LiDAR Quality Assurance (QA) Report
Orangeburg County, South Carolina
February 13, 2008

Submitted to:
USGS
Prepared by:
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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 Orangeburg County, SC, produced by Dewberry's subcontractor, Fugro EarthData, under the referenced USGS task order. The LiDAR data was acquired by Fugro EarthData 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 1,399 tiles (each 5000 ft x 5000 ft) were delivered covering all of Orangeburg 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 shown 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	7.6 cm
FVA	20	23	36.3 cm	18.9 cm
CVA	60	94	36.3 cm	14.5 cm
SVA-bare earth	20	23	36.3 cm	17.4 cm
SVA-vegetated	20	48	36.3 cm	13.4 cm
SVA-urban	20	23	36.3 cm	11.0 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 (<2%) like poor LiDAR penetration, small misclassifications, and negligible flight line differences. Two anomalies were seen in the intensity images, i.e., white stripes over land at nadir and tonally dark areas in some flight lines, but these did not affect DEM accuracy or usability. 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 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 Orangeburg 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.

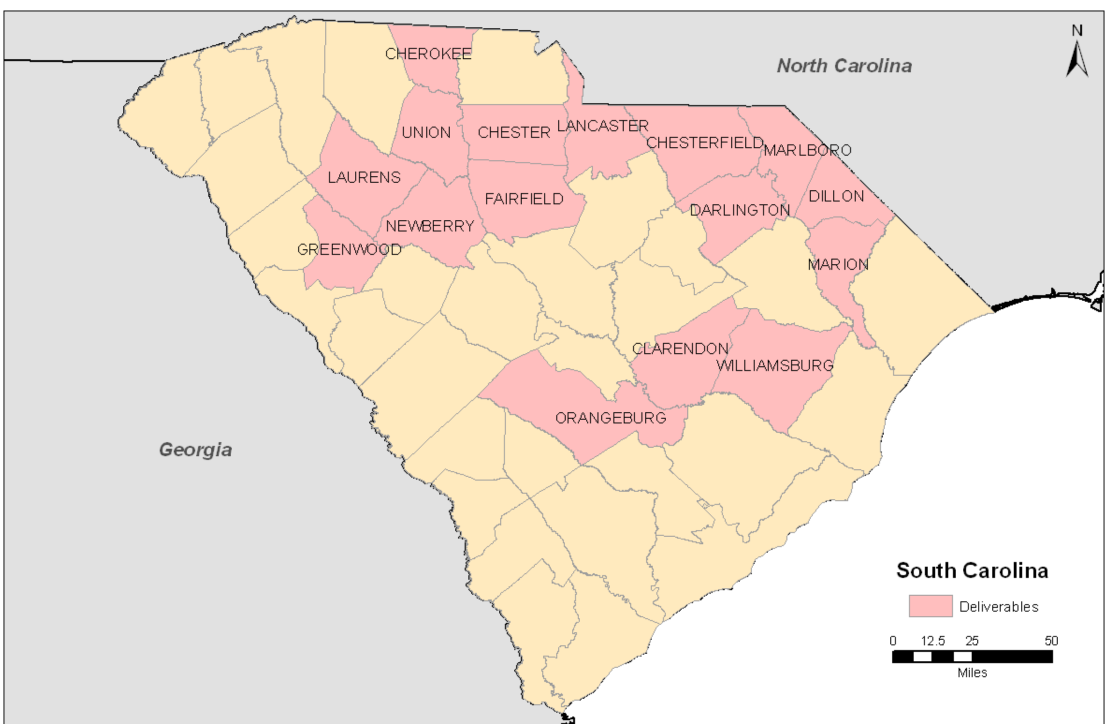

***Figure 1** – Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

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	1 feature class
Ground masspoints	ESRI feature class multipoints	1 feature 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, the terrain, and the intensity images extend outside the project boundary with a 50 ft buffer (Figure 4 and Figure 5) as expected.

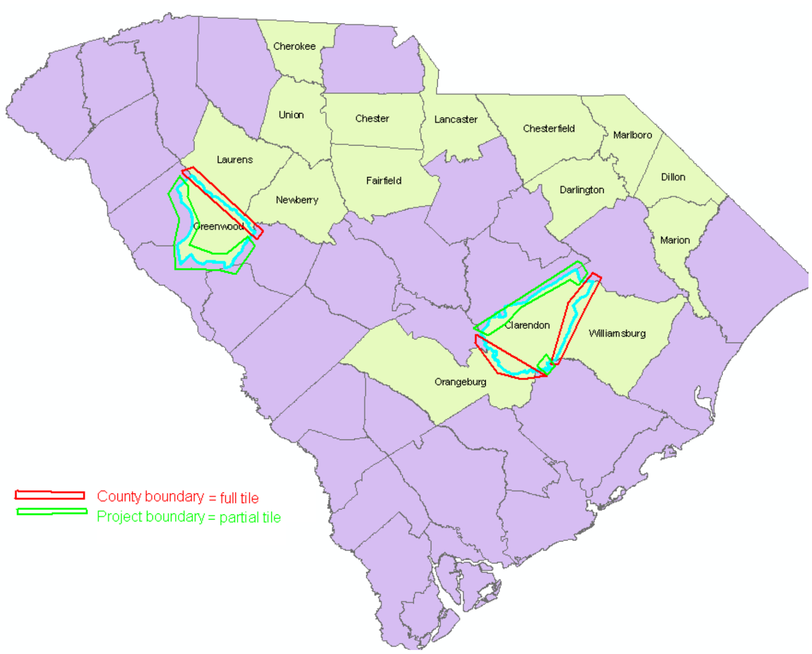

***Figure 2** – Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

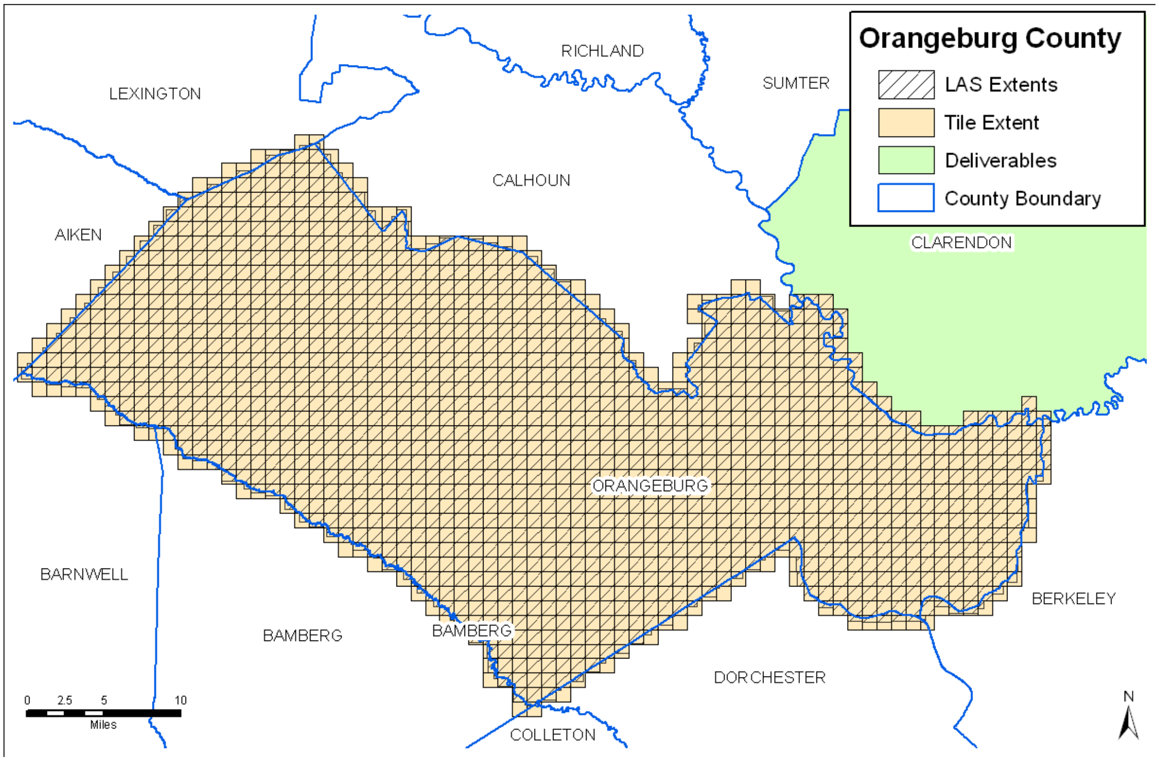

***Figure 3** – The LiDAR coverage of Orangeburg County. Neighboring deliverable counties are shown in green.*

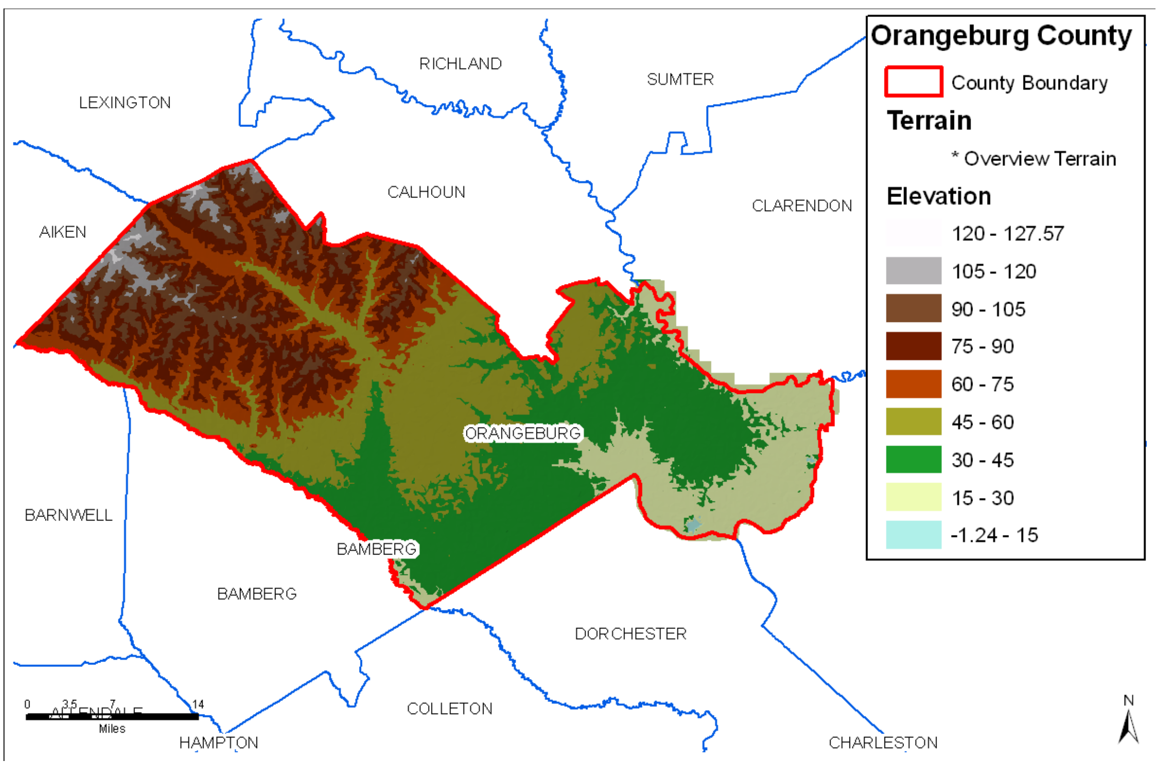

***Figure 4** – The terrain for Orangeburg has a 50 ft buffer outside of the project boundary.*

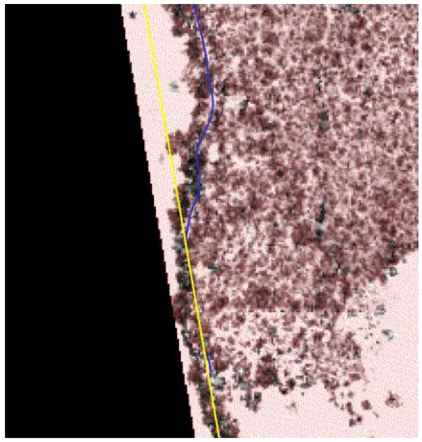

Figure 5 *- Ground masspoints (red) and intensity images extent 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydrolines are clipped at the project boundary and the watershed boundary.*

3 QA of intensity images

1,399 intensity images in GeoTiff format were delivered for Orangeburg 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: 0505-04.tif	0 0 0
File Information:	2005000 555000 0
Standard : : TIFF File	ModelPixelScaleTag (1,3):
Format : : Byte integers (8 bits)	4 4 0
Pixels per Line : 1250	End_Of_Tags.
Number of Lines : 1250	Keyed_Information:
Samples per pixel : 1	GTModelTypeGeoKey (Short,1): ModelTypeProjected
File bits per sample : 8	GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
Actual bits per sample : 8	ProjectedCSTypeGeoKey (Short,1): Unknown-3361
Untiled file	ProjLinearUnitsGeoKey (Short,1): Linear_Foot
Number of overviews : 0	End_Of_Keys.
Scanning device resolution : 72 : lines/inch	End_Of_Geotiff.
Orientation : 4 : Row major order, origin at top left	PCS = 3361 (NAD83(HARN) / South Carolina (ft))
NO scan line headers : non-scannable file	Projection = 15355 (SPCS83 South Carolina zone (International feet))
Packet size (16-bit words) : 0	Projection Method: CT_LambertConfConic_2SP
Free vlt space (16-bit words) : 2000000000	ProjFalseOriginLatGeoKey: 31.833333 (31d50' 0.00"N)
Free packet space (16-bit words) : 2000000000	ProjFalseOriginLongGeoKey: -81.000000 (81d 0' 0.00"W)
Raster to UOR matrix:	ProjStdParallel1GeoKey: 34.833333 (34d50' 0.00"N)
Unspecified or All Zero Matrix	ProjStdParallel2GeoKey: 32.500000 (32d30' 0.00"N)
Raster to World Matrix:	ProjFalseEastingGeoKey: 609600.000000 m
Units: Feet	ProjFalseNorthingGeoKey: 0.000000 m
amx[0]= 4, amx[1]= 0, amx[2]= 2005000	GCS: 4152/NAD83(HARN)
amx[3]= 0, amx[4]= -4, amx[5]= 555000	Datum: 6152/NAD83 (High Accuracy Regional Network)
2005000 , 555000	Ellipsoid: 7019/GRS 1980 (6378137.00,6356752.31)
2010000 , 555000	Prime Meridian: 8901/Greenwich (0.000000/ 0d 0' 0.00"E)
2010000 , 550000	Projection Linear Units: 9002/foot (0.304800m)
2005000 , 550000	Corner Coordinates:
Geotiff_Information:	Upper Left (2005000.000, 555000.000)
Version: 1	Lower Left (2005000.000, 550000.000)
Key_Revision: 1.0	Upper Right (2010000.000, 555000.000)
Tagged_Information:	Lower Right (2010000.000, 550000.000)
ModelTiepointTag (2,3):	Center (2007500.000, 552500.000)

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

Two anomalies were seen in the intensity images. These were white stripes over land at nadir and tonally dark areas in some flight lines (Figure 6). Fugro EarthData was informed of both of these issues. The white stripes at nadir are expected over water, but when we see them over the land this is an issue. The white stripes occur when the intensity becomes saturated at nadir. The cause of the dark areas within flight lines is unknown. However, these small anomalies in the intensity images have not significantly affected the overall product.

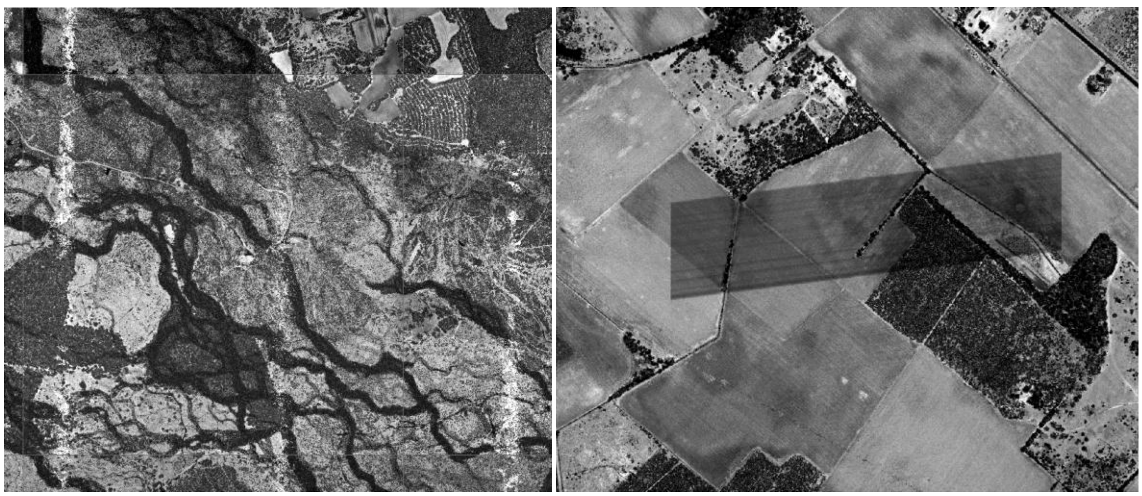

Figure 6 *– Left intensity image displays white stripes at nadir. Right intensity image includes tonally dark area.*

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 1,399 LiDAR files covering the Orangeburg 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 1.4m, the number of point per tile should be around 3.9 million. The mean over Orangeburg County is around 4.8 million which proves that the average density is more than what is required and 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 7.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 18 m and 127 m, no noticeable anomalies were identified because this is consistent with the expected range of elevation in the county (max elevation in Orangeburg County: around 130 m). Figure 8 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography. Lower elevations are found near hydrographic features; see Figure 8 (left) for the Z min elevations.

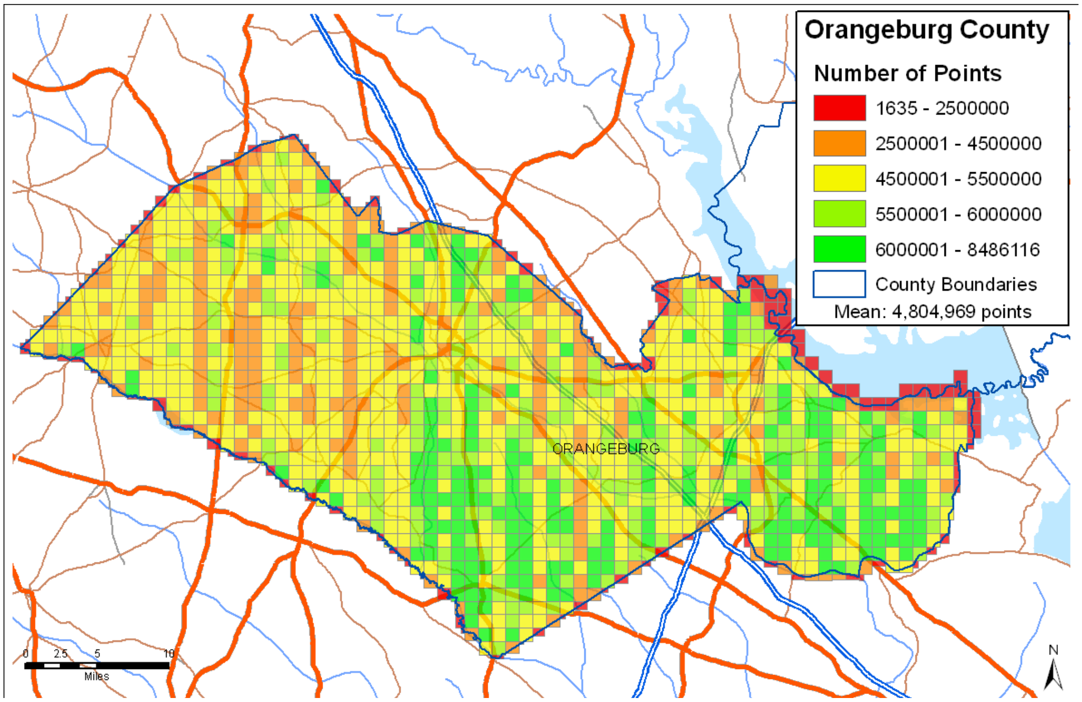

Figure 7 *– Number of points per tile. The red tiles at the border between Orangeburg and Clarendon are over the Lake Marion and area expected to have few points.*

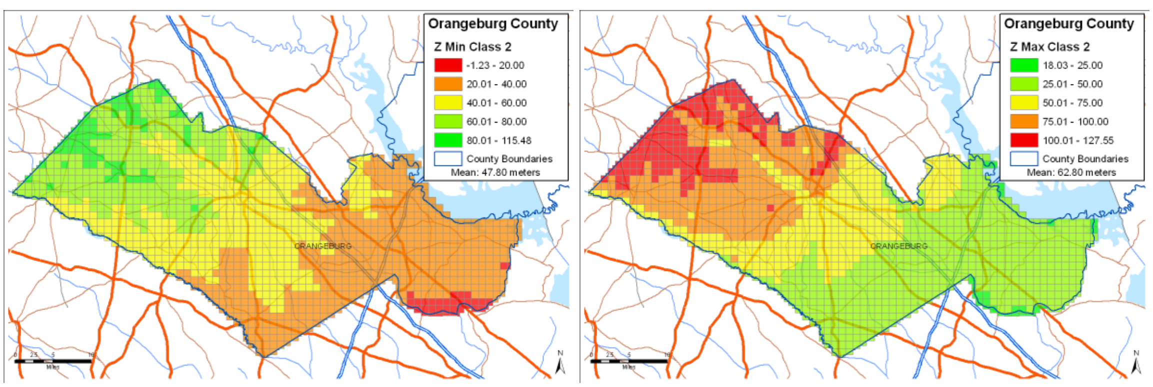

Figure 8 *– Z min and Z max elevation for ground points (class 2) per tile.*

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 96 points were collected, as presented in Table 3, with 48 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 9 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	25
b - Bush	0	17
h - High Grass	10	18
w - Woods	10	13
u - Urban	20	23
Total	**60**	**96**

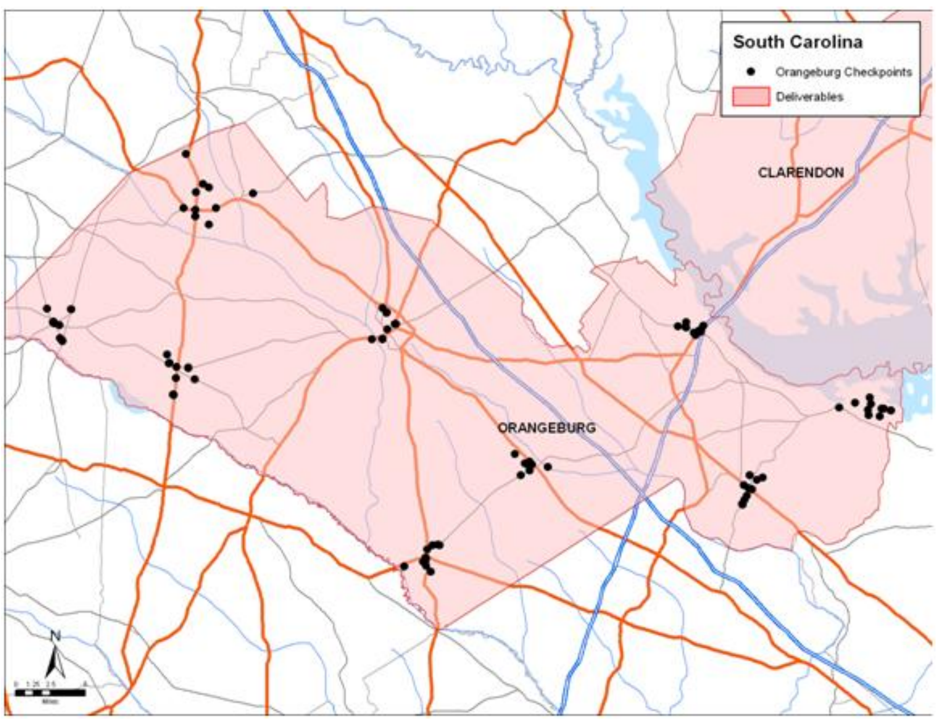

Figure 9 *– Survey Checkpoints from South Carolina Geodetic Survey.*

5.2.2 Vertical Accuracy Assessment Methodologies

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

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

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

The following tables and graphs outline the vertical accuracy and the statistics of the associated errors as computed by the different methods. Table 4 shows the complete results of the Orangeburg 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 (0.076 m) x 1.9600, or 0.149 m (14.9 cm).

Table 4 - Final statistics for Orangeburg 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	0.076	0.013	0.020	-0.485	0.076	94	-0.254	0.176
Bare Earth	0.097	-0.043	-0.057	0.055	0.089	23	-0.254	0.176
Vegetated	0.072	0.046	0.058	-0.022	0.056	48	-0.065	0.165
Urban	0.060	0.001	0.010	0.034	0.062	23	-0.111	0.115

Table **5** shows the complete results of the Orangeburg data set run through the NDEP/ASPRS process; the CVA value is 0.145 m (14.5 cm). The similar results between the two methods (14.9 cm and 14.5 cm) demonstrate that the errors did approximate a normal error distribution, even in vegetation. All of the calculated statistics for Orangeburg County fall well within the specifications.

Table 5 – Final statistics for Orangeburg 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		14.5 cm	
Bare Earth	23	18.9 cm		17.4 cm
Vegetated	48			13.4 cm
Urban	23			11.0 cm

Figure 10 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed checkpoints. The majority of delta Z values are concentrated on the positive side (LiDAR higher than the checkpoints) pointing toward a slight positive bias in the data.

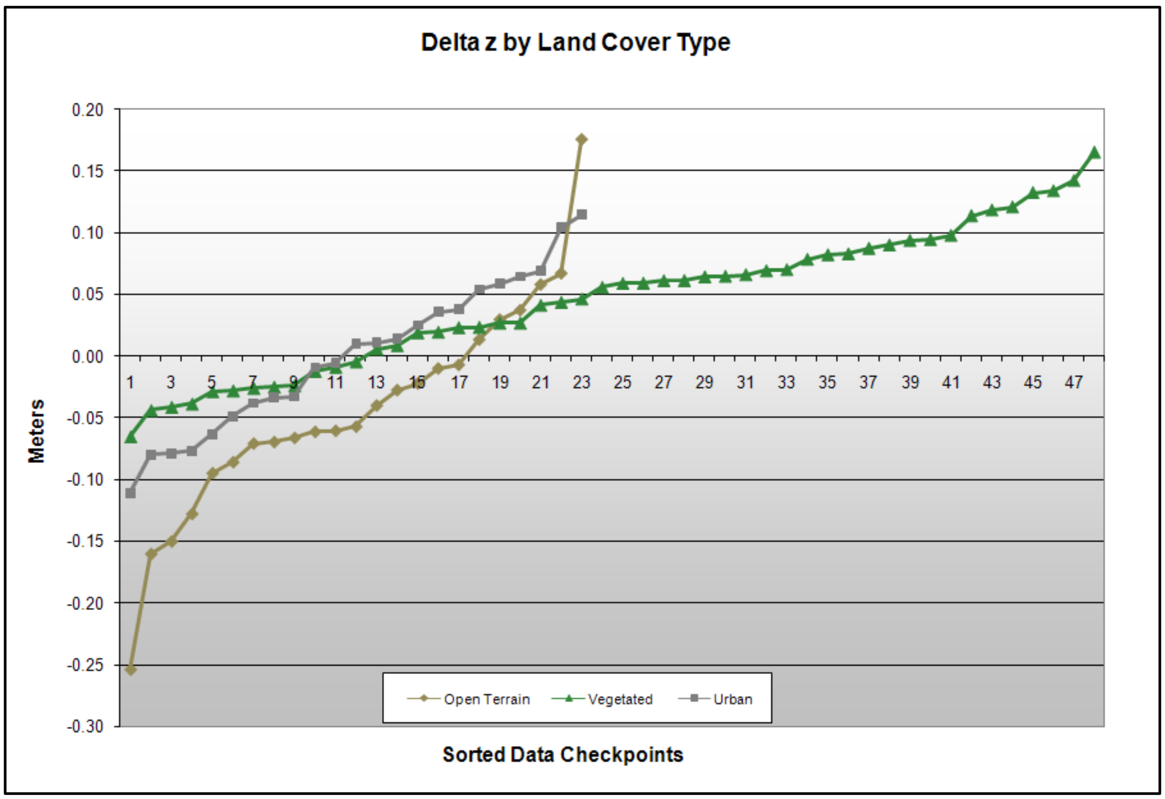

Figure 10 *– Checkpoints shown per land cover type and sorted by errors (deltaZ).*

Given the good results and the high number of checkpoints used, Dewberry is confident that the data meets the accuracy requirement despite the less 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 18.9 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 14.9 cm Consolidated Vertical Accuracy at 95% confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 14.5 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 11). 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.

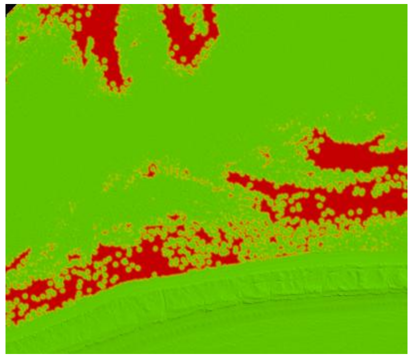

Figure 11 *– Ground model with density information (red means sparse data).*

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 12) or by class (Figure 13). 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 seem to logically represent the terrain.

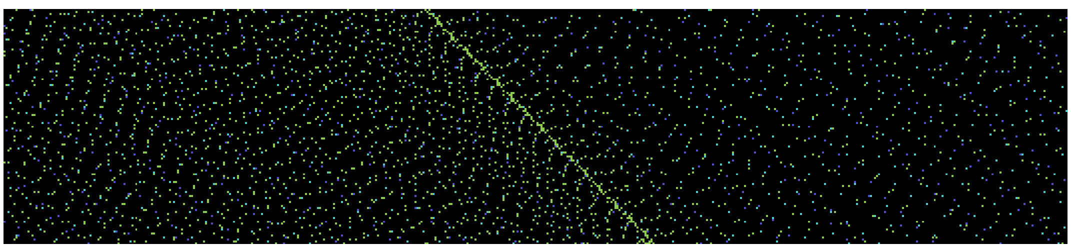

Figure 12 *– LiDAR points colored by flight line. Detail of the point distribution. Note the variations in the scan pattern.*

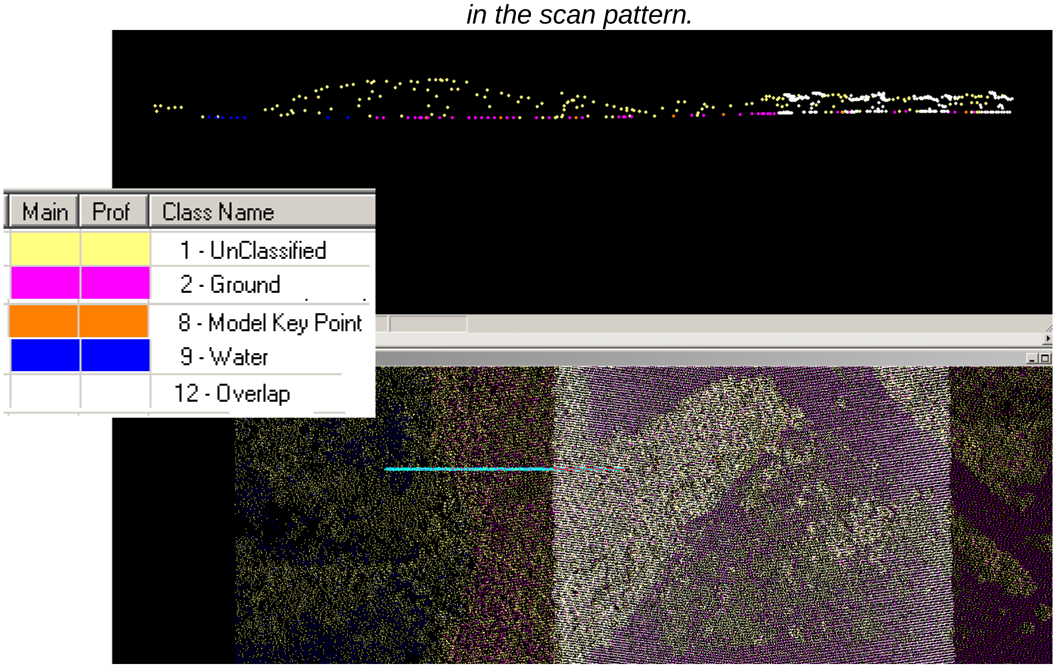

Figure 13 *- Full point cloud colored by classification.*

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 mass point), along with cross section extraction, surface measurements, density evaluation, constitutes our micro level of review.

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 minor misclassifications and poor LiDAR penetration. However, these issues are not serious enough to render the data unusable.

Artifacts

It is not uncommon for the classification algorithms to occasionally misclassify non-ground points. This misclassification results in remnants of vegetation or manmade structures known as artifacts that do not represent the bare-earth terrain. Figure 14 shows an example of one bridge which was partially left in the ground. This type of issue is minor.

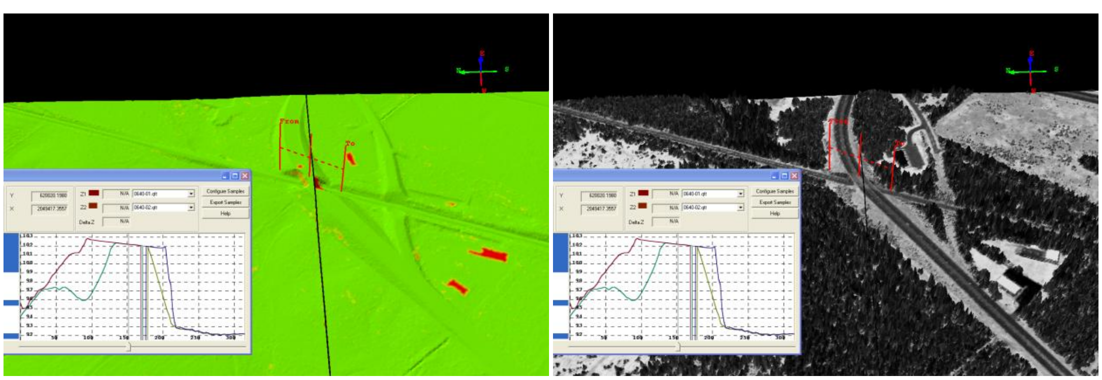

***Figure 14** – 0642-04 Bridge artifact. (Left: Ground density model, Right: Full point cloud intensity model).*

Negligible Flight Line Ridges

A few tiles within the dataset included small ridges at seamlines 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 seamline is used to cut the data from one line to the next. The result is two flight lines which do not perfectly 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 negligible. See Figure 15.

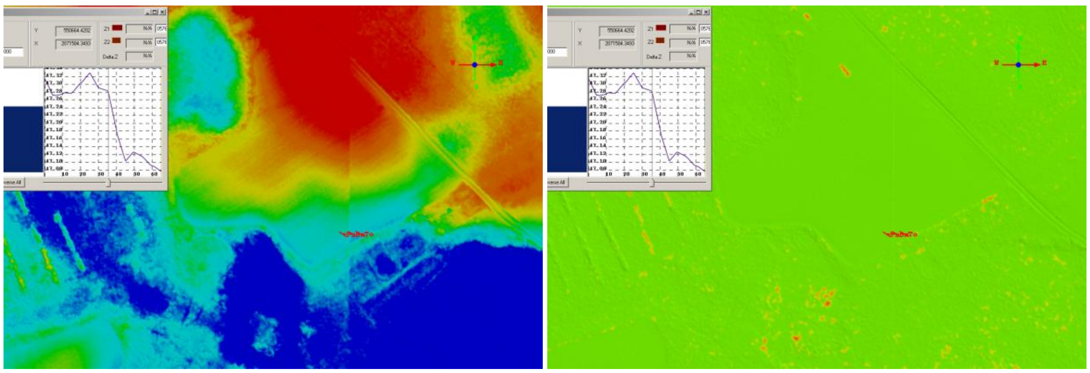

***Figure 15** – 0575-03 Negligible flight line offset.*

Inconsistent Editing

Several instances of inconsistent editing of natural features were found in this dataset. In the case illustrated in Figure 16 it is apparent that different parameters were used to classify vegetation, resulting in low point density in the tile on the left and high density in the tile on the right. These artifacts/inconsistencies are fairly low and isolated, and they have almost no impact on the usability of the ground data.

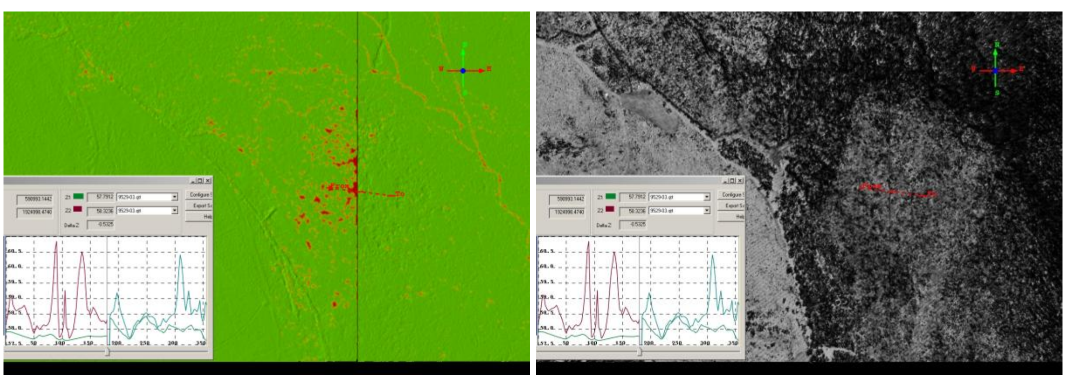

***Figure 16** – 9529-03 Inconsistent editing (L: Ground density model, R: Full point cloud intensity).*

Misclassification

One of the more common problems seen in Orangeburg County was misclassification of points. There were numerous areas in which ground points had been classified to an incorrect class. There was a correlation in some instances between areas having a high intensity value and those lacking ground points. In the left image of Figure 17, the red area signifies an absence of ground points. While in the right image, the ground is very apparent. While this issue occurred at a higher frequency than the others, its presence has an insignificant effect on the accuracy of the data. However, if future users want to focus on particular areas that included this misclassification some redefinition of the ground may be necessary.

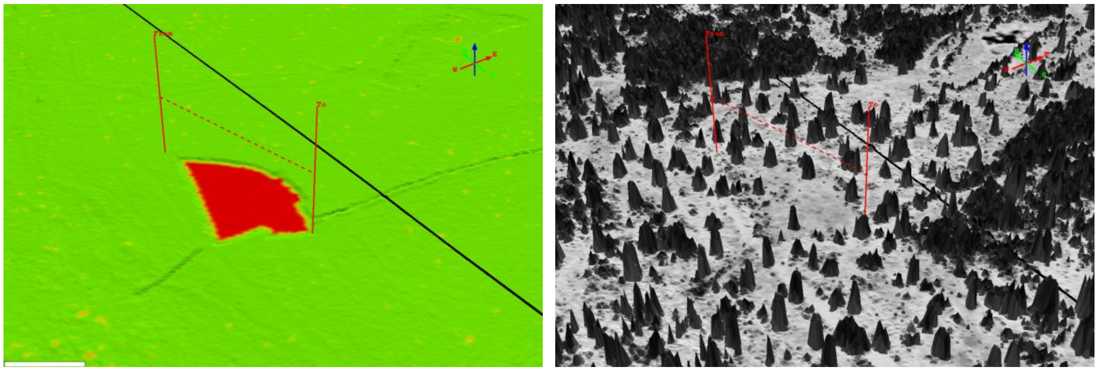

Figure 17 *– 0562-01 Misclassification of ground. (L: Ground density model, R: Full point cloud intensity).*

Dewberry believes that one particular area of misclassification was caused by a previously mentioned intensity issue. In a small subset of the tiles high intensity values were seen at nadir in the intensity images. This problem may have been the reason for the misclassification in Figure 18. The LAS file for this area shows that some areas, which should have been classified as ground, were moved into class 1 (unclassified). See Figure 19.

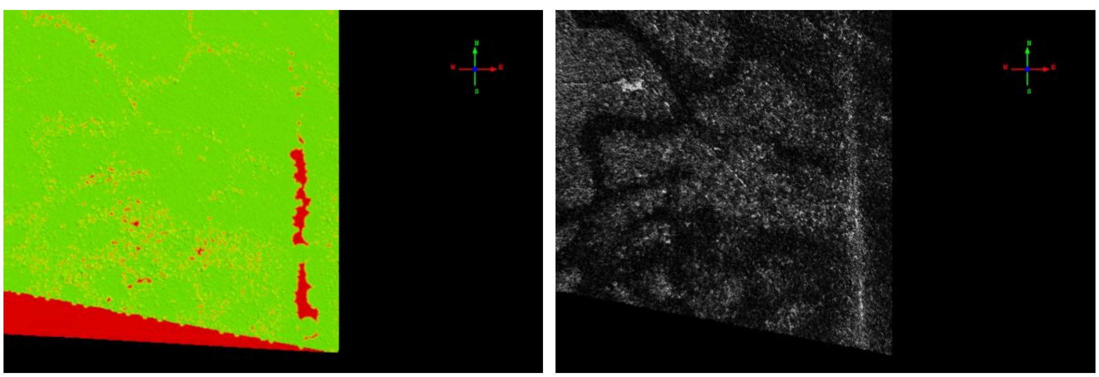

Figure 18 *– 1571-02 Misclassification due to intensity issue. (L: Ground Density Model, R: Full Point Cloud Intensity).*

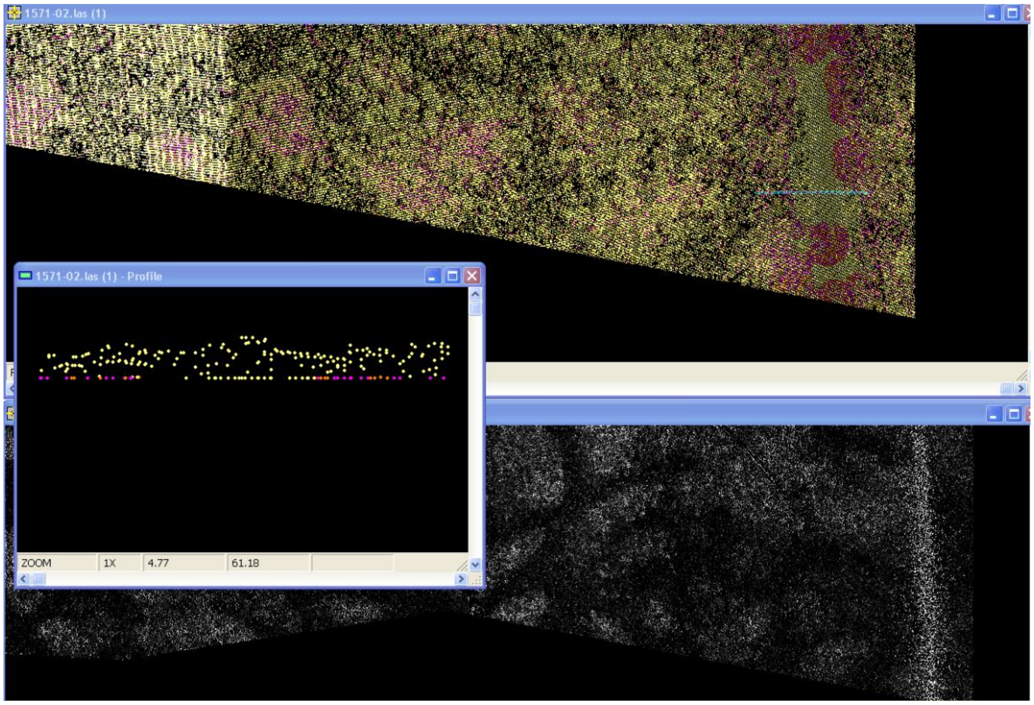

Figure 19 *– 1571-02 Misclassification due to intensity value. On the left is the LAS file with classes shown (yellow: unclassified class 1; purple: Ground class 2). On the right is the LAS file with the intensity shown. The diagram in the middle shows a cross section through one of the areas of misclassification.*

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 20. 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.

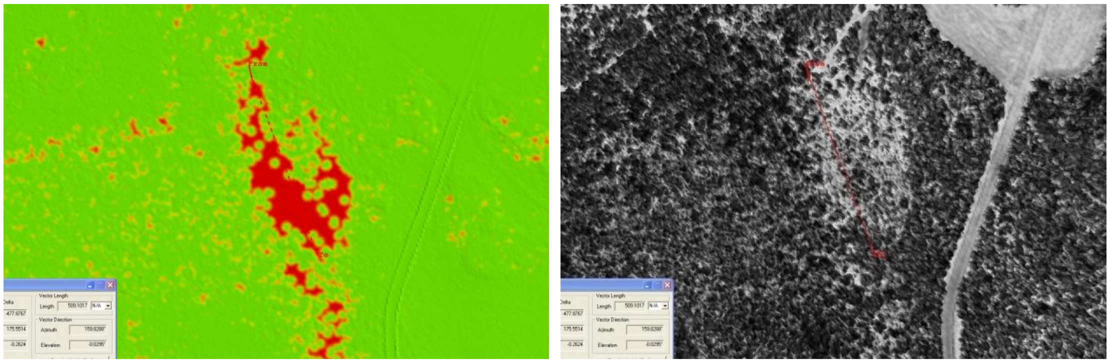

Figure 20 *– 1502-04 Poor LiDAR penetration in vegetated area. (L: Ground density model, R: Full point cloud intensity).*

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	AbsDeltaZ
oM 25 RESET	2056370.791	515979.206	38.250	37.996	-0.254	0.254
o38-1-3	1914573.376	605692.032	91.012	90.852	-0.160	0.160
oROCK	2233063.659	572251.842	23.402	23.256	-0.146	0.146
o38-4-1/ORG 393	2041235.020	609373.215	79.523	79.394	-0.129	0.129
o38-4-7	2041555.271	603027.933	74.183	74.088	-0.095	0.095
o38-2-3	1968538.884	645996.903	79.544	79.458	-0.086	0.086
o38-2-4	1968590.802	648350.521	84.019	83.948	-0.071	0.071
o38-8-9	2180332.033	542155.641	31.544	31.475	-0.069	0.069
o38-4-5/STATE	2044565.143	605026.621	81.004	80.938	-0.067	0.067
o38-4-3	2041298.443	609277.714	79.083	79.021	-0.062	0.062
o38-9-5	2228712.673	570005.166	25.991	25.931	-0.060	0.060
o38-7-6	2155260.521	603685.580	42.500	42.443	-0.057	0.057
o38-5-3	2055284.379	514753.854	36.111	36.071	-0.040	0.040
o38-6-9	2090069.473	555512.192	42.707	42.680	-0.027	0.027
o38-1-2	1912261.257	610800.161	93.053	93.031	-0.022	0.022
o38-2-7/BULL	1990492.747	654713.432	92.905	92.895	-0.010	0.010
o38-1-1/THREE	1918195.594	598648.338	70.954	70.948	-0.006	0.006
oBOWYER	2176538.982	536649.161	27.967	27.980	0.013	0.013
o38-1-1a/THREE	1918195.650	598648.349	70.931	70.948	0.017	0.017
o38-6-CP1	2095858.663	551491.142	41.206	41.236	0.030	0.030
o38-5-6	2058686.654	520893.357	41.736	41.772	0.036	0.036
oMILLER	2160732.737	602065.357	36.865	36.923	0.058	0.058
o38-6-CP1 REO	2095858.698	551491.130	41.171	41.236	0.065	0.065
o38-3-6/M59	1960236.162	578211.071	69.766	69.834	0.068	0.068
o38-3-2/BRUSH	1957943.801	593375.841	72.830	73.004	0.174	0.174
u38-9-10	2233027.531	572242.990	23.584	23.473	-0.111	0.111
u38-4-2	2041356.245	609533.444	81.182	81.103	-0.079	0.079
u38-8-4	2178833.010	542571.932	30.748	30.669	-0.079	0.079
u38-2-2	1968546.737	646031.859	79.558	79.481	-0.077	0.077
u38-8-8	2184351.403	546767.325	33.067	33.002	-0.065	0.065
u38-5-8	2056165.090	514842.347	37.057	37.007	-0.050	0.050
u38-1-11	1914886.954	605272.876	91.330	91.291	-0.039	0.039
u38-2-10	1968876.708	655192.333	102.314	102.281	-0.033	0.033
u38-3-10	1965983.677	588443.550	81.623	81.590	-0.033	0.033
u38-2-1	1973821.426	642842.935	80.204	80.194	-0.010	0.010
u38-3-1	1961431.492	588821.045	71.749	71.744	-0.005	0.005

u38-4-6	2044924.877	605007.571	79.310	79.320	0.010	0.010
u38-1-8	1918163.750	598701.092	71.127	71.137	0.010	0.010
u38-3-8	1960306.072	578131.819	68.817	68.832	0.015	0.015
u38-7-4	2158754.177	600751.806	40.073	40.098	0.025	0.025
u38-1-5	1914667.845	605725.195	90.439	90.475	0.036	0.036
u38-9-8	2224968.106	577110.196	25.008	25.046	0.038	0.038
u38-7-3	2160017.895	602497.541	35.638	35.692	0.054	0.054
u38-9-9	2213287.601	573255.995	25.970	26.031	0.061	0.061
u38-4-8	2035754.970	599139.518	49.450	49.515	0.065	0.065
u38-6-2	2095745.724	552793.466	39.716	39.784	0.068	0.068
u38-5-7	2056835.932	519458.558	40.257	40.362	0.105	0.105
u38-6-8	2096685.685	551579.921	42.366	42.481	0.115	0.115
b38-7-9	2152096.560	604170.062	43.550	43.485	-0.065	0.065
w38-2-9	1964198.057	649073.480	78.148	78.104	-0.044	0.044
h38-5-1	2056116.448	516191.097	37.410	37.369	-0.041	0.041
h38-9-3	2225456.298	574649.188	25.225	25.187	-0.039	0.039
w38-7-2	2161673.085	604393.118	36.899	36.870	-0.029	0.029
h38-7-7	2154888.275	603938.426	42.734	42.706	-0.028	0.028
h38-8-5	2177165.455	543644.429	30.493	30.467	-0.026	0.026
w38-4-4	2039705.137	611079.079	86.592	86.567	-0.025	0.025
b38-4-9	2039875.908	599184.640	47.857	47.833	-0.024	0.024
b38-8-3	2178340.691	539635.710	29.576	29.562	-0.014	0.014
h38-5-2	2047984.363	512856.415	31.793	31.785	-0.008	0.008
h38-6-1	2095573.901	551322.939	42.139	42.135	-0.004	0.004
b38-1-6	1921517.094	610685.605	91.982	91.987	0.005	0.005
h38-3-3	1958616.817	590147.172	68.614	68.621	0.007	0.007
b38-2-11/WOODFORD	1965033.504	669745.584	122.896	122.914	0.018	0.018
h38-6-4	2093814.886	551922.421	42.389	42.408	0.019	0.019
h38-8-6	2179436.836	547574.298	33.258	33.281	0.023	0.023
w38-5-10	2058187.451	510809.539	35.945	35.969	0.024	0.024
h38-1-10	1917175.132	599680.973	72.253	72.279	0.026	0.026
b38-7-5	2158053.156	601722.391	39.160	39.187	0.027	0.027
w38-1-9	1916986.954	604506.203	89.906	89.949	0.042	0.042
b38-2-6	1971642.957	658203.757	107.997	108.040	0.043	0.043
h38-3-5	1961345.887	584393.520	74.954	75.000	0.046	0.046
h38-2-5	1973857.798	656842.813	99.264	99.320	0.056	0.056
b38-3-11	1965975.023	588349.564	82.719	82.777	0.058	0.058
b38-8-1	2176616.261	536449.348	27.721	27.780	0.059	0.059
w38-5-9	2056426.258	513117.426	35.455	35.516	0.061	0.061
b38-5-4	2060870.800	521262.763	42.552	42.615	0.063	0.063
h38-7-1	2160799.124	602179.223	32.279	32.344	0.065	0.065
b38-9-1	2230444.955	572804.223	23.708	23.773	0.065	0.065
h38-3-7	1960297.395	578067.324	68.631	68.697	0.066	0.066
h38-9-2	2229566.644	572895.333	24.700	24.770	0.070	0.070
h38-1-7	1921490.911	610575.766	91.969	92.039	0.070	0.070
b38-3-9	1968367.456	584119.245	67.352	67.430	0.078	0.078
w38-3-4	1958713.233	590256.897	68.475	68.558	0.083	0.083
h38-1-4	1914800.160	605908.481	89.807	89.890	0.083	0.083

b38-6-5	2095796.245	549419.089	42.797	42.884	0.087	0.087
w38-7-8	2155152.317	605662.946	41.619	41.710	0.091	0.091
b38-6-3	2094732.068	551813.468	41.869	41.964	0.095	0.095
w38-6-6	2092322.530	547605.215	43.484	43.579	0.095	0.095
b38-5-5	2061482.556	520836.804	42.608	42.706	0.098	0.098
b38-9-4	2224505.823	570318.969	25.375	25.488	0.113	0.113
w38-8-2	2177409.844	538138.562	28.806	28.925	0.119	0.119
w38-6-7	2102628.879	550775.014	37.165	37.286	0.121	0.121
w38-8-7	2182144.531	545706.069	32.478	32.612	0.134	0.134
h38-4-10	2039816.938	599429.957	48.085	48.219	0.134	0.134
b38-2-8	1976512.892	649056.357	99.360	99.502	0.142	0.142
w38-9-6	2224355.619	572375.335	25.453	25.619	0.166	0.166