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FL West Everglades National Park (NP) 2018 B18

Report Produced for U.S. Geological Survey

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1. EXECUTIVE SUMMARY

The primary purpose of this project was to support the National Park Service with high-accuracy light detection and ranging (lidar) technology for the USGS FL West Everglades NP project area.

Lidar data were processed and classified according to project specifications. Topobathymetric Digital Elevation Models (DEMs) were produced for the project area. Project components were formatted based on a tile grid with each tile covering an area 1,000 m by 1,000 m. A total of 2,601 tiles were produced for the project, providing approximately 869 sq. miles of coverage.

1.1 Project Team

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for lidar acquisition flight planning/coordination, ground survey, LAS classification, breakline production, digital elevation model (DEM) and digital surface model production, and quality assurance.

Dewberry's William Donley, PSM completed the ground survey for the project and delivered surveyed ground control points and accuracy assessment checkpoints. His task was to acquire surveyed checkpoints for independent testing of the vertical accuracy of the calibrated LAS and the lidar-derived surface model. He also verified the GPS base station coordinates used during lidar data acquisition to calibrate the data.

Leading Edge Geomatics (LEG) completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The project area, shown in figure 1, includes portions of Monroe, Miami-Dade, and Collier counties in Florida.

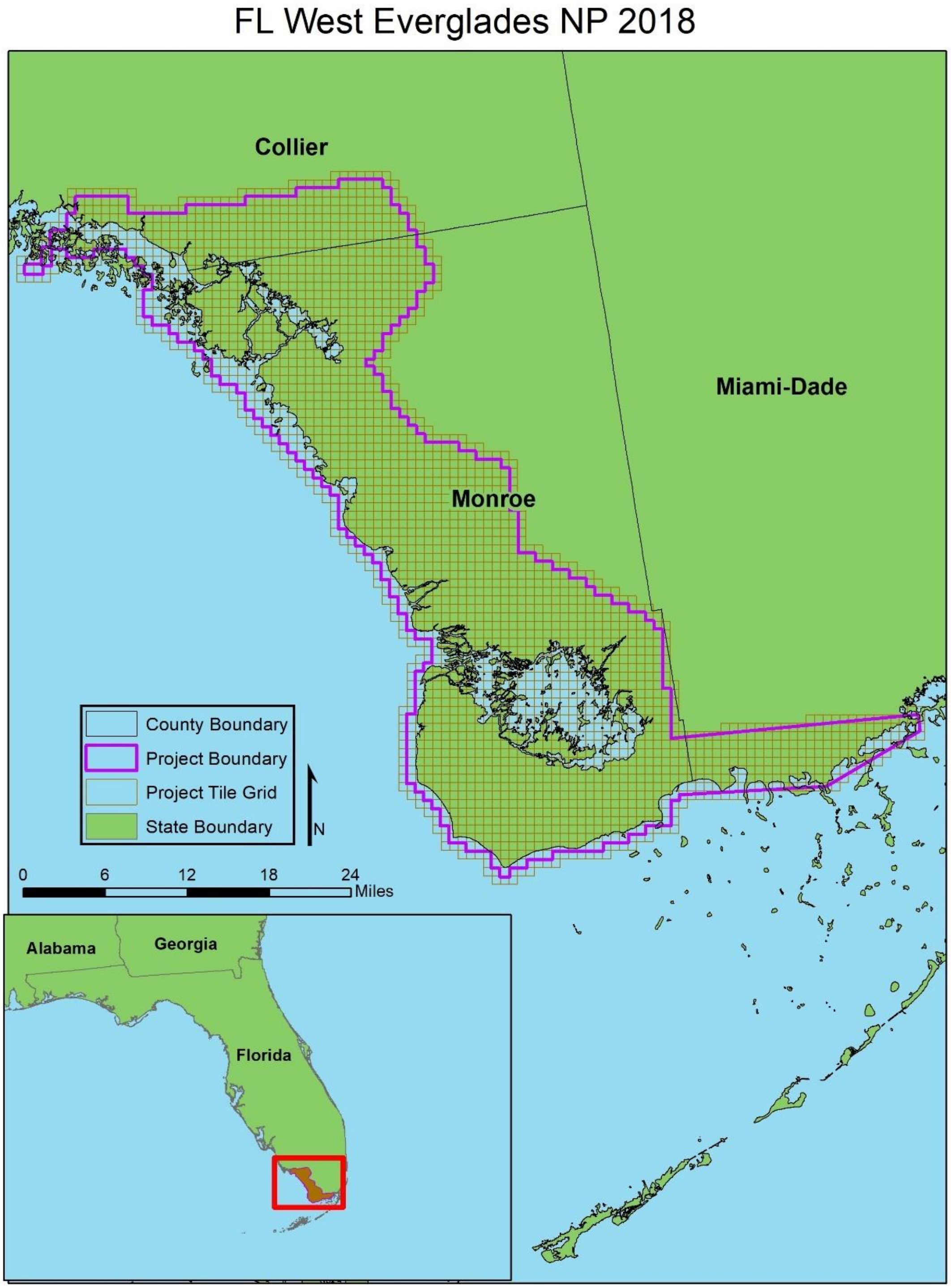


Figure 1. Project map and tile grid.

1.3 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: Contiguous USA Albers Equal Area Conic
Horizontal Units: Meters
Vertical Units: Meters

1.4 Project Deliverables

The deliverables for the project are as follows:

1. Project Extents (Esri SHP)
2. Flightline Extents (Esri GDB)
3. Static Control (coordinates, Esri shapefile)
4. Classified Point Cloud (tiled LAS)
5. Independent Survey Checkpoint Data (report, photos, coordinates, Esri shapefiles)
6. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
7. Topobathymetric DEM (tiled raster DEM, GeoTIFF format)
8. Refraction Extents (Esri GDB)
9. Digital Surface Models (tiled raster DSM, GeoTIFF format)
10. Swath Separation Images (tiled, 24-bit RGB, GeoTIFF format)
11. Aerial Imagery Collected Coincidently with Lidar (GeoTIFF format)
12. Metadata (XML)
13. Project Report

2. LIDAR ACQUISITION REPORT

Dewberry elected to subcontract the lidar acquisition and calibration activities to Leading Edge Geomatics. Leading Edge Geomatics was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

The lidar survey was conducted between March 2, 2019 to July 4, 2019.

2.1 Summary

As described in detail in section 2.2 Pre-Flight Monitoring, water level gauges were monitored and coordination with the U.S. National Park Service occurred to assess the location of controlled burns. Both of these activities resulted in modified flight plans and delayed acquisition in an effort to only acquire data during optimal environmental conditions. Acquisition started in March, 2019 but was on-going until July, 2019. Additionally, several missions to acquire re-flights occurred. Re-flights were necessary primarily due to ground fog and/or smoke that occurred along a given swath.

The length of the acquisition coupled with the dynamic nature of the Everglades environment resulted in temporal differences in water levels, water clarity, and environmental conditions between adjacent missions. This project was not tidally coordinated so some variances may also be a result of different tidal conditions throughout acquisition. These variances are visible in some areas of the dataset as both grounded flightline ridges/seams and as inconsistent bathymetric coverage, including hard or abrupt edges in bathymetric coverage. Grounded flightline ridges resulted from temporal changes in water levels because in wetland environments, such as the Everglades, the lidar penetrated as much as possible through vegetation but the underlying water beneath the vegetation impacts the behaviour of the lidar pulse and different water levels (including different soil saturation levels) beneath the vegetation impact how far the lidar pulse can penetrate vegetation to “ground.” In many areas, the lowest available lidar points are grounded and the elevation of these points are dependent on water levels beneath the vegetation. Differences in water levels, water clarity, and other environmental conditions (e.g. reflectivity of bottom, sediment in water, water currents, etc.) have direct impacts on how well the lidar pulse is able to travel through the water column. These differences in bathymetric coverage are visible throughout the dataset.

LEG began acquisition using a Riegl VG880-G topobathymetric lidar sensor but switched to a Riegl VQ880-GII topobathymetric lidar sensor because the original sensor broke during acquisition.

2.2 Pre-Flight Monitoring

Prior to mobilizing for the lidar acquisition, Dewberry monitored several water level gauges within the project’s boundary to determine if levels were low compared to historical information. This was accomplished by accessing the Everglades Depth Estimation Network (EDEN) which is an integrated network of water-level gages, interpolation models, and applications that generates daily water-level data and derived hydrologic data across the freshwater part of the greater Everglades landscape. EDEN provides consistent, documented, and readily accessible hydrologic data for the Everglades.

Dewberry closely monitored the weather by checking forecasts at least twice daily. Recent rainfall data was assessed and potential impacts from upcoming storm events were evaluated. Our goal was to ensure that weather conditions were acceptable for mobilization.

The U.S. National Park Service implements controlled burns regularly within Everglades National Park (Park) which are problematic for lidar collection. We coordinated regularly with the Park and received reports describing upcoming controlled burns and their location. These reports, combined with wind direction/speed analysis, helped us determine where and when to fly in order to avoid hazy conditions due to smoke.

As soon as conditions were conducive to acquisition, LEG was given approval to mobilize for data collection in March, 2019.

2.3 Lidar Acquisition Details

LEG planned 639 passes for the project area as a series of parallel flight lines. Before the first flightline of each mission was collected, an “S-Turn” was performed to account for IMU drifts. In order to reduce any margin for error in the flight plan, Leading Edge Geomatics followed FEMA’s Appendix A “guidelines” for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Track’Air’s TRACKER flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, LEG will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

LEG monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include no rain, fog, smoke, mist or low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. LEG accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, LEG closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team and project leads worked together for weather and in-situ analysis.

LEG lidar sensors are calibrated at a designated site located over Fredericton, NB, Canada however; in this case, the calibration occurred over Poinciana, FL with assistance from RIEGL USA.

2.4 Lidar System parameters

LEG operated a Piper Aztec (Tail # N762SU) outfitted with a RIEGL VQ880-G Topobathy lidar system as well as another Piper Aztec (Tail # N25FT) outfitted with a RIEGL VQ880-GII (not concurrently). Table 1 and Table 2 illustrate LEG’s system parameters for lidar acquisition on this project. Note, both of these sensors operated with two lasers each: one green laser and one NIR laser contained within each sensor.

Table 1. LEG lidar system parameters for VQ880-G.

Parameter	Green Laser	NIR Laser
System	VQ880-G	VQ880-G
Altitude (m above ground level)	500	500
Nominal flight speed (kts)	130	130
Scanner pulse rate (kHz)	245	245
Scan frequency (Hz)	80	137
Pulse duration of the scanner (ns)	1.5	3
Pulse width of the scanner (m)	0.45	0.9
Central wavelength of the sensor laser (nm)	532	1064
Multiple pulses in the air	Yes	yes
Beam divergence (mrad)	0.7	0.3
Swath width (m)	364	364
Swath overlap (%)	55	55
Total sensor scan angle (degrees)	40	40
Nominal pulse spacing (NPS) (single swath) (m)	0.5	0.58
Nominal Pulse Density (NPD) (single swath) (points per sq m)	4	3
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.35	0.41
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	8	6
Maximum Number of Returns per Pulse	7	7

Table 2. LEG lidar system parameters for VQ880-GII.

Parameter	Green Laser	NIR Laser
System	VQ880-GII	VQ880-GII
Altitude (m above ground level)	450	450
Nominal flight speed (kts)	130	130
Scanner pulse rate (kHz)	200	300
Scan frequency (Hz)	80	142
Pulse duration of the scanner (ns)	1.5	3
Pulse width of the scanner (m)	0.45	0.9
Central wavelength of the sensor laser (nm)	532	1064
Multiple pulses in the air	Yes	yes
Beam divergence (mrad)	0.7	0.3
Swath width (m)	328	328
Swath overlap (%)	20	20
Total sensor scan angle (degrees)	40	40
Nominal pulse spacing (NPS) (single swath) (m)	0.41	0.5
Nominal Pulse Density (NPD) (single swath) (points per sq m)	6	4
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.41	0.5
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	6	4
Maximum Number of Returns per Pulse	7	7

2.5 Acquisition Status Report and Flight Lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The acquisition manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the lidar sensor, the position dilution of precision (PDOP), and performed the first quality control review during acquisition. The flight crew reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows an example of a trajectory from mission 090A flown on March 31' 2019 with the VQ880-G using a SmartBase network in Applanix PosPAC.

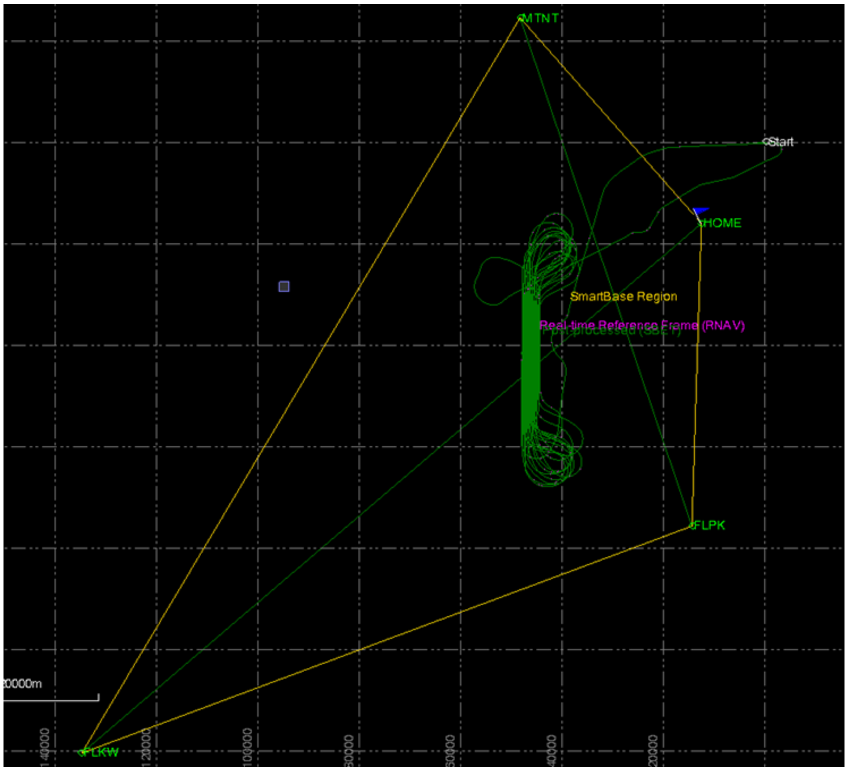


Figure 2. 090A Trajectory as flown by Leading Edge Geomatics.

2.6 Acquisition Static Control

LEG deployed static GPS base stations during the acquisition of the FL West Everglades NP project to try to account for potential inconsistencies in the active networks around Florida. Considerations were made for location access and clear visibility of the horizon. Additionally, these static sessions were recorded at 1 Hz samples for the highest quality post processed solution. These static base sessions were then incorporated during the kinematic post-processing of aircraft position. These base stations were either set on existing control monumentation, or new benchmarks established. The coordinates of these base stations are provided in the table below. The CORS and FPRN networks were used the most for this project.

Table 3. Base stations used to control lidar acquisition.

Name	NAD83(2011) Lat, Lon		Ellipsoid Ht (NAD83(2011), m)
	Latitude (N)	Longitude (W)	
CORS			
LAUD	26 11 46.34158	080 10 23.01431	-18.135
MTNT	25 51 56.76077	080 54 25.18638	-18.928
FLF1	25 36 55.24087	80 23 09.91295	-20.451
NAPL	26 08 55.10363	81 46 34.62675	-17.462
CHIN	24 33 01.70871	81 48 25.64262	-13.515
FLKW	24 33 13.26693	81 45 15.39940	-10.263
FPRN			
FLD6	25 46 49.67372	80 22 35.34917	-15.099
FLKW	24 33 13.26679	81 45 15.39967	-10.252
FLMB	26 46 57.83809	80 08 14.16814	-15.513
FLMK	24 43 33.26185	81 02 56.70275	-13.908
FLPK	24 57 47.22551	80 34 05.39892	-13.196
FMYR	26 35 27.50815	81 51 50.97247	-13.273
GLAD	26 43 18.13035	80 40 03.31206	-19.229
HOME	25 30 03.79586	80 33 00.43270	-19.129
IMMO	26 25 04.22117	81 25 00.24741	-8.142
NAPL	26 08 55.10363	81 46 34.62675	-17.454
RMND	25 36 49.58940	80 23 02.14135	-13.971
BCYP	25 53 36.03025	81 19 32.05726	-20.494
LEG			
BASE1	25 08 37.66859	080 55 30.21410	-21.661
BASE2	25 50 48.41937	081 23 07.08740	-22.65
BASE3	25 45 38.33986	081 00 54.05468	-21.661
BASE4	25 26 26.72954	080 47 01.00031	-22.725

2.7 Airborne Kinematic Control

Airborne GPS data was processed using PosPAC MMS provided by Applanix. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. To help correct for any incorrect antenna heights that may have been listed by the Florida Permanent Reference Network (FPRN), trajectories were processed holding stations with accurate heights as the primary control.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded.

GPS processing reports for each mission are included in Appendix A.

2.8 Generation and Calibration of Raw Lidar Data

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using RIEGL’s RiProcess version 1.8.5.1. The data is reviewed for any concerns. Calibration values are determined by RIEGL LMS and reviewed. The resulting values were used throughout the project and checked if there was a chance of the sensor losing its calibration.

Data processing and refraction is all performed using a combination of RiProcess and internal classification before being fully exported to LAS format. Data is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present. There are also checks performed to determine the quality of bathymetric returns.

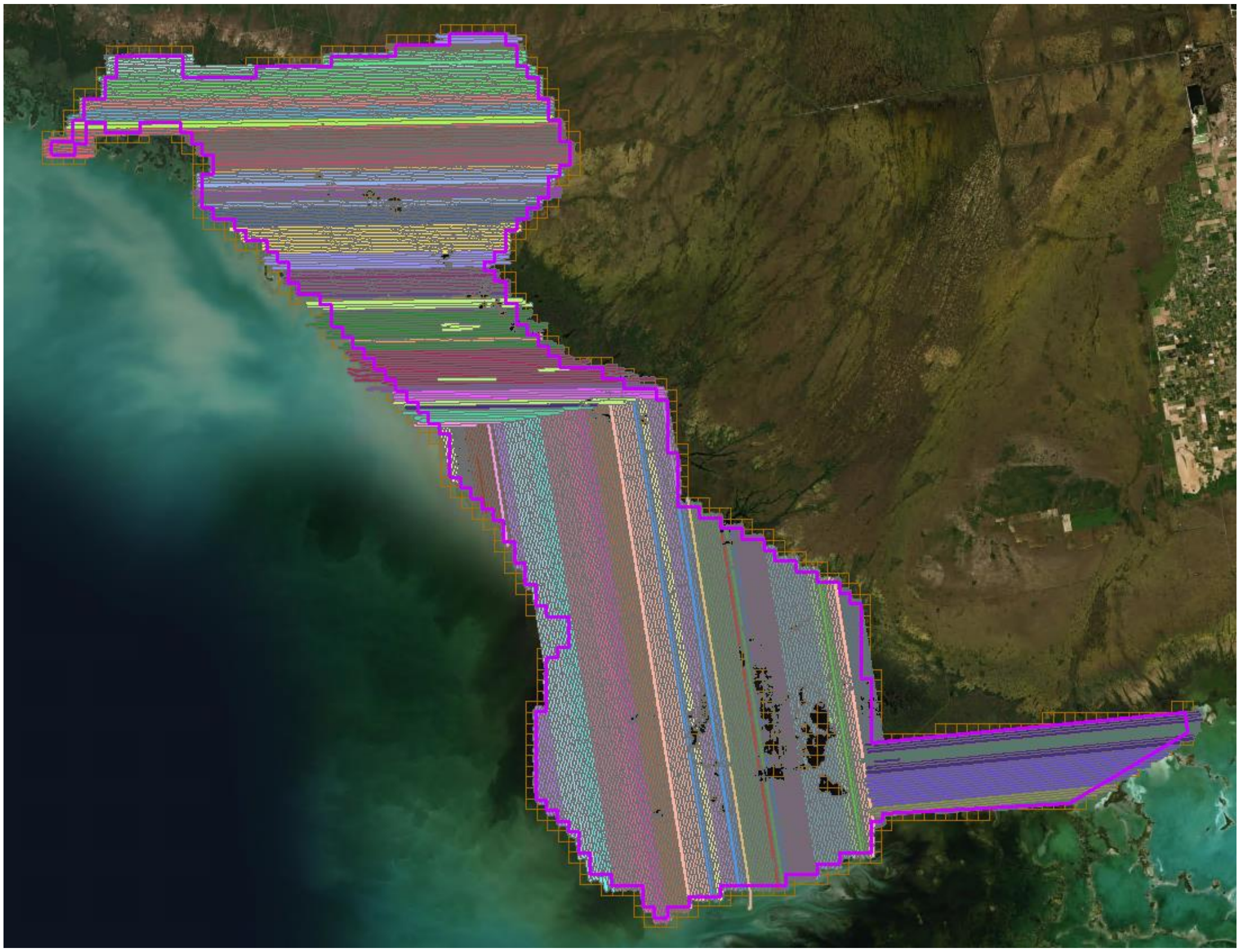


Figure 3. Lidar flightline extents (colored by mission/lift) showing complete coverage of the project area (project boundary in purple), overlaid on Esri basemap imagery.

2.8.1 Boresight and Relative accuracy

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and yaw are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using between swaths. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

The following relative accuracy specifications were used for this project:

- ≤ 6 cm maximum difference within individual swaths (intra-swath); and
- ≤ 8 cm RMSDz between adjacent and overlapping swaths (inter-swath).

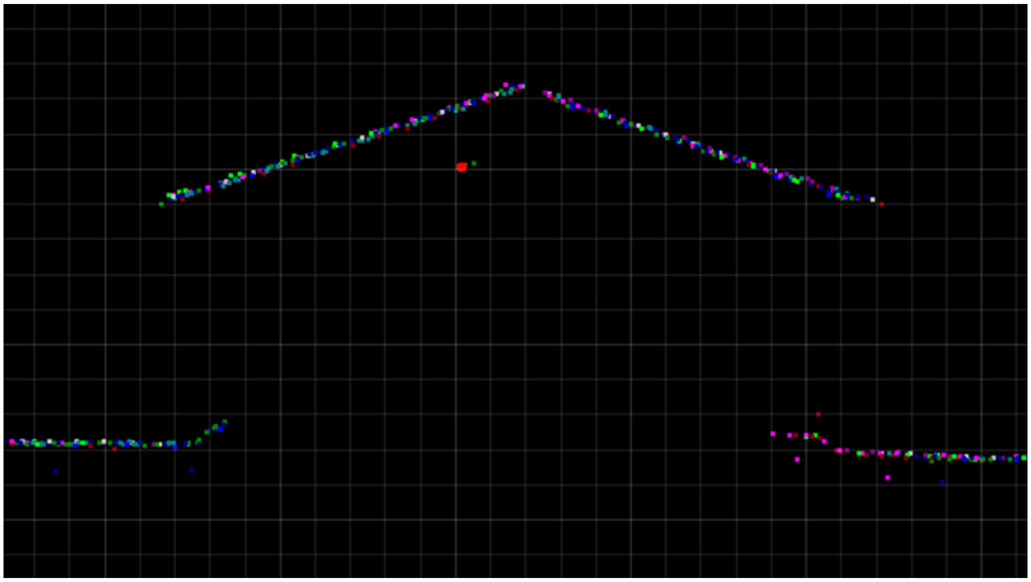


Figure 4. Profile view showing correct roll and pitch adjustments.

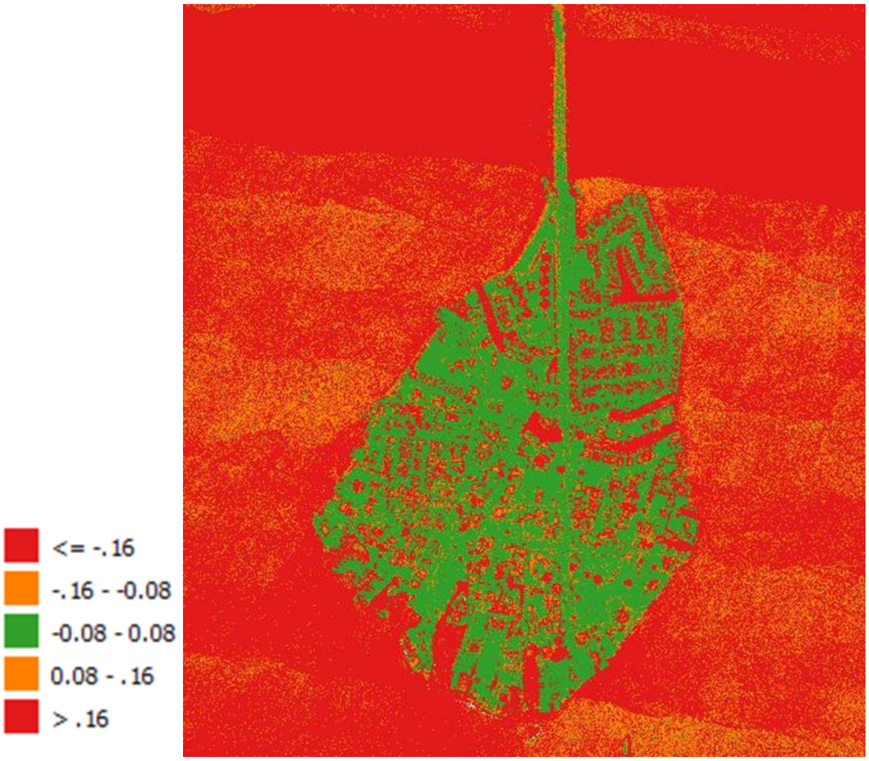


Figure 5. QC block colored by vertical difference to ensure accuracy at swath edges and throughout.

2.9 Preliminary Vertical Accuracy Assessment

Leading Edge Geomatics conducted a survey for 183 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 183 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs as well as their comparative results to the lidar are provided in Appendix B. A control bias of -8 cm was applied to the data as a whole, reflected in the results in table 4.

Table 4. Summary of acquisition provider's vertical accuracy assessment results.

Land Cover Type	# of Points	RMSE$_z$ (m) (Project Spec=0.10)	NVA (m)	Mean (m)	Std Dev (m)
Non-Vegetated Terrain	183	0.068	0.133	0.005	0.068

Dewberry surveyed an additional 51 (GCPs) in flat, non-vegetated areas to test the accuracy of the final calibrated swath data. These GCPs were not used in the calibration process to control the data but were only used to test the calibrated data. To assess the accuracy of calibration, the heights of the ground control points were compared with a surface derived from the calibrated swath lidar. A full list of GCPs used for accuracy testing is included in the Dewberry GCP Survey Report included in the survey deliverables for this project.

3. LIDAR PROCESSING & QUALITATIVE ASSESSMENT

3.1 Initial Processing

Following receipt of the calibrated swath data from the acquisition provider, Dewberry performed vertical accuracy validation of the swath data, inter-swath relative accuracy validation, intra-swath relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allowed Dewberry to determine whether the data was suitable for full-scale production. Details are provided in the following sections.

3.1.1 Refraction Correction

Bathymetric data must have a refraction correction applied, which corrects the horizontal and vertical (depth) positions of each data point by accounting for the change in direction and speed of light as it enters and travels through water. The refraction correction was performed by LEG as part of the swath data processing and calibration. LEG refracted all noticeable bathymetric areas. Dewberry received refracted swath data for review and continued production.

3.1.2 Post Calibration Lidar Review

The table below identifies requirements verified by Dewberry prior to tiling the swath data, running initial ground macros, and starting manual classification.

Table 5. Post calibration and initial processing data verification steps.

Requirement	Description of Deliverables	Additional Comments
Non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 19.6 cm at the 95% confidence level based on RMSEz (10 cm) x 1.96	The swath NVA was tested and passed specifications.	None
The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 8 ppsm or 0.35 m NPS. The NPD (ANPD) is calculated from first return points only.	Due to two lasers being utilized per each sensor and the high amount of overlap, the average calculated (A)NPD of the original AOI is 23 ppsm and the average calculated (A)NPD of the add-on portion of this AOI is 14 ppsm. Density raster visualization also passed specifications.	None
Spatial Distribution requires 90% of the project grid, calculated with cell sizes of 2*NPS, to contain at least one lidar point. This is calculated from first return points only.	Approximately 98.7% of cells (2*NPS cell size) in this AOI had at least 1 lidar point within the cell.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm RMSDz.	Within swath relative accuracy passed specification.	See additional information and graph in the sections below

Requirement	Description of Deliverables	Additional Comments
Between swath (Inter-swath or swath overlap) relative accuracy must meet ≤ 8 cm RMSDz. These thresholds are tested in open, flat terrain.	Between swath relative accuracy passed specification, calculated from single return lidar points.	See additional information and graph in the sections below
Horizontal Calibration-There should not be horizontal offsets (or vertical offsets) between overlapping swaths that would negatively impact the accuracy of the data or the overall usability of the data. Assessments made on rooftops or other hard planar surfaces where available.	Horizontal calibration met project requirements.	None
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation was acceptable.	Ground penetration was assessed relative to the environment and land cover conditions. Ground penetration in densely vegetated, wetland environments is much different compared to other vegetated land covers, e.g. upland forests.
Edge of Flight line bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired, regardless of which type of sensor is used	Edge of Flight line bits were populated correctly	None
Scan Direction bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired with sensors using oscillating (back-and-forth) mirror scan mechanism. These fields should show a minimum and maximum of 0 for each swath acquired with Riegl sensors as these sensors use rotating mirrors.	Scan Direction bits were populated correctly	None
Swaths are in LAS v1.4 formatting	Swaths were in LAS v1.4 as required by the project.	None
All swaths must have File Source IDs assigned (these should equal the Point Source ID or the flight line number)	File Source IDs were correctly assigned	None
GPS timestamps must be in Adjusted GPS time format and Global Encoding field must also indicate Adjusted GPS timestamps	GPS timestamps were Adjusted GPS time and Global Encoding field were correctly set to 17	None
Intensity values must be 16-bit, with values ranging between 0-65,535	Intensity values were 16-bit	None

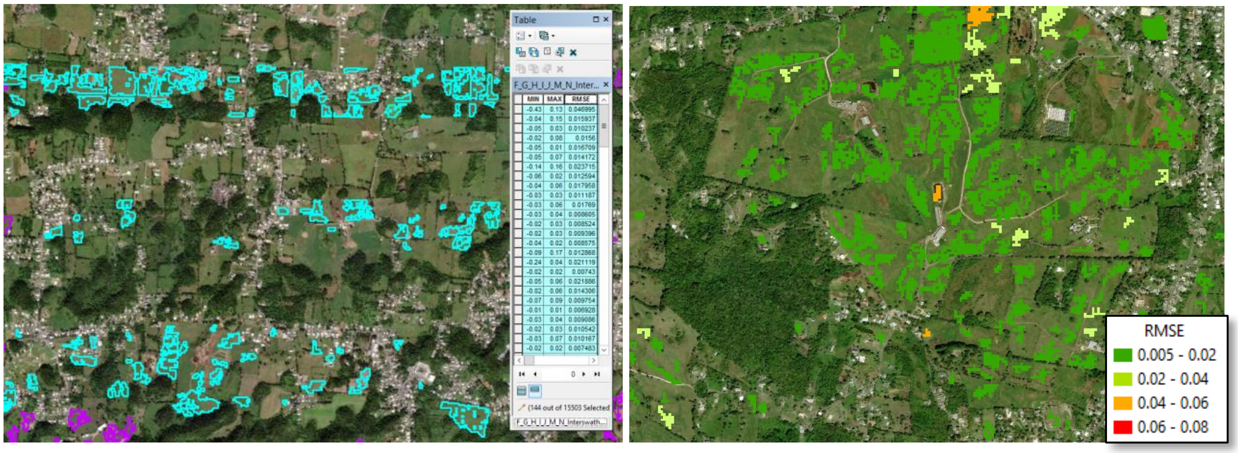
Requirement	Description of Deliverables	Additional Comments
Point Source IDs must be populated and swath Point Source IDs should match the File Source IDs	Point Source IDs were assigned and match the File Source IDs	None

Interswath (Between Swath) Relative Accuracy

In addition to a visual qualitative review of interswath values (see section 4.2 Swath Separation Images of this report), USGS Lidar Base Specifications also outline specific testing procedures and deliverables to verify that this data is within specification. The specification requires that non-vegetated areas of overlap with slopes less than 10 degrees are tested and reported in a polygon shapefile. This polygon deliverable should contain the minimum, maximum, and RMSDz of the differences in each sample polygon area.

Dewberry has developed a relatively robust process for generating these interswath polygons across the entire dataset. The current specification does not explicitly state the amount of areas to be tested. Dewberry therefore ensures that the assessment is as detailed as possible by creating test polygons for all overlap areas. The test areas are generated such that they are on slopes less than 10 degrees and not in vegetated areas. The generated polygons are then attributed with the min/max/RMSDz statistics. Polygons that intersect large waterbodies are removed from the final results, as these are not reliable test locations.

The result of the process is a shapefile of test polygons with their test values, distributed in all of the overlapping areas across the project area. These polygons are then reviewed for any systematic interswath errors that should be considered of concern.



MIN	MAX	RMSE
-0.43	0.13	0.046995
-0.04	0.15	0.015937
-0.05	0.03	0.010237
-0.02	0.08	0.0156
-0.05	0.01	0.016709
-0.05	0.07	0.014172
-0.14	0.16	0.023715
-0.06	0.02	0.012594
-0.04	0.08	0.017958
-0.03	0.03	0.011187
-0.03	0.06	0.01769
-0.03	0.04	0.008605
-0.02	0.03	0.008524
-0.02	0.03	0.009396
-0.04	0.02	0.008575
-0.09	0.17	0.012868
-0.24	0.04	0.021119
-0.02	0.02	0.00743
-0.05	0.06	0.021886
-0.02	0.06	0.014306
-0.07	0.09	0.009754
-0.01	0.01	0.006928
-0.03	0.04	0.009086
-0.02	0.03	0.010542
-0.03	0.07	0.010167
-0.02	0.02	0.007483

(144 out of 15503 Selected

F_G_H_I_J_M_N_Interswath...

Figure 6. Left: Example interswath polygons and example statistics. Right: Example interswath polygons colored by RMSDz values.

Due to the heavily vegetated environment of the FL West Everglades NP project area, there were very few non-vegetated areas for testing and even fewer non-vegetated areas large enough to generate reliable statistics (due to nearby and overhanging vegetation, slopes, etc). Only five interswath polygons were generated from our automated testing. As a limited number of interswath polygons were generated from our testing process, Dewberry performed additional visual reviews of the swath separation rasters supported by the LAS point cloud.

The eastern add-on portion of the FL West Everglades NP project area was particularly difficult to align due to relatively few hard surfaces present which could reliably be used during the alignment process. Only one road is present in this add-on area. Due to the nature of relative swath alignment being based off the "ground" surface within each swath (which in reality is just the lowest plane of points), the process of using the lowest points can introduce some discrepancies due to these assumptions. In some areas one sensor may penetrate the vegetation to a greater extent, resulting in a lower last return surface. The alignment process bases the corrections from the statistical trends found in these offsets. This means that if there is a much greater coverage of vegetated areas than hard surfaces, those vegetated areas can have a much larger impact on the relative alignment of the data. In the case of this area the discrepancy resulted in a misalignment along a portion of the roadway while the vegetated areas nearby show no misalignment. Examining the park road in the east of the project shows that several of the swaths have some bias between the NIR and green swaths (approx. 7-11 cm), but there are 3-4 flightlines with larger offsets approaching 15 cm. Areas along the road exhibiting the most measurable offsets are identified in the provided shapefile, named "W_Everglades_NP_Lidar_Interswath_Issues". One survey checkpoint, NVA 100, is located on the NP road within the eastern add-on area and testing shows a 12 cm difference between the lidar and surveyed checkpoint. As comparison, two other checkpoints (NVA 31 and NVA 44) located on the same NP road but within the original AOI boundary and not the add-on portion have vertical accuracy differences between the lidar and surveyed checkpoints of 4.4 cm and 0.6 cm, respectively.

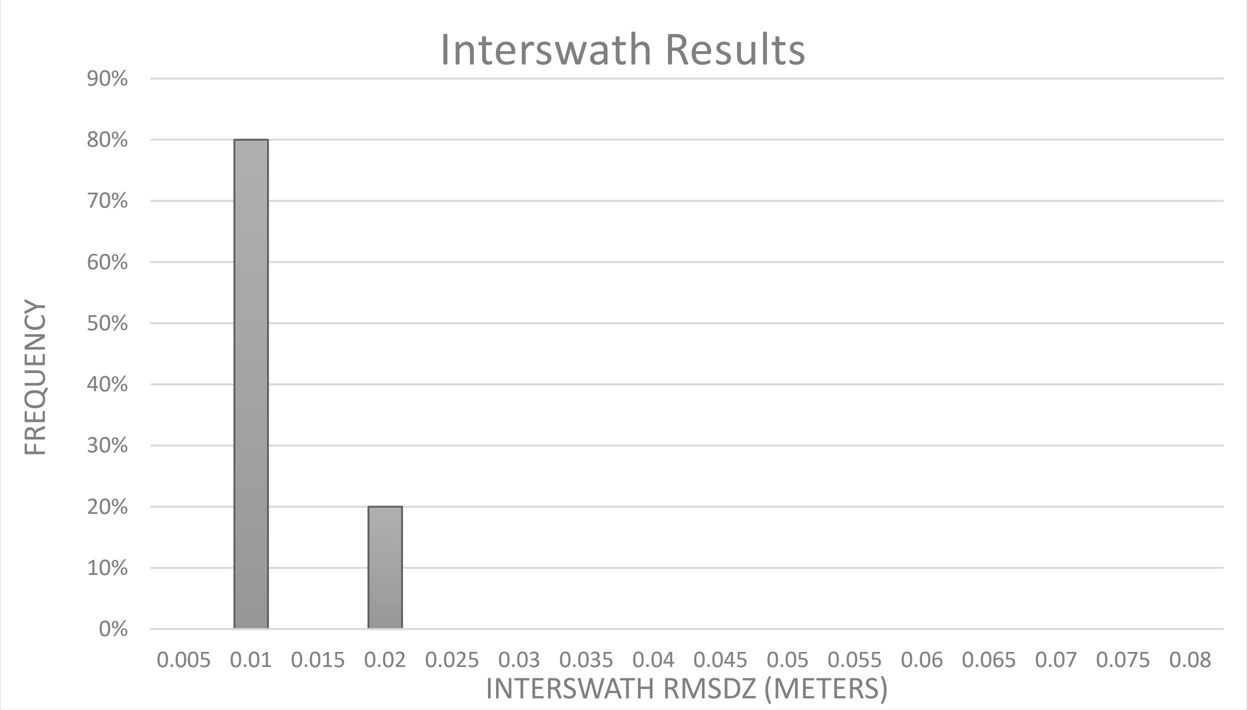
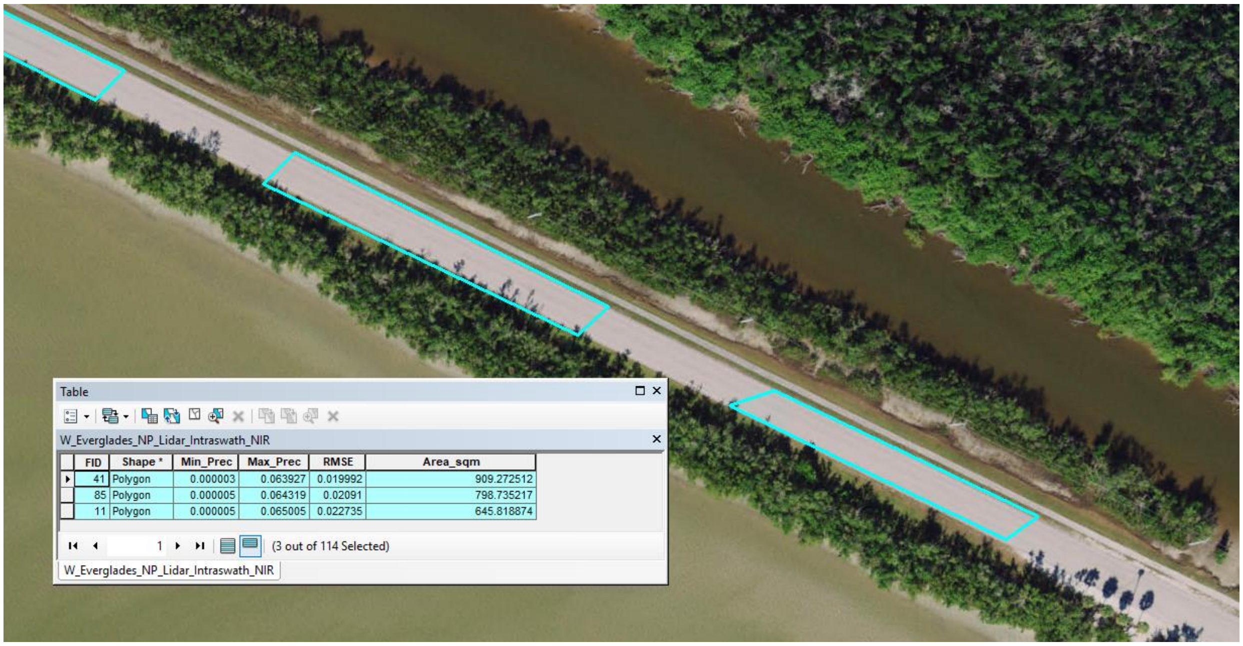


Figure 7. Frequency distribution of interswath RMSDz results for the FL West Everglades NP project.

Intraswath (Within Swath) Relative Accuracy

In addition to a visual qualitative review of intraswath values, the USGS Lidar Base Specifications also outline specific testing procedures and deliverables to verify that this data is within specification. The specification requires that test polygons should be drawn in hard surface areas and precision statistical values be computed. The specification calls for each lift to have three (3) test locations. However, the Everglades environment and the FL West Everglades NP project area in general has limited hard surface features. Everglades City provides suitable testing sites, but very few suitable testing sites exist in the southern and eastern portions of the AOI. A single hard surface road was able to be utilized for intraswath testing in the southern and eastern portions of the AOI. Dewberry was able to create 114 intraswath polygons where hard surfaces exist within the project area. The intraswath polygon distribution is illustrated in Figure 8; each polygon contains statistics for the minimum, maximum, and RMSDz of the differences in the sample polygon area as illustrated in Figure 9. This project utilized the Riegl VQ880-G and Riegl VQ880-GII sensor. Both sensors were configured with a NIR laser and a green laser. As two separate lasers were utilized, intraswath testing was completed on each individual laser, separately, resulting in two separate intraswath results. Two sets of intraswath polygons are included in the deliverables; one set corresponds to the NIR data and one set corresponds to the green data.

Figure 8. Intraswath polygons used to test intraswath vertical accuracy.



	FID	Shape *	Min_Prec	Max_Prec	RMSE	Area_sqm
▸	41	Polygon	0.000003	0.063927	0.019992	909.272512
	85	Polygon	0.000005	0.064319	0.02091	798.735217
	11	Polygon	0.000005	0.065005	0.022735	645.818874

(3 out of 114 Selected)

Figure 9. Example test polygon for intraswath testing, and its results.

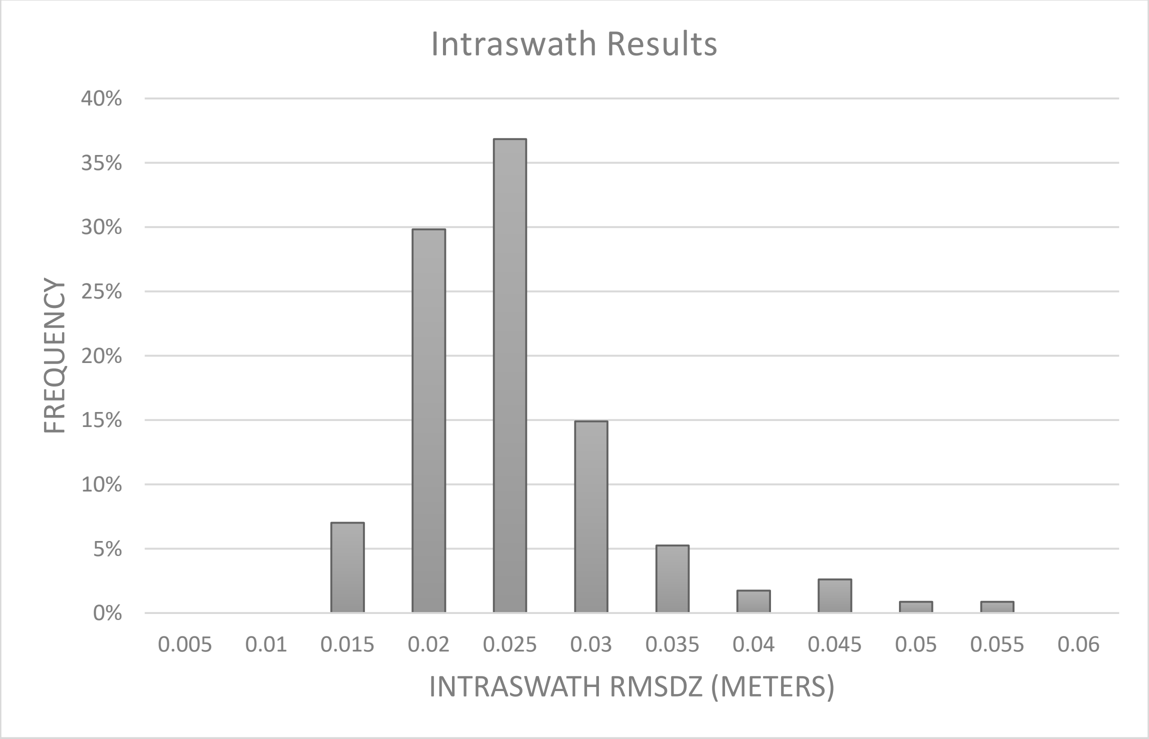


Figure 10. Frequency distribution of NIR intraswath RMSDz results for the FL West Everglades NP project

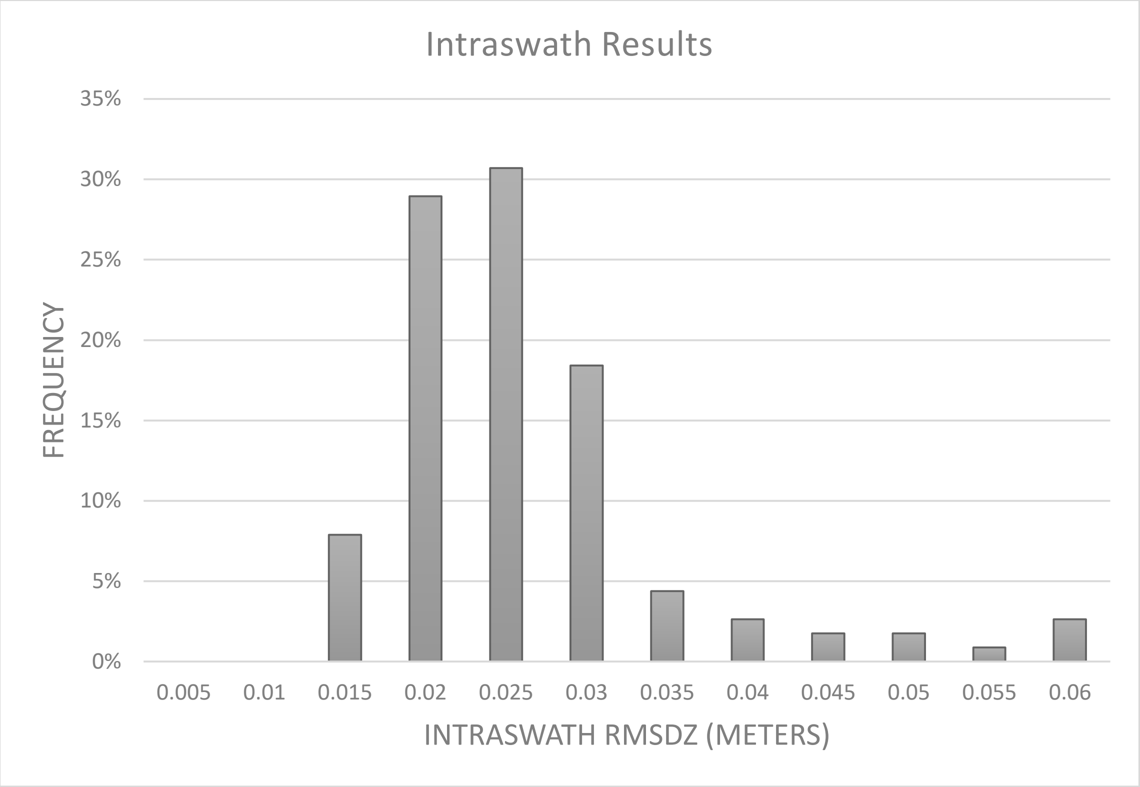


Figure 11. Frequency distribution of green intraswath RMSDz results for the FL West Everglades NP project

3.2 Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. Data processing included creating automated refraction extents and minimal/focused editing of the refraction extents, automated and manual editing of the lidar tiles, QA/QC, and final formatting of the LAS files.

3.2.1 Refraction Extents

Dewberry used rasterized aggregate extents of refracted points to create automated 2-D breaklines with LAStools and ArcGIS. These breaklines delineate areas where the refraction correction was applied to the lidar data by Riegl's automated refraction correction software based on the software's detection of water. As these breaklines reflect where refraction corrections were applied, minimal changes or edits are applied to the refraction extents in order to keep them “true” and consistent the source lidar point cloud.

The refraction extents are used in the finalization of data to ensure the bathy domain (classes 40, 41, and 45) is used on refracted points and the topographic domain (classes 1, 2, and 17) is used on un-refracted points. Noise classes 7 and 18 are used in both the topographic and bathymetric domains.

3.2.2 GeoCue and Terrascan Processing

Next is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan to create the initial automated ground and bathy bottom classifications, using the final project classification schema.

This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified by their scan angle and classified to a separate class so that they will not be used in the initial ground algorithm. These point with higher scan angles will be set to withheld later in the lidar processing. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

The final refraction extents are then used to classify “ground” points within the refraction extents as bathymetric bottom. The refraction extents are also used as part of the classification routines to ensure water surface and water column points are classified correctly.

Each tile was then imported into Terrascan and a surface model was created to examine the ground (class 2) and bathy bottom (class 40) classification. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification and that class 40 accurately represents submerged topography. Dewberry analysts visually reviewed the surface models and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry.

Bridge decks are manually classified to class 17.

The withheld bit is set on the points with higher scan angles previously identified in Terrascan before the ground classification routine was performed.

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, are updated in GeoCue software and then verified using proprietary Dewberry tools.

3.3 Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a topobathymetric Digital Elevation Model (DEM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, a series of Digital Elevation Models (DEM) from different inputs, void polygons and 3-dimensional models as well as reviewing the actual point cloud data.

3.3.1 Visual Review

During QA/QC, reviewers check for consistent and correct classification. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, areas where bathymetry was not classified correctly to produce an accurate submerged topography model, and other classification errors.

3.3.2 Create Void Polygons

Void polygons were created as part of the QA/QC (creation methodology described in section 6.1). The void polygons identify areas of sparse to no bathy bottom points. The void polygons were loaded when reviewing the data to ensure correct and full classification of bathy bottom.

3.3.3 Formatting

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

Table 6. Classified Lidar Formatting.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) Albers Conus, meters and NAVD88 (Geoid 12B), meters in WKT Format	Pass
Global Encoder Bit	Set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Set to the lidar sensor and is set to "VQ880-G; VQ880-GII"	Pass

Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 17: Bridge Deck Class 18: High Noise Class 40: Bathymetric Bottom Class 41: Water Surface Class 45: No bathymetric bottom found (water column)	Pass
Overlap and Withheld Points	Withheld points are set to the Withheld bit. The overlap (Overage) bit is not utilized on this project.	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 7. Final lidar point counts per class.

Class	1 (Unclassified)	2 (Ground)	7 (Low Noise)	17 (Bridge Deck)	18 (High Noise)	40 (Bathy Bottom)	41 (Water Surface)	45 (Water Column)
Point Count	91,358,378,397	5,853,995,149	3,599,979,803	67,781	238,676,579	752,239,395	813,842,340	4,681,718,172

4. DERIVATIVE LIDAR PRODUCTS

USGS required several derivative lidar products to be created. Each type of derived product is described below.

4.1 Low Confidence Polygons

Low confidence polygons are included with this dataset. These polygons represent areas where heavy vegetation reduced penetration of the lidar pulse, resulting in a bare earth surface that is potentially less accurate than in surrounding environments. VVA standards may not be met in these areas. The low confidence polygons created for this dataset were delineated according to the criteria and assumptions outlined in the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014). Low confidence areas were identified using a ground density raster. All areas with a Nominal Ground Point Density less than two points per square meter (2 ppsm) were identified as low confidence cells in the ground density raster. The low confidence cells were exported and aggregated into generalized polygons. Areas of expected low density in the ground, such as water or where buildings/structures were removed, were deleted from the aggregated low confidence polygons. The size of each polygon was then calculated and polygons below the minimum size threshold of 5 acres were removed from the final low confidence polygon dataset.

It should be noted that the ASPRS low confidence polygon method relies on the classification of the lidar point cloud. Ground is generally classified from the lowest available points in the point cloud, excluding noise and below ground features. In a wetland environment such as the Everglades, the lowest available points may still be within the wetland vegetation. The combination of dense vegetation, saturated soils, standing water, and the dynamic nature of wetlands, can make it extremely difficult to determine what is “true” ground in the classic sense. As a ground is classified from best available data, these areas exhibit a higher calculated ground density, resulting in fewer low confidence polygons than expected for the heavily vegetated, wetland environment of the Everglades.

4.2 Swath Separation Images

Dewberry verified inter-swath or between swath relative accuracy of the dataset by generating swath separation images in conjunction with interswath polygons (section 3.1.2). These images were created from the last return of all points except points classified as noise or flagged as withheld. Color-coding is used to help visualize elevation differences between overlapping swaths. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values.

The swath separation images are symbolized by the following ranges:

- 0-8 cm: **Green**
- 8-16 cm: **Yellow**
- >16 cm: **Red**

Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across one raster pixel) are expected to appear yellow or red in the DZ orthos. Flat, open areas are expected to be green in the DZ orthos. Bathymetric areas may be yellow or red due to varying elevations of returns within the water column. Large or continuous sections of yellow or red pixels following flight line patterns and not the terrain, vegetation, or bathymetric areas can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data.

As noted in section 3.1.2., the eastern add-on portion of the FL West Everglades NP project area was particularly difficult to align due to relatively few hard surfaces present which could reliably be used during the alignment process. Please see the noted section for full details, but the swath separation rasters will confirm a bias between the NIR and green swaths (approx. 7-11 cm) on the park road in the east of the project, along with 3-4 flightlines with larger offsets approaching 15 cm. Areas along the road exhibiting the most measurable offsets are identified in the provided shapefile, named “W_Everglades_NP_Lidar_Interswath_Issues.”

Swath separation images created by Dewberry for internal verification of interswath alignment have been delivered. The images are in TIFF format.

4.3 Lidar Intensity Images

4.3.1 Green Intensity

Within the green intensity there are areas of tile-tile variation. An example is shown in Figure 12. This variation is due to the reprocessing of some swaths due to unrelated issues, and these reprocessed swaths being exported with a different intensity value. With these reprocessed areas some tiles may have only been retiled where necessary. Due to the variance in the source swath intensity between processed versions, there is variation in intensities from tile to tile. Additionally, there are some areas of swath to swath variation. This swath to swath variation is typically due to a mission-mission variation from different environmental conditions, different reflectance export ranges, or areas where the two different topobathymetric sensors were used. Both inconsistencies will exist in both the LAS file intensity value and the intensity imagery.

4.3.2 NIR Intensity

Within the NIR intensity there again are some swath to swath variations in intensity with some darker and some brighter areas. Typically, these correspond with different missions or the two different sensors used on the project. An example is shown in Figure 13.

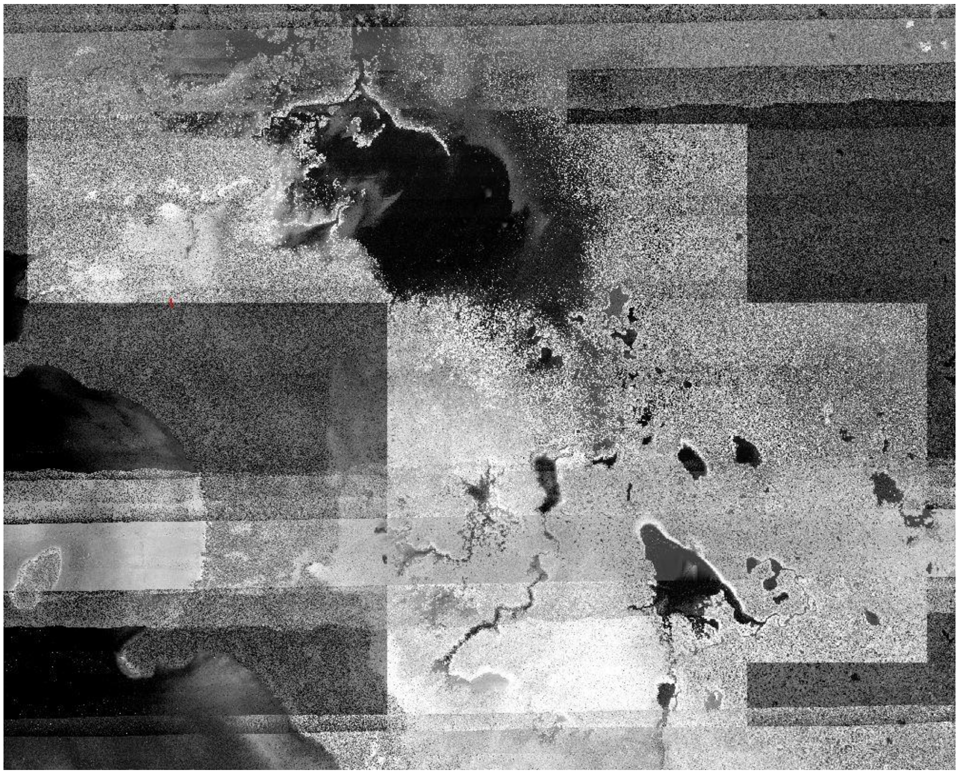


Figure 12. An example of the green intensity imagery tile-tile variation.

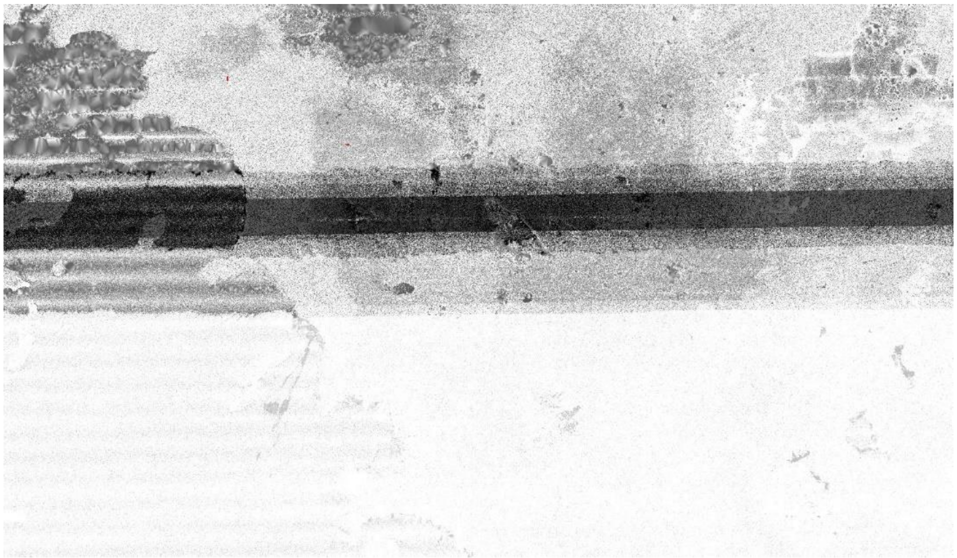


Figure 13. An example of the NIR Intensity variation with some darker and brighter areas.

5. LIDAR POSITIONAL ACCURACY

5.1 Background

Dewberry quantitatively tested the vertical accuracy of the lidar to confirm adherence of the dataset to project specifications. Discrete surveyed (real-world) checkpoint elevation coordinates were compared to the surface elevation values at the corresponding X and Y coordinates on TIN surfaces created from the classified lidar data. Relative accuracy testing determined how consistently the lidar data was collected and enabled extrapolation of the point-based absolute accuracy results to the broader dataset. I.e., if the relative accuracy of the dataset was found to be within specifications *and* the dataset passed absolute vertical accuracy requirements at the locations of survey checkpoints, the vertical accuracy results were considered valid throughout the whole dataset with high confidence. Dewberry used LP360 to test the swath lidar vertical accuracy, TerraScan to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different methods were used to validate the vertical accuracy for the project.

Horizontal accuracy testing requires survey checkpoints located such that the checkpoints are photo-identifiable in the intensity imagery. No photo-identifiable checkpoints were surveyed for this project, so the horizontal accuracy was not tested.

5.2 Survey Vertical Accuracy Checkpoints

Dewberry surveyed 125 accuracy checkpoints to assess the vertical accuracy of the final data. However, some surveyed points were placed in poor locations and had to be removed from accuracy testing. Once poorly placed checkpoints were removed, there were not enough checkpoints to meet ASPRS checkpoint number requirements for NVA: 55 NVA (and 45 VVA) points are required for this project. Dewberry also surveyed an additional 51 GCPs to test the calibrated swath data. Dewberry surveys GCPs in case the acquisition provider needs additional control for use during the calibration process. But for this project, LEG collected 183 control points to use during the calibration process. As the Dewberry surveyed GCPs were not used to calibrate or post process the data, 12 of these GCPs were used in the final vertical accuracy testing. As the Dewberry surveyed GCPs were not used in any calibration processing and were only used to test calibrated data, all surveyed points used in final accuracy testing (Dewberry surveyed checkpoints and Dewberry surveyed GCPs) are an independent validation of the final calibrated, processed, and edited data.

Additionally, one NVA point (NVA-20) was actually located in vegetation so it was used to assess VVA despite its checkpoint ID name. The ID name was kept as NVA-20 to match the survey report, photos, and survey documentation. A total of 113 surveyed points (55 NVA, 45 VVA, and 13 Bathymetric Bottom) were used in the final vertical accuracy testing.

The delivered survey reports (one for checkpoints and one for GCPs) and photos are structured as acquired and delivered by the surveyor, e.g. all GCPs, including the 12 used in vertical accuracy testing, are located in the GCP survey report and all surveyed points are referenced in the reports. The coordinate listing Excel files and the shapefiles delivered with the survey data have been updated to reflect their use, e.g., points removed due to poor placement are removed from these files and the 12 GCPs used in final accuracy testing have been moved into the “checkpoint” shapefile and coordinate listing.

The survey reports include images showing the locations of the surveyed points used to test the positional accuracy of the dataset and coordinate listings can be found in the reports, coordinate listing Excel files, and the delivered shapefiles.

5.3 Vertical Accuracy Test Procedures

NVA reflects the calibration and performance of the lidar sensor. NVA was determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas. In these locations it is likely that the lidar sensor detected the bare-earth ground surface and random errors are expected to follow a normal error distribution. Assuming a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the FL West Everglades NP lidar project, the vertical accuracy specification is 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

VVA was determined with all checkpoints in vegetated land cover categories, including wetlands, tall grass, weeds, crops, brush and low trees, and fully forested areas. In these locations 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 West Everglades NP 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.

Bathymetric Vertical Accuracy is determined with check points located only in submerged topography. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the FL West Everglades NP lidar project, bathymetric vertical accuracy was not required but Dewberry targeted 35.3 cm or less based on an $RMSE_z$ of 18 cm x 1.9600.

The relevant testing criteria are summarized in Table 8.

Table 8. Vertical accuracy acceptance criteria

Land Cover Type	Quantitative Criteria	Measure of Acceptability
NVA	Accuracy in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm
VVA	Accuracy in vegetated land cover categories combined at the 95% confidence level	30 cm
Bathymetric Vertical Accuracy	Accuracy in submerged topography using $RMSE_z$ *1.9600	35.3 cm Target

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

1. Dewberry's team surveyed X, Y, and Z coordinates for discrete checkpoints in accordance with project specifications.
2. Dewberry interpolated the bare-earth lidar DTM to determine a lidar surface Z coordinate for every surveyed X and Y coordinate.
3. Dewberry computed differences between each surveyed Z coordinate and lidar surface Z coordinate.

4. The difference data was analyzed by Dewberry to assess the accuracy of the data. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The results are provided in the following section.

5.4 Vertical Accuracy Results

The table below summarizes the tested vertical accuracy of the classified lidar LAS files.

Table 9. Vertical accuracy results

Land Cover Type	# of Points	NVA (m)	VVA (m)	Bathymetric Vertical Accuracy (m)
Project Specification		**0.196**	**0.300**	**0.353 (Target)**
NVA	55	0.131		
VVA	45		0.246	
Bathymetric Vertical Accuracy	13			0.311

The topographic portion of 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 $RMSE_z$ =6.7 cm, equating to +/- 13.1 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 24.6 cm at the 95th percentile. The bathymetric portion of this lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for an 18.5 cm RMSEz Vertical Accuracy Class. Actual bathymetric vertical accuracy was found to be RMSEz = 15.9 cm, equating to +/- 31.1 cm at 95% confidence level.

The 5% outliers are listed in Table 10. Descriptive statistics for both sets of checkpoints are presented in Table 11.

Table 10. VVA 5% outliers

Point ID	NAD83(2011) Albers Conus, m		NAVD88 Geoid 12B, m		Delta Z (m)
	Easting (X)	Northing (Y)	Survey Z	Lidar Z	
VVA-11	1473540.078	416984.991	0.911	0.47	+0.441
VVA-17	1485812.367	407114.102	0.229	0.48	-0.251
VVA-103	1550784.581	365475.297	-0.179	0.28	-0.459

Table 11. Classified lidar vertical accuracy descriptive statistics

Land Cover Type	# of Points	RMSE$_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	55	0.067	0.011	0.019	-0.818	0.067	-0.221	0.139	1.883
VVA	45	N/A	-0.023	0.001	-0.031	0.142	-0.459	0.441	2.983
Submerged Topography	13	0.159	0.082	0.088	0.215	0.141	-0.142	0.363	-0.189

5.5 Horizontal Accuracy Test Procedures

Horizontal accuracy testing requires well-defined checkpoints that can be visually identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. Dewberry reviewed all NVA checkpoints to determine which, if any, of these checkpoints were located on photo-identifiable features in the intensity imagery.

5.6 Horizontal Accuracy Results

No checkpoints were photo-identifiable in the intensity imagery; horizontal accuracy could not be tested on this dataset.

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSE$_x$/RMSE$_y$ horizontal accuracy class which equates to a positional horizontal accuracy = ± 1 meter at the 95% confidence level.

6. DEM PRODUCTION & QUALITATIVE ASSESSMENT

The final topobathy DEMs are GeoTIFF format with 0.5 meter pixel cell size, tiled, named according to project specifications. Void polygons were enforced in the DEMs so that bathymetric areas where no bathymetry was collected are NoData in the DEMs.

6.1 Final Void Polygons

Final void polygons, after all lidar edits and corrections, were created for use in the topobathymetric DEM production. The void polygon layer was generated using LAStools and ArcGIS to eliminate interpolation across areas greater than 9 square meters in the bathy class (40) in the final elevation raster. A DEM was created using LAStools' 'las2dem' utility, which created and rasterized a TIN from the LAS data. A user-defined threshold specifying the maximum allowable edge length during triangulation was set to 4 m, restricting rasterization in areas of sparse data. Once the constrained DEM was created, ArcGIS was used to vectorize the void (NoData) areas

Once the final void polygons had been created, these polygons were used as a mask during final topobathymetric DEM generation.

6.2 DEM Generation

After the final void polygons are created, Dewberry utilized lastools and Esri to generate DEM products. DEMs were created using only ground (2) and submerged topography (40) lidar point data. A triangulated irregular network (TIN) was generated from these data and rasterized via linear interpolation using LAStools ‘blast2dem’ utility. Using Esri ArcMap, void polygons representing areas of extremely sparse or non-existent bathymetric coverage were used to eliminate areas of interpolation in the DEM. The DEM was clipped to the tile grid to create individual tiled DEMs and named according to project specifications.

Once the qualitative review and any necessary corrections were complete (outlined in the section below), Dewberry then used proprietary tools to finalize the raster formatting and raster properties. GDAL version 2.4.0 was used to write the final Coordinate Reference System (CRS) information into the raster files.

6.3 DEM Qualitative Review

The final topobathy DEMs were then reviewed in both ArcGIS and Global Mapper for QA/QC. A review with the void polygons visible and another review without the void polygons visible was performed in order to ensure voids were enforced properly and there were no issues along the boundaries of the void layer. Special attention was given along the land/water interface to ensure there were no hard edges along the interface. Any remaining lidar issues and DEM artifacts were flagged by the reviewer and corrected by the editing team as necessary.

Once all corrections were performed, rasters were finalized. After the finalization process, Dewberry performed a formatting review to ensure all tiled DEM products were delivered with the proper extents, formatting, and contained the proper CRS information. This process was performed using a proprietary tool to verify all raster properties were consistent and correct on the final deliverable tiles.

6.4 DEM Quantitative Assessment

The same 113 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. 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 linearly interpolated TIN created from the source LAS. The vertical accuracy of the DEM was tested by comparing the elevation of a given surveyed checkpoint with the elevation of the horizontally coincident pixel in the DEM. Dewberry used Esri ArcMap to test the DEM vertical accuracy.

Table 12. DEM vertical accuracy results

Land Cover Type	# of Points	NVA (m)	VVA (m)	Bathymetric Vertical Accuracy (m)
Project Specification		**0.196**	**0.300**	**0.353 (Target)**
NVA	55	0.128		
VVA	45		0.240	
Bathymetric Vertical Accuracy	13			0.316

The topographic portion of 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 $RMSE_z$ =6.6 cm, equating to +/- 12.8 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 24 cm at the 95th percentile. The bathymetric portion of this DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for an 18.5 cm RMSEz Vertical Accuracy Class. Actual bathymetric vertical accuracy was found to be RMSEz = 16.1 cm, equating to +/- 31.6 cm at 95% confidence level.

The 5% outliers are listed in Table 13. Descriptive statistics for both sets of checkpoints are presented in Table 14.

Table 13. DEM VVA 5% outliers

Point ID	NAD83(2011) Albers Conus, m		NAVD88 Geoid 12B, m		Delta Z (m)
	Easting (X)	Northing (Y)	Survey Z	DEM Z	
VVA-11	1473540.078	416984.991	0.911	0.45	+0.461
VVA-17	1485812.367	407114.102	0.229	0.474	-0.245
VVA-103	1550784.581	365475.297	-0.179	0.281	-0.460

Table 14. DEM vertical accuracy descriptive statistics

Land Cover Type	# of Points	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	55	0.066	0.012	0.017	-0.875	0.065	-0.236	0.144	2.985
VVA	45	N/A	-0.016	-0.001	0.040	0.144	-0.460	0.461	3.157
Submerged Topography	13	0.161	0.079	0.089	0.272	0.146	-0.150	0.377	-0.059

7. DSM PRODUCTION & QUALITATIVE ASSESSMENT

The final first return DSMs are GeoTIFF format with 0.5 meter pixel cell size, tiled, named according to project specifications.

7.1 DSM Generation

Dewberry utilized LP360 to generate DSMs. The final classified lidar points were loaded into LP360 along with the project tile grid. The first returns from all point classes except for noise (classes 7 and 18), points flagged as withheld, and submerged bottom (class 40) were used to create the DSMs. A raster was generated from the lidar data using linear interpolation and clipped to the project tile grid. Bathymetric voids are not enforced in the DSMs. The image below shows the final DSMs for the FL West Everglades NP project area.

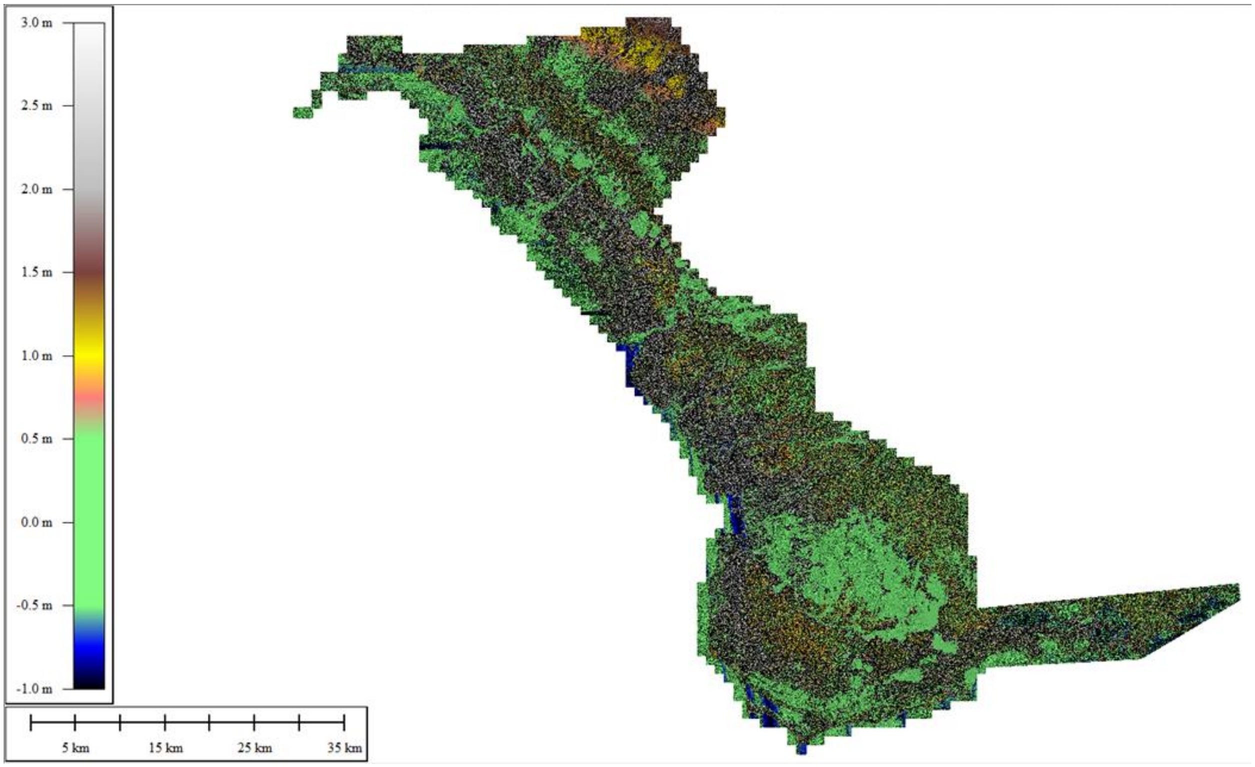


Figure 14. DSMs created for the FL West Everglades NP project are colored by elevation. DSMs were generated from the first return of all points, excluding noise classes and points flagged as withheld.

Once the qualitative review and any necessary corrections were complete (outlined in the section below), Dewberry then used proprietary tools to finalize the raster formatting and raster properties. GDAL version 2.4.0 was used to write the final Coordinate Reference System (CRS) information into the raster files.

7.2 DSM Qualitative Review

The final DSMs were then reviewed in both ArcGIS and Global Mapper for QA/QC. The review of the DSMs included looking for spikes, divots, noise points not properly classified to the noise classes, other lidar misclassifications, and processing artifacts.

Once all corrections were performed, rasters were finalized. After the finalization process, Dewberry performed a formatting review to ensure all tiled DSM products were delivered with the proper extents, formatting, and contained the proper CRS information. This process was performed using a proprietary tool to verify all raster properties were consistent and correct on the final deliverable tiles.

8. GEOREFERENCED IMAGERY

LEG acquired three-band (Red, Green, and Blue or RGB) digital imagery covering the project area. LEG performed the aerotriangulation and delivered the image frames to Dewberry. Dewberry reviewed the data for completeness but did not perform any imagery processing.

8.1 Imagery Processing

LEG processed trajectories using PosPAC MMS 8.3/8.4, ensuring acceptable positional quality, satellite geometry and full coverage. The collection was co-flown which allowed for generation of both LAS files and TIFs out of RiProcess 1.8.5.1. The Exterior Orientation (EO) was also exported for each mission using the RIEGL Software Suite, and it is tied to the same trajectory produced for the LAS.

As part of QC, the TIFs are georeferenced using python scripting. Information is obtained from the Camera Calibration Report, EO, and lidar elevation values. The following variables are calculated for each frame that allows a world file (TFW) to be created:

- X and Y Scale
- X and Y Skewness
- X and Y Centroid

Although the TIF files have associated .TFW files and can be properly placed, they are not full GeoTIFFs. Two tools are utilized in ArcGIS 10.7; Define Projection and Copy Raster. The supporting .TFW file ensures that the .TIF is rotated properly so the projection can simply be defined. The Copy Raster tool commits the projection and produces a GeoTIFF with overviews built for ArcGIS.

The final output contains internal projection information with correct rotations and compatibility with ArcGIS and other software.