LiDAR Quality Assurance (QA) Report
Marion County, South Carolina
February 13, 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 Marion, 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 high 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 masspoint data has an average point spacing less than 1.4m, that 504 tiles (each 5000 ft x 5000 ft) were delivered covering all of Cherokee 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	94	18.5 cm	8.4 cm
FVA	20	32	36.3 cm	14.1 cm
CVA	60	94	36.3 cm	15.6 cm
SVA-bare earth	20	32	36.3 cm	13.2 cm
SVA-vegetated	20	33	36.3 cm	18 cm
SVA-urban	20	29	36.3 cm	13.9 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 poor LiDAR penetration and misclassification. All of the deliverables extend to the county boundaries where adjoining counties are not delivered; where adjoining counties are delivered there is no clipping of the tiles.

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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 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 Marion County that are directly derived from the LiDAR. The hydro-lines, 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.

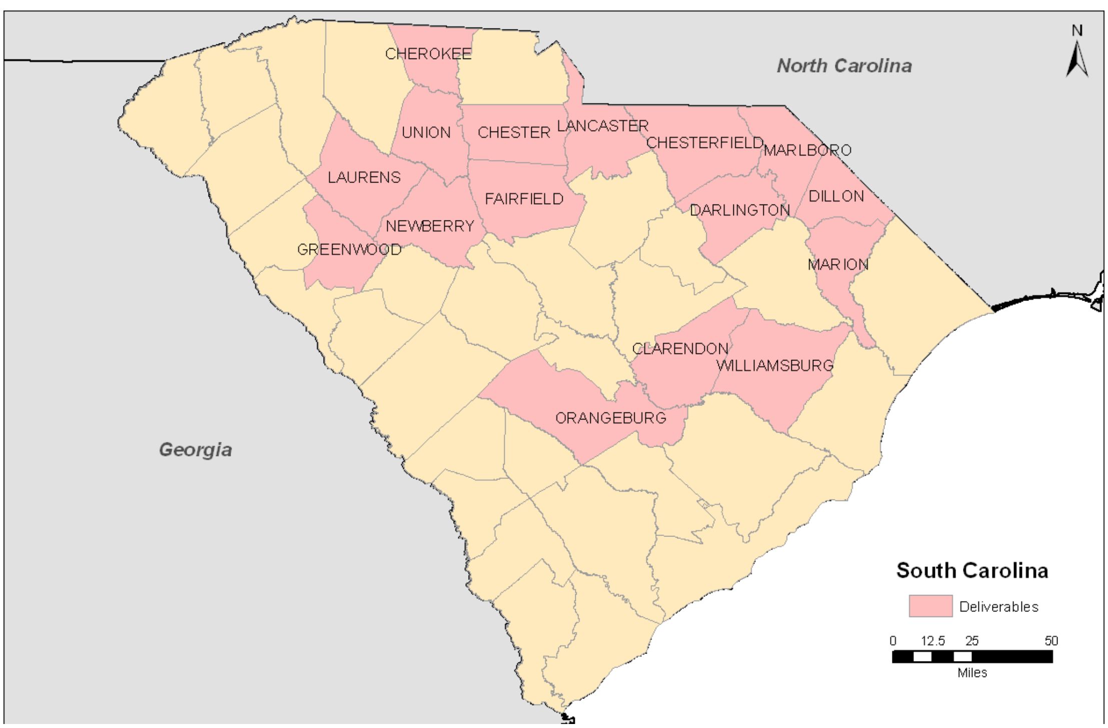

Figure 1 *– Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

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	1 feature class
Ground masspoints	ESRI feature class multipoints	1 feature class
Boundary	ESRI feature class - polygons	3 feature classes (county/tile/LiDAR)

Tiles at the county boundary were supposed to be full or partial based on 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, the terrain, and the intensity images extend outside the project boundary with a 50 ft buffer (Figure 4 and Figure 5) as expected.

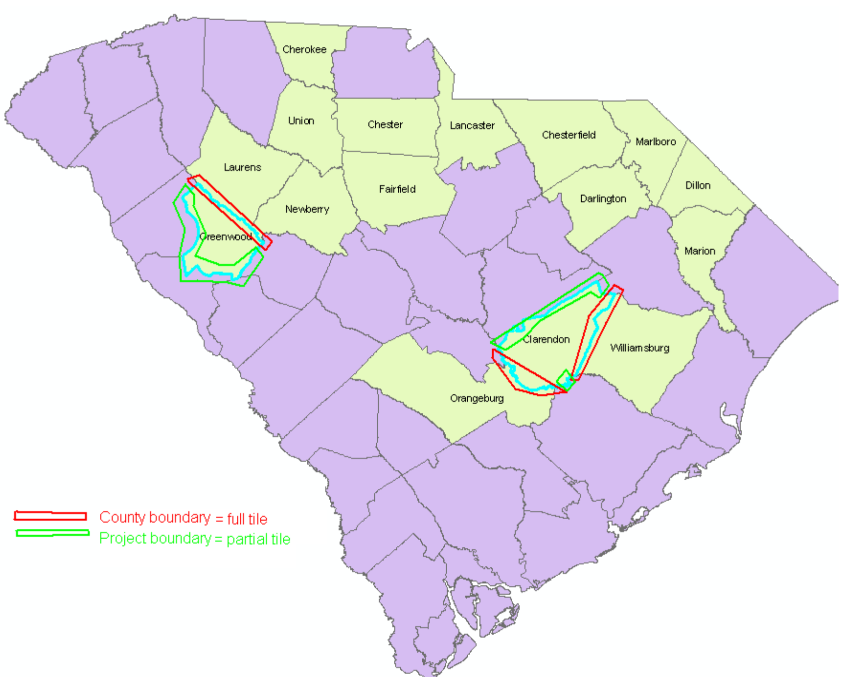

***Figure 2** – Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

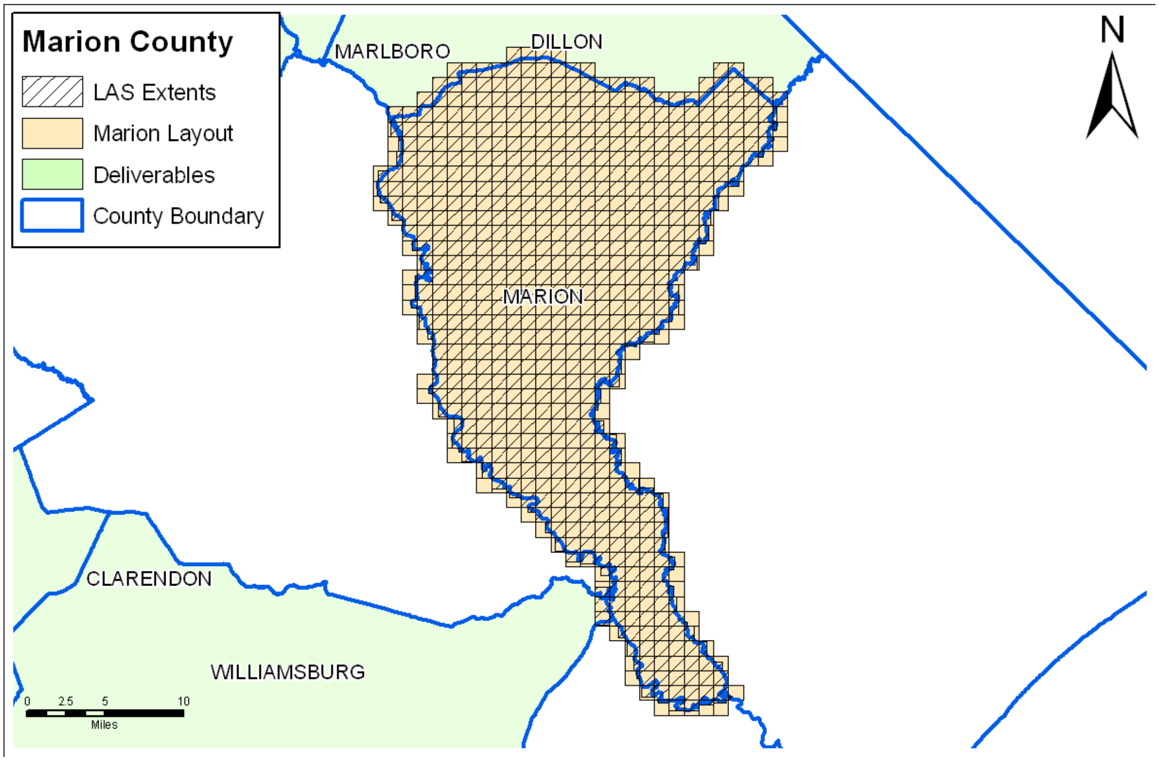

***Figure 3** – The LiDAR coverage of Marion County. Neighboring deliverable counties are shown in green.*

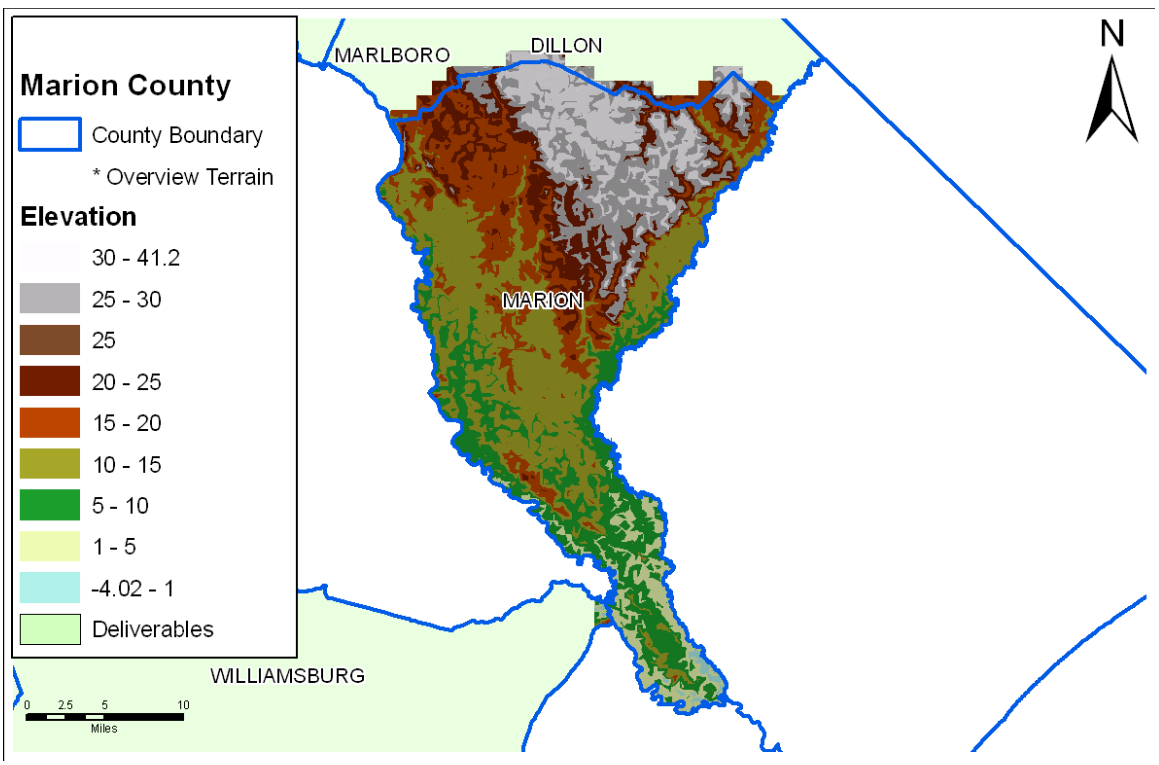

***Figure 4** – The terrain for Marion has a 50 ft buffer outside of the project boundary.*

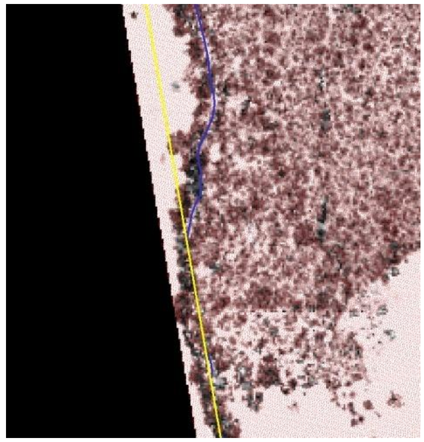

Figure 5 *- Ground masspoints (red) and intensity images extend 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydro-lines are clipped at the project boundary and the watershed boundary.*

3 QA of intensity images

650 intensity images in GeoTiff format were delivered for Marion 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: 4748-02.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	2445000 790000 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 (2445000.000, 790000.000)
amx[0]= 4, amx[1]= 0, amx[2]= 2445000	Lower Left (2445000.000, 785000.000)
amx[3]= 0, amx[4]= -4, amx[5]= 790000	Upper Right (2450000.000, 790000.000)
2445000 , 790000	Lower Right (2450000.000, 785000.000)
2450000 , 790000	Center (2447500.000, 787500.000)
2450000 , 785000	
2445000 , 785000	

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).

Two anomalies were noticed in the intensity images: white stripes over land at nadir (Figure 6) and tonal changes within tiles (Figure 7). The white stripes occur when the intensity becomes saturated at nadir. This is expected over water but should not be observed over land. The cause of the sharp tonal transition across tiles is unknown but it seems to follow the flight line boundaries, as shown in the right image in Figure 7. These intensity anomalies do not significantly affect the dataset as a whole.

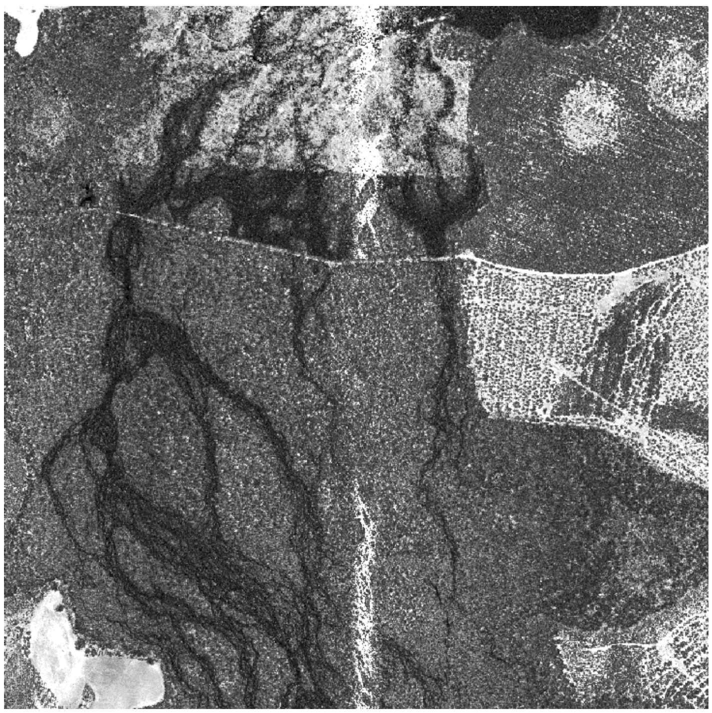

Figure 6 *- 5869-03 White stripe at nadir.*

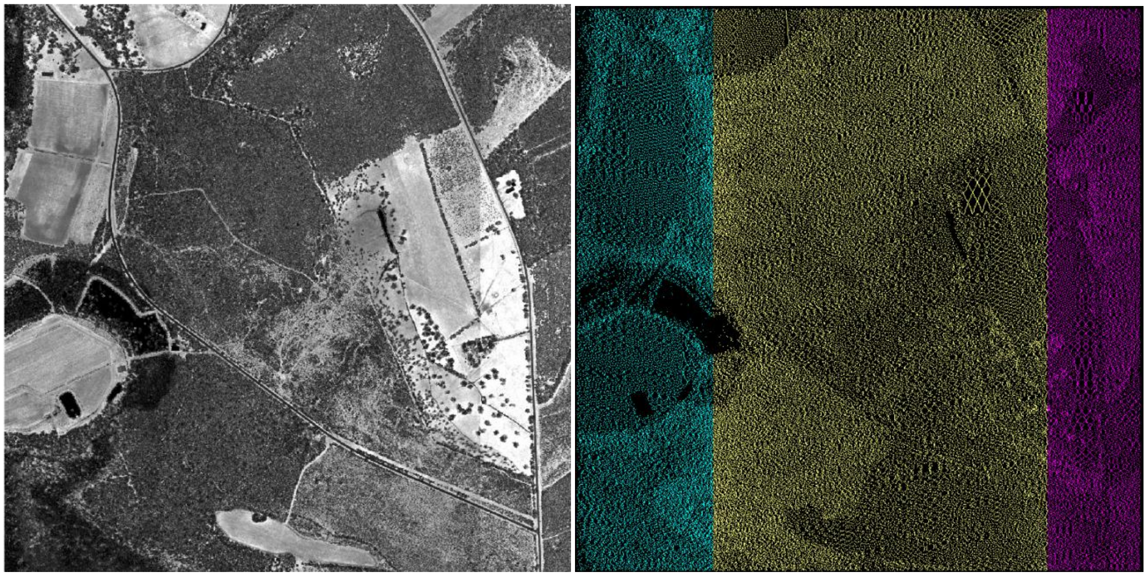

***Figure 7** – 4778-02 Tonal changes in intensity values within a tile (Left is intensity image, Right is image of LAS points colored by flight line).*

4 Metadata

Dewberry verified the metadata and all of the xml files were FGDC complaint. 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 650 LiDAR files covering the Marion 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 (Meters);
  - 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 Marion County is around 4.7 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 8.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 1.4 m and 41.1 m, no noticeable anomalies were identified because this is consistent with the expected range of elevation in the county. Figure 9 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography. Lower elevations are found near hydrographic features; see Figure 9 (left) for the Z min elevations.

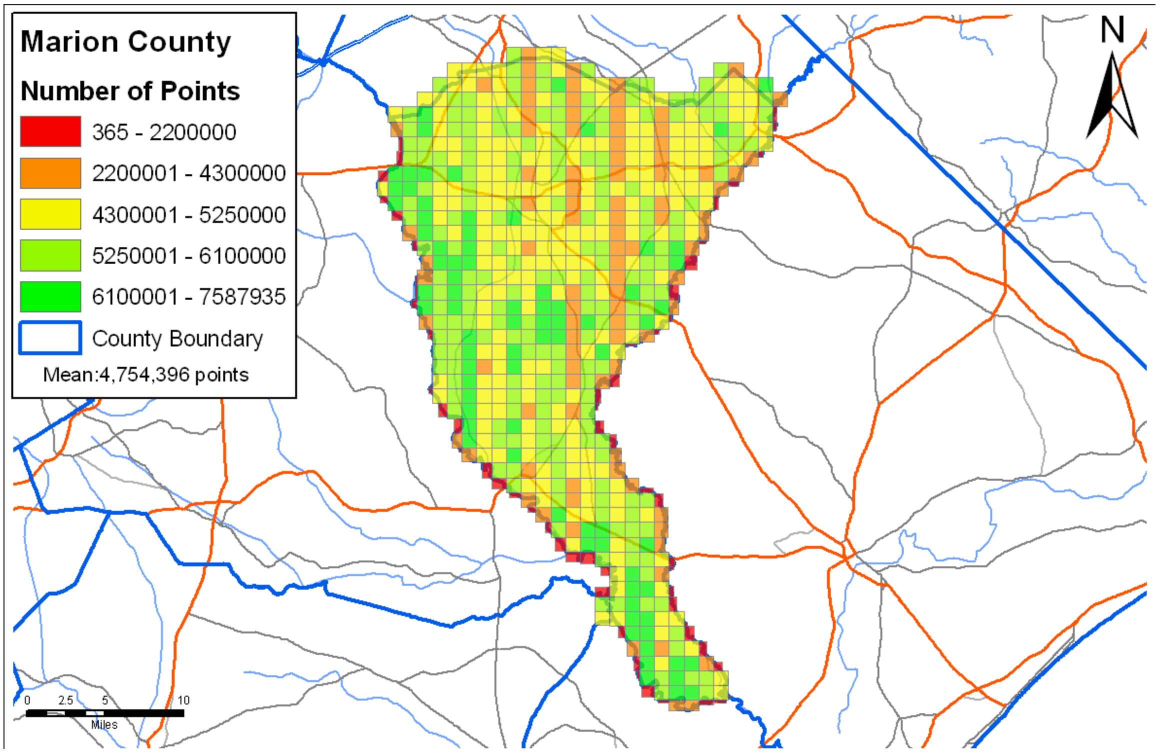

Figure 8 *– Number of points per tile. The red tiles at the border are expected to have fewer points.*

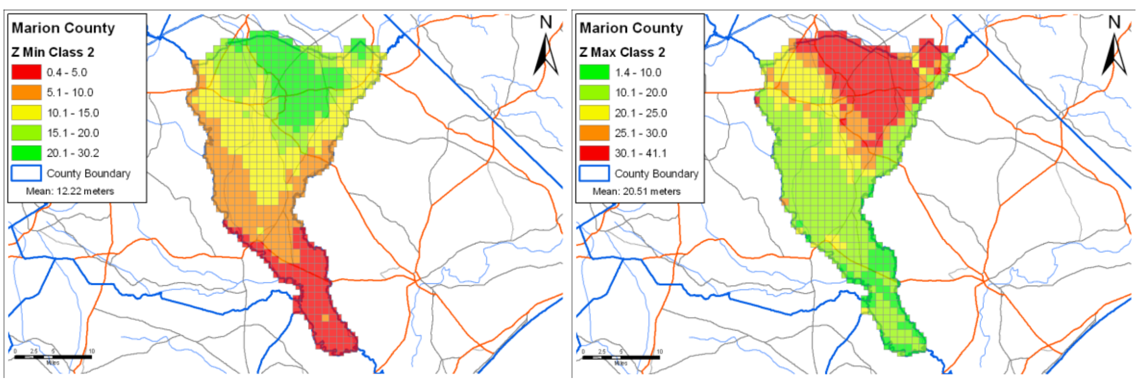

Figure 9 *– Z min and Z max elevation by tile for ground points (class 2).*

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 has been 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 94 points were collected, as presented in Table 3, with 33 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 10 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 Checkpoints Required and Acquired.

Class	Guidelines	Acquired
o - Open Terrain	20	32
b - Bush	0	11
h - High Grass	10	11
w - Woods	10	11
u - Urban	20	29
Total	**60**	**94**

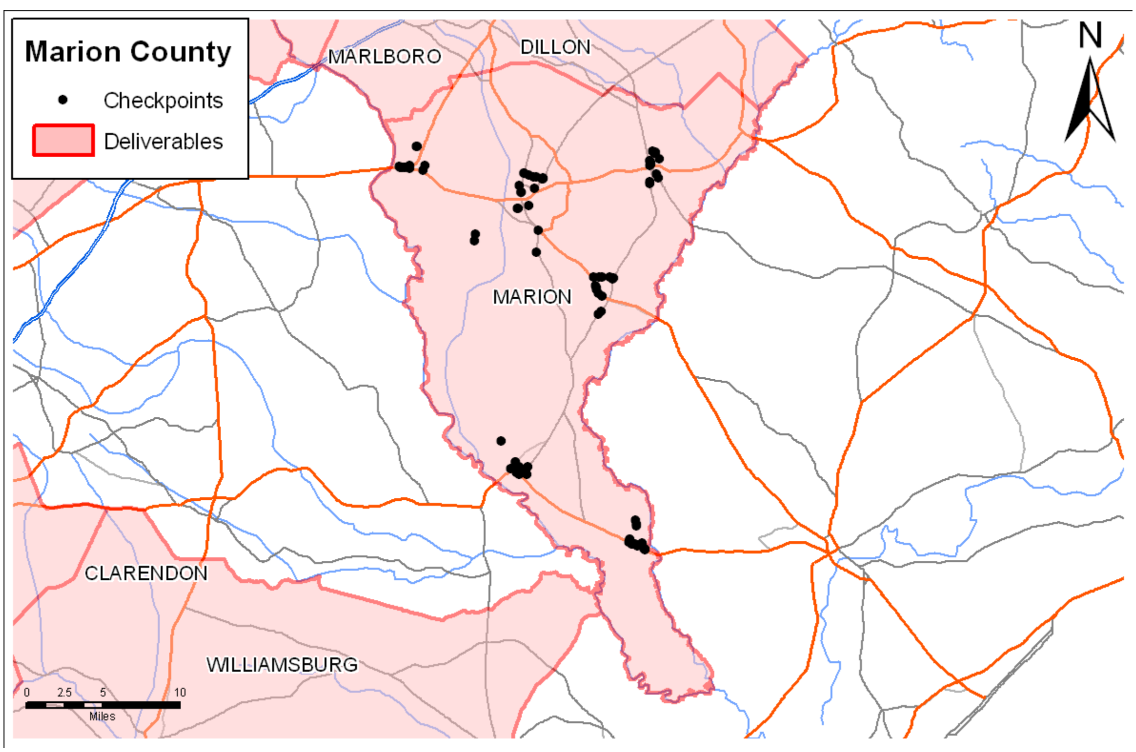

***Figure 10** – Survey checkpoints from South Carolina Geodetic Survey.*

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. This 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 Marion 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 (0.084 m) x 1.9600, or 0.165 m (16.5 cm).

Table 4** - **Final Statistics for Marion 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	0.084	-0.008	-0.013	-0.954	0.084	94	-0.433	0.232
Bare Earth	0.072	-0.026	-0.026	0.068	0.068	32	-0.166	0.125
Vegetated	0.085	0.031	0.036	0.636	0.080	33	-0.118	0.232
Urban	0.096	-0.034	-0.015	-3.211	0.091	29	-0.433	0.080

Table 5 shows the complete results of the Marion data set run through the NDEP/ASPRS process; the CVA value is 0.156 m (15.6 cm). The similar results between the two methods (16.5 cm and 15.6 cm) demonstrate that the errors did approximate a normal error distribution. All of the calculated statistics for Marion County fall well below the specifications.

Table 5 - Final Statistics for Marion 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	94		15.6	
Bare Earth	32	16.5		13.2
Vegetated	33			18.0
Urban	29			13.9

Figure 11 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed checkpoints. The majority of delta Z values are centered on zero which indicates a relatively normal error distribution.

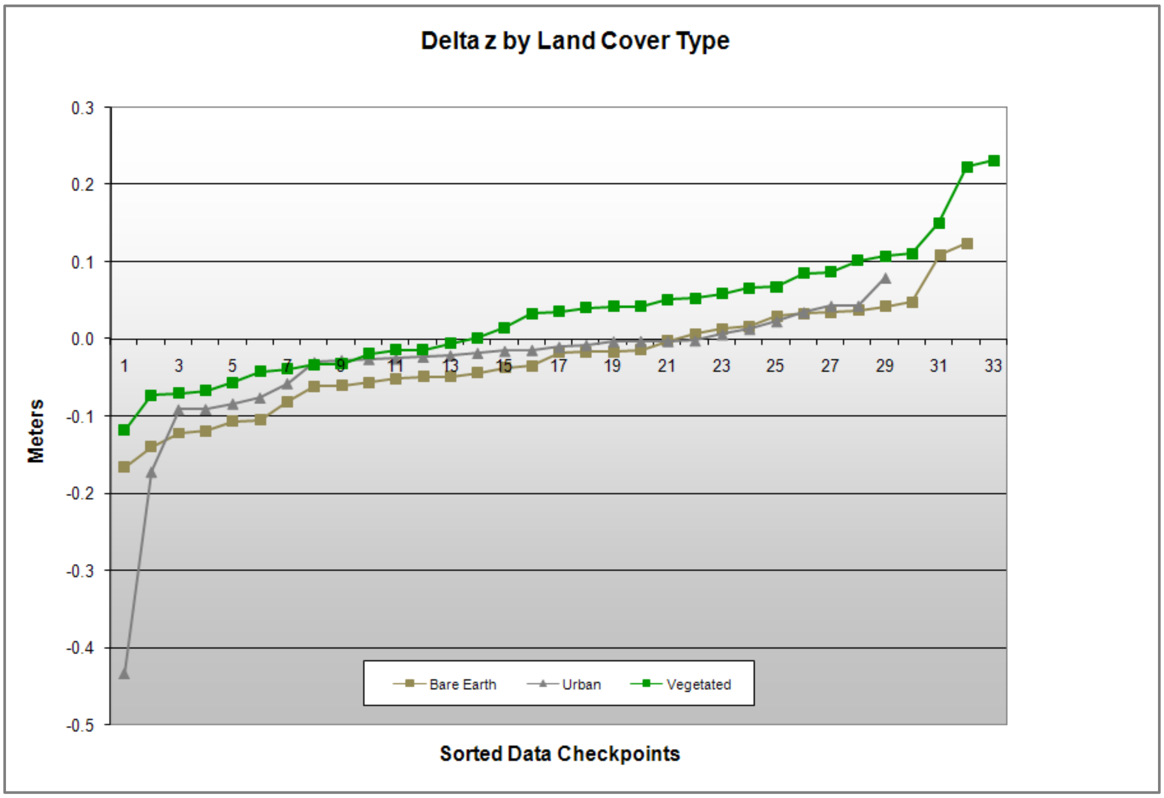

Figure 11 – *Checkpoints shown per land cover type and sorted by errors (deltaZ).*

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 16.5 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 15.6 cm Consolidated Vertical Accuracy at 95% confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 11.0 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 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 12). 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.

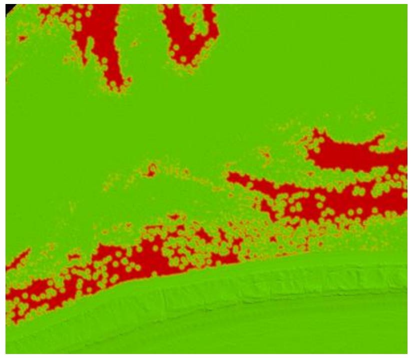

Figure 12 *– Ground model with density information (red means sparse data).*

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 13**) or by class (Figure **14**). This particular type of display helps us visualize and better understand the scan pattern, the flight line orientation, flight coverage, and gives additional confirmation that all classes are present and logically represent the terrain.

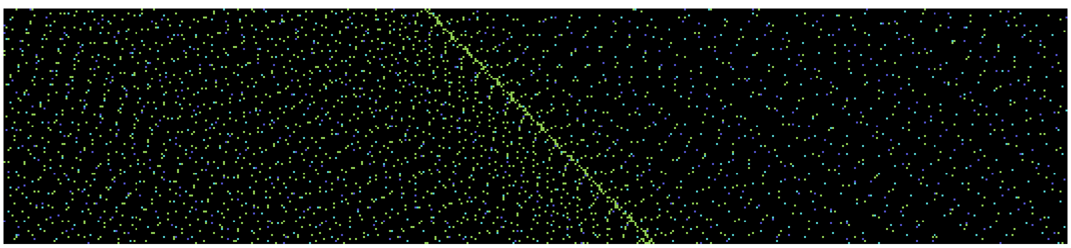

Figure 13 *– Detail of LiDAR points colored by flight line. Note the variations in the scan pattern.*

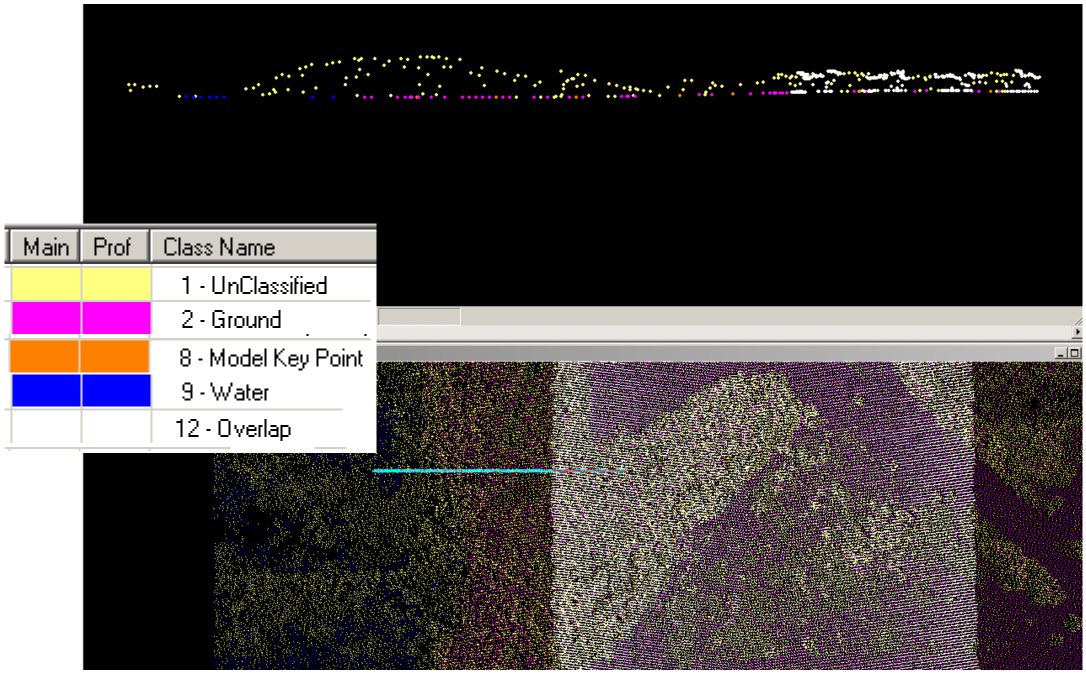

***Figure 14** - Full point cloud colored by classification.*

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 high quality. The data set is very clean with nearly zero artifacts. Dewberry found very few errors in the data as outlined in the text and images below. The majority of the calls are due to inconsistent editing, minor misclassifications and poor LiDAR penetration. However, these issues are not serious enough to render the data unusable.

Poor LiDAR Penetration

Several areas were identified 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; this is 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 to reach the ground. Regardless, the accuracy of the data is always expected to diminish in vegetated area, and when a few ground points are available an elevation model can be interpolated with acceptable precision especially in flat terrain.

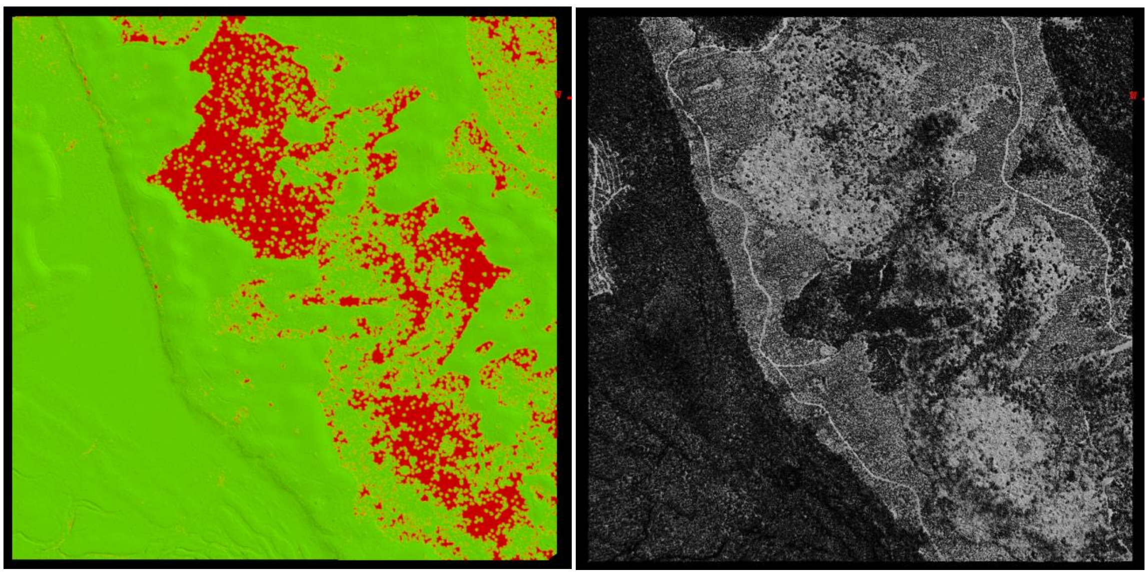

Figure 15 *- 5629-02 Poor LiDAR penetration in vegetated area (L: Ground density model, R: Full point cloud intensity model).*

Inconsistent Editing

Several instances of inconsistent editing of natural features were found in this dataset. In the example illustrated in Figure 16, it seems as though different parameters were used to classify the tile on the top than the tile on the bottom, resulting in an abrupt and unnatural change in classification. This type of error was not found to be very common in the dataset and has minimal impact on the quality of the data.

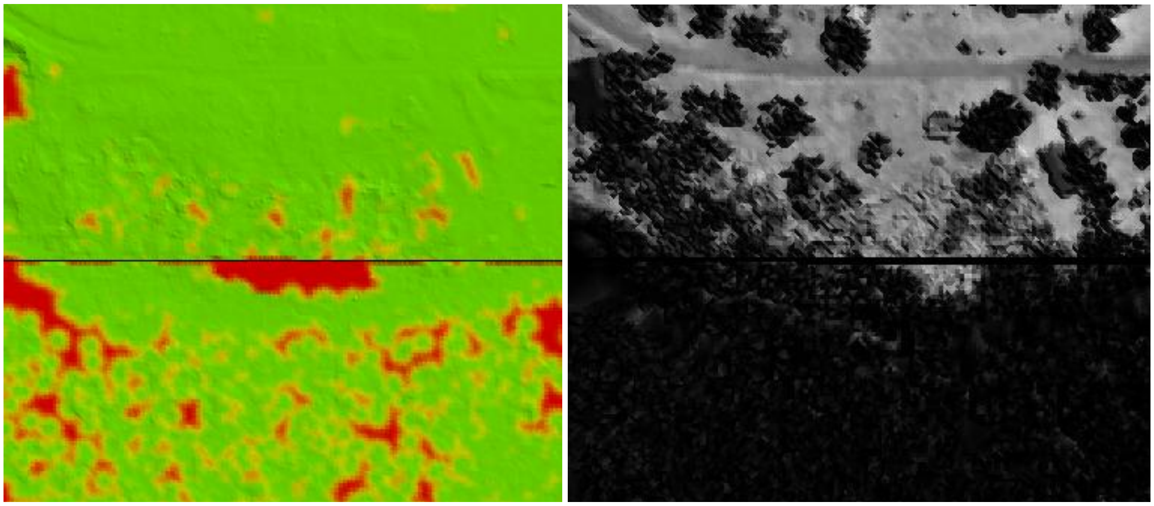

Figure 16 *– 4895-03 Inconsistent Editing (L: Ground Density Model, R: Full Point Cloud Intensity)*

Misclassification

One of the more common problems seen in Marion County was misclassification of ground points as water. During the classification process, it appears that hydro-lines were used to classify water points. At the time of acquisition however, many of these retention 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 17, the red area signifies an absence of ground points. The full point cloud intensity image in the middle shows that the LiDAR sensor actually returned a few ground points as the retention area was partially dry at the time. The image on the right illustrates that these points were classified as water.

Figure 17 *– 4879-04 Misclassification of ground points. Left image is ground density model and middle is full point cloud with intensity. 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 image is profile of cross-section.*

Dewberry believes that one particular area of misclassification was caused by a previously mentioned intensity issue. A small subset of tiles displayed high intensity values at nadir. This problem could be the reason for the misclassification in Figure 18. The LAS file for this region shows that some areas, which should be classified as ground, were moved into class 1 (unclassified). This misclassification can result in a strip of elevated ground points that resembles a small berm. As shown in the cross-section in Figure 18, some of these elevated areas can be up to 30 cm higher than the surrounding area. Although this is considered a relatively significant change, it is easily fixable and will not render the data unusable.

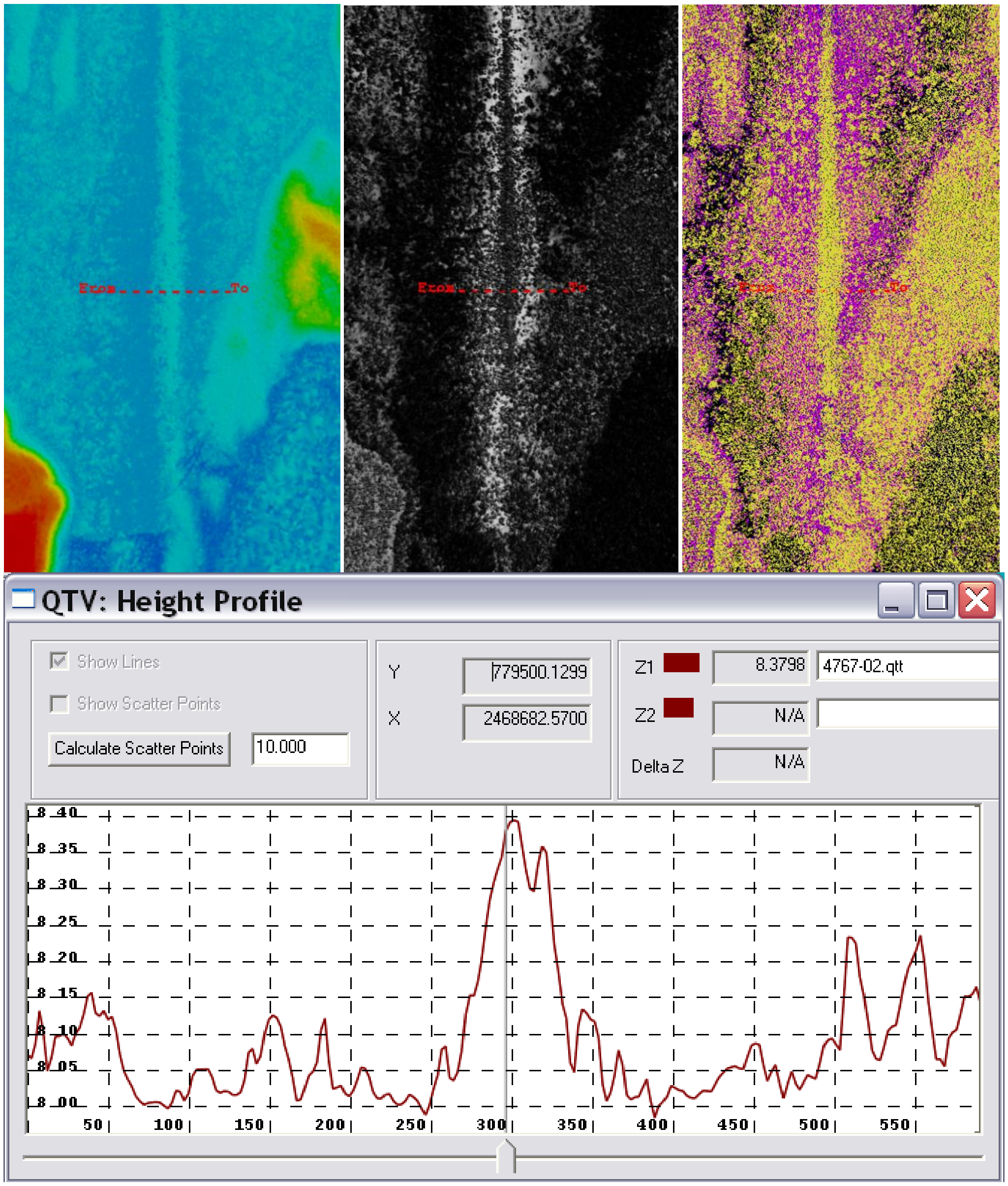

***Figure 18** – 4767-02 Misclassification due to saturation of intensity at nadir. Left is ground model colored by elevation, middle is full point cloud with intensity, and right is full point cloud colored by classification (yellow is unclassified, purple is ground, and blue is water). Bottom is cross-section showing the "false berm".*

Flight Line Ridges

Small ridges at seam lines caused by a vertical mismatch between two adjacent flight lines were noticed during the QA process. Smoothing of the flight lines does not occur; therefore it is possible to find flight line ridges. Although most of the flight line ridges found within the Marion data were below the commonly accepted threshold of 20 cm, there were a few instances where the elevation difference was larger as shown in Figure 19.

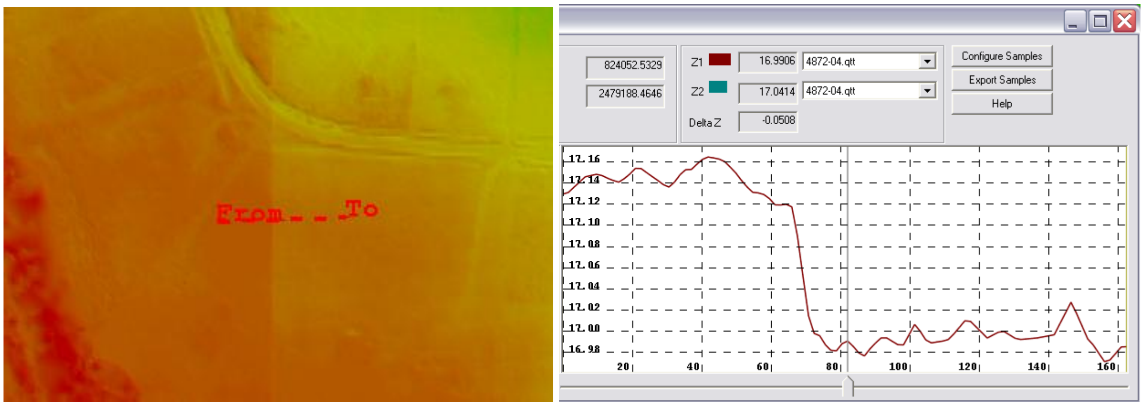

Figure 19 *– 4872-04 Flight line offset.*

Conclusions

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 minor misclassification when focusing on portions of the data, but the data set as a whole is of high 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, which is of high quality. 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	DeltaZ
h34-1-1	2530097.289	870878.244	30.569	30.6209	0.052
o34-1-10	2528270.909	860446.129	28.553	28.5048	-0.048
w34-1-11	2528164.400	859925.830	28.504	28.6117	0.108
w34-1-12	2531136.110	861952.464	27.538	27.6042	0.066
u34-1-13	2530516.170	863337.548	28.826	28.9057	0.080
u34-1-2	2529759.878	870415.512	29.162	29.1443	-0.018
h34-1-3	2529344.610	871044.677	30.527	30.488	-0.039
b34-1-4	2531396.665	868408.416	27.997	28.0329	0.036
u34-1-5	2528169.593	867645.870	30.447	30.4446	-0.002
o34-1-6	2528212.587	867774.063	30.370	30.3533	-0.017
b34-1-7	2528598.297	866977.466	29.498	29.5406	0.043
o34-1-8	2528460.410	866339.031	29.172	29.121	-0.051
u34-1-9	2528051.848	866171.651	29.524	29.5014	-0.023
o34-2-1	2443969.397	865376.517	18.541	18.4604	-0.081
o34-2-10	2442919.626	865388.778	17.805	17.7446	-0.060
h34-2-2	2443864.879	865407.050	18.202	18.1608	-0.041
b34-2-3	2445531.896	866201.309	20.121	20.0487	-0.072
w34-2-5	2450710.431	866179.672	22.141	22.1357	-0.005
u34-2-6	2442175.210	865630.052	18.866	18.775	-0.091
o34-2-7	2448001.682	872664.325	17.027	16.9662	-0.061
h34-2-8	2448124.463	872739.377	17.144	17.3758	0.232
u34-2-9	2442975.344	865508.517	18.133	18.0573	-0.076
w34-5-1	2511717.861	821197.263	24.229	24.2312	0.002
u34-5-10	2515780.341	827517.548	28.376	28.3685	-0.008
o34-5-11	2515569.198	827029.105	28.298	28.3313	0.033
u34-5-12	2511524.739	815995.383	24.264	24.2542	-0.010
o34-5-13	2510605.005	815038.741	24.429	24.4125	-0.016
u34-5-2	2510462.496	822036.356	18.600	18.5847	-0.015
w34-5-3	2509950.897	823588.399	23.990	24.0053	0.015
b34-5-4	2509870.871	824039.677	24.376	24.3621	-0.014
h34-5-5	2509374.367	824778.461	24.657	24.6905	0.034
h34-5-6	2508783.882	827793.239	24.739	24.8071	0.068

u34-5-7	2510981.983	827657.639	18.775	18.7981	0.023
b34-5-8	2511757.047	827643.441	19.295	19.5184	0.223
o34-5-9	2514461.531	827633.422	28.804	28.8389	0.035
u34-6-1	2483892.089	856806.522	22.754	22.697	-0.057
u34-6-10	2491351.244	861764.996	26.804	26.8104	0.006
b34-6-12	2488596.889	858292.140	22.019	22.1209	0.102
o34-6-13	2483807.603	856857.025	22.832	22.8182	-0.014
u34-6-14	2482789.167	851415.644	19.024	19.0223	-0.002
o34-6-15	2486557.749	852425.584	22.258	22.21	-0.048
u34-6-2	2483123.091	859316.870	20.885	20.8579	-0.027
o34-6-3	2484889.867	863450.259	21.258	21.2216	-0.036
w34-6-38	2482617.440	851497.851	18.524	18.5652	0.041
u34-6-4	2485059.295	863366.614	21.259	21.234	-0.025
h34-6-5	2486642.174	862715.788	21.721	21.6517	-0.069
o34-6-6	2488050.039	862184.010	22.875	22.8405	-0.035
w34-6-7	2489272.938	862057.913	21.624	21.7093	0.085
b34-6-8	2491099.437	861458.971	24.768	24.8216	0.054
o34-6-9	2491335.973	861464.037	26.175	26.2056	0.031
h34-7-1	2526588.423	734175.071	5.296	5.3386	0.043
o34-7-10	2521205.137	737419.584	6.284	6.2909	0.007
u34-7-11	2521304.404	737519.445	6.6	6.6133	0.013
u34-7-12	2522256.130	735863.270	8.449	8.4466	-0.002
o34-7-13	2523710.375	742136.468	6.314	6.3623	0.048
u34-7-14	2523607.762	742742.368	5.983	6.0264	0.043
w34-7-15	2523140.536	744004.231	6.388	6.4474	0.059
u34-7-16	2523879.569	735171.213	8.338	8.3729	0.035
o34-7-2	2526579.763	734087.221	5.421	5.4585	0.037
b34-7-3	2526114.585	734365.952	5.768	5.7358	-0.032
b34-7-4	2525514.887	736171.946	5.173	5.3234	0.150
o34-7-5	2523975.414	735459.320	5.304	5.3466	0.043
o34-7-6	2522871.315	735833.995	6.173	6.1863	0.013
h34-7-7	2522796.375	735864.519	5.911	5.8922	-0.019
o34-7-8	2522095.584	736051.131	6.018	5.9129	-0.105
u34-7-9	2520937.421	736528.632	8.569	8.6123	0.043
w34-8-1	2486169.569	762582.543	15.375	15.3618	-0.013
h34-8-10	2485856.690	759914.895	17.267	17.2344	-0.033
u34-8-11	2483307.696	760004.422	18.089	18.0752	-0.014
o34-8-12	2483091.034	760086.841	17.957	17.9741	0.017
u34-8-13	2482187.516	760602.231	17.128	17.1023	-0.026
o34-8-14	2480208.647	761818.613	12.675	12.659	-0.016
w34-8-15	2476931.979	771378.656	12.009	12.0962	0.087
u34-8-2	2485414.065	761401.561	18.066	17.8943	-0.172

o34-8-3	2485366.825	761320.163	18.028	17.9091	-0.119
h34-8-4	2484985.160	760943.516	18.249	18.1312	-0.118
b34-8-5	2484373.268	761495.490	18.486	18.4188	-0.067
o34-8-6	2484342.803	761409.971	17.752	17.63	-0.122
b34-8-7	2483230.132	762622.719	16.838	16.7822	-0.056
u34-8-8	2481886.690	764115.387	14.953	14.9321	-0.021
o34-8-9	2481928.470	764091.880	14.925	14.9232	-0.002
u34-10-1	2442018.708	865694.727	18.843	18.7597	-0.083
o34-10-2	2445463.078	865132.037	18.061	18.0049	-0.056
o34-10-3	2450134.053	864342.705	21.919	21.8751	-0.044
o34-10-4	2468111.615	842615.723	16.502	16.362	-0.140
u34-10-5	2467823.085	840085.232	14.881	14.7904	-0.091
u34-10-6	2489112.535	836304.289	16.811	16.8082	-0.003
u34-10-7	2489855.509	843832.518	19.875	19.8452	-0.030
oJIMMY CARTERS	2441965.372	865650.403	18.866	18.7597	-0.106
oMULLINS	2529958.364	871117.977	30.842	30.9666	0.125
ot 31	2483693.712	857291.684	23.080	22.914	-0.166
o034 006 AZ MK	2511907.734	820971.181	25.374	25.4833	0.109
w034 014 AZ MK	2529383.253	732633.695	8.568	8.6788	0.111
u34 051	2487675.319	764513.096	13.275	12.8421	-0.433