FINAL REPORT OF SPECIFIC PURPOSE LIDAR SURVEY

LiDAR-Generated Breaklines and Contours for

Flagler County, Florida

State of Florida

Division of Emergency Management

Contract 07-HS-34-14-00-22-469

Task Order 200712004-49271

PDS Task Order D

November 18, 2008

Prepared by:

Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031-4666
for
Program & Data Solutions (PDS)
1625 Summit Lake Drive, Suite 200
Tallahassee, FL 32317

Final Report of Specific Purpose LiDAR Survey,

LiDAR-Generated Breaklines and Contours for Flagler County, Florida

Contract 07-HS-34-14-00-22-469; T.O. No. 200712004-49271, Task Order D

For:
State of Florida
Division of Emergency Management
2555 Shumard Oak Blvd.
Tallahassee, FL 32399

By:
Program & Data Solutions (PDS)
1625 Summit Lake Drive, Suite 200
Tallahassee, FL 32317

Prepared by:
David F. Maune, PhD, PSM, PS, GS, CP, CFM
Florida Professional Surveyor and Mapper No. LS6659
Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031

Table of Contents

Report of Specific Purpose LiDAR Survey, LiDAR-Generated Breaklines and Contours Flagler County, Florida

Type of Survey: Specific Purpose Survey

This report pertains to a Specific Purpose LiDAR Survey of Flagler County, Florida, conducted in the spring of 2004 by Merrick & Company. In 2008, the LiDAR data was processed into .LAS files and the breaklines and contours were generated for the Florida Division of Emergency Management (FDEM) using Merrick's existing LiDAR data from 2004.

The LiDAR .LAS data, breaklines and contours were prepared by the Program and Data Solutions (PDS) team under FDEM contract 07-HS-34-14-00-22-469, Task Order 200712004-49271 (PDS Task Order D) using Merrick's existing LiDAR dataset that remained unprocessed until 2008. The LiDAR dataset of Flagler County was not required to satisfy FDEM Baseline Specifications because the LiDAR data was acquired in 2004 and the Baseline Specifications were developed several years later. Nevertheless, the final LiDAR dataset as delivered to PDS by Merrick did satisfy the accuracy requirements in the FDEM Baseline Specifications as summarized in Table 1 below.

Table 1. Comparison of FDEM Baseline Specifications and Flagler County Accuracy Test Results

Vertical Accuracy Criteria	FDEM Specifications	Flagler County Accuracy Test Results
Fundamental Vertical Accuracy (FVA) at the 95% confidence level, in open terrain (non-vegetated) land cover only	0.60-ft (based on $RMSE_z$ of 030-ft x 1.9600)	0.59-ft (based on $RMSE_z$ of 030-ft x 1.9600)
Consolidated Vertical Accuracy (CVA) at the 95% confidence level, in all land cover categories combined	1.19-ft (based on 95th percentile or $RMSE_z$ of 0.60-ft x 1.9600)	0.88-ft (based on 95th percentile) or 0.87-ft (based on $RMSE_z$ of 0.44-ft x 1.9600)

Under Task Order D, this is one of four similar reports prepared by the PDS team of coastal counties of northeast Florida from Nassau County through Brevard County, considered by FDEM to be vulnerable to hurricane tidal surges. Of these four reports, only Flagler County is based on LiDAR data previously acquired. LiDAR data for Nassau, Clay/Putnam, and Brevard counties was acquired in 2007-2008 based on the FDEM baseline specifications. The LiDAR .LAS data, breaklines and contours for all counties, including Flagler County, were all produced to the FDEM Baseline Specifications. Other northeastern counties, including Duval and Volusia, were mapped by other contracts.

The map at Appendix A displays the 164 tiles of Flagler County for which LiDAR .LAS data as well as LiDAR-derived breaklines and contours were produced by the PDS team under Task Order D.

For Nassau, Clay/Putnam, and Brevard counties, the FDEM Baseline Specifications require a maximum post spacing of 4 feet, i.e., an average point density of less than 1 point per square meter. However, the PDS team required a much higher point density of its subcontractors in order to increase the probability of penetrating dense foliage; with nominal post spacing of 0.7 meters per flight line and 50% sidelap between flight lines, the average point density is 4 points per square meter. These point densities were not required in 2004 when Merrick acquired the LiDAR data for Flagler County. With higher point density there is a greater probability of penetrating dense vegetation and minimizing areas defined as "low confidence areas."

The PDS Team

PDS is a Joint Venture consisting of PBS&J, Dewberry, and URS Corp:

- PBS&J provided local client liaison in Tallahassee. PBS&J was also responsible for the overall ground survey of QA/QC checkpoints. Mr. Glenn Bryan, PSM, was PBS&J's technical lead for all ground surveys.

- Dewberry was responsible for the overall Work Plan and aerial survey effort for the new counties, including management of LiDAR subcontractors that performed the LiDAR data acquisition and post-processing and produced LAS classified data, breaklines and contours. A separate staff of QA/QC specialists at Dewberry's Fairfax (VA) office performed quality assessments of the Flagler County breaklines and contours. Dewberry served as the single point of contact with FDEM. Dr. David Maune, PSM, was Dewberry's technical lead for the LiDAR surveys and derived products.

- URS Corp. was responsible for data management and information management. URS developed the GeoCue Distributed Production Management System (DPMS), managed and tracked the flow of data, performed independent accuracy testing and quality assessments of the LiDAR data, tracked and reported the status of individual tiles during production, and produced all final deliverables for FDEM. Mr. Robert Ryan, CP, of URS, was the technical lead for this effort.

Name of Company in Responsible Charge

Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031-4666

Name of Responsible Surveyor

David F. Maune, PhD, PSM, PS, GS, CP, CFM
Florida Professional Surveyor and Mapper (PSM) No. LS6659

Survey Area

The project area for this report encompasses approximately 147 square miles within Flagler County.

Map Reference

There are no hardcopy map sheets for this project. The map at Appendix A provides graphical reference to the 5000-ft x 5000-ft tiles covered by this report.

Summary of FDEM Baseline Specifications

All new data produced for FDEM under the referenced contract are required to satisfy the Florida Baseline Specifications, included as appendices to PDS's Task Order D, dated December 04, 2007, from FDEM.

The official State Plane Coordinate System tiling scheme was provided by FDEM to the PDS team on August 8, 2007 for Florida's East Zone. The Flagler County tiling footprint graphic is shown at Appendix A.

Primary deliverables for Flagler County include .LAS-classified LiDAR mass points, breaklines, contours, metadata, and a LiDAR Vertical Accuracy Report certified by a Florida Professional Surveyor and Mapper (PSM).

Table 2 summarizes the LiDAR LAS classes specified by the FDEM Baseline Specifications.

Table 2. FDEM LAS Classes

Class 1 – Unclassified, including vegetation, buildings, bridges, piers
Class 2 – Ground points (used for contours)
Class 7 – Noise
Class 9 – Water
Class 12 – Overlap points deliberately removed

The LiDAR Vertical Accuracy Assessment Report of Flagler County is at Appendix F. The LiDAR Qualitative Assessment Report of Flagler County is at Appendix G. The LiDAR dataset for Flagler County passed the FDEM Baseline Specifications.

A second major deliverable consists of nine types of breaklines, produced in accordance with the PDS team's Data Dictionary at Appendix C:

1. Coastal shoreline features
2. Single-line hydrographic features
3. Dual-line hydrographic features
4. Closed water body features
5. Road edge-of-pavement features
6. Bridge and overpass features
7. Soft breakline features
8. Island features
9. Low confidence areas

Another major deliverable includes both one-foot and two-foot contours, produced from the mass points and breaklines, certified to meet or exceed NSSDA standards for one-foot contours. Two-foot contours within obscured vegetated areas are not required to meet NSSDA standards. These contours were also produced in accordance with the PDS team's Data Dictionary at Appendix C.

Table 3 is included below for ease in understanding the accuracy requirements when comparing the traditional National Map Accuracy Standard (NMAS) and the newer National Standard for Spatial Data Accuracy (NSSDA). This table is extracted from Table 13.2 of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published in January, 2007 by ASPRS. The traditional

NMAS uses Vertical Map Accuracy Standard (VMAS) to define vertical accuracy at the 90% confidence level, whereas the NSSDA uses Accuracy_z to define vertical accuracy at the 95% confidence level. Both the VMAS and Accuracy_z are computed with different multipliers for the very same RMSE_z value which represents vertical accuracy at the 68% confidence level for each equivalent contour interval specified. The term Accuracy_z (vertical accuracy at the 95% confidence level) is comparable to the terms described below as Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) which also define vertical accuracy at the 95% confidence level. In open (non-vegetated) terrain, Accuracy_z is exactly the same as FVA (both computed as RMSE_z x 1.9600) because there is no logical justification for elevation errors to depart from a normal error distribution. In vegetated areas, vertical accuracy at the 95% confidence level (Accuracy_z) can also be computed as RMSE_z x 1.9600; however, because vertical errors do not always have a normal error distribution in vegetated terrain, alternative guidelines from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) allow the 95^{th} percentile method to be used (as with the CVA and SVA) to report the vertical accuracy at the 95% confidence level in land cover categories other than open terrain.

Table 3. Comparison of NMAS/NSSDA Vertical Accuracy

NMAS Equivalent Contour Interval	**NMAS** VMAS (90 percent confidence level)	**NSSDA** RMSE_z (68 percent confidence level)	**NSSDA** $\text{Accuracy}_{z,}$ (95 percent confidence level)
1 ft	0.5 ft	0.30 ft	0.60 ft
2 ft	1.0 ft	0.61 ft	1.19 ft

The next major deliverable includes metadata compliant with the Federal Geographic Data Committee's (FGDC) Content Standard for Spatial Metadata in an ArcCatalog-compatible XML format. Copies of all survey reports, including this Report of Specific Purpose LiDAR Survey, must be delivered in PDF format as attachments to the metadata.

The last major deliverable includes the Vertical Accuracy Report of Flagler County, based on independent comparison of the LiDAR data with the QA/QC checkpoints, surveyed and tested in accordance with guidelines of the National Standard for Spatial Data Accuracy (NSSDA), American Society for Photogrammetry and Remote Sensing (ASPRS), Federal Emergency Management Agency (FEMA), and National Digital Elevation Program (NDEP), and using the QA/QC checkpoints surveyed by Dewberry and listed at Appendix E.

Datums and Coordinates: North American Datum of 1983 (NAD 83)/HARN for horizontal coordinates and North American Vertical Datum of 1988 (NAVD 88) for vertical coordinates. All coordinates are Florida State Plane Coordinate System (SPCS) in U.S. Survey Feet. All northeast Florida counties listed are in the Florida SPCS East Zone.

Appendix I to this report provides the Geodatabase structure for all digital vector deliverables in Flagler County.

Acronyms and Definitions

Accuracy_r	Horizontal (radial) accuracy at the 95% confidence level, defined by the NSSDA
Accuracy_z	Vertical accuracy at the 95% confidence level, defined by the NSSDA
ASFPM	Association of State Floodplain Managers
ASPRS	American Society for Photogrammetry and Remote Sensing
CFM	Certified Floodplain Manager (ASFPM)
CMAS	Circular Map Accuracy Standard, defined by the NMAS
CP	Certified Photogrammetrist (ASPRS)
CVA	Consolidated Vertical Accuracy, defined by the NDEP and ASPRS
DEM	Digital Elevation Model (gridded DTM)
DTM	Digital Terrain Model (mass points and breaklines to map the bare earth terrain)
DSM	Digital Surface Model (top reflective surface, includes treetops and rooftops)
FDEM	Florida Division of Emergency Management
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FOV	Field of View
FVA	Fundamental Vertical Accuracy, defined by the NDEP and ASPRS
GS	Geodetic Surveyor
GIS	Geographic Information System Surveyor
LAS	LiDAR data format as defined by ASPRS
LiDAR	Light Detection and Ranging
LMSI	Laser Mapping Specialists Inc.
MHHW	Mean Higher High Water
MHW	Mean High Water, defines official shoreline in Florida
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NDEP	National Digital Elevation Program
NMAS	National Map Accuracy Standard
NOAA	National Oceanic and Atmospheric Administration
NSSDA	National Standard for Spatial Data Accuracy
NSRS	National Spatial Reference System
NWFWMD	Northwest Florida Water Management District
PDS	Program & Data Solutions, joint venture between PBS&J, Dewberry and URS Corp
PS	Photogrammetric Surveyor
PSM	Professional Surveyor and Mapper (Florida)
QA/QC	Quality Assurance/Quality Control
RMSE_h	Vertical Root Mean Square Error (RMSE) of ellipsoid heights
RMSE_r	Horizontal (radial) Root Mean Square Error (RMSE) computed from RMSE_x and RMSE_y
RMSE_z	Vertical Root Mean Square Error (RMSE) of orthometric heights
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SRWMD	Suwannee River Water Management District
SVA	Supplemental Vertical Accuracy, defined by the NDEP and ASPRS
TIN	Triangulated Irregular Network
VMAS	Vertical Map Accuracy Standard, defined by the NMAS

Ground Control

The ground control and checkpoints used by Merrick & Company are described in Appendix D. Three ground Airborne GPS base stations, for the LiDAR data collection, were set up every mission to include: (1) the Daytona Beach Regional Airport, (2) Deland Airport, and (3) Flagler Airport. Also, the Ormond CORS Station was used as a check base station. The airborne GPS base stations were tied directly to each other by post-processing using Trimble Geomatics Office Software, version 1.62. Additionally, Jones Edmunds & Associates surveyed 48 newly established GPS ground control points as internal LiDAR QA/QC checkpoints used by Merrick.

LiDAR Aerial Survey Areas and Dates

Merrick & Company collected the LiDAR data for all of Flagler County between February 28, 2004 and May 5, 2004.

LiDAR Processing Methodology

A LiDAR Mapping Report from Merrick is provided at Appendix D. This report includes Merrick's LiDAR processing methodology

LiDAR Vertical Accuracy Testing

URS Corporation performed the LiDAR vertical accuracy assessments for Flagler County in accordance with *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, May 24, 2004, and Section 1.5 of the *Guidelines for Digital Elevation Data*, published by the National Digital Elevation Program (NDEP), May 10, 2004. These guidelines call for the mandatory determination of Fundamental Vertical Accuracy (FVA) and Consolidated Vertical Accuracy (CVA) and optional determination of Supplemental Vertical Accuracy (SVA).

Table 4. FDEM Checkpoint Requirements

Land cover categories tested by QA/QC checkpoints	Four land cover categories tested: 1. Open terrain; bare-earth, low grass 2. Brush lands and low trees 3. Forested areas 4. Urban, built-up areas
Number of checkpoints per category	30 checkpoints, per category, for each 500 square mile area

The LiDAR dataset of Flagler County passed the FDEM Baseline Specifications for vertical accuracy in all land cover categories.

Fundamental Vertical Accuracy (FVA) is determined with QA/QC checkpoints located only in open terrain (bare-earth, low grass, dirt, sand, and rocks) where there is a high probability that the LiDAR sensor detected the bare-earth ground surface, and where errors are expected to follow a normal error distribution. With a normal error distribution, the FVA at the 95 percent confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. The FVA is the same as $Accuracy_z$ at the 95% confidence level (for open terrain), as specified in Appendix 3-A of the *National Standard for Spatial Data Accuracy*, FGDC-STD-007.3-1998, see http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3. For FDEM, the FVA standard is .60 feet, corresponding to an $RMSE_z$ of 0.30 feet, the accuracy expected from 1-foot contours. ***In Flagler County, the $RMSE_z$ in open terrain equaled 0.30-ft compared with FDEM's 0.30-ft specification; and the FVA computed using $RMSE_z$ x 1.9600 was equal to 0.59-ft compared with FDEM's 0.60-ft specification.***

Consolidated Vertical Accuracy (CVA) is determined with all checkpoints, representing open terrain and all other land cover categories combined. If errors follow a normal error distribution, the CVA can be computed by multiplying the consolidated $RMSE_z$ by 1.9600. However, because bare-earth elevation errors often vary based on the height and density of vegetation, a normal error distribution cannot be assumed, and $RMSE_z$ cannot necessarily be used to calculate the 95 percent confidence level. Instead, a nonparametric testing method, based on the 95^{th} percentile, may be used to determine CVA at the 95 percent confidence level. NDEP guidelines state that errors larger than the 95^{th} percentile should be documented in the quality control report and project metadata. For FDEM, the CVA specification for all classes combined should be less than or equal to 1.19 feet. ***In Flagler County, the CVA computed using $RMSE_z$ x 1.9600 was equal to 0.87-ft, compared with FDEM's 1.19-ft specification; and the CVA computed using the 95^{th} percentile was equal to 0.88-ft, also bettering FDEM's 1.19-ft specification.***

Supplemental Vertical Accuracy (SVA) is determined separately for each individual land cover category, recognizing that the LiDAR sensor and post-processing may not have mapped the bare-earth ground surface, and that errors may not follow a normal error distribution. SVA specifications are "target" values and not mandatory, recognizing that larger errors in some categories are offset by smaller errors in other land cover categories, so long as the overall mandatory CVA specification is satisfied. For each land cover category, the SVA at the 95 percent confidence level equals the 95^{th} percentile error for all checkpoints in that particular land cover category. For FDEM's specification, the SVA target is 1.19 feet for each category. ***In Flagler County, the SVA tested as 0.52-ft in open terrain, bare earth and low grass; 0.82-ft in brushlands and low trees; 0.87-ft in forested areas; and 0.76-ft in urban terrain, bettering the FDEM Baseline Specifications of 1.19-ft in all land cover categories.***

The complete LiDAR Vertical Accuracy Report for Flagler County is at Appendix F.

LiDAR Qualitative Assessments

In addition to vertical accuracy testing, URS also performed the LiDAR qualitative assessment.

An assessment of the vertical accuracy alone does not yield a complete picture with regard to the usability of LiDAR data for its intended purpose. It is very possible for a given set of LiDAR data to meet the accuracy requirements, yet still contain artifacts (non-ground points) in the bare-earth surface, or a lack of ground points in some areas that may render the data, in whole or in part, unsuitable for certain applications.

Based on the extremely large volume of elevation points generated, it is neither time efficient, cost effective, nor technically practical to produce a perfectly clean (artifact-free) bare-earth terrain surface. The purpose of the LiDAR Qualitative Assessment Report (see Appendix G) is to provide a qualitative analysis of the "cleanliness" of the bare-earth terrain surface for use in supporting riverine and coastal analysis, modeling, and mapping.

The main software programs used by URS in performing the bare-earth data cleanliness review include the following:

- *GeoCue*: a geospatial data/process management system especially suited to managing large LiDAR data sets
- *TerraModeler*: used for analysis and visualization
- *TerraScan*: runs inside of MicroStation; used for point classification and points file generation
- *GeoCue LAS EQC:* is also used for data analysis and edit

The following systematic approach was followed by URS in performing the cleanliness review and analysis:

- Uploaded data to the GeoCue data warehouse (enhanced data management)
  - LiDAR: cut the data into uniform tiles measuring 5,000 feet by 5,000 feet – using the State Plane tile index provided by FDEM
  - Imagery: Best available orthophotography was used to facilitate the data review. Additional LiDAR Orthos were created from the LiDAR intensity data and used for review purposes.
- Performed coverage/gap check to ensure proper coverage of the project area
  - Created a large post grid (~30 meters) from the bare-earth points, which was used to identify any holes or gaps in the data coverage.
- Performed tile-by-tile analyses
  - Using TerraScan and LAS EQC, checked for gross errors in profile mode (noise, high and low points)
  - Reviewed each tile for anomalies; identified problem areas with a polygon, annotated comment, and screenshot as needed for clarification and illustration. Used ortho imagery when necessary to aid in making final determinations with regards to:
    - Buildings left in the bare-earth points file
    - Vegetation left in the bare-earth points file
    - Water points left in the bare-earth points file
    - Proper definition of roads
    - Bridges and large box culverts removed from the bare-earth points file
    - Areas that may have been "shaved off" or "over-smoothed" during the auto-filtering process
- Prepared and sent the error reports to LiDAR firm for correction
- Reviewed revisions and comments from the LiDAR firm
- Prepared and submitted final reports to FDEM

Breakline Production Methodology

Merrick uses a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring LiDAR bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage centerline in 2D with the elevation being attributed directly from the bare-earth .LAS data. Merrick's proprietary MARS® software has the capability of "flipping" views between the TIN and ortho imagery, as necessary, to further assist in the determination of the drainage centerline.

All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a 5-ft search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent points remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow. As with other PDS subcontractors, Merrick relies on the bare-earth data to attribute breakline elevations. As a result of this methodology, there is no mismatch between LiDAR bare-earth data and breaklines that might otherwise be collected photogrammetrically in stereo 3D. This is particularly important in densely vegetated areas, such as Flagler County, where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically) the more reliable LiDAR bare-earth data.

Merrick has the capability of "draping" 2D breaklines to a bare-earth elevation model to attribute the "z" as opposed to the forced downhill attribution methodology described above. However, the problem with this process in the "pooling" effect or depressions along the drainageway caused by a lack of consistent penetration in densely vegetated areas.

Water bodies are digitized from the color ramped TIN, similar to the process described above. Ortho imagery is also used, as necessary, to determine the waterbody outline. The elevation attribute is determined as a post-process using the lowest determined bare-earth point within the polygon.

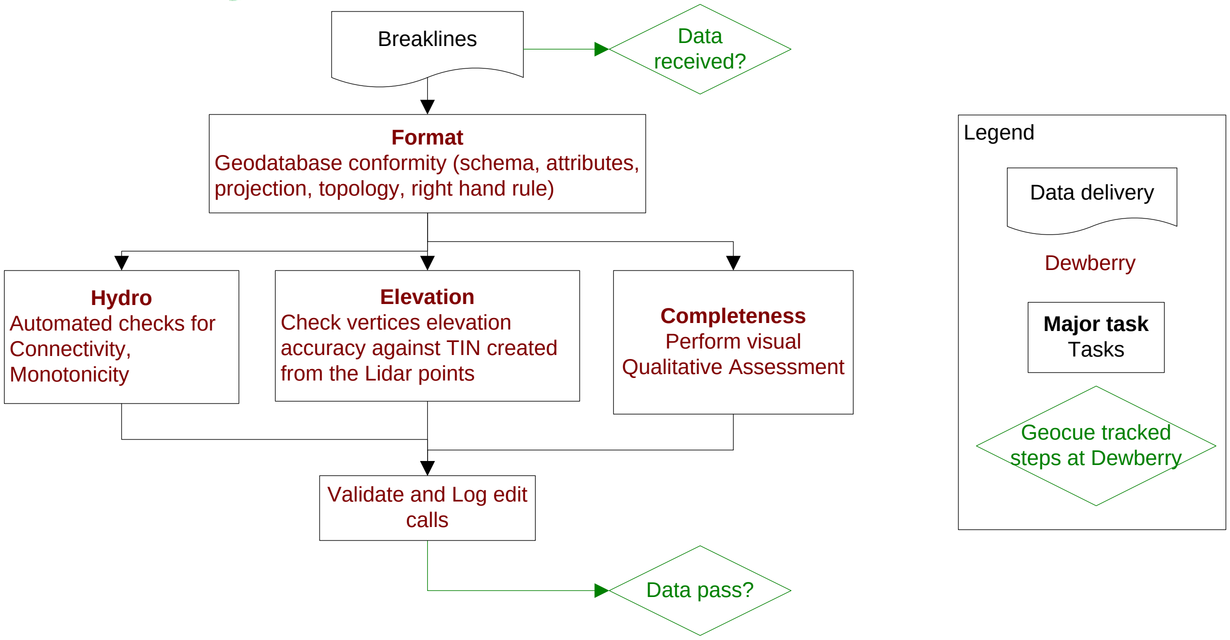
All breaklines conform with data format requirements outlined by the FDEM Baseline Specifications.

Contour Production Methodology

Using MARS® proprietary software, contours are generated at the desired contour intervals of 1-foot and 2-foot in accordance with the Data Dictionary at Appendix C. Prior to contour generation, breaklines are buffered to remove points within 1 foot; this enhances the aesthetics of the final contours. Topology QC checks are completed for breaklines and contours based on script provided by Dewberry. Additional QC checks for dangles and appropriate attribution are also completed before shipment. The contours conform with data format requirements outlined by the FDEM Baseline Specifications.

Breakline Qualitative Assessments

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



In order to ensure a correct database format, Dewberry provided all subcontractors with geodatabase shells containing the required feature classes in the required format. Upon receipt of the data, Dewberry verified that the correct shell was used and validated the topology rules associated with it.

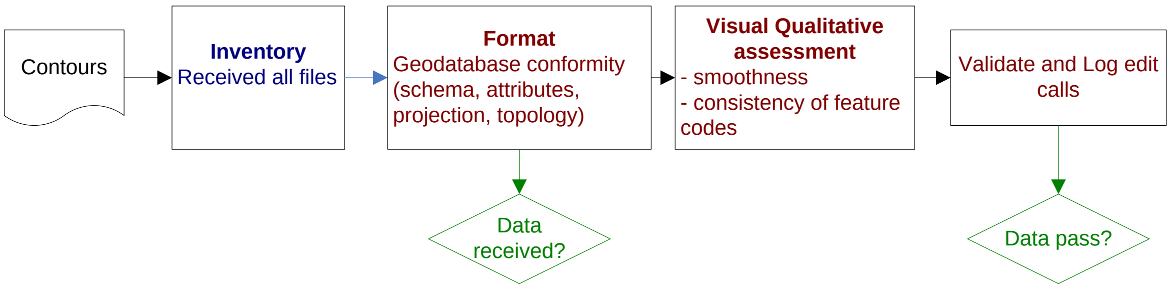
Feature Class	Rule	Feature Class
SOFTFEATURE	Must Not Intersect	
OVERPASS	Must Not Intersect	
ROADBREAKLINE	Must Not Intersect	
HYDROGRAPHIC...	Must Not Intersect	
SOFTFEATURE	Must Not Overlap With	ROADBREAKLINE
SOFTFEATURE	Must Not Overlap With	HYDROGRAPHICF
ROADBREAKLINE	Must Not Overlap With	HYDROGRAPHICF
SOFTFEATURE	Must Not Self-Intersect	
OVERPASS	Must Not Self-Intersect	
ROADBREAKLINE	Must Not Self-Intersect	
HYDROGRAPHIC...	Must Not Self-Intersect	

Then automated checks were applied on hydrofeatures to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step compared the elevation of the breakline vertices against the elevation extracted from the TIN 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 do not differ too much from the LiDAR.

Dewberry's final check for the breaklines was to perform a full qualitative analysis of the breaklines. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations.

Contour Qualitative Assessments



Upon receipt of each delivery area, the first step performed by Dewberry was a series of data topology validations. Dewberry checked for the following instances in the data:

1. Contours must not overlap
2. Contours must not intersect
3. Contours must not have dangles (except at project boundary)
4. Contours must not self-overlap
5. Contours must not self-intersect

After the topology and geodatabase format validation was complete, Dewberry checked the elevation attribute of each contour to ensure NULL values are not included. Finally, Dewberry loaded the contour data plus the Lidar intensity images into ArcGIS and performed a full qualitative review of the contour data for smoothness and consistency of feature codes.

Appendix H summarizes Dewberry's qualitative assessments of the breaklines and contours, with graphic examples of what the breaklines and contours look like.

Deliverables

The deliverables listed at Table 5 are included on the external hard drive that accompanies this report.

Table 5. Summary of Deliverables

Copies	Deliverable Description	Format	Location
1	Data Dictionary	pdf	Appendix C
3	LiDAR Processing Report	Hardcopy and pdf	Appendix D
3	LiDAR Vertical Accuracy Report	Hardcopy and pdf	Appendix F
1	LiDAR Qualitative Assessment Report	pdf	Appendix G
1	Breakline/Contour Qualitative Assessment Report	pdf	Appendix H
1	Breaklines, Contours, Network-Adjusted Control Points, Vertical accuracy checkpoints, Tiling Footprint, Lidar ground masspoints	Geodatabase	Submitted separately

References

ASPRS, 2007, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

ASPRS, 2004, *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, May 24, 2004, http://www.asprs.org/society/committees/lidar/downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf.

Bureau of the Budget, 1947, *National Map Accuracy Standards*, Office of Management and Budget, Washington, D.C.

FDEM, 2006, Florida GIS, *Baseline Specifications for Orthophotography and LiDAR*, Appendix B, *Terrestrial LiDAR Specifications*, Florida Division of Emergency Management, Tallahassee, FL, October, 2006.

FEMA, 2004, Appendix A, *Guidance for Aerial Mapping and Surveying*, to "Guidelines and Specifications for Flood Hazard Mapping Partners," Federal Emergency Management Agency, Washington, D.C.

FGCC, 1984, *Standards and Specifications for Geodetic Control Networks*, Federal Geodetic Control Committee, Silver Spring, ,MD, reprinted August 1993.

FGCC, 1988, *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques*, Federal Geodetic Control Committee, Silver Spring, MD, reprinted with corrections, August, 1989.

FGDC, 1998a, *Geospatial Positioning Accuracy Standards, Part I: Reporting Methodology*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/.

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 2, Standards for Geodetic Networks*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 3, National Standard for Spatial Data Accuracy*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998d, Content Standard for Digital Geospatial Metadata (CSDGM), Federal Geographic Data Committee, c/o USGS, Reston, VA, www.fgdc.gov/metadata/contstan.html.

NDEP, 2004, *Guidelines for Digital Elevation Data*, Version 1.0, National Digital Elevation Program, May 10, 2004, http://www.ndep.gov/

NOAA, 1997, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm),* NOAA Technical Memorandum NOS NGS-58, November, 1997.

General Notes

This report is incomplete without the external hard drives of the LiDAR masspoints, breaklines, contours, and control. See the Geodatabase structure at Appendix I.

This digital mapping data complies with the Federal Emergency Management Agency (FEMA) "Guidelines and Specifications for Flood Hazard Mapping Partners," Appendix A: *Guidance for Aerial Mapping and Surveying.*

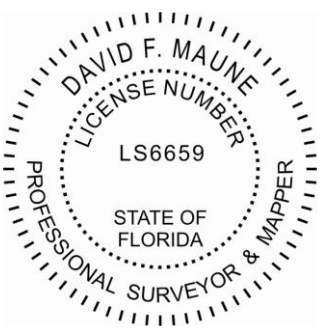
The LiDAR vertical accuracy report at Appendix F conforms with the National Standard for Spatial Data Accuracy (NSSDA).

The digital mapping data is certified to conform to Appendix B, *Terrestrial LiDAR Specifications*, of the "Florida Baseline Specifications for Orthophotography and LiDAR." This report is certified to conform with Chapter 61G17-6, Minimum Technical Standards, of the Florida Administrative Code, as pertains to a Specific Purpose LiDAR Survey.

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

Surveyor and Mapper in Responsible Charge:
David F. Maune, PhD, PSM, PS, GS, CP, CFM
Professional Surveyor and Mapper
License #LS6659

Signed: _______________________________ Date: ________________



List of Appendices

A. County Project Tiling Footprint
B. County Geodetic Control Points
C. Data Dictionary
D. LiDAR Processing Report
E. QA/QC Checkpoints and Associated Discrepancies
F. LiDAR Vertical Accuracy Report
G. LiDAR Qualitative Assessment Report
H. Breakline/Contour Qualitative Assessment Report
I. Geodatabase Structure

Appendix A: County Project Tiling Footprint (164 Tiles)

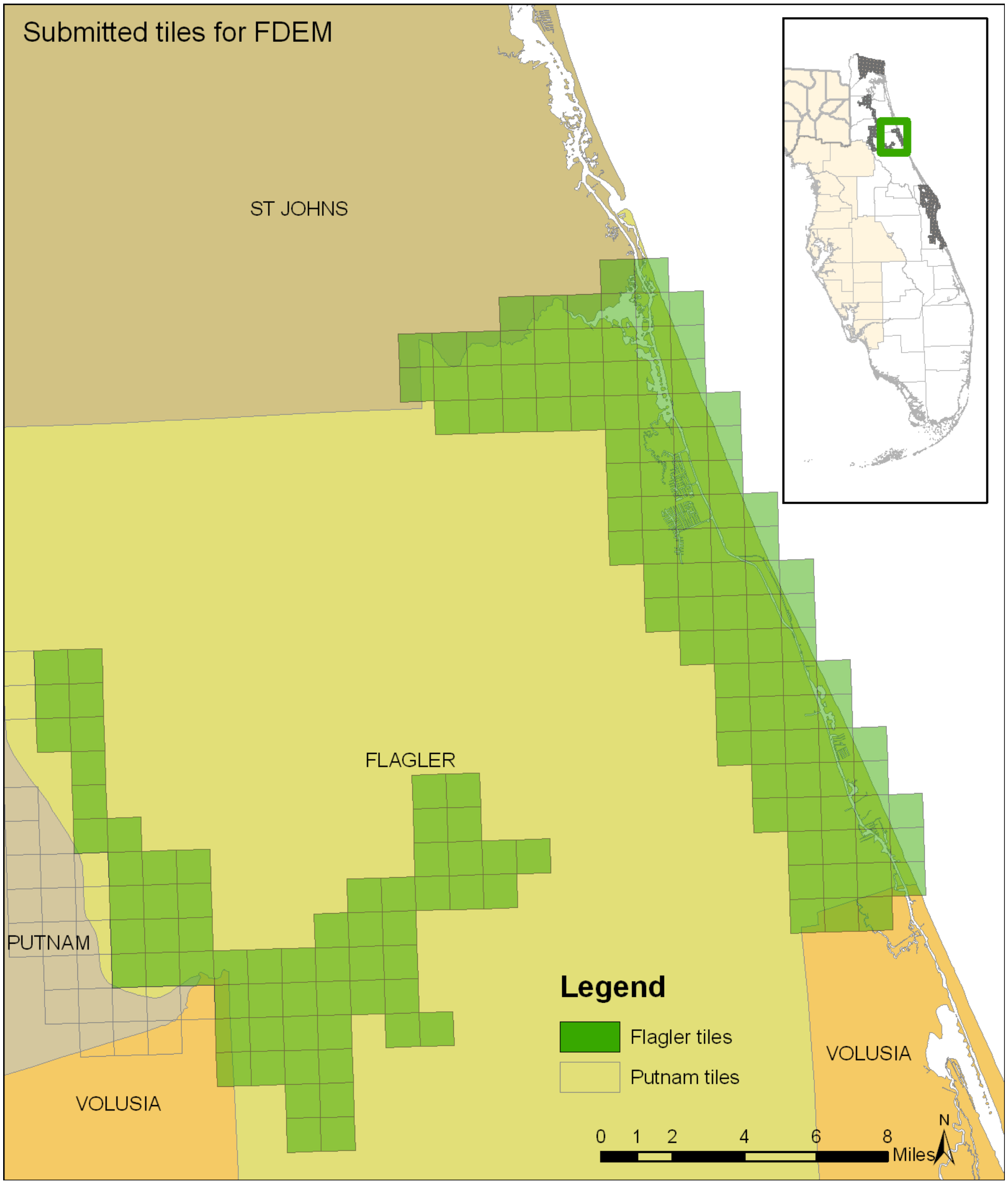


Figure 1 – Flagler - delivered tiles

List of complete tiles (164):

CELLNUM	034986_E	037086_E	038878_E	040371_E
034084_E	035585_E	037087_E	038889_E	040372_E
034085_E	035887_E	037367_E	039174_E	040373_E
034078_E	035886_E	037386_E	039175_E	040973_E
034079_E	037977_E	037387_E	039176_E	040974_E
034080_E	038267_E	037667_E	039468_E	
034081_E	038278_E	037978_E	039469_E	
034082_E	036186_E	038577_E	039471_E	
034083_E	034378_E	038578_E	039772_E	
034077_E	034379_E	038579_E	039774_E	
038291_E	034380_E	038580_E	040071_E	
033484_E	034381_E	037089_E	040073_E	
038290_E	034382_E	037389_E	040374_E	
033483_E	034678_E	038568_E	038870_E	
038287_E	035283_E	038591_E	038877_E	
038288_E	035284_E	036788_E	038879_E	
038289_E	035285_E	037088_E	038888_E	
033780_E	035586_E	037366_E	039168_E	
033782_E	035587_E	037967_E	039169_E	
033784_E	036188_E	038590_E	039170_E	
033785_E	035583_E	036485_E	039470_E	
034377_E	035584_E	036486_E	039472_E	
034384_E	035883_E	036487_E	039771_E	
034683_E	035884_E	036488_E	039773_E	
034684_E	035885_E	036766_E	040072_E	
034685_E	036184_E	036767_E	040673_E	
034686_E	036185_E	036785_E	040674_E	
034679_E	037388_E	036786_E	038875_E	
034681_E	037687_E	036787_E	038876_E	
034983_E	037688_E	037987_E	038890_E	
034985_E	039188_E	037988_E	038891_E	
035286_E	039189_E	037989_E	039473_E	
036187_E	039190_E	037990_E	039474_E	
033781_E	037689_E	038569_E	039475_E	
033783_E	037690_E	038570_E	039476_E	
034383_E	038268_E	038588_E	039775_E	
034385_E	038277_E	038589_E	039776_E	
034680_E	036484_E	037686_E	040074_E	
034682_E	037066_E	038868_E	040076_E	
034984_E	037067_E	038869_E	040077_E	

Appendix B: County Geodetic Control Points

Project: Daytona Beach Florida
Job#: 02015783
Date: June 2008

Coordinate System: US State Plane 1983 Florida East 0901
Zone: Florida East 0901
Project Datum: NAD 1983 (Conus)
Vertical Datum: NAVD88 (GEOID2003)
Units: US survey feet (Meters as labeled)

Pt#	Geodetic NAD83		Ellipsoid	Description
Name	Latitude	Longitude	Height	
	North	West	Geoid2003	
	Deg Min Sec	Deg Min Sec	US Feet	
Daytona_Base	29° 11' 05.45857"N	81° 03' 21.38452"W	-64.66	Daytona_Base
Deland_Base	29° 03' 54.64824"N	81° 17' 01.94245"W	-19.09	Deland_Base
Flagler_Base	29° 28' 05.20197"N	81° 12' 06.50055"W	-64.84	Flagler_Base
CORS_Ormond	29°1 7' 03.46960"N	81° 06' 32.02459"W	-59.84	CORS_Ormond

Pt#	SP NAD83(1999) Zone Florida East		NAVD88	Description
Name	Northing	Easting	Elevation	
	Y	X	Z	
	US Feet	US Feet	US Feet	
Daytona_Base	1763508.16	638316.63	28.37	Daytona_Base
Deland_Base	1720098.93	565480.07	73.11	Deland_Base
Flagler_Base	1866562.13	591949.78	29.19	Flagler_Base
CORS_Ormond	1804732.05	621457.21	33.60	CORS_Ormond

Appendix C: Data Dictionary

LiDARgrammetry Data Dictionary & Stereo Compilation Rules

FINAL

FDEM (Florida Department of Emergency Management)

January 25, 2008

Table of Contents

Horizontal and Vertical Datum

Horizontal datum shall be referenced to the appropriate Florida State Plane Coordinate System. The horizontal datum shall be North American Datum of 1983/HARN adjustment in US Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). Geoid03 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to the appropriate Florida State Plane Coordinate System Zone, Units in US Survey Feet.

Contour Topology Rules

The following contour topology rules have been incorporated into each geodatabase shell provided by PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

Name: CONTOURS_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
CONTOUR_1FT	5	1	1	No
CONTOUR_2FT	5	1	1	No

Topology Rules

Name	**Rule Type**	**Trigger Event**	**Origin** (*FeatureClass::Subtype*)	**Destination** (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All

Breakline Topology Rules

The following breakline topology rules have been incorporated into each geodatabase shell provided by PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

Name: BREAKLINES_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
COASTALSHORELINE	5	1	1	No
HYDROGRAPHICFEATURE	5	1	1	No
OVERPASS	5	1	1	No
ROADBREAKLINE	5	1	1	No
SOFTFEATURE	5	1	1	No

Topology Rules

Name	Rule Type	Trigger Event	Origin (*FeatureClass::Subtype*)	Destination (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	OVERPASS::All	OVERPASS::All
Must not intersect	The rule is a line-no intersection rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	ROADBREAKLINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	OVERPASS::All	OVERPASS::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Coastal Shoreline

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: COASTALSHORELINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Coast	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Coastal Shoreline	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 require some feathering or edge matching to ensure a smooth transition. Orthophotography will not be use to delineate this shoreline.	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. For the polygon closure vertices and segments, null values or a value of 0 are acceptable since this is not an actual shoreline. The digital orthophotography is not a suitable source for capturing this feature. Efforts should be taken to gradually feather the difference between tidal conditions of neighboring flights. Stair-stepping of the breakline feature will not be allowed. 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.

Linear Hydrographic Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: HYDROGRAPHICFEATURE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict linear hydrographic features with a length of 0.5 miles or longer as breaklines.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	HydroL	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Single Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, embankments, etc. with an average width less than or equal to 8 feet. . In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line. Each vertex placed should maintain vertical integrity.
2	Dual Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, etc. with an average width greater than 8 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class.	Capture features showing dual line (one on each side of the feature). Average width shall be great than 8 feet to show as a double line. Each vertex placed should maintain vertical integrity and data is not required to show "closed polygon". 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.
3	Soft Hydro Single Line Feature	Linear hydro features with an average width less than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line.
4	Soft Hydro Dual Line Feature	Linear hydro features with an average width greater than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 8 feet to show as a double line. Data is not required to show "closed polygon".

Note: Carry through bridges for all linear hydrographic features.

Closed Water Body Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: WATERBODY
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict closed water body features and will have the associated water elevation available as an attribute.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
WATERBODY_ELEVATION_MS	Double	Yes			0	0		Assigned by PDS
TYPE	Long Integer	No	1	HydroP	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Water Body	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 one-half 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. The field “WATERBODY_ELEVATION_MS” shall be automatically computed from the z-value of the vertices. An Island within a Closed Water Body Feature will also have a “donut polygon” compiled in addition to an Island polygon. 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.

Road Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ROADBREAKLINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict apparent edge or road pavement as breaklines but will not include bridges or overpasses.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Road	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Edge of Pavement	Capture edge of pavement (non-paved or compact surfaces as open to compiler interpretability) on both sides of the road. Runways are not to be included.	DO NOT INCLUDE Bridges or Overpasses within this feature type. Capture apparent edge of pavement (including paved shoulders). Each vertex placed should maintain vertical integrity and data is not required to show “closed polygon”. Box culverts should be continued as edge of pavement unless a clear guardrail system is in place; in that case, feature should be shown as bridge / overpass.

Bridge and Overpass Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: OVERPASS
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict bridges and overpasses as separate entities from the edge of pavement feature class.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Bridge	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bridge Overpass	Feature should show edge of bridge or overpass.	Capture apparent edge of pavement on bridges or overpasses. Do not capture guard rails or non-drivable surfaces such as sidewalks. Capture edge of drivable pavement only. Each vertex placed should maintain vertical integrity and data is not required to show "closed polygon". Box culverts should be captured in this feature class if a clear guardrail system is in place; otherwise, show as edge-of-pavement.

Soft Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: SOFTFEATURE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict soft changes in the terrain to support better hydrological modeling of the LiDAR data and sub-sequent contours.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Soft	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Soft Breakline	Supplemental breaklines where LiDAR mass points are not sufficient to create a hydrologically correct DTM. Soft features shall include ridges, valleys, top of banks, etc. Soft features may also include natural Embankments that act as small ponding areas. Top of Banks can also be included in the soft breakline class so long as it does not define the edge of a water feature.	Capture breaklines to depict soft changes in the elevation. If the elevation changes are easily visible, go light on the breakline capture. Each vertex placed should maintain vertical integrity.

Island Features

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: ISLAND
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict natural and man-made islands as closed polygons.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Island	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Island	Apparent boundary of natural or man-made island feature captured with a constant elevation. Island features will be captured for features one-half acres in size or greater.	Island shall take precedence over Coastal Shore Line Features. Islands shall be captured as closed polygons with the land feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed around the island. 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.

Low Confidence Areas

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONFIDENCE
Contains Z Values: No
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation meaning that the resultant contours may not meet the required accuracy specifications.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	Apparent boundary of vegetated areas that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. These features are for reference only to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.	Capture as closed polygon with the obscured area to the right of the line. Compiler does not need to worry about z-values of vertices; feature class will be 2-D only.

Note: Area must be ½ acre or larger. Only outline areas where you are not sure about vegetative penetration of the LiDAR data. This is not the same as a traditional obscured area.

Masspoints

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: MASSPOINT
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts masspoints as determined by the LiDAR ground points (LAS Class 2).

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
TYPE	Long Integer	No	1	Masspoint	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Masspoint	Only the bare earth classification (Class 2) shall be loaded into the MASSPOINT feature class.	None. Data should be loaded from LAS Class 2 (Ground)

1 Foot Contours

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONTOUR_1FT
Contains Z Values: No
Z Resolution: N/A
Z Tolerance: N/A

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict 1’ contours modeled from the LiDAR ground points and the supplemental breaklines.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are shown as screened lines so that they are distinguishable from the basic contours, yet not	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between. If the horizontal distance between two adjacent contours is

		unduly prominent on the published map.	larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

2 Foot Contours

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: CONTOUR_2FT
Contains Z Values: No
Z Resolution: N/A
Z Tolerance: N/A

Feature Type: Polyline
Annotation Subclass: None

Description

This polyline feature class will depict 1' contours modeled from the LiDAR ground points and the supplemental breaklines.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between.

		shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map.	If the horizontal distance between two adjacent contours is larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

Ground Control

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: GROUNDCONTROL
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts the points used in the acquisition and calibration of the LiDAR and aerial photography collected by Aero-Metric, Sanborn and Terrapoint.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
TYPE	Long Integer	No	1	Control	0	0		Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Control Point	Primary or Secondary PDS control points used for either base station operations or in the calibration and adjustment of the control.	None.

Vertical Accuracy Test Points

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: VERTACCTESTPTS
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

Description

This feature class depicts the points used by PDS to test the vertical accuracy of the data produced.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS
LANDCOVER	Long Integer	No	1	dLANDCOVERTYPE	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bare-Earth and Low Grass	None.	None.
2	Brush Lands and Low Trees	None.	None.
3	Forested Areas Fully Covered by Trees	None.	None.
4	Urban Areas	None.	None.

Footprint (Tile Boundaries)

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: FOOTPRINT
Contains Z Values: No
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

Description

This polygon feature class includes the Florida 5,000’ x 5,000’ tiles for each countywide geodatabase produced.

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
CELLNUM	String	No			0	0	8	Assigned by PDS

Contact Information

Any questions regarding this document should be addressed to:

Brian Mayfield, C.P., GISP, G.L.S.
Associate / Sr. Project Manager
Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031
(703) 849-0254 – voice
(703) 340-4141 – cell
bmayfield@dewberry.com

Appendix D: LiDAR Processing Report

Flagler County, Florida
LiDAR Mapping Report
(Daytona Beach Florida Project)

Prepared for:

Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031
Phone: 703-849-0100
Fax: 703-849-0182
www.dewberry.com

Prepared by:

Merrick & Company
2450 South Peoria Street
Aurora, CO 80014
Phone: (303) 751-0741
Fax: (303) 745-0964
www.merrick.com

EXECUTIVE SUMMARY

In the year of 2004, Merrick & Company (Merrick) started LiDAR data collection for the Daytona Beach project that included flight lines over Flagler and Volusia Counties located in the state of Florida. Merrick executed a LiDAR (Light Detection And Ranging) survey for the Daytona Beach Project located in the north eastern part of the state of Florida. The purpose of the project was to produce accurate, high-resolution data for planning, analysis, and for use with other data sets. Merrick obtained LiDAR data over approximately 1200 square miles covering Flagler and Volusia Counties. The LiDAR data was processed to result in a data set that is suitable for the future generation of 1-foot contours.

CONTRACT INFORMATION

Questions regarding this report should be addressed to:

Doug Jacoby, CMS, GISP
Director of Projects / Project Manager
Merrick & Company
GeoSpatial Solutions
2450 South Peoria Street
Aurora, CO 80014-5472
303-353-3903
303-745-0964 Fax
800-544-1714, x-3903
doug.jacoby@merrick.com
www.merrick.com/servicelines/gis

Project Completion Report for Flagler County - Daytona Beach Project.

The contents of this report summarize the methods used to establish the GPS base station network, perform the LiDAR data collection and post-processing as well as the results of these methods for Flagler County - Daytona Beach Project Florida.

LiDAR FLIGHT and SYSTEM REPORT

Project Location
The project location for Daytona Beach Project is defined by the shapefiles "All_Boundaries_Merged.shp".

Duration/Time Period
The LiDAR aircraft, a Cessna 402C, arrived on site on February 27, 2004 and the LiDAR data collection was accomplished on February 28, 2004 thru May 05, 2004. The Daytona Beach Regional Airport (DAB) was used as the airfield of operations.

Flight Diagrams
See Below.

Mission Parameters for Flagler County - Daytona Beach Project

LiDAR Sensor	Leica Geosystems ALS40
Nominal Ground Sample Distance	1.35 meters
Average Altitude	5,500 Feet MSL
Average Airspeed	~125 Knots
Scan Rate	25.6 Hertz
Scan FOV (scan angle)	37˚
Pulse Rate	35,000 Hertz

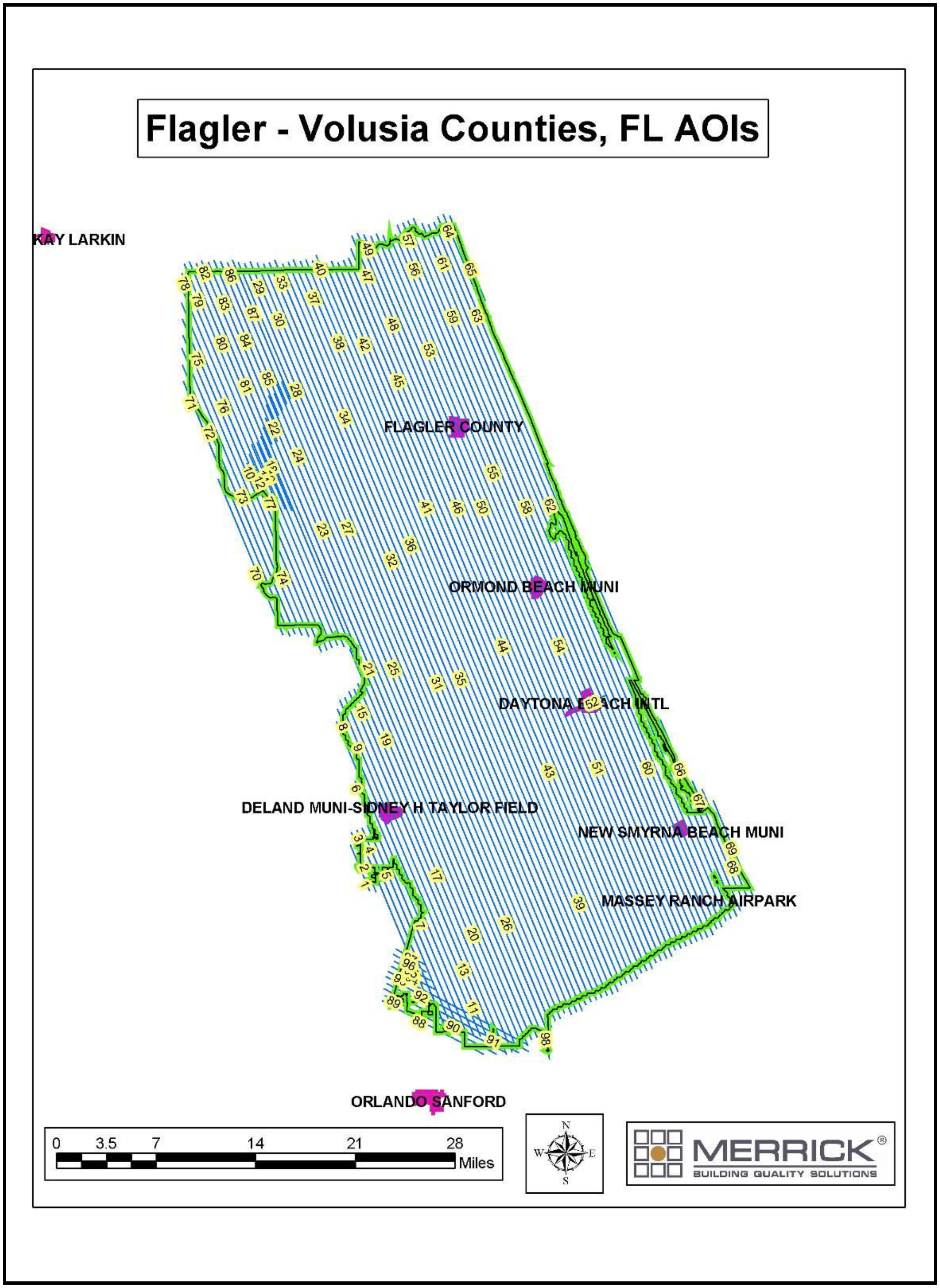
Mission	Date	Start Time	End Time	County Coverage
040228A	Feb. 28, 2004	14:38:01 GMT 571081 GPS sec.	20:56:18 GMT 593778 GPS sec.	Over Flagler County
040308A	March 08, 2004	13:56:57 GMT 136617 GPS sec.	19:02:02 GMT 154922 GPS sec.	Over Flagler County
040309A	March 09, 2004	13:40:37 GMT 222037 GPS sec.	19:39:59 GMT 243599 GPS sec.	Over Flagler County
040311A	March 11, 2004	14:40:27 GMT 398427 GPS sec.	21:01:09 GMT 421269 GPS sec.	Over Flagler County
040318B	March 18, 2004	17:55:01 GMT 410101 GPS sec.	20:55:51 GMT 420951 GPS sec.	Over Flagler County
040319A	March 19, 2004	13:36:33 GMT 480993 GPS sec.	19:33:03 GMT 502383 GPS sec.	Over Flagler County
040320A	March 20, 2004	13:34:15 GMT 567255 GPS sec.	18:38:39 GMT 585519 GPS sec.	Over Flagler County
040321A	March 21, 2004	15:11:26 GMT 54686 GPS sec.	18:07:43 GMT 65263 GPS sec.	Not Over Flagler County
040428A	April 28, 2004	13:54:02 GMT 309242 GPS sec.	16:45:22 GMT 319522 GPS sec.	Over Flagler County
040429A	April 29, 2004	12:28:37 GMT 390517 GPS sec.	15:30:40 GMT 401440 GPS sec.	Over Flagler County
040505A	May 05, 2004	11:45:21 GMT 301521 GPS sec.	17:04:02 GMT 320642 GPS sec.	Over Flagler County

Field Work / Procedures

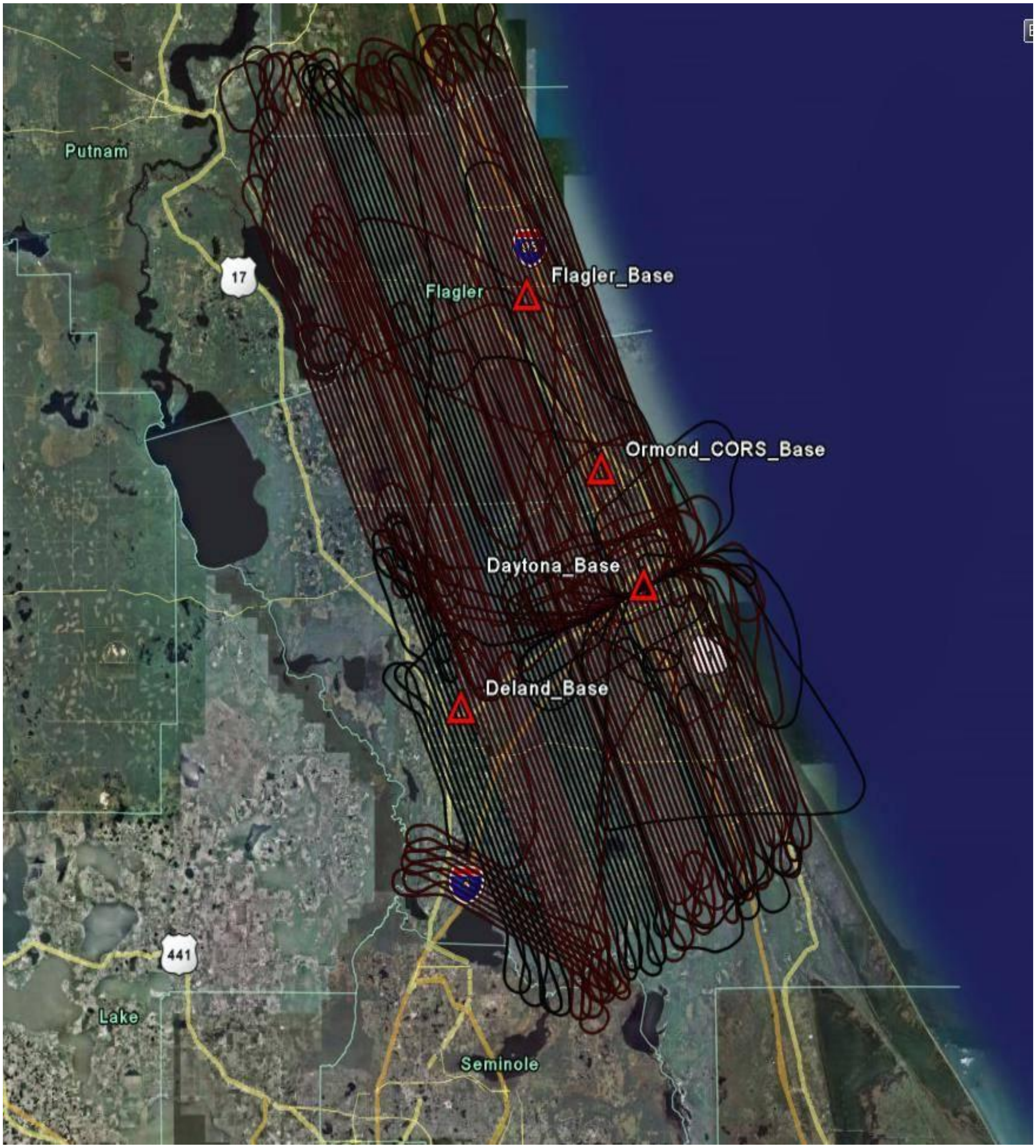
Three ground Airborne GPS Base Stations, for the LiDAR data collection, were set up every mission, one main ground GPS receiver located at the Daytona Beach Regional Airport, another ground GPS receiver located at the Deland Airport and another ground GPS receiver located at the Flagler Airport. Also the Ormond CORS Station was used as a check Base Station.
Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the aircraft engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations. During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near

the end of the mission, GPS ambiguities were again resolved by flying within ten kilometers of the base stations to aid in post-processing. Data was sent back to the main office and preliminary data processing was performed for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be reflown immediately as required. Final data processing was completed in the Aurora, Colorado office.

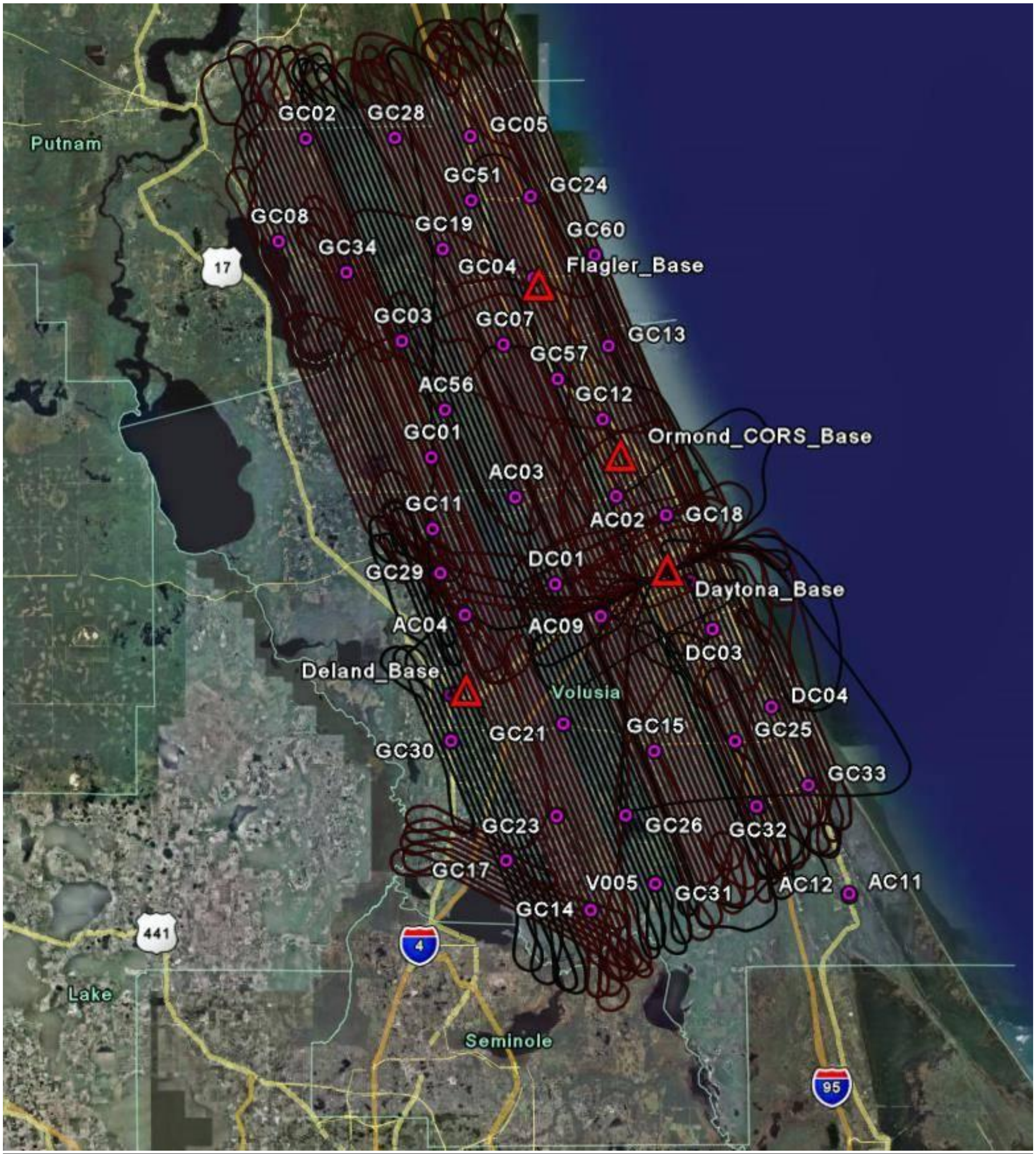
Planned Flight Diagram for the Daytona Beach Project showing Airports



<u>Flight Diagram for the Daytona Beach Project showing Actual Flight Lines and Base Station Locations</u>

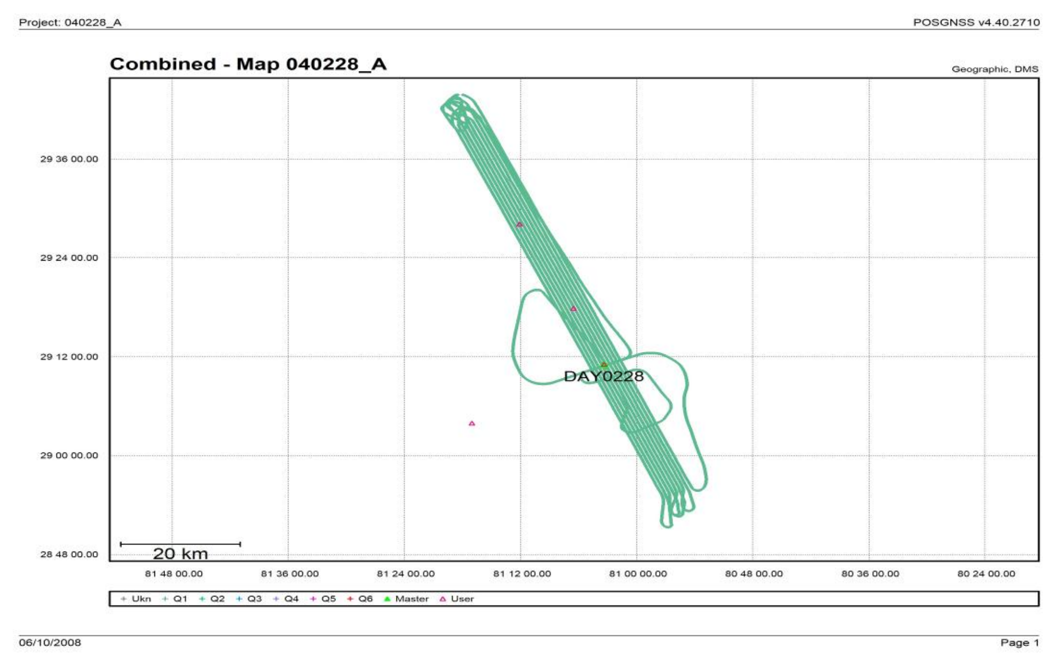


<u>Flight Diagram for the Daytona Beach Project showing Actual Flight Lines, Base Station Locations and Ground Control</u>

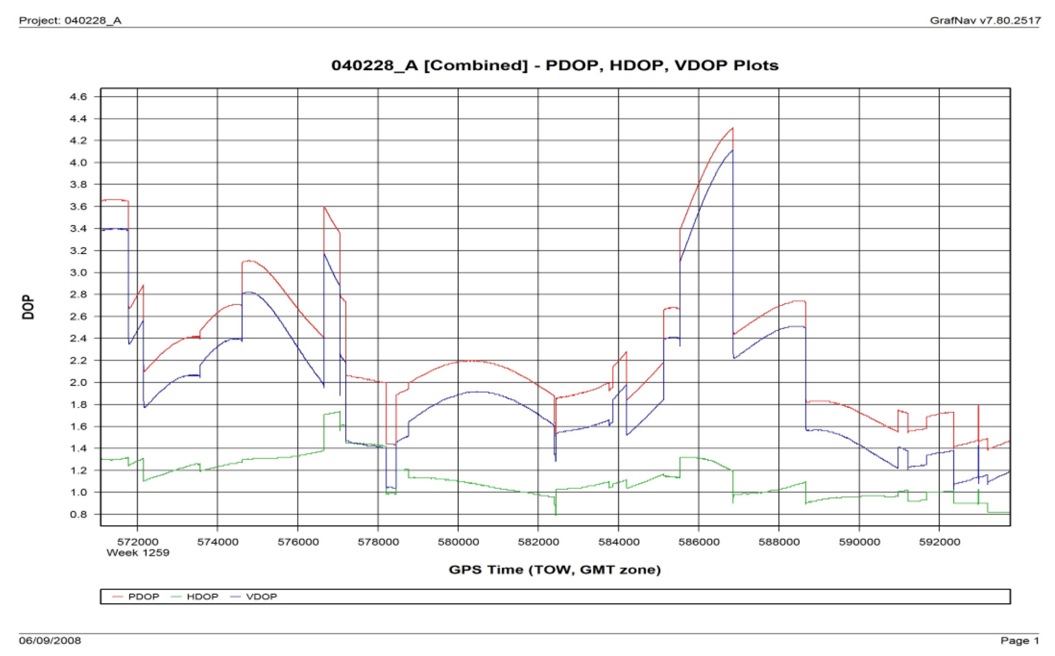


The following graphs show the mission by mission GPS derived flight tracks and PDOP (Positional Dilution Of Precision) Plots.

GPS derived flight tracks for mission 040228A

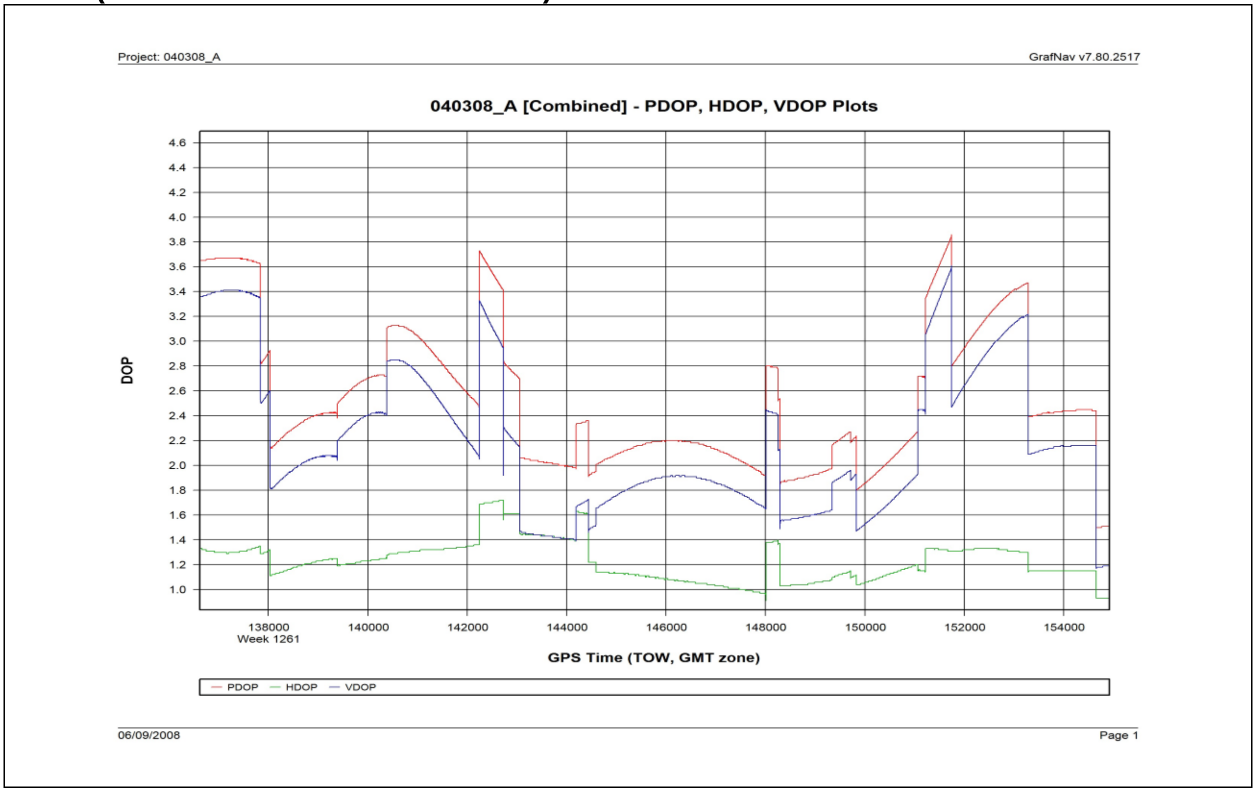


PDOP (Positional Dilution Of Precision) Plot for mission 040228A

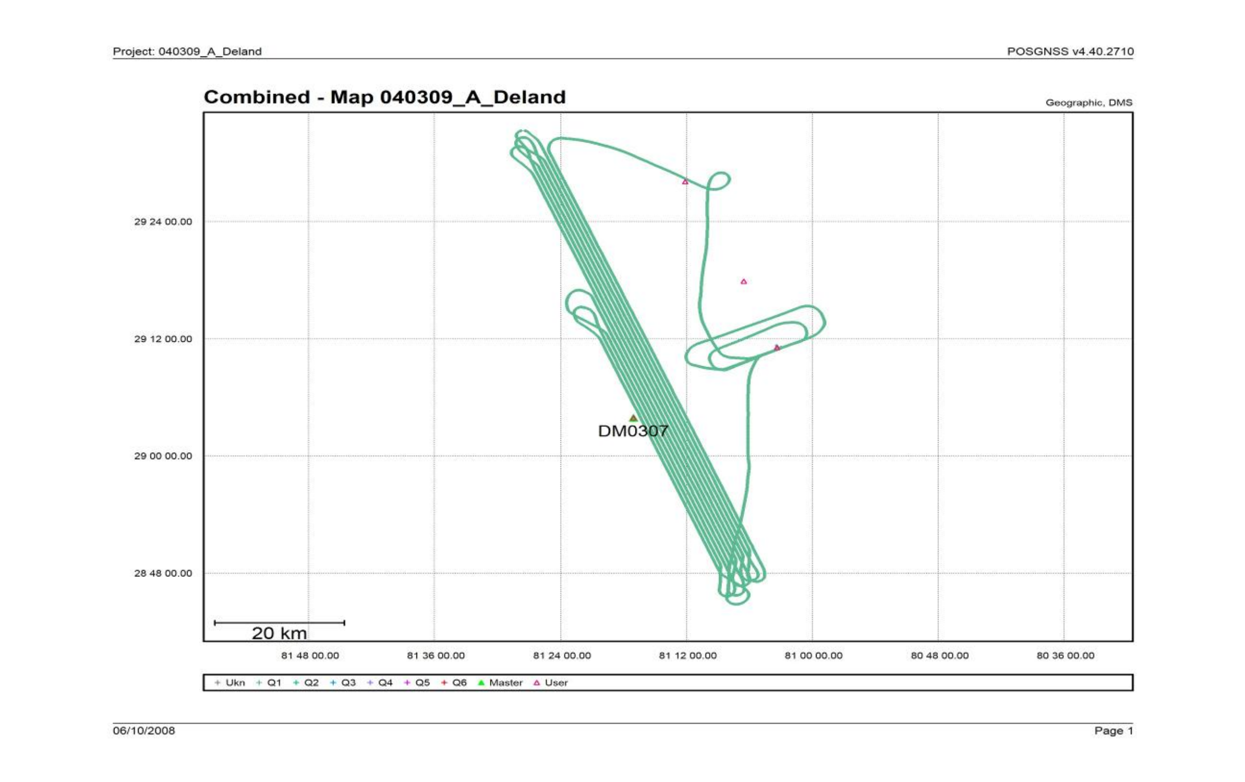


GPS derived flight tracks for mission 040308A

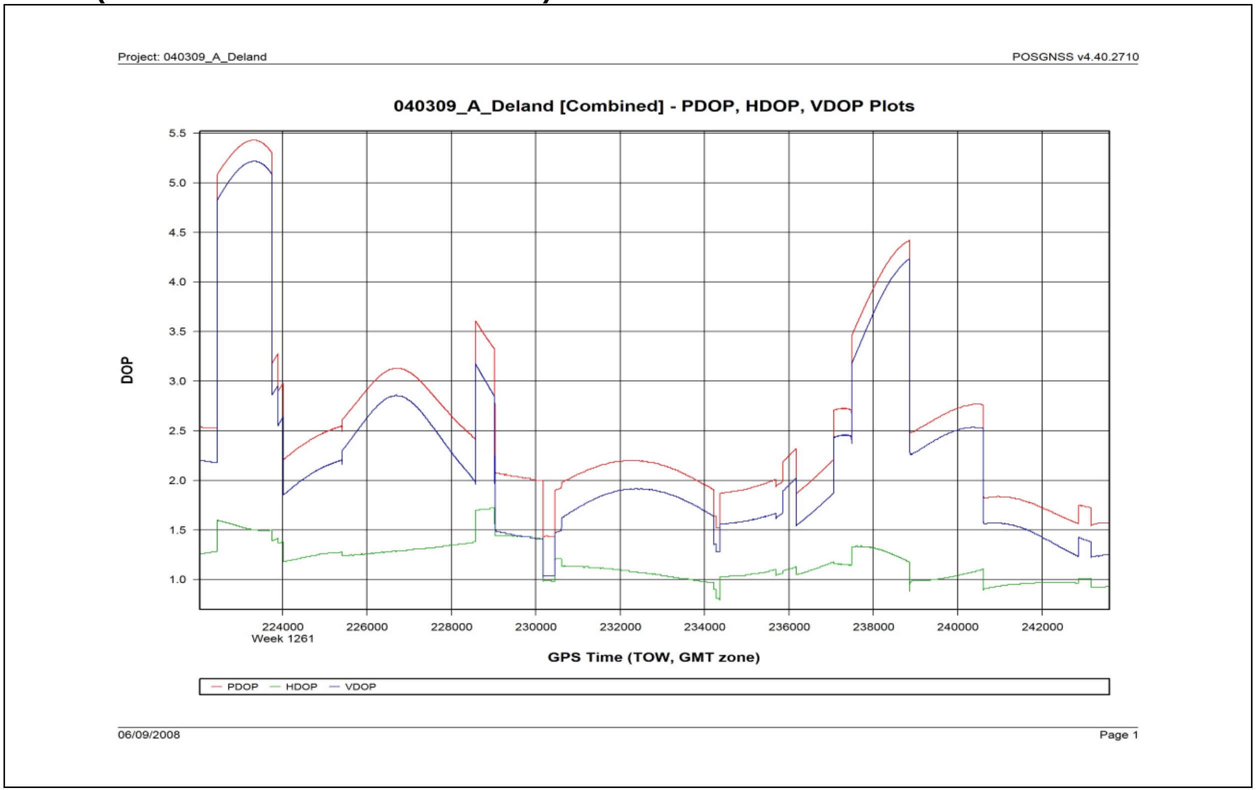
PDOP (Positional Dilution Of Precision) Plot for mission 040308A



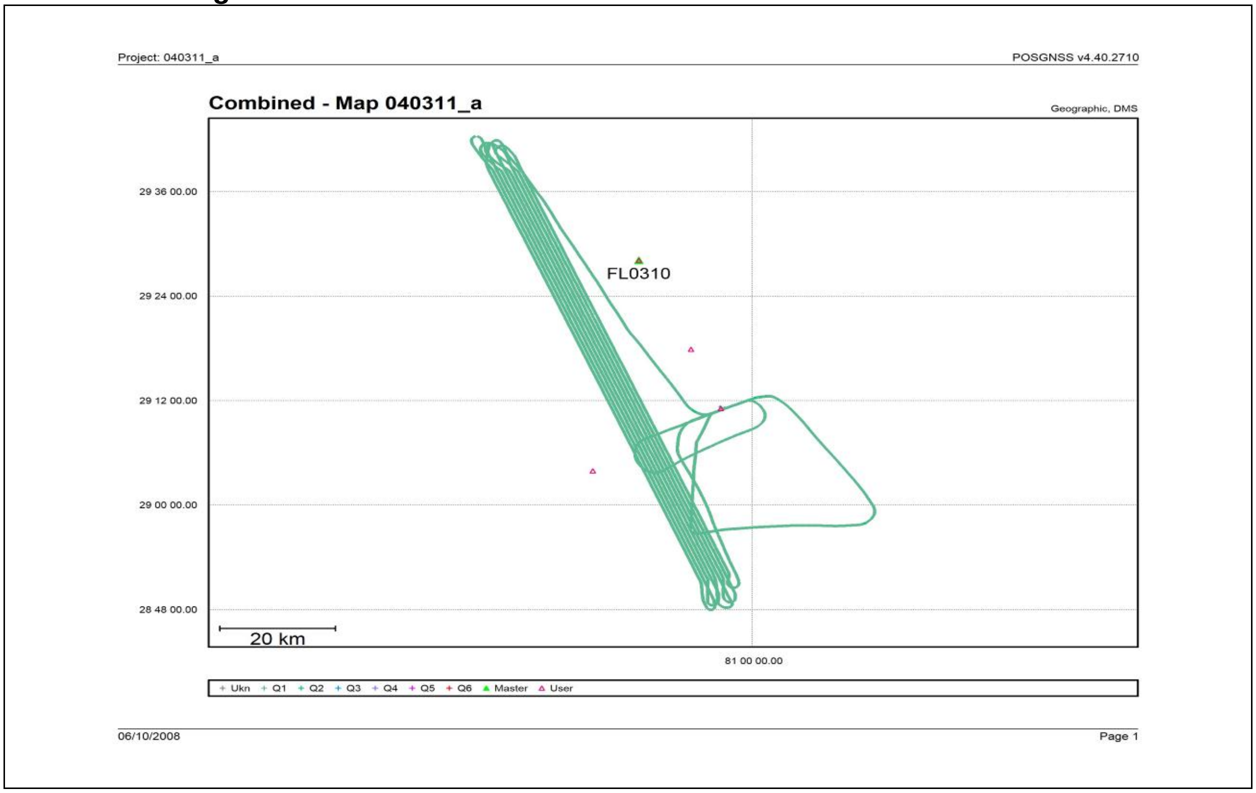
GPS derived flight tracks for mission 040309A



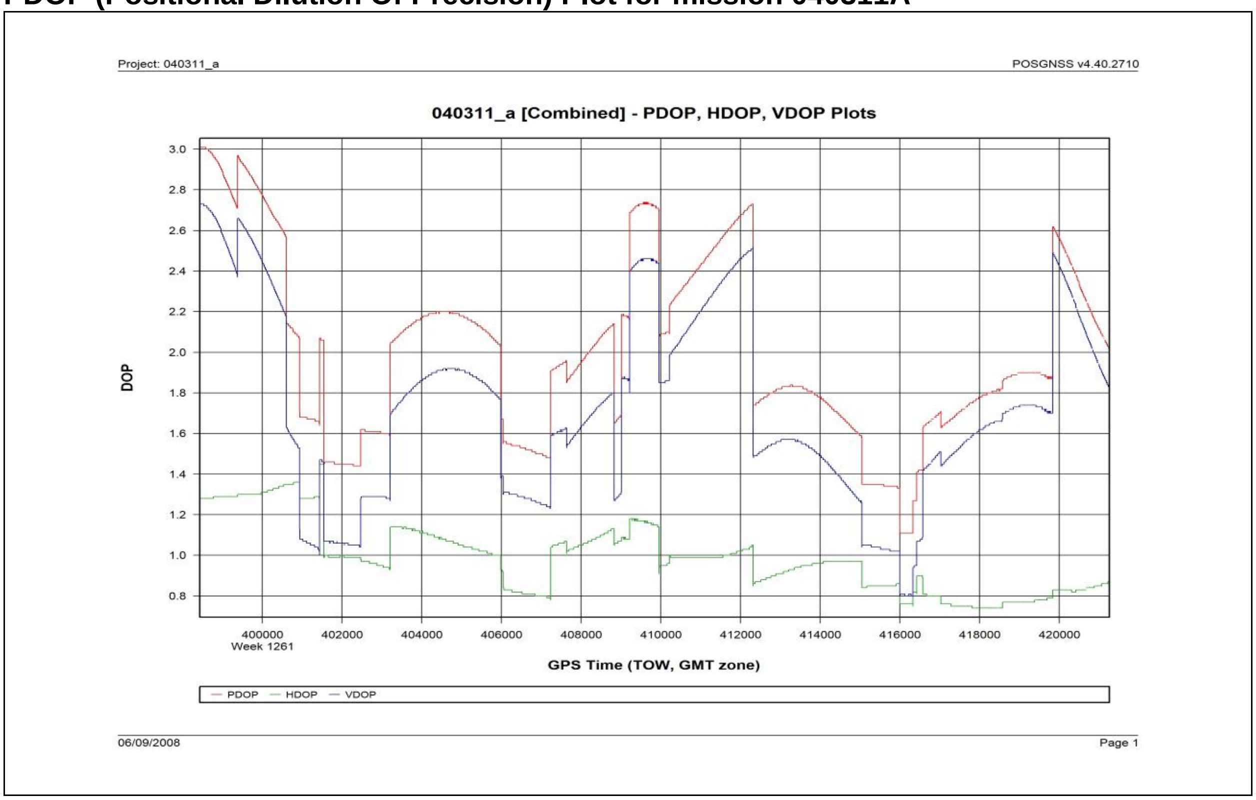
PDOP (Positional Dilution Of Precision) Plot for mission 040309A



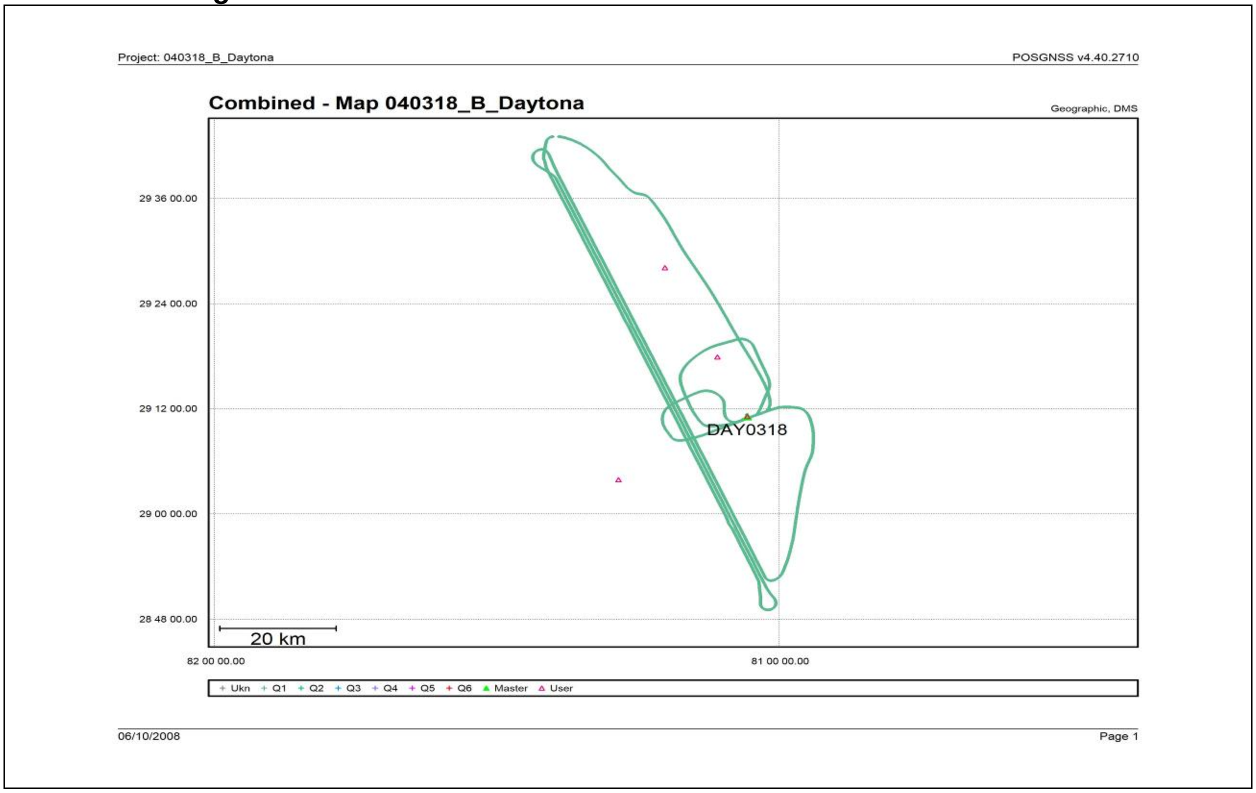
GPS derived flight tracks for mission 040311A



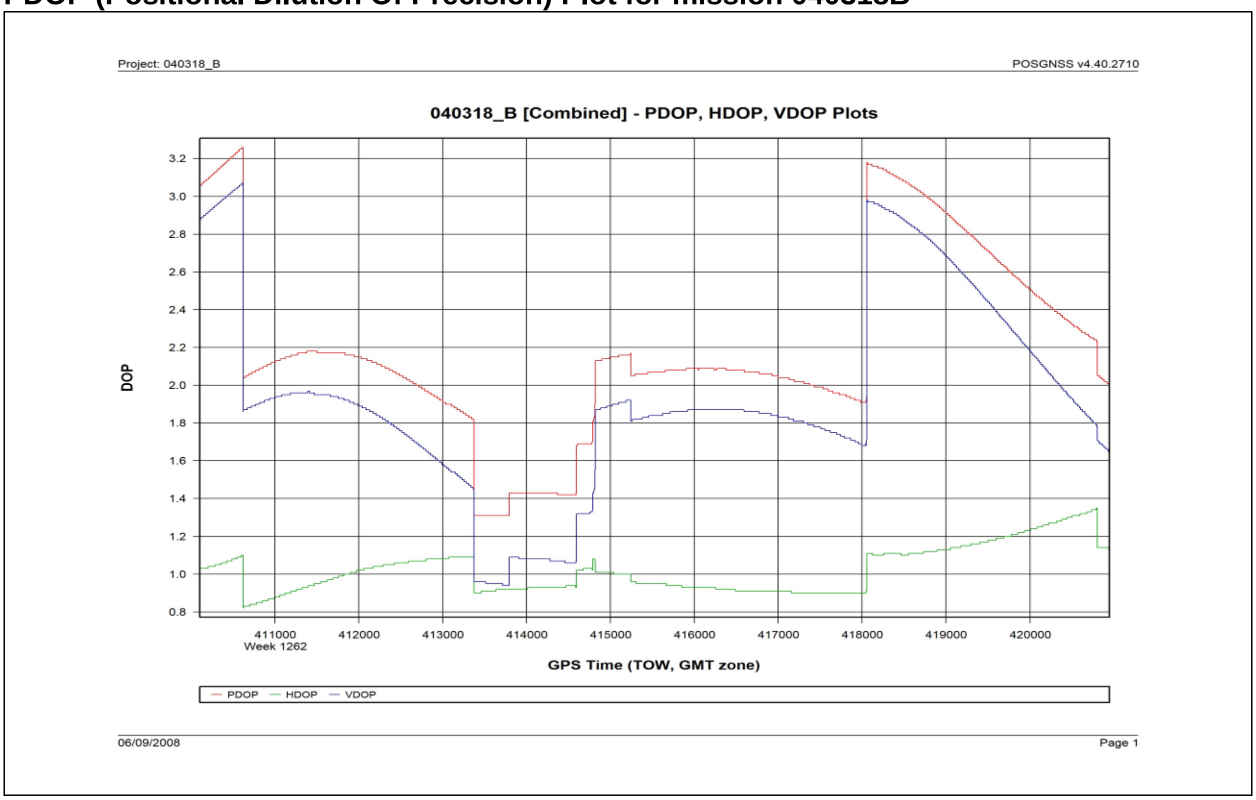
PDOP (Positional Dilution Of Precision) Plot for mission 040311A



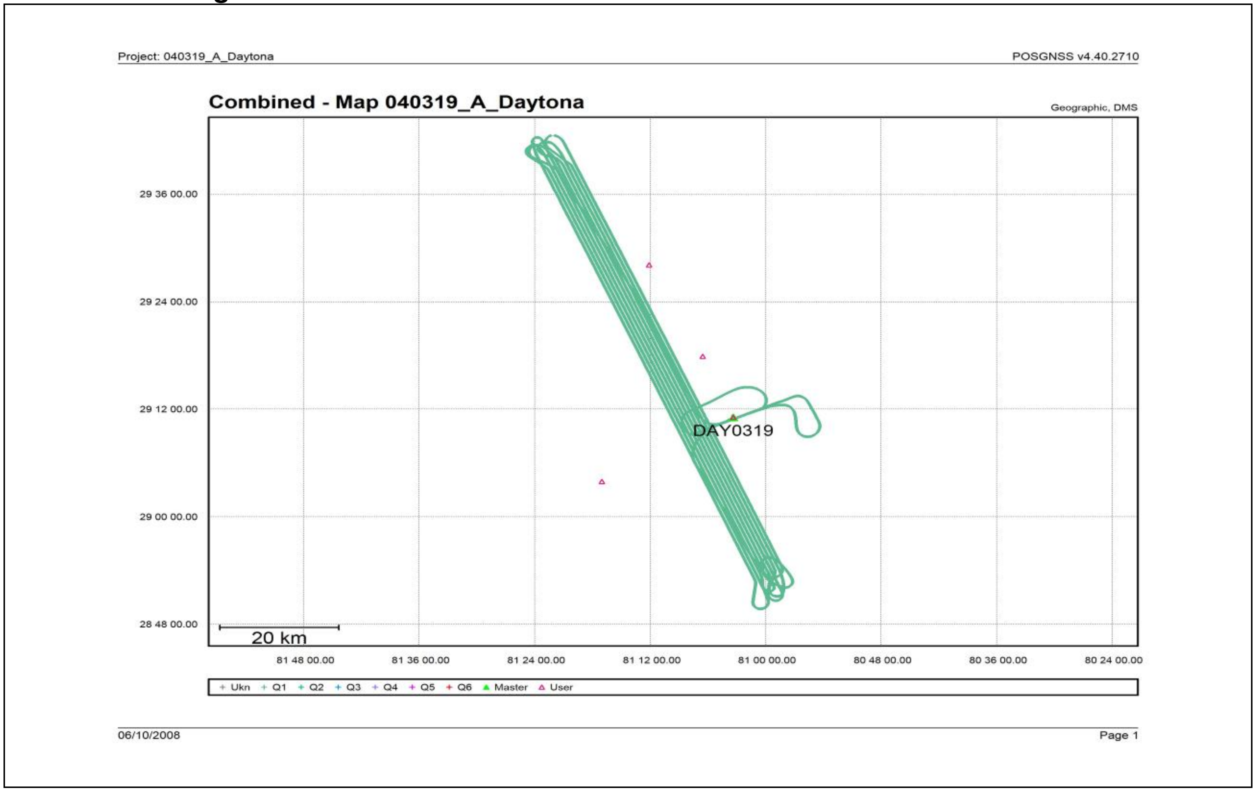
GPS derived flight tracks for mission 040318B



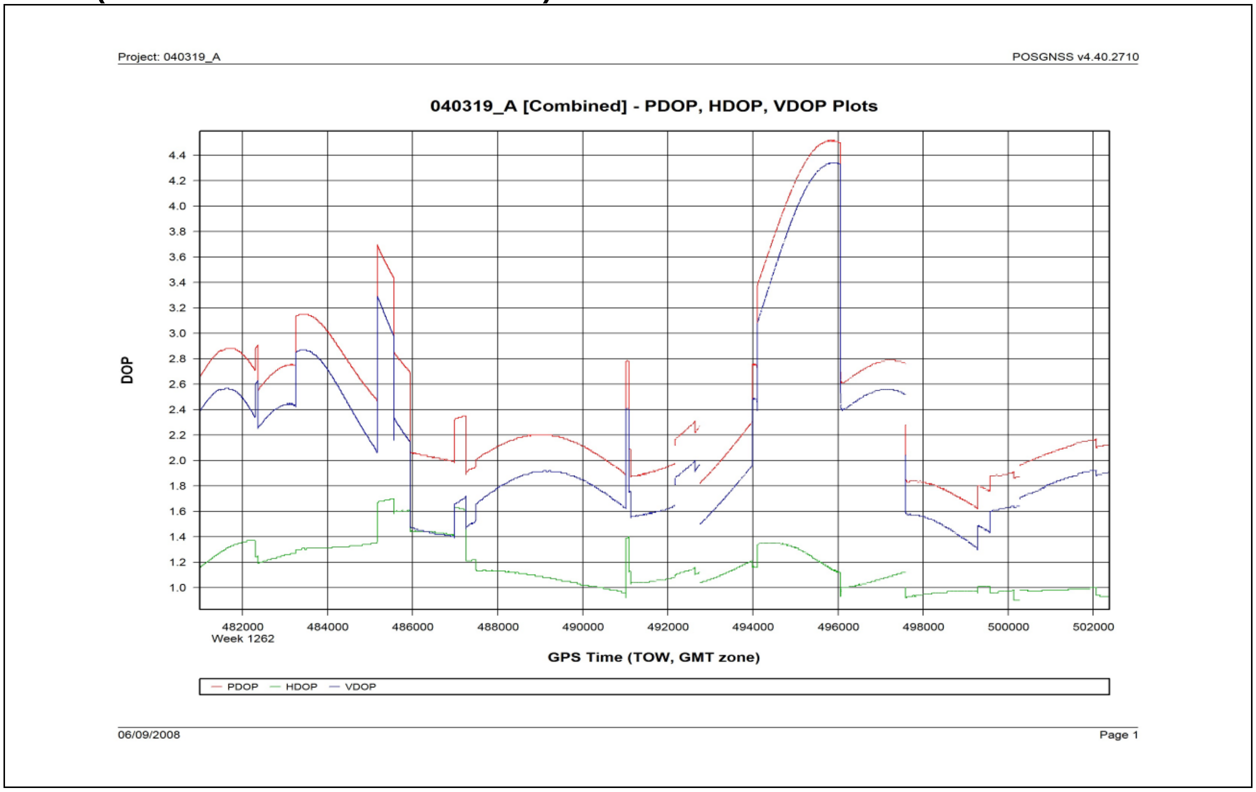
PDOP (Positional Dilution Of Precision) Plot for mission 040318B



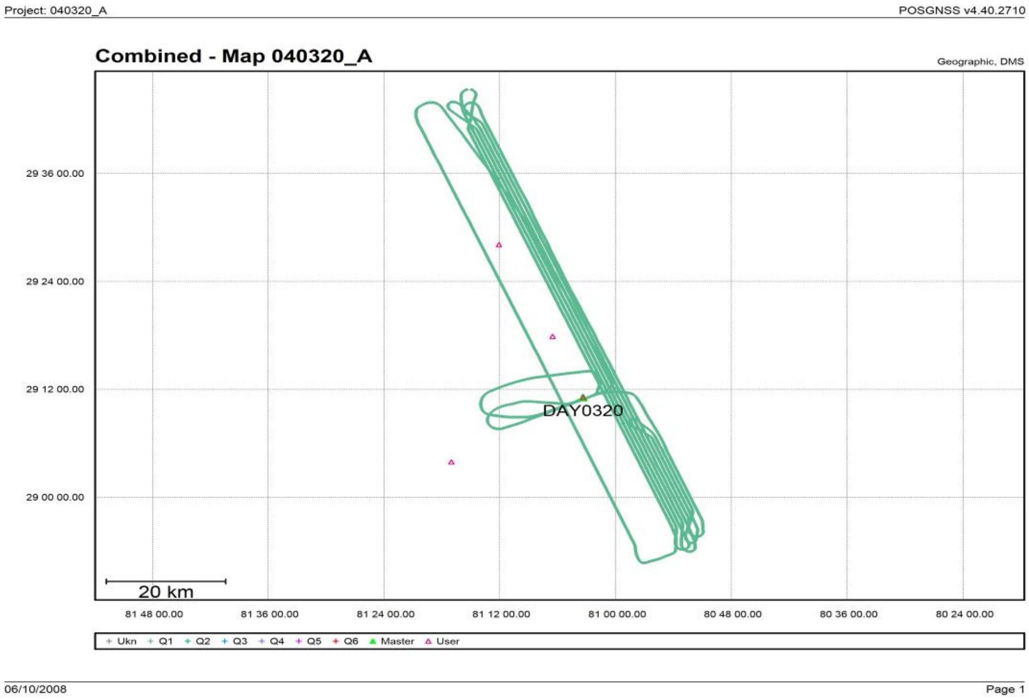
GPS derived flight tracks for mission 040319A



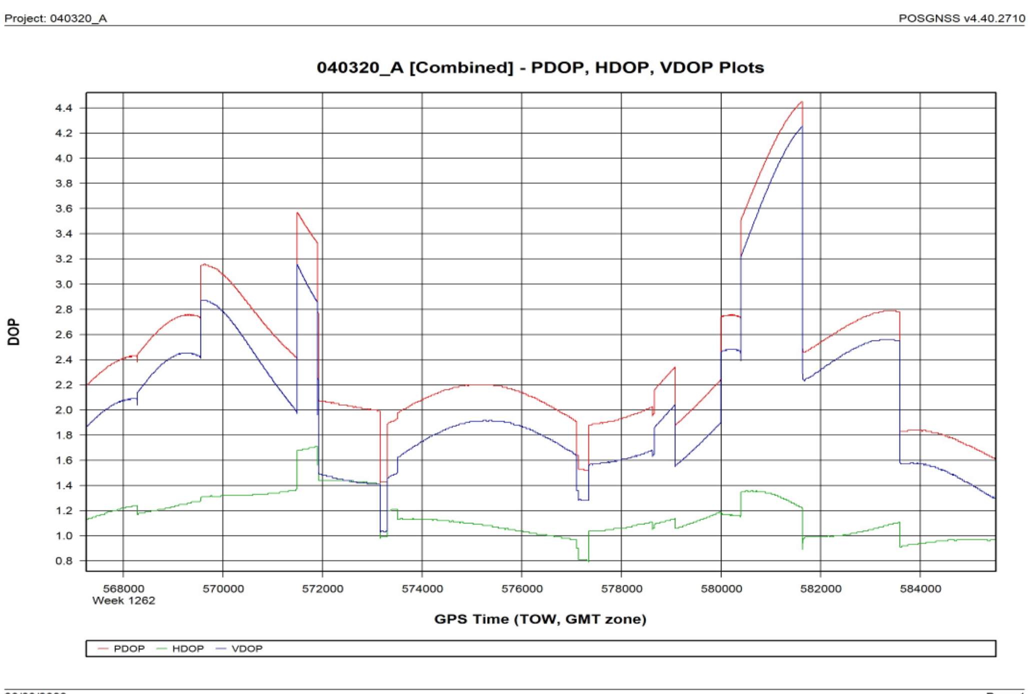
PDOP (Positional Dilution Of Precision) Plot for mission 040319A



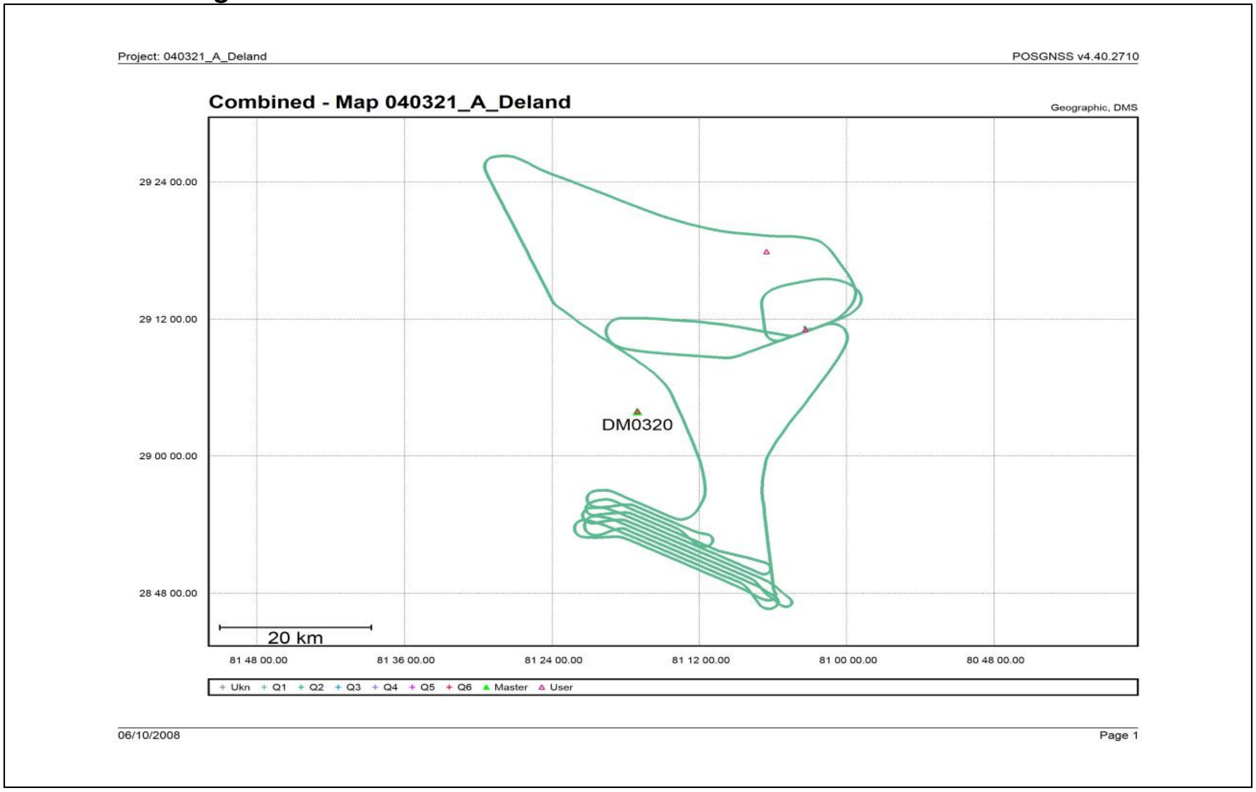
GPS derived flight tracks for mission 040320A



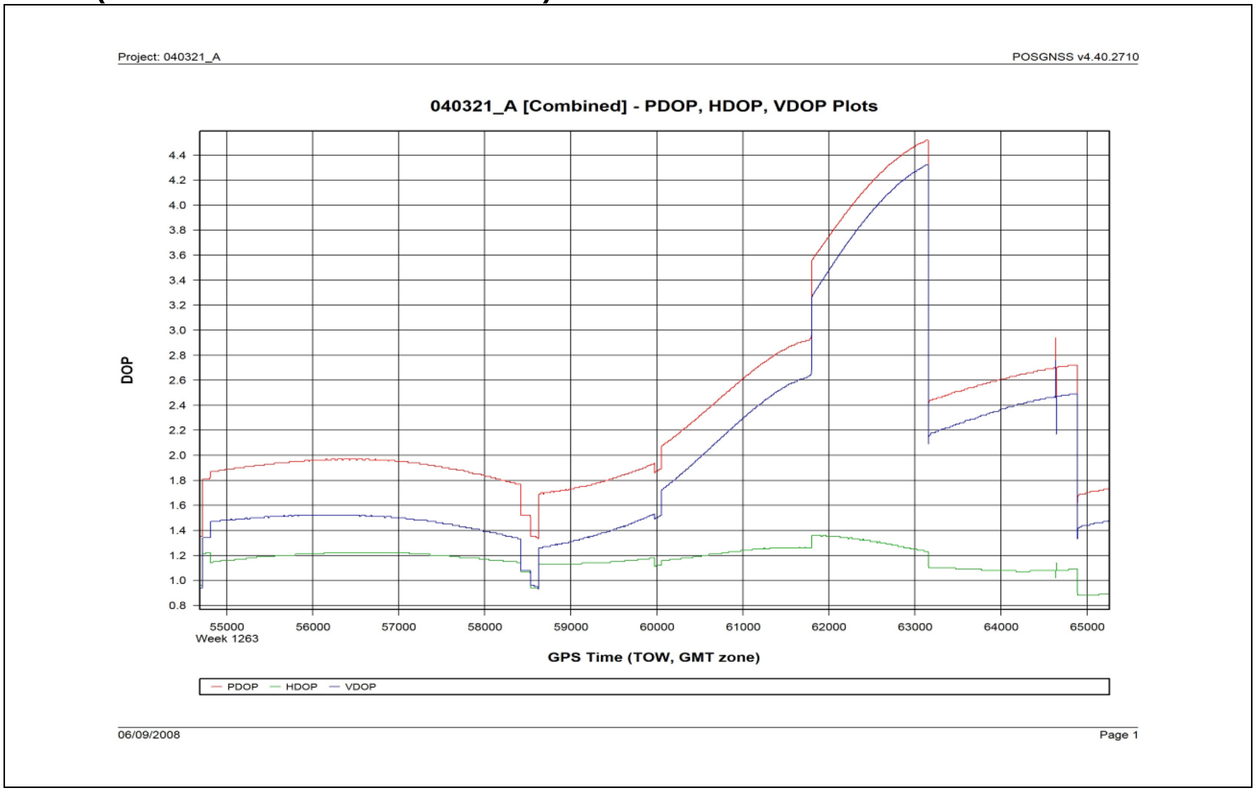
PDOP (Positional Dilution Of Precision) Plot for mission 040320A



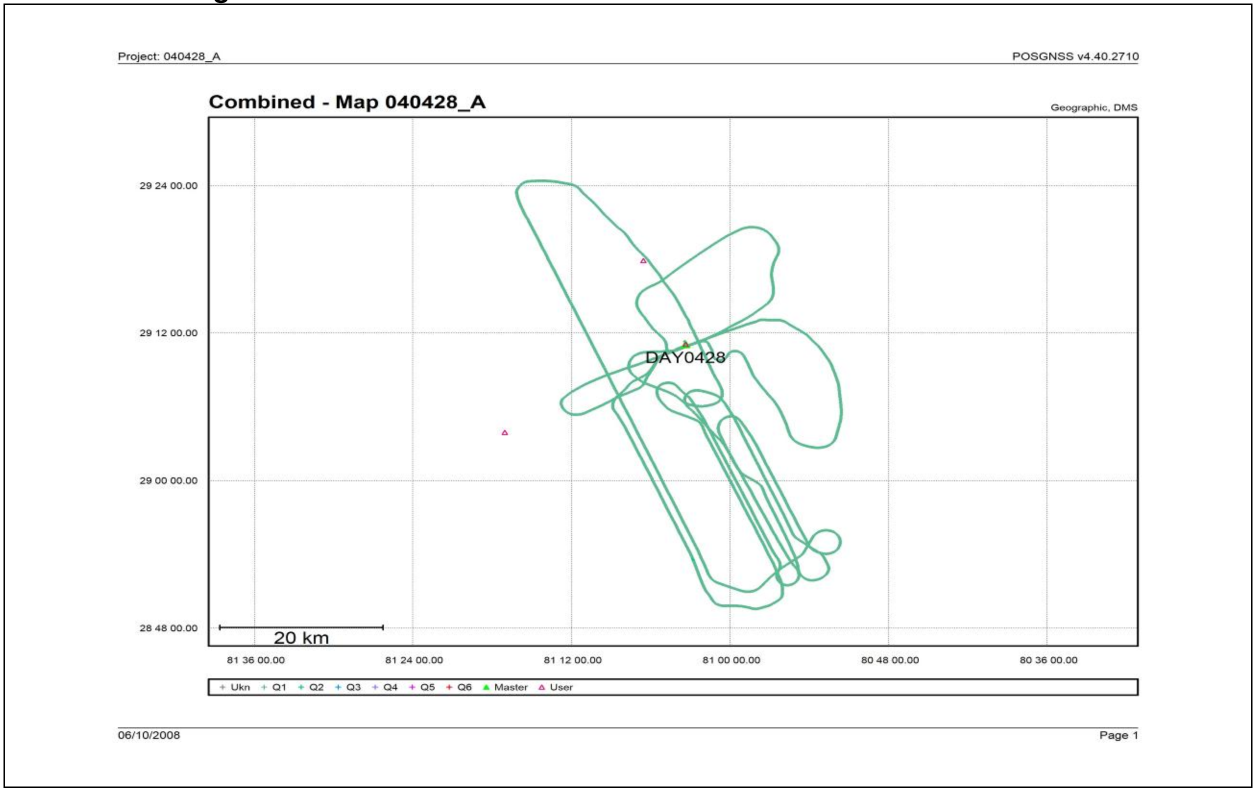
GPS derived flight tracks for mission 040321A



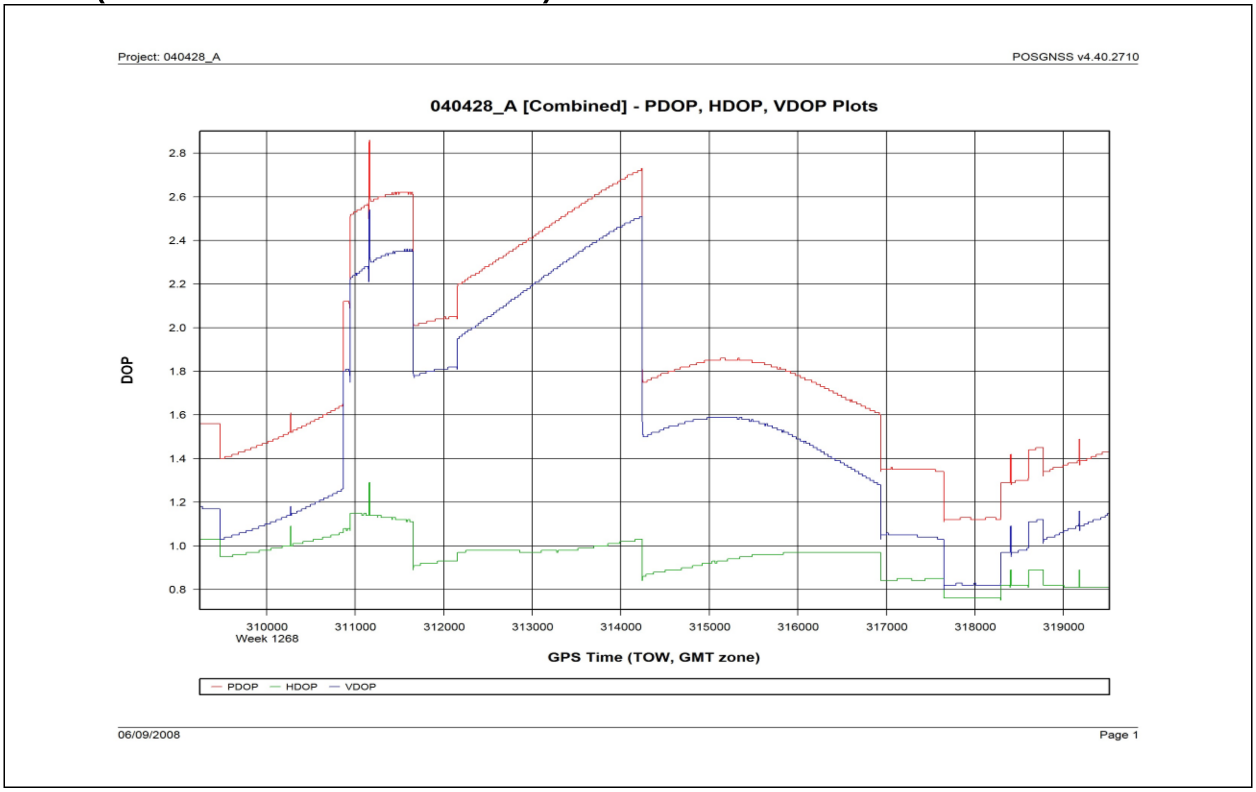
PDOP (Positional Dilution Of Precision) Plot for mission 040321A



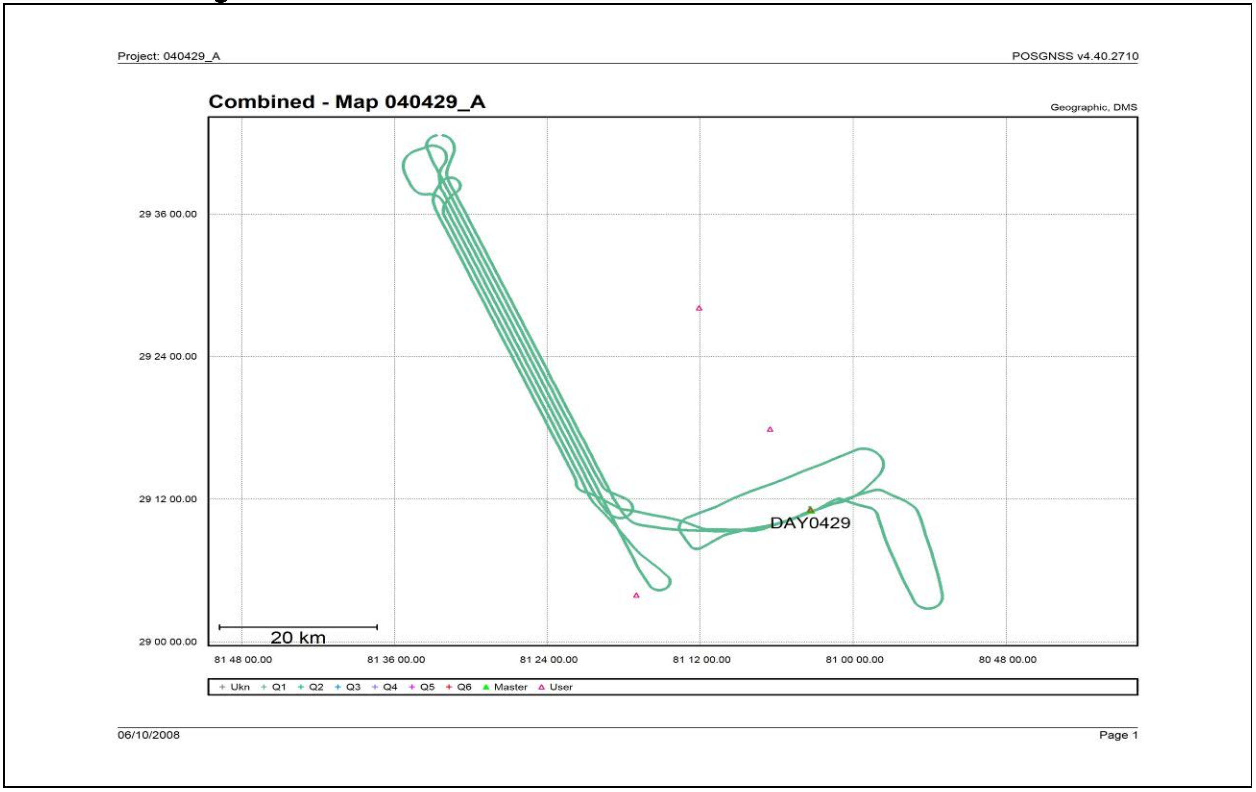
GPS derived flight tracks for mission 040428A



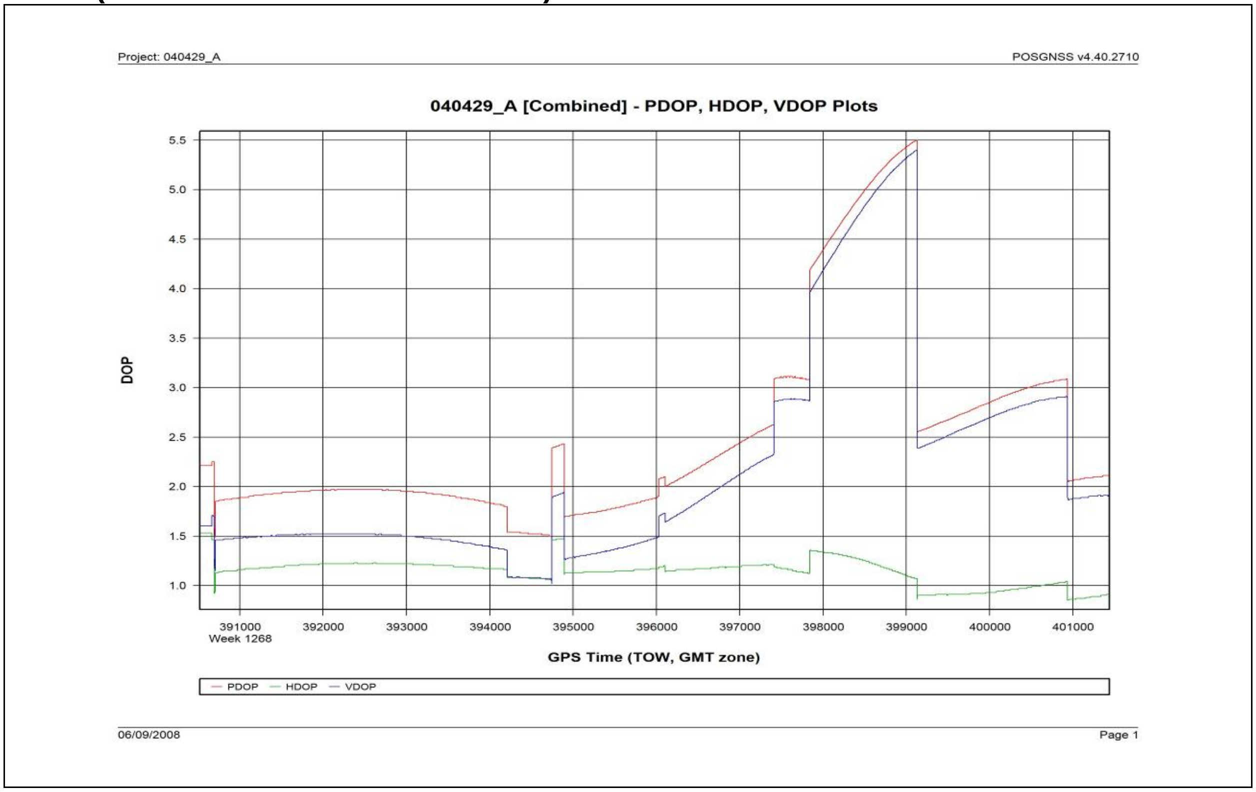
PDOP (Positional Dilution Of Precision) Plot for mission 040428A



GPS derived flight tracks for mission 040429A

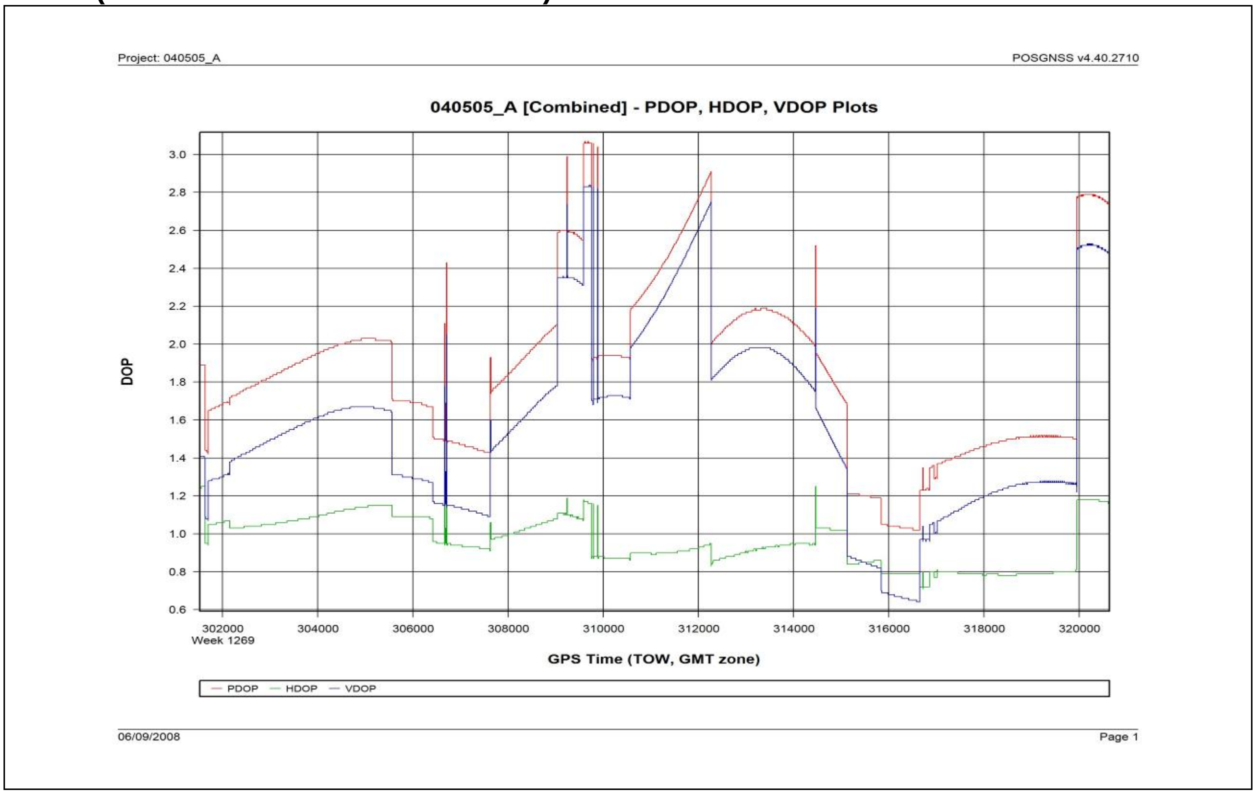


PDOP (Positional Dilution Of Precision) Plot for mission 040429A



GPS derived flight tracks for mission 040505A

PDOP (Positional Dilution Of Precision) Plot for mission 040505A



LiDAR Data Processing

The airborne GPS data was post-processed using Waypoint's GravNAV software version 4.2. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, LiDAR acquisition was limited to periods when the PDOP (Positional Dilution Of Precision) was less than 4.0. PDOP indicates satellite geometry relating to position. Generally PDOP's of 4.0 or less result in a good solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. HDOP stands for Horizontal Dilution Of Precision and VDOP stands for Vertical Dilution Of Precision. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. Basically this is difference between the two trajectories. Also analysis of the number of satellites present during the flight and data collection times.

The GPS trajectory was combined with the raw IMU data and post-processed using POSPac version 4.2. The smoothed best estimated trajectory (SBET) and refined attitude data are then utilized in the ALS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to three return values are produced within the ALS Post Processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

Laser point classification was completed using Merrick Advanced Remote Sensing (MARS®) LiDAR processing and modeling software. Several algorithms are used when comparing points to determine the best automatic ground solution. Each filter is built based on the projects terrain and land cover to provide a surface that is 90% free of anomalies and artifacts. After the auto filter has been completed the data is then reviewed by an operator utilizing MARS® to remove any other anomalies or artifacts not resolved by the automated filter process. During these final steps the operator also verifies that the data set is consistent and complete with no data voids.

Note: The high PDOP (5.4) shown on the charts above for mission 040309 did not occur during any LiDAR data collection period. The high PDOP for mission 040309 occurred before any flight lines were flown. The high PDOP (max. 5.5) shown on the charts above for mission 040429 did occur during the LiDAR data collection period, however further analysis of this high PDOP period showed good results.

GROUND CONTROL REPORT / CHECK POINT SURVEY RESULTS

GPS Controls

Three ground Airborne GPS Base Stations, for the LiDAR data collection, were set up every mission, one main ground GPS receiver located at the Daytona Beach Regional Airport, another ground GPS receiver located at the Deland Airport and another ground GPS receiver located at the Flagler Airport. Also the Ormond CORS Station was used as a Check Base Station. The airborne GPS base stations were tied directly to each other by post processing using Trimble Geomatics Office Software version 1.62.

See Spreadsheet Below for Airborne GPS Base Station information.

Project: Daytona Beach Florida
Job#: 02015783
Date: June 2008

Coordinate System: US State Plane 1983 Florida East 0901
Zone: Florida East 0901
Project Datum: NAD 1983 (Conus)
Vertical Datum: NAVD88 (GEOID2003)
Units: US survey feet (Meters as labeled)

Pt#	Geodetic NAD83		Ellipsoid	Description
Name	Latitude	Longitude	Height	
	North	West	Geoid2003	
	Deg Min Sec	Deg Min Sec	US Feet	
Daytona_Base	29°11'05.45857"N	81°03'21.38452"W	-64.66	Daytona_Base
Deland_Base	29°03'54.64824"N	81°17'01.94245"W	-19.09	Deland_Base
Flagler_Base	29°28'05.20197"N	81°12'06.50055"W	-64.84	Flagler_Base
CORS_Ormond	29°17'53.46960"N	81°06'32.02459"W	-59.84	CORS_Ormond

Pt#	SP NAD83(1999) Zone Florida East		NAVD88	Description
Name	Northing	Easting	Elevation	
	Y	X	Z	
	US Feet	US Feet	US Feet	
Daytona_Base	1763508.16	638316.63	28.37	Daytona_Base
Deland_Base	1720098.93	565480.07	73.11	Deland_Base
Flagler_Base	1866562.13	591949.78	29.19	Flagler_Base
CORS_Ormond	1804732.05	621457.21	33.60	CORS_Ormond

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is NAD83 (1999) (North American Datum of 1983, adjustment 1999) (NAD 83/99).

Coordinate System: The project coordinate system is NAD83 (1999) State Plane, Zone Florida East.

Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88).

Geiod Model: Geoid03 (Geoid 03 will be used to convert ellipsoid heights to orthometric heights).

Units: Horizontal units are in US Survey Feet, Vertical units are in US Survey Feet.

Ground Survey Control

The following listing shows the newly established GPS ground control, collected for LiDAR check points. The new ground control points (check points) were established and surveyed by JEA (Jones Edmunds & Associates) Surveyors and Engineers.

JEA_id	Northing	Easting	Elev	Comments
GC31	1650498.276	634055.78	21.6	JEA
GC10	1718854.035	560049.286	85.912	JEA
GC14	1640954.966	610679.871	40.247	JEA
GC16	1747639.421	565352.751	50.138	JEA
GC17	1658930.567	580062.66	92.16	JEA
GC30	1702094.198	560173.81	20.825	JEA
AC02	1790291.924	620124.784	22.918	JEA
V005	1650498.628	634033.065	20.519	JEA (NGS PID AK7051)
AC04	1747554.733	565260.431	49.64	JEA
AC05	1702301.146	560211.083	21.429	JEA
GC26	1675171.726	623379.562	36.357	JEA
71_A10	1678432.281	671940.519	24.279	JEA (NGS PID AK0520)
GC01	1804458.279	553177.267	26.356	JEA
GC03	1846501.215	542491.375	10.669	JEA
GC08	1882705.473	497736.698	8.609	JEA
GC11	1778578.596	553635.401	41.087	JEA
GC29	1762673.99	556407.24	48.455	JEA
GC34	1871372.729	522372.394	21.344	JEA
GC15	1698357.366	633781.797	38.336	JEA
GC21	1708271.697	600866.447	41.793	JEA
GC23	1674962.349	598396.093	54.66	JEA
GC25	1701893.726	662976.814	26.422	JEA
GC32	1678378.446	670767.986	24.306	JEA
GC33	1685963.955	689520.317	10.55	JEA
AC10	1675240.544	598737.453	52.057	JEA

AC12	1645921.079	704398.079	8.8	JEA
AC11	1646854.374	704226.84	19.974	JEA
GC28	1920086.559	540006.027	41.095	JEA
GC05	1920625.821	567393.234	25.355	JEA
GC13	1844564.419	617394.49	4.159	JEA
GC19	1879686.721	557327.874	28.771	JEA
GC24	1898732.223	589186.94	21.51	JEA
GC02	1919956.404	507564.737	16.699	JEA
GC60	1877455.487	612436.73	4.214	JEA
GC04	1869125.074	590279.307	28.336	JEA
GC07	1845176.65	579382.985	24.635	JEA
GC51	1897330.875	567714.092	31.219	JEA
AC56	1821596.986	558161.115	14.024	JEA (F611-DEP)
GC57	1832624.133	598978.91	27.95	JEA
GC18	1783451.444	638141.558	8.668	JEA
GC12	1818072.613	615243.458	30.707	JEA
AC09	1747039.734	614442.852	38.767	JEA
DC05	1757265.138	663058.135	17.261	JEA
DC02	1759548.563	646780.183	11.314	JEA
DC03	1742253.989	654935.539	8.985	JEA
DC04	1714212.033	676229.203	9.922	JEA
DC01	1758660.702	597987.462	35.524	JEA
AC03	1790022.894	583564.255	30.554	JEA

LiDAR Control Report (LiDAR Accuracy / Validation Results)

The following listing shows the results of the LiDAR data compared to the GPS ground survey control data. The listing is sorted by the **Z Error** column showing, in ascending order, the vertical difference between the LiDAR points and the surveyed ground control points.

Project File	Daytona_Beach_Area
Vertical Accuracy Objective:	
Requirement Type	Accuracy(z)
Accuracy(z) Objective	1
Confidence Level	95%
Control Points in Report	48
Elevation Calculation Method	Interpolated from TIN
Control Points with LiDAR Coverage	46
Control Points with Required Accuracy (+/- 1.00)	46
Percent of Control Points with Required Accuracy (+/- 1.00)	100
Average Control Error Reported	-0.03

Maximum (highest) Control Error Reported	0.42
Median Control Error Reported	0.01
Minimum (lowest) Control Error Reported	-0.46
Standard deviation (sigma) of Z for sample	0.19
RMSE of Z for sample (RMSE(z)) PASS	0.19
FGDC/NSSDA Vertical Accuracy (Accuracy(z)) PASS	0.37
NSSDA Achievable Contour Interval	0.70
ASPRS Class 1 Achievable Contour Interval	0.60
NMAS Achievable Contour Interval	0.70

Control Point Id	Control Pt. X(East) USFeet	Control Pt. Y(North) USFeet	Coverage	Control Pt. Z(Elev) USFeet	from LiDAR Z(Elev) USFeet	**Z Error** USFeet	Min Z USFeet	Median Z USFeet	Max Z USFeet
GC18	638141.56	1783451.44	Yes	8.67	8.21	-0.46	8.13	8.27	8.35
DC05	663058.14	1757265.14	Yes	17.26	16.83	-0.44	16.58	16.84	17.08
GC51	567714.09	1897330.88	Yes	31.22	30.87	-0.35	30.67	30.85	31.01
AC02	620124.78	1790291.92	Yes	22.92	22.66	-0.26	22.52	22.58	22.74
AC03	583564.26	1790022.89	Yes	30.55	30.29	-0.26	30.27	30.29	30.4
DC03	654935.54	1742253.99	Yes	8.98	8.74	-0.25	8.66	8.86	8.89
GC24	589186.94	1898732.22	Yes	21.51	21.28	-0.23	20.99	21.16	21.4
DC02	646780.18	1759548.56	Yes	11.31	11.09	-0.23	10.9	11.04	11.21
GC31	634055.78	1650498.28	Yes	21.6	21.38	-0.22	21.36	21.39	21.58
GC08	497736.7	1882705.47	Yes	8.61	8.42	-0.19	8.41	8.41	8.51
GC16	565352.75	1747639.42	Yes	50.14	49.96	-0.18	49.78	50.09	50.31
GC60	612436.73	1877455.49	Yes	4.21	4.04	-0.17	3.57	3.67	4.24
GC32	670767.99	1678378.45	Yes	24.31	24.16	-0.15	24.03	24.24	24.37
GC33	689520.32	1685963.96	Yes	10.55	10.40	-0.15	10.34	10.48	10.56
GC07	579382.98	1845176.65	Yes	24.64	24.49	-0.14	24.43	24.50	24.50
GC34	522372.39	1871372.73	Yes	21.34	21.21	-0.13	21.12	21.23	21.25
GC12	615243.46	1818072.61	Yes	30.71	30.62	-0.09	29.83	30.54	30.96
GC03	542491.38	1846501.22	Yes	10.67	10.59	-0.08	10.45	10.61	10.69
GC11	553635.40	1778578.60	Yes	41.09	41.01	-0.08	40.93	40.99	41.02
GC14	610679.87	1640954.97	Yes	40.25	40.19	-0.06	40.18	40.23	40.26
V005	634033.06	1650498.63	Yes	20.52	20.46	-0.06	19.56	20.94	20.95
GC25	662976.81	1701893.73	Yes	26.42	26.41	-0.01	26.36	26.50	26.64
DC04	676229.20	1714212.03	Yes	9.92	9.93	0.00	9.91	9.91	9.93
GC13	617394.49	1844564.42	Yes	4.16	4.17	0.01	3.98	4.19	4.25
AC04	565260.43	1747554.73	Yes	49.64	49.67	0.03	49.46	49.60	49.71
GC21	600866.45	1708271.70	Yes	41.79	41.83	0.04	41.79	41.82	41.93
GC10	560049.29	1718854.03	Yes	85.91	85.97	0.05	85.92	85.94	86.07
GC19	557327.87	1879686.72	Yes	28.77	28.82	0.05	28.56	28.76	28.89
GC30	560173.81	1702094.20	Yes	20.82	20.91	0.08	20.79	20.92	21.06

AC56	558161.11	1821596.99	Yes	14.02	14.10	0.08	13.99	14.12	14.13
GC15	633781.80	1698357.37	Yes	38.34	38.43	0.09	38.17	38.47	38.51
GC02	507564.74	1919956.40	Yes	16.70	16.79	0.09	16.75	16.78	16.81
GC29	556407.24	1762673.99	Yes	48.45	48.55	0.10	48.49	48.65	48.70
GC05	567393.23	1920625.82	Yes	25.36	25.49	0.13	25.45	25.49	25.60
AC05	560211.08	1702301.15	Yes	21.43	21.57	0.14	21.42	21.92	21.92
GC23	598396.09	1674962.35	Yes	54.66	54.80	0.14	54.55	54.78	54.81
AC10	598737.45	1675240.54	Yes	52.06	52.20	0.14	52.07	52.12	52.25
GC17	580062.66	1658930.57	Yes	92.16	92.31	0.15	92.18	92.25	92.41
GC04	590279.31	1869125.07	Yes	28.34	28.49	0.15	28.15	28.44	28.87
GC57	598978.91	1832624.13	Yes	27.95	28.10	0.15	28.03	28.11	28.11
DC01	597987.46	1758660.70	Yes	35.52	35.69	0.16	35.45	35.71	35.87
GC26	623379.56	1675171.73	Yes	36.36	36.53	0.17	36.48	36.52	36.60
GC01	553177.27	1804458.28	Yes	26.36	26.55	0.19	26.48	26.54	26.57
GC28	540006.03	1920086.56	Yes	41.09	41.30	0.21	41.26	41.30	41.60
AC09	614442.85	1747039.73	Yes	38.77	39.00	0.24	38.90	39.01	39.11
71_A10	671940.52	1678432.28	Yes	24.28	24.70	0.42	24.67	24.72	24.73

LiDAR CALIBRATION

Introduction

A LiDAR calibration or 'boresight' is performed on every mission to determine and eliminate systemic biases that occur within the hardware of the Leica ALS40 laser scanning system, the inertial measurement unit (IMU), and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include roll, pitch, and heading.

Calibration Procedures

In order to correct the error in the data, misalignments of features in the overlap areas of the LiDAR flightlines must be detected and measured. At some point within the mission, a specific flight pattern must be flown which shows all the misalignments that can be present. Typically, Merrick flies a pattern of at least three opposing direction and overlapping lines, three of which provide all the information required to calibrate the system.

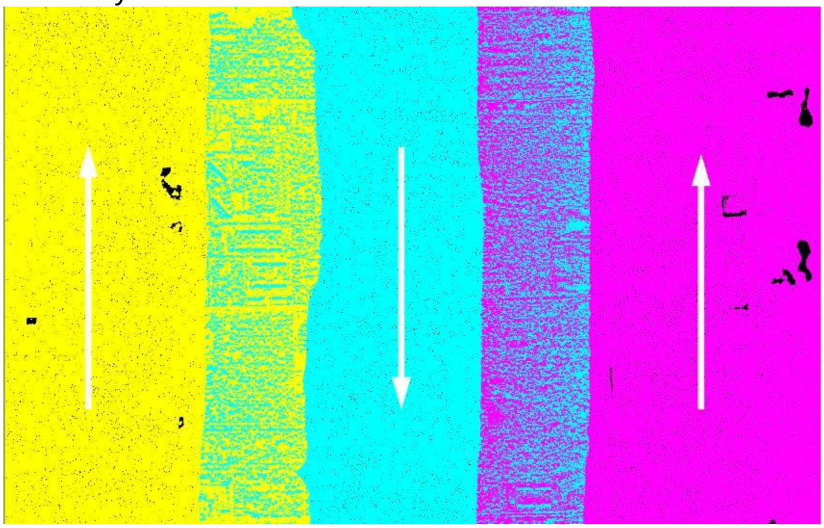


Figure 1: Flight pattern required for calibration

Correcting for Pitch and Heading Biases

There are many settings in the ALS40/50 post processor that can be used to manipulate the data; six are used for boresighting. They are roll, pitch, heading, torsion, range and atmospheric correction. The order in which each is evaluated is not very important and may be left to the discretion of the operator. For this discussion, pitch and heading will be evaluated first. It is important to remember that combinations of error can be very confusing, and this is especially true with pitch and heading. They affect the data in similar ways, so error attributed to pitch may be better blamed on heading and vice versa. To see a pitch/heading error, one must use the profile tool to cut along the flight path at a pitched roof or any elevation feature that is perpendicular to the flight path. View the data by elevation to locate these scenarios.

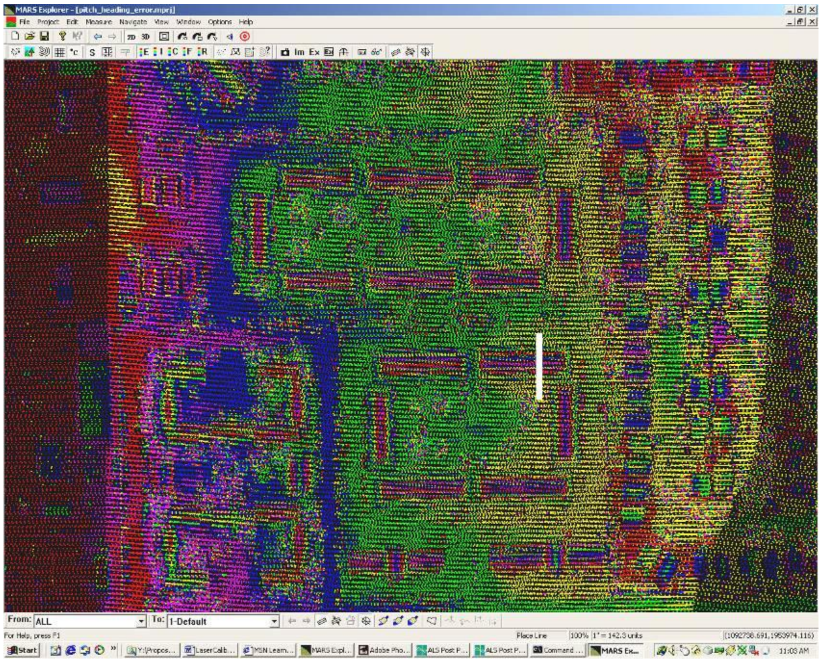


Figure 2: Orthographic view with profile line

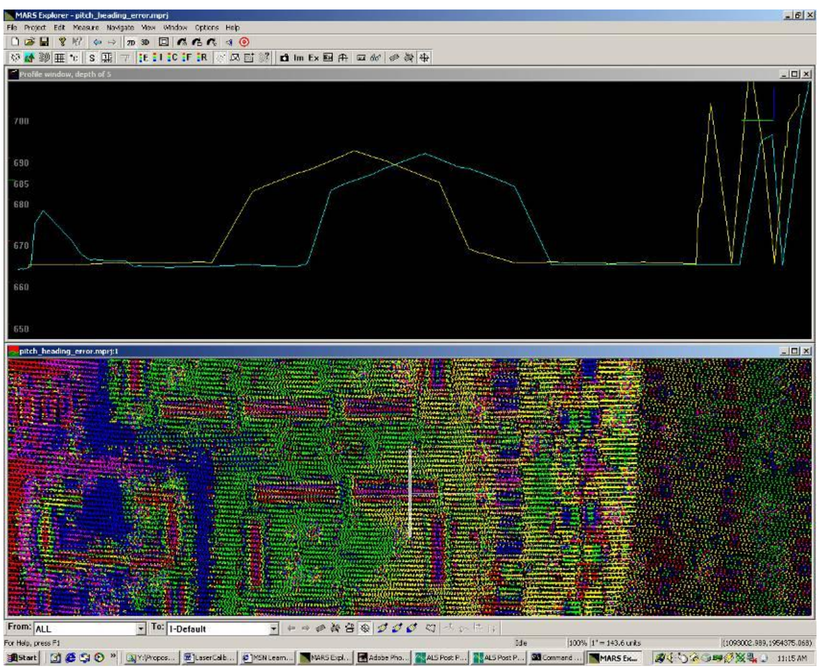


Figure 3: Profile view of misalignment

The profile line in figures 2 and 3 has an additional thin line perpendicular to the cut that shows the direction of the view. In this case, the line is pointing to the right, or east. In the profile window, we are looking through two separate TINs, so there are two lines showing the location of the same building. The yellow line is from the flight line on the left (flown north); the light blue line is from the flight line in the middle (flown south).

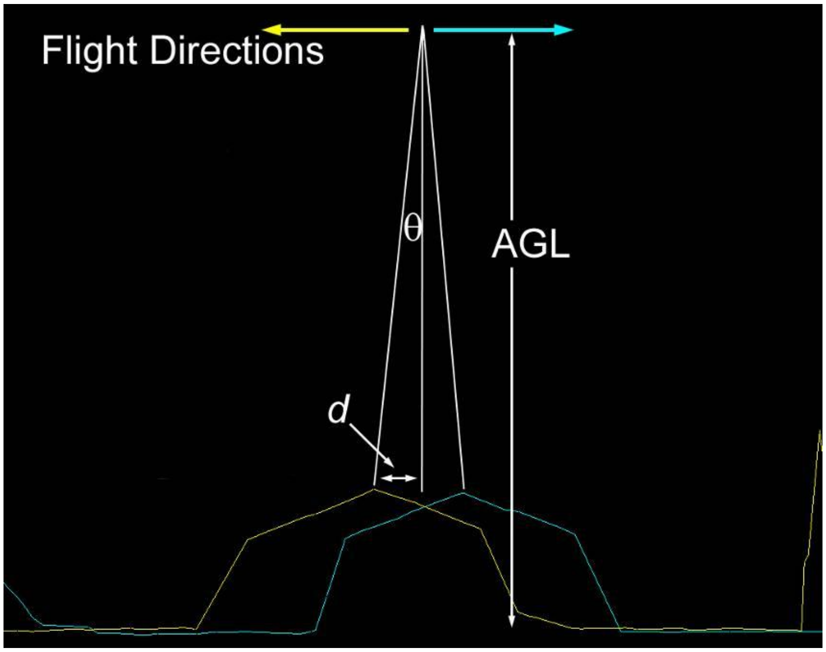


Figure 4: Adjusting pitch

The top arrows represent each respective flight direction. We are looking east, the yellow flight line was flown north, and the blue line is flown south. Adjusting pitch changes the relationship between the pitch from the IMU and the actual pitch of the plane. Increasing pitch sends the nose of the plane up and the data ahead in the flight direction. Lowering pitch does the opposite. In this example, pitch needs to decrease in order to bring these two roof lines together. The angle thetạ must be expressed in radians. The formula to arrive at this angle is…

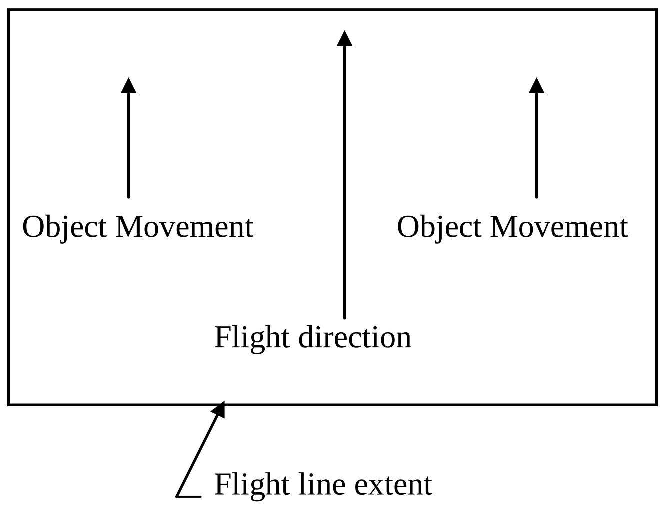
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

where *d* is the distance from nadir (directly under the plane) to the peak of the roof and AGL is the 'above ground level' of the plane. The conversion from degrees to radians is one radian equals 57.2958 degrees. This number is then subtracted from the pitch value that was used to create the data.

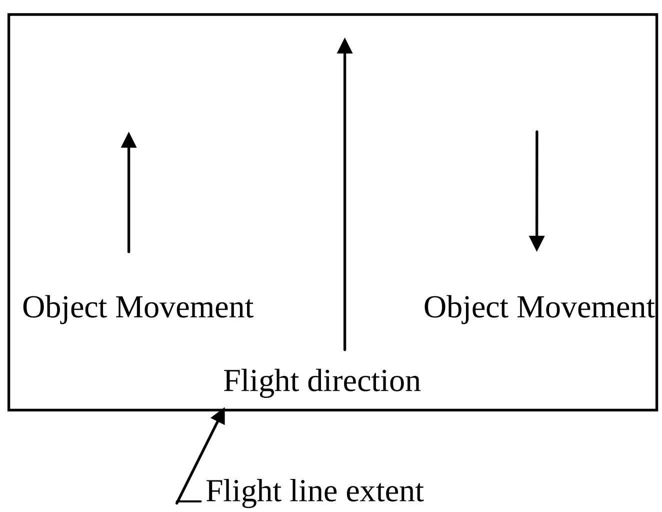
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects on opposite sides of the swath move in opposite directions.

Figures 5 and 6: Pitch and Heading movement

Pitch increases, objects throughout the data move forward.



Heading increases, objects move clockwise.



When heading changes, objects on the sides of the flight line move in opposite directions. If heading is increased, objects in the flight line move in a clockwise direction. If heading is decreased, objects move in a counter-clockwise direction.

To find out if heading is correct, a similar profile line must be made in the overlap area between the middle flight line and the one to the east, or right side. If the distance *d* (see figure 4) is different on the right verses the left, then heading is partially responsible for the error. If the distance *d* is the same on both sides then heading *or* pitch is fully responsible.

Correcting for the Roll Bias

The purpose of a 'truth survey' is to evaluate roll and to ensure that the surface is accurate vertically. This survey is typically done in a localized area and the purpose is to provide a truth reference to every mission and to help in the calibration effort. Since every mission's data must be compared to this survey, it makes sense for this survey to be done at a place where the plane will be for every mission, i.e., the airport. The survey is done along a taxiway or runway, and the calibration flight lines are flown perpendicular to it, which makes it perfect for evaluating roll.

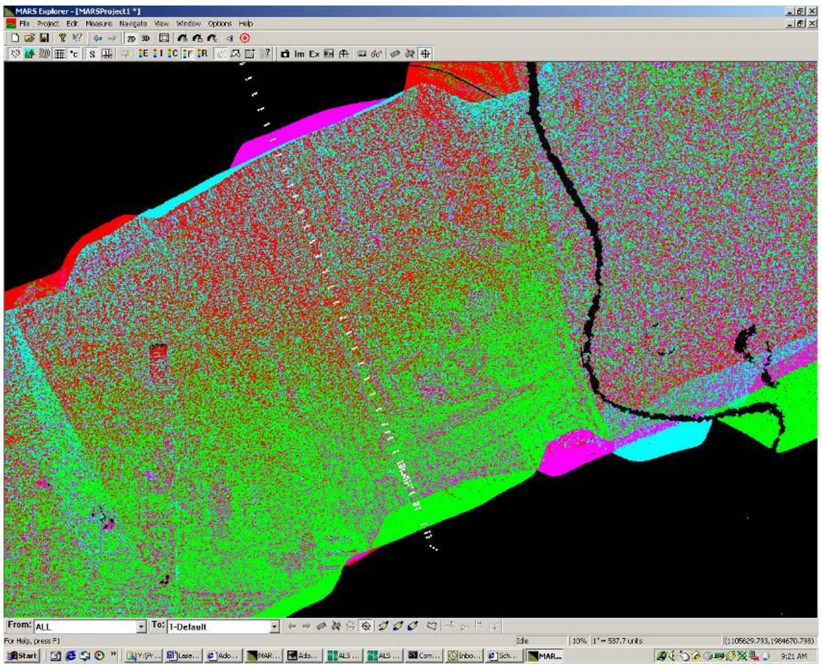


Figure 7: The truth survey

The white dots represent the survey, and four flight lines, two from the beginning of the mission and two from the end, have been flown. Each pair of flight lines was flown in opposite directions, and in this case the red and blue lines were flown east and the green and magenta lines were flown west. The first step is to make a profile line across the survey. It is important to create this cut on one side of the taxiway so as to avoid cutting through and over the crown. Once the profile is created, exaggeration of the elevation by 100 times is necessary to see the pattern. (figure 8)

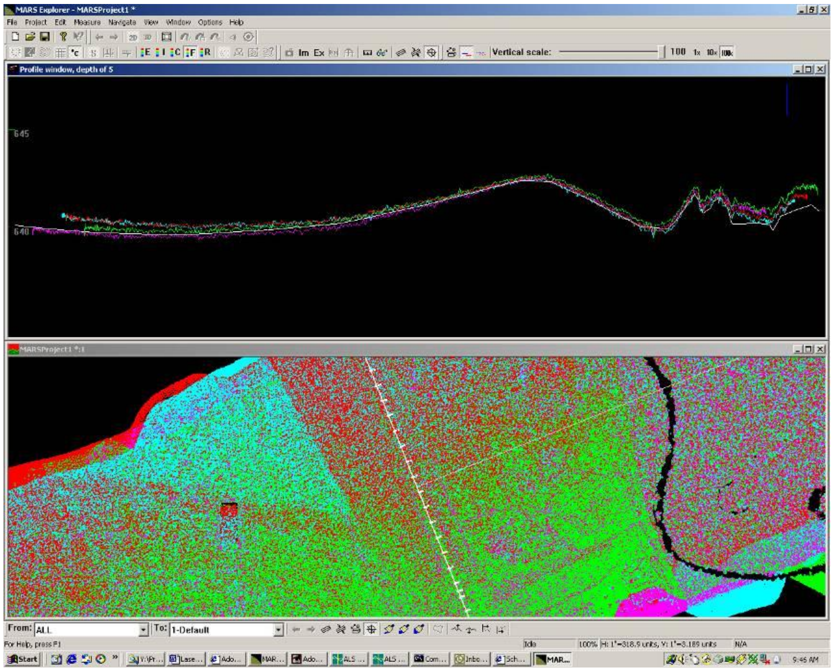


Figure 8: Profile view of calibration flight lines

Even without zooming in, a pattern is already apparent. The two east flown lines, red and blue, are high on the left compared to the west flown lines, and low on the right. Since the profile line was created with the view eastward, it is easiest to think about what the east lines are doing. The east lines are low on the right, which means the relationship between the IMU and the right wing of the plane must be adjusted up. As in heading adjustments, sending the data in a clockwise direction is positive. If the axis of the clock is the tail/nose axis of the plane, then it is obvious this data must go in a counter clock-wise, or negative direction. The method for determining the magnitude of the adjustment is similar to determining the magnitude of the adjustment for the pitch. The only difference is how the triangles are drawn in relationship to the data. (figures 9 and 10)

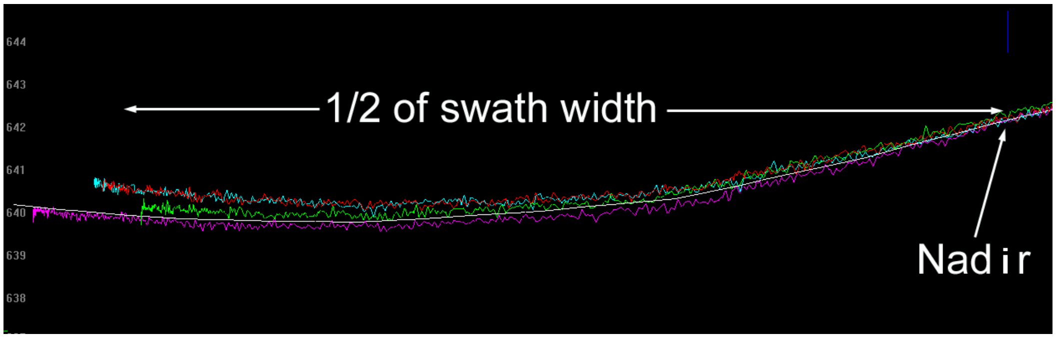


Figure 9: Half of calibration profile

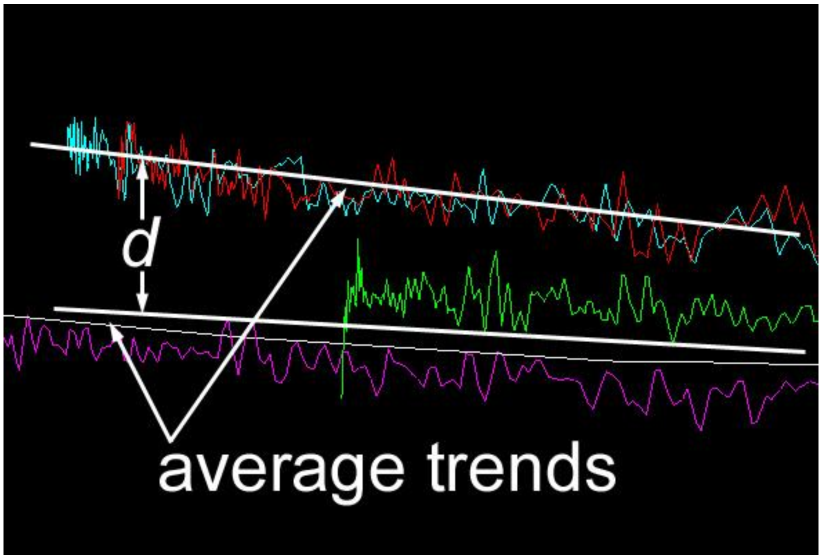


Figure 10: Differences in average roll trends

The important measurements for this formula are the distance from nadir to the edge of the swath, or ½ swath width, and d, the distance from the two average trend lines for each group. Since any adjustments made to roll effect both east and west lines, we are really interested in ½ d; this will give the value that will bring both sets of lines together. The formula is:

$$\theta = \frac{\arctan\left(\dfrac{d/2}{EdgeToNadir}\right)}{57.2958}$$

Correcting the Final Elevation

The next step is to ensure that all missions have the same vertical offset. Two techniques are used to achieve this. The first is to compare all calibration flight lines and shift the missions appropriately. The second is to fly an extra 'cross flight' which touches all flight lines in the project. Each mission's vertical differences can then be analyzed and corrected. However, the result of this exercise is only proof of a high level of relative accuracy. Since many of the calibration techniques affect elevation, project wide GPS control must be utilized to place the surface in the correct location. This can be achieved by utilizing the elevation offset control in the post processor or by shifting the data appropriately in MARS®. The control network may be pre-existing or collected by a licensed surveyor. This is always the last step and is the only way to achieve the high absolute accuracy that is the overall goal.

Data Collection and Contour Generation

Drainage Breaklines

Merrick uses a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring LiDAR bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage centerline in 2D with the elevation being attributed directly from the bare-earth .LAS data. Merrick's proprietary MARS® software has the capability of "flipping" views between the TIN and ortho imagery, as necessary, to further assist in the determination of the drainage centerline. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a 5' search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent point remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow.

This methodology may differ from those of other vendors in that Merrick relies on the bare-earth data to attribute breakline elevations. As a result of our methodology, there is no mismatch between LiDAR bare-earth data and breaklines that might otherwise be collected in stereo 3D as a separate process. This is particularly important in densely vegetated areas, such as Flagler County, where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically), the more reliable LiDAR bare-earth data.

Merrick has the capability of "draping" 2D breaklines to a bare-earth elevation model to attribute the "z" as opposed to the forced downhill attribution methodology described above. However, the problem with this process is the "pooling"effect or depressions along the drainagway caused by a lack of consistent penetration in densely vegetated areas.

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. Ortho imagery is also used, as necessary, to determine the waterbody outline. The elevation attribute is determined as a post-process using the lowest determined bare-earth point within the polygon.

Contour Generation

Prior to contour generation, breaklines are buffered to remove points within 1 foot. This enhances the aesthetics of the final contours. Contours are generated using MARS® proprietary software at the desired contour interval. Topology QC checks are completed for breaklines and contours based script provided by the Dewberry. Additional QC checks for dangles and appropriate attribution are also completed before shipment.

Flagler County QC Checklist

Geodatabase Technical Specifications

QC Checked	Checked By	Comment
Completeness of Coverage for Each Feature Class		
☐ Mass Point		
☐ Footprint		
☐ Coastal Shoreline		
☐ Contour 1 - Ft		
☐ Contour 2 - Ft		
☐ Ground Control Points		
☐ Vertical Control Points		
☐ Linear Hydrographic		
☐ Island		
☐ Closed Waterbody		
☐ Low Confidence		
☐ Overpasses / Bridges		
☐ Road Breakline		
☐ Soft Features		
☐ Geodatabase schema matches target schema		
Checked topology rules (all tiles)		
☐ Breaklines (client provided script)		
☐ Contours (client provided script)		
☐ Dangles		
☐ Attribution		

LiDAR Technical Specifications

QC Checked	Checked By	
☐ Tiles show complete LAS coverage		
☐ LAS header information correct		
☐ LAS classifications per project specifications		
☐ LAS filtering completed		
☐ LAS range values validated		
☐ Vertical accuracy tests completed		
☐ Horizontal accuracy tests completed		
☐ Flightline calibration completed		
☐ Ground sampling distance validated		

LiDAR Deliverables

QC Checked	Checked By	Delivered	Delivery Date	Comment
☐ LiDAR Masspoints (LAS format)		☐ LiDAR Masspoints (LAS format)		

Geodatabase Feature Class Deliverables

QC Checked	Checked By	Delivered	Delivery Date	Comment
☐ Mass Point		☐ Mass Point		
☐ Footprint		☐ Footprint		
☐ Coastal Shoreline		☐ Coastal Shoreline		
☐ Contour 1 - Ft		☐ Contour 1 - Ft		
☐ Contour 2 - Ft		☐ Contour 2 - Ft		
☐ Ground Control Points		☐ Ground Control Points		
☐ Vertical Control Points		☐ Vertical Control Points		
☐ Linear Hydrographic		☐ Linear Hydrographic		
☐ Island		☐ Island		
☐ Closed Waterbody		☐ Closed Waterbody		
☐ Low Confidence		☐ Low Confidence		
☐ Overpasses / Bridges		☐ Overpasses / Bridges		
☐ Road Breakline		☐ Road Breakline		
☐ Soft Features		☐ Soft Features		
☐ Cutlines		☐ Cutlines		Not Applicable
☐ Ortho Checkpoints		☐ Ortho Checkpoints		Not Applicable

Metadata and Report Deliverables

QC Checked	Checked By	Delivered	Delivery Date	Comment
FGDC Metadata per Feature Class		FGDC Metadata per Feature Class		
☐ Mass Point		☐ Mass Point		
☐ Footprint		☐ Footprint		
☐ Coastal Shoreline		☐ Coastal Shoreline		
☐ Contour 1 - Ft		☐ Contour 1 - Ft		
☐ Contour 2 - Ft		☐ Contour 2 - Ft		
☐ Ground Control Points		☐ Ground Control Points		
☐ Vertical Control Points		☐ Vertical Control Points		
☐ Linear Hydrographic		☐ Linear Hydrographic		
☐ Island		☐ Island		
☐ Closed Waterbody		☐ Closed Waterbody		
☐ Low Confidence		☐ Low Confidence		
☐ Overpasses / Bridges		☐ Overpasses / Bridges		
☐ Road Breakline		☐ Road Breakline		
☐ Soft Features		☐ Soft Features		
☐ Cutlines		☐ Cutlines		Not Applicable
☐ Ortho Checkpoints		☐ Ortho Checkpoints		Not Applicable
☐ Survey Report (ortho) - 2 Hardcopies				Not Applicable
☐ Survey Report (ortho) – 1 PDF				Not Applicable
☐ Orthophoto DEM				Not Applicable
☐ Survey Report (LiDAR) - 2 Hardcopies		☐ Survey Report (LiDAR) - 2 Hardcopies		
☐ Survey Report (LiDAR) - 1 PDF		☐ Survey Report (LiDAR) - 1 PDF		

☐ LiDAR Processing Report – 3 Hardcopies		☐ LiDAR Processing Report – 3 Hardcopies		
☐ LiDAR Processing Report – 1 PDF		☐ LiDAR Processing Report – 1 PDF		
☐ Vertical Control Report – 3 Hardcopies		☐ Vertical Control Report – 3 Hardcopies		
☐ Vertical Control Report – 1 PDF		☐ Vertical Control Report – 1 PDF		

Appendix E: QA/QC Checkpoints and Associated Discrepancies

Point Number	Land Cover Class		SPCS NAD83/99 East Zone Easting-X (Ft)	Northing-Y (Ft)	NAVD88 Survey-Z (Ft)	LIDAR-Z	ΔZ
FL01A	1	BE & Low Grass	519,896.29	1,850,419.63	5.03	5.04	0.01
FL02A	1	BE & Low Grass	543,387.11	1,835,819.18	9.38	9.51	0.13
FL03A	1	BE & Low Grass	556,123.32	1,866,784.41	11.60	11.64	0.04
FL04A	1	BE & Low Grass	622,356.88	1,854,521.16	18.54	18.07	-0.47
FL05A	1	BE & Low Grass	614,048.98	1,872,549.25	2.79	2.24	-0.60
FL06A	1	BE & Low Grass	601,583.07	1,869,750.01	16.31	16.01	-0.30
FL07A	1	BE & Low Grass	597,873.43	1,906,688.63	10.09	9.94	-0.15
FL08A	1	BE & Low Grass	590,386.14	1,933,869.93	5.67	5.42	-0.25
FL04	1	BE & Low Grass	622,426.96	1,854,231.35	17.94	17.75	-0.19
FL08	1	BE & Low Grass	590,383.42	1,934,132.35	6.65	6.31	-0.34
FL02B	2	Brush & Low Trees	543,438.73	1,836,245.19	6.33	6.38	0.05
FL03B	2	Brush & Low Trees	556,410.41	1,866,899.65	11.40	11.50	0.10
FL04B	2	Brush & Low Trees	622,315.94	1,854,311.52	18.53	18.15	-0.38
FL05B	2	Brush & Low Trees	613,767.61	1,872,727.22	6.25	5.58	-0.67
FL06B	2	Brush & Low Trees	601,707.04	1,869,698.90	16.96	17.43	0.47
FL07B	2	Brush & Low Trees	597,774.11	1,906,385.21	9.00	9.88	0.88
FL08B	2	Brush & Low Trees	590,614.14	1,933,594.41	8.27	8.38	0.11
FL02C	3	Forested	543,835.98	1,835,942.88	7.69	7.38	-0.31
FL03C	3	Forested	556,243.98	1,866,993.12	10.80	11.69	0.89
FL04C	3	Forested	622,087.18	1,854,573.00	16.72	16.22	-0.50
* FL05C	3	Forested	614,458.41	1,872,594.53	10.52	N/A	N/A
FL06C	3	Forested	601,166.13	1,869,747.52	20.73	19.92	-0.81
* FL07C	3	Forested	597,631.01	1,906,188.45	8.33	9.86	1.53
FL08C	3	Forested	590,376.41	1,933,811.54	6.11	5.98	-0.13
FL02D	4	Urban	543,538.33	1,836,445.07	10.66	10.38	-0.28
FL03D	4	Urban	555,681.57	1,866,989.08	16.89	16.98	0.09
FL04D	4	Urban	622,268.51	1,854,578.94	19.31	18.40	-0.91
FL05D	4	Urban	613,971.57	1,872,417.57	3.65	3.05	-0.60
FL06D	4	Urban	601,681.59	1,869,511.28	22.10	21.86	-0.24
FL07D	4	Urban	597,206.48	1,906,573.41	8.06	7.77	-0.30
FL08D	4	Urban	590,291.33	1,934,458.72	7.37	6.97	-0.40
FL01	4	Urban	519,941.92	1,850,394.27	5.55	5.25	-0.30
FL02	4	Urban	543,554.98	1,835,681.26	12.15	11.70	-0.45
FL03	4	Urban	556,050.33	1,866,847.28	17.13	17.06	-0.07
FL05	4	Urban	613,839.43	1,872,653.96	3.00	2.31	-0.69
FL06	4	Urban	601,763.97	1,869,525.88	21.48	21.27	-0.22
FL07	4	Urban	597,799.49	1,906,224.12	12.58	12.18	-0.40

Important notes regarding the vertical accuracy assessment:

* FL05C located in low confidence area, ΔZ not calculated, not used in the vertical accuracy assessment
* FL07C was located in a low confidence area and was not used in the vertical accuracy assessment

The following points, which were established as Ortho Checkpoints, were included in the assessment as additional Urban points in the assessment: FL01 through FL03 and FL06 through FL07

The following points, which were established as Ortho Checkpoints, were included in the assessment as additional Bare-earth points in the assessment: FL04 and FL08

100 % of Totals	# of Points	RMSE (ft) Spec = 0.61 (BE = 0.30)	Mean (ft)	Median (ft)	Min (ft)	Max (ft)
Consolidated	35	0.44	-0.21	-0.28	-0.81	0.89
BE & Low Grass	10	0.30	-0.21	-0.22	-0.60	0.13
Brush & Low Trees	7	0.48	0.08	0.10	-0.67	0.88
Forested	5	0.60	-0.17	-0.31	-0.81	0.89
Urban	13	0.44	-0.37	-0.30	-0.91	0.09

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Consolidated	35		0.88	
BE & Low Grass	10	0.60		0.54
Brush & Low Trees	7			0.82
Forested	5			0.87
Urban	13			0.78

Appendix F: LiDAR Vertical Accuracy Report

Vertical Accuracy Assessment Report
2007 LiDAR Bare-Earth Dataset for
Flagler County, Florida

Date: November 17, 2008

References: A — State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a
B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
C — Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003
D — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004
E — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Background
FDEM Guidance: Reference A tasked PDS to validate the bare-earth LiDAR dataset of Flagler County, FL, both quantitatively (for accuracy) and qualitatively (for usability). This report addresses the vertical accuracy assessment only, for which FDEM's major specifications are summarized as follows:

- Vertical accuracy: $\leq$ 0.30 feet $RMSE_z$ = $\leq$ 0.60 feet vertical accuracy at 95% confidence level, tested in flat, non-vegetated terrain only, employing NSSDA procedures in Reference B.
- Validation that the data also satisfies FEMA requirements in Reference C.
- Vertical units (orthometric heights) are in US Survey Feet, NAVD88.

NSSDA Guidance: Section 3.2.2 of Reference B specifies: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

FEMA Guidance: Section A.8.6 of Reference C specifies the following LiDAR testing requirement for data to be used by the National Flood Insurance Program (NFIP): "For the NFIP, TINs (and DEMs derived there from) should normally have a maximum RMSE of 18.5 centimeters, equivalent to 2-foot contours, in flat terrain; and a maximum RMSE of 37 centimeters, equivalent to 4-foot contours, in rolling to hilly terrain. The Mapping Partner shall field verify the vertical accuracy of this TIN to ensure that the 18.5- or 37.0-centimeter RMSE requirement is satisfied for all major vegetation categories that predominate within the floodplain being studied … The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following: [followed by explanations of seven potential categories]… Ground cover Categories 1 through 5 are fairly common everywhere … The assigned Mapping Partner shall select a minimum of 20 test points for each major vegetation category identified. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on."

Note: for this project PDS followed the FDEM guidelines in Reference A, which stipulates that the vertical accuracy report will be based on a minimum of 30 ground measurements for each of four land cover categories, totaling 120 test points for each 500 square mile area of new topographic data collection. Note Flagler County contained a relatively small number of tiles and there was only and average of 7 checkpoints established in each land cover category. The land cover measurements distributed through each project area will be collected for each of the following land cover categories:

1. Bare-earth and low grass
2. Brush Lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

NDEP and ASPRS Guidance: NDEP guidelines (Reference D) and ASPRS guidelines (Reference E) also recommend a minimum of 60 checkpoints, with up to 100 points preferred. (These guidelines are referenced because FEMA's next update to Appendix A will include these newer NDEP and ASPRS guidelines, now recognizing that vertical errors for LiDAR bare-earth datasets in vegetated terrain do not necessarily follow a normal error distribution as assumed by the NSSDA.)

Vertical Accuracy Test Procedures

Ground Truth Surveys: The PDS team established a primary geodetic network covering approximately 6,000 square miles along the panhandle area of Northwest Florida to provide accurate and consistent control throughout the project area, which includes Flagler County. The Primary Network was used to establish base stations to support airborne GPS data acquisition. Two Secondary control networks were established to support the measurement of checkpoints used in the accuracy validation process for newly generated LiDAR and Orthophotography.

Assessment Procedures and Results: The LiDAR accuracy assessment for Flagler County was performed in accordance with References D and E which assume that LiDAR errors in some land cover categories may not follow a normal error distribution. This assessment was also performed in accordance with References B and C which assume that LiDAR bare-earth datasets errors do follow a normal error distribution. Comparisons between the two methods help determine the degree to which *systematic errors* may exist in Flagler County's four major land cover categories: (1) bare-earth and low grass, (2) brush lands and low trees, (3) forested areas fully covered by trees, (4) urban areas. When a LiDAR bare-earth dataset passes testing by both methods, compared with criteria specified in Reference A, the dataset clearly passes all vertical accuracy testing criteria for a digital terrain model (DTM) suitable for FDEM and FEMA requirements.

The relevant testing criteria, as stipulated in Reference A are summarized in Table 1.

Table 1 — DTM Acceptance Criteria for Flagler County

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	0.60 ft (0.30 ft $RMSE_z$ x 1.96000) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual land cover categories = 95% confidence level	1.19 ft (based on 95th percentile per land cover category)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence lever	1.19 ft (based on combined 95th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

References D and E specify the mandatory determination of Fundamental Vertical Accuracy (FVA) and the optional determination of Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). FVA determines how well the LiDAR sensor performed in category (1), open terrain, where errors are random and normally distributed; whereas SVA determines how well the vegetation classification algorithms worked in land cover categories (2) and (3) where LiDAR elevations are often higher than surveyed elevations and category (4) where LiDAR elevations are often lower.

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), 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 FVA 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, as specified in Reference B. For Flagler County, for which floodplains are essentially flat, FDEM required the FVA to be 0.60 ft (18.29 cm) at the 95% confidence level (based on an $RMSE_z$ of 0.30 ft (9.14 cm), equivalent to 1 ft contours).

CVA is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. FDEM's CVA standard is 1.19 ft at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA is determined separately for each individual land cover category, again recognizing that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for bare-earth and low grass, brush lands and low trees, forested areas, and urban areas, in order to facilitate the analysis of the data based on each of these land cover categories that exist within Flagler County. The SVA criteria in Table 1 (1.19 ft at the 95% confidence level for each category) are target values only and are not mandatory; it is common for some SVA criteria to fail individual target values, yet satisfy FEMA's mandatory CVA criterion.

<u>QA/QC Steps</u>: The primary QA/QC steps used by PDS were as follows:

1. PDS surveyed "ground truth" QA/QC vertical checkpoints in accordance with guidance in references B, C, D and E. Figure 1 shows the location of "cluster areas" where PDS attempted to survey a minimum of 7 QA/QC checkpoints in each of the four land cover categories. Some cluster areas did not include all land cover categories. The final totals were 10 checkpoints in bare-earth and low grass (2 ortho checkpoints were added to this category); 7 checkpoints in brush and low trees; 5 checkpoints in forested areas (2 points were in low confidence areas and were not used); and 13 checkpoints in urban areas, for a total of 35 checkpoints (6 ortho checkpoints were added to this category).
2. Next, PDS interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 35 checkpoints.

3. PDS then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed the FVA, CVA and SVA values using procedures in References D and E.
4. The data were analyzed by PDS to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by FDEM guidelines. Also, the overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The following tables, graphs and figures illustrate the data quality.

Figure 1 shows the location of the QA/QC checkpoint clusters within Flagler County. Each point represents a checkpoint cluster. There are nominally four checkpoints in each cluster, one per land cover category.

Figure 1 — Location of QA/QC Checkpoint Clusters for Flagler County

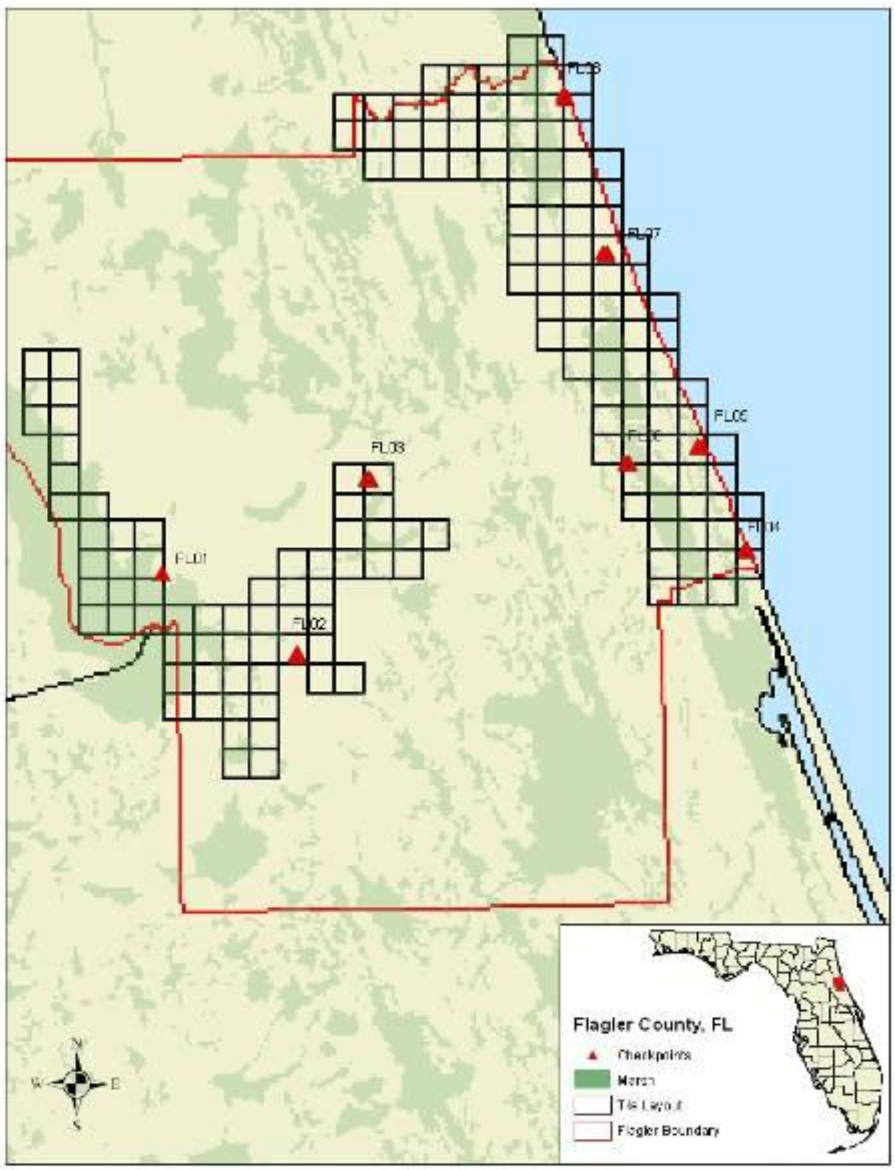


Table 2 summarizes the vertical accuracy by fundamental, consolidated and supplemental methods:

Table 2 — FVA, CVA and SVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Total Combined	35		0.88	
BE & Low Grass	10	0.60		0.54
Brush & Low Trees	7			0.82
Forested	5			0.87
Urban	13			0.78

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NDEP/ASPRS methodology:

The $RMSE_z$ in bare-earth and low grass was within the target criteria of 0.30 ft, and the FVA tested 0.60 ft at the 95% confidence level in open terrain, based on $RMSE_z$ x 1.9600.

Compared with the 1.19 ft specification, CVA tested 0.88 ft at the 95% confidence level in bare-earth and low grass, brush and low trees, forested, and urban areas combined, based on the 95th Percentile. Table 3 lists the 5% outliers larger than the 95th percentile error; whereas 5% of the points could have exceeded the 1.19 ft criterion, no points actually exceeded this criterion.

Table 3 — 5% Outliers Larger than 95th Percentile

Land Cover Category	Elevation Diff. (ft)	
		No points exceeded the 1.19 ft 95th percentile criteria

Compared with the 1.19 ft SVA target values, SVA tested 0.60 ft at the 95% confidence level in bare-earth and low grass; 0.82 ft in brush and low trees; 0.87 ft in forested areas; and 0.78 ft in urban areas, based on the 95th Percentile. Each of the four land cover categories were well within the target value of 1.19 ft.

Figure 2 illustrates the SVA by specific land cover category.

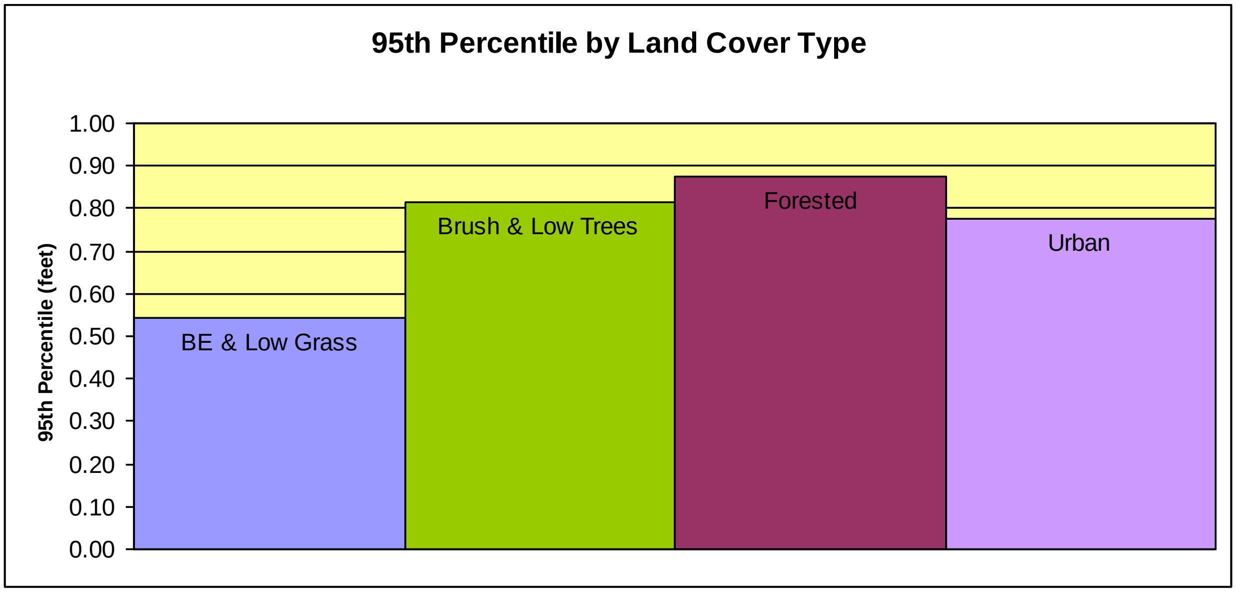


Figure 2 — Graph of SVA Values by Land Cover

Figure 3 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data by specific land cover category and sorted from lowest to highest. This shows a normal distribution of points in brush and low grass. All other land cover classifications indicate a negative skew.

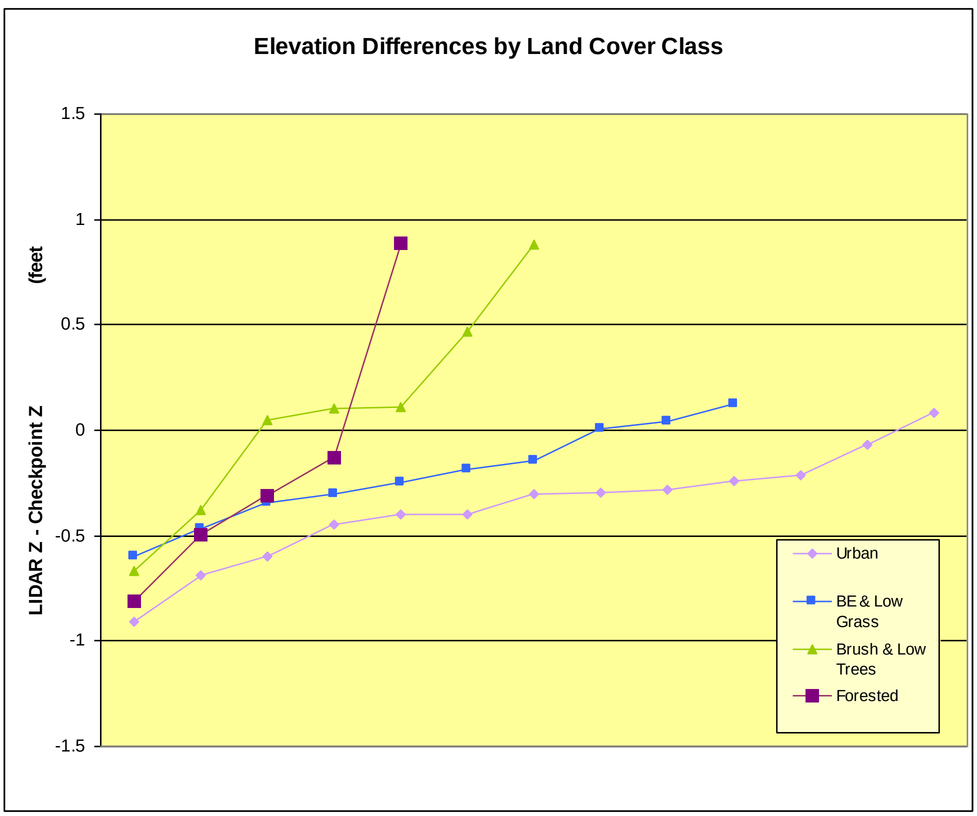


Figure 3 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA guidelines were both published before it was recognized that LiDAR errors do not always follow a normal error distribution. Future changes to these FGDC and FEMA documents are expected to follow the lead of the NDEP and ASPRS. Nevertheless, to comply with FEMA's current guidelines in Reference C, $RMSE_z$ statistics were computed in all four land cover categories, individually and combined, as well as other statistics that FEMA recommends to help identify any unusual characteristics in the LiDAR data. These statistics are summarized in Figures 4 and 5 and Table 4 below, consistent with Section A.8.6.3 of Reference C.

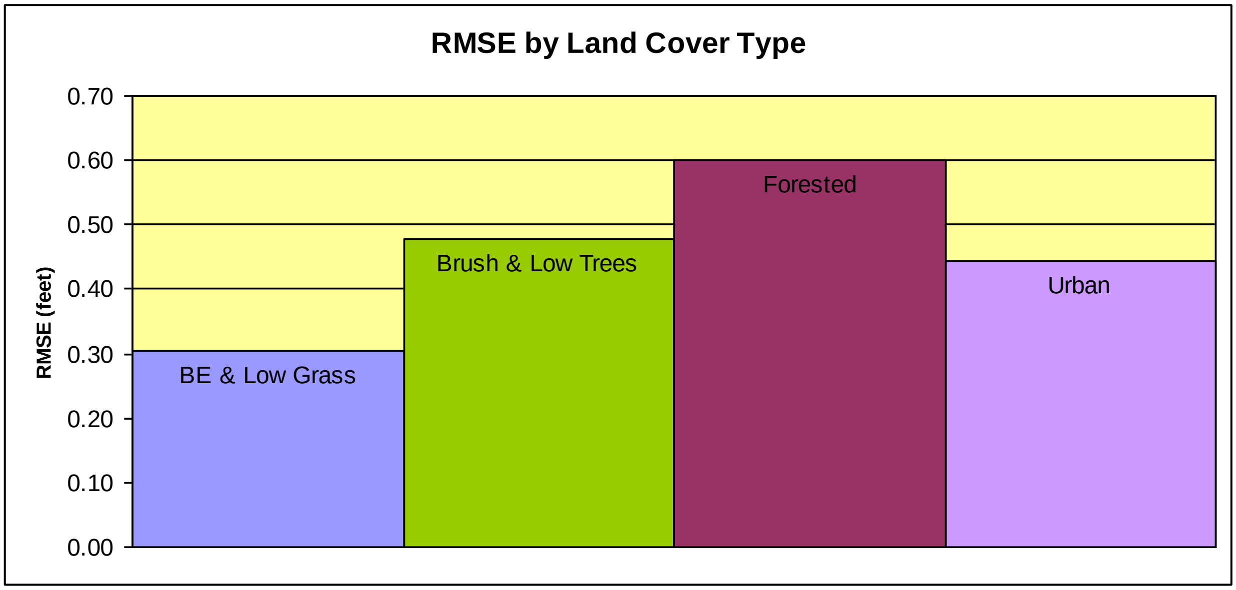


Figure 4 — $RMSE_z$ statistics by Land Cover Category

Table 4 — Overall Descriptive Statistics by Land Cover Category and Consolidated

Descriptive Statistics							
Land Cover Category	**Points**	**RMSE (feet)**	**Mean Error (feet)**	**Median Error (feet)**	**SKEW**	**STDEV (feet)**	**95th Percentile (feet)**
Consolidated	35	0.44	-0.21	-0.28	1.02	0.40	0.88
BE & Low Grass	10	0.30	-0.21	-0.22	-0.15	0.23	0.54
Brush & Low Trees	7	0.48	0.08	0.10	0.10	0.51	0.82
Forested	5	0.60	-0.17	-0.31	1.40	0.64	0.87
Urban	13	0.44	-0.37	-0.30	-0.45	0.26	0.78

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NSSDA/FEMA methodology:

Although the NSSDA and FEMA guidelines predated FVA and CVA terminology, vertical accuracy at the 95% confidence level (called $Accuracy_z$) is computed by the formula $RMSE_z$ x 1.9600. $Accuracy_z$ in open terrain = 0.30 ft x 1.9600 = 0.60 ft, satisfying the 0.60 ft FVA standard. $Accuracy_z$ in consolidated categories = 0.44 ft x 1.9600 = 0.88 ft, satisfying the 1.19 ft CVA standard.

Figure 5 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 -0.91 ft and a high of +0.89 ft, the histogram shows that the majority of the discrepancies are skewed on the negative side of what would be a "bell curve," with mean of zero, if the data were truly normally distributed. Typically the discrepancies tend to skew a bit more to the positive side, because discrepancies in vegetation are typically positive. The negative skew difference in this case, though minor, may indicate a slight systematic error. We saw no cause for concern, based on the fact that there are relatively few tiles in this county and that the checkpoints passed the vertical accuracy criterion.

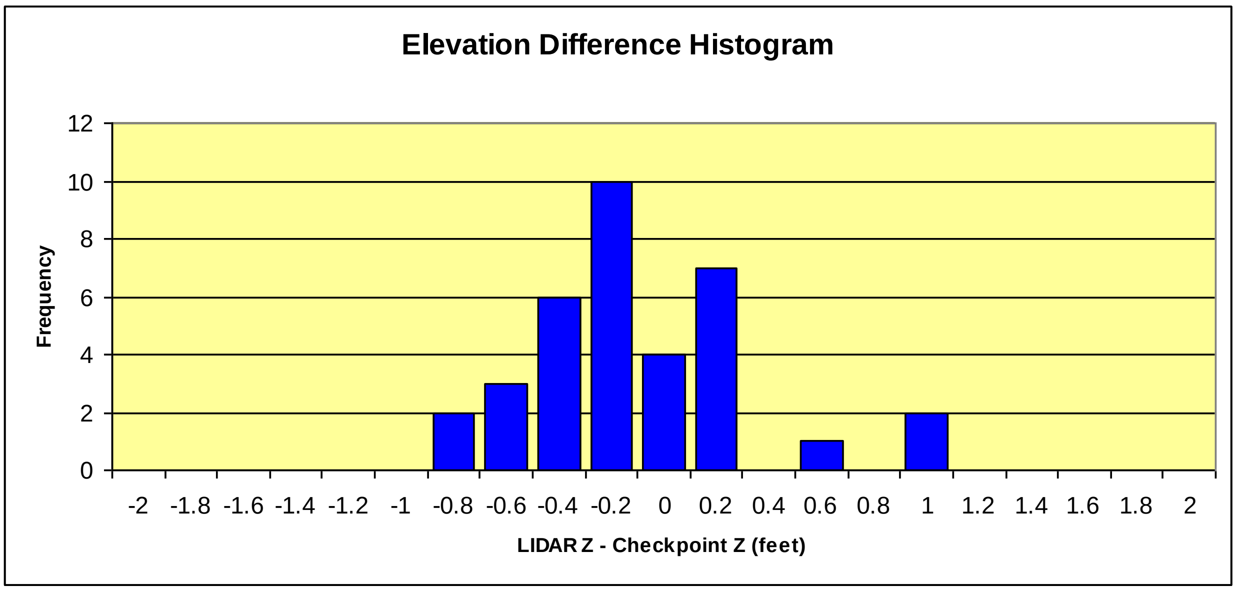


Figure 5 — Histogram of Elevation Discrepancies within 0.10 m Bands

Checkpoints That Were Not Used

The following Category 3 (forested area) checkpoints were located in the low confidence areas exhibiting limited point density: FL05C and FL07C. These checkpoints were not used in the vertical accuracy assessment.

Checkpoints That Were Added

Ortho checkpoints FL01 – FL03 and FL06 – FL07 were added to the CAT 4, Urban category. Ortho checkpoints FL04 and FL08 met the general requirements for Bare-earth and low grass and were added to that land cover classification

Figure 6 shows CAT 3 – Forested checkpoint FL05C digital ortho image and the density grid image, side-by-side, with the picture captured in the field underneath. The density grids were generated at a default cell size of 4 ft. “Dense” data is color green; dense is defined as a data point with an adjacent point equal to or less than the selected grid spacing of 4 ft. Sparse data is colored red; dense data is defined a point with the closest adjacent point greater than four times the selected grid spacing of 4 ft.

Figure 6 — Checkpoint FL05C Digital Ortho, Intensity Image and Field Picture

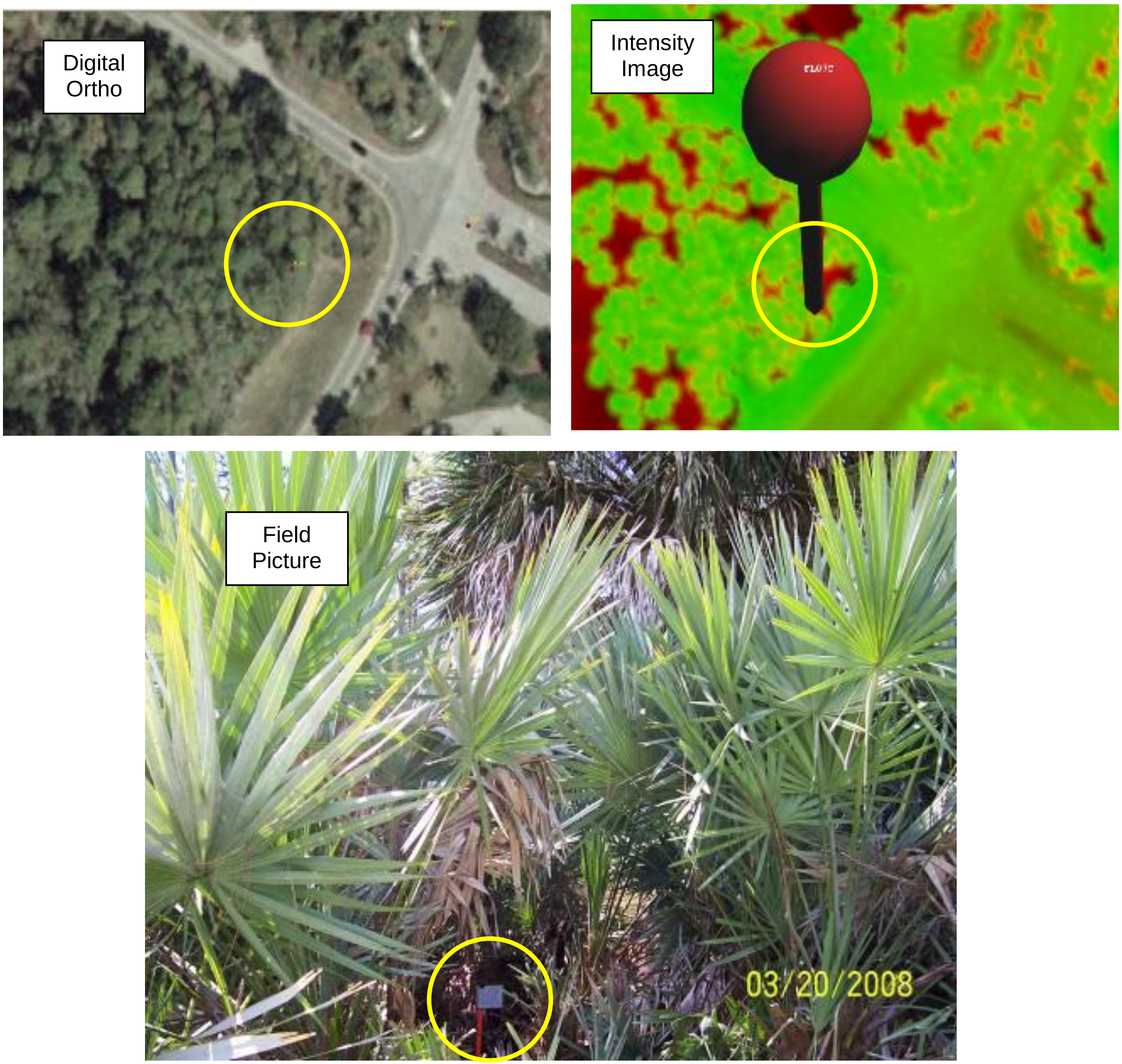


Figure 7 — Checkpoint FL07C Digital Ortho, Intensity Image and Field Picture

Figures 8 & 9 shows Ortho Checkpoints FL04 and FL08 that were included in the CAT 1 BE & Low Grass land cover category. These points generally meet the criterion for BE checkpoints.

Figurer 8 – Checkpoint FL04

Figurer 9 – Checkpoint FL08

Conclusions

Based on the vertical accuracy testing conducted by PDS, the undersigned certifies that the LiDAR dataset for Flagler County, Florida satisfies the criteria established by Reference A:

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 0.60’ vertical accuracy at 95% confidence level in open terrain.**

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 0.88’ vertical accuracy at 95% confidence level in all land cover categories combined.**

David F. Maune, Ph.D., PSM, PS, GS, CP
QA/QC Manager

Appendix G: LiDAR Qualitative Assessment Report

References:

A ─ State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a
B ─ Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
C ─ Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003
D ─ *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004
E ─ *ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Qualitative Assessment

The PDS qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model. Overall the data are of good quality and should satisfy most users for an accurate bare-earth elevation data product.

Overview

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR point spacing for this project is two meters or less. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional, elevation mapping technologies, and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the data set is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and 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. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the bare-earth was measured, but that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, PDS employs a combination of statistical and visualization processes. 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. By creating multiple images and using overlay techniques, not only can potential errors be found, but the PDS team can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

Analysis

PDS utilizes GeoCue software products as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. PDS uses Microsoft SQL Server as the database of choice.

The PDS qualitative assessment process flow for Flagler County, FL incorporated the following reviews:

1. *Statistical Analysis*- A statistical analysis routine was run on the .LAS files upon receipt to verify that the .LAS files met project specifications. This routine checked for the presence of Variable Length Records, verified .LAS classifications, verified header records for min/max x,y,z, and parsed the .LAS point file to confirm that the min/max x,y,z matched the header records. These statistics were run on the all-return point data set as well as the bare-earth point data set for every deliverable tile.
    a. All LAS files contained Variable Length Records with georeferencing information.
    b. All LiDAR points in the LAS files were classified in accordance with project specifications: Class 1 - Unclassified, Class 2 - Ground, Class 7 - Noise, and Class 9 - Water. No records were present in Class 12 - Overlap as this dataset consists of pre-contractual LiDAR acquired in 2004.
    c. Min/max x,y,z values matched the header files.

2. *Spatial Reference Checks*- The .LAS files were imported into the GeoCue processing environment. As part of the URS process workflow the GeoCue import produced a minimum bounding polygon for each data file. This minimum bounding polygon was one of the tools used

in conjunction with the statistical analysis to verify spatial reference integrity. No issues were identified with the spatial referencing of this dataset.

3. *Data Void/ Gap Checks*-The imported .LAS files were used to create LiDAR "Orthos". The LiDAR "Orthos" were one of the tools used to verify data coverage. The standard QA process flow used Data Point Elevation and LiDAR pulse return intensity returns. The intensity returns were used as delivered with no normalization. The Flagler County LiDAR dataset was an existing collection. Due to the point density of the initial acquisition, the final product was a 4 ft pixel produced from the All Return Data Set. The maximum density area allowed to generate the pixel was 254 ft. This product was produced to review the LiDAR collection to verify data density and to review for any Data Gaps/Data Voids. It was also used as a reference image during the artifact checks. It is not intended as a final product. (Figure 1)

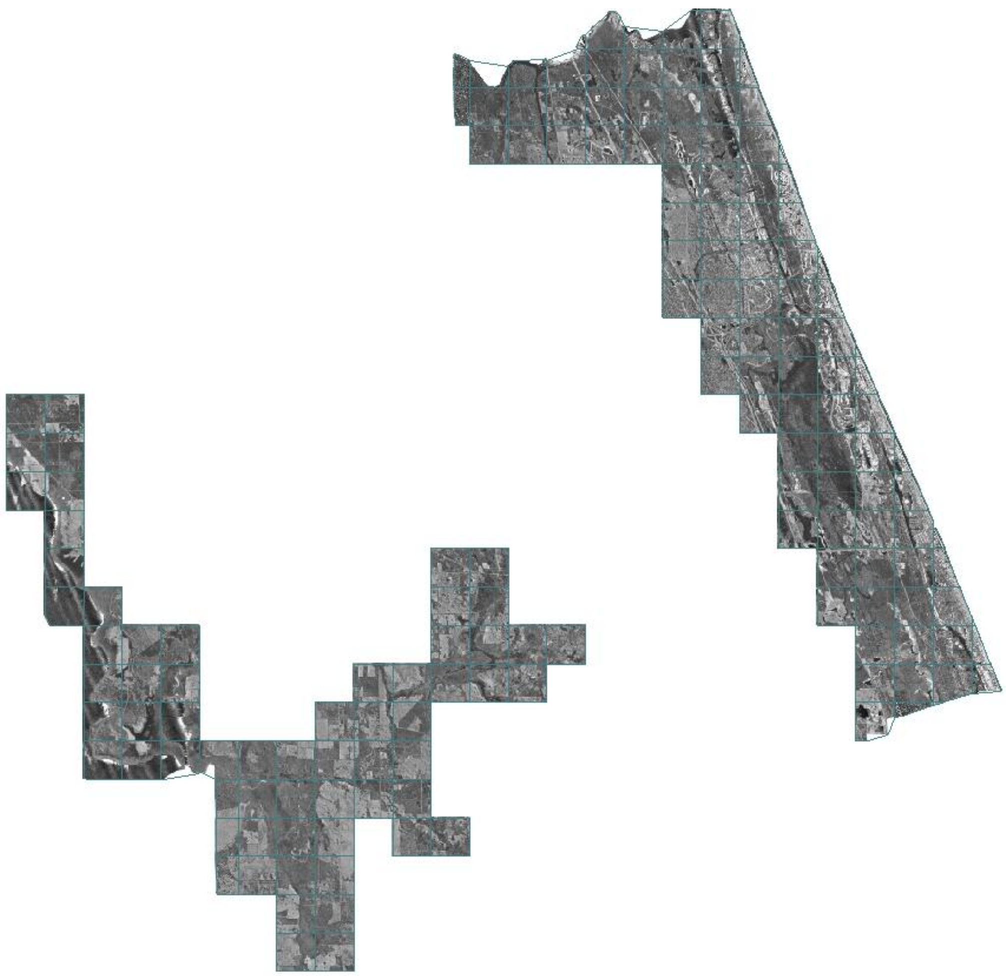


Figure 2 LiDAR Ortho Sample

4. *Initial Data Verification:* PDS performs an initial 10% random check of the data delivery by looking at each tile individually in great detail utilizing TIN surfaces and profiles. If the data set passes the 10 % the tiles continue through the process work flow where every tile is reviewed. If

the data set fails the 10% check it is normally due to a systematic process error and the data set is rejected.

5. *Data Density/Elevation checks:* The .LAS files are used to produce a Digital Elevation Model. These DEMs are produced using the software package QT Modeler which produces a 3dimensional data model. This data model is created from the Class 2 ground points using the project density deliverable requirement for unobscured areas.

   The QC for Flagler County was done at the most stringent data density requirement. For the FDEM project this requirement was that LiDAR point cloud data meet a maximum post spacing of 4 ft in un- obscured areas for random point data. Model statistics were produced and characterized by density as well as elevation. This data model was created from class 2 ground points and model statistics were characterized by density, scale, intensity as well as elevation. (Figure 2) The low confidence area polygons were referenced with the density grids to ensure that all low confidence areas are properly identified with a low confidence area polygon. Again, these products were produced for Quality Assessment purposes only.

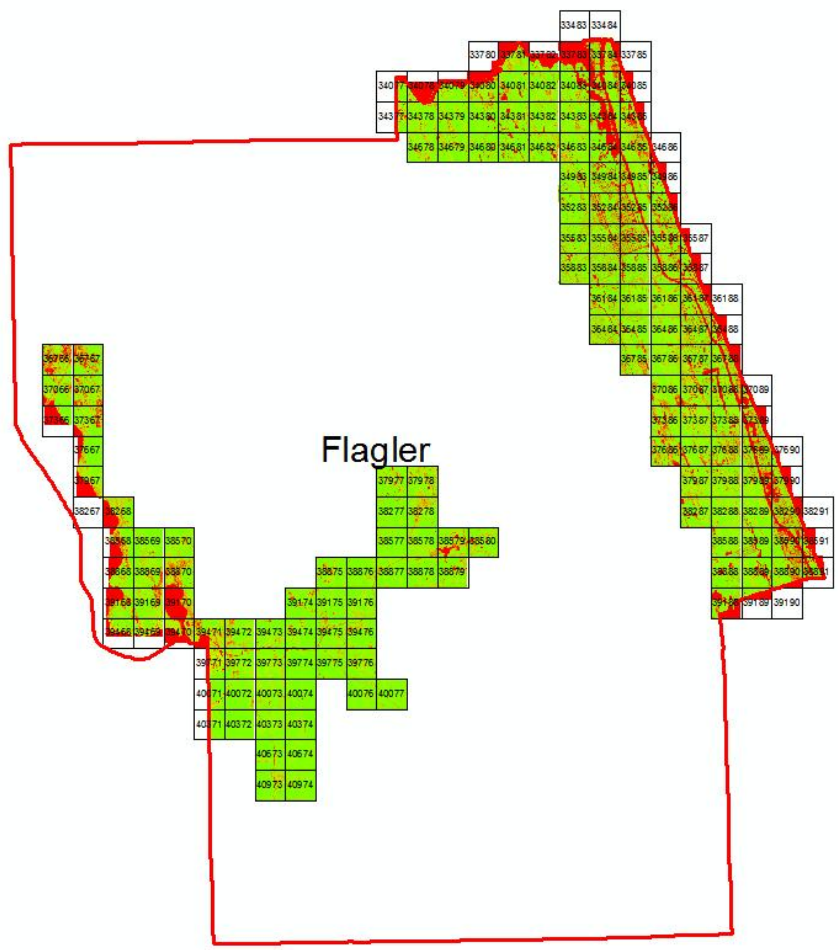


Figure 3 Sample density grid

Density grids were created at a 4 foot cell size using a green to red color ramp. Green areas indicate that the grid meets the 4 foot specification. Yellow to Red indicates that the 4 foot specification is not met these areas are defined as low confidence areas and outlined with low confidence polygons.

.

Artifact Anomaly Checks. The final step was to review every tile for anomalies that may exist in the bare-earth terrain surface. Items that were checked include, but are not limited to: buildings, bridges, vegetation and water points classified as Class 2 points and elevation "steps" that may occur in the overlap between adjacent flight lines. Any issues found are addressed in the below "General comments and issues".

General comments and issues.

The LiDAR data for Flagler County, Florida was acquired in 2004 and does not cover the entire county. The project area in Flagler County is characterized by heavy vegetation, marshes and swamp areas. There are few developed and urban areas. There are no national or state forests or state parks in the project area located off of the mainland (Figure 3).

The concern with this LiDAR collection for the final product is that the existing LiDAR data acquisition was dense enough to penetrate through the vegetation in the marsh areas to produce the contract specifications for open terrain. Because of the heavy vegetation, delineation of low confidence areas is critical due to the deliverable requirement for topography (Contours).

The LiDAR data was acquired between February 28, 2004 and May 5, 2004. This existing dataset was processed to a bare earth surface model in 2008 for the Florida Division of Emergency Management Task order D. Due to the fact that this LiDAR dataset was existing, the data is not as dense as the other counties flown under Task order D.

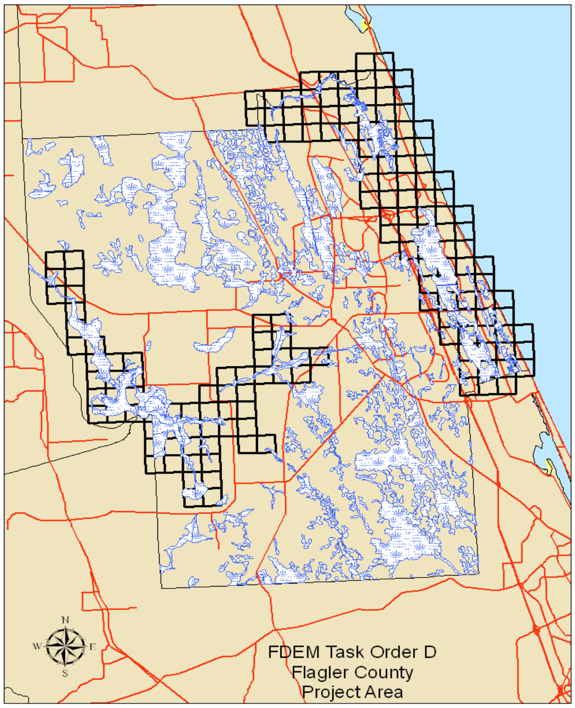


Figure 4 Map of Flagler County Florida with Marsh areas from Florida Geographic Data Library (FGDL)

The nominal post spacing averages about 1 meter. The results of the review confirmed that the deliverable data tiles were complete to the county boundary line. The county edge tiles are partial and clipped to the county boundary. In general, the LAS files were very clean of artifacts, and very few qualitative issues were noted.

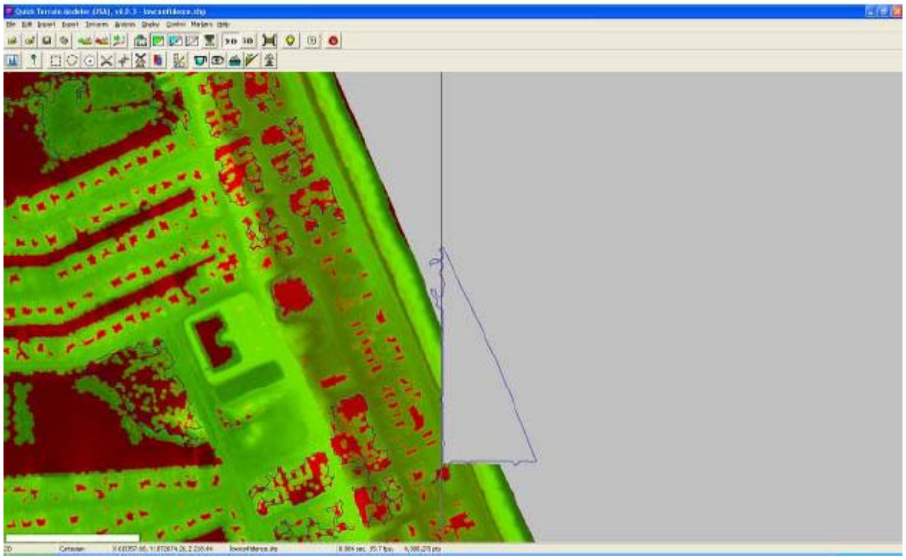
The bare earth terrain model was checked for consistency in bare earth processing, tile edgematch with neighboring tiles and match of features across tiles, flightline edgematch, correct water classification and bridge, building and vegetation removal. There were some issues noted in the qualitative assessment but these were minor and repaired by the contractor. Of the 164 tiles LAS files reviewed, only 4 tiles showed issues that required redelivery.

Points		
Tile	**Issue**	**Code**
LID 037690	Data Void	Fixed
LID 039168	Minimum z-value	Fixed
LID 039771	Minimum z-value	Fixed
LID 040071	Minimum z-value	Fixed

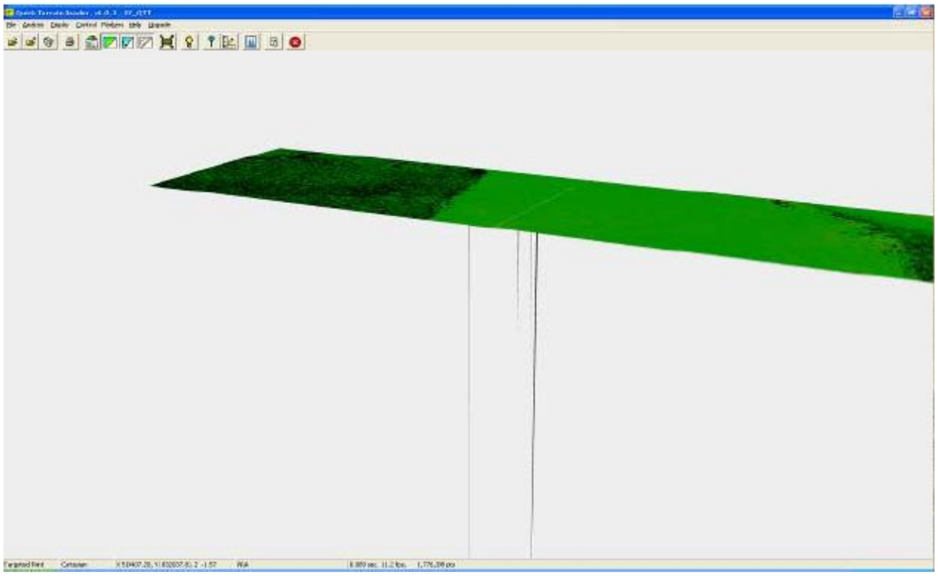
Conclusion

Overall the data meets the project specifications. The processing was executed well given the low relief and highly vegetated areas. There are some minor issues but they are not a detriment to a usable data product.

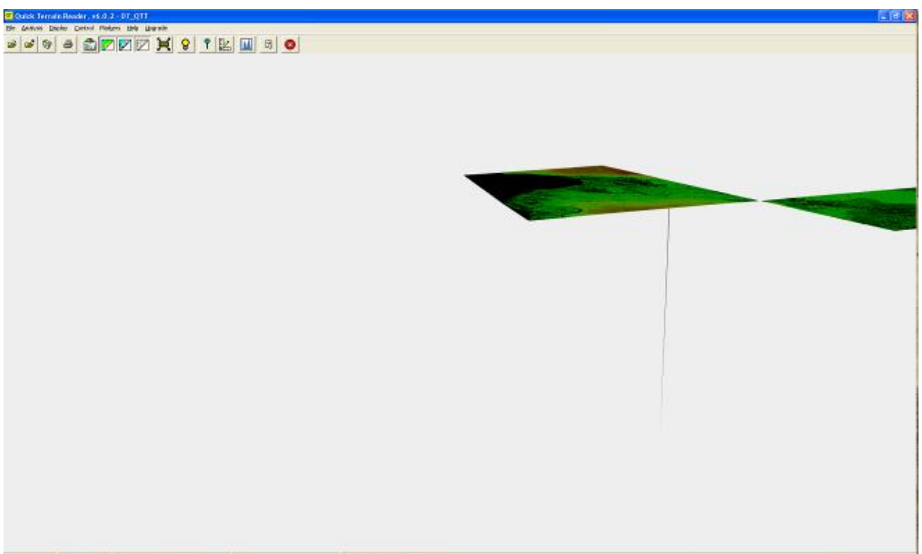
Review Examples:



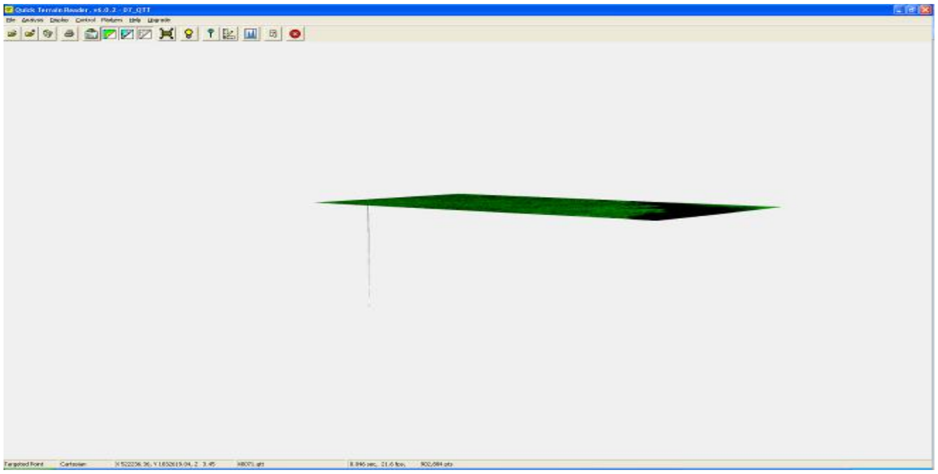
LID 037690 Data void – corrected by contractor



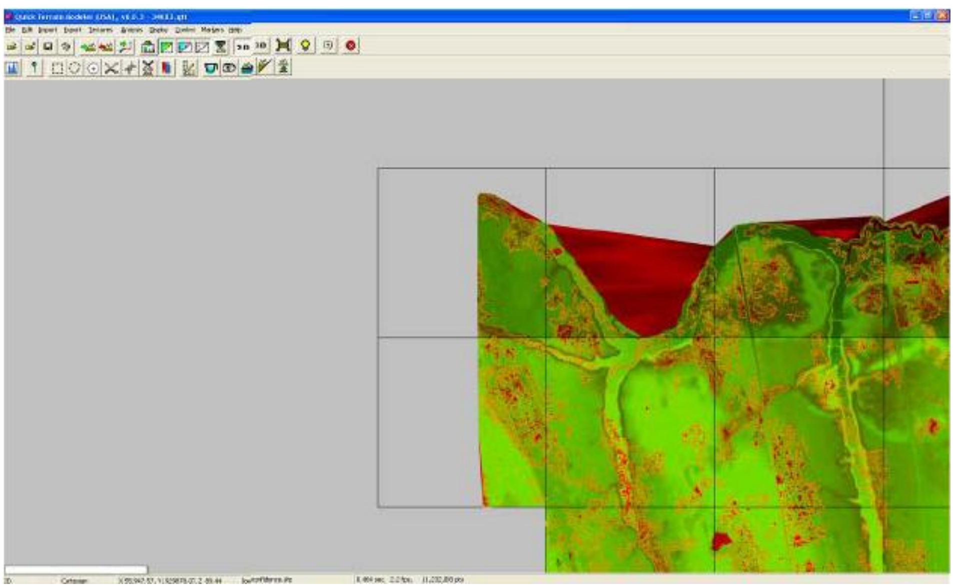
LID 039771 Noise points- corrected by contractor



LID 039168 Noise points- corrected by contractor



LID 040071 Noise point corrected by contractor



Example of Partial tile coverage from existing LAS collection

Appendix H: Breakline/Contour Qualitative Assessment Report

Coastal Shorelines

Coastal shorelines are correctly captured as two-dimensional polygon features, extracted from the LiDAR data and not from digital orthophotos, except for manmade features with varying heights such as seawalls which are captured as three-dimensional breaklines. Coastal breaklines merge seamlessly with linear hydrographic features. Shorelines continue beneath docks and piers. There is no “stair-stepping” of coastal shorelines. Figure 1 shows example coastal breaklines and contours.

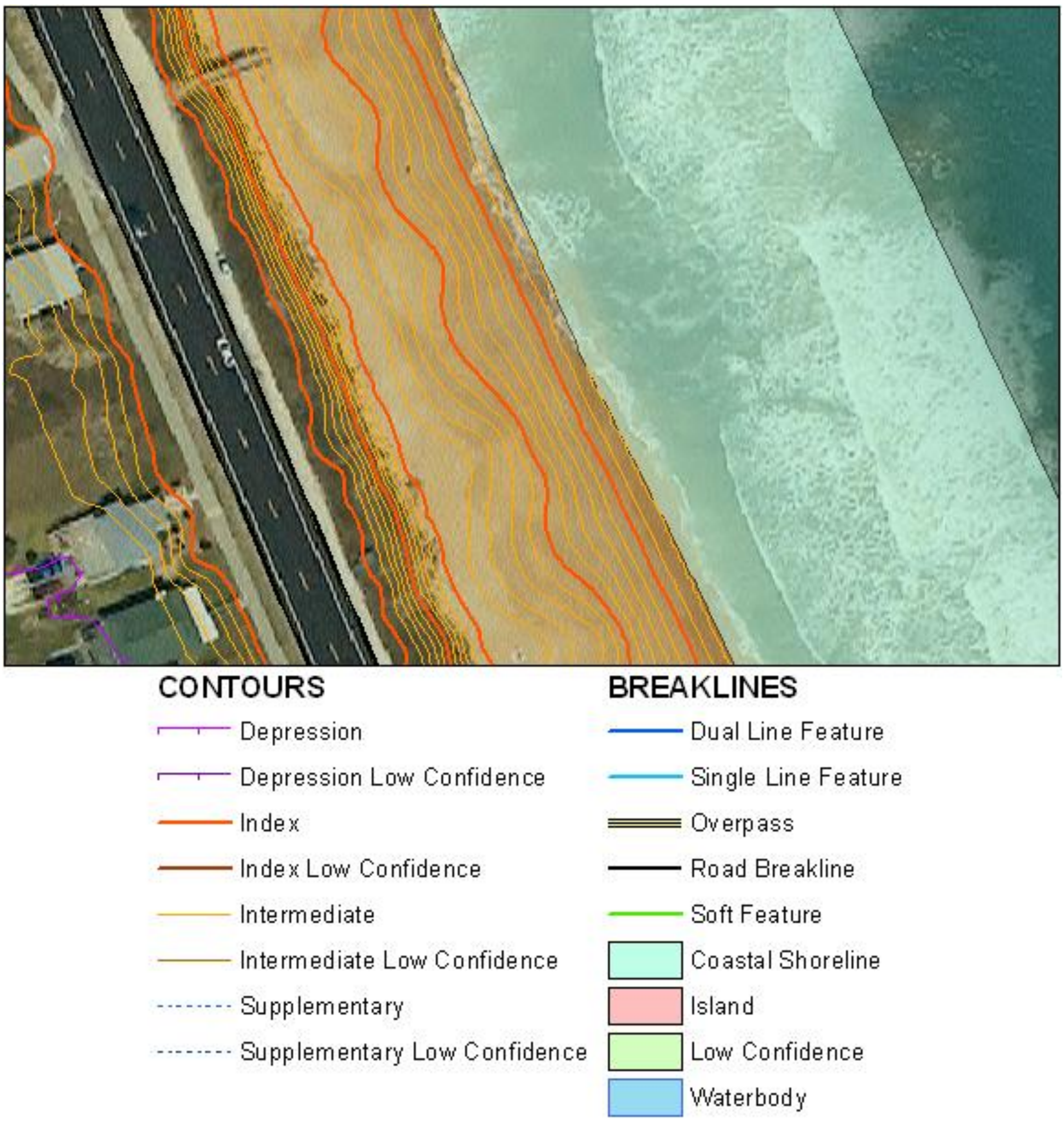


Figure 1. Example coastal breaklines and contours from tile #37990

Linear Hydrographic Features

Linear hydrographic features are correctly captured as three-dimensional breaklines – single line features if the average width is 8 feet or less and dual line features if the average width is greater than 8 feet. Each vertex maintains vertical integrity. Figure 2 shows example breaklines and contours of linear hydrographic features.

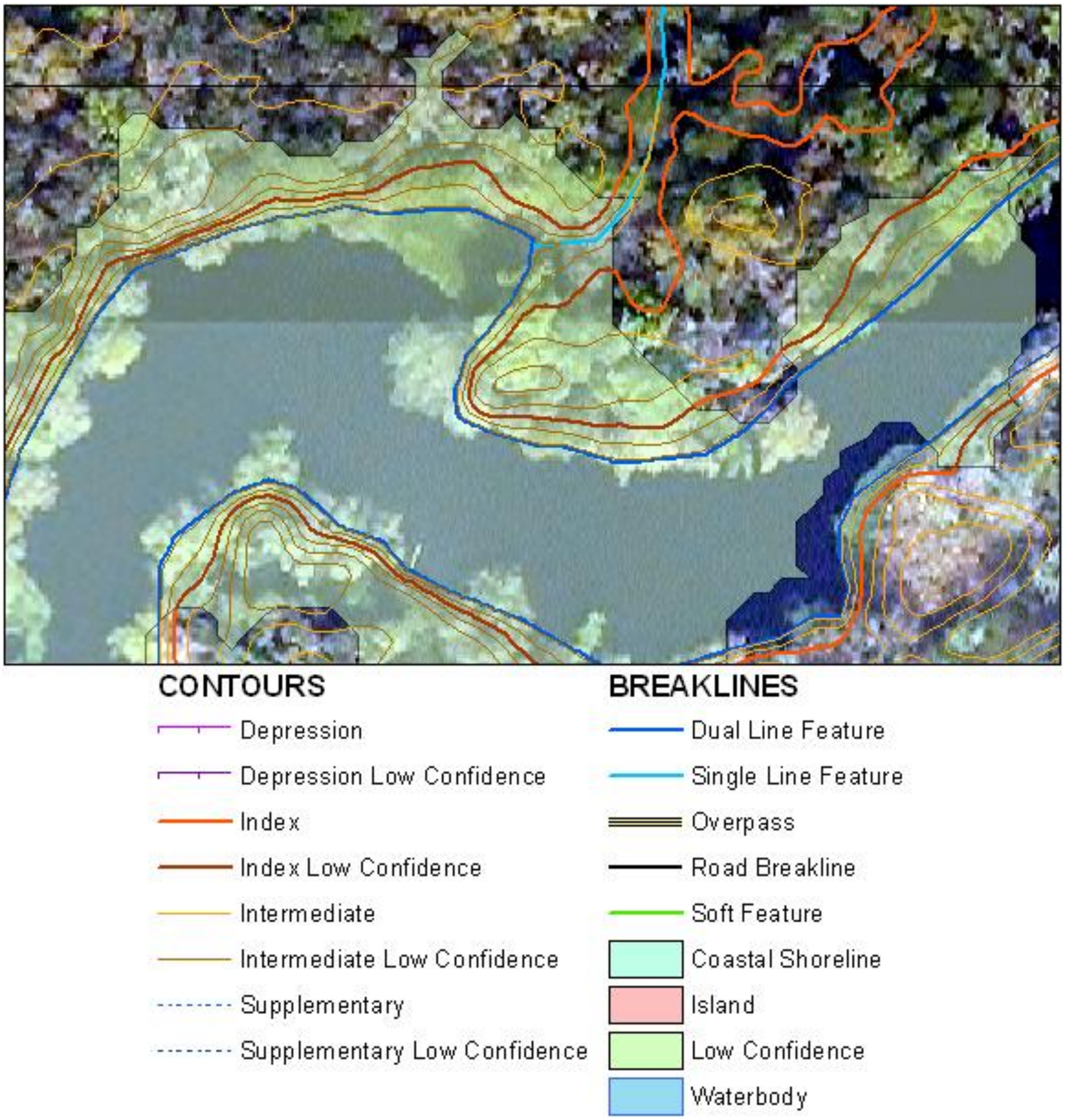


Figure 2. Example linear hydrographic feature breaklines and contours from tile #39474 and #39774

Closed Water Body Features

Closed water body features with an area of one-half acre or greater are correctly captured as two-dimensional closed polygons with a constant elevation that reflects the best estimate of the water elevation at the time of data capture. “Donuts” exist where there are islands within a closed water body feature. Figure 3 shows example breaklines and contours of closed water body features.

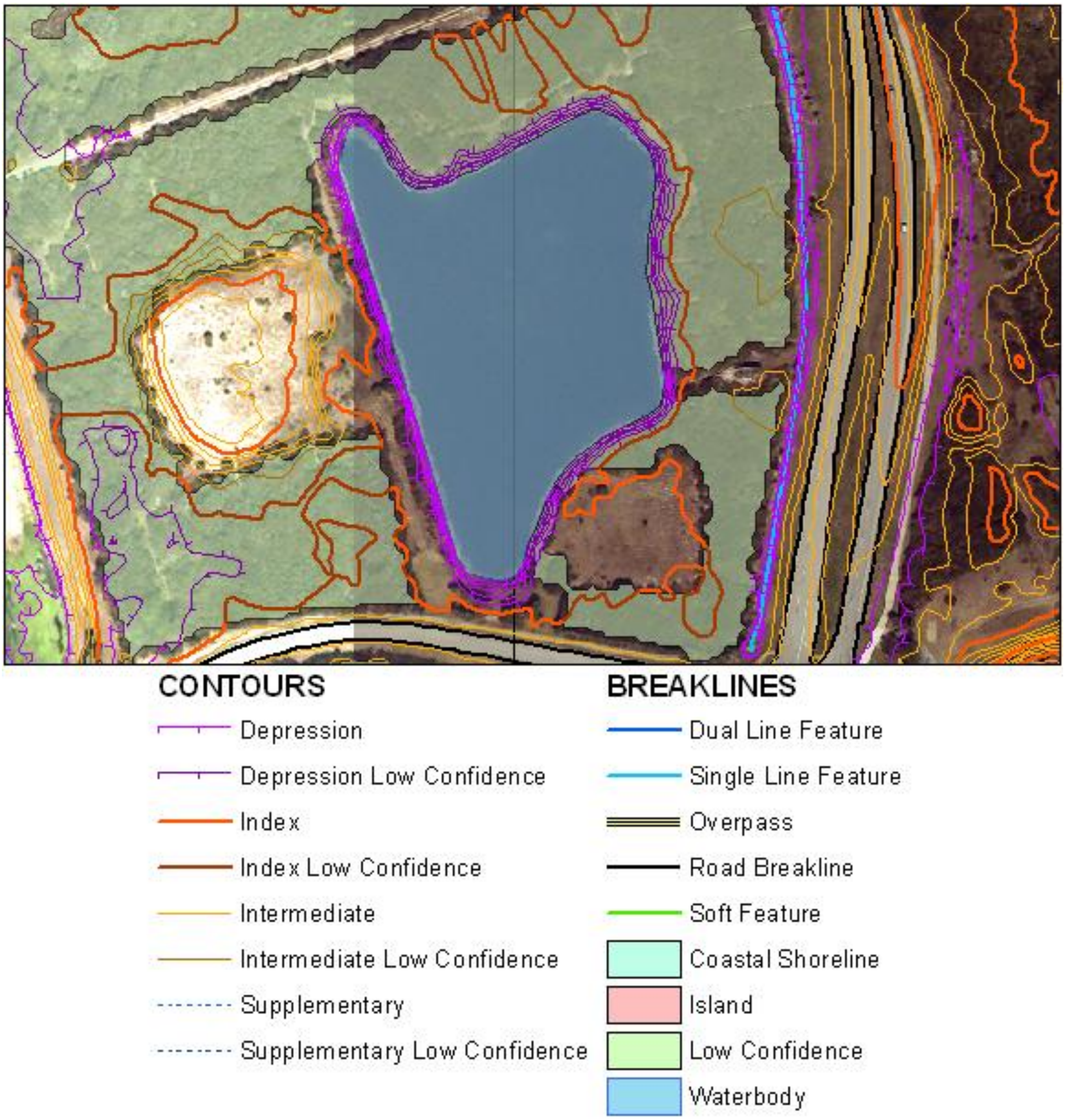


Figure 3. Example closed water body feature breaklines and contours from tiles #34084 & #34085

Road Features

Road edge of pavement features are correctly captured as three-dimensional breaklines on both sides of paved roads. Box culverts are continued as edge of pavement unless a clear guardrail system is in place; in that case, culverts are captured as a bridge or overpass feature. Each vertex maintains vertical integrity. Figure 4 shows example breaklines and contours of road features.

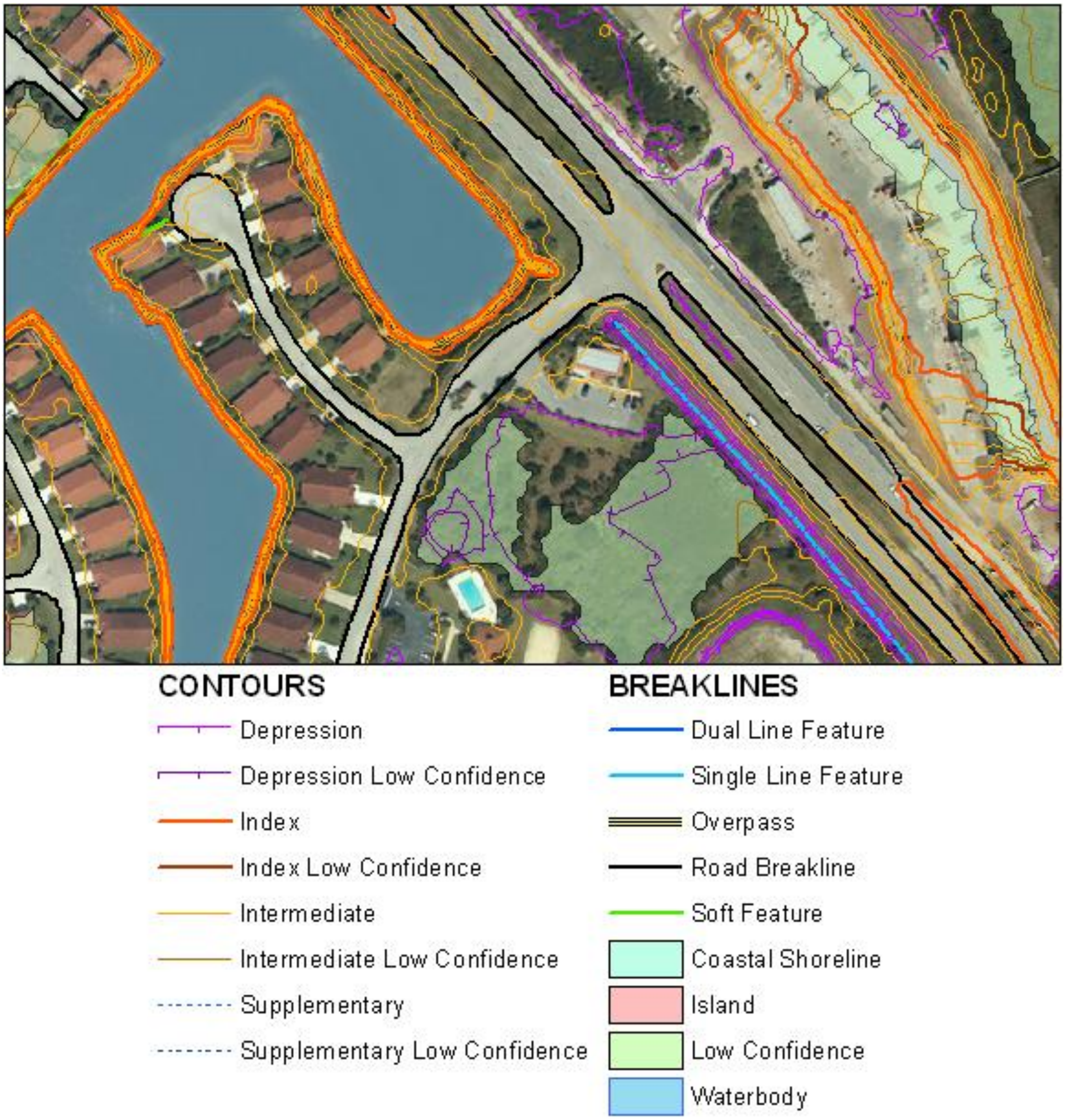


Figure 4. Example road feature breaklines and contours from tile #34085

Bridge and Overpass Features

Bridges and overpasses are correctly captured as three-dimensional breaklines, capturing the edge of pavement on the bridge, rather than the elevation of guard rails or other bridge surfaces. Each vertex maintains vertical integrity. Figure 5 shows example breaklines and contours of bridge and overpass features.

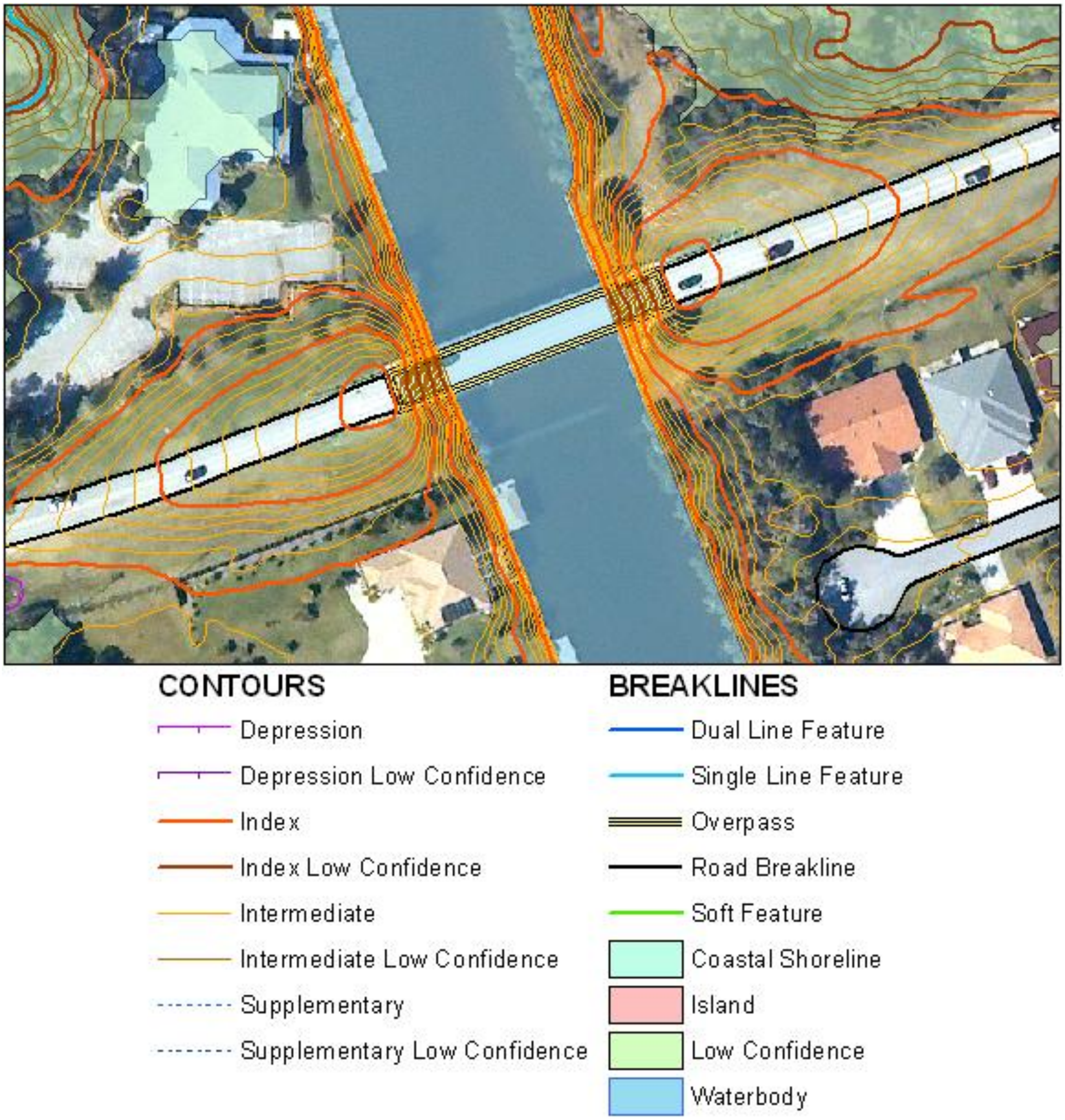


Figure 5. Example bridge and overpass feature breaklines and contours from tile #35584

Soft Features

Soft features such as ridges, valleys, top of banks, etc. are correctly captured as three-dimensional breaklines so as to support better hydrological modeling of the LiDAR data and contours. Each vertex maintains vertical integrity. Figure 6 shows example breaklines and contours of soft features.

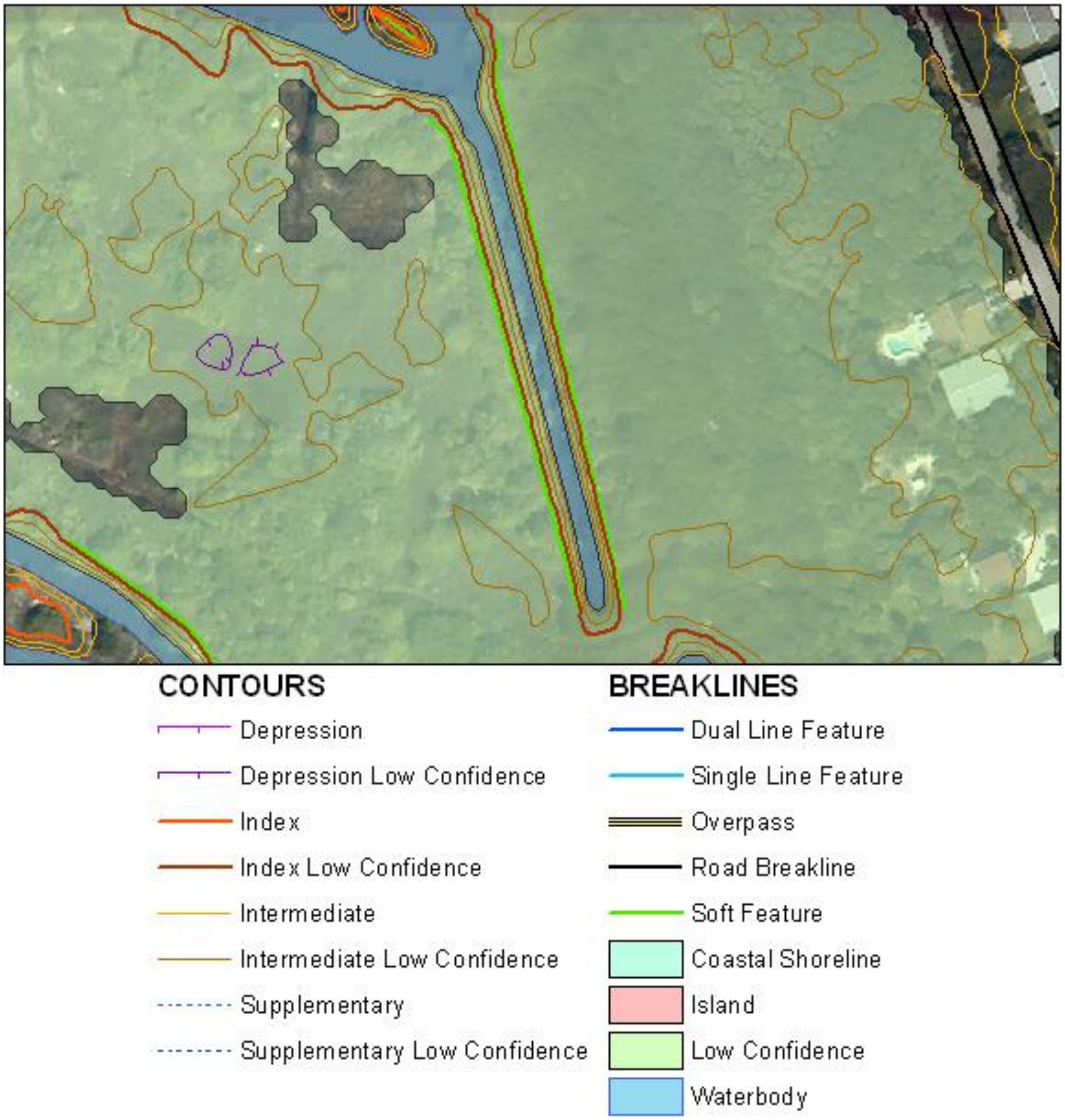


Figure 6. Example soft feature breaklines and contours from tile #37990

Island Features

The shoreline of islands within water bodies are correctly captured as two-dimensional breaklines in coastal and/or tidally influenced areas and as three-dimensional breaklines in non-tidally influenced areas for island features one-half acre in size or greater. All natural and man-made islands are depicted as closed polygons with constant elevation. Figure 7 shows example breaklines and contours for island features.

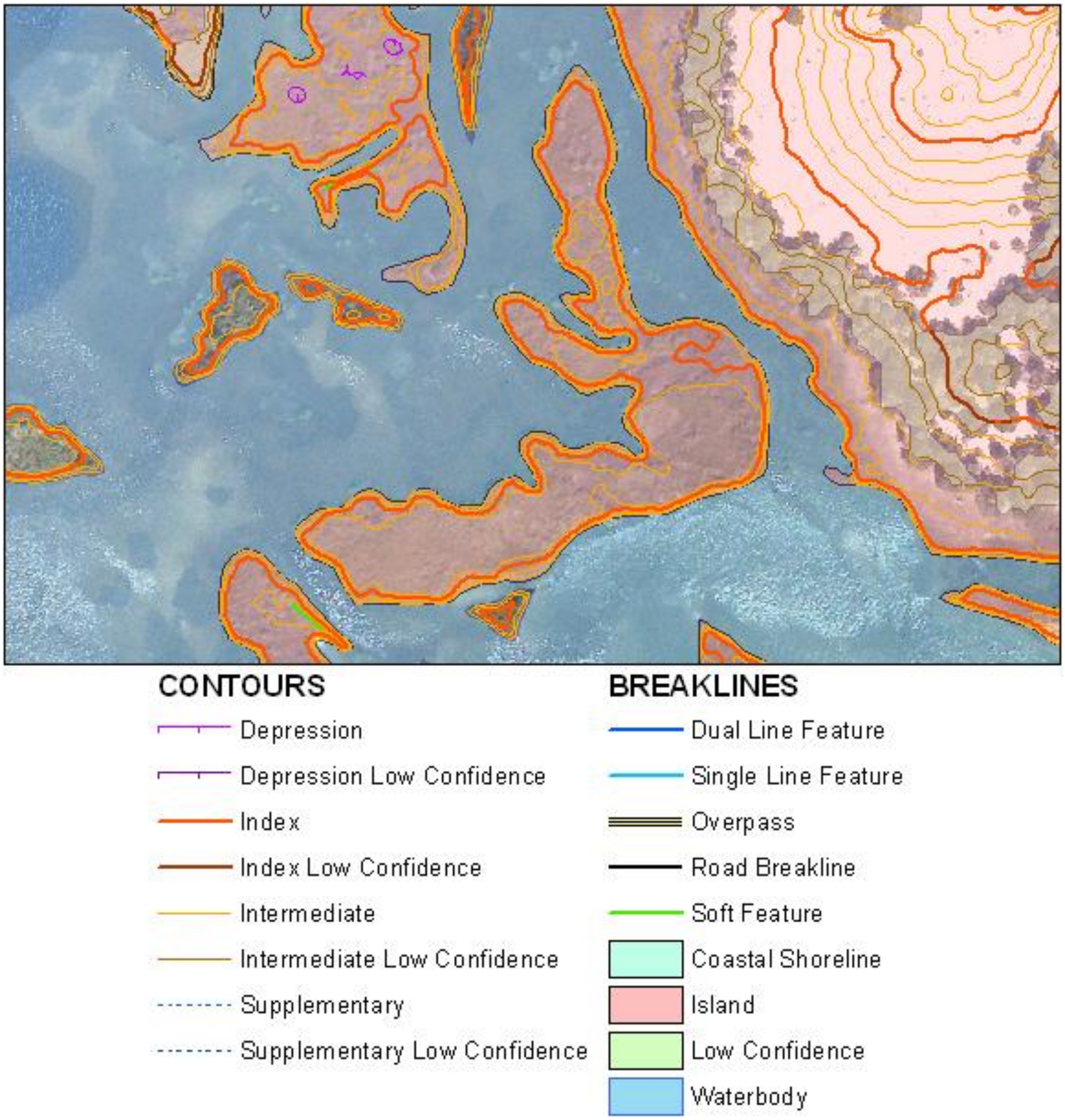


Figure 7. Example island feature breaklines and contours from tiles #33784

Low Confidence Areas

The apparent boundary of vegetated areas (1/2 acre or larger) that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM are correctly captured as two-dimensional features with no z-values. Figure 8 shows example breaklines and contours for low confidence areas.

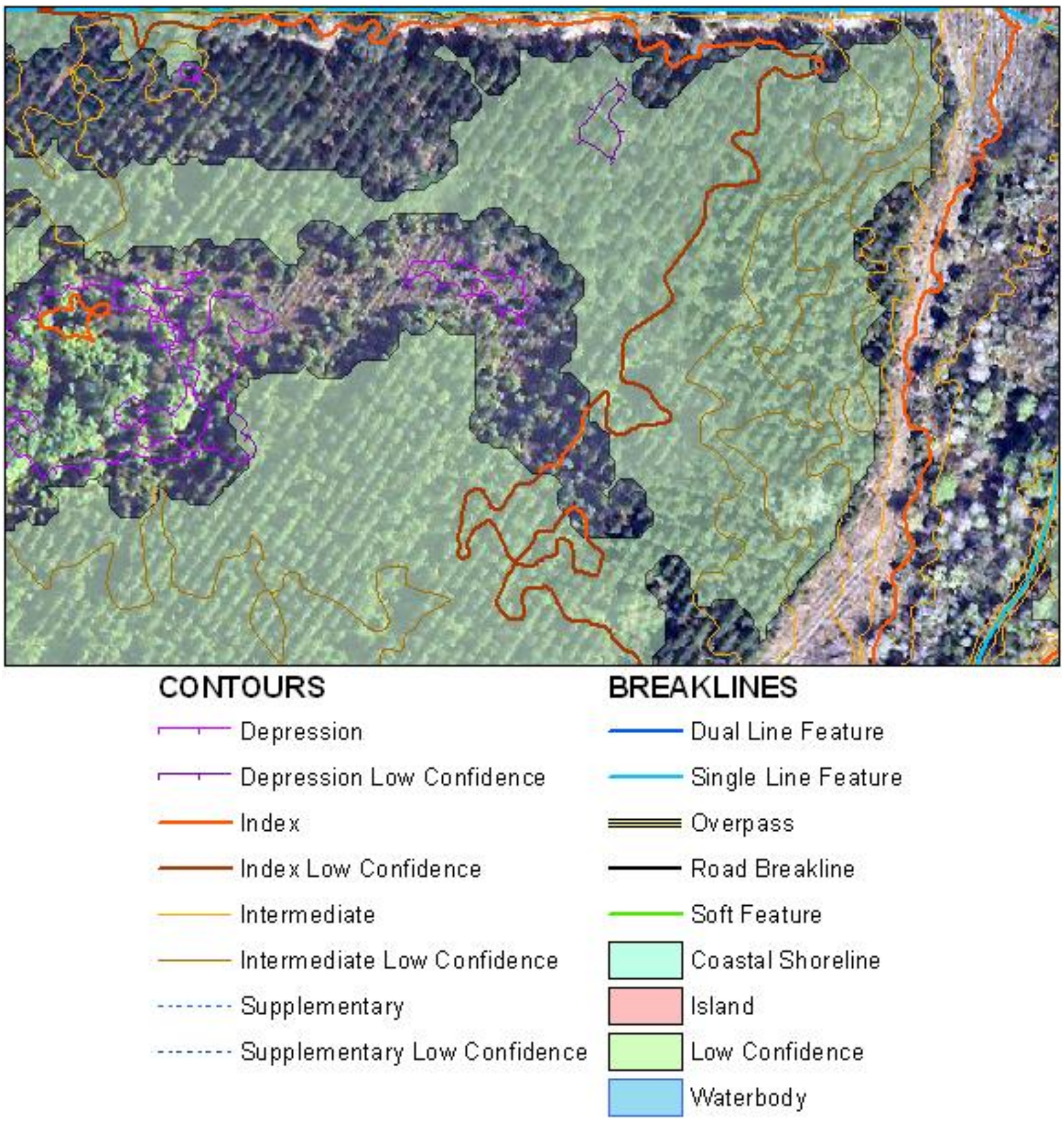


Figure 8. Example low confidence area feature breaklines and contours from tile #39475

Appendix I: Geodatabase Structure