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ID NCENTRAL 4 D22

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ORIGINAL

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ID NCentral 4 D22

Table of Contents

Attachments 3

1. Executive Summary 3

1.1 The Project Team 4

1.2 Project Area 4

1.3 Coordinate Reference System 5

1.4 Project Deliverables 5

2. Lidar Acquisition Report 5

2.1 Acquisition Extents 5

2.2 Acquisition Summary 6

2.3 Sensor Calibration and Boresight 10

2.4 Lidar Acquisition and Processing Details 11

2.5 Lidar System Parameters 11

2.6 Acquisition Static Control 12

2.7 Airborne Kinematic Control 12

2.8 ABGNSS-Inertial Processing 12

2.9 Calibration Process (Project Mission Calibration) 13

2.10 Final Calibration Verification 13

3. Lidar Processing & Qualitative Assessment 13

3.1 Initial Processing 13

3.1.1 Post Calibration Lidar Review 13

3.2 Data Classification and Editing 16

3.2.1 Qualitative Review 16

3.2.2 Formatting Review 19

3.3 Positional Accuracy Validation 20

3.3.1 Interswath Accuracy 20

3.3.2 Intraswath Accuracy 21

4. Breakline Processing & Qualitative Assessment 22

4.1 Breakline Production Methodology 22

4.1.1 Breakline Collection Requirements 22

4.2 Breakline Qualitative Assessment 23

5. DEM Processing & Qualitative Assessment 25

5.1 DEM Production Methodology 25

5.2 DEM Qualitative Assessment 25

6. Derivative Lidar Products 26

6.1 Swath Separation Images (SSIs) 26

6.2 Maximum Surface Height Rasters (MSHRs) 27

6.3 Flightline Extents GDB 27

Table of Tables

Table 1. Lidar acquisition details ... 11

Table 2. Dewberry lidar system parameters ... 11

Table 3. Spatial reference system used for ABGNSS-Inertial Processing ... 13

Table 4. Summary of calibrated swath vertical accuracy tested with ground control points ... 13

Table 5. Post calibration and initial processing data verification steps ... 14

Table 6. Lidar editing and review guidelines ... 17

Table 7. Classified lidar formatting parameters ... 19

Table 8. Breakline collection requirements ... 22

Table 9. Breakline verification steps ... 23

Table 10. DEM verification steps ... 25

Table of Figures

Figure 1. Project Map and tile grid. ... 4

Figure 2. ID NCentral 4 D22 swaths 6

Figure 3. Each of the images above show the same area of dense evergreen vegetation. Even though the area was flown with less than a 20-degree scan angle (middle image), there is little to no ground penetration through the evergreen trees, resulting in laser shadowing and lower density. 8

Figure 4. The top image shows a 1m first-return density raster created for the entire ID NCentral D22 AOI. The bottom image shows the density distribution for the entire project. 96.4% of the project area achieves greater than 8 ppsm density, with small areas of lower density distributed throughout the project area. 9

Figure 5. The top image shows a worst-case scenario example in a highly vegetated and sloped terrain where the first-return density is below 8 ppsm. The bottom image shows the density ppsm distribution for this area. 10

Figure 6. A typical calibration and boresight flight plan where above ground features are acquired from all four cardinal directions, any offsets of the above ground features between overlapping and other directional flight lines is analyzed, and corrections are applied as necessary to ensure proper configuration of the sensor. 11

Figure 7. Interswath raster generated using proprietary software and symbolized according to the ranges specified above. Inter-swath relative accuracy passes specifications. 20

Figure 8. Intra-swath relative accuracy. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications. ... 21

Figure 9. Swath Separation Images (SSIs) generated for ID NCentral 4 D22. ... 27

Attachments

Appendix A: Mission GPS and IMU Processing Reports

1. Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the ID NCentral 4 D22 Project Area.

This task order was for Planning, Acquisition, processing, and derivative products of lidar data to be collected at an aggregate nominal pulse spacing (ANPS) of ≤0.35 meters (QL1). Lidar data and derivative products produced in compliance with this task order are based on the “National Geospatial Program Lidar Base Specification 2024, Revision A”. Lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1,000 m by 1,000 m. A total of 46,763 tiles were produced for the project encompassing an area of approximately 17,297 sq. miles. A total of 5,954 tiles were produced for ID NCentral 4 D22, providing approximately 2,080 sq. miles of coverage.

1.1 The Project Team

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry completed the ground survey for the project and delivered surveyed checkpoints. Ground control points and checkpoints were surveyed for the project. Ground control points were used in calibration activities and checkpoints were used in independent testing of the vertical accuracy of the lidar-derived surface model.

Dewberry completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The WUID area is shown in Figure 1. ID NCentral 4 D22 contains 5,594 1,000 m by 1,000 m tiles. The project tile grid contains 46,763 1,000 m by 1,000 m tiles.

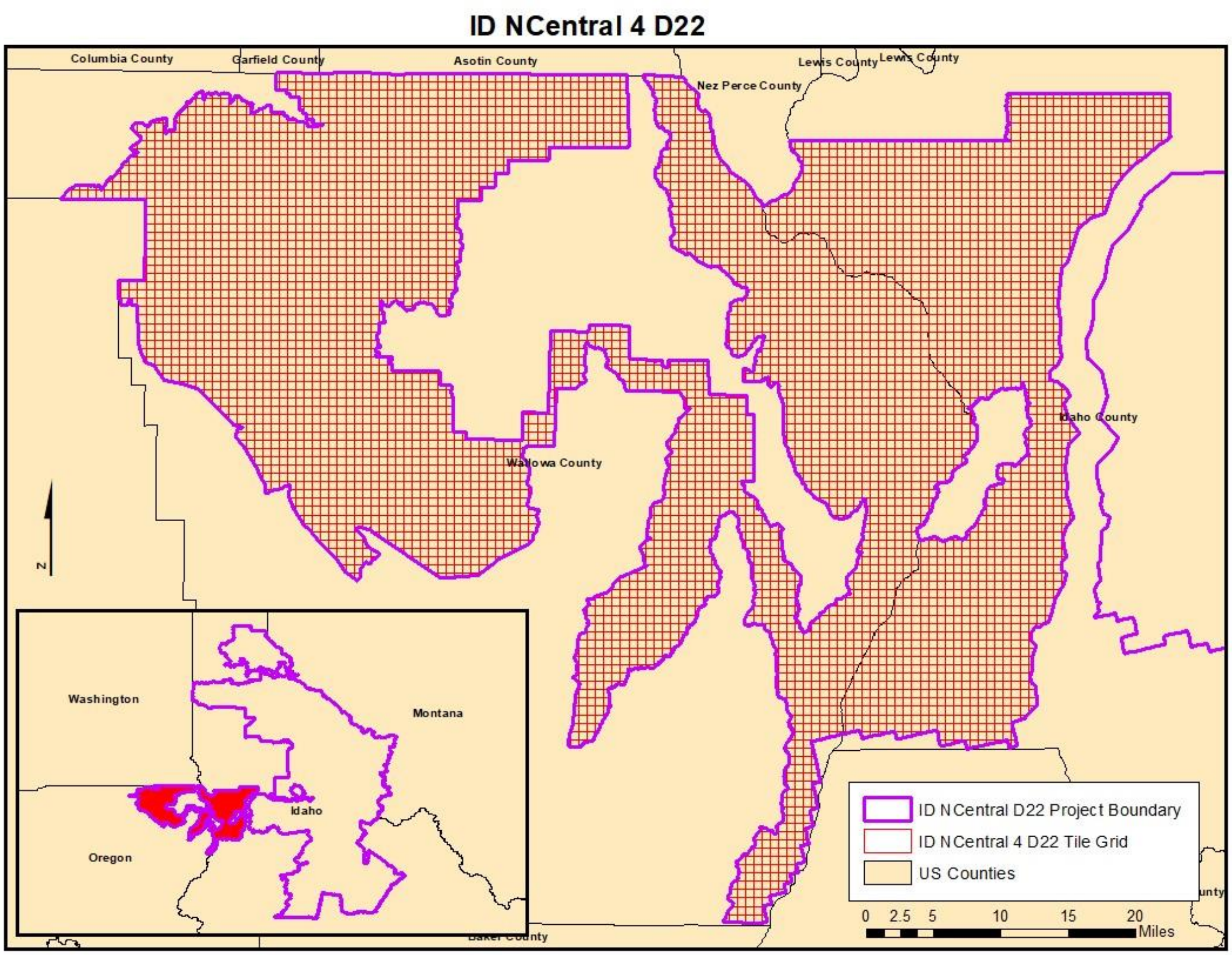


Figure 1. Project Map and tile grid.

1.3 Coordinate Reference System
Data produced for the project were delivered in the following reference system:

Horizontal Datum: North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM zone 11N
Units: Meters
Geoid Model: Geoid18

1.4 Project Deliverables
The deliverables for the project are listed below.

1. Project Extents (Esri SHP)
2. Classified Point Cloud (tiled LAS)
3. Breakline Data (Esri geopackage)
4. Bare Earth Surface (tiled raster DEM, COG GeoTIFF format)
5. Swath Separation Images
6. Metadata (XML)
7. Project Report
8. Flightline Extents GDB
9. Maximum Surface Height Rasters (tiled raster MSHRs, GeoTIFF format)

2. Lidar Acquisition Report

Dewberry acquired and calibrated the lidar data for this project. Acquisition was completed in October 2023.

2.1 Acquisition Extents
Figure 2 shows flightline vectors by lift.

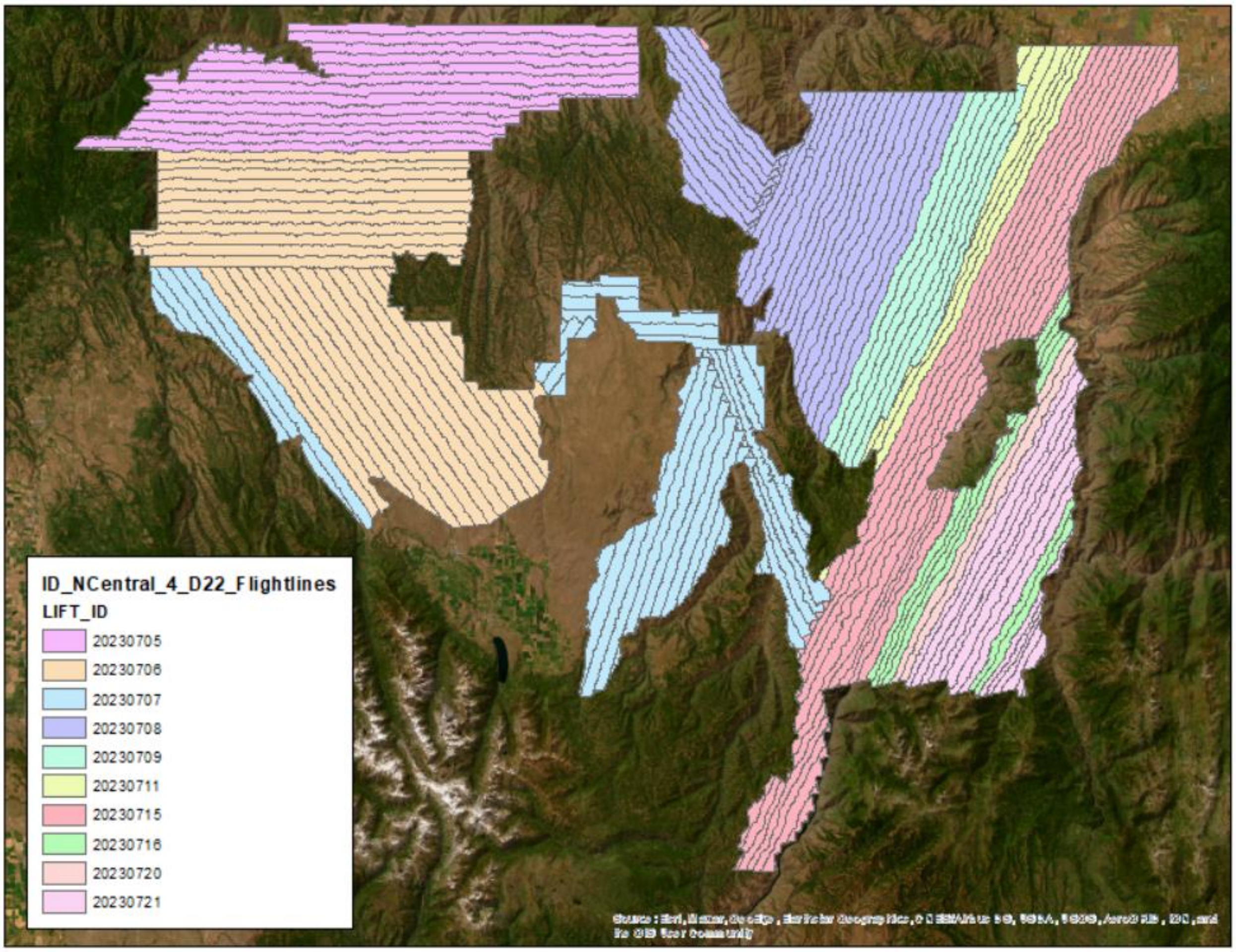


Figure 2. ID NCentral 4 D22 swaths

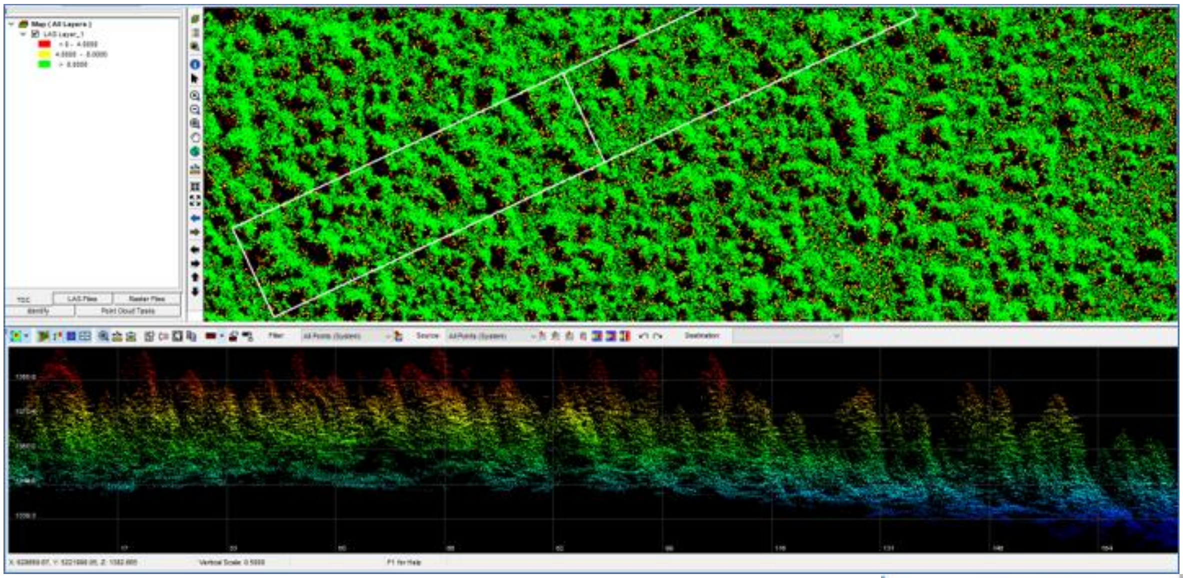
2.2 Acquisition Summary

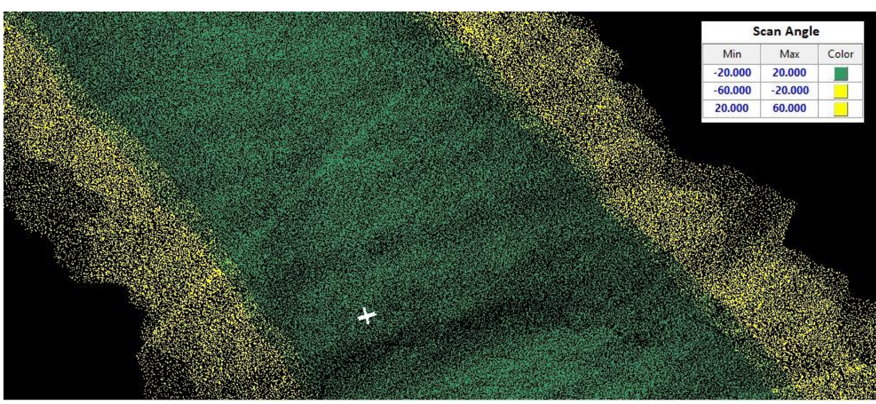
Dewberry planned 165 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Dewberry followed industry standards and best practices and, at a minimum, includes the following criteria:

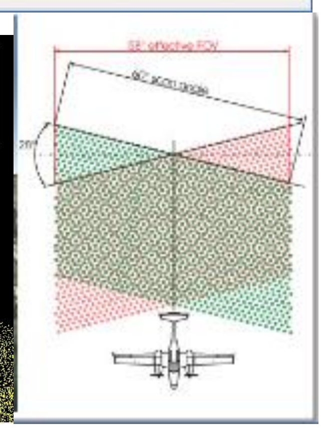
- A digital flight line layout using Teledyne Airborne Mission Manager (AMM) flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Dewberry filed our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Snow density and snow coverage in the project area was closely monitored in spring and early Summer 2023. As soon as the snow dissipated, Dewberry mobilized to Idaho. Acquisition for ID NCentral 4 D22 started in early July 2023 and lasted until late July 2023. Flight lines were only collected when the atmosphere between the aircraft and the ground was cloud and fog-free. Acquisition was completed before snowfall began at higher elevations.

Dewberry planned flightlines with a minimum of 10 ppsm to exceed the 8 ppsm requirement, based on an overlap of 20% to greater than 50%, depending on terrain. Flight lines were planned at a height above ground level (AGL) of 6067 ft or 1850 m. First-return point density in the steep slopes and dense forested areas had instances of less than 8 ppsm density due to dense vegetation and steep slopes that cause lidar shadowing. While some small areas of sloped and/or vegetated terrain were identified to have less than the 8 ppsm requirement, statistically each swath exceeds 8 ppsm and are closer to 10 ppsm. Sufficient density to produce accurate and detailed bare earth DEMs was achieved.







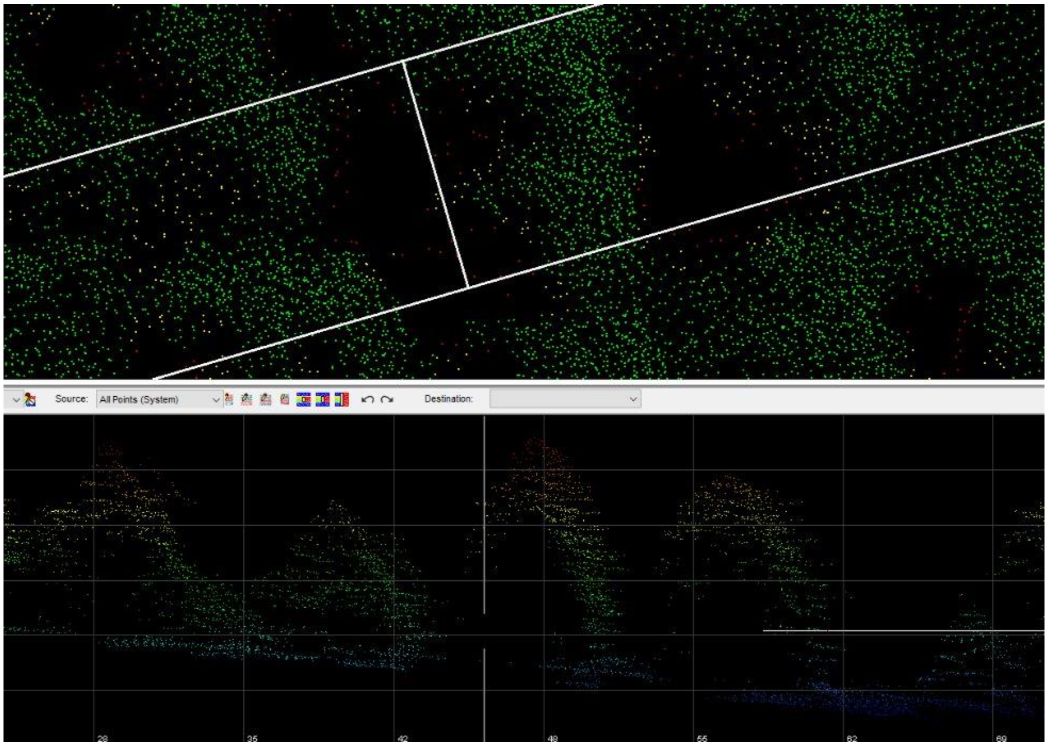
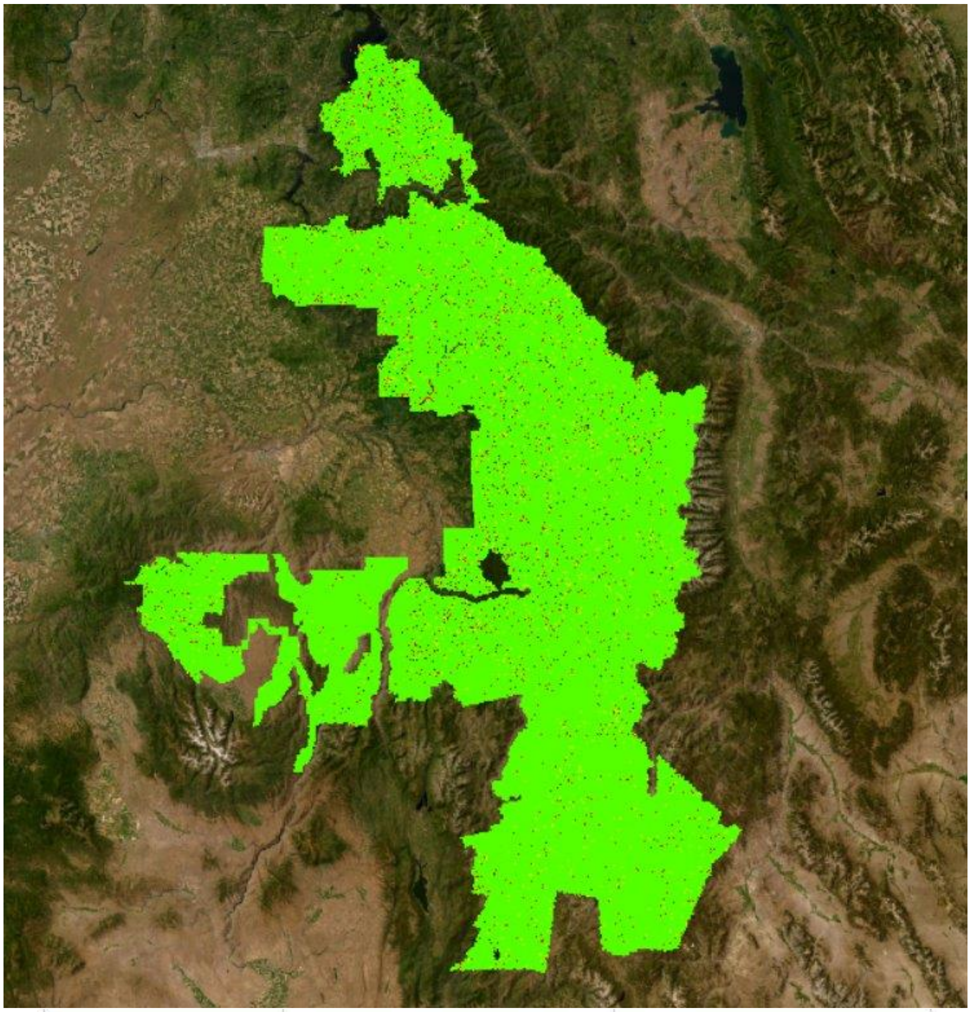
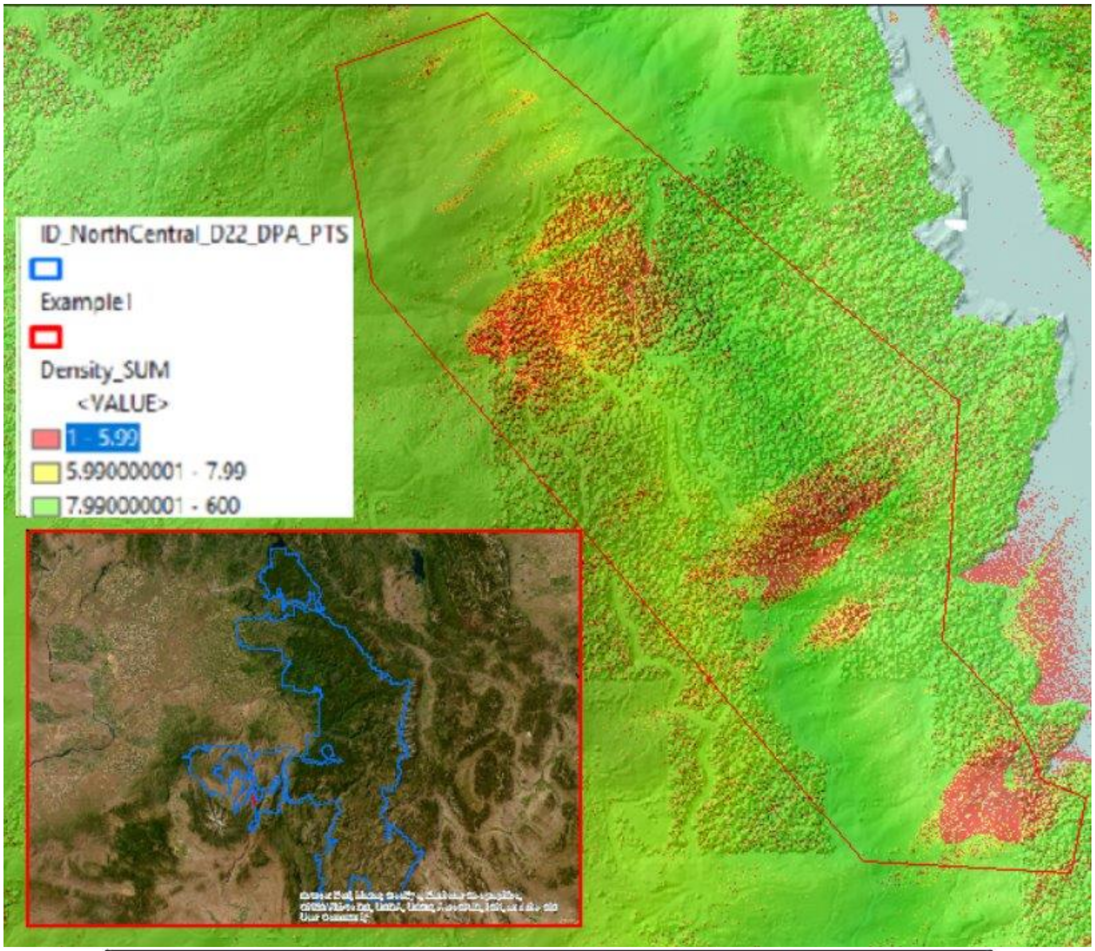


Figure 3. Each of the images above show the same area of dense evergreen vegetation. Even though the area was flown with less than a 20-degree scan angle (middle image), there is little to no ground penetration through the evergreen trees, resulting in laser shadowing and lower density.



ID_NorthCentral_D22_QL1		
Density Range	# of Cells	% of Cells Within Stated Range
1 to 5.99	939271435	2.11008566
5.99 to 7.99	675162090	1.516760535
>7.99	42898993240	96.3731538

Figure 4. The top image shows a 1m first-return density raster created for the entire ID NCentral D22 AOI. The bottom image shows the density distribution for the entire project. 96.4% of the project area achieves greater than 8 ppsm density, with small areas of lower density distributed throughout the project area.



ID_NorthCentral_D22_QL1 - Example 1		
Density Range	# of Cells	% of Cells Within Stated Range
1 to 5.99	235022	15.44336715
5.99 to 7.99	1686979	10.76614899
>7.99	286710117	73.79048386

Figure 5. The top image shows a worst-case scenario example in a highly vegetated and sloped terrain where the first-return density is below 8 ppsm. The bottom image shows the density ppsm distribution for this area.

2.3 Sensor Calibration and Boresight

Prior to the ID NCentral 4 D22 Acquisition, Dewberry completed a sensor boresight on 3/2/23 in Tampa, FL. The boresight consisted of multiple opposing lines in an E-W direction as well as multiple opposing lines in a N-S direction. The swaths have a large overlap (>60%) with neighbors. The trajectory (.sbet) was processed using Applanix POSPac and raw swath data (.las) was produced using Riegl RiProcess. The boresight was calibrated and then analyzed. All deemed necessary corrections are then applied to the senor orientation internal files.

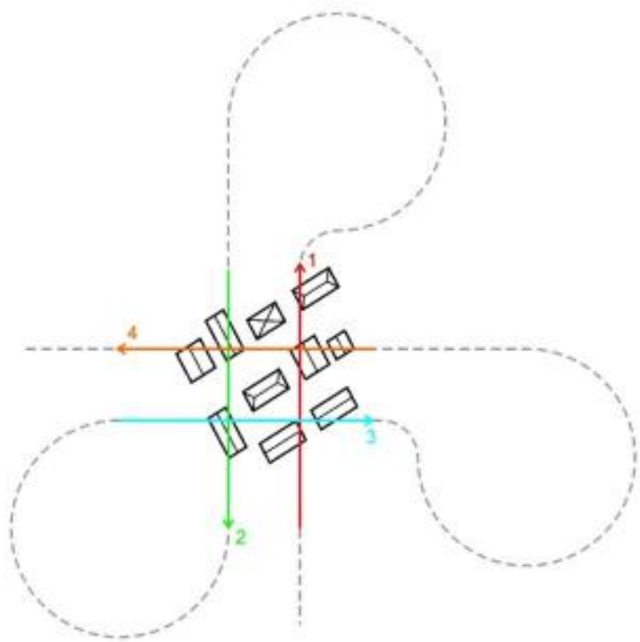


Figure 6. A typical calibration and boresight flight plan where above ground features are acquired from all four cardinal directions, any offsets of the above ground features between overlapping and other directional flight lines is analyzed, and corrections are applied as necessary to ensure proper configuration of the sensor.

2.4 Lidar Acquisition and Processing Details

Table 1 outlines lidar acquisition details, including the project spatial reference system, and processing software used for this project.

Table 1. Lidar acquisition details

Parameter	Value
Number of Flight lines	165
Approximate Area	2,080 sq. miles
Acquisition Dates	July 5, 2023 – July 21, 2023
Horizontal Datum	North American Datum of 1983 with the 2011 Adjustment (NAD83(2011))
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid Model	Geoid 18
Coordinate Reference System	UTM Zone 11N
Horizontal Units	Meters
Vertical Units	Meters
Kinematic Solution Processing Software	Applanix POSPac
Point Cloud Generation Software	Riegl RiProcess
Calibration Software	BayesMap StripAlign

2.5 Lidar System Parameters

Dewberry operated a Cessna 208 (Tail # N167PM) outfitted with a Riegl VQ-1560II-S lidar system during data collection. Table 2 details the lidar system parameters used during acquisition for this project.

Table 2. Dewberry lidar system parameters

Parameter	Value
System	Riegl VQ-1560II-S

Parameter	Value
Altitude (m above ground level)	1850
Nominal flight speed (kts)	140
Scanner pulse rate (kHz)	2700
Scan frequency (Hz)	158
Pulse duration of the scanner (ns)	3
Pulse width of the scanner (m)	9
Central wavelength of the sensor laser (nm)	1064
Multiple pulses in the air	Yes
Beam divergence (mrad)	0.17
Swath width (m)	2072
Nominal swath width on the ground (m)	2072
Swath overlap (%)	25
Total sensor scan angle (degrees)	58.5
Nominal pulse spacing (NPS) (single swath) (m)	0.32
Nominal Pulse Density (NPD) (single swath) (points per sq m)	10
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.32
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	10
Maximum Number of Returns per Pulse	7

2.6 Acquisition Static Control

The airborne lidar data was post-processed by Dewberry with Applanix IN-Fusion PP-RTX, a Precise Point Position (PPP) processing solution. Therefore, no static base station control was required.

2.7 Airborne Kinematic Control

Airborne GPS data was processed using the POSPac Mobile Mapping Suite (MMS) software. Flights were flown with a minimum of 16 satellites in view (10° above the horizon) and with PDOP less than 2.

The GPS average residuals for all flights were 3 cm or better, with no residuals greater than 10 cm recorded.

GPS processing reports for each mission are provided in Appendix A: Mission GPS and IMU Processing Reports.

2.8 ABGNSS-Inertial Processing

ABGNSS-Inertial processing was performed using the software identified in Table 1. The reference frame used for this processing does not always match the project spatial reference system and is shown in Table 3.

Appendix A contains additional mission GPS and IMU processing covering:

- POSPac graphics and processing
- Graphics of any reference stations used for differential correction
- Graphics of processing interface to show trajectory data and labeled reference stations for each lift (only graphics of trajectory when precise point position is used).
- Graphics of processed plots for each mission/flight/lift to include:
    1. Forward/reverse separation of trajectory
    2. Estimated accuracy of trajectory
    3. Any additional plots used in the analyses of trajectory quality

Table 3. Spatial reference system used for ABGNSS-Inertial Processing

Parameter	Value
Horizontal Datum	North American Datum of 1983 with the 2011 Adjustment (NAD83(2011))
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid Model	Geoid18
Coordinate Reference System	UTM Zone 11N
Horizontal Units	Meters
Vertical Units	Meters

2.9 Calibration Process (Project Mission Calibration)

Availability and status of all required GPS and laser data were verified against field reports and any data inconsistencies were addressed.

Lidar mission flight trajectories were combined with raw point files in Riegl RiProcess. The initial points (.las) for each mission calibration were inspected for flight line errors, spatial distribution, data voids, density, or issues with the lidar sensor. If a calibration error greater than specification was observed within the mission, the necessary roll, pitch, and scanner scale corrections were calculated and corrections were applied to each individual swath using the BayesMap StripAlign software. In addition, all GPS, aircraft trajectory, mission information, and ground control files were reviewed and logged into a database. The missions with the new calibration values were regenerated and validated internally once again to ensure quality.

The methodology and assessment for the spatial distribution, density, and sensor anomaly reviews are outlined further in the Post Calibration Lidar Review table.

2.10 Final Calibration Verification

Dewberry surveyed 68 ground control points (GCPs) in flat, non-vegetated areas to test the accuracy of the calibrated swath data. GCPs were located in open, non-vegetated terrain. To assess the accuracy of calibration, the heights of the ground control points were compared with a surface derived from the calibrated swath lidar. A full list of GCPs used for accuracy testing is included in the GCP Survey Report provided with project deliverables.

Table 4. Summary of calibrated swath vertical accuracy tested with ground control points

Land Cover Type	# of Points	$RMSE_z$ (m)	NVA (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Ground Control Points (GCPs)	68	0.047	0.092	0.000	-0.004	0.483	0.047	-0.098	0.144	0.307

3. Lidar Processing & Qualitative Assessment

3.1 Initial Processing

Dewberry performed vertical accuracy validation of the swath data, inter-swath relative accuracy validation, intra-swath relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allowed Dewberry to determine whether the data was suitable for full-scale production.

The methodology and assessment for the absolute and relative accuracy, density, and spatial distribution reviews performed are outlined further in the Post Calibration Lidar Review table.

3.1.1 Post Calibration Lidar Review

The table below identifies requirements verified by Dewberry prior to tiling the swath data, running initial ground macros, and starting manual classification.

Table 5. Post calibration and initial processing data verification steps

Methodology and Requirement	Description of Deliverables	Additional Comments
Using proprietary software it was determined the non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 19.6 cm at the 95% confidence level based on $RMSE_z$ (10 cm) x 1.96	The swath NVA was tested and passed specifications.	None
Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing density mean statistics output by proprietary tool, the project area was determined to meet the required specification of 8 ppsm or 0.35 m NPS. A visual review of a 1-square meter density grid is also performed to confirm most 1-square meter cells satisfies the project requirements. Density is also viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds) to confirm density passes with no issues.	The average calculated (A)NPD of this project is 24.1 ppsm. Density raster visualization also passed specifications.	None
The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. Proprietary tools are then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.	98.7% of cells (2*NPS cell size) had at least 1 lidar point within the cell.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm maximum difference. Dewberry verifies the intra-swath or within swath relative accuracy by using proprietary scripting to output intra-swath rasters. Proprietary scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry performs a visual review of planar surfaces and ensures the data passes specification.	Within swath relative accuracy passed specification.	None
Between swath (Inter-swath or swath overlap) relative accuracy must meet 8 cm RMSDz/16 cm maximum	Between swath relative accuracy passed specification, calculated from single return lidar points.	None

Methodology and Requirement	Description of Deliverables	Additional Comments
difference. These thresholds are tested in open, flat terrain. Dewberry verifies the inter-swath or between swath relative accuracy by using proprietary scripting to output inter-swath rasters and LP360 generated Swath Separation Images which are both reviewed visually at multiple stages of production to ensure the data passes specification.		
Horizontal Calibration-There should not be horizontal offsets (or vertical offsets) between overlapping swaths that would negatively impact the accuracy of the data or the overall usability of the data. Assessments made on rooftops or other hard planar surfaces where available.	Horizontal calibration met project requirements.	None
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation was acceptable.	None
Sensor Anomalies-The sensor should perform as expected without anomalies that negatively impact the usability of the data, including issues such as excessive sensor noise and intensity gain or range-walk issues	No sensor anomalies were present.	None
Edge of Flight line bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired	Edge of Flight line bits were populated correctly	None
Scan Direction bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired with sensors using oscillating (back-and-forth) mirror scan mechanism. These fields should show a minimum and maximum of 0 for each swath acquired with Riegl sensors as these sensors use rotating mirrors.	Scan Direction bits were populated correctly	None
Swaths are in LAS v1.4 formatting	Swaths were in LAS v1.4 as required by the project.	None
All swaths must have File Source IDs assigned (these should equal the Point Source ID or the flight line number)	File Source IDs were correctly assigned	None
GPS timestamps must be in Adjusted GPS time format and Global Encoding field must also indicate Adjusted GPS timestamps	GPS timestamps were Adjusted GPS time and Global Encoding field were correctly set to 17	None
Intensity values must be 16-bit, with values ranging between 0-65,535	Intensity values were 16-bit	None
Point Source IDs must be populated and swath Point Source IDs should match the File Source IDs	Point Source IDs were assigned and match the File Source IDs	None

3.2 Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, Dewberry utilized proprietary and TerraScan software for processing. The acquired 3D laser point clouds were tiled according to the project tile grid using proprietary software. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classified any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that may be geometrically unusable were flagged as withheld and classified to a separate class so that they would be excluded from the initial ground algorithm. After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

This surface model was generated using four main parameters: building size, iteration angle, iteration distance, and maximum terrain angle. The initial model was based on low points being selected by a "roaming window" with the assumption that these were the ground points. The size of this roaming window was determined by the building size parameter. The low points were triangulated and the remaining points were evaluated and subsequently added to the model if they met the iteration angle and distance constraints. This process was repeated until no additional points were added within iterations. Points that did not relate to classified ground within the maximum terrain angle were not captured by the initial model.

After the initial automated ground routine, each tile was imported into TerraScan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing. Dewberry analysts employed 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points were removed from the ground classification.

Bridge decks were classified to class 17 and bridge saddle breaklines were used where necessary. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilized breaklines to automatically classify hydro features. The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydro-flattening artifacts along the edges of hydro features.

The withheld bit was set on the withheld points previously identified in TerraScan before the ground classification routine was performed. The withheld bit was set on points classified as noise (classes 7 and 18) after manual clean-up.

After manual classification, the LAS tiles were peer reviewed and then underwent a final independent QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, were updated and verified using proprietary Dewberry software.

3.2.1 Qualitative Review

Dewberry's qualitative assessment of lidar point cloud data utilized a combination of statistical analyses and visual interpretation. Methods and products used in the assessment included profile- and map view-based point cloud review, pseudo image products (e.g., intensity orthoimages), TINs, DEMs, DSMs, and point density rasters. This assessment looked for incorrect classification and other errors sourced in the LAS data. Lidar data are peer reviewed, reviewed by task leads (senior level analysts), and verified by an independent QA/QC team at key points within the lidar workflow.

The following table describes Dewberry's standard editing and review guidelines for specific types of features, land covers, and lidar characteristics.

Table 6. Lidar editing and review guidelines

Category	Editing Guideline	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids greater than 4 x $ANPS^2$, or 1.96 m^2, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) points for review.	No unacceptable voids were identified in this dataset
Artifacts	Artifacts in the point cloud are typically caused by misclassification of points in vegetation or man-made structures as ground. Low-lying vegetation and buildings are difficult for automated grounding algorithms to differentiate and often must be manually removed from the ground class. Dewberry identified these features during lidar editing and reclassified them to Class 1 (unassigned). Artifacts up to 0.3 m above the true ground surface may have been left as Class 2 because they do not negatively impact the usability of the dataset.	None
Bridge Saddles	The DEM surface models are created from TINs or terrains. TIN and terrain models create continuous surfaces from the input points, interpolating surfaces beneath bridges where no lidar data was acquired. The surface model in these areas tend to be less detailed. Bridge saddles may be created where the surface interpolates between high and low ground points. Dewberry identifies problems arising from bridge removal and resolves them by reclassifying misclassified ground points to class 1 and/or adding bridge saddle breaklines where applicable due to interpolation.	None
Culverts and Bridges	It is Dewberry's standard operating procedure to leave culverts in the bare earth surface model and remove bridges from the model. In instances where it is difficult to determine whether the feature was a culvert or bridge, Dewberry errs on the side of culverts, especially if the feature is on a secondary or tertiary road.	None
In-Ground Structures	In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. When present, Dewberry	No in-ground structures present in this dataset

Category	Editing Guideline	Additional Comments
	identifies these structures in the project and includes them in the ground classification.	
Dirt Mounds	Irregularities in the natural ground, including dirt piles and boulders, are common and may be misinterpreted as artifacts that should be removed. To verify their inclusion in the ground class, Dewberry checked the features for any points above or below the surface that might indicate vegetation or lidar penetration and reviews ancillary layers in these locations as well. Whenever determined to be natural or ground features, Dewberry edits the features to class 2 (ground)	No dirt mounds or other irregularities in the natural ground were present in this dataset
Irrigated Agricultural Areas	Per project specifications, Dewberry collected all areas of standing water greater than or equal to 0.8 hectare, including areas of standing water within agricultural areas and not within wetland or defined waterbody, hydrographic, or tidal boundaries. Areas of standing water that did not meet the 0.8 hectare size criteria were not collected.	Standing water within agricultural areas not present in the data
Wetland/Marsh Areas	Vegetated areas within wetlands/marsh areas are not considered water bodies and are not hydroflattened in the final DEMs. However, it is sometimes difficult to determine true ground in low wet areas due to low reflectivity. In these areas, the lowest points available are used to represent ground, resulting in a sparse and variable ground surface. Open water within wetland/marsh areas greater than or equal to 2 acres is collected as a waterbody.	No marshes present in the data
Flight Line Ridges	Flight line ridges occur when there is a difference in elevation between adjacent flight lines or swaths. If ridges are visible in the final DEMs, Dewberry ensures that any ridges remaining after editing and QA/QC are within project relative accuracy specifications.	No flight line ridges are present in the data
Temporal Changes	If temporal differences are present in the dataset, the offsets are identified with a shapefile.	No temporal offsets are present in the data
Low NIR Reflectivity	Some materials, such as asphalt, tars, and other petroleum-based products, have low NIR reflectivity. Large-scale applications of these products, including roadways and roofing, may have diminished to absent lidar	No Low NIR Reflectivity is present in the data

Category	Editing Guideline	Additional Comments
	returns. USGS LBS allow for this characteristic of lidar but if low NIR reflectivity is causing voids in the final bare earth surface, these locations are identified with a shapefile.	
Laser Shadowing	Shadows in the LAS can be caused when solid features like trees or buildings obstruct the lidar pulse, preventing data collection on one or more sides of these features. First return data is typically collected on the side of the feature facing toward the incident angle of transmission (toward the sensor), while the opposite side is not collected because the feature itself blocks the incoming laser pulses. Laser shadowing typically occurs in areas of single swath coverage because data is only collected from one direction. It can be more pronounced at the outer edges of the single coverage area where higher scanning angles correspond to more area obstructed by features. Building shadow in particular can be more pronounced in urban areas where structures are taller. Data are edited to the fullest extent possible within the point cloud. As long as data meet other project requirements (density, spatial distribution, etc.), no additional action taken.	Laser Shadowing is present in the data

3.2.2 Formatting Review

After the final QA/QC was performed and all corrections were applied to the dataset, all lidar files were updated to the final format requirements and the final formatting, header information, point data records, and variable length records were verified using proprietary tools. The table below lists the primary lidar header fields that are updated and verified.

Table 7. Classified lidar formatting parameters

Parameter	Project Specification	Pass/Fail
LAS Version	1.4	Pass
Point Data Record Format	6	Pass
Horizontal Coordinate Reference System	NAD83 (2011) UTM Zone 11N, meters in WKT format	Pass
Vertical Coordinate Reference System	NAVD88 (Geoid 18), meters in WKT format	Pass
Global Encoder Bit	17 for adjusted GPS time	Pass
Time Stamp	Adjusted GPS time (unique timestamps)	Pass
System ID	Sensor used to acquire data	Pass- AR15S
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass

Parameter	Project Specification	Pass/Fail
Intensity	16-bit intensity values recorded for each pulse	Pass
Classification	Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground	Pass
Withheld Points	Withheld bits, set for geometrically unreliable points and for noise points in classes 7 and 18.	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Recorded for each pulse	Pass

3.3 Positional Accuracy Validation

3.3.1 Interswath Accuracy

The Interswath accuracy, or overlap consistency, measures the variation in the lidar data within the swath overlap. Interswath accuracy measures the quality of the calibration and boresight adjustment of the data in each lift. Dewberry reviews the overlap consistency of the lidar dataset during multiple stages of production. Each review is performed by an initial reviewer and then reviewed by a second reviewer to verify the overlap consistency meets expectations. After calibration, Dewberry uses a proprietary software to generate a point statistics interswath raster. The interswath raster is reviewed for any systematic interswath errors that should be considered of concern. If issues are identified it will be corrected by the calibration team. The interswath rasters are symbolized by the following ranges:

- +/- 0-8 cm: **Green**
- +/- 8-16 cm: **Yellow**
- +/- 16 cm: **Red**

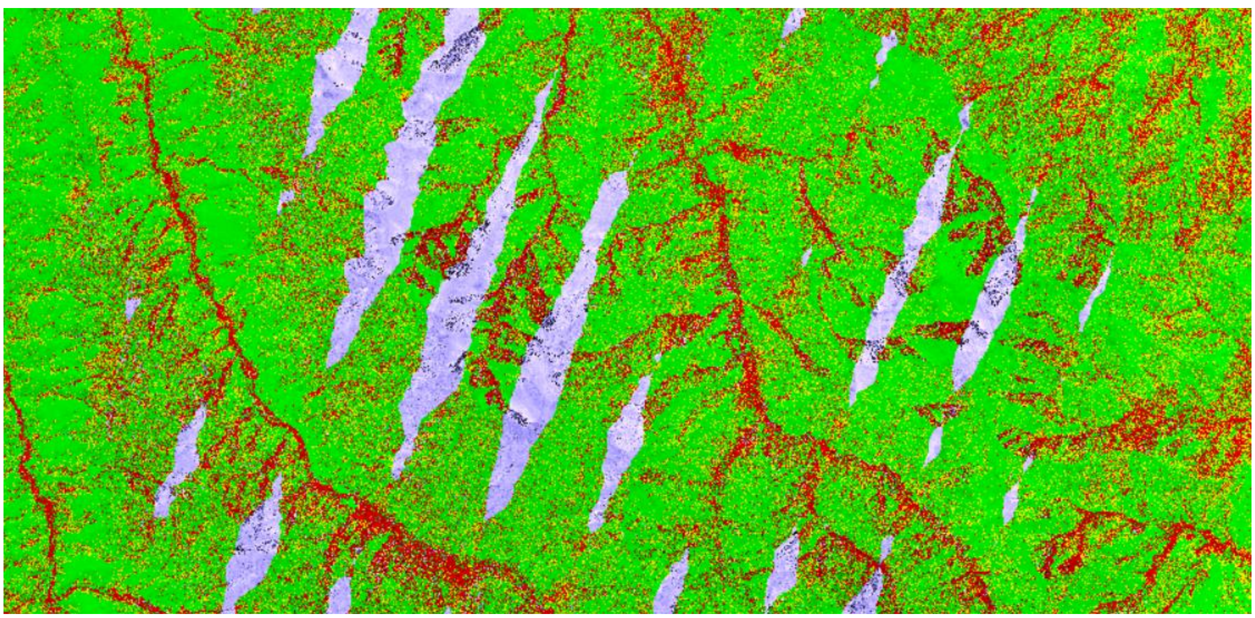


Figure 7. Interswath raster generated using proprietary software and symbolized according to the ranges specified above. Inter-swath relative accuracy passes specifications.

Once the initial ground macro has been run on the dataset, Dewberry uses LP360 to generate swath separation images. The swath separation images are generated using the same settings as the final deliverable swath separation images outlined in 6.1 Swath Separation Images (SSIs) and in accordance with USGS Lidar Base Specification v2024 Rev A. If the lidar dataset is heavily vegetated, Dewberry will generate swath separation images using the last return of ground points only to better confirm no offsets are present in the bare earth DEM. If issues are identified, dependent on the cause of the issue, it will be corrected by recalibrating the affected data or classifying the impacting points to withheld.

Lastly, the final deliverable swath separation images are generated using LP360. A final review is performed by the final product producer and then verified by a member of the quality management team prior to sending to USGS.

3.3.2 Intraswath Accuracy

The intraswath accuracy, or the precision of lidar, measures variations on a surface expected to be flat and without variation. Precision is evaluated to confirm that the lidar system is performing properly and without gross internal error that may not be otherwise apparent. Dewberry reviews the precision of the lidar dataset during multiple stages of production. Each review is performed by an initial reviewer and then reviewed by a second reviewer to verify the precision of the lidar meets expectations. Dewberry performs an intraswath accuracy review for each mission within 1-2 days of collection. The precision of the lidar dataset is then reviewed before calibration on the lidar dataset to ensure no systematic errors.

Dewberry uses a proprietary software to generate point statistics intraswath rasters. Swath data in non-overlap areas were assessed using only first returns in non-vegetated areas. To measure the precision of a lidar dataset, level or flat surfaces were assessed. If the lidar dataset is located in area with sloped or steep terrain, a slope raster will be used in conjunction with the intraswath raster to ensure only level or flat surfaces are being assessed. The intraswath raster is reviewed for any systematic intraswath errors that should be considered of concern.

The intraswath rasters are symbolized by the following ranges:

- 0-6 cm: **Green**
- >6 cm: **Red**

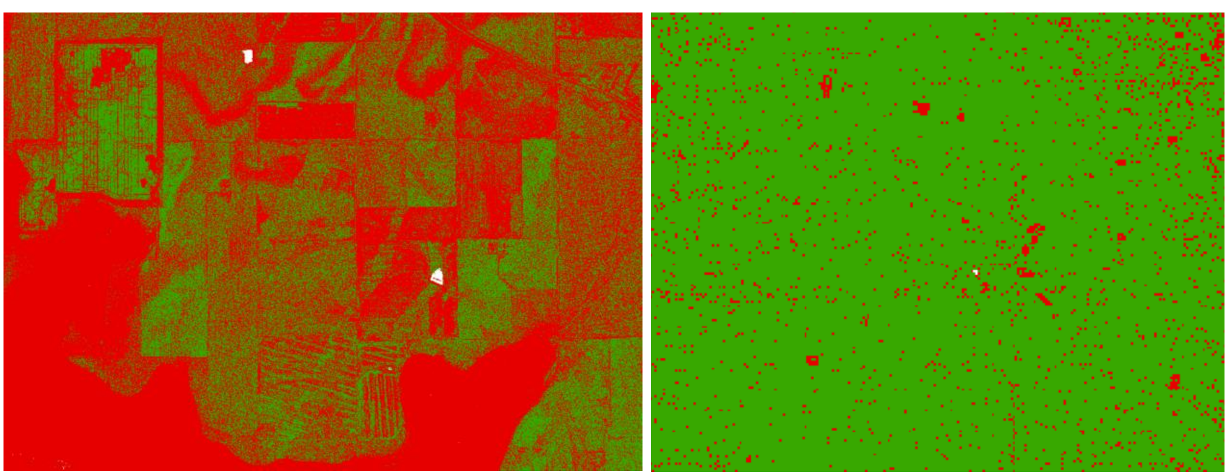


Figure 8. Intra-swath relative accuracy. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

4. Breakline Processing & Qualitative Assessment

4.1 Breakline Production Methodology

Breaklines were manually digitized within an Esri software environment, using full point cloud intensity imagery, bare earth terrains and DEMs, the lidar point cloud, and ancillary ortho imagery where appropriate.

Breakline features with static or semi-static elevations (ponds and lakes, bridge saddles, and soft feature breaklines) were converted to 3D breaklines within the Esri environment where breaklines were draped on terrains or the lidar point cloud. Subsequent processing was done on ponds/lakes to identify the minimum z-values within these features and re-applied that minimum elevation to all vertices of the breakline feature.

Linear hydrographic features show downhill flow and maintain monotonicity. These breaklines underwent conflation by using a combination of Esri and LP360 software. Centerlines were draped on terrains, enforced for monotonicity, and those elevations were then assigned to the bank lines for the final river/stream z-values.

Tidal breaklines may have been converted to 3D using either method, dependent on the variables within each dataset.

4.1.1 Breakline Collection Requirements

The table below outlines breakline collection requirements for this dataset.

Table 8. Breakline collection requirements

Parameter	Project Specification	Additional Comments
Ponds and Lakes	Breaklines are collected in all inland ponds and lakes ~0.8 hectare or greater. These features are flat and level water bodies at a single elevation for each vertex along the bank.	None
Rivers and Streams	Breaklines are collected for all streams and rivers ~30 m nominal width or wider. These features are flat and level bank to bank, gradient will follow the surrounding terrain and the water surface will be at or below the surrounding terrain. Streams/river channels will break at culvert locations however not at elevated bridge locations.	None
Tidal	Breaklines are collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations. Tidal variations over the course of collection, and between different collections, can result in discontinuities along shorelines. This is considered normal and should be retained. Variations in water surface elevation resulting from tidal variations during collection should not be removed or adjusted. Features should be captured as a dual line with	No tidally influenced features are in this dataset so no tidal breaklines were collected.

Parameter	Project Specification	Additional Comments
	one line on each bank. Each vertex placed shall maintain vertical integrity. Parallel points on opposite banks of the tidal waters must be captured at the same elevation to ensure flatness of the water feature. The entire water surface edge is at or below the immediate surrounding terrain.	
Islands	Donuts will exist where there are islands greater than 1 acre in size within a hydro feature.	None
Bridge Saddle Breaklines	Bridge Saddle Breaklines are collected where bridge abutments were interpolated after bridge removal causing saddle artifacts.	None
Soft Features	Soft Feature Breaklines are collected where additional enforcement of the modeled bare earth terrain was required, typically on hydrographic control structures or vertical waterfalls, due to large vertical elevation differences within a short linear distance on a hydrographic feature.	Soft features were not applicable to this dataset so no soft feature breaklines were collected.

4.2 Breakline Qualitative Assessment

Dewberry performed both manual and automated checks on the collected breaklines. Breaklines underwent peer reviews, breakline lead reviews (senior level analysts), and final reviews by an independent QA/QC team. The table below outlines high level steps verified for every breakline dataset.

Table 9. Breakline verification steps

Parameter	Requirement	Pass/Fail
Collection	Collect breaklines according to project specifications using lidar-derived data, including intensity imagery, bare earth ground models, density models, slope models, and terrains.	Pass
Placement	Place the breakline inside or seaward of the shoreline by 1-2 x NPS in areas of heavy vegetation or where the exact shoreline is hard to delineate.	Pass
Completeness	Perform a completeness check, breakline variance check, and all automated checks on each block before designating that block complete.	Pass
Merged Dataset	Merge completed production blocks. Ensure correct horizontal and vertical snapping between all production blocks. Confirm correct horizontal placement of breaklines.	Pass
Merged Dataset Completeness Check	Check entire dataset for features that were not captured but that meet baseline specifications or other metrics	Pass

Parameter	Requirement	Pass/Fail
	for capture. Features should be collected consistently across tile boundaries.	
Edge Match	Ensure breaklines are correctly edge-matched to adjoining datasets. Check completion type, attribute coding, and horizontal placement.	Pass
Vertical Consistency	Waterbodies shall maintain a constant elevation at all vertices Vertices should not have excessive min or max z-values when compared to adjacent vertices Intersecting features should maintain connectivity in X, Y, Z planes Dual line streams shall have the same elevation at any given cross-section of the stream	Pass
Vertical Variance	Using a terrain created from lidar ground (class 2, 8, and 20 as applicable) and water points (class 9) to compare breakline Z values to interpolated lidar elevations to ensure there are no unacceptable discrepancies.	Pass
Monotonicity	Dual line streams generally maintain a consistent down-hill flow and collected in the direction of flow – some natural exceptions are allowed	Pass
Topology	Features must not overlap or have gaps Features must not have unnecessary dangles or boundaries	Pass
Hydro-classification	The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydroflattening artifacts along the edges of hydro features.	Pass
Hydro-flattening	Perform hydro-flattening and hydro-enforcement checks. Tidal waters should preserve as much ground as possible and can be non-monotonic.	Pass

5. DEM Processing & Qualitative Assessment

5.1 DEM Production Methodology

Dewberry utilized LP360 to generate DEMs. LP360 uses TIN (Triangulated Irregular Network) as the interpolated surface method. A TIN divides a surface into a set of contiguous, non-overlapping, Delaunay triangles. The height of each triangle vertex interpolates together to construct the surface. Dewberry utilized both ArcGIS and Global Mapper for QA/QC.

The final classified lidar points in all bare earth classes were loaded into LP360 along with the final 3D breaklines and the project tile grid. A raster was generated from the lidar data with breaklines enforced and clipped to the project tile grid. The DEM was reviewed for any issues requiring corrections, including remaining lidar misclassifications, erroneous breakline elevations, incorrect or incomplete hydro-flattening or hydro-enforcement, and processing artifacts. The formatting of the DEM tiles was verified before the tiles were loaded into Global Mapper to ensure that there was no missing or corrupt data and that the DEMs matched seamlessly across tile boundaries. A final qualitative review was then conducted by an independent review department within Dewberry.

5.2 DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. Dewberry conducted the review in ArcGIS using a hillshade model of the full dataset with a partially transparent colorized elevation model overlaid. The tiled DEMs were reviewed at a scale of 1:5,000 to look for artifacts caused by the DEM generation process and to verify correct enforcement of void areas. Upon correction of any outstanding issues, the DEM data was loaded into Global Mapper for its second review and to verify corrections.

Table 10 below outlines high level steps verified for every DEM dataset.

Table 10. DEM verification steps

Parameter	Requirement	Pass/Fail
Digital Elevation Model (DEM) of bare-earth with voids	DEM of bare-earth terrain surface (0.5 m) is created from lidar ground and bathymetric bottom points and void polygons. DEMs are tiled without overlaps or gaps, show no edge artifact or mismatch, DEM deliverables are COG GeoTIFF format	Pass
DEM Compression	DEMs are not compressed	Pass
DEM NoData	Areas outside survey boundary are coded as NoData. Internal voids (e.g., open water areas) are coded as NoData (-999999)	Pass
Hydro-flattening	Ensure DEMs were hydro-flattened or hydro-enforced as required by project specifications	Pass
Monotonicity	Verify monotonicity of all linear hydrographic features	Pass
Breakline Elevations	Ensure adherence of breaklines to bare-earth surface elevations, i.e., no floating or digging hydrographic feature	Pass
Bridge Removal	Verify removal of bridges from bare-earth DEMs and no saddles present	Pass
DEM Artifacts	Correct any issues in the lidar classification that were visually	Pass

Parameter	Requirement	Pass/Fail
	expressed in the DEMs. Reprocess the DEMs following lidar corrections.	
DEM Tiles	Split the DEMs into tiles according to the project tiling scheme	Pass
DEM Formatting	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression is not applied to the tiled DEMs. GDAL version 3.6.3 used for all DEM formatting.	Pass
DEM Extents	Load all tiled DEMs into ArcMap and verify complete coverage within the (buffered) project boundary and verify that no tiles are corrupt	Pass

6. Derivative Lidar Products

USGS required several derivative lidar products to be created. Each type of derived product is described below.

6.1 Swath Separation Images (SSIs)

Dewberry verified inter-swath or between swath relative accuracy of the dataset by generating swath separation images in conjunction with interswath polygons. Color-coding is used to help visualize elevation differences between overlapping swaths. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values.

The swath separation images are symbolized by the following ranges:

- 0-8 cm: **Green**
- 8-16 cm: **Yellow**
- 16 cm: **Red**

Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across one raster pixel) are expected to appear yellow or red in the SSIs. Flat, open areas are expected to be green in the SSIs. Large or continuous sections of yellow or red pixels following flight line patterns and not the terrain or vegetation can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data.

Dewberry generated swath separation images using LP360 software. These images were created from the last return of all points except points classified as noise and/or flagged as withheld. Point Insertion was used as the Surface Method and the cell size was set to 2x the deliverable DEM cell size. The three interval bins used are bulleted above and the parameter to “Modulate source differences by Intensity” was set to 50%. The output GeoTIFF rasters are tiled to the project tile grid, clipped to the master DPA, and formatted (including defining the CRS which matches the project CRS) using GDAL software, version 3.6.3.

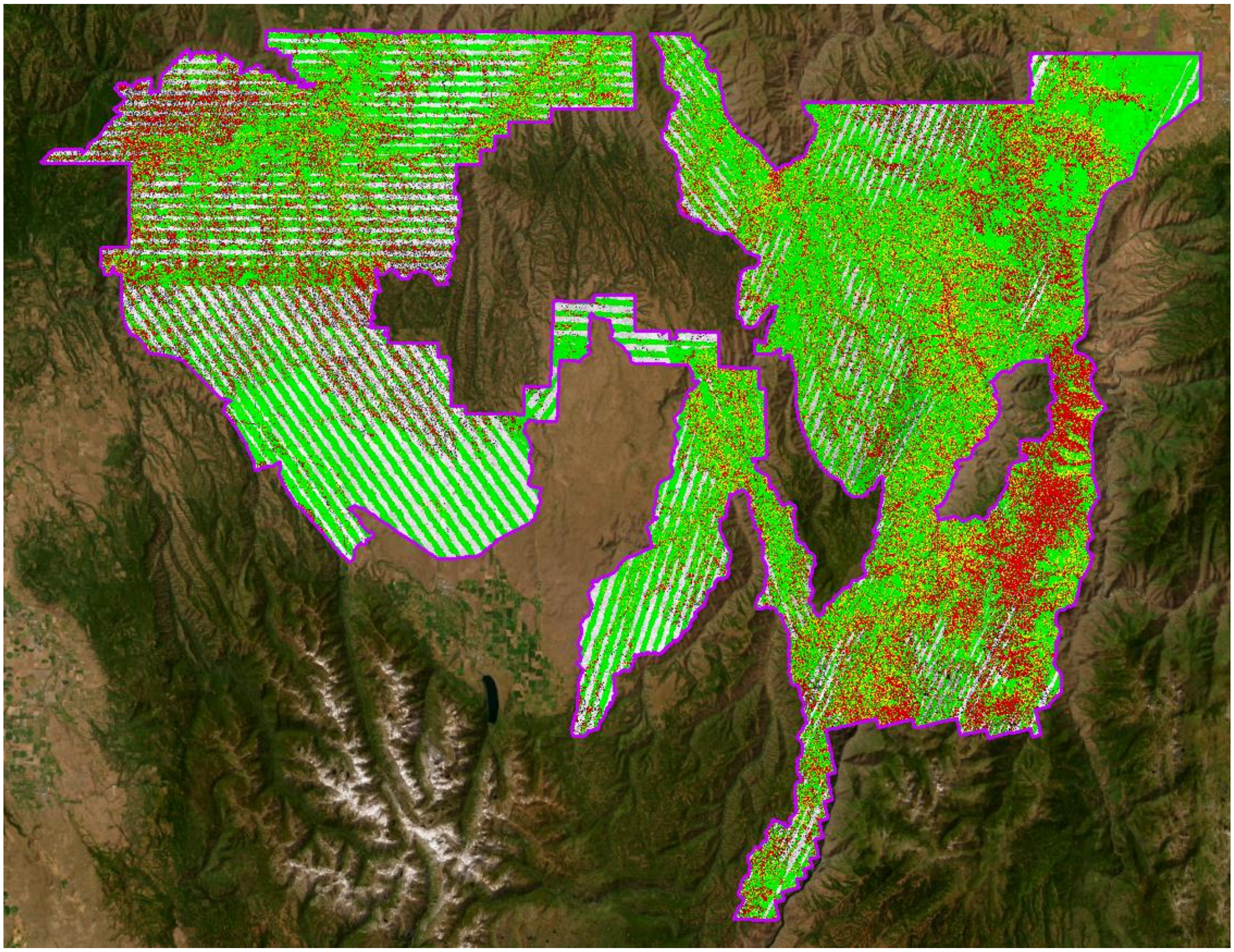


Figure 9. Swath Separation Images (SSIs) generated for ID NCentral 4 D22.

6.2 Maximum Surface Height Rasters (MSHRs)

MSHRs are delivered as tiled GeoTIFFs (32-bit, floating point), with the tile size and naming convention matching the project tile grid, tiled point cloud, and tiled DEM deliverables. MSHRs are provided as proof of performance that Dewberry's withheld bit flag has been properly set on all points, including noise, which are not deemed valid returns and which should be excluded from all derivative product development. All points, all returns, excluding points flagged as withheld, are used to produce MSHRs. The rasters are produced with a binning method in which the highest elevation of all lidar points intersecting each pixel is applied as the pixel elevation in the resulting raster. Final MSHRs are formatted using GDAL software version 3.6.3, spatially defined to match the project CRS, and the cell size equals 2x the deliverable DEM cell size (unless lidar density at the defined DEM cell size is insufficient for MSHR analysis and then a larger cell size for the MSHRs may be used). Prior to delivery, all MSHRs are reviewed for complete coverage, correct formatting, and any remaining point cloud misclassifications specifically in regard to the use of the withheld bit.

6.3 Flightline Extents GDB

Flightline extents are delivered as polygons in an Esri GDB, delineating actual coverage of each swath used in the project deliverables. Dewberry delivered this GDB using USGS's provided template so that each polygon contains the following attributes:

- Lift/Mission ID (unique per lift/mission)
- Point Source ID (unique per swath)

- Type of Swath (project, cross-tie, fill-in, calibration, or other)
- Start time in adjusted GPS seconds
- End time in adjusted GPS seconds

Prior to delivery, a final flightline GDB is created from the final, tiled point cloud deliverables to ensure all correct swaths are represented in the flightline GDB. The flightline GDB is then reviewed for complete coverage and correct formatting.