# Florida Southeast Lidar

## Report Produced for U.S. Geological Survey

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# 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 Florida Southeast Lidar Project Area.

The 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 1,000m by 1,000m. A total of 4,737 tiles were produced for the project encompassing an area of approximately 1,641 sq. miles.

## 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's William D. Donley completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Dewberry completed lidar data acquisition and data calibration for the project area. Kinetics completed some breakline production in Block 2 of Florida Southeast. Dewberry was responsible for all QA/QC of the final deliverables.

## SURVEY AREA

The project area addressed by this report falls within the Florida counties of Broward, Collier, Hendry, Miami-Dade, Monroe, and Palm Beach.

## DATE OF SURVEY

The lidar aerial acquisition for Block 1 was conducted on June 2, 2018, and the lidar aerial acquisition for Block 2 was conducted over 7 days, November 28, 29, & 30, and December 06, 07, 12, & 17, 2018.

## COORDINATE REFERENCE SYSTEM

Data produced for the project were delivered in the following reference system.

> **Horizontal Datum:** The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment
> **Vertical Datum:** The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
> **Coordinate System:** Contiguous U.S. Albers Conical Equal Area
> **Units:** Horizontal units are in meters, Vertical units are in meters.
> **Geiod Model:** Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

## LIDAR VERTICAL ACCURACY

For the Florida Southeast Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled 4.1 cm compared with the 10.0 cm specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to 8.0 cm, compared with the 19.6 cm specification.

For the Florida Southeast Lidar Project, the tested VVA of the classified lidar data computed using the $95^{th}$ percentile was equal to 21.3 cm, compared with the 30.0 cm specification.

Additional accuracy information and statistics for the classified lidar data, raw swath data, and bare earth DEM data are found in the following sections of this report.

## PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (File GDB)
5. Independent Survey Checkpoint Data (Report, Photos, Coordinates)
6. Calibration Points
7. Relative Accuracy Data (Shapefile)
8. Metadata
9. Project Report
10. Edge-Tie Analysis Report
11. Project Extents (Shapefiles)

## PROJECT TILING FOOTPRINT

The project delivery consists of 4,737 tiles. Each tile's extent is 1,000 meters by 1,000 meters (see Appendix B for a complete listing of delivered tiles).

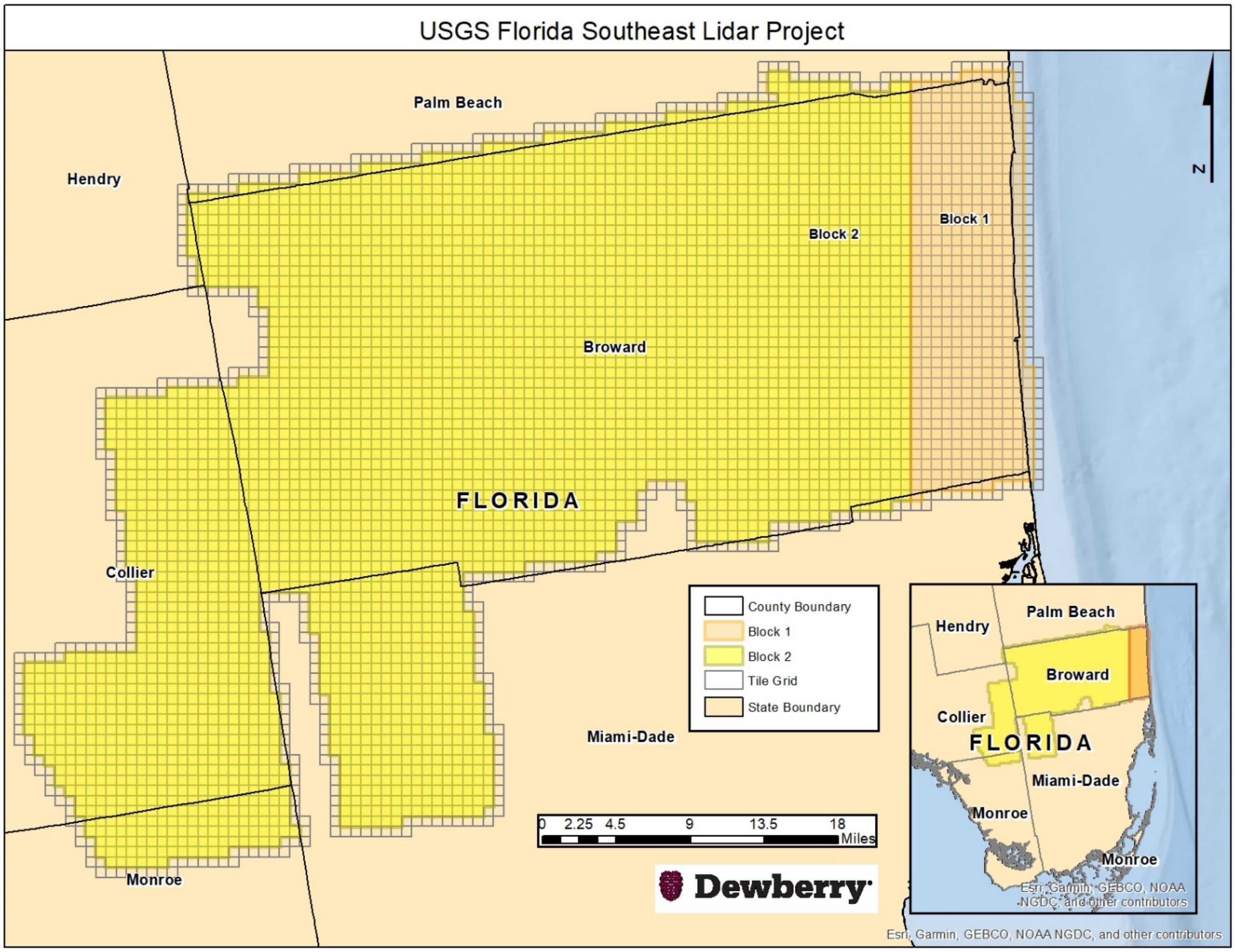



*Figure 1—Project Map*

# Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Airborne Imaging Inc. Airborne Imaging Inc. was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

Dewberry received calibrated swath data from Airborne Imaging Inc. on January 29, 2019.

## LIDAR ACQUISITION DETAILS

Airborne Imaging Inc. planned 90 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, Airborne Imaging Inc. followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO 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, Airborne Imaging Inc. will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Airborne Imaging Inc. 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 leaf-off for hardwoods, no snow, rain, fog, smoke, mist and 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. Airborne Imaging Inc. 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, Airborne Imaging Inc. 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 took responsibility for weather analysis.

Airborne Imaging Inc. lidar sensors are calibrated at a designated site located at Red Deer, Alberta, Canada, St. Hubert, Quebec, Canada, and Provost, Utah, USA, and are periodically checked and adjusted to minimize corrections at project sites.

## LIDAR SYSTEM PARAMETERS

Airborne Imaging Inc. operated a Piper Navajo PA-31 (tail no. C-GMEC) outfitted with a Riegl VQ-1560i lidar system during the collection of Block 1 of the study area, and two Piper Navajo PA-31s (tail nos. C-GMEC and C-FKMA) outfitted with a Riegl VQ-1560i lidar system during the collection of Block 2 of the study area. Table 1 illustrates Airborne Imaging Inc. system parameters for lidar acquisition on this project.

| Item | Parameter |
|---|---|
| System | Riegl VQ-1560i |
| Altitude (AGL meters) | 1300 |
| Approx. Flight Speed (knots) | 160 |
| Scanner Pulse Rate (kHz) | 2000 |
| Scan Frequency (hz) | 375 |
| Pulse Duration of the Scanner (nanoseconds) | 3 |
| Pulse Width of the Scanner (m) | 0.9 |
| Swath width (m) | 1500 |
| Central Wavelength of the Sensor Laser (nanometers) | 1064 |
| Did the Sensor Operate with Multiple Pulses in The Air? (yes/no) | Yes |

| Item | Parameter |
|---|---|
| Beam Divergence (milliradians) | 0.25 |
| Nominal Swath Width on the Ground (m) | 1456 |
| Swath Overlap (%) | 30 |
| Total Sensor Scan Angle (degree) | 60 |
| Computed Down Track spacing (m) per beam | 0.38 |
| Computed Cross Track Spacing (m) per beam | 0.43 |
| Nominal Pulse Spacing (single swath), (m) | 0.35 |
| Nominal Pulse Density (single swath) (ppsm), (m) | 8 |
| Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal) | 0.35 |
| Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal) | 8 |
| Maximum Number of Returns per Pulse | 7+ |

***Table 1—Airborne Imaging Inc. lidar system parameters***

## ACQUISITION STATUS REPORT AND FLIGHTLINES

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 aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly 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 shows the combined trajectory of the flightlines.

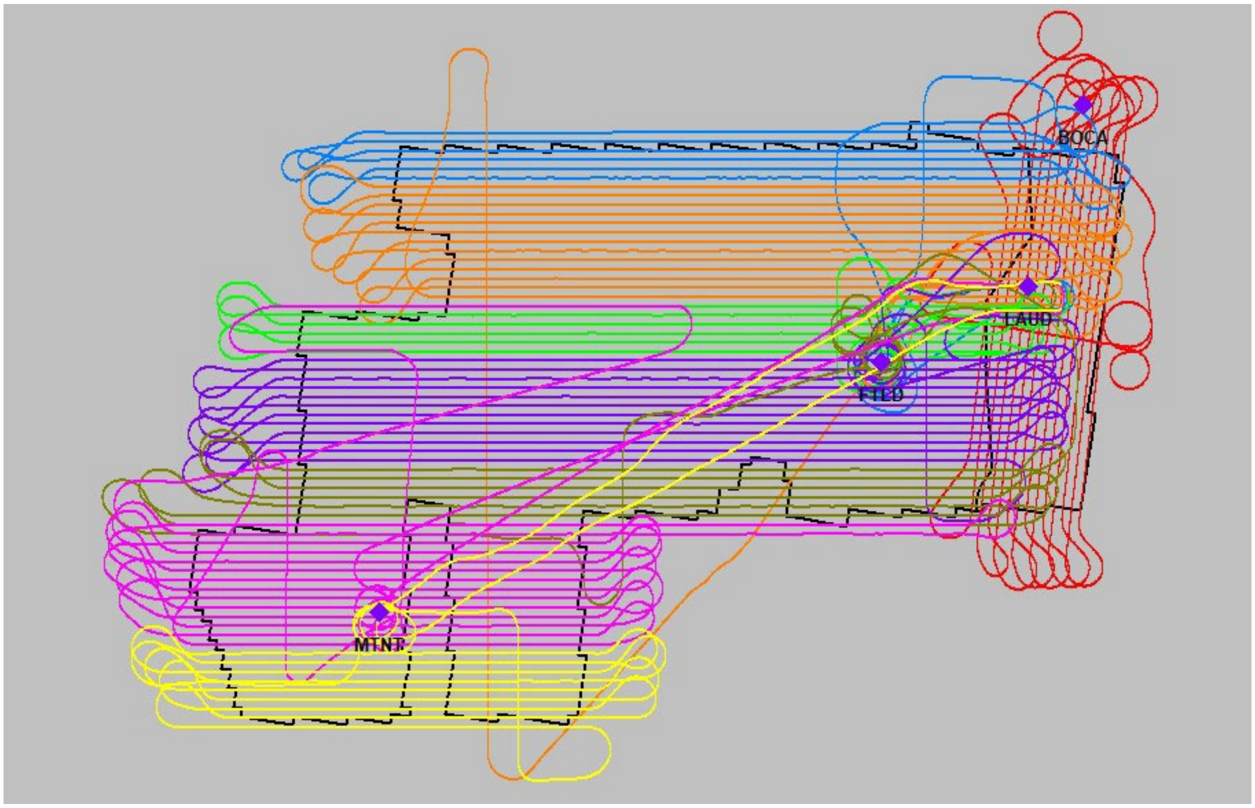



*Figure 2—Trajectories as flown by Airborne Imaging Inc.*

## LIDAR CONTROL

Five Florida DOT Permanent Reference Network (FPRN) stations were used to control the lidar acquisition for the Florida Southeast lidar project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

| Name | NAD83(2011) Contiguous U.S. Albers | | Ellipsoid Ht (NAD83(2011), m) | Orthometric Ht (NAVD88 Geoid12B, m) |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | | |
| LAUD | 454914.156 | 2958559.308 | -18.142 | 7.496 |
| BOCA | 422992.713 | 3091868.432 | -19.274 | 6.622 |
| FTLD | 565962.546 | 2889209.119 | -15.332 | 9.814 |
| MTNT | 509318.157 | 2860821.807 | -18.928 | 5.399 |
| GLAD | 533061.371 | 2955655.002 | -19.234 | 5.914 |

*Table 2—Base stations used to control lidar acquisition*

## AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the Applanix POSPac MMS software suite and Novatel's GrafNav software. 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 and 50 km for Block 1 and Block 2, respectively.

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 C.

## GENERATION AND CALIBRATION OF LASER POINTS (RAW 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 Riegl's RiProcess, initially with default values for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. 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.

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.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

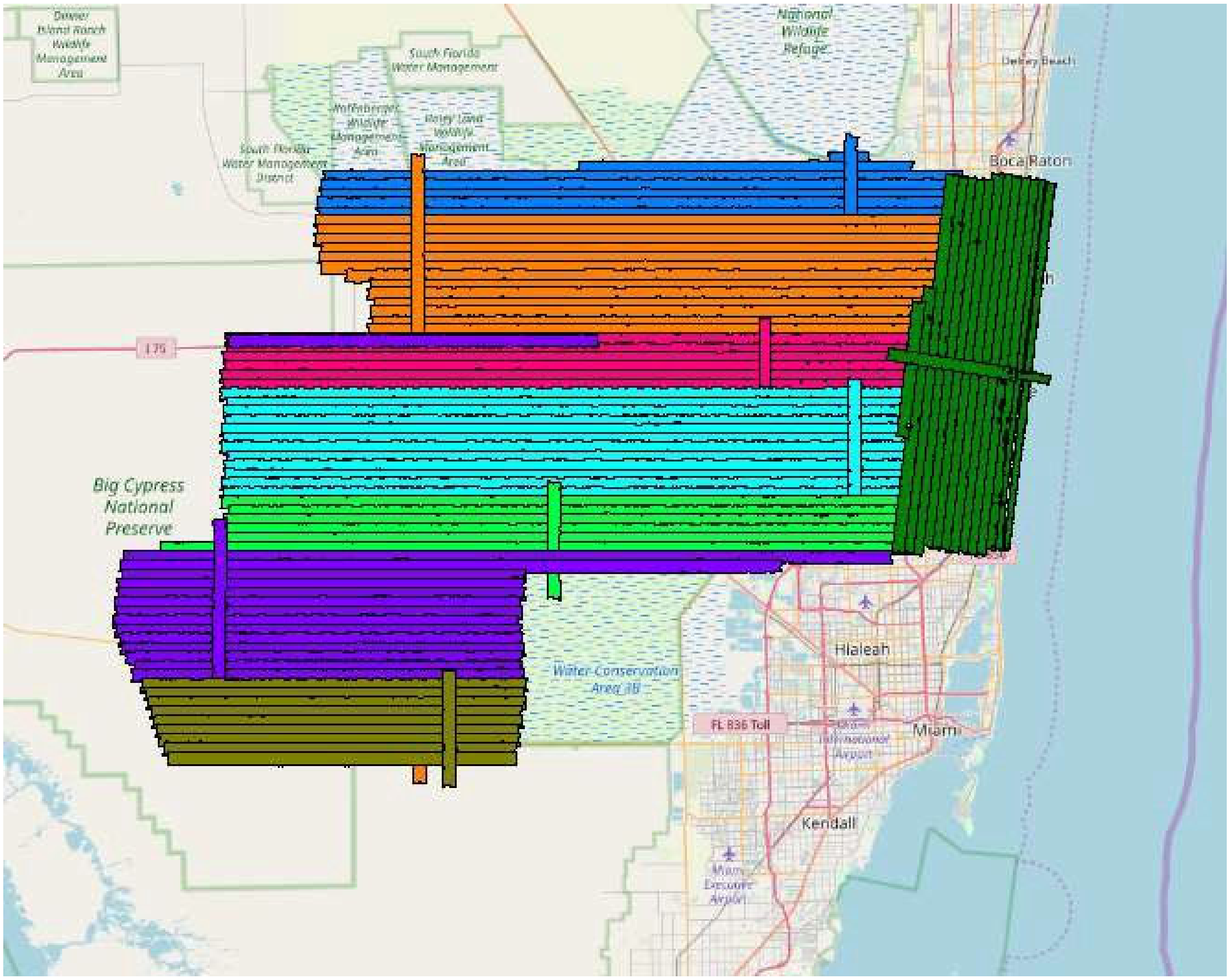



*Figure 3—Lidar swath output showing complete coverage, colored by flight mission.*

## 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 scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. 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.

For this project the specifications used are as follows: Relative accuracy <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

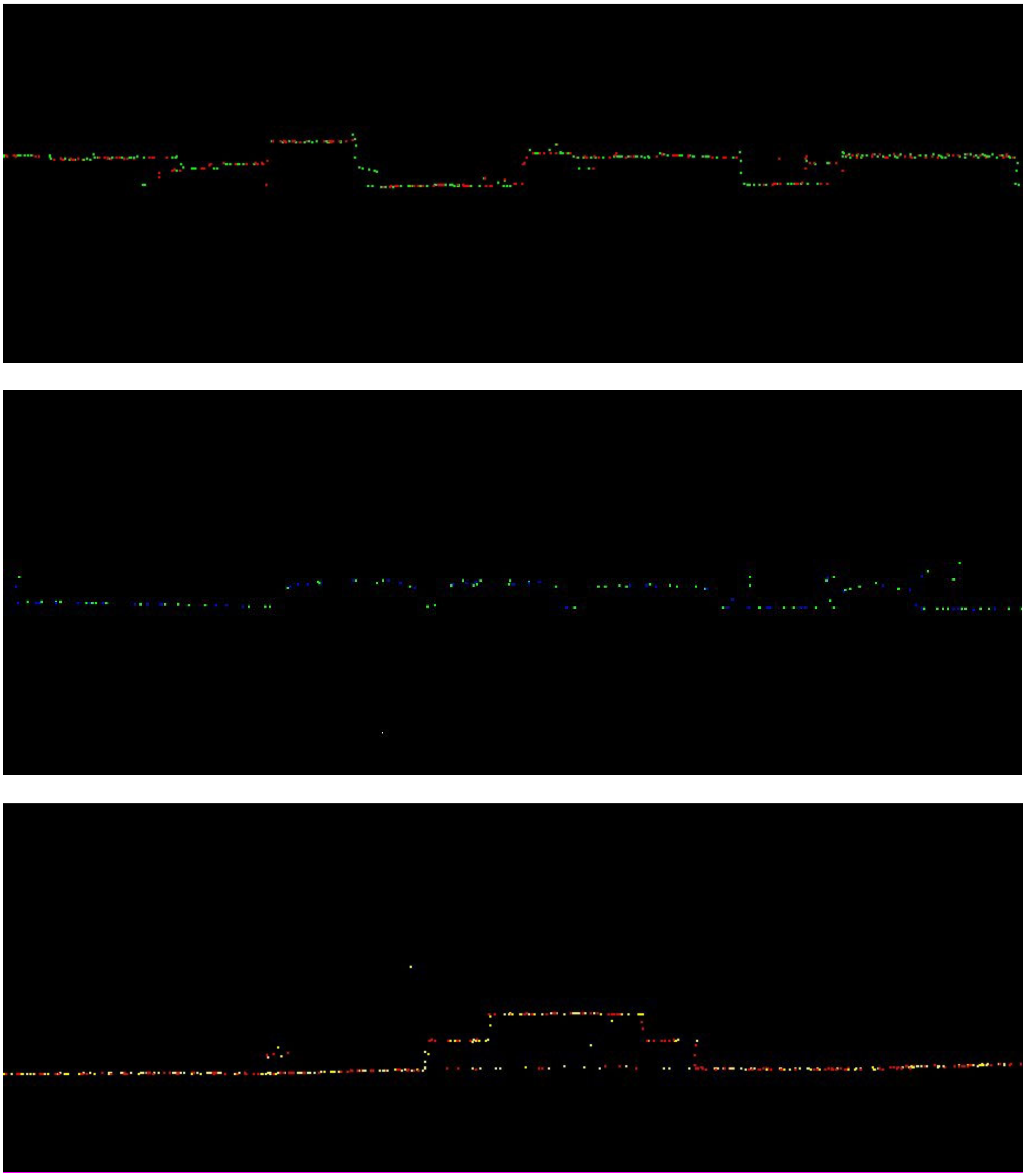


*Figure 4—Profile views showing correct roll and pitch adjustments.*

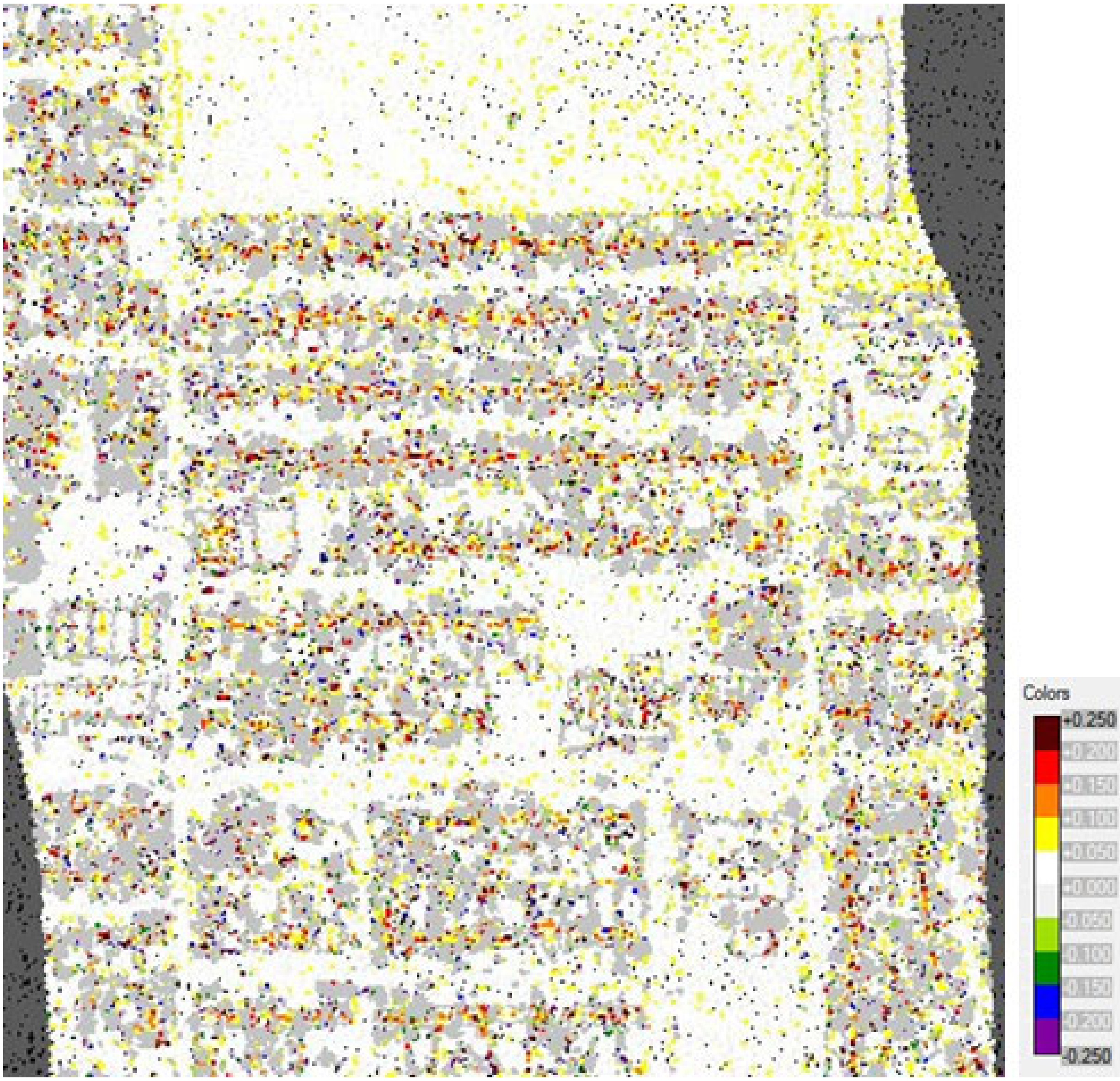



*Figure 5—QC block colored by distance to ensure accuracy at swath edges.*

A different set of QC blocks are generated for final review after all transformations have been applied.

## PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by Airborne Imaging Inc. at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The lidar data is examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z$ ≤ 10 cm and Accuracy at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated Florida Southeast lidar dataset was tested to 0.071 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.036 m) x 1.9600 when compared to 20 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Airborne Imaging Inc. to internally verify vertical accuracy.

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | NVA at 95% Spec=0.196 m | Mean (m) | Std Dev (m) | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 20 | 0.036 | 0.071 | -0.010 | 0.035 | -0.057 | 0.089 |

*Table 3—Static GPS Vertical Accuracy Results*

Overall, the calibrated lidar data products collected by Airborne Imaging Inc. meet or exceed the requirements set out in the Statement of Work. The quality control requirements of the Airborne Imaging Inc. quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

# Lidar Processing & Qualitative Assessment

## INITIAL PROCESSING

Once Dewberry receives the calibrated swath data from the acquisition provider, Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

### Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Airborne Imaging Inc., Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the 69 non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the Florida Southeast Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 4.5 cm, equating to ± 8.9 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

| 100 % of Totals | # of Points | $RMSE_z$ NVA Spec=0.10 m | NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Min (m) | Max (m) | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 69 | 0.045 | 0.089 | 0.015 | 0.010 | 0.564 | 0.043 | -0.059 | 0.125 | 0.208 |

*Table 4—NVA at 95% Confidence Level for Raw Swaths*

## Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.3, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL1 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. Large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data, especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for Block 1 and Block 2 of the Florida Southeast Lidar Project are shown in the figures below; this project meets inter-swath relative accuracy specifications.

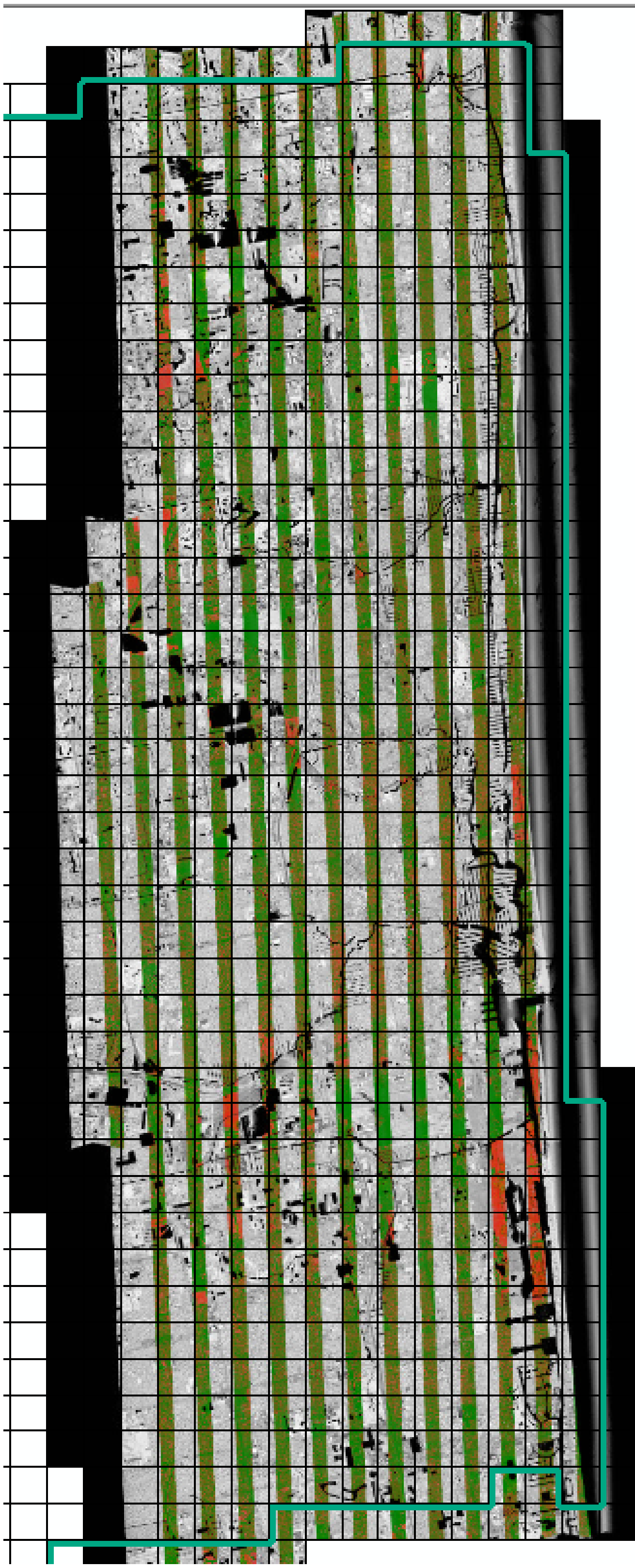


*Figure 6—Single return DZ Orthos for Block 1 of the Florida Southeast Lidar Project. Block 1 inter-swath relative accuracy passes specifications.*

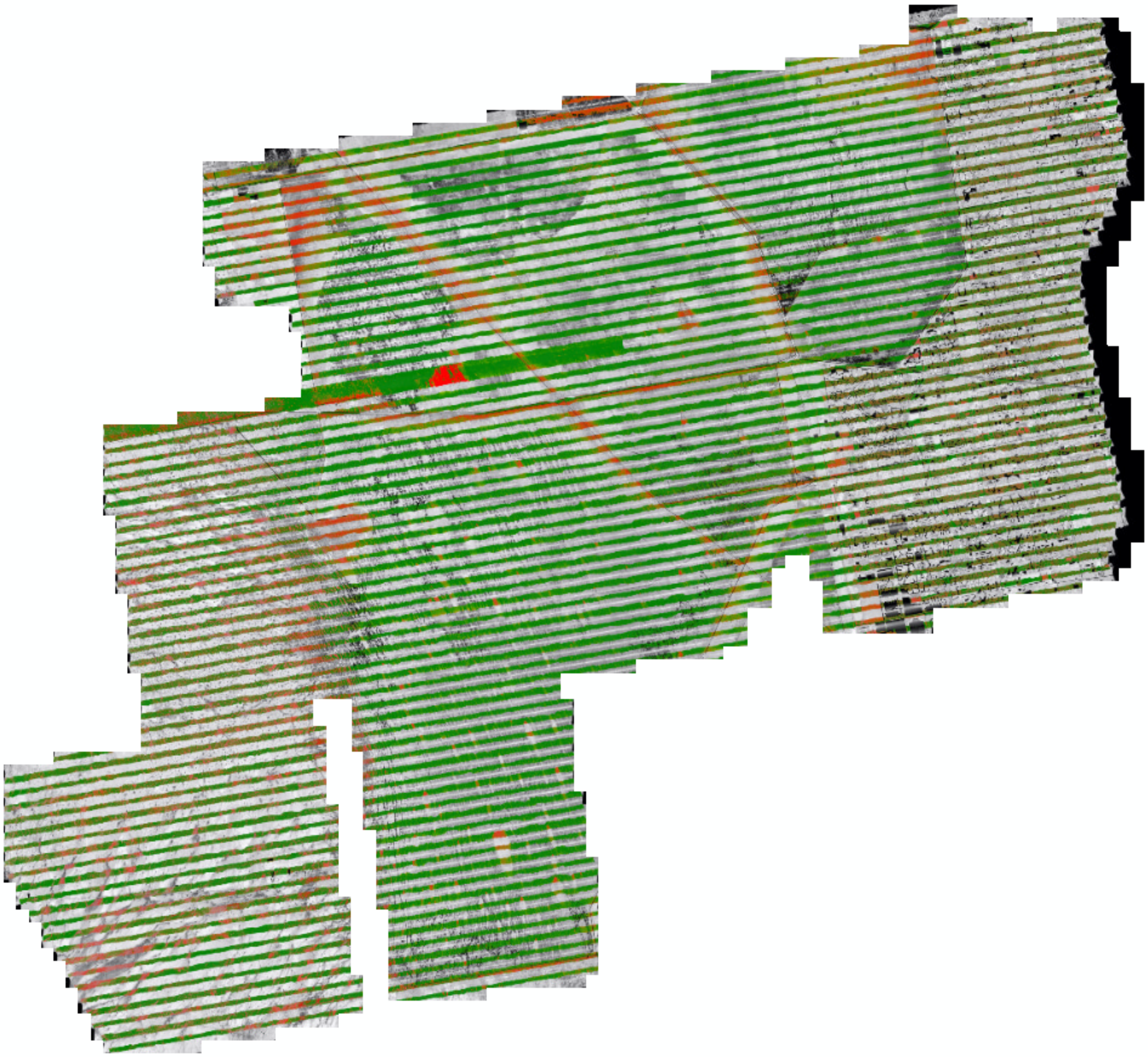


***Figure 7—Single return DZ Orthos for Block 2 of the Florida Southeast Lidar Project. Block 2 inter-swath relative accuracy passes specifications.***

In addition to the visual qualitative review of interswath values, the Lidar Base Specification 1.3 also outlines 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.

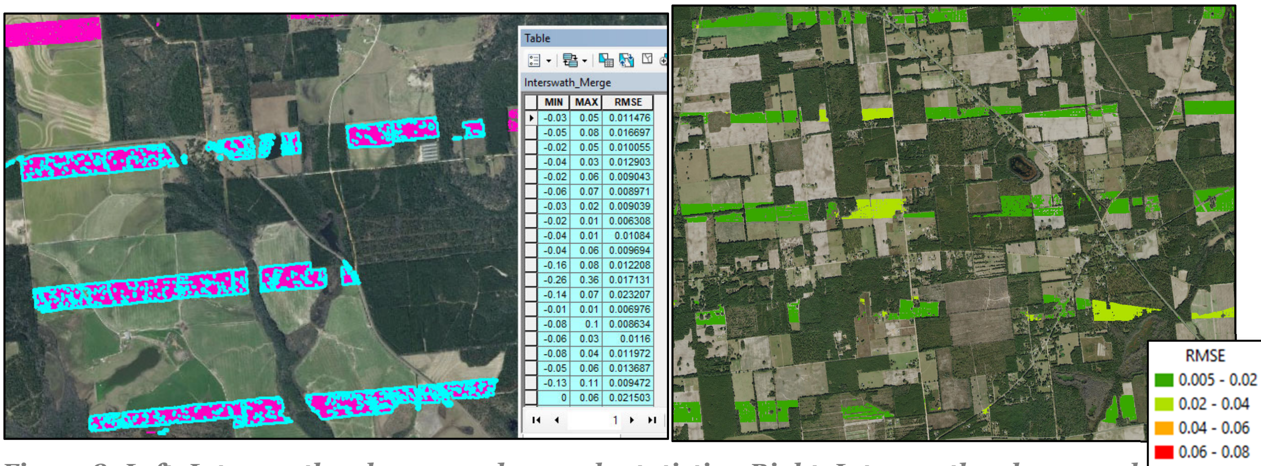



*Figure 8–Left: Interswath polygons and example statistics. Right: Interswath polygons colored by RMSDz values*

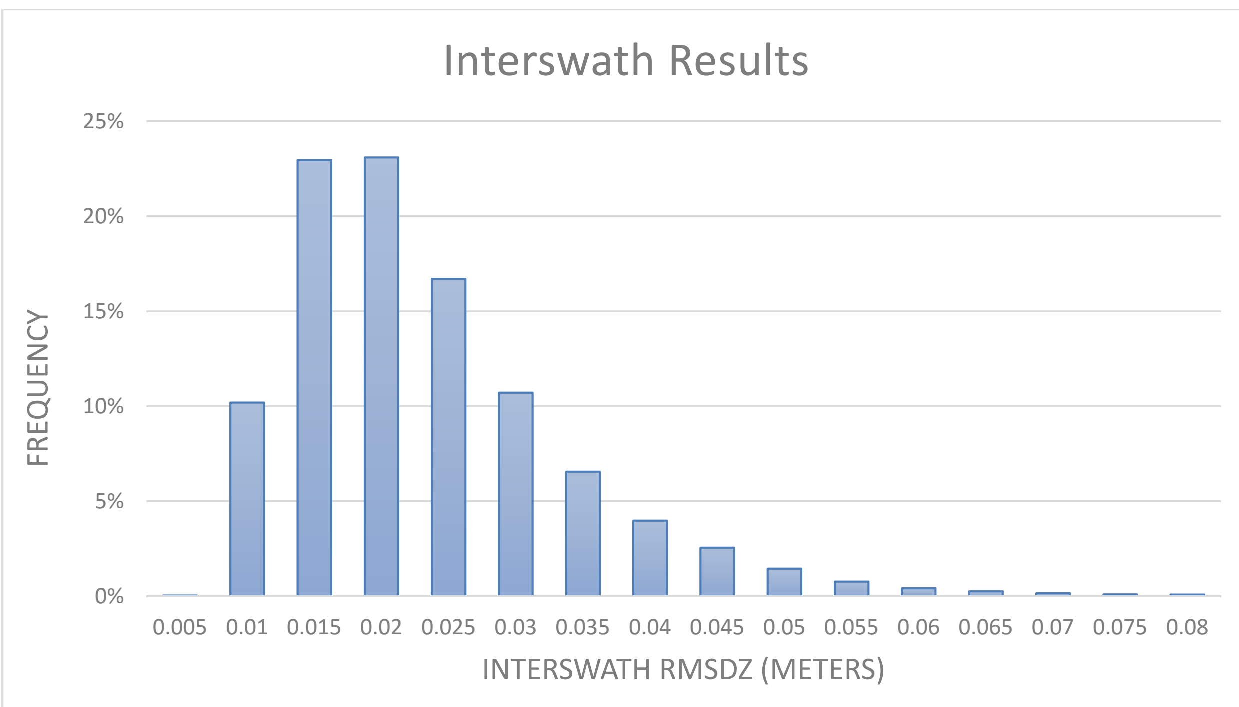



*Figure 9–Frequency distribution of interswath RMSDz results*

## Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.3, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL1 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The images below show two examples of the intra-swath relative accuracy of Block 1 and Block 2 of the Florida Southeast Lidar Project; this project meets intra-swath relative accuracy specifications.

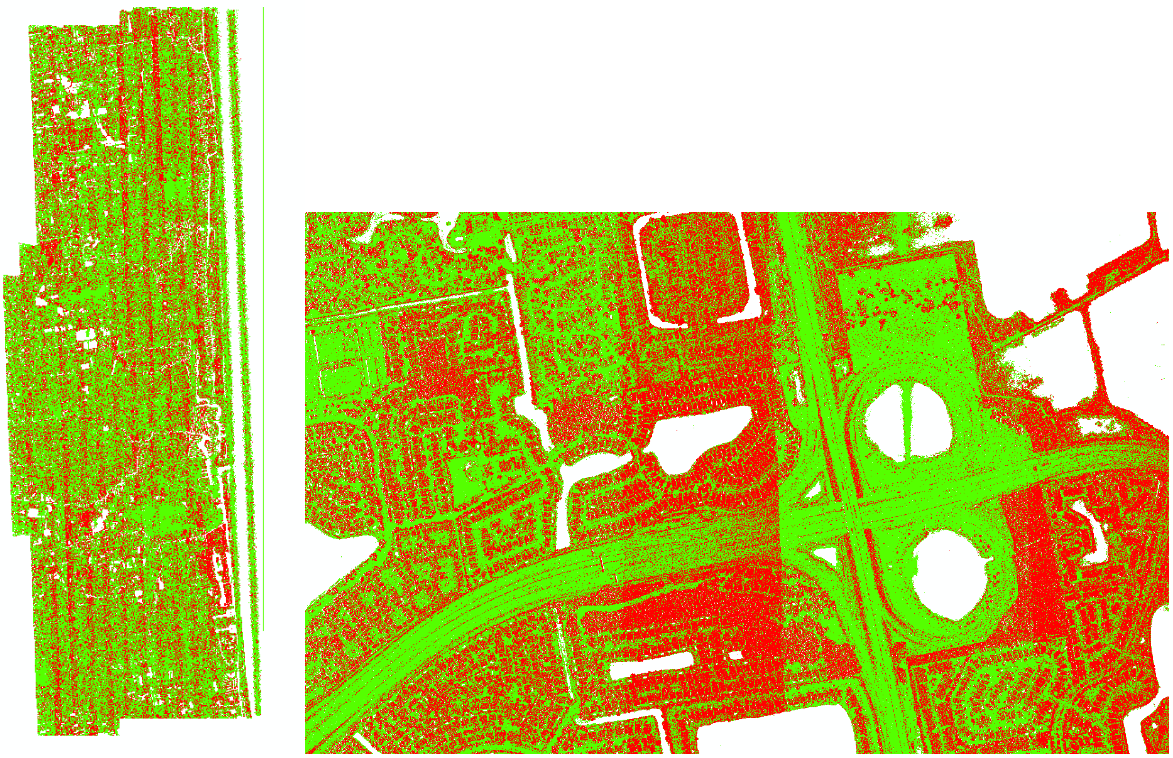
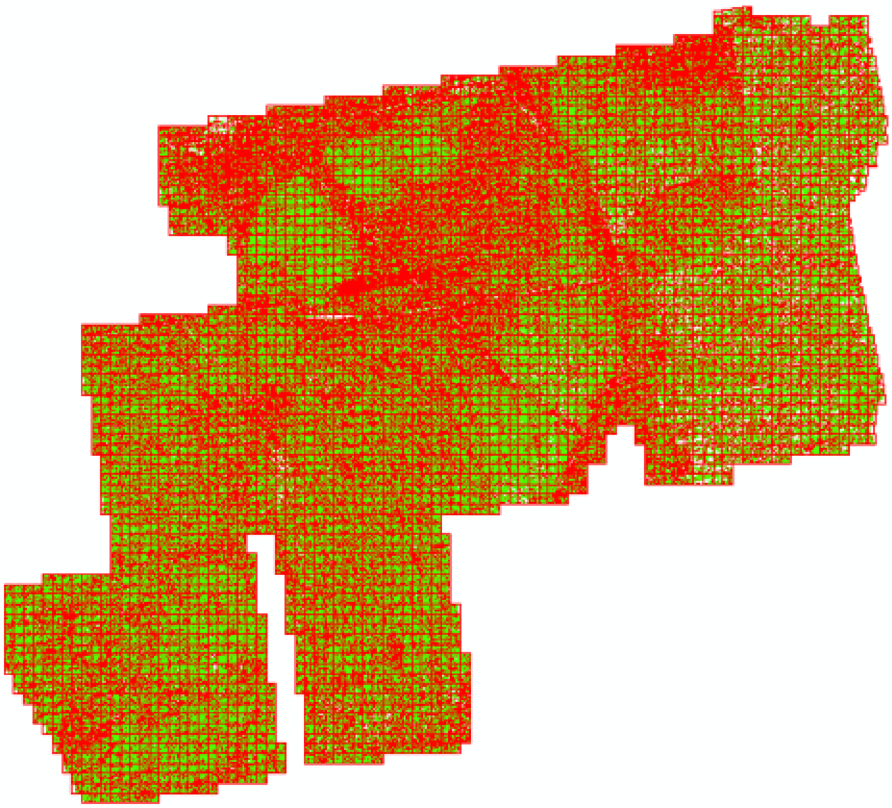


***Figure 10—Block 1 intra-swath relative accuracy. The left image shows the full Block 1. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The right image is a close-up of a flat area. With the exception of the surrounding vegetation and buildings (shown in red as the elevation/height difference in vegetated/built-up areas will exceed 6 cm), this open flat area is acceptable for repeatability testing. Block 1 intra-swath relative accuracy passes specifications.***



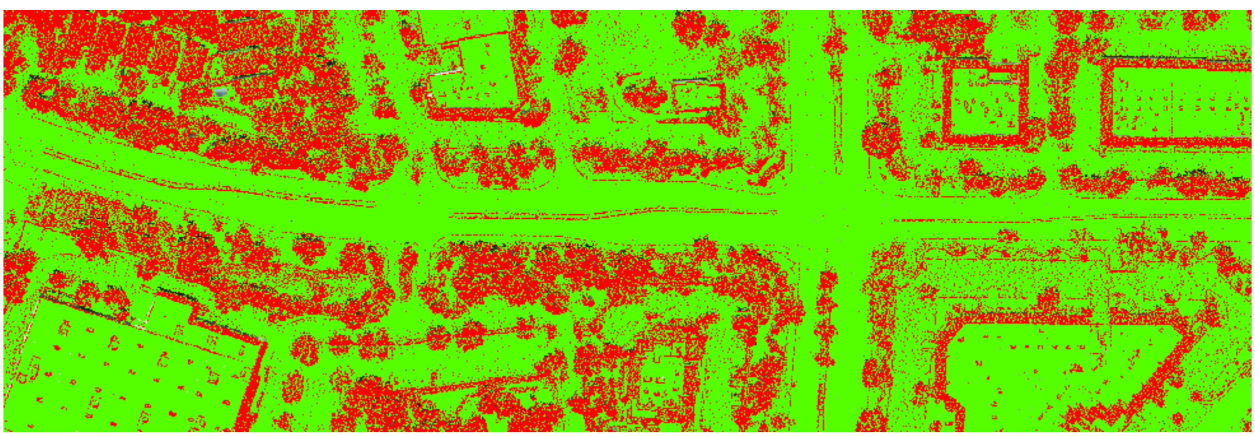


***Figure 11—Block 2 intra-swath relative accuracy. The top image shows the full Block 2. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The bottom image is a close-up of a flat area. With the exception of the surrounding vegetation and buildings (shown in red as the elevation/height difference in vegetated/built-up areas will exceed 6 cm), this open flat area is acceptable for repeatability testing. Block 2 intra-swath relative accuracy passes specifications.***

In addition to the visual qualitative review of intraswath values, the Lidar Base Specification 1.3 also outlines 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. These test locations are open terrain hard surface areas at the left, center, and right of a swath within the lift. The polygon deliverable should contain the minimum, maximum, and RMSDz of the differences in the sample polygon area.


*Figure 12–Example test polygon for intraswath testing, and its results*

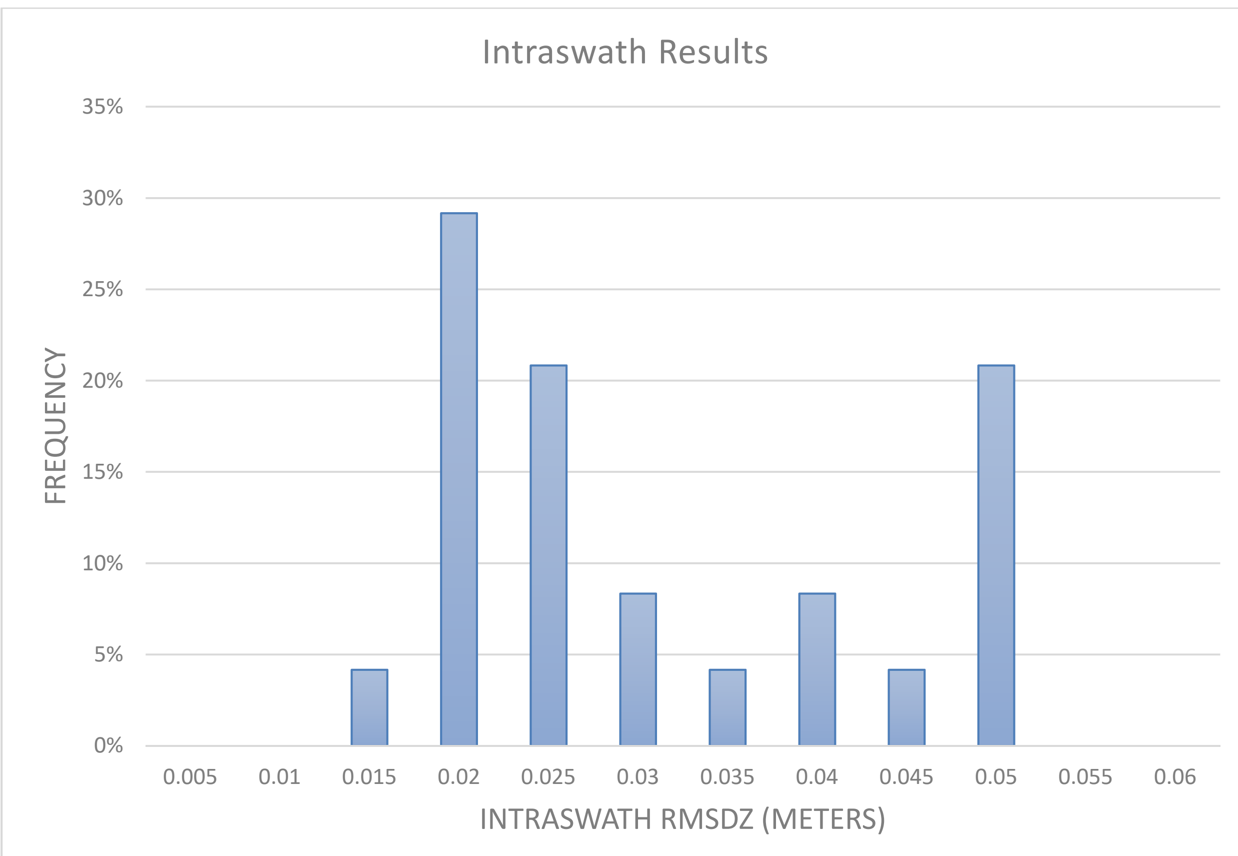



*Figure 13–Frequency distribution of intraswath RMSDz results*

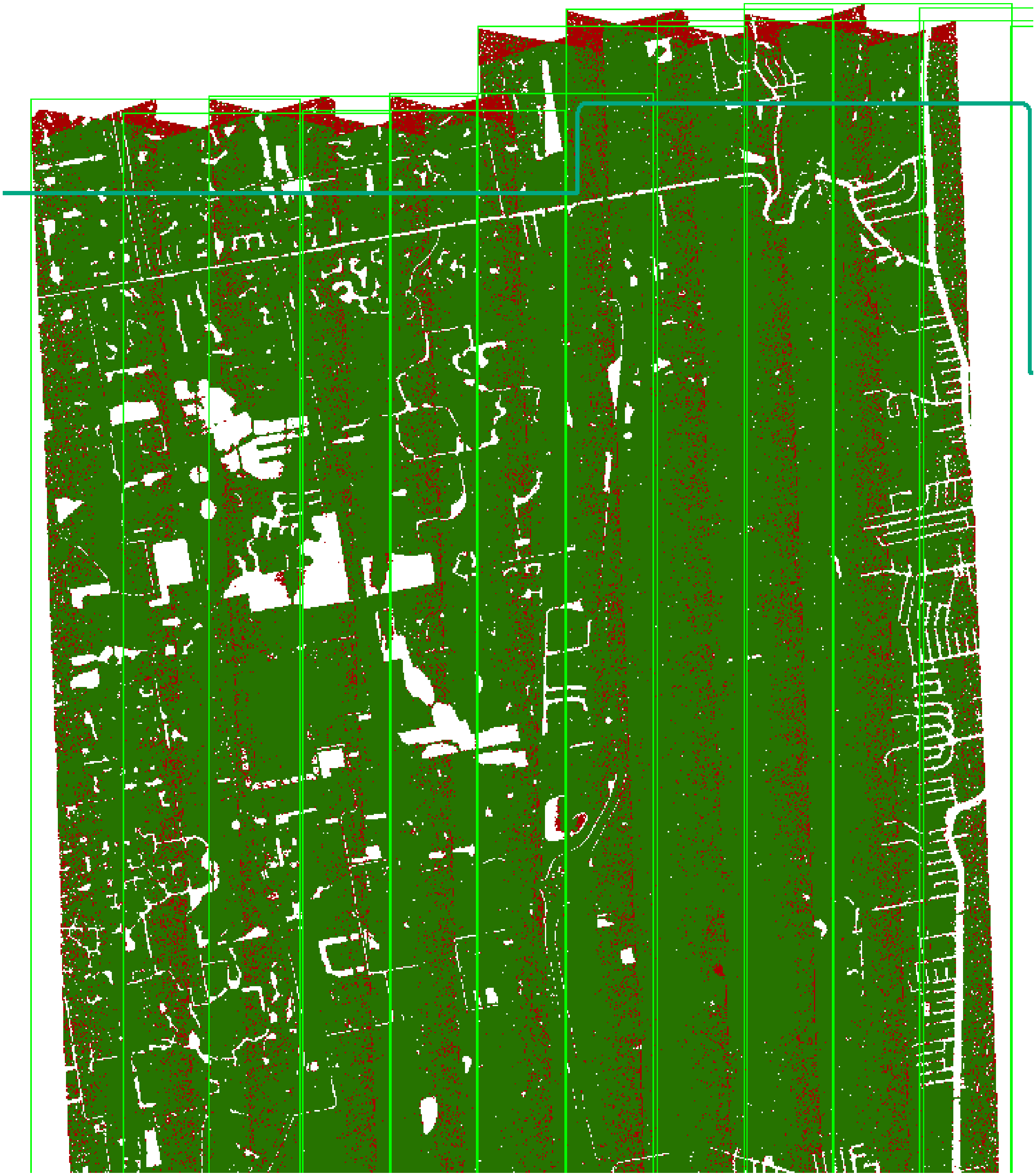
## Horizontal Alignment

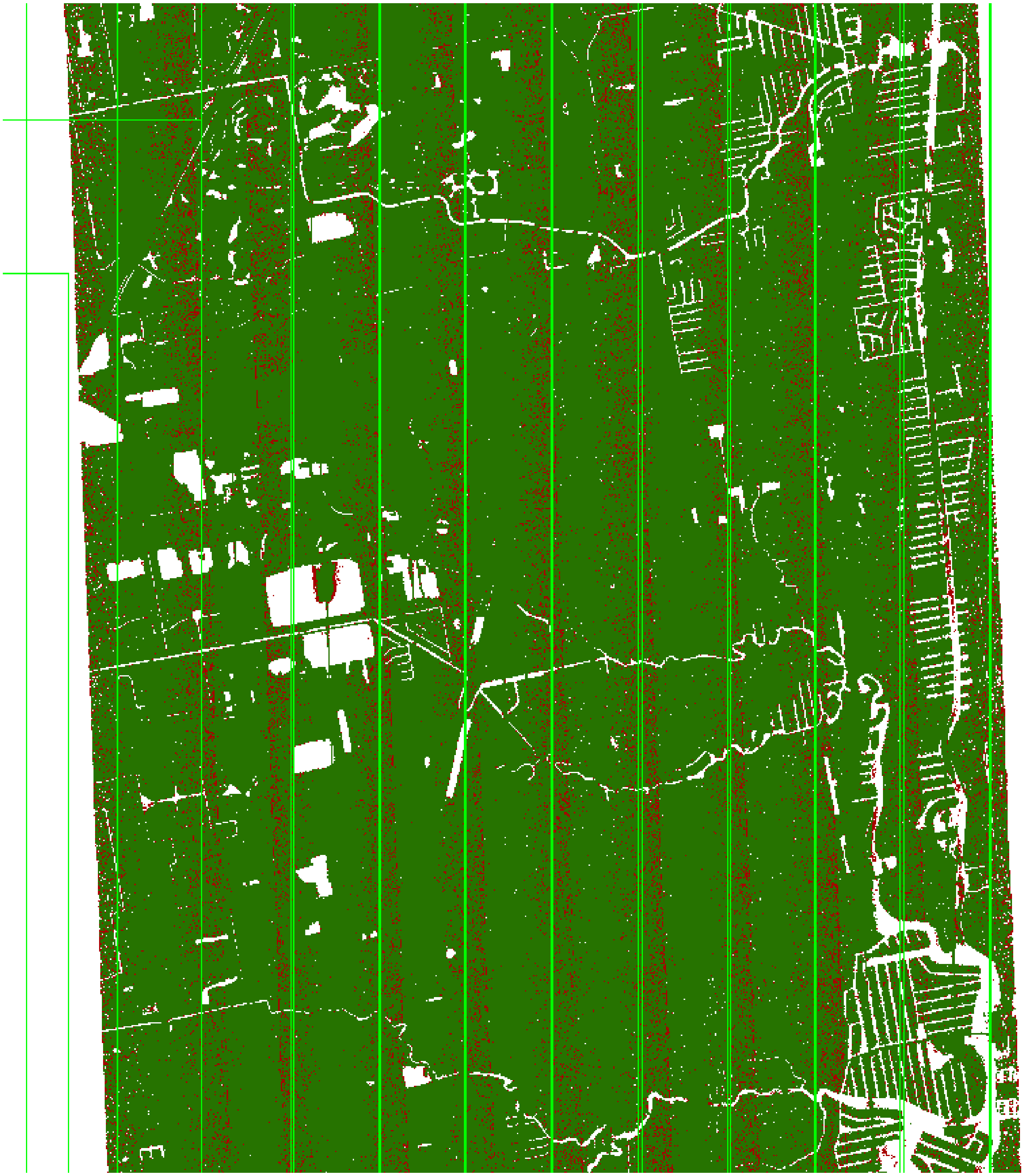
To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. In particular, horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. The image below shows an example of the horizontal alignment between swaths for Florida Southeast Lidar Project; no horizontal alignment issues were identified.

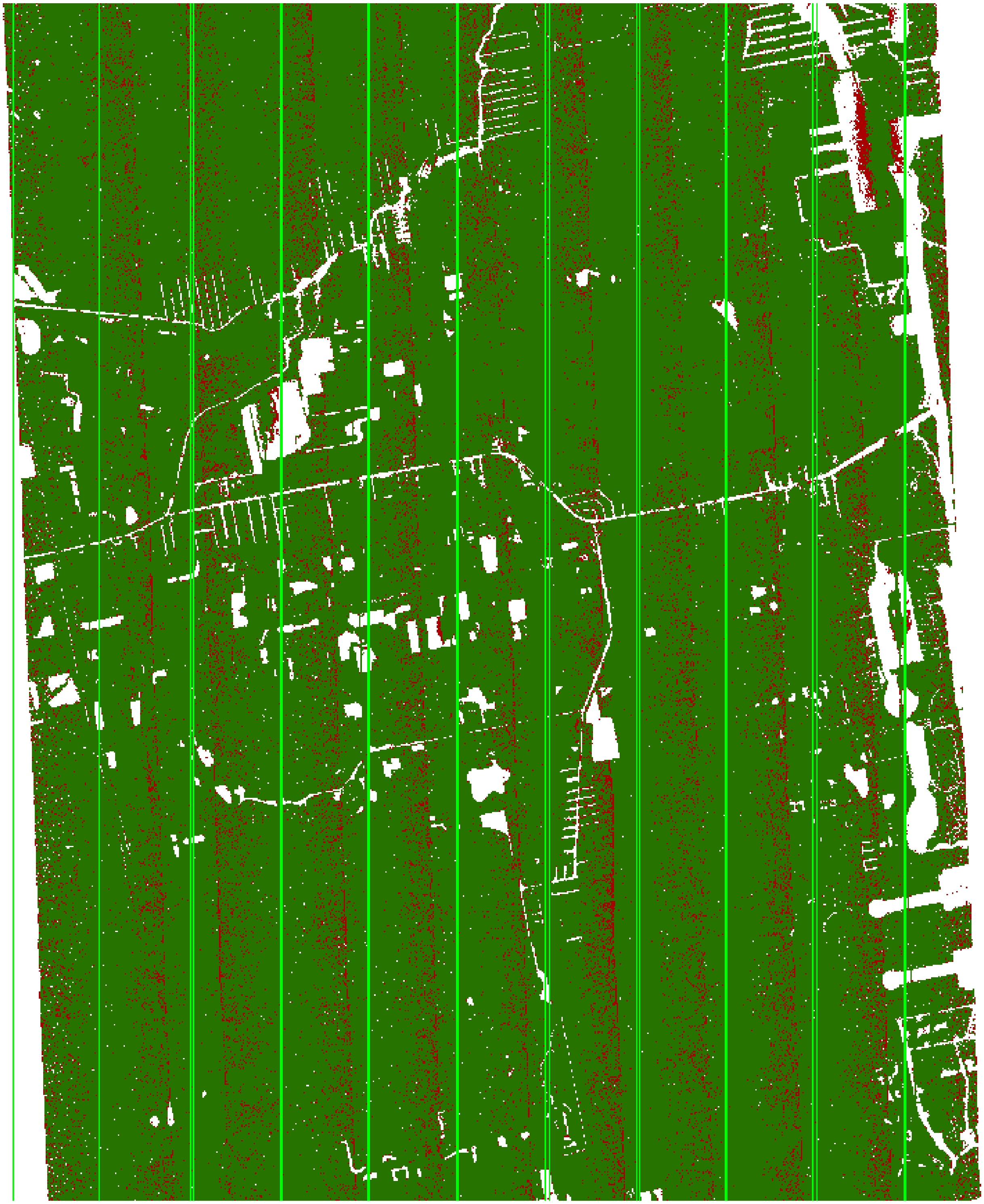
***Figure 14—Horizontal Alignment. Two separate flight lines differentiated by color (Yellow/Red) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.***

## Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.35 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 8 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. Block 1 was determined to have an ANPS of 0.31 meters or an ANPD of 10.4 points per square meter, which satisfies the project requirements. Block 2 was determined to have an ANPS of 0.28 meters or an ANPD of 13.04 points per square meter, which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 8 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.







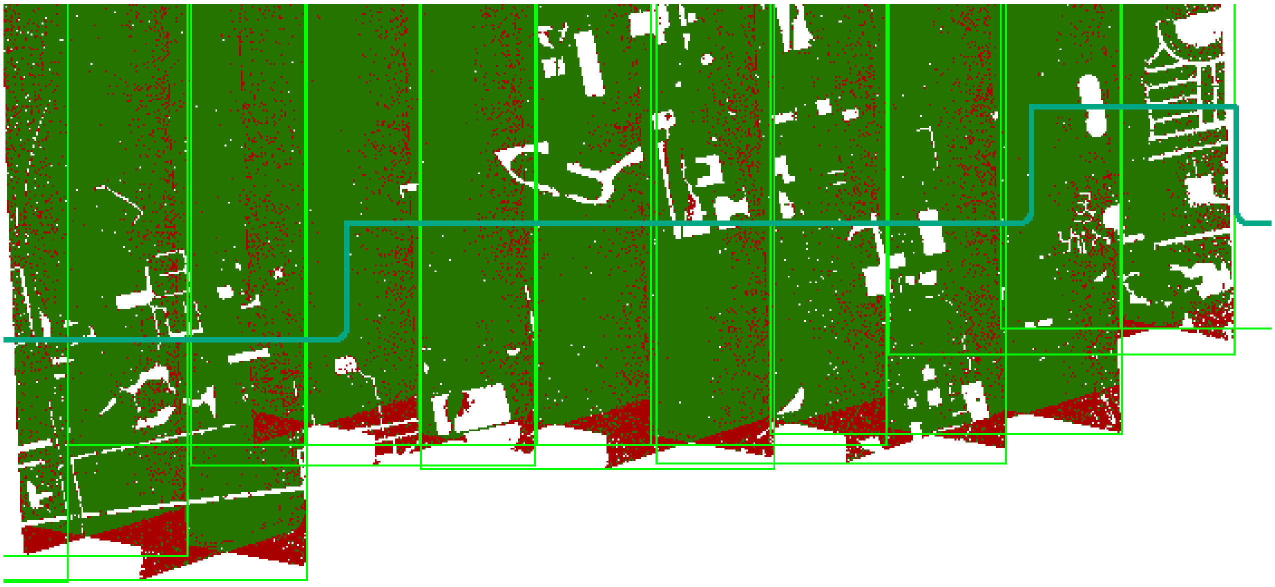


***Figure 15—1-square meter density grid. There are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 8 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.***

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. ArcGIS 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.

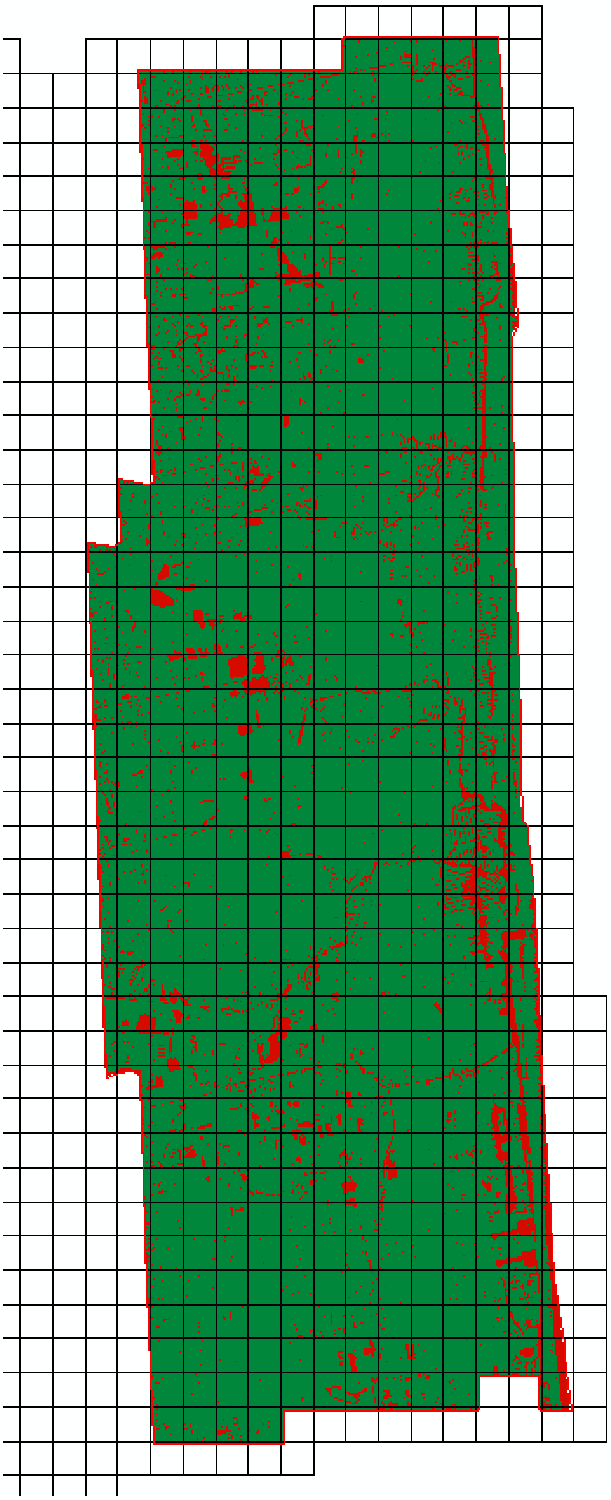


*Figure 16—Spatial Distribution. All cells (2*NPS cell size) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies and other acceptable NoData areas, are colored red. Without removing acceptable NoData areas, 91.48% of cells contain at least one lidar point.*

## DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies 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 are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

Each tile was then 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 conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 20, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 17 = Bridge Decks

- Class 18 = High Noise
- Class 20 = Ignored Ground due to breakline proximity

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

# 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 terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. 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. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

## VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for Florida Southeast Lidar Project.

### Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. No unacceptable voids are present in the Florida Southeast lidar project.

### Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

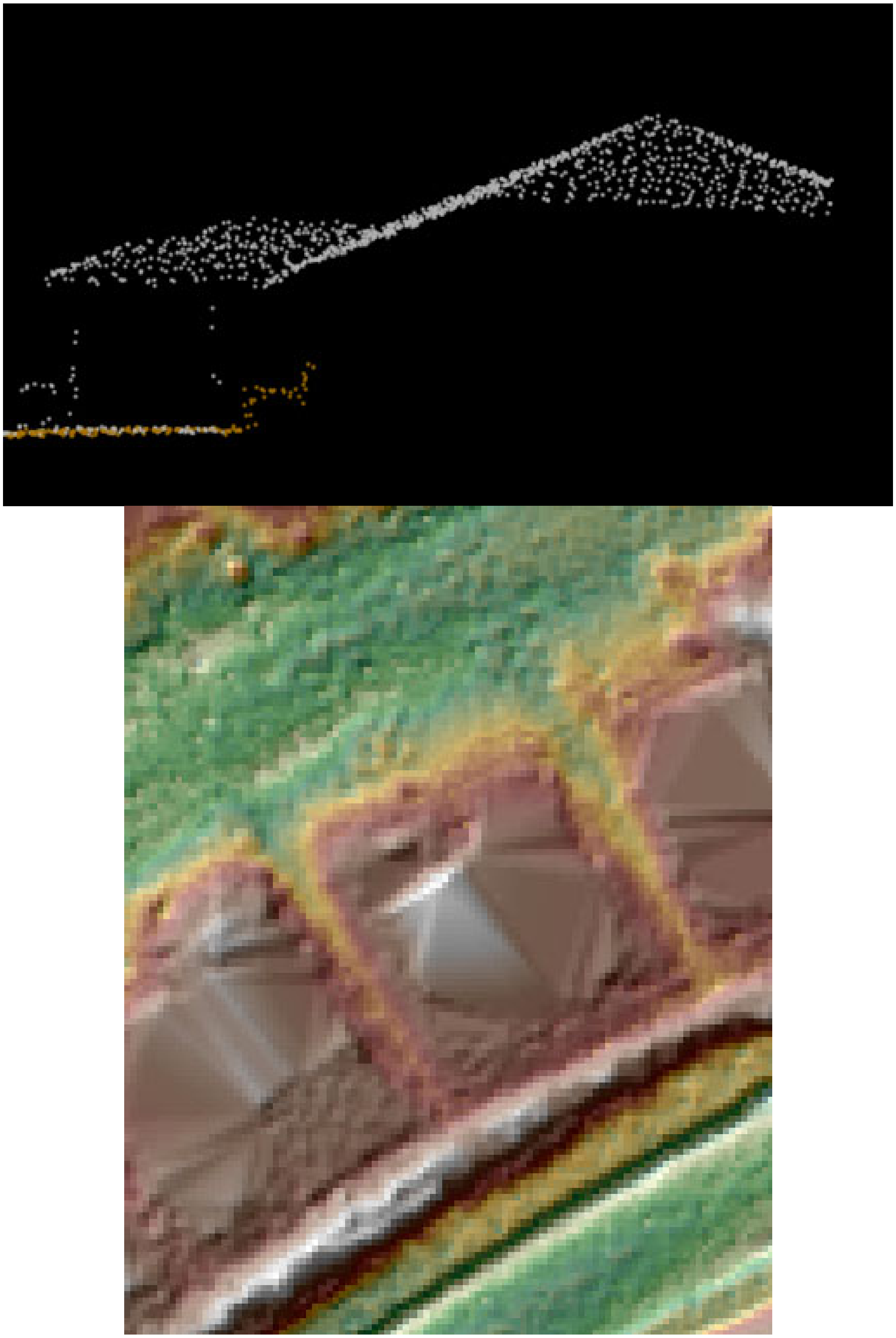


*Figure 17— Tile number e1585n0493. A profile with points colored by class (class 1=grey, class 2=brown) is shown in the top view and a TIN of the surface is shown in the bottom view. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.*

## Vegetation Identification and Removal

The Southeast Florida LiDAR project covers areas of dense stands of vegetation where the LiDAR system was not able to consistently penetrate the foliage to reach the ground. These areas are primary located in the water conservation areas, Big Cypress National Preserve, and the Everglades Wildlife Management Area. In order to provide a more accurate DEM in these areas Dewberry developed a process to identify these locations and perform additional filtering to maintain only the lowest points. First, polygons were defined that encompassed dense vegetation areas. Then the points that exist outside the vegetation polygons were identified and the lidar inside the polygons was refiltered to maintain only points that fall within a ± 30 cm vertical range of the ground points outside the polygons. The threshold was based on the vegetated vertical accuracy requirements for the project. The result is a surface with fewer vertical artifacts, as well as a polygon feature representing where dense vegetation is present.

In the northwest portion of the project area, it was not possible to identify only the vegetation area, as the majority of the area was covered by tall grasses. In this area, a separate grounding macro was used to be more aggressive with the vegetation removal. This was segmented at a levee so as to not impact the consistency across the remainder of the project. Figure 18 is an example area where the vegetation in ground has been more aggressively filtered out. The DEM on the left shows the original dataset and the image on right shows the revised version.

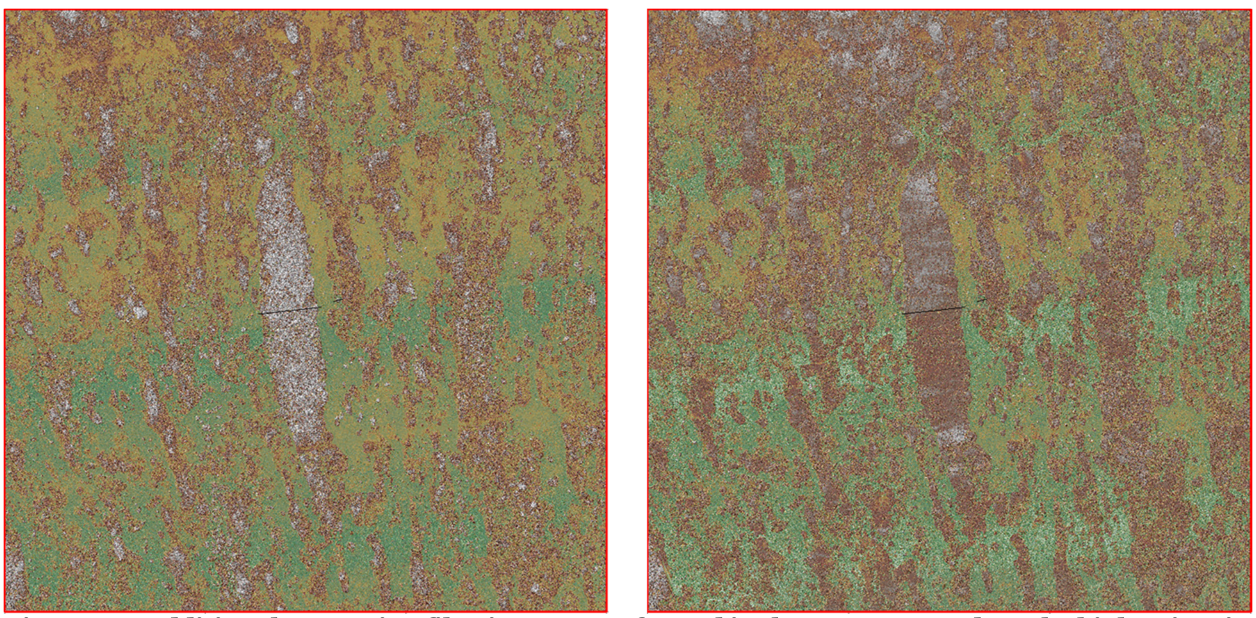


*Figure 18—Additional vegetation filtering was performed in these areas to reduce the high points in the ground classification.*

This additional filtering moved high points to class 1 (unclassified) and revised three percent of the ground points. The average change in the DEM heights was approximately 2.8 cm. All areas that underwent additional processing have been included as a polygon shapefile showing these areas as 'low confidence' due to the reduced density of the ground and lower confidence in those points than in open terrain or areas where a consistent ground was identified beneath the vegetation. Figure 19 shows the areas highlighted in blue as those with lower confidence.

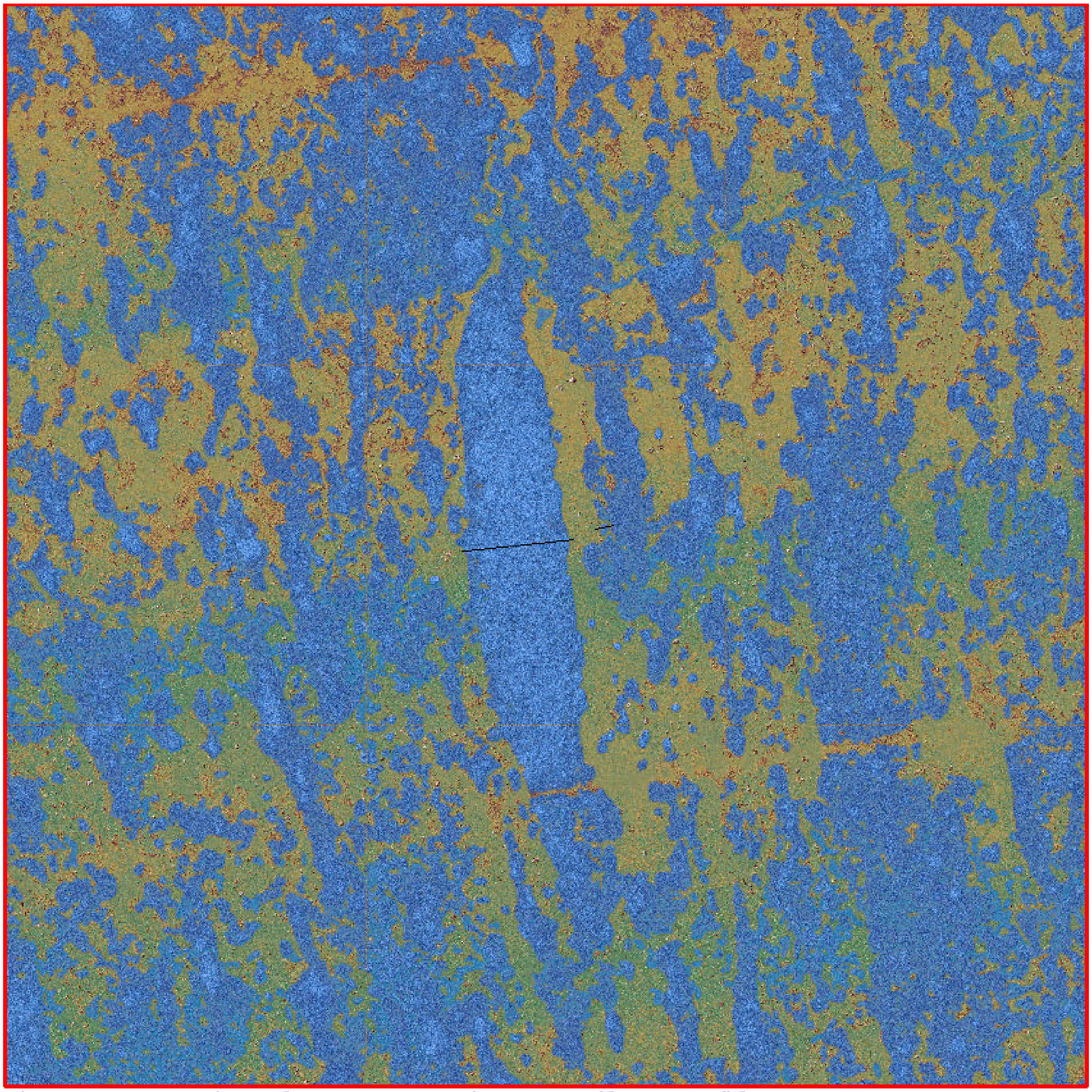


*Figure 19—Vegetation polygons representing areas of lower confidence*

## Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no lidar data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

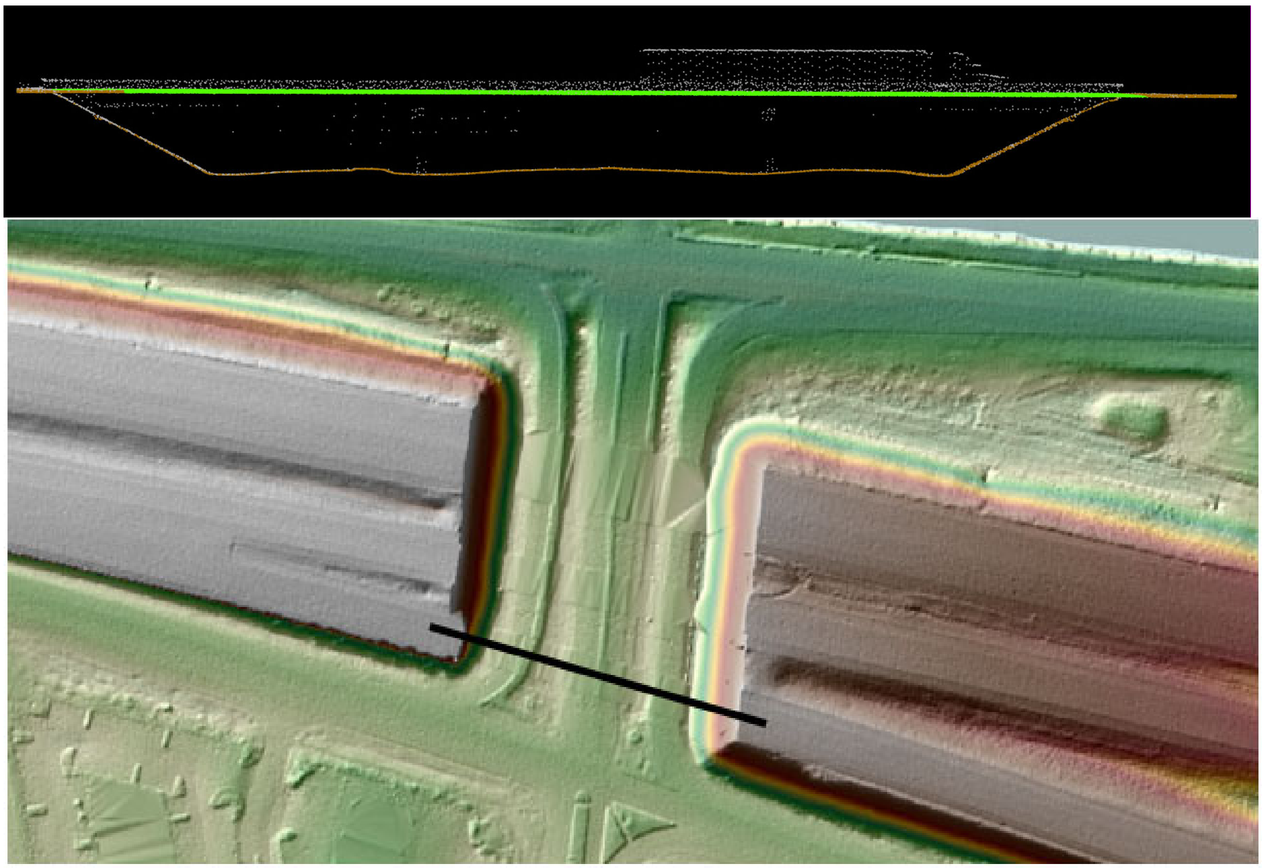


*Figure 20—Tile numbers e1570n0471 and e1570n0470. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view (taken at the location of the black line in the bottom view) shows the lidar points of this particular feature colored by class. All bridge points have been reclassified from ground (orange) or unclassified (gray) and are classified as bridge deck (green).*

## Culverts and Bridges

Bridges have been removed from the bare earth surface, while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts, especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

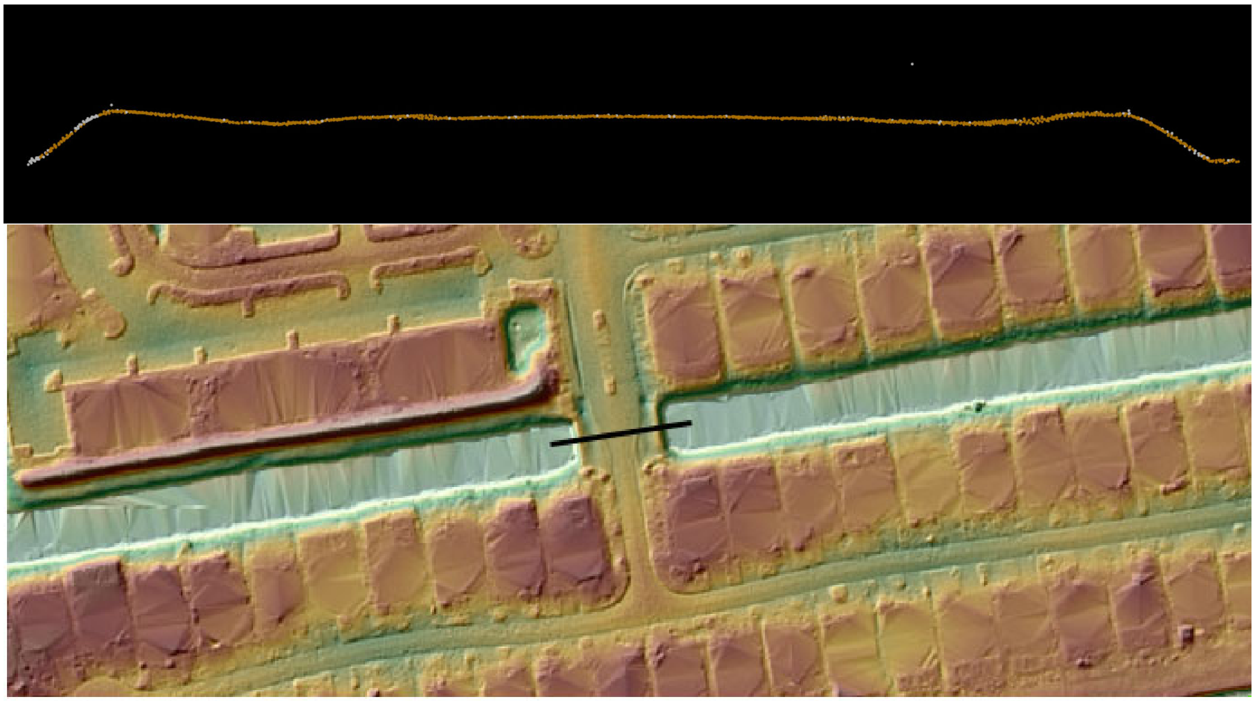


***Figure 21—Tile number e1575n0483. Profile (taken at the location of the black line in the bottom view) with points colored by class (class 1=gray, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been reclassified from the bare earth surface or unclassified to bride deck, class 17.***

## Hydrographic Structures including Dams and Impoundments

There are numerous dams, impoundments, and hydrographic structures within this dataset. When the presence of a hydrographic structure affects flow and acts as an impoundment, Dewberry classified the hydrographic structure to ground. When larger building-like structures were also present on or near the hydrographic structure, as shown it the provided example, the building-like structures were classified as class 1, unclassified. Many of the hydrographic structures in this dataset are located on narrower hydrographic features that may not meet minimum collection capture criteria. Due to the nature of the hydrographic structure and the narrow hydrographic feature, there is interpolation present in the DEMs at most of these features. An example is shown below.

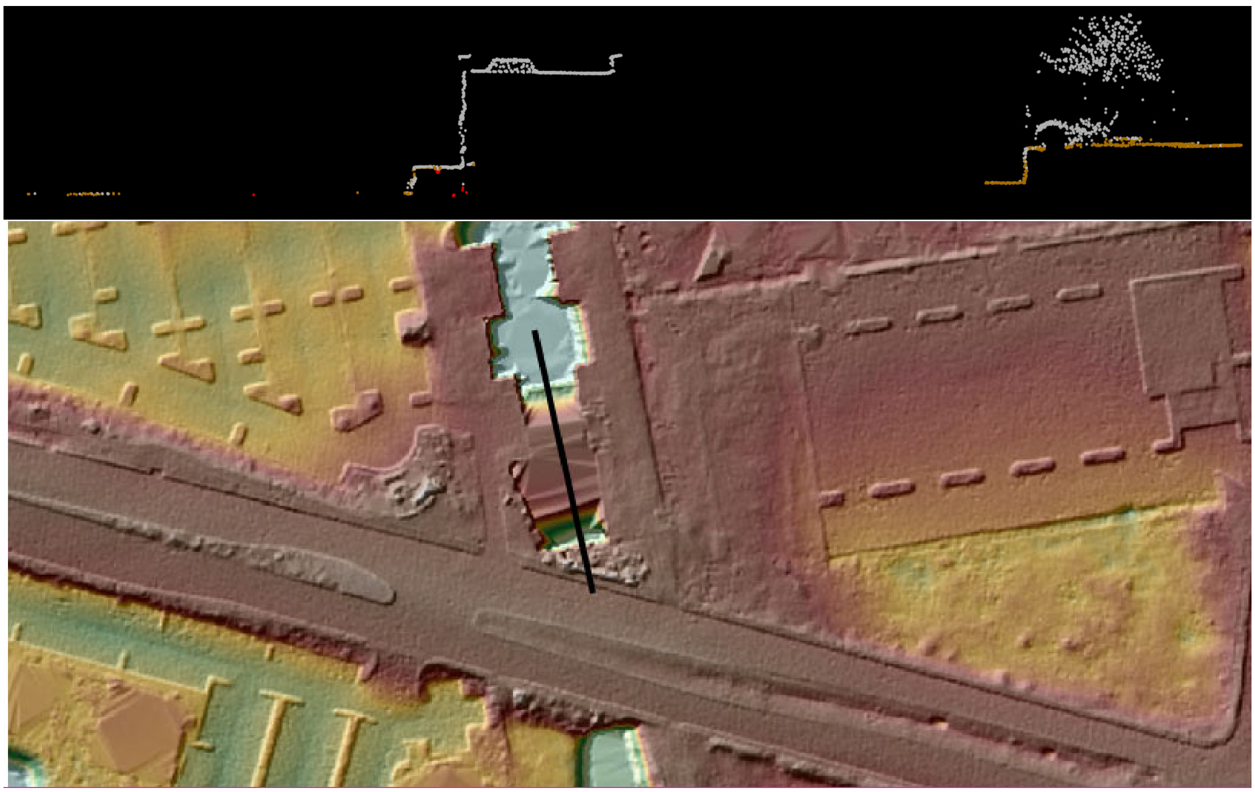


*Figure 22—Tile number e1580n0487. Profile (taken at the location of the black line in the bottom view) with points colored by class (class 1=gray, class 2=orange, class 7=red) is shown in the top view and the DEM is shown in the bottom view. The main hydrographic structure has been classified to class 2, ground, as it is causing a 0.6 m difference in water levels above and below the structure. The tall building-like structure has been classified to class 1, unclassified. This structure is located on hydrographic features too narrow for breakline collection. Interpolation is present in the DEM at this location, due to the building-like structure being classified as non-ground and no other "ground" points available to model the surface underneath. Figure 23 shows Esri basemap imagery at this same location.*

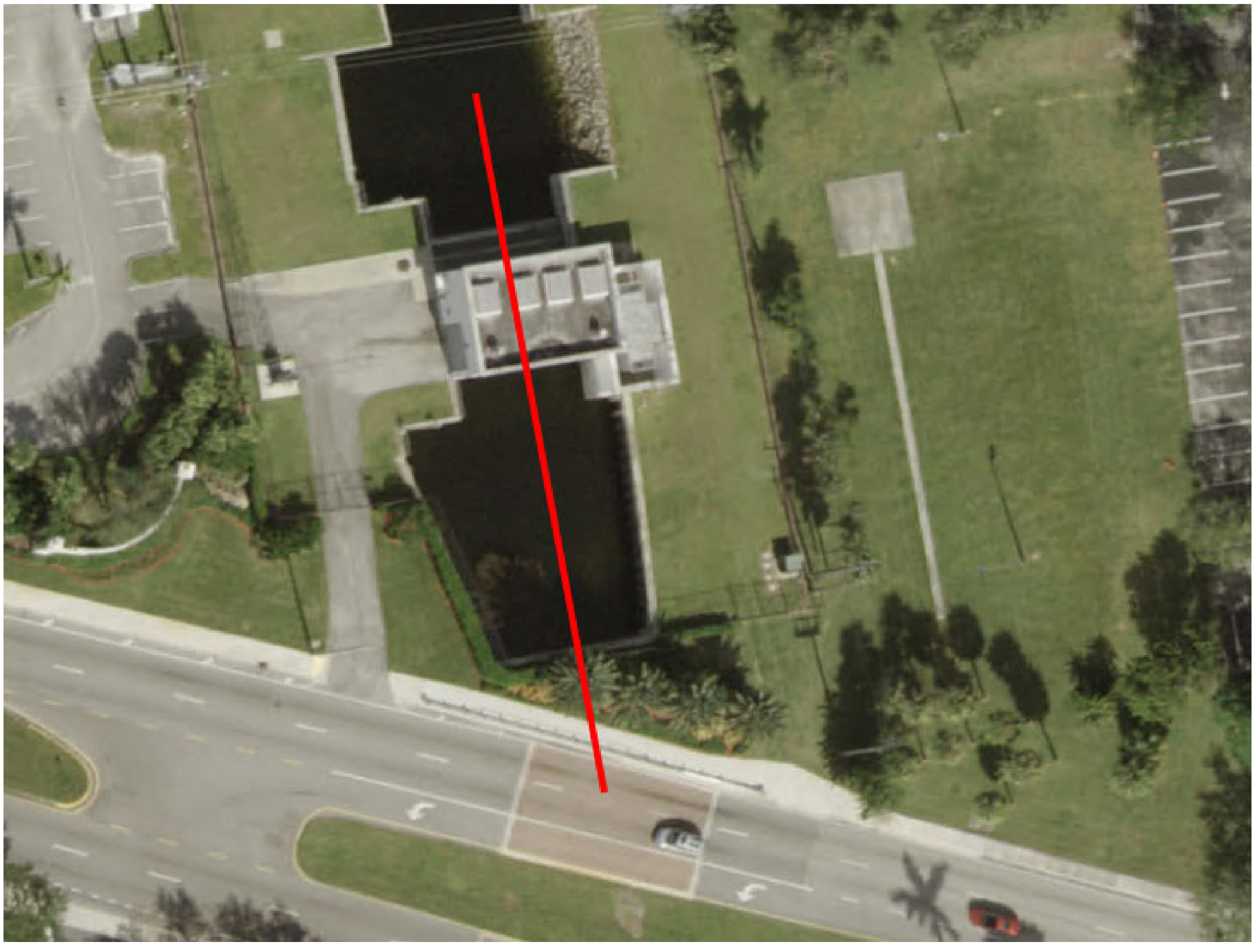


*Figure 23—Tile number e1580n0487. Esri basemap imagery of the same location shown in Figure 22. The profile in Figure 22 was taken at the location of the red line.*

## Dirt Mounds

Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are classified as ground.

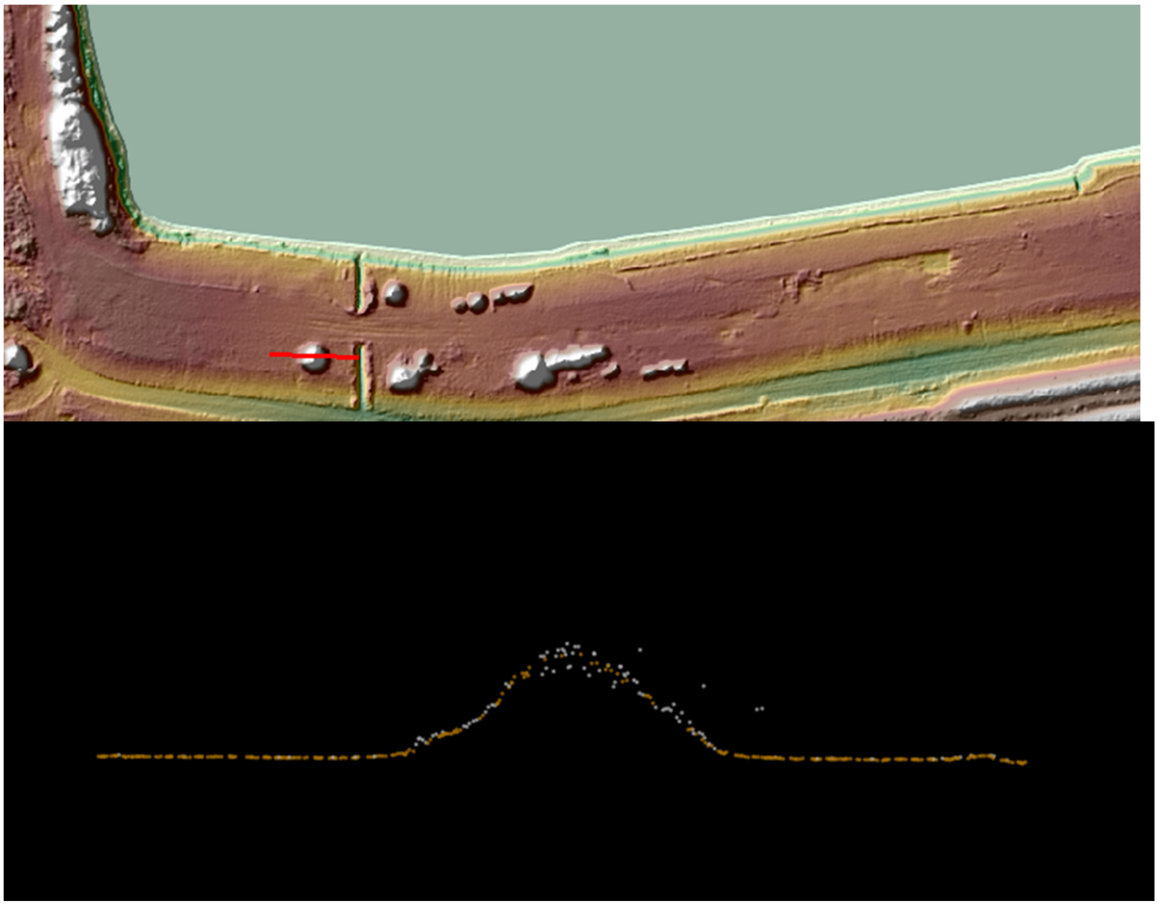


***Figure 24—Tile e1573n0494. Profile with the points colored by class (class 1=grey, class 2=brown) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are included in the ground classification.***

## Flight line Ridges

Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flight line ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

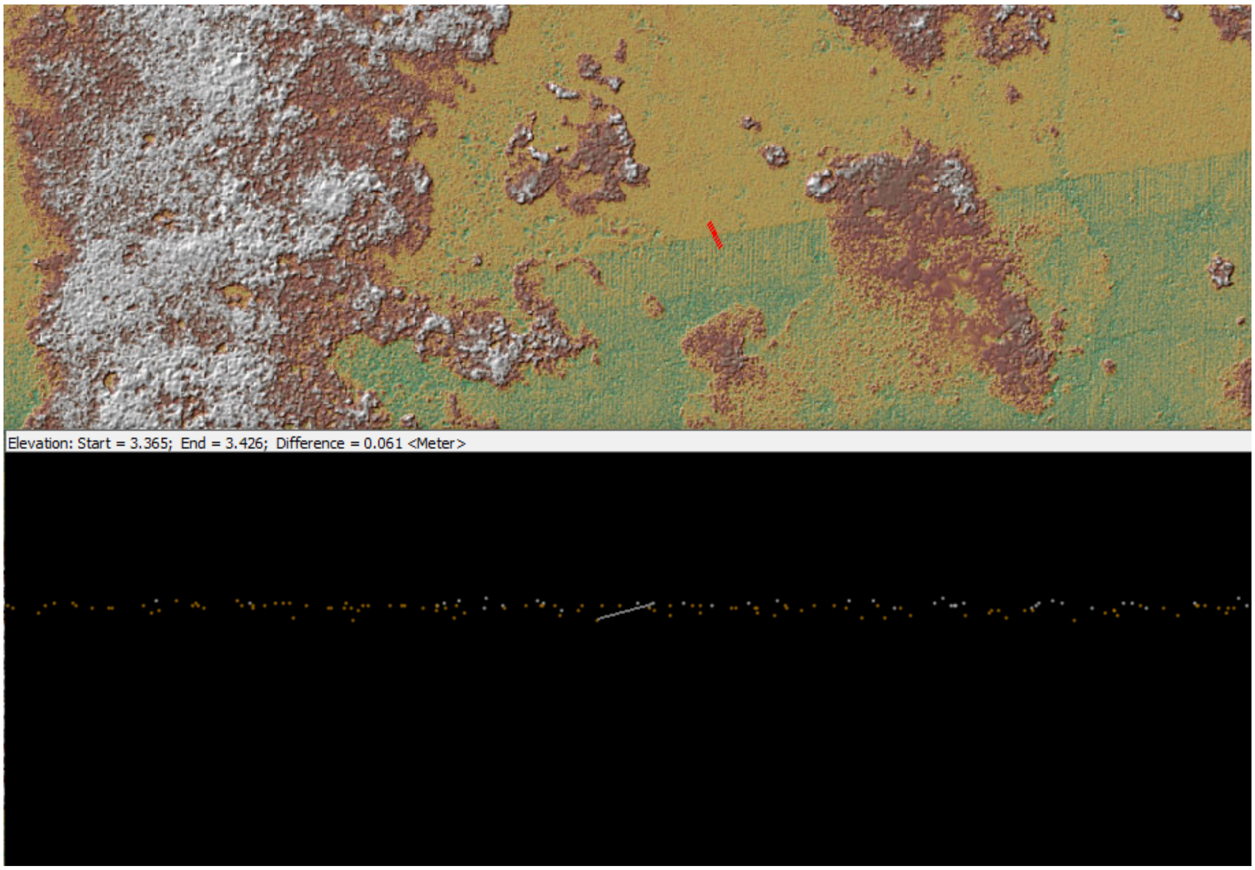



***Figure 25—Tile number e1563n0488. The flight line ridge is less than 10 cm. Overall, the Florida Southeast Lidar data meets the project specifications for 10 cm RMSE relative accuracy.***

## Temporal Changes

### Vertical Edge Matching

Delivery blocks 1 and 2 of this project were collected during two different acquisition windows. As a result, there are temporal differences in the water levels between blocks 1 and 2. All breaklines between blocks 1 and 2 could be horizontally edge-matched but not all could be vertically edge-matched. The vertical differences were generally 30 cm or less due to differing water levels. As block 1 data have already been delivered to and accepted by USGS, Dewberry did not change any block 1 breaklines. If the block 1 elevations were slightly lower than the block 2 elevations, Dewberry dropped the block 2 elevations to match the block 1 elevations, resulting in vertically edge-matched, monotonic, flat, non-floating hydrographic features. However, there were several instances where the block 1 breakline elevation were higher than the block 2 elevations. In these instances, Dewberry did not raise the block 2 breakline elevations as this would result in floating and, in some cases, non-monotonic hydrographic features. All locations where breaklines could not be vertically edge-matched due to temporal differences are identified in the shapefile named "FL_Southeast_Temporal_Change_Vertical_Edgematch", included in this delivery. Examples are shown below.

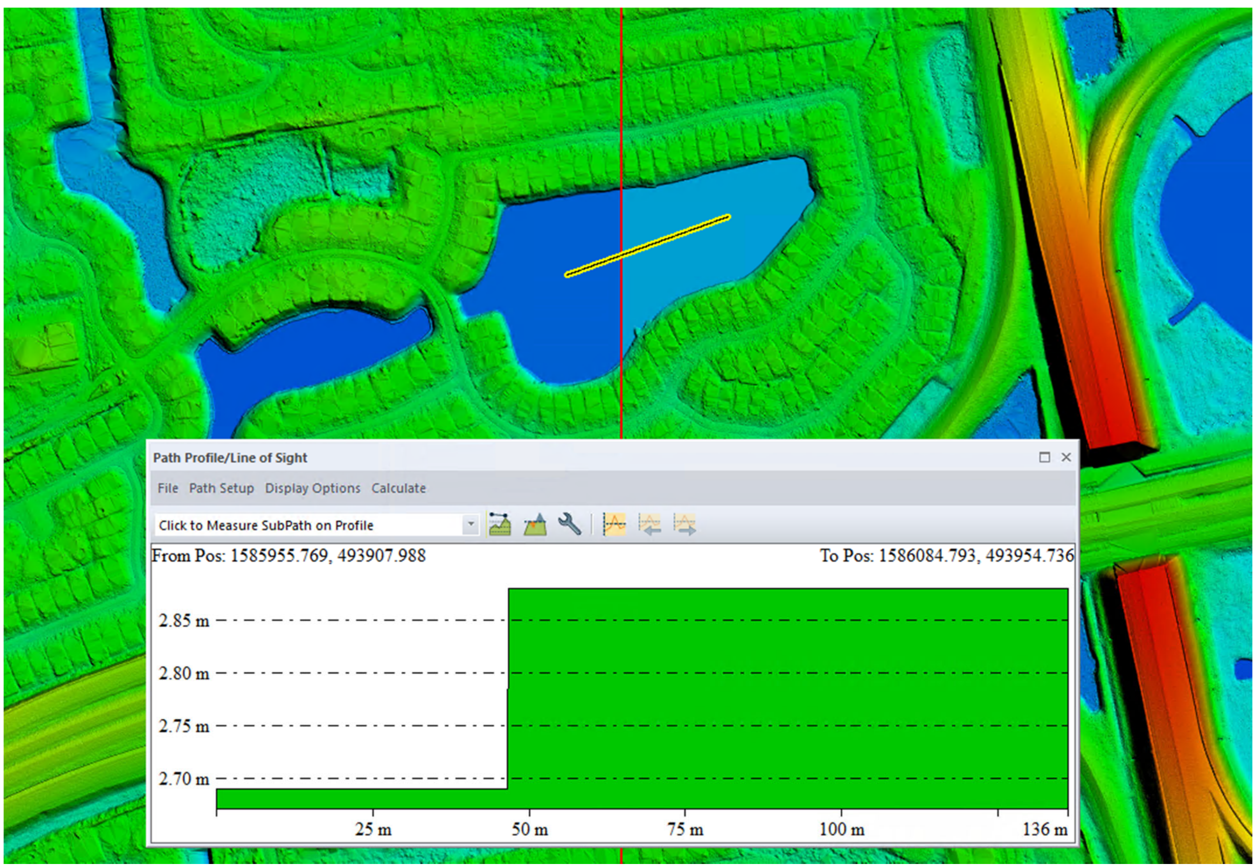



***Figure 26—Tile numbers e1585n0493 and e1586n0493. DEM with profile taken at the location of the yellow line. The Block 1/Block 2 boundary is shown as a red line. This waterbody is located in both blocks. However, Block 1 and Block 2 were acquired as part of different acquisitions and there are temporal differences in the water levels of each acquisition. In some locations, this temporal difference could not be mitigated and will be present in the DEM.***

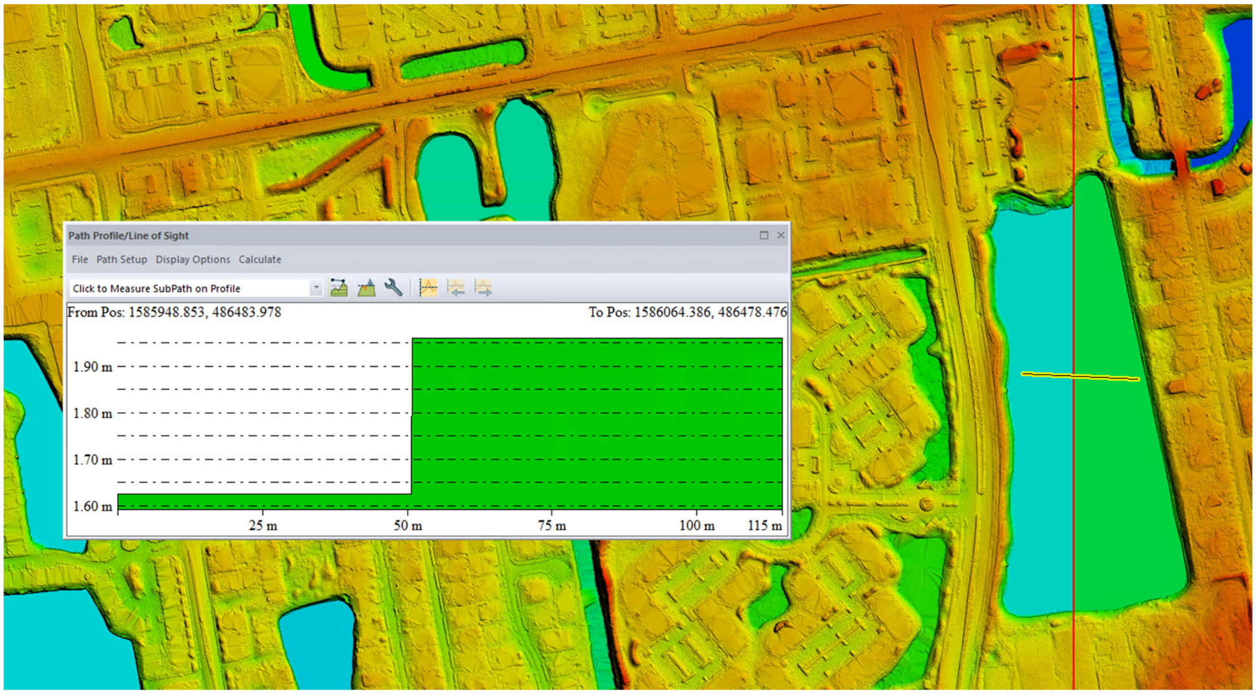



*Figure 27—Tile numbers e1585n0486 and e1586n0486. DEM, overlaid with profile taken at location of yellow line. The Block 1/Block 2 boundary is shown as the red line. This waterbody is located in both blocks. However, Block 1 and Block 2 were acquired as part of different acquisitions and there are temporal differences in the water levels of each acquisition. In some locations, this temporal difference could not be mitigated and will be present in the DEM.*

## Brush Fire

Dewberry noted a temporal issue with the LAS that is represented in the DZ Orthos Imagery, DEM and Intensity Imagery. We believe this temporal issue is due to a brush fire that occurred near Alligator Alley in South Florida on November 30, 2018. As a result of the brush fire, vegetation was burned away, causing a significant temporal change that is evident in the DZ Orthos, DEM, and Intensity Imagery.

Data for the flattened area encompassed by the polygon were acquired after the brush fire, on November 30, 2018 and December 12, 2018; data for the surrounding areas, where vegetation appears consistent, were acquired before the brush fire, on November 29, 2018.

All locations where the lack of vegetation caused temporal differences are identified in the shapefile named “FL_Southeast_Temporal_Change_Fire”, included in this delivery. Examples are shown below.

***Figure 28—Tiles e1531n0469, e1532n0469, e1533n0469, e1531n0470, e1532n0470, e1533n0470, e1534n0470, e1535n0470, e1532n0471, e1533n0471, e1534n0471, and e1535n0471. Lack of vegetation following a brush fire is causing the temporal differences depicted in the DZ Orthos.***

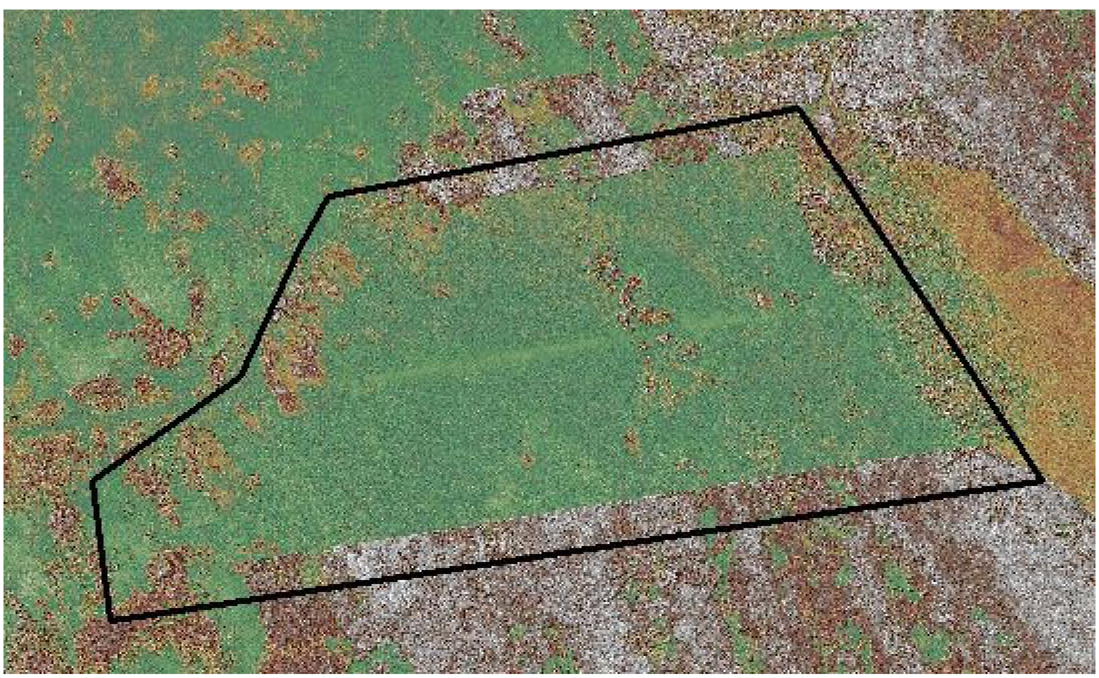


***Figure 29— Tiles e1531n0469, e1532n0469, e1533n0469, e1531n0470, e1532n0470, e1533n0470, e1534n0470, e1535n0470, e1532n0471, e1533n0471, e1534n0471, e1535n0471. Lack of vegetation following a brush fire is causing the temporal differences depicted in the DZ Orthos.***

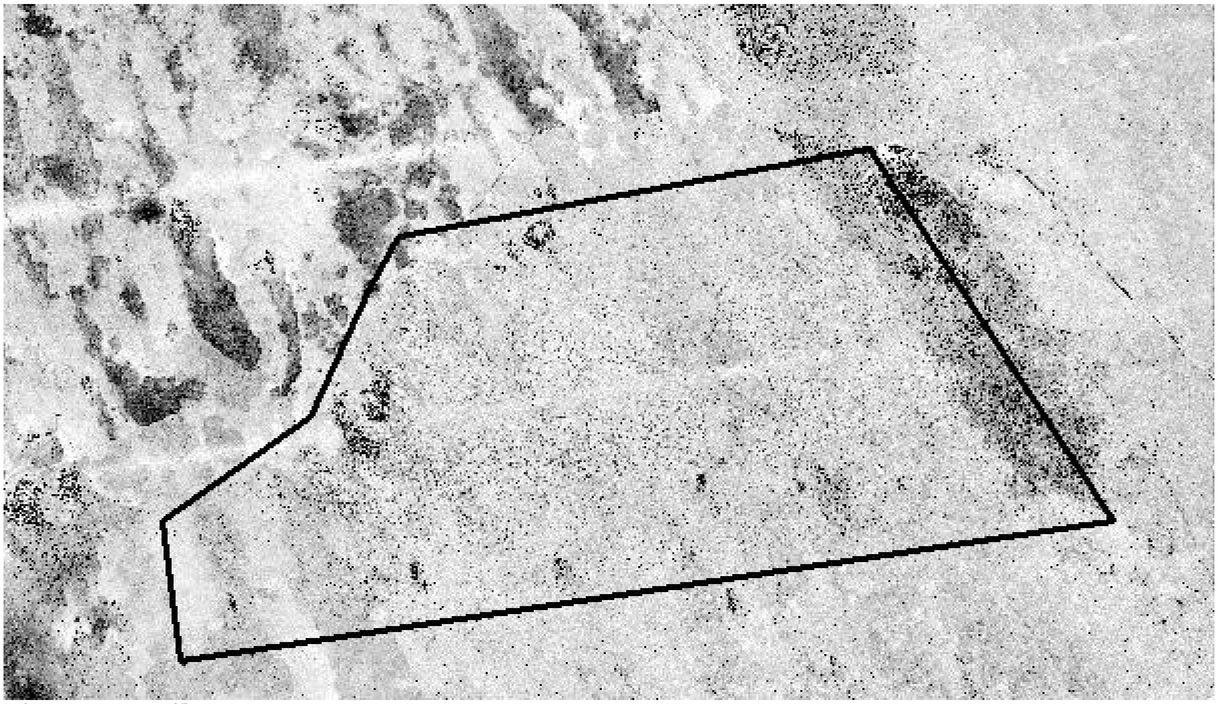


***Figure 30— Tiles e1531n0469, e1532n0469, e1533n0469, e1531n0470, e1532n0470, e1533n0470, e1534n0470, e1535n0470, e1532n0471, e1533n0471, e1534n0471, e1535n0471. Lack of vegetation following a brush fire is causing the temporal differences depicted in the intensity imagery.***

# Brush fire burns alongside Alligator Alley

Image Gallery

3 PHOTOS

By FOX 13 News staff

**Posted** Nov 30 2018 05:16PM EST
**Updated** Nov 30 2018 05:20PM EST

**By** FOX 13 News staff

**Posted** Nov 30 2018 05:16PM EST
**Updated** Nov 30 2018 05:20PM EST

**BIG CYPRESS, Fla. (FOX 13)** - A large brush fire in South Florida, burning just north of Alligator Alley, has consumed 800 acres so far.

The blaze is burning in west Broward County within sight of Interstate 75. The Florida Forest Service says the smoke could be an issue for drivers between mile markers 38 through 45.

According to WSVN-TV, firefighters plan to let the blaze burn itself out. No structures are currently being threatened.

*Figure 31—Image of news article from FOX 13.*

## 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.

| Classified Lidar Formatting | | |
|---|---|---|
| **Parameter** | **Requirement** | **Pass/Fail** |
| LAS Version | 1.4 | Pass |
| Point Data Format | LAS v1.4 | Pass |
| Coordinate Reference System | NAD 83 (2011) Contiguous U.S. Albers in WKT Format | Pass |
| Global Encoder Bit | Should be set to 17 for Adjusted GPS Time | Pass |
| Time Stamp | Adjusted GPS Time (unique timestamps) | Pass |
| System ID | Should be set to the processing system/software and is set to NIIRS10 for GeoCue software | 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:<br>Class 1: Unclassified<br>Class 2: Ground<br>Class 7: Low Noise<br>Class 9: Water<br>Class 17: Bridge Decks<br>Class 18: High Noise<br>Class 20: Ignored Ground | Pass |
| Overlap and Withheld Points | Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits. Overage points are flagged with the overlap bit for points in all classes except class 2. All ground (class 2) points are used in the final DEM generation. | Pass |
| Scan Angle | Recorded for each pulse | Pass |
| XYZ Coordinates | Unique Easting, Northing, and Elevation coordinates are recorded for each pulse | Pass |

*Table 5—Classified Lidar Formatting*

### Synthetic Points

Time of flight laser measurements have their maximum unambiguous range restricted by the maximum distance the laser can travel round-trip before the next laser pulse is emitted. One solution to this problem is to limit "valid" returns to a certain window between specified elevations, or a "range gate"; however, this technique can prevent some returns from being captured if there is terrain outside of the range gate. It can also cause some late returns to be georeferenced as part subsequent pulses.

The multiple time around (MTA) capabilities of Riegl sensors enable the recording of lidar returns any distance from the laser (within detection capabilities) without forcing range gate restrictions. However, there is still a possibility that a late return will occur simultaneously with a pulse emission. The backscatter energy from the laser optics and the atmosphere directly below the aircraft during this event can effectively blind the sensor, making it unable to discern information about the laser return. Because this occurs more consistently with later returns, this blind zone is typically found in a narrow band along the edges of the sensor's range. The result is a predictable geometry of voids (typically within project specifications) in the point cloud.

During post-processing of the lidar data, Riegl software interpolates coordinates within the blind zones between last returns on each side of the gap. These are flagged as "synthetic" points and are assigned a valid time stamp, though they do not have any waveform data or pulse width information. Amplitude and reflectance are averaged from surrounding points. The assignment of synthetic points does not change the original raw point cloud data.

This dataset contains flagged synthetic points. The images below show an example (from a different dataset) of synthetic points applied to the ground class of the lidar point cloud.

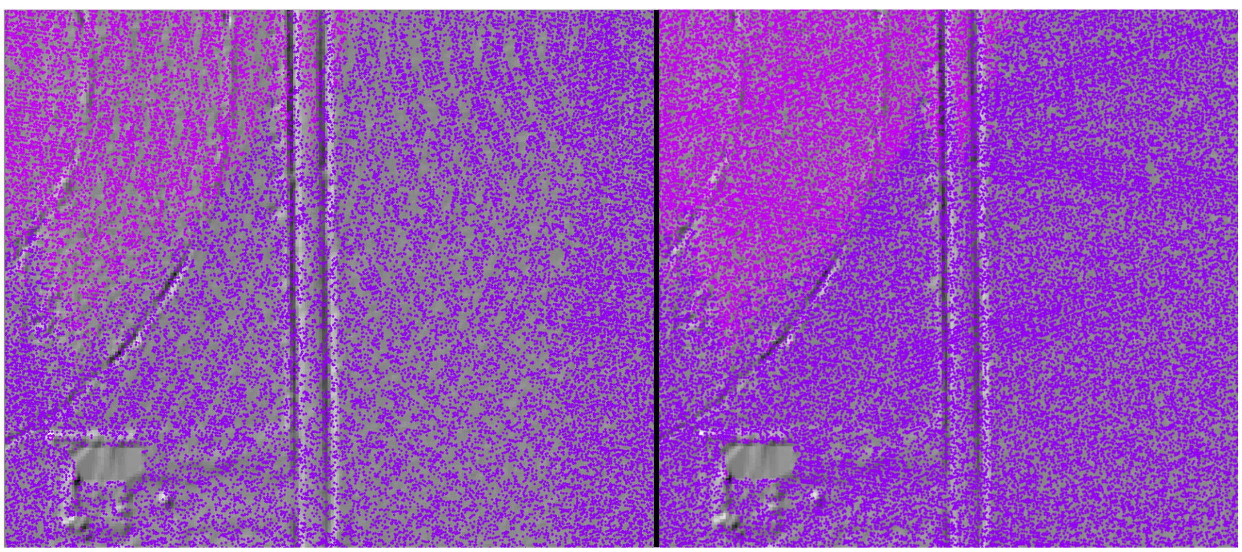


*Figure 32 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area*

# Lidar Positional Accuracy

## BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each 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.

## SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred twenty-five (125) checkpoints were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Appendix A details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

| Point ID | NAD 83 (2011) Contiguous U.S. Albers | | NAVD88 (Geoid 12B) |
|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Elevation (m) |
| NVA1 | 1501563.013 | 430630.758 | 2.380 |
| NVA2 | 1521096.532 | 422436.772 | 2.590 |
| NVA3 | 1509771.774 | 420449.119 | 2.310 |
| NVA4 | 1532692.033 | 424372.795 | 4.020 |

| Point ID | NAD 83 (2011) Contiguous U.S. Albers | | NAVD88 (Geoid 12B) |
|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Elevation (m) |
| NVA5 | 1543556.973 | 426161.696 | 3.940 |
| NVA6 | 1526026.187 | 447155.683 | 5.140 |
| NVA7 | 1519738.598 | 434131.802 | 3.200 |
| NVA8 | 1524745.549 | 448745.143 | 2.450 |
| NVA9 | 1523357.433 | 467816.163 | 5.040 |
| NVA10 | 1543350.480 | 468720.245 | 4.220 |
| NVA11 | 1508757.976 | 465981.685 | 5.500 |
| NVA12 | 1518259.943 | 480958.078 | 4.370 |
| NVA13 | 1574418.150 | 475201.214 | 2.160 |
| NVA14 | 1539718.050 | 489082.192 | 4.290 |
| NVA15 | 1534622.408 | 467726.188 | 3.820 |
| NVA16 | 1523286.621 | 459704.669 | 3.960 |
| NVA17 | 1524634.331 | 428410.696 | 2.790 |
| NVA18 | 1519178.736 | 432374.144 | 3.220 |
| NVA19 | 1516866.433 | 466702.977 | 4.470 |
| NVA20 | 1515226.107 | 484922.503 | 6.960 |
| NVA21 | 1536638.268 | 425012.511 | 3.860 |
| NVA22 | 1540735.476 | 425713.094 | 3.350 |
| NVA23 | 1508427.601 | 431054.804 | 2.790 |
| NVA24 | 1520691.575 | 434281.343 | 3.190 |
| NVA25 | 1519303.360 | 431593.190 | 2.880 |
| NVA26 | 1587031.007 | 479592.127 | 1.640 |
| NVA27 | 1521410.778 | 478833.506 | 3.120 |
| NVA28 | 1515285.520 | 480134.691 | 4.480 |
| NVA29 | 1520547.584 | 467749.226 | 8.990 |
| NVA30 | 1522041.320 | 486182.698 | 3.990 |
| NVA31 | 1518585.321 | 483963.814 | 3.450 |
| NVA32 | 1533427.885 | 488054.322 | 4.870 |
| NVA34 | 1553292.633 | 486792.161 | 4.290 |
| NVA35 | 1558677.106 | 481203.912 | 4.800 |
| NVA36 | 1561969.034 | 472433.649 | 3.970 |
| NVA37 | 1564421.997 | 463435.950 | 3.410 |
| NVA38 | 1566508.678 | 452400.647 | 2.900 |
| NVA39 | 1569830.410 | 471094.936 | 2.770 |
| NVA40 | 1578165.999 | 456182.357 | 2.280 |
| NVA41 | 1571208.831 | 458148.504 | 1.630 |
| NVA43 | 1592837.581 | 458174.832 | 1.620 |
| NVA44 | 1596633.027 | 467675.717 | 1.010 |

| Point ID | NAD 83 (2011) Contiguous U.S. Albers | | NAVD88 (Geoid 12B) |
|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Elevation (m) |
| NVA45 | 1590693.877 | 464126.047 | 1.080 |
| NVA46 | 1596949.406 | 462636.637 | 0.200 |
| NVA47 | 1575238.407 | 462732.087 | 1.580 |
| NVA48 | 1582368.347 | 467316.790 | 1.780 |
| NVA49 | 1589619.027 | 469878.439 | 1.540 |
| NVA50 | 1594878.398 | 496068.525 | 1.230 |
| NVA51 | 1573294.493 | 494676.298 | 3.200 |
| NVA52 | 1594362.127 | 488134.091 | 2.400 |
| NVA53 | 1595687.761 | 480495.651 | 1.960 |
| NVA54 | 1584784.531 | 492888.172 | 4.140 |
| NVA55 | 1580582.858 | 475402.131 | 1.900 |
| NVA56 | 1579295.047 | 485378.055 | 3.550 |
| NVA57 | 1587100.009 | 483115.698 | 3.230 |
| NVA58 | 1555482.224 | 451265.090 | 5.190 |
| NVA59 | 1561261.455 | 466902.666 | 3.130 |
| NVA60 | 1573961.959 | 489661.208 | 5.810 |
| NVA61 | 1575586.086 | 478933.617 | 6.180 |
| NVA62 | 1569234.954 | 481638.433 | 5.320 |
| NVA63 | 1561145.961 | 475311.955 | 4.980 |
| NVA64 | 1549303.285 | 469905.984 | 3.410 |
| NVA65 | 1559644.191 | 471496.353 | 4.890 |
| NVA66 | 1565571.970 | 457092.839 | 2.790 |
| NVA67 | 1590890.431 | 475950.395 | 1.660 |
| NVA68 | 1580554.907 | 482052.438 | 3.120 |
| NVA69 | 1581791.437 | 490761.542 | 3.950 |
| NVA70 | 1578932.063 | 496276.747 | 4.250 |
| NVA71 | 1572496.227 | 497040.132 | 5.310 |
| VVA1 | 1525307.724 | 448610.422 | 3.120 |
| VVA2 | 1518984.736 | 464402.291 | 2.920 |
| VVA3 | 1521073.363 | 461900.839 | 3.940 |
| VVA4 | 1516869.248 | 466417.715 | 3.160 |
| VVA5 | 1525597.365 | 460042.825 | 3.890 |
| VVA6 | 1524006.059 | 464859.655 | 2.600 |
| VVA7 | 1537449.395 | 467957.169 | 3.950 |
| VVA8 | 1507584.598 | 465744.849 | 3.850 |
| VVA9 | 1519017.356 | 433237.636 | 2.160 |
| VVA10 | 1502838.266 | 430752.000 | 1.690 |
| VVA11 | 1519278.188 | 431562.035 | 2.370 |

| Point ID | NAD 83 (2011) Contiguous U.S. Albers | | NAVD88 (Geoid 12B) |
|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Elevation (m) |
| VVA12 | 1523534.199 | 429195.497 | 2.170 |
| VVA13 | 1532125.411 | 487710.438 | 2.910 |
| VVA14 | 1500011.385 | 431266.171 | 1.620 |
| VVA15 | 1501687.898 | 430639.696 | 1.880 |
| VVA16 | 1504151.634 | 430810.767 | 1.800 |
| VVA17 | 1506646.310 | 430936.329 | 1.840 |
| VVA18 | 1507595.597 | 430978.325 | 1.850 |
| VVA20 | 1513974.030 | 421128.990 | 2.040 |
| VVA21 | 1525697.461 | 423183.584 | 2.430 |
| VVA22 | 1533475.472 | 424365.111 | 2.940 |
| VVA23 | 1531484.890 | 424208.451 | 3.250 |
| VVA24 | 1538078.812 | 425204.838 | 2.820 |
| VVA25 | 1542793.502 | 425938.066 | 2.940 |
| VVA26 | 1558832.908 | 455527.591 | 3.040 |
| VVA27 | 1563578.229 | 462408.339 | 2.150 |
| VVA28 | 1566277.093 | 454098.782 | 1.580 |
| VVA29 | 1578607.353 | 458475.284 | 1.290 |
| VVA30 | 1570288.017 | 454674.542 | 0.340 |
| VVA31 | 1527870.524 | 486942.284 | 3.030 |
| VVA32 | 1515032.197 | 485996.191 | 5.570 |

*Table 6—Florida Southeast Lidar Project surveyed accuracy checkpoints*

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

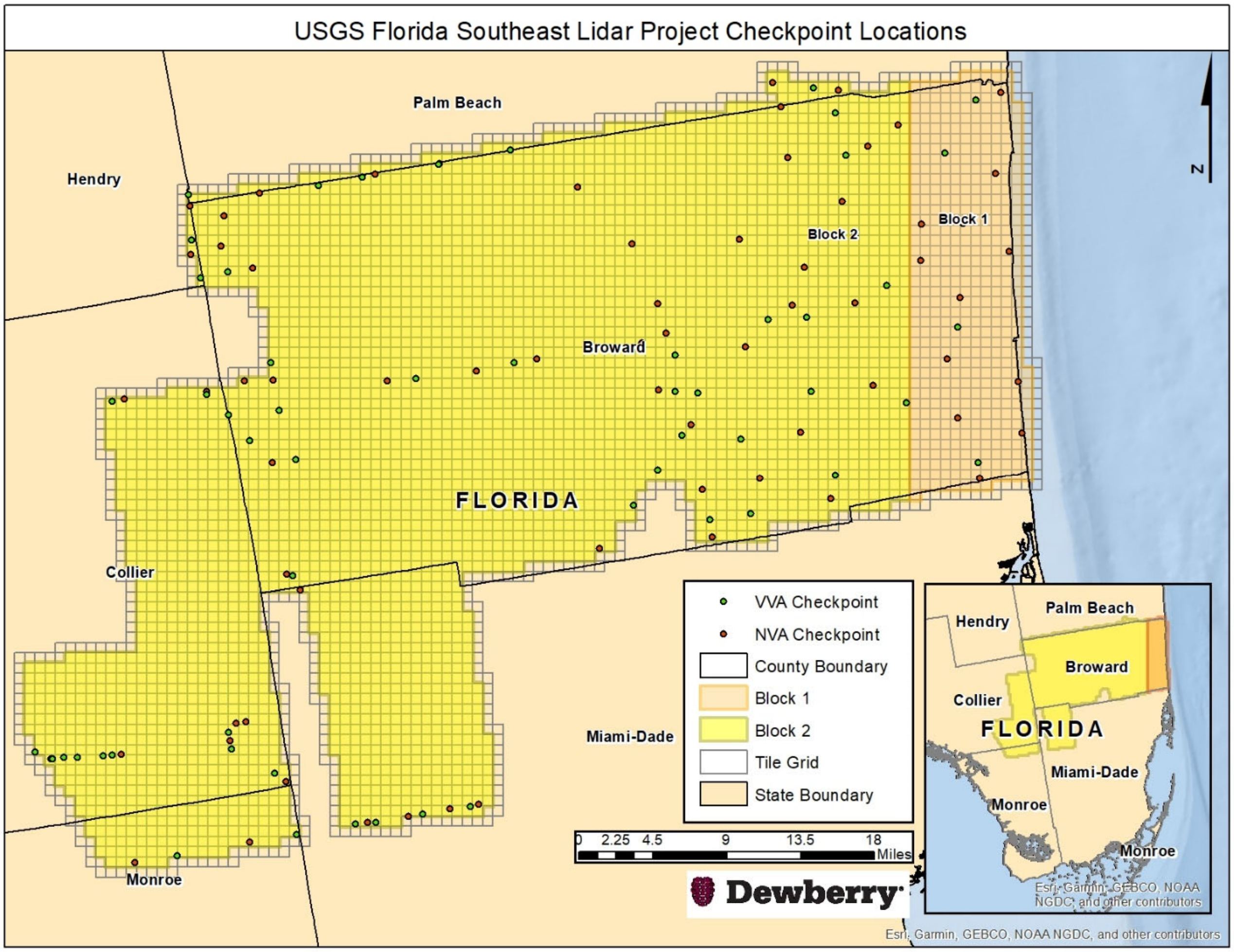



*Figure 33—Location of QA/QC Checkpoints*

## VERTICAL ACCURACY TEST PROCEDURES

**NVA** (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With 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 Florida Southeast lidar project, vertical accuracy must be 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

**VVA** (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where 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 $95^{th}$ percentile error for all checkpoints in all vegetated land cover categories combined. The Florida Southeast Lidar Project VVA standard is 30.0 cm based on the $95^{th}$ percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the $95^{th}$ percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 7.

| Quantitative Criteria | Measure of Acceptability |
|---|---|
| Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600 | 19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600) |
| Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level | 30.0 cm (based on combined 95$^{th}$ percentile) |

*Table 7—Acceptance Criteria*

The primary QA/QC vertical 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.
2. Next, Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

## VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

| Land Cover Category | # of Points | NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm | VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=30.0 cm |
|---|---|---|---|
| NVA | 69 | 8.0 | |
| VVA | 56 | | 21.3 |

*Table 8—Tested NVA and VVA*

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 $RMSE_z$ = 4.1 cm, equating to ± 8.0 cm at 95% confidence level. Actual VVA accuracy was found to be ± 21.3 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within ± 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +70 cm.

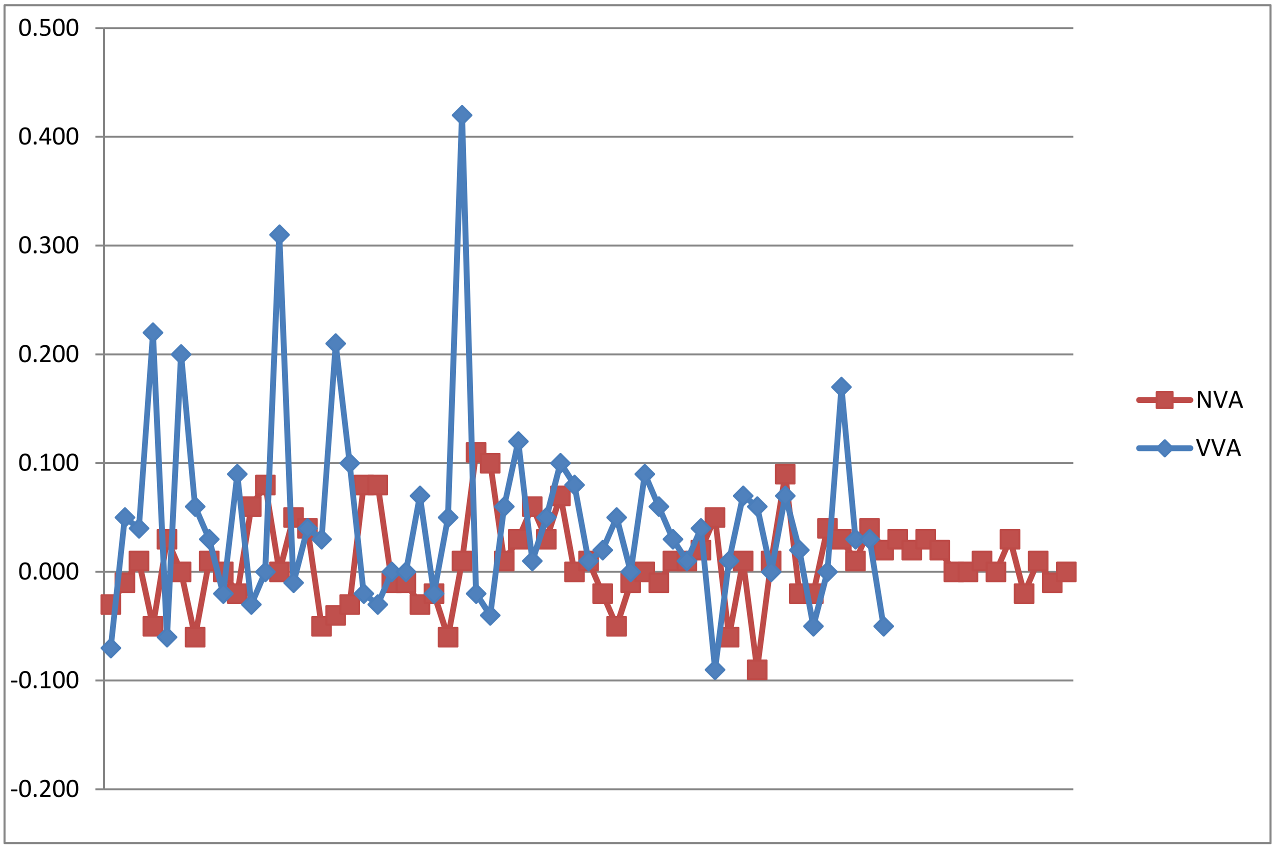



*Figure 34—Magnitude of elevation discrepancies per land cover category*

Table 9 lists the 5% outliers that are larger than the VVA 95th percentile.

| Point ID | NAD83 (2011), Albers Equal Area | | NAVD88 (Geoid 12B) | Lidar Z (m) | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Survey Z (m) | | | |
| VVA 4 | 1516869.250 | 466417.720 | 3.160 | 3.380 | 0.220 | 0.220 |
| VVA 13 | 1532125.410 | 487710.440 | 2.910 | 3.220 | 0.310 | 0.310 |
| VVA 27 | 1563578.230 | 462408.340 | 2.150 | 2.570 | 0.420 | 0.420 |

*Table 9—5% Outliers*

Table 10 provides overall descriptive statistics.

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Kurtosis | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|---|---|
| Open Terrain | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Urban | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **NVA** | **69** | **0.041** | **0.009** | **0.010** | **0.256** | **0.040** | **0.322** | **-0.090** | **0.110** |
| Tall Weeds and Crops | 0 | N/A | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brush Lands and Trees | 0 | N/A | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Forested and Fully Grown | 0 | N/A | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **VVA** | **56** | **N/A** | **0.046** | **0.030** | **1.950** | **0.090** | **5.399** | **-0.090** | **0.420** |

***Table 10—Overall Descriptive Statistics***

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.09 meters and a high of +0.42 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the range of -0.025 meters to +0.025 meters.

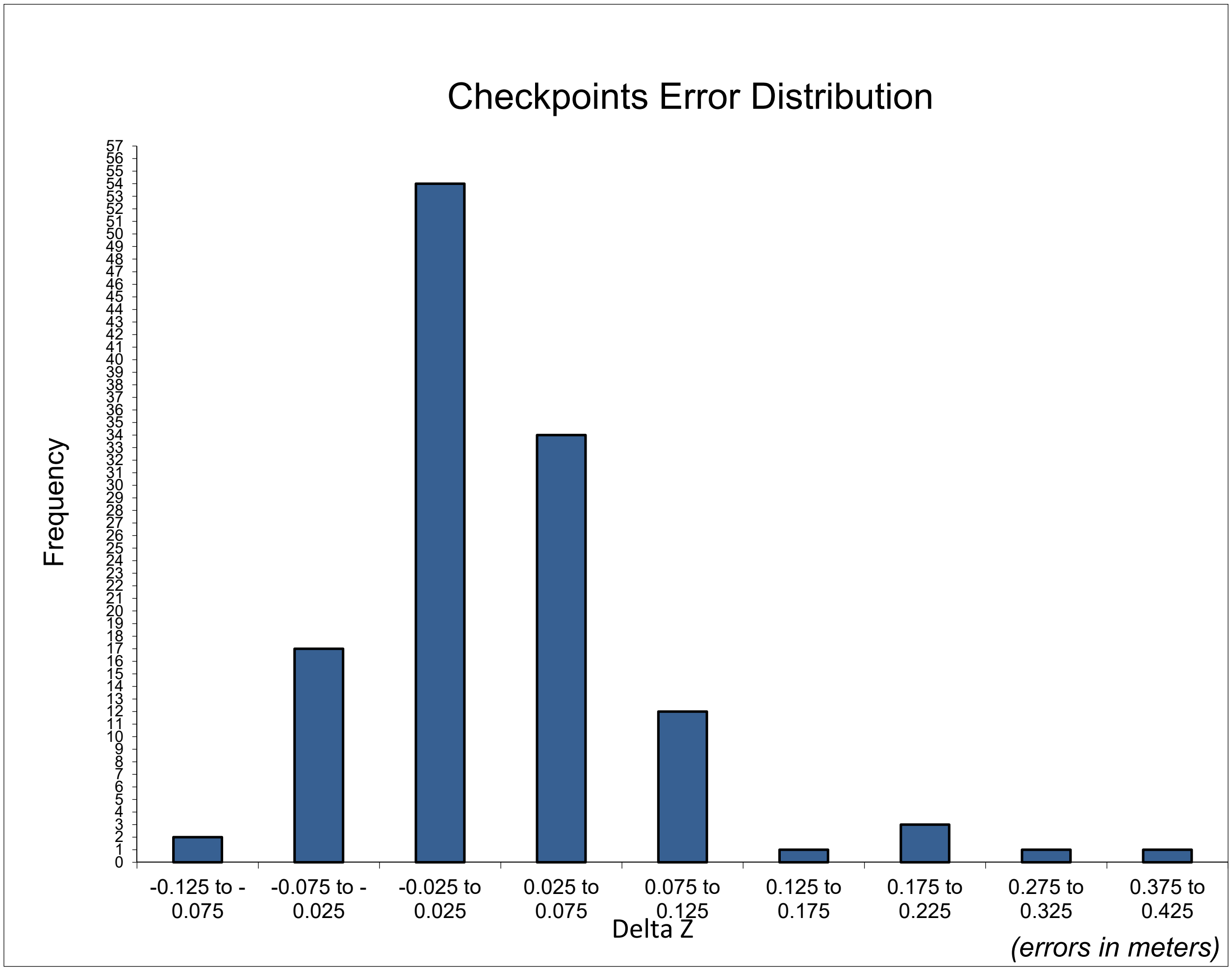



*Figure 35—Histogram of Elevation Discrepancies with errors in meters*

**Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Florida Southeast Lidar Project satisfies the project's pre-defined vertical accuracy criteria.**

## HORIZONTAL ACCURACY TEST PROCEDURES

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.

## HORIZONTAL ACCURACY RESULTS

Five 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 five (5) 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.

| # of Points | $RMSE_x$ (Spec = 40.9 cm) | $RMSE_y$ (Spec = 40.9 cm) | $RMSE_r$ (Spec = 57.8 cm) | $ACCURACY_r$ ($RMSE_r$ x 1.7308) Spec = 100 cm |
|---|---|---|---|---|
| 5 | 20.2 | 20.7 | 28.9 | 50.0 |

*Table 11—Tested horizontal accuracy at the 95% confidence level*

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. Five (5) 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 = 20.2 cm and RMSEy = 20.7 cm which equates to ± 50.0 cm at 95% confidence level. While not statistically significant, the results of the small sample set of checkpoints are within the designated horizontal accuracy.

# Breakline Production & Qualitative Assessment Report

## BREAKLINE PRODUCTION METHODOLOGY

Dewberry used a combination of lidargrammetry and automated techniques to collect breaklines for this project. The delineation of lakes and ponds and tidal waters, or other water bodies at a constant elevation, was achieved using eCognition software. Dewberry produced full point cloud intensity imagery, bare earth ground models, density models, and slope models. These files were ingested into eCognition, segmented into polygons, and training samples were created to identify water. eCognition used the training samples and defined parameters to identify water segments throughout the project area. Water segments were then reviewed for completeness. Segments identified as lakes and ponds or tidal waters were merged and smoothed. 3D elevations were then applied to the breakline features. Lidargrammetry was used to monotonically collect streams and rivers, or features that have gradient 3D elevations. Dewberry used GeoCue software to develop lidar stereo models of the project area so the lidar derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using lidargrammetry procedures with lidar intensity imagery, Dewberry used the stereo models to stereo-compile the streams and rivers in accordance with the project's Data Dictionary. Kinetics used LP360 and intensity imagery to collect the Lakes and Ponds and Rivers and Streams for a portion of the project, in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

Based on the discussion held with USGS on March 25, 2019, Dewberry has developed a modified version of the breakline collection process to better show where open water is located even when the banks of these feature may not be well defined. These features were collected through the use of an automated process that is defined later in this section. The intent was to provide additional detail of these small interconnected features that would not have otherwise been collected. Figure 36 shows and example of such a region where the interconnected nature of these open water features results in an area that is larger than 2 acres but is made up of very narrow channels and smaller pools of open water.

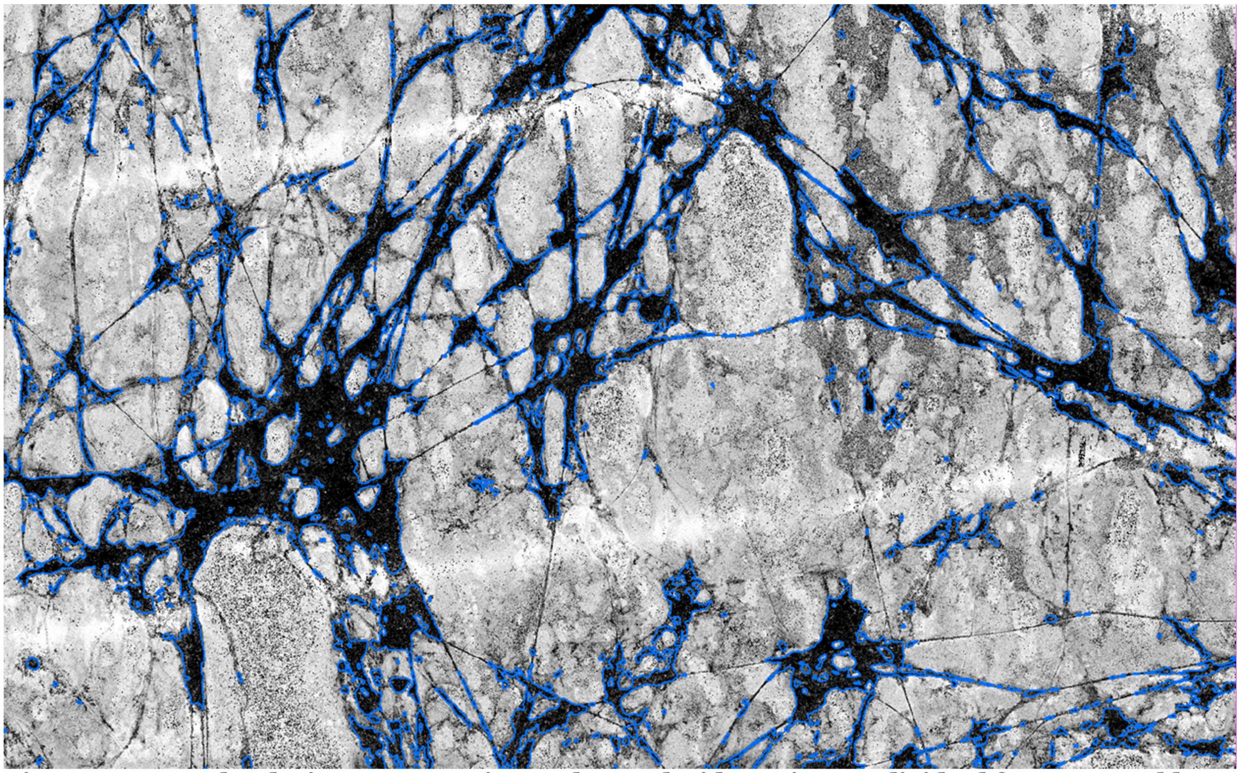


***Figure 36—Complex drainage pattern in Southeast Florida project. Individual features would normally not have been collected due to the transient nature of these features (no well-defined edges).***

It was determined during the discussion that it would not be beneficial to attempt to flatten these types of features as the DEM would not be improved. As a result Dewberry only performed flattening on the more perennial features and supplied an additional layer showing where intermittent/transient features are located. No additional editing has been done to these features other than simple smoothing through eCognition. Figure 37 shows what the product would have looked like if flattened and highlights some of the data that would be missing (smaller visible channels visible on the left image) if the entire extent of shallow water was flattened.

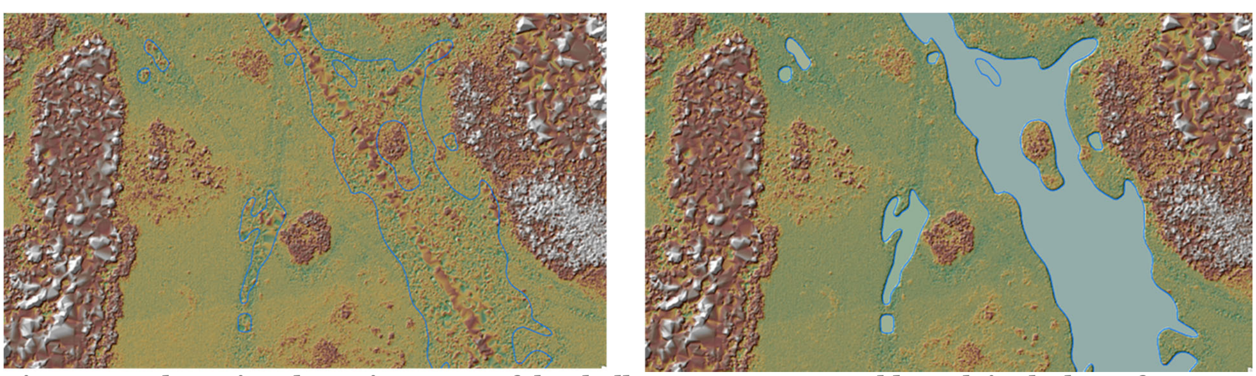


***Figure 37—Flattening the entire extent of the shallow open water would result in the loss of valuable information in the DEM such as the smaller narrow channels that likely carry water during lower levels.***

Trimble eCognition software was used to segment and classify water bodies based on the lidar data. Image segmentation is the process of dividing an image into image segments, or objects, which ideally represent features of interest. The eCognition segmentation algorithms have parameters that the analyst can set to define which rasters are used for segmentation and which affect the size and shape of the resulting image objects. These image objects can then be classified into thematic classes using supervised classification algorithms, a rule set-based classification built by an analyst, or a combination of these.

Initially, the following rasters were derived from the lidar .las files:

- DEM
- DSM
- Ground Density
- Intensity

These data were mosaicked into processing areas for input into the Trimble eCognition software. The following additional rasters were created from the lidar-derived datasets using tools in ArcGIS:

- Normalized DSM (nDSM)—created by subtracting the DEM from the DSM
- Slope—created from the DEM
- Curvature—created from the DEM

These seven raster datasets were input into eCognition. A boundary shapefile of the las tiles for each mosaic processing area was also included as an input to constrain the analysis. Each processing area was processed in eCognition using the following steps.

1. Initial Segmentation: the first segmentation process recreated the shapefile boundary. Further analysis was done only within this boundary object (i.e. areas outside of the boundary but still within the raster extents were not processed after this step, see Figure 38).

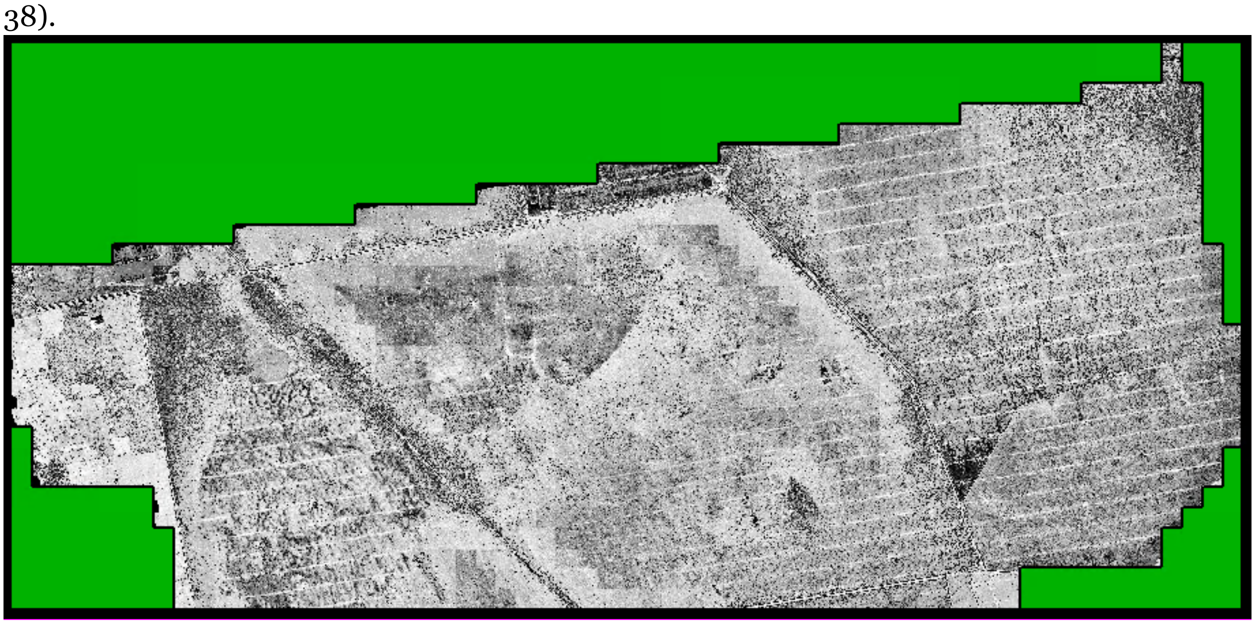


*Figure 38—Shapefile boundary as an image object in eCognition (lidar intensity is displayed). The green area represents the regions that are within the raster extents but outside of the lidar analysis area of interest.*

2. Primary Segmentation: the next segmentation process created the image objects that were to be used to extract water bodies from the data (Figure 39).

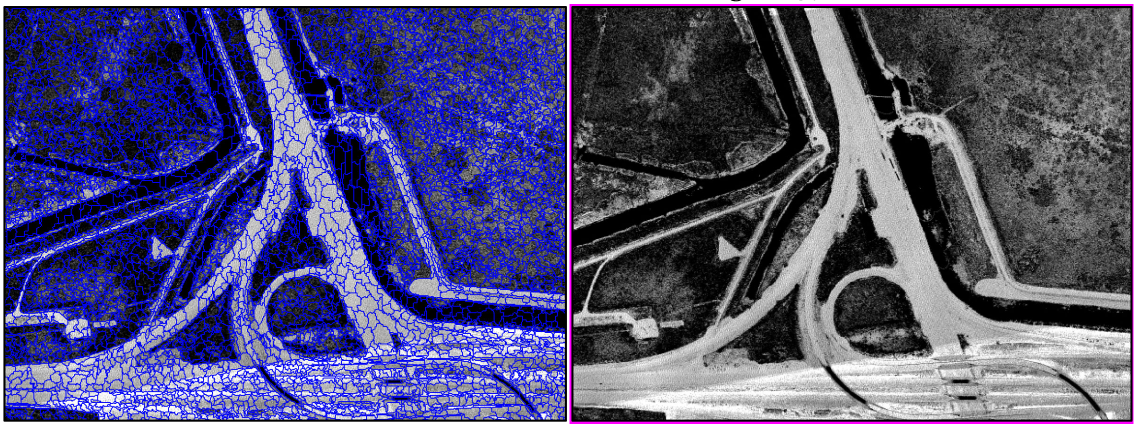


*Figure 39—eCognition image objects (left) and lidar ground density raster (right).*

3. Classification: the image objects were classified as either 'Water' or 'Ground' using a decision tree classifier. First, training objects for each class were chosen throughout the analysis area. Large groups of each class were chosen in easily identifiable areas. These training sites were input into the classifier along with a set of 25 independent variables in order to train the classifier. The classification rules created by the classifier were then used to classify all of the image objects in the analysis area (Figure 40).

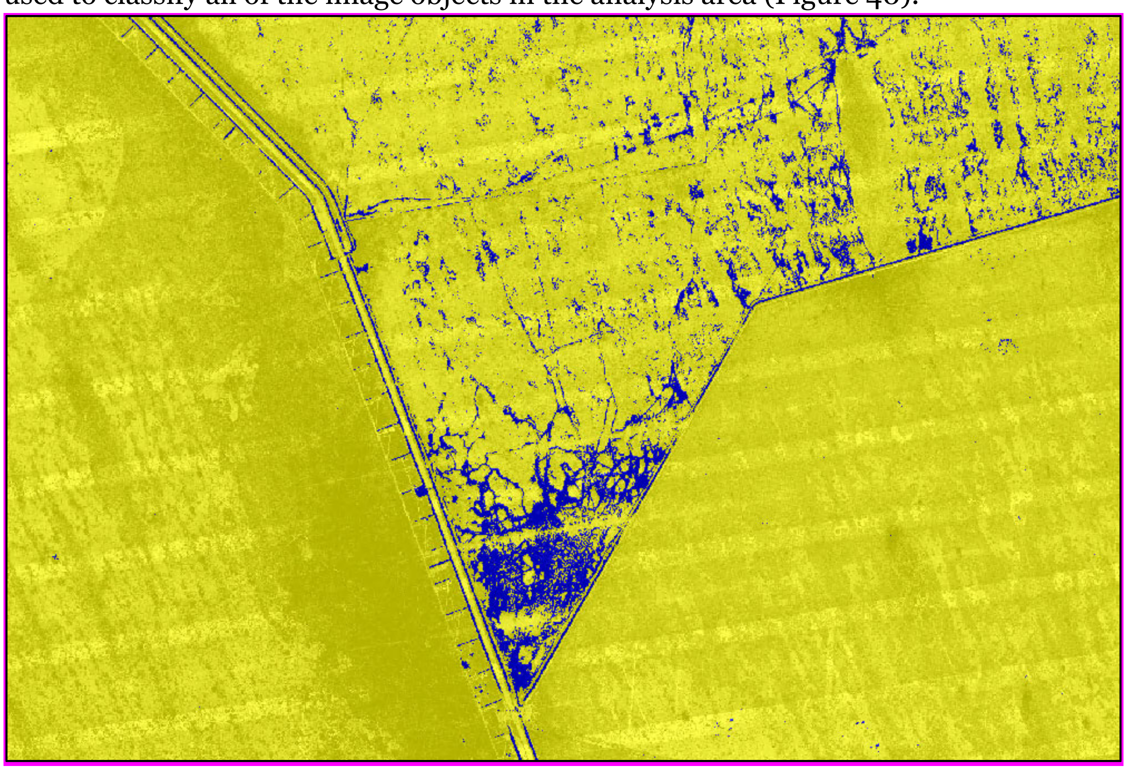


*Figure 40—Image objects classified as Water (blue) and Ground (yellow).*

4. The classified Water objects went through several post-classification processing steps in eCognition and ArcGIS to merge neighboring objects of the same classification and

smooth the vectors to remove the jagged, stair-step lines that come from eCognition drawing segment lines along the raster pixel edges. The final water body polygons were produced in shapefile format.

## BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the lidar.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

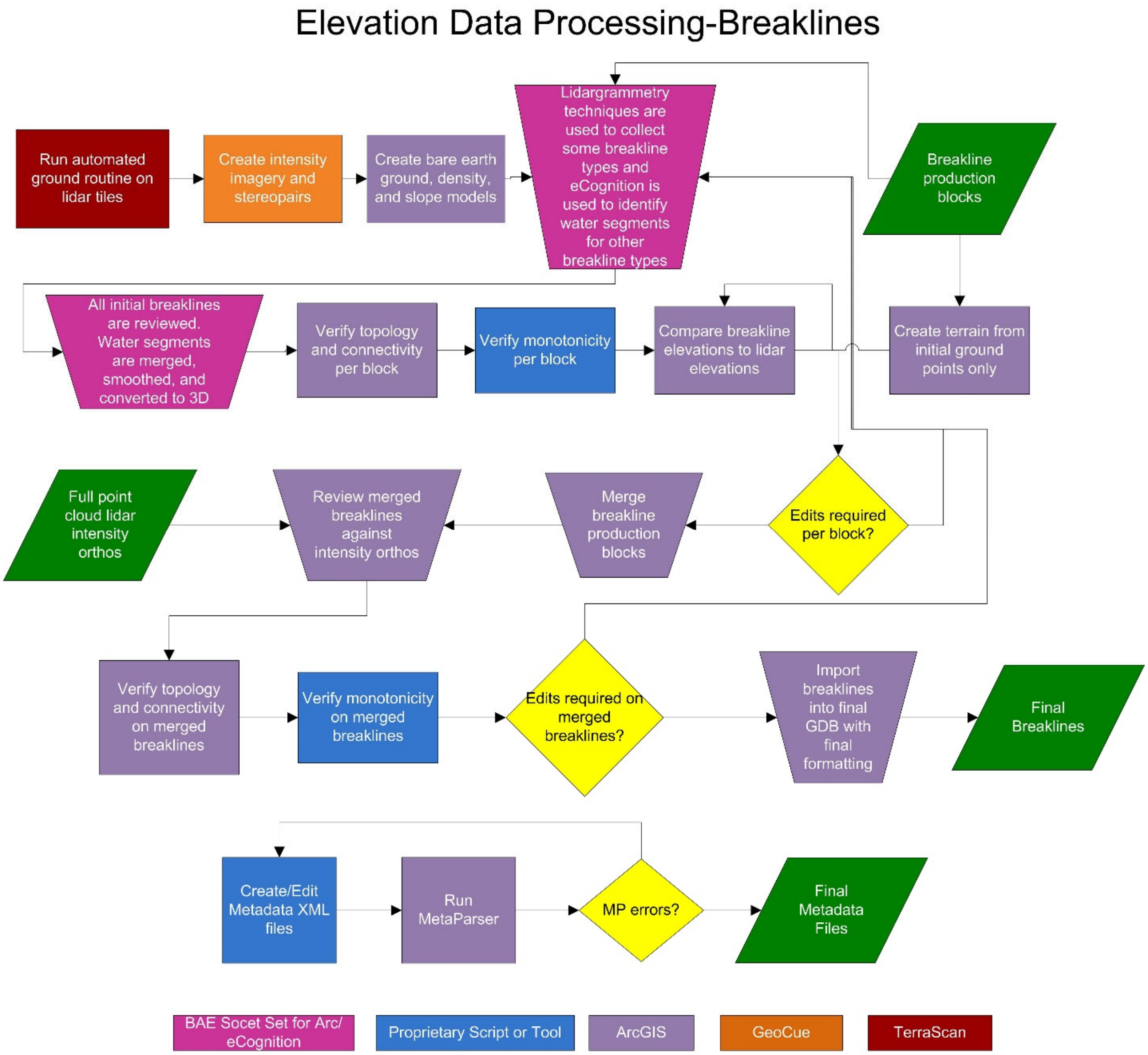



*Figure 41—Breakline QA/QC workflow*

## BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

| Pass/Fail | Validation Step |
|---|---|
| Pass | Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications. |
| Pass | In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS). |

| | |
|---|---|
| Pass | After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC |
| Pass | After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks. |
| Pass | Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains |
| Pass | Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement. |
| Pass | Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations. |
| Pass | Perform all Topology and Data Integrity Checks |
| Pass | Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic. |

*Table 12—a subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.*

# DATA DICTIONARY

The following data dictionary was used for this project.

## Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011) Contiguous U.S. Albers, Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

## Coordinate System and Projection

All data shall be projected to Contiguous U.S. Albers, Horizontal Units in Meters and Vertical Units in Meters.

## Inland Streams and Rivers

**Feature Dataset:** BREAKLINES
**Feature Type:** Polygon
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XY Tolerance:** 0.001

**Feature Class:** STREAMS_AND_RIVERS
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

## Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |
| SHAPE_AREA | Double | Yes | | | 0 | 0 | | Calculated by Software |

## Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Streams and Rivers | Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project. | Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present.<br><br>The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance.<br><br>Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually.<br><br>These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.<br><br>Every effort should be made to avoid breaking a stream or river into segments. |

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| | | Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge.<br><br>Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature. |

## Inland Ponds and Lakes

**Feature Dataset:** BREAKLINES
**Feature Type:** Polygon
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XY Tolerance:** 0.001

**Feature Class:** PONDS_AND_LAKES
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polygon feature class will depict closed water body features that are at a constant elevation.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |
| SHAPE_AREA | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Ponds and Lakes | Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater.<br><br>"Donuts" will exist where there are islands within a closed water body feature. | Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.<br><br>Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually.<br><br>An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a "donut polygon" compiled.<br><br>These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of |

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| | | water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. |

## Tidal Waters

**Feature Dataset**: BREAKLINES
**Feature Type**: Polygon
**Contains Z Values**: Yes
**XY Resolution**: Accept Default Setting
**XY Tolerance**: 0.001

**Feature Class**: TIDAL_WATERS
**Contains M Values**: No
**Annotation Subclass**: None
**Z Resolution**: Accept Default Setting
**Z Tolerance**: 0.001

### Description

This polygon feature class will outline the land / water interface at the time of lidar acquisition.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |
| SHAPE_AREA | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| TIDAL_WATERS | The coastal breakline will delineate the land water interface using lidar data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected data permits. | The feature shall be extracted at the apparent land/water interface, as determined by the lidar intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering.<br><br>Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually.<br><br>If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is |

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| | | evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.<br><br>Breaklines shall snap and merge seamlessly with linear hydrographic features. |

## Beneath Bridge Breaklines

**Feature Dataset:** BREAKLINES
**Feature Type:** Polyline
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XY Tolerance:** 0.001

**Feature Class:** Bridge_Breaklines
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Bridge Breaklines | Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs. | Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs.<br><br>Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck.<br><br>The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming. |

## Soft Feature Breaklines

**Feature Dataset:** BREAKLINES
**Feature Type:** Polyline
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XYTolerance:** 0.001

**Feature Class:** Soft_Features
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polyline feature class is used to enforce the terrain where enforcement is necessary but other breaklines are not applicable. In this project, soft feature breaklines are used to enforce hydrographic structures and to help model elevation changes in the terrain around those hydrographic structures. This additional enforcement is used to help model flow on either side of a hydrographic structure and reduce interpolation in the DEM when the hydrographic structure is located on a river or stream below minimum collection requirements.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Soft Features | Soft feature breaklines should be used where necessary to enforce hydrographic structures and to help model elevation changes in the terrain around those hydrographic structures. | Soft features should be used to enforce the terrain where enforcement is necessary but other breaklines are not applicable, including along hydrographic structures. This additional enforcement is used to help model flow on either side of a hydrographic structure and reduce interpolation in the DEM when the hydrographic structure is located on a river or stream below minimum collection requirements.<br><br>Soft feature breaklines should be collected along hydrographic structures when elevation changes on either side of the hydrographic structure are not modeled well in the DEM and result in excessive interpolation.<br><br>The exact placement of the soft feature will depend on the individual structure but should be placed in a manner to limit interpolation and enforce hydrographic elevations above and below the structure. Common placement is parallel to the hydrographic structure with one soft feature breakline at water level above the structure and one soft feature breakline at water level below the structure.<br><br>The endpoints of each soft feature breakline will match the elevation of the water level at their xy position in order to |

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| | | enforce flow levels on either side of the structure and prevent excessive interpolation in the DEM. |

# DEM Production & Qualitative Assessment

## DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software, LP360, and Global Mapper for the DEM production and QC process. ArcGIS software and LP360 is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production, starting from the lidar swath processing.

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.


*Figure 42—DEM Production Workflow*

## 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. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The image below shows an example of a bare earth DEM.

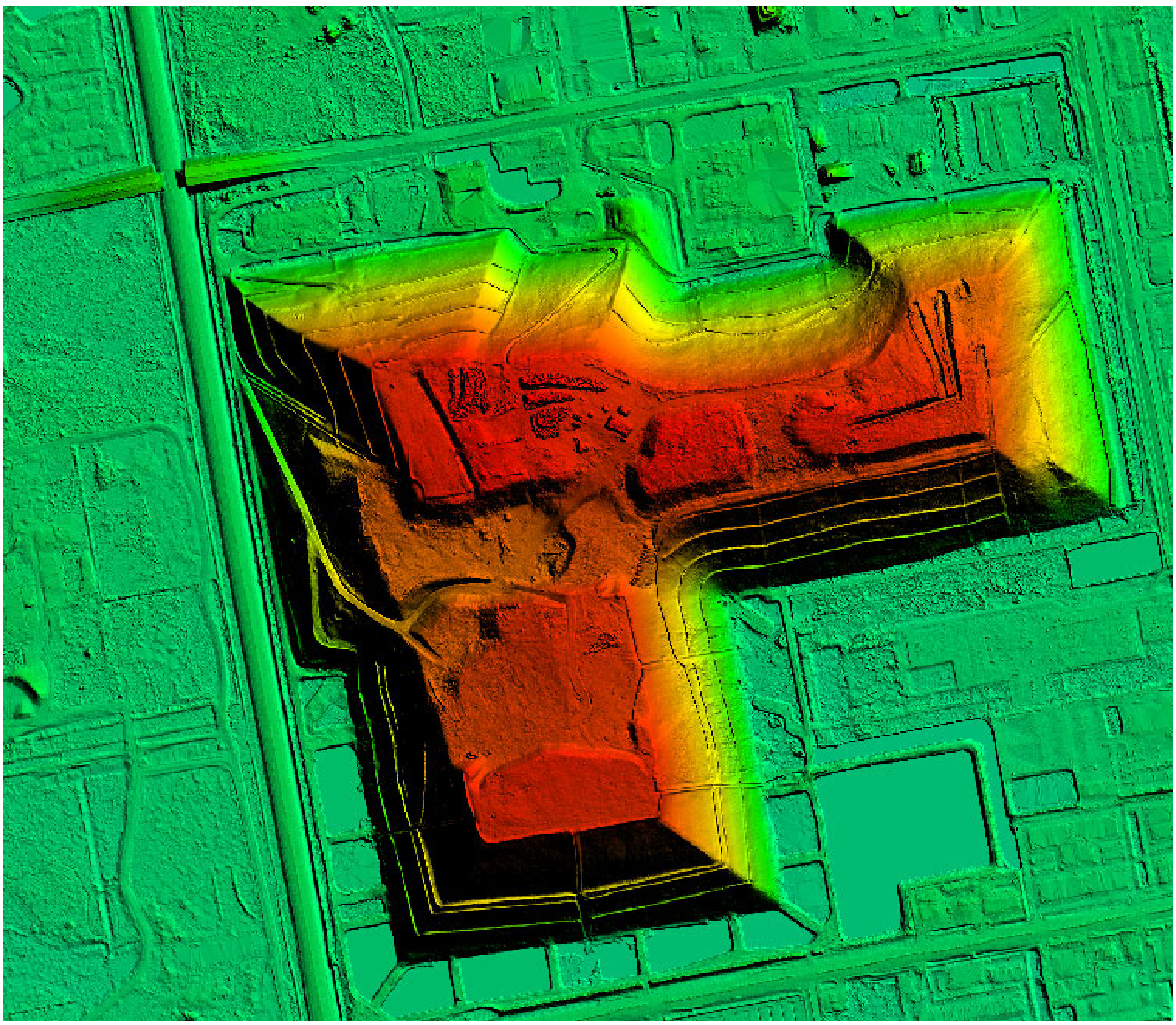

*Figure 43—Tile e1587n0491. The bare earth DEM is shown in the image above.*

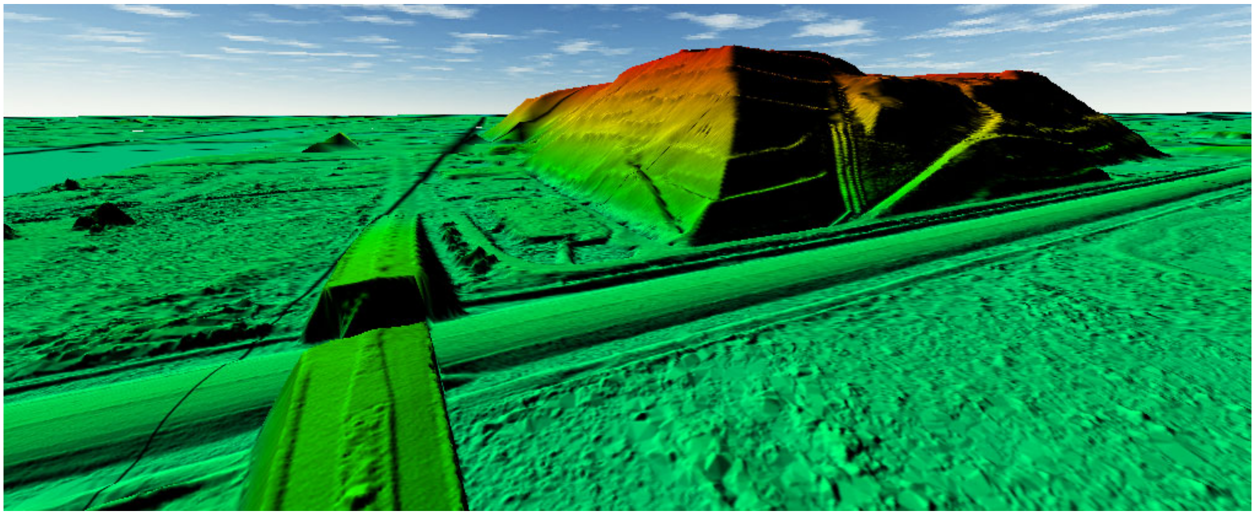

*Figure 44—Tile e1587n04913D. Profile view of the bare earth DEM*

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts (Figure 45).

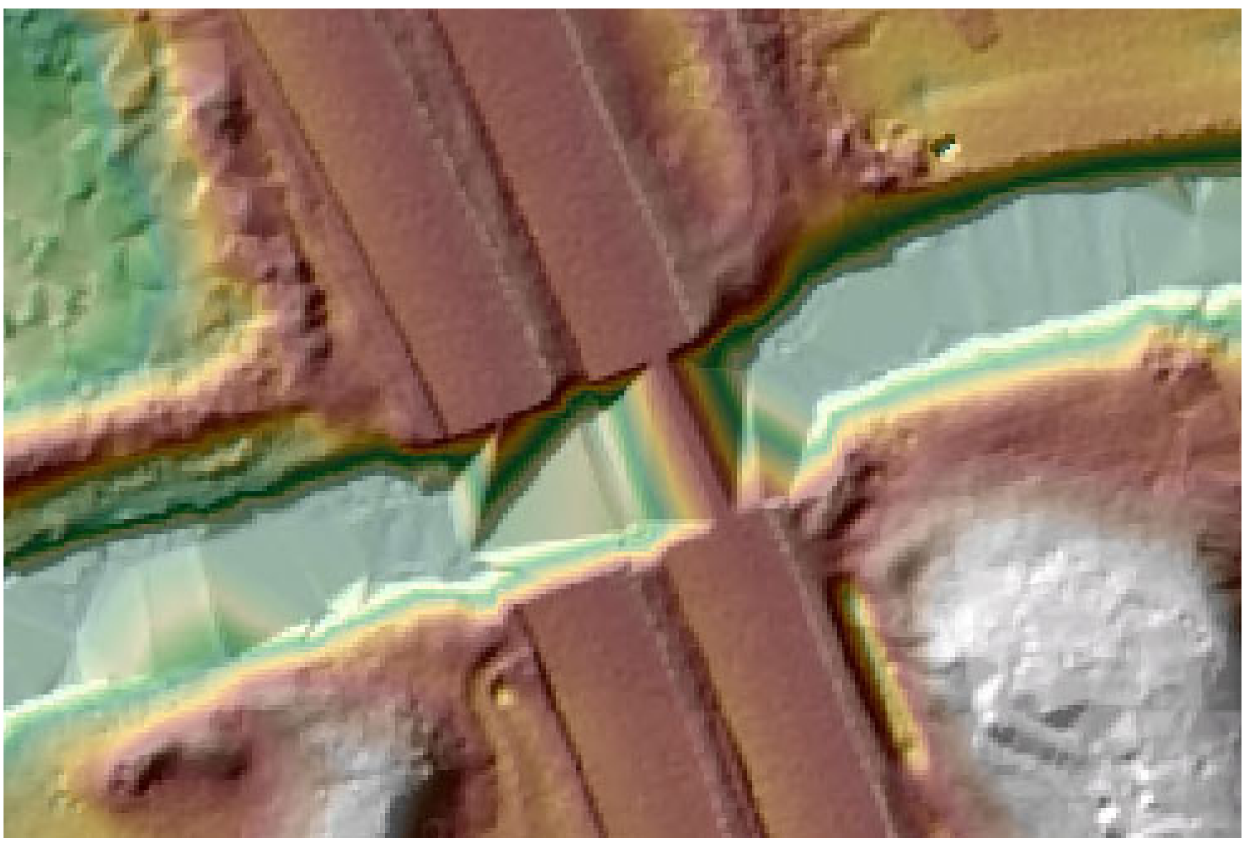

*Figure 45—Tile e1579n0484. The DEM on the top shows a bridge saddle artifact, while the DEM on the bottom shows the same location after bridge saddle breaklines have been enforced.*

## DEM VERTICAL ACCURACY RESULTS

The same 125 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. 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 source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 13 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

| Land Cover Category | # of Points | NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm | VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=30.0 cm |
|---|---|---|---|
| NVA | 69 | 8.0 cm | |
| VVA | 56 | | 20.9 |

*Table 13—DEM tested NVA and VVA*

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 $RMSE_z$ = 8.0 cm, equating to ± 10 cm at 95% confidence level. Actual VVA accuracy was found to be ± 20.9 cm at the 95th percentile.

Table 14 lists the 5% outliers that are larger than the VVA 95th percentile.

| Point ID | NAD83 (2011), Albers Equal Area | | NAVD88 (Geoid 12B) | DEM Z (m) | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Survey Z (m) | | | |
| VVA 4 | 1516869.250 | 466417.720 | 3.160 | 3.388 | 0.228 | 0.228 |
| VVA 13 | 1532125.410 | 487710.440 | 2.910 | 3.225 | 0.315 | 0.315 |
| VVA 27 | 1563578.230 | 462408.340 | 2.150 | 2.576 | 0.426 | 0.426 |

*Table 14—5% Outliers*

Table 15 provides overall descriptive statistics.

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Kurtosis | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|---|---|
| Open Terrain | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Urban | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **NVA** | **69** | **0.041** | **0.010** | **0.006** | **0.309** | **0.040** | **0.138** | **-0.077** | **0.110** |
| Tall Weeds and Crops | 0 | N/A | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brush Lands and Trees | 0 | N/A | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Forested and Fully Grown | 0 | N/A | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **VVA** | **56** | **N/A** | **0.047** | **0.034** | **1.911** | **0.091** | **5.348** | **-0.084** | **0.426** |

*Table 15—Overall Descriptive Statistics*

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Florida Southeast Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

## DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

| Pass/Fail | Validation Step |
|---|---|
| Pass | Masspoints (LAS to multipoint) are created from ground points only (class 2 and class 8 if model key points created, but no class 10 ignored ground points or class 9 water points |
| Pass | Create a terrain for each production block using the final bare earth lidar points and final breaklines. |
| Pass | Convert terrains to rasters using project specifications for grid type, formatting, and cell size |
| Pass | Create hillshades for all DEMs |
| Pass | Manually review bare-earth DEMs in ArcMap with hillshades to check for issues |
| Pass | DEMs should be hydro-flattened or hydro-enforced as required by project specifications |
| Pass | DEMs should be seamless across tile boundaries |
| Pass | Water should be flowing downhill without excessive water artifacts present |
| Pass | Water features should NOT be floating above surrounding |
| Pass | Bridges should NOT be present in bare-earth DEMs. |
| Pass | Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing. |
| Pass | All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected. |
| Pass | Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics |
| Pass | Split the DEMs into tiles according to the project tiling scheme |
| Pass | Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs |
| Pass | Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt. |

*Table 16—a subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.*