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FL Escambia Santa Rosa NWFWMD Lidar 2017

Report Produced for Northwest Florida Water Management District

Report Date: 03/01/2018

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the FL Escambia Santa Rosa NWFWMD Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1500m by 1500m. A total of 1986 tiles were produced for the project encompassing an area of approximately 1440 sq. miles.

THE PROJECT TEAM

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

Dewberry's Frederick C. Rankin completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Airborne Imaging Inc. completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Florida counties of Okaloosa, Santa Rosa and Escambia.

DATE OF SURVEY

The lidar aerial acquisition was conducted from March 31, 2017 thru April 8, 2017.

COORDINATE REFERENCE SYSTEM

Two sets of data were produced for the project. One dataset has vertical units in meters and one dataset has vertical units in feet. The full reference systems for each dataset are shown below.

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 16
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))

Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 16
Units: Horizontal units are in meters, Vertical units are in feet.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the FL Escambia Santa Rosa NWFWMD Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **4.9 cm** compared with the 10 cm specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **9.7 cm**, compared with the 19.6 cm specification.

For the FL Escambia Santa Rosa NWFWMD Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to **13.1 cm,** compared with the 29.4 cm specification.

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

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Project Extents including boundary and tile grid (Shapefiles)
2. Breaklines (GDB)
3. Raw point cloud data (LAS)
4. Final classified lidar tiles (LAS)
5. Tiled bare earth DEMs (Raster DEM – IMG Format)
6. Low confidence areas (shapefile)
7. Intensity Images (tiled, GeoTIFF)
8. Survey data
9. Calibration points
10. Metadata (XML)
11. Final Project report

PROJECT TILING FOOTPRINT

One thousand nine hundred eighty six (1986) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered tiles).

Figure 1 - Project Map

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Airborne Imaging Inc. Airborne Imaging Inc. was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

Dewberry received calibrated swath data from Airborne Imaging Inc. on May 10, 2017.

LIDAR ACQUISITION DETAILS

Airborne Imaging Inc. planned 48 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Airborne Imaging Inc. followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

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

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

Within 72-hours prior to the planned day(s) of acquisition, Airborne Imaging Inc. closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Airborne Imaging Inc. lidar sensors are calibrated at a designated site located at the Plant City Airport, Florida and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Airborne Imaging Inc. operated a Piper PA-31 Navajo (Tail # C-GKSX) outfitted with a Riegl Q-1560 LiDAR system during the collection of the study area. Table 1 illustrates Airborne Imaging Inc. system parameters for lidar acquisition on this project.

Item	Parameter

Item	Parameter
System	Riegl LMS-Q1560
Altitude (AGL meters)	2000
Approx. Flight Speed (knots)	150
Scanner Pulse Rate (kHz)	800 kHz (true) 533-3 kHz (effective)
Scan Frequency (hz)	185 Scanlines/s
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	0.9
Swath width (m)	2309
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.25
Nominal Swath Width on the Ground (m)	2309
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	60
Computed Down Track spacing (m) per beam	0.89 per channel
Computed Cross Track Spacing (m) per beam	0.89 per channel
Nominal Pulse Spacing (single swath), (m)	0.63
Nominal Pulse Density (single swath) (ppsm), (m)	2.5
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.63
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.5
Maximum Number of Returns per Pulse	4

Table 1: Airborne Imaging Inc. lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

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

Figure 2 shows the combined trajectory of the flightlines.

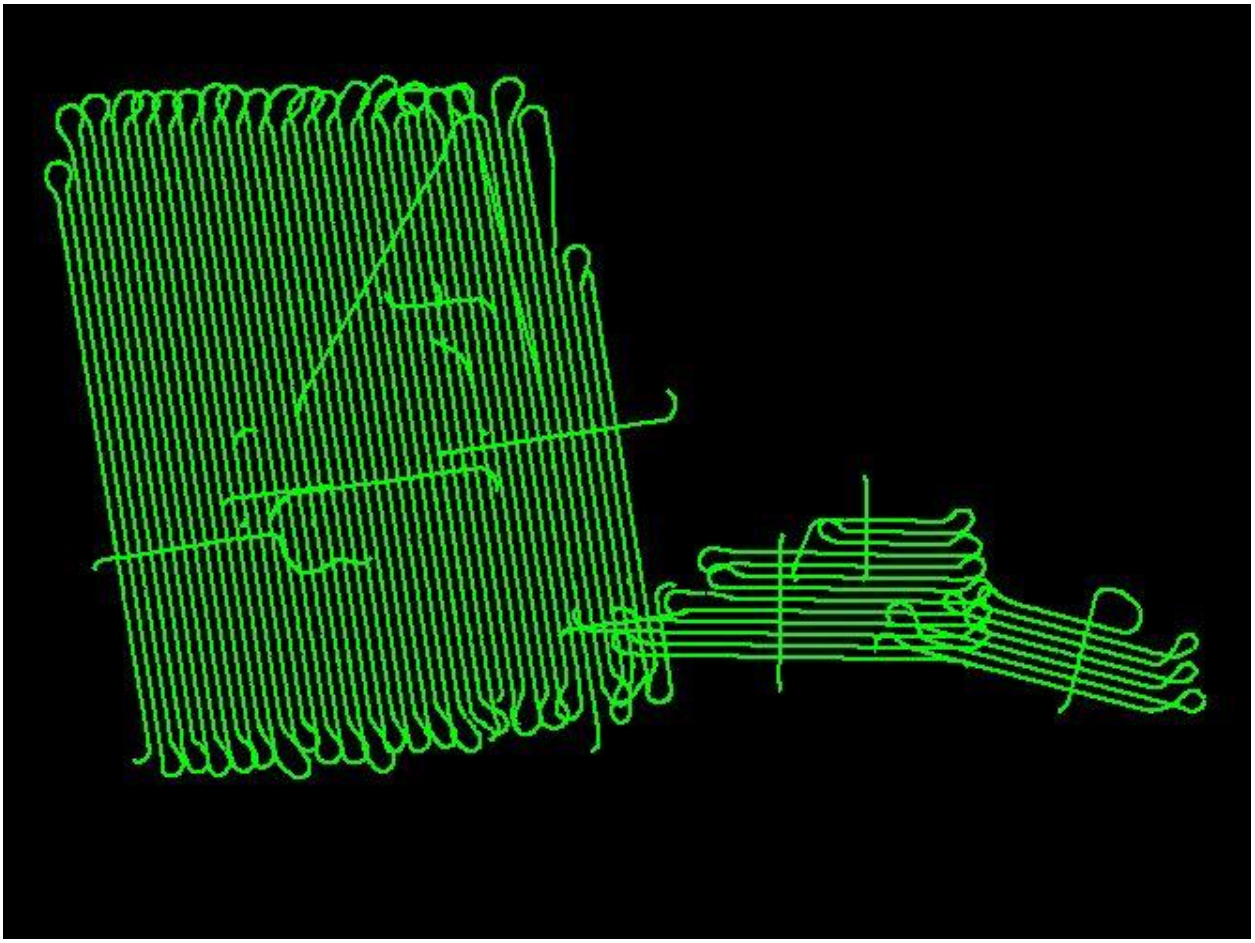


Figure 2: Trajectories as flown by Airborne Imaging Inc.

LIDAR CONTROL

Airborne Imaging conducted the survey which provided the two existing NGS monuments, three Continuous Operating Reference Stations (CORS), and three newly established base stations were used to control the lidar acquisition for the FL Escambia Santa Rosa NWFWMD Lidar project area.

Name	NAD83 (2011) UTM16		Ellipsoid Ht (m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
ALEB	494693.288	3439738.413	14.891	42.543
ALFO	435163.990	3365181.704	4.425	32.265
B163	511856.154	3391266.400	15.526	42.856
B164	466592.092	3412012.224	40.430	68.324
B165	466249.798	3412097.356	42.333	70.231
BG0005	474328.687	3424932.415	-5.990	21.855
BG0447	500571.132	3388670.036	-4.414	22.955
PCLA	481818.037	3370773.337	3.362	30.782

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the Applanix POSPac MMS software suite and Novatel's GrafNav software. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 45 km.

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

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

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

Subsequently the mission points are output using Riegl's RiProcess, initially with default values calibrated from the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

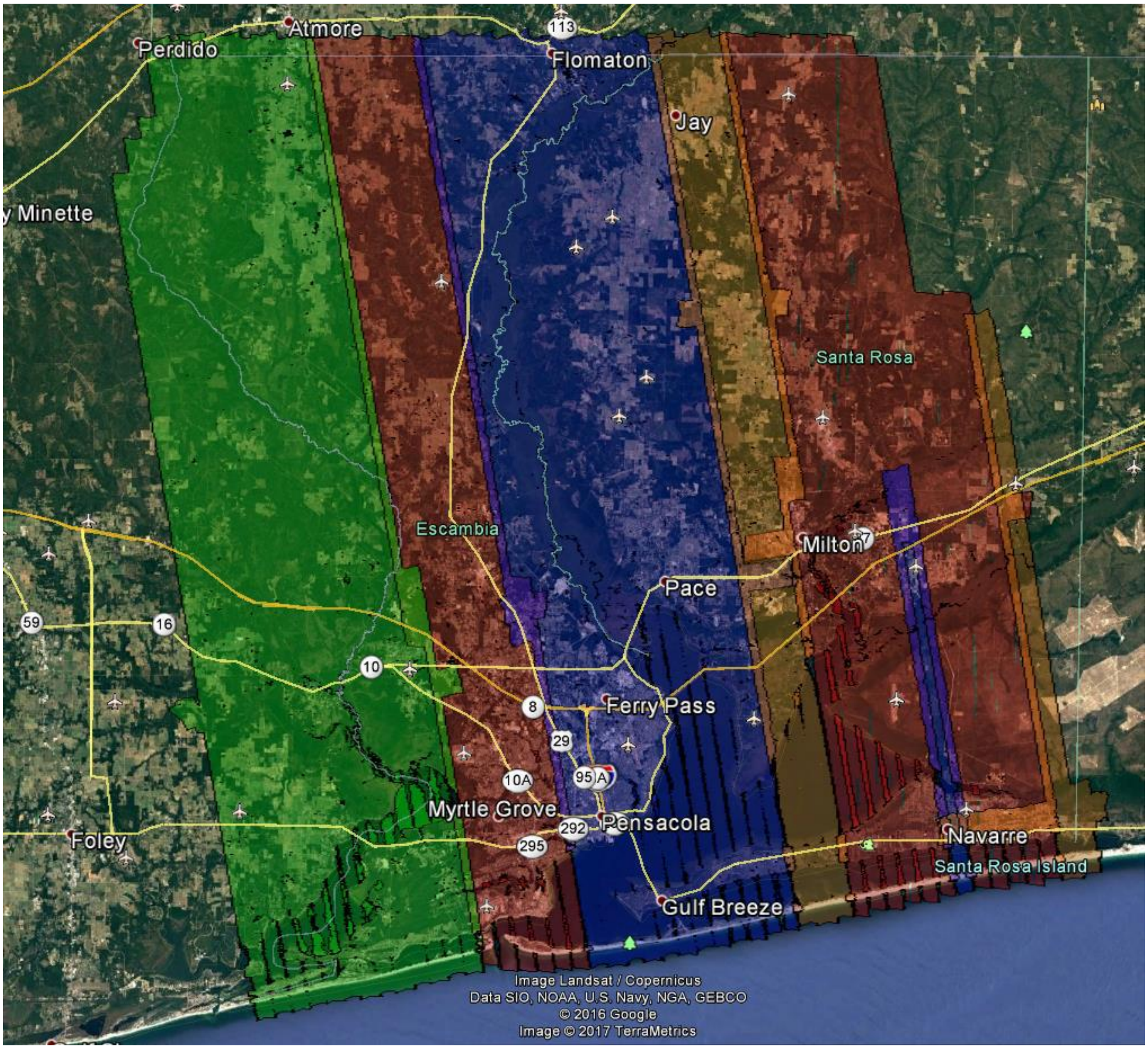


Figure 3 – Lidar swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

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

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

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

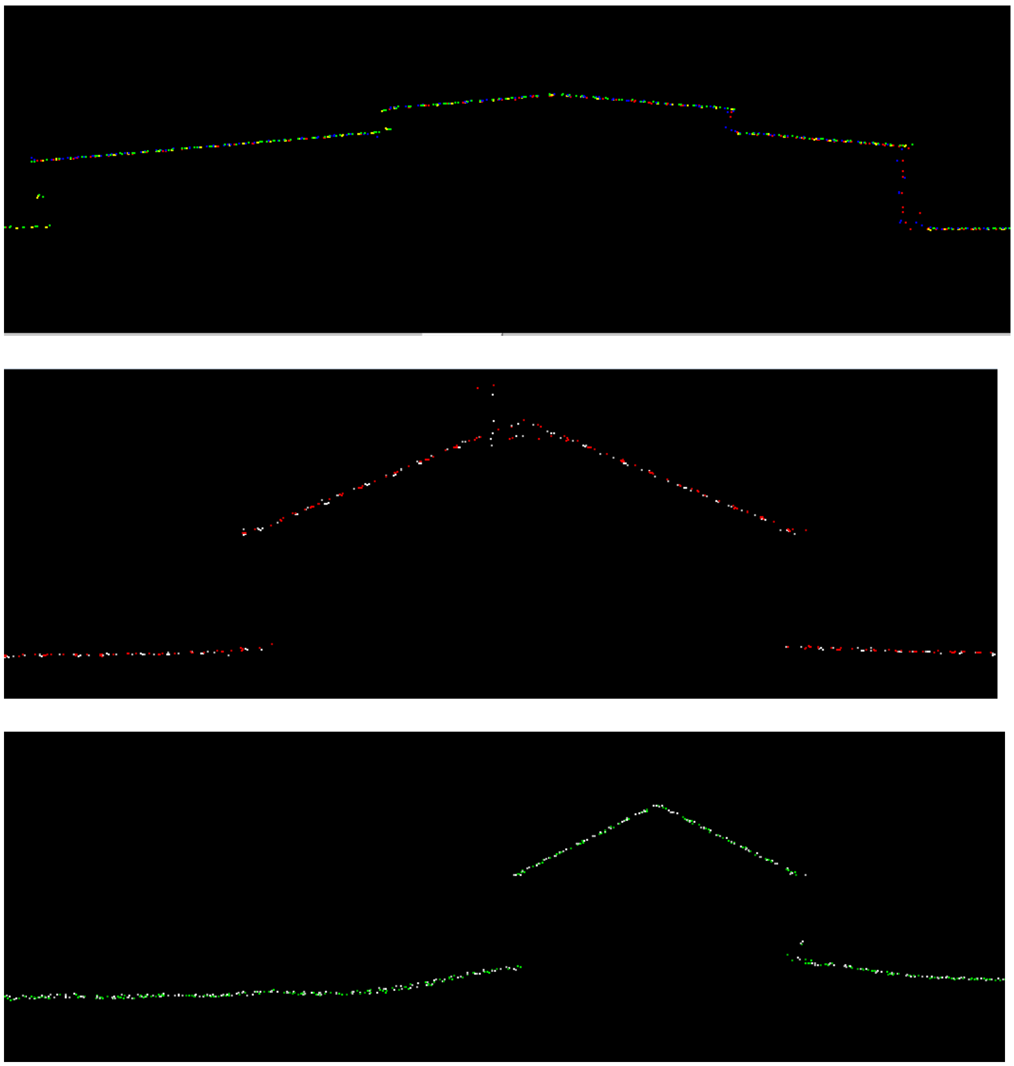


Figure 4 – Profile views showing correct roll and pitch adjustments.

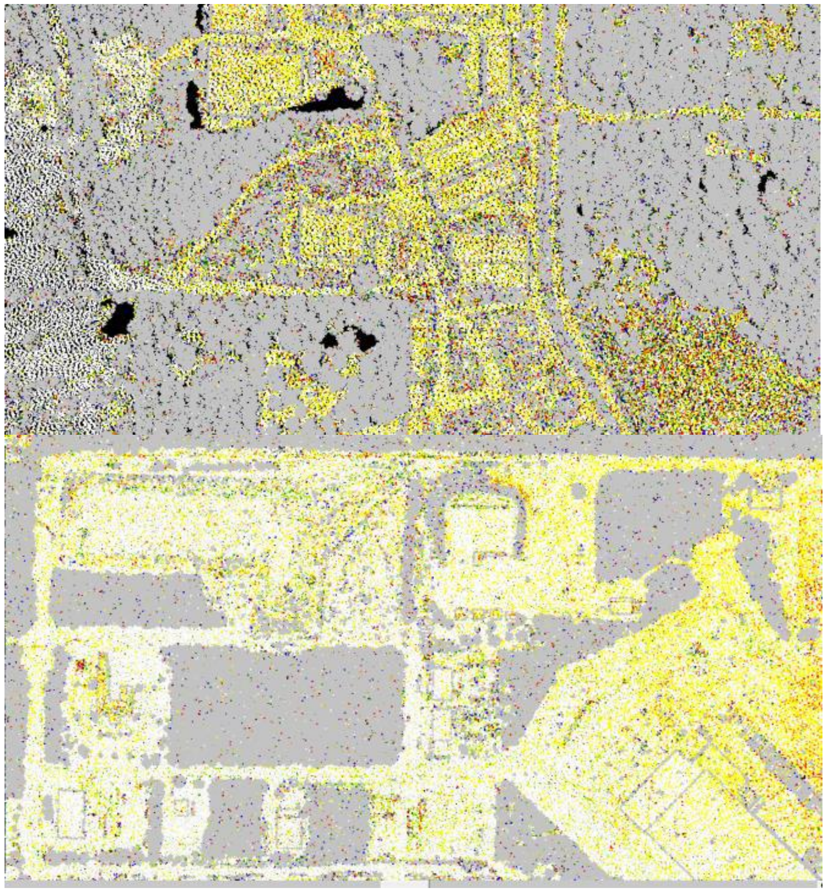


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by Airborne Imaging Inc. at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The lidar data is examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated FL Escambia Santa Rosa NWFWMD lidar dataset was tested to 0.096 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.049 m x 1.9600) when compared to over 5000 GPS static check points.
The following are the final statistics for the GPS static checkpoints used by Airborne Imaging Inc. to internally verify vertical accuracy.

100 % of Totals	# of Points	RMSEz (NVA) Spec=0.1 m	NVA at 95% Spec=0.196 m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	5,172	0.049	0.096	-0.01	0.048	-0.258	0.176

Table 3 – Kinematic GNSS Vertical Results

Overall the calibrated lidar data products collected by Airborne Imaging Inc. meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Airborne Imaging Inc. quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

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

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Airborne Imaging Inc., Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the sixty-six non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the FL Escambia Santa Rosa NWFWMD Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 5.1 cm, equating to +/- 10 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.100 m	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	66	0.051	0.100	-0.007	-0.013	0.671	0.051	-0.109	0.180	1.960

Table 4: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath (Between Swath) Relative Accuracy

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

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

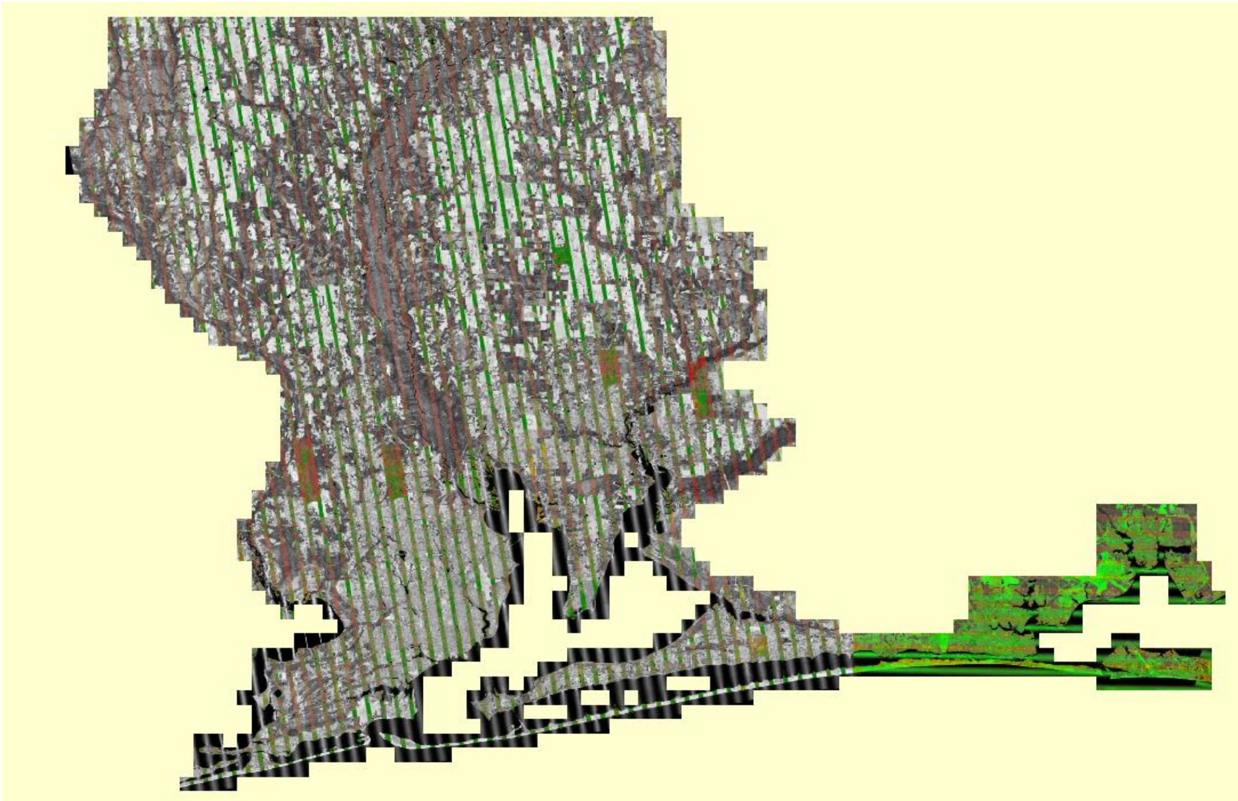


Figure 6– Single return DZ Orthos for the FL Escambia Santa Rosa NWFWMD lidar project. Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

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

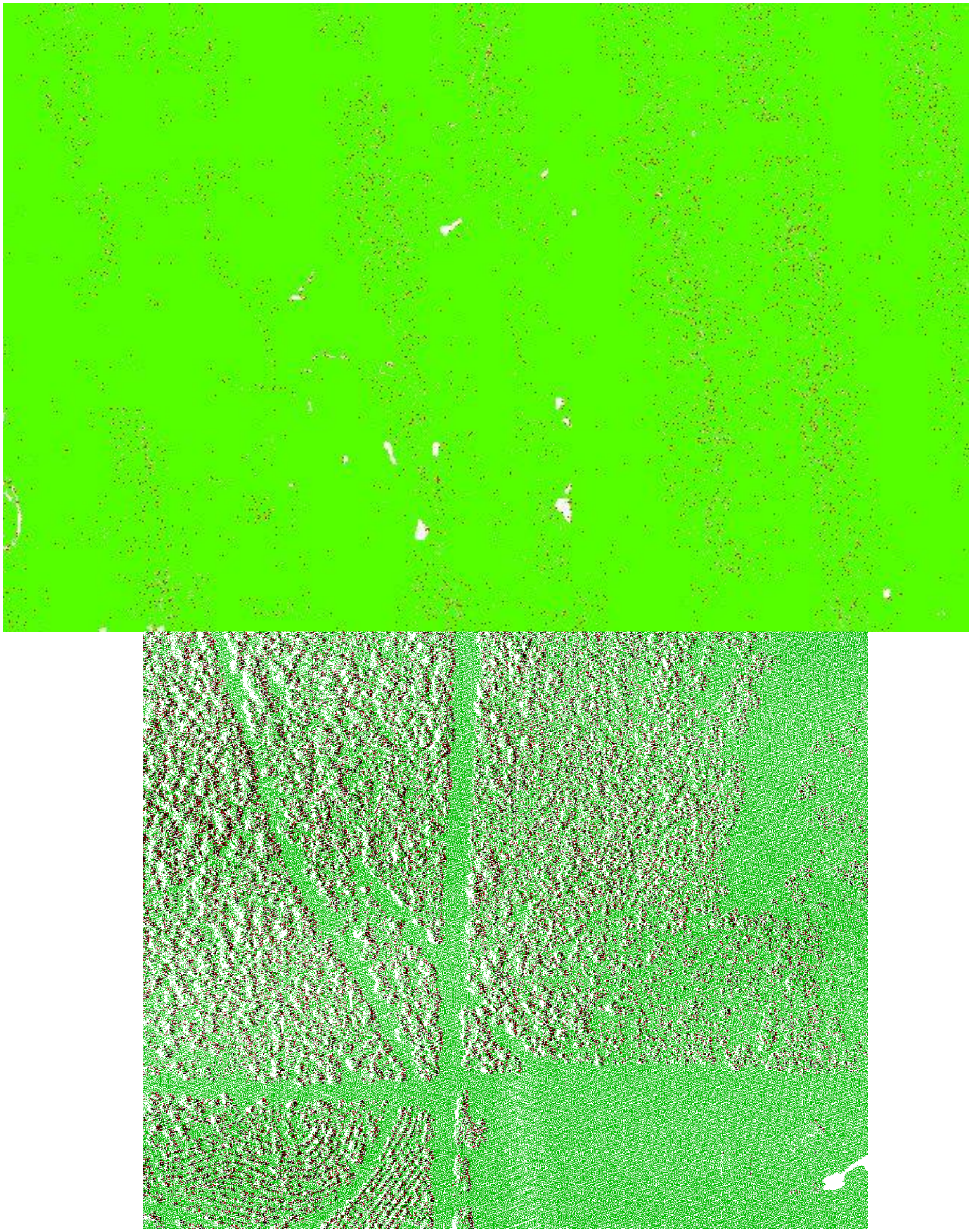


Figure 7–Intra-swath relative accuracy. These images show a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped and vegetated terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change and vegetation height differences. Intra-swath relative accuracy passes specifications. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

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

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

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.50 meters or an ANPD of 3.97 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

Figure 9– 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data (or the presence of water). Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

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

Figure 10– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 97.6% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

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

Each tile was then imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

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

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

Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for the FL Escambia Santa Rosa NWFWMD lidar project .

Data Voids

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

Artifacts

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

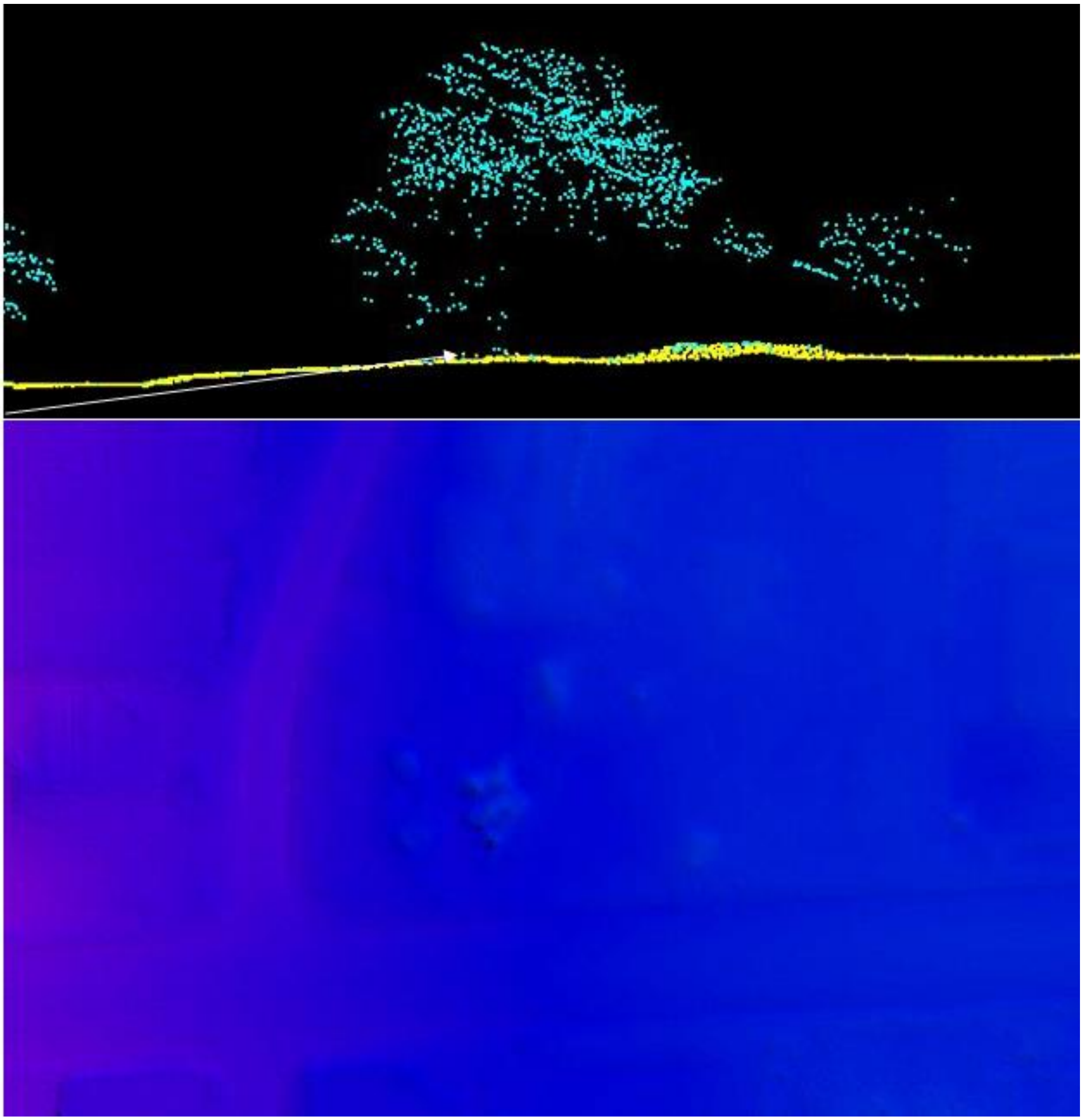


Figure 11 – Tile number 16RDU770735. Profile with points colored by class (class 1=Cyan, class 2=Yellow) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

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

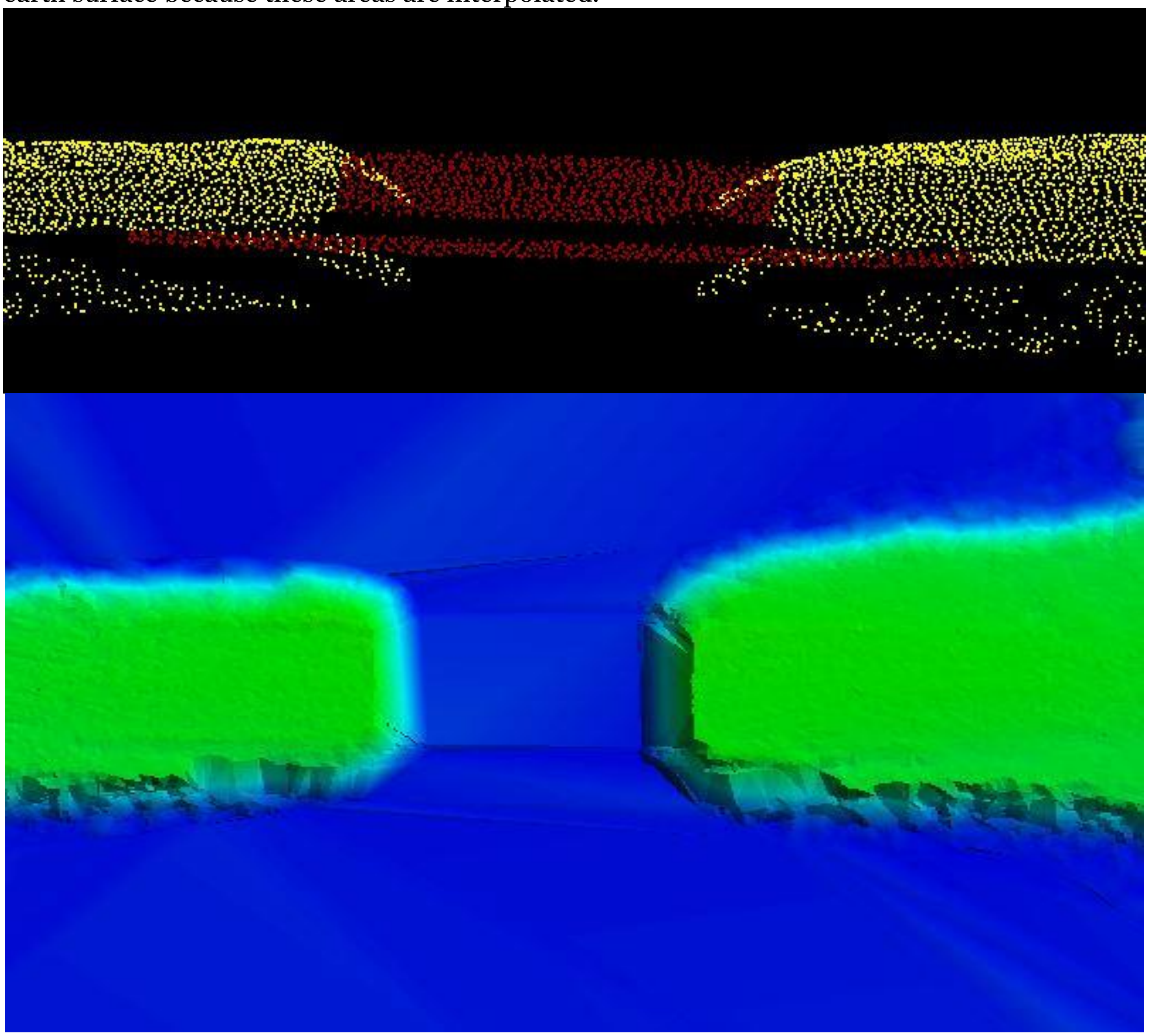


Figure 12 – Tile number 16RFU420750. The DEM in the bottom view shows an area where two bridges have been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (Yellow) and are now classed as Bridge Deck-17 (Brown).

Culverts and Bridges

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

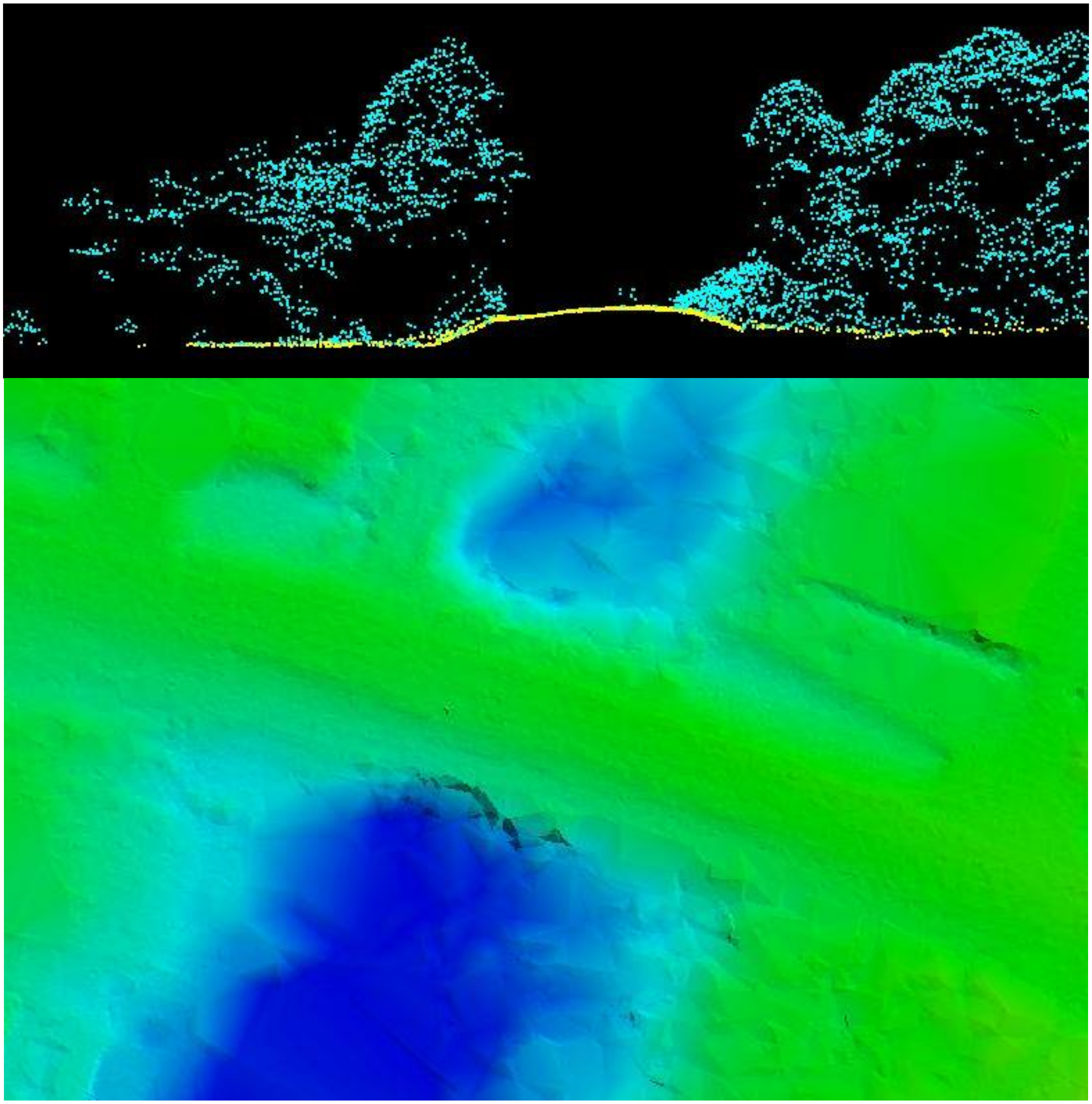


Figure 13– Tile number 16RFU420750. Profile with points colored by class (class 1=Cyan, class 2=Yellow) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Raised Platforms

In ground features, including terraced or built-up earth and concrete for building foundations and structures, exist within the project area. The terraced and built-up earth or concrete features are correctly included in the ground classification while buildings and other above ground structures are correctly removed.

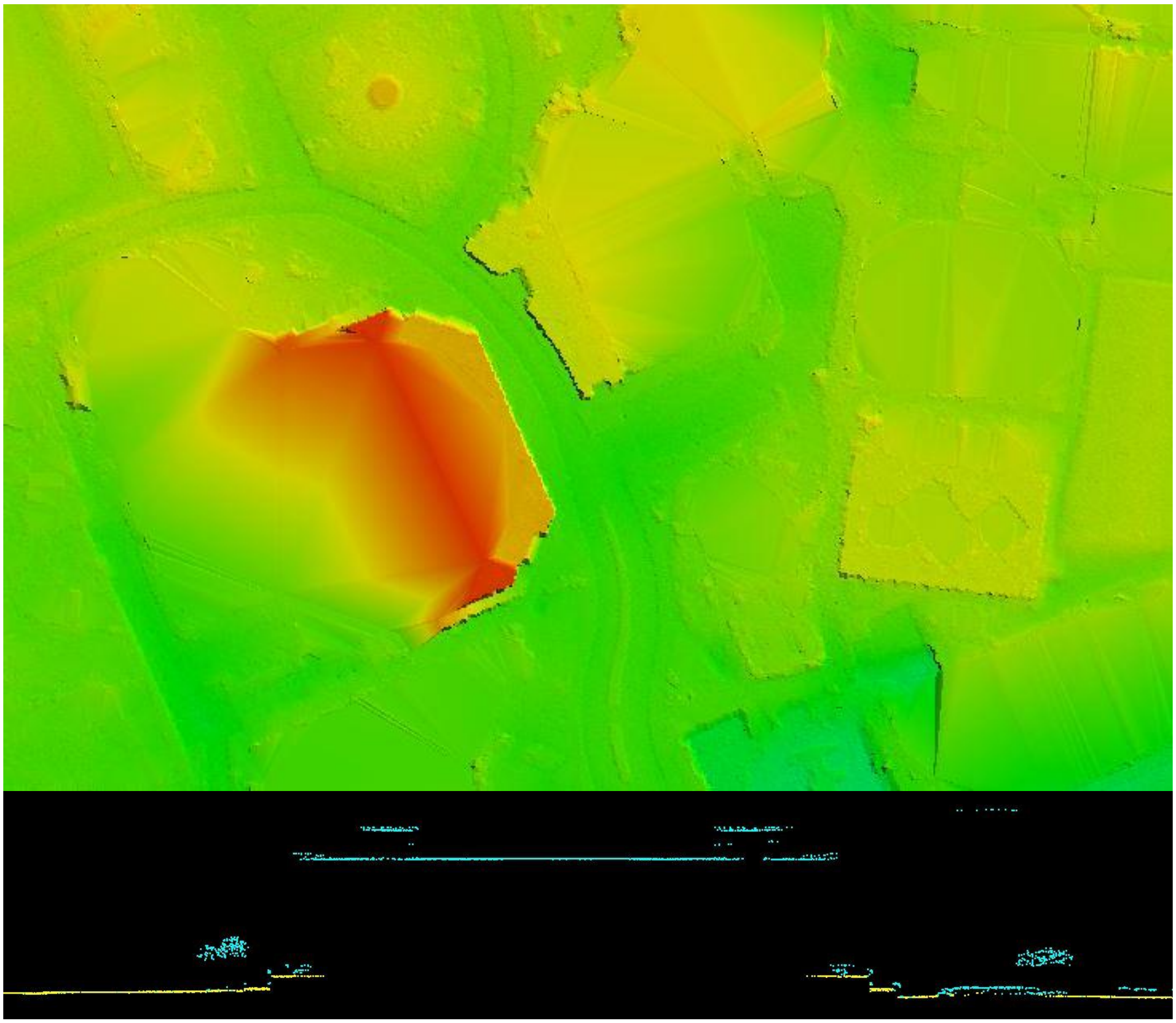


Figure 14 – Tile number 16RDU770705. Profile with the points colored by class (class 1 =cyan and class 2=yellow) is shown in the bottom view and a DEM of the surface is shown in the top view. These features are correctly included in the ground classification.

Dirt Mounds

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

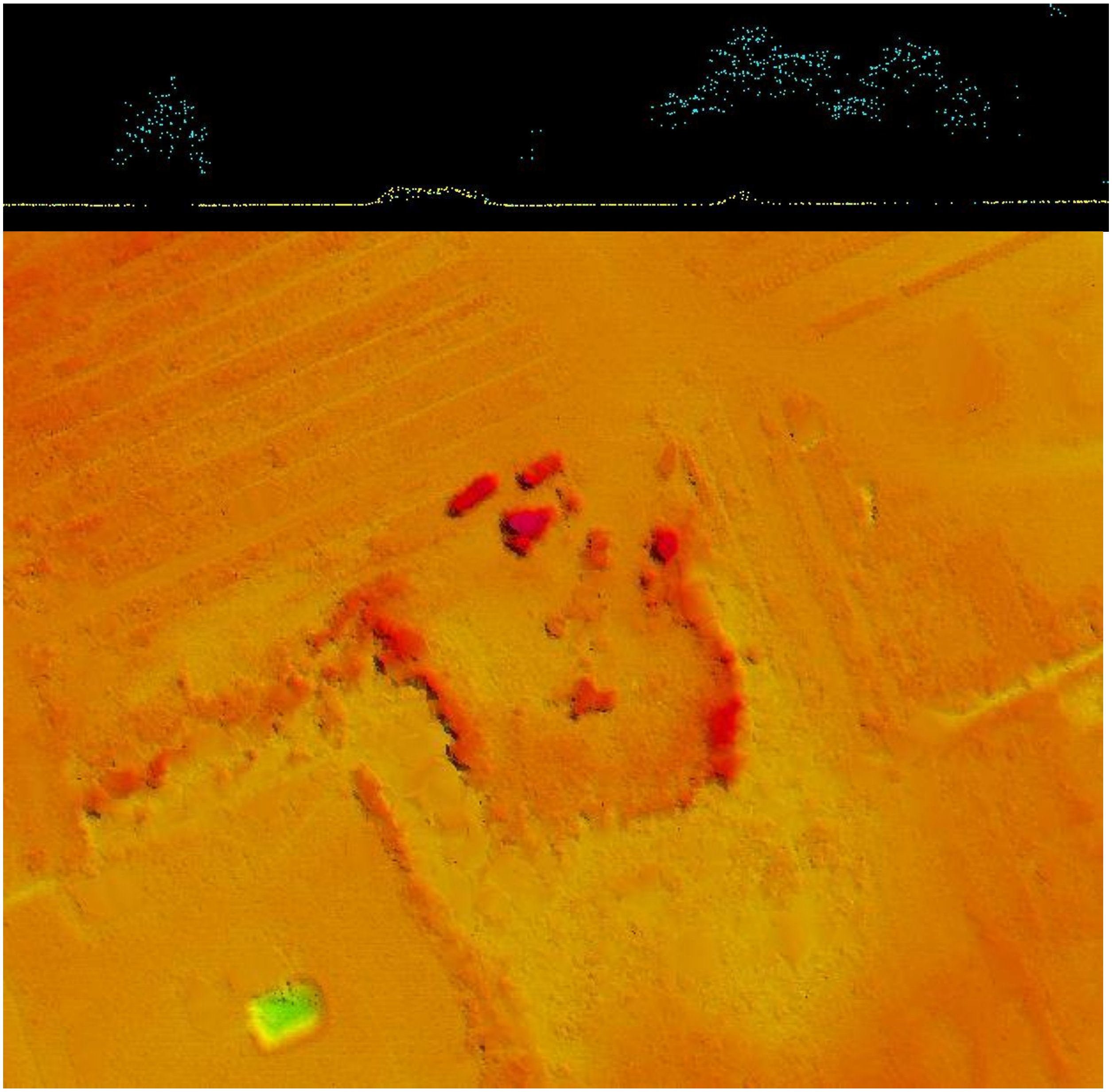


Figure 15 - Tile 16RDU770705. Profile with the points colored by class (class 1=cyan and class 2=yellow) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification

FORMATTING

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

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) UTM Zone 16, meters and NAVD88 (Geoid 12B), meters in WKT Format/NAD83 (2011) UTM Zone 16, meters and NAVD88 (Geoid 12B), feet in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Derivative Lidar Products

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

LOW CONFIDENCE POLYGONS

Low confidence polygons have been delivered with this dataset. These polygons represent areas where heavy vegetation greatly diminishes penetration of the lidar pulse, resulting in a bare earth surface that is potentially less accurate due to the lack of lidar returns from the ground beneath the vegetation. Low confidence polygons delineate areas where conformance to VVA standards may not be met. The low confidence polygons created for this dataset were delineated according to the criteria and assumptions outlined in the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014). Low confidence areas are identified using a ground density raster. All areas with a Nominal Ground Point Density less than a specified threshold are identified as low confidence cells in the ground density raster. The low confidence cells are exported to polygons and aggregated into larger shapes. Areas of expected low density in the ground, such as water or where buildings/structures have been removed, are deleted from the aggregated low confidence polygons. The size of all polygons are then calculated and polygons below the minimum size threshold are removed from the final low confidence polygon dataset.

Lidar Positional Accuracy

BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

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

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred and twenty (120) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

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

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

Point ID	NAD83(2011) UTM Zone 16		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
NVA01	445451.051	3427901.586	83.830
NVA02	457534.327	3427559.378	84.940
NVA03	468057.148	3428073.543	83.653
NVA04	477933.910	3428255.118	18.020
NVA05	485579.641	3428361.459	56.400
NVA06	498219.590	3428021.782	73.378
NVA07	449766.488	3422528.794	70.400
NVA08	453496.615	3422025.509	80.940
NVA09	471878.688	3422682.941	24.360
NVA10	483249.507	3422909.134	79.640
NVA11	488329.332	3423120.189	73.347
NVA12	492296.607	3424091.831	70.941
NVA13	444282.358	3417236.365	70.016
NVA14	455735.529	3417393.461	74.578
NVA15	465665.748	3417660.856	76.220
NVA16	469305.942	3417368.161	35.678
NVA17	481278.621	3416566.087	76.514
NVA18	498665.063	3418461.089	73.300
NVA19	455118.193	3411942.075	73.966
NVA20	465639.624	3412049.199	76.313
NVA21	470106.515	3411985.024	9.641
NVA22	480788.174	3411688.403	70.557
NVA23	491680.510	3412728.445	38.884
NVA24	449864.349	3406768.125	69.780
NVA25	460028.988	3406764.297	64.344
NVA26	480620.347	3406809.844	63.142
NVA27	486319.521	3407070.76	65.102
NVA28	491184.250	3407383.032	62.385
NVA29	496834.711	3407334.445	32.731
NVA30	461287.998	3402213.739	58.104
NVA31	465258.133	3401088.877	63.346
NVA32	481504.666	3401528.555	58.108
NVA33	492371.304	3401753.295	61.588
NVA34	505583.769	3404039.974	62.569
NVA35	458326.185	3395828.191	16.212

NVA36	470412.220	3396322.341	17.193
NVA37	482559.893	3397185.450	59.816
NVA38	495221.483	3396664.612	46.145
NVA39	502165.770	3396725.194	14.550
NVA40	472743.566	3390359.827	21.286
NVA41	485537.231	3391257.565	48.493
NVA42	495319.260	3391843.370	46.090
NVA43	504327.863	3390797.935	40.329
NVA44	468709.654	3386271.931	44.553
NVA45	482496.241	3385247.264	16.484
NVA46	487887.030	3385634.379	43.191
NVA47	507733.002	3386383.664	33.011
NVA48	472735.632	3379571.961	40.546
NVA49	479213.885	3380117.564	18.696
NVA50	491721.826	3380053.852	8.139
NVA51	458879.485	3377585.376	9.239
NVA52	469725.157	3374766.447	15.873
NVA53	475560.490	3375106.850	39.966
NVA54	480261.552	3374954.830	30.217
NVA55	475286.639	3369038.689	25.057
NVA56	481173.921	3369373.413	10.796
NVA57	473423.976	3363510.295	8.541
NVA58	480160.700	3364859.827	5.369
NVA59	467649.987	3359634.342	6.305
NVA60	451743.409	3350449.432	3.967
NVA61	463323.546	3352907.190	2.121
NVA62	494000.006	3362148.805	5.726
NVA63	507492.049	3367643.003	6.262
NVA64	513378.014	3364608.784	10.191
NVA65	482615.640	3354921.603	1.577
NVA66	513514.941	3361200.454	1.742
VVA01	450738.707	3428307.083	86.003
VVA02	463241.717	3428257.634	84.043
VVA03	471759.120	3429021.305	59.417
VVA04	491995.886	3428428.922	85.736
VVA05	445347.594	3422688.185	83.056
VVA06	459964.450	3422323.678	77.915
VVA07	466187.868	3422824.024	78.344
VVA08	479117.928	3423102.012	34.186
VVA09	496790.670	3423879.673	80.353
VVA10	449124.250	3417182.140	67.070
VVA11	460759.297	3416870.449	69.001
VVA12	475967.064	3416614.953	50.326
VVA13	486797.822	3417629.720	69.560

VVA14	492563.589	3417644.121	45.409
VVA15	448969.805	3412065.924	64.959
VVA16	458955.132	3412930.165	74.506
VVA17	475095.497	3412206.688	24.437
VVA18	487093.484	3413087.973	53.354
VVA19	497341.277	3411944.599	52.853
VVA20	454535.727	3405683.366	67.521
VVA21	467169.322	3407851.638	46.553
VVA22	476145.498	3406860.626	31.737
VVA23	501512.776	3407279.996	52.148
VVA24	456259.312	3400817.903	38.446
VVA25	469201.051	3401563.801	13.173
VVA26	477641.735	3401666.537	30.791
VVA27	487060.409	3401817.300	51.385
VVA28	499843.971	3401468.866	50.947
VVA29	464780.649	3395821.805	54.078
VVA30	477786.752	3396221.554	30.861
VVA31	489275.384	3396944.445	49.085
VVA32	508569.994	3396591.220	10.649
VVA33	464894.665	3390550.872	28.806
VVA34	480140.347	3390658.317	21.951
VVA35	489712.209	3390477.817	24.982
VVA36	500608.080	3390949.420	2.747
VVA37	462501.916	3386271.757	23.036
VVA38	473478.132	3387571.813	21.223
VVA39	494105.606	3386002.583	1.202
VVA40	499554.390	3386231.844	2.237
VVA41	466666.007	3379680.652	20.561
VVA42	496592.718	3381301.734	7.115
VVA43	464044.133	3374898.404	21.767
VVA44	493104.054	3374979.048	5.649
VVA45	500377.824	3375603.457	3.065
VVA46	467661.349	3369549.029	22.288
VVA47	492127.307	3371354.284	3.193
VVA48	464553.786	3364452.225	2.050
VVA49	468083.187	3363442.911	9.245
VVA50	461287.128	3359599.083	7.977
VVA51	458862.893	3352133.242	1.816
VVA52	487005.766	3359192.613	3.624
VVA53	500837.642	3363025.687	10.154
VVA54	494222.836	3357278.443	0.916

Table 5: FL Escambia Santa Rosa NWFWMD lidar surveyed accuracy checkpoints

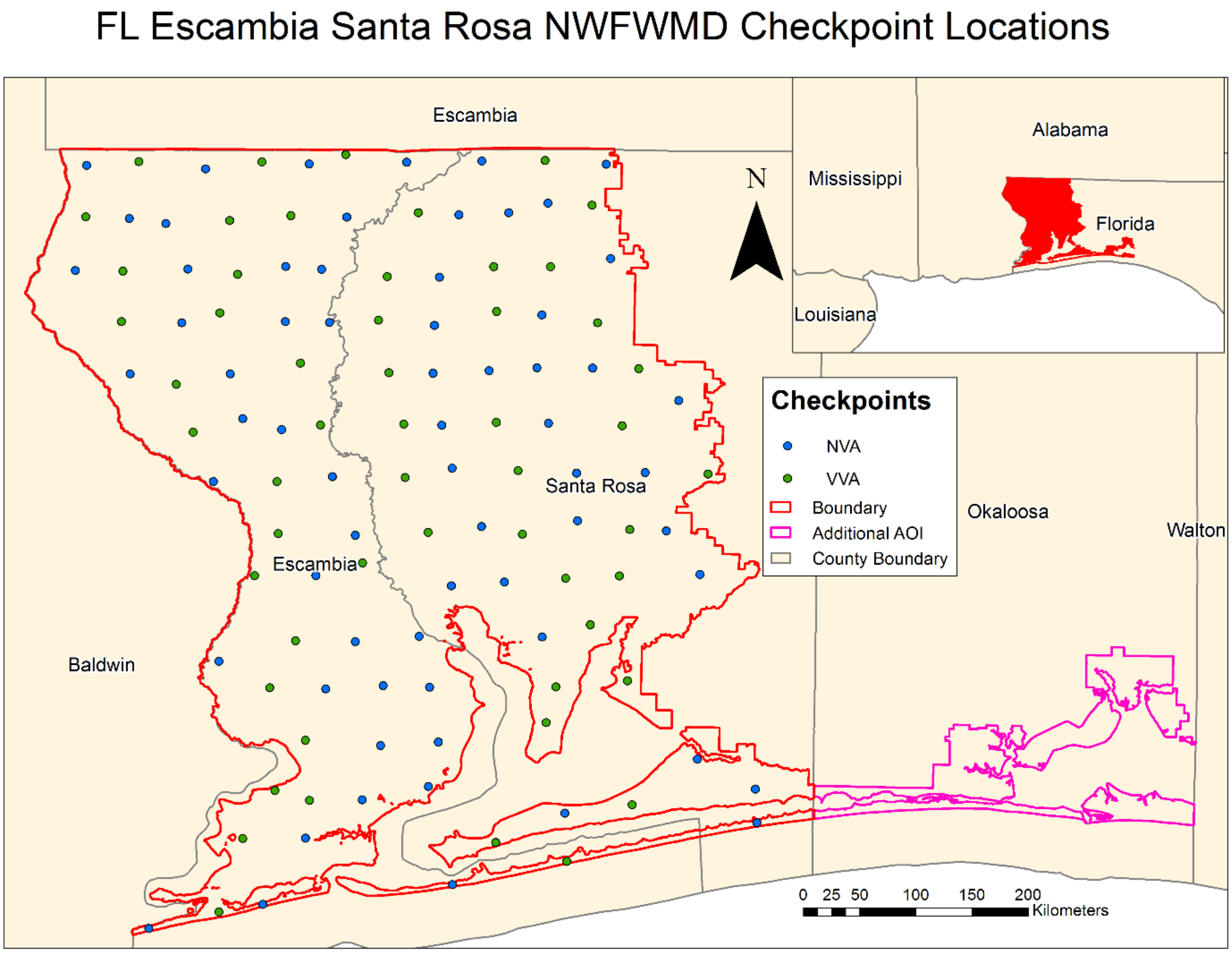


Figure 16 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

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

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The FL Escambia Santa Rosa NWFWMD lidar Project VVA standard is 29.4 cm based on the 95th

percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 6.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	29.4 cm (based on combined 95th percentile)

Table 6 — Acceptance Criteria

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

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

VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	66	9.7	
VVA	54		13.1

Table 7 — Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 4.9 cm, equating to +/- 9.7 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 13.1 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 8 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +27 cm.

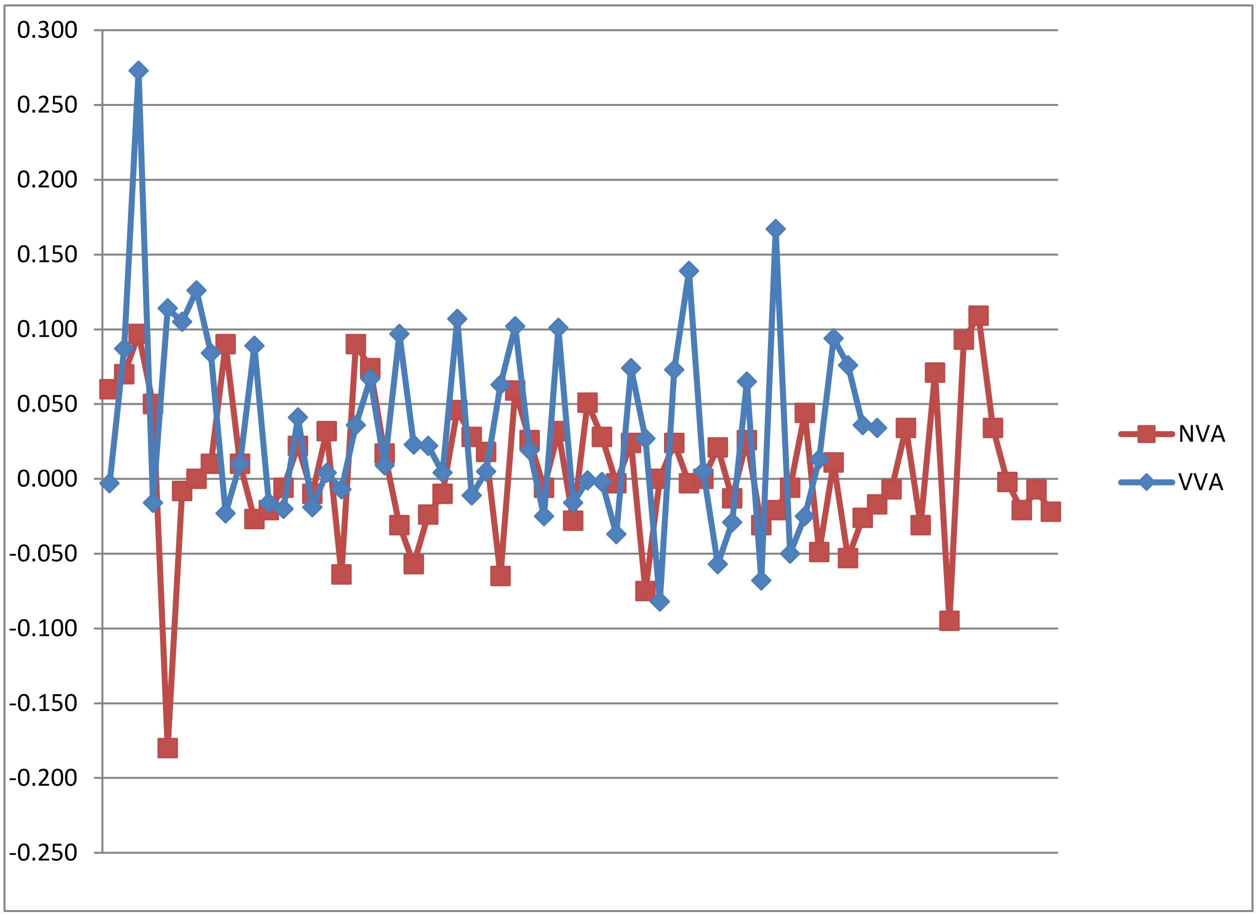


Figure 17 – Magnitude of elevation discrepancies per land cover category

Table 8 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) UTM Zone 16		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			

VVA41	485537.231	3391257.565	20.561	20.700	0.139	0.139
VVA47	507733.002	3386383.664	3.193	3.360	0.167	0.167
VVA03	471759.120	3429021.305	59.417	59.690	0.273	0.273

Table 8 — 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	66	0.049	0.006	0.000	-0.575	0.049	2.177	-0.180	0.109
VVA	54	N/A	0.035	0.020	0.974	0.066	1.871	-0.082	0.273

Table 9 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.180 meters and a high of +0.273 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.075 meters to +0.075 meters.

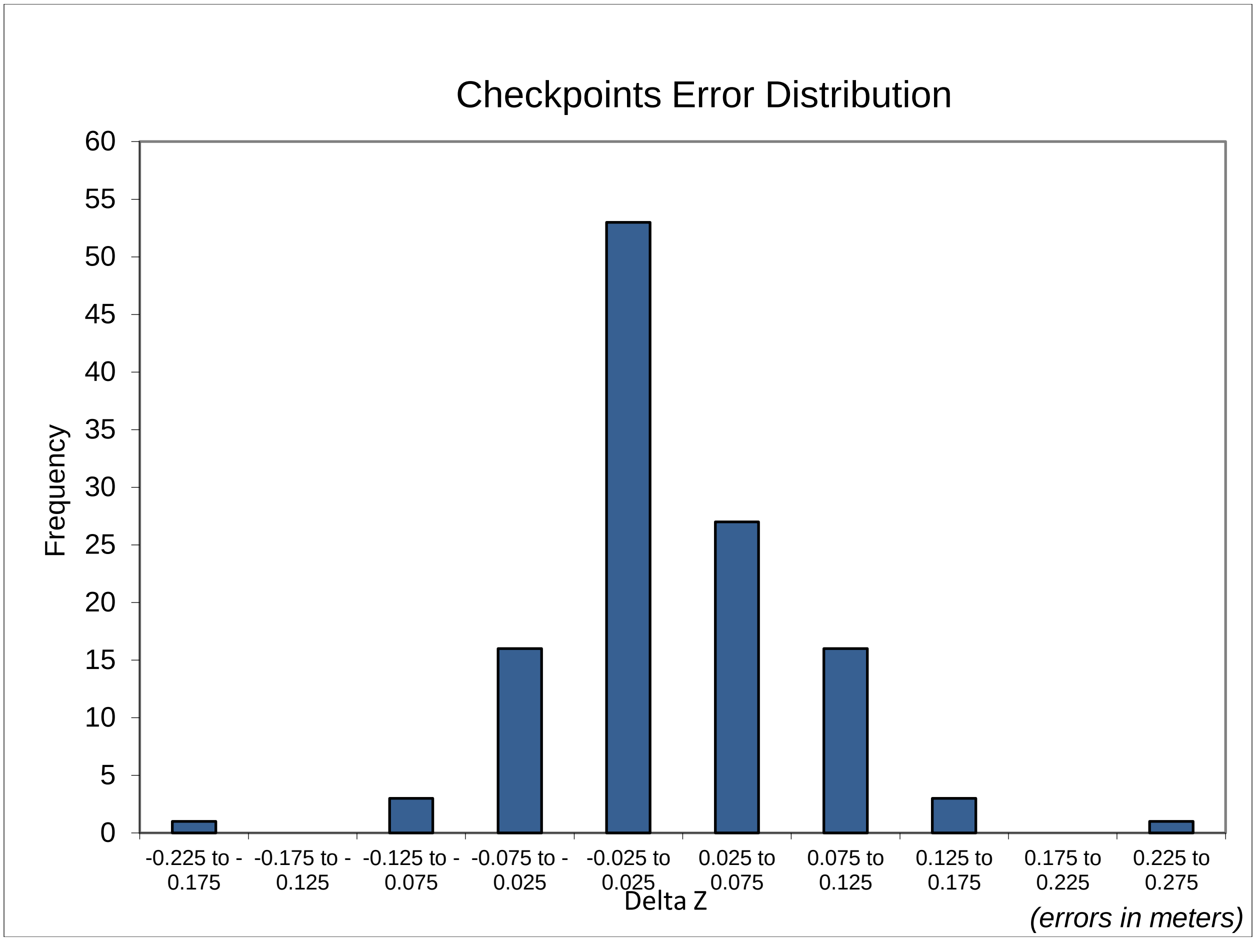


Figure 18 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the FL Escambia Santa Rosa NWFWMD lidar Project satisfies the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

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

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

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

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

HORIZONTAL ACCURACY RESULTS

Twenty nine checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As twenty nine (29) checkpoints were photo-identifiable, the results are statistically significant enough to report as a final tested value.

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

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

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
29	9.5	15.0	17.8	30.8

Table 10 - Tested horizontal accuracy at the 95% confidence level

Twenty nine (29) checkpoints were used for horizontal accuracy testing. This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Actual positional accuracy of this dataset was found to be RMSEx = 9.5 cm and RMSEy = 15.0 cm which equates to +/- 30.8 cm at 95% confidence level.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop lidar stereo models of the project area so the lidar derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using lidargrammetry procedures with lidar intensity imagery, Dewberry used the stereo models to stereo-compile the three types of hydrographic breaklines in accordance with the project's Data Dictionary.

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

BREAKLINE QUALITATIVE ASSESSMENT

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

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

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

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

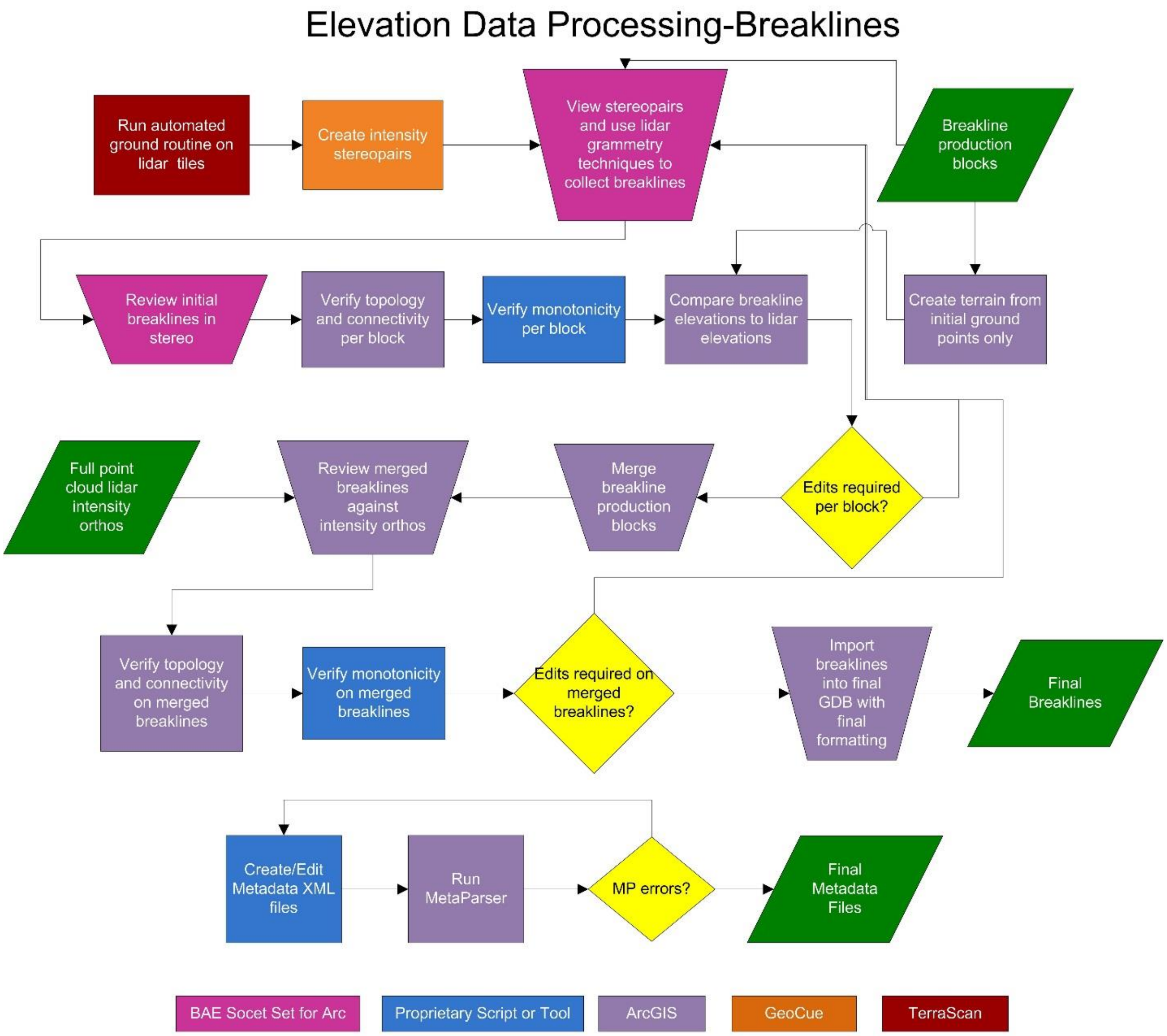


Figure 19-Breakline QA/QC workflow

BREAKLINE CHECKLIST

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

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).
Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC

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

Table 11-A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters (a second dataset was created and delivered where vertical units were converted from meters to feet). Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to UTM Zone 16, Horizontal Units in Meters and Vertical Units in Meters (a second dataset was created and delivered where vertical units were converted from meters to feet)..

Inland Streams and Rivers

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

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

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

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

SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes

Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None

XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

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

Table Definition

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

Feature Definition

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

Tidal Waters

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

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

Description

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

Table Definition

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

Feature Definition

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

Beneath Bridge Breaklines

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

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

Description

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

Table Definition

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

Feature Definition

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

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

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

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

Figure 20-DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

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

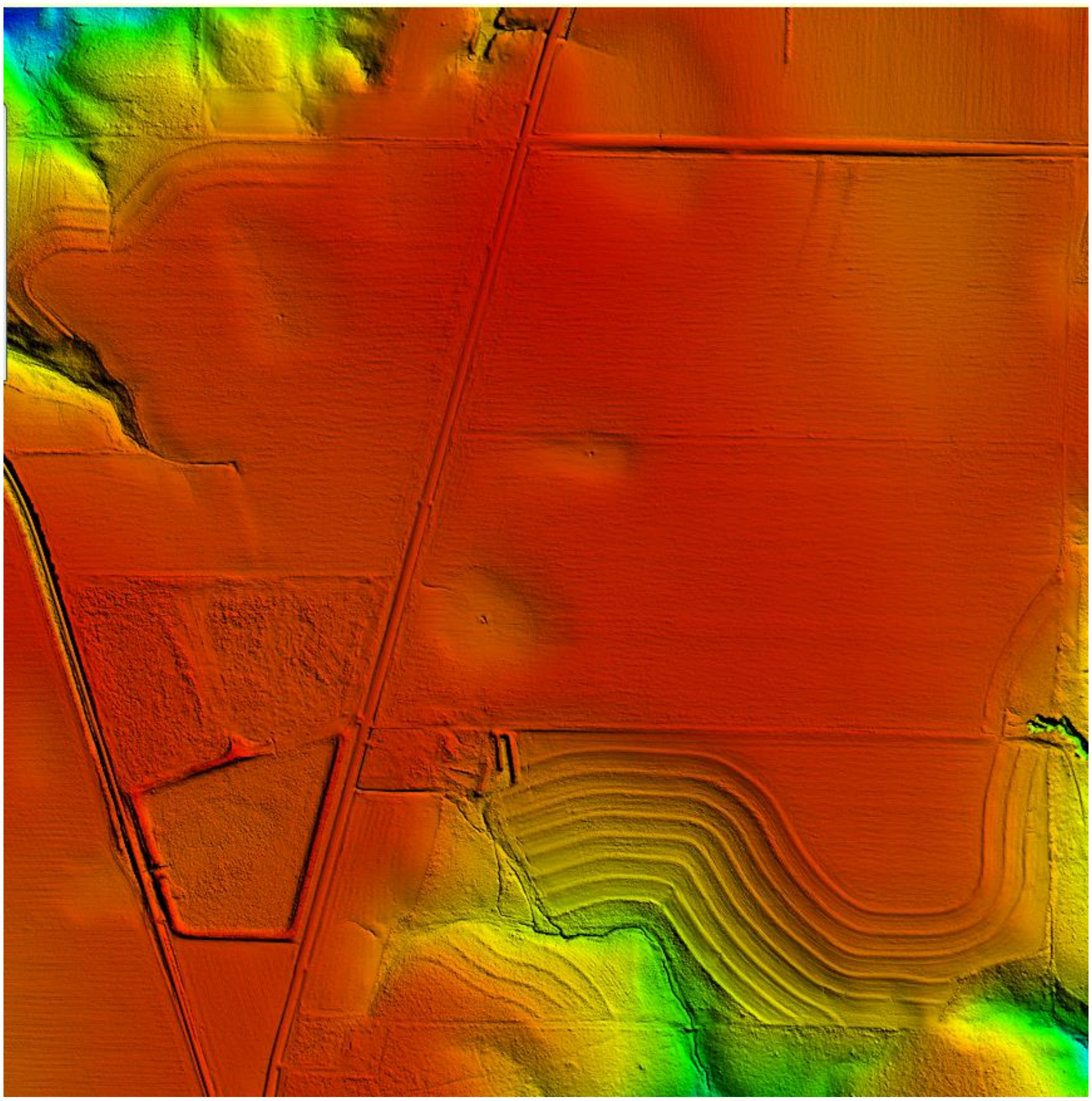


Figure 21-Tile 16RDV545110. Image of a bare earth DEM

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

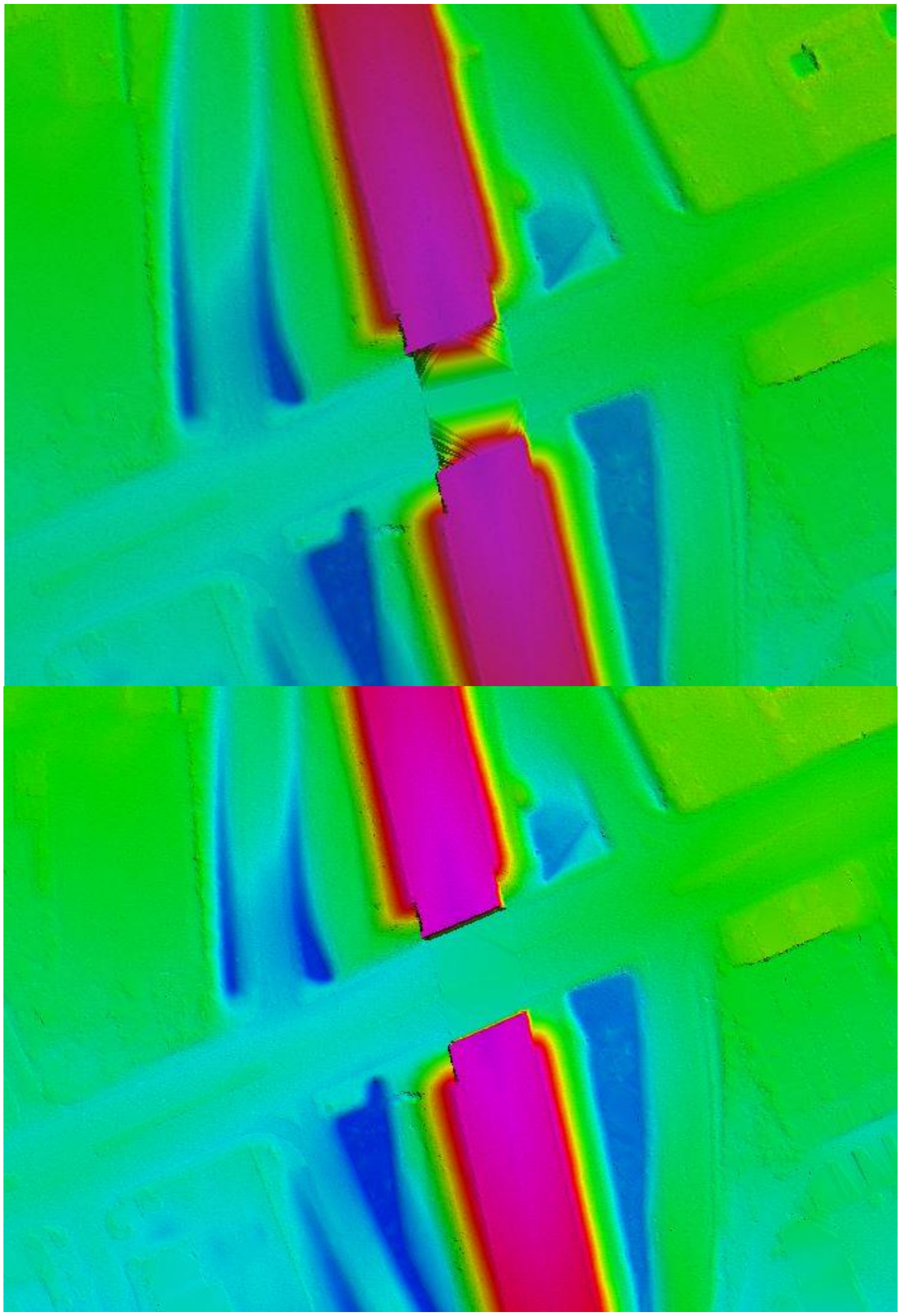


Figure 22 - Tile 16RDU770705. The DEM on top shows a bridge saddle artifact while the DEM on the bottom shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 120 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 12 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	66	9.6	
VVA	54		14.9

Table 12 — DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =4.9 cm, equating to +/- 9.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 14.9 cm at the 95th percentile.

Table 13 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) UTM Zone 16		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA41	485537.231	3391257.565	20.561	20.722	0.161	0.161
VVA07	507733.002	3386383.664	73.344	78.503	0.159	0.159
VVA03	471759.120	3429021.305	59.417	59.682	0.265	0.265

Table 13 — 5% Outliers

Table 14 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	66	0.049	0.003	-0.001	-0.326	0.049	2.086	-0.177	0.119
VVA	54	N/A	0.040	0.021	0.771	0.068	0.792	-0.075	0.265

Table 14 – Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Escambia Santa Rosa NWFWMD lidar Project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

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

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

Table 15-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Survey Report

1. Introduction

1.1 *Project Summary*

Dewberry|Preble-Rish is under subcontract to Dewberry Consultants, LLC, to provide a minimum of 66 Non-vegetated Vertical Accuracy (NVA – total number actually surveyed = 66), and 54 Vegetated Vertical Accuracy (VVA – total number actually surveyed = 54) check points for NWFWMD in the State of Florida. A minimum of half (33) of the NVA points shall also be horizontal accuracy check points (total number actually surveyed = 33). Under the above referenced NWFWMD Task Order, Dewberry|Preble-Rish was tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As part of this work, Dewberry|Preble-Rish staff completed checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR.

Existing NGS Control Points were recovered and surveyed to verify the accuracy of the RTK/GPS survey equipment with the results shown in Section 2.4 and Appendix 1 of this report.

As an internal QA/QC procedure, and to verify that the LiDAR check points meet the 95% confidence level, 34 of the NVA check points, and 28 of the VVA check points were re-surveyed and are shown in Section 5 of this report. For check points that were surveyed twice, an average of the two observations was computed to generate final coordinates and elevations.

Final horizontal coordinates are referenced to the Florida State Plane Coordinate System, NAD83, North Zone, Meters. Final vertical elevations are referenced to NAVD88 in feet using Geoid model 2012B (Geoid12B).

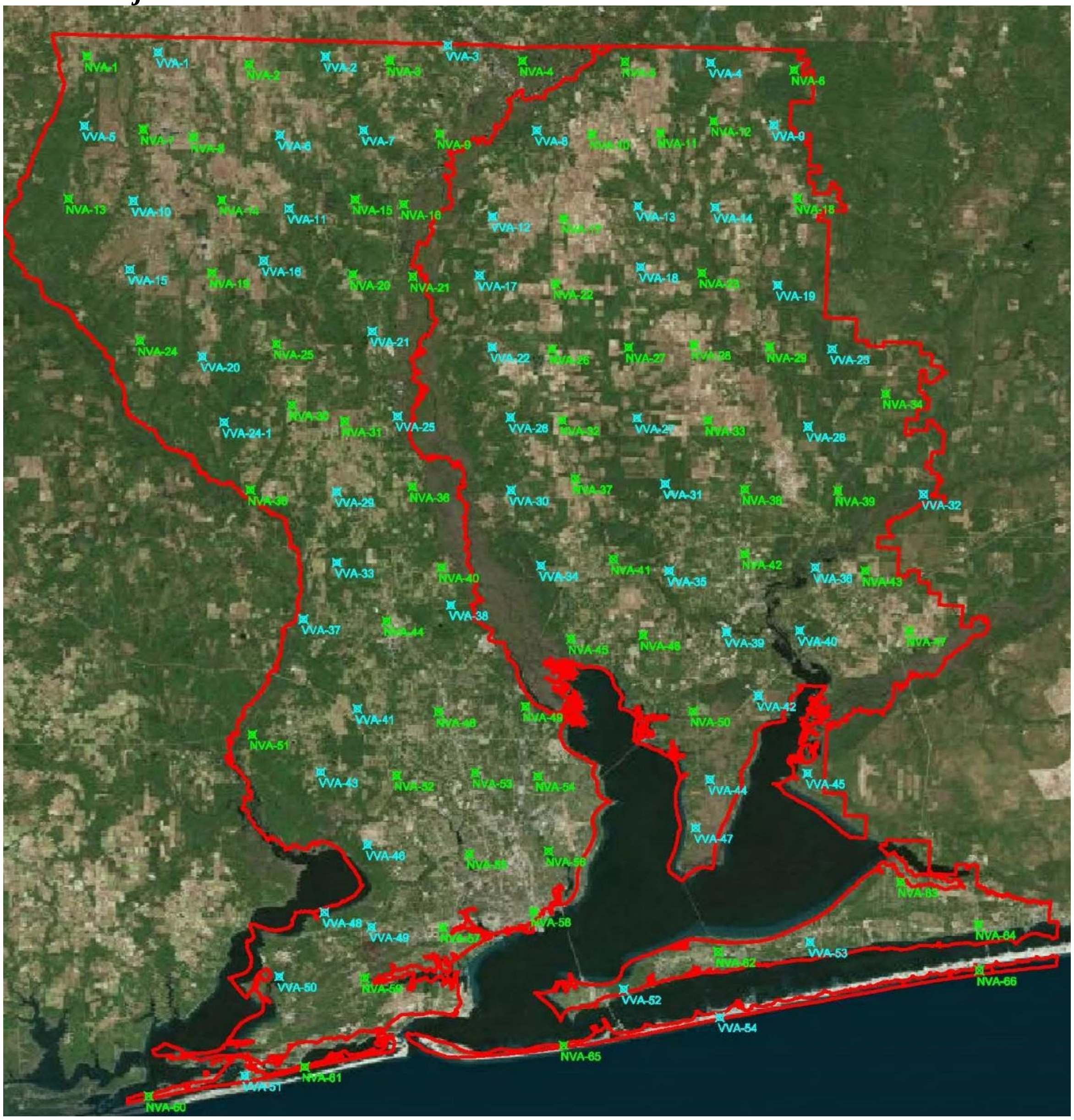
1.2 *Points of Contact*

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

Dewberry|Preble-Rish

Frederick C. Rankin, P.S.M.
Professional Surveyor & Mapper
203 Aberdeen Parkway
Panama City, Florida 32405
(850) 522-0644 office
(850) 522-1011 fax

1.3 *Project Area*



2. Project details

2.1 *Survey Equipment*

In performing the GPS observations, Spectra Precision Epoch 80 GNSS RTK GPS receiver/antenna attached to a 6.56 foot (2 meter) fixed height pole was used, together with a Spectra Precision Ranger Data Collector equipped with SurveyPro Software (version 5.5.2), to collect GPS raw data for the field surveys.

2.2 *Survey Point Detail*

66 Non-vegetated Check Points, and 54 Vegetated Check Points were distributed throughout the project area.

A sketch was made for each location and a nail was set at the point where possible, unless said point was already located at a photo identifiable point. The LiDAR Check Point locations are detailed on the "Ground Control Point Documentation Report", which is delivered via electronic transfer, see appendix 5a on sheet 2.

2.3 *Network Design*

The GPS survey performed by Dewberry|Preble-Rish was tied to the Florida Permanent Reference Network (FPRN), a Real Time Network (RTN) managed by the Florida Department of Transportation. The FPRN consists of a series of approximately 100 continuously operating dual-frequency reference stations (CORS) located throughout Florida, which are tied to the National Geodetic Survey's National CORS network. Each CORS site provides Global Positioning System (GPS) carrier phase and code range measurements in support of 3-dimensional positioning activities through Florida and surrounding states. All of the reference stations have been linked together, creating a Virtual Reference Station System (VRS).

2.4 *Field Survey Procedures and Analysis*

Dewberry|Preble-Rish field surveyors used Spectra Precision Epoch 80 GNSS RTK GPS systems, which is a geodetic quality dual frequency GPS receiver, to collect data at each check point location.

A total of five (5) existing NGS monuments were located as an additional QA/QC procedure, for the purpose of verifying the accuracy of the VRS network. All NGS monuments used are published in the NSRS database, and represent the primary project control for this survey. Field GPS observations are detailed in the "Project Network Control Monument Report", see appendix 1 on sheets 7-8.

A total of 34 of the NVA check point locations, and 28 of the VVA check point locations were occupied twice. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation utilized the VRS network, was occupied for approximately three (3) minutes in duration, and measured to 180 epochs. Field GPS observations are detailed in the "Ground Control Point Documentation Report", and delivered via electronic transfer, see appendix 5a on sheet 2.

2.5 *Adjustment*

The survey data was collected using Virtual Reference Stations (VRS) methodology within a Virtual Reference System (VRS).

The system is designed to provide a true Network RTK performance, the RTK software enables high-accuracy positioning in real time across a geographic region. The RTK software package uses real-time data streams from the GPS system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. Therefore, corrections were applied to the points as they were being collected, thus negating the need for a post process adjustment.

2.6 *Data Processing Procedures*

After field data is collected the information is downloaded from the data collectors into the office software. Text files are created that show the point number, northing, easting, elevation, and description (PNEZD format) for each point surveyed. Points are then entered into a Microsoft Excell spreadsheet, which contains formulas for calculating differences between published and field survey data, as well as, comparing differences between points surveyed multiple times. This data is used to confirm point accuracy and precision.

After review of the point data, an “ASCII” or “txt” file (PNEZD format) is created, which is the industry standard. Point files are loaded into our CADD program (AutoCAD Civil 3D) to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). For check points that were surveyed twice, an average of the two observations was computed to generate final northings, eastings, and elevations. The data can now be imported into the final product.

Appendix B: Complete List of Delivered Tiles

16RDU500495
16RDU515495
16RDU530495
16RDU545495
16RDU515510
16RDU530510
16RDU545510
16RDU560510
16RDU575510
16RDU590510
16RDU605510
16RDU620510
16RDU515525
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16REU070585
16REU085585
16RDU575600
16RDU590600
16RDU605600
16RDU620600
16RDU635600
16RDU650600
16RDU665600
16RDU680600
16RDU695600
16RDU710600
16RDU725600
16RDU740600
16RDU815600
16RDU830600
16RDU860600
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16REU070600
16REU085600
16REU100600
16REU115600
16REU130600
16REU145600
16REU160600
16REU175600
16REU460600
16REU475600
16REU490600
16REU505600
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16REU565600
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16RDU950615
16RDU965615
16RDU980615
16RDU995615
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16REU025615
16REU040615
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16REU070615
16REU085615
16REU100615
16REU115615
16REU130615
16REU145615
16REU160615
16REU175615
16REU190615
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16RDV515065
16RDV530065
16RDV545065
16RDV560065
16RDV575065
16RDV590065
16RDV605065
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16RDV680065
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16RDV710065
16RDV725065
16RDV740065
16RDV755065
16RDV770065
16RDV785065
16RDV800065
16RDV815065
16RDV830065
16RDV845065
16RDV860065
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16RDV890065
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16RDV935065
16RDV950065
16RDV965065
16RDV980065
16RDV995065
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16REV025065
16REV040065
16REV055065
16REV070065
16REV085065
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16RDV440080
16RDV455080
16RDV470080
16RDV485080
16RDV500080
16RDV515080
16RDV530080
16RDV545080
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16RDV575080
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16REV010125
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16RDV455140
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16RDV785290
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16RDV815290
16RDV830290
16RDV845290
16RDV860290
16RDV875290
16RDV890290
16RDV905290
16RDV920290
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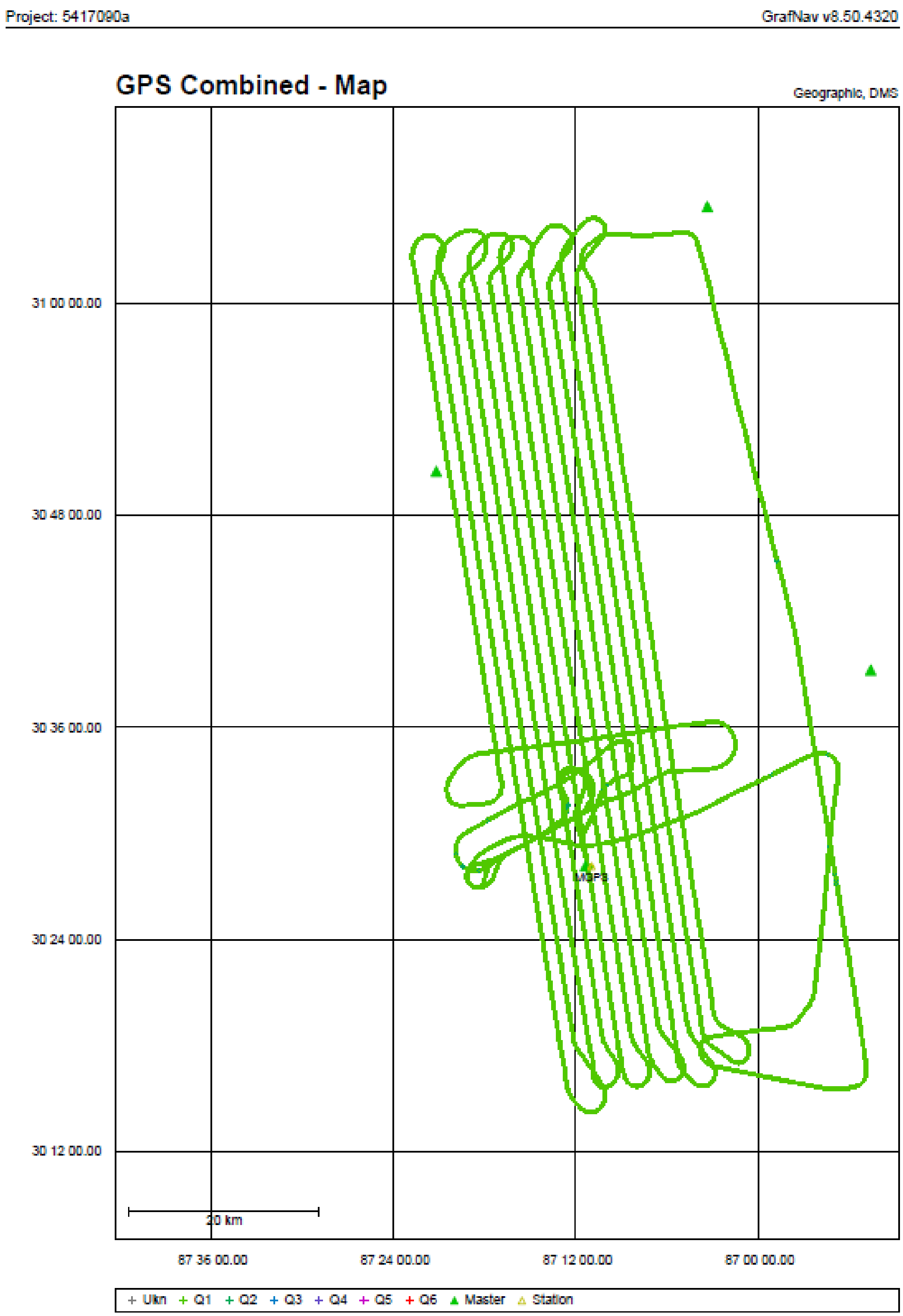
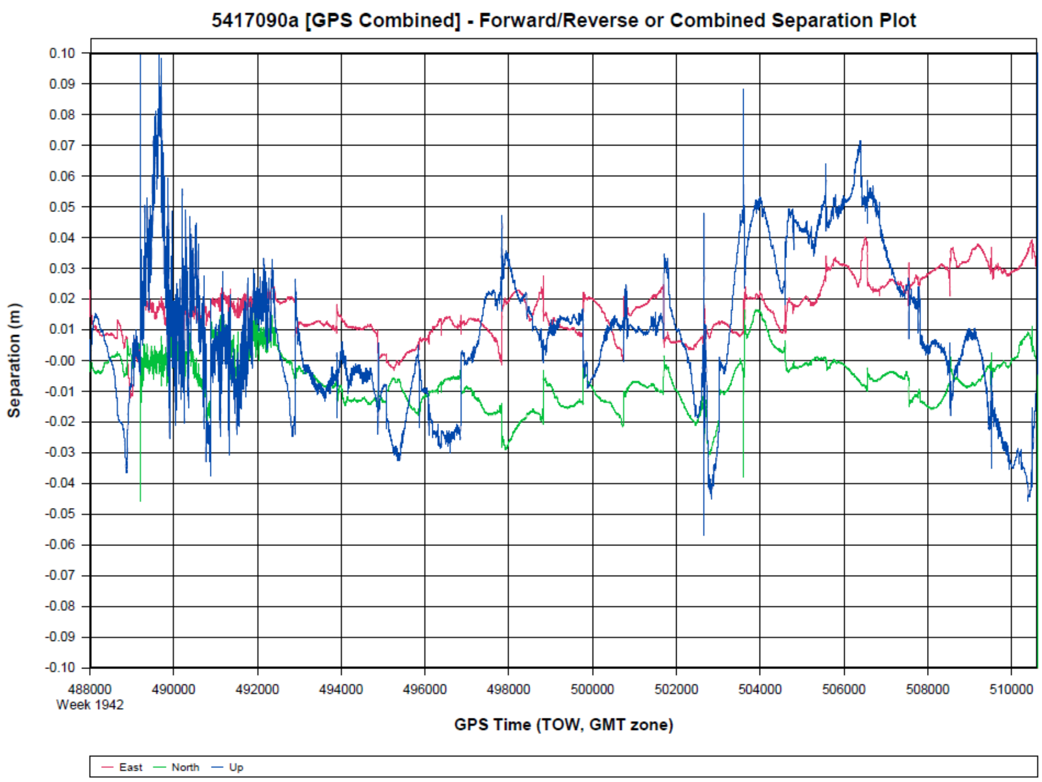
16RDV950290
16RDV965290
16RDV980290

Appendix C: GPS Processing

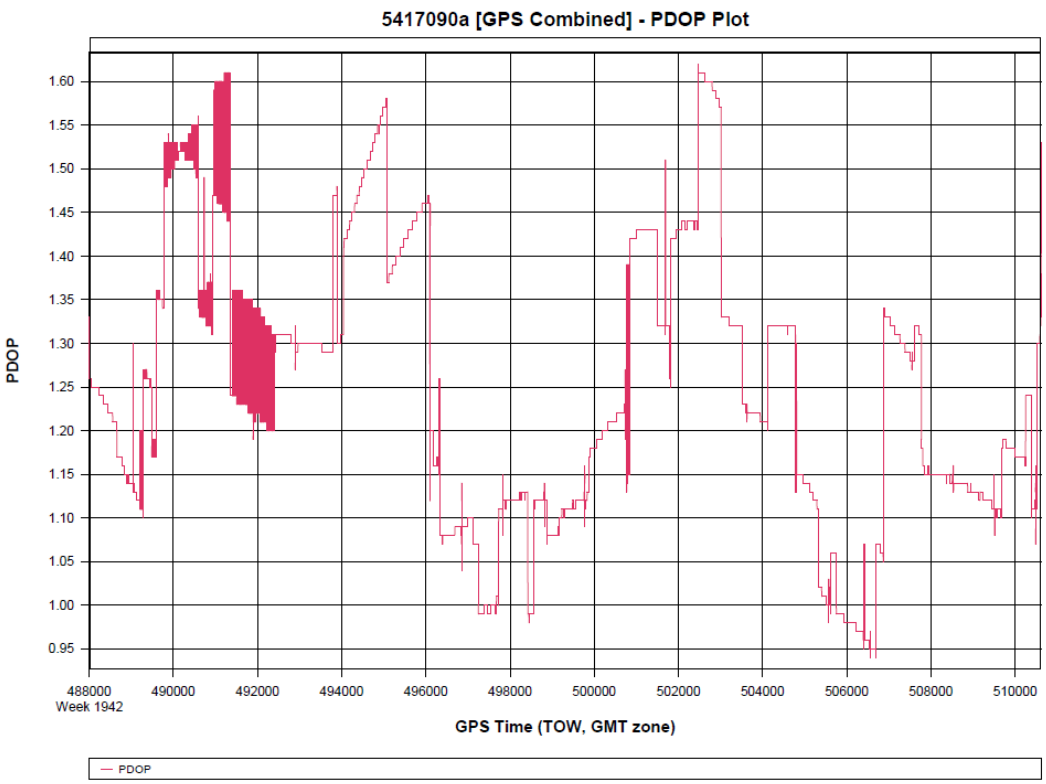
MISSION 1 – 5417090A GNSS PROCESSING



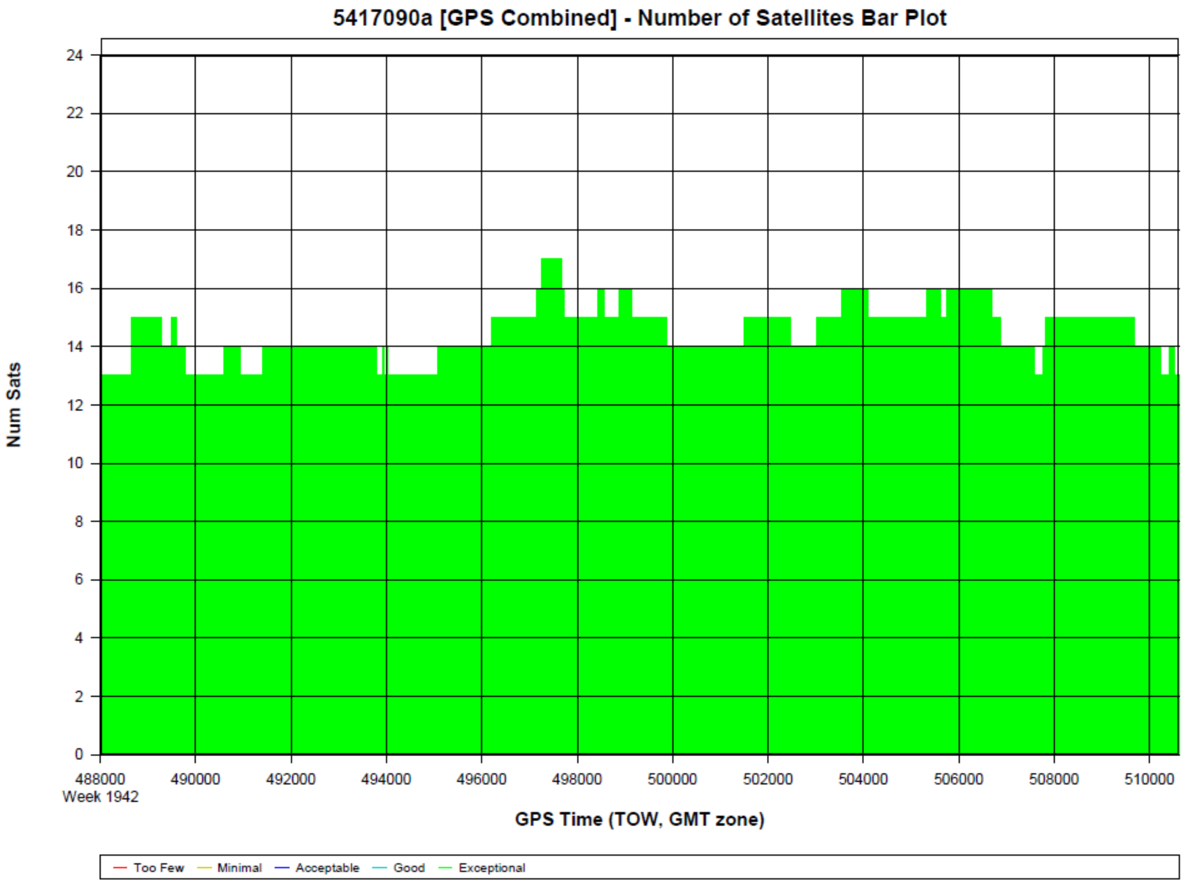
Project: 5417090a GrafNav v8.50.4320



Project: 5417090a GrafNav v8.50.4320



Project: 5417090a GrafNav v8.50.4320



Processing Summary Information

Program: GrafNav
Version: 8.50.4320
Project: D:\Projects\3124_Escambia-SantaRosa\LiDAR\5417090a\05_INS-GPS_PROC\01_POS\5417090a\5417090a\GNSS\5417090a.gnv

Solution Type: Combined

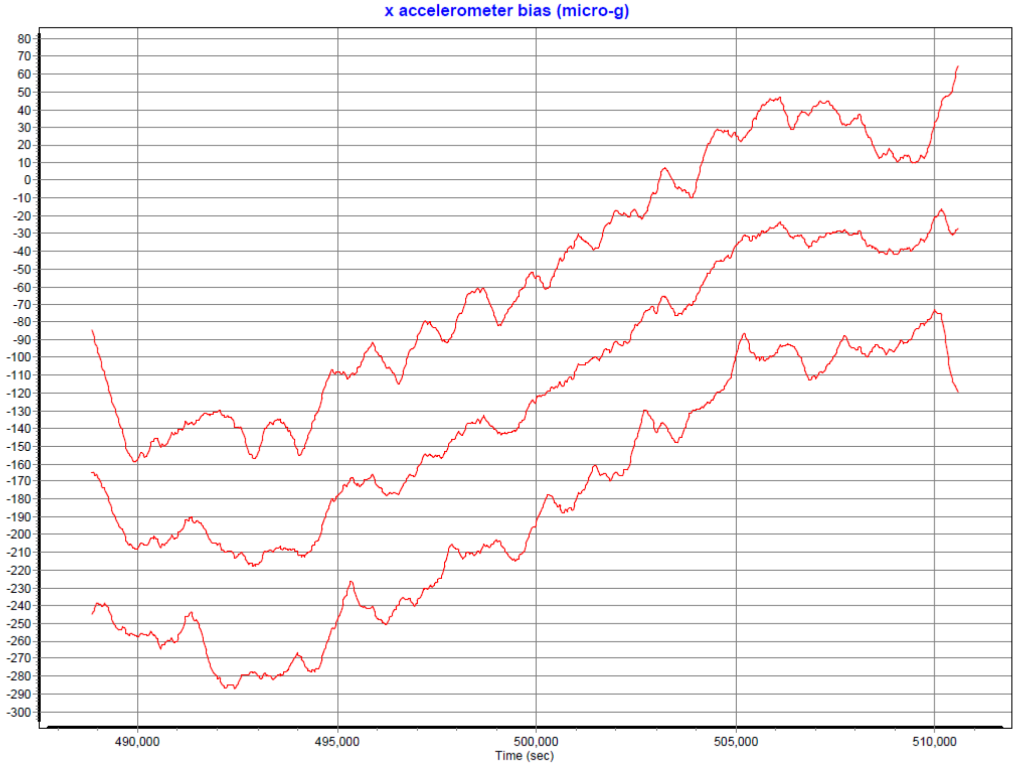
Number of Epochs:
Total in GPB file: 22635
No processed position: 0
Missing Fwd or Rev: 5
With bad C/A code: 0
With bad L1 Phase: 0

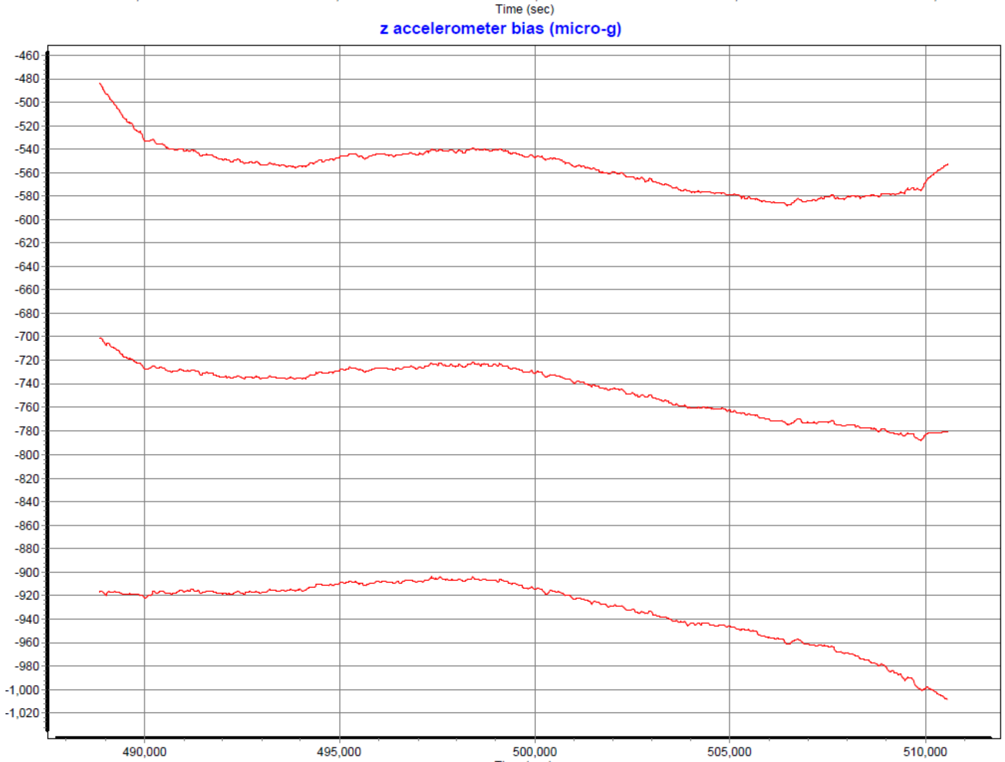
Measurement RMS Values:
L1 Phase: 0.0159 (m)
C/A Code: 0.81 (m)
L1 Doppler: 0.040 (m/s)

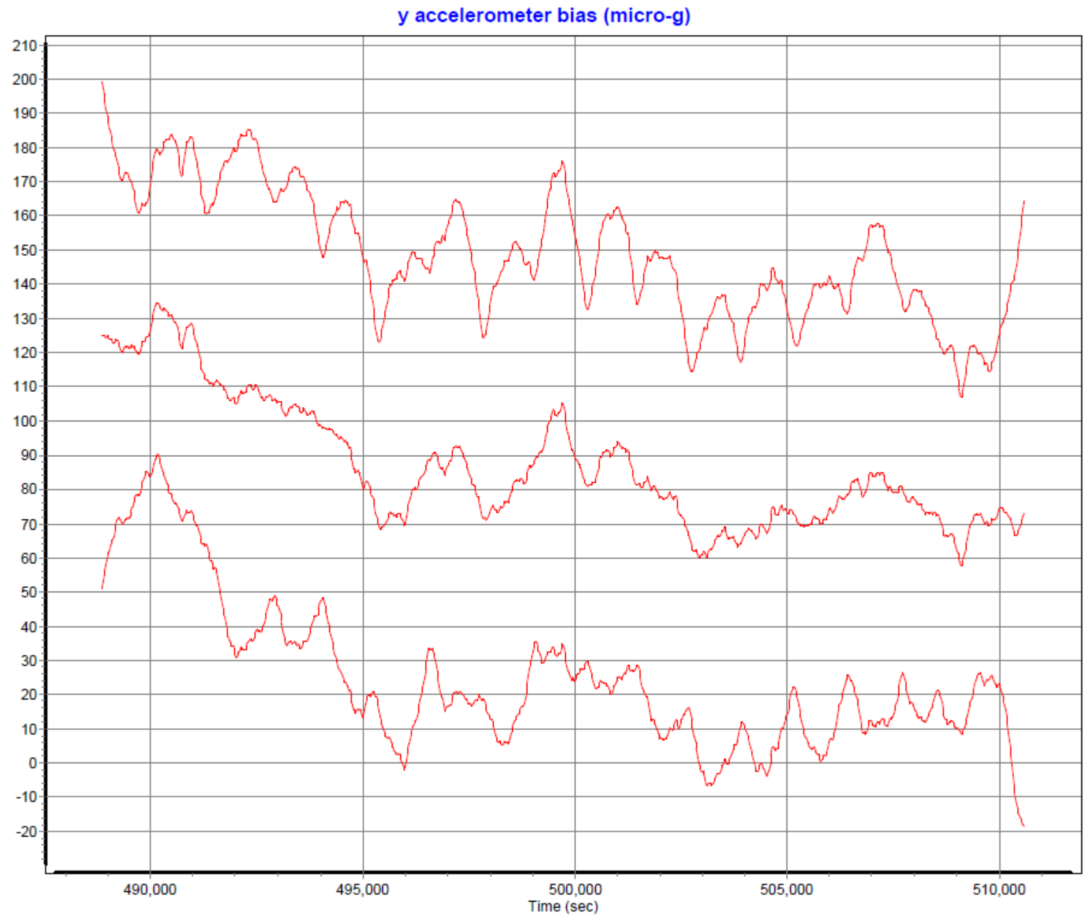
Fwd/Rev Separation RMS Values:
East: 0.020 (m)

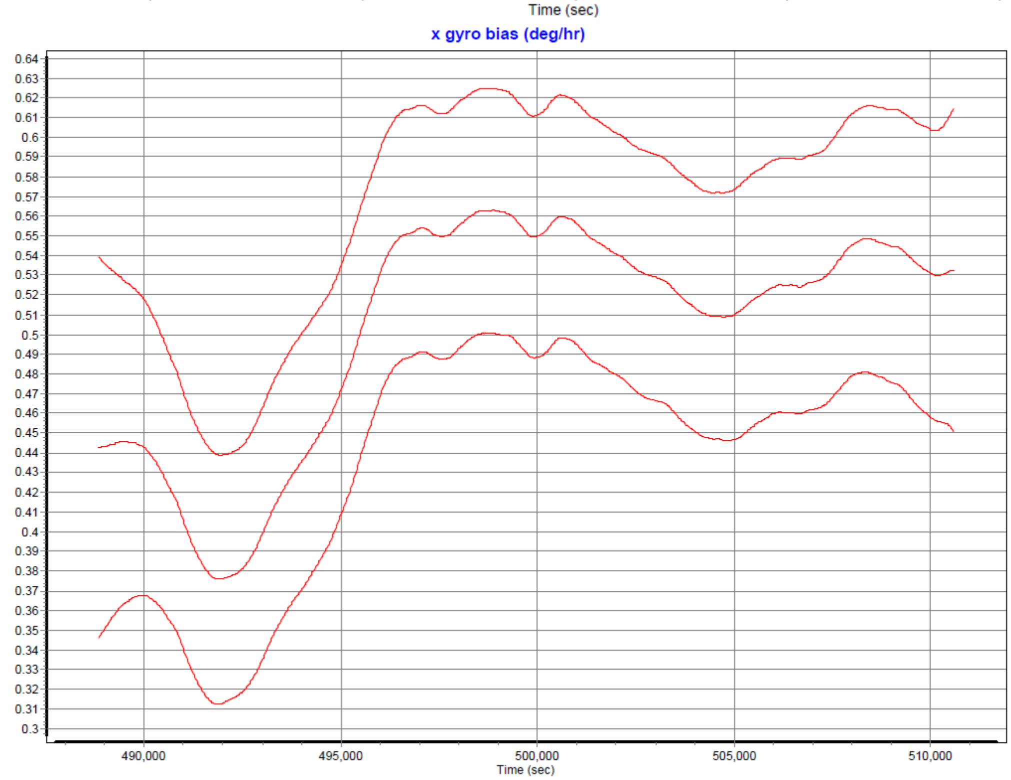
```
      North:       0.011 (m)
      Height:      0.029 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (22628 occurances):
      East:        0.019 (m)
      North:       0.010 (m)
      Height:      0.025 (m)

Quality Number Percentages:
      Q 1:  99.6 %
      Q 2:   0.4 %
      Q 3:   0.0 %
      Q 4:   0.0 %
      Q 5:   0.0 %
      Q 6:   0.0 %

Position Standard Deviation Percentages:
      0.00 - 0.10 m:    100.0 %
      0.10 - 0.30 m:      0.0 %
      0.30 - 1.00 m:      0.0 %
      1.00 - 5.00 m:      0.0 %
      5.00 m + over:      0.0 %

Percentages of epochs with DD_DOP over 10.00:
      DOP over Tol:     0.0 %

Baseline Distances:
      Maximum:          89.663 (km)
      Minimum:          2.386 (km)
      Average:          28.916 (km)
      First Epoch:      33.302 (km)
      Last Epoch:       34.430 (km)
```

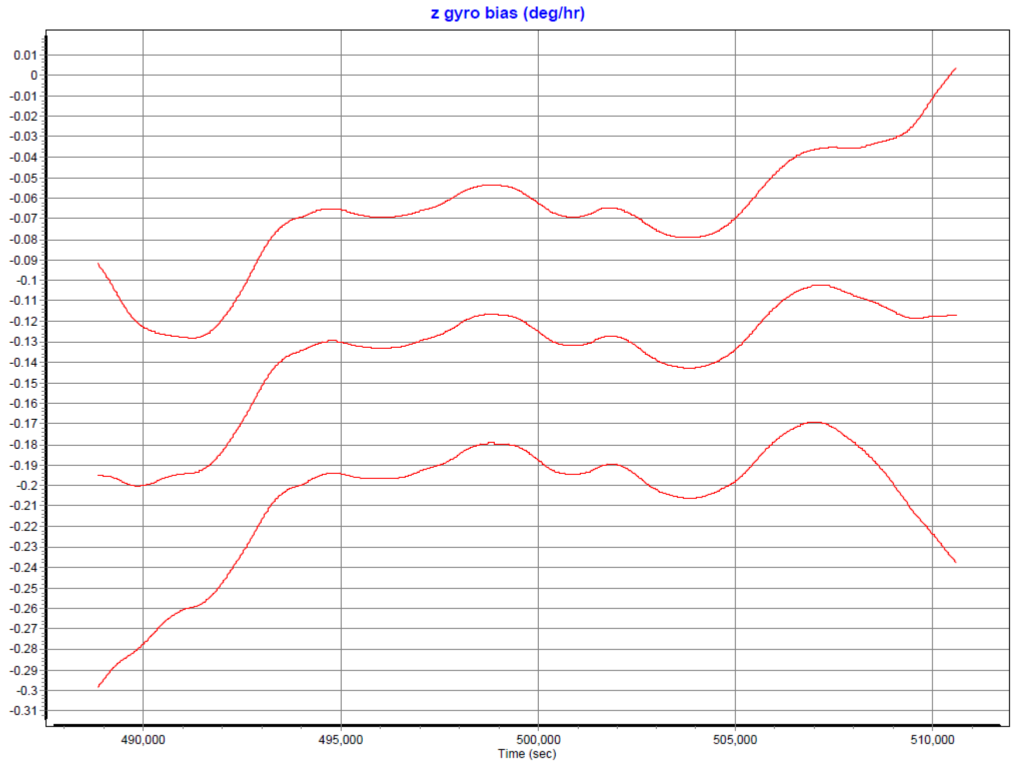
MISSION 1 – 5417090A SENSOR ERRORS

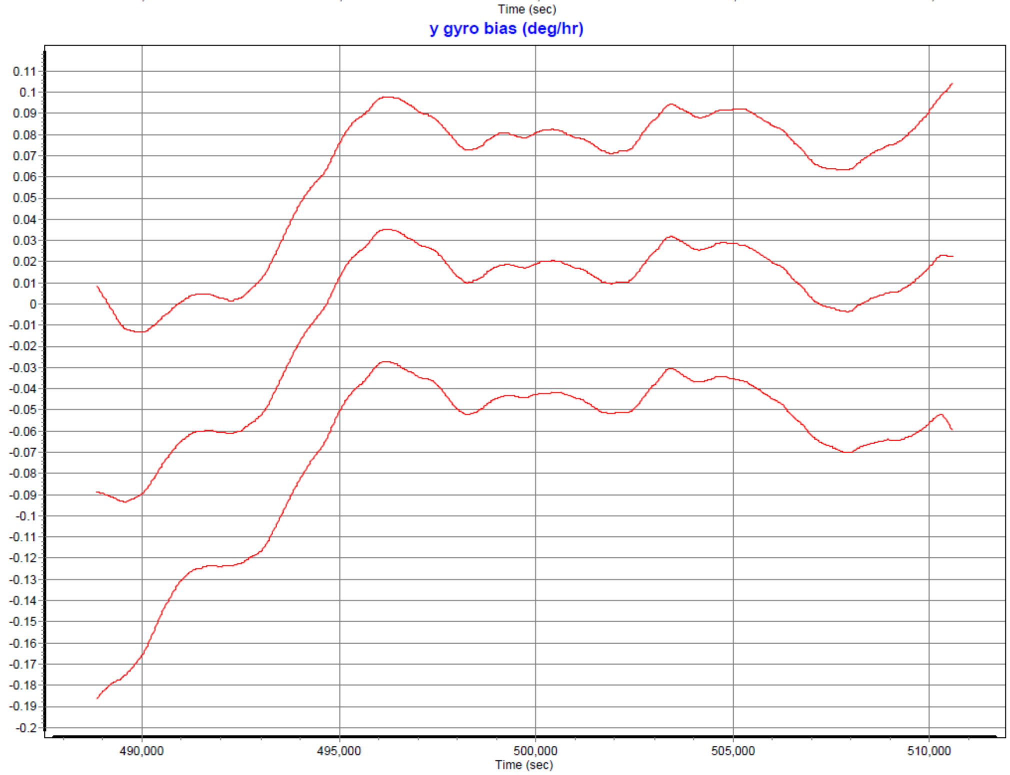




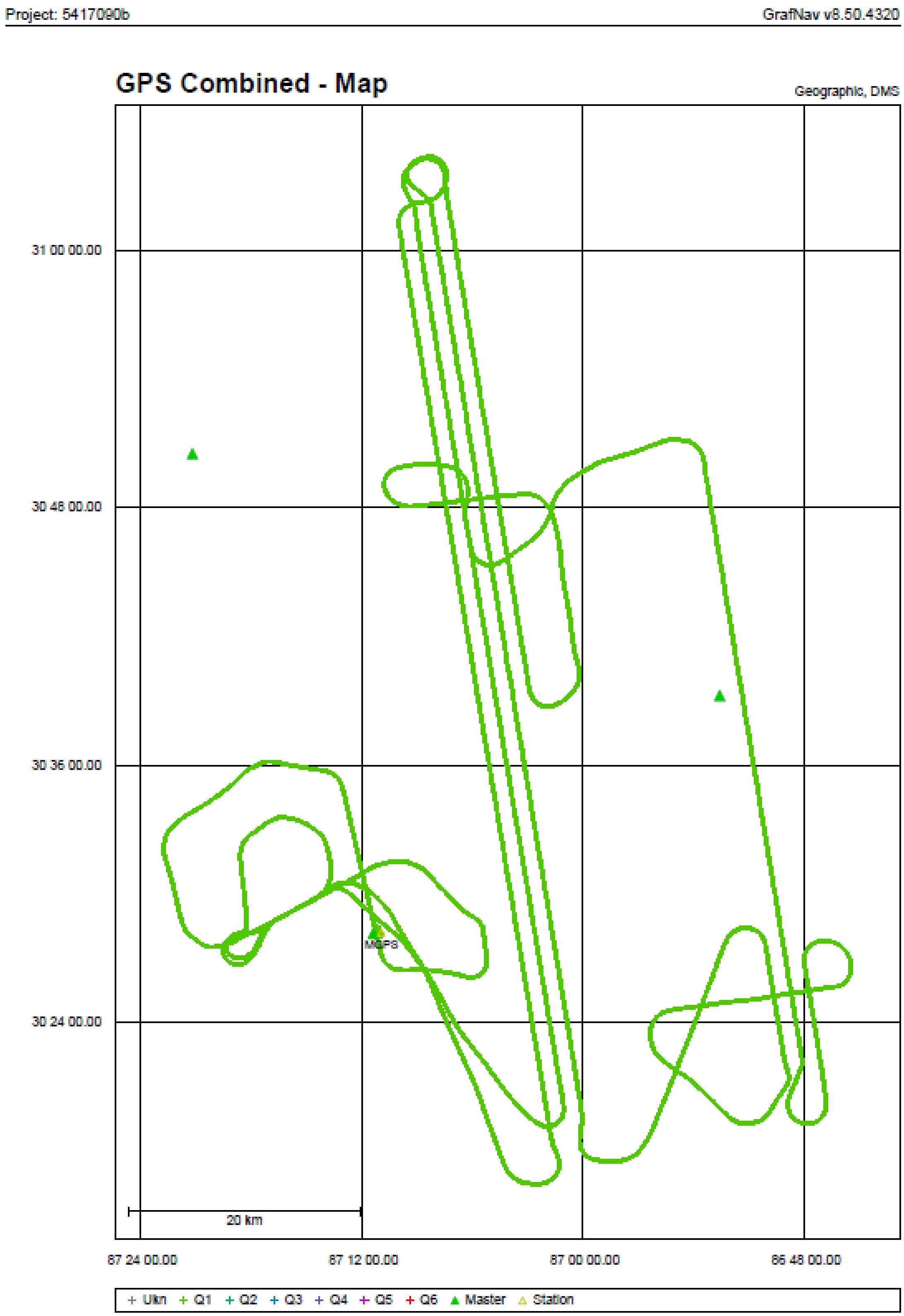

y accelerometer bias (micro-g)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
490,000
495,000
500,000
505,000
510,000
Time (sec)

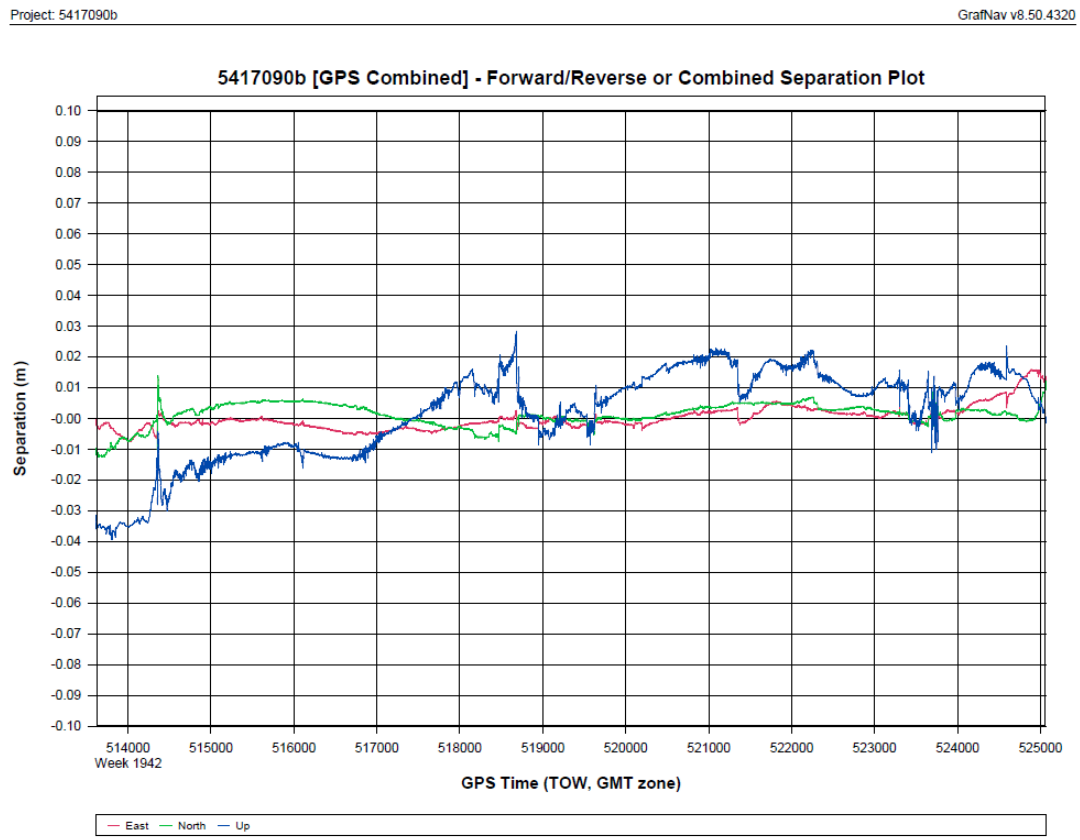

x gyro bias (deg/hr)
0.64
0.63
0.62
0.61
0.6
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0.52
0.51
0.5
0.49
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.3
490,000
495,000
500,000
505,000
510,000
Time (sec)

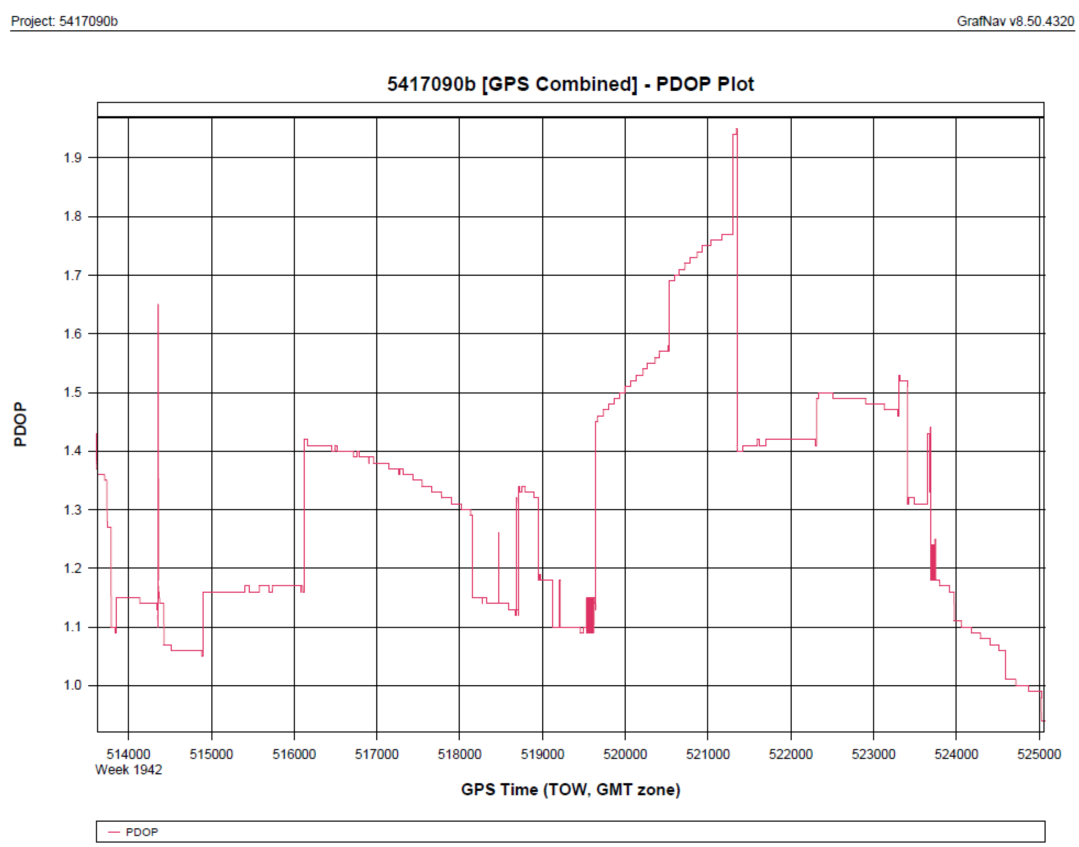

z gyro bias (deg/hr)
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
-0.21
-0.22
-0.23
-0.24
-0.25
-0.26
-0.27
-0.28
-0.29
-0.3
-0.31
490,000
495,000
500,000
505,000
510,000
Time (sec)


y gyro bias (deg/hr)
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
490,000
495,000
500,000
505,000
510,000
Time (sec)

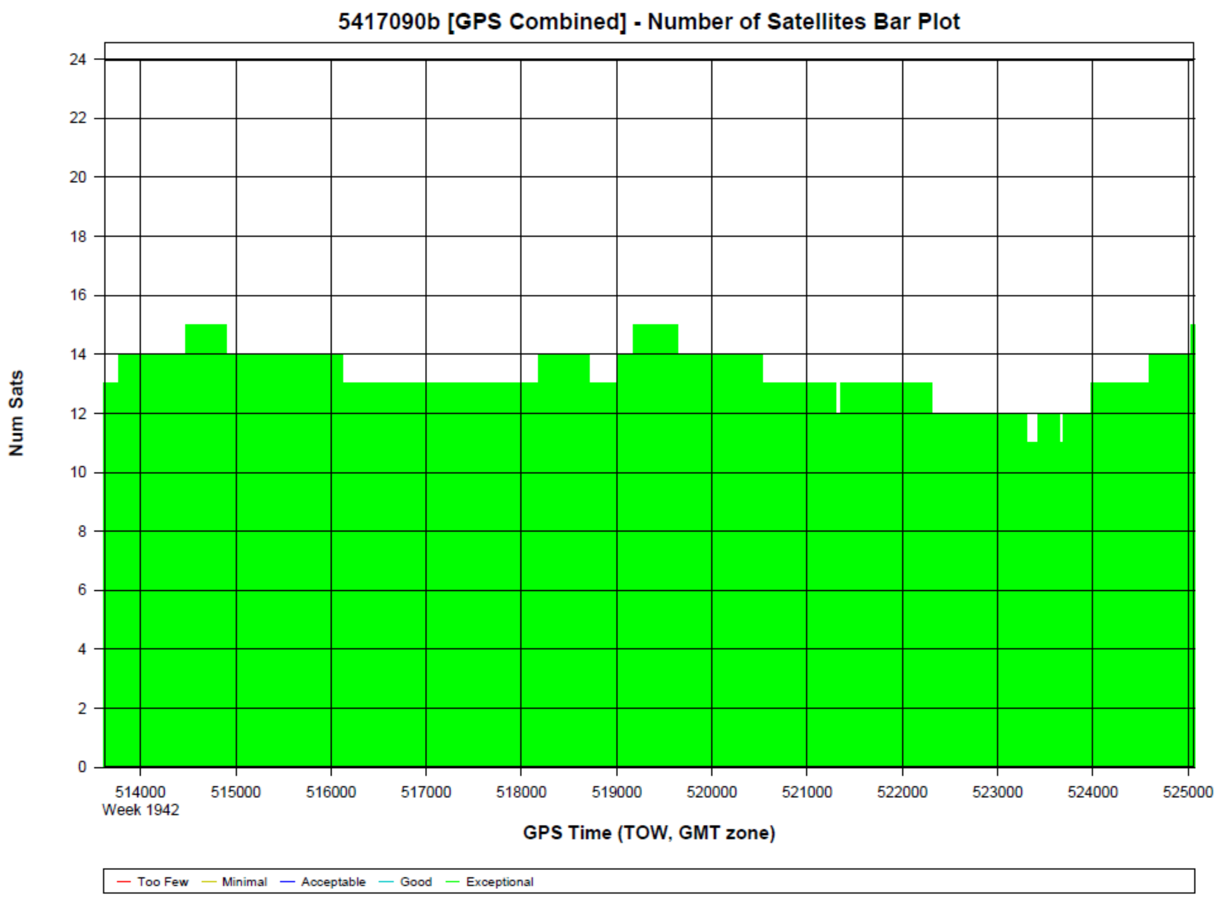
MISSION 2 – 5417090B GNSS PROCESSING




Project: 5417090b
GrafNav v8.50.4320
5417090b [GPS Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
-0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
514000
Week 1942
515000
516000
517000
518000
519000
520000
521000
522000
523000
524000
525000
GPS Time (TOW, GMT zone)
East
North
Up


Project: 5417090b
GrafNav v8.50.4320
5417090b [GPS Combined] - PDOP Plot
PDOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
514000
Week 1942
515000
516000
517000
518000
519000
520000
521000
522000
523000
524000
525000
GPS Time (TOW, GMT zone)
PDOP

Project: 5417090b GrafNav v8.50.4320



Processing Summary Information

Program: GrafNav
Version: 8.50.4320
Project: D:\Projects\3124_Escambia-SantaRosa\LiDAR\5417090b\05_INS-GPS_PROC\01_POS\5417090b\5417090b\GNSS\5417090b.gnv

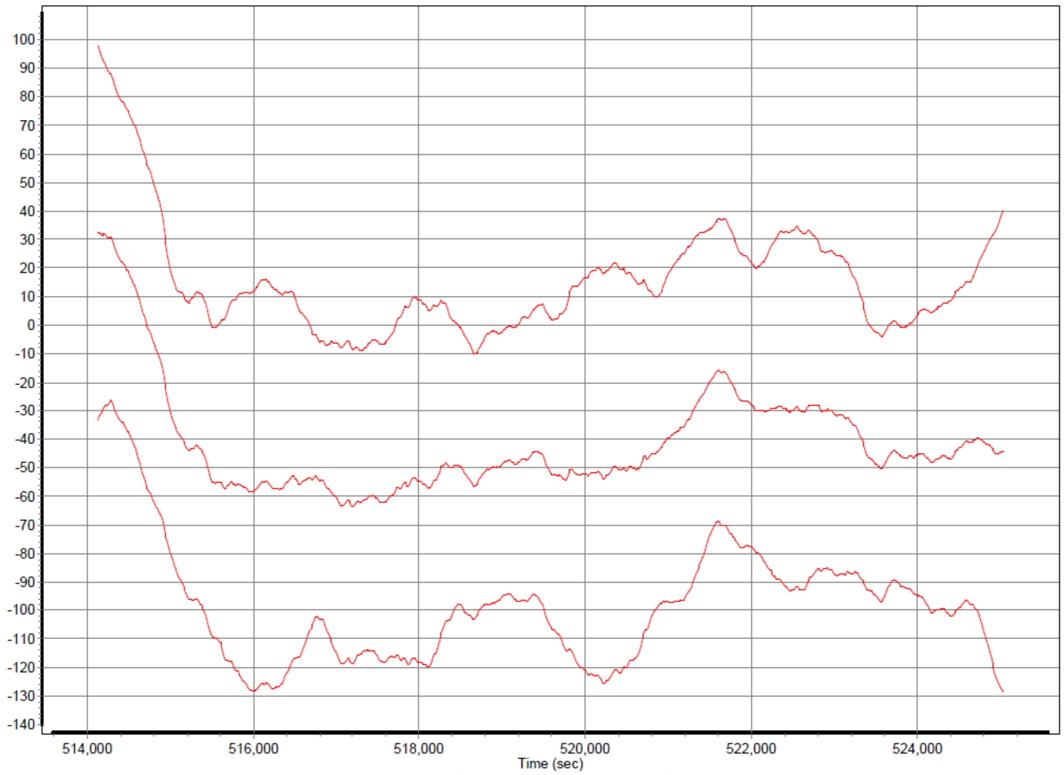
Solution Type: Combined

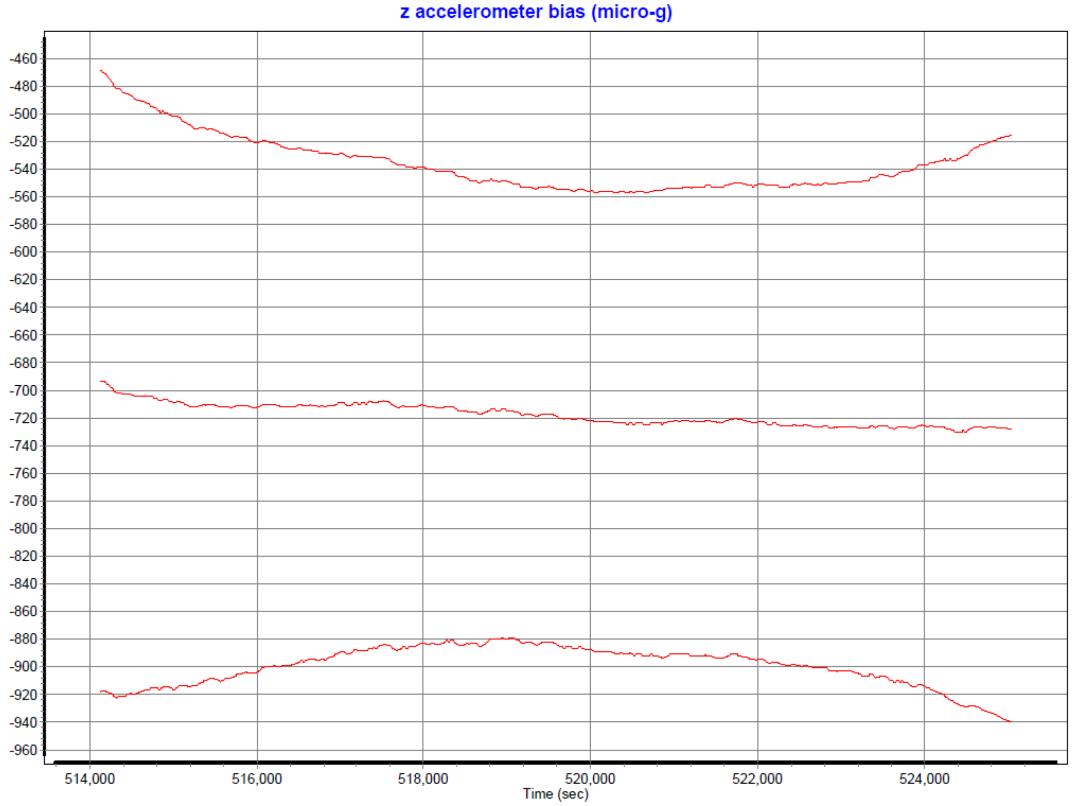
Number of Epochs:
- Total in GPB file: 11461
- No processed position: 0
- Missing Fwd or Rev: 5
- With bad C/A code: 0
- With bad L1 Phase: 0

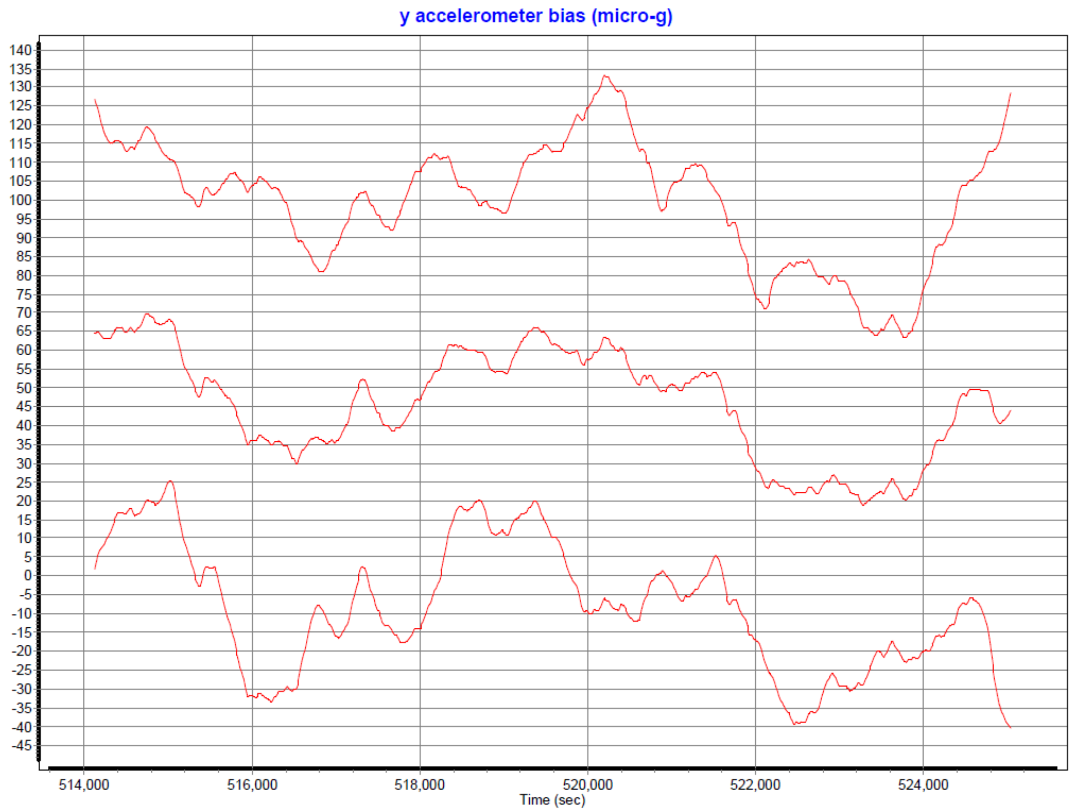
Measurement RMS Values:
- L1 Phase: 0.0157 (m)
- C/A Code: 0.69 (m)
- L1 Doppler: 0.046 (m/s)

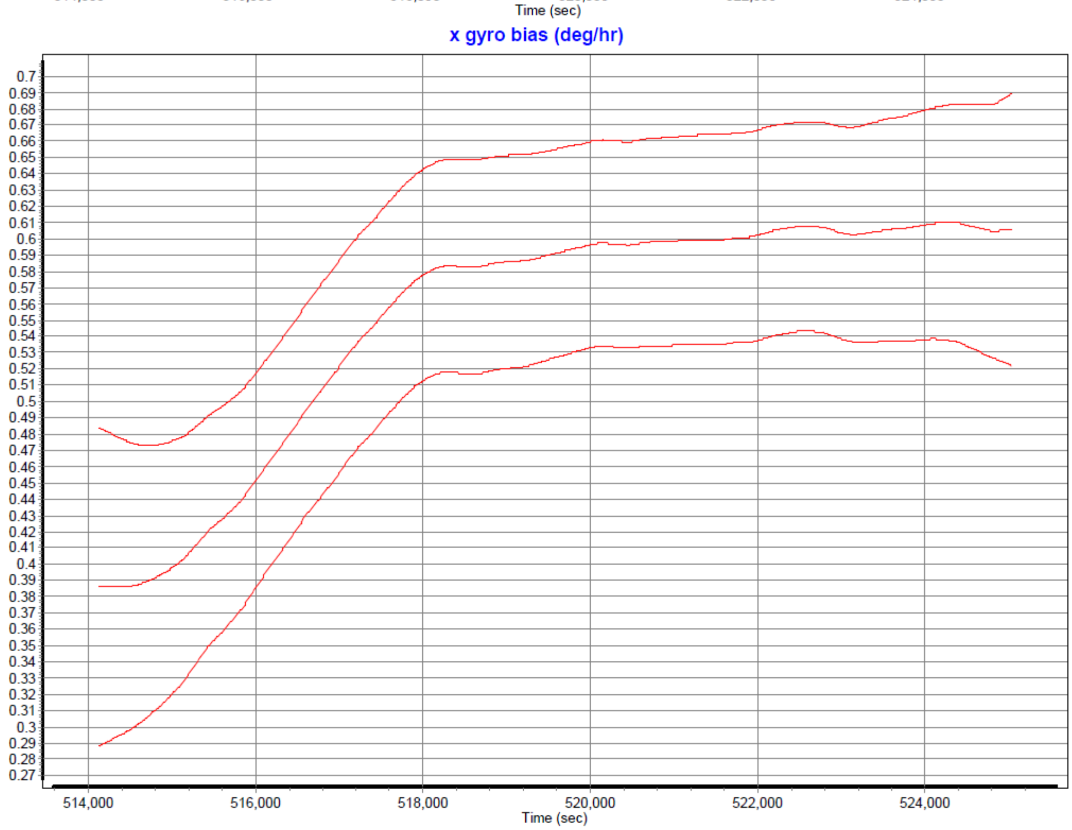
```
Fwd/Rev Separation RMS Values:
      East:        0.004 (m)
      North:       0.004 (m)
      Height:      0.015 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (11456 occurances):
      East:        0.004 (m)
      North:       0.004 (m)
      Height:      0.015 (m)

Quality Number Percentages:
      Q 1:  99.9 %
      Q 2:   0.1 %
      Q 3:   0.0 %
      Q 4:   0.0 %
      Q 5:   0.0 %
      Q 6:   0.0 %

Position Standard Deviation Percentages:
      0.00 - 0.10 m:    100.0 %
      0.10 - 0.30 m:     0.0 %
      0.30 - 1.00 m:     0.0 %
      1.00 - 5.00 m:     0.0 %
      5.00 m + over:     0.0 %

Percentages of epochs with DD_DOP over 10.00:
      DOP over Tol:     0.0 %

Baseline Distances:
      Maximum:          59.039 (km)
      Minimum:          2.019 (km)
      Average:          29.231 (km)
      First Epoch:      33.190 (km)
      Last Epoch:       33.041 (km)
```

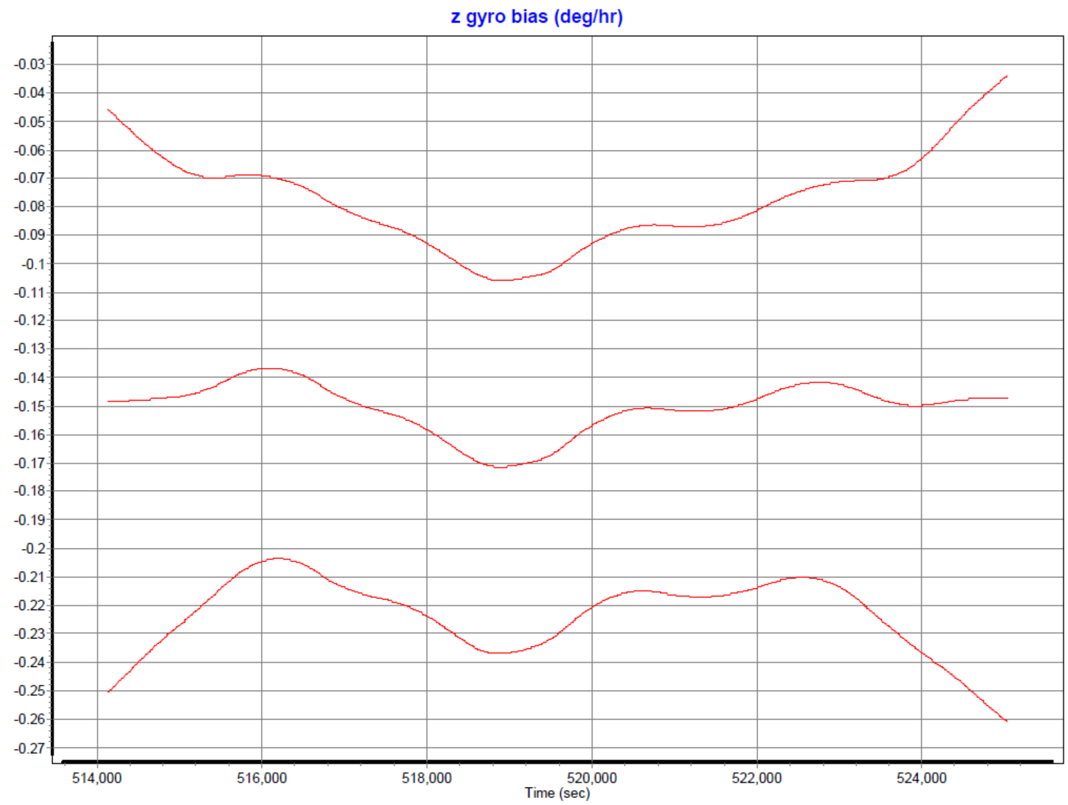
MISSION 2 – 5417090B SENSOR ERRORS

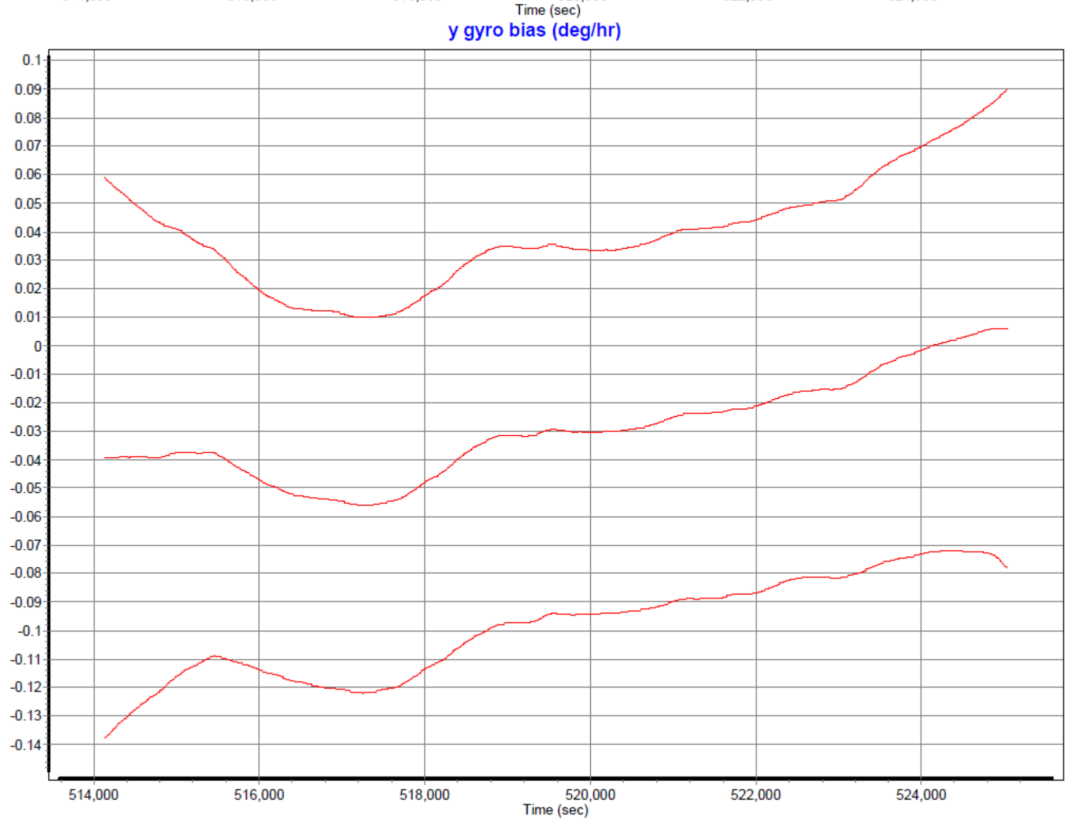




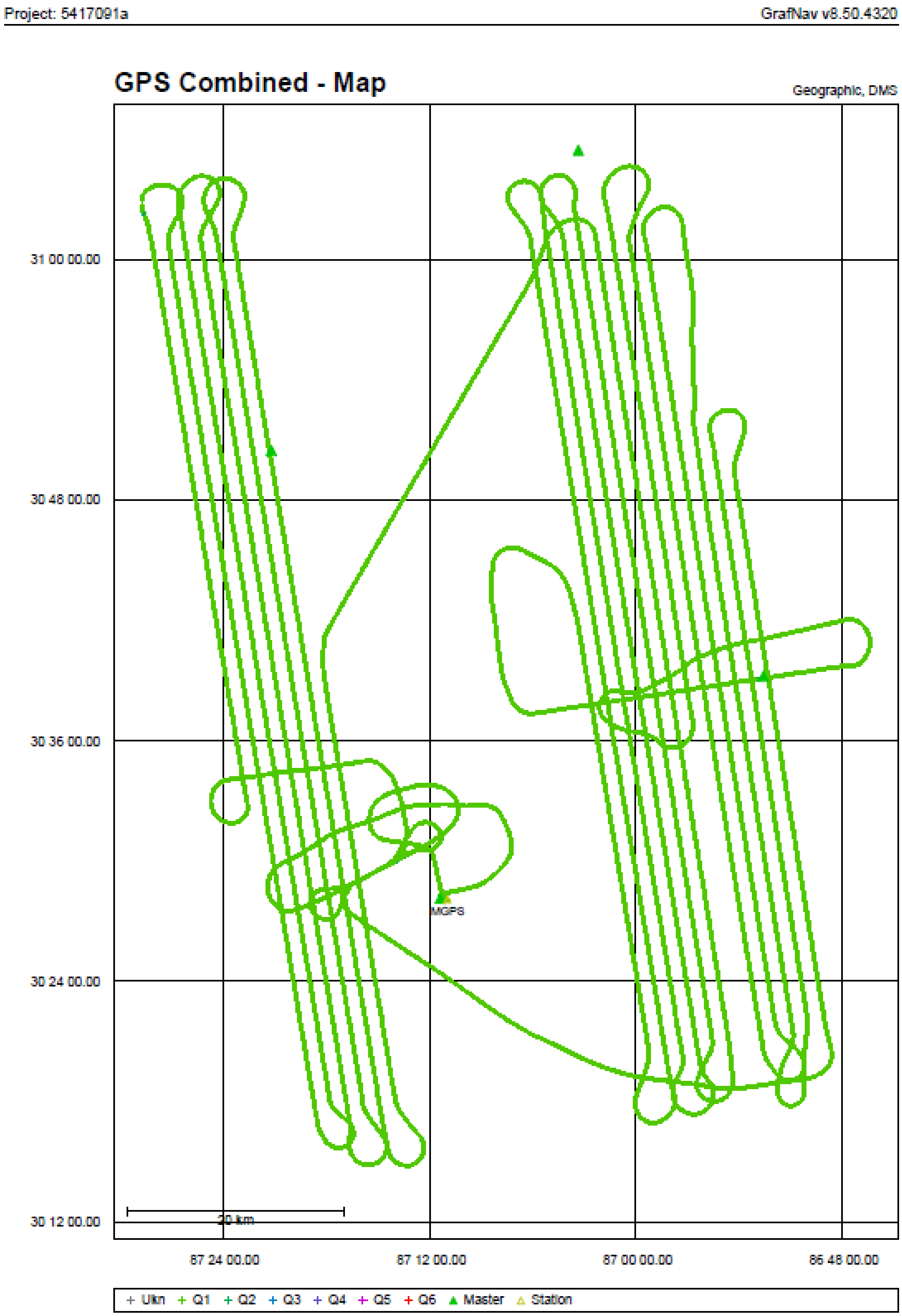

y accelerometer bias (micro-g)
Time (sec)

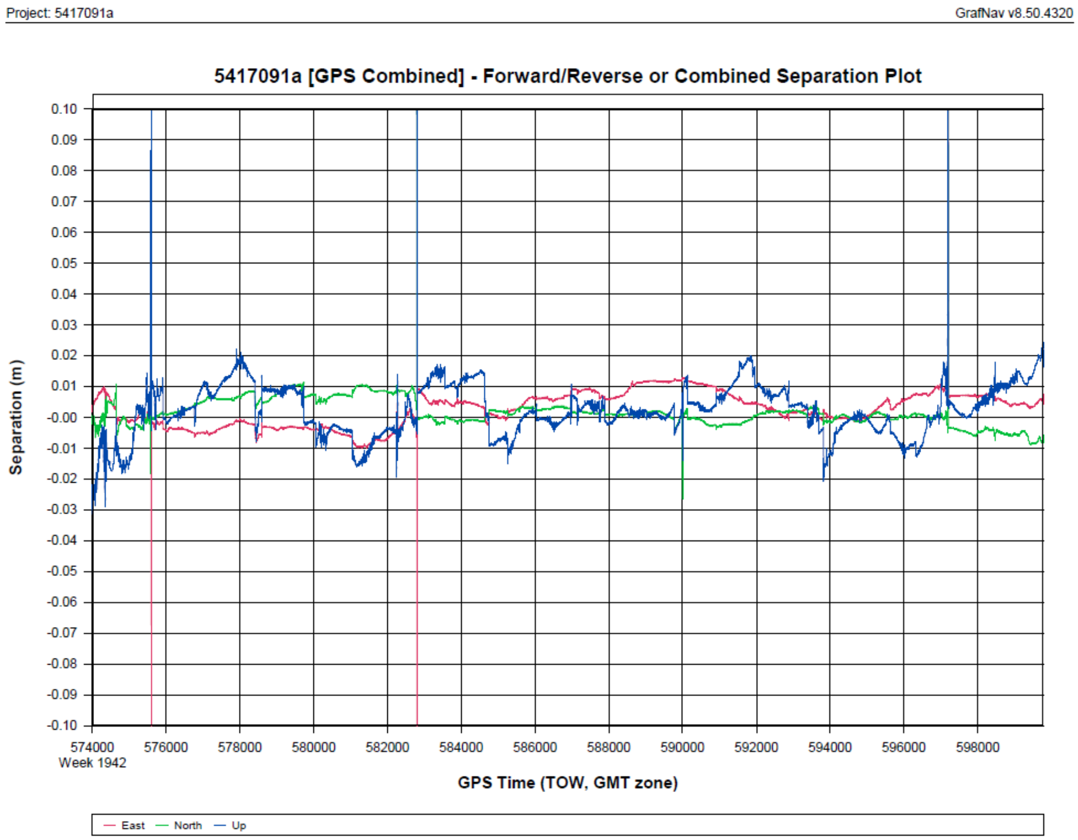

x gyro bias (deg/hr)
Time (sec)

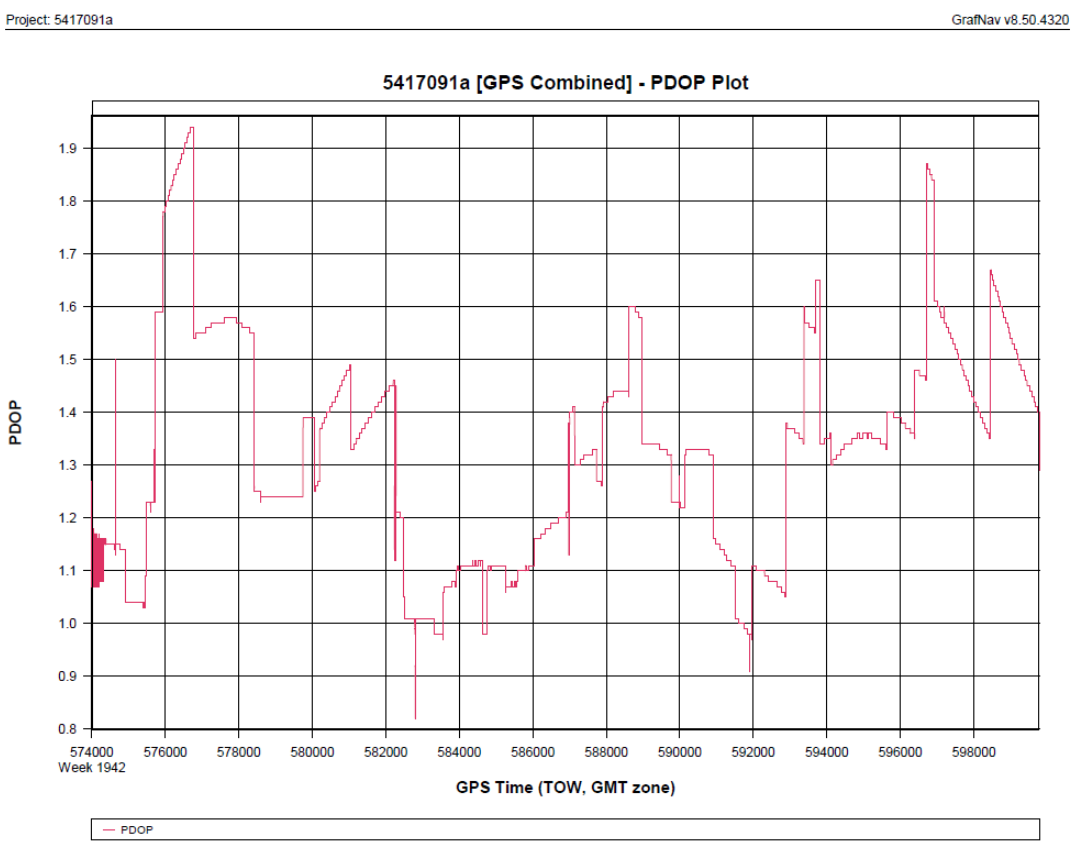

z gyro bias (deg/hr)
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
-0.21
-0.22
-0.23
-0.24
-0.25
-0.26
-0.27
514,000
516,000
518,000
520,000
522,000
524,000
Time (sec)


y gyro bias (deg/hr)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
514,000
516,000
518,000
520,000
522,000
524,000
Time (sec)

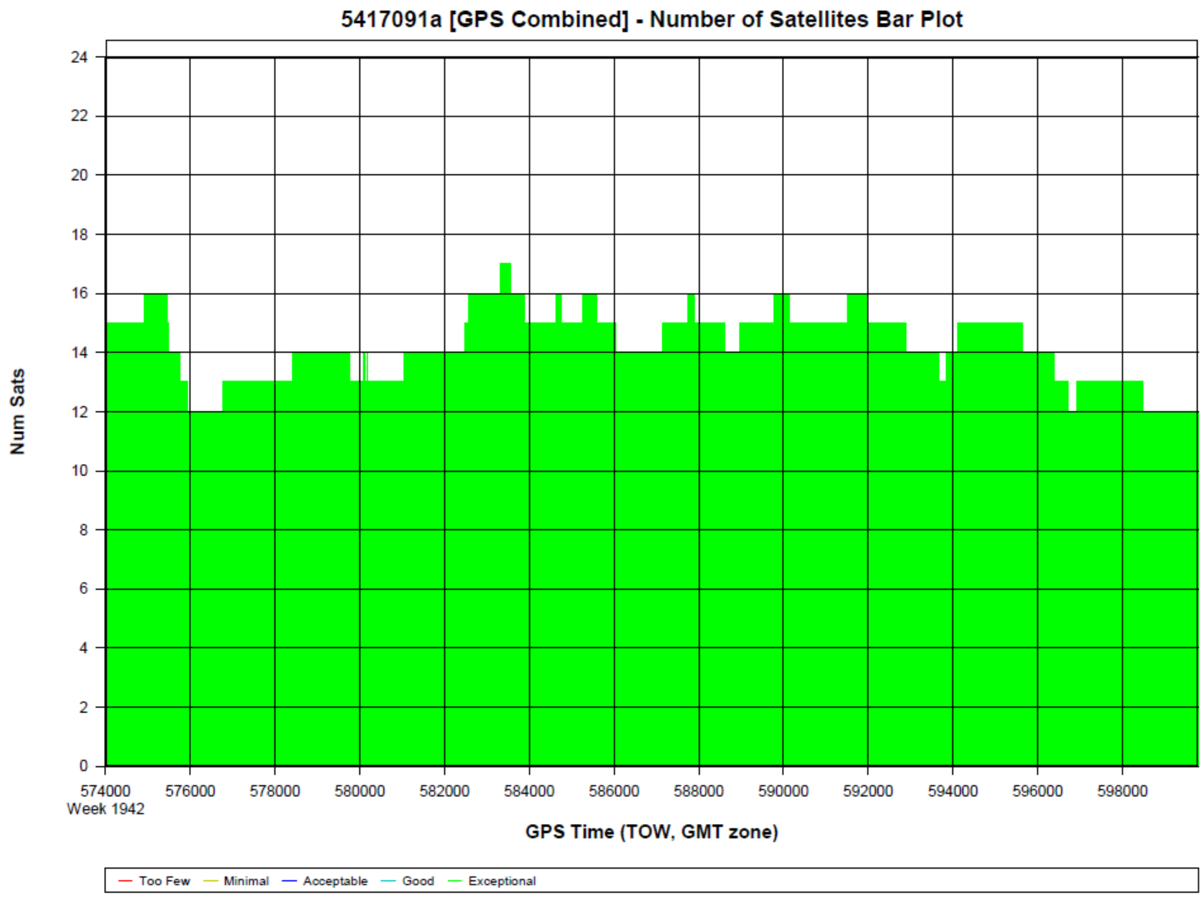
MISSION 3 – 5417091A GNSS PROCESSING




Project: 5417091a
GrafNav v8.50.4320
5417091a [GPS Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
-0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
574000
Week 1942
576000
578000
580000
582000
584000
586000
588000
590000
592000
594000
596000
598000
GPS Time (TOW, GMT zone)
East
North
Up


Project: 5417091a
GrafNav v8.50.4320
5417091a [GPS Combined] - PDOP Plot
PDOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
574000
Week 1942
576000
578000
580000
582000
584000
586000
588000
590000
592000
594000
596000
598000
GPS Time (TOW, GMT zone)
PDOP

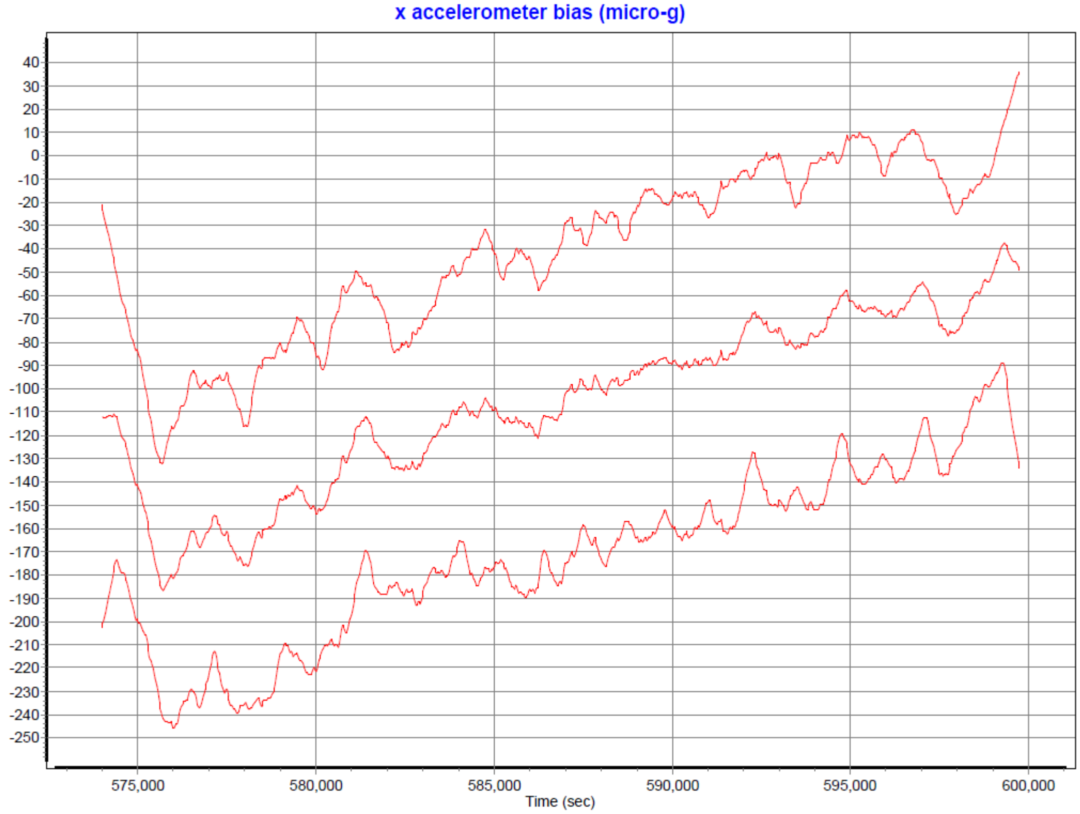
Project: 5417091a GrafNav v8.50.4320

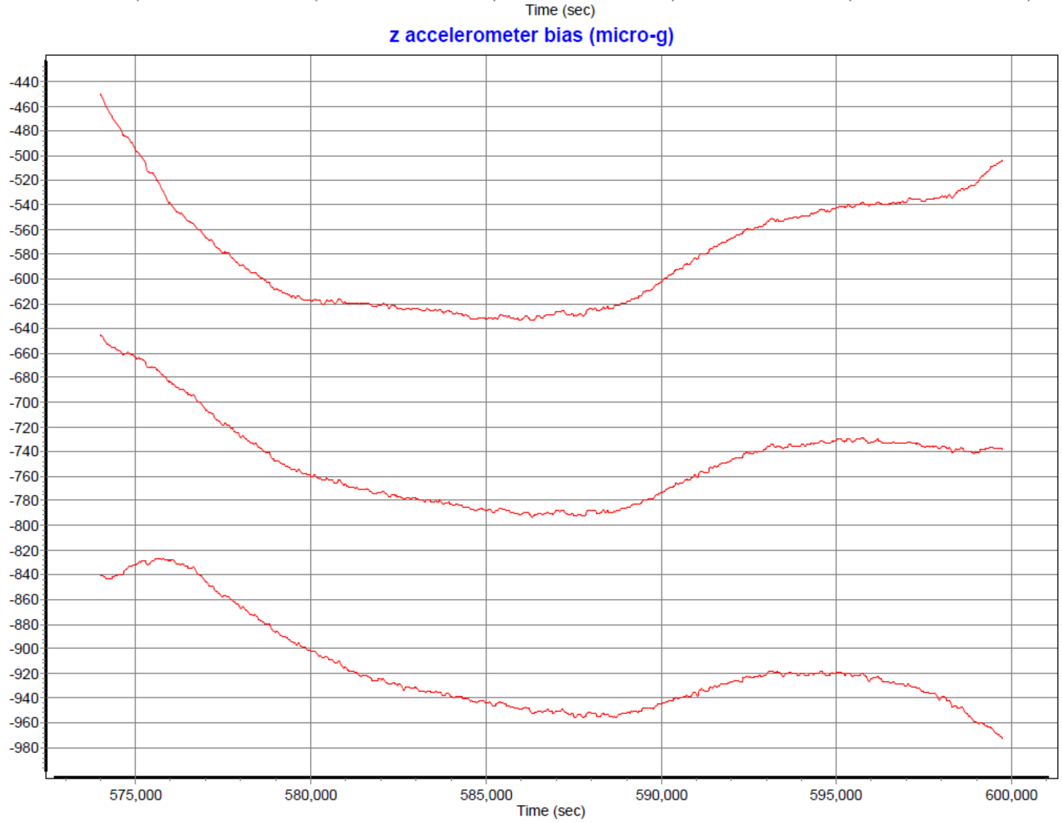


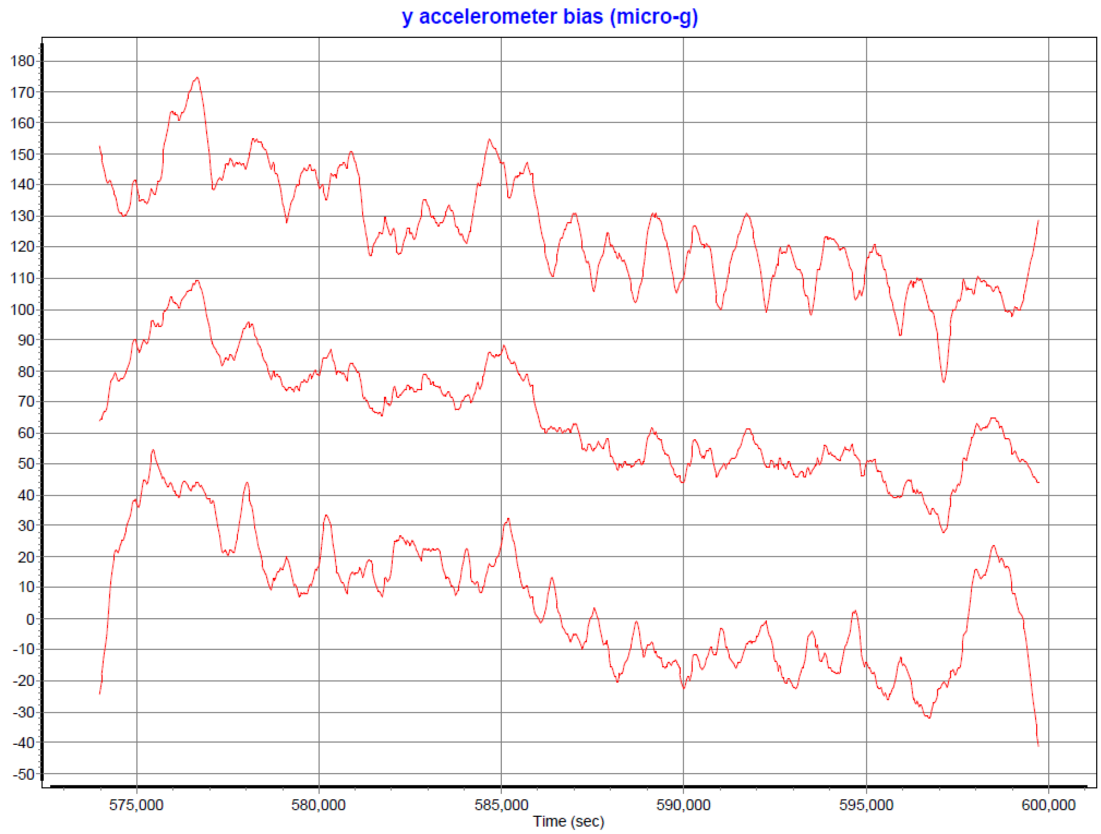

```
      Processing Summary Information

Program: GrafNav
Version: 8.50.4320
Project: D:\Projects\3124_Escambia-SantaRosa\LiDAR\5417091a\05_INS-
GPS_PROC\01_POS\5417091a\5417091a\GNSS\5417091a.gnv

Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      25808
      No processed position:  0
      Missing Fwd or Rev:     8
      With bad C/A code:      0
      With bad L1 Phase:      0

Measurement RMS Values:
      L1 Phase:   0.0163 (m)
      C/A Code:   0.77 (m)
      L1 Doppler: 0.041 (m/s)
```

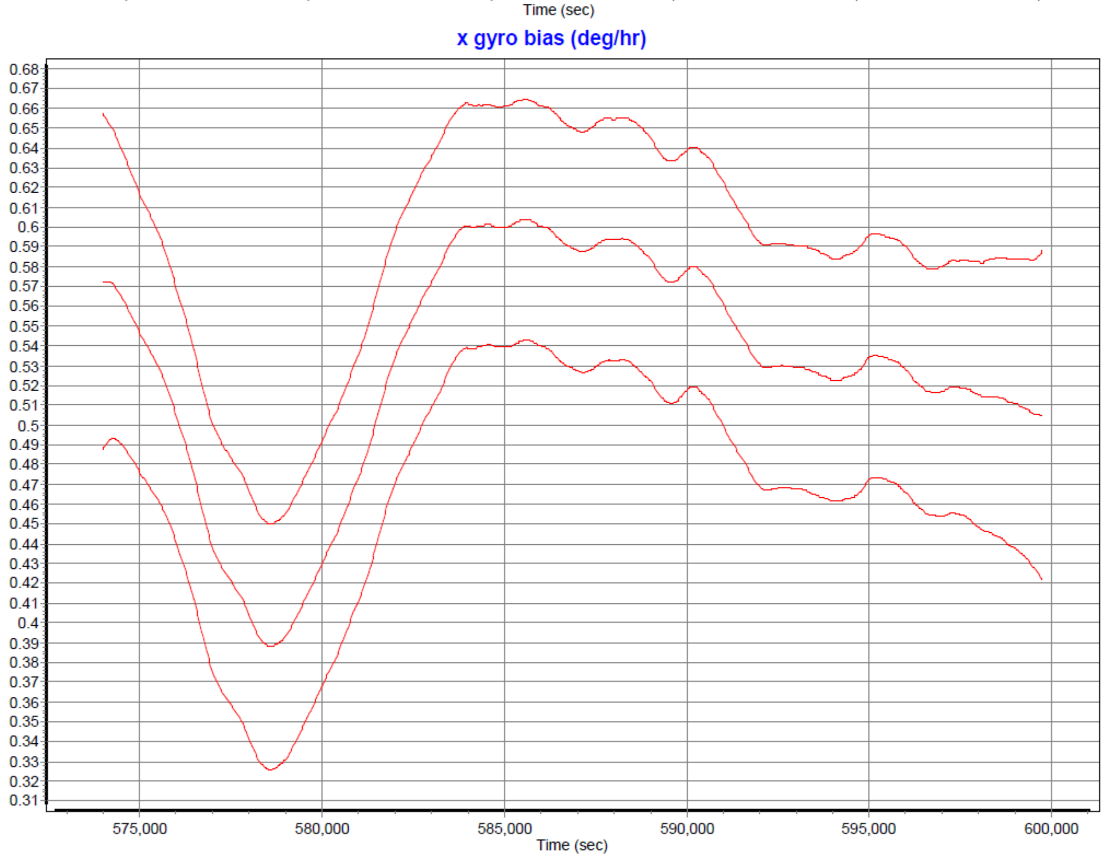
```
Fwd/Rev Separation RMS Values:
      East:        0.007 (m)
      North:       0.006 (m)
      Height:      0.016 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (25797 occurances):
      East:        0.006 (m)
      North:       0.004 (m)
      Height:      0.009 (m)

Quality Number Percentages:
      Q 1:  99.9 %
      Q 2:   0.1 %
      Q 3:   0.0 %
      Q 4:   0.0 %
      Q 5:   0.0 %
      Q 6:   0.0 %

Position Standard Deviation Percentages:
      0.00 - 0.10 m:    100.0 %
      0.10 - 0.30 m:     0.0 %
      0.30 - 1.00 m:     0.0 %
      1.00 - 5.00 m:     0.0 %
      5.00 m + over:     0.0 %

Percentages of epochs with DD_DOP over 10.00:
      DOP over Tol:     0.0 %

Baseline Distances:
      Maximum:          58.818 (km)
      Minimum:          2.114 (km)
      Average:          30.649 (km)
      First Epoch:      32.840 (km)
      Last Epoch:       33.283 (km)
```

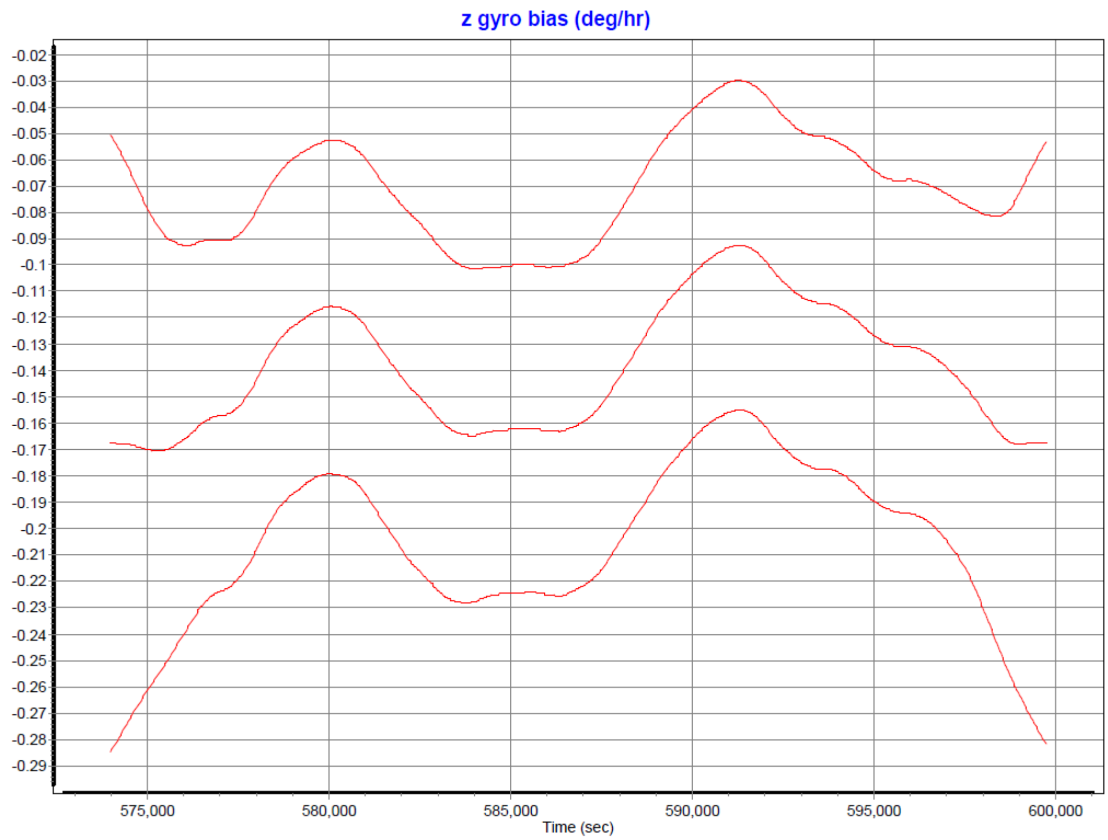
MISSION 3 – 5417091A SENSOR ERRORS

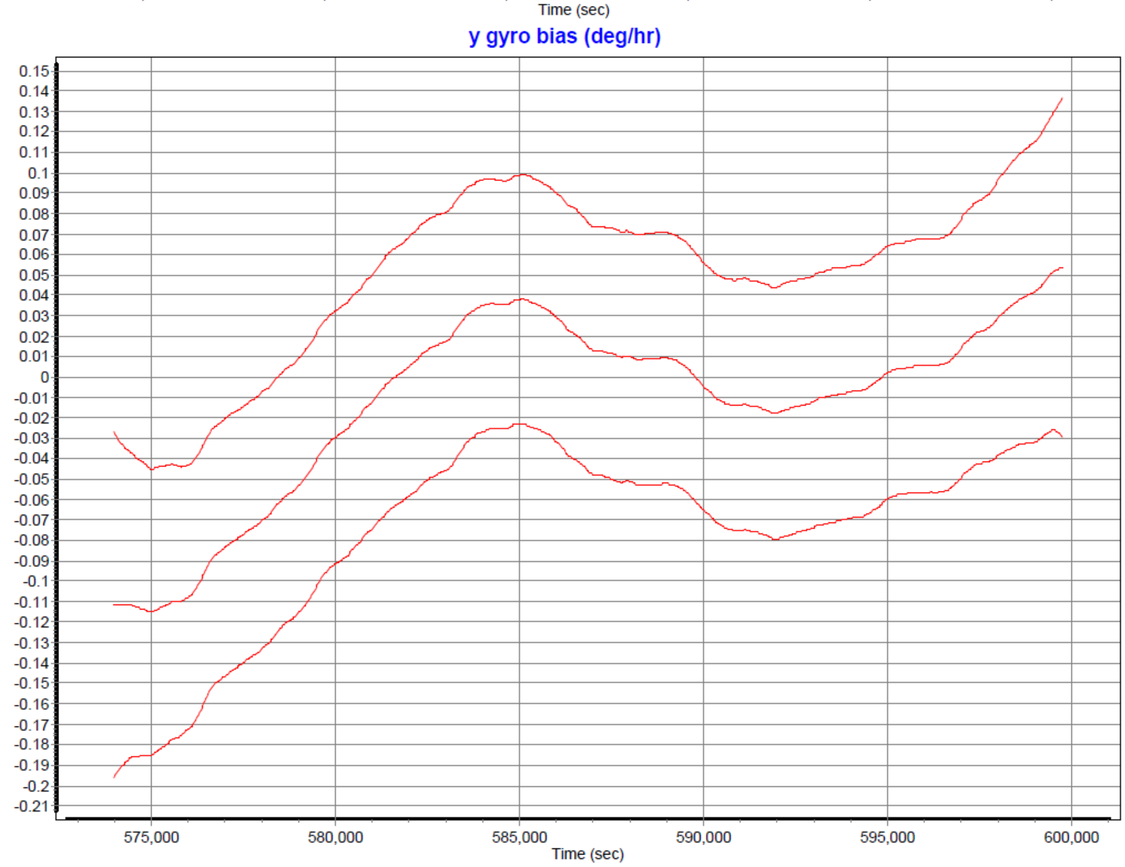




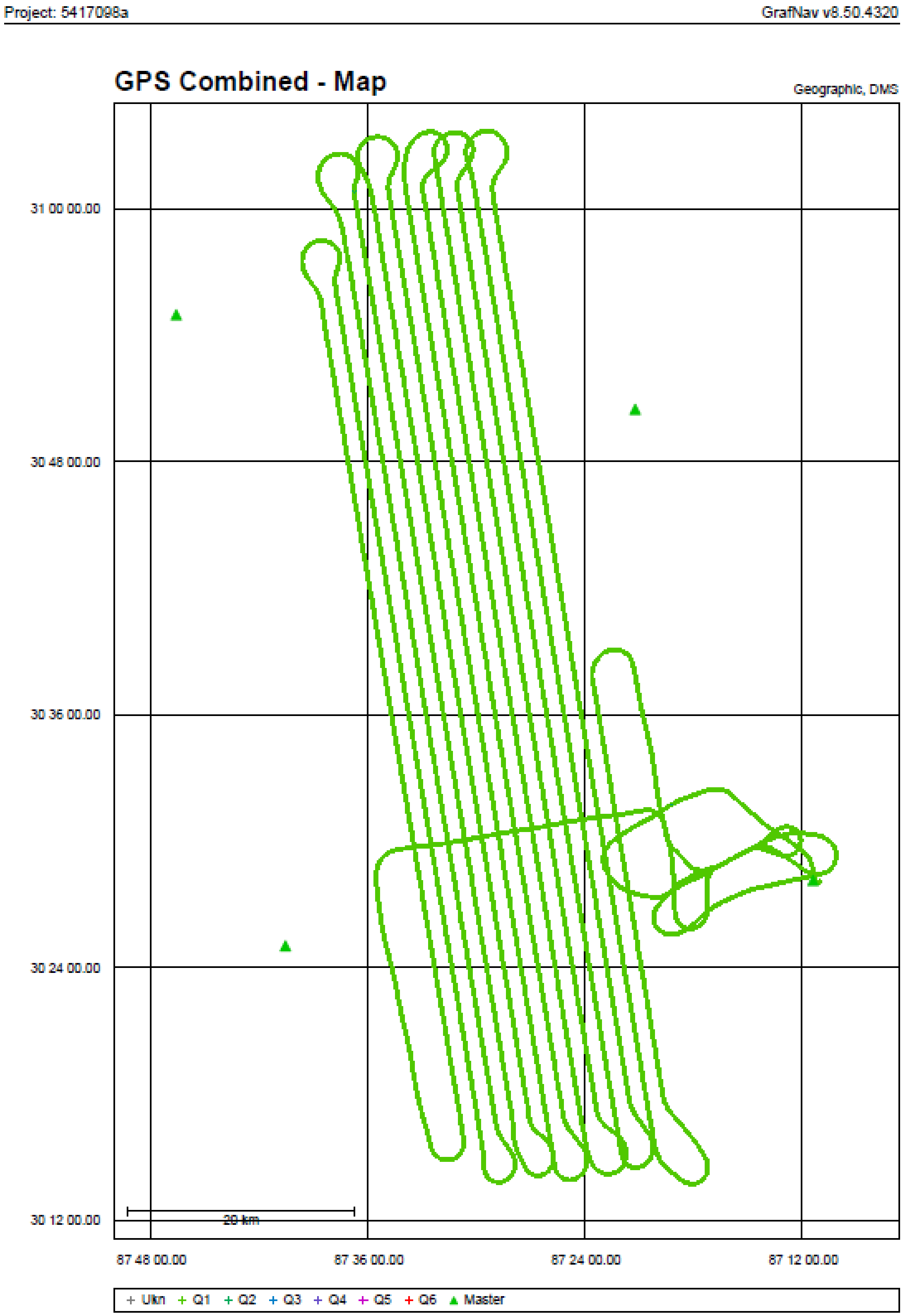

y accelerometer bias (micro-g)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
575,000
580,000
585,000
590,000
595,000
600,000
Time (sec)


x gyro bias (deg/hr)
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.6
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0.52
0.51
0.5
0.49
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
575,000
580,000
585,000
590,000
595,000
600,000
Time (sec)

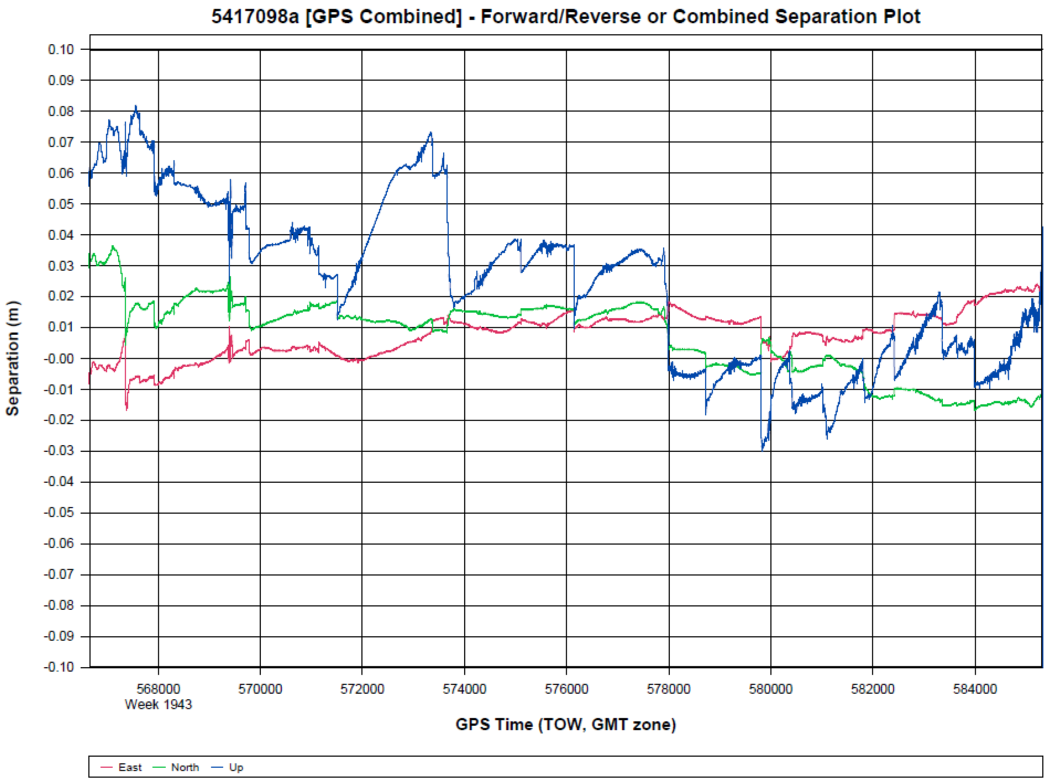

z gyro bias (deg/hr)
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
-0.21
-0.22
-0.23
-0.24
-0.25
-0.26
-0.27
-0.28
-0.29
575,000
580,000
585,000
590,000
595,000
600,000
Time (sec)


y gyro bias (deg/hr)
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
-0.21
575,000
580,000
585,000
590,000
595,000
600,000
Time (sec)

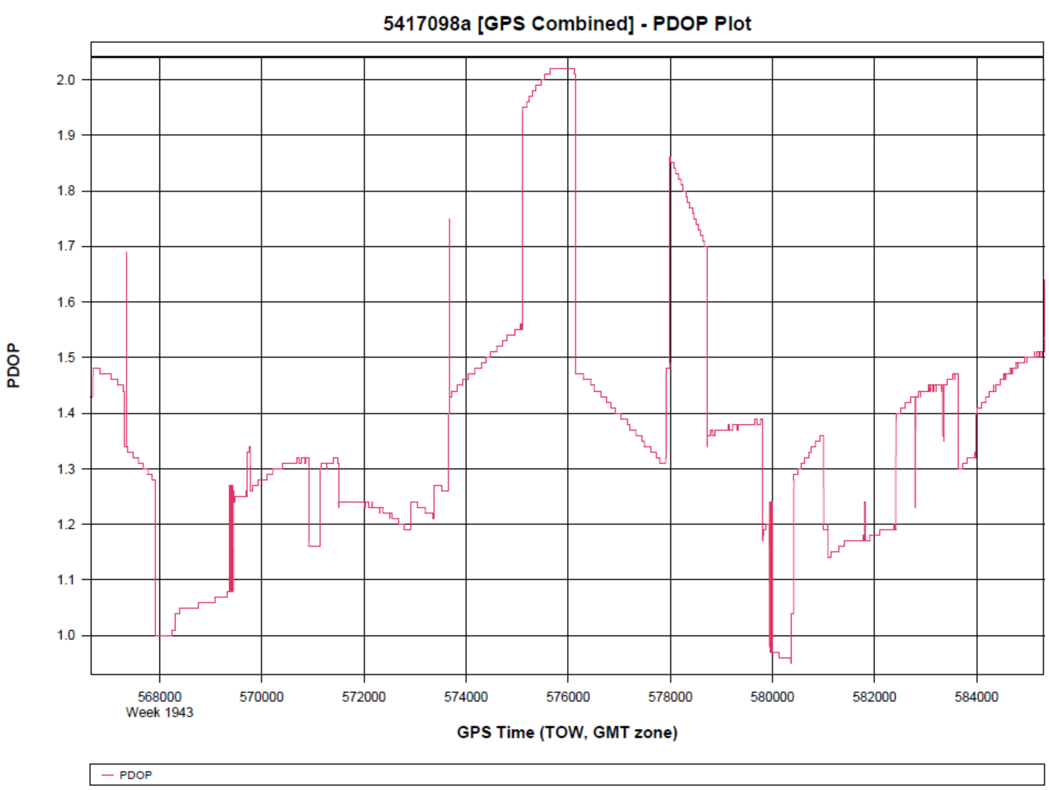
MISSION 4 – 5417098A GNSS PROCESSING

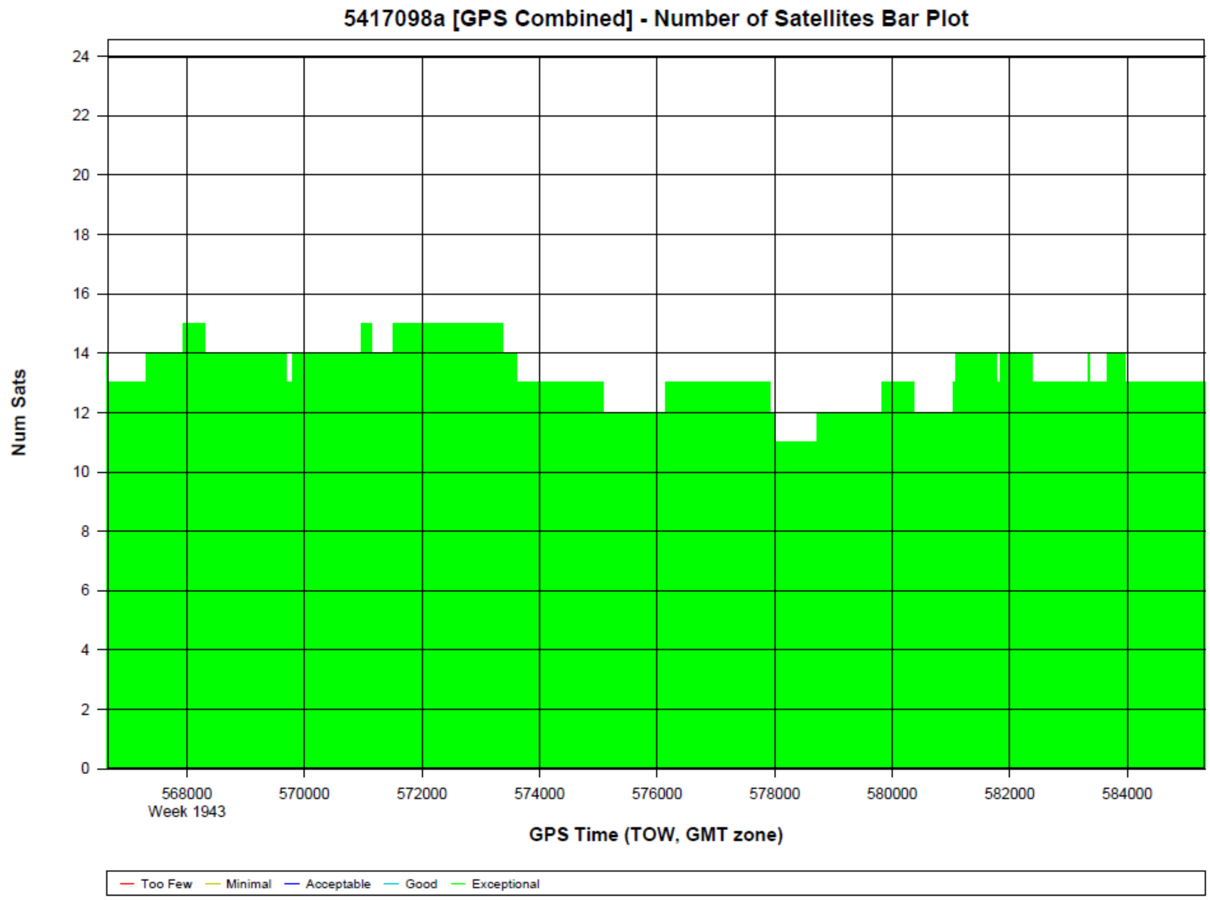


Project: 5417098a GrafNav v8.50.4320



Project: 5417098a GrafNav v8.50.4320

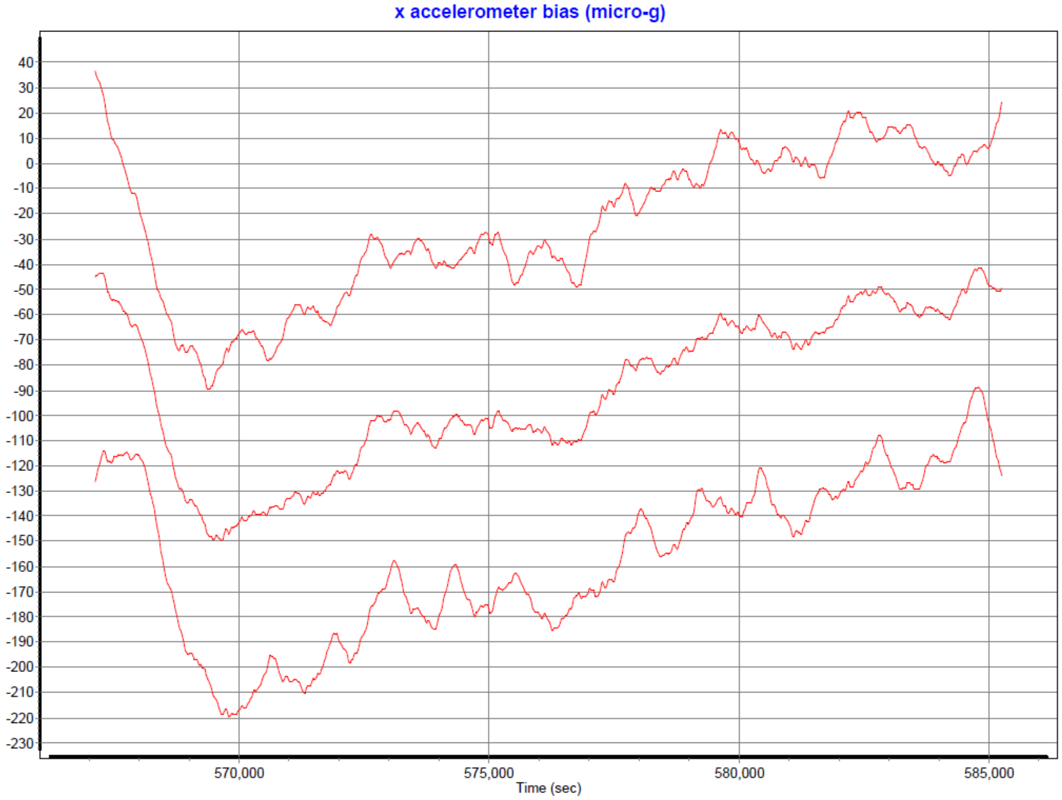


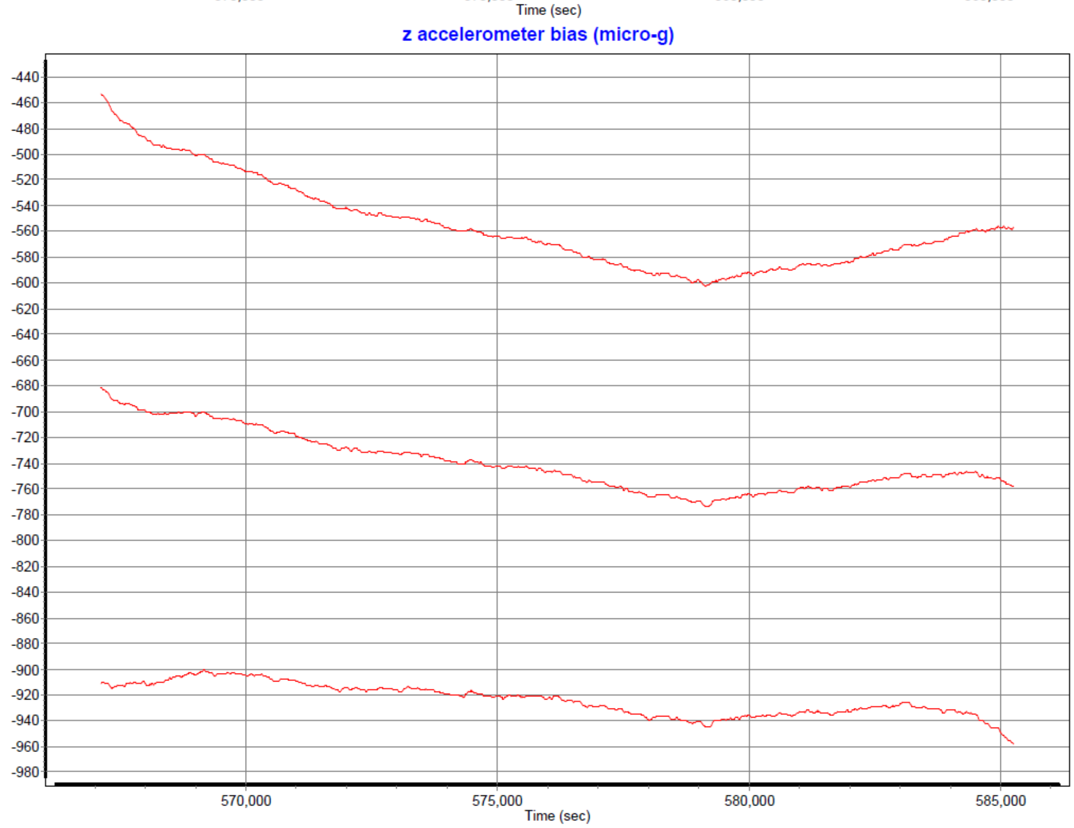


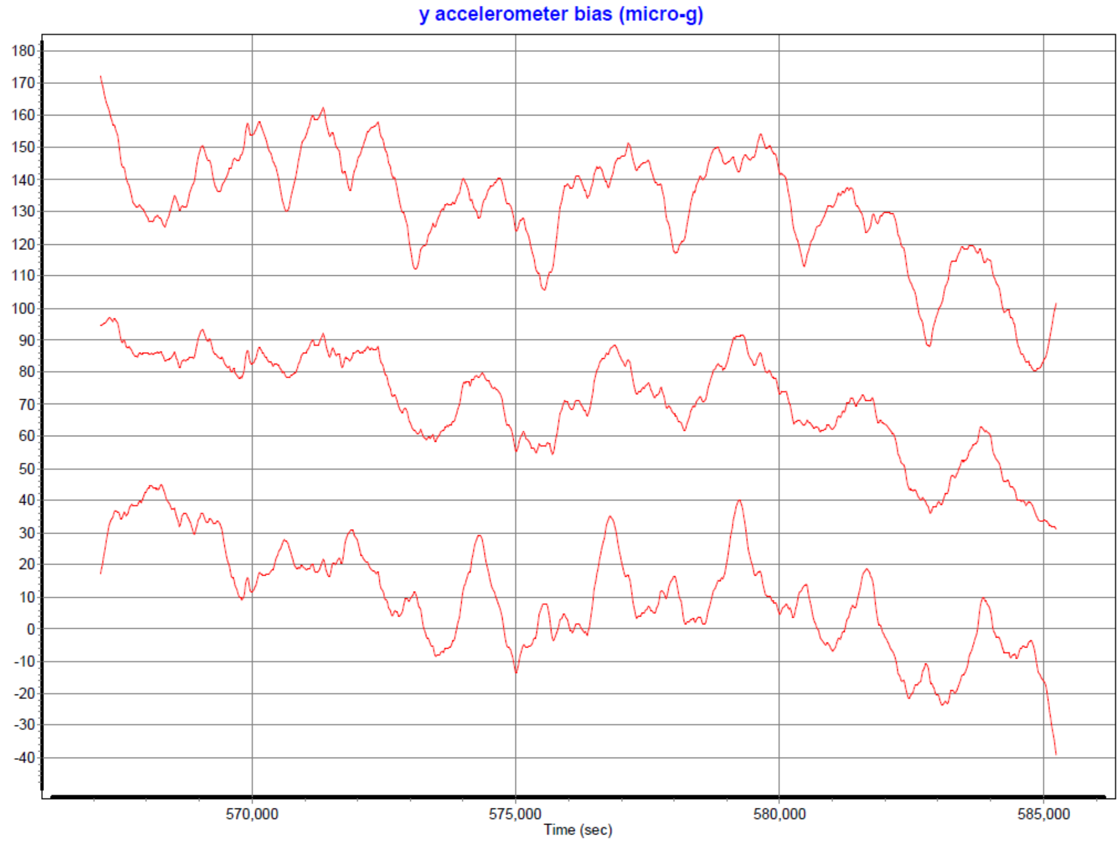

```
      Processing Summary Information

Program: GrafNav
Version: 8.50.4320
Project: D:\Projects\3124_Escambia-SantaRosa\LiDAR\5417098a\05_INS-
GPS_PROC\01_POS\5417098a\5417098a\GNSS\5417098a.gnv

Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      19294
      No processed position:  600
      Missing Fwd or Rev:     4
      With bad C/A code:      0
      With bad L1 Phase:      0

Measurement RMS Values:
      L1 Phase:   0.0172 (m)
      C/A Code:   0.64 (m)
      L1 Doppler: 0.031 (m/s)
```

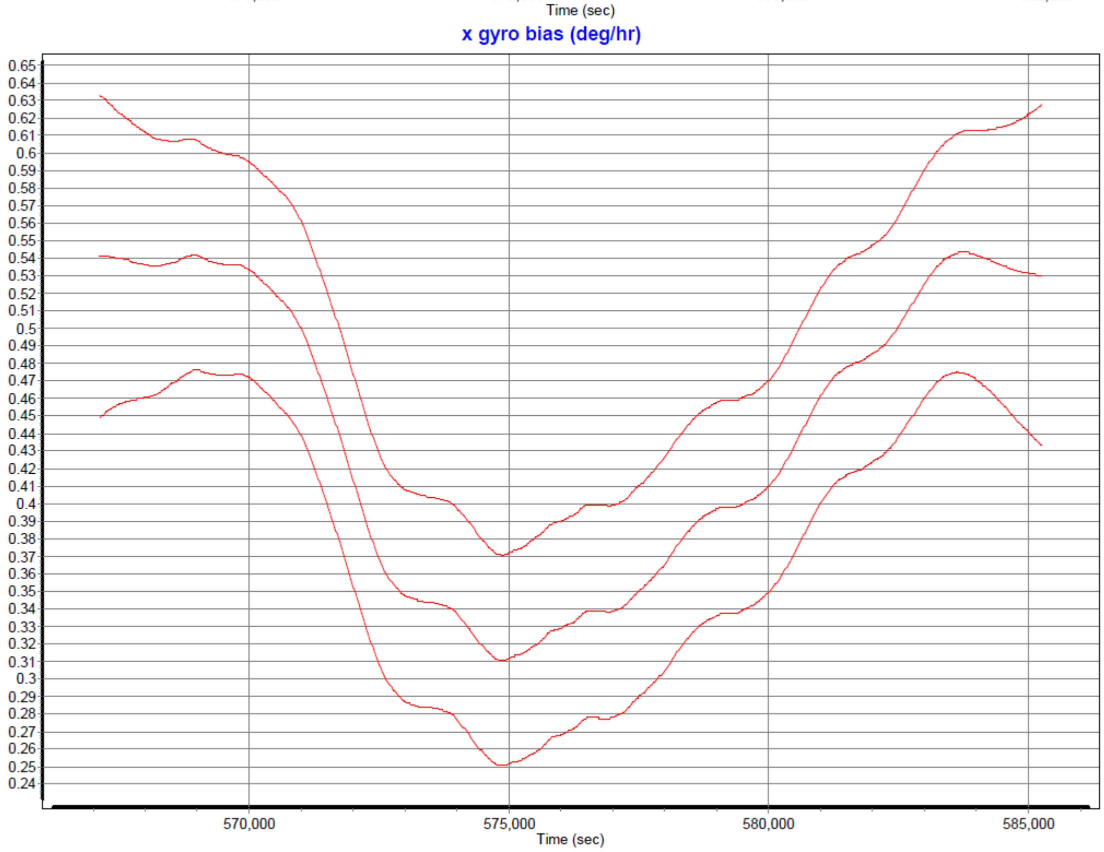
```
Fwd/Rev Separation RMS Values:
      East:        0.011 (m)
      North:       0.014 (m)
      Height:      0.036 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (18689 occurances):
      East:        0.011 (m)
      North:       0.014 (m)
      Height:      0.036 (m)

Quality Number Percentages:
      Q 1:  99.9 %
      Q 2:   0.1 %
      Q 3:   0.0 %
      Q 4:   0.0 %
      Q 5:   0.0 %
      Q 6:   0.0 %

Position Standard Deviation Percentages:
      0.00 - 0.10 m:    100.0 %
      0.10 - 0.30 m:     0.0 %
      0.30 - 1.00 m:     0.0 %
      1.00 - 5.00 m:     0.0 %
      5.00 m + over:     0.0 %

Percentages of epochs with DD_DOP over 10.00:
      DOP over Tol:     0.0 %

Baseline Distances:
      Maximum:          51.373 (km)
      Minimum:          2.361 (km)
      Average:          25.988 (km)
      First Epoch:      37.610 (km)
      Last Epoch:       37.660 (km)
```

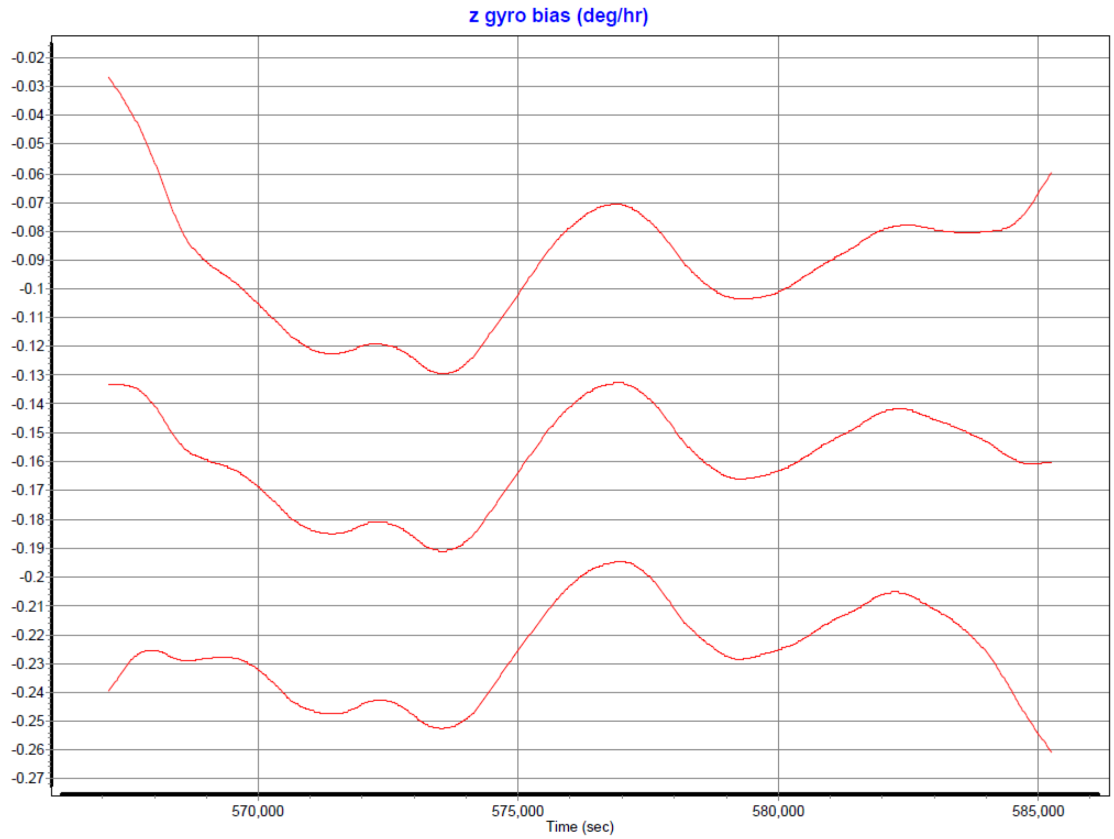
MISSION 4 – 5417098A SENSOR ERRORS

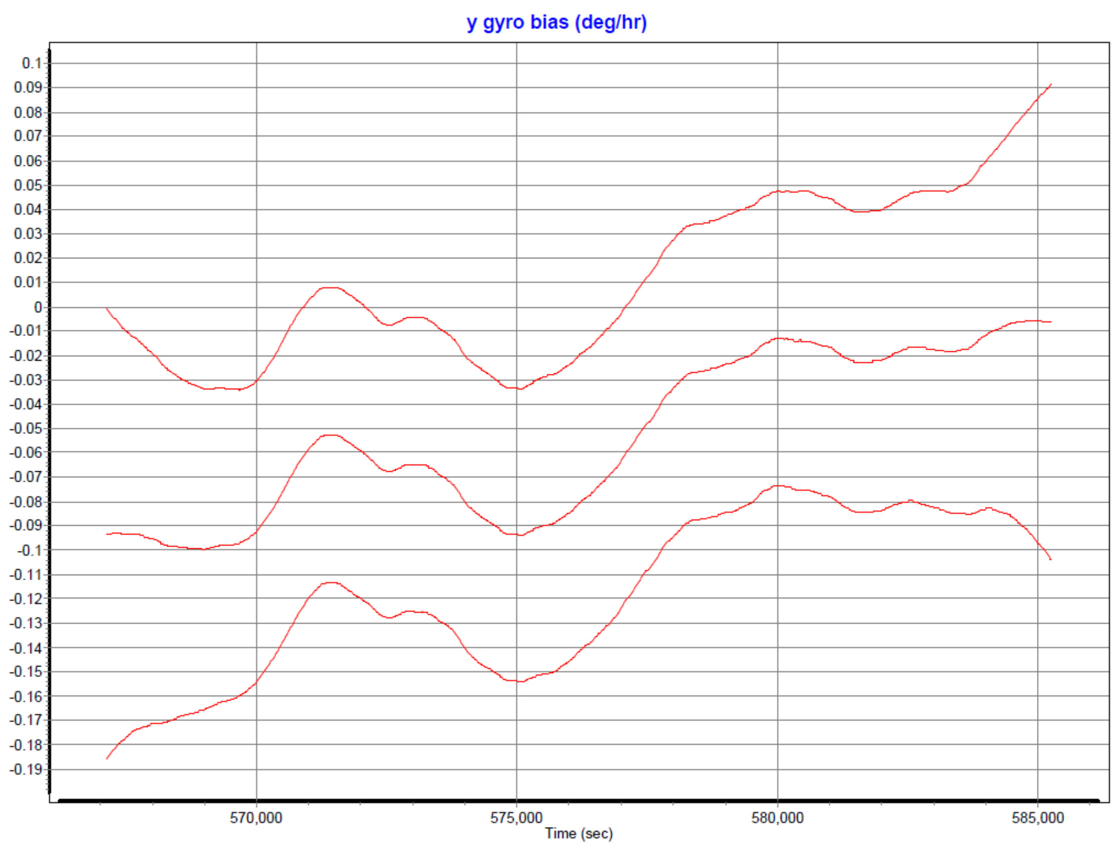





y accelerometer bias (micro-g)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
570,000
575,000
580,000
585,000
Time (sec)


x gyro bias (deg/hr)
0.65
0.64
0.63
0.62
0.61
0.6
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0.52
0.51
0.5
0.49
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.3
0.29
0.28
0.27
0.26
0.25
0.24
570,000
575,000
580,000
585,000
Time (sec)


z gyro bias (deg/hr)
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
-0.21
-0.22
-0.23
-0.24
-0.25
-0.26
-0.27
570,000
575,000
580,000
585,000
Time (sec)


y gyro bias (deg/hr)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
570,000
575,000
580,000
585,000
Time (sec)