City of Palm Coast Lidar Project

Report Produced for St. Johns River Water Management District

Contract Number: 28743

Work Order: 002

Report Date: 11/3/2017

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Dewberry

Table of Contents

Executive Summary

The primary purpose of this project was to acquire, process, and classify lidar data for the City of Palm Coast AOI.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 5000 ft by 5000 ft. A total of 161 tiles were produced for the project encompassing an area of approximately 144.38 sq. miles.

THE PROJECT TEAM

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry elected to subcontract the lidar acquisition and calibration activities to Digital Aerial Solutions (DAS). DAS was responsible for acquiring lidar, all calibration activities, and delivery of calibrated lidar data to Dewberry.

Dewberry surveyors completed ground surveying for the project and surveyed ground control points and checkpoints. Their task was to acquire ground control points for DAS to use in the calibration of the lidar swath data and to acquire surveyed checkpoints to use in independent testing of the vertical accuracy of the lidar-derived surface model. Please see Appendices A and B to view the separate Ground Control and Checkpoint Survey Reports that were created for this portion of the project.

SURVEY AREA

The project area addressed by this report falls within the Florida county of Flagler.

DATE OF SURVEY

The lidar aerial acquisition was conducted from March 28, 2017 thru March 29, 2017.

COORDINATE REFERENCE SYSTEM

Data produced for the project were delivered in the following reference system.

- **Horizontal Datum:** The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment NAD 83 (2011))
- **Vertical Datum:** The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
- **Coordinate System:** State Plane Florida East FIPS 0901
- **Units:** U.S. Survey Feet
- **Geiod Model:** Geoid12B

LIDAR VERTICAL ACCURACY

Non-vegetated Vertical Accuracy (NVA) for the City of Palm Coast Lidar Project was tested using surveyed check points. The tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **0.14 ft (4.2 cm)** compared with the 0.33 ft (10 cm) specification.

The NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **0.27 ft (8.2 cm)**, compared with the 0.64 ft (19.6 cm) specification.

The tested Vegetated Vertical Accuracy (VVA) of the classified lidar data computed using the 95th percentile was equal to **0.34 ft (10.4 cm)** compared with the 0.96 ft (29.4 cm) specification.

Additional accuracy information and statistics for the classified lidar data, raw swath data, and bare earth DEM data are found in the following sections of this report.

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – IMG Format and GRID Format)
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Independent Survey Checkpoint Data (Report, Photos, & Points)
7. Calibration Points
8. Metadata
9. Project Report (Acquisition, Processing, QC)
10. Project Extents, Including a shapefile derived from the lidar deliverable
11. Low Confidence Polygons (shapefile format)
12. Acquisition Data including GPS, IMU, and trajectory information

PROJECT TILING FOOTPRINT

One hundred sixty one (161) tiles were delivered for the project. Each tile's extent is 5,000 feet by 5,000 feet (see Appendix C for a complete listing of delivered tiles).

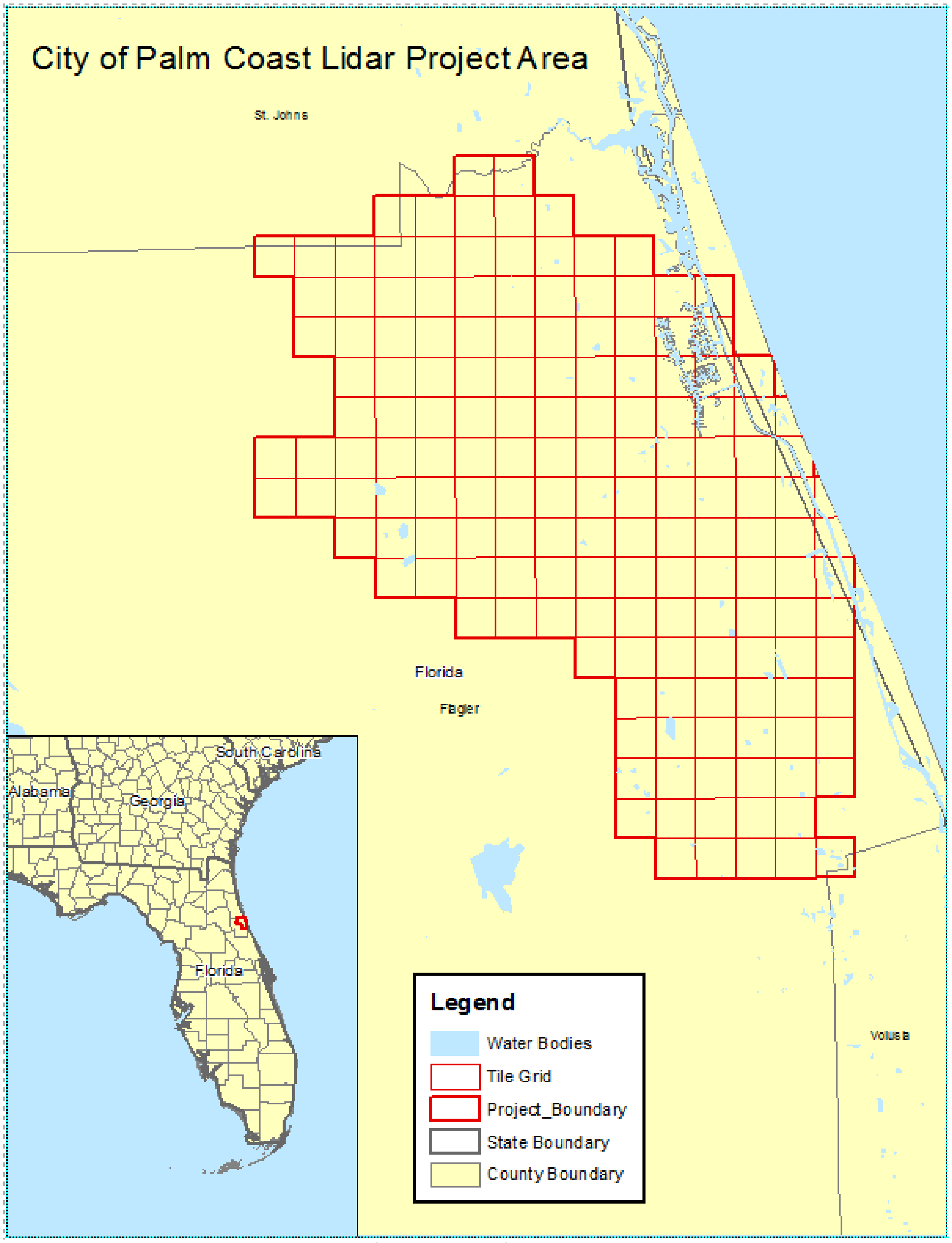


Figure 1 - Project Map

REPORT CERTIFICATION

I hereby certify that this survey report meets the applicable Standards of Practice as set forth by the Florida Board of Professional Surveyors and Mappers in Chapter 5J-17.051.

Professional Surveyor and Mapper Business:
Dewberry Consultants LLC
1000 N. Ashley Drive, Suite 801
Tampa, FL 3602
License #LB7663

Professional Surveyor and Mapper in Responsible Charge:
Keith Patterson, PSM, SP, GISP
Professional Surveyor and Mapper
License #LS5431

Approved by: ____________________ Date: 3/26/2018

THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA PROFESSIONAL SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Digital Aerial Solutions LLC. Digital Aerial Solutions LLC was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

LIDAR ACQUISITION DETAILS

Digital Aerial Solutions LLC planned 50 passes for the project area as a series of parallel flight lines with cross flight lines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Digital Aerial Solutions LLC followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO 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, Digital Aerial Solutions LLC will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Digital Aerial Solutions LLC monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that would negatively affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and 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. Digital Aerial Solutions LLC 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, Digital Aerial Solutions LLC closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, the aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Digital Aerial Solutions LLC lidar sensors are calibrated at a designated site located at the Plant City Airport, Florida and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Digital Aerial Solutions LLC operated a Cessna 421 (Tail # N112MJ) outfitted with a LEICA ALS80-HP lidar system during the collection of the study area. Table 1 illustrates Digital Aerial Solutions LLC system parameters for lidar acquisition on this project.

Item	Parameter
System	Leica ALS-80 HP
Altitude (AGL feet)	4731
Approx. Flight Speed (knots)	150
Scanner Pulse Rate (kHz)	361.6
Scan Frequency (hz)	52.0
Pulse Duration of the Scanner (nanoseconds)	0.003
Pulse Width of the Scanner (m)	0.88
Swath width (m)	1074.64
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes MPIA 2
Beam Divergence (milliradians)	0.15-0.25
Nominal Swath Width on the Ground (m)	1074.64
Swath Overlap (%)	55
Total Sensor Scan Angle (degree)	40
Computed Down Track spacing (m) per beam	0.67
Computed Cross Track Spacing (m) per beam	0.74
Nominal Pulse Spacing (single swath), (m)	0.50
Nominal Pulse Density (single swath) (ppsm), (m)	4.0
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.35
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	8.0
Maximum Number of Returns per Pulse	8

Table 1: Digital Aerial Solutions LLC lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

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 aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly 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 the combined trajectory of the flight lines.

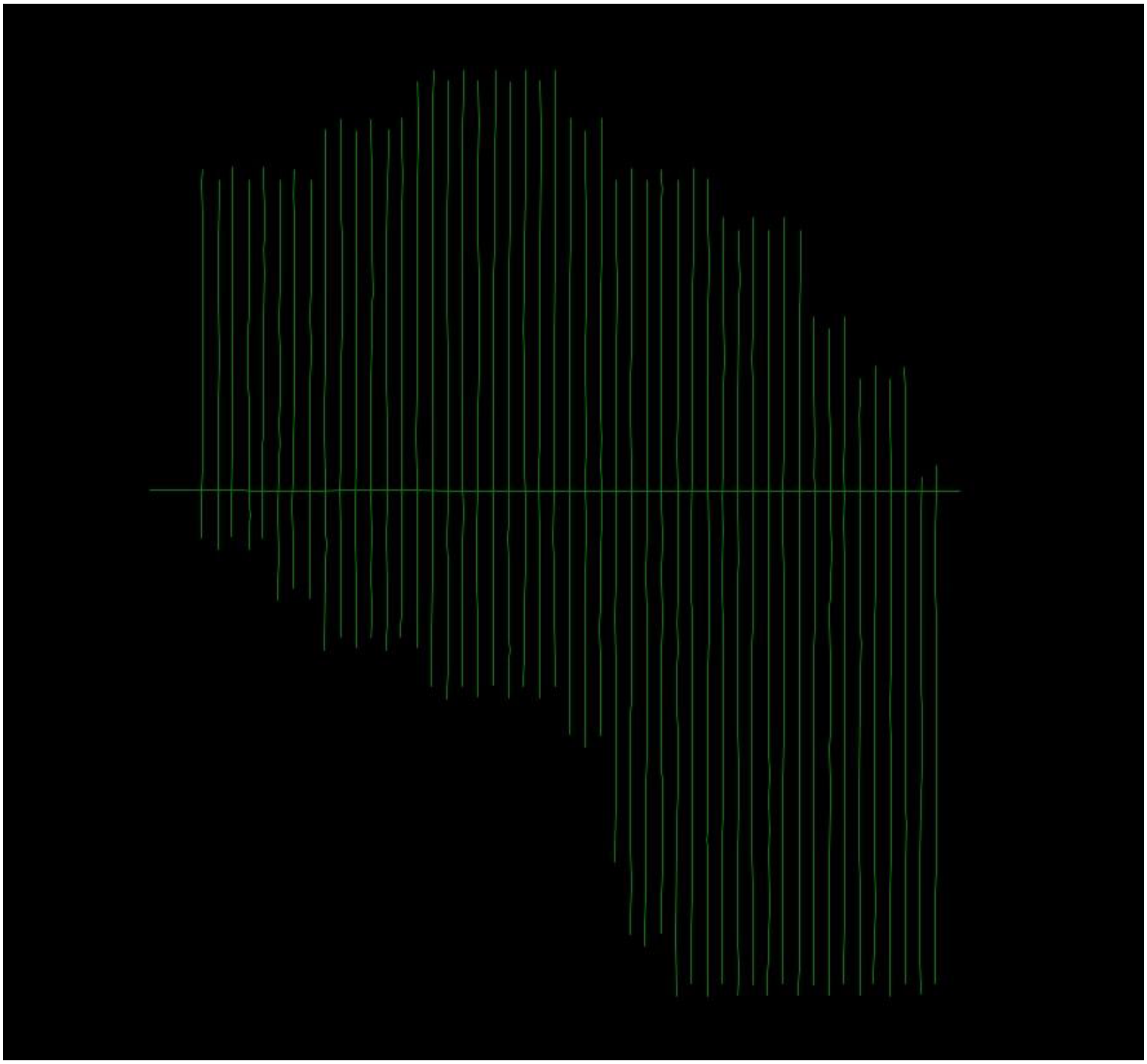


Figure 2: Trajectories as flown by Digital Aerial Solutions LLC

LIDAR CONTROL

Digital Aerial Solutions conducted the survey which provided the one newly established base station that was used to control the lidar acquisition for the City of Palm Coast Lidar Project area. The coordinates of this base station is provided in the table below.

Name	GCS North America Datum 1983 (2011)		Ellipsoid Ht (NAD83(2011), m)
	Latitude (DMS)	Longitude (DMS)	
PALAPORT	437510.15	1937487.19	26.62

Table 2 – Base Station used to control lidar acquisition for the City of Palm Coast Lidar Project.

AIRBORNE GPS KINEMATIC

Airborne GPS data was processed using the Inertial Explorer software suite. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with PDOP of better than 4. Distances form base stations to aircraft were kept to a maximum of 55 km. For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but not larger than 10 cm being recorded.

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

GENERATION AND CALIBRATION OF LASER POINTS (RAW 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 Leica CloudPro, initially with default values from CloudPro or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit 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.

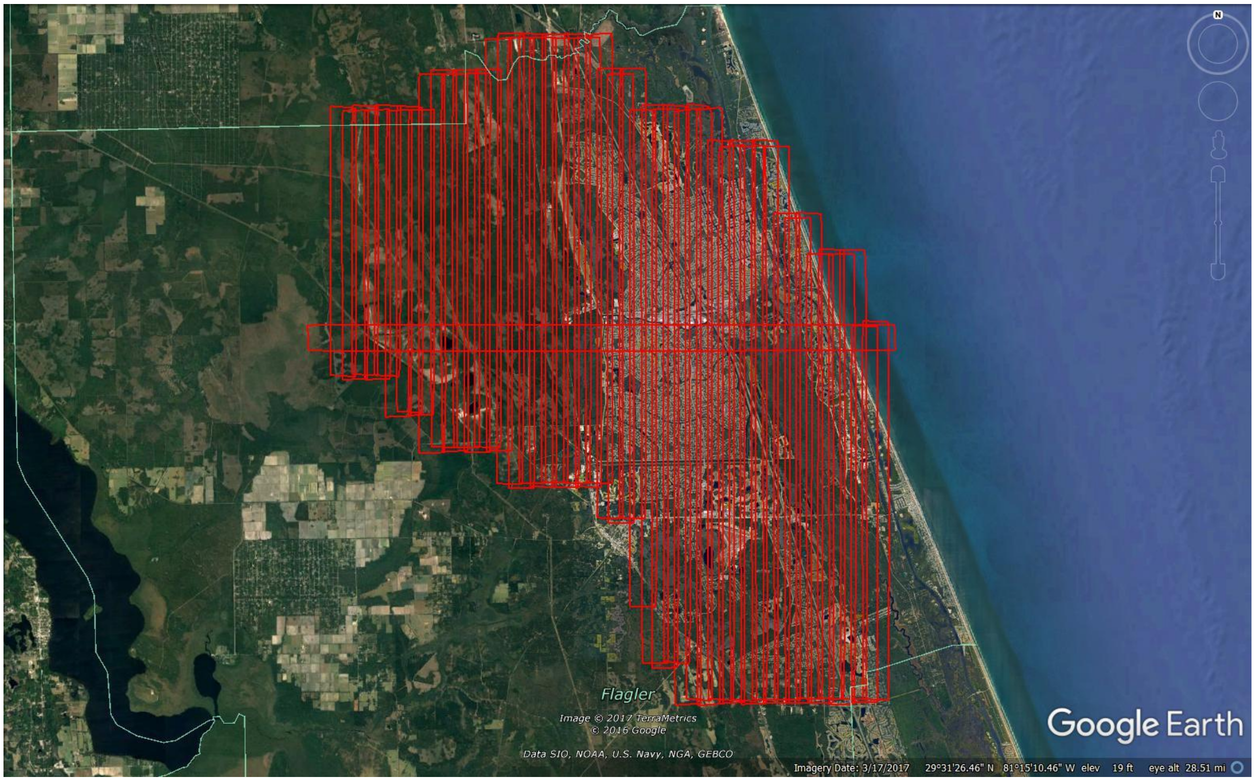


Figure 3 – Lidar swath output showing complete coverage.

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 scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. 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.

For this project the specifications used are as follow:
Relative accuracy <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

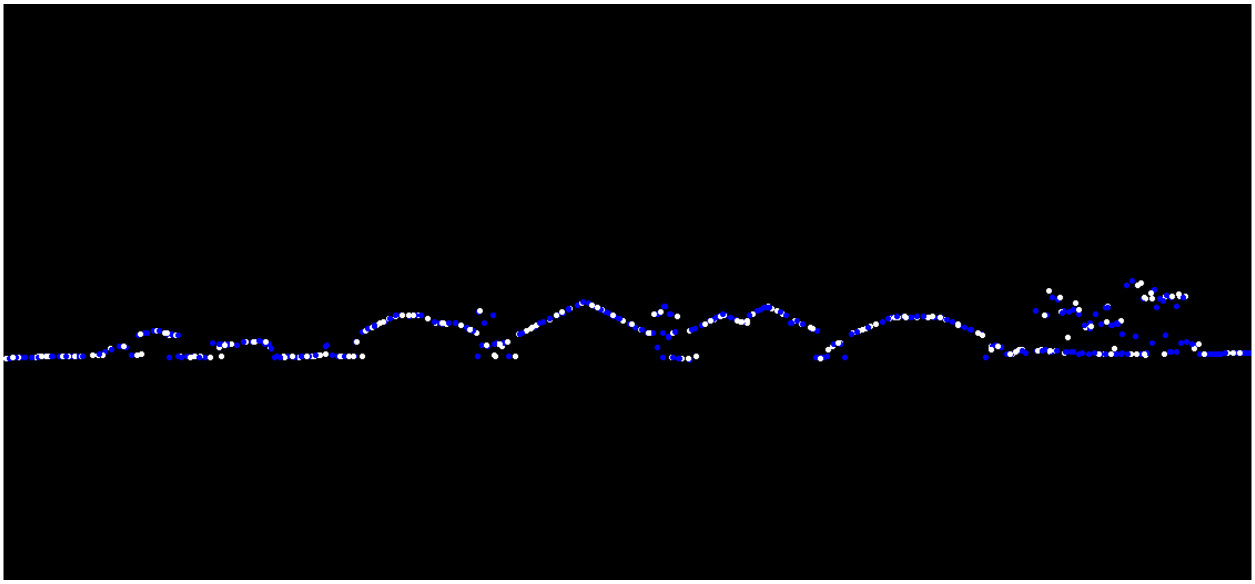


Figure 4 – Profile views showing correct roll and pitch adjustments.

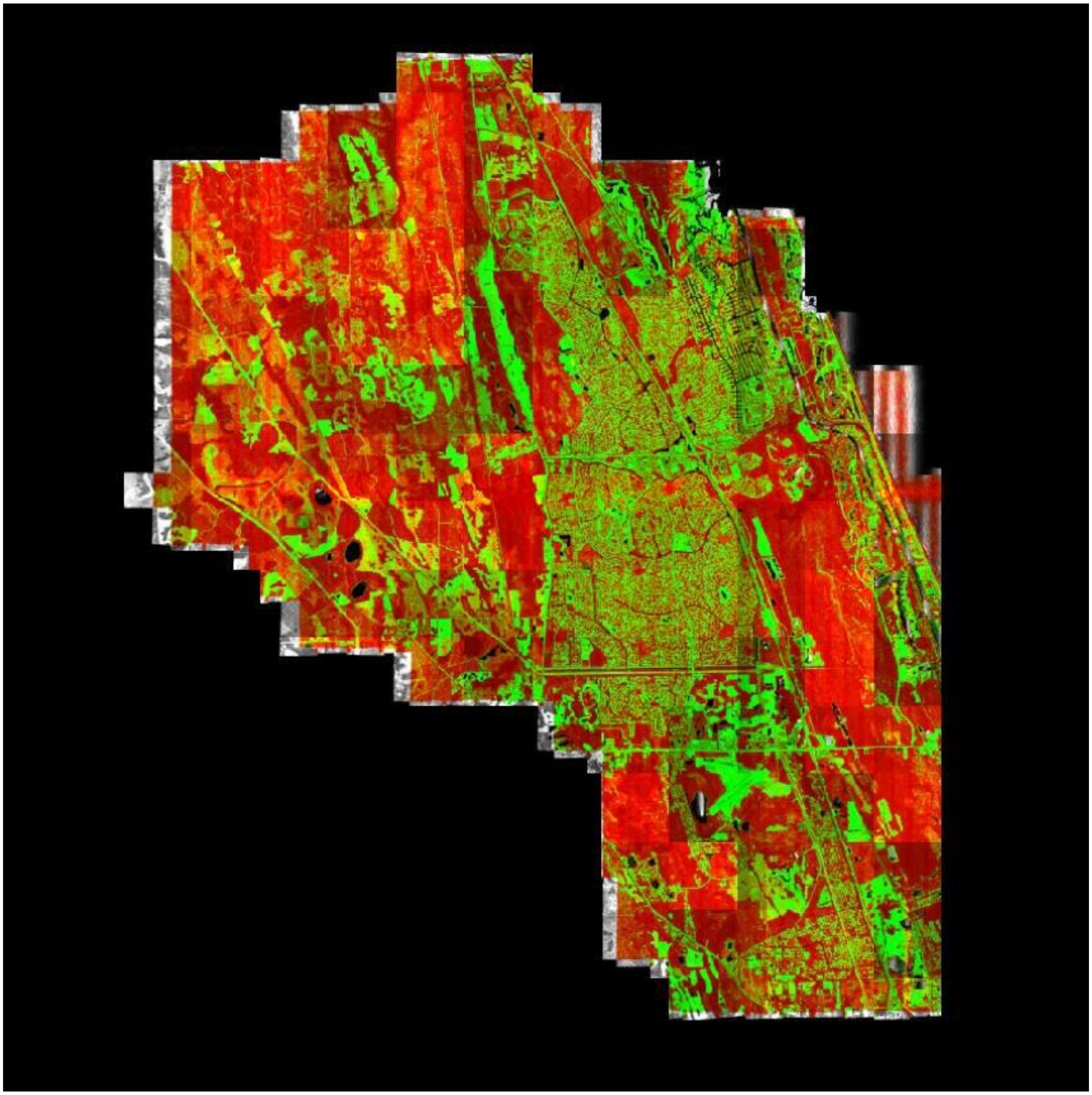


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

A different set of QC blocks are generated for final review after all transformations have been applied.

Final Calibration Verification

Dewberry conducted the survey for 19 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 19 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 are provided in table 3 and the accuracy results from testing the calibrated swath data against the GCPs is provided in table 4; no further adjustments to the swath data were required based on the accuracy results of the GCPs.

Point ID	NAD83 (2011) State Plane Florida East FIPS 0901 US Survey Feet		NAVD88 (Geoid 12B)	
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)
GCP-1	566464.50	1929224.12	29.75	29.74
GCP-2	555321.80	1922112.49	33.79	33.62
GCP-3	566587.62	1915614.19	28.12	28.40
GCP-4	585894.84	1911308.80	10.29	10.36
GCP-5	571994.27	1897393.65	31.09	31.18
GCP-6	584412.71	1887049.18	29.37	29.43
GCP-7	595859.86	1897047.62	10.51	10.48
GCP-8	603932.36	1884158.94	17.15	17.04
GCP-9	607055.75	1869635.34	14.57	14.58
GCP-10	601556.03	1850390.86	24.85	24.85
GCP-11	585738.34	1851312.02	25.63	25.81
GCP-12	581812.27	1869286.67	28.55	28.56
GCP-14	572163.99	1881715.34	30.32	30.16
GCP-15	556513.13	1886596.32	36.91	36.85
GCP-16	555735.23	1903007.05	34.49	34.41
GCP-17	540244.51	1894860.03	45.68	45.62
GCP-18	545556.07	1910290.86	41.45	41.57
GCP-19	576775.12	1923663.25	29.25	29.13
GCP-20	589027.86	1894041.21	21.20	21.28

Table 3 – City of Palm Coast surveyed ground control points (GCPs).

This project must meet Non-vegetated Vertical Accuracy (NVA) ≤ 0.64 ft (19.6 cm) at the 95% confidence level based on $RMSE_z$ ≤ 0.33 ft (10 cm) x 1.9600.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.64 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
GCP	19	0.11	0.22	0.01	0.00	0.54	0.12	-0.17	0.28	0.27

Table 4 - Ground control points (GCPs) vertical accuracy results.

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

Once Dewberry received the calibrated swath data from the acquisition provider, Dewberry performed several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Digital Aerial Solutions LLC, 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 twenty six non-vegetated (open terrain and urban) independent survey check points. 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, 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. Project specifications require a NVA of 0.64 ft (19.6 cm) based on the $RMSE_z$ (0.33 ft/10 cm) x 1.96. The dataset for the City of Palm Coast lidar project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.15 ft (4. cm), equating to +/- 0.30 ft (9.1 cm) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

Swath Vertical Accuracy Results										
100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.64 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
NVA	26	0.15	0.30	0.07	0.06	0.59	0.14	-0.18	0.42	0.22

Table 5: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. Large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data, especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for the City of Palm Coast Lidar Project are shown in the figure below; this project meets inter-swath relative accuracy specifications.

Figure 6– Single return DZ Orthos for the Palm Coast Lidar Project. The red areas are due to vegetation. Open, flat areas are colored green. Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The image below shows examples of the intra-swath relative accuracy of the City of Palm Coast Lidar Project; this project meets intra-swath relative accuracy specifications.

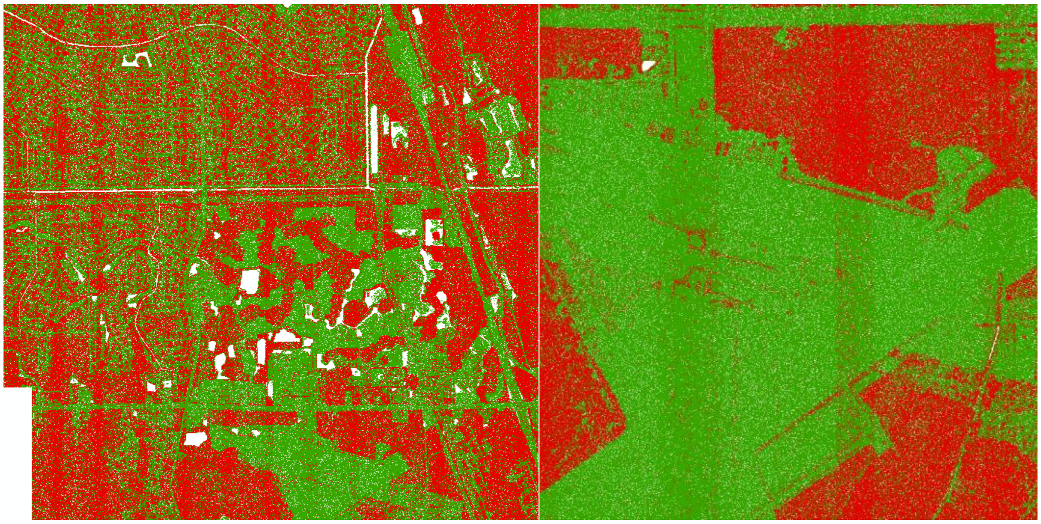


Figure 7–Intra-swath relative accuracy. The top image shows the full project area; areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. In particular, horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. The image below shows an example of the horizontal alignment between swaths for City of Palm Coast Lidar Project; no horizontal alignment issues were identified.

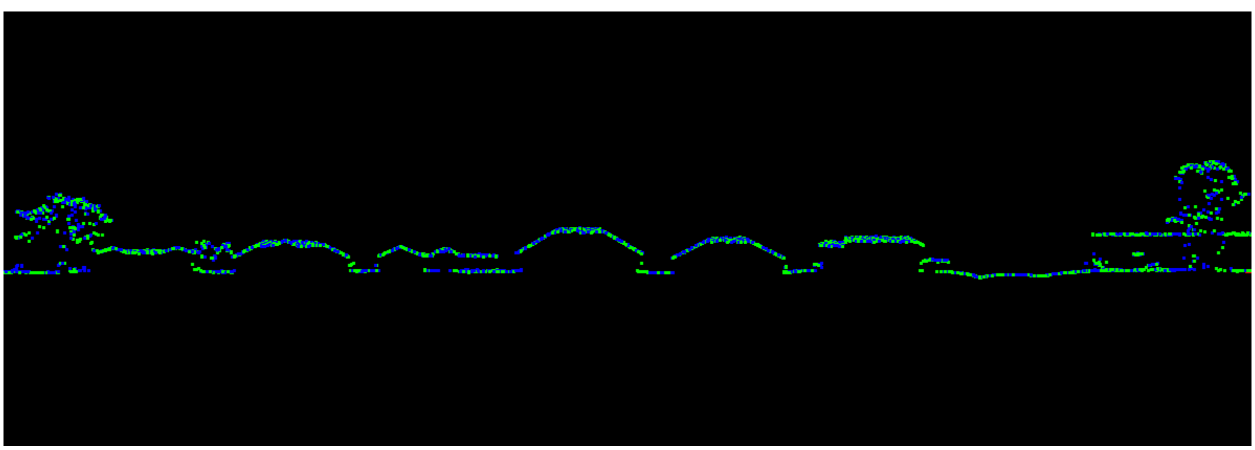


Figure 8– Horizontal Alignment. Two separate flight lines differentiated by color (Green/Blue) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.35 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 8 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.33 meters or an ANPD of 9.4 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 8 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

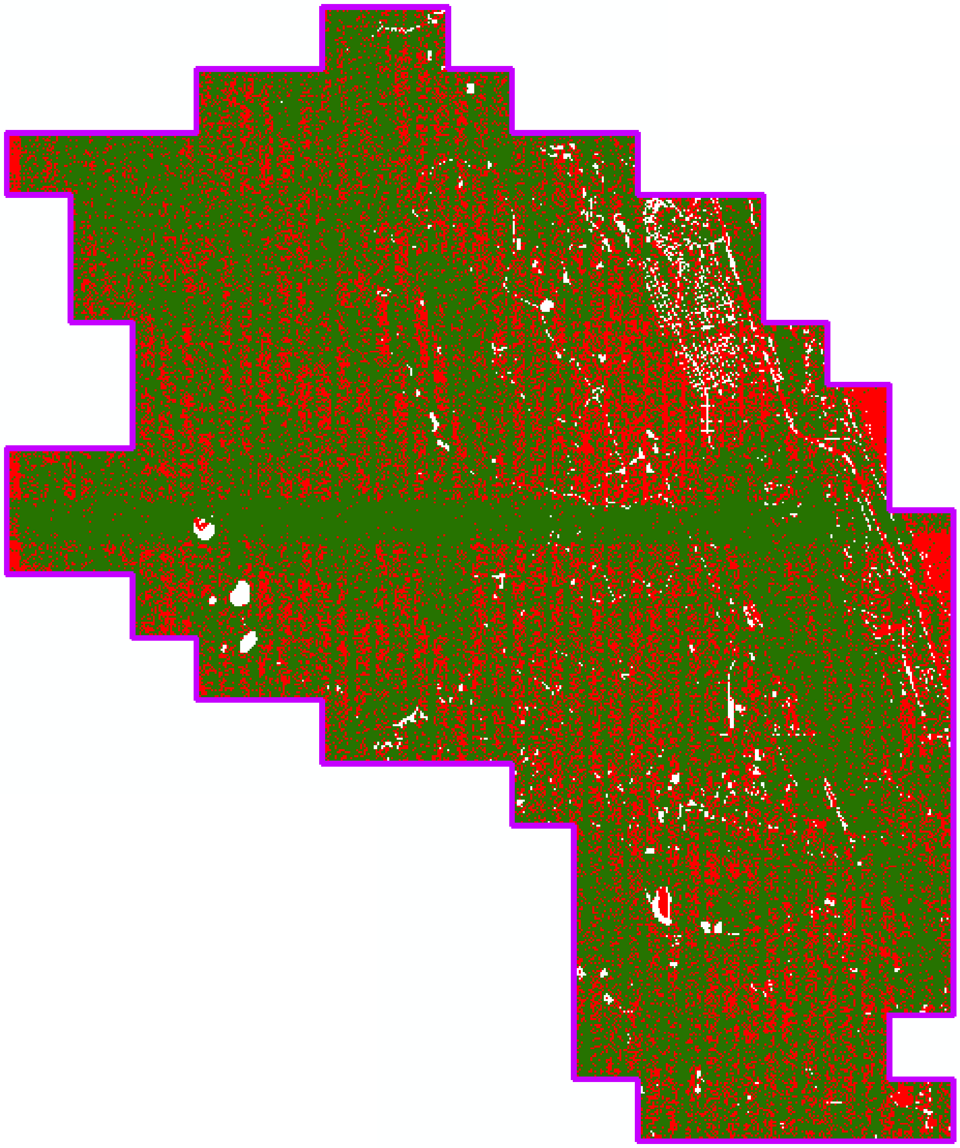


Figure 9– 1-square meter density grid. There are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 8 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

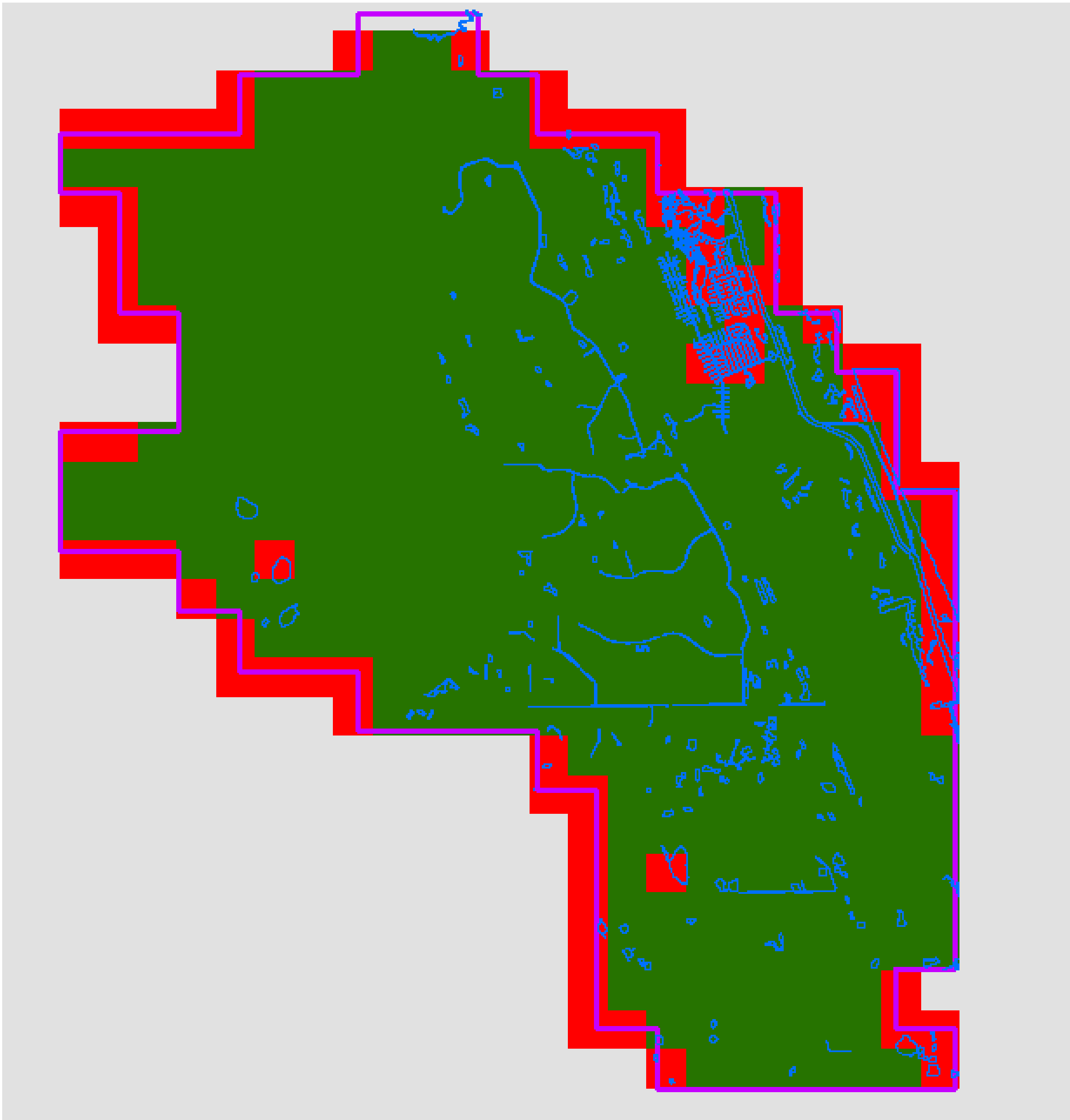


Figure 10 - When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues with every 1 km cell averaging 8 ppsm or greater (green cells) except for those cells along the project boundary (purple outline) or those cells containing large hydrographic features (blue outlines). Cells along the project boundary and those containing large hydrographic features will have acceptably lower point counts due to edge of data and water absorption of the NIR laser.

Dewberry also analyzed the ground density of the entire City of Palm Coast AOI. The ground density grid was calculated using 1 kilometer cell sizes, consistent with the project density calculated from first return points shown in Figure 10. The average ground density for the City of Palm Coast AOI is 2.5 points per square meter. The ground density grid is shown in the figure below.

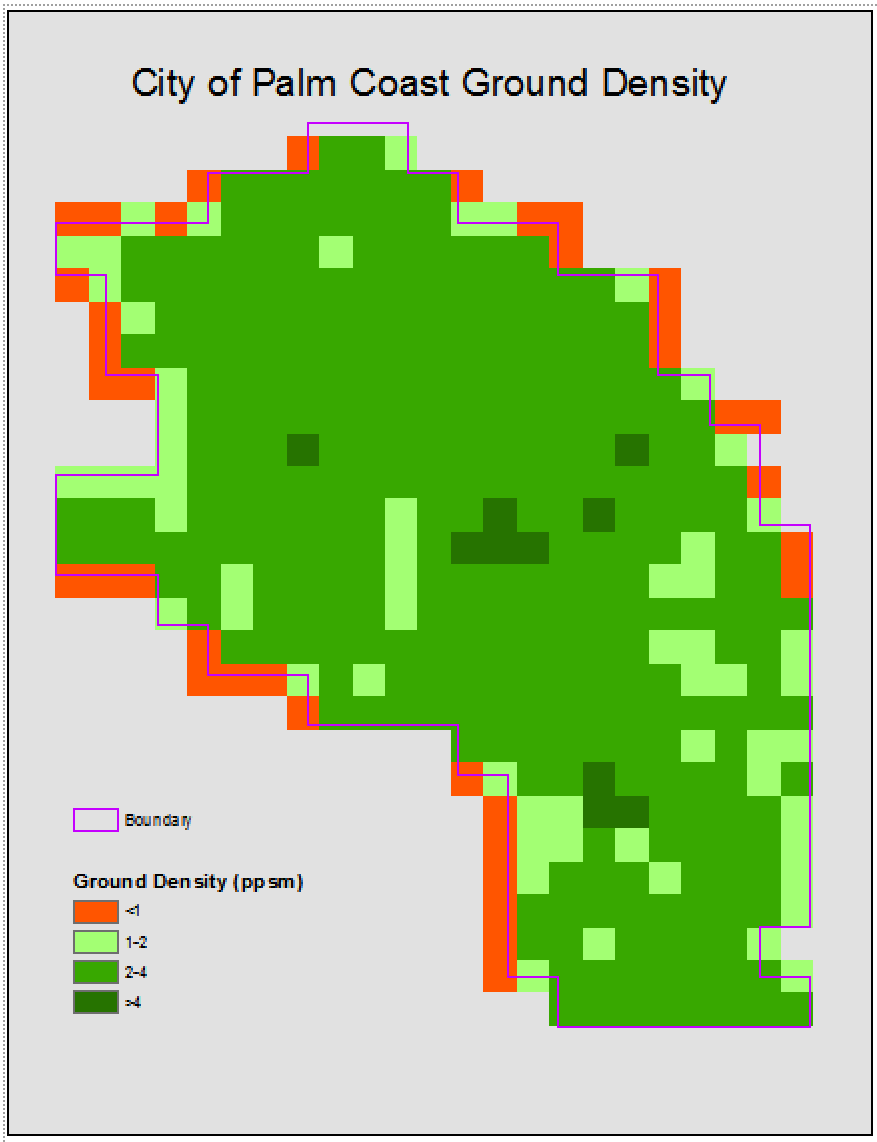


Figure 11– 1-square kilometer ground density grid.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. ArcGIS tools are then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.

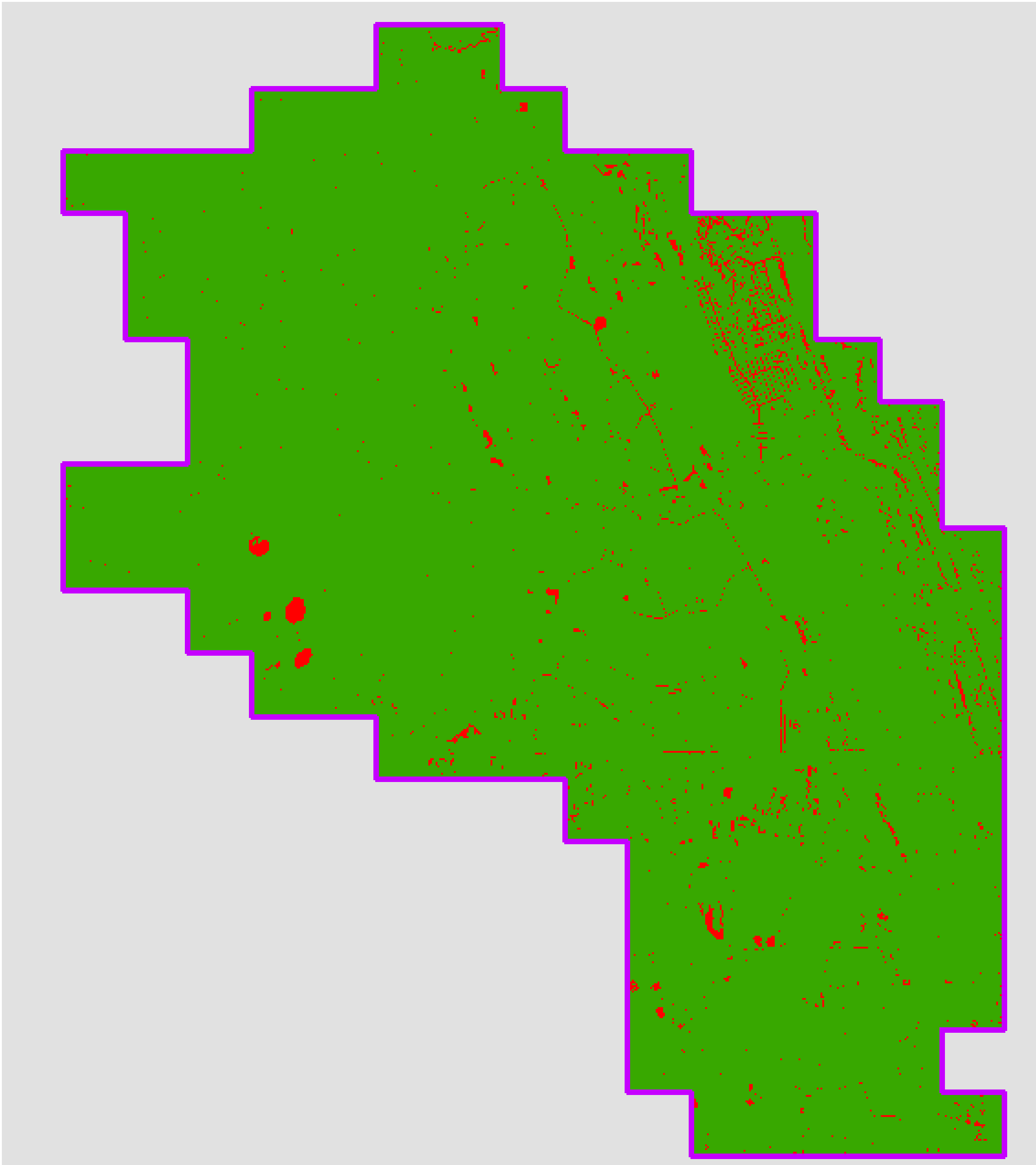


Figure 12– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 97.5% of cells contain at least one lidar point.

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. The data was processed using GeoCue and TerraScan software. The initial step 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. 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 as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. 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.

Each tile was then imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. 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. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise

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.

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 bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. 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, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for the City of Palm Coast Lidar Project.

Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. No unacceptable voids are present in the City of Palm Coast Lidar Project.

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

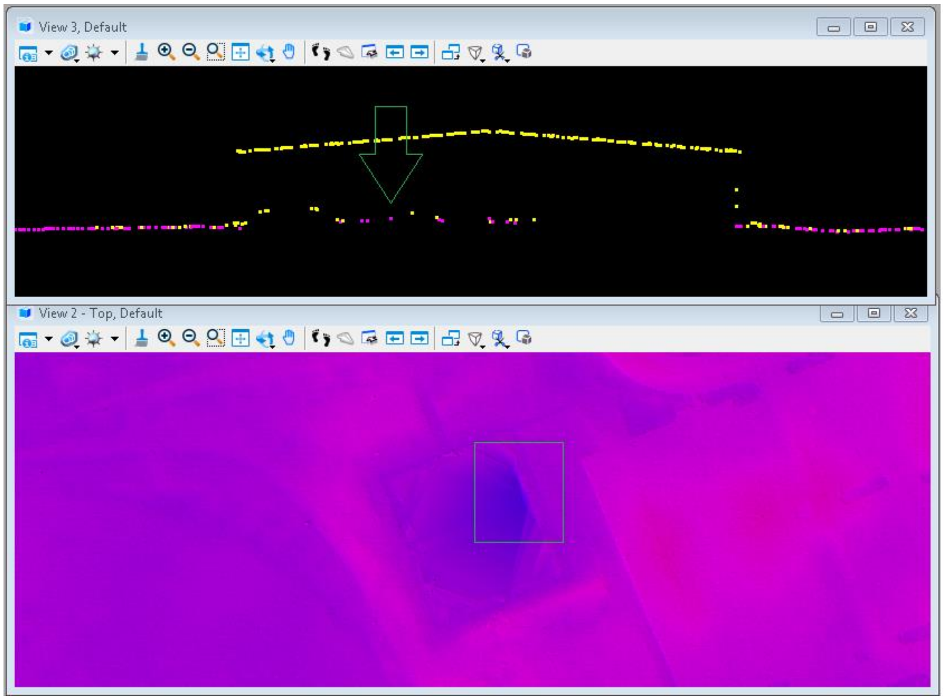


Figure 13 – Tile 235283. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no lidar data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

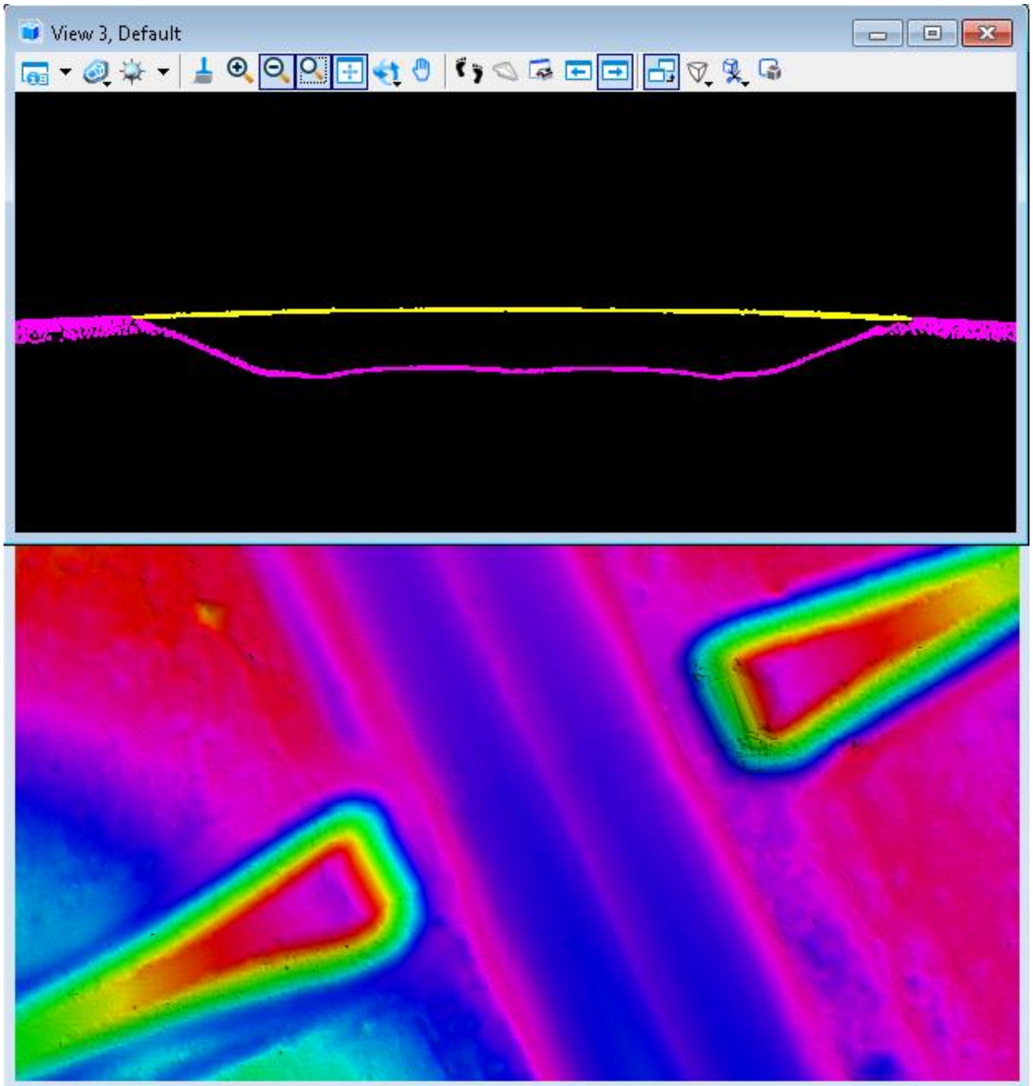


Figure 14 – Tile 234080. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (pink) and are bridge deck (yellow).

Culverts and Bridges

Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

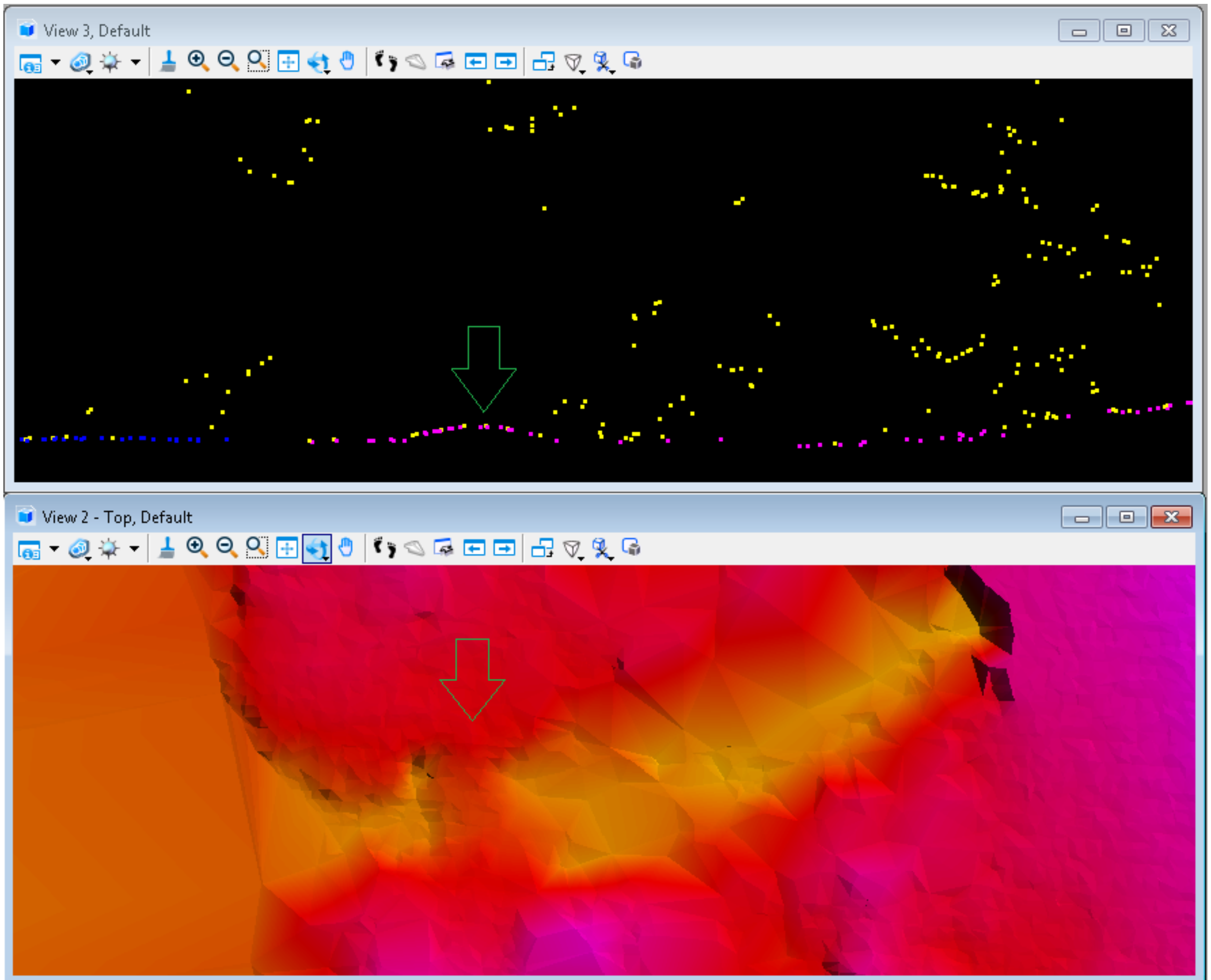


Figure 15– Tile 236785. Profile with points colored by class (class 1=yellow, class 2=pink, class 9=blue) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Dirt Mounds

Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

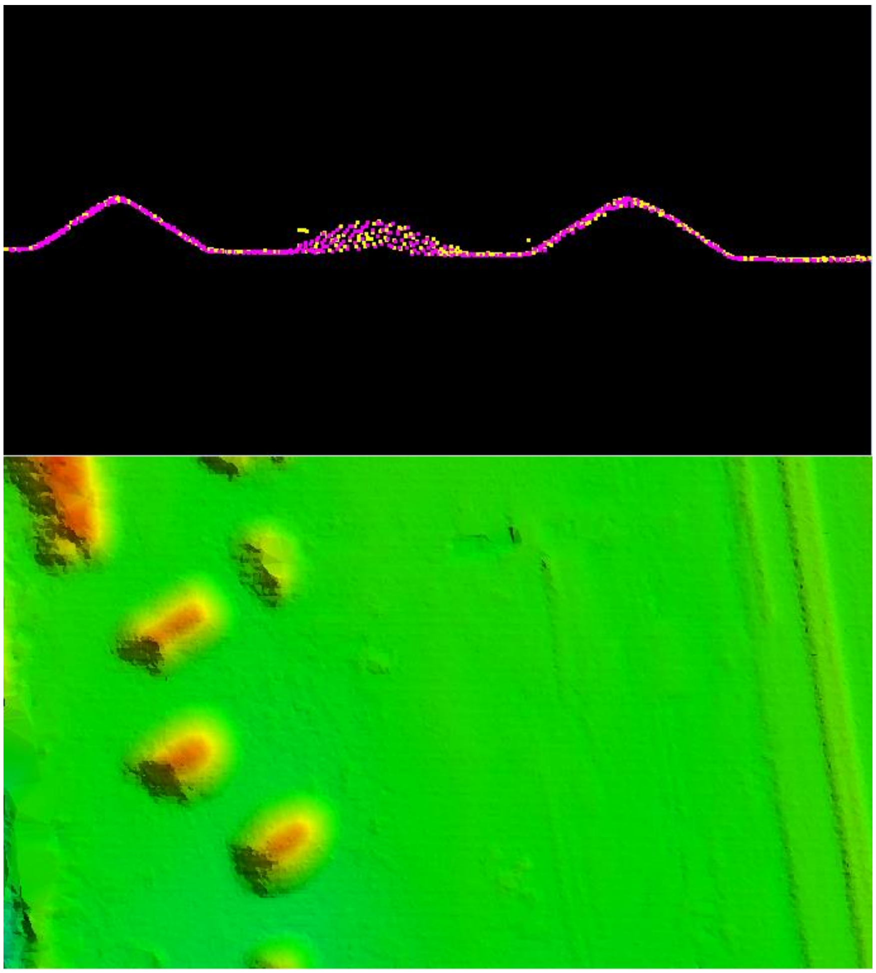


Figure 16 - Tile 234079. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Flight line Ridges

Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flight line ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

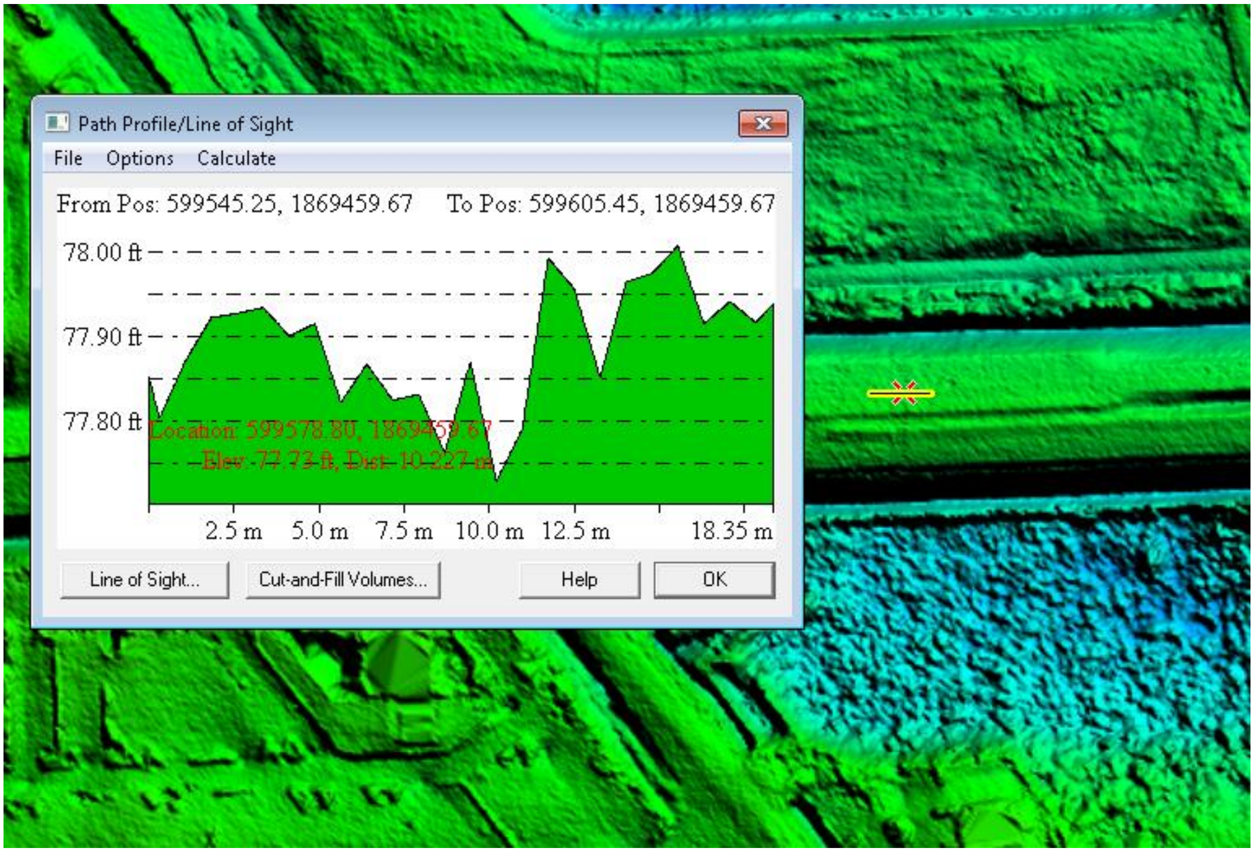


Figure 17– Tile 237986. The flight line ridge is less than 0.26 ft (8 cm). Overall, the City of Palm Coast lidar data meets the project specifications for 8 cm RMSDz relative accuracy.

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.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass

Coordinate Reference System	NAD83(2011) State Plane Florida East FIPS 0901 and NAVD88 (Geoid 12B), US Survey Feet in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	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 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Derivative Lidar Products

St. Johns River Water Management District required low confidence polygons to be derived from the lidar data, described below.

LOW CONFIDENCE POLYGONS

Low confidence polygons have been delivered with this dataset. These polygons represent areas where heavy vegetation greatly diminishes penetration of the lidar pulse, resulting in a bare earth surface that is potentially less accurate due to the lack of lidar returns from the ground beneath the vegetation. Low confidence polygons delineate areas where conformance to VVA standards may not be met. 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 are identified using a ground density raster. All areas with a Nominal Ground Point Density less than a specified threshold are identified as low confidence cells in the ground density raster. The low confidence cells are exported to polygons and aggregated into larger shapes. Areas of expected low density in the ground, such as water or where buildings/structures have been removed, are deleted from the aggregated low confidence polygons. The size of all polygons are then calculated and polygons below the minimum size threshold are removed from the final low confidence polygon dataset.

Lidar Positional Accuracy

BACKGROUND

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. 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.

Dewberry also 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.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, thirty six (36) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix B to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)
	Easting X (ft)	Northing Y (ft)	Elevation (ft)
NVA-100	566272.59	1924141.78	27.22
NVA-101	557129.48	1918986.51	31.07

NVA-102	566843.79	1911641.75	38.58
NVA-103	579227.81	1914720.48	28.44
NVA-104	582773.79	1906880.49	23.09
NVA-105	569294.66	1903584.76	37.00
NVA-106	583556.85	1893195.43	25.69
NVA-107	588983.91	1901461.43	18.19
NVA-108	596807.20	1906304.10	13.93
NVA-109	600049.96	1895157.95	12.46
NVA-110	588006.37	1884801.20	24.13
NVA-111	595681.35	1881985.84	20.54
NVA-112	601263.03	1869484.10	23.06
NVA-113	606161.08	1872993.67	17.52
NVA-114	602194.35	1888974.32	18.88
NVA-115	603265.36	1861071.75	22.20
NVA-116	591002.17	1858257.81	24.53
NVA-117	585567.60	1864180.27	23.39
NVA-118	578413.27	1877207.87	31.86
NVA-119	577671.86	1888076.98	28.85
NVA-120	572684.17	1890431.55	32.71
NVA-121	557229.95	1880220.38	29.76
NVA-122	563054.95	1876210.39	27.19
NVA-124	548148.86	1888345.97	35.41
NVA-125	575074.71	1906732.66	30.34
NVA-126	590773.34	1846545.29	25.46
VVA-200	557623.15	1912538.18	32.25
VVA-201	582522.08	1915131.07	22.64
VVA-202	600045.39	1899038.90	16.36
VVA-203	607218.29	1878248.82	6.99
VVA-204	596154.62	1850888.28	28.81
VVA-205	587877.84	1870782.39	28.03
VVA-206	563522.96	1896883.46	29.44
VVA-207	553780.95	1892821.15	39.61
VVA-209	539987.55	1920088.62	41.79
VVA-210	561092.90	1889176.32	31.84

Table 6: City of Palm Coast lidar surveyed accuracy checkpoints

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

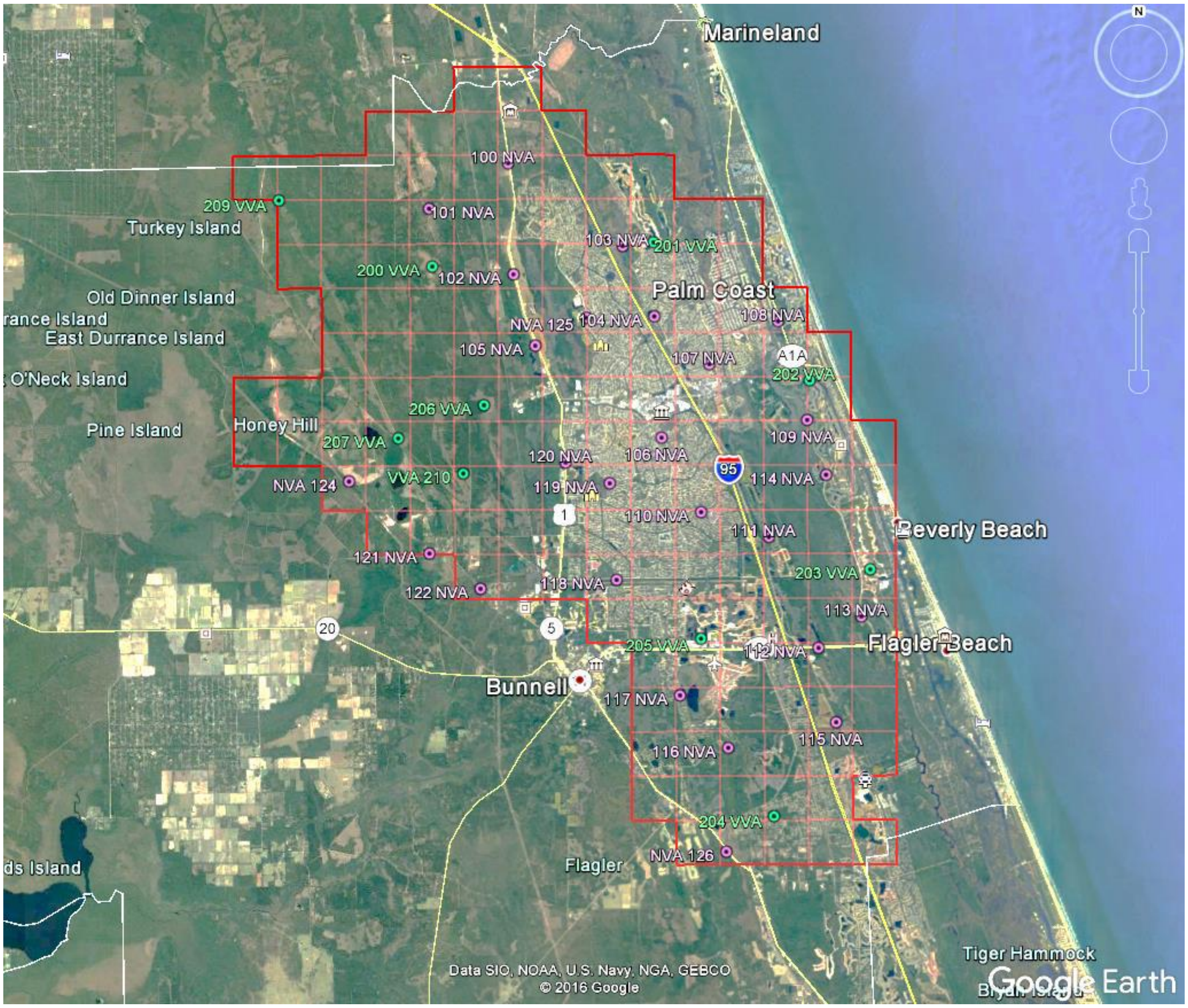


Figure 18 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points 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 ($RMSE_z$) of the checkpoints x 1.9600. For the City of Palm Coast lidar project, vertical accuracy must be 0.64 ft (19.6 cm) or less based on an $RMSE_z$ of 0.33 ft (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 City of Palm Coast lidar project VVA standard is 0.96 ft (29.4 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, $Accuracy_z$ differs from VVA because $Accuracy_z$ 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 7.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	0.64 ft (based on $RMSE_z$ (0.33 ft) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	0.96 ft (based on combined 95th percentile)

Table 7 — Acceptance Criteria

The primary QA/QC vertical 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.
2. Next, Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

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 files.

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=0.96 ft
NVA	26	0.27	
VVA	10		0.34

Table 8 — Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.14 ft (4.2) cm, equating to +/- 0.27 ft (8.2 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.34 ft (10.4 cm) at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to -0.46 ft.

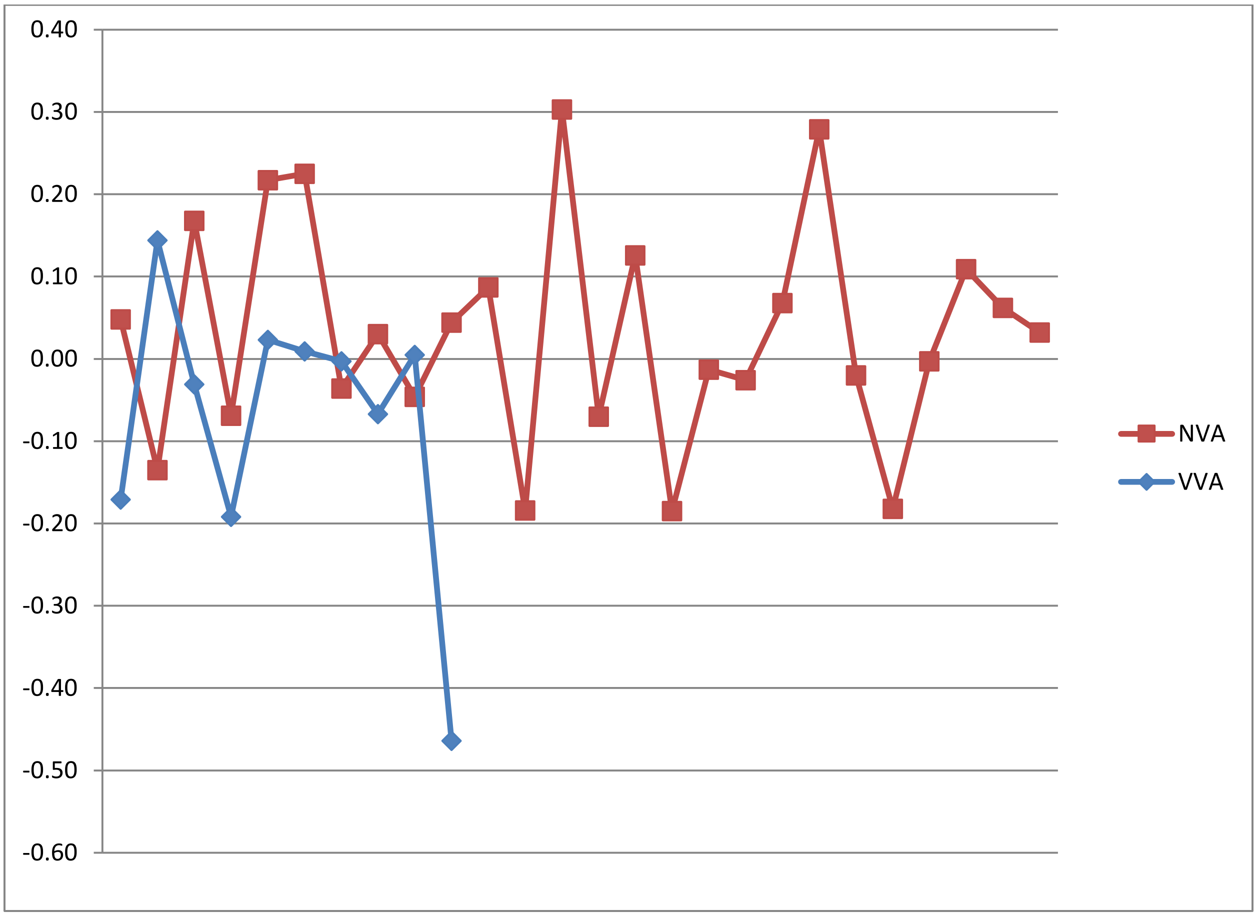


Figure 19 – Magnitude of elevation discrepancies per land cover category

Table 9 lists the 5% outliers that are larger than the VVA 95th percentile.

LiDAR 5% Outliers						
Point ID	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA-210	561092.90	1889176.32	31.84	31.38	-0.46	0.46

Table 9 — 5% Outliers

Table 10 provides overall descriptive statistics.

LiDAR 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	26.00	0.14	0.03	0.03	0.26	0.13	-0.34	-0.18	0.30
VVA	10.00	N/A	-0.07	-0.02	-1.44	0.17	2.80	-0.46	0.14

Table 10 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.46 ft and a high of +0.30 ft, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.25 ft to +0.25 ft.

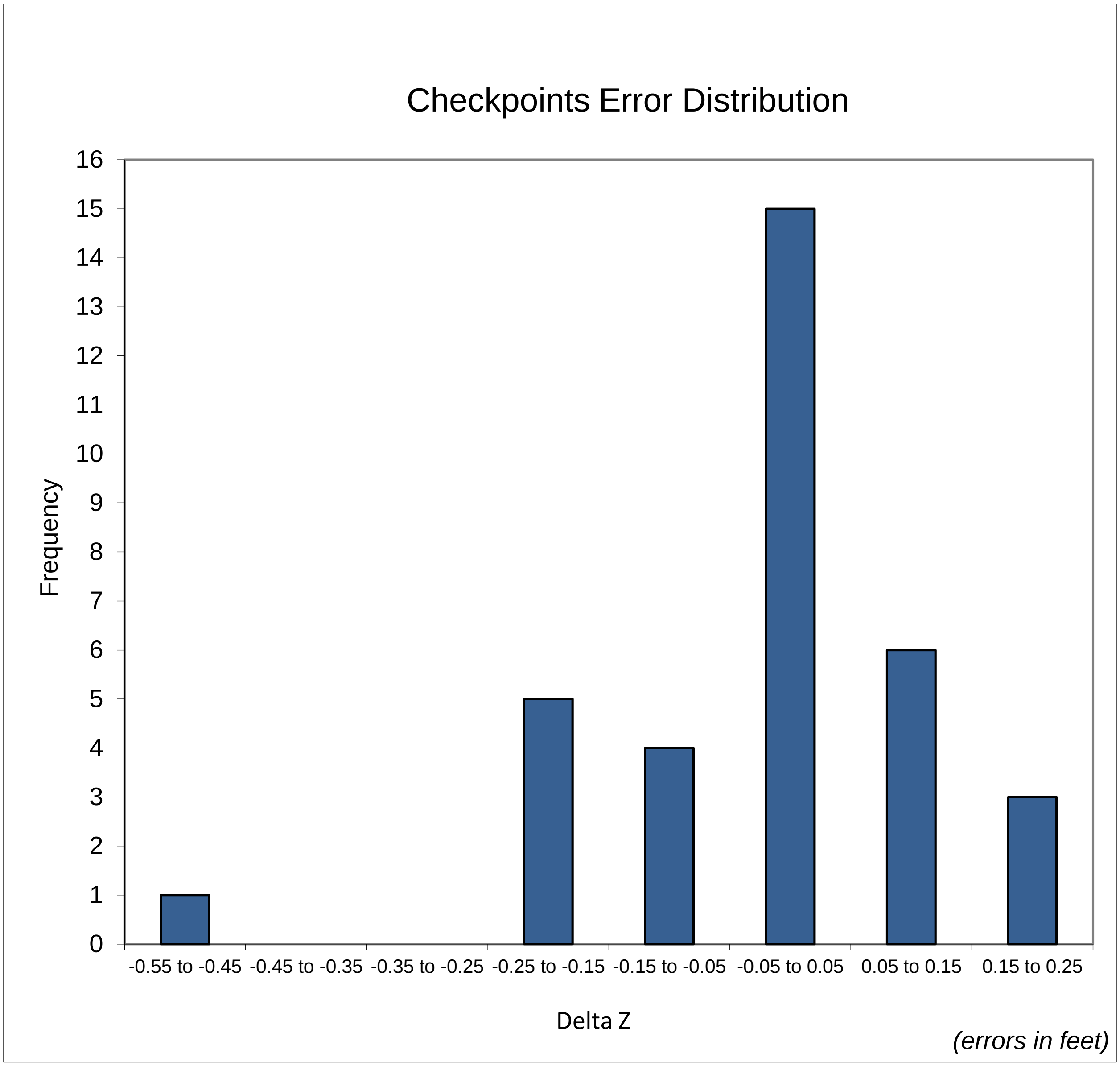


Figure 20 – Histogram of Elevation Discrepancies with errors in feet

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the City of Palm Coast Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

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 check points 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 check points.

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 are 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.

HORIZONTAL ACCURACY RESULTS

Four checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only four (4) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the Table below.

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.

# of Points	$RMSE_x$ (Spec=1.35 ft)	$RMSE_y$ (Spec=1.35 ft)	$RMSE_r$ (Spec=1.9 ft)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Spec=3.28 ft
4	0.67	0.80	1.05	1.81

Table 11-Tested horizontal accuracy at the 95% confidence level

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 1.35 ft (41 cm) RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 3.28 ft (1 meter) at a 95% confidence level. Four (4) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSEx = 0.67 ft (20.4 cm) and RMSEy = 0.80 ft (24.4 cm) which equates to +/- 1.81 ft (55.1 cm) at 95% confidence level. While not statistically significant, the results of the small sample set of checkpoints are within the produced to meet horizontal accuracy.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry produced full point cloud intensity imagery, bare earth ground models, density models, and slope models. These files were ingested into eCognition software, segmented into polygons, and training samples were created to identify water. eCognition used the training samples and defined parameters to identify water segments throughout the project area. Water segments were then reviewed for completeness. Segments identified as each type of required breakline type, i.e. lakes and ponds, streams and rivers, or tidal waters, were merged and smoothed. 3D elevations were then applied to the breakline features.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the lidar.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

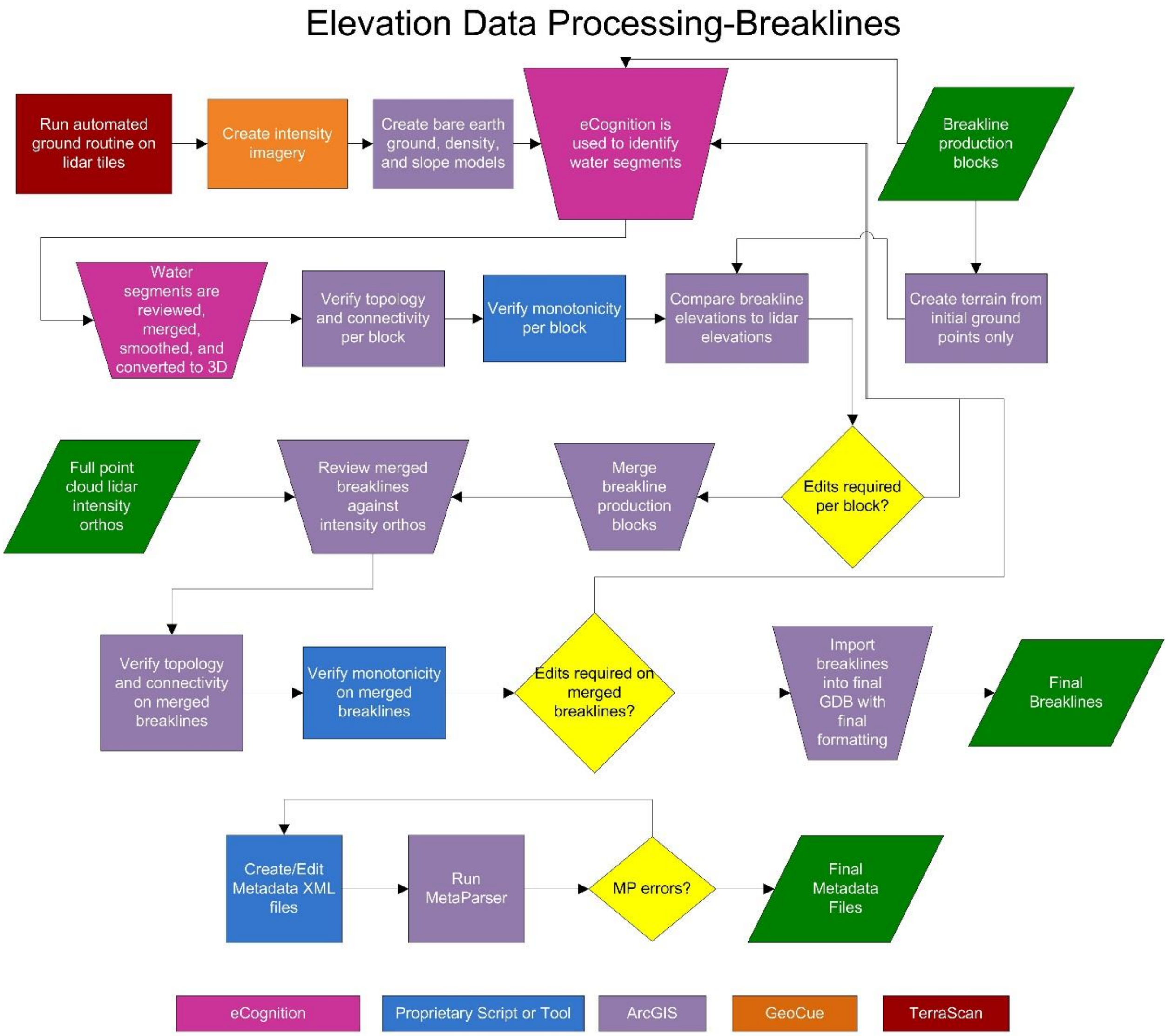


Figure 21-Breakline QA/QC workflow

BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).

Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 12-A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983 (2011), Units in U.S. Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in U.S. Survey Feet. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to NAD83 (2011) State Plane Florida East FIPS 0901, U.S. Survey Feet.

Inland Streams and Rivers

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: STREAMS_AND_RIVERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 50 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software

SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 50 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 50 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. “Donuts” will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a “donut polygon” compiled. These instructions are only for docks or piers that follow the coastline or water’s edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water’s edge beneath

		the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Tidal Waters

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: TIDAL_WATERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will outline the land / water interface at the time of lidar acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using lidar data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected data permits.	The feature shall be extracted at the apparent land/water interface, as determined by the lidar intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Beneath Bridge Breaklines

Feature Dataset: BREAKLINES
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Bridge_Breaklines
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Bridge Breaklines	Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs.	Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs. Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck. The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming.

Bridge Decks

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Bridges
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict bridge decks.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Bridges	Elevated bridge decks. Culverts should not be captured as part of this feature class.	Bridges should be collected to show the full extents of the elevated portion of the bridge deck only. As bridges represent elevated structures, the bridge polygon vertex elevations will not match ground lidar elevations but should be consistent with first return elevations for the bridge deck structures. All features other than the actual bridge deck, including guardrails, cars, vegetation, etc, should be excluded.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production, starting from the lidar swath processing.

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

Figure 22-DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The images below show an example of a bare earth DEM tile.

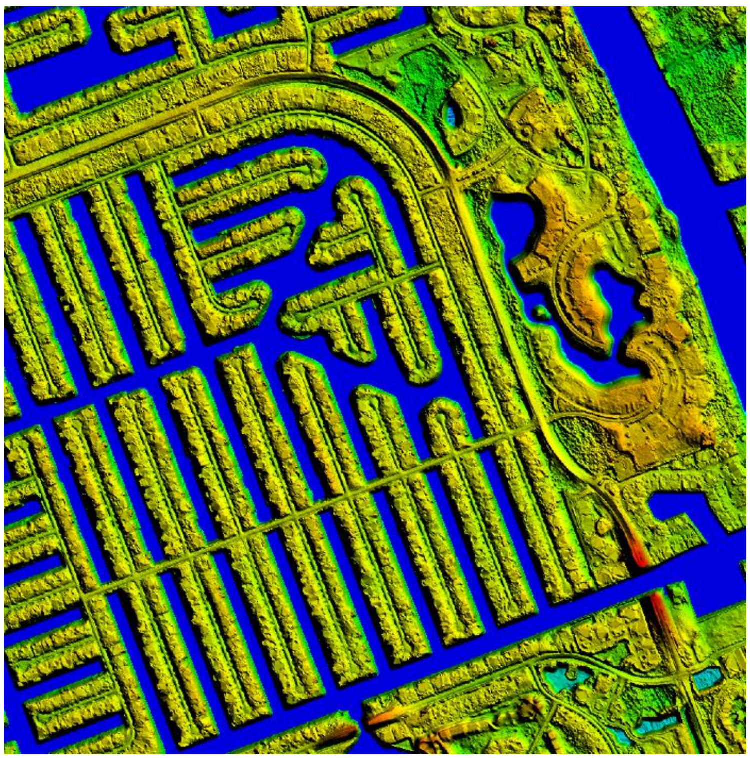


Figure 23-Tile 235585. The bare earth DEM.

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after bridge breaklines have been enforced.

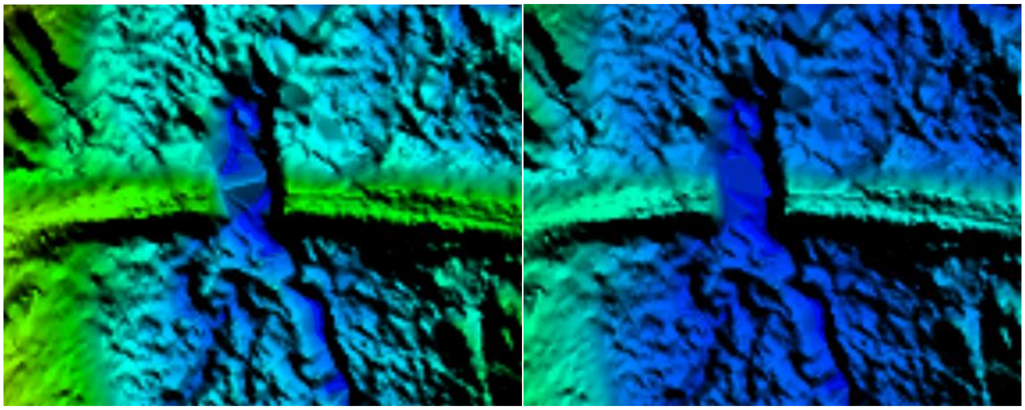


Figure 24-Tile 234079. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 36 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. 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.

Table 13 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

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=0.96 ft
NVA	26	0.28	
VVA	10		0.35

Table 13 – DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =0.14 ft (4.2 cm), equating to +/- 0.28 ft (8.5 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.35 ft (10.7 cm) at the 95th percentile.

Table 14 lists the 5% outliers that are larger than the VVA 95th percentile.

DEM 5% Outliers				
Point ID	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet	NAVD88 (Geoid 12B)	DeltaZ	AbsDeltaZ

	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA-210	561092.90	1889176.32	31.84	31.35	-0.49	0.49

Table 14 — 5% Outliers

Table 15 provides overall descriptive statistics.

DEM 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	26.00	0.14	0.04	0.04	0.41	0.14	-0.12	-0.19	0.35
VVA	10.00	N/A	-0.06	0.00	-1.83	0.17	3.99	-0.49	0.13

Table 15 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the City of Palm Coast Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Masspoints (LAS to multipoint) are created from ground points only (class 2 and class 8 if model key points created, but no class 10 ignored ground points or class 9 water points
Pass	Create a terrain for each production block using the final bare earth lidar points and final breaklines.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size
Pass	Create hillshades for all DEMs
Pass	Manually review bare-earth DEMs in ArcMap with hillshades to check for issues
Pass	DEMs should be hydro-flattened or hydro-enforced as required by project specifications
Pass	DEMs should be seamless across tile boundaries
Pass	Water should be flowing downhill without excessive water artifacts present
Pass	Water features should NOT be floating above surrounding
Pass	Bridges should NOT be present in bare-earth DEMs.
Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.
Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics

Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 16-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: GCP Survey Report

Ground Control Point Survey Report

SJRWMD

CITY OF PALM COAST LiDAR

Prepared for:

The City of Palm Coast

Prepared By:
Dewberry Engineers, Inc.
131 W. Kaley Street
Orlando, Florida, 32806
Phone (407) 843-5120

1. INTRODUCTION

1.1 *Project Summary*

Dewberry Consultants LLC is under contract to the Saint Johns River Water Management (SJRWMD) to provide 19 Ground Control Points in the City of Palm Coast, in the State of Florida. Dewberry is tasked to complete the quality assurance of LiDAR products. As part of this work, Dewberry staff will complete a Ground Control Point surveys that will be used to evaluate vertical and horizontal accuracy. The field work was conducted from April 10, 2017 – April 19, 2017.

Existing NGS Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in Section 2.4 of this Report.

As an internal QA/QC procedure and to verify that the Check Points meet the 95% confidence level approximately 50% of the points were re-observed and their corresponding coordinate differences are shown in Section 5 of this report.

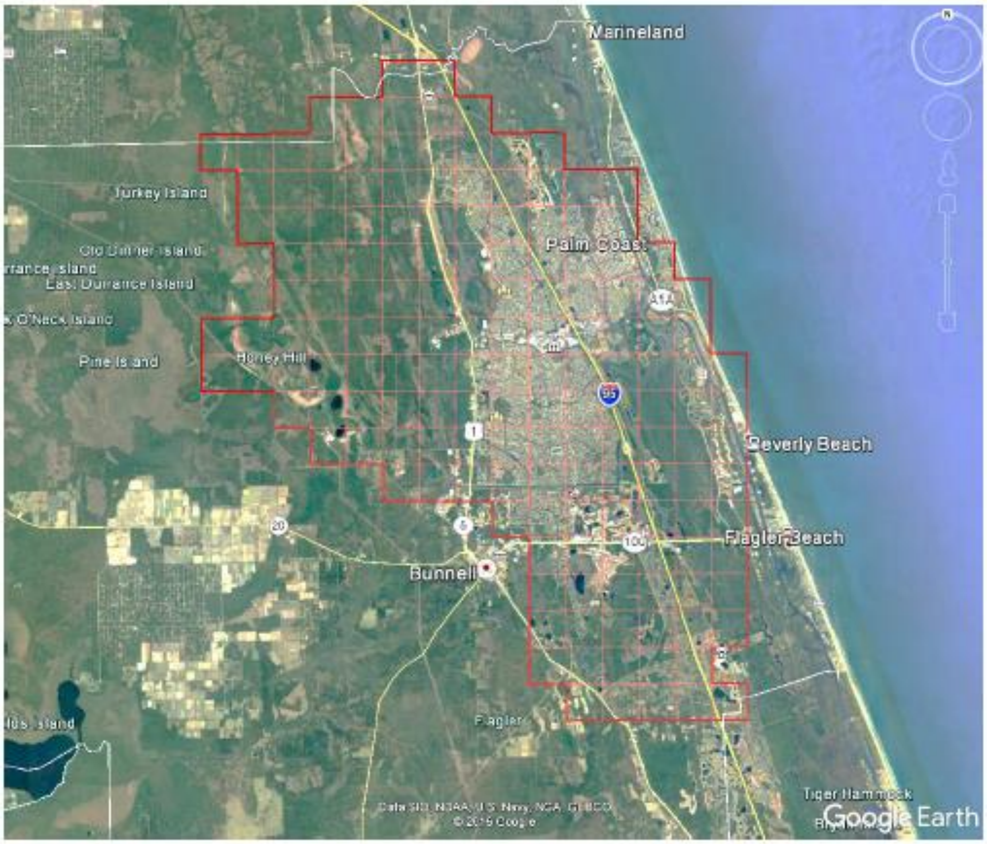
Final horizontal coordinates are referenced to Florida State Plane Coordinate System, East Zone, NAD83 (2011 Adjustment) in U.S. Survey feet. Final vertical elevations are referenced to NAVD88 in U.S. Survey feet using Geoid model 2012B (Geoid12B).

1.2 *Point of Contact*

Questions regarding the technical aspects of this report should be addressed to:

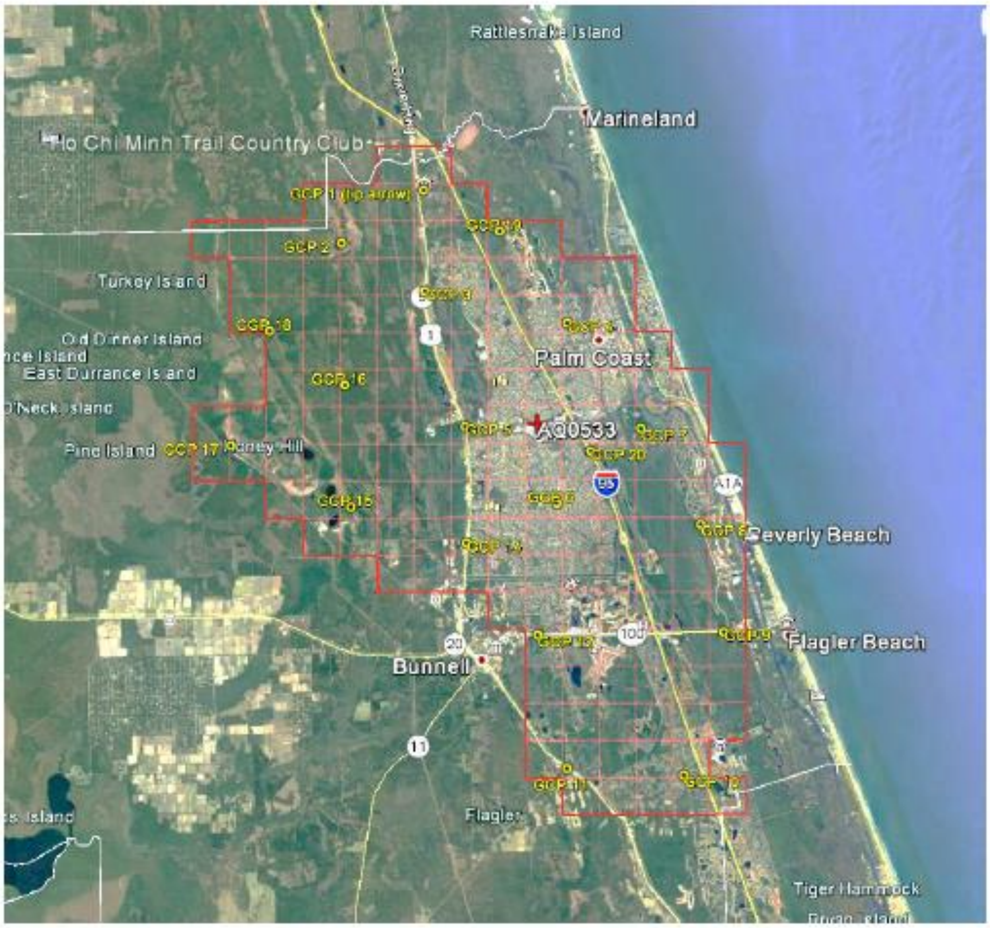
Dewberry Engineers, Inc.
William D. Donley, PSM
Associate Vice President
131 West Kaley Street
Orlando, Florida 32806
(321) 354-9834

1.3 *Project Area*



Overall Project Limits

1.3 *Project Area (continued)*



Ground Control Point Locations

2. PROJECT DETAILS

2.1 *Survey Equipment*

In performing the GPS observations, a Spectra Precision SP80 receiver/antenna and a Spectra Precision Epoch 50 receiver/antenna attached to a two meter fixed height pole with a Spectra Precision Ranger 3 Data Collector were used. These receivers are geodetic quality dual frequency GPS receivers and were used to collect data at each surveyed location.

2.2 *Survey Point Details*

The 20 Ground Control Points were well distributed throughout the project area.

A sketch was made for each location and a nail & disk or iron rod & cap were set at the point where possible or at an identifiable point. The Ground Control Point locations are detailed on the "Ground Control Point Documentation Report" sheets attached to this report.

2.3 *Network Design*

The GPS survey performed by Dewberry Engineers, Inc. office located in Orlando, FL was tied to VRS Now, a Real Time Network (RTN) managed by Trimble. The network is a series of "real-time" continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System.

2.4 *Field Survey Procedures and Analysis*

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately 1.5 minutes in duration and measured to 90 epochs.

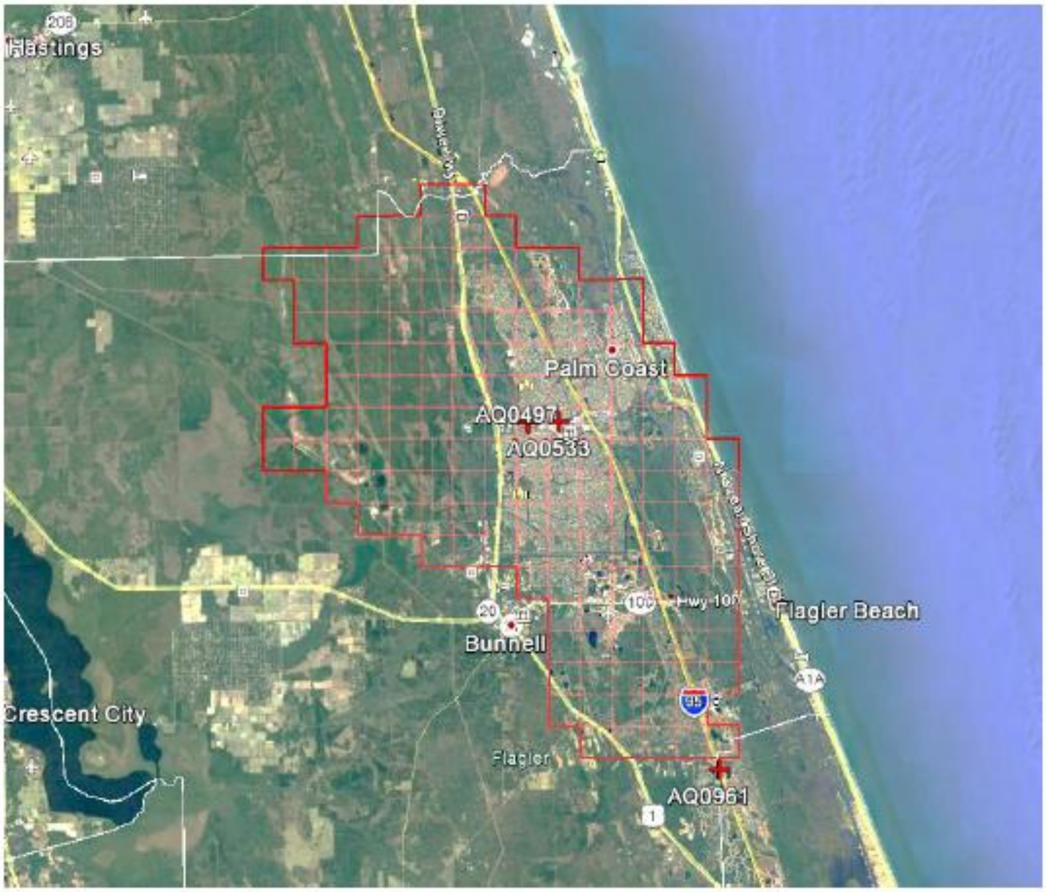
Field GPS observations are detailed on the "Check Point Documentation Reports" submitted as part of this report.

Three (3) existing NGS monuments listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network. An NGS monument was located at the beginning and end of observations each day to ensure measurement quality. The checks all individually conformed to the required accuracy and the average coordinates for the surveyed NGS monuments are shown below and compared to the published coordinates.

NGS PT. ID	Designation	As Surveyed (ft)			Published (ft)			Differences (ft)		
		Northing	Easting	Elevation	Northing	Easting	Elevation	Δ N	Δ E	Δ Elevation
AQ0497		1897586.94	576792.71	27.9	1897586.94	576792.71	27.90	0.00	0.00	0.00
AQ0533		1897660.01	581693.12	26.07	1897660.03	581693.05	26.10	0.02	0.09	0.03
AQ0961		1843124.46	606894.34	50.966	1843124.46	606894.33	51.06	0.00	0.01	0.09

The above results indicate that the VRS network is providing positional values within the ±5cm parameters for this survey.

2.4 *Field Survey Procedures and Analysis (continued)*



NGS Monuments

Legend:

- Horizontal + Vertical NGS Benchmark
- Horizontal NGS Benchmark
- Vertical NGS Benchmark

2.5 *Adjustment*

The survey data was collected using Virtual Reference Stations within the Trimble VRS Now Virtual Reference System. The system is designed to provide a true Network RTK performance, enabling high-accuracy positioning in real time across a geographic region. Trimble VRS Now uses real-time data streams from the system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. These corrections are applied to the points as they are being collected, negating the need for a post process adjustment.

2.6 *Data Processing Procedures*

After field data is collected the information is downloaded from the data collectors Spectra Precision – Survey Office. Downloaded data is run through the Survey Office program to obtain the following reports: points list, point derivations and a vector spreadsheet. The reports are reviewed for point accuracy and precision.

After review of the point data an "ASCII" or "txt" file, which is the industry standard is created. Point files are loaded into AutoCAD Civil 3D 2016 to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data is now imported into the final product.

3. *FINAL COORDINATES*

Palm Coast LiDAR Points			
POINT ID	NORTHING (SPC FL E)	EASTING (SPC FL E)	ELEV. (FT)
GCP			
GCP-1	1929224.12	566464.50	29.75
GCP-2	1922112.49	555321.80	33.79
GCP-3	1915614.19	566587.62	28.12
GCP-4	1911308.80	585894.84	10.29
GCP-5	1897393.65	571994.27	31.09
GCP-6	1887049.18	584412.71	29.37
GCP-7	1897047.62	595859.86	10.51
GCP-8	1884158.94	603932.36	17.15
GCP-9	1869635.34	607055.75	14.57
GCP-10	1850390.86	601556.03	24.85
GCP-11	1851312.02	585738.34	25.63
GCP-12	1869286.67	581812.27	28.55
GCP-14	1881715.34	572163.99	30.32
GCP-15	1886596.32	556513.13	36.91
GCP-16	1903007.05	555735.23	34.49
GCP-17	1894860.03	540244.51	45.68
GCP-18	1910290.86	545556.07	41.45
GCP-19	1923663.25	576775.12	29.25
GCP-20	1894041.21	589027.86	21.19

4. GPS OBSERVATIONS & RE-OBSERVATION SCHEDULE

POINT #	OBSERVE DATE	JULIAN DATE	TIME OF DAY	REOBSERVE DATE	REOBSERVE JULIAN DATE	REOBSERVE TIME
GCP						
GCP-1	4/13/2017	103	10:19	4/13/2017	103	13:36
GCP-2	4/12/2017	102	14:10	N/A	N/A	N/A
GCP-3	4/13/2017	103	11:01	4/13/2017	103	13:45
GCP-4	4/17/2017	107	14:15	4/18/2017	108	8:30
GCP-5	4/13/2017	103	12:45	N/A	N/A	N/A
GCP-6	4/19/2017	109	10:11	N/A	N/A	N/A
GCP-7	4/18/2017	108	9:46	4/19/2017	109	8:54
GCP-8	4/18/2017	108	11:14	4/19/2017	109	7:58
GCP-9	4/18/2017	108	11:00	N/A	N/A	N/A
GCP-10	4/17/2017	107	10:15	N/A	N/A	N/A
GCP-11	4/17/2017	107	9:00	4/18/2017	108	9:50
GCP-12	4/17/2017	107	12:46	N/A	N/A	N/A
GCP-14	4/17/2017	107	8:45	N/A	N/A	N/A
GCP-15	4/10/2017	100	13:55	N/A	N/A	N/A
GCP-16	4/12/2017	102	13:15	N/A	N/A	N/A
GCP-17	4/12/2017	102	11:15	N/A	N/A	N/A
GCP-18	4/10/2017	100	12:35	4/10/2017	100	17:10
GCP-19	4/17/2017	107	11:58	4/18/2017	108	7:51
GCP-20	4/18/2017	108	14:04	4/19/2017	109	9:04

5. *POINT COMPARISON REPORT*

LiDAR QA/QC				
POINT ID	CHECK POINT ID	Δ NORTH	Δ EAST	VERTICAL Δ
GCP				
GCP-1A	GCP-1B	0.03	0.05	0.15
GCP-3A	GCP-3B	0.02	0.03	0.06
GCP-4A	GCP-4B	0.02	0.05	0.03
GCP-7A	GCP-7B	0.02	0.01	0.00
GCP-8A	GCP-8B	0.02	0.02	0.08
GCP-11A	GCP-11B	0.01	0.00	0.08
GCP-18A	GCP-18B	0.01	0.03	0.05
GCP-19A	GCP-19B	0.00	0.07	0.15
GCP-20A	GCP-20B	0.02	0.06	0.08

6. *SURVEY NOTES*

1) Coordinates shown hereon are based on the Florida State Plane Coordinate System, East Zone, North American Datum of 1983 with 2011 adjustment.
2) Elevations shown hereon are based on the North American Vertical Datum of 1988.
3) The purpose of this survey was to survey points across the City of Palm Coast for the verification of LiDAR data.

7. *GLOSSARY*

CHK	Check
ELEV	Elevation
ft	feet
GPS	Global Positioning System
ID	Identification
LiDAR	Light Detection and Ranging
LS	Land Surveyor
NAD	North American Datum
NAVD	North American Verrtical Datum
NGS	National Geodetic Survey
NVA	Non-Vegetated Vertical Accuracy Ground Control Point
QA/QC	Quality Assurance/Quality Control
RTK	Real Time Kinematic
RTN	Real-Time Network
SPC	State Plane Coordinate
SJRWMD	Saint John's River Water Management District
VRS	Virtual Reference System

8. *SURVEYOR'S CERTIFICATION*

I hereby certify this survey report meets the applicable "Standards of Practice" as set forth by the Florida Board of Professional Surveyors and Mappers in rule 5J17.050-.052, Florida Administrative Code.

William D. Donley -- 04-26-2017
William D. Donley
Florida Licensed Surveyor & Mapper No. LS 5381

Date

This Survey is not valid without the signature and original raised seal of a Florida Licensed Surveyor and Mapper.

Appendix B: Checkpoint Survey Report

Check Point Survey Report

SJRWMD

CITY OF PALM COAST LiDAR

Prepared for:

The City of Palm Coast

Prepared By:
Dewberry Engineers, Inc.
131 W. Kaley Street
Orlando, Florida, 32806
Phone (407) 843-5120

1. INTRODUCTION

1.1 *Project Summary*

Dewberry Consultants LLC is under contract to the St. John's River Water Management District to provide 36 Check Points in the City of Palm Coast, in the County of Flagler, in the State of Florida. Dewberry is tasked to complete the quality assurance of LiDAR products. As part of this work, Dewberry staff will complete a Control Survey of Check Points that will be used to evaluate vertical and horizontal accuracy. The field work was conducted from April 10, 2017 – April 19, and May 16, 2017.

Existing NGS Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in Section 2.4 of this Report.

As an internal QA/QC procedure and to verify that the Check Points meet the 95% confidence level approximately 50% of the points were re-observed and their corresponding coordinate differences are shown in Section 5 of this report.

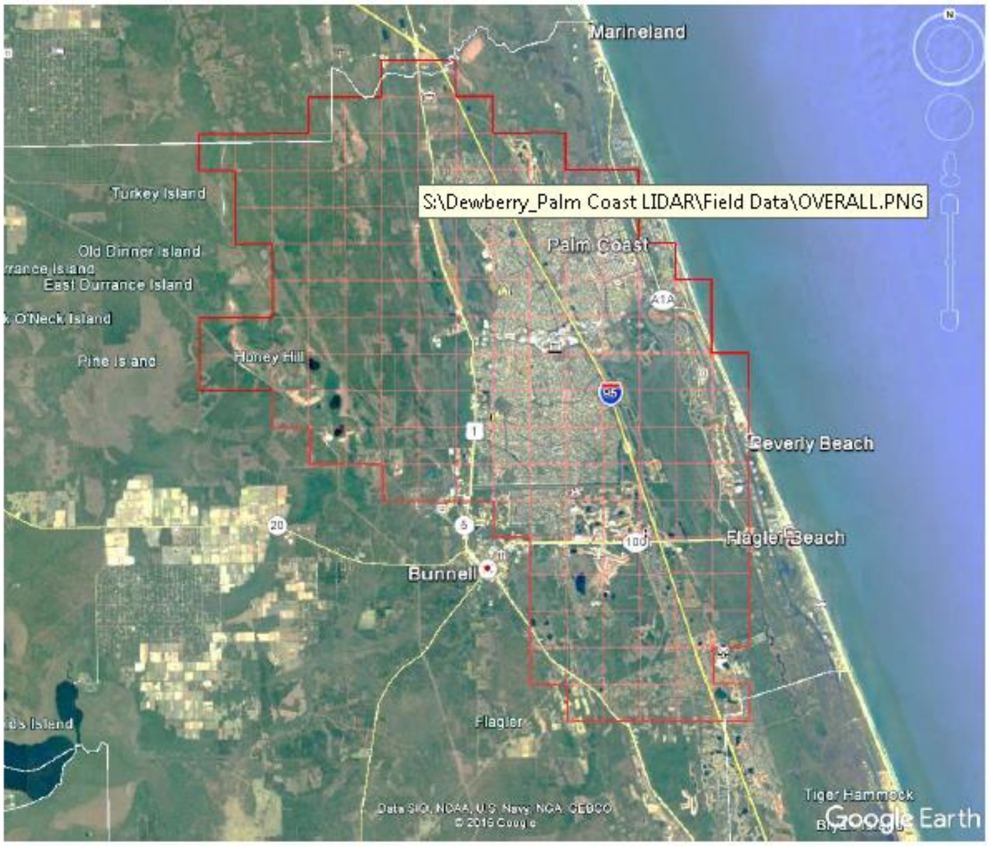
Final horizontal coordinates are referenced to Florida State Plane Coordinate System, East Zone, NAD83 (2011 Adjustment) in U.S. Survey feet. Final vertical elevations are referenced to NAVD88 in U.S. Survey feet using Geoid model 2012B (Geoid12B).

1.2 *Point of Contact*

Questions regarding the technical aspects of this report should be addressed to:

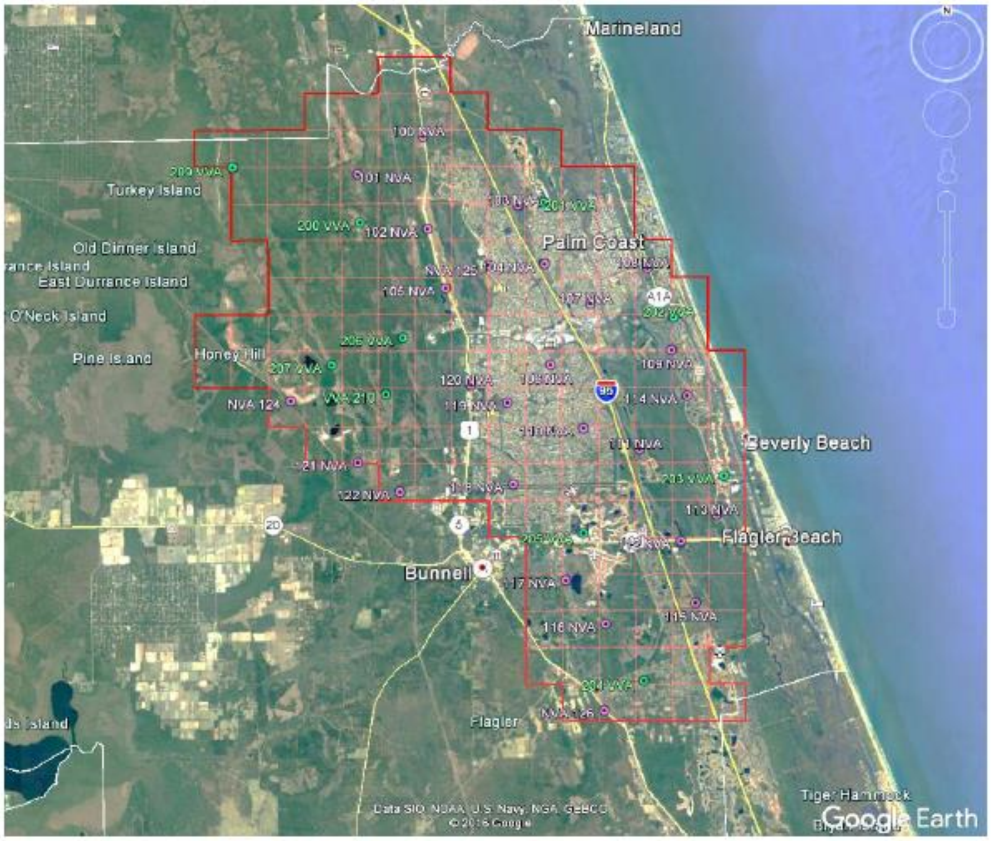
Dewberry Engineers, Inc.
William D. Donley, PSM
Associate Vice President
131 West Kaley Street
Orlando, Florida 32806
(321) 354-9834

1.3 *Project Area*



Overall Project Limits

1.3 Project Area (continued)



Check Point Locations

2. PROJECT DETAILS

2.1 *Survey Equipment*

In performing the GPS observations, a Spectra Precision SP80 receiver/antenna and a Spectra Precision Epoch 50 receiver/antenna attached to a two meter fixed height pole with a Spectra Precision Ranger 3 Data Collector were used. These receivers are geodetic quality dual frequency GPS receivers and were used to collect data at each surveyed location.

2.2 *Survey Point Details*

The 36 LiDAR Check Points were well distributed throughout the project area.

A sketch was made for each location and a nail & disk or iron rod & cap were set at the point where possible or at an identifiable point. The Check Point locations are detailed on the "Check Point Documentation Report" sheets attached to this report.

2.3 *Network Design*

The GPS survey performed by Dewberry Engineers, Inc. office located in Orlando, FL was tied to VRS Now, a Real Time Network (RTN) managed by Trimble. The network is a series of "real-time" continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System.

2.4 *Field Survey Procedures and Analysis*

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately 1.5 minutes in duration and measured to 90 epochs.

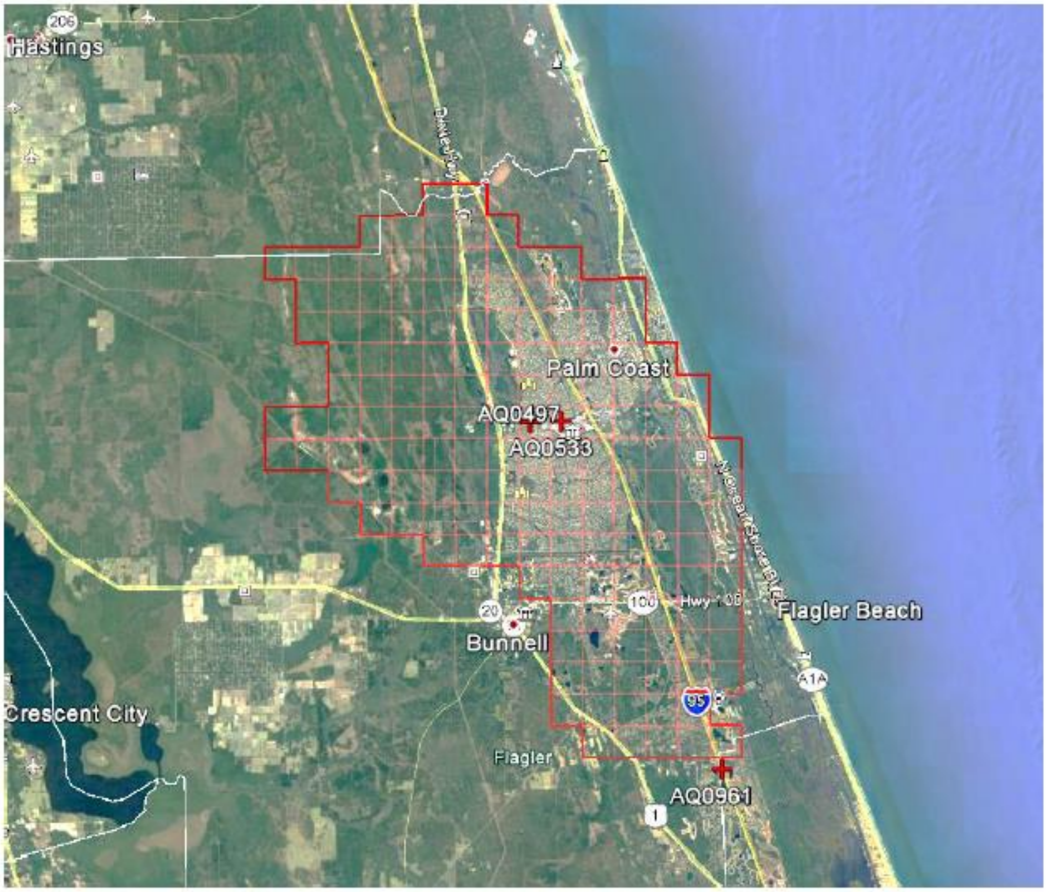
Field GPS observations are detailed on the "Check Point Documentation Reports" submitted as part of this report.

Three (3) existing NGS monuments listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network. An NGS monument was located at the beginning and end of observations each day to ensure measurement quality. The checks all individually conformed to the required accuracy and the average coordinates for the surveyed NGS monuments are shown below and compared to the published coordinates.

NGS PT. ID	Designation	As Surveyed (ft)			Published (ft)			Differences (ft)		
		Northing	Easting	Elevation	Northing	Easting	Elevation	Δ N	Δ E	Δ Elevation
AQ0497		1897586.94	576792.71	27.90	1897586.94	576792.71	27.90	0.00	0.00	0.00
AQ0533		1897660.01	581693.12	26.07	1897660.03	581693.05	26.10	0.02	0.09	0.03
AQ0961		1843124.46	606894.34	50.97	1843124.46	606894.33	51.06	0.00	0.01	0.09

The above results indicate that the VRS network is providing positional values within the ±5cm parameters for this survey.

2.4 *Field Survey Procedures and Analysis (continued)*



NGS Monuments

Legend:

Horizontal + Vertical NGS Benchmark
Horizontal NGS Benchmark
Vertical NGS Benchmark

2.5 *Adjustment*

The survey data was collected using Virtual Reference Stations within the Trimble VRS Now Virtual Reference System. The system is designed to provide a true Network RTK performance, enabling high-accuracy positioning in real time across a geographic region. Trimble VRS Now uses real-time data streams from the system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. These corrections are applied to the points as they are being collected, negating the need for a post process adjustment.

2.6 *Data Processing Procedures*

After field data is collected the information is downloaded from the data collectors Spectra Precision – Survey Office. Downloaded data is run through the Survey Office program to obtain the following reports: points list, point derivations and a vector spreadsheet. The reports are reviewed for point accuracy and precision.

After review of the point data an "ASCII" or "txt" file, which is the industry standard is created. Point files are loaded into AutoCAD Civil 3D 2016 to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data is now imported into the final product.

3. *FINAL COORDINATES*

Palm Coast LiDAR Points			
POINT ID	NORTHING (SPC FL E)	EASTING (SPC FL E)	ELEV. (FT)
NVA			
NVA-100	1924141.78	566272.59	27.22
NVA-101	1918986.51	557129.48	31.07
NVA-102	1911641.75	566843.79	38.58
NVA-103	1914720.48	579227.81	28.44
NVA-104	1906880.49	582773.79	23.09
NVA-105	1903584.76	569294.66	37.00
NVA-106	1893195.43	583556.85	25.69
NVA-107	1901461.43	588983.91	18.19
NVA-108	1906304.10	596807.20	13.93
NVA-109	1895157.95	600049.96	12.46
NVA-110	1884801.20	588006.37	24.13
NVA-111	1881985.84	595681.35	20.54
NVA-112	1869484.10	601263.03	23.06
NVA-113	1872993.67	606161.08	17.52
NVA-114	1888974.32	602194.35	18.88
NVA-115	1861071.75	603265.36	22.20
NVA-116	1858257.81	591002.17	24.53
NVA-117	1864180.27	585567.60	23.39
NVA-118	1877207.87	578413.27	31.86
NVA-119	1888076.98	577671.86	28.85
NVA-120	1890431.55	572684.17	32.71
NVA-121	1880220.38	557229.95	29.76
NVA-122	1876210.39	563054.95	27.19
NVA-124	1888345.97	548148.86	35.41
NVA-125	1906732.66	575074.71	30.34
NVA-126	1846545.29	590773.34	25.46

3. *FINAL COORDINATES (continued)*

Palm Coast LiDAR Points			
POINT ID	NORTHING (SPC FL E)	EASTING (SPC FL E)	ELEV. (FT)
VVA			
VVA-200	1912538.18	557623.15	32.25
VVA-201	1915131.07	582522.08	22.64
VVA-202	1899038.90	600045.39	16.36
VVA-203	1878248.82	607218.29	6.99
VVA-204	1850888.28	596154.62	28.81
VVA-205	1870782.39	587877.84	28.03
VVA-206	1896883.46	563522.96	29.44
VVA-207	1892821.15	553780.95	39.61
VVA-209	1920088.62	539987.55	41.79
VVA-210	1889176.32	561092.90	31.84

4. GPS OBSERVATIONS & RE-OBSERVATION SCHEDULE

POINT #	OBSERVE DATE	JULIAN DATE	TIME OF DAY	REOBSERVE DATE	REOBSERVE JULIAN DATE	REOBSERVE TIME
NVA						
NVA-100	4/13/2017	103	10:43	N/A	N/A	N/A
NVA-101	4/12/2017	102	13:52	N/A	N/A	N/A
NVA-102	4/13/2017	103	11:26	N/A	N/A	N/A
NVA-103	4/17/2017	107	12:33	4/18/2017	108	8:12
NVA-104	4/17/2017	107	14:35	4/18/2017	108	8:42
NVA-105	4/13/2017	103	11:48	N/A	N/A	N/A
NVA-106	4/19/2017	109	9:53	N/A	N/A	N/A
NVA-107	4/17/2017	107	15:05	4/18/2017	108	9:02
NVA-108	4/18/2017	108	9:22	N/A	N/A	N/A
NVA-109	4/18/2017	108	10:36	4/19/2017	109	8:38
NVA-110	4/19/2017	109	10:21	N/A	N/A	N/A
NVA-111	4/18/2017	108	13:38	N/A	N/A	N/A
NVA-112	4/17/2017	107	11:57	4/19/2017	109	13:29
NVA-113	4/18/2017	108	12:02	4/19/2017	109	7:40
NVA-114	4/18/2017	108	10:55	4/19/2017	109	8:10
NVA-115	4/17/2017	107	11:40	4/18/2017	108	11:20
NVA-116	4/17/2017	107	13:22	4/18/2017	108	10:00
NVA-117	4/17/2017	107	13:00	N/A	N/A	N/A
NVA-118	4/19/2017	109	11:33	N/A	N/A	N/A
NVA-119	4/19/2017	109	10:47	N/A	N/A	N/A
NVA-120	4/17/2017	107	8:22	N/A	N/A	N/A
NVA-121	4/10/2017	100	11:00	4/10/2017	100	15:00
NVA-122	4/10/2017	100	10:30	4/10/2017	100	14:33
NVA-124	4/12/2017	102	10:45	4/12/2017	102	15:35
NVA-125	4/18/2017	108	14:33	4/19/2017	109	9:24
NVA-126	4/17/2017	107	9:20	4/18/2017	108	9:15

4. *GPS OBSERVATIONS & RE-OBSERVATION SCHEDULE (continued)*

POINT #	OBSERVE DATE	JULIAN DATE	TIME OF DAY	REOBSERVE DATE	REOBSERVE JULIAN DATE	REOBSERVE TIME
VVA						
VVA-200	4/18/2017	108	13:10	N/A	N/A	N/A
VVA-201	5/14/2017	134	10:50	N/A	N/A	N/A
VVA-202	5/13/2017	133	10:20	5/14/2017	134	10:30
VVA-203	5/13/2017	133	9:45	N/A	N/A	N/A
VVA-204	5/13/2017	133	13:36	5/14/2017	134	9:29
VVA-205	5/13/2017	133	13:00	5/14/2017	134	9:48
VVA-206	4/14/2017	104	11:45	4/18/2017	108	12:45
VVA-207	4/10/2017	100	11:49	N/A	N/A	N/A
VVA-209	4/10/2017	100	13:05	4/14/2017	104	12:57
VVA-210	5/14/2017	134	13:00	N/A	N/A	N/A

5. *POINT COMPARISON REPORT*

LiDAR QA/QC				
POINT ID	CHECK POINT ID	Δ NORTH	Δ EAST	VERTICAL Δ
NVA				
NVA-103A	NVA-103B	0.07	0.03	0.16
NVA-104A	NVA-104B	0.07	0.09	0.11
NVA-107A	NVA-107B	0.08	0.01	0.15
NVA-109A	NVA-109B	0.04	0.08	0.10
NVA-112B	NVA-112C	0.01	0.05	0.14
NVA-113A	NVA-113B	0.00	0.02	0.09
NVA-114A	NVA-114B	0.00	0.03	0.06
NVA-115A	NVA-115B	0.03	0.00	0.14
NVA-116A	NVA-116B	0.03	0.05	0.13
NVA-121A	NVA-121B	0.03	0.04	0.15
NVA-122A	NVA-122B	0.10	0.06	0.06
NVA-124A	NVA-124B	0.14	0.03	0.01
NVA-125A	NVA-125B	0.07	0.02	0.08
NVA-126A	NVA-126B	0.03	0.00	0.12
VVA				
VVA-201A	VVA-201B	0.10	0.04	0.11
VVA-202A	VVA-202B	0.04	0.01	0.03
VVA-203A	VVA-203B	0.04	0.03	0.12
VVA-204A	VVA-204B	0.03	0.02	0.06
VVA-205A	VVA-205B	0.01	0.06	0.02
VVA-206A	VVA-206B	0.04	0.03	0.13

6. *SURVEY NOTES*

1) Coordinates shown hereon are based on the Florida State Plane Coordinate System, East Zone, North American Datum of 1983 with 2011 adjustment.
2) Elevations shown hereon are based on the North American Vertical Datum of 1988.
3) The purpose of this survey was to survey points across the City of Palm Coast for the verification of LiDAR data.

7. *GLOSSARY*

CHK	Check
ELEV	Elevation
ft	feet
GPS	Global Positioning System
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LiDAR	Light Detection and Ranging
LS	Land Surveyor
NAD	North American Datum
NAVD	North American Vertical Datum
NGS	National Geodetic Survey
NVA	Non-Vegetated Vertical Accuracy Ground Control Point
QA/QC	Quality Assurance/Quality Control
RTK	Real Time Kinematic
RTN	Real-Time Network
SPC	State Plane Coordinate
SJRWMD	Saint John's River Water Management District
VRS	Virtual Reference System

8. *SURVEYOR'S CERTIFICATION*

I hereby certify this survey report meets the applicable "Standards of Practice" as set forth by the Florida Board of Professional Surveyors and Mappers in rule 5J17.050-.052, Florida Administrative Code.

William D. Donley -- 05-24-2017

William D. Donley
Florida Licensed Surveyor & Mapper No. LS 5381

Date

This Survey is not valid without the signature and original raised seal of a Florida Licensed Surveyor and Mapper.

Appendix C: Complete List of Delivered Tiles

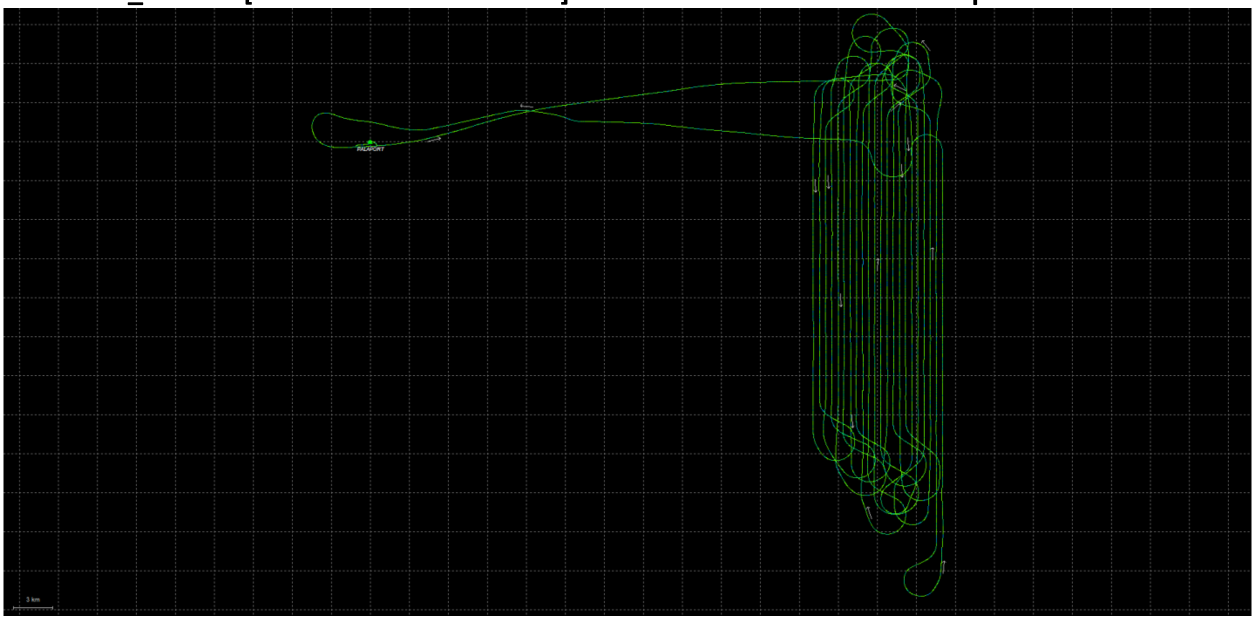
234975	235881	236486	237383	238588
234976	235882	236487	237384	237983
234977	235883	236488	237385	237984
234979	235884	236776	237386	237985
234980	235885	236777	237387	237986
234981	235886	236778	237388	237987
234982	235887	236779	237685	237988
234983	236174	236780	237686	238287
234984	236175	236781	237687	238288
234985	236176	236782	237688	234377
235275	236177	236783	239184	234378
235276	236178	236784	239185	234379
235277	236179	236785	239186	234380
235279	236180	236786	239187	234381
235280	236181	236787	237682	234674
235281	236182	236788	237683	234675
235282	236183	239188	237684	234676
235283	236184	237077	238883	234677
235284	236185	237078	238884	234678
235285	236186	237079	238885	234679
235576	236187	237080	238886	234680
235577	236474	237081	238887	234681
235579	236475	237082	234079	234682
235580	236476	237083	234080	234683
235581	236477	237084	238283	235879
235582	236478	237085	238284	235878
235583	236479	237086	238285	235578
235584	236480	237087	238286	234978
235585	236481	237088	238583	235278
235586	236482	237379	238584	
235876	236483	237380	238585	
235877	236484	237381	238586	
235880	236485	237382	238587	

Appendix D: GPS and IMU Processing Reports for Each Mission

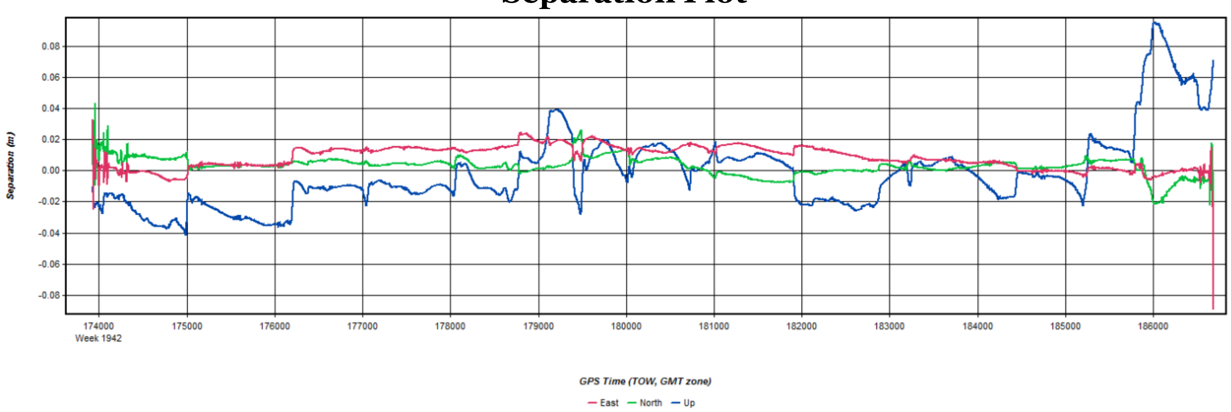
Program:	Inertial Explorer
Version:	8.60.6129

Mission 2017-03-28 A

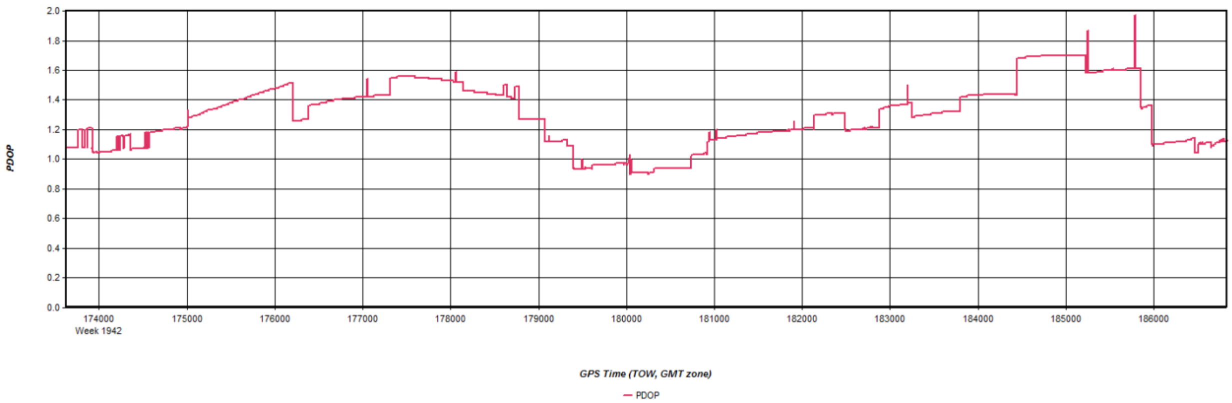
20170328_000907 [Smoothed TC Combined] - Smoothed TC Combined – Map



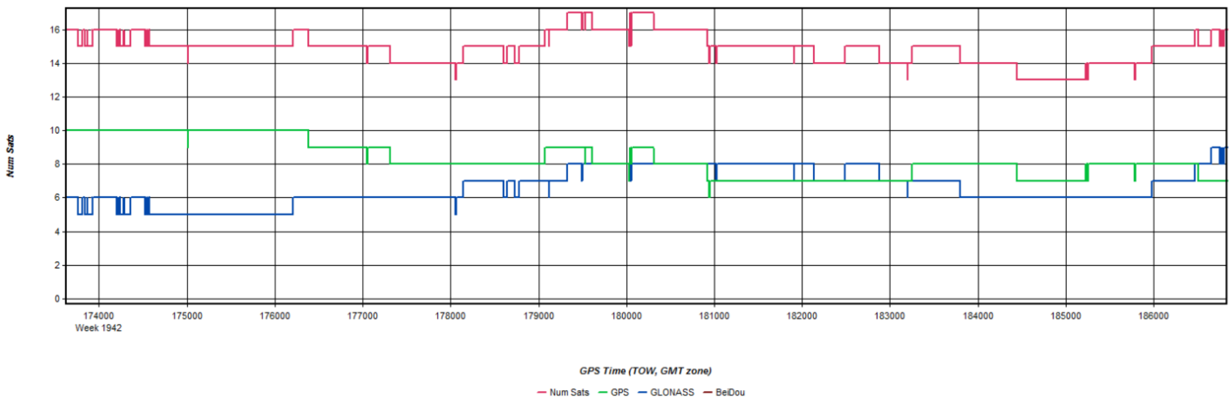
20170328_000907 [Smoothed TC Combined] - Forward/Reverse or Combined Separation Plot



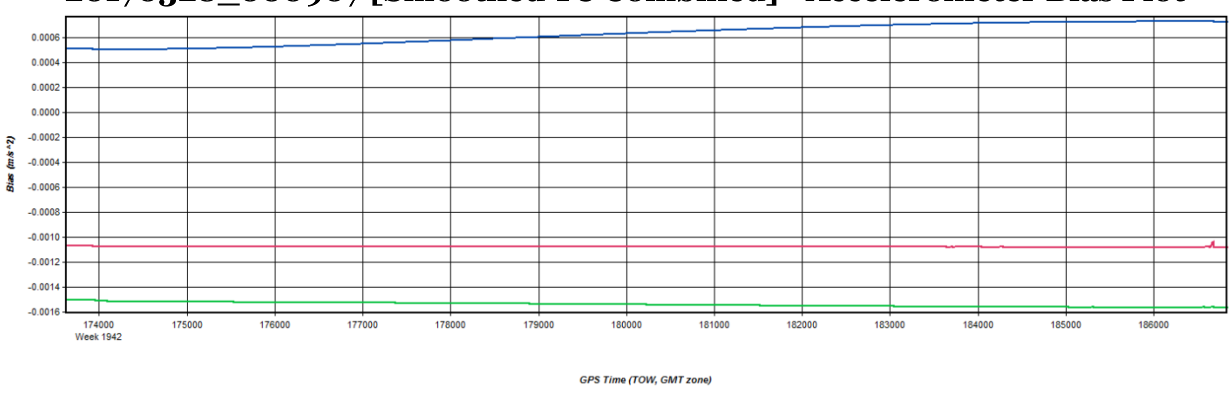
20170328_000907 [Smoothed TC Combined] - PDOP Plot



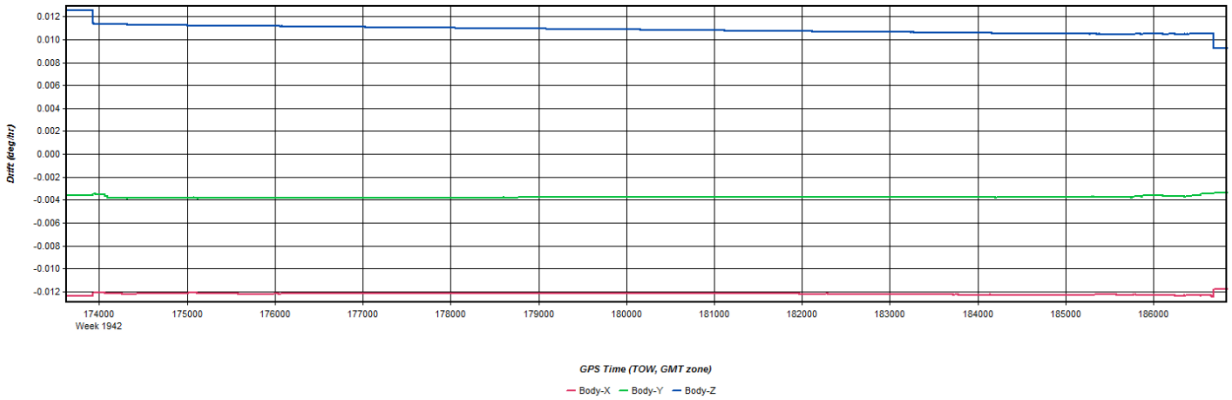
20170328_000907 [Smoothed TC Combined] - Number of Satellites Line Plot



20170328_000907 [Smoothed TC Combined] - Accelerometer Bias Plot



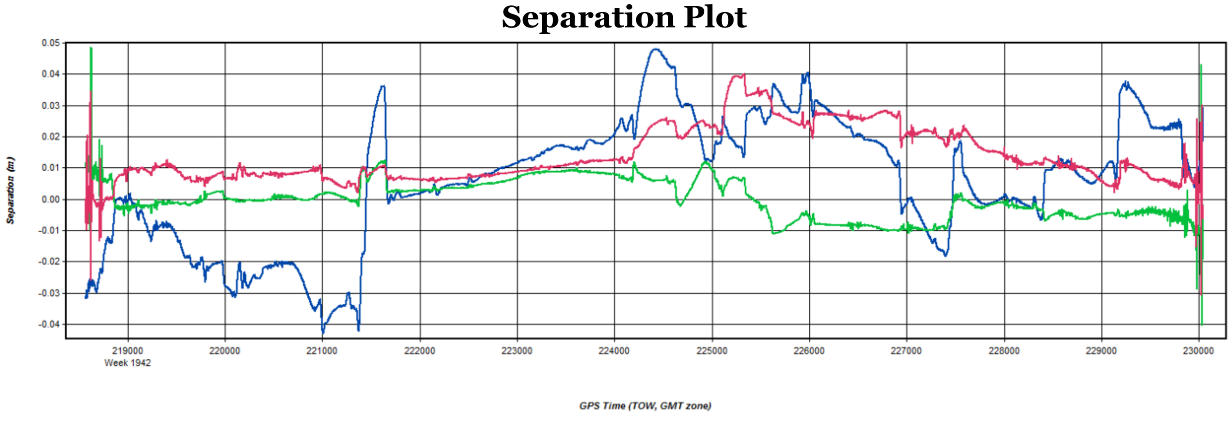
20170328_000907 [Smoothed TC Combined] - Gyro Drift Plot



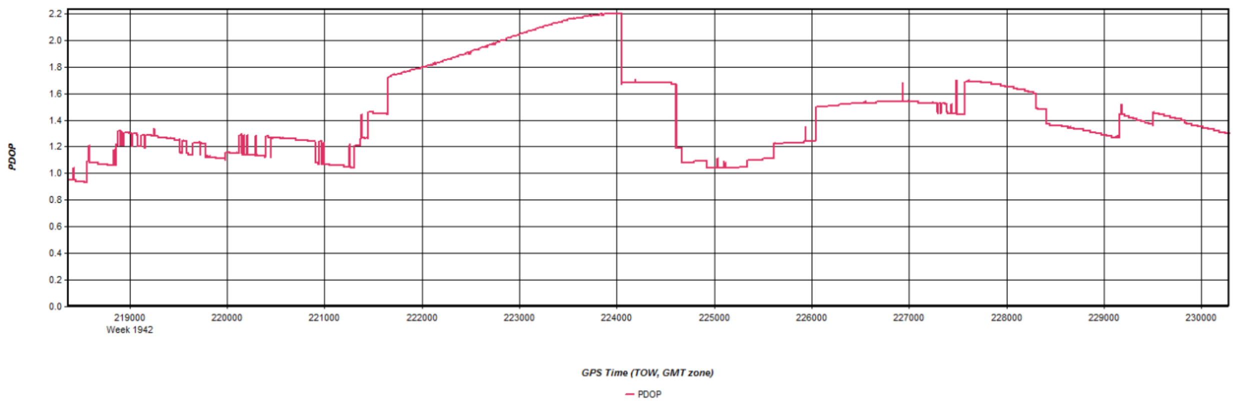
Mission 2017-03-28 B

20170328_123643 [Smoothed TC Combined] - Smoothed TC Combined – Map

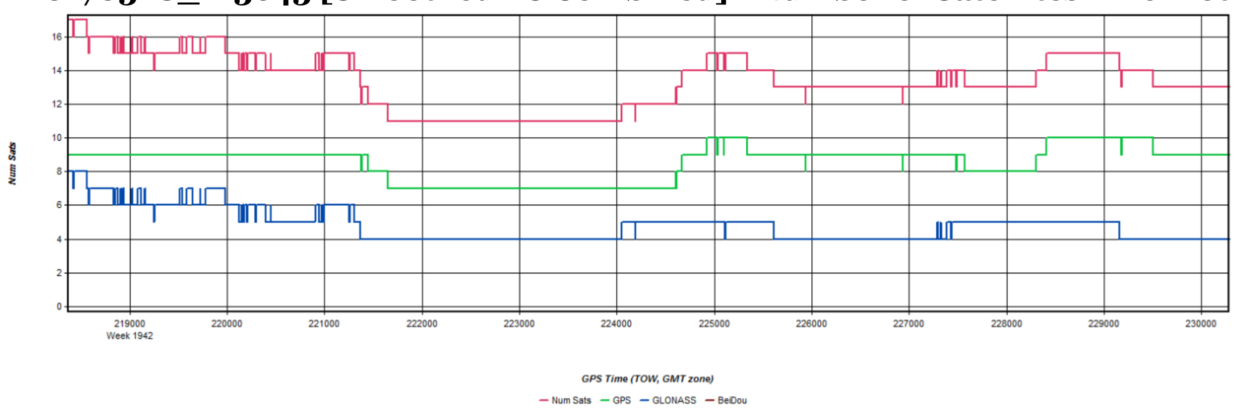
20170328_123643 [Smoothed TC Combined] - Forward/Reverse or Combined Separation Plot



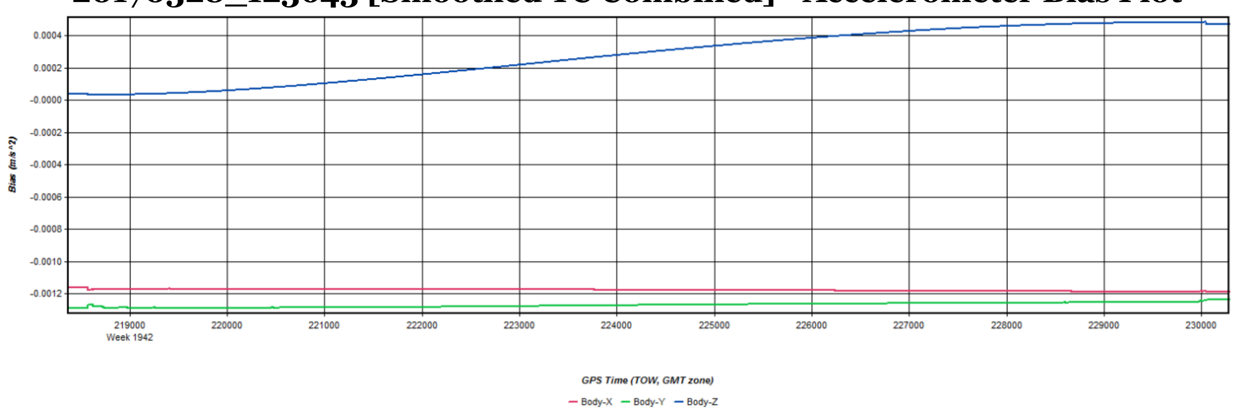
20170328_123643 [Smoothed TC Combined] - PDOP Plot



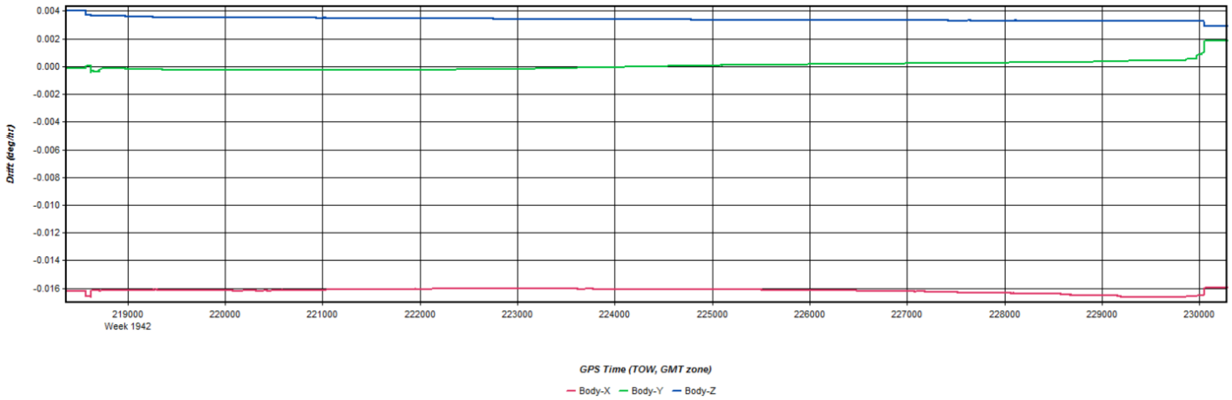
20170328_123643 [Smoothed TC Combined] - Number of Satellites Line Plot



20170328_123643 [Smoothed TC Combined] - Accelerometer Bias Plot



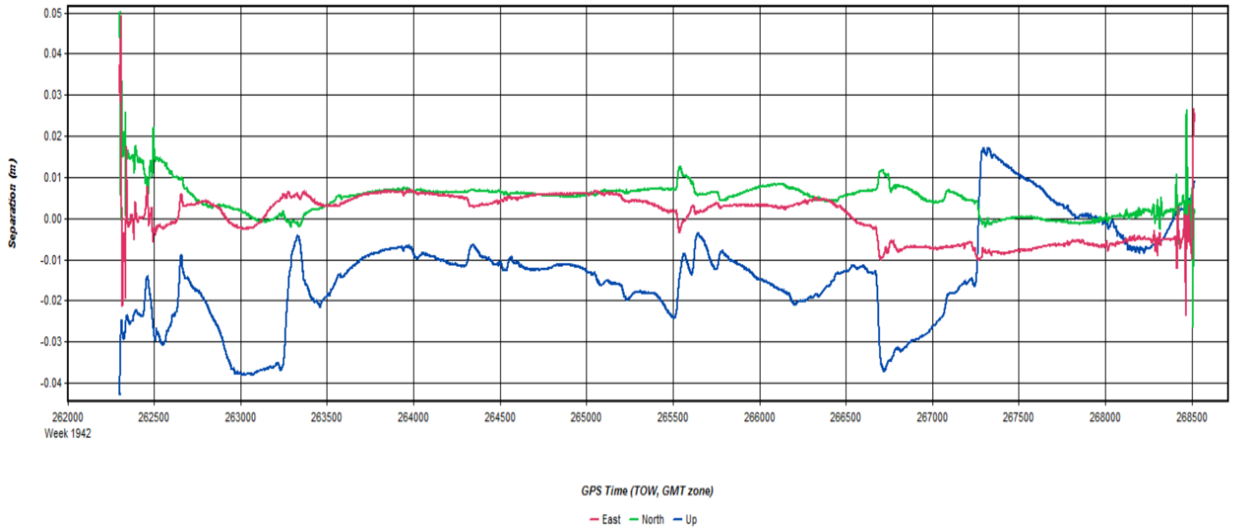
20170328_123643 [Smoothed TC Combined] - Gyro Drift Plot



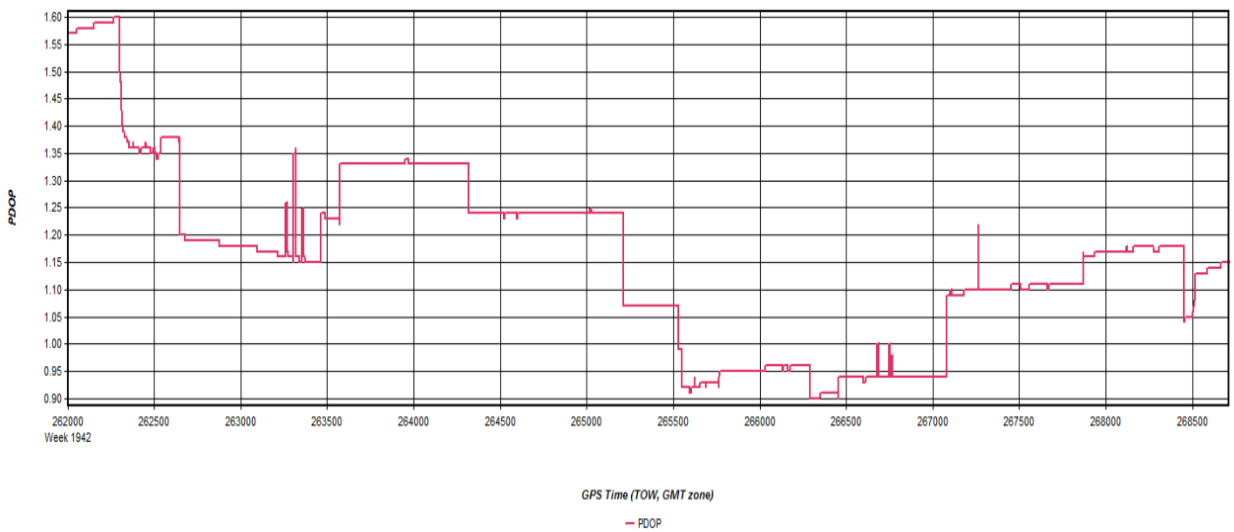
Mission 2017-03-29 A

20170329_004344 [Smoothed TC Combined] - Smoothed TC Combined – Map

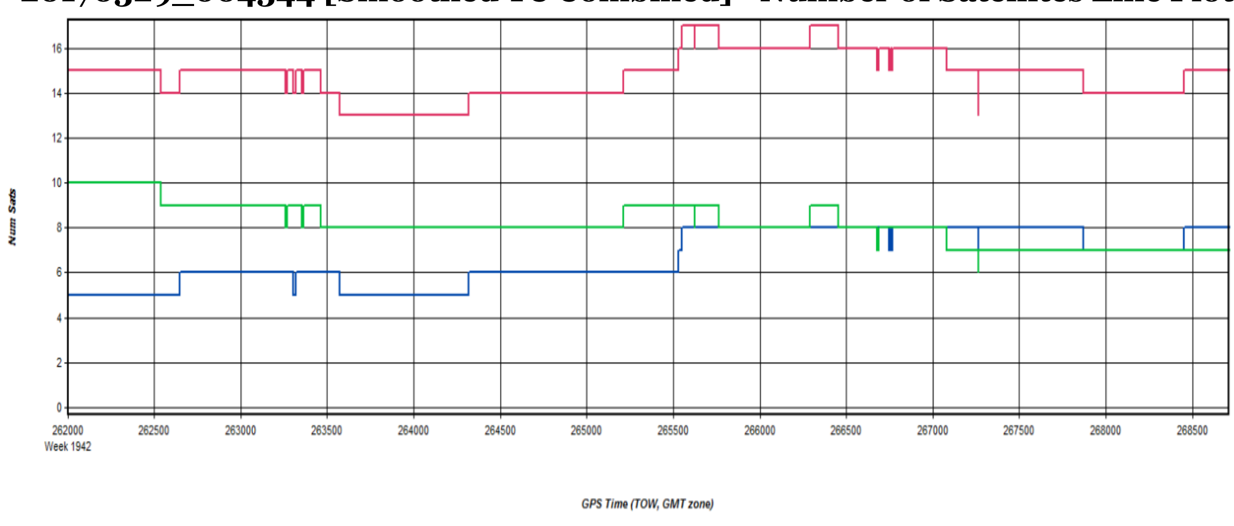
20170329_004344 [Smoothed TC Combined] - Forward/Reverse or Combined Separation Plot



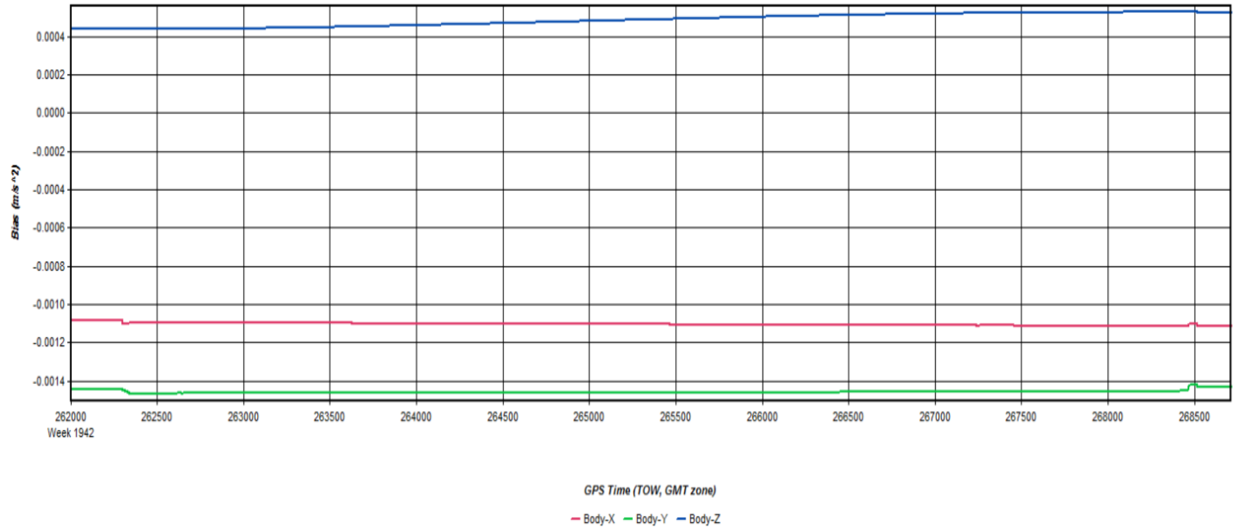
20170329_004344 [Smoothed TC Combined] - PDOP Plot



20170329_004344 [Smoothed TC Combined] - Number of Satellites Line Plot



20170329_004344 [Smoothed TC Combined] - Accelerometer Bias Plot



20170329_004344 [Smoothed TC Combined] - Gyro Drift Plot