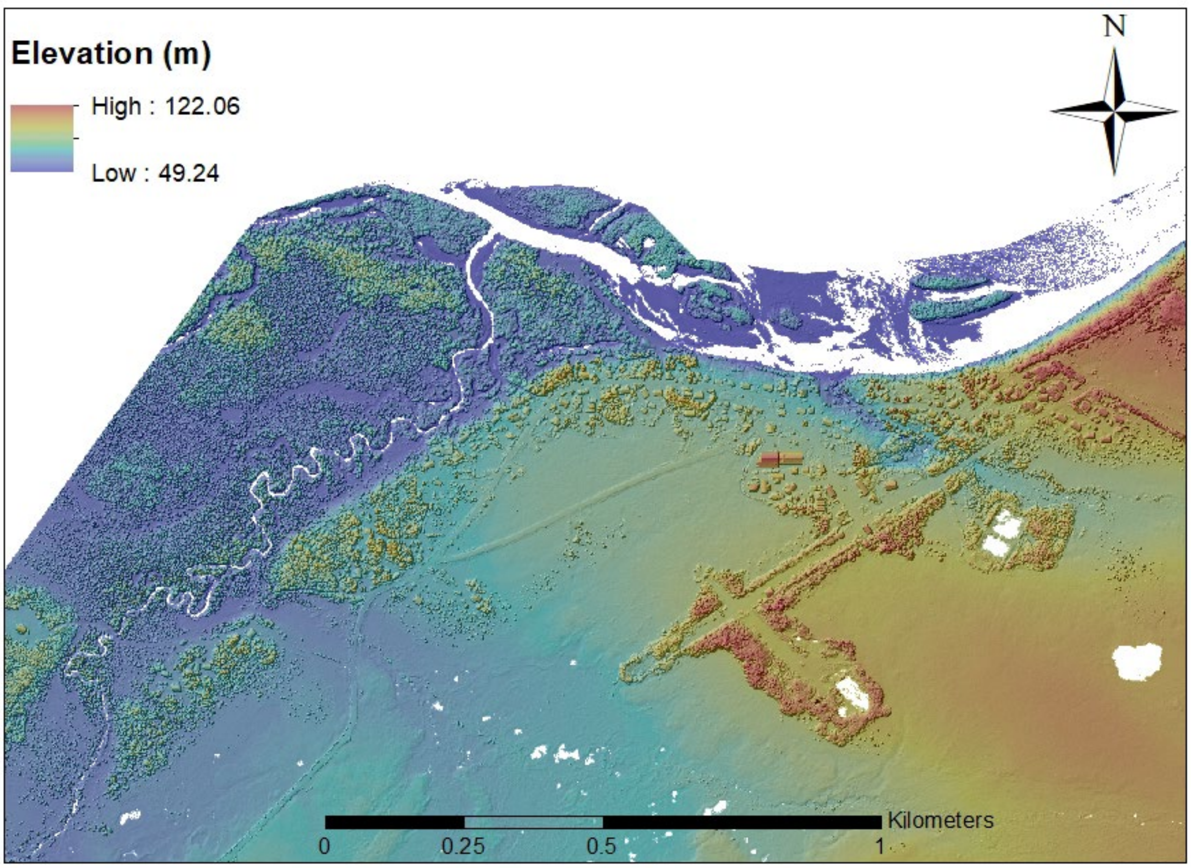
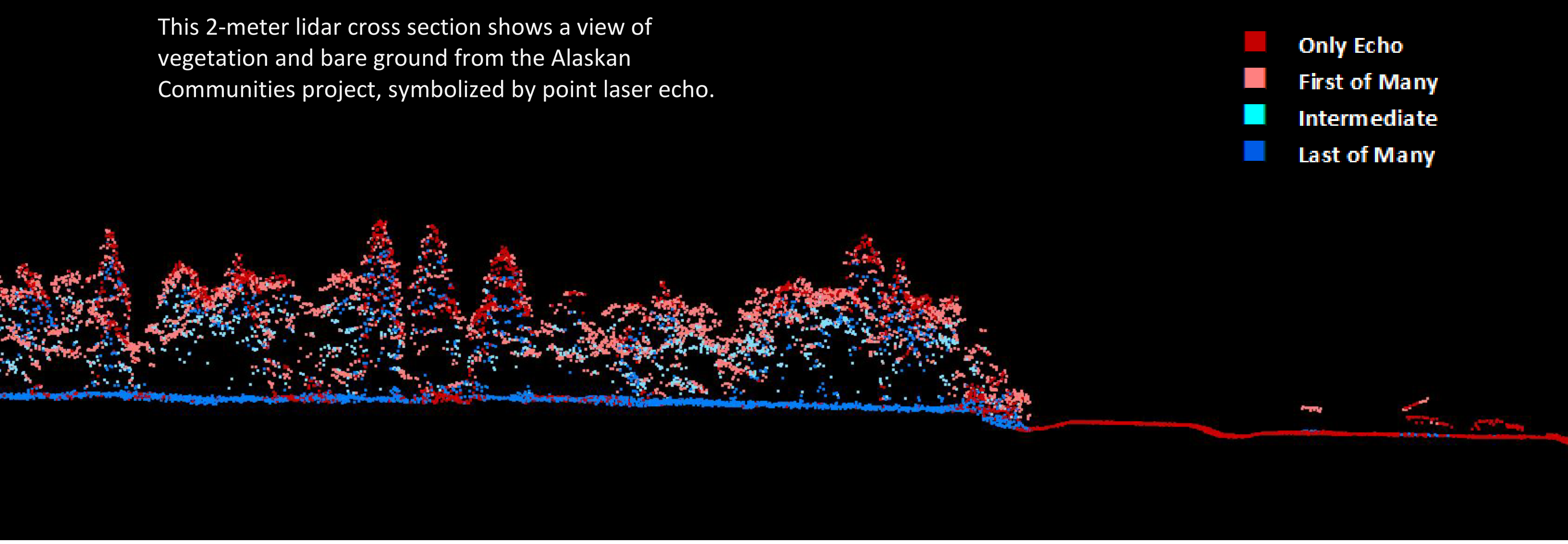


Figure 7: Example of MSHR model viewing the Koliganek community

This 2-meter lidar cross section shows a view of vegetation and bare ground from the Alaskan Communities project, symbolized by point laser echo.



Lidar Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m^2. 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 the 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 2023 collection of the Alaskan Communities project was 13.84 points/m^2, while the average ground classified density was 3.05 points/m^2 (Table 11). The statistical and spatial distributions of first return densities and classified ground return densities per 100 meter x 100 meter cell are portrayed in Figure 8 through Figure 11.

Table 11: Average lidar point densities

Classification	Point Density
First-Return	13.84 points/m^2
Ground Classified	3.05 points/m^2

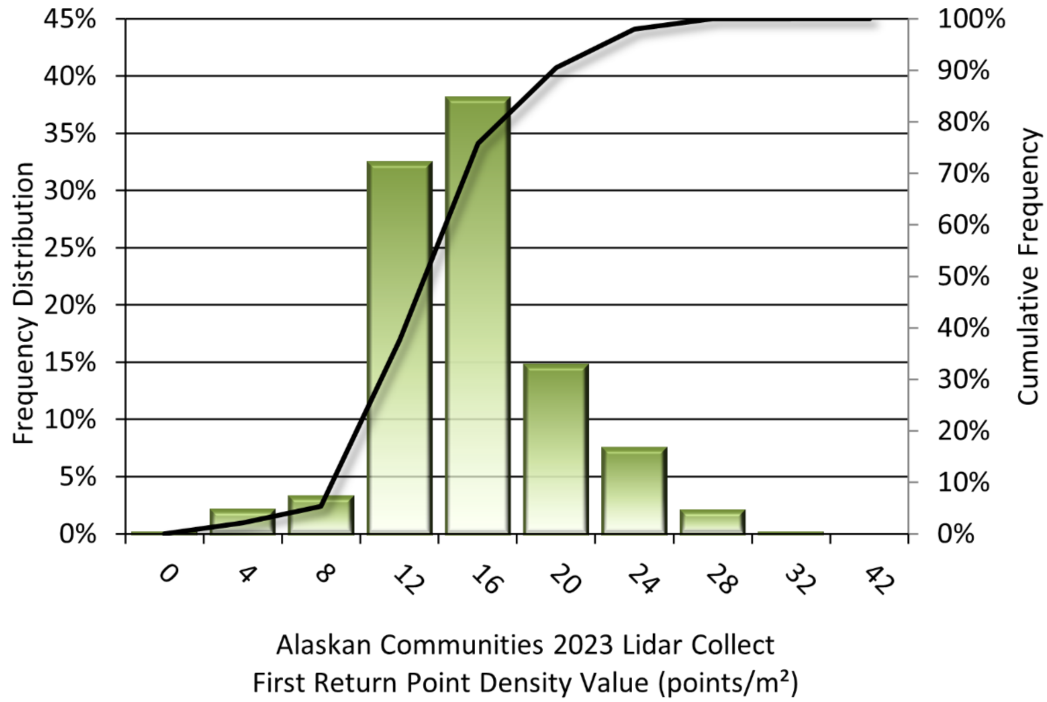


Figure 8: Frequency distribution of first return point density values per 100 m x 100 m cell

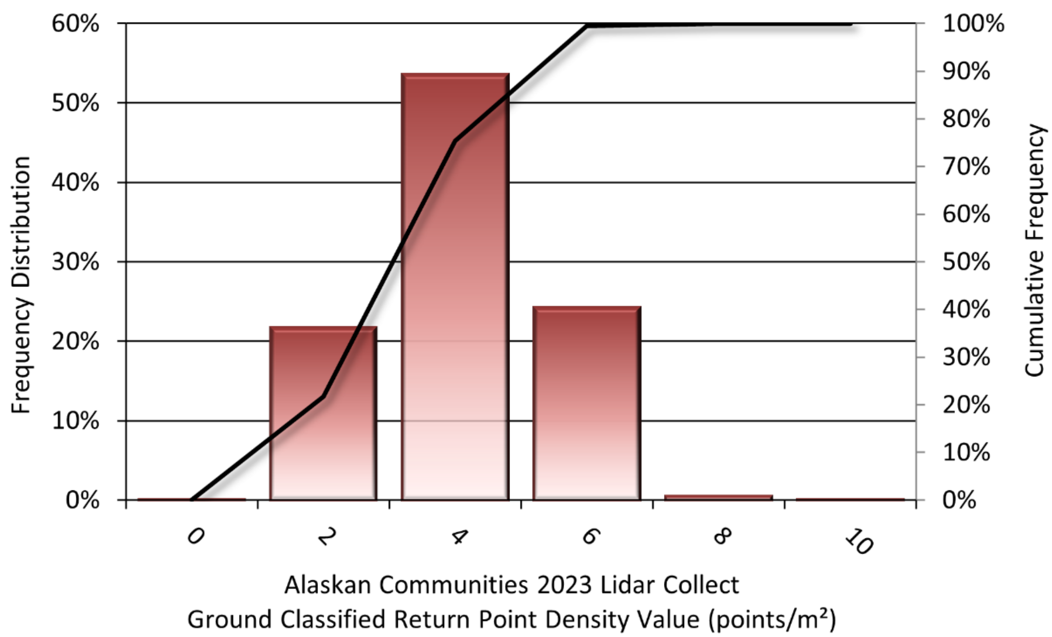


Figure 9: Frequency distribution of ground-classified return point density values per 100 m x 100 m cell

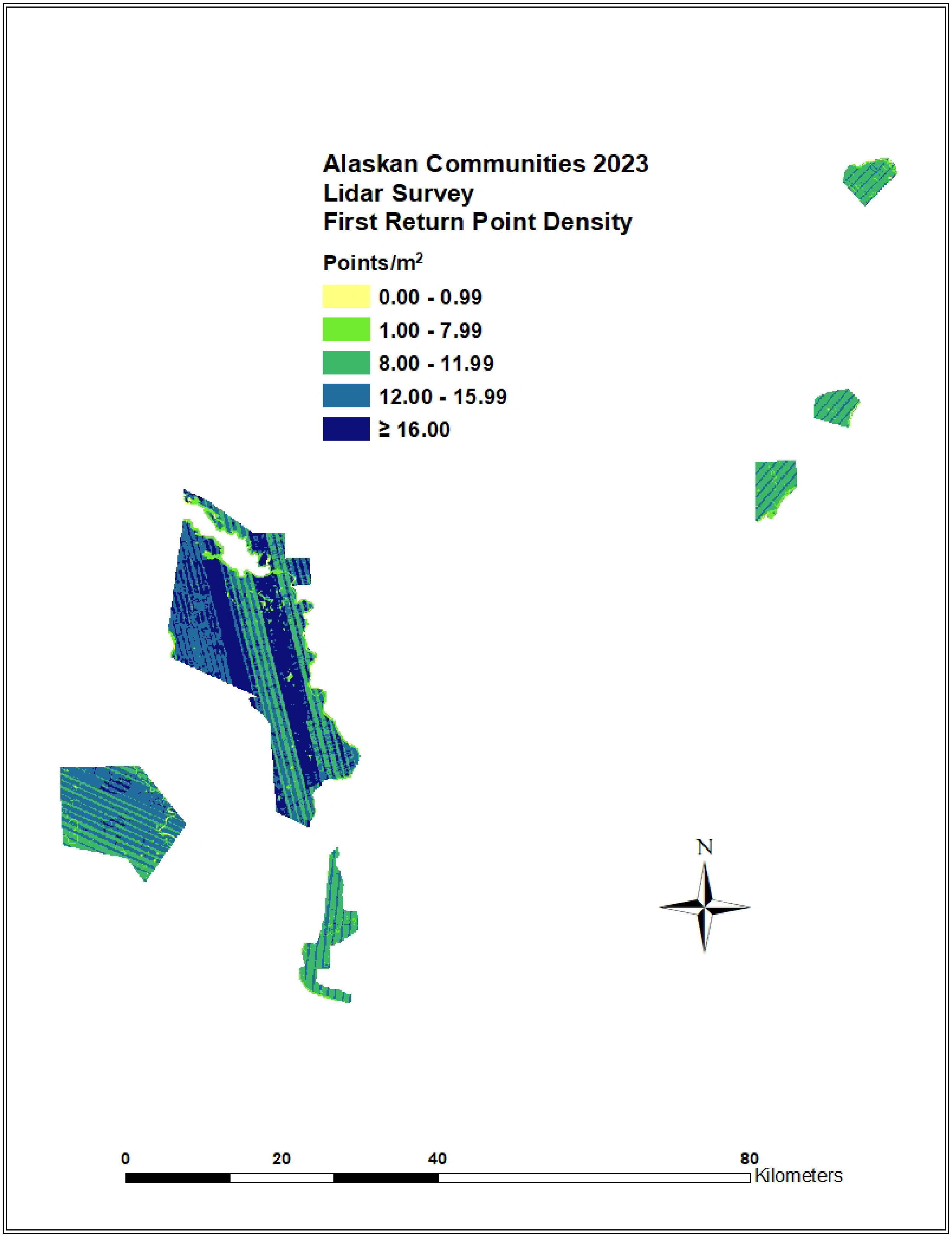


Figure 10: First return point density map for the Alaskan Communities (100 m x 100 m cells)

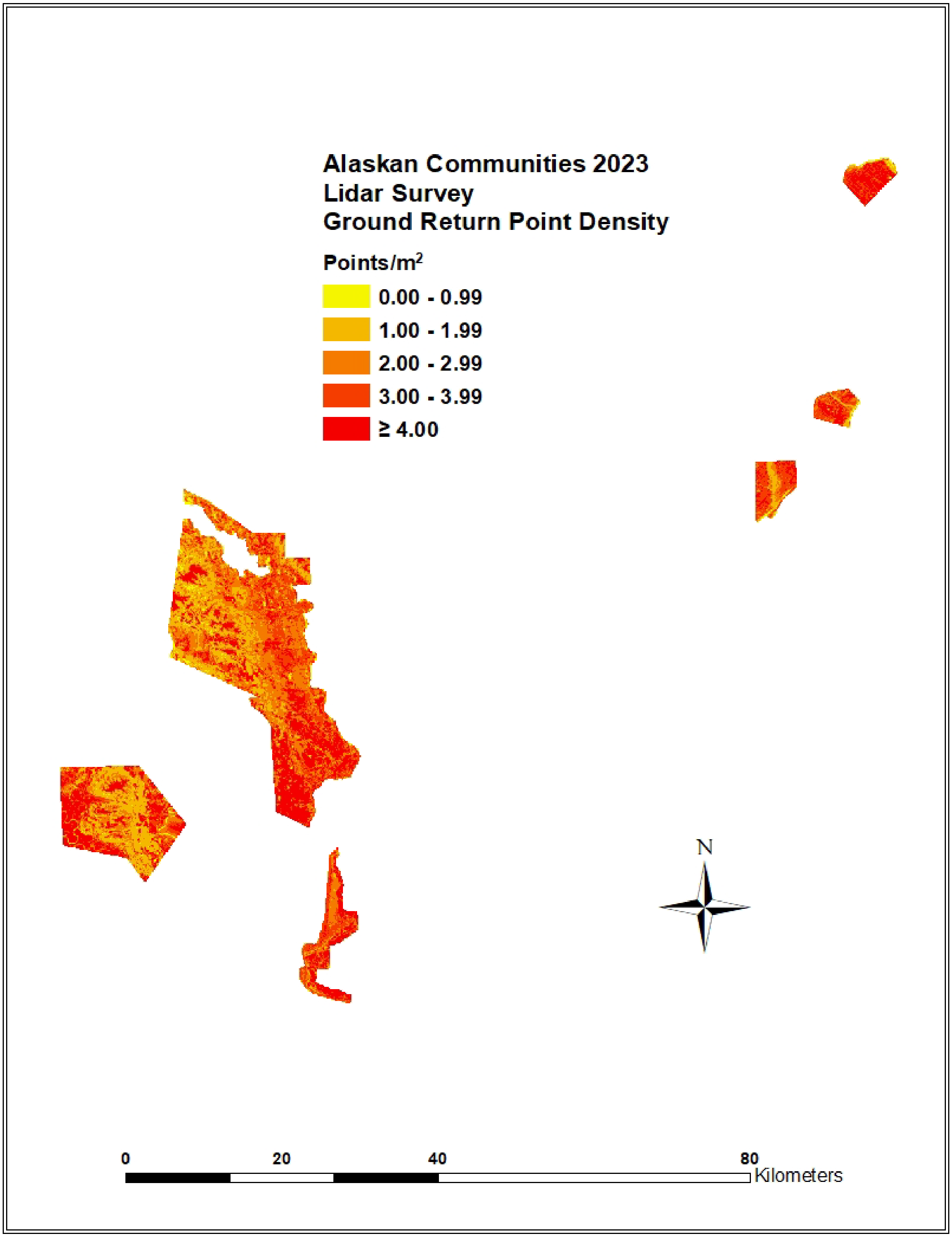


Figure 11: Ground-classified point density map for the Alaskan Communities (100 m x 100 m cells)

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 Accuracy[1]. NVA compares known ground check point data that were withheld from the calibration and post-processing of the lidar point cloud to the triangulated surface generated by the classified lidar point cloud as well as the derived gridded bare earth DEM. 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). For the Alaskan Communities 2023 data, NVA was calculated for each area of interest and as a project whole. These results are summarized by area of interest in Table 12 and for the complete 2023 survey in Table 13.

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 Alaskan Communities 2023 survey, 124 ground checkpoints were withheld from the calibration and post processing of the lidar point cloud, with resulting non-vegetated vertical accuracy of 0.096 meters as compared to classified LAS (Figure 12), and 0.096 meters as compared to the bare earth DEM, with 95% confidence (Figure 13) as a project whole.

NV5 Geospatial also assessed absolute accuracy using 21 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 presented here as a project whole (Table 13 and Figure 14).

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[1] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. https://www.asprs.org/a/society/committees/standards/Positional_Accuracy_Standards.pdf.

Table 12: Non vegetated vertical accuracy results as compared to the classified LAS per area of interest

Project Site	Number of Sample Points	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation
Manokotak	21	0.069 m	-0.001 m	0.001 m	0.035 m	0.036 m
Dillingham/Aleknagik	22	0.061 m	0.009 m	0.014 m	0.031 m	0.030 m
Ekuk	21	0.057 m	0.007 m	0.006 m	0.029 m	0.029 m
Ekwok	21	0.117 m	-0.007 m	0.008 m	0.060 m	0.061 m
New Stuyahok	19	0.169 m	-0.009 m	0.010 m	0.086 m	0.088 m
Koliganek	20	0.060 m	0.012 m	0.018 m	0.031 m	0.029 m

Table 13: Absolute accuracy results summarized for the full 2023 survey

Parameter	NVA, as compared to classified LAS	NVA, as compared to bare earth DEM	Ground Control Points
Sample	124 points	124 points	21 points
95% Confidence (1.96*RMSE)	0.096 m	0.096 m	0.094 m
Average	0.002 m	0.003 m	0.012 m
Median	0.009 m	0.011 m	0.008 m
RMSE	0.049 m	0.049 m	0.048 m
Standard Deviation (1σ)	0.049 m	0.049 m	0.048 m

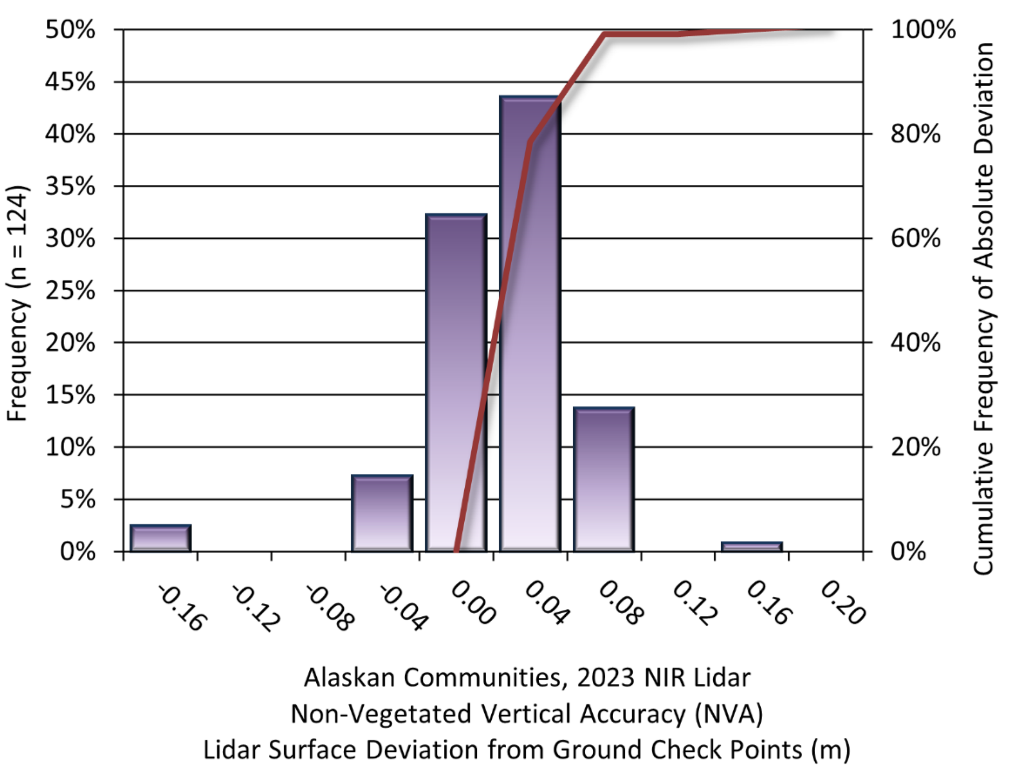

Figure 12: Frequency histogram for lidar classified LAS deviation from ground check point values (NVA)

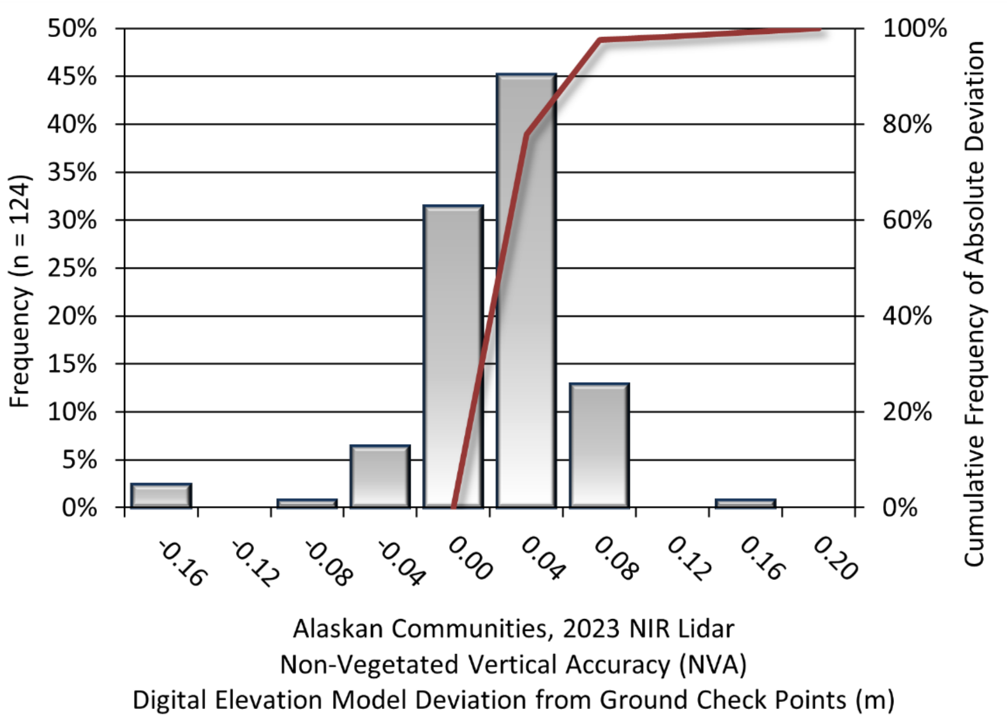

Figure 13: Frequency histogram for the lidar bare earth DEM surface deviation from ground check point values (NVA)

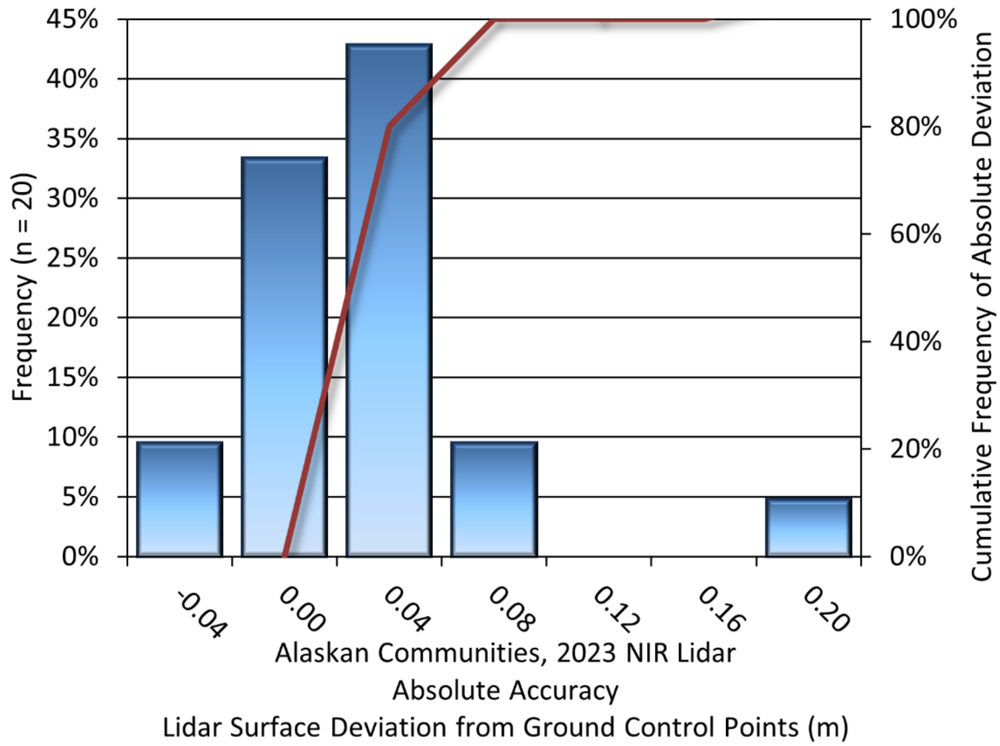

Figure 14: Frequency histogram for the lidar surface deviation from ground control point values

Lidar Vegetated Vertical Accuracies

NV5 Geospatial also assessed vertical accuracy 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. For the Alaskan Communities survey, 37 vegetated checkpoints were collected, with resulting vegetated vertical accuracy of 0.408 meters as compared to the classified LAS, and 0.424 meters as compared to the bare earth DEM evaluated at the 95^{th} percentile (Table 14, Figure 15, and Figure 16).

Table 14: Vegetated vertical accuracy results

Parameter	VVA, as compared to classified LAS	VVA, as compared to bare earth DEM
Sample	37 points	37 points
95^{th} Percentile	0.408 m	0.424 m
Average	0.139 m	0.139 m
Median	0.102 m	0.111 m
RMSE	0.189 m	0.193 m
Standard Deviation (1σ)	0.130 m	0.136 m

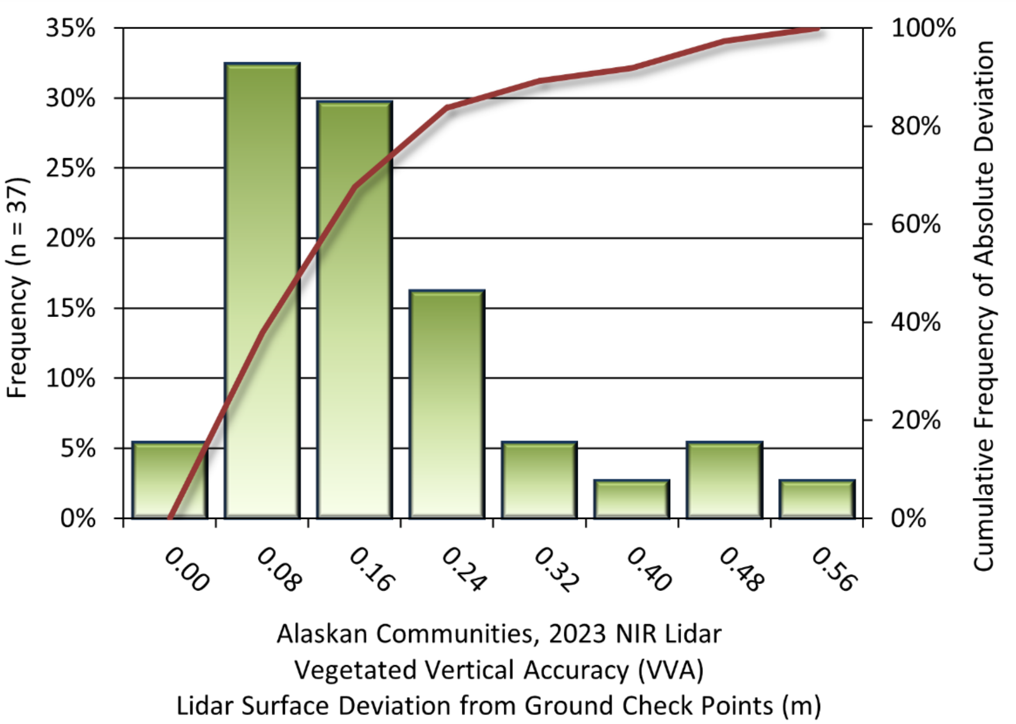

Figure 15: Frequency histogram for the lidar surface deviation from all land cover class point values (VVA)

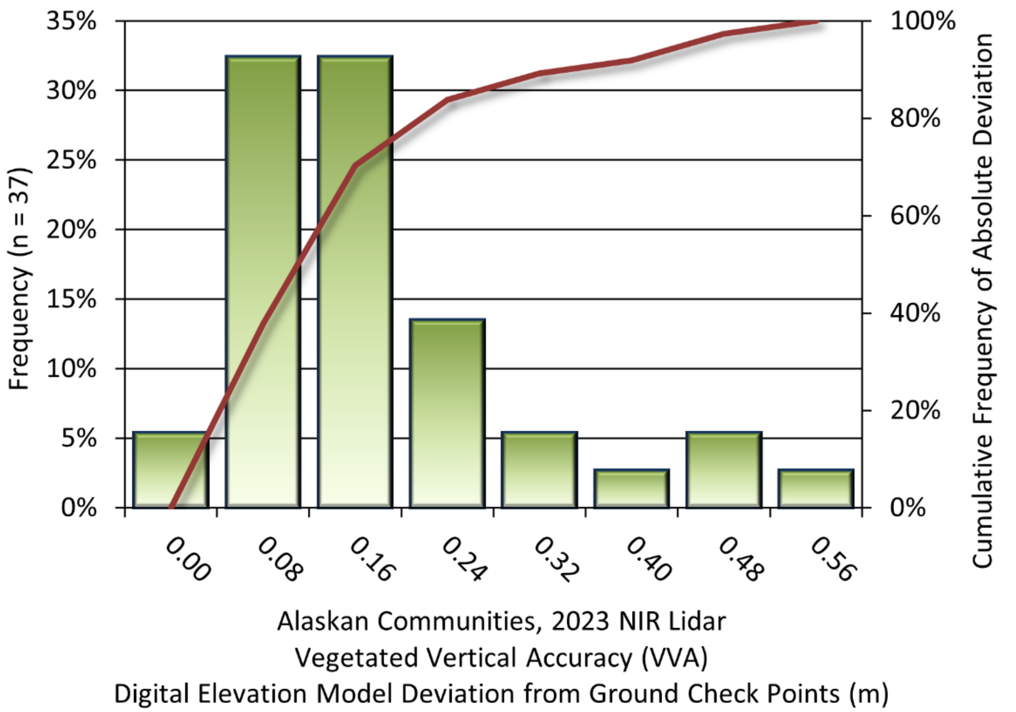

Figure 16: Frequency histogram for the lidar bare earth DEM deviation from vegetated check point values (VVA)

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 relative vertical accuracy for the Alaskan Communities 2023 Lidar project was 0.033 meters (Table 15, Figure 17).

Table 15: Relative accuracy results

Parameter	Relative Accuracy
Sample	73 surfaces
Average	0.033 m
Median	0.032 m
RMSE	0.034 m
Standard Deviation (1σ)	0.007 m
1.96σ	0.013 m

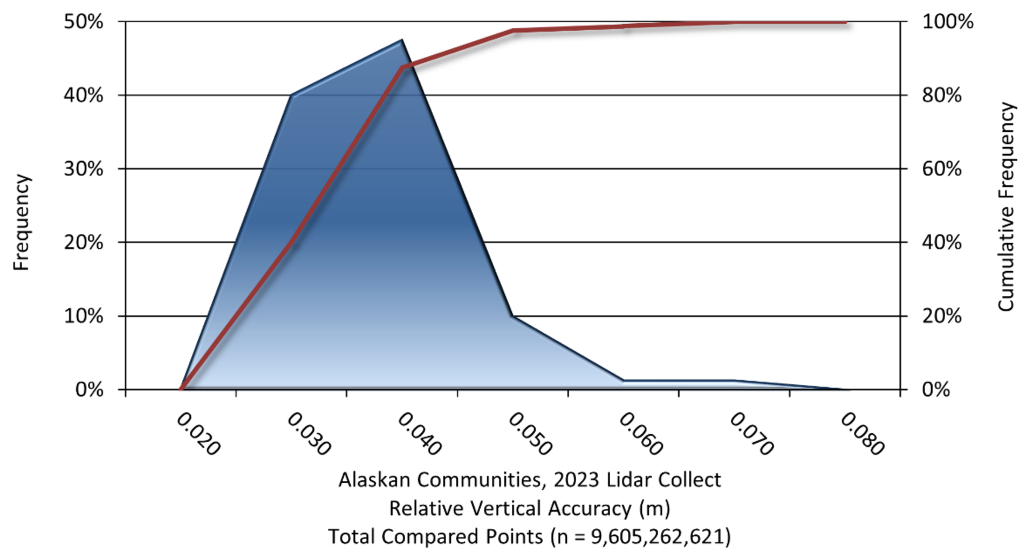

Figure 17: Frequency plot for relative vertical accuracy between flight lines

Lidar Horizontal Accuracy

Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and INS derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95 percent of the time. Based on a flying altitude of 2478 meters, an IMU error of 0.015 decimal degrees, and a GNSS positional error of 0.027 meters, this project was produced to meet 2.009 m horizontal accuracy at the 95% confidence level (Table 16).

Table 16: Horizontal accuracy

Parameter	Horizontal Accuracy
$RMSE_r$	1.161 m
ACC_r	2.009 m

CERTIFICATIONS

NV5 Geospatial provided lidar services for the Alaskan Communities project as described in this report.

I, Andrew Herbst, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Andrew Michael Herbst
Andrew Michael Herbst (Aug 6, 2024 14:20 AKDT) Aug 6, 2024

Andrew Herbst
Project Manager
NV5 Geospatial

I, Evon P. Silvia, PLS, being duly registered as a Professional Land Surveyor in and by the state of Alaska, hereby certify that the methodologies and static GNSS occupations used during airborne flights were performed using commonly accepted standard practices. Field work conducted for the airborne survey for this report was conducted on August 22, 2023, and September 4-18, 2023. Fieldwork for the ground survey to support this work was conducted by DOWL and under the supervision of their survey staff.

Accuracy statistics shown in the Accuracy section of this report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

Evon P. Silvia Aug 6, 2024

Evon P. Silvia, PLS
NV5 Geospatial
Corvallis, OR 97330

STATE OF ALASKA
49TH
EVON PETER SILVIA
No. 119313
REGISTERED PROFESSIONAL LAND SURVEYOR

Signed: Aug 6, 2024
COA: 125659

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.

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:

Source	Type	Post Processing Solution
Long Base Lines	GPS	None
Poor Satellite Constellation	GPS	None
Poor Antenna Visibility	GPS	Reduce Visibility Mask
Poor System Calibration	System	Recalibrate IMU and sensor offsets/settings
Inaccurate System	System	None
Poor Laser Timing	Laser Noise	None
Poor Laser Reception	Laser Noise	None
Poor Laser Power	Laser Noise	None
Irregular Laser Shape	Laser Noise	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 ± 29.25° 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.

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.