LiDAR Quality Assurance (QA) Report
Union County, South Carolina
February 25, 2009

Submitted to:
USGS
Prepared by:
Dewberry
Fairfax, VA

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 Union County, SC, produced by Dewberry's subcontractor, Fugro EarthData, under the referenced USGS task order. The LiDAR data was acquired in January, 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 good 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 646 tiles (each 5000 ft x 5000 ft) were delivered covering all of Union 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	131	18.5 cm	6.3 cm
FVA	20	41	36.3 cm	11.1 cm
CVA	60	131	36.3 cm	12.0 cm
SVA-bare earth	20	41	36.3 cm	14.3 cm
SVA-vegetated	20	50	36.3 cm	12.0 cm
SVA-urban	20	40	36.3 cm	8.9 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 misclassification, inconsistent editing, 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 Union 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.

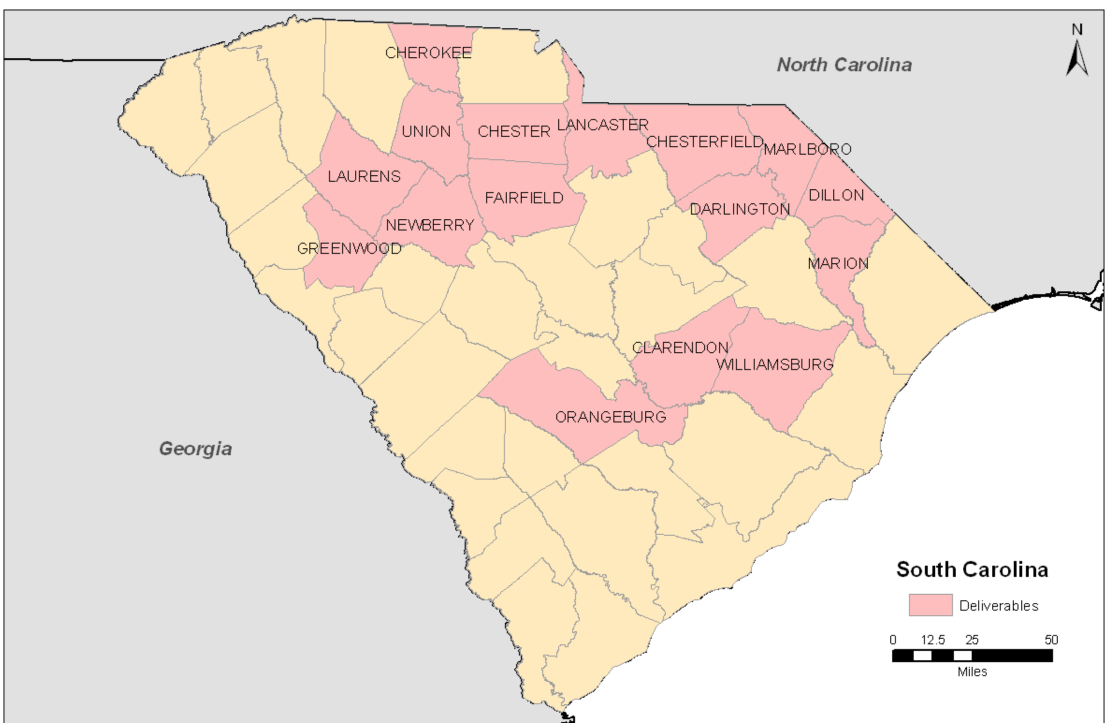

***Figure 1** – Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

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.

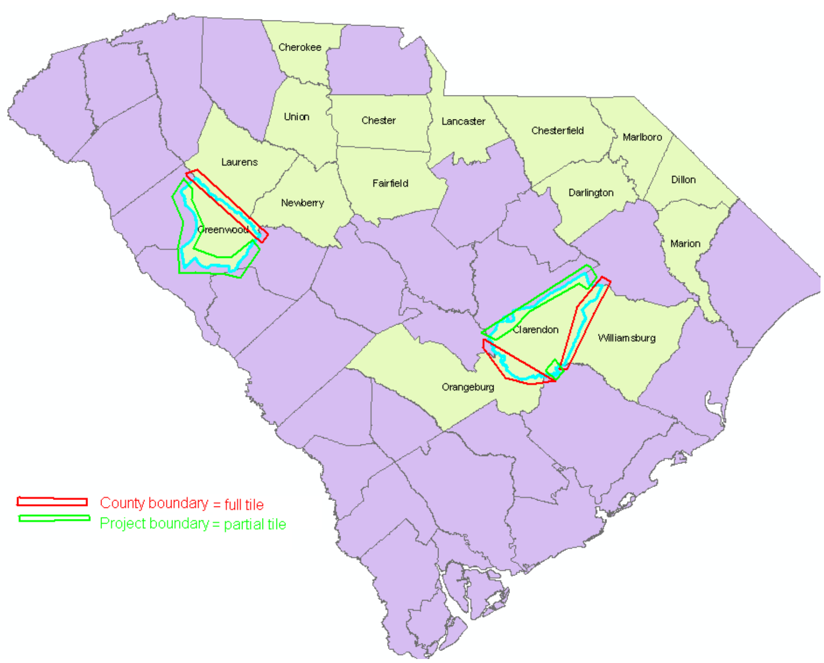

***Figure 2** – Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

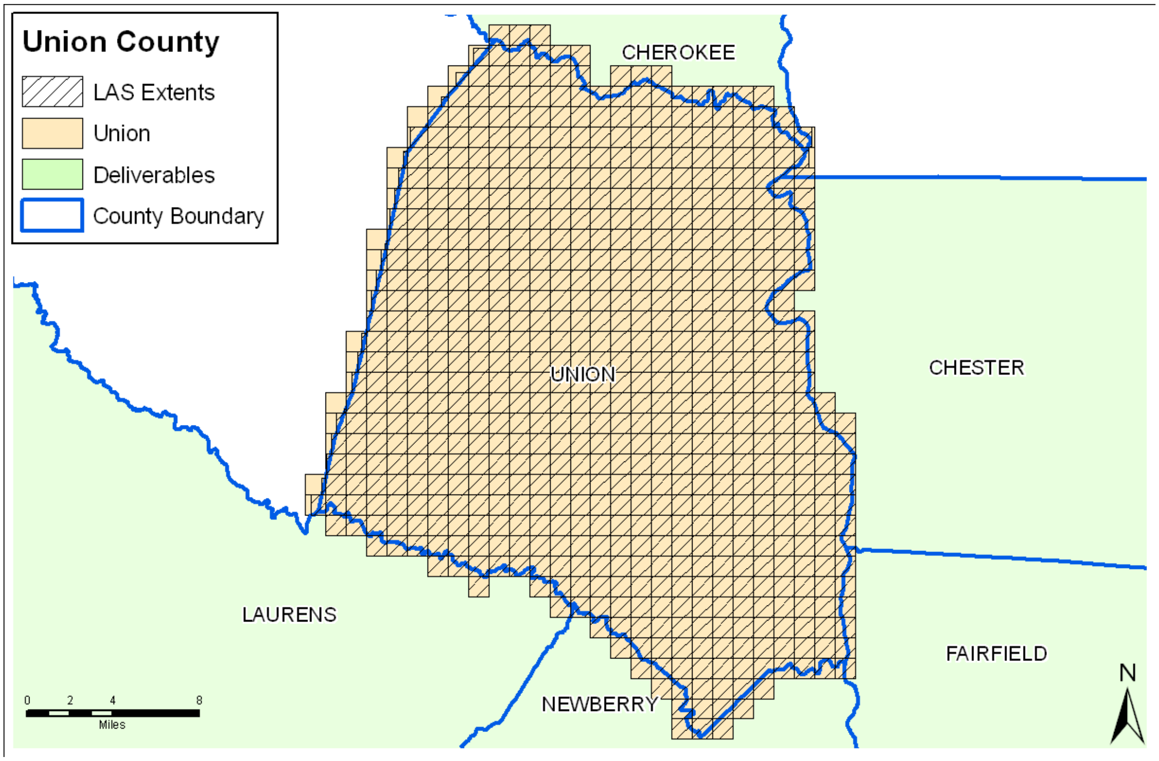

Figure 3 *– The LiDAR coverage of Union County. Neighboring deliverable counties are shown in green.*

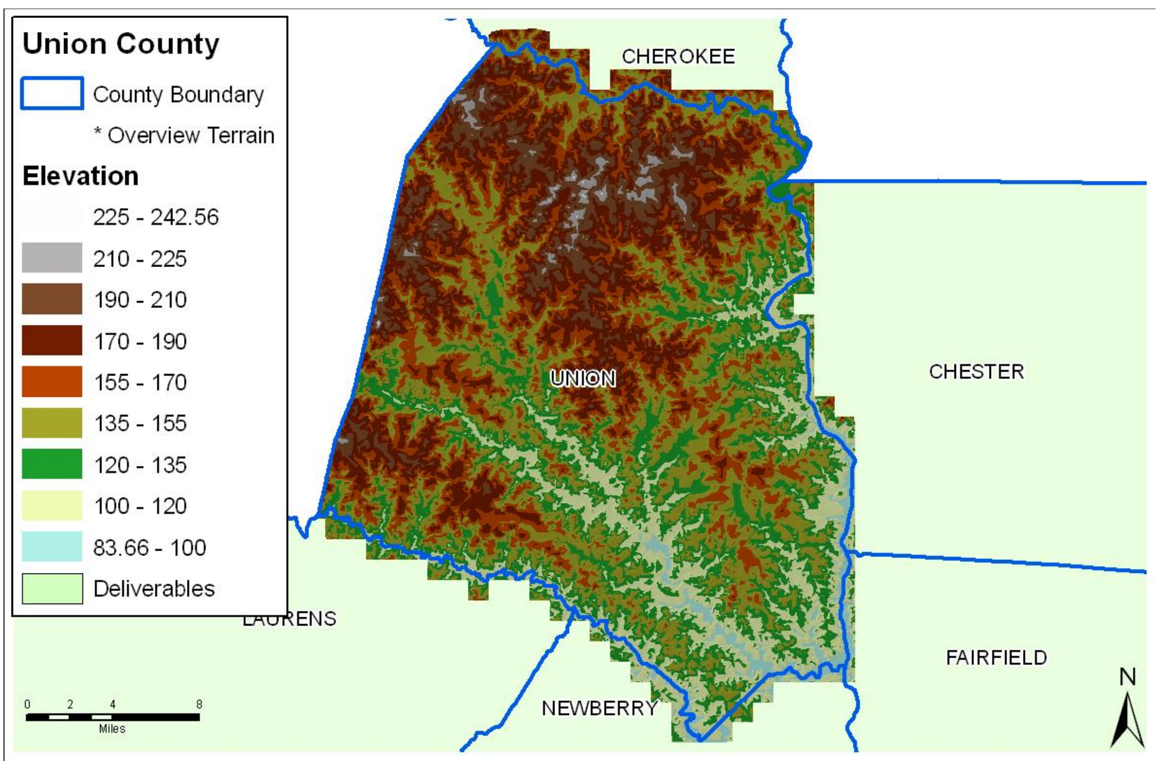

Figure 4 *– The terrain for Union has a 50 ft buffer outside of the project boundary.*

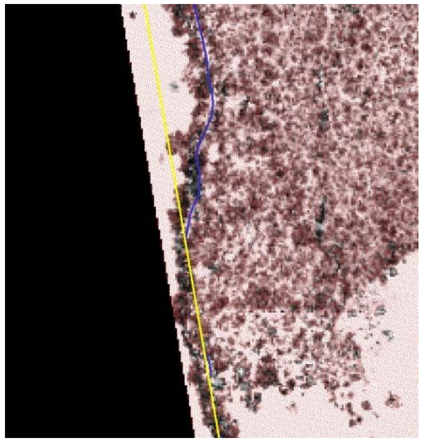

Figure 5 *- Ground masspoints (red) and intensity images extend 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydrolines are clipped at the project boundary and the watershed boundary.*

3 QA of intensity images

646 intensity images in GeoTiff format were delivered for Union 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: 7040-01.tif	Geotiff_Information:
File Information:	Version: 1
Standard : : TIFF File	Key_Revision: 1.0
Format : : Byte integers (8 bits)	Tagged_Information:
Pixels per Line : 1250	ModelTiepointTag (2,3):
Number of Lines : 1250	0 0 0
Samples per pixel : 1	1740000 1010000 0
File bits per sample : 8	ModelPixelScaleTag (1,3):
Actual bits per sample : 8	4 4 0
Untiled file	End_Of_Tags.
Number of overviews : 0	Keyed_Information:
Scanning device resolution : 72 : lines/inch	GTModelTypeGeoKey (Short,1): ModelTypeProjected
Orientation : 4 : Row major order, origin at top left	GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
NO scan line headers : non-scannable file	ProjectedCSTypeGeoKey (Short,1): Unknown-3361
Packet size (16-bit words) : 0	ProjLinearUnitsGeoKey (Short,1): Linear_Foot
Free vlt space (16-bit words) : 2000000000	End_Of_Keys.
Free packet space (16-bit words) : 2000000000	End_Of_Geotiff.
Raster to UOR matrix:	PCS = 3361 (name unknown)
Unspecified or All Zero Matrix	Projection Linear Units: 9002/foot (0.304800m)
Raster to World Matrix:	Corner Coordinates:
Units: Feet	Upper Left (1740000.000,1010000.000)
amx[0]= 4, amx[1]= 0, amx[2]= 1740000	Lower Left (1740000.000,1005000.000)
amx[3]= 0, amx[4]= -4, amx[5]= 1010000	Upper Right (1745000.000,1010000.000)
1740000 , 1010000	Lower Right (1745000.000,1005000.000)
1745000 , 1010000	Center (1742500.000,1007500.000)
1745000 , 1005000	
1740000 , 1005000	

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 646 LiDAR files covering the Union County area. They are in the correct format and projection:

- LAS version: 1.1
- Point data format: 1
- Projection set in the header:
  - o NAD_1983_HARN_StatePlane_South_Carolina_FIPS_3900_Feet_Intl;
  - o Horizontal unit: linear feet;
  - o NAVD88 - Geoid03;
  - o 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 Union County is around 5.3 million which proves that the average density is more than what is required. The tiles are within the anticipated size range except for where fewer points are expected (near the external project boundary where tiles are clipped). It was discovered during the completeness check that the tiles located along the northern boundary of Union County contain a noticeably higher density of points (Figure 6). Upon further investigation it was revealed that several flight lines from both the Union data and the Cherokee data to the north overlapped each other. The overlap points from both datasets were classified into LAS class 12 (overlap) however the ground class remains at the appropriate density.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 116.6m and 242.5m, 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.

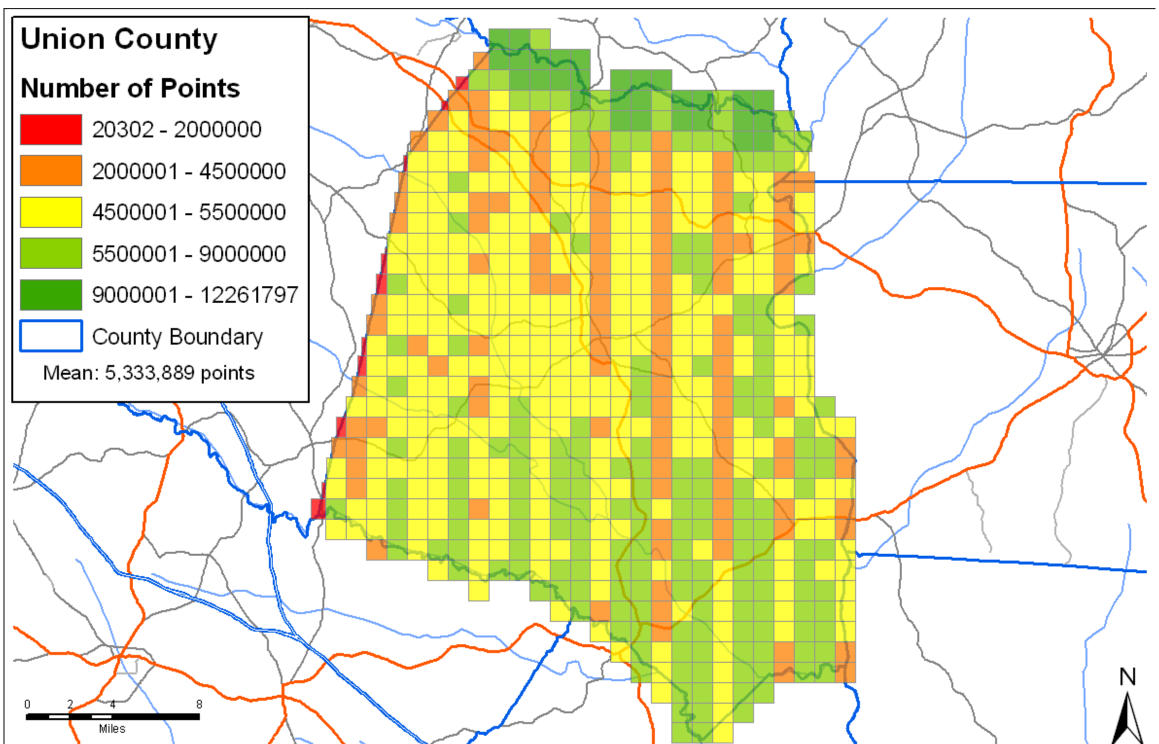

Figure 6 *– Number of points per tile. The red tiles at the border are expected to have fewer points.*

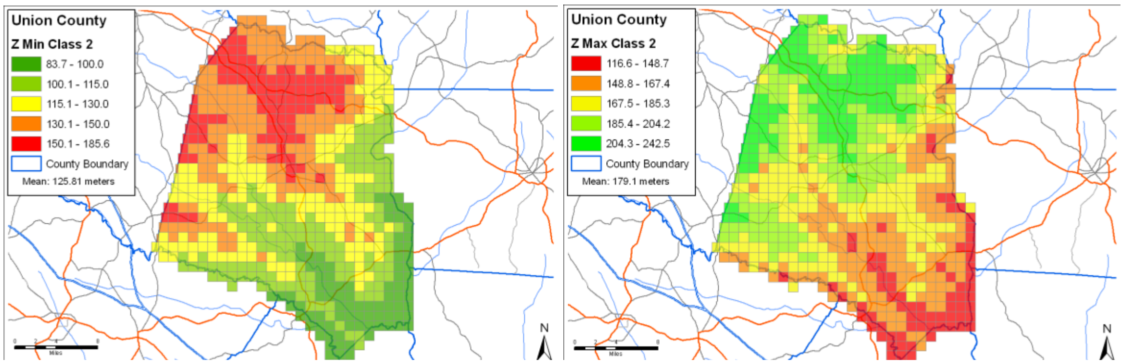

Figure 7 *– Z min and Z max elevation by tile for ground points (class 2).*

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 131 points were collected, as presented in Table 3, with 50 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 Appendix A. 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	41
b - Bush	0	16
h - High Grass	10	18
w - Woods	10	16
u - Urban	20	40
Total	**60**	**131**

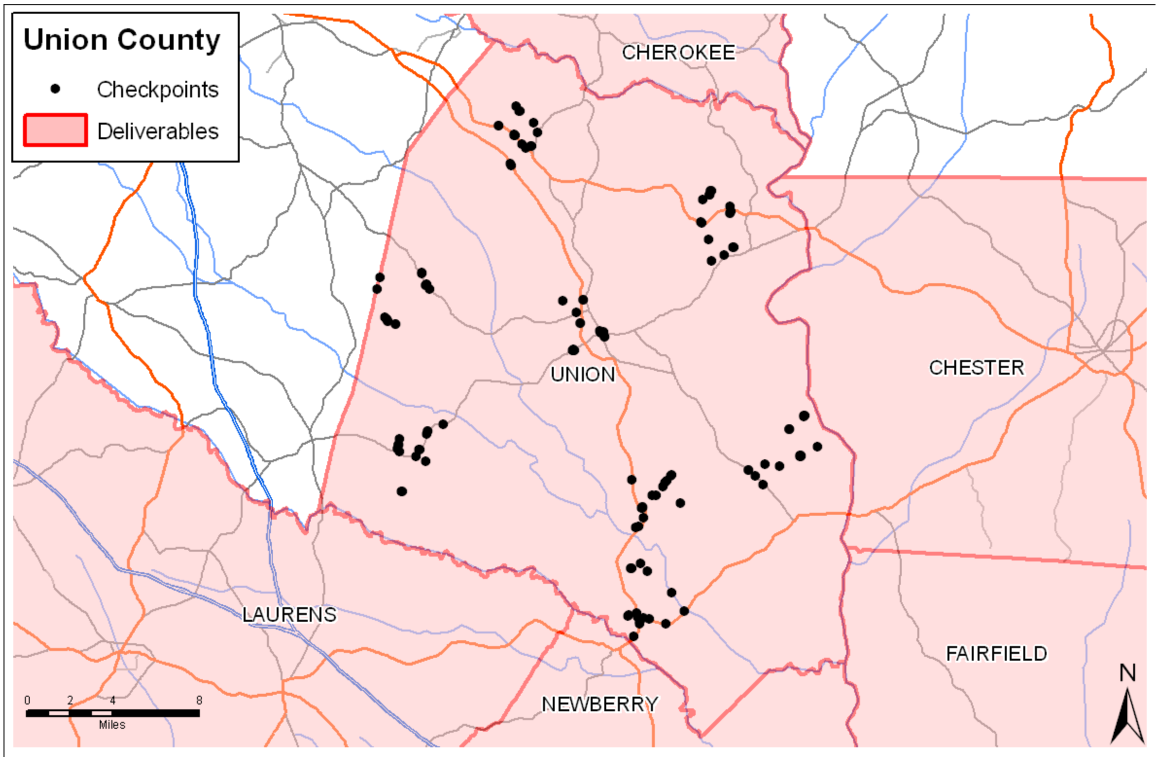

***Figure 8** – Survey checkpoints from South Carolina Geodetic Survey.*

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 95^{th} 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 95^{th} 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 Union 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 (0.068 m) x 1.9600, or 0.123 m (12.3 cm).

Table 4 - Final statistics for Union 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	0.063	0.034	0.039	-0.248	0.053	131	-0.143	0.166
Bare Earth	0.056	0.025	0.024	-0.424	0.051	41	-0.143	0.146
Vegetated	0.077	0.051	0.067	-0.613	0.057	50	-0.089	0.166
Urban	0.049	0.023	0.021	0.025	0.043	40	-0.081	0.140

Table 5 shows the complete results of the Union data set run through the NDEP/ASPRS process; the CVA value is 0.120 m (12.0 cm). The similar results between the two methods (12.3 cm and 12.0 cm) demonstrate that the errors approximate a normal error distribution. All of the calculated statistics for Union County fall well below the specifications.

Table 5 - Final statistics for Union 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	131		12.0	
Bare Earth	41	11.1		14.3
Vegetated	50			12.0
Urban	40			8.9

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

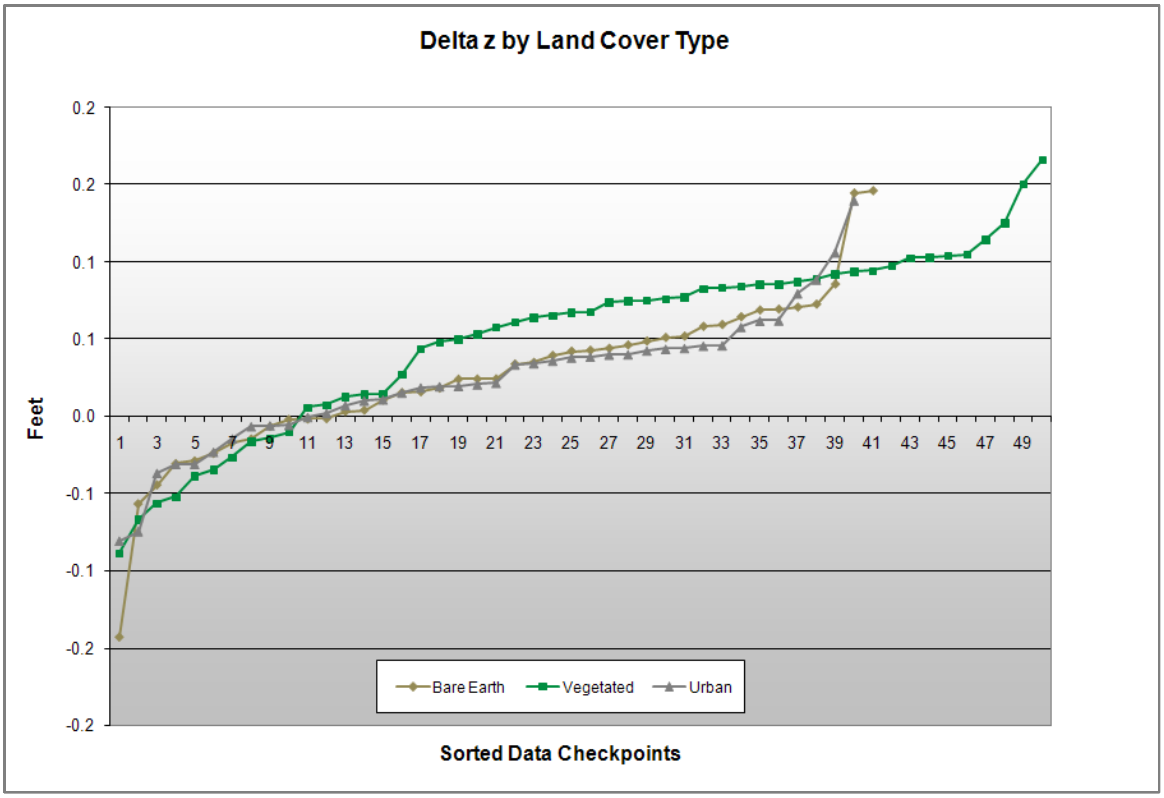

Figure 9 - *Checkpoints shown per land cover type and sorted by errors (DeltaZ).*

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 11.1 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 12.3 cm Consolidated Vertical Accuracy at 95% confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 12.0 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.

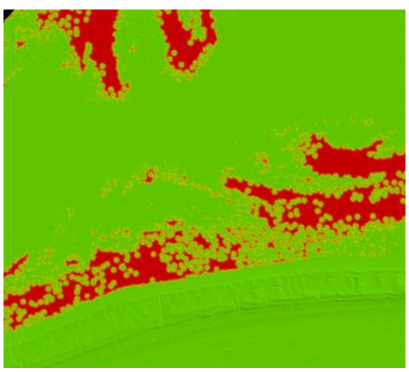

Figure 10 *– Ground model with density information (red means sparse data).*

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.

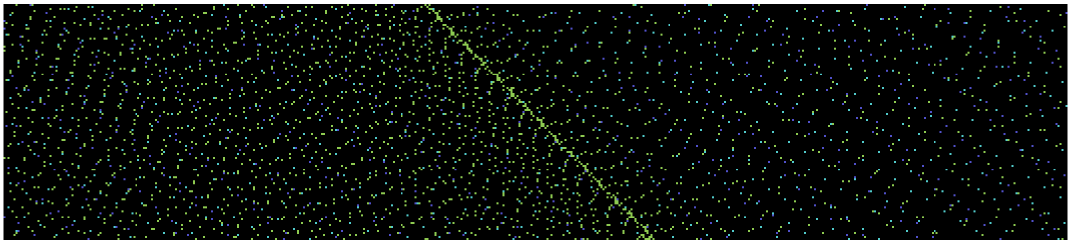

Figure 11 *– Detail of LiDAR points colored by flight line. Note the variations in the scan pattern.*

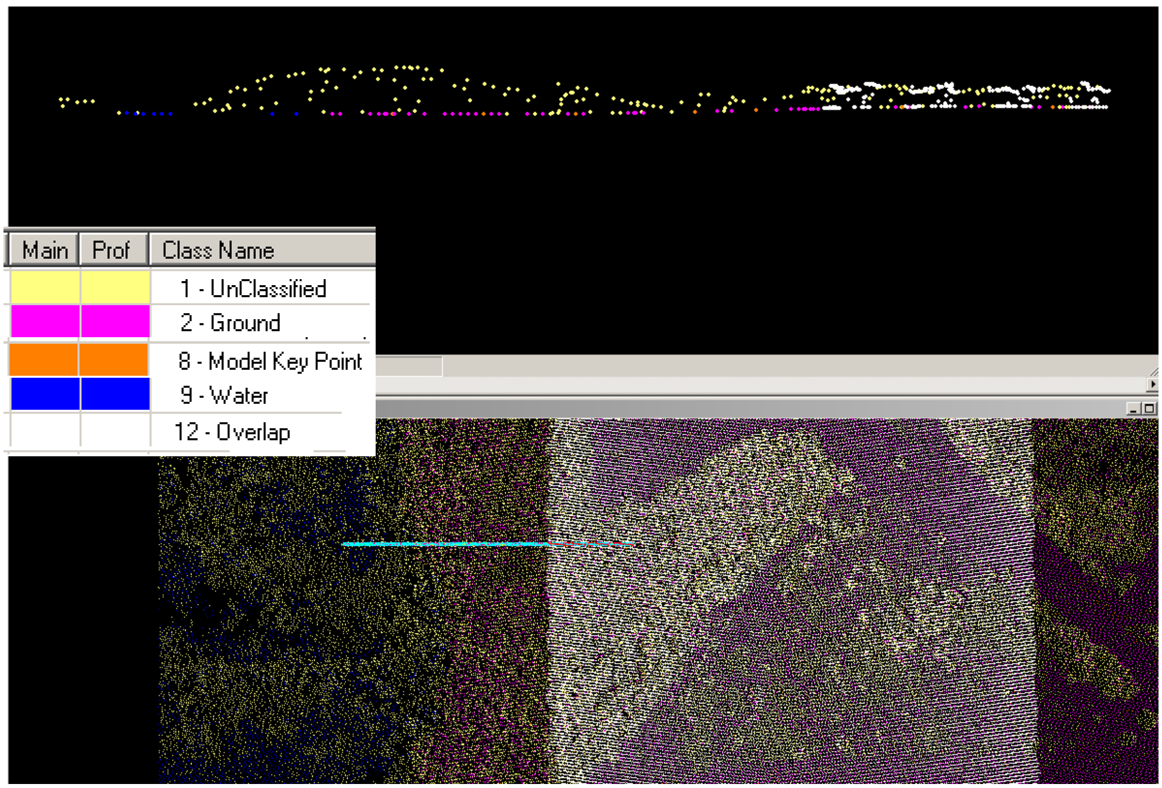

Figure 12 *- Full point cloud colored by classification.*

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 good 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 misclassifications, inconsistent editing, and acquisition drop-off. However, these issues are not serious enough to render the data unusable.

Misclassification

One of the more common problems seen in Union County was misclassification of ground points as water. During the classification process, it appears that hydrolines were used to classify water points. At the time of acquisition however, many of these areas were partially dry and the LiDAR sensor was able to return ground points resulting in a good representation of the ground surface in these areas. In the left image of Figure 13, the red area signifies an absence of ground points in a water retention area. The full point cloud intensity image in the middle shows that the LiDAR sensor actually returned some points in this area. The image on the right illustrates that these points were classified as water.

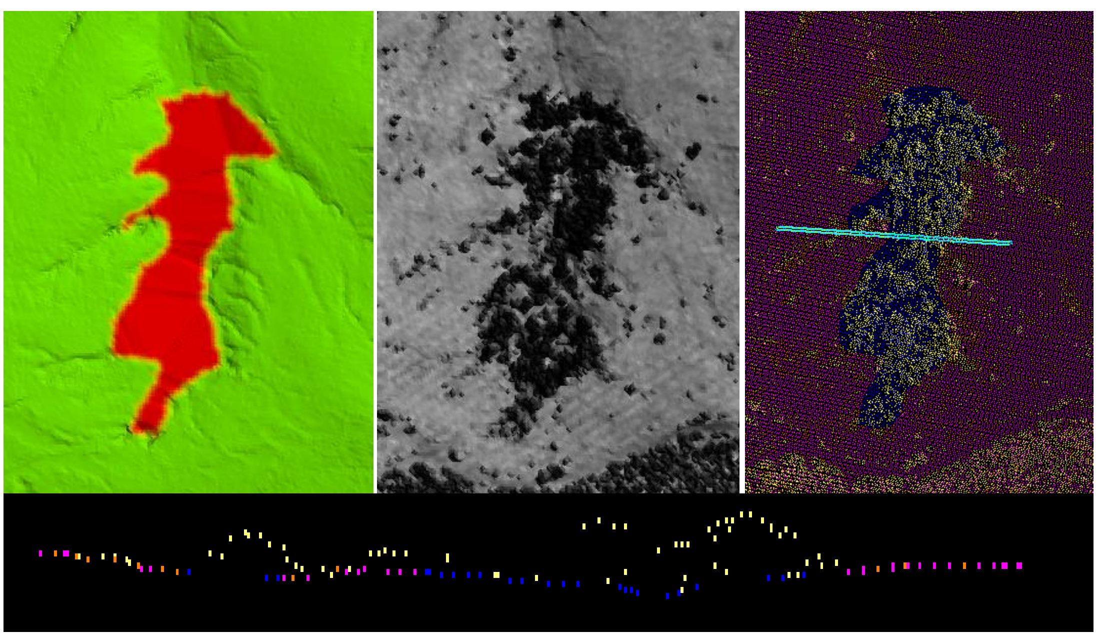

Figure 13 *- 7096-03 Misclassification of ground points. Top left image is ground density model and middle is full point cloud with intensity. Top right image is full point cloud colored by*

classification, yellow is unclassified (class 1), purple is ground (class 2), and blue is water (class 9). Bottom is cross-section showing the misclassified ground and water points.

A second type of misclassification found in Union County appears to be more editor error than systematic error. Figure 14 displays a small sliver of points that seem to have been accidentally placed into class 1 (unclassified). This type of misclassification was found a few times in the dataset and can be easily fixed.

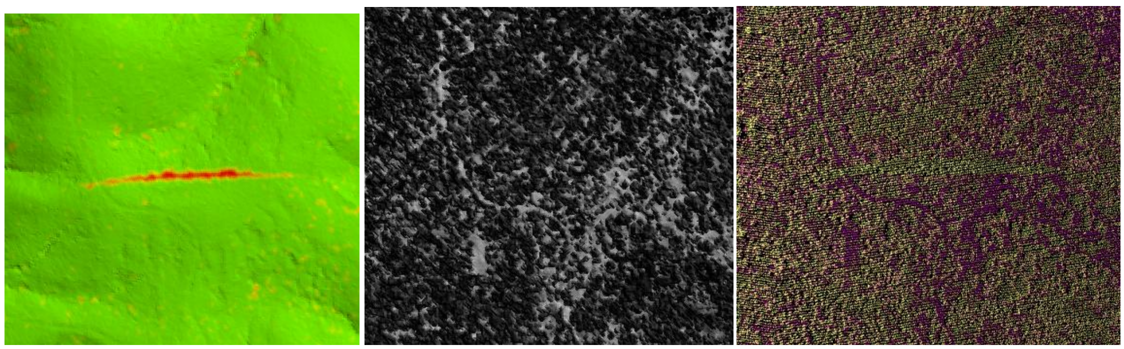

Figure 14 *- 7065-01 Misclassification of ground points. Left is ground density model and middle is full point cloud with intensity. Right is full point cloud colored by classification, yellow is unclassified (class 1) and purple is ground (class 2).*

Inconsistent Editing

The example of inconsistent editing shown in Figure 15 is not necessarily considered problematic, but is a good example of how classification procedures can be in inaccurate. In the images below, the berm located towards the bottom of the image was removed from the ground class while the berms at the top of the image were left in. In this case, these formations may in fact be temporary and would not have a significant effect on modeling.

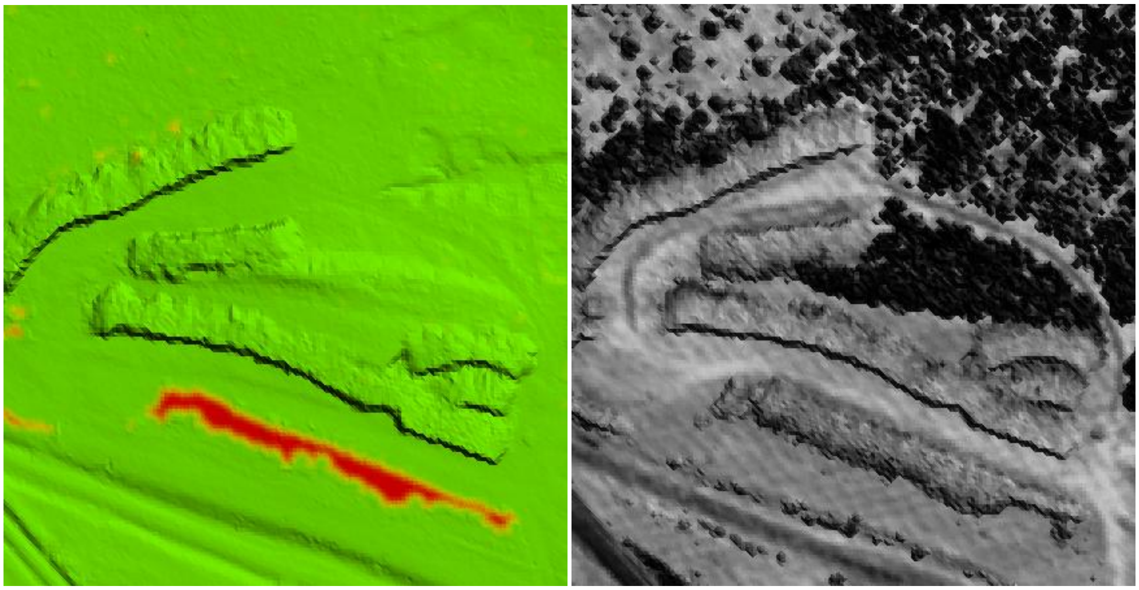

Figure 15 *- 8042-01 Inconsistent editing (Left: ground density model, Right: full point cloud model with intensity).*

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 16. 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.

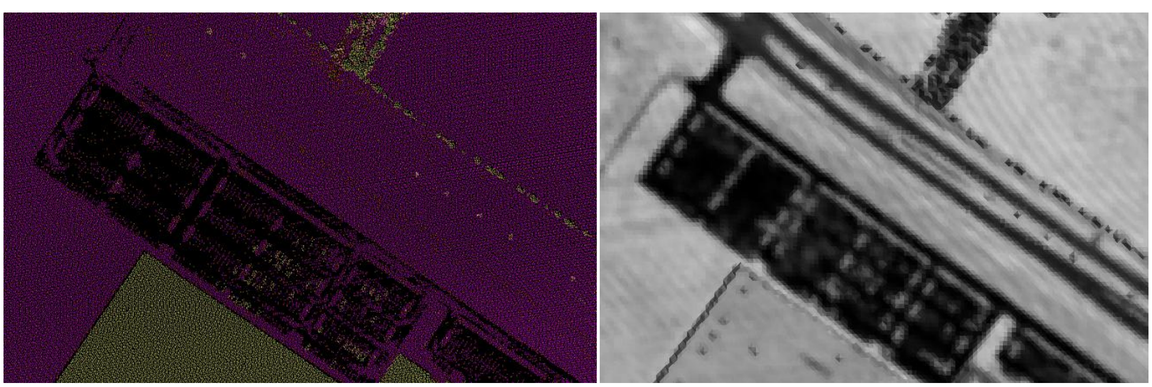

Figure 16 *- 7170-04 Acquisition drop-off in areas where the LiDAR pulse did not return a strong signal. Left image is full point cloud colored by classification, the black area is the absence of points. Right image is full point cloud model with intensity.*

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 user should be aware of the areas of minor misclassification when focusing on portions of the data, but the data set as a whole is of excellent quality. 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.

Appendix A 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	landCoverType	deltaZ
w44-7-11	1757916.745	1060151.438	211.211	211.294	Vegetated	0.083
u44-7-12	1758561.110	1063113.645	201.924	201.967	Urban	0.042
b44-7-10	1759957.768	1053212.815	203.963	204.050	Vegetated	0.087
o44-7-9	1760372.174	1052754.742	204.186	204.244	Bare Earth	0.058
u44-7-8	1760423.436	1052783.031	204.933	204.967	Urban	0.034
o44-7-7	1760587.769	1052443.040	199.925	199.974	Bare Earth	0.049
u44-7-6	1760607.291	1052405.484	199.940	199.986	Urban	0.046
h44-7-4	1762400.426	1051714.841	191.006	190.979	Vegetated	-0.027
b44-7-5	1762442.759	1051612.652	191.031	190.979	Vegetated	-0.052
o44-5-4	1762924.921	1021094.865	189.807	189.783	Bare Earth	-0.024
u44-5-3	1762973.322	1021061.340	190.476	190.470	Urban	-0.006
w44-5-1	1763061.120	1022052.932	182.158	182.219	Vegetated	0.061
b44-5-2	1763121.685	1022057.880	182.834	182.848	Vegetated	0.014
hSC49 B	1763147.067	1021990.539	183.496	183.598	Vegetated	0.102
o44-5-15	1763439.716	1023445.495	181.935	181.920	Bare Earth	-0.015
o44-5-14	1763493.328	1020365.318	189.278	189.288	Bare Earth	0.010
b44-5-8	1763961.086	1010581.110	176.195	176.289	Vegetated	0.094
h44-5-7	1764081.215	1010577.337	178.303	178.287	Vegetated	-0.016
u44-5-12	1767373.459	1019240.279	196.801	196.881	Urban	0.080
w44-5-6	1768238.764	1020924.353	193.443	193.450	Vegetated	0.007
u44-5-5	1768380.236	1020848.682	192.291	192.306	Urban	0.015
u44-7-13	1768776.998	1064211.699	204.495	204.557	Urban	0.062
o44-7-14	1768910.884	1064115.166	205.633	205.702	Bare Earth	0.069
o44-5-13	1769898.740	1018105.340	188.077	188.075	Bare Earth	-0.002
h44-7-1	1769901.114	1061078.706	202.546	202.622	Vegetated	0.076
oFIRE WATER	1769916.228	1061141.369	203.549	203.406	Bare Earth	-0.143
hYANKEE LANE	1770048.864	1024669.772	184.332	184.436	Vegetated	0.104
u44-7-2	1770064.445	1061241.944	203.873	203.883	Urban	0.010
w44-7-3	1770168.461	1061377.666	202.998	202.964	Vegetated	-0.034
o44-5-10	1770317.662	1025386.230	180.458	180.482	Bare Earth	0.024
u44-5-11	1770340.461	1025332.088	182.219	182.259	Urban	0.040
o44-7-15	1770878.476	1060238.933	199.207	199.222	Bare Earth	0.015

u44-5-9	1774106.807	1027199.495	168.341	168.363	Urban	0.022
oC 184	1787681.966	1100185.185	202.208	202.353	Bare Earth	0.144
o44-4-1	1787794.698	1100321.563	202.110	202.162	Bare Earth	0.052
u44-4-14	1790489.024	1090963.814	200.604	200.744	Urban	0.140
o44-4-15	1790742.333	1090487.475	200.189	200.253	Bare Earth	0.064
h44-4-2	1791503.860	1098174.111	205.434	205.498	Vegetated	0.064
b44-4-4	1791544.794	1097902.312	205.846	205.939	Vegetated	0.093
w44-4-3	1791697.765	1097944.697	207.119	207.244	Vegetated	0.125
b44-4-7	1792043.786	1104989.874	172.906	172.981	Vegetated	0.075
w44-4-5	1792795.615	1103778.290	194.111	194.214	Vegetated	0.103
h44-4-6	1792888.715	1103758.809	193.610	193.596	Vegetated	-0.014
u44-4-8	1793478.705	1095694.381	203.683	203.694	Urban	0.011
u44-4-9	1794486.294	1094870.619	206.469	206.471	Urban	0.002
u44-4-10	1795615.203	1095270.792	211.052	211.072	Urban	0.019
o44-4-11	1795713.408	1095246.836	211.285	211.301	Bare Earth	0.016
u44-4-12	1796374.474	1101079.160	169.650	169.684	Urban	0.034
o44-4-13	1797266.487	1098460.665	197.178	197.264	Bare Earth	0.085
b44-2-9	1803543.917	1057447.264	162.608	162.774	Vegetated	0.166
u44-2-4	1805789.177	1045122.671	158.725	158.746	Urban	0.020
oLIONS CLUB	1806032.924	1045333.395	161.251	161.295	Bare Earth	0.044
h44-2-3	1806037.116	1045166.953	160.995	161.092	Vegetated	0.097
b44-2-1	1806128.020	1045279.108	160.774	160.848	Vegetated	0.074
w44-2-2	1806301.108	1045115.558	158.162	158.246	Vegetated	0.084
w44-2-10	1806877.833	1054594.171	195.136	195.225	Vegetated	0.089
u44-2-5	1807709.934	1051874.395	187.595	187.631	Urban	0.036
o44-2-6	1807782.653	1051864.155	188.706	188.724	Bare Earth	0.018
o44-2-8	1808409.934	1057668.738	196.333	196.479	Bare Earth	0.146
u44-2-7	1808479.871	1057634.814	196.277	196.383	Urban	0.106
h44-2-11	1812578.601	1050071.693	188.784	188.837	Vegetated	0.053
u44-2-12	1812748.062	1049420.454	190.564	190.604	Urban	0.040
o44-2-15	1813397.958	1049754.997	192.043	192.041	Bare Earth	-0.002
u44-2-13	1813692.590	1048479.931	191.699	191.668	Urban	-0.031
o44-2-14	1813794.136	1048504.126	191.377	191.360	Bare Earth	-0.017
o44-8-15	1819434.873	980183.526	148.709	148.751	Bare Earth	0.042
u44-8-14	1819558.544	980463.207	151.014	151.013	Urban	-0.001
w44-8-control	1820081.981	991834.481	150.640	150.705	Vegetated	0.065
o44-1-11	1820399.493	1013600.303	146.421	146.424	Bare Earth	0.003
w44-8-1	1820483.082	991851.881	151.361	151.405	Vegetated	0.044
u44-8-10	1820797.678	975070.206	125.853	125.899	Urban	0.046
u44-1-14	1821229.584	1001941.603	105.738	105.757	Urban	0.019
u44-8-13	1821446.624	980822.544	148.040	148.102	Urban	0.062
b44-8-12	1821854.493	979972.678	146.766	146.841	Vegetated	0.075

u44-1-13	1821921.829	1001982.014	106.550	106.519	Urban	-0.031
u44-8-9	1822230.213	978345.525	146.298	146.317	Urban	0.018
o44-8-11	1822381.476	978804.754	146.894	146.898	Bare Earth	0.004
o44-8-2	1822456.353	992957.535	148.972	148.996	Bare Earth	0.024
w44-1-3	1822824.764	1006650.976	143.662	143.668	Vegetated	0.005
o44-1-2	1822905.418	1006792.276	140.964	140.919	Bare Earth	-0.045
u44-1-1	1822968.886	1006699.064	140.814	140.777	Urban	-0.037
b44 012	1823042.388	1006741.465	140.462	140.519	Vegetated	0.057
u44-1-15	1823225.104	1004133.384	130.964	130.971	Urban	0.007
h44-8-8	1823282.416	979647.986	151.651	151.718	Vegetated	0.067
b44-8-3	1824172.163	991031.375	136.657	136.705	Vegetated	0.048
h44-8-7	1824646.127	979352.423	156.707	156.720	Vegetated	0.013
w44-1-4	1825270.588	1009737.021	130.369	130.461	Vegetated	0.092
b44-1-5	1826402.691	1009773.947	145.432	145.393	Vegetated	-0.039
h44-1-10	1827906.938	1011746.449	143.420	143.487	Vegetated	0.067
h44-1-9	1828571.119	1012864.273	149.141	149.155	Vegetated	0.014
o44-8-6	1828661.853	978148.094	151.321	151.319	Bare Earth	-0.002
o44-1-8	1828831.188	1013295.906	149.279	149.222	Bare Earth	-0.057
u44-1-6	1829977.595	1014567.108	144.406	144.391	Urban	-0.015
o44-1-7	1830041.103	1014679.281	144.004	144.043	Bare Earth	0.039
o44-8-4	1830072.094	985888.700	123.506	123.540	Bare Earth	0.034
o44-1-12	1832268.119	1007704.453	149.049	149.100	Bare Earth	0.051
u44-8-5	1833239.229	981332.130	126.271	126.360	Urban	0.088
o44-3-16	1837329.267	1076568.898	189.692	189.751	Bare Earth	0.059
u44-3-15	1837456.774	1076491.169	189.576	189.615	Urban	0.038
o44-3-2	1837775.676	1082109.878	178.670	178.694	Bare Earth	0.024
h44-3-12	1839084.189	1072411.065	182.787	182.901	Vegetated	0.114
hBALD ROCK	1839318.553	1083349.709	179.215	179.159	Vegetated	-0.056
o44-3-1	1839325.178	1083325.651	178.999	179.068	Bare Earth	0.069
b44-3-5	1839694.870	1084272.653	187.201	187.305	Vegetated	0.104
o44-3-4	1839762.599	1084324.514	187.507	187.578	Bare Earth	0.071
u44-3-11	1839948.267	1067072.736	174.168	174.226	Urban	0.058
w44-3-3	1839997.649	1084336.018	185.725	185.875	Vegetated	0.150
u44-3-10	1843064.009	1068457.466	168.516	168.435	Urban	-0.081
w44-3-9	1844401.567	1078773.185	194.045	194.072	Vegetated	0.027
b44-3-8	1844452.885	1078819.936	194.362	194.352	Vegetated	-0.010
o44-3-6	1844473.745	1080578.123	180.369	180.340	Bare Earth	-0.029
u44-3-7	1844648.009	1079189.948	189.277	189.271	Urban	-0.006
u44-3-13	1845173.515	1070485.355	136.199	136.176	Urban	-0.023
o44-3-14	1845277.069	1070510.063	134.904	134.873	Bare Earth	-0.031
u44-6-13	1848954.417	1015859.562	167.623	167.667	Urban	0.044
o44-6-14	1849031.412	1015824.714	167.334	167.380	Bare Earth	0.046

o44-6-16	1850645.754	1014366.803	164.777	164.850	Bare Earth	0.073
o44-6-15	1852516.327	1012418.417	163.918	163.953	Bare Earth	0.035
o44-6-12	1852923.882	1017196.452	171.700	171.743	Bare Earth	0.043
h44-6-11	1856537.325	1016864.101	156.449	156.534	Vegetated	0.085
u44-6-2	1858887.081	1025990.247	145.353	145.278	Urban	-0.075
hMOUNT PILOT	1859065.848	1026002.046	144.736	144.669	Vegetated	-0.067
w44-6-1	1859073.609	1025985.151	144.727	144.639	Vegetated	-0.089
u44-6-9	1861542.233	1019452.515	154.546	154.539	Urban	-0.007
o44-6-10	1861622.230	1019174.837	150.332	150.325	Bare Earth	-0.007
b44-6-8	1861811.993	1019483.958	152.625	152.710	Vegetated	0.085
h44-6-7	1861869.933	1019310.701	149.562	149.612	Vegetated	0.050
w44-6-4	1862516.057	1029109.090	129.347	129.430	Vegetated	0.082
u44-6-3	1862651.640	1029162.304	129.217	129.255	Urban	0.038
b44-6-5	1862726.080	1029224.640	128.892	128.969	Vegetated	0.077
u44-6-6	1865990.979	1021630.075	139.227	139.271	Urban	0.044