LiDAR Quality Assurance (QA) Report
Dillon County, South Carolina
February 23, 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 Dillon 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 514 tiles (each 5000 ft x 5000 ft) were delivered covering all of Dillon 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	134	18.5 cm	6.0 cm
FVA	20	40	36.3 cm	9.2 cm
CVA	60	134	36.3 cm	11.0 cm
SVA-bare earth	20	40	36.3 cm	8.9 cm
SVA-vegetated	20	55	36.3 cm	14.8 cm
SVA-urban	20	39	36.3 cm	10.9 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, negligible flight line ridges, and misclassifications. 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.

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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 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 Dillon 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.

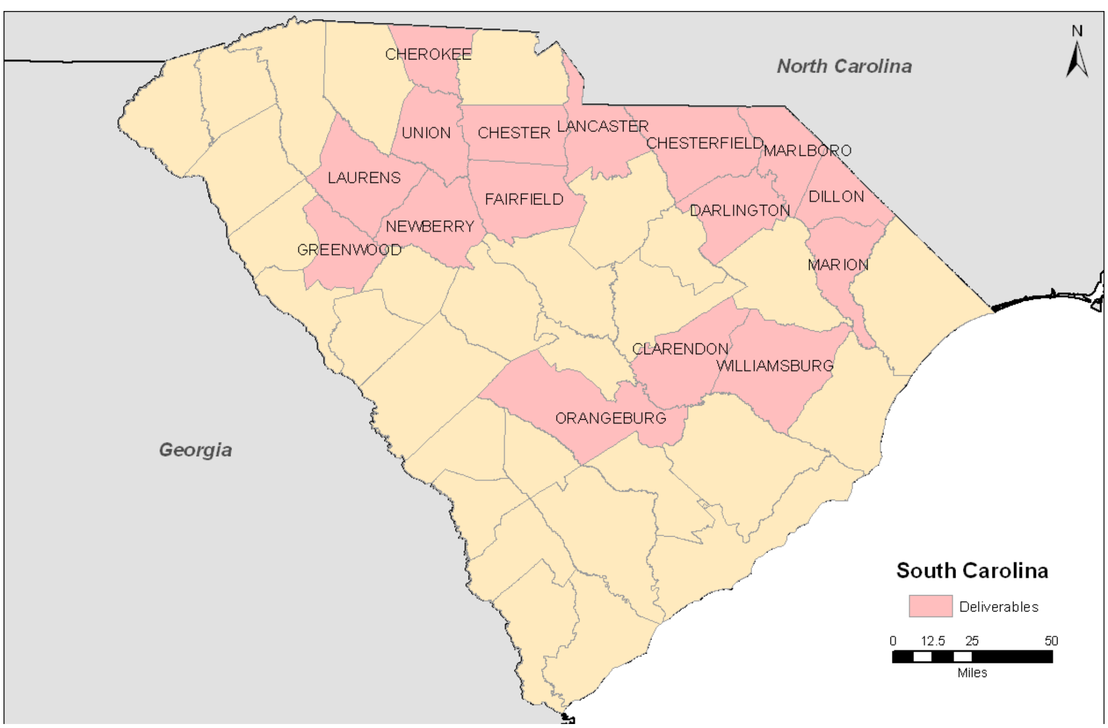

Figure 1 *– Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

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.

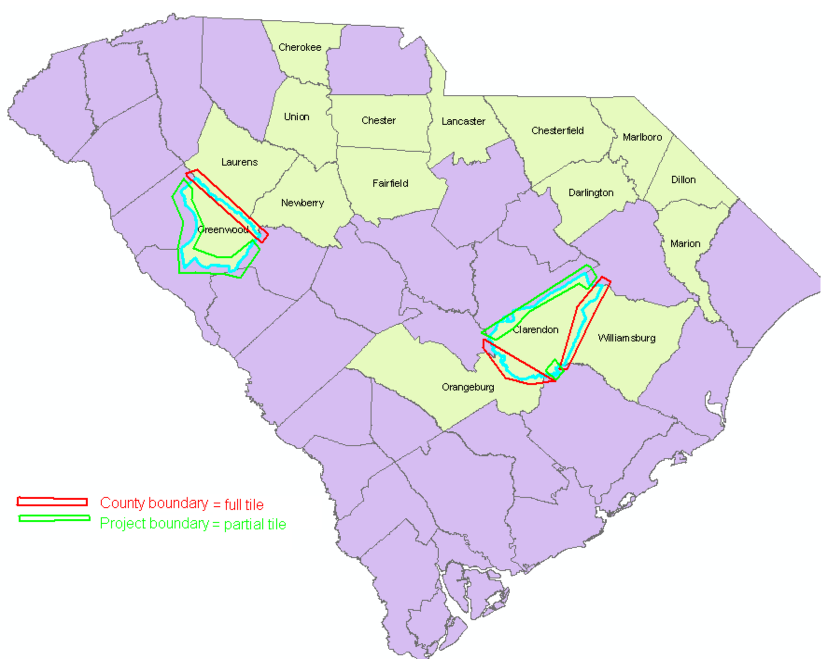

***Figure 2** – Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

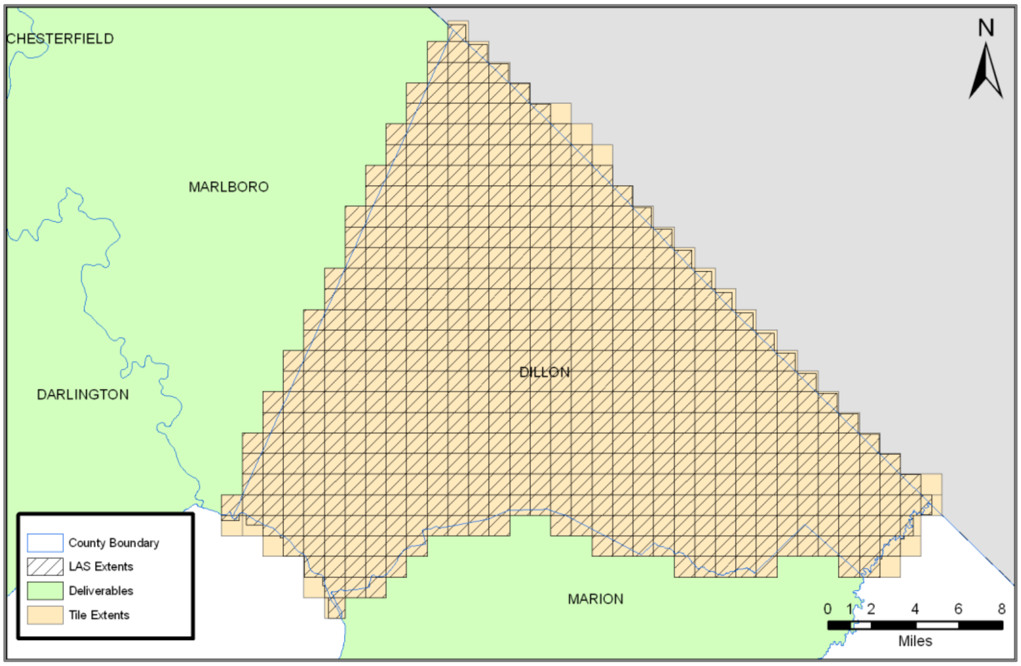

***Figure 3** – The LiDAR coverage of Dillon County. Neighboring deliverable counties are shown in green.*

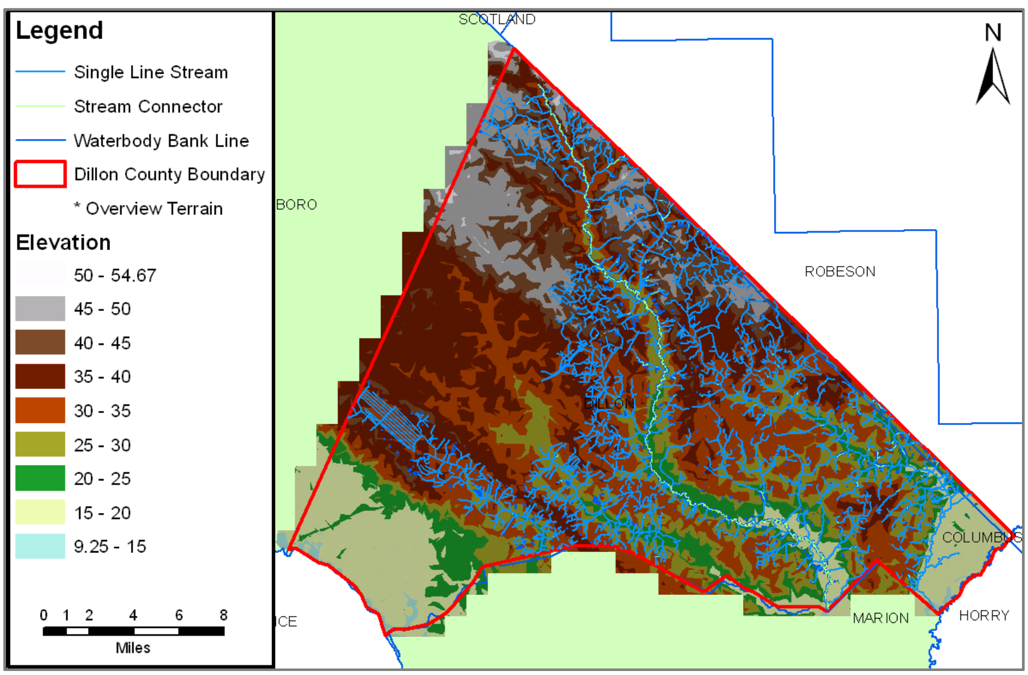

***Figure 4** – The terrain for Dillon has a 50 ft buffer outside of the project boundary.*

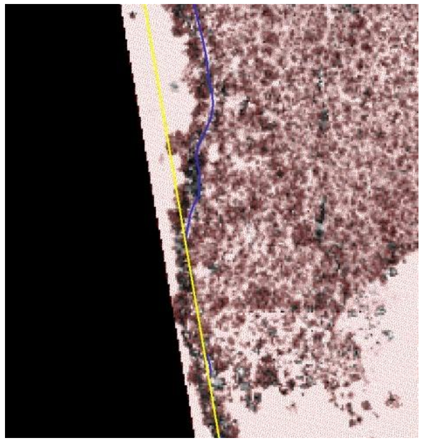

***Figure 5** - Ground masspoints (red) and intensity images extend 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydrolines are clipped at the project boundary and the watershed boundary.*

3 QA of intensity images

514 intensity images in GeoTiff format were delivered for Dillon 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: 4060-02.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]= 2465000
amx[3]= 0, amx[4]= -4, amx[5]= 1010000
2465000 , 1010000
2470000 , 1010000
2470000 , 1005000
2465000 , 1005000
Geotiff_Information:
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 (NAD83(HARN) / South Carolina (ft))
Projection = 15355 (SPCS83 South Carolina zone (International feet))
Projection Method: CT_LambertConfConic_2SP
ProjFalseOriginLatGeoKey: 31.833333 (31d50' 0.00"N)
ProjFalseOriginLongGeoKey: -81.000000 (81d 0' 0.00"W)
ProjStdParallel1GeoKey: 34.833333 (34d50' 0.00"N)
ProjStdParallel2GeoKey: 32.500000 (32d30' 0.00"N)
ProjFalseEastingGeoKey: 609600.000000 m
ProjFalseNorthingGeoKey: 0.000000 m
GCS: 4152/NAD83(HARN)
Datum: 6152/NAD83 (High Accuracy Regional Network)

Ellipsoid: 7019/GRS 1980 (6378137.00,6356752.31)

Prime Meridian: 8901/Greenwich (0.000000/ 0d 0' 0.00"E)
Projection Linear Units: 9002/foot (0.304800m)
Corner Coordinates:
Upper Left (2465000.000,1010000.000)
Lower Left (2465000.000,1005000.000)
Upper Right (2470000.000,1010000.000)

```
Version: 1                                  Lower Right   (2470000.000,1005000.000)
Key_Revision: 1.0                           Center        (2467500.000,1007500.000)
Tagged_Information:
  ModelTiepointTag (2,3):
    0          0          0
    2465000    1010000    0
```

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 514 LiDAR files covering the Dillon 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 Dillon County is around 4.9 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 14.7m and 54.6m, 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.

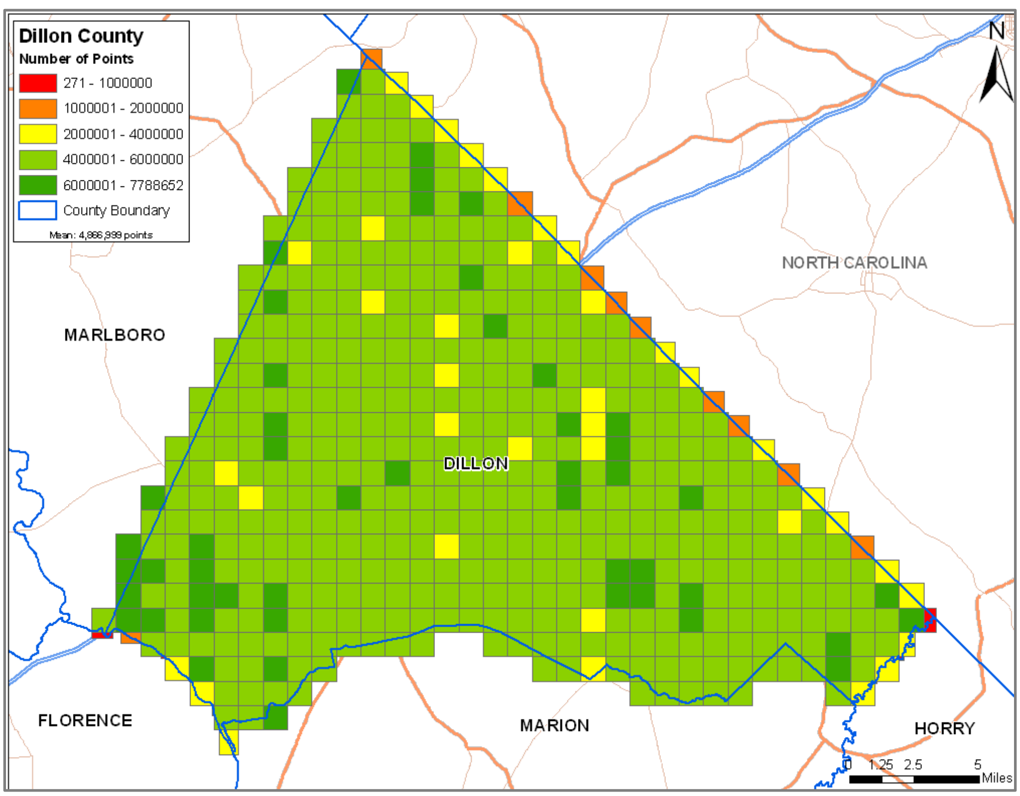

Figure 6 *– Number of points per tile. The red tiles at the border are expected to have fewer points.*

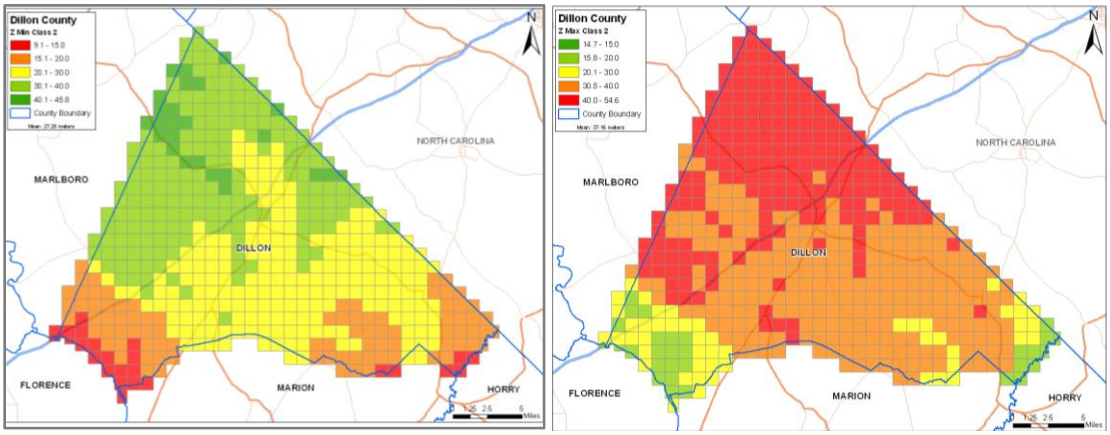

***Figure 7** – Z min and Z max elevation by tile for ground points (class 2).*

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 55 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	40
b - Bush	0	16
h - High Grass	10	23
w - Woods	10	16
u - Urban	20	39
Total	**60**	**134**

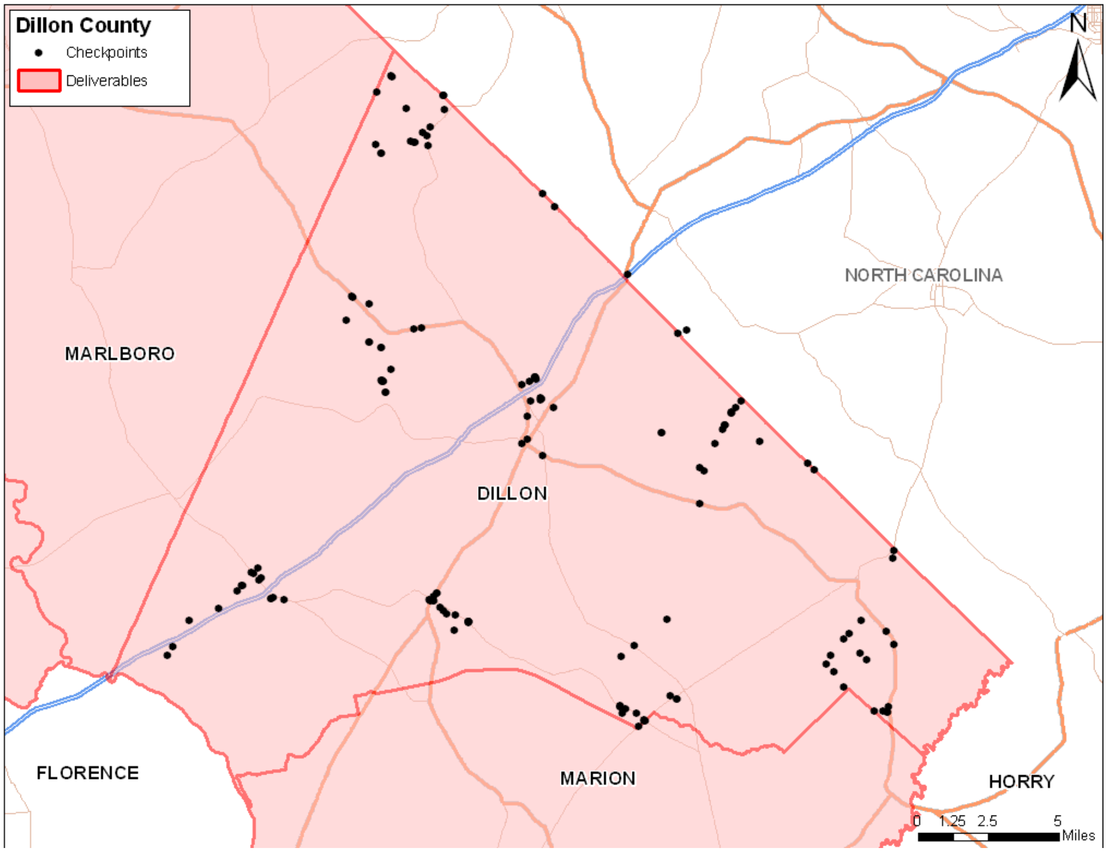

Figure 8 *– Survey checkpoints from South Carolina Geodetic Survey.*

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 Dillon 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 (0.060 m) x 1.9600, or 0.118 m (11.8 cm).

Table 4 - Final statistics for Dillon 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	0.060	-0.014	-0.018	1.245	0.059	134	-0.130	0.252
Bare Earth	0.047	-0.030	-0.031	0.058	0.037	40	-0.106	0.041
Vegetated	0.071	0.014	0.013	1.012	0.070	55	-0.130	0.252
Urban	0.056	-0.038	-0.032	-0.201	0.043	39	-0.127	0.048

Table 5 shows the complete results of the Dillon data set run through the NDEP/ASPRS process; the CVA value is 0.110 m (11.0 cm). The similar results between the two methods 11.8 cm and 11.0 cm demonstrate that the errors approximate a normal error distribution. All of the calculated statistics for Dillon County fall well below the specifications.

Table 5 - Final statistics for Dillon 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	134		11.0	
Bare Earth	40	9.2		8.9
Vegetated	55			14.8
Urban	39			10.9

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

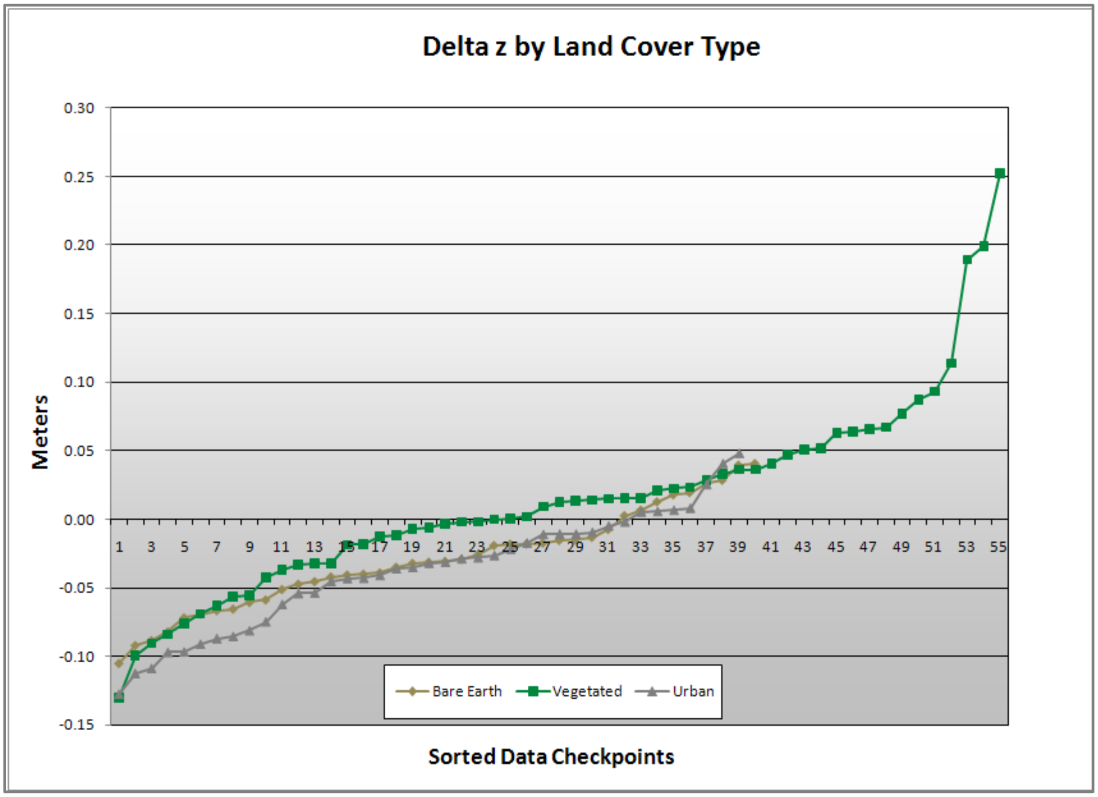

Figure 9 - *Checkpoints shown per land cover type and sorted by errors (DeltaZ).*

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 9.2 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 11.8 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'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.

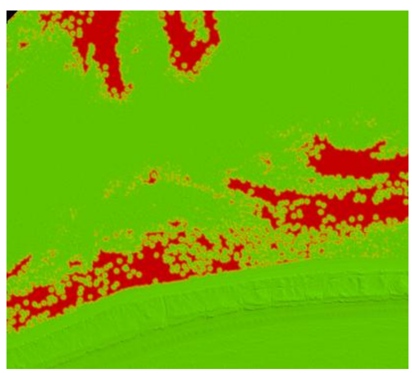

Figure 10 *– Ground model with density information (red means sparse data).*

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.

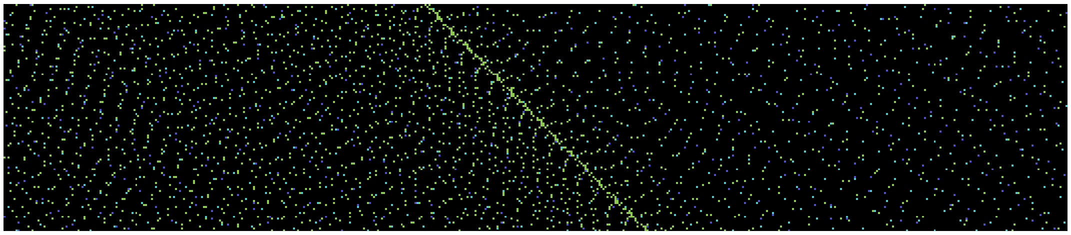

Figure 11 *– Detail of LiDAR points colored by flight line. Note the variations in the scan pattern.*

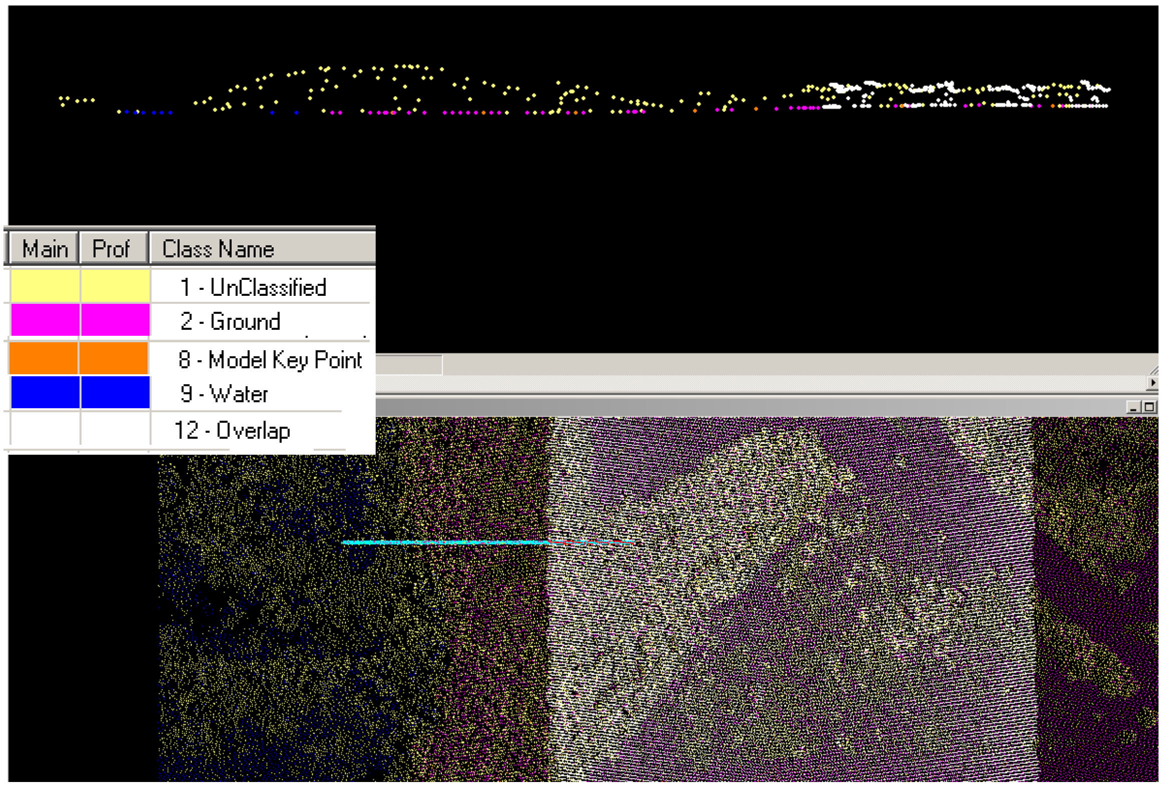

Figure 12 *- Full point cloud colored by classification.*

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 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.

Misclassification

One of the more common problems seen in Dillon 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 13, the red area signifies an absence of ground points in a water retention area. The full point cloud intensity image on the right shows that the LiDAR sensor actually returned points as there was no water present at the time.

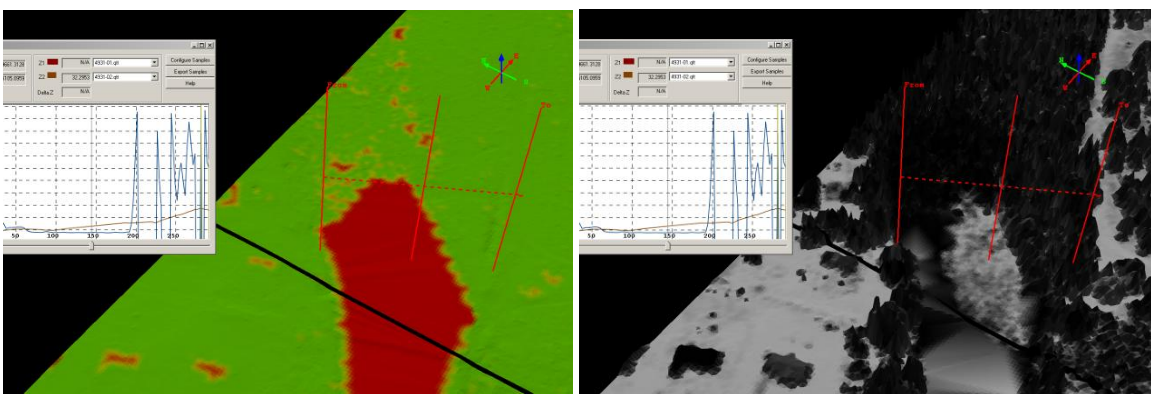

Figure 13 *- 4931-02 Misclassification of ground points.*

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 14 shows an example of an area where bleacher points were left in during the classification process. Figure 15 shows possible vegetation artifacts within a right-of-way. It should be mentioned that these tiles have not been ground-truthed and therefore are only identified as potential issues. This type of error is very common in LiDAR datasets, but it is easy to fix and does not alter the usability of the LiDAR product.

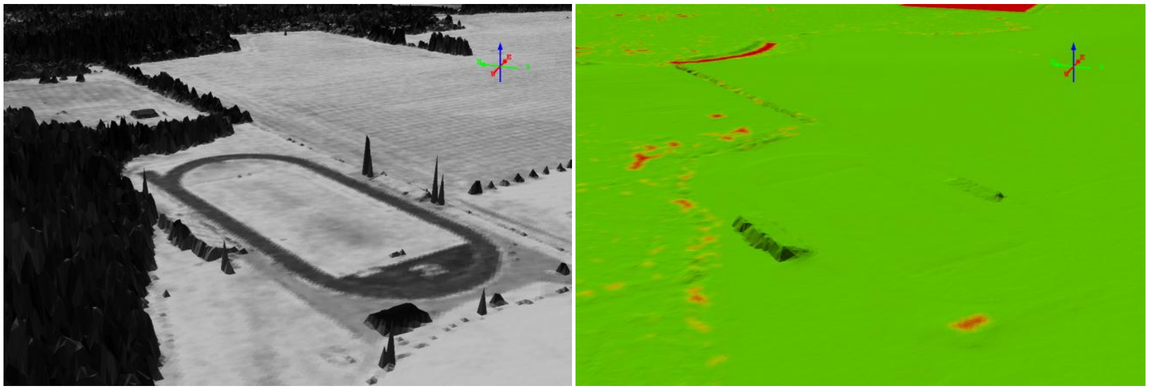

Figure 14 *- 4971-02 Potential artifacts. Left image is full point cloud model with intensity, right is ground density model.*

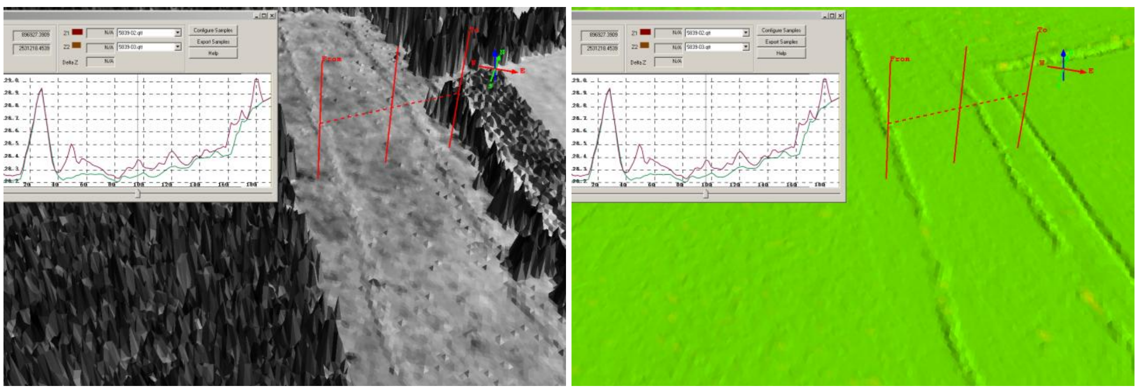

Figure 15 *- 5839-01 Potential vegetation artifacts. Left image is full point cloud model with intensity, right is ground density model.*

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 16.

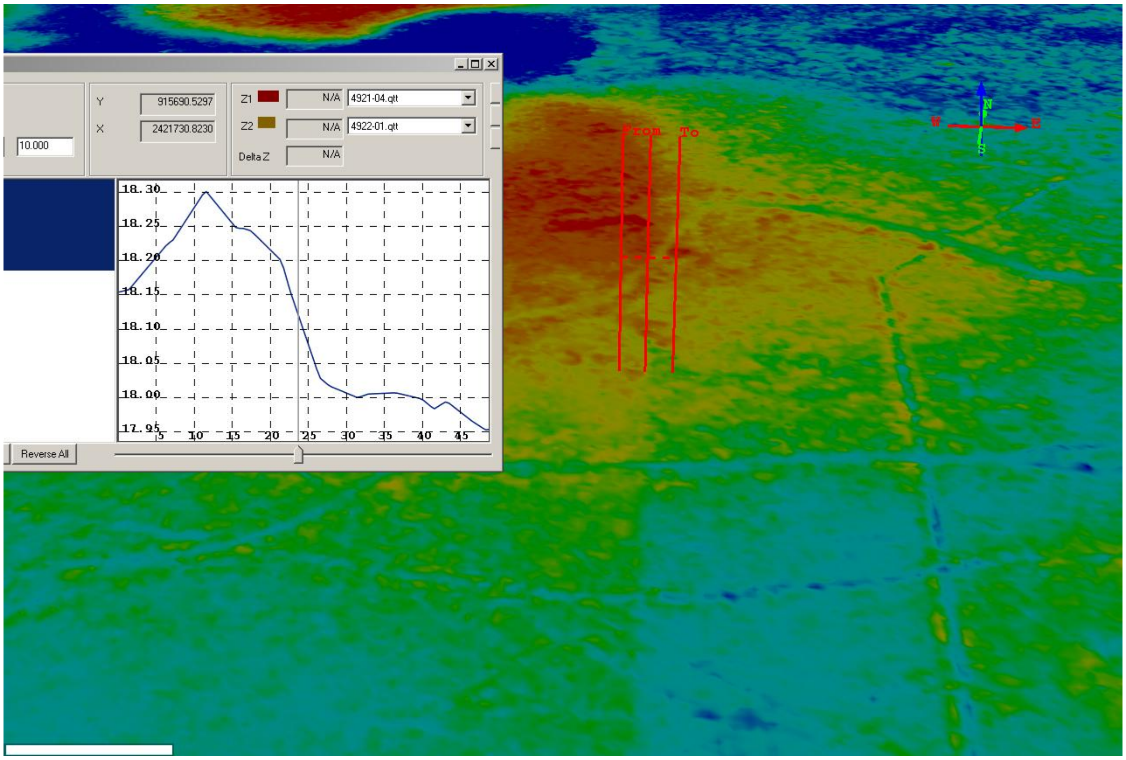

Figure 16 *- 4921-01 Negligible flight line offset.*

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; this is illustrated in Figure 16. 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.

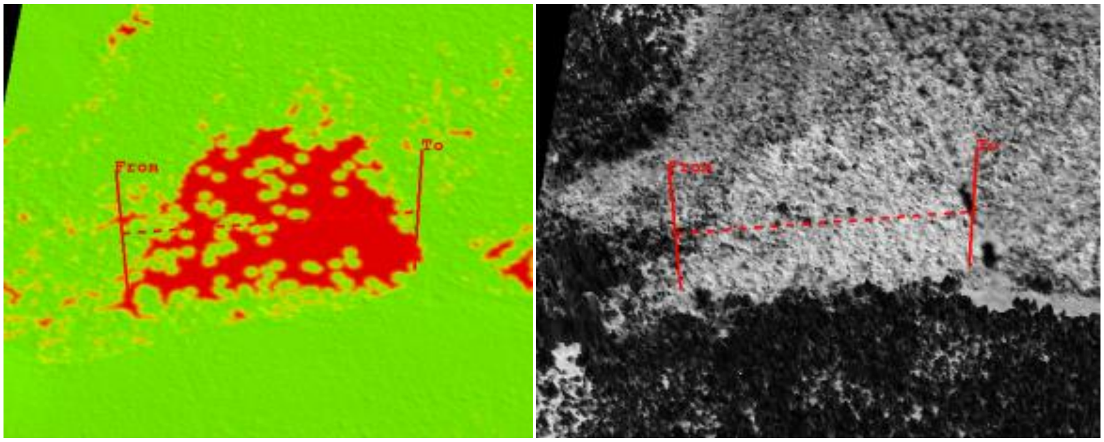

Figure 17 *- 5903-03 Poor LiDAR penetration. Left image is ground density model, right is full point cloud model with intensity.*

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
b17-1-12	2468679.363	1006849.096	44.997	45.019	B	0.022
b17-1-4	2471800.886	1002313.215	42.193	42.280	B	0.087
b17-2-1	2423807.957	904039.562	18.403	18.371	B	-0.032
b17-2-Control	2443168.574	914821.337	37.217	37.210	B	-0.007
b17-3-5	2463968.429	955825.008	37.350	37.363	B	0.013
b17-3-8	2465710.931	957852.092	36.361	36.324	B	-0.037
b17-4-2	2492890.444	956409.753	35.841	35.828	B	-0.013
b17-4-7	2494071.735	952223.561	36.306	36.353	B	0.047
b17-5-10	2523877.285	939419.749	31.158	31.139	B	-0.019
b17-5-4	2528547.655	947290.725	35.357	35.393	B	0.036
b17-6-11	2555190.533	903337.480	30.879	30.881	B	0.002
b17-6-3	2558214.510	893535.643	27.520	27.535	B	0.015
b17-7-15	2477986.174	911769.690	30.001	30.016	B	0.015
b17-7-6	2475696.298	912591.129	30.178	30.199	B	0.021
b17-8-15	2517650.349	910763.245	22.475	22.508	B	0.033
b17-8-5	2511990.782	893306.500	23.817	24.069	B	0.252
h17-1-11	2463030.953	1000121.087	45.276	45.192	B	-0.084
h17-1-5	2472591.502	1001729.444	40.889	40.953	B	0.064
h17-2-11	2441389.557	918668.197	39.832	39.763	B	-0.069
h17-2-7	2437944.313	917299.324	35.251	35.161	B	-0.090
h17-3-4	2464304.190	955648.005	36.454	36.355	B	-0.099
h17-3-7	2464884.443	953524.023	37.713	37.583	B	-0.130
h17-4-4	2492821.385	956336.993	36.693	36.675	B	-0.018
h17-4-6	2492005.251	951956.851	36.922	36.846	B	-0.076
h17-5-3	2529748.981	949636.232	38.395	38.462	B	0.067
h17-6-5	2551006.745	898182.341	32.913	32.913	B	0.000
h17-7-2	2480427.550	910425.577	31.425	31.383	B	-0.042
h17-7-5	2476246.856	911816.916	32.277	32.275	B	-0.002
h17-8-1	2508889.187	894490.698	29.709	29.698	B	-0.011
h17-8-4	2509309.605	893172.832	31.890	31.890	B	0.000
hFATTUESDAY	2560243.744	922319.921	27.814	27.808	B	-0.006
hFUTURE	2494256.009	990821.075	45.347	45.291	B	-0.056

hHIGGINS	2464041.047	961953.980	47.825	48.014	B	0.189
hKENTYRE	2519803.187	964520.453	46.224	46.287	B	0.063
hNICHOLS	2559363.654	894438.285	31.846	31.860	B	0.014
hOAKDALE	2545279.283	938983.519	33.106	33.074	B	-0.032
hPERFECT	2496626.991	988464.600	44.805	44.856	B	0.051
hPINESTUMP	2531668.962	951793.007	40.468	40.504	B	0.036
hPRESSURE	2544093.839	940191.170	36.784	36.793	B	0.009
o17024	2464198.025	955672.492	37.330	37.248	A	-0.082
o17-1-10	2463931.373	998401.852	45.682	45.623	A	-0.059
o17-1-15	2465916.162	1012825.909	47.945	47.879	A	-0.066
o17-1-6	2470252.950	1000458.860	43.414	43.427	A	0.013
o17-2-12	2440901.011	918232.386	39.639	39.534	A	-0.106
o17-2-4	2433447.865	912846.675	22.065	22.017	A	-0.048
o17-2-5	2436871.623	916189.295	26.092	26.000	A	-0.092
o17-2-6	2437712.706	917146.809	34.494	34.455	A	-0.039
o17-2-8	2440729.091	920552.675	39.284	39.195	A	-0.089
o17-3-10	2471623.312	965701.833	45.701	45.661	A	-0.040
o17-3-12	2458464.117	971472.893	48.901	48.883	A	-0.018
o17-3-15	2461775.715	962920.507	39.712	39.640	A	-0.072
o17-3-16	2457339.530	967141.873	47.426	47.394	A	-0.032
o17-4-10	2494393.179	941585.116	35.134	35.092	A	-0.042
o17-4-11	2490370.588	943894.778	34.402	34.367	A	-0.035
o17-5-12	2516566.891	945932.674	38.005	37.964	A	-0.041
o17-5-2	2529797.878	949719.200	38.762	38.780	A	0.018
o17-5-6	2528565.330	947404.642	35.857	35.796	A	-0.061
o17-5-8	2523869.512	932635.211	32.425	32.452	A	0.027
o17-6-10	2553982.137	904577.128	30.900	30.892	A	-0.008
o17-6-12	2560363.969	906046.511	29.711	29.693	A	-0.018
o17-6-2	2559148.433	893332.891	24.279	24.264	A	-0.015
o17-6-4	2556576.638	893666.130	30.344	30.327	A	-0.018
o17-6-8	2548371.133	904111.374	36.298	36.231	A	-0.067
o17-7-11	2474495.854	915869.396	32.846	32.817	A	-0.029
o17-7-14	2473804.900	914442.255	30.773	30.757	A	-0.016
o17-7-7	2475017.768	913170.610	29.698	29.647	A	-0.052
o17-7-8	2473148.559	914282.485	31.807	31.835	A	0.028
o17-7-ControlREO	2480382.714	910362.823	32.161	32.135	A	-0.026
o17-8-11	2519567.482	895946.623	28.661	28.664	A	0.002
o17-8-6	2513357.352	891952.464	26.409	26.416	A	0.007
o17-8-7	2513488.374	891802.135	25.814	25.768	A	-0.046
o17-8-9	2512320.027	890823.225	30.753	30.792	A	0.039
oDILPORT	2491790.362	955660.091	36.904	36.835	A	-0.070
oDILPORTAZMK	2490395.843	955007.799	39.813	39.854	A	0.041

oDLCA	2493076.239	956066.158	34.968	34.955	A	-0.013
oMARDIGRAS	2560311.631	923809.959	28.264	28.245	A	-0.019
oT148	2508913.333	894568.236	29.269	29.288	A	0.019
oVISION	2475801.460	1006592.633	49.599	49.568	A	-0.031
oWARDSTORE	2530650.445	950597.640	38.936	38.905	A	-0.031
u17-1-13	2463202.394	1009848.575	46.587	46.525	E	-0.062
u17-1-14	2465862.796	1012901.514	48.294	48.213	E	-0.081
u17-1-16	2472701.649	999871.452	43.881	43.888	E	0.007
u17-1-7	2470164.707	1000440.496	43.668	43.663	E	-0.005
u17-1-9	2464060.907	998335.121	45.889	45.846	E	-0.043
u17-2-10	2439505.916	919751.567	40.119	40.011	E	-0.108
u17-2-13	2445660.786	914633.072	37.804	37.763	E	-0.041
u17-2-14	2443613.780	914907.785	37.689	37.602	E	-0.087
u17-2-9	2439956.634	919446.684	40.381	40.284	E	-0.097
u17-3-1	2464006.507	961928.972	48.091	48.060	E	-0.031
u17-3-11	2458595.180	971383.021	49.343	49.332	E	-0.011
u17-3-2	2464143.183	955666.336	37.754	37.700	E	-0.054
u17-3-6	2464857.549	953465.078	37.749	37.637	E	-0.112
u17-3-9	2470077.196	965409.684	45.878	45.883	E	0.005
u17-4-1	2492939.164	956162.889	35.890	35.879	E	-0.011
u17-4-12	2491394.141	944703.075	35.955	35.859	E	-0.096
u17-4-13	2496465.443	950695.968	36.559	36.600	E	0.041
u17-4-5	2491506.446	948964.246	38.299	38.172	E	-0.127
u17-4-8	2493936.658	952127.100	36.359	36.365	E	0.006
u17-5-1	2529863.556	949750.935	38.874	38.882	E	0.008
u17-5-11	2516579.048	945831.443	37.747	37.704	E	-0.043
u17-5-13	2528239.052	946504.123	37.486	37.411	E	-0.075
u17-5-14	2535164.932	944209.892	33.011	33.009	E	-0.002
u17-5-7	2526729.332	943858.561	32.675	32.700	E	0.025
u17-6-13	2558920.396	908653.973	29.908	29.863	E	-0.045
u17-6-14	2554177.868	910595.397	37.144	37.109	E	-0.035
u17-6-15	2551887.216	908234.638	36.526	36.509	E	-0.017
u17-6-7	2547712.734	902451.995	34.832	34.806	E	-0.026
u17-6-9	2551009.983	907104.086	36.314	36.260	E	-0.054
u17-7-10	2474436.367	915814.743	32.807	32.722	E	-0.085
u17-7-12	2473756.259	915263.096	30.767	30.739	E	-0.028
u17-7-13	2473905.967	914320.573	31.215	31.124	E	-0.091
u17-7-3	2480453.234	910307.974	32.086	32.050	E	-0.036
u17-7-9	2472937.722	914606.399	33.027	32.998	E	-0.029
u17-8-12	2518247.225	896474.926	29.885	29.933	E	0.048
u17-8-13	2509065.153	903857.959	28.092	28.083	E	-0.009
u17-8-2	2508933.396	894536.163	29.241	29.209	E	-0.032

u17-8-3	2509954.796	894082.080	30.199	30.188	E	-0.011
u17-8-8	2513540.068	891816.997	25.692	25.670	E	-0.022
w17-1-3	2473256.913	1003367.342	36.413	36.527	B	0.114
w17-1-8	2469413.181	1000715.183	44.522	44.615	B	0.093
w17-2-2	2424777.202	905794.687	18.485	18.452	B	-0.033
w17-2-3	2427910.763	910603.538	17.781	17.796	B	0.015
w17-3-13	2461747.416	970121.960	46.777	46.714	B	-0.063
w17-3-3	2464176.059	955540.754	37.513	37.537	B	0.023
w17-4-3	2492933.407	956457.811	34.291	34.357	B	0.066
w17-4-9	2493922.048	952391.322	36.794	36.993	B	0.199
w17-5-5	2528611.420	947285.917	36.048	35.993	B	-0.056
w17-5-9	2524749.020	938739.614	31.274	31.302	B	0.028
w17-6-1	2559171.128	893425.606	25.071	25.123	B	0.051
w17-6-6	2549030.759	900930.569	30.654	30.652	B	-0.002
w17-7-1	2480323.501	910426.412	32.218	32.231	B	0.013
w17-7-4	2477729.304	908813.172	36.937	36.934	B	-0.003
w17-8-10	2519511.385	895937.453	28.216	28.256	B	0.040
w17-8-14	2511501.245	905917.189	31.927	32.004	B	0.077