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NC Sparta Earthquake Lidar

Report Produced for U.S. Geological Survey

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ATTACHMENTS

Appendix A: ABGNSS-Inertial Processing Graphics

1. EXECUTIVE SUMMARY

The primary purpose of this project was to acquire detailed surface elevation data that will support the USGS National Geologic Mapping Program, North Carolina Geological Survey – Department of Environmental Quality, Virginia Department of Mines, Minerals, and Energy, and the 3DEP mission in conservation planning, design, research, floodplain mapping, dam safety assessments and elevation modeling, etc.

Lidar data were processed and classified according to project specifications. Topographic Digital Elevation Models (DEMs) were produced for the project area. Project components were formatted based on a tile grid with each tile covering an area 750 m by 750 m. A total of 511 tiles were produced for the project, providing approximately 100 sq. miles of coverage.

1.1 Project Team

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for lidar acquisition flight planning/coordination, data calibration, ground survey, LAS classification, bridge saddle breakline production, digital elevation model (DEM) production and quality assurance.

Dewberry’s Timothy A. Rudolph, PLS completed the ground survey for the project and delivered surveyed ground control points and accuracy assessment checkpoints. His task was to acquire surveyed checkpoints for independent testing of the vertical accuracy of the calibrated LAS and the lidar-derived surface model. He also verified the GPS base station coordinates used during lidar data acquisition to calibrate the data.

SurvTech Solutions, Inc. completed lidar data acquisition for the project area.

1.2 Project Area

The project area, shown in figure 1, falls within the North Carolina counties of Alleghany and Wilkes and Virginia county of Grayson.

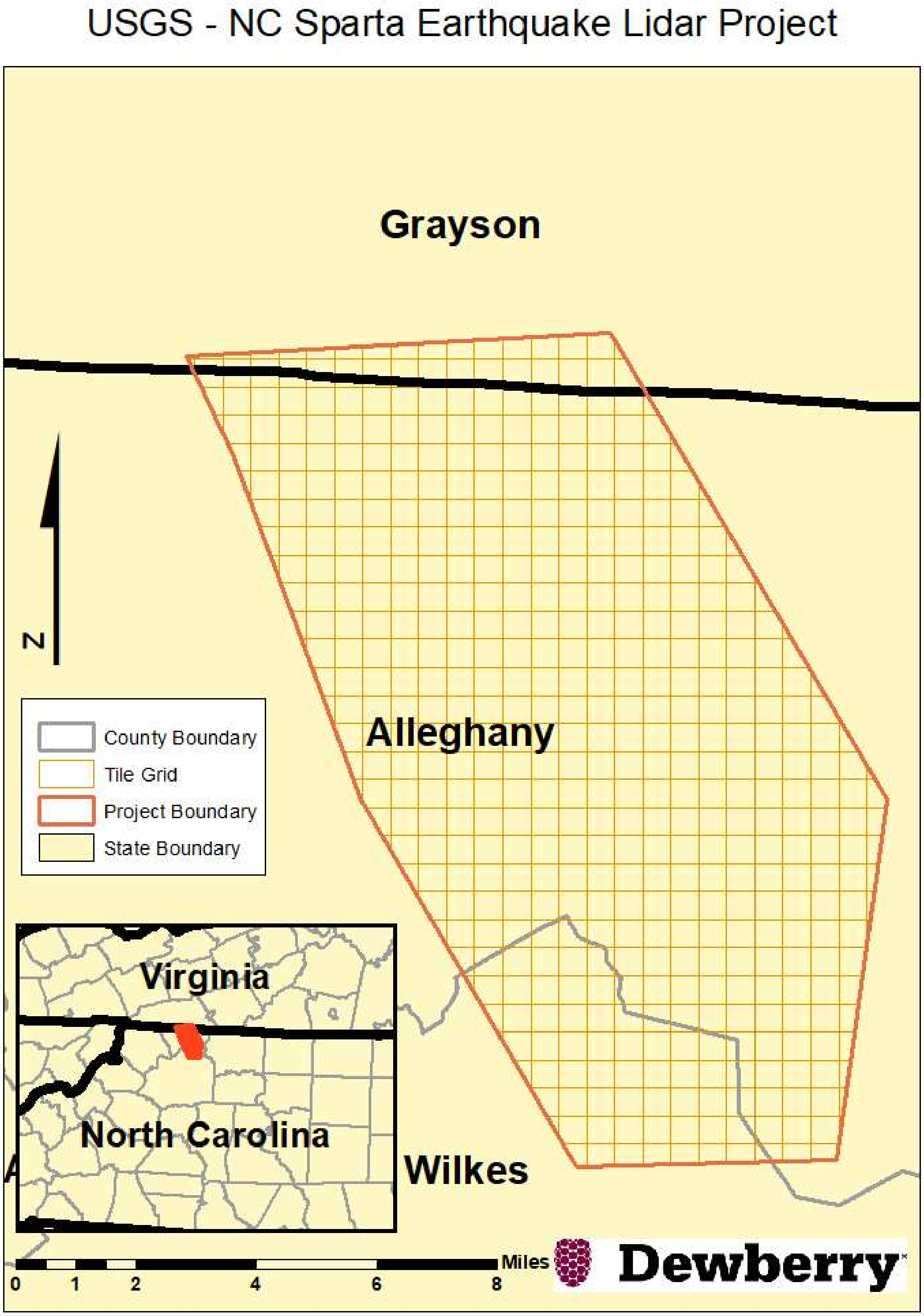


Figure 1. Project map and tile grid.

1.3 Coordinate Reference System

Data produced for the project are delivered in the following spatial 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)
Geoid Model:	Geoid18
Coordinate System:	UTM Zone 17 N
Horizontal Units:	Meters
Vertical Units:	Meters

1.4 Project Deliverables

The deliverables for the project are as follows:

1. Project Extents (Esri SHP)
2. Flightline Extents (Esri GDB)
3. Static Control (coordinates, Esri shapefile)
4. Classified Point Cloud (tiled LAS)
5. Independent Survey Checkpoint Data (report, photos, coordinates, Esri shapefiles)
6. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
7. Topographic DEM (tiled raster DEM, GeoTIFF format)
8. Bridge Saddle Breakline (Esri shapefile)
9. Swath Separation Images (tiled, 24-bit RGB, GeoTIFF format)
10. Metadata (XML)
11. Project Report

2. LIDAR ACQUISITION REPORT

Dewberry elected to subcontract the lidar acquisition to SurvTech Solutions, Inc. SurvTech Solutions, Inc. was responsible for providing lidar acquisition and delivery of uncalibrated lidar data files to Dewberry.

The lidar acquisition was conducted between December 12, 2020 to December 14, 2020.

2.1 Summary

The NC Sparta Earthquake Project was flown to acquire detailed surface elevation data and will support the USGS National Geologic Mapping Program, North Carolina Geological Survey – Department of Environmental Quality, Virginia Department of Mines, Minerals, and Energy, and the 3DEP mission. The project AOI is in both North Carolina and Virginia, including the partial counties of Alleghany and Wilkes in North Carolina and the partial county of Grayson in Virginia, covering approximately 100 square miles. NC Sparta Earthquake, USGS 2020 Lidar project called for the planning, acquisition, processing and derivative products of lidar data to be collected at a nominal pulse spacing (NPS) of 0.35 meter. Project specifications are based on the U.S. Geological Survey National Geospatial Program Base Lidar Specification, Version 1.3. The data was developed based on a horizontal projection/datum of NAD83 (2011), Universal Transverse Mercator, meters and vertical datum of NAVD88 (GEOID18), meters. Lidar data was delivered as processed Classified LAS 1.4 files, formatted to 511 individual 750 m x 750 m tiles, as tiled Intensity Imagery, and as tiled bare earth DEMs; all tiled to the same 750 m x 750 m schema. Ground Conditions: Lidar was collected in late 2020, while no snow was on the ground and rivers were at or below normal levels. In order to post process the lidar data to meet task order specifications and meet ASPRS vertical accuracy guidelines, Dewberry established a total of 10 ground control points that were used to calibrate the lidar to known ground locations established throughout the Sparta Earthquake, North Carolina project area. An additional 30 independent accuracy checkpoints, 23 in Bare Earth and Urban landcovers (23 NVA points), 7 in Tall Grass and Brushland/Low Trees categories (7 VVA points), were used to assess the vertical accuracy of the data.

2.2 Lidar Acquisition Details

SurvTech Solutions, Inc. planned 57 passes for the project area as a series of parallel flight lines. Before the first flightline of each mission was collected, an "S-Turn" was performed to account for IMU drifts. In order to reduce any margin for error in the flight plan, SurvTech followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Teledyne Optech's 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, SurvTech filed flight plans as required by local Air Traffic Control (ATC) prior to each mission.

SurvTech monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include no rain, fog, smoke, mist or low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. SurvTech accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, SurvTech closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team and project leads worked together for weather and in-situ analysis.

SurvTech lidar sensors are calibrated at a designated site located over Griffin, Ga.

2.3 Lidar System parameters

SurvTech operated a Cessna 401B (Tail # N41GD) outfitted with an Optech Galaxy T2000 Topographic lidar system during the collection of the NC Sparta Earthquake study area. Table 1 illustrate SurvTech's system parameters for lidar acquisition on this project.

Table 1. SurvTech lidar system parameters for Galaxy T2000.

Item	Parameter
System	Galaxy T2000
Altitude (m above ground level)	1067
Nominal flight speed (kts)	145
Scanner pulse rate (kHz)	1000
Scan frequency (Hz)	100
Pulse duration of the scanner (ns)	.003
Pulse width of the scanner (m)	.25 mrad
Central wavelength of the sensor laser (nm)	1064
Multiple pulses in the air	Yes
Beam divergence (mrad)	0.16
Swath width (m)	776
Swath overlap (%)	60
Total sensor scan angle (degrees)	40
Nominal pulse spacing (NPS) (single swath) (m)	0.28
Nominal Pulse Density (NPD) (single swath) (points per sq m)	12.6
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.28
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	12.6
Maximum Number of Returns per Pulse	8

2.4 Acquisition Status Report and Flight Lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The acquisition manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the lidar sensor, the position dilution of precision (PDOP), and performed the first quality control review during acquisition. The flight crew reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

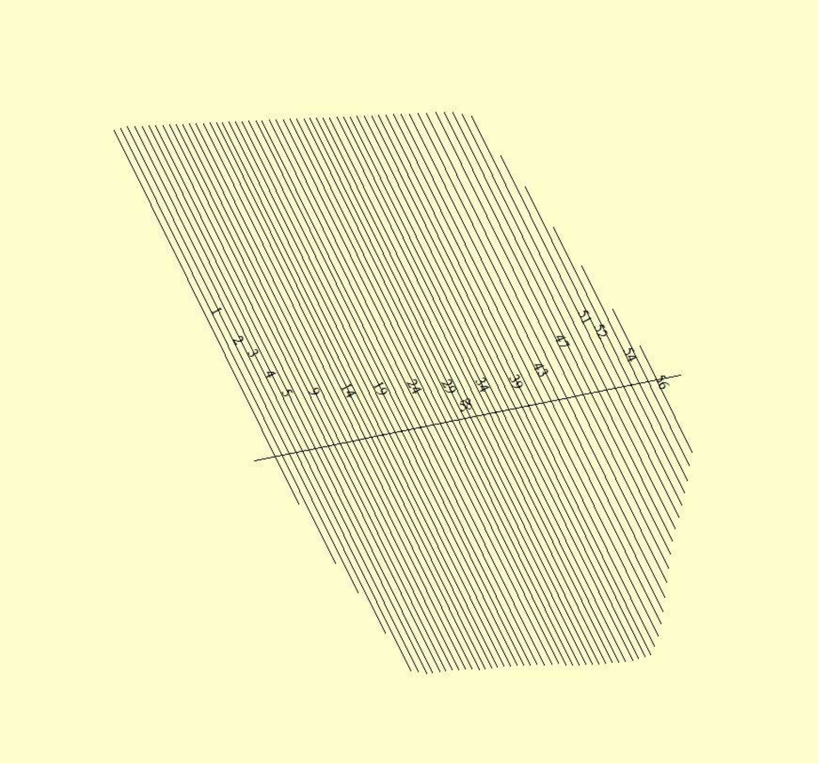


Figure 2. Trajectories as flown by SurvTech.

2.5 Acquisition Static Control

SurvTech deployed static GPS base stations during the acquisition of the NC Sparta Earthquake project. Considerations were made for location access and clear visibility of the horizon. Additionally, these static sessions were recorded at 1 Hz samples for the highest quality post processed solution. These static base sessions were then incorporated during the kinematic post-processing of aircraft position. These base stations were either set on existing control monumentation, or new benchmarks established. The coordinates of these base stations are provided in the table below.

Table 2. Base stations used to control lidar acquisition.

Name	NAD83(2011) UTM 17 N		Ellipsoid Ht (NAD83(2011), m)	Orthometric Ht (NAVD88 Geoid18B, m)
	Easting (Y)	Northing (X)		
NGS Monument				
SPARTA (NCSR)	489727.395	4039164.815	839.993	871.973

2.6 Airborne Kinematic Control

Airborne GPS data was processed using PosPAC MMS provided by Applanix. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded.

GPS processing reports for each mission are included in Appendix A.

2.7 Generation and Calibration of Raw Lidar Data

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Optech's Dashmap, initially with default values from Optech or the last mission calibrated for the system. The uncalibrated swath data is received by Dewberry and data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database. Using BayesMap Solutions Strip Alignment software a Lidar Swath alignment is performed to correct systematic biases. Once all relative and absolute uncertainties are reduced an optimal swath combination is output. Ground control points (GCPs) were used as control in case the swath data exhibited any biases which would need to be adjusted or removed.

If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Once data is internally calibrated by Dewberry the lidar is reviewed a second time for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database. On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

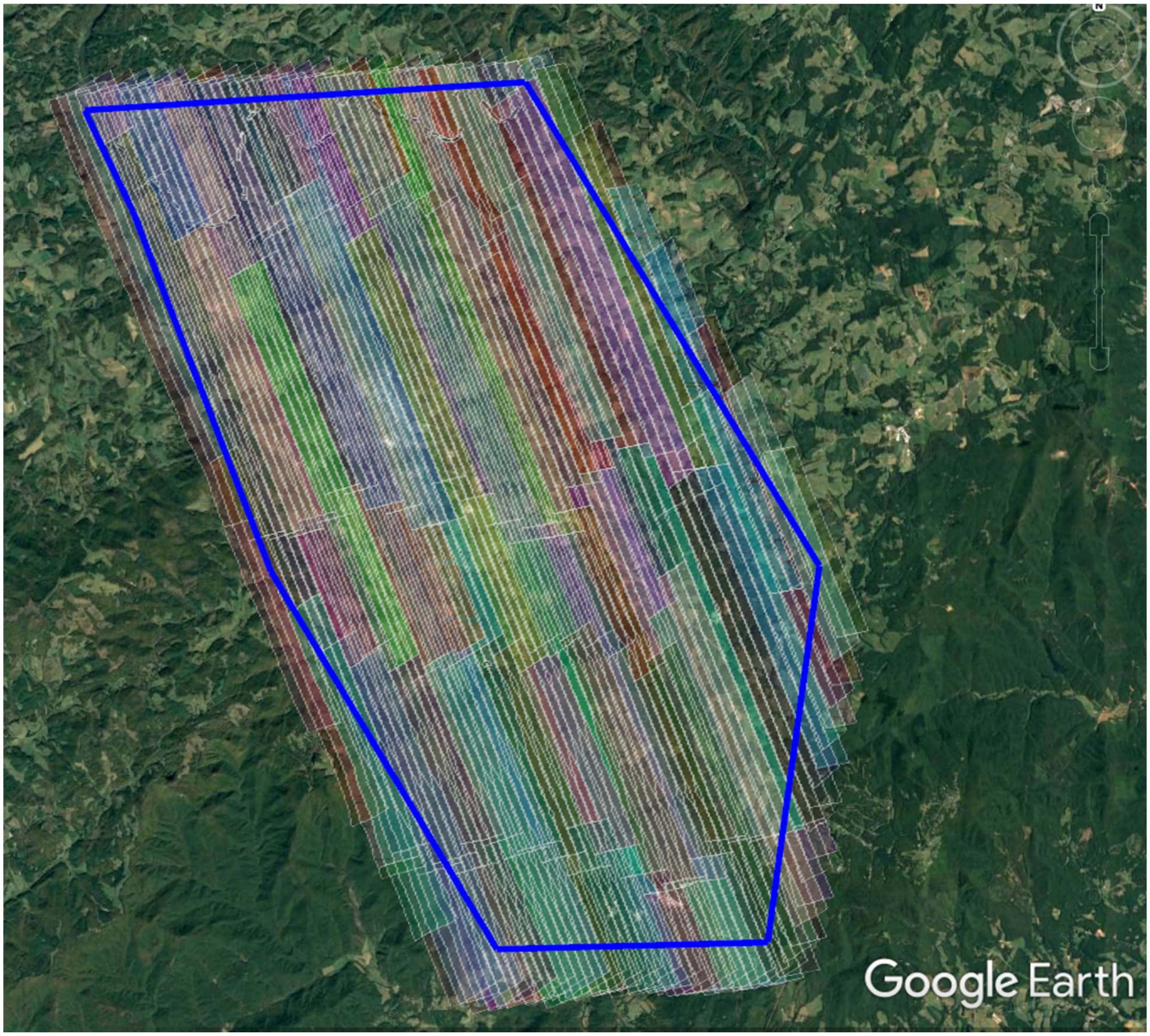


Figure 3. Lidar flightline extents (colored by mission/lift) showing complete coverage of the project area (project boundary in blue), overlaid on Google Earth imagery.

2.7.1 Boresight and Relative accuracy

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and yaw are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using between swaths. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

The following relative accuracy specifications were used for this project:

- ≤ 6 cm maximum difference within individual swaths (intra-swath); and
- ≤ 8 cm RMSDz between adjacent and overlapping swaths (inter-swath).

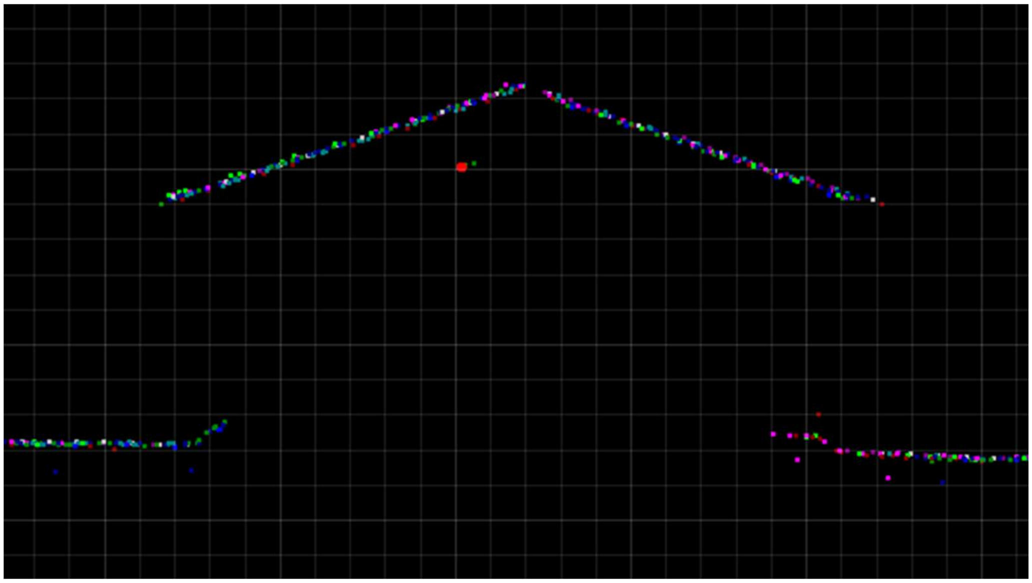


Figure 4. Profile view showing correct roll and pitch adjustments.

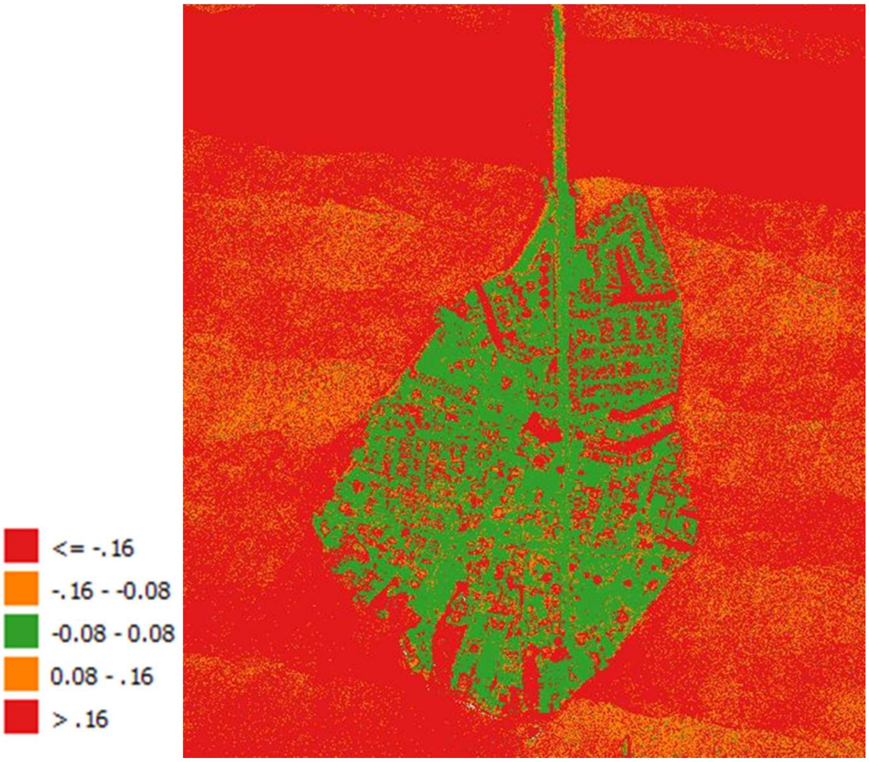


Figure 5. QC block colored by vertical difference to ensure accuracy at swath edges and throughout.

3. LIDAR PROCESSING & QUALITATIVE ASSESSMENT

3.1 Initial Processing

Following internal calibration of the swath data, 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. Details are provided in the following sections.

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 3. Post calibration and initial processing data verification steps.

Requirement	Description of Deliverables	Additional Comments
Non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 10 cm at the 95% confidence level based on RMSEz (10 cm) x 1.96	The swath NVA was tested and passed specifications.	None
The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 8 ppsm or 0.35 m NPS. The NPD (ANPD) is calculated from first return points only.	The average calculated (A)NPD of this project is 13.3 ppsm. Density raster visualization also passed specifications.	None
Spatial Distribution requires 90% of the project grid, calculated with cell sizes of 2*NPS, to contain at least one lidar point. This is calculated from first return points only.	Approximately 99.6% of cells (2*NPS cell size) in this AOI had at least 1 lidar point within the cell.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm RMSDz.	Within swath relative accuracy passed specification.	See additional information and graph in the sections below
Between swath (Inter-swath or swath overlap) relative accuracy must meet ≤ 8 cm RMSDz. These thresholds are tested in open, flat terrain.	Between swath relative accuracy passed specification, calculated from single return lidar points.	See additional information and graph in the sections below
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

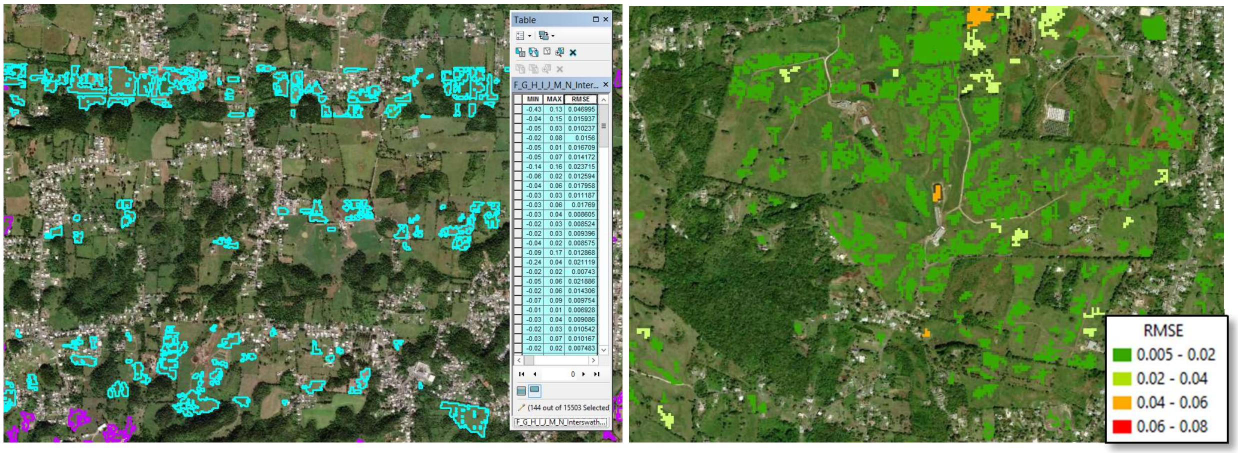
Requirement	Description of Deliverables	Additional Comments
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation was acceptable.	Ground penetration was assessed relative to the environment and land cover conditions. Ground penetration in densely vegetated, wetland environments is much different compared to other vegetated land covers, e.g. upland forests.
Edge of Flight line bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired, regardless of which type of sensor is used	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

Interswath (Between Swath) Relative Accuracy

In addition to a visual qualitative review of interswath values (see section 4.1 Swath Separation Images of this report), USGS Lidar Base Specifications also outline specific testing procedures and deliverables to verify that this data is within specification. The specification requires that non-vegetated areas of overlap with slopes less than 10 degrees are tested and reported in a polygon shapefile. This polygon deliverable should contain the minimum, maximum, and RMSDz of the differences in each sample polygon area.

Dewberry has developed a relatively robust process for generating these interswath polygons across the entire dataset. The current specification does not explicitly state the amount of areas to be tested. Dewberry therefore ensures that the assessment is as detailed as possible by creating test polygons for all overlap areas. The test areas are generated such that they are on slopes less than 10 degrees and not in vegetated areas. The generated polygons are then attributed with the min/max/RMSDz statistics. Polygons that intersect large waterbodies are removed from the final results, as these are not reliable test locations.

The result of the process is a shapefile of test polygons with their test values, distributed in all of the overlapping areas across the project area. These polygons are then reviewed for any systematic interswath errors that should be considered of concern.



MIN	MAX	RMSE
-0.43	0.13	0.046995
-0.04	0.15	0.015937
-0.05	0.03	0.010237
-0.02	0.08	0.0156
-0.05	0.01	0.016709
-0.05	0.07	0.014172
-0.14	0.16	0.023715
-0.06	0.02	0.012594
-0.04	0.06	0.017958
-0.03	0.03	0.011187
-0.03	0.06	0.01769
-0.03	0.04	0.008605
-0.02	0.03	0.008524
-0.02	0.03	0.009396
-0.04	0.02	0.008575
-0.09	0.17	0.012868
-0.24	0.04	0.021119
-0.02	0.02	0.00743
-0.05	0.06	0.021886
-0.02	0.06	0.014306
-0.07	0.09	0.009754
-0.01	0.01	0.006928
-0.03	0.04	0.009086
-0.02	0.03	0.010542
-0.03	0.07	0.010167
-0.02	0.02	0.007483

(144 out of 15503 Selected

Figure 6. Left: Example interswath polygons and example statistics. Right: Example interswath polygons colored by RMSDz values.

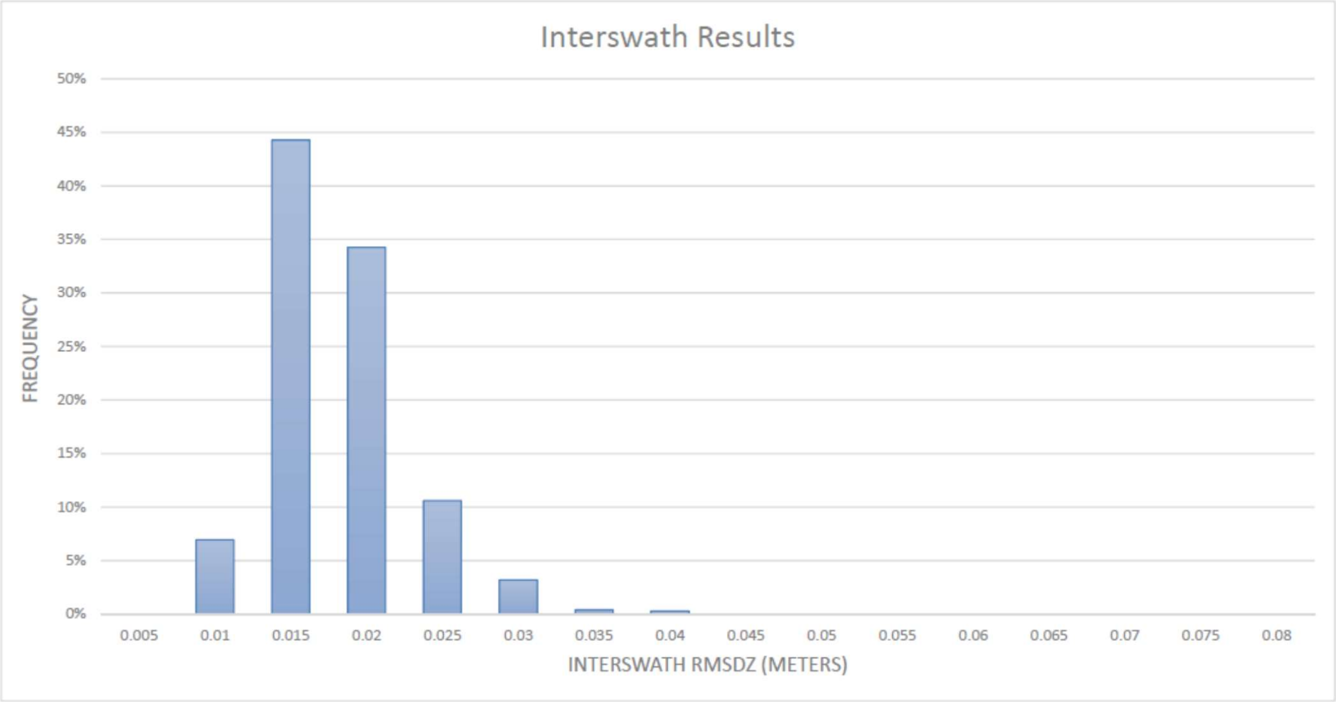


Figure 7. Frequency distribution of interswath RMSDz results for the NC Sparta Earthquake Lidar project.

Intraswath (Within Swath) Relative Accuracy

In addition to a visual qualitative review of intraswath values, the USGS Lidar Base Specifications also outline specific testing procedures and deliverables to verify that this data is within specification. The specification requires that test polygons should be drawn in hard surface areas and precision statistical values be computed. The specification calls for each lift to have three (3) test locations. Dewberry was able to create 9 intraswath polygons where hard surfaces exist within the project area. The intraswath polygon distribution is illustrated in Figure 8; each polygon contains statistics for the minimum, maximum, and RMSDz of the differences in the sample polygon area as illustrated in Figure 9. This project utilized the Optech Galaxy T2000 sensor.

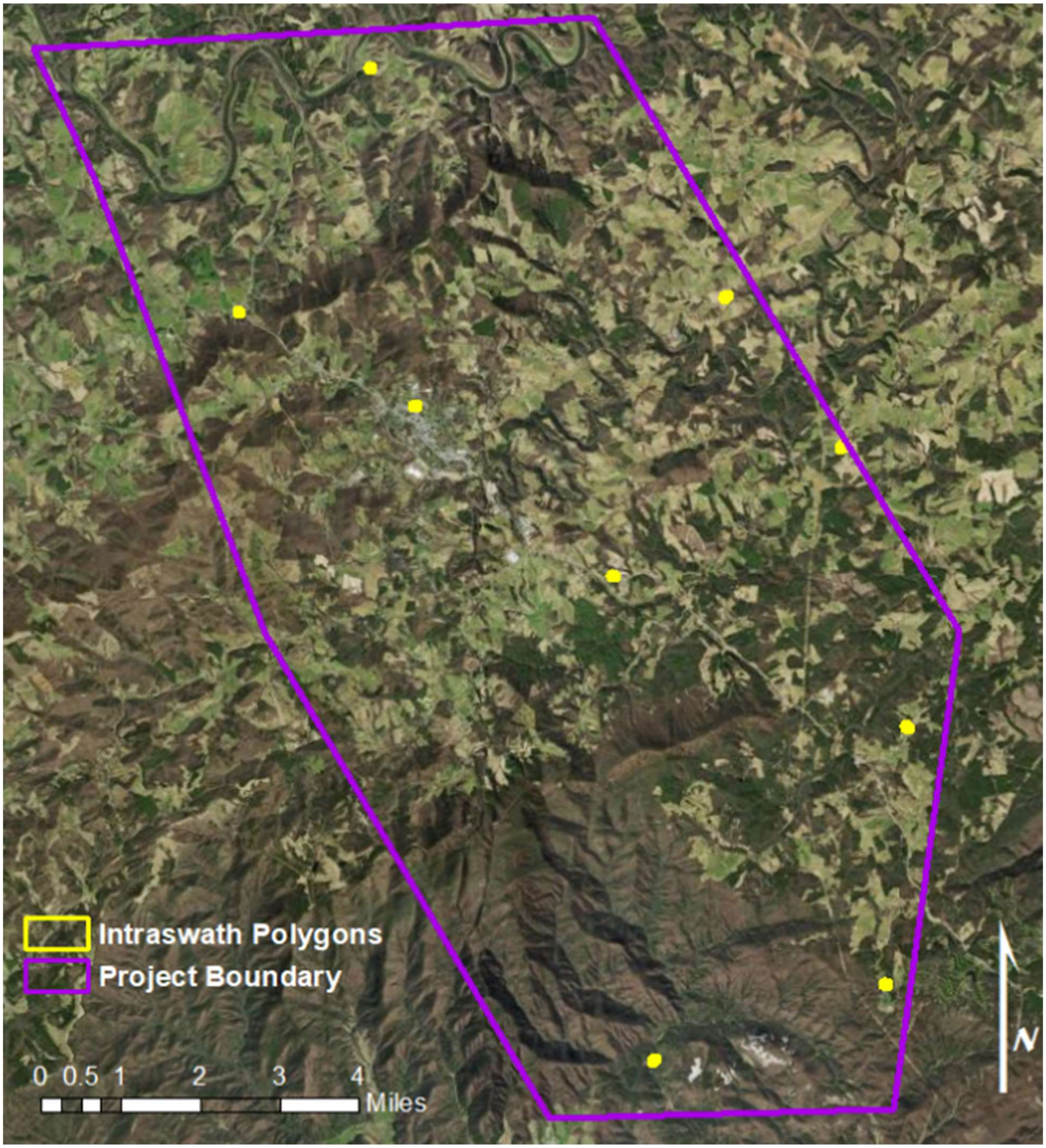
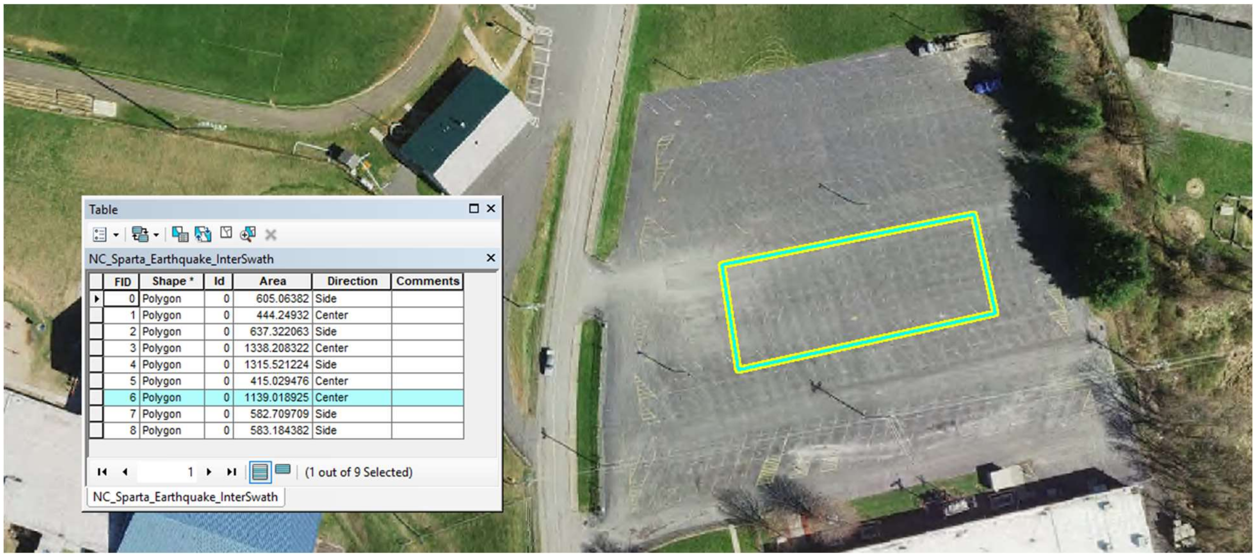


Figure 8. Intraswath polygons used to test intraswath vertical accuracy.



FID	Shape *	Id	Area	Direction	Comments
0	Polygon	0	605.06382	Side	
1	Polygon	0	444.24932	Center	
2	Polygon	0	637.322063	Side	
3	Polygon	0	1338.208322	Center	
4	Polygon	0	1315.521224	Side	
5	Polygon	0	415.029476	Center	
6	Polygon	0	1139.018925	Center	
7	Polygon	0	582.709709	Side	
8	Polygon	0	583.184382	Side	

Figure 9. Example test polygon for intraswath testing, and its results.

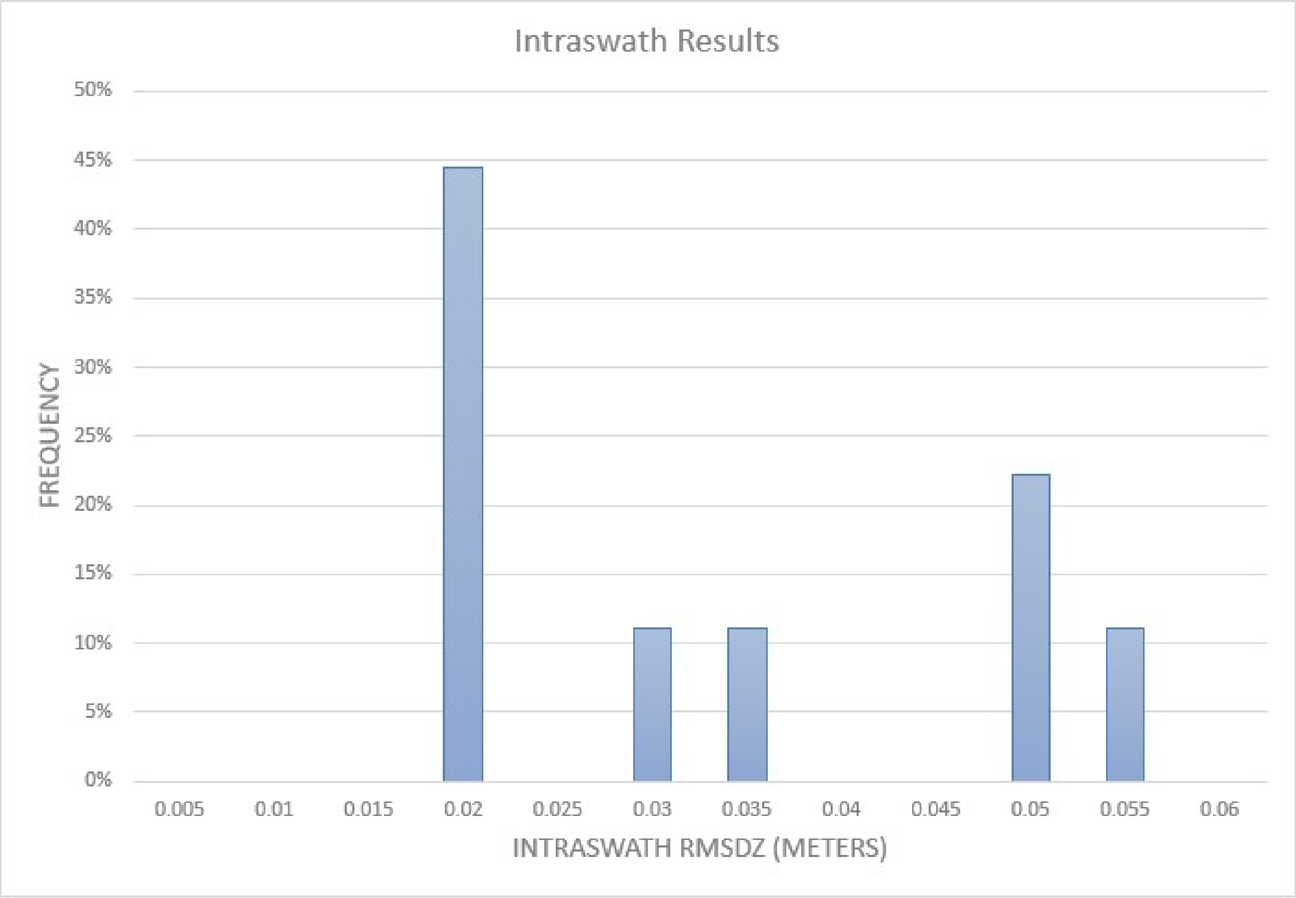


Figure 10. Frequency distribution of intraswath RMSDz results for the NC Sparta Earthquake Lidar project

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 were 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.

The withheld bit was set on the withheld points previously identified in TerraScan before the ground classification routine was performed.

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.

3.3 Lidar Qualitative Assessment

Dewberry’s qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth Digital Elevation Model (DEM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)’s, a series of Digital Elevation Models (DEM) from different inputs, void polygons and 3-dimensional models as well as reviewing the actual point cloud data.

3.3.1 Visual Review

During QA/QC, reviewers check for consistent and correct classification. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model and other classification errors.

3.3.2 Formatting

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

Table 4. Classified Lidar Formatting.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) UTM Zone 17 N, meters and NAVD88 (Geoid 18), meters in WKT Format	Pass
Global Encoder Bit	Set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Set to the lidar sensor and is set to “Galaxy”	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 17: Bridge Deck Class 18: High Noise	Pass
Overlap and Withheld Points	Withheld points are set to the Withheld bit. The overlap (Overage) bit is not utilized on this project.	Pass

Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 5. Final lidar point counts per class.

Class	1 (Unclassified)	2 (Ground)	7 (Low Noise)	17 (Bridge Deck)	18 (High Noise)
Point Count	24,310,576,042	6,337,475,814	2,527,182	462,696	117,625

4. DERIVATIVE LIDAR PRODUCTS

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

4.1 Swath Separation Images

Dewberry verified inter-swath or between swath relative accuracy of the dataset by generating swath separation images in conjunction with interswath polygons (section 3.1.1). These images were created from the last return of all points except points classified as noise or flagged as withheld. 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 DZ orthos. Flat, open areas are expected to be green in the DZ orthos~~.~~

Swath separation images created by Dewberry for internal verification of interswath alignment have been delivered. The images are in TIFF format.

5. LIDAR POSITIONAL ACCURACY

5.1 Background

Dewberry quantitatively tested the vertical accuracy of the lidar to confirm adherence of the dataset to project specifications. Discrete surveyed (real-world) checkpoint elevation coordinates were compared to the surface elevation values at the corresponding X and Y coordinates on TIN surfaces created from the classified lidar data. Relative accuracy testing determined how consistently the lidar data was collected and enabled extrapolation of the point-based absolute accuracy results to the broader dataset. I.e., if the relative accuracy of the dataset was found to be within specifications and the dataset passed absolute vertical accuracy requirements at the locations of survey checkpoints, the vertical accuracy results were considered valid throughout the whole dataset with high confidence. Dewberry used LP360 to test the swath lidar vertical accuracy, TerraScan to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different methods were used to validate the vertical accuracy for the project.

Dewberry also tests the horizontal accuracy of lidar datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the lidar cannot always be tested.

5.2 Survey Vertical Accuracy Checkpoints

Dewberry surveyed 30 accuracy checkpoints to assess the vertical accuracy of the final data. Dewberry surveys GCPs in case the acquisition provider needs additional control for use during the calibration process. But for this project, Dewberry collected 10 control points to use during the calibration process. As the Dewberry surveyed GCPs were not used to calibrate or post process the data, 30 of these GCPs were used in the final vertical accuracy testing. As the Dewberry surveyed GCPs were not used in any calibration processing and were only used to test calibrated data, all surveyed points used in final accuracy testing (Dewberry surveyed checkpoints and Dewberry surveyed GCPs) are an independent validation of the final calibrated, processed, and edited data.

A total of 30 surveyed points (23 NVA, 7 VVA) were used in the final vertical accuracy testing.

The delivered survey reports (one for checkpoints and one for GCPs) and photos are structured as acquired and delivered by the surveyor, e.g. all GCPs, including the 30 used in vertical accuracy testing, are located in the GCP survey report and all surveyed points are referenced in the reports. The coordinate listing Excel files and the shapefiles delivered with the survey data have been updated to reflect their use.

The survey reports include images showing the locations of the surveyed points used to test the positional accuracy of the dataset and coordinate listings can be found in the reports, coordinate listing Excel files, and the delivered shapefiles.

5.3 Vertical Accuracy Test Procedures

NVA reflects the calibration and performance of the lidar sensor. NVA was determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas. In these locations it is likely that the lidar sensor detected the bare-earth ground surface and random errors are expected to follow a normal error distribution. Assuming a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the NC Sparta Earthquake lidar project, the vertical accuracy specification is 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

VVA was determined with all checkpoints in vegetated land cover categories, including wetlands, tall grass, weeds, crops, brush and low trees, and fully forested areas. In these locations there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The NC Sparta Earthquake lidar project VVA standard is 30 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA.

The relevant testing criteria are summarized in Table 6.

Table 6. Vertical accuracy acceptance criteria

Land Cover Type	Quantitative Criteria	Measure of Acceptability
NVA	Accuracy in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm
VVA	Accuracy in vegetated land cover categories combined at the 95% confidence level	30 cm

The QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed X, Y, and Z coordinates for discrete checkpoints in accordance with project specifications.
2. Dewberry interpolated the bare-earth lidar DEM to determine a lidar surface Z coordinate for every surveyed X and Y coordinate.
3. Dewberry computed differences between each surveyed Z coordinate and lidar surface Z coordinate.
4. The difference data was analyzed by Dewberry to assess the accuracy of the data. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The results are provided in the following section.

5.4 Vertical Accuracy Results

The table below summarizes the tested vertical accuracy of the classified lidar LAS files.

Table 7. Vertical accuracy results

Land Cover Type	# of Points	NVA (m)	VVA (m)

Project Specification	30	0.196	0.300
NVA	23	0.055	
VVA	7		0.152

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE_z = 2.8 cm, equating to +/- 5.5 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 15.2 cm at the 95th percentile.

The 5% outliers are listed in Table 8. Descriptive statistics for both sets of checkpoints are presented in Table 9.

Table 8. VVA 5% outliers

Point ID	NAD83(2011) UTM Zone 17N, m		NAVD88 Geoid 12B, m		Delta Z (m)
	Easting (X)	Northing (Y)	Survey Z	Lidar Z	
VVA-003	489000.079	4040637.214	909.361	909.560	0.199

Table 9. Classified lidar vertical accuracy descriptive statistics

Land Cover Type	# of Points	RMSE_z (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	23	0.028	-0.003	-0.001	-0.852	0.029	-0.085	0.041	1.580
VVA	7	N/A	0.042	0.030	1.870	0.075	-0.037	0.199	4.506

5.5 Horizontal Accuracy Test Procedures

Horizontal accuracy testing requires well-defined checkpoints that can be visually identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. Dewberry reviewed all NVA checkpoints to determine which, if any, of these checkpoints were located on photo-identifiable features in the intensity imagery.

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal check points.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.

4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

5.6 Horizontal Accuracy Results

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm $RMSE_x$/$RMSE_y$ horizontal accuracy class which equates to a positional horizontal accuracy = ± 1 meter at the 95% confidence level.

Eight checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only eight (8) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the Table below.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However, lidar datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter or less at the 95% confidence level.

Table 10-Tested horizontal accuracy at the 95% confidence level

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
8	8.9	11.9	14.9	25.7

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Eight (8) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSEx = 8.9 cm and RMSEy = 11.9 cm which equates to +/- 25.7 cm at 95% confidence level. While not statistically significant, the results of the small sample set of checkpoints are within the produced to meet horizontal accuracy.

6. DEM PRODUCTION & QUALITATIVE ASSESSMENT

The final bare-earth DEMs are GeoTIFF format with 0.5 meter pixel cell size, tiled, named according to project specifications.

6.1 DEM Generation

Dewberry utilized LP360 to generate DEM products and 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 project tile grid. A raster was generated from the lidar data and clipped to the project tile grid. The DEM was reviewed for any issues requiring corrections, including remaining lidar misclassifications 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.

Once the qualitative review and any necessary corrections were complete (outlined in the section below), Dewberry then used proprietary tools to finalize the raster formatting and raster properties. GDAL version 2.4.0 was used to write the final Coordinate Reference System (CRS) information into the raster files.

6.2 DEM Qualitative Review

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 and complete hydro-flattening and hydro-enforcement. Upon correction of any outstanding issues, the DEM data was loaded into Global Mapper for its second review and to verify corrections.

Once all corrections were performed, rasters were finalized. After the finalization process, Dewberry performed a formatting review to ensure all tiled DEM products were delivered with the proper extents, formatting, and contained the proper CRS information. This process was performed using a proprietary tool to verify all raster properties were consistent and correct on the final deliverable tiles.

6.3 DEM Quantitative Assessment

The same 30 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. DEMs are created by averaging several lidar points within each pixel, which may result in slightly different elevation values at each survey checkpoint when compared to the linearly interpolated TIN created from the source LAS. The vertical accuracy of the DEM was tested by comparing the elevation of a given surveyed checkpoint with the elevation of the horizontally coincident pixel in the DEM. Dewberry used Esri ArcMap to test the DEM vertical accuracy.

Table 11. DEM vertical accuracy results

Land Cover Type	# of Points	NVA (m)	VVA (m)

Project Specification		**0.196**	**0.300**
NVA	23	0.056	
VVA	7		0.150

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 2.9 cm, equating to +/- 5.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 15 cm at the 95th percentile~~.~~

The 5% outliers are listed in Table 12. Descriptive statistics for both sets of checkpoints are presented in Table 13.

Table 12. DEM VVA 5% outliers

Point ID	NAD83(2011) UTM 17 N, m		NAVD88 Geoid 12B, m		Delta Z (m)
	Easting (X)	Northing (Y)	Survey Z	DEM Z	
VVA-003	489000.079	4040637.214	909.361	909.549	0.188

Table 13. DEM vertical accuracy descriptive statistics

Land Cover Type	# of Points	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	23	0.029	-0.007	-0.007	-0.529	0.028	-0.082	0.045	1.016
VVA	7	N/A	0.044	0.028	1.768	0.069	-0.027	0.188	3.891