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FL Peninsular Lidar Project- Final Accuracy Report

Report Produced for U.S. Geological Survey

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1. EXECUTIVE SUMMARY

The following report documents the comprehensive final project accuracy results for The FL Peninsular lidar project. Preliminary accuracy testing was verified at the county level for individual deliveries to ensure project-wide accuracy would meet specification.

The FL Peninsular lidar project survey report includes all information regarding the survey checkpoints, please refer to that report for details on the survey. However, there are six checkpoints that were collected for this project that fell outside of the project boundary. These six checkpoints were not used in final accuracy tested and are not reported out in the checkpoint geodatabases but have been delivered in the coordinate excel file to ensure all survey points are being delivered to USGS. These points are listed here: NVA47057_2018_FL, NVA47092_2018_FL, NVA47097_2018_FL, VVA48068_2018_FL, VVA48103_2018_FL, VVA48155A_2018_FL.

For accuracy testing, Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Below is a description of the types of checkpoints utilized and the acceptable criteria for the FL Peninsular lidar project accuracy requirements.

NVA (Non-vegetated Vertical Accuracy) is determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSEz) of the checkpoints x 1.9600. For the FL Peninsular lidar project, vertical accuracy must be 19.6 cm or less based on an RMSEz of 10 cm x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The FL Peninsular lidar project VVA standard is 30 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, Accuracyz differs from VVA because Accuracyz assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid. The relevant testing criteria are summarized in Table 1.

Table 1. Acceptance Criteria

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	30 cm (based on combined 95^{th} percentile)

1.1 Project Area

The FL Peninsular lidar project encompasses approximately 35,132 square miles within the state of Florida, covering three different state plane zones. The figure below shows the three state plane zones for the FL Peninsular project and the checkpoints that were collected in each zone.

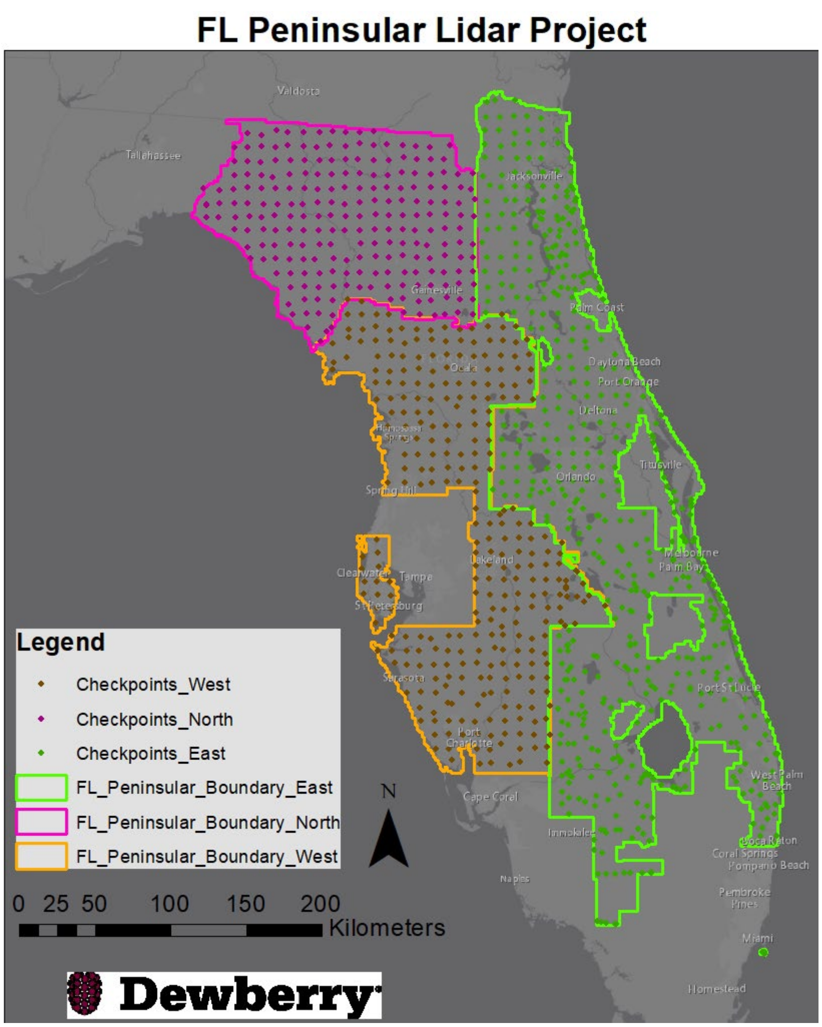

Figure 1. Project map with state plane zones outlined and checkpoints in each state plane zone displayed.

1.2 Coordinate Reference System

Data produced for the project are delivered in the following spatial reference system:

Horizontal Datum:	North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum:	North American Vertical Datum of 1988 (NAVD88)
Geoid Model:	Geoid12B
Coordinate System:	State Plane Zone: East, West, or North as applicable
Horizontal Units:	Feet
Vertical Units:	Feet

2. LIDAR POSITIONAL ACCURACY

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However, 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 the next contiguous lidar measurement and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy.

2.1 Final Swath Vertical Accuracy Assessment

Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the non-vegetated (open terrain and urban) independent survey checkpoints. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy. The table below summarizes the swath project accuracy specification, the amount of NVA points tested, and the final tested swath accuracy results.

Table 2. NVA at 95% Confidence Level for Raw Swaths

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.33 ft	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
Non-Vegetated Terrain	654	0.19	0.36	0.02	0.01	1.33	0.19	-0.49	1.43	8.52

Three checkpoints (NVA 87, NVA 193, and NVA 163) were removed from the raw swath vertical accuracy testing due to their location underneath power lines or overhanging vegetation. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While all three excluded checkpoints are in open terrain, the overhead power lines and overhanging vegetation are modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing, so these points were removed from the final calculations. Once the data underwent the classification process, the power lines were removed from the final ground classification, these points could be used in the final vertical accuracy testing for the fully classified lidar data. Table 3, below, provides the coordinates for these checkpoints and the vertical accuracy results from the raw swath data. Table 4, below, provides the usable vertical accuracy results of these checkpoints from the fully classified lidar. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 2, below, shows a 3D model of the lidar point cloud and the location of one of the checkpoints beneath a power line.

Table 3. Checkpoints removed from raw swath vertical accuracy testing

Point ID	NAD83(2011) State Plane East		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
NVA 193	440340.86	1851711.42	12.05	19.56	7.51	7.51
NVA 163	346787.73	1910543.59	98.57	100.54	1.97	1.97
	NAD83(2011) State Plane North		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
NVA 87	394372.66	2250216.50	35.34	70.39	35.05	35.05

Table 4. Final tested vertical accuracy for the three checkpoints post ground classification. These points were originally removed from the raw swath vertical accuracy testing.

Point ID	NAD83(2011) State Plane East		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
NVA 163	346787.73	1910543.59	98.57	98.79	0.22	0.22
NVA 193	440340.86	1851711.42	12.05	12.20	0.15	0.15
	NAD83(2011) State Plane North		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
NVA 87	2250216.50	394372.66	35.34	35.45	0.11	0.11

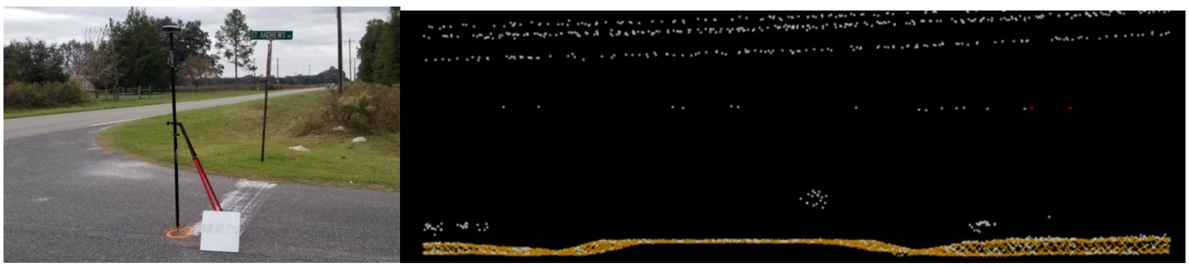

Figure 2. Open terrain checkpoint NVA 87 is shown in the survey photo on the left, the right image is a screen capture of the lidar point cloud in this area. The checkpoint is located underneath power line features. This point was removed from raw swath vertical accuracy testing because above ground features, including power lines, have not been separated from the ground classification yet.

2.2 Vertical Accuracy Results

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Table 5. Tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.98 ft
NVA	657	0.37	N/A
VVA	450	N/A	0.58

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.7 cm, equating to +/- 11.1 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 17.5 cm at the 95th percentile.

Table 6 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 6. 5% Lidar Outliers

Point ID	NAD83(2011) State Plane East		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA48076_2019_FL	818654.82	1310103.10	2.28	3.00	0.72	0.72
VVA48104_2018_FL	742269.18	1386636.94	17.71	18.76	1.05	1.05
VVA69	377579.57	2097795.23	52.21	52.83	0.62	0.62
VVA 60	494345.36	2134870.85	40.12	40.77	0.65	0.64
VVA 130	499205.08	1883390.15	15.06	15.82	0.76	0.76
VVA48131_2018_FL	674545.69	752477.26	14.61	15.23	0.61	0.61
48099_2018_FL	549010.66	1015761.11	163.00	163.72	0.72	0.72
48079_2019_FL	845251.52	1258814.07	5.26	5.91	0.65	0.65
VVA 161	758224.74	1760287.17	32.56	33.26	0.70	0.70
VVA 32	373925.71	2282006.49	65.89	66.50	0.61	0.61
VVA 193	471699.83	1582931.03	68.28	69.27	0.98	0.99
48024_2018_FL_V	654019.69	1432577.47	64.91	65.52	0.61	0.61
VVA48087_2018_FL	961548.20	746520.84	16.17	16.84	0.67	0.67
48033_2018_FL	499917.09	2084943.95	24.60	25.27	0.66	0.66
48037_2018_FL	505290.37	2063921.58	28.80	306	0.66	0.66
48043_2018_FL	510557.48	2088013.38	38.28	39.00	0.72	0.72
48047_2018_FL	588320.25	1938480.76	5.04	6.00	0.96	0.96
VVA48084_2019_FL	877785.69	1165163.30	11.06	11.82	0.76	0.76
VVA48120_2018_FL	771490.97	1132604.02	26.36	27.19	0.83	0.83
VVA 155	498489.26	1787525.23	20.67	21.30	0.63	0.63
VVA 175	634344.16	1734054.49	22.31	23.11	0.80	0.80
VVA 176	530811.02	1699826.22	15.50	16.10	0.60	0.60
Point ID	**NAD83(2011) State Plane North**		**NAVD88 (Geoid 12B)**		**DeltaZ**	**AbsDeltaZ**
	Easting X (ft)	**Northing Y (ft)**	**Z-Survey (ft)**	**Z-LiDAR (ft)**		
VVA 65	2640416.88	407753.49	151.25	151.83	0.58	0.58

Table 7 provides overall descriptive statistics for lidar vertical accuracy.

Table 7. Overall Descriptive Statistics

100 % of Totals	# of Points	RMSEz (ft) Spec=0.33 ft NVA	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	657	0.19	0.01	0.01	1.30	0.19	8.42	-0.49	1.43
VVA	450	N/A	0.17	0.15	0.32	0.24	0.41	-0.50	1.05

2.3 Final Horizontal Accuracy Results

Dewberry tests the horizontal accuracy of lidar datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90-degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the lidar cannot always be tested.

2.4 Horizontal Accuracy Test Procedures

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical checkpoints should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal checkpoints.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints is then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

2.5 Horizontal Accuracy Results

One-hundred and eighty-six checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However, lidar datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter or less at the 95% confidence level.

One hundred and eighty-six checkpoints were used for horizontal accuracy testing. This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Actual positional accuracy of this dataset was found to be RMSEx = 20 cm and RMSEy = 23.5 cm which equates to +/- 53.5 cm at 95% confidence level.

Table 8. Tested horizontal accuracy at the 95% confidence level

# of Points	$RMSE_x$ (Spec=1.34 ft)	$RMSE_y$ (Spec=1.34 ft)	$RMSE_r$ (Spec=1.9 ft)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Spec=3.28 ft
186	0.66	0.77	1.01	1.75

3. DEM POSITIONAL ACCURACY

The same checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations.

Table 9 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Table 9. DEM tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy (RMSEz x 1.9600) Spec=0.64 ft	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.98 ft
NVA	657	0.36	
VVA	450		0.65

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.7 cm, equating to +/- 11.1 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 19.9 cm at the 95th percentile.

Table 10 lists the 5% outliers that are larger than the VVA 95^{th} percentile.

Table 10. DEM 5% Outliers

NAD83(2011) State Plane East			NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
Point ID	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA 175	634344.16	1734054.49	22.31	23.09	0.78	0.78
VVA48076_2019_FL	818654.82	1310103.10	2.28	3.06	0.78	0.78
VVA48077_2019_FL	830784.75	1289903.27	4.58	5.26	0.68	0.68
VVA48104_2018_FL	742269.18	1386636.94	17.71	19.00	1.29	1.29
VVA 60	494345.36	2134870.85	40.12	40.82	0.70	0.70
VVA 130	499205.08	1883390.15	15.06	15.80	0.74	0.74
48092_2018_FL	509009.29	885337.53	13.42	14.12	0.70	0.70
48099_2018_FL	549010.66	1015761.11	163.00	163.69	0.70	0.70
48079_2019_FL	845251.52	1258814.07	5.26	5.91	0.65	0.65
VVA 161	758224.74	1760287.17	32.56	33.28	0.72	0.72
VVA 193	471699.83	1582931.03	68.28	69.32	1.04	1.04
48024_2018_FL	654019.69	1432577.47	64.91	65.70	0.79	0.79
48102_2018_FL	693057.01	1344062.08	40.09	40.92	0.84	0.84
VVA48087_2018_FL	961548.20	746520.84	16.17	16.93	0.75	0.75
VVA 129	342350.18	1887092.17	90.92	91.57	0.65	0.65
48033_2018_FL	499917.09	2084943.95	24.60	25.27	0.66	0.66
VVA 186	644382.61	1682865.35	23.58	24.29	0.71	0.71
48043_2018_FL	510557.48	2088013.38	38.28	39.15	0.86	0.86
48047_2018_FL	588320.25	1938480.76	5.04	5.93	0.90	0.90
VVA48084_2019_FL	877785.69	1165163.30	11.06	11.80	0.74	0.74
VVA48120_2018_FL	771490.97	1132604.02	26.36	27.22	0.86	0.86
NAD83(2011) State Plane West			NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
Point ID	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA243	638243.16	1185420.33	126.98	127.68	0.70	0.70
VVA_122	389893.89	1909592.66	49.69	50.36	0.67	0.67
VVA 152	692351.58	1790551.10	41.05	41.70	0.65	0.65

Table 11 provides overall descriptive statistics.

Table 11. Overall Descriptive Statistics

100 % of Totals	# of Points	RMSEz (ft) Spec=0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	657	0.19	0.01	0.00	1.37	0.19	8.96	-0.50	1.46
VVA	450	N/A	0.19	0.17	0.40	0.26	0.73	-0.50	1.29

4. FINAL ACCURACY SUMMARY

Based on the accuracy testing conducted by Dewberry, the lidar and DEM dataset for the FL Peninsular lidar project satisfies the project's pre-defined accuracy criteria as described throughout this report.