LiDAR Quality Assurance (QA) Report
Greenwood County, South Carolina
March 12, 2009

Submitted to:
USGS
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EXECUTIVE SUMMARY

Reference: USGS Contract 07CRCN0004, Task Order 07004C0009, South Carolina 16 County LiDAR, dated January 17, 2008.

This report documents Dewberry's actions to quality assure the LiDAR deliverables of Greenwood County, SC, produced by Dewberry's subcontractor, Fugro EarthData, under the referenced USGS task order. The LiDAR data was acquired in January of 2008 and delivered as LiDAR LAS point cloud data in five ASPRS LAS classes (class 1 = non-ground; class 2 = ground; class 8 = intelligently-thinned model key points; class 9 = water; and class 12 = overlap points not used in other classes). The LiDAR data was determined to be of excellent quality.

Completeness: Dewberry verified the completeness of the classified LiDAR points, intensity images, and an ESRI geodatabase containing a terrain (triangulated irregular network) and ground masspoints. Hydrographic breaklines were delivered separately by watershed. Dewberry verified that the high density mass point data has an average point spacing less than 1.4m, that 593 tiles (each 5000 ft x 5000 ft) were delivered covering all of Greenwood County, that all data was delivered in the correct file format and projected to the South Carolina State Plane Coordinate System in International feet, NAD83 HARN, with elevations in meters, NAVD88; and that the FGDC-complaint metadata satisfies project requirements.

Quantitative: Using checkpoints surveyed by the South Carolina Geodetic Survey, Dewberry tested the RMSEz, Fundamental Vertical Accuracy (FVA) in open terrain, Consolidated Vertical Accuracy (CVA) in all land cover categories, and Supplemental Vertical Accuracy (SVA) in each of three major land cover categories per FEMA requirements, and the accuracy easily surpassed the specified accuracy required, as summarized below, when tested per FEMA, NSSDA, NDEP and ASPRS guidelines.

Criterion	Checkpoints Required	Checkpoints Used	Accuracy Specification	Results Achieved
RMSEz	60	120	18.5 cm	11.0 cm
FVA	20	38	36.3 cm	22.2 cm
CVA	60	120	36.3 cm	17.2 cm
SVA-bare earth	20	38	36.3 cm	16.3 cm
SVA-vegetated	20	55	36.3 cm	15.1 cm
SVA-urban	20	27	36.3 cm	17.2 cm

Qualitative: Dewberry visually inspected 100% of the data; no remote-sensing data voids were found and the data is free of major systematic errors. The cleanliness of the bare earth model meets expectations; minor errors were found in less than 2% of the data, including poor LiDAR penetration and acquisition drop-off. All of the deliverables extend to the county boundaries where adjoining counties are not delivered; and where adjoining counties are delivered there is no clipping of the tiles.

TABLE OF CONTENTS

QA REPORT

1 Introduction

The following definitions are provided to distinguish between steps taken by Dewberry, as prime contractor, to provide Quality Assurance (QA) of the LiDAR data produced by Fugro EarthData, and steps taken by Fugro EarthData, as data producer, to perform Quality Control (QC) of the data that it provides to Dewberry. Collectively, this QA/QC process ensures that the LiDAR data delivered to USGS and its client (South Carolina Department of Natural Resources) are accurate, usable, and in conformance with the deliverables specified in the Scope of Work. These definitions are taken from the DEM Quality Assessment chapter of the 2nd edition of “Digital Elevation Model Technologies and Applications: The DEM Users Manual,” published by the American Society for Photogrammetry and Remote Sensing (ASPRS), 2007:

> **Quality Assurance (QA)** — Steps taken: (1) to ensure the end client receives the quality products it pays for, consistent with the Scope of Work, and/or (2) to ensure an organization’s Quality Program works effectively. Quality Programs include quality control procedures for specific products as well as overall Quality Plans that typically mandate an organization’s communication procedures, document and data control procedures, quality audit procedures, and training programs necessary for delivery of quality products and services.
>
> **Quality Control (QC)** — Steps taken by data producers to ensure delivery of products that satisfy standards, guidelines and specifications identified in the Scope of Work. These steps typically include production flow charts with built-in procedures to ensure quality at each step of the work flow, in-process quality reviews, and/or final quality inspections prior to delivery of products to a client.

Dewberry’s role is to provide overall project management as well as quality management that include QA of the data including a completeness validation of the LiDAR masspoints, vertical accuracy assessment and reporting, and a qualitative review of the derived bare earth surface. In addition, Dewberry provides an extensive review of other derived products such as 3D streamlines, TIN-terrain, and LiDAR intensity images.

First, the completeness verification is conducted at a project scale (files are considered as the entities) for all products. It consists of a file inventory and a validation of conformity to format, projection, and georeference specifications. At this point Dewberry also ensures that the data adequately covers the project area for all products. The LiDAR data review begins with the computation of general statistics over all fields per file, followed by an analysis of the results to identify anomalies, especially in the elevation fields and LAS class fields.

The quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. Although only a small amount of points are actually tested through the quantitative assessment, 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 surrounding LiDAR measurements as acquisition conditions remain similar from one point to the next.

To fully address the LiDAR data for overall accuracy and quality, a manual qualitative review for anomalies and artifacts is conducted on each tile. This includes creating pseudo-image products such as 3-dimensional models. The QA analyst uses multiple images and using overlays to find potential errors in the data as well as areas where the data meets and exceeds expectations.

Three fundamental questions are addressed during Dewberry’s QA process:

- Was the data complete?
- Did the LiDAR system perform to specifications?
- Did the ground classification process yield desirable results for the intended bare-earth terrain product?

Under the referenced task order, LiDAR data was acquired for 16 counties in South Carolina (Figure 1). This report focuses on the deliverables covering Greenwood County that are directly derived from the LiDAR. The hydrolines, derived from the LiDAR, are being delivered per watershed and thus will be discussed in a subsequent report. All quality assurance processes and results are given in the following sections.

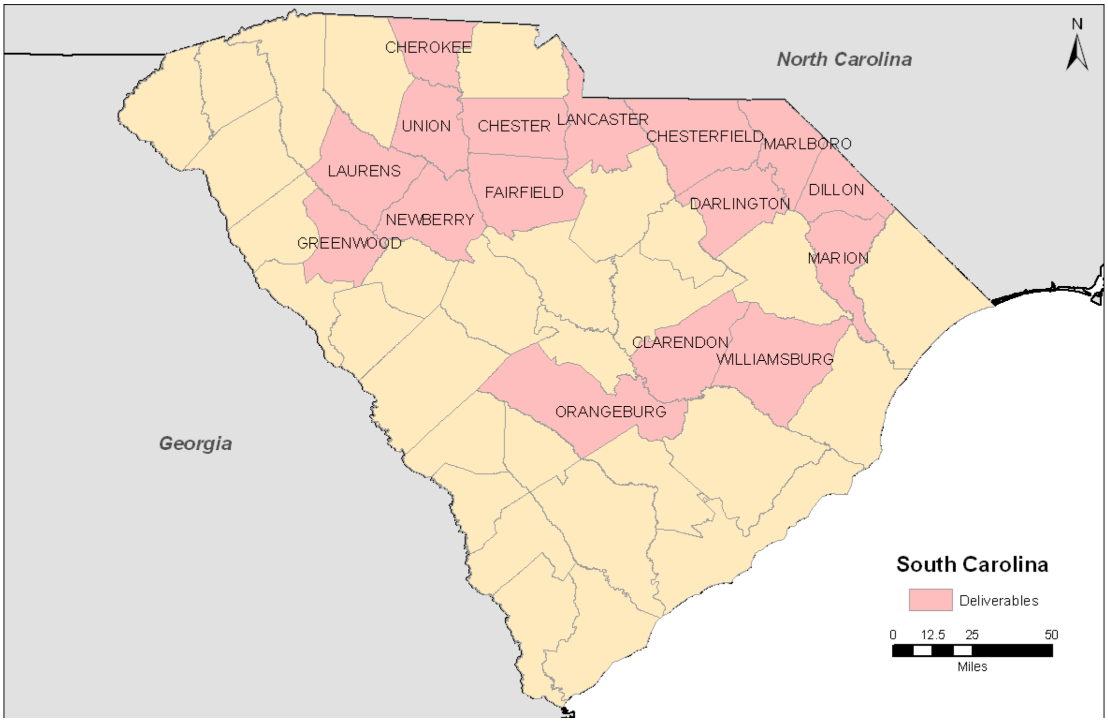


Figure 1 *– Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

2 Completeness of deliverables

Dewberry reviews the inventory of the data delivered by validating the format, projection, and georeferencing. County based deliverables are listed in **Table 1**.

Table 1 - County deliverables.

Dataset	Format	Spatial
LiDAR	LAS	Tiled
Intensity images	GeoTiff	Tiled
Terrain (bare earth)	ESRI feature class Terrain	1feature class
Ground masspoints	ESRI feature class multipoints	1feature class
Boundary	ESRI geodatabase feature class - polygons	3 feature classes (county/tile/LiDAR)

Clipping of the data along the county boundary was performed according to the following rules (Figure 2):

- a partial tile is delivered at the boundary with a county that is not part of the project,
- a full tile is delivered at the boundary with a county that is part of the project

LAS files and intensity images were delivered in tiles that adhere to these rules and to the State of South Carolina's 5000 ft x 5000 ft tile schema (see Figure 3). The LAS, the ground masspoint feature class, terrain, and intensity images extend outside the project boundary with a 50 ft buffer (Figure 4 and Figure 5) as expected.

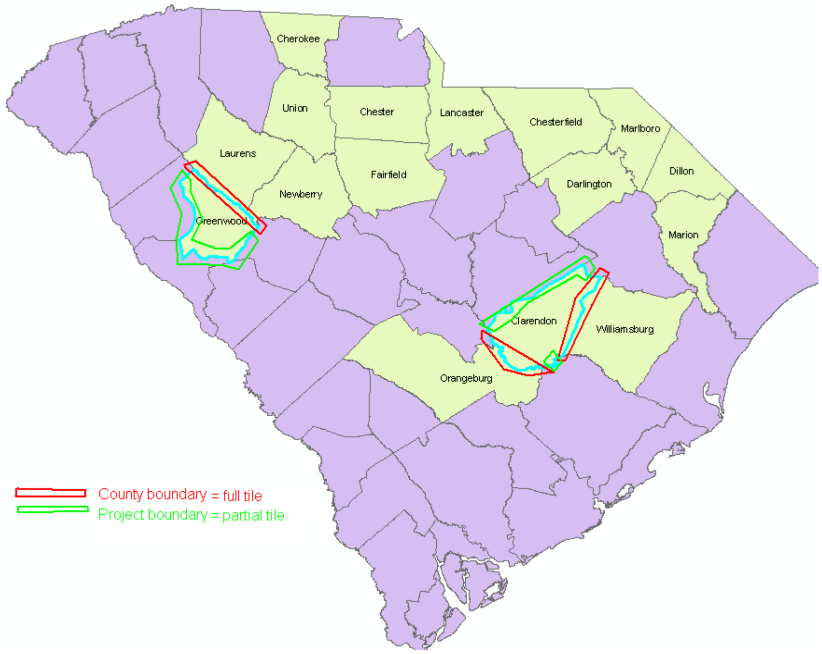


Figure 2 *– Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

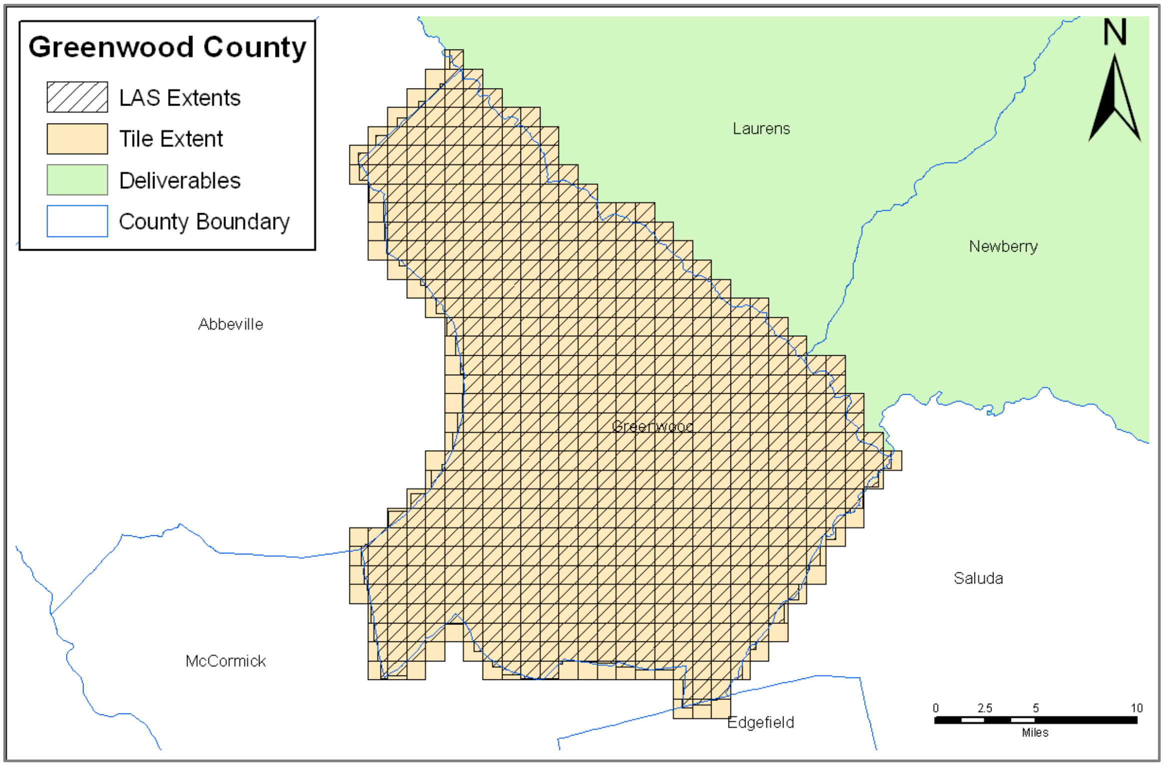


Figure 3 *– The LiDAR coverage of Greenwood County. Neighboring deliverable counties are shown in green.*

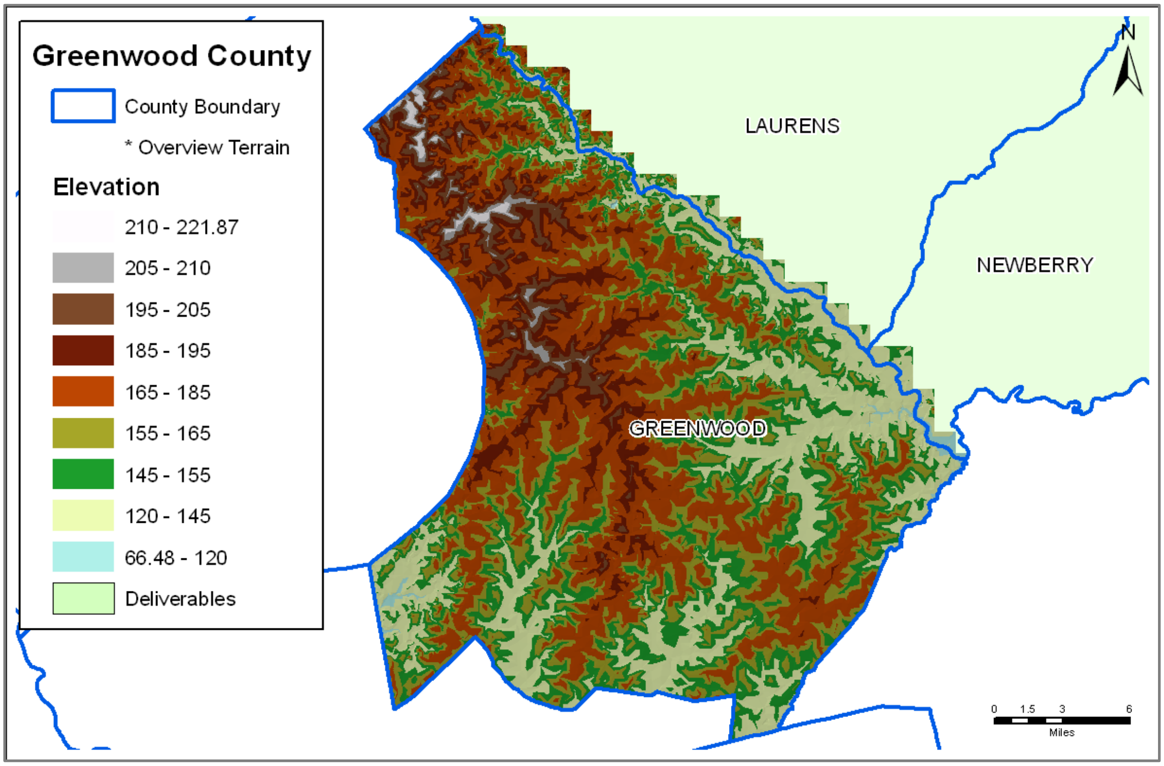


Figure 4 *– The terrain for Greenwood has a 50 ft buffer outside of the project boundary.*

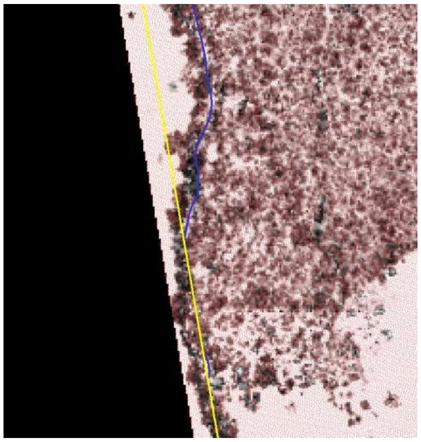


Figure 5 *- Ground masspoints (red) and intensity images extend 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydrolines are clipped at the project boundary and the watershed boundary.*

3 QA of intensity images

593 intensity images in GeoTiff format were delivered for Greenwood County. An automated script was used to validate that intensity values are integers ranging between 0 and 255, that the cell size is 4 ft, and that the column and row count is 1250. 1250 multiplied by 4 (the pixel size in feet) equals 5000 feet which is the required size of the tiles: 5000 ft x 5000 ft. Another automated script was used to validate the header information on all of the GeoTiffs. There were no issues with these checks. An example of the header is shown in Table 2.

Table 2 – Intensity header.

```
File Name:  5890-02.tif
File Information:
 Standard : : TIFF File
 Format : : Byte integers (8 bits)
 Pixels per Line :  1250
 Number of Lines :  1250
 Samples per pixel :  1
 File bits per sample : 8
 Actual bits per sample : 8
 Untiled file
 Number of overviews :  0
 Scanning device resolution :  72  : lines/inch
 Orientation :  4  : Row major order, origin at top left
 NO scan line headers : non-scannable file
 Packet size (16-bit words) : 0
 Free vlt space (16-bit words) : 2000000000
 Free packet space (16-bit words) : 2000000000
Raster to UOR matrix:
 Unspecified or All Zero Matrix
Raster to World Matrix:
 Units: Feet
 amx[ 0]=         4, amx[ 1]=         0, amx[ 2]=     1595000
 amx[ 3]=         0, amx[ 4]=        -4, amx[ 5]=      810000
       1595000 ,      810000
       1600000 ,      810000
       1600000 ,      805000
       1595000 ,      805000
```

```
Geotiff_Information:
   Version: 1
   Key_Revision: 1.0
   Tagged_Information:
      ModelTiepointTag (2,3):
         0            0            0
         1595000      810000       0
      ModelPixelScaleTag (1,3):
         4            4            0
      End_Of_Tags.
   Keyed_Information:
      GTModelTypeGeoKey (Short,1): ModelTypeProjected
      GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
      ProjectedCSTypeGeoKey (Short,1): Unknown-3361
      ProjLinearUnitsGeoKey (Short,1): Linear_Foot
      End_Of_Keys.
   End_Of_Geotiff.
PCS = 3361 (name unknown)
Projection Linear Units: 9002/foot (0.304800m)
Corner Coordinates:
Upper Left    (1595000.000, 810000.000)
Lower Left    (1595000.000, 805000.000)
Upper Right   (1600000.000, 810000.000)
Lower Right   (1600000.000, 805000.000)
Center        (1597500.000, 807500.000)
```

Dewberry also visually checked the tile-matching in ArcMap. Overall, the intensity is consistent between adjacent tiles. Tiles over the boundary between two delivered counties are delivered in full for each county. Tiles over the outside project boundary are partial; the section outside the buffered project area is filled with black pixels (value 0).

4 Metadata

Dewberry verified the metadata and all of the xml files were FGDC compliant. Metadata is delivered for the project, terrain, intensity images, and the LAS.

5 LiDAR QA

5.1 Completeness

5.1.1 LAS inventory

Dewberry received 593 LiDAR files covering the Greenwood County area. They are in the correct format and projection:

- LAS version: 1.1
- Point data format: 1
- Projection set in the header:
  - NAD_1983_HARN_StatePlane_South_Carolina_FIPS_3900_Feet_Intl;
  - Horizontal unit: linear feet;
  - NAVD88 - Geoid03;
  - Vertical unit: meters

The point spacing matches the requirement of an average point spacing of 1.4 meters.

Each record includes the following fields:

- XYZ coordinates
- Flight line
- Intensity
- Return number, number of return, scan direction, edge of a flight line and scan angle
- Classification:
  - class 1 for non-ground,
  - class 2 for ground (must be combined with class 8 to be complete),
  - class 8 for (intelligently-thinned) model key points,
  - class 9 for water,
  - class 12 for overlap
- GPS time (this is expressed in second of the week; note that the date of collection will be given in the metadata file because the date contained in the LAS header is the file creation date according to LAS standard)

5.1.2 Statistical analysis of LAS tile content

To verify the content of the data and to validate the data integrity, a statistical analysis was performed on all the data. This process allows Dewberry to statistically review 100% of the data to identify any gross outliers. This statistical analysis consists of:

1. Extracting the header information

2. Reading the actual records and computing the number of points, minimum, maximum and mean elevation for each class. Minimum and maximum for other relevant variables are also evaluated.

Each tile was queried to extract the number of LiDAR points. With a nominal point spacing of less than 1.4m, the number of points per tile should be around 3.9 million. The mean in Greenwood County is around 5.1 million which proves that the average density is more than what is required. All tiles are within the anticipated size range except for where fewer points are expected (near the external project boundary where tiles are clipped or over large rivers and lakes) as illustrated in Figure 6.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 128.2 and 221.6, no noticeable anomalies were identified because this is consistent with the expected range of elevation in the county. Figure 7 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography. Lower elevations are found near hydrographic features; see Figure 7 (left) for the Z min elevations.

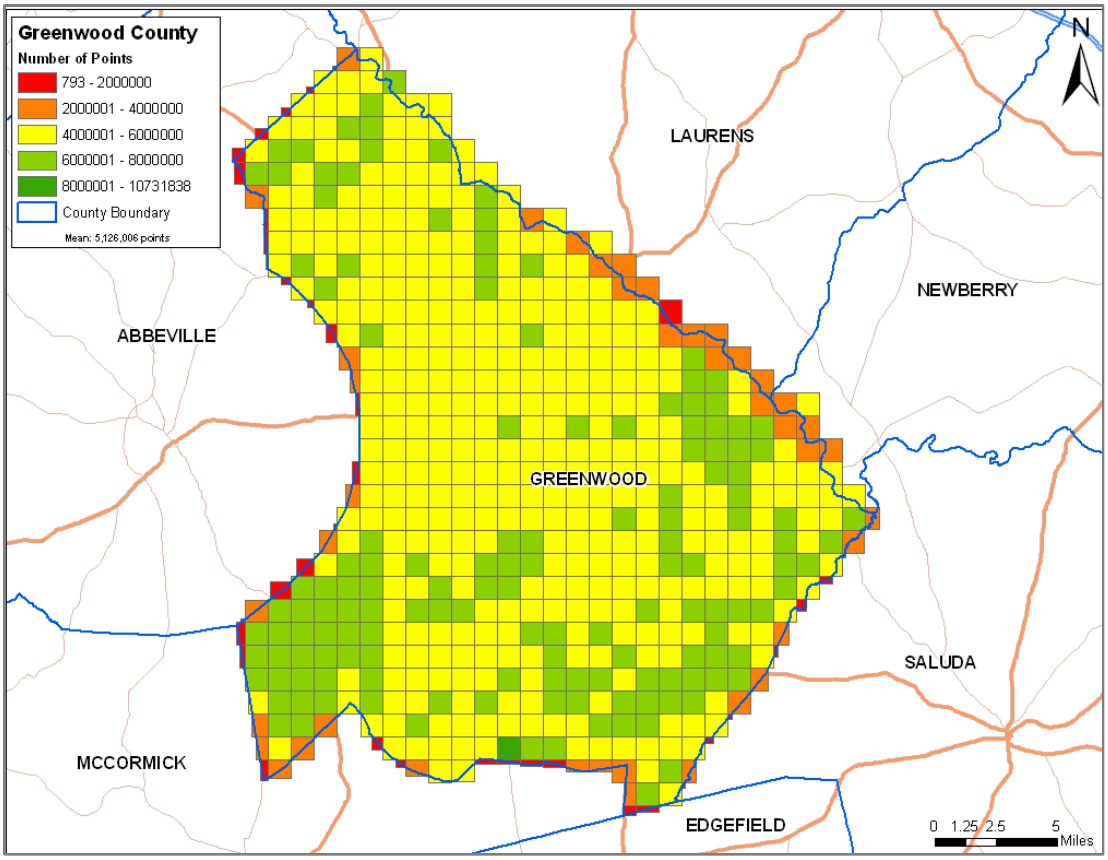


***Figure 6** – Number of points per tile. The red tiles at the border are expected to have fewer points.*

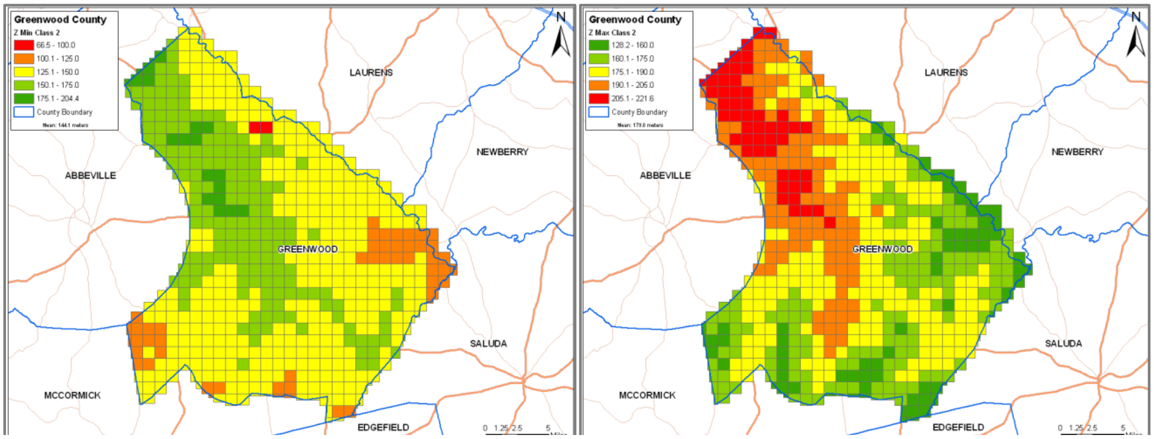


Figure 7 *– Z min and Z max elevation by tile for ground points (class 2).*

5.2 LiDAR Quantitative Assessment

5.2.1 Checkpoint inventory

Typically for this type of data collection, a ground truth survey is conducted following the *FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial mapping and Surveying* which is based on the NSSDA. This methodology collects a minimum of 20 points for each of the predominant land cover types (i.e. bare-earth, weeds and crop, forest, urban etc.) for a minimum of three land cover classes. By verifying the data in these different classes, the data accuracy is tested, but it also tests whether the classification of the LiDAR was performed correctly at those test point locations. In this project the predominant land covers selected are bare-earth, mixed vegetation, and urban.

The field survey was conducted and prepared by the South Carolina Geodetic Survey in April 2008. The guidelines were to collect 60 checkpoints in 3 different land covers: 20 points in Urban Areas, 20 points in Open Terrain, and 20 points divided equally in Medium Vegetation and Forested Areas.

In reality 134 points were collected, as presented in Table 3, with 57 vegetation points instead of 20, including an additional class (bush). All the checkpoints used for the vertical assessment of the LiDAR data are available in 0. Figure 8 shows the distribution of the checkpoints throughout the area. The points are grouped together in clusters. In some cases the checkpoints within a cluster are less than 100 ft apart which is not ideal but still acceptable.

Table 3 - Number of points required and acquired.

Class	Guidelines	Acquired
o - Open Terrain	20	38
b - Bush	0	14
h - High Grass	10	22
w - Woods	10	19
u - Urban	20	27
Total	**60**	**120**

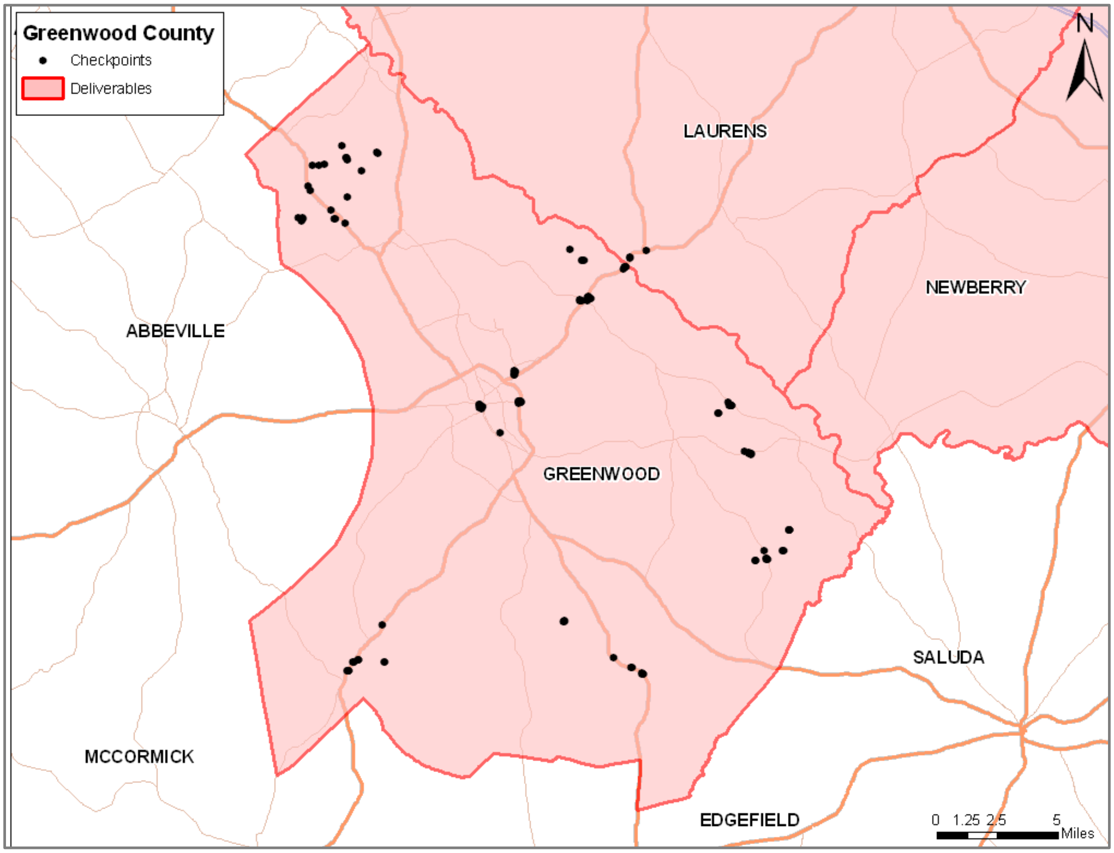


***Figure 8** – Survey checkpoints from South Carolina Geodetic Survey.*

5.2.2 Vertical Accuracy Assessment Methodologies

The first method of testing vertical accuracy used the FEMA specifications which follows the National Standard for Spatial Data Accuracy (NSSDA) procedures. The accuracy is reported at the 95% confidence level using the Root Mean Square Error (RMSE) which is valid when errors follow a normal distribution. By this method, vertical accuracy at the 95% confidence level equals RMSEz x 1.9600. This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the TIN as generated from the bare-earth LiDAR. The X/Y locations of the survey checkpoints are overlaid on the TIN and the interpolated Z values are recorded. These interpolated Z values are then compared with the survey checkpoint Z values and this difference represents the amount of error between the measurements.

The second method of testing vertical accuracy, endorsed by the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) uses the same (RMSE) method in open terrain only; an alternative method uses the 95th percentile to report vertical accuracy in each of the other land cover categories (defined as Supplemental Vertical Accuracy – SVA) and all land cover categories combined (defined as Consolidated Vertical Accuracy – CVA). The 95th percentile method is used when vertical errors may not follow a normal error distribution, as in vegetated terrain.

The Fundamental Vertical Accuracy (FVA) is the same for both methods; both methods utilize RMSE x 1.9600 in open terrain where there is no reason for LiDAR errors to depart from a normal error distribution.

The following tables and graphs outline the vertical accuracy and the statistics of the associated errors as computed by the different methods.

Table 4 shows the complete results of the Greenwood County data set run through the FEMA/NSSDA process; vertical accuracy at the 95% confidence level equals the RMSE x 1.9600. By this method, the consolidated vertical accuracy equals the RMSE (0.110 m) x 1.9600, or 0.216 m (21.6 cm).

Table 4 - Final statistics for Greenwood County using FEMA/NSSDA processes.

100 % of Totals	RMSE (m) Spec=0.185m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.110	-0.069	-0.078	-0.438	0.086	120	-0.496	0.238
Open Terrain	0.113	-0.097	-0.091	-0.440	0.060	38	-0.285	0.012
Vegetated	0.105	-0.034	-0.039	-1.356	0.100	55	-0.496	0.238
Urban	0.115	-0.098	-0.104	0.857	0.061	27	-0.194	0.056

Table 5 shows the complete results of the Greenwood data set run through the NDEP/ASPRS process; the CVA value is 0.172 m (17.2 cm). These statistics include “outlier” points or points that are two times the standard deviation. This explains why the CVA calculated by the NDEP/ASPRS method is lower than the CVA calculated by the FEMA/NSSDA method. Even with these outliers all of the calculated statistics for Greenwood County fall well below the specifications.

Table 5 - Final statistics for Greenwood County using NDEP/ASPRS processes.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=36.3 cm	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=36.3 cm	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=36.3 cm
Consolidated	120		0.172	
Open Terrain	38	0.222		0.163
Vegetated	55			0.151
Urban	27			0.172

Figure 9 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed checkpoints. The majority of delta Z values are below zero which indicates a slightly negative error distribution.

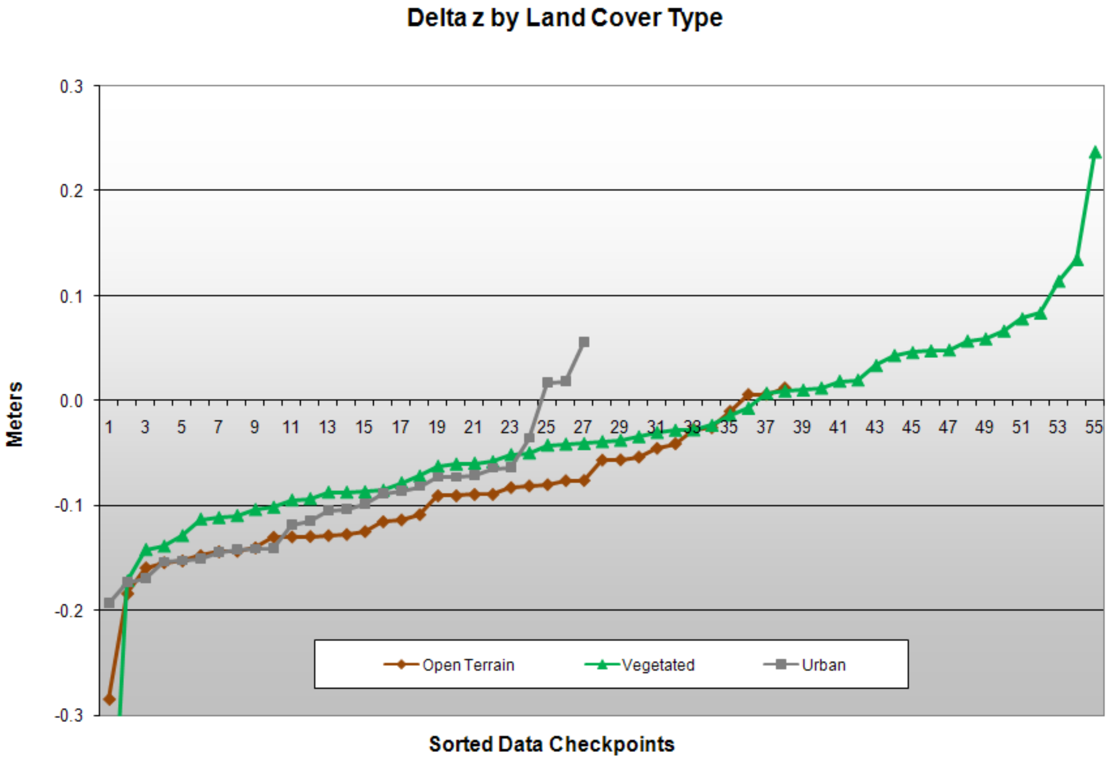


***Figure 9 –** Checkpoints shown per land cover type and sorted by errors (DeltaZ).*

Given the good results and the high number of checkpoints used, Dewberry is confident that the data meets the accuracy requirements despite the less than ideal spatial dispersion of the checkpoints.

Compared with the 36.3 cm specification for vertical accuracy at the 95% confidence level, equivalent to 2-foot contours, the dataset passes by all methods of accuracy assessment:

- Tested 22.2 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 21.6 cm Consolidated Vertical Accuracy at 95% confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 17.2 cm Consolidated Vertical Accuracy at 95th percentile in all land cover categories combined (NDEP/ASPRS methodology).

5.3 LiDAR Qualitative Assessment

5.3.1 Protocol

The goal of Dewberry's qualitative review is to assess the continuity and the level of cleanliness of the bare earth product. Each LiDAR tile is expected to meet the following acceptance criteria:

- ➢ The point density is homogeneous and sufficient to meet the user's needs;

- The ground points have been correctly classified (no manmade structures and vegetation remains, no gap except over water bodies);
- The ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing);
- No obvious anomalies due to sensor malfunction or systematic processing artifact is present (data holidays, spikes, divots, ridges between tiles, cornrows…);
- 90% or more of the artifacts have been removed, 95% of the outliers, 95% of the vegetation, and 98% of the buildings.

Dewberry analysts, experienced in evaluating LIDAR data, performed a visual inspection of the bare-earth digital elevation model (bare-earth DEM). LiDAR masspoints were first gridded with a grid distance of 2x the full point cloud resolution. Then, a triangulated irregular network (TIN) was built based on this gridded DEM and displayed as a 3D surface. A shaded relief effect was applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies.

One of the variables established when creating the models is the threshold for missing data. For each individual triangle, the point density information is stored; if it meets the threshold, the corresponding surface will be displayed in green, if not it will be displayed in red (see Figure 10). It should also be noted that if this density model is created with the ground points only, it is expected to have void areas where buildings exist or in water; vegetation can also reduce the number of points hitting the ground, resulting in more distanced points.

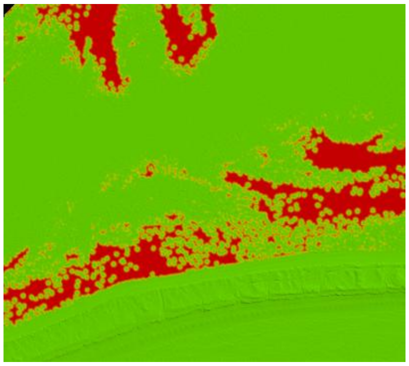


Figure 10 *– Ground model with density information (red means sparse data).*

The first step of Dewberry's qualitative workflow was to verify the point distribution by systematically loading a percentage of the tiles as masspoints colored by flight line (Figure 11) or by class (Figure 12). This particular type of display helps us visualize and better understand the scan pattern, the flight line orientation, flight coverage, and gives an additional confirmation that all classes are present and seem to logically represent the terrain.

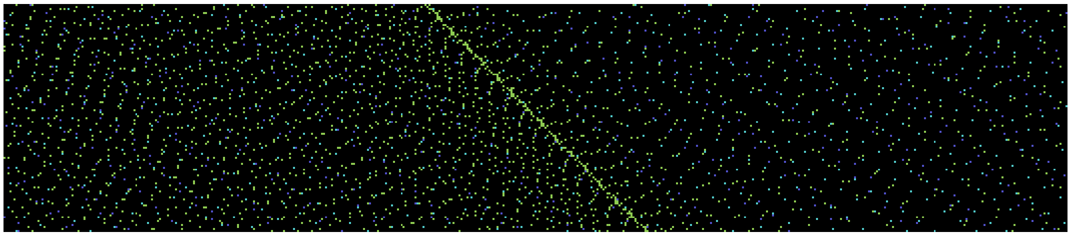
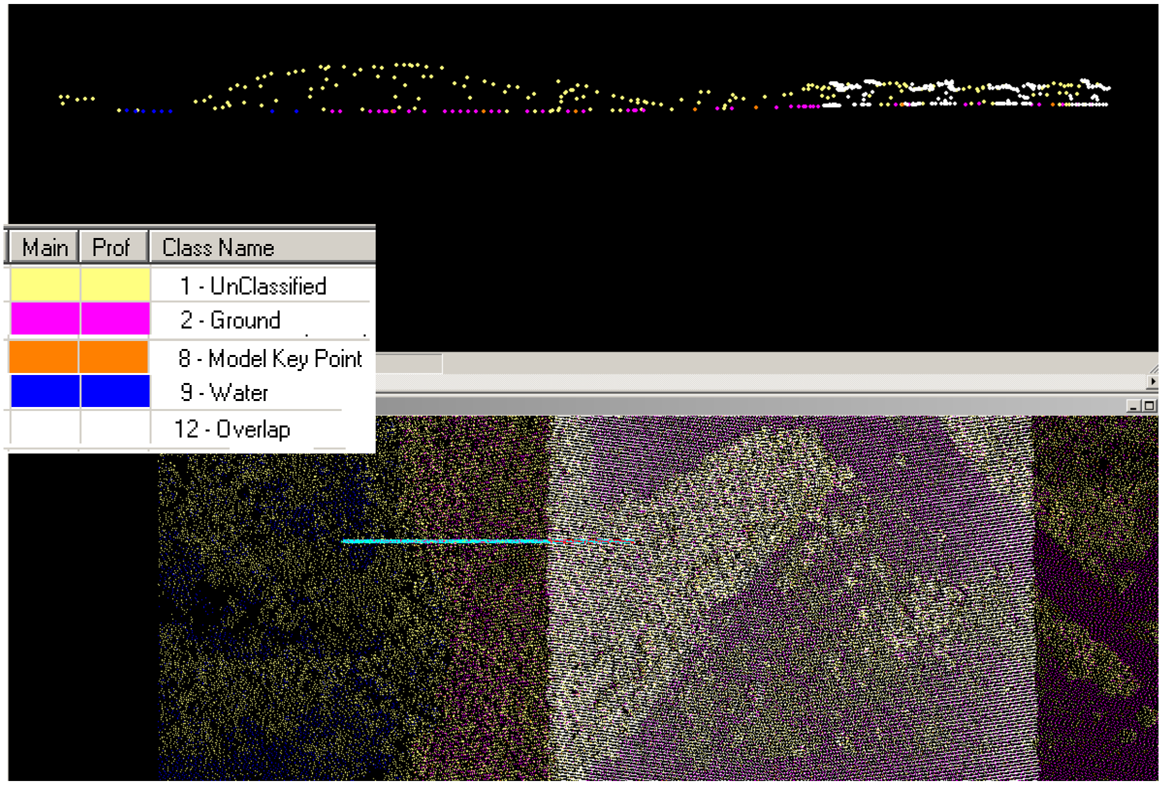


Figure 11 *– Detail of LiDAR points colored by flight line. Note the variations in the scan pattern.*



Main	Prof	Class Name
🟨	🟨	1 - UnClassified
🟪	🟪	2 - Ground
🟧	🟧	8 - Model Key Point
🟦	🟦	9 - Water
⬜	⬜	12 - Overlap

Figure 12 *- Full point cloud colored by classification.*

The second step was to verify data completeness and continuity using the bare-earth DEM with density information, displayed at a macro level. If, during this macro review of the ground models, potential artifacts or large voids are found, the digital surface model (DSM) based on the full point cloud including vegetation and buildings will be used to pinpoint the extent and the cause of the issue. Moreover, the intensity information stored in the LiDAR data can be visualized over this surface model, helping in interpretation of the terrain. Finally, if the analyst suspects a systematic error relating to data collection, a visualization of the 3D raw masspoints is performed, rather than visualizing as a surface.

Dewberry's micro-level qualitative review is the process of importing, comparing and analyzing these two later types of models (DSM with intensity and raw masspoints), along with cross section extraction, surface measurements, and density evaluation.

5.3.2 Quality report

Dewberry's qualitative review consists of a micro visual inspection of all the tiles. There is no automated toolset more effective than the manual inspection by a GIS analyst to find errors in automated processing of LiDAR data. The analyst will inspect the data for processing anomalies, classification errors, and full point cloud artifacts remaining in the ground surface models.

After closely examining the dataset, the bare earth model was determined to be of excellent quality. Dewberry found very few errors in the data as outlined in the text and images below. The majority of the calls are due to minor artifacts and poor LiDAR penetration due to the dense vegetation. However, these issues are not serious enough to render the data unusable.

Artifacts

It is not uncommon for the classification algorithms to occasionally misclassify non-ground points. This misclassification results in remnants of vegetation or manmade structures known as artifacts that do not represent the bare-earth terrain. Figure 13 shows an example of an area where building points were left in during the classification process. This type of error is very common in LiDAR datasets however it is easy to fix and does not alter the usability of the LiDAR product.

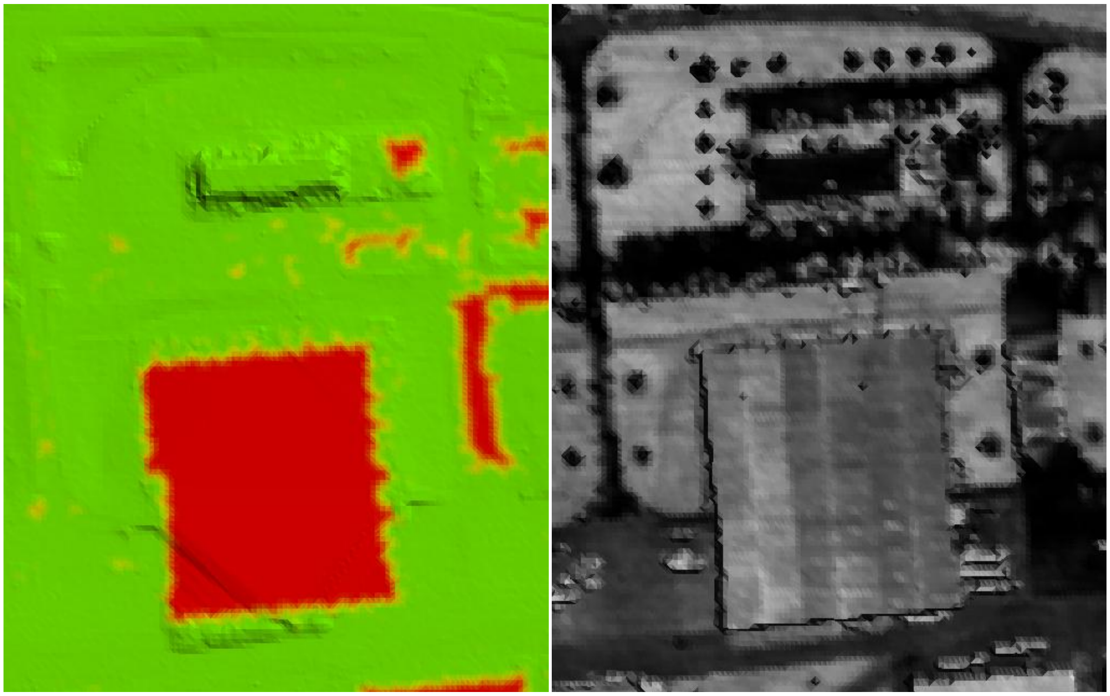


Figure 13 *- 6866-02 Building artifact.*

Acquisition "Drop-Off"

Another anomaly detected in the data is the lack of returns on certain type of roads, buildings, runways, and parking lots, as depicted in Figure 14. Several possible explanations for this anomaly are low gain setting or low emission power, both resulting in a non detection of a weak reflected signal. A weak reflected signal can occur on certain types of asphalt that absorb the near infrared wavelength. For the roads and buildings there is no simple fix possible except a re-flight without a guarantee of success. The data user should be aware that this issue has almost no impact on the ground integrity: buildings are removed regardless and roads edges are present allowing a proper definition of the terrain. Moreover, this kind of acquisition “drop-off” had a limited occurrence.

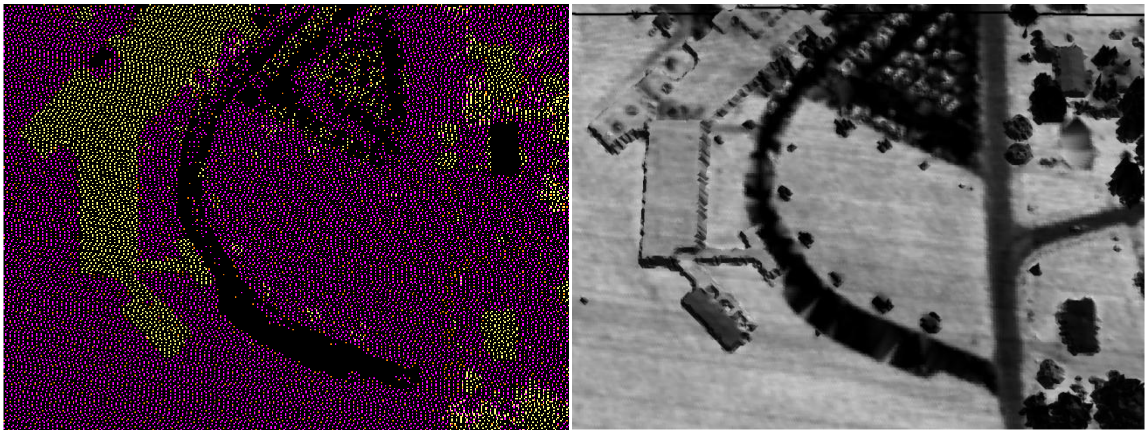


Figure 14 *- 6895-03 Acquisition drop-off. Left is full point cloud LAS file, yellow is unclassified (class 1), purple is ground (class 2) and black is the absence of points. Right is full point cloud model with intensity.*

Negligible Flight Line Ridges

A few tiles within the dataset included small ridges at seam lines caused by a vertical mismatch between two adjacent flight lines. Since the overlap is stored in a different class, no real blending of flight lines is done and a seam line is used to cut the data from one line to the next. The result is two flight lines that do not precisely match vertically. Although they are easily visible in the shaded ground model with vertical exaggeration, these ridges are below the commonly accepted threshold of 20 cm and are therefore minor. See Figure 15.

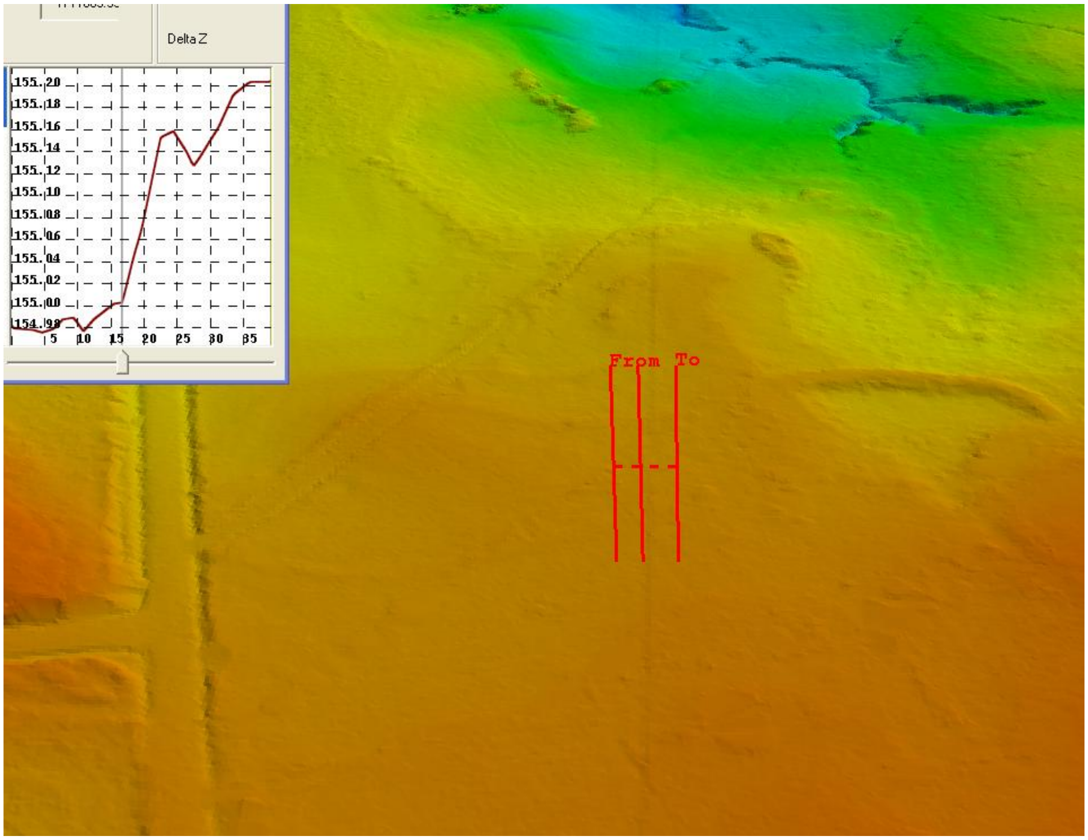


Figure 15 *– 7814-03 Negligible flight line offset.*

Poor LiDAR Penetration

Dewberry identified a couple areas with patches of low density of ground points. This may be unavoidable. When the vegetation is very dense, the LiDAR may not penetrate the canopy all the way to the ground as illustrated in Figure 15. This type of sparse density of ground points was found throughout the dataset and causes the surface to be sometimes less accurate. Poor LiDAR penetration cannot be fixed without a re-flight, but even then, this might be inherent to the type of vegetation surveyed. While increasing the flight line overlap would provide different angles of incidence and would increase the chance of penetrating the canopy, this is more expensive, and it is possible that the density of the vegetation prevents any point from reaching the ground. Regardless, the accuracy of the data is always expected to diminish in vegetated areas, and when a few ground points are available an elevation model can be interpolated with acceptable precision, especially in flat terrain.

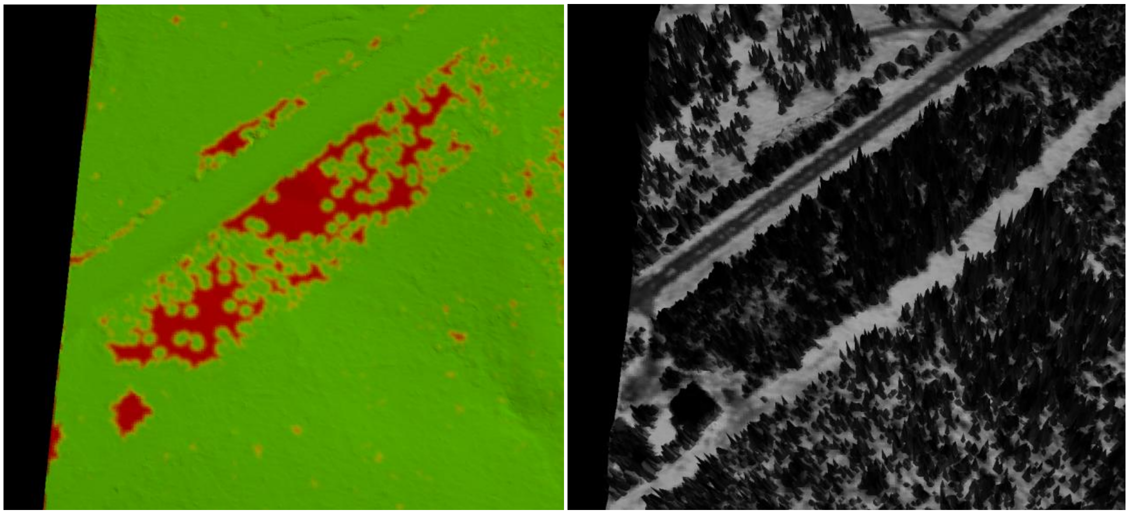


Figure 16 *– 6829-03 Poor LiDAR penetration. Left image is ground density model, right is full point cloud model with intensity.*

Conclusion

Overall the LiDAR data meets the minimum standards for absolute and relative accuracy. The level of cleanliness for the bare-earth terrain easily meets the specifications and no major anomalies were found. The processing performed exceptionally well given the low relief terrain. The figures highlighted above are a sample of the minor issues that were encountered and are not representative of the majority of the data. The intensity images meet specifications and the terrain and multipoint entities are correctly derived from the classified bare earth LiDAR points.

Checkpoints

The horizontal coordinate system is South Carolina State Plane **International feet,** horizontal datum NAD83 **HARN** with **elevation in meters** (NAVD88).

The point numbering scheme uses a three digit sequence starting with the county number (SC numbers its counties in alphabetical order), a dash, followed by zone number, a dash and then a sequence number corresponding to order of collection within the zone, the land cover code was concatenated in front of the number.

pointNo	easting	northing	elevation	zLidar	LandCoverCode	DeltaZ	AbsDeltaZ
b24-1-4	1611562.542	907835.138	203.494	203.407	B	-0.088	0.088
b24-1-6	1616839.747	901473.836	206.783	206.673	B	-0.110	0.110
b24-2-18	1657132.988	861943.713	177.295	177.373	B	0.078	0.078
b24-2-18a	1657133.027	861943.675	177.327	177.375	B	0.048	0.048
b24-3-18	1670710.099	892611.638	158.389	158.285	B	-0.104	0.104
b24-3-19	1670979.097	892645.221	159.705	159.610	B	-0.095	0.095
b24-4-13	1700228.143	859244.068	144.680	144.714	B	0.034	0.034
b24-4-14	1700166.229	859251.892	145.009	144.968	B	-0.041	0.041
b24-4-15	1700311.067	859309.812	145.181	145.200	B	0.019	0.019
b24-5-16	1708386.325	827216.425	169.699	169.709	B	0.010	0.010
b24-5-7	1714304.550	829416.301	172.937	172.946	B	0.009	0.009
b24-6-11	1677423.275	806129.326	147.794	147.722	B	-0.072	0.072
b24-7-12	1619717.544	803439.673	165.434	165.493	B	0.059	0.059
b24-7-9	1619532.127	803392.482	167.763	167.847	B	0.084	0.084
h24-1-10	1622583.576	912078.099	185.696	185.636	C	-0.060	0.060
h24-1-12	1619020.093	900556.581	205.363	205.251	C	-0.112	0.112
h24-1-13	1611948.981	913207.155	208.794	208.681	C	-0.113	0.113
h24-1-2	1608870.590	901770.761	197.202	197.248	C	0.046	0.046
h24-1-5	1611032.956	908777.589	206.813	206.752	C	-0.061	0.061
h24-1-7	1616700.472	901633.213	203.480	203.402	C	-0.078	0.078
h24-2-12	1648370.491	860928.650	203.459	203.697	C	0.238	0.238
h24-2-25	1655940.279	867589.985	186.573	186.630	C	0.057	0.057
h24-2-27	1655909.739	867854.062	189.162	189.120	C	-0.043	0.043
h24-3-11	1680998.854	893146.449	140.835	140.821	C	-0.014	0.014
h24-3-9	1679612.796	890730.352	142.633	142.548	C	-0.085	0.085
h24-4-2	1702700.651	860949.113	158.410	158.386	C	-0.024	0.024
h24-4-5	1702259.811	861673.815	162.976	162.988	C	0.012	0.012
h24-4-7/SPEARMAN	1706775.282	850652.876	148.461	148.481	C	0.020	0.020
h24-5-11	1710871.948	827484.963	178.980	178.886	C	-0.094	0.094
h24-5-15	1708259.479	827188.287	169.725	169.697	C	-0.028	0.028
h24-5-6	1714345.028	829524.343	173.250	173.222	C	-0.028	0.028
h24-5-8	1714304.039	829352.431	171.312	171.447	C	0.135	0.135

h24-6-4	1683964.036	802537.130	159.990	159.949	C	-0.042	0.042
h24-6-8	1666514.060	813950.226	164.263	164.224	C	-0.039	0.039
h24-7-13	1619834.847	803427.487	165.004	164.997	C	-0.007	0.007
h24-7-14	1619860.345	803334.512	164.401	164.363	C	-0.038	0.038
o24-1-1	1609499.541	901008.578	199.658	199.528	A	-0.130	0.130
o24-1-14	1613275.171	913209.725	209.536	209.495	A	-0.041	0.041
o24-1-15	1616039.161	903501.512	201.033	200.905	A	-0.128	0.128
o24-1-3	1609894.878	901898.633	204.078	203.948	A	-0.131	0.131
o24-1-8	1619481.350	914418.348	207.434	207.318	A	-0.116	0.116
o24-1-9	1614473.272	913481.976	211.422	211.281	A	-0.141	0.141
o24-2-13	1648307.322	861138.053	203.718	203.588	A	-0.130	0.130
o24-2-15	1648360.885	860551.913	200.364	200.250	A	-0.114	0.114
o24-2-16	1648882.421	860701.920	202.791	202.638	A	-0.153	0.153
o24-2-19	1657013.036	861870.058	179.069	178.987	A	-0.082	0.082
o24-2-20	1657138.780	861710.962	178.108	178.082	A	-0.026	0.026
o24-2-26	1655927.073	867654.158	186.880	186.892	A	0.012	0.012
o24-2-28/2424	1655820.154	868470.406	192.533	192.505	A	-0.028	0.028
o24-2-30	1656125.453	868343.603	194.336	194.342	A	0.005	0.005
o24-2-8/HAMPTON	1648665.378	860644.469	202.418	202.335	A	-0.083	0.083
o24-3-1	1671750.153	883827.183	178.309	178.024	A	-0.285	0.285
o24-3-10	1679810.905	891045.869	136.459	136.350	A	-0.109	0.109
o24-3-14	1668044.742	894846.300	147.424	147.334	A	-0.090	0.090
o24-3-2	1671812.406	884391.555	177.682	177.522	A	-0.160	0.160
o24-3-3	1672067.398	884649.972	181.908	181.783	A	-0.125	0.125
o24-4-1/BAKE	1703096.179	861078.937	160.338	160.344	A	0.006	0.006
o24-4-12	1705938.863	851022.414	149.522	149.431	A	-0.091	0.091
o24-4-8	1706848.823	850677.893	148.679	148.622	A	-0.057	0.057
o24-5-1	1715754.491	833818.798	172.828	172.751	A	-0.077	0.077
o24-5-13	1710734.234	827657.684	178.300	178.171	A	-0.129	0.129
o24-5-14/WOMAC2AZMK	1710140.439	829500.552	174.675	174.491	A	-0.184	0.184
o24-5-4	1715610.150	833936.449	170.278	170.198	A	-0.080	0.080
o24-5-9/WOMAC2	1710635.732	827779.378	180.049	179.905	A	-0.144	0.144
o24-6-2	1683689.453	802627.818	159.844	159.689	A	-0.155	0.155
o24-6-5	1683860.280	802611.880	159.547	159.456	A	-0.091	0.091
o24-6-6	1666818.060	814001.572	166.657	166.581	A	-0.076	0.076
o24-7-15/SEMAPHORE	1620925.257	805120.239	176.697	176.686	A	-0.011	0.011
o24-7-2	1620854.065	805151.300	176.002	175.956	A	-0.046	0.046
o24-7-6/CUTBANK	1627086.776	813318.242	151.684	151.594	A	-0.090	0.090
o24-7-7/CALLISON	1627702.538	805187.292	156.187	156.133	A	-0.054	0.054
oCP1REO	1609852.579	901500.791	201.153	201.009	A	-0.144	0.144
oCP2	1619366.977	914783.597	204.864	204.807	A	-0.057	0.057
oLUMLEYEta	1672356.867	884316.591	183.329	183.181	A	-0.148	0.148

u24-1-11	1619644.160	906227.346	192.822	192.717	E	-0.105	0.105
u24-1-17	1626114.870	915836.524	190.894	190.775	E	-0.119	0.119
u24-2-10	1648662.865	860541.436	199.479	199.393	E	-0.086	0.086
u24-2-11	1648482.684	860472.610	198.928	198.813	E	-0.115	0.115
u24-2-14	1648154.581	861142.917	203.191	203.109	E	-0.082	0.082
u24-2-21	1657038.131	861726.687	181.267	181.231	E	-0.036	0.036
u24-2-22a	1656884.585	861855.715	180.852	180.779	E	-0.073	0.073
u24-2-24	1656739.291	861492.207	182.895	182.831	E	-0.064	0.064
u24-2-29	1655939.473	868407.075	192.190	192.207	E	0.017	0.017
u24-2-31/CAMBRIDGE	1656874.241	861624.749	182.500	182.519	E	0.018	0.018
u24-2-9	1648802.993	860380.986	199.531	199.389	E	-0.142	0.142
u24-3-12	1680927.368	892929.948	137.336	137.195	E	-0.141	0.141
u24-3-13	1684648.338	894663.688	173.719	173.577	E	-0.142	0.142
u24-3-15/GRELAU	1680091.569	891201.821	135.678	135.734	E	0.056	0.056
u24-3-4	1670154.925	883872.534	175.053	174.902	E	-0.151	0.151
u24-3-5	1670249.497	883730.889	175.340	175.146	E	-0.194	0.194
u24-3-6	1670558.327	883793.814	174.166	174.021	E	-0.145	0.145
u24-3-7	1670184.789	883936.779	175.396	175.223	E	-0.173	0.173
u24-4-27	1703134.793	861045.145	160.362	160.291	E	-0.071	0.071
u24-4-9	1707231.612	850484.952	148.029	147.964	E	-0.065	0.065
u24-5-10	1710896.956	827619.365	177.644	177.474	E	-0.170	0.170
u24-5-17	1708291.345	827281.055	170.907	170.834	E	-0.073	0.073
u24-5-55	1715756.434	833908.292	171.479	171.380	E	-0.099	0.099
u24-6-1/KIRKSEY	1683729.007	802755.205	160.035	159.881	E	-0.154	0.154
u24-6-3	1683843.204	802581.876	159.237	159.084	E	-0.153	0.153
u24-6-7	1666672.797	814190.451	167.611	167.523	E	-0.088	0.088
u24-7-8	1627653.146	805248.596	156.749	156.645	E	-0.104	0.104
w/b24-7-11	1619682.751	803381.671	165.997	166.045	D	0.048	0.048
w24-1-18	1625964.189	916037.217	192.116	192.064	D	-0.052	0.052
w24-1-19	1618402.834	917499.894	183.377	183.235	D	-0.142	0.142
w24-2-32	1657205.667	861766.581	177.122	177.129	D	0.007	0.007
w24-2-34	1657240.592	861847.086	176.368	176.435	D	0.067	0.067
w24-2-35	1652814.081	855033.540	190.977	190.848	D	-0.129	0.129
w24-3-16	1670634.040	892621.057	158.470	158.331	D	-0.139	0.139
w24-3-17	1670657.504	892584.293	157.965	157.793	D	-0.172	0.172
w24-4-10a	1707271.621	850347.042	148.455	148.397	D	-0.058	0.058
w24-4-3	1702736.078	860903.862	157.886	157.929	D	0.043	0.043
w24-5-12	1710736.946	827417.523	177.474	177.387	D	-0.087	0.087
w24-5-2	1715718.738	833928.986	171.037	170.974	D	-0.063	0.063
w24-5-3	1715706.085	833966.746	171.038	170.542	D	-0.496	0.496
w24-6-10	1681349.675	804011.180	154.180	154.130	D	-0.050	0.050
w24-6-9	1681417.723	803981.983	154.110	154.008	D	-0.102	0.102

w24-7-10	1619660.360	803387.020	166.464	166.377	D	-0.087	0.087
w24-7-3	1621843.748	805658.575	167.148	167.262	D	0.114	0.114
w24-7-4	1621934.025	805777.640	169.658	169.628	D	-0.030	0.030
w24-7-5	1621863.569	805813.645	170.432	170.398	D	-0.034	0.034