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FL Lower Choctawhatchee NWFWMD Lidar 2017 B17

Report Produced for NWFWMD

Report Date: 9/11/2018

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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 Lower Choctawhatchee 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 3,893 tiles were produced for the project encompassing an area of approximately 3,081 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 Walton, Holmes, Jackson, Washington, Bay, Calhoun and Gulf.

DATE OF SURVEY

The lidar aerial acquisition was conducted from April 9, 2017 thru May 17, 2017.

COORDINATE REFERENCE SYSTEM

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

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 16N
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 Lower Choctawhatchee NWFWMD Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **5.1 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 **9.9 cm**, compared with the 19.6 cm specification.

For the FL Lower Choctawhatchee NWFWMD Lidar Project, the tested VVA of the classified lidar data computed using the 95th percentile was equal to **14.3 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. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – IMG Format)
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Independent Survey Checkpoint Data (Report, Photos, & Points)
7. Low Confidence Polygons (shapefile)
8. Calibration Points
9. Metadata
10. Project Report (Acquisition, Processing, QC)
11. Project Extents, Including a shapefile derived from the lidar deliverable

PROJECT TILING FOOTPRINT

Three thousand eight hundred ninety two (3,893) 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).

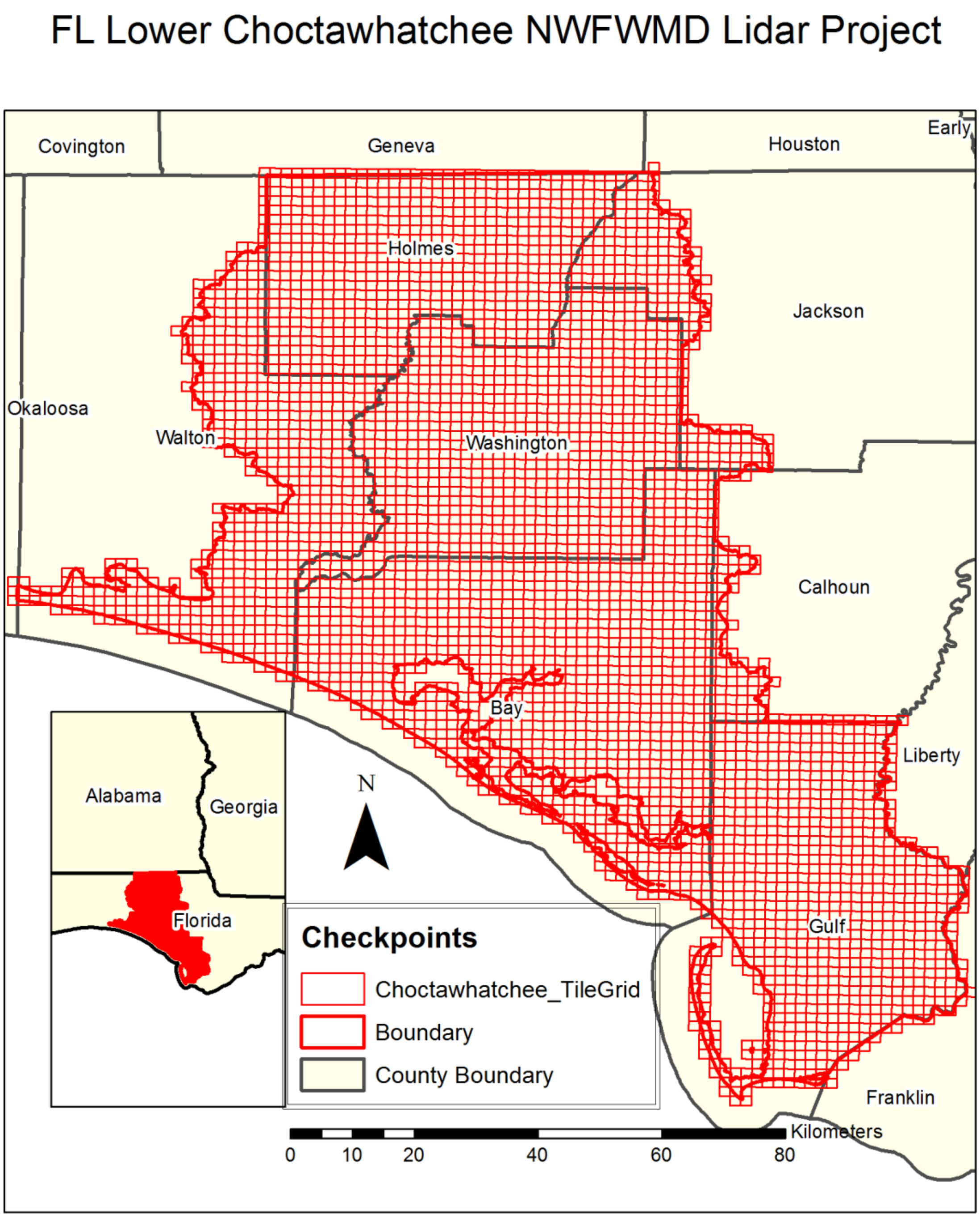

Figure 1 - Project Map

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 July 15, 2017.

LIDAR ACQUISITION DETAILS

Airborne Imaging Inc. planned 117 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 lidar sensors are calibrated at a designated site located at Red Deer, Alberta, Canada or St. Hubert, Quebec, Canada 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
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)	0.7
Nominal Pulse Density (single swath) (ppsm), (m)	2.0
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.7
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.0
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.

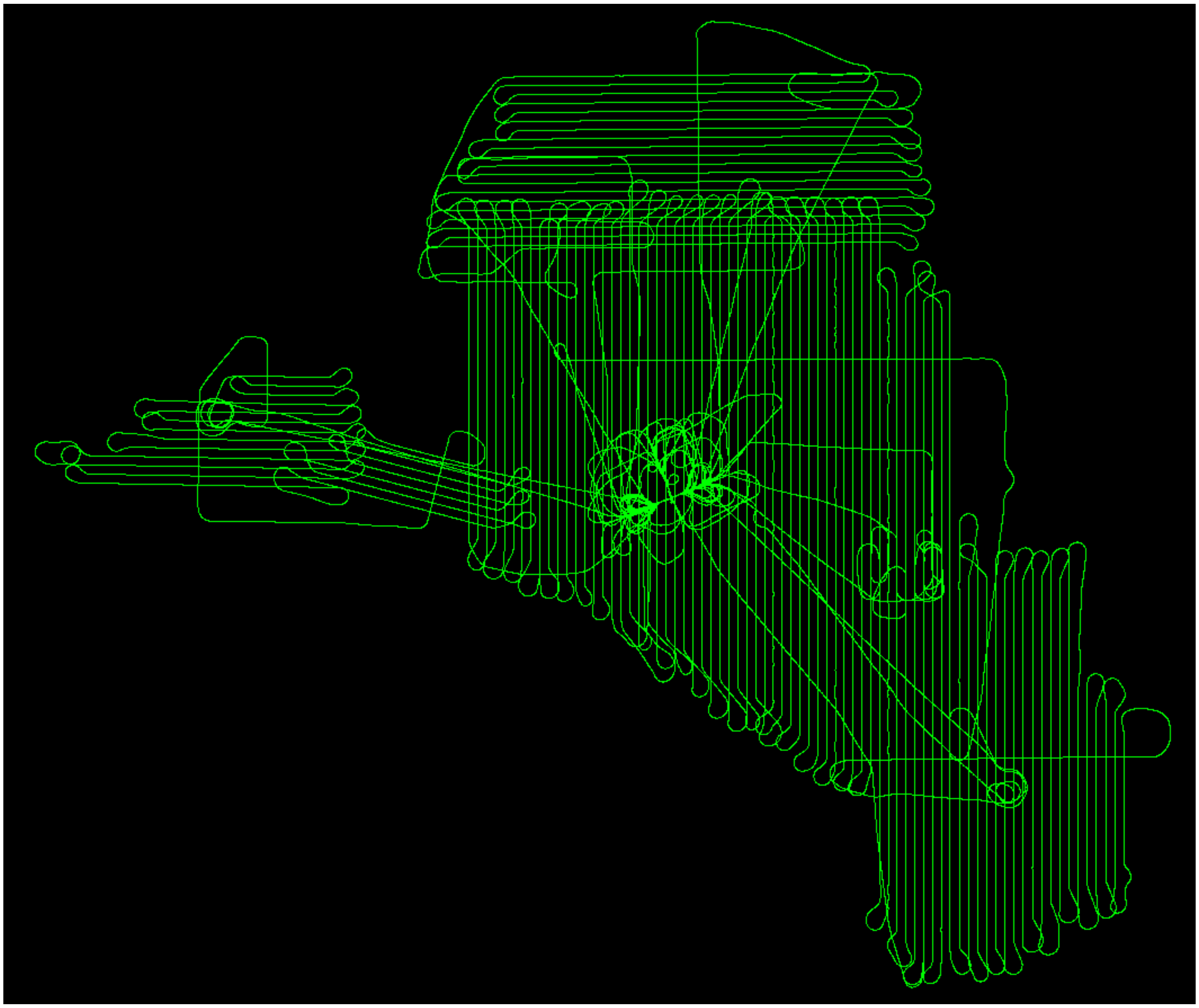

Figure 2: Trajectories as flown by Airborne Imaging, Inc.

LIDAR CONTROL

Airborne Imaging Inc. conducted the survey which provided the six newly established base stations and seven existing NGS monuments that were used to control the lidar acquisition for the FL Lower Choctawhatchee NWFWMD lidar project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	NAD83(2011) UTM 16		Ellipsoid Ht (NAD83(2011), m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
AS0886	681913.979	3317375.706	-22.369	5.148
B159	619846.104	3401350.025	-0.571	27.232
B160	672845.360	3309317.449	-21.597	5.797
B161	579293.765	3361938.111	-25.542	1.983

B162	615768.044	3357324.550	-11.587	16.229
B170	619823.783	3401252.405	0.967	28.771
B171	646616.757	3336475.978	-16.914	10.857
BE0841	642162.835	3321970.295	-21.678	5.906
BE2979	618998.107	3355844.172	-23.441	4.385
BE3768	614404.316	3391605.106	2.580	30.388
BG1452	584006.895	3393146.716	36.362	63.923
BG5044	538984.309	3371984.612	-25.041	2.326
TO06	628830.893	3419736.416	31.543	59.275

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GNSS data was processed using the Applanix POSPac software suite and Novatel's GrafNav software. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with PDOP of better than 4. Distances form base stations 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 not 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.

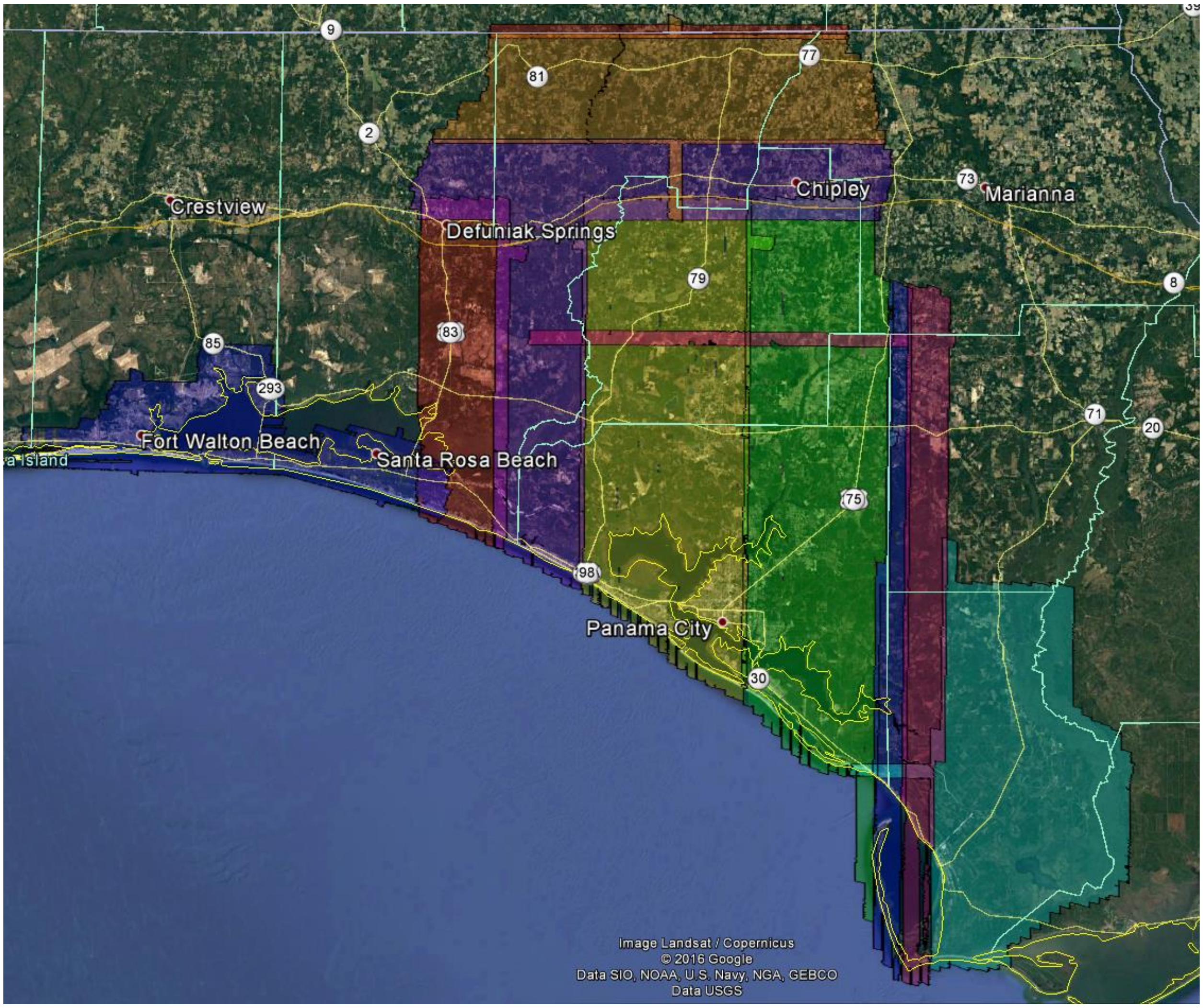

Figure 3 – Lidar swath output showing complete coverage.

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.

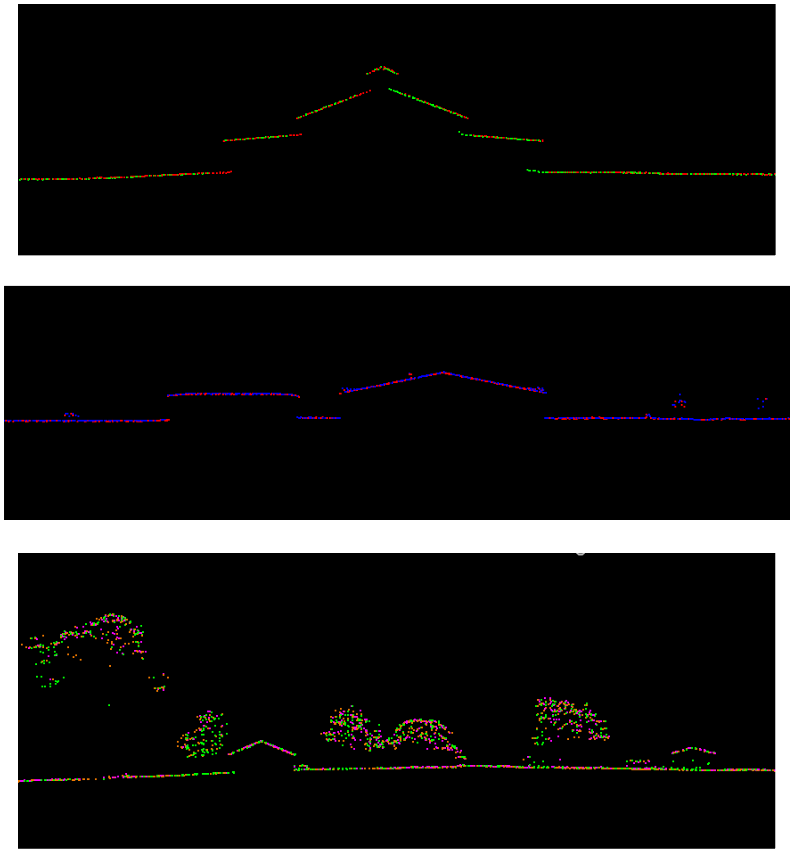

Figure 4 – Profile views showing correct roll and pitch adjustments.

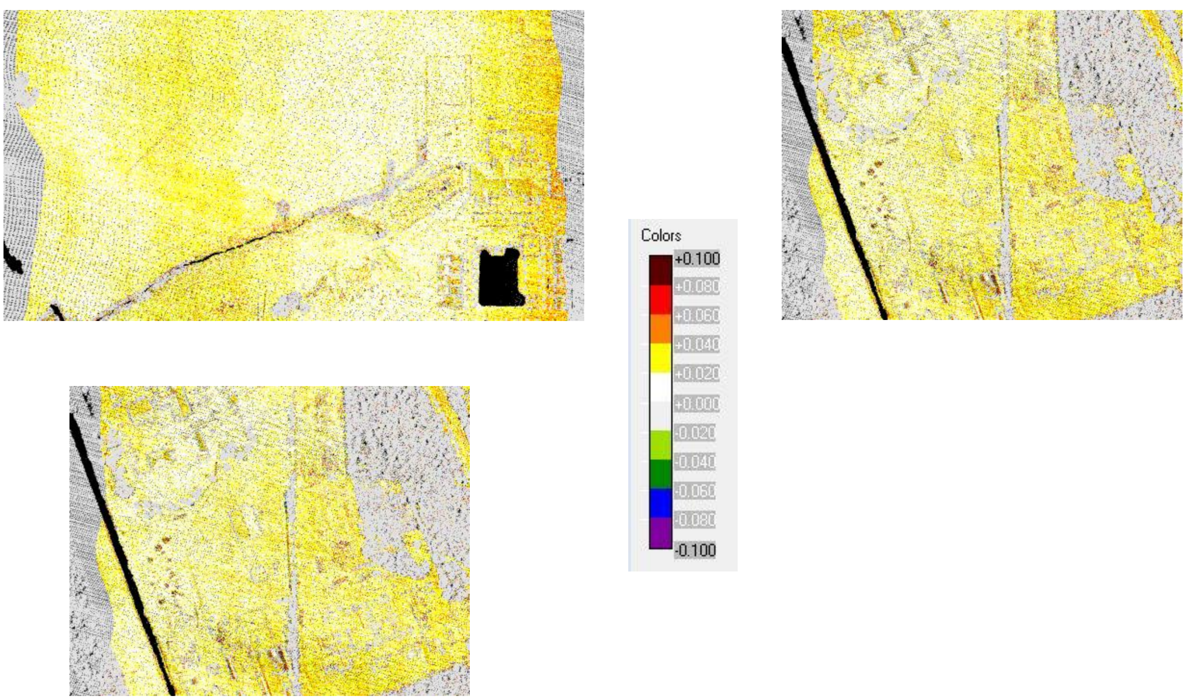

Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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 Lower Choctawhatchee NWFWMD lidar dataset was tested to 0.094 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.048 m x 1.9600) when compared to over 14,500 GNSS kinematic 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 (m) NVA Spec=0.1 m	NVA at 95% Spec=0.196 m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	14,525	0.048	0.094	-0.001	0.048	-0.165	0.175

Table 3 - Kinematic GPS Vertical Accuracy 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, 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 one hundred and one 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 Lower Choctawhatchee 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 $RMSE_z$ = 4.7 cm, equating to +/- 9.3 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	100	0.047	0.093	0.005	0.002	-0.133	0.047	-0.148	0.143	1.023

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

Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification.

One checkpoint (NVA99) was removed from the raw swath vertical accuracy testing due to its location outside the project boundary. Table 5, below, provides the coordinates for this checkpoint.

Point ID	NAD83(2011) UTM Zone 16N		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA-99	537472.548	3368388.832	5.280	OUTSIDE	N/A	N/A

Table 5: Checkpoint removed from raw swath vertical accuracy testing

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 Lower Choctawhatchee are shown in the figure below; this project meets inter-swath relative accuracy specifications.

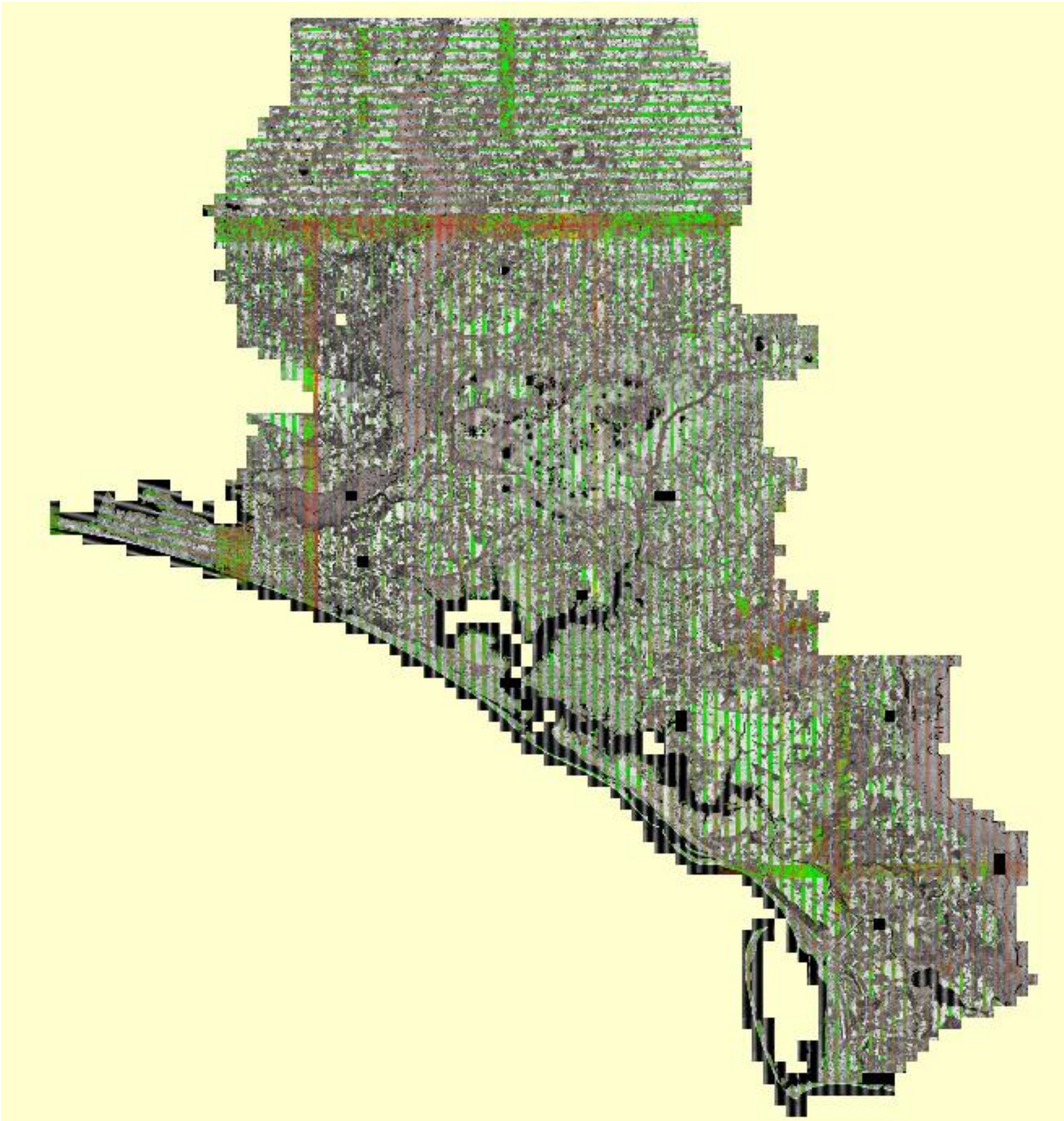

Figure 6– Single return DZ Orthos for the FL Lower Choctawhatchee. Inter-swath relative accuracy passes specifications.

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 the FL Lower Choctawhatchee lidar Project; this project meets intra-swath relative accuracy specifications.

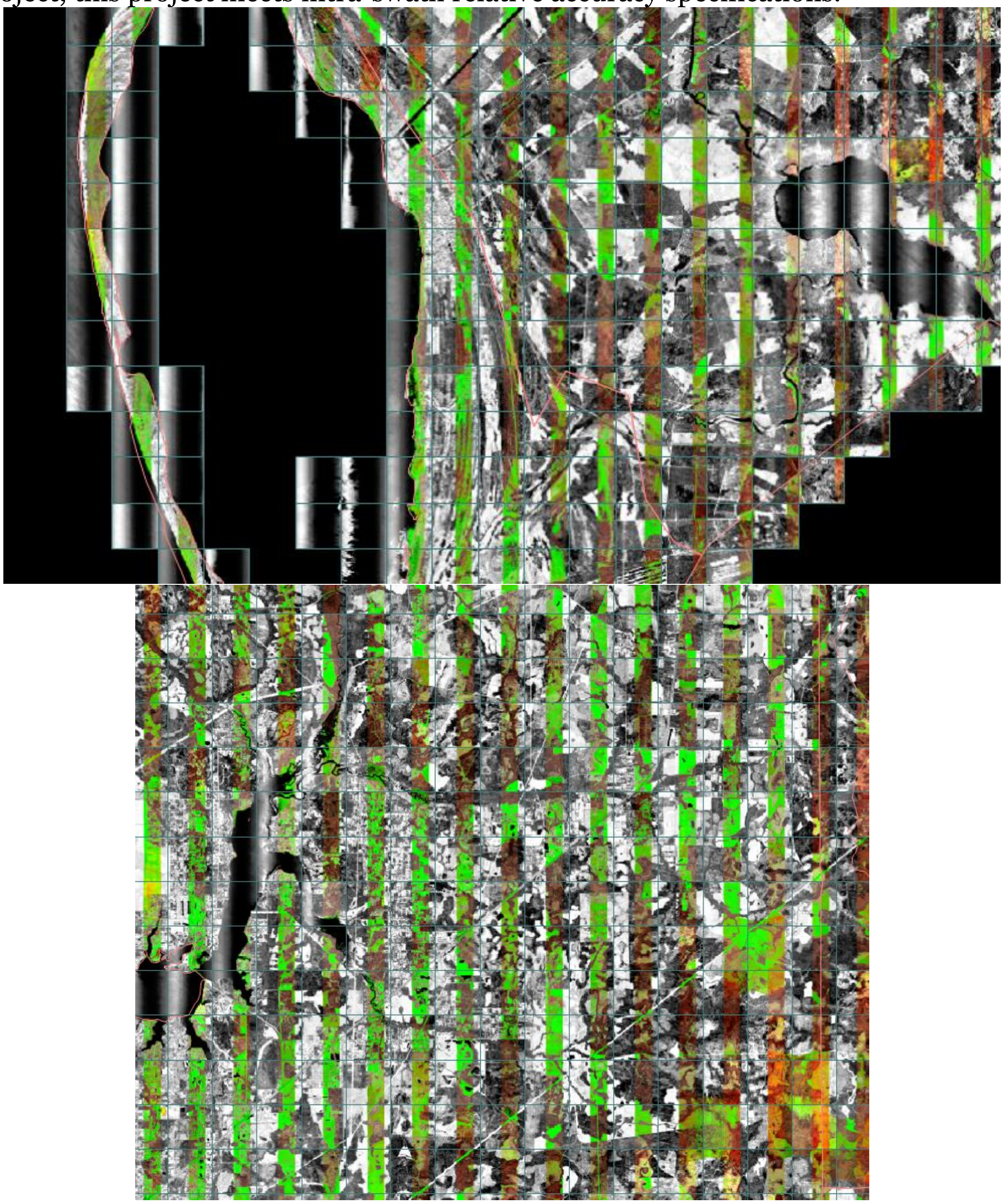

Figure 7–Intra-swath relative accuracy. These images show a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped and vegetated terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change and vegetation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

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 Lower Choctawhatchee; no horizontal alignment issues were identified.

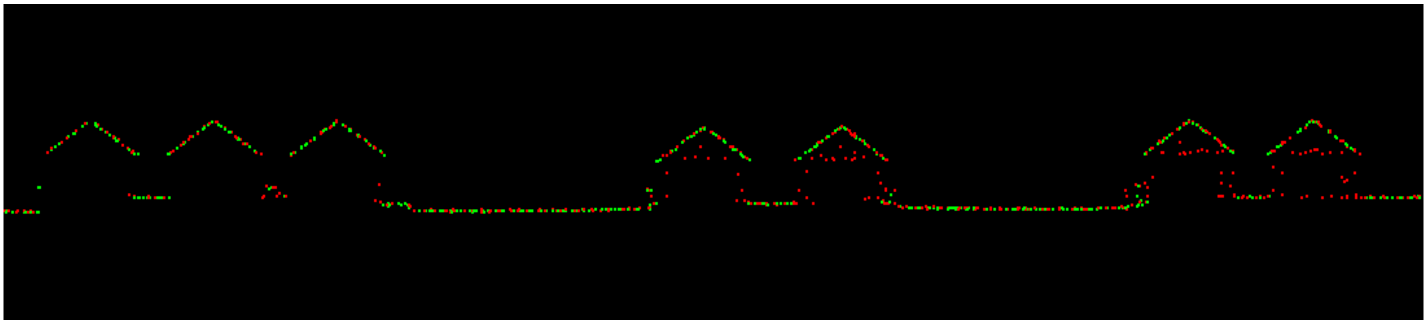

Figure 8– Horizontal Alignment. Two separate flight lines differentiated by color (red/green) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.7 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 0.4 meters or an ANPD of 4.05 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 (purple 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.

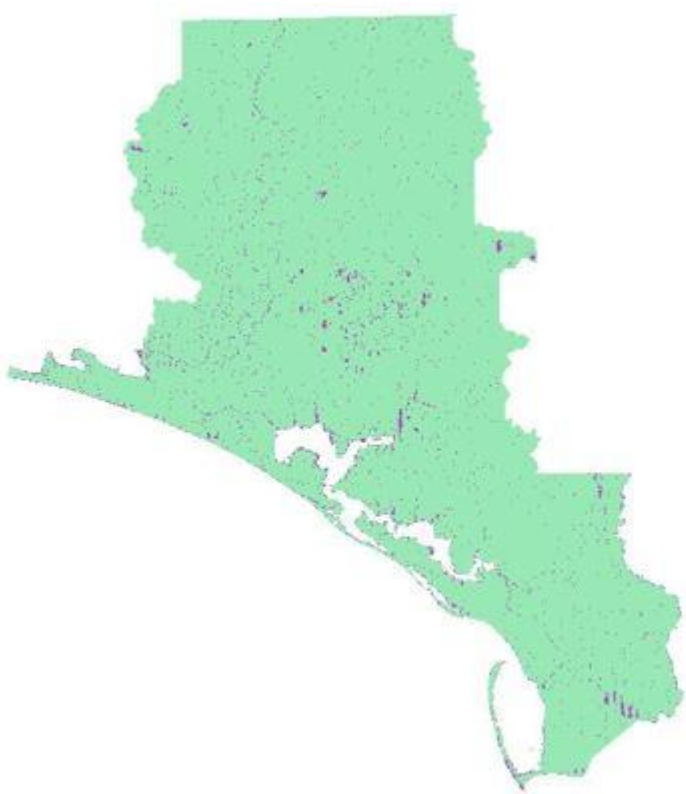

Figure 9– 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (purple areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density 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.

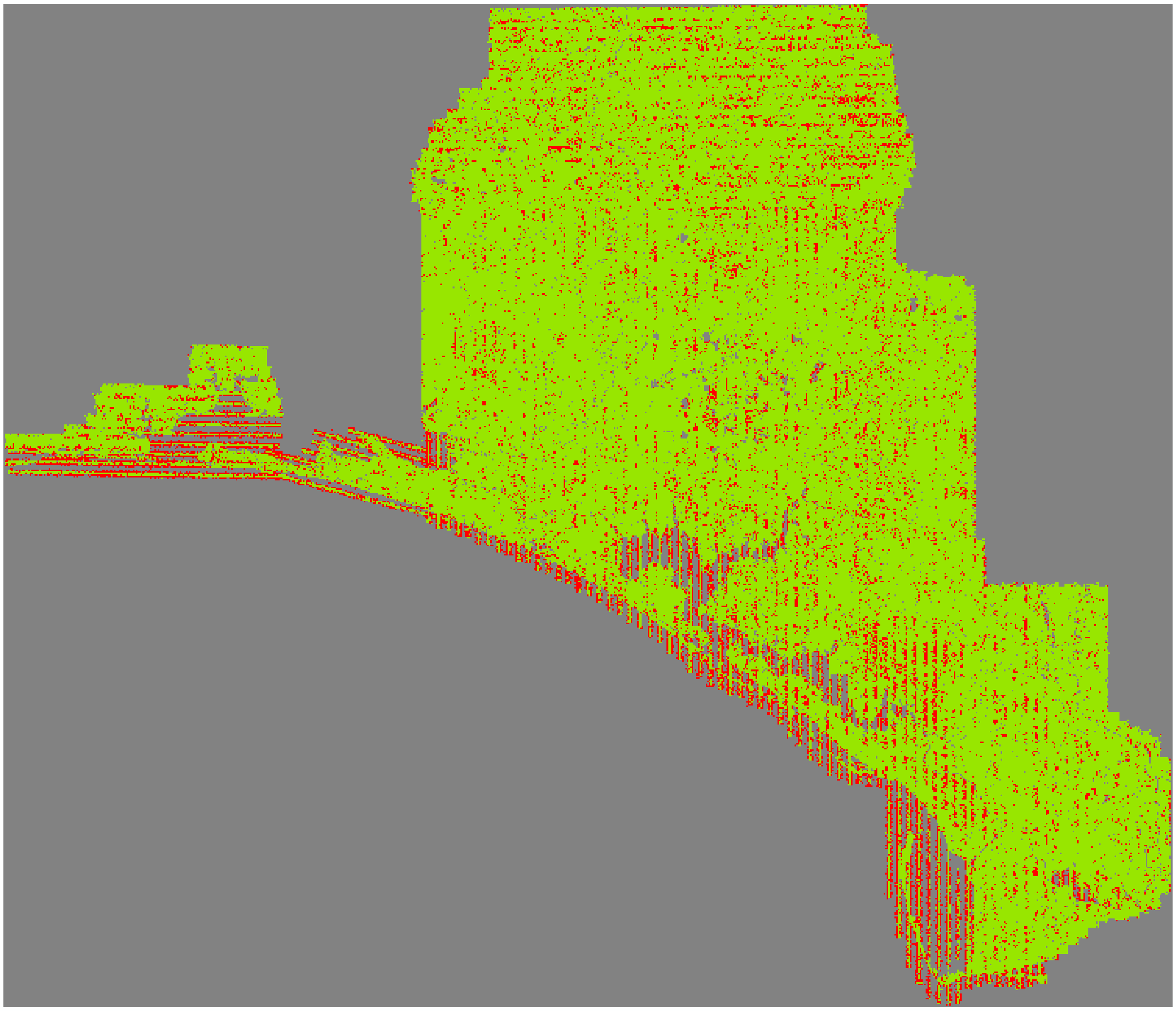

Figure 10– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 97.5% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

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

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

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

The lidar tiles were classified to the following classification schema:

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

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

Lidar Qualitative Assessment

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

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for FL Lower Choctawhatchee.

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 Lower Choctawhatchee 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.

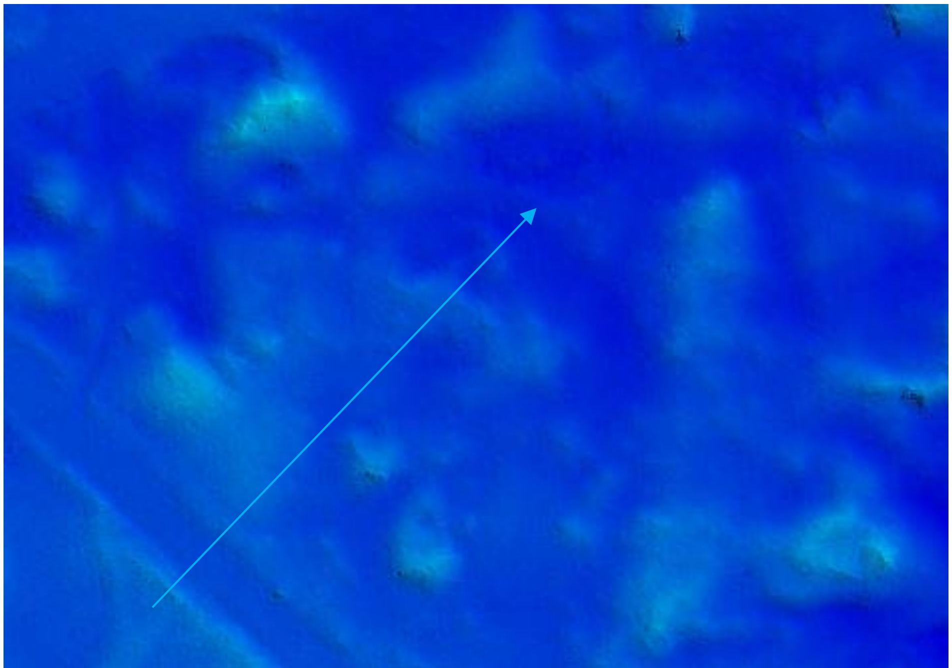

Figure 11 – Tile number 16REV640585. Profile with points colored by class (class 1=cyan, class 2=yellow) is shown in the bottom view and a TIN of the surface is shown in the top view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but 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

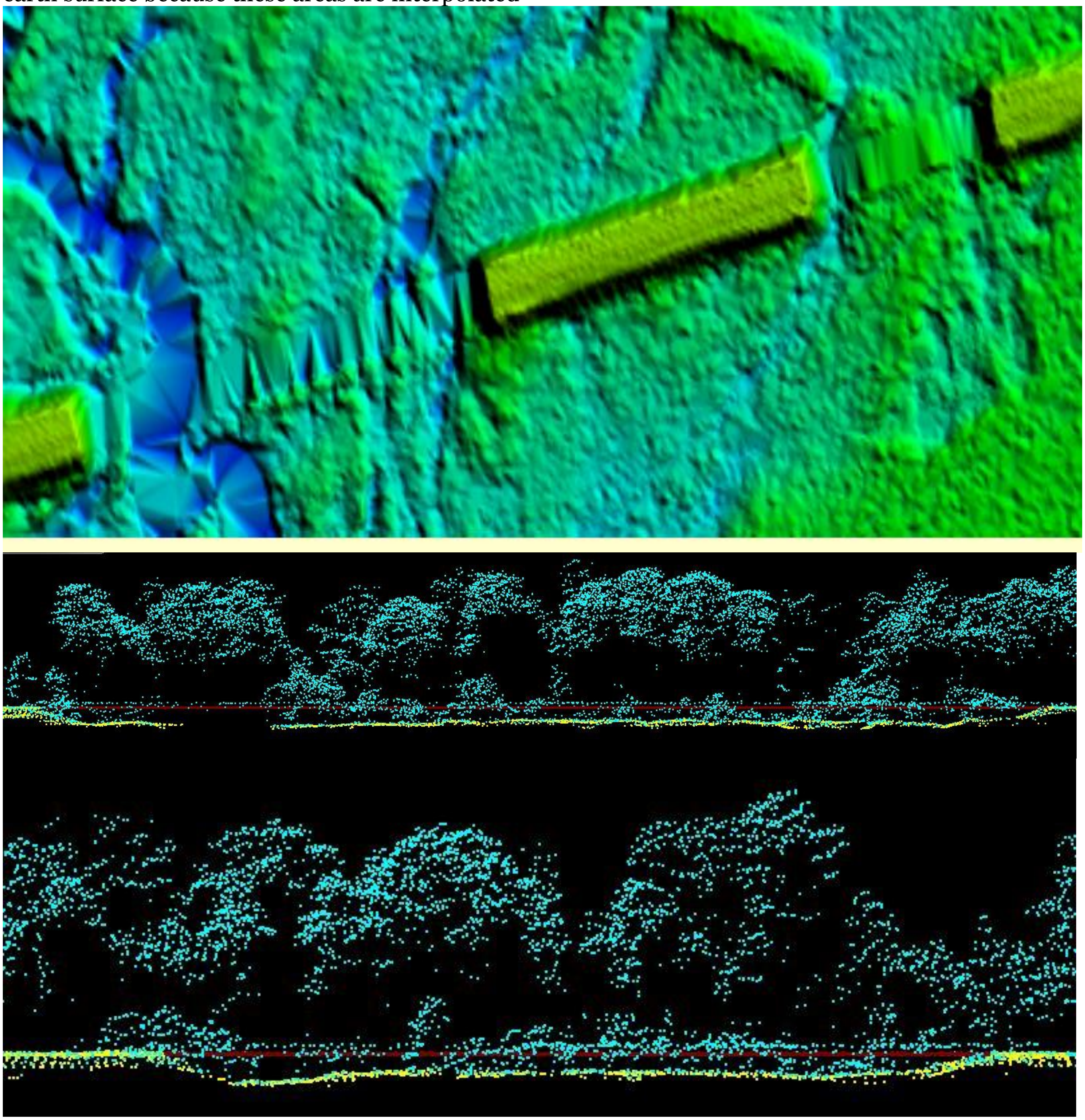

Figure 12 – Tile number 16RFV315005. The DEM in the top view shows an area where two bridges have been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profiles in the bottom views show the lidar points of these particular features colored by class. All bridge points have been removed from ground (yellow) and are classified to bridge deck (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.

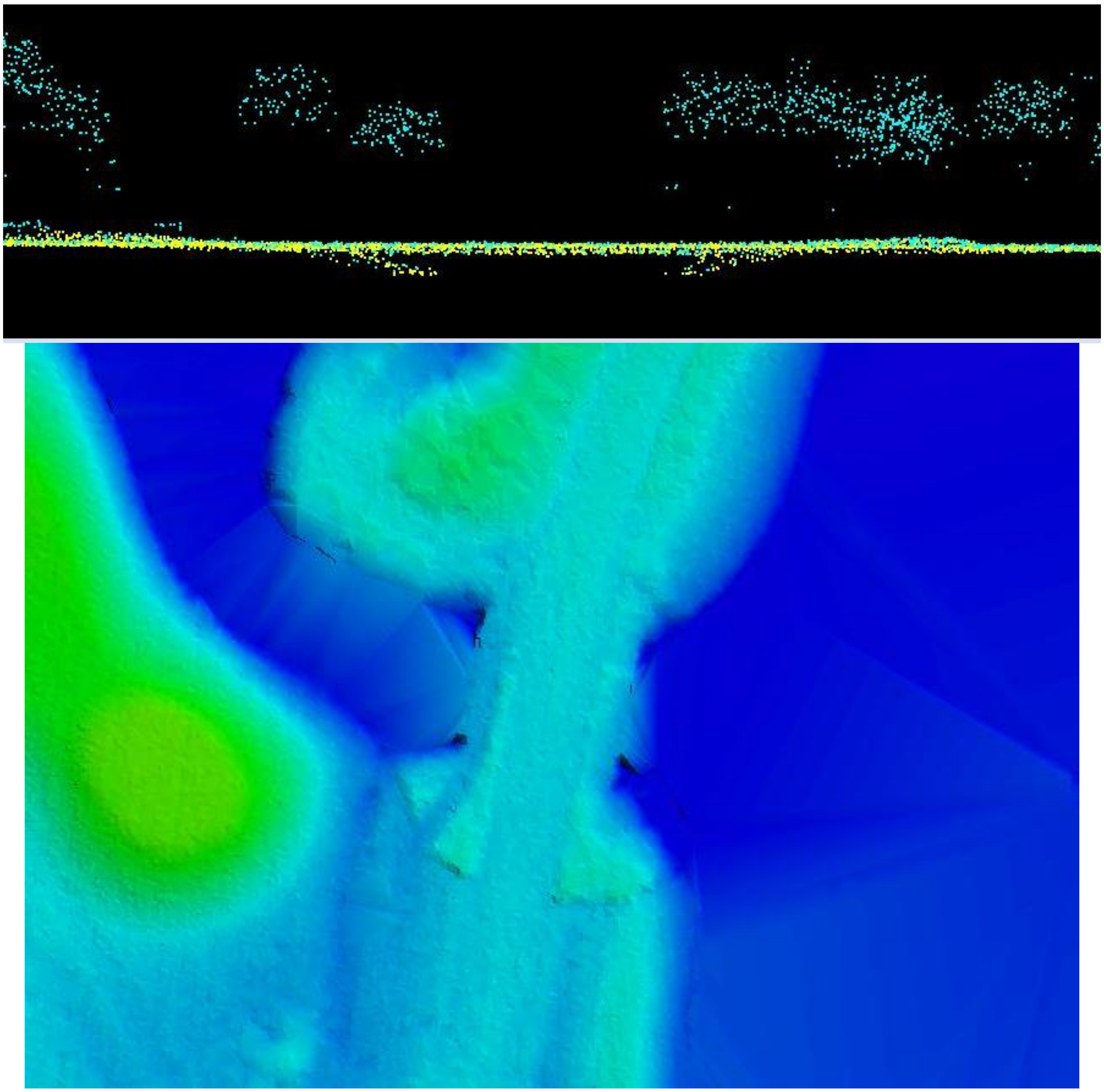

Figure 13– Tile number 16REV640615. Profile with points colored by class (class 1=cyan, class 2=yellow) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Interpolation within Resort Areas

Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath large resort area structures which have been removed from the ground classification. Locations where resort area structures were removed will generally contain less detail in the bare-earth surface because these areas are interpolated. In some areas there are also varying ground levels, which can make the interpolation between the different elevations stand out more in the DEMs.

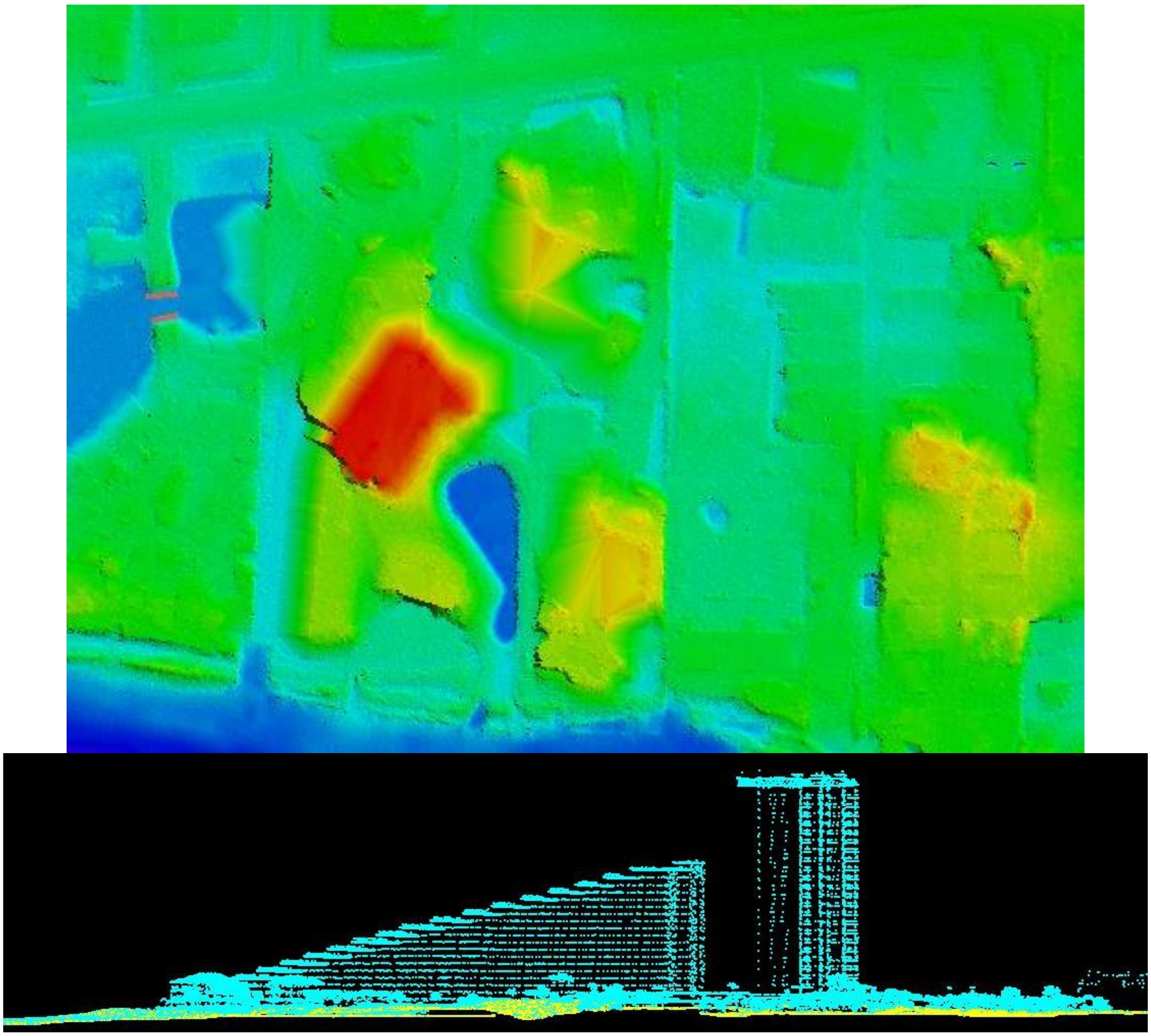

Figure 14 – Tile number 16REV610600. Profile with the points colored by class (class 1=cyan, class 2=yellow) is shown in the bottom view and a DEM of the surface is shown in the top view. Large resort area structures are correctly excluded from the ground classification, resulting in large areas of interpolation in the DEMs.

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.

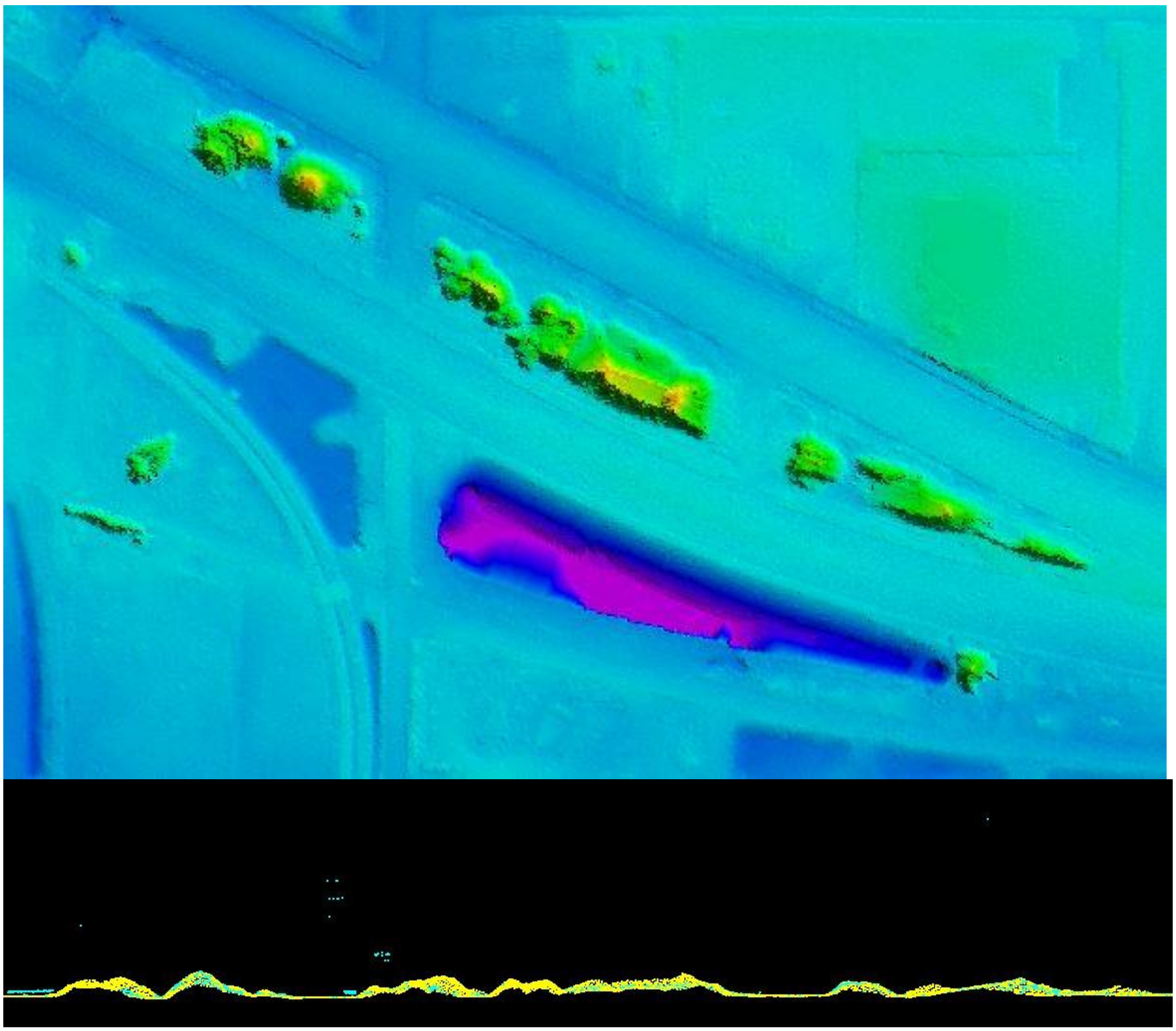

Figure 15 - Tile 16RFU225390. Profile with the points colored by class (class 1=cyan, class 2=yellow) is shown in the bottom view and a DEM of the surface is shown in the top view. These features are correctly included in the ground classification.

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	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

Previous versions of Riegl software would set the Edge of Flightline flags as 0 for all points collected with Riegl sensors so that minimum and maximum values for this field would be 0 on lidar data collected from Riegl sensors. Newer software versions used to process Riegl data are now retaining the Edge of Flightline information and setting the flag as 1 on the point at the edge of swaths so that lidar data collected and processed with more recent Riegl software have minimum values of 0 and maximum values of 1 for the Edge of Flightline field.

Some datasets, including the Lower Choctawhatchee Lidar Project, have been processed using multiple versions of Riegl software as these projects were in-production when the software was updated. This has resulted in a mix of some lidar tiles having the Edge of Flightline point flagged and some tiles do not. When looking at the LAS statistics, some tiles will show a minimum and maximum of 0 for the Edge of Flightline field whereas some tiles will show a minimum of 0 and a maximum of 1 if the edge points are flagged.

Because Riegl sensors use a rotating mirror system and not an oscillating mirror system, the Scan Direction field continues to show a minimum and maximum of 0 as points do not have either a positive or negative scan direction.

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 seventy nine (179) checkpoints 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)
NVA-1	595715.292	3427369.690	53.867
NVA-2	607543.243	3427863.020	31.081
NVA-3	629244.668	3428318.233	73.181
NVA-4	635232.999	3428192.049	53.638
NVA-5	596995.965	3420161.434	41.790
NVA-6	609904.379	3421235.175	23.684
NVA-7	623912.416	3421737.963	31.490
NVA-8	639149.053	3421926.740	50.297
NVA-9	645167.450	3421884.841	49.289
NVA-10	590851.027	3413966.627	77.517
NVA-11	603072.148	3414643.069	53.370
NVA-12	617474.999	3415148.462	22.018
NVA-13	630897.553	3414562.470	53.222
NVA-14	643558.391	3414614.836	40.099
NVA-15	649670.273	3414934.751	39.904
NVA-16	584941.324	3406396.063	80.993
NVA-17	597425.006	3407364.683	59.571
NVA-18	609324.107	3407084.199	19.254

NVA-19	624019.644	3407062.838	40.608
NVA-20	637522.913	3407842.833	22.826
NVA-21	651623.937	3407313.872	43.663
NVA-22	584705.698	3399883.795	67.780
NVA-23	598347.937	3400055.954	26.950
NVA-24	614964.310	3400508.592	18.024
NVA-25	625844.917	3400845.149	28.543
NVA-26	633069.280	3400771.473	18.422
NVA-27	583922.890	3393167.410	63.509
NVA-28	600124.669	3393131.934	65.415
NVA-29	612209.943	3393242.582	21.824
NVA-30	626239.014	3393584.869	14.114
NVA-31	638987.160	3393907.136	45.712
NVA-32	592867.219	3384682.422	58.088
NVA-33	607432.963	3386007.162	10.268
NVA-34	620616.314	3386423.925	16.719
NVA-35	634788.978	3386762.378	41.998
NVA-36	639566.996	3387021.447	36.072
NVA-37	599357.042	3377865.282	41.151
NVA-38	612036.829	3379507.199	32.968
NVA-39	625866.125	3379729.205	23.260
NVA-40	633000.118	3379933.383	40.615
NVA-41	654333.909	3380547.206	70.664
NVA-42	592898.210	3372002.330	17.529
NVA-43	599251.991	3371920.699	12.864
NVA-44	619107.865	3368187.612	27.444
NVA-45	632967.594	3372748.284	33.183
NVA-46	639164.561	3373297.282	28.554
NVA-47	651755.814	3373519.379	52.030
NVA-48	585063.277	3367742.010	4.593
NVA-49	601982.637	3363989.510	5.182
NVA-50	608019.709	3366329.897	13.065
NVA-51	625787.917	3365217.321	25.230
NVA-52	640770.276	3366344.629	30.257
NVA-53	646673.607	3368113.453	36.301
NVA-54	559404.421	3361719.169	4.666
NVA-55	573253.184	3361037.390	4.316
NVA-56	593207.124	3358865.566	10.620
NVA-57	606935.711	3357694.309	18.492
NVA-58	615072.604	3358476.819	16.143
NVA-59	627964.976	3359229.452	20.659
NVA-60	640433.226	3360073.171	20.877
NVA-61	645986.731	3362347.955	35.337
NVA-62	592966.471	3351708.252	10.016

NVA-63	607678.665	3351890.017	6.740
NVA-64	619142.888	3354119.873	2.796
NVA-65	633308.904	3352147.842	5.814
NVA-66	640064.066	3353071.128	14.916
NVA-67	646256.514	3353460.037	20.037
NVA-68	605363.725	3345647.030	10.140
NVA-69	627494.744	3344839.817	2.094
NVA-70	640305.301	3346356.974	15.986
NVA-71	653115.585	3344579.302	21.250
NVA-72	611207.457	3342160.909	9.187
NVA-73	619655.066	3338097.766	5.028
NVA-74	626247.405	3338460.791	10.897
NVA-75	648261.232	3338956.307	15.761
NVA-76	667568.223	3339112.030	16.471
NVA-77	674413.188	3339424.704	8.062
NVA-78	629968.369	3331623.428	4.907
NVA-79	642043.523	3334971.350	4.029
NVA-80	655080.540	3332337.227	10.639
NVA-81	673513.082	3333048.573	14.147
NVA-82	634643.823	3327743.350	9.082
NVA-83	658683.190	3321377.682	2.935
NVA-84	661215.279	3326132.047	5.894
NVA-85	674715.738	3325911.529	10.298
NVA-86	656121.485	3318307.952	2.688
NVA-87	674621.983	3319865.166	6.423
NVA-88	681728.230	3319056.051	6.095
NVA-89	656101.646	3311409.653	6.847
NVA-90	669117.539	3312365.699	5.688
NVA-91	684483.781	3312404.507	3.213
NVA-92	660596.619	3304715.530	3.497
NVA-93	668881.340	3304021.342	4.387
NVA-94	684720.667	3305862.353	3.064
NVA-95	655150.809	3291553.313	2.656
NVA-96	664760.459	3298074.108	1.850
NVA-97	664125.003	3288627.278	1.469
NVA-98	675190.505	3291301.240	2.696
NVA-99	537472.548	3368388.832	5.280
NVA-100	660172.986	3385533.646	80.355
NVA-101	660877.932	3332544.763	12.817
VVA01	600285.155	3427213.411	51.634
VVA02	613329.949	3426900.294	31.972
VVA03	620191.585	3428424.993	57.329
VVA04	641382.308	3429413.219	51.258
VVA05	602380.242	3421393.381	44.820

VVA06	617435.430	3420784.946	44.846
VVA07	632789.410	3421796.772	51.920
VVA08	597724.220	3413664.743	87.036
VVA09	610573.034	3413967.274	24.845
VVA10	623955.984	3414981.020	32.056
VVA11	637883.876	3415096.481	29.962
VVA12	589016.075	3406534.860	49.928
VVA13	604058.561	3407147.470	30.301
VVA14	616963.963	3407386.397	29.230
VVA15	630675.176	3407473.863	22.588
VVA16	644347.246	3407701.116	32.664
VVA17	591362.671	3399596.327	76.073
VVA18	604301.238	3400251.974	20.301
VVA19	621219.073	3400503.553	25.800
VVA20	638798.681	3400366.584	39.349
VVA21	592141.220	3392023.334	66.423
VVA22	604262.723	3392193.044	12.572
VVA23	620330.081	3393530.219	14.437
VVA24	632915.161	3393914.987	26.389
VVA25	646926.065	3393957.087	53.204
VVA26	598682.635	3384729.649	55.399
VVA27	614233.150	3385997.612	12.529
VVA28	627037.877	3387482.315	24.985
VVA29	646612.256	3387611.841	46.696
VVA30	604767.664	3378505.127	8.976
VVA31	619324.837	3382148.074	60.267
VVA32	639988.912	3380652.933	53.463
VVA33	648892.776	3382102.425	72.128
VVA34	587245.808	3372282.058	16.270
VVA35	609680.274	3372216.049	28.145
VVA36	626074.047	3372977.905	40.797
VVA37	646272.343	3373118.920	51.229
VVA38	593016.977	3366315.613	8.228
VVA39	614596.409	3365957.828	27.207
VVA40	620153.805	3368169.799	27.641
VVA41	632043.118	3366783.301	25.046
VVA42	651666.027	3368085.252	46.791
VVA43	566842.341	3361490.117	3.348
VVA44	579460.145	3359303.680	7.287
VVA45	585070.736	3356330.230	11.608
VVA46	600350.942	3358592.002	14.276
VVA47	621510.979	3358605.935	12.549
VVA48	633835.767	3358536.107	12.538
VVA49	652240.795	3360098.492	27.309

VVA50	599727.926	3350702.483	5.892
VVA51	613591.177	3351908.575	2.046
VVA52	626384.167	3351459.100	5.007
VVA53	654002.497	3353544.124	23.400
VVA54	615970.946	3344417.370	1.256
VVA55	633750.389	3344987.988	10.686
VVA56	647066.202	3343692.593	18.988
VVA57	634069.344	3339189.489	10.001
VVA58	642028.884	3338475.646	14.001
VVA59	655028.109	3338954.863	13.549
VVA60	660554.400	3339015.153	16.785
VVA61	647773.698	3331981.611	9.530
VVA62	658801.753	3348210.028	23.994
VVA63	666961.010	3332586.272	11.494
VVA64	639309.378	3324368.893	7.040
VVA65	647620.538	3323957.524	2.394
VVA66	667226.544	3326610.347	9.043
VVA67	647280.380	3317513.717	5.749
VVA68	661545.818	3319253.969	3.545
VVA69	668095.920	3319272.261	5.602
VVA70	662839.361	3311246.740	5.915
VVA71	675397.135	3311916.668	4.348
VVA72	653926.133	3296474.957	0.575
VVA73	678081.343	3305565.997	1.705
VVA74	669491.740	3294716.878	1.603
VVA75	674993.028	3297670.209	0.579
VVA76	658631.727	3284081.090	1.279
VVA77	671315.404	3286314.663	1.554

Table 6: FL Lower Choctawhatchee NWFWMD Lidar surveyed accuracy checkpoints

Two checkpoints (NVA 99, VVA 78) were removed from the vertical accuracy testing for the classified lidar due to the fact that they fall outside the Choctawhatchee boundary.

Point ID	NAD83(2011) UTM Zone 16N		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA78	554471.321	3373862.977	8.966	OUTSIDE	N/A	N/A
NVA99	537472.548	3368388.832	5.280	OUTSIDE	N/A	N/A

Table 7: Checkpoints removed from vertical accuracy testing due to their location outside of the project boundary.

Dewberry

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

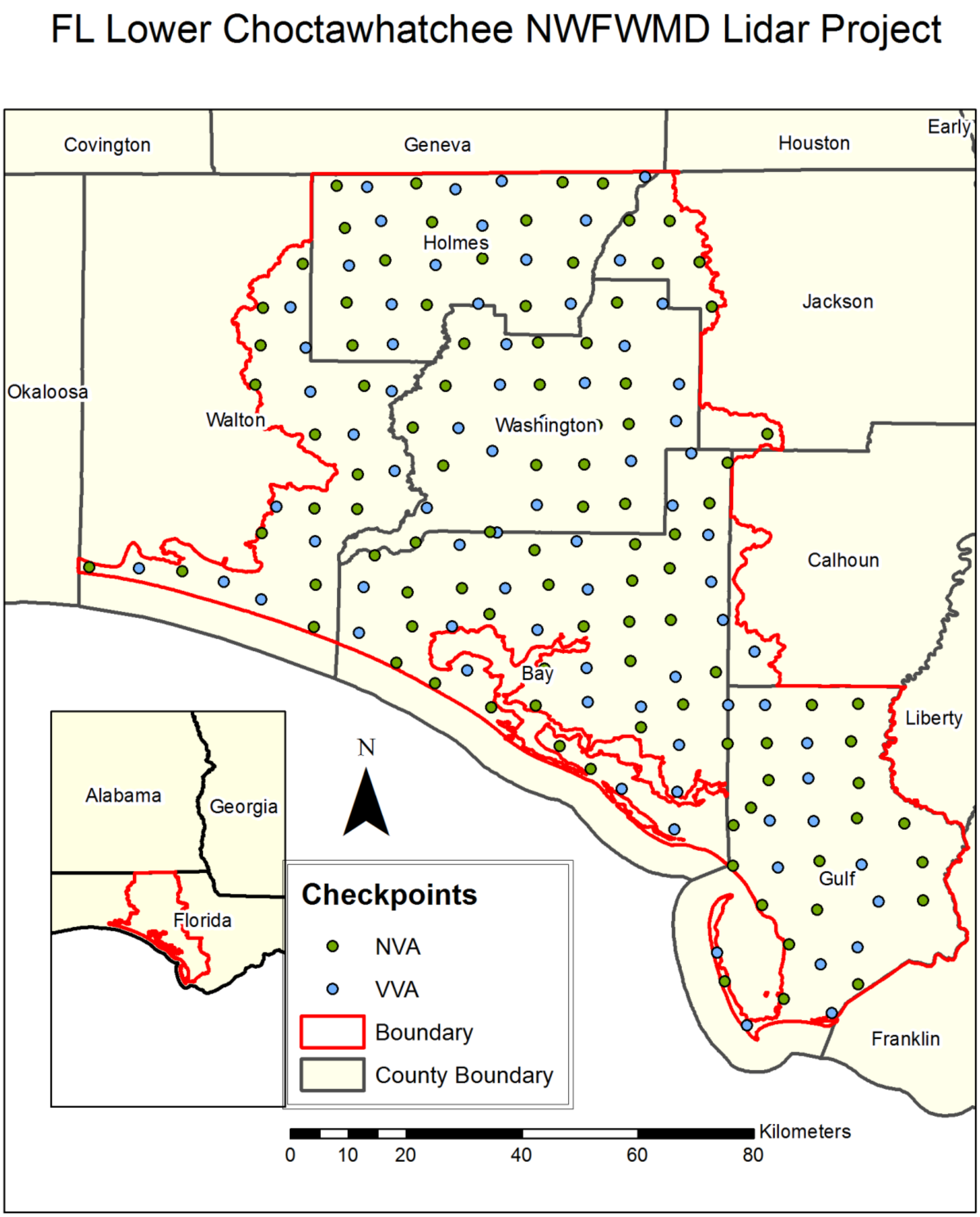

Figure 16 – Location of QA/QC Checkpoints

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 Lower Choctawhatchee 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 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. The FL Lower Choctawhatchee NWFWMD lidar project VVA standard is 29.4 cm based on the 95^{th} percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} 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 8.

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 95^{th} percentile)

Table 8 — 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	100	9.9	
VVA	77		14.3

Table 9 – 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 $RMSE_z$ =5.1 cm, equating to +/- 9.9 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 14.3 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 +20 cm.

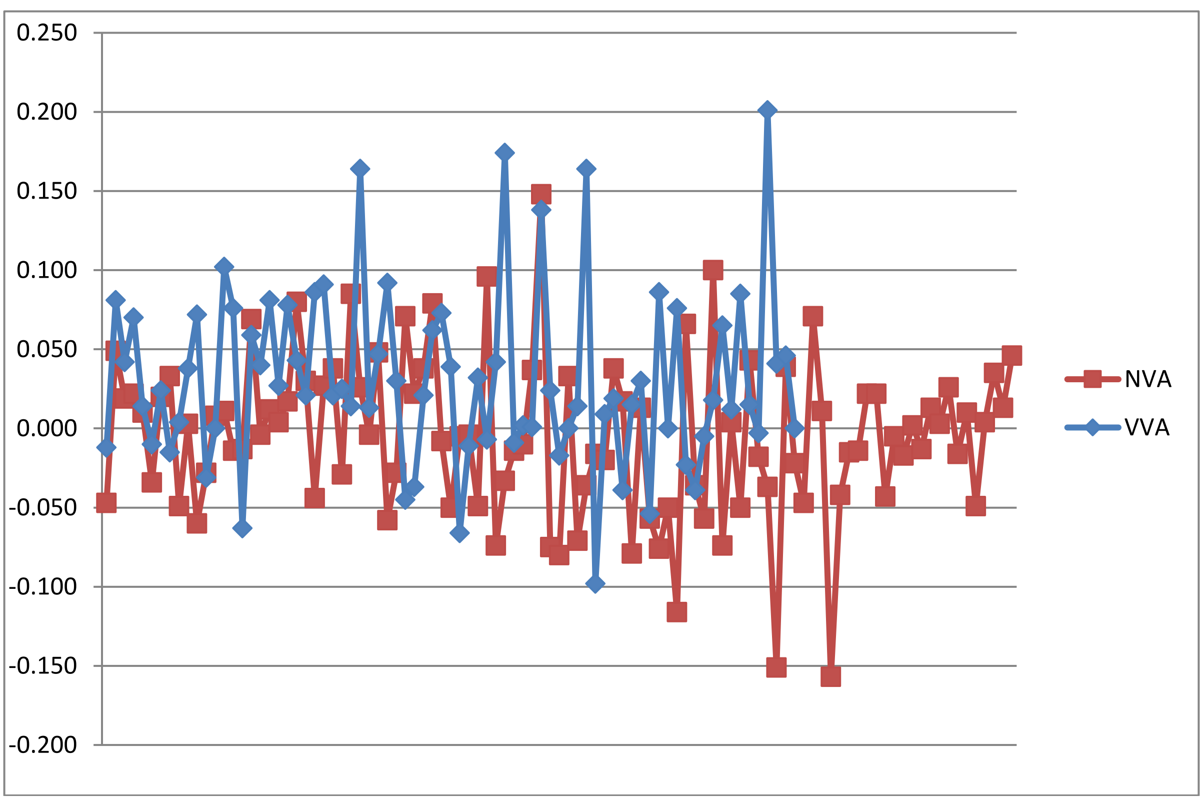

Figure 17 – Magnitude of elevation discrepancies per land cover category

Table 10 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)			
VVA30	604767.664	3378505.127	8.976	9.140	0.164	0.164
VVA46	600350.942	3358592.002	14.276	14.450	0.174	0.174
VVA55	633750.389	3344987.988	10.686	10.850	0.164	0.164
VVA75	674993.028	3297670.209	0.579	0.780	0.201	0.201

Table 10 — 5% Outliers

Table 11 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	100	0.051	-0.005	-0.004	-0.109	0.051	1.012	-0.157	0.148
VVA	77	N/A	0.031	0.024	0.678	0.055	1.142	-0.098	0.201

Table 11 — 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 -0.15 meters and a high of +0.2 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.

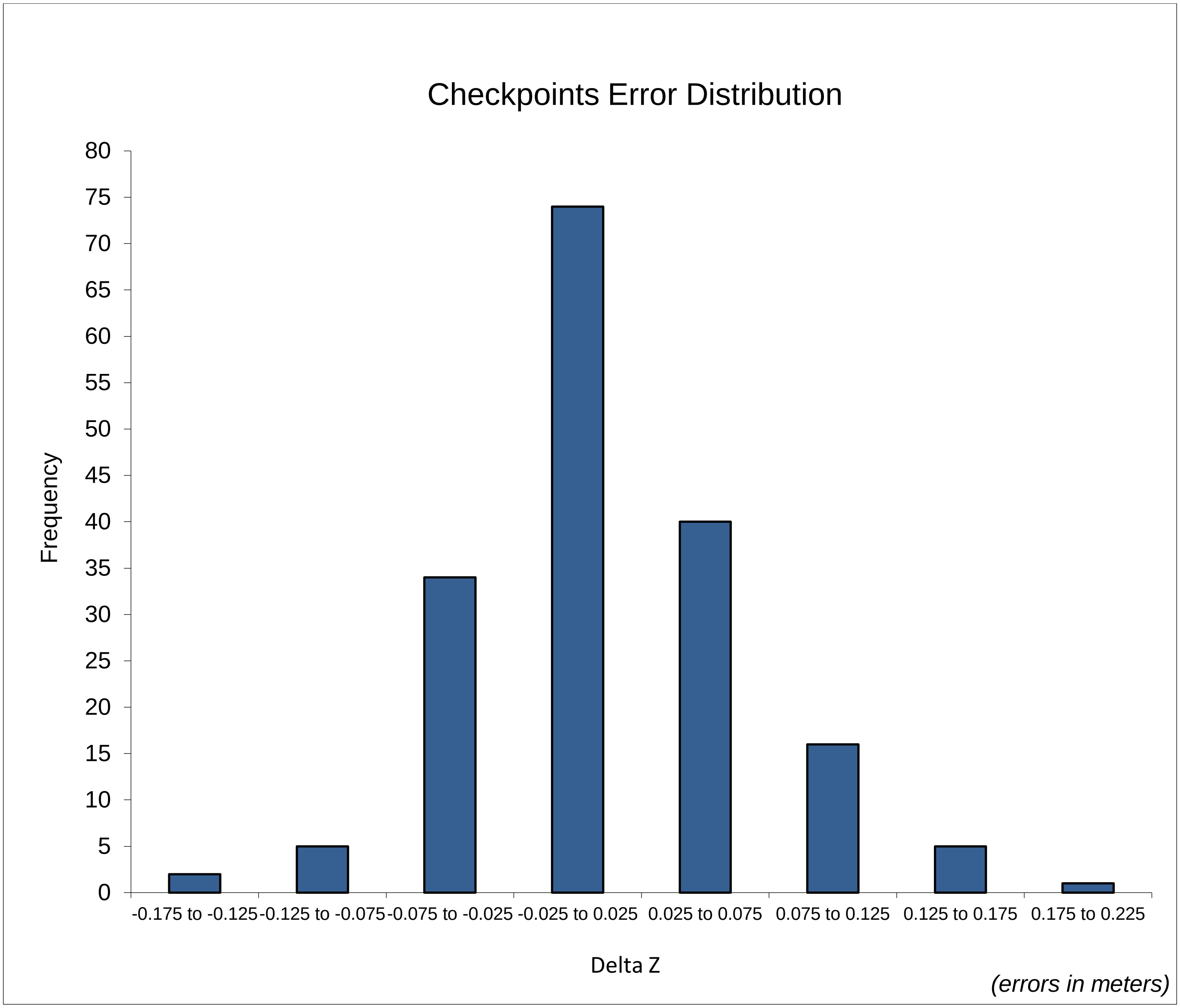

Figure 18 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the FL Lower Choctawhatchee 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 two 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 two (22) checkpoints were photo-identifiable, the results are statistically significant enough to report as a final tested value, so the results of the testing are shown in the Table below.

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

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

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
22	30.5	24.9	39.4	68.1

Table 12-Tested horizontal accuracy at the 95% confidence level

Twenty-two (22) 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 = 30.5 cm and RMSEy = 24.9 cm which equates to +/- 68.1 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.

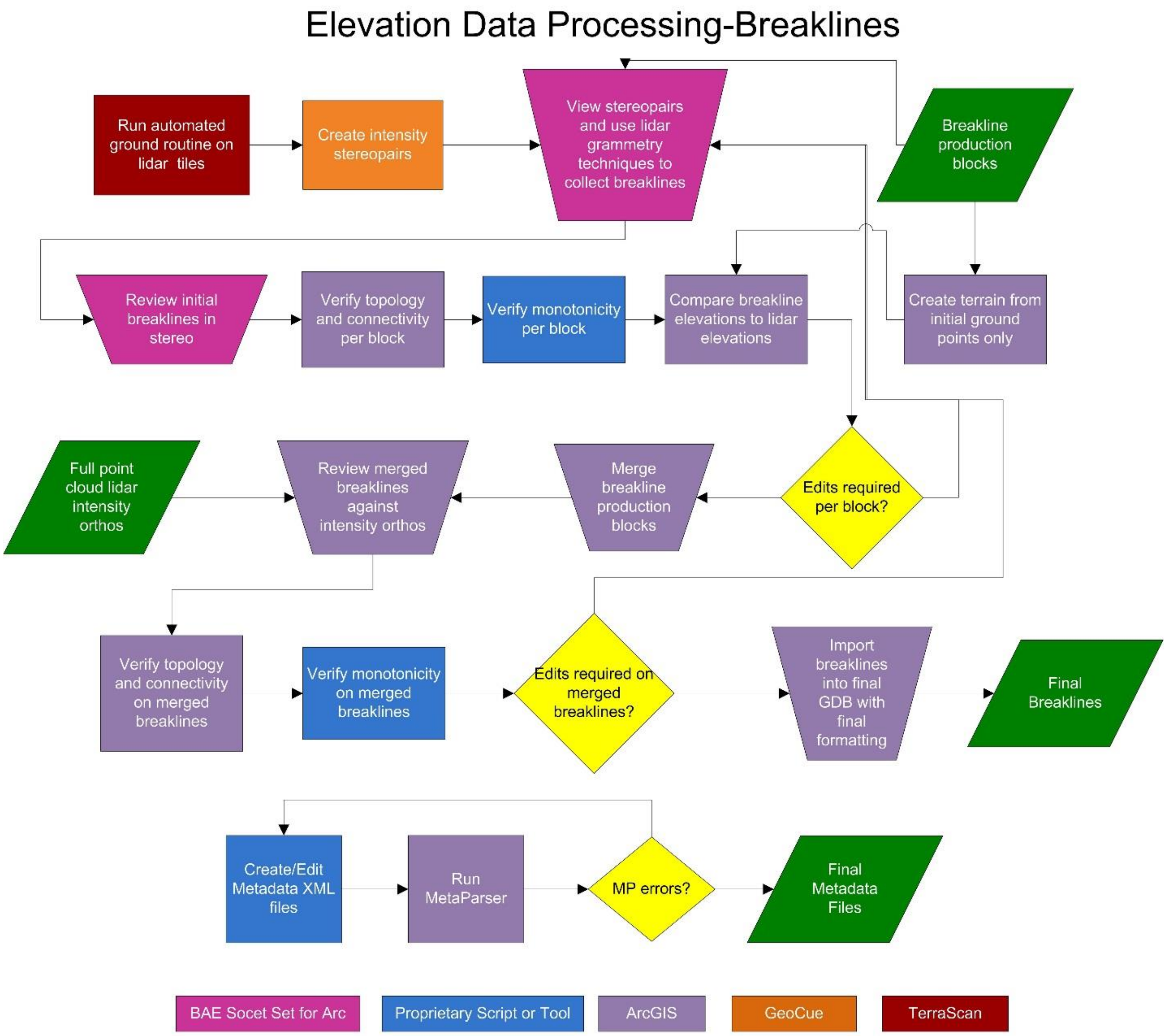

Figure 19 - Breakline QA/QC workflow

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 13-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 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 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
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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

Description

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

Table Definition

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

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. <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_Saddle_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.

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

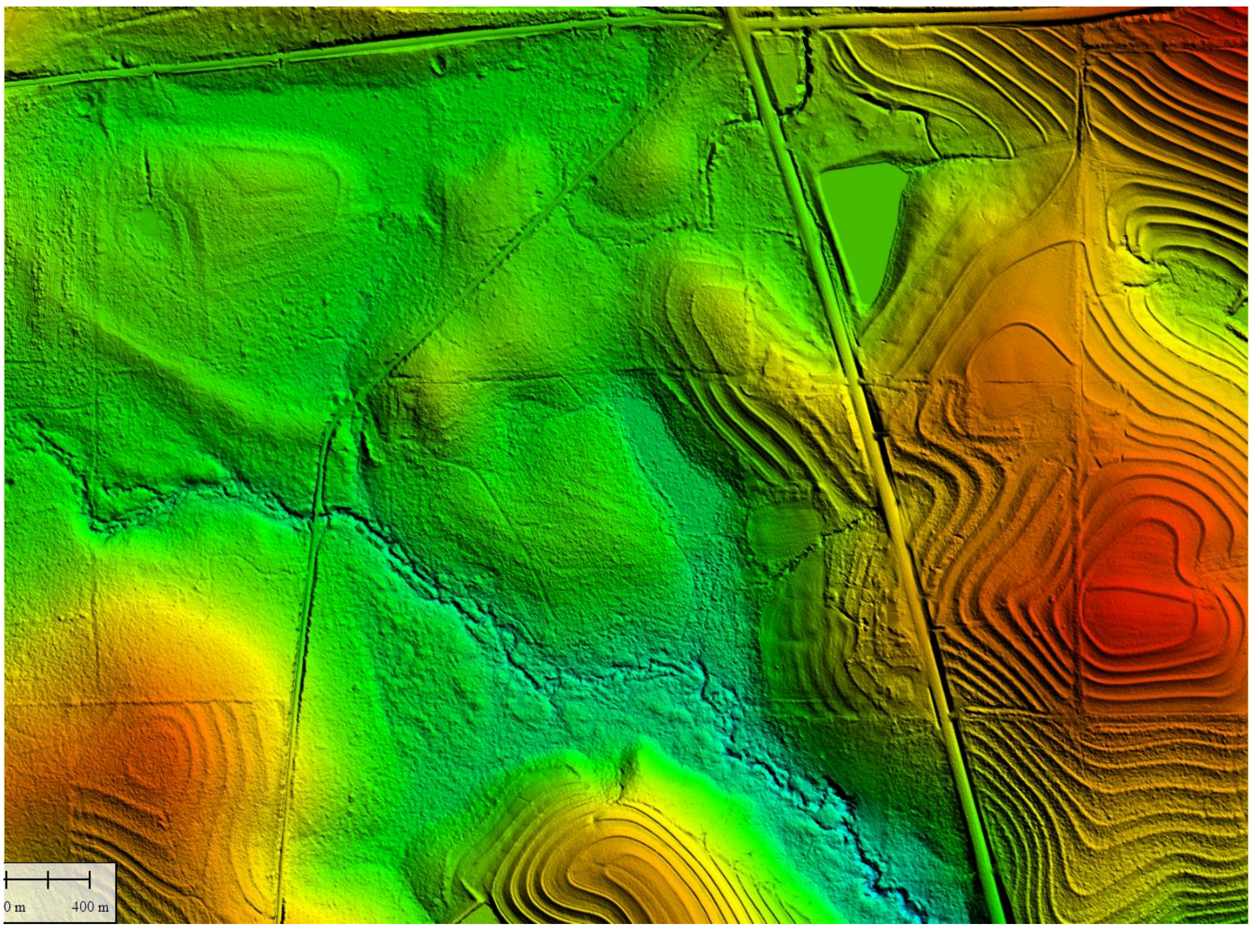

Figure 21 - Tiles 16REV985200 and 16REV985185. Example Bare earth DEM

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

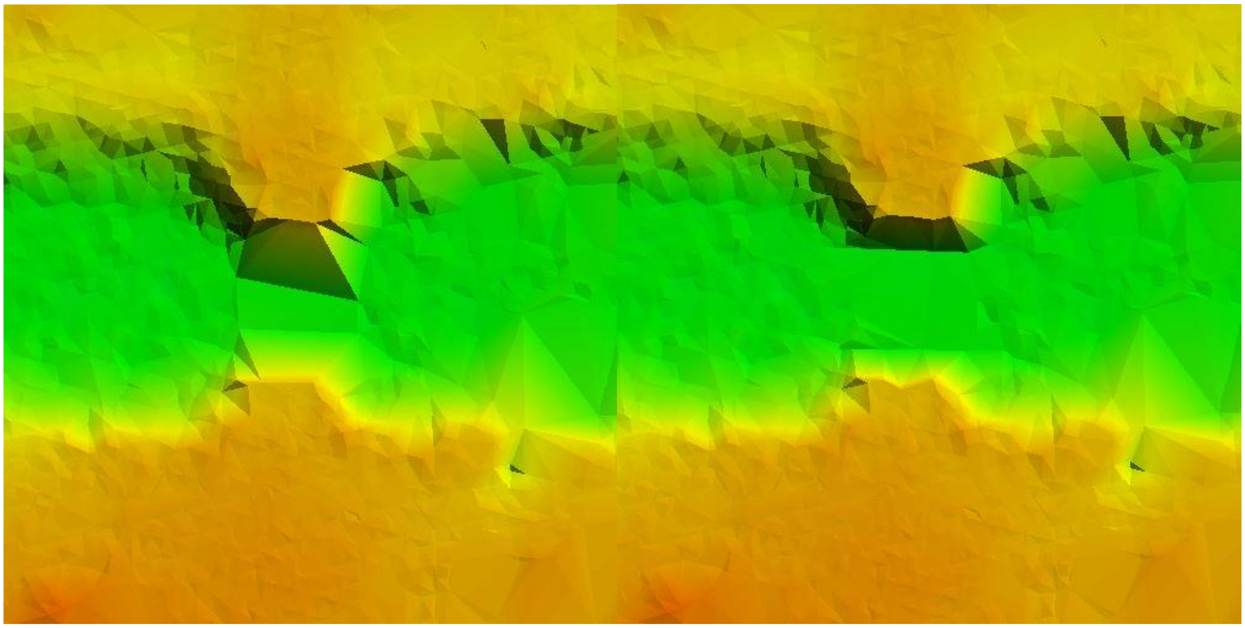

Figure 22 The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 177 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.

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 $RMSE_z$ = 4.7 cm, equating to +/- 9.3 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 14 cm at the 95th percentile.

Table 15 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)			
VVA-30	464901.182	170914.709	8.976	9.167	0.191	0.191
VVA-46	460046.241	151099.019	14.276	14.493	0.217	0.217
VVA-50	459249.880	143223.290	5.892	6.036	0.144	0.144
VVA-75	533345.626	88551.247	0.579	0.738	0.159	0.159

Table 15 — 5% Outliers

Table 16 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	100	0.047	-0.004	-0.005	-0.007	0.047	1.438	-0.161	0.147
VVA	77	N/A	0.038	0.034	0.572	0.055	1.211	-0.099	0.217

Table 16 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the FL Lower Choctawhatchee 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 17-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 101 Non-vegetated Vertical Accuracy (NVA – total number actually surveyed = 101), and 78 Vegetated Vertical Accuracy (VVA – total number actually surveyed = 78) check points for USGS in the State of Florida. A minimum of half (51) of the NVA points shall also be horizontal accuracy check points (total number actually surveyed = 51). Under the above referenced USGS 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, 52 of the NVA check points, and 40 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 Meters 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

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Professional Surveyor & Mapper
203 Aberdeen Parkway
Panama City, Florida 32405
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(850) 522-1011 fax

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*

101 Non-vegetated Check Points, and 78 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 six (6) 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 52 of the NVA check point locations, and 40 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

16REU000915	16REU000945	16REU805945	16REU805990	16REU820915	16REU820930
16REU820945	16REU820960	16REU820975	16REU820990	16REU835900	16REU835915
16REU835930	16REU835945	16REU835960	16REU835975	16REU835990	16REU850900
16REU850915	16REU850930	16REU850945	16REU850960	16REU850975	16REU850990
16REU865900	16REU865915	16REU865930	16REU865945	16REU865960	16REU865975
16REU865990	16REU880900	16REU880915	16REU880930	16REU880945	16REU880960
16REU880975	16REU880990	16REU895900	16REU895915	16REU895930	16REU895945
16REU895960	16REU895975	16REU895990	16REU910900	16REU910915	16REU910930
16REU910945	16REU910960	16REU910975	16REU910990	16REU925900	16REU925915
16REU925930	16REU925945	16REU925960	16REU925975	16REU925990	16REU940900
16REU940915	16REU940930	16REU940945	16REU940960	16REU940975	16REU940990
16REU955900	16REU955915	16REU955930	16REU955945	16REU955960	16REU955975
16REU955990	16REU970900	16REU970915	16REU970930	16REU970945	16REU970960
16REU970975	16REU970990	16REU985900	16REU985915	16REU985930	16REU985945
16REU985960	16REU985975	16REU985990	16REV000005	16REV000020	16REV000065
16REV000110	16REV000155	16REV000170	16REV000185	16REV000215	16REV000230
16REV000245	16REV000260	16REV000275	16REV805005	16REV805020	16REV805035
16REV805050	16REV820005	16REV820020	16REV820035	16REV820050	16REV820065
16REV820080	16REV820095	16REV835005	16REV835020	16REV835035	16REV835050
16REV835065	16REV835080	16REV835095	16REV835110	16REV850005	16REV850020
16REV850035	16REV850050	16REV850065	16REV850080	16REV850095	16REV850110
16REV850125	16REV865005	16REV865020	16REV865035	16REV865050	16REV865065
16REV865080	16REV865095	16REV865110	16REV865125	16REV865140	16REV865155
16REV880005	16REV880020	16REV880035	16REV880050	16REV880065	16REV880080
16REV880095	16REV880110	16REV880125	16REV880140	16REV880155	16REV895005
16REV895020	16REV895035	16REV895050	16REV895065	16REV895080	16REV895095
16REV895110	16REV895125	16REV895140	16REV895155	16REV895170	16REV910005
16REV910020	16REV910035	16REV910050	16REV910065	16REV910080	16REV910095
16REV910110	16REV910125	16REV910140	16REV910155	16REV910170	16REV910185
16REV910200	16REV910215	16REV910230	16REV910245	16REV910260	16REV910275
16REV910290	16REV925005	16REV925020	16REV925035	16REV925050	16REV925065
16REV925080	16REV925095	16REV925110	16REV925125	16REV925140	16REV925155
16REV925170	16REV925185	16REV925200	16REV925215	16REV925230	16REV925245
16REV925260	16REV925275	16REV925290	16REV940005	16REV940020	16REV940035
16REV940050	16REV940065	16REV940080	16REV940095	16REV940110	16REV940125
16REV940140	16REV940155	16REV940170	16REV940185	16REV940200	16REV940215
16REV940230	16REV940245	16REV940260	16REV940275	16REV940290	16REV955005
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16REV955290	16REV970005	16REV970020	16REV970035	16REV970050	16REV970065
16REV970080	16REV970095	16REV970110	16REV970125	16REV970140	16REV970155
16REV970170	16REV970185	16REV970200	16REV970215	16REV970230	16REV970245
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16REV985140	16REV985155	16REV985170	16REV985185	16REV985200	16REV985215
16REV985230	16REV985245	16REV985260	16REV985275	16REV985290	16RFT525000
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16RFT540910	16RFT540925	16RFT540940	16RFT540955	16RFT540970	16RFT555850
16RFT555865	16RFT555880	16RFT555895	16RFT555910	16RFT555925	16RFT570820
16RFT570835	16RFT570850	16RFT570865	16RFT585805	16RFT585820	16RFT585835
16RFT600805	16RFT600820	16RFT600835	16RFT600850	16RFT600880	16RFT600895
16RFT615835	16RFT615850	16RFT615865	16RFT615895	16RFT615985	16RFT630835
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16RFT630940	16RFT630955	16RFT630970	16RFT630985	16RFT645835	16RFT645850
16RFT645865	16RFT645880	16RFT645895	16RFT645910	16RFT645925	16RFT645940
16RFT645955	16RFT645970	16RFT645985	16RFT660835	16RFT660850	16RFT660865
16RFT660880	16RFT660895	16RFT660910	16RFT660925	16RFT660940	16RFT660955
16RFT660970	16RFT660985	16RFT675835	16RFT675850	16RFT675865	16RFT675880
16RFT675895	16RFT675910	16RFT675925	16RFT675940	16RFT675955	16RFT675970
16RFT675985	16RFT690835	16RFT690850	16RFT690865	16RFT690880	16RFT690895
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16RFT705835	16RFT705850	16RFT705865	16RFT705880	16RFT705895	16RFT705910
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16RFU045630	16RFU045645	16RFU045660	16RFU045675	16RFU045690	16RFU045705
16RFU045720	16RFU045735	16RFU045750	16RFU045765	16RFU045780	16RFU045795
16RFU045810	16RFU045825	16RFU045840	16RFU045855	16RFU045870	16RFU045885
16RFU045900	16RFU045915	16RFU045930	16RFU045945	16RFU045960	16RFU045975
16RFU045990	16RFU060420	16RFU060435	16RFU060450	16RFU060465	16RFU060480
16RFU060495	16RFU060510	16RFU060525	16RFU060540	16RFU060555	16RFU060570
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16RFU060675	16RFU060690	16RFU060705	16RFU060720	16RFU060735	16RFU060750
16RFU060765	16RFU060780	16RFU060795	16RFU060810	16RFU060825	16RFU060840
16RFU060855	16RFU060870	16RFU060885	16RFU060900	16RFU060915	16RFU060930
16RFU060945	16RFU060960	16RFU060975	16RFU060990	16RFU075420	16RFU075435
16RFU075450	16RFU075465	16RFU075480	16RFU075495	16RFU075510	16RFU075525
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16RFU075720	16RFU075735	16RFU075750	16RFU075765	16RFU075780	16RFU075795
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16RFU090750	16RFU090765	16RFU090780	16RFU090795	16RFU090810	16RFU090825
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16RFU105780	16RFU105795	16RFU105810	16RFU105825	16RFU105840	16RFU105855

16RFU105870	16RFU105885	16RFU105900	16RFU105915	16RFU105930	16RFU105945
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16RFU135675	16RFU135690	16RFU135705	16RFU135720	16RFU135735	16RFU135750
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16RFU150525	16RFU150540	16RFU150555	16RFU150570	16RFU150585	16RFU150600
16RFU150615	16RFU150630	16RFU150645	16RFU150660	16RFU150675	16RFU150690
16RFU150705	16RFU150720	16RFU150735	16RFU150750	16RFU150765	16RFU150780
16RFU150795	16RFU150810	16RFU150825	16RFU150840	16RFU150855	16RFU150870
16RFU150885	16RFU150900	16RFU150915	16RFU150930	16RFU150945	16RFU150960
16RFU150975	16RFU150990	16REU820645	16RFU165360	16REU820660	16REU835630
16RFU165375	16REU835645	16RFU165390	16REU835660	16RFU165405	16REU835675
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16REU880645	16RFU180450	16RFU180465	16RFU180510	16RFU180525	16RFU180540
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16REU940705	16RFU195825	16REU940720	16REU940735	16REU940750	16REU940765
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16REU955600	16REU955615	16REU955630	16REU955645	16RFU195900	16REU955660
16REU955675	16REU955690	16REU955705	16REU955720	16REU955735	16RFU195915
16REU955750	16REU955765	16REU955780	16REU955795	16REU955810	16REU955825
16RFU195930	16REU955840	16REU955855	16REU955870	16REU955885	16RFU195945
16REU970480	16REU970495	16REU970510	16RFU195960	16REU970525	16REU970540
16REU970555	16REU970570	16REU970585	16RFU195975	16REU970600	16REU970615
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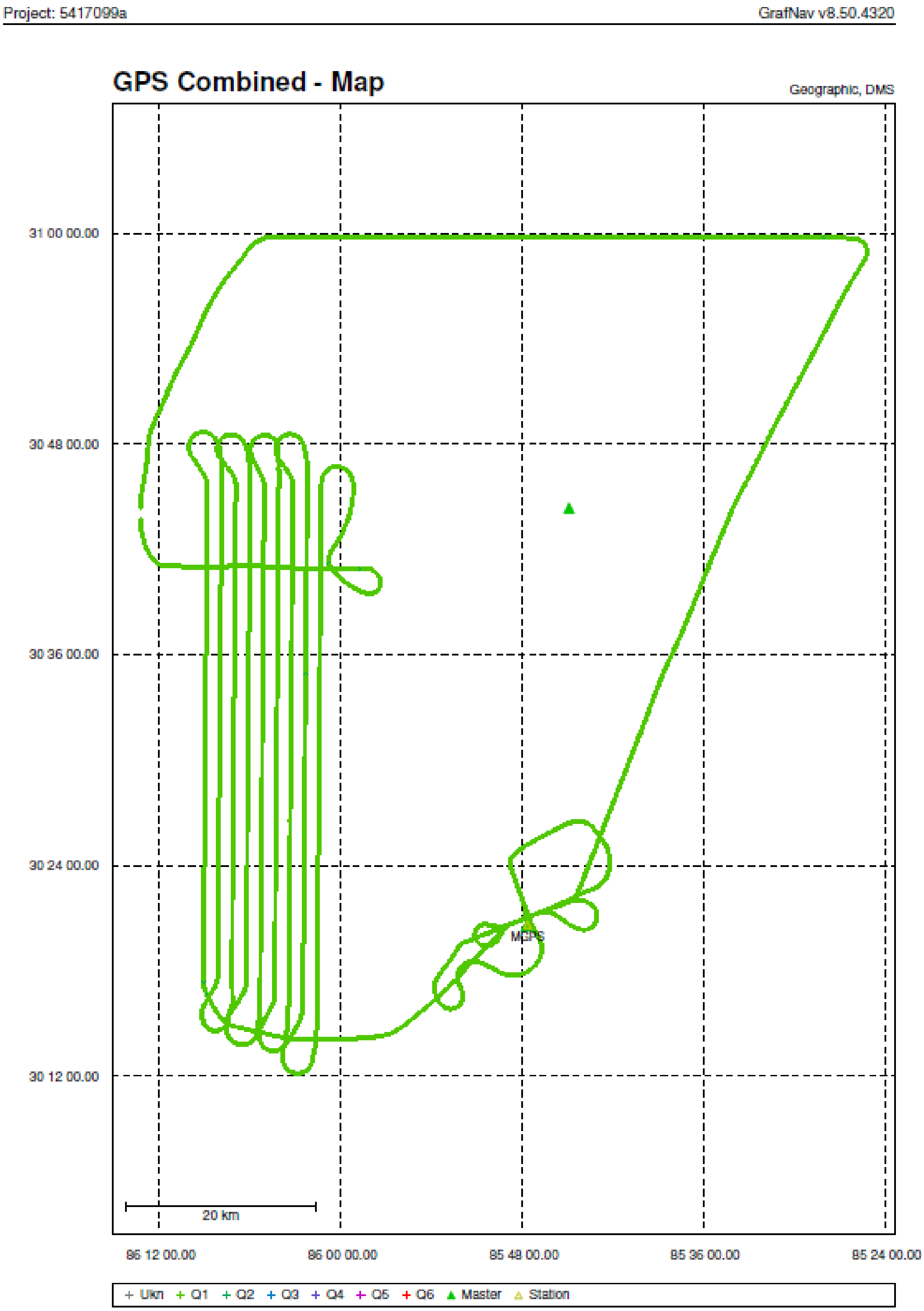
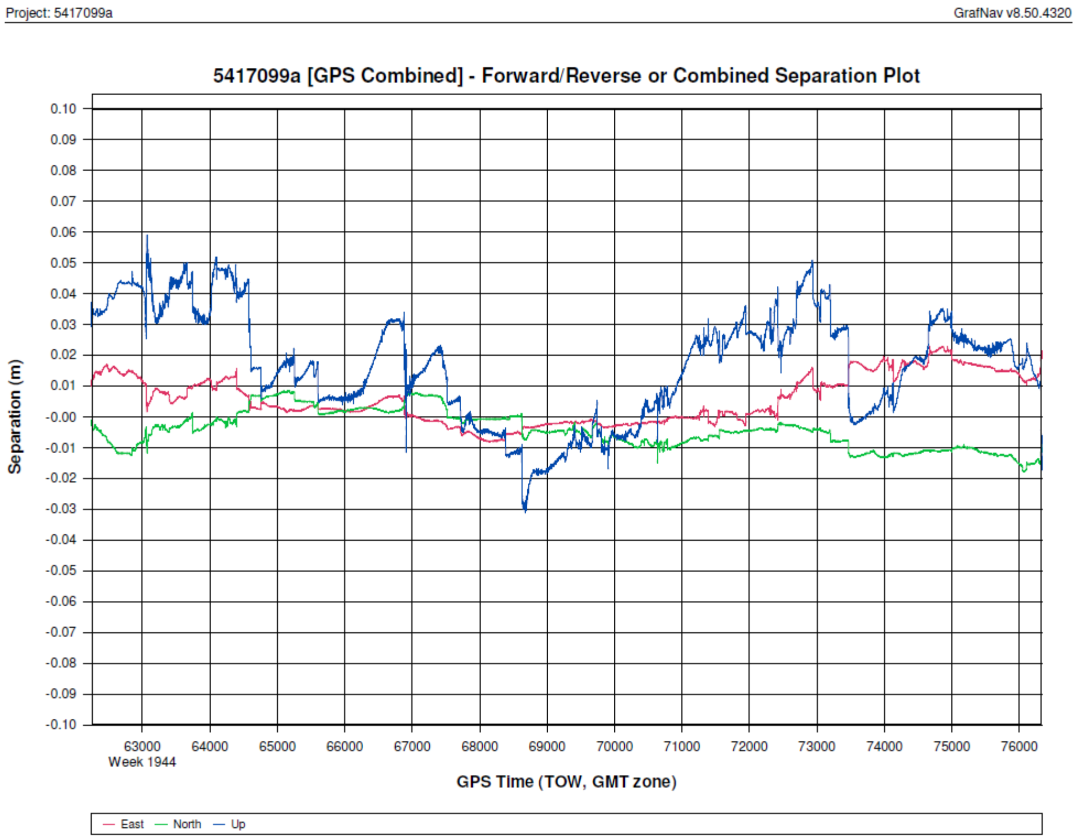
16RFV345215	16RFV345230	16RFV345245	16RFV345260	16RFV345275	16RFV345290
16RFV360005	16RFV360020	16RFV360035	16RFV360050	16RFV360065	16RFV360080
16RFV360095	16RFV360110	16RFV360125	16RFV360140	16RFV360155	16RFV360170
16RFV360185	16RFV360200	16RFV360215	16RFV360230	16RFV360245	16RFV360260
16RFV360275	16RFV360290	16RFV375005	16RFV375020	16RFV375035	16RFV375050
16RFV375065	16RFV375080	16RFV375095	16RFV375110	16RFV375125	16RFV375140
16RFV375155	16RFV375170	16RFV375185	16RFV375200	16RFV375215	16RFV375230
16RFV375245	16RFV375260	16RFV375275	16RFV375290	16RFV390005	16RFV390020
16RFV390035	16RFV390050	16RFV390065	16RFV390080	16RFV390095	16RFV390110
16RFV390125	16RFV390140	16RFV390155	16RFV390170	16RFV390185	16RFV390200
16RFV390215	16RFV390230	16RFV390245	16RFV390260	16RFV390275	16RFV390290
16RFV405005	16RFV405020	16RFV405035	16RFV405050	16RFV405065	16RFV405080
16RFV405095	16RFV405110	16RFV405125	16RFV405140	16RFV405155	16RFV405170
16RFV405185	16RFV405200	16RFV405215	16RFV405230	16RFV405245	16RFV405260
16RFV405275	16RFV405290	16RFV420005	16RFV420020	16RFV420035	16RFV420050
16RFV420065	16RFV420080	16RFV420095	16RFV420110	16RFV420125	16RFV420140
16RFV420155	16RFV420170	16RFV420185	16RFV420200	16RFV420215	16RFV420230
16RFV420245	16RFV420260	16RFV420275	16RFV420290	16RFV435005	16RFV435020
16RFV435035	16RFV435050	16RFV435065	16RFV435080	16RFV435095	16RFV435110
16RFV435125	16RFV435140	16RFV435155	16RFV435170	16RFV435185	16RFV435200
16RFV435215	16RFV435230	16RFV435245	16RFV435260	16RFV435275	16RFV435290
16RFV450005	16RFV450020	16RFV450035	16RFV450050	16RFV450065	16RFV450080
16RFV450095	16RFV450110	16RFV450125	16RFV450140	16RFV450155	16RFV450170
16RFV450185	16RFV450200	16RFV450215	16RFV450230	16RFV450245	16RFV450260
16RFV450275	16RFV450290	16RFV465005	16RFV465020	16RFV465035	16RFV465050
16RFV465065	16RFV465080	16RFV465095	16RFV465110	16RFV465125	16RFV465140
16RFV465155	16RFV465170	16RFV465185	16RFV465200	16RFV465215	16RFV465230
16RFV465245	16RFV480005	16RFV480020	16RFV480035	16RFV480050	16RFV480065
16RFV480080	16RFV480095	16RFV480110	16RFV480125	16RFV480140	16RFV480155
16RFV480170	16RFV480185	16RFV480200	16RFV480215	16RFV480230	16RFV495005
16RFV495020	16RFV495035	16RFV495050	16RFV495065	16RFV495080	16RFV495095

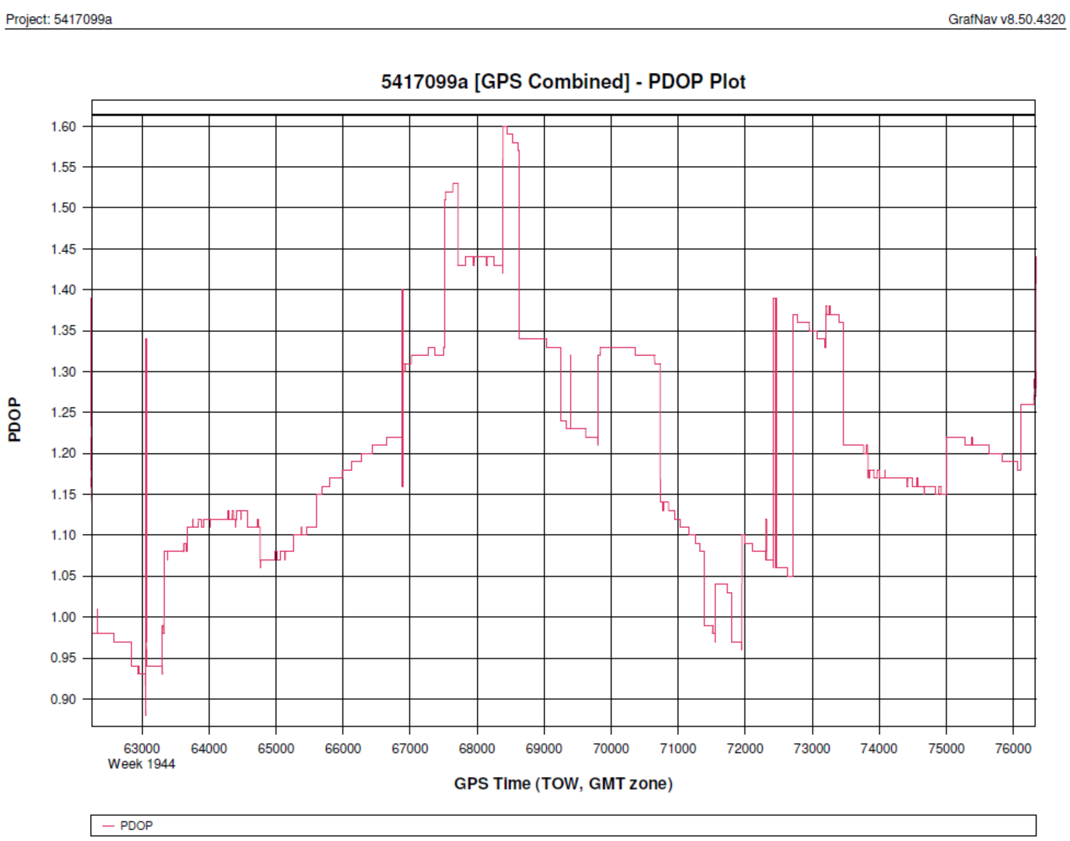
16RFV495110 16RFV495125 16RFV495140 16RFV495155 16RFV495170 16RFV495185
16RFV495200 16RFV495215 16RFV495230 16RFV510020 16RFV510035 16RFV510050
16RFV510065 16RFV510080 16RFV510095 16RFV510110 16RFV510125 16RFV510140
16RFV510155 16RFV510170 16RFV525050 16RFV525065 16RFV525080 16RFV525095
16RFV165215 16RFV165230 16RFV165245 16RFV165260 16RFV165275 16RFV165290
16REU000495 16REU000540 16REU000585 16REU000690 16REU000780 16REU865840
16REU940780 16RFT525925 16RFT540985 16RFT585850 16RFT615880 16RFT735865
16RFT915985 16RFU405165 16RFU540000 16RFU570570 16RFU585810 16RFU885090
16RFV525125 16REU895810 16REV790035 16REV820110 16REV880170 16RFT810925
16RFU135495 16RFU195450 16RFU210465 16RFU255360 16RFU420285 16RFU435255
16RFU435270 16RFU450135 16REU580600 16REU580615 16REU580630 16REU595600
16REU595615 16REU610600 16REU610615 16REU625585 16REU625600 16REU625615
16REU640585 16REU640600 16REU640615 16REU640630 16REU640645 16REU655585
16REU655600 16REU655615 16REU655630 16REU655645 16REU670585 16REU670600
16REU670615 16REU670630 16REU685570 16REU685585 16REU685600 16REU685615
16REU685630 16REU700570 16REU700585 16REU700600 16REU700615 16REU700630
16REU700645 16REU700660 16REU715570 16REU715585 16REU715600 16REU715615
16REU715630 16REU715645 16REU715660 16REU730570 16REU730585 16REU730615
16REU730630 16REU730645 16REU730660 16REU745555 16REU745570 16REU745585
16REU745600 16REU745615 16REU745630 16REU745645 16REU760555 16REU760570
16REU760585 16REU760600 16REU760615 16REU760630 16REU775555 16REU775570
16REU775585 16REU775600 16REU775615 16REU790540 16REU790555 16REU790570
16REU790585 16REU790600 16REU790615 16REU790630 16REU805540 16REU805555
16REU805570 16REU805585 16REU805600 16REU820540 16REU820555 16REU820570
16REU820585 16REU820600 16REU835525 16REU835540 16REU835555 16REU835570
16REU835585 16REU835600 16REU835615 16REU850525 16REU850540 16REU850555
16REU850570 16REU850585 16REU850600 16REU850615 16REU865510 16REU865525
16REU865540 16REU865555 16REU865570 16REU865585 16REU865600 16REU865615
16REU880510 16REU880525 16REU880540 16REU880555 16REU880570 16REU880585
16REU880600 16REU895510 16REU895525 16REU895540 16REU895555 16REU895570
16REU895585 16REU910495 16REU910510 16REU910525 16REU910540 16REU910555
16REU910570 16REU925495 16REU925510 16REU925525 16REU925540 16REU925555
16REU925570 16REU940495 16REU940510 16REU940525 16REU940540 16REU940555
16REU940570 16REU955480 16REU955495 16REU955510 16REU955525 16REU955540
16REU955555 16REU955570 16REU730600 16REU565600 16REU565615 16REU565630
16REU940480

Appendix C: GPS Processing

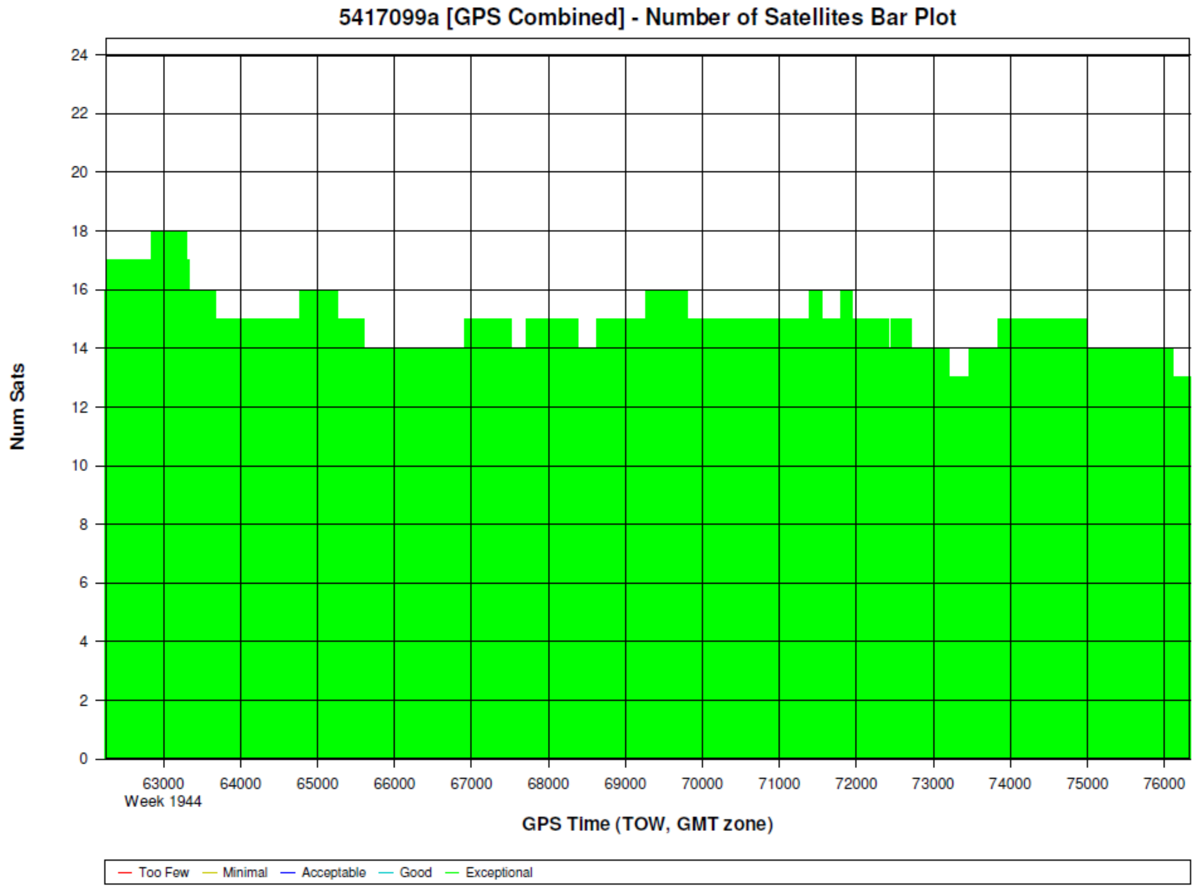
MISSION 1 – 5417099A GNSS PROCESSING




Project: 5417099a
GrafNav v8.50.4320
5417099a [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
63000
Week 1944
64000
65000
66000
67000
68000
69000
70000
71000
72000
73000
74000
75000
76000
GPS Time (TOW, GMT zone)
East
North
Up


Project: 5417099a
GrafNav v8.50.4320
5417099a [GPS Combined] - PDOP Plot
PDOP
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
63000
Week 1944
64000
65000
66000
67000
68000
69000
70000
71000
72000
73000
74000
75000
76000
GPS Time (TOW, GMT zone)
PDOP

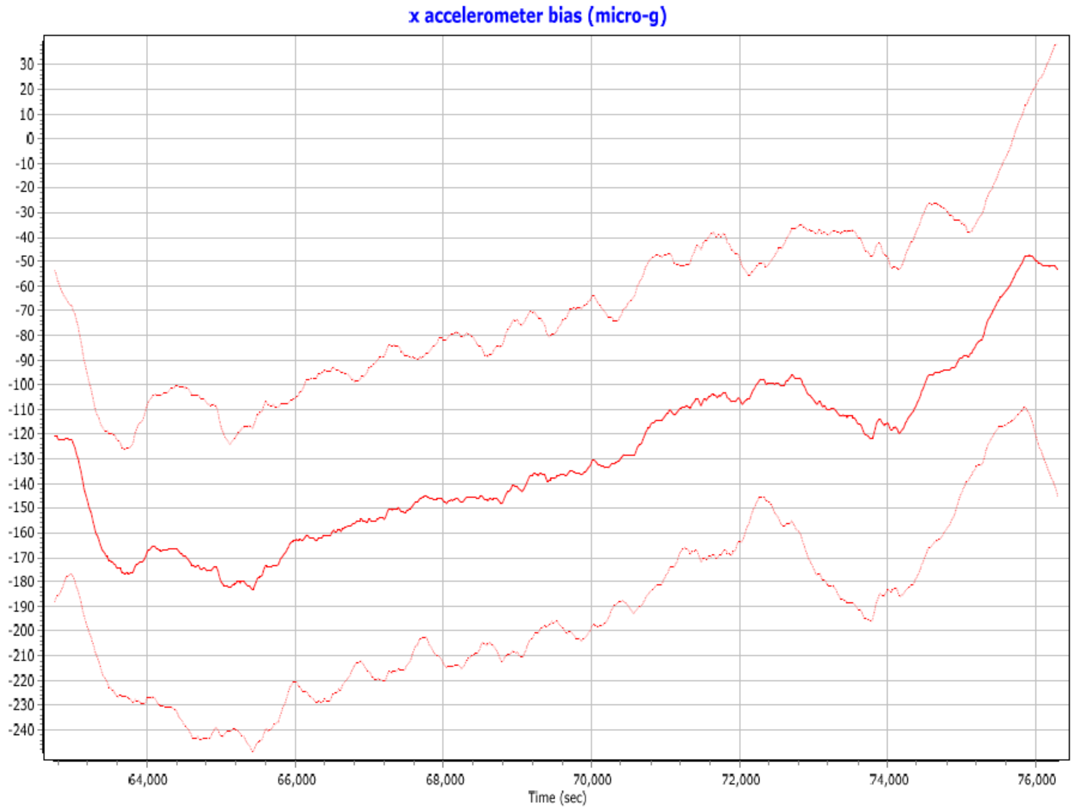
Project: 5417099a GrafNav v8.50.4320

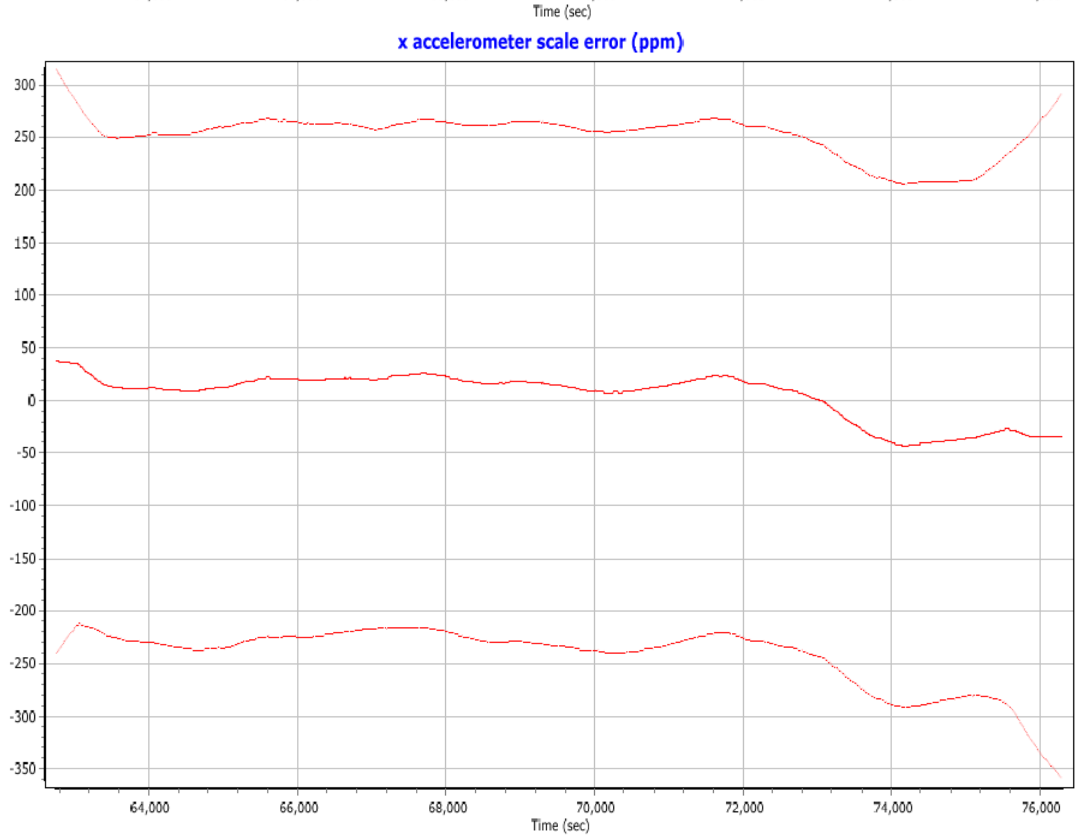


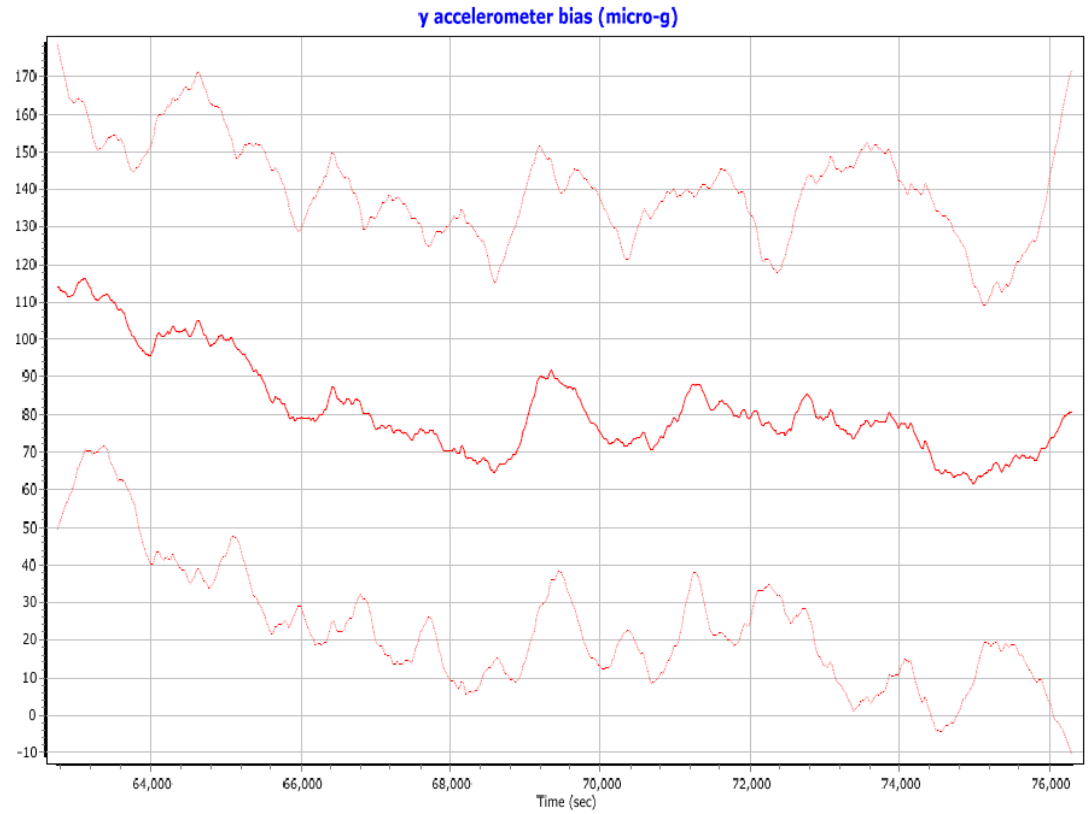

```
      Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417099a\05_INS-
GPS_PROC\01_POS\5417099a\5417099a\GNSS\5417099a.gnv
Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      14104
      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:    0.0185 (m)
      C/A Code:    0.78  (m)
      L1 Doppler: 0.037  (m/s)

Fwd/Rev Separation RMS Values:
      East:        0.010  (m)
      North:       0.007  (m)
```

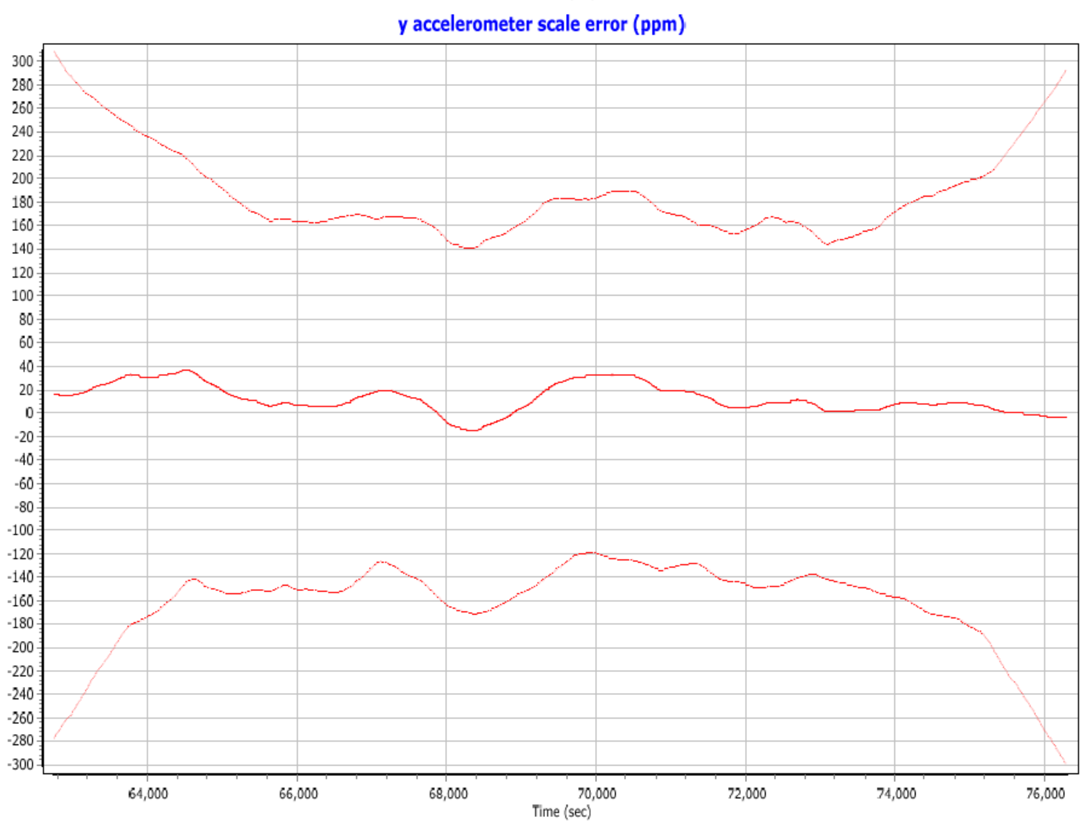
```
      Height:     0.024 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (14099 occurances):
      East:       0.010 (m)
      North:      0.007 (m)
      Height:     0.024 (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:          60.048 (km)
      Minimum:          0.213 (km)
      Average:          33.575 (km)
      First Epoch:      21.483 (km)
      Last Epoch:       0.213 (km)
```

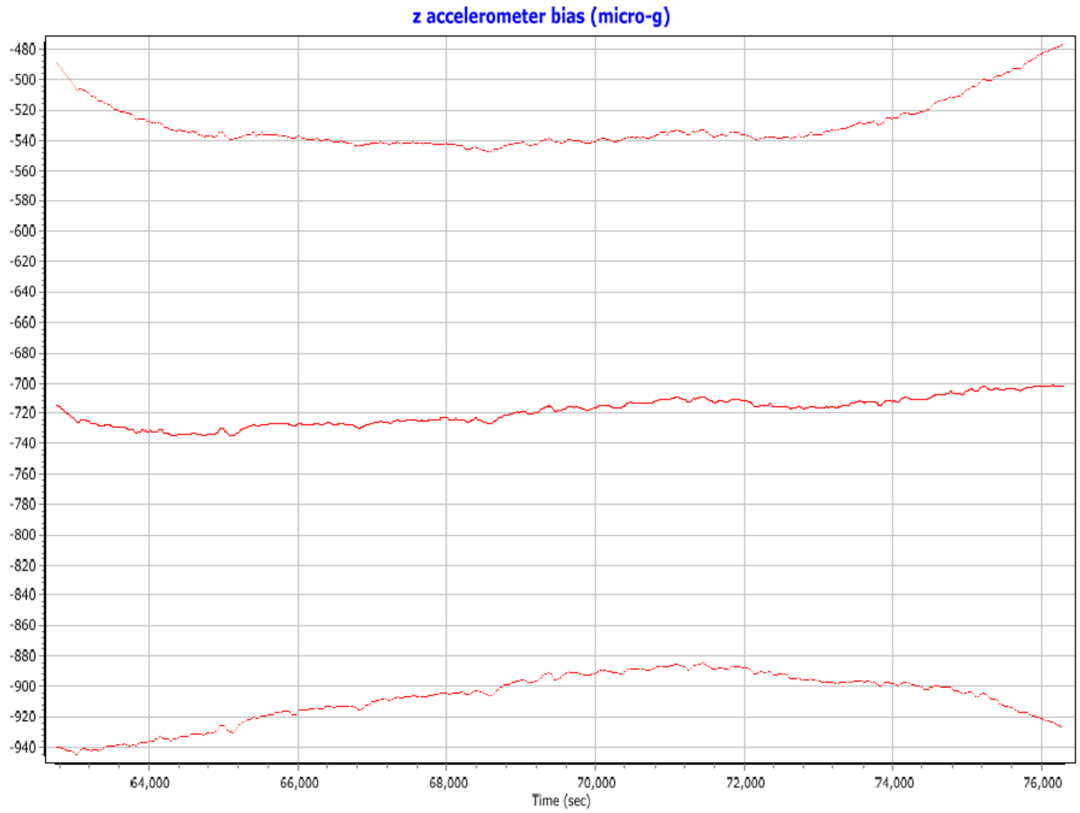
MISSION 1 – 5417099A SENSOR ERRORS

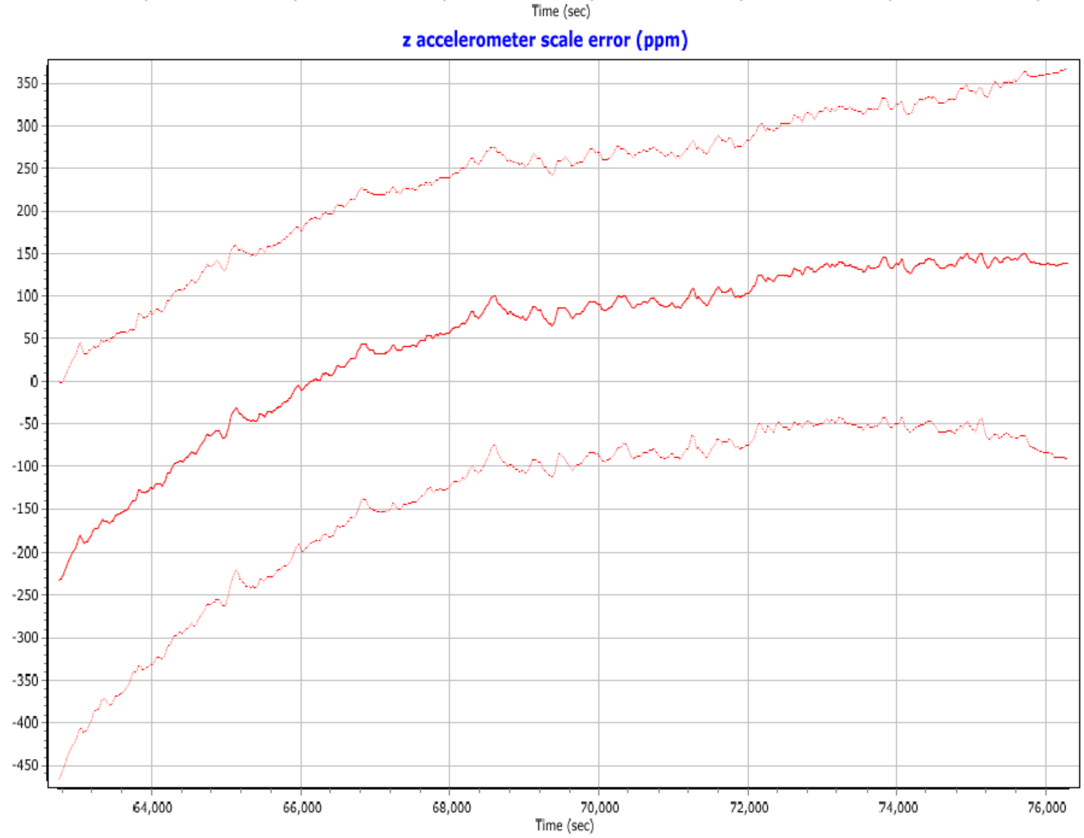


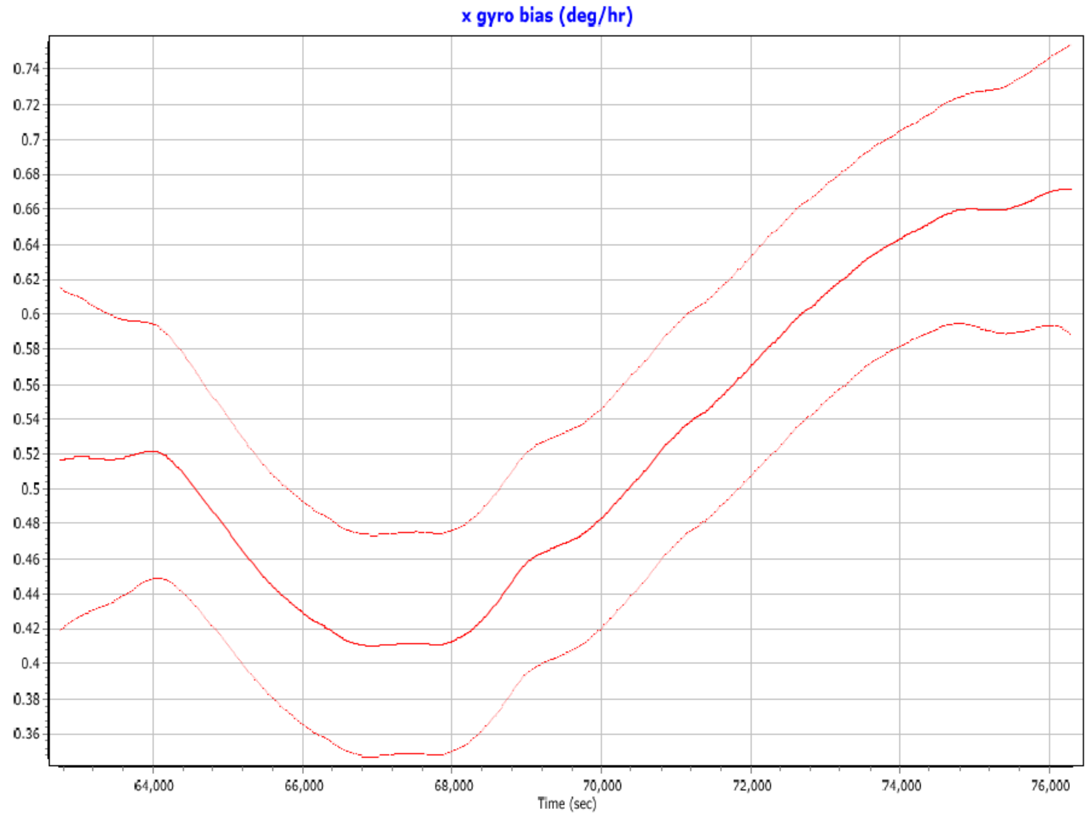


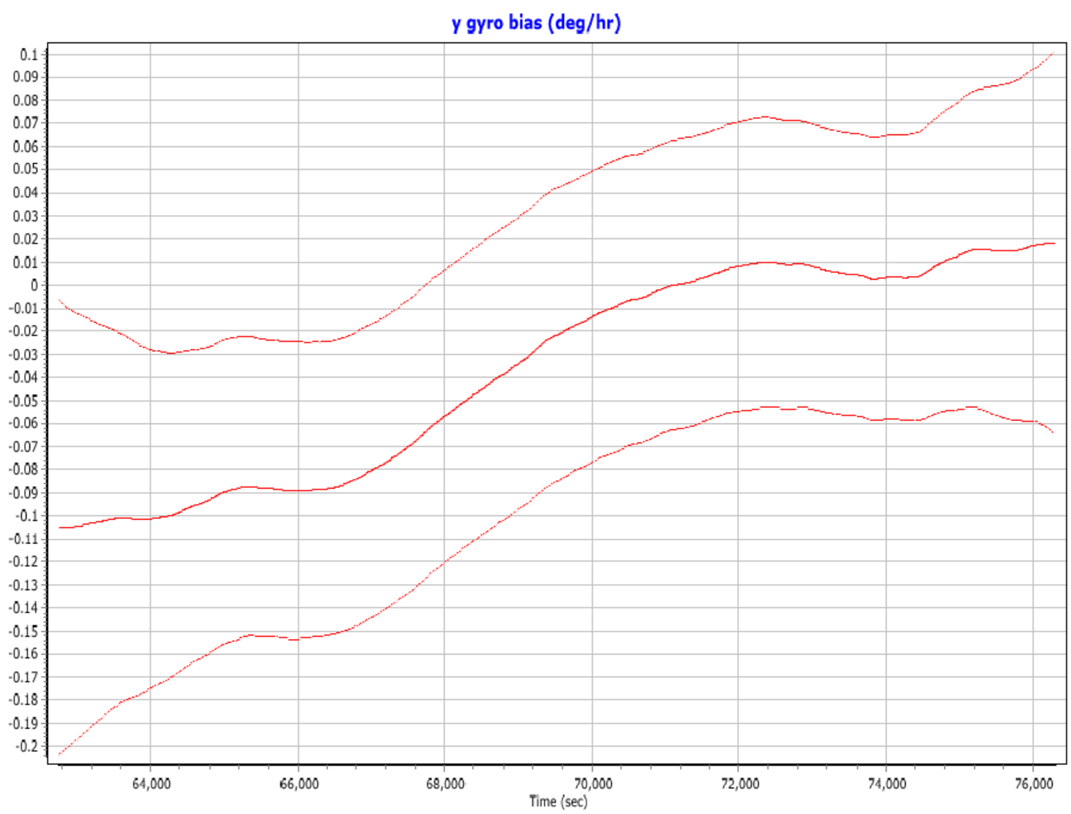

y accelerometer bias (micro-g)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)


y accelerometer scale error (ppm)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
-300
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)


z accelerometer bias (micro-g)
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
-920
-940
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)

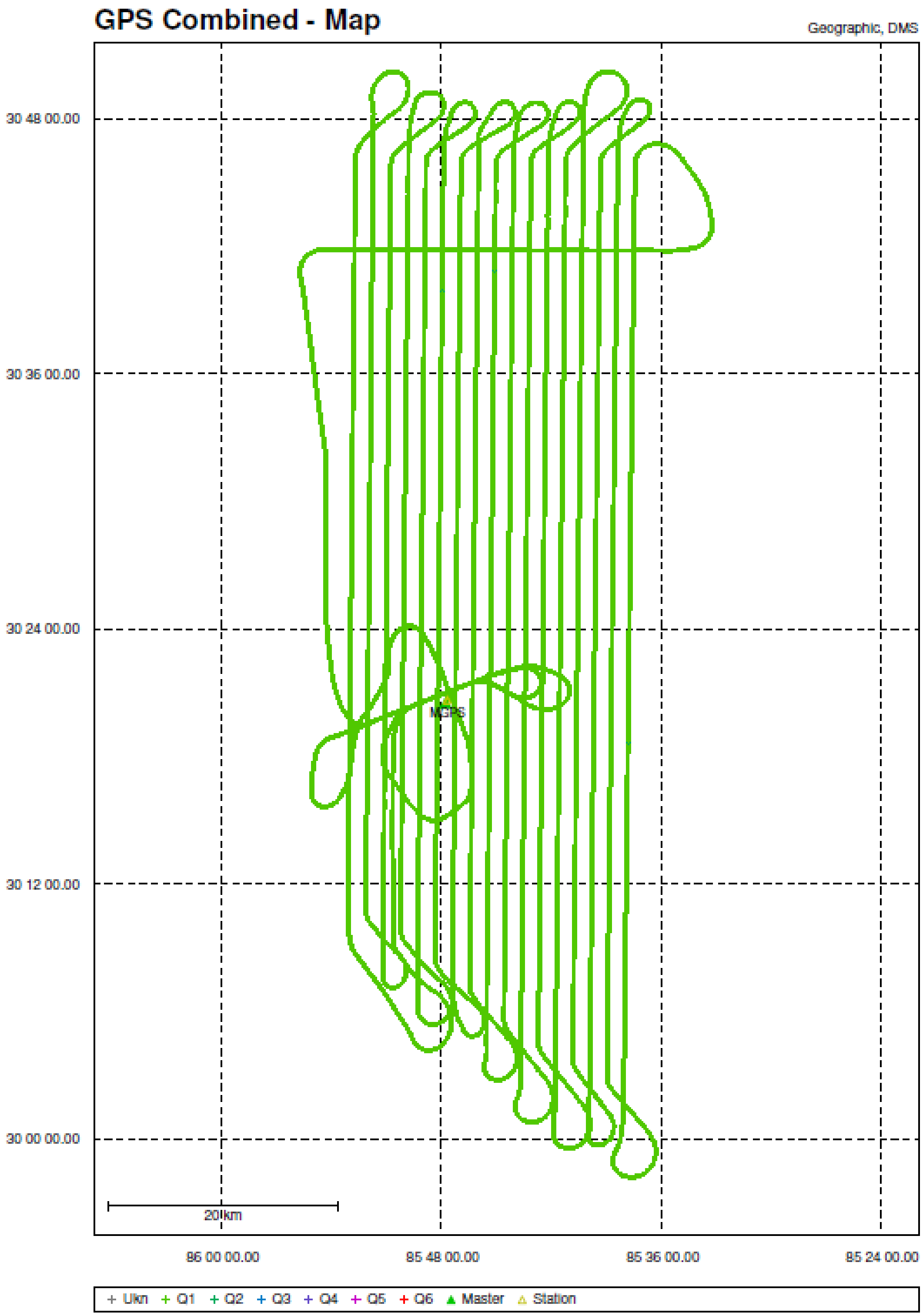

z accelerometer scale error (ppm)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)



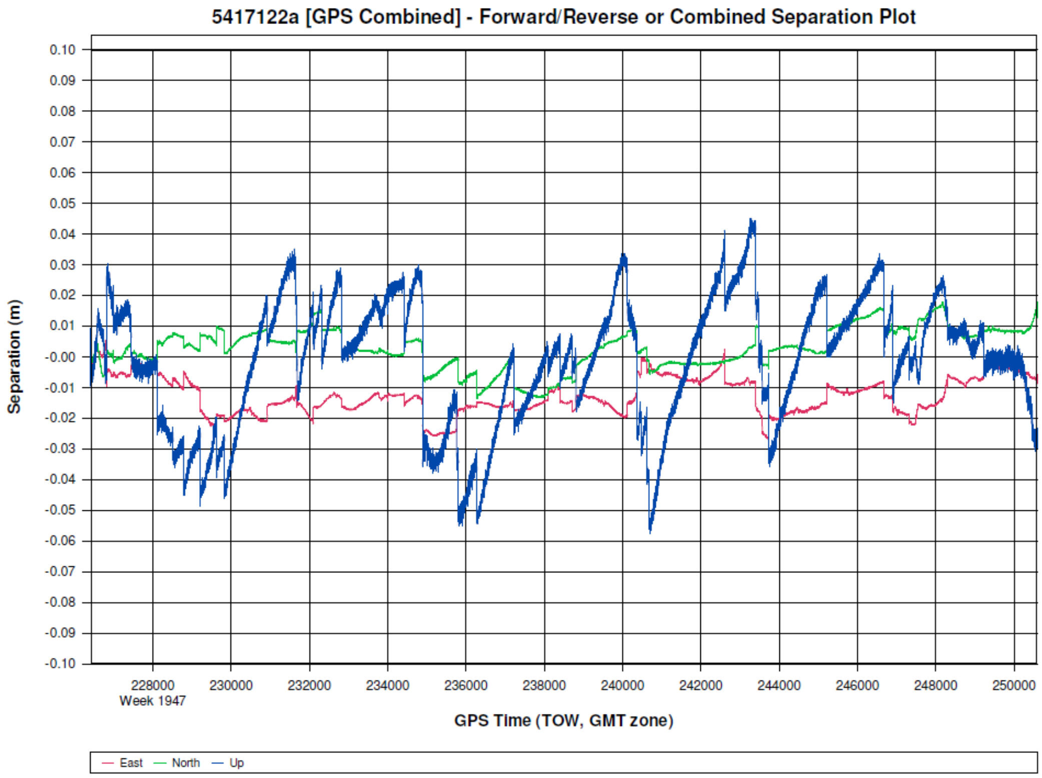


MISSION 2 – 5417122A GNSS PROCESSING

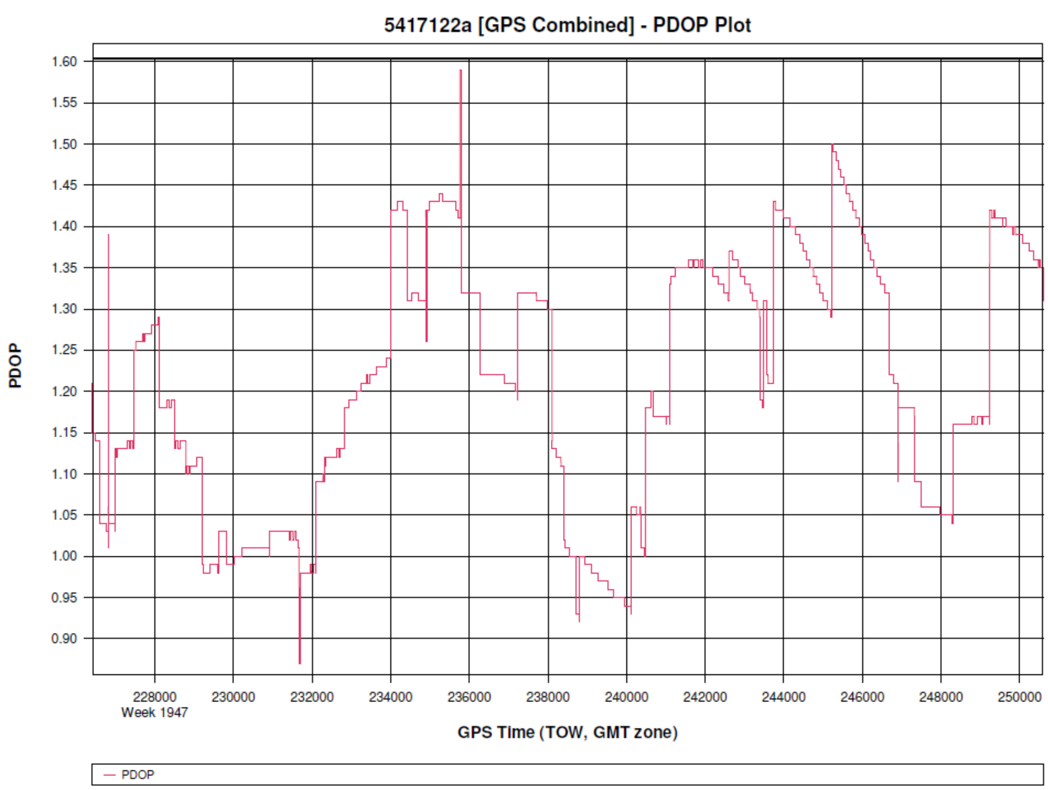
Project: 5417122a GrafNav v8.50.4320



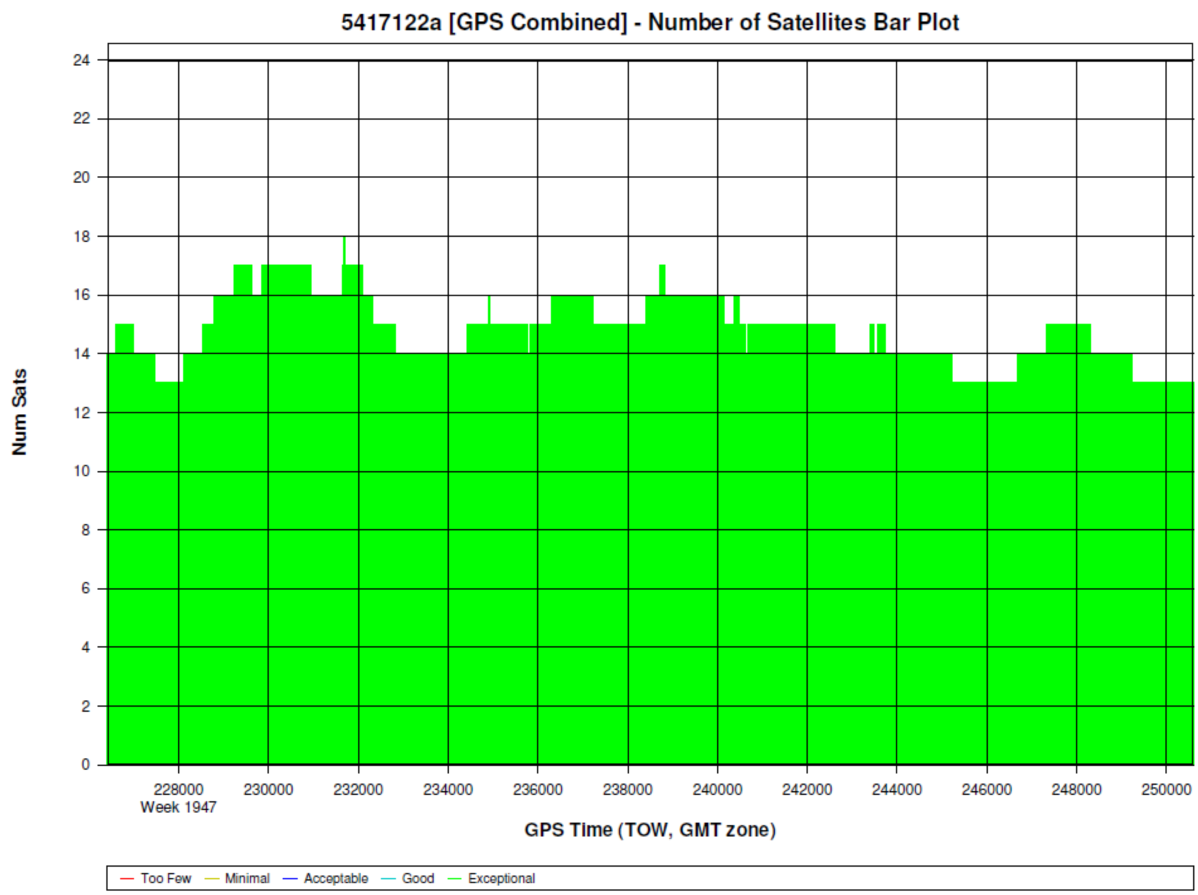
Project: 5417122a GrafNav v8.50.4320



Project: 5417122a GrafNav v8.50.4320



Project: 5417122a GrafNav v8.50.4320



Processing Summary Information

Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417122a\05_INS-GPS_PROC\01_POS\5417122a\5417122a\GNSS\5417122a.gnv

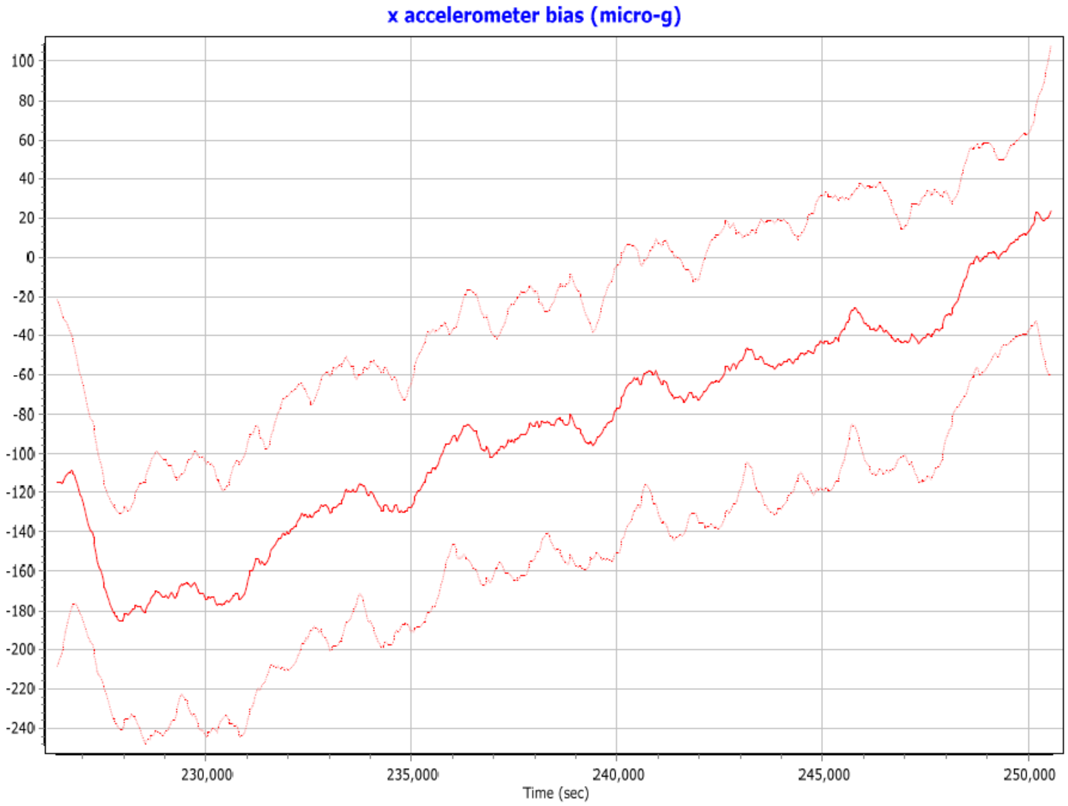
Solution Type: Combined

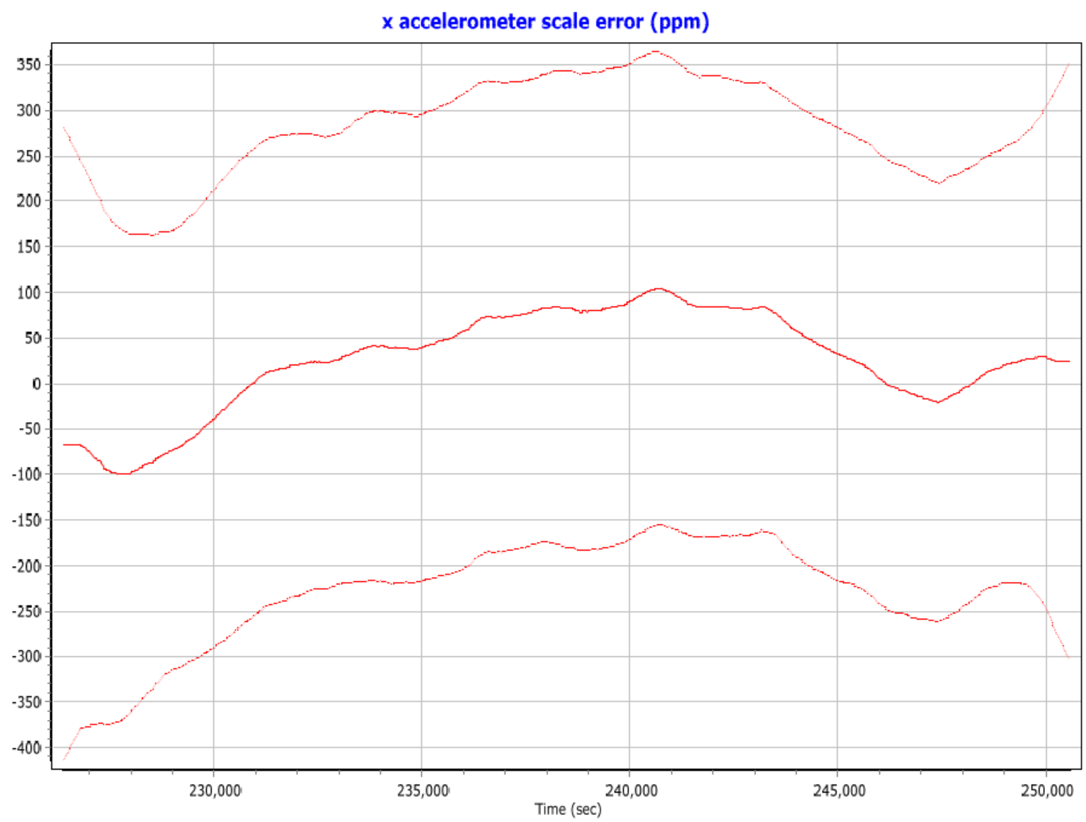
Number of Epochs:
- Total in GPB file: 24210
- No processed position: 0
- Missing Fwd or Rev: 5
- With bad C/A code: 0
- With bad L1 Phase: 0

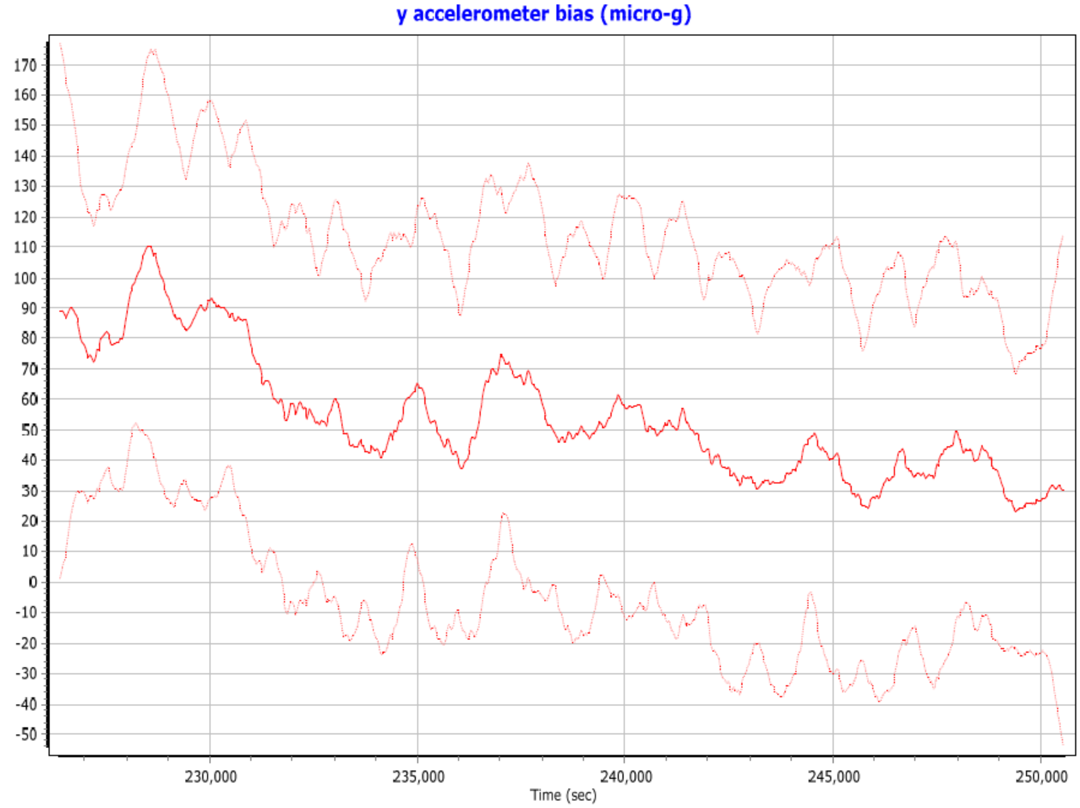
Measurement RMS Values:
- L1 Phase: 0.0210 (m)
- C/A Code: 0.74 (m)
- L1 Doppler: 0.806 (m/s)

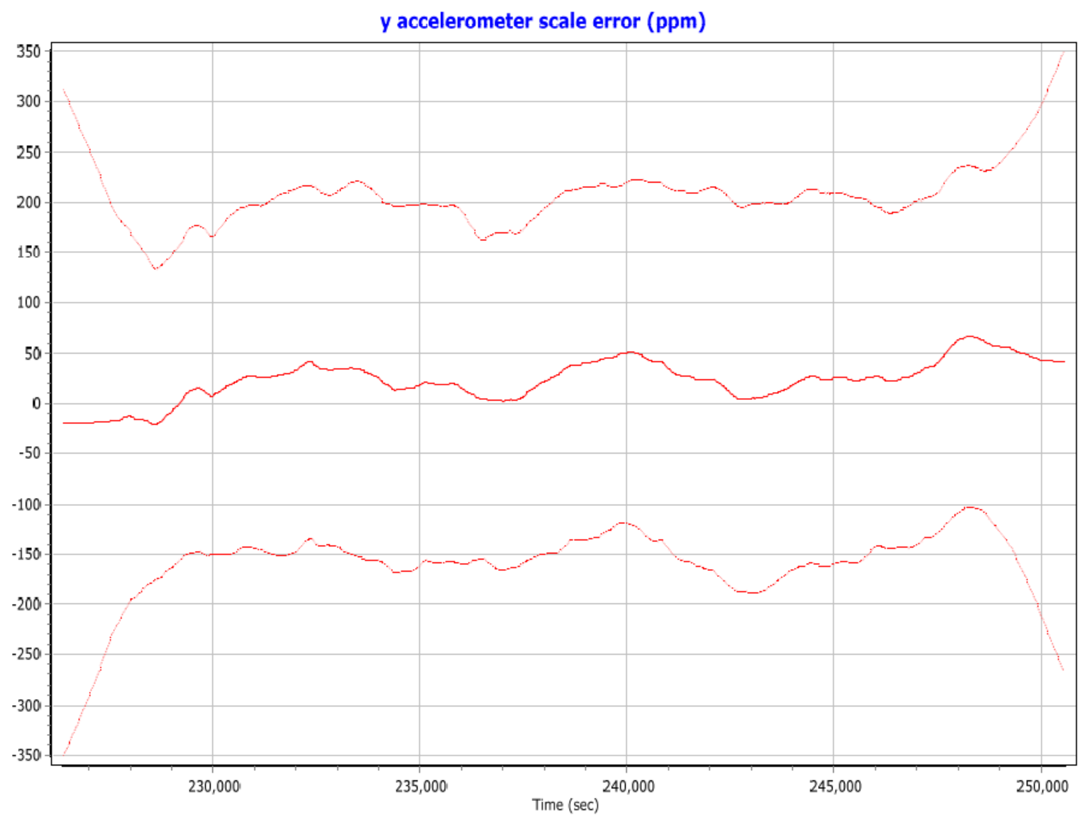
```
Fwd/Rev Separation RMS Values:
      East:        0.014 (m)
      North:       0.007 (m)
      Height:      0.021 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (24205 occurances):
      East:        0.014 (m)
      North:       0.007 (m)
      Height:      0.021 (m)

Quality Number Percentages:
      Q 1:  100.0 %
      Q 2:    0.0 %
      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:          56.740 (km)
      Minimum:          0.257 (km)
      Average:          23.396 (km)
      First Epoch:      0.327 (km)
      Last Epoch:       0.263 (km)
```

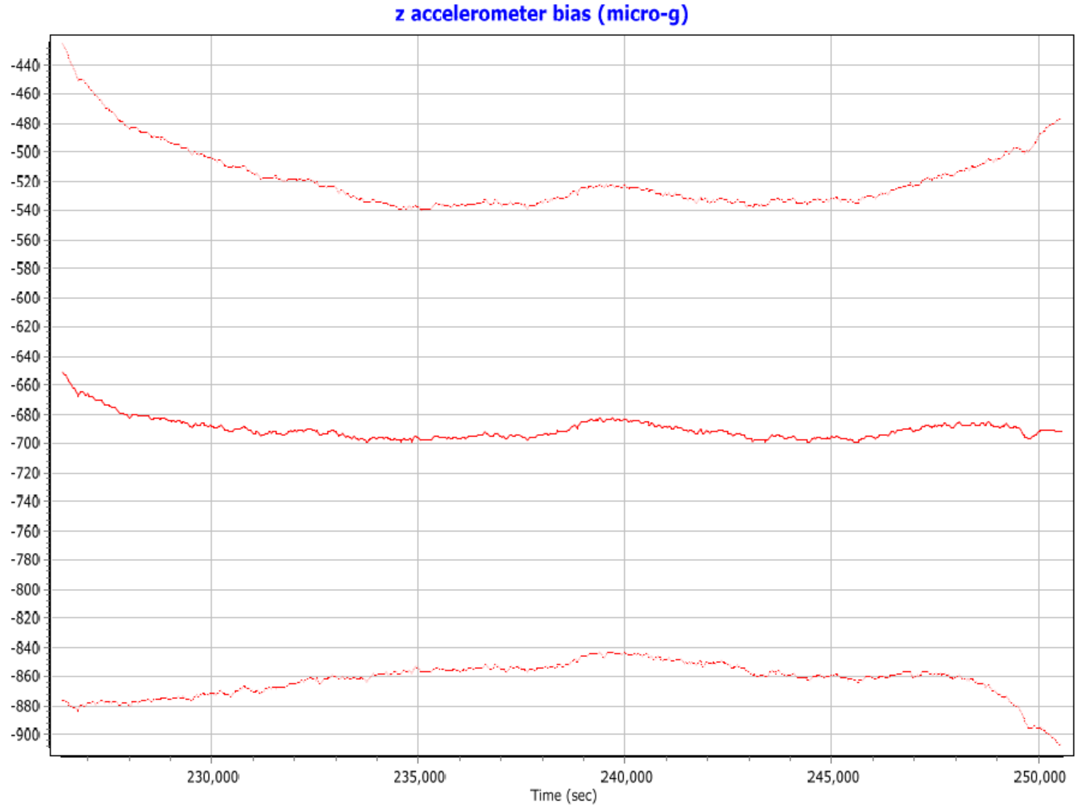
MISSION 2 – 5417122A SENSOR ERRORS

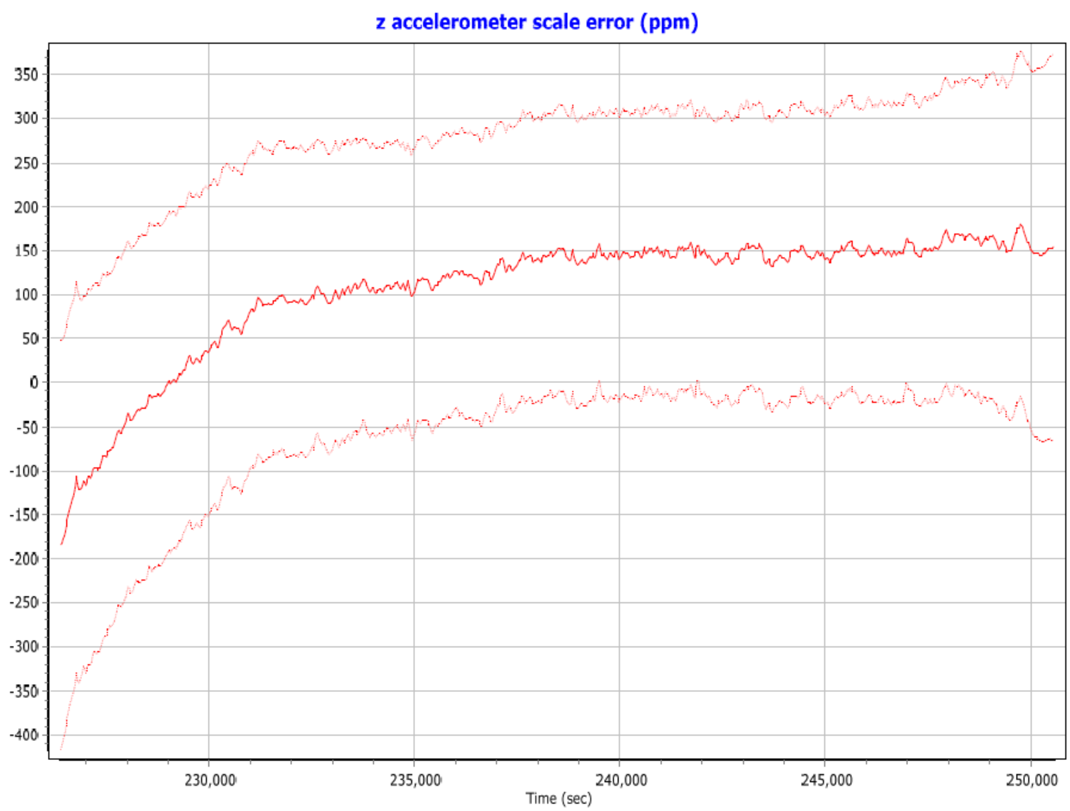

x accelerometer bias (micro-g)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
230,000
235,000
240,000
245,000
250,000
Time (sec)

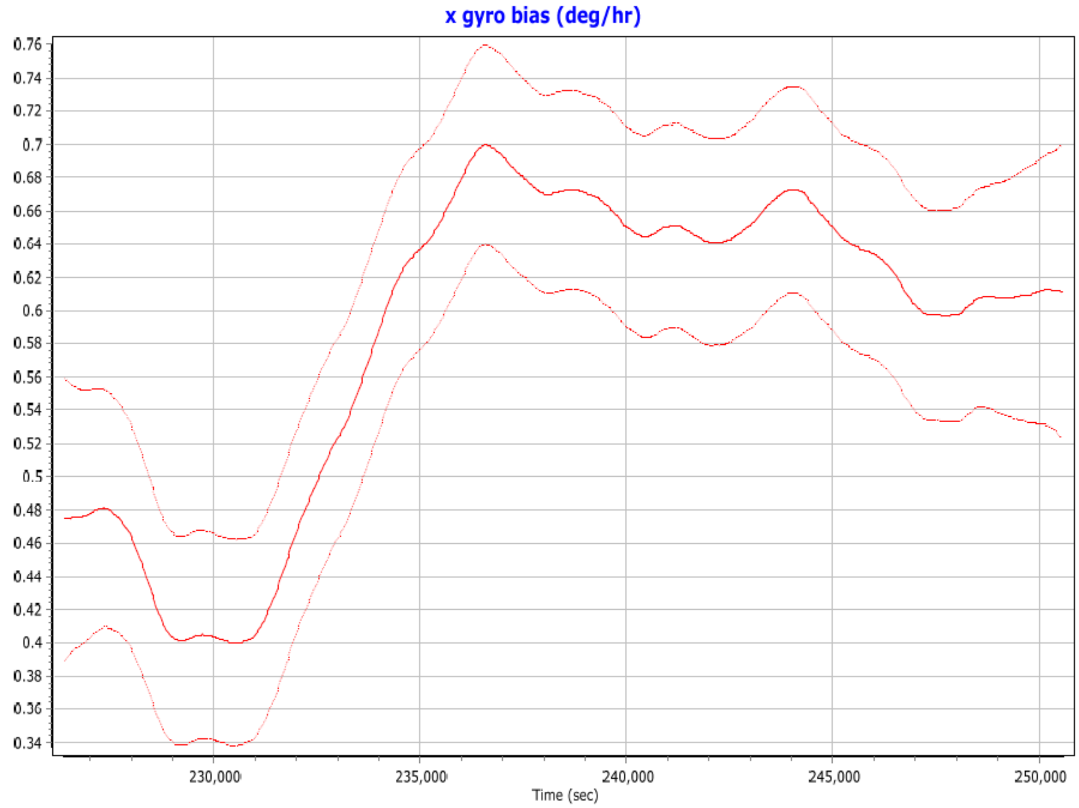

x accelerometer scale error (ppm)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
230,000
235,000
240,000
245,000
250,000
Time (sec)

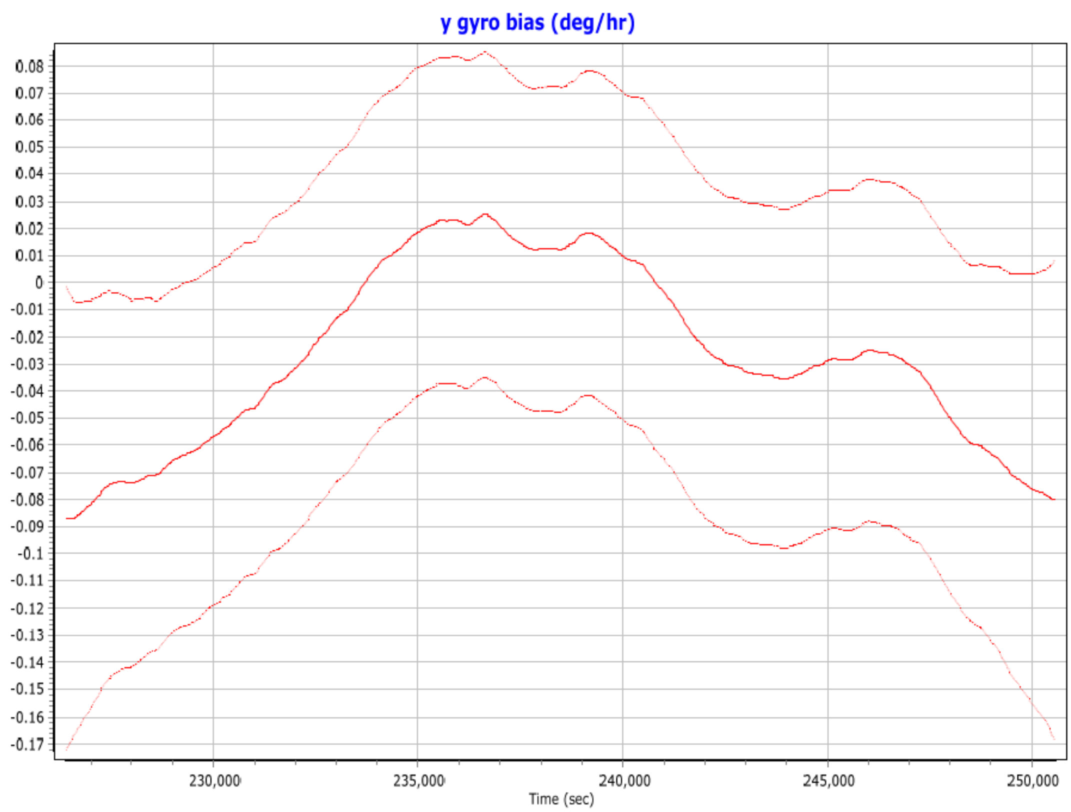

y accelerometer bias (micro-g)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
230,000
235,000
240,000
245,000
250,000
Time (sec)

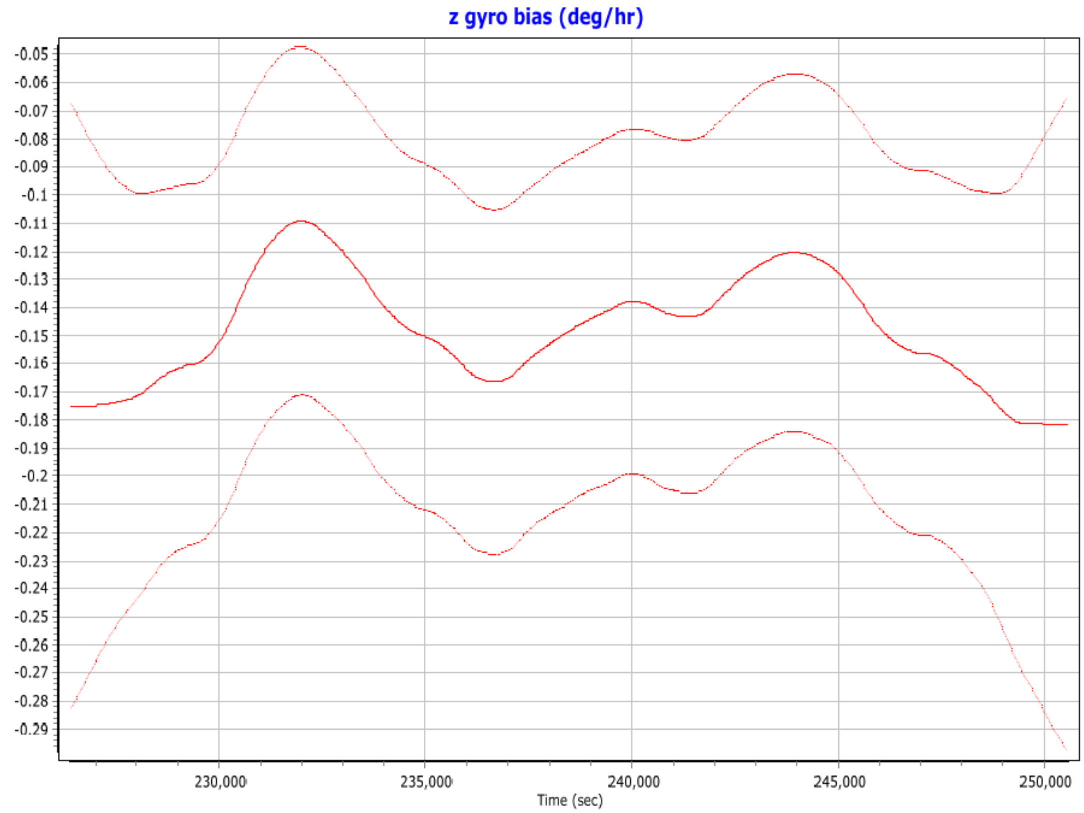

y accelerometer scale error (ppm)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
230,000
235,000
240,000
245,000
250,000
Time (sec)


z accelerometer bias (micro-g)
-440
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
230,000
235,000
240,000
245,000
250,000
Time (sec)


z accelerometer scale error (ppm)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
230,000
235,000
240,000
245,000
250,000
Time (sec)


x gyro bias (deg/hr)
0.76
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
230,000
235,000
240,000
245,000
250,000
Time (sec)

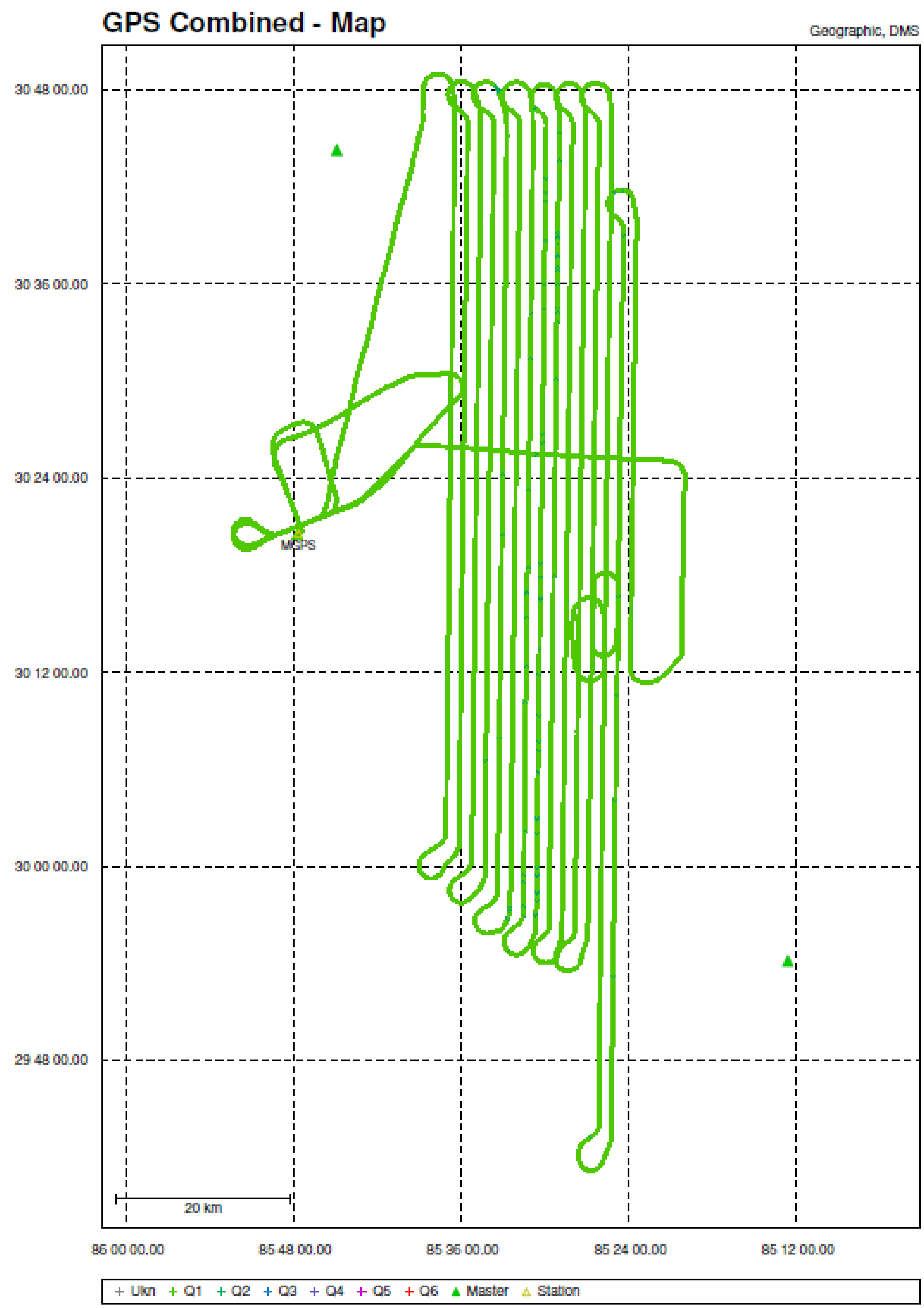

y gyro bias (deg/hr)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
230,000
235,000
240,000
245,000
250,000
Time (sec)

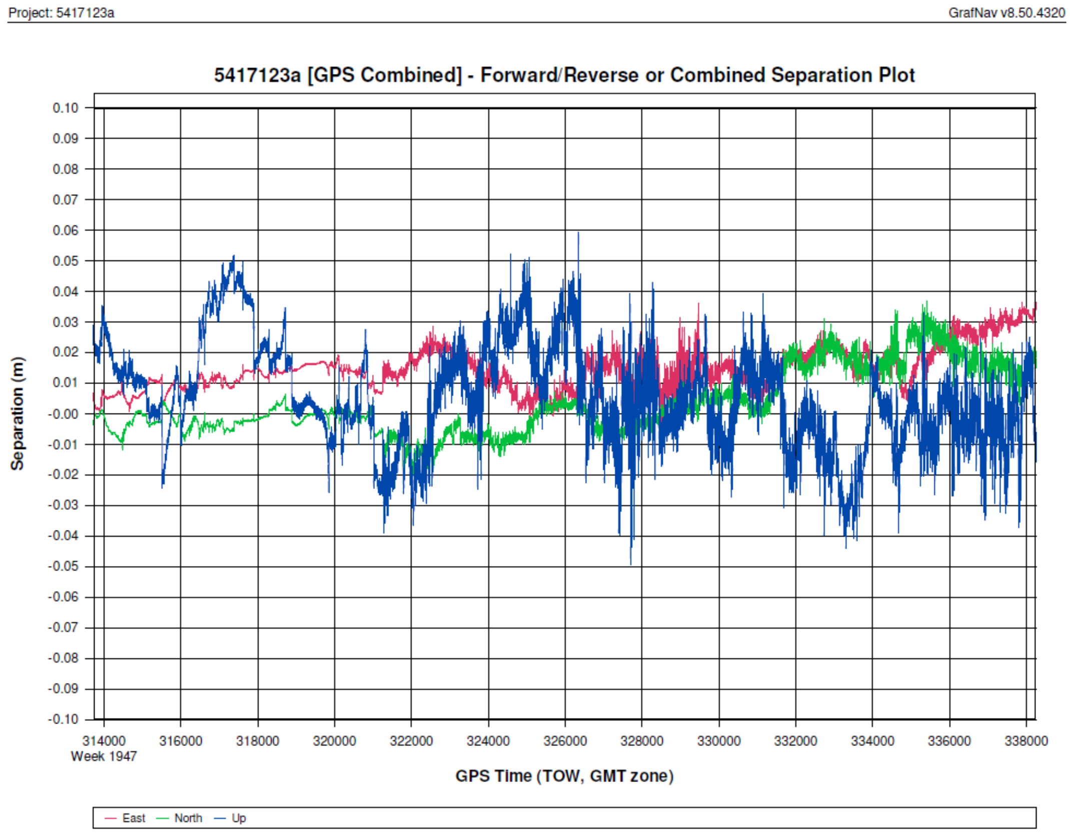


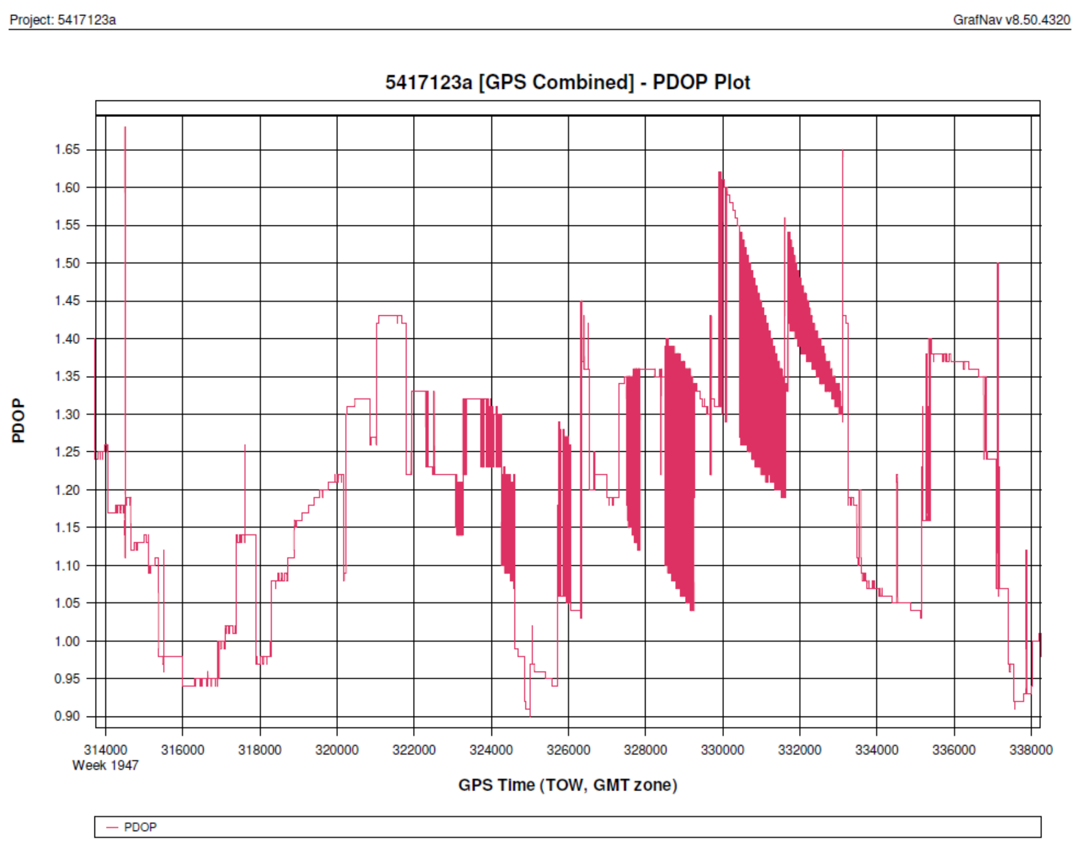
MISSION 3 – 5417123A GNSS PROCESSING

Project: 5417123a GrafNav v8.50.4320

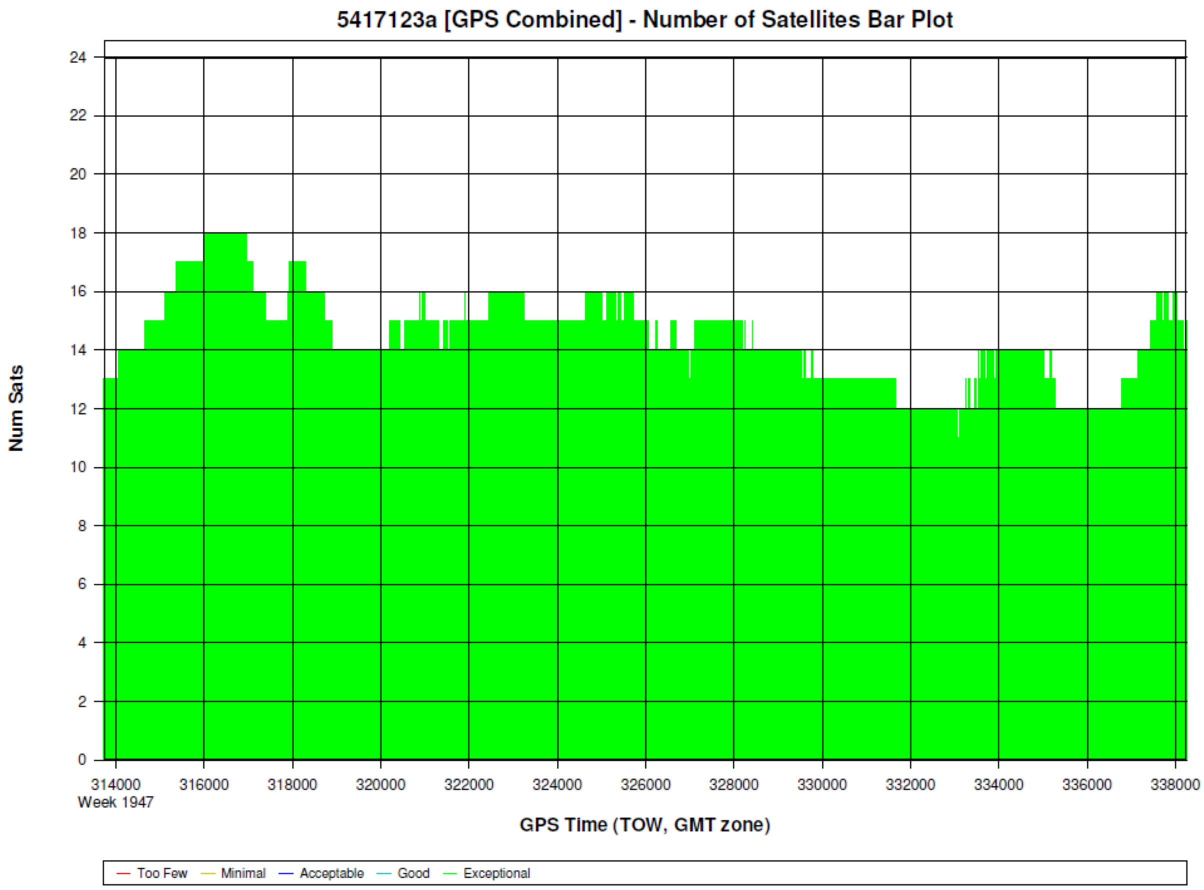
GPS Combined - Map




Project: 5417123a
GrafNav v8.50.4320
5417123a [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
314000
Week 1947
316000
318000
320000
322000
324000
326000
328000
330000
332000
334000
336000
338000
GPS Time (TOW, GMT zone)
East
North
Up


Project: 5417123a
GrafNav v8.50.4320
5417123a [GPS Combined] - PDOP Plot
PDOP
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
314000
Week 1947
316000
318000
320000
322000
324000
326000
328000
330000
332000
334000
336000
338000
GPS Time (TOW, GMT zone)
PDOP

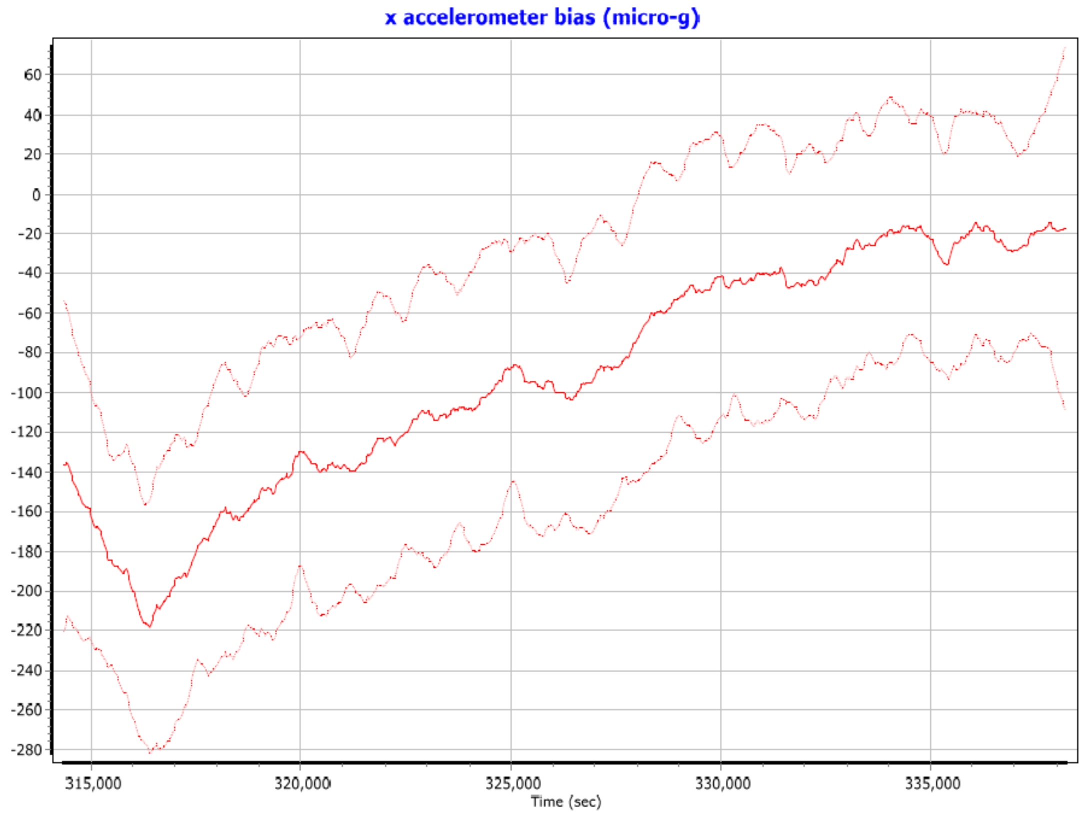
Project: 5417123a GrafNav v8.50.4320

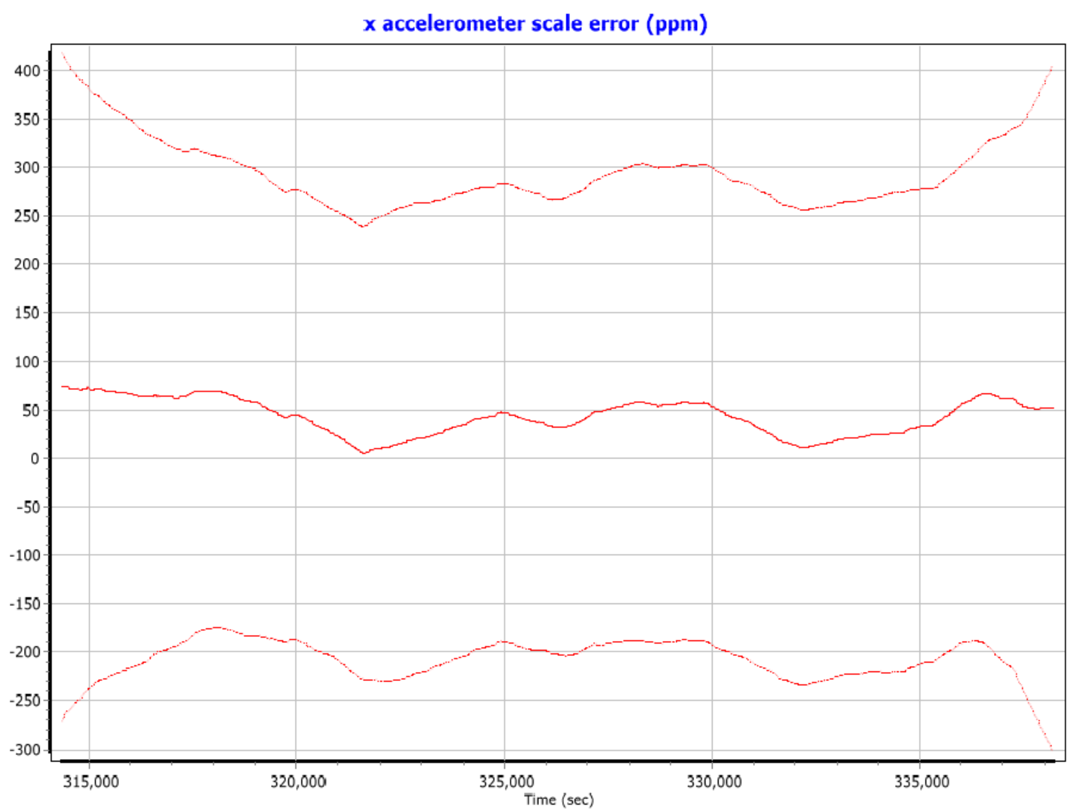


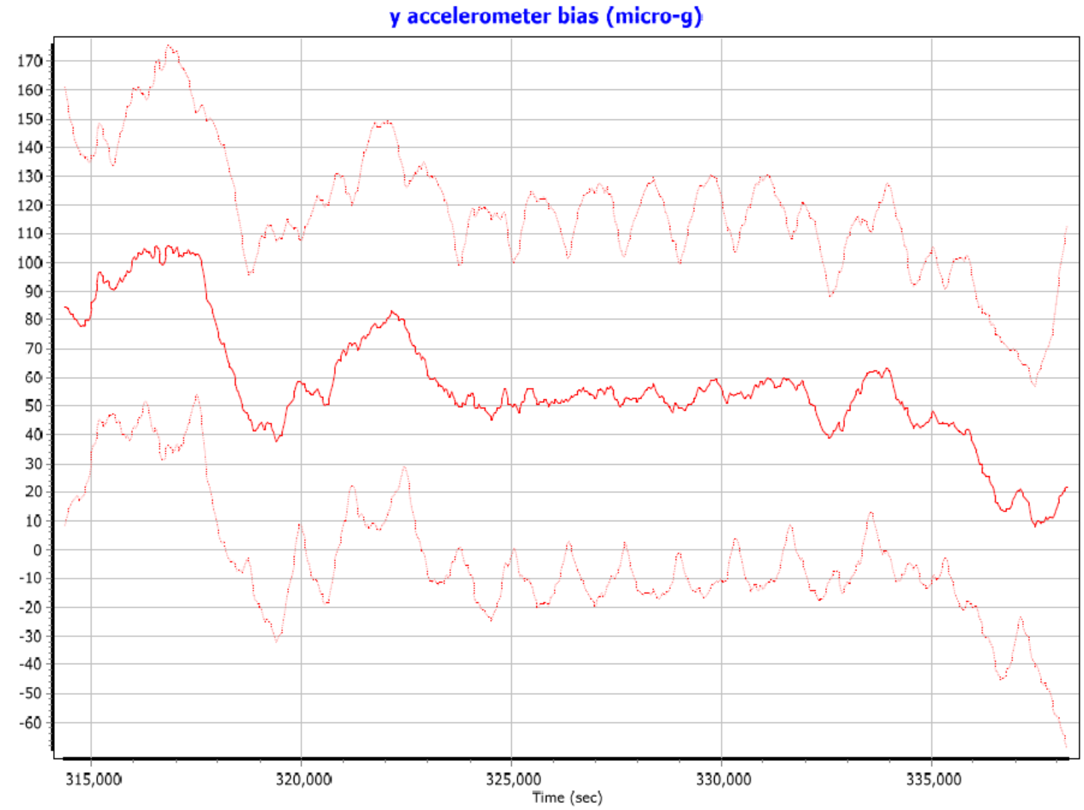

```
          Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417123a\05_INS-
GPS_PROC\01_POS\5417123a\5417123a\GNSS\5417123a.gnv
Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      24546
      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:    0.0209 (m)
      C/A Code:    0.84 (m)
      L1 Doppler: 0.719 (m/s)

Fwd/Rev Separation RMS Values:
      East:        0.016 (m)
      North:       0.011 (m)
```

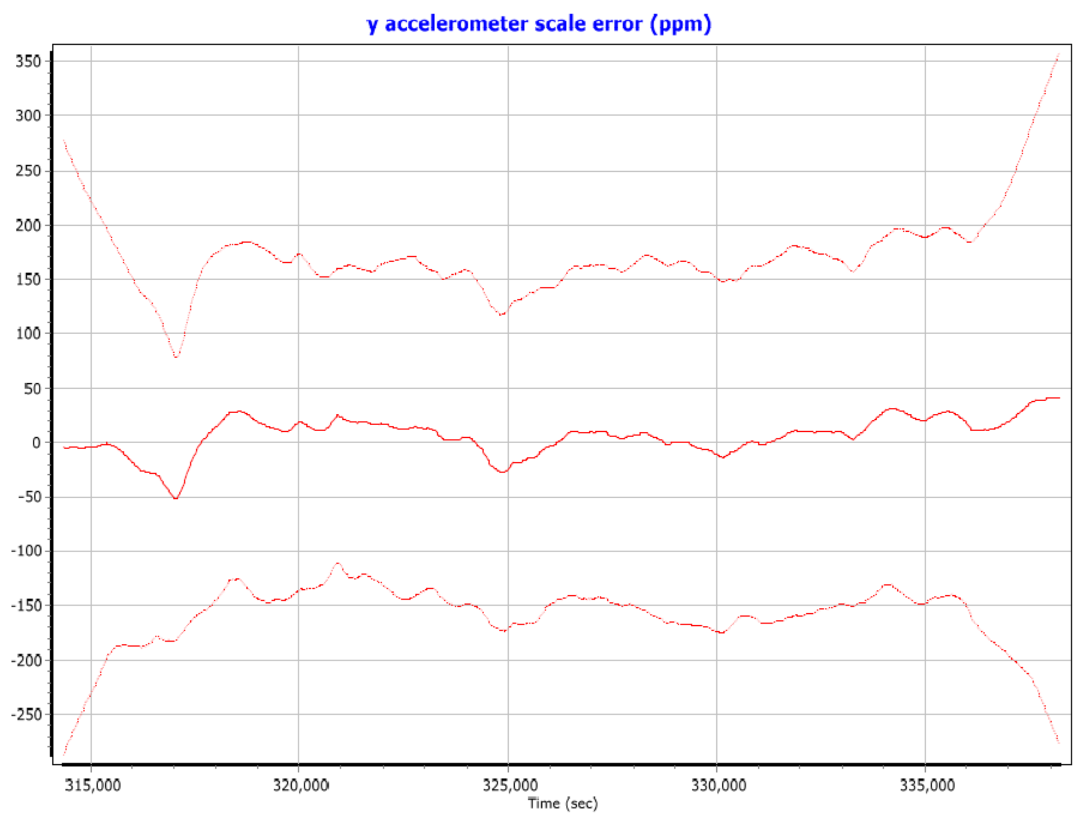
```
      Height:      0.018 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (24541 occurances):
      East:        0.016 (m)
      North:       0.011 (m)
      Height:      0.018 (m)

Quality Number Percentages:
      Q 1:  99.1 %
      Q 2:   0.9 %
      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:          76.349 (km)
      Minimum:          4.701 (km)
      Average:          28.586 (km)
      First Epoch:      21.732 (km)
      Last Epoch:       17.061 (km)
```

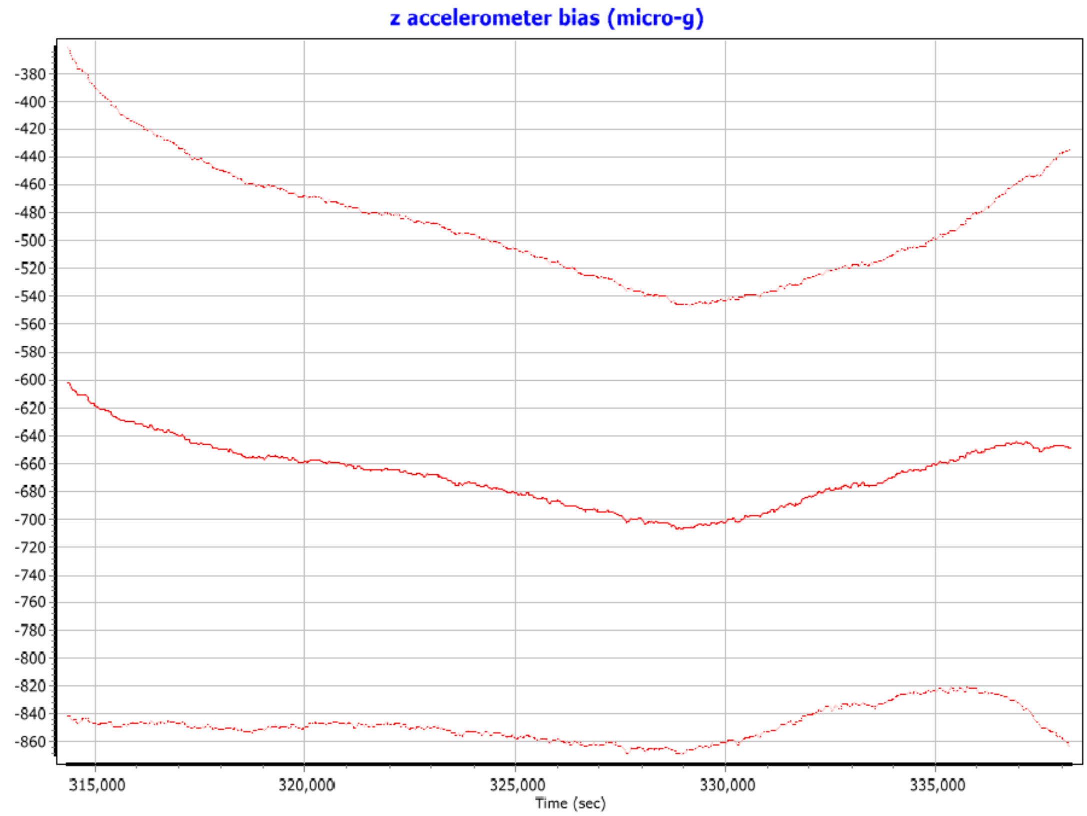
MISSION 3 – 5417123A SENSOR ERRORS

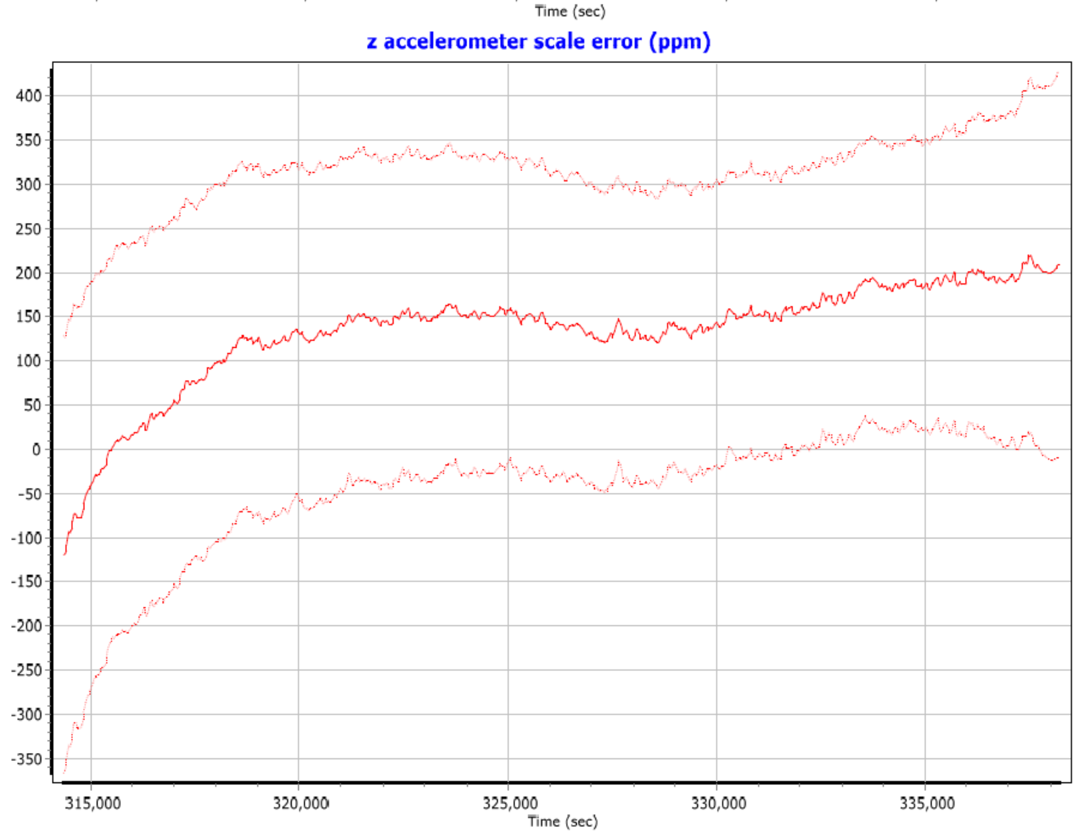

x accelerometer bias (micro-g)
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
315,000
320,000
325,000
330,000
335,000
Time (sec)

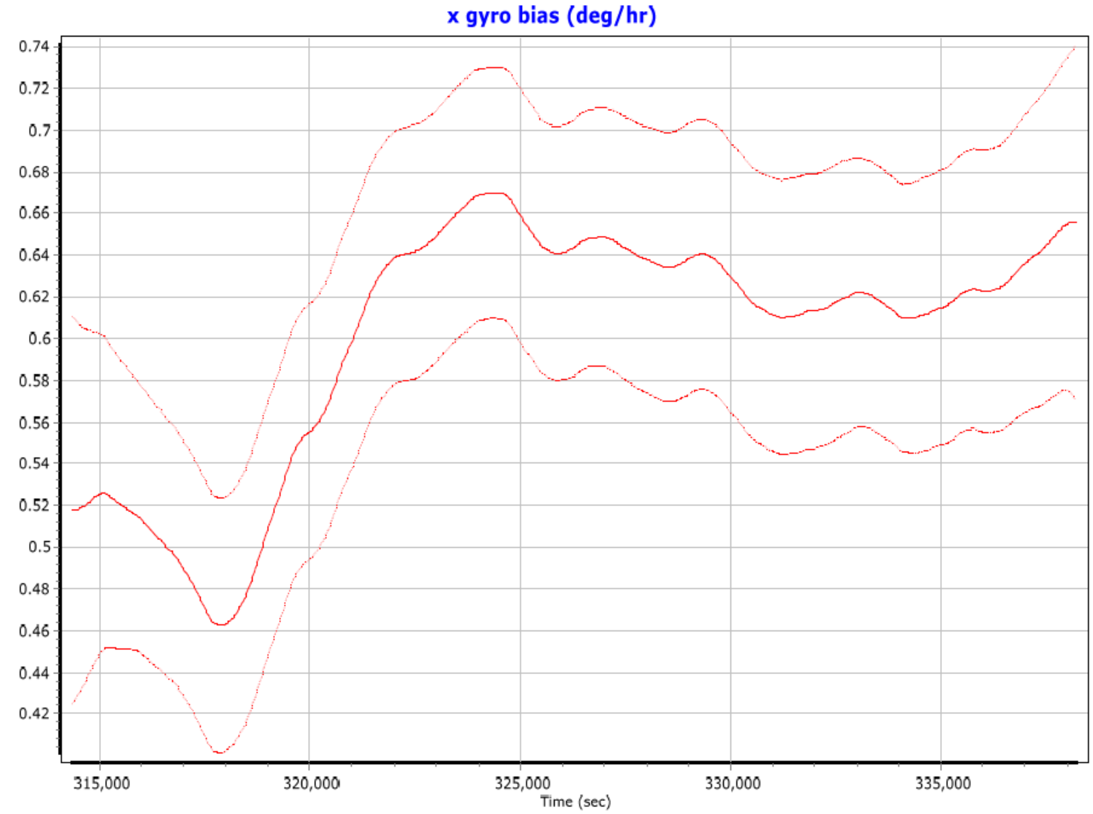

x accelerometer scale error (ppm)
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
315,000
320,000
325,000
330,000
335,000
Time (sec)

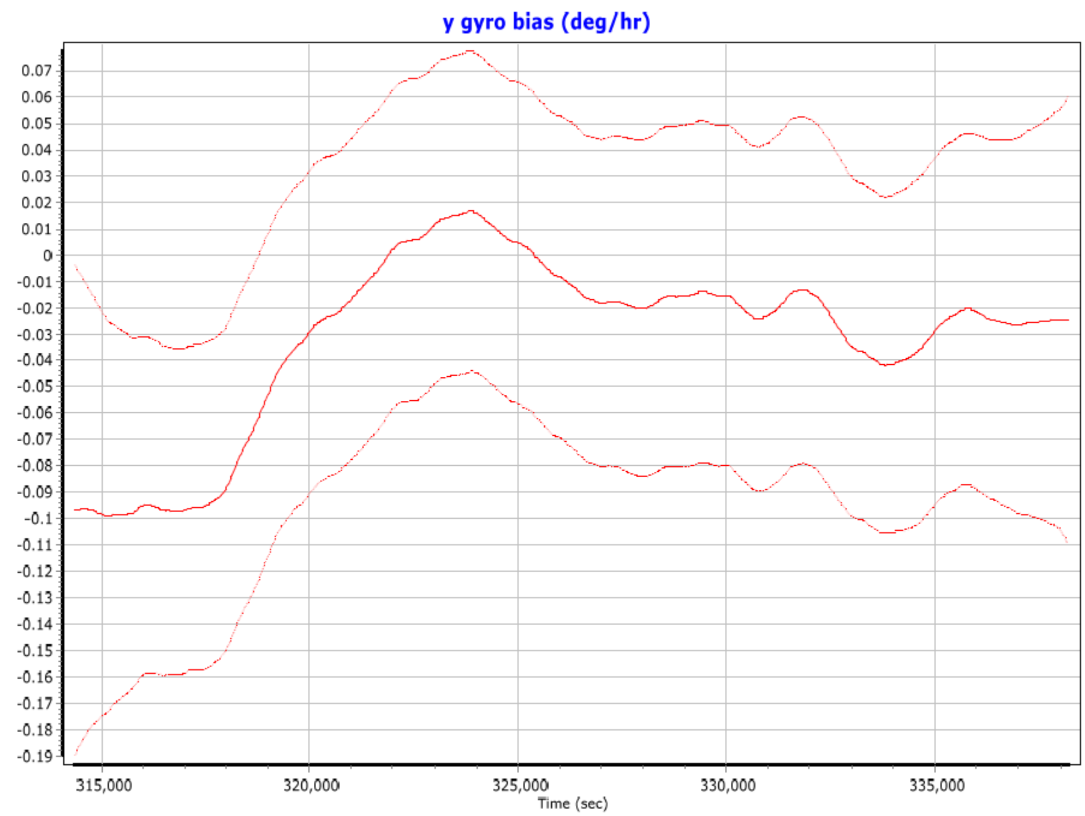

y accelerometer bias (micro-g)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
315,000
320,000
325,000
330,000
335,000
Time (sec)

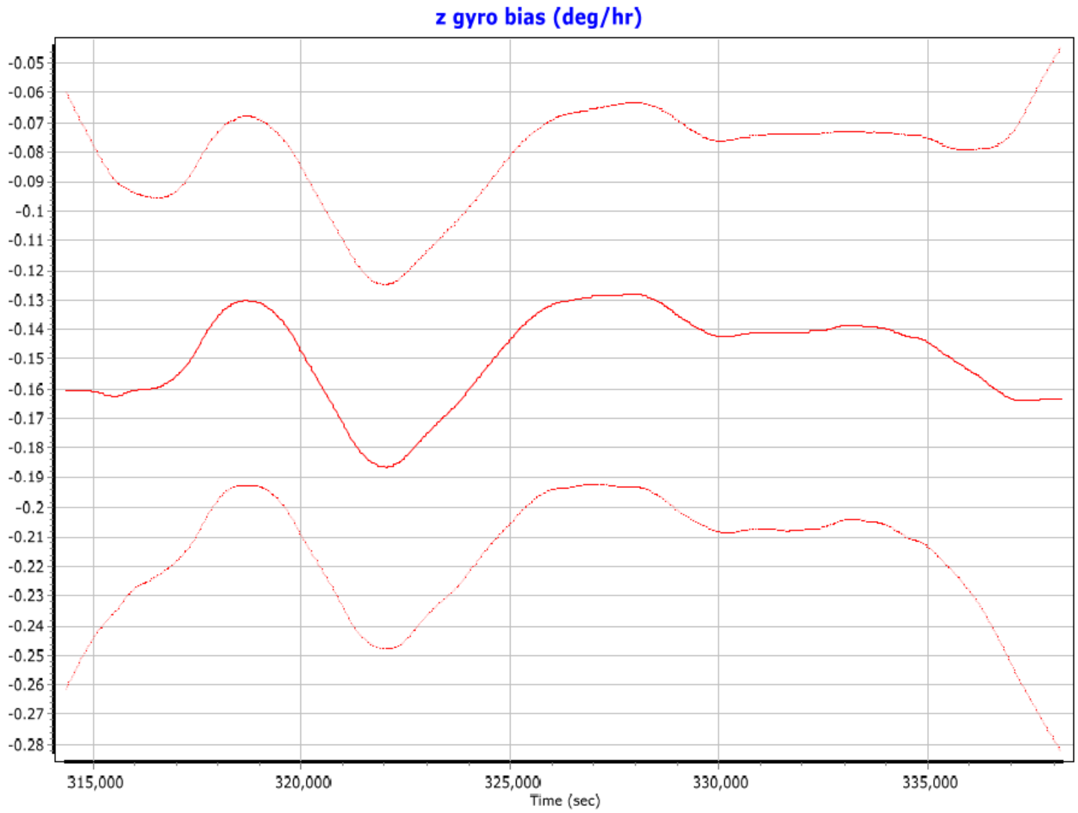

y accelerometer scale error (ppm)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
315,000
320,000
325,000
330,000
335,000
Time (sec)


z accelerometer bias (micro-g)
-380
-400
-420
-440
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
315,000
320,000
325,000
330,000
335,000
Time (sec)


z accelerometer scale error (ppm)
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
315,000
320,000
325,000
330,000
335,000
Time (sec)

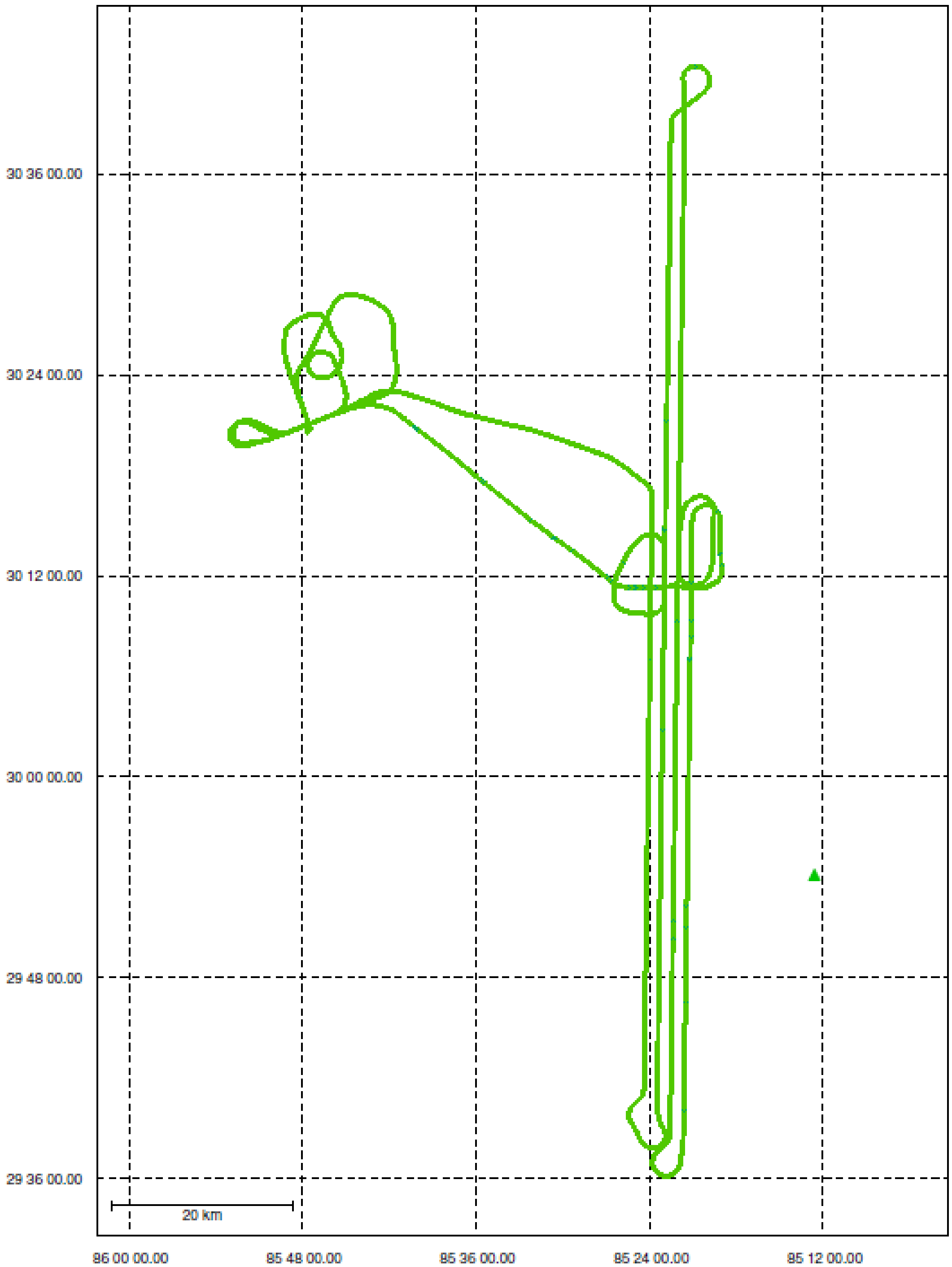

x gyro bias (deg/hr)
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
315,000
320,000
325,000
330,000
335,000
Time (sec)


y gyro bias (deg/hr)
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
315,000
320,000
325,000
330,000
335,000
Time (sec)



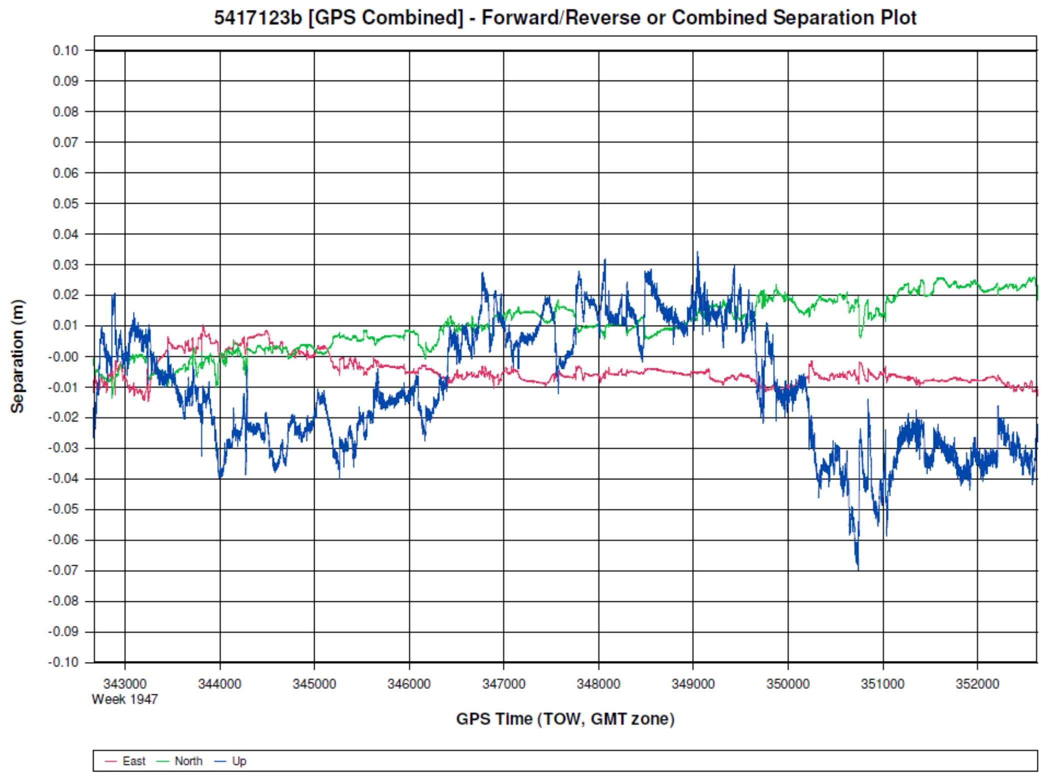
MISSION 4 – 5417123B GNSS PROCESSING

Project: 5417123b GrafNav v8.50.4320

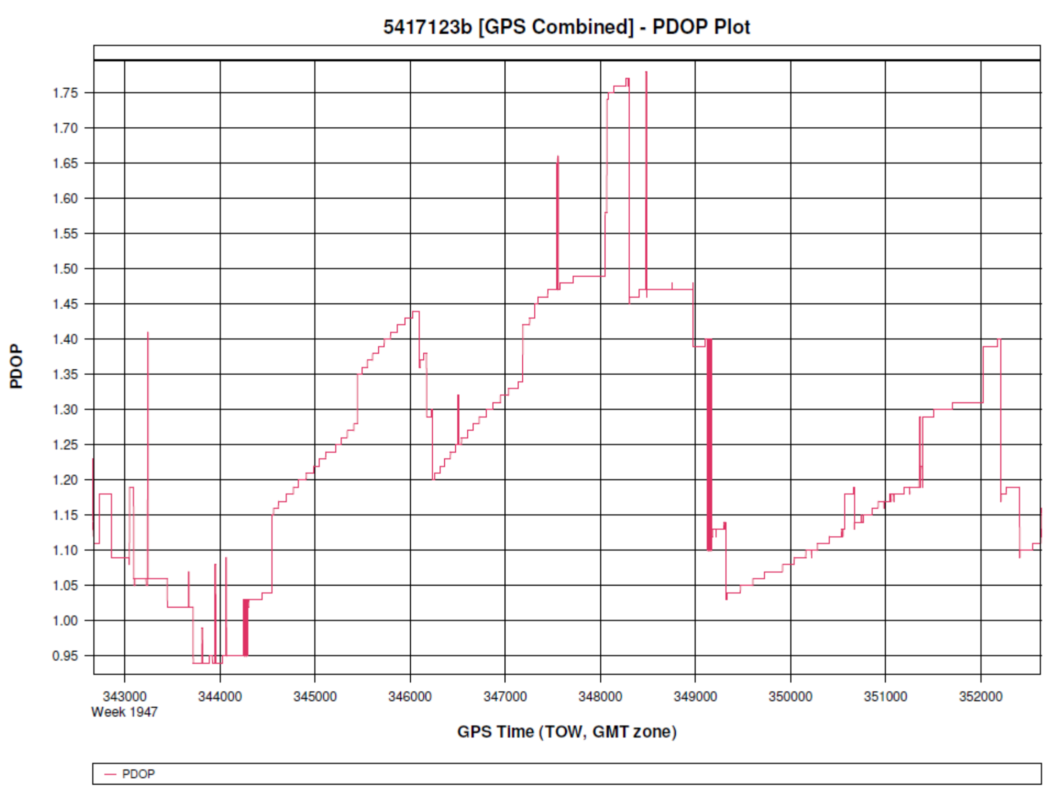


Dewberry

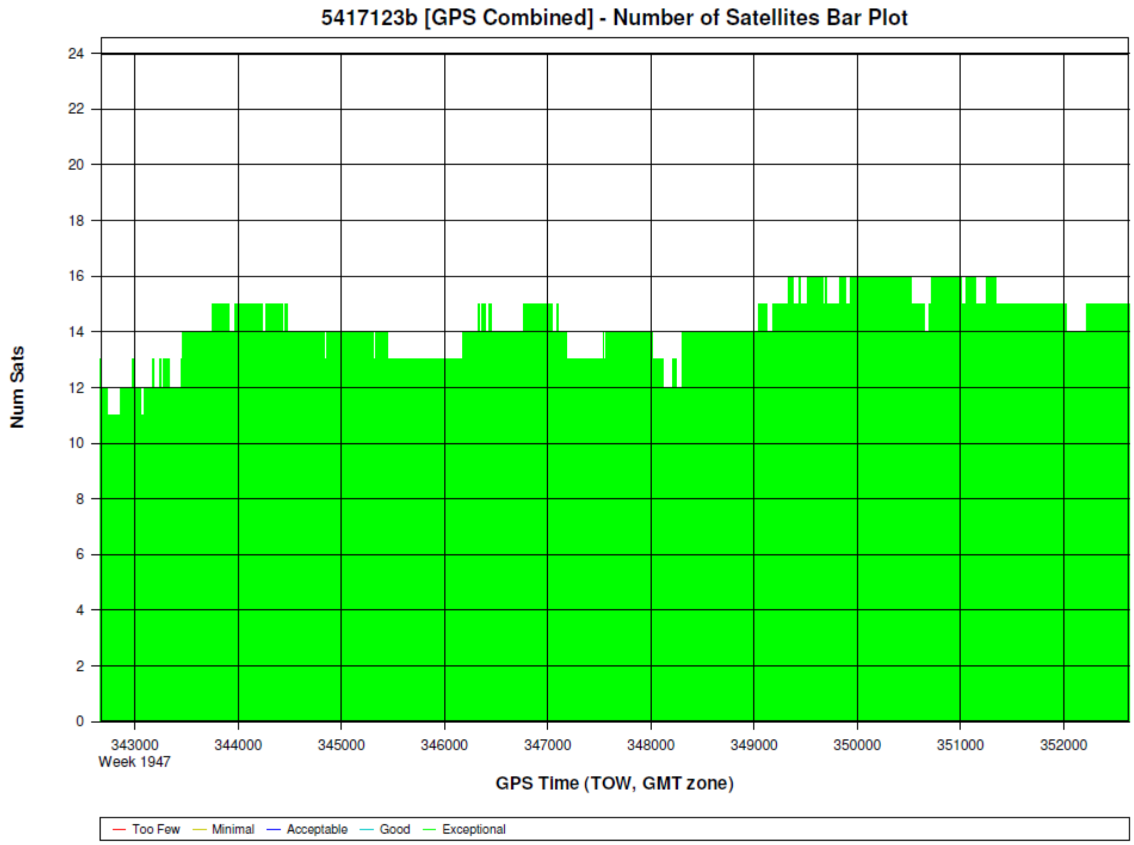
Project: 5417123b GrafNav v8.50.4320



Project: 5417123b GrafNav v8.50.4320



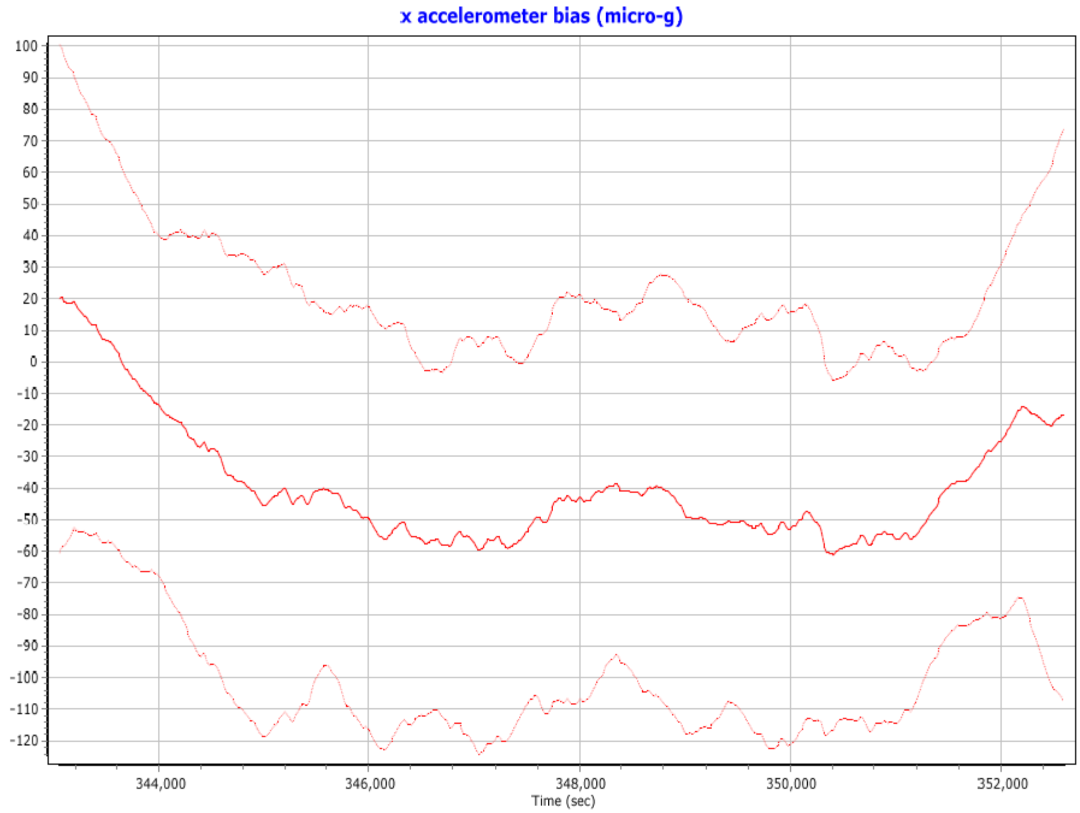
Project: 5417123b GrafNav v8.50.4320

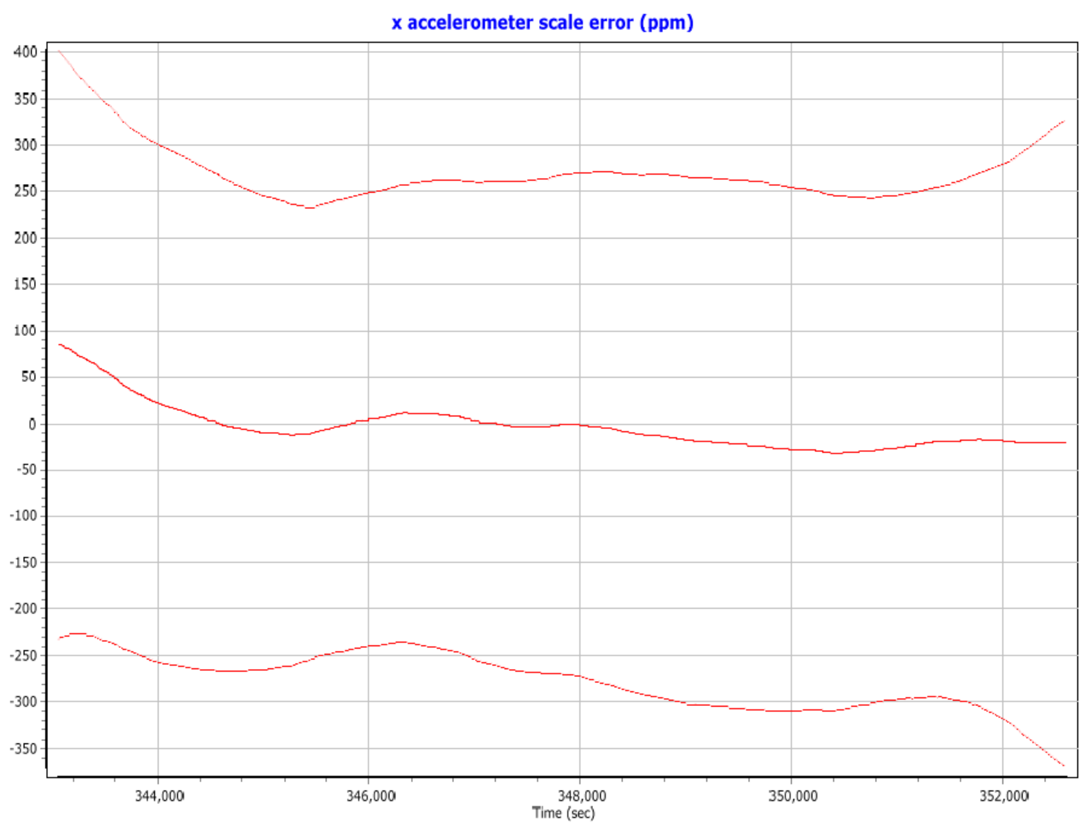


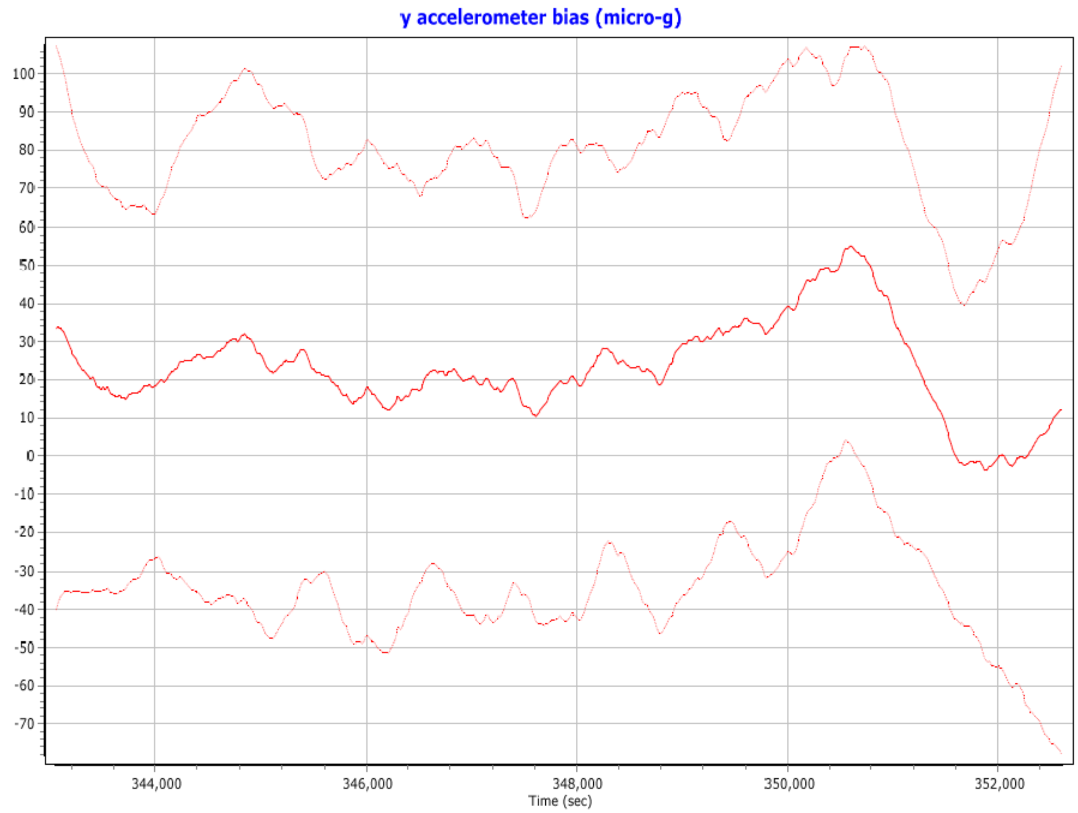

```
          Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417123b\05_INS-
GPS_PROC\01_POS\5417123b\5417123b\GNSS\5417123b.gnv
Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      9977
      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:   0.0209 (m)
      C/A Code:   1.01 (m)
      L1 Doppler: 0.775 (m/s)

Fwd/Rev Separation RMS Values:
      East:       0.007 (m)
      North:      0.013 (m)
      Height:     0.023 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (9972 occurances):
```

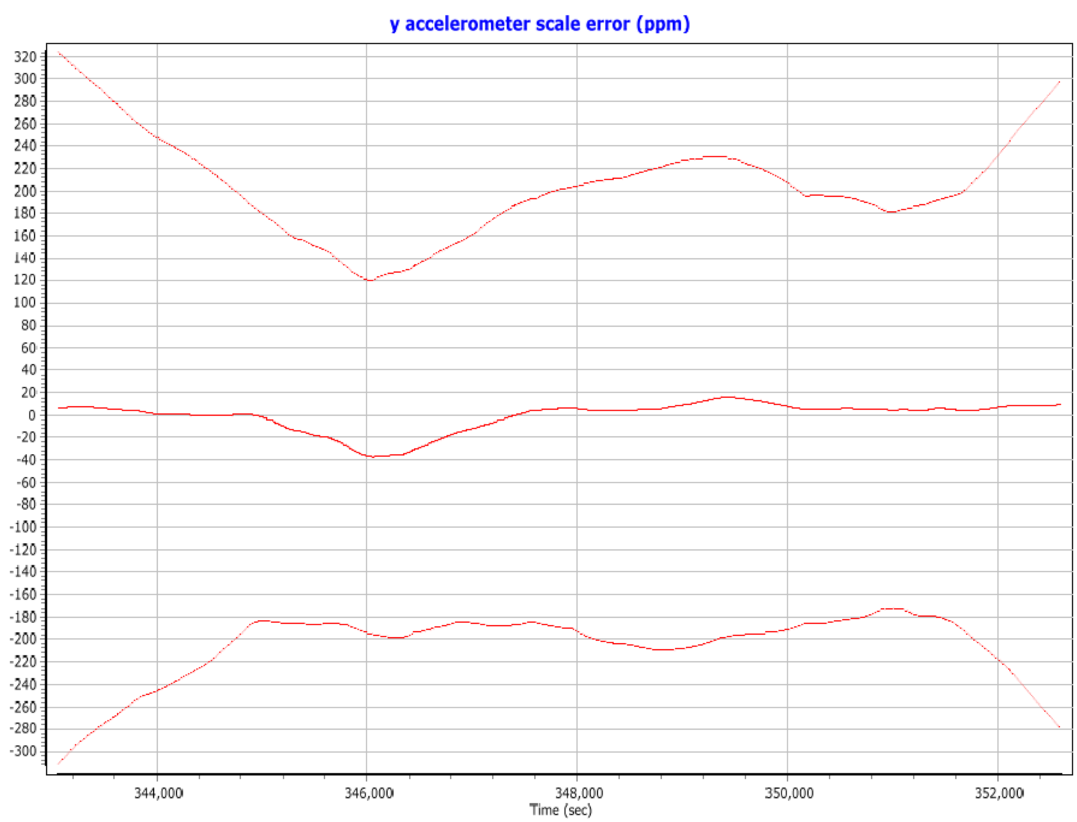
```
      East:        0.007 (m)
      North:       0.013 (m)
      Height:      0.023 (m)

Quality Number Percentages:
      Q 1:  98.7 %
      Q 2:   1.3 %
      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:          90.847 (km)
      Minimum:          2.628 (km)
      Average:          33.138 (km)
      First Epoch:      15.534 (km)
      Last Epoch:       16.451 (km)
```

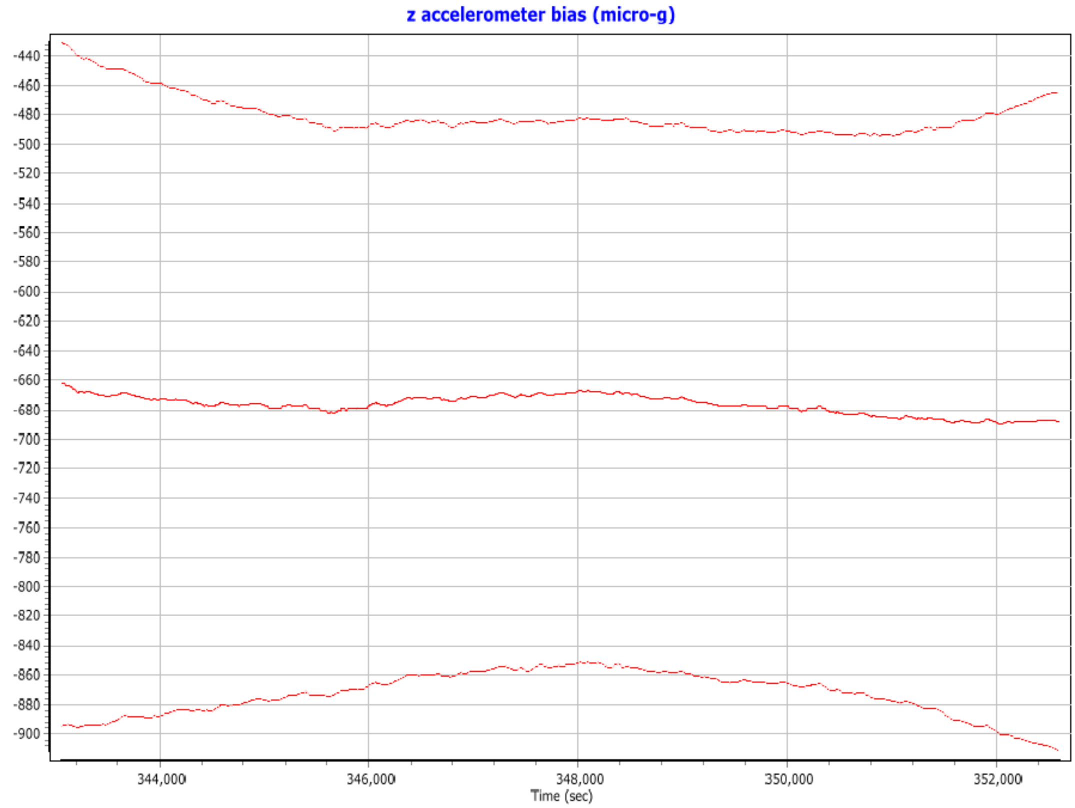
MISSION 4 – 5417123B SENSOR ERRORS


x accelerometer bias (micro-g)
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
344,000
346,000
348,000
350,000
352,000
Time (sec)

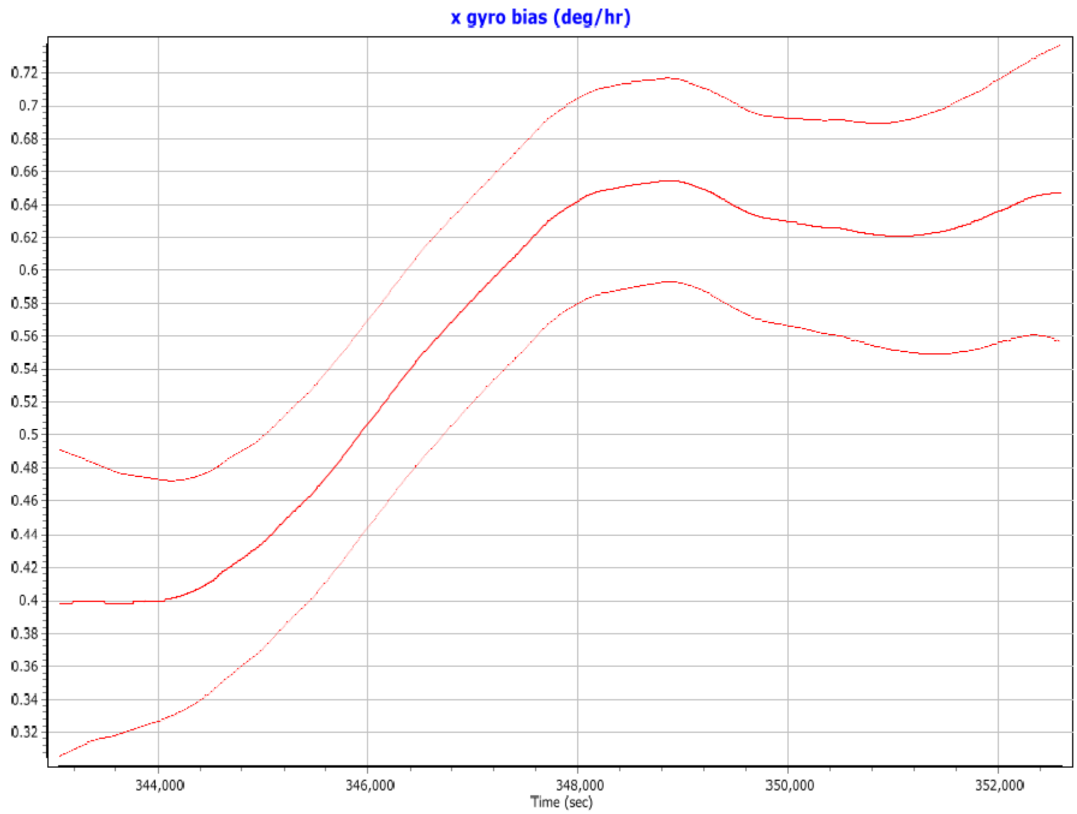

x accelerometer scale error (ppm)
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
344,000
346,000
348,000
350,000
352,000
Time (sec)

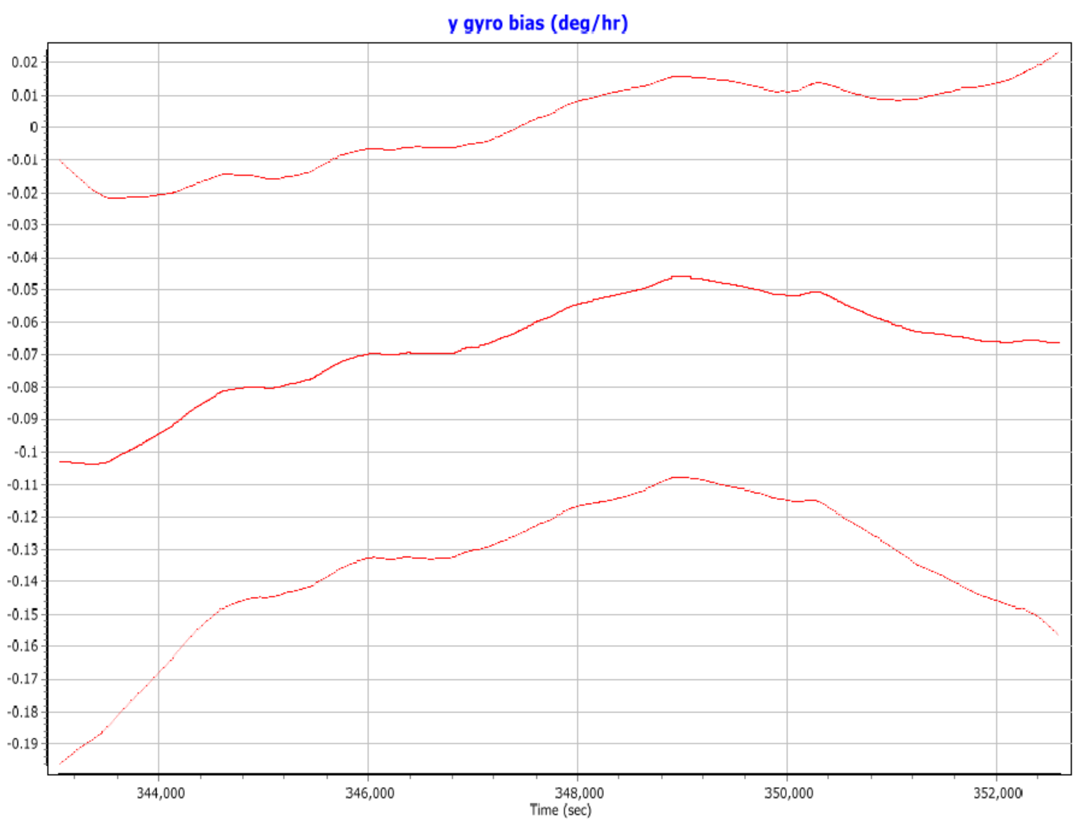

y accelerometer bias (micro-g)
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
344,000
346,000
348,000
350,000
352,000
Time (sec)

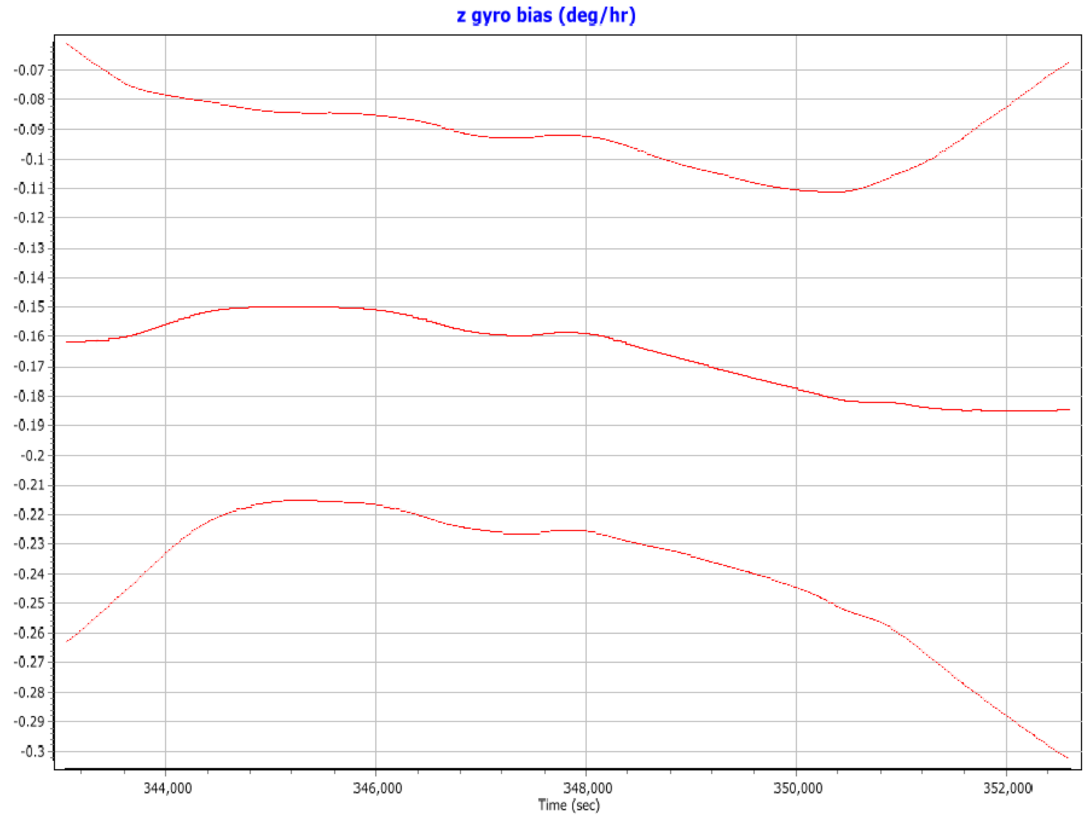

y accelerometer scale error (ppm)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
-300
344,000
346,000
348,000
350,000
352,000
Time (sec)


z accelerometer bias (micro-g)
-440
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
344,000
346,000
348,000
350,000
352,000
Time (sec)

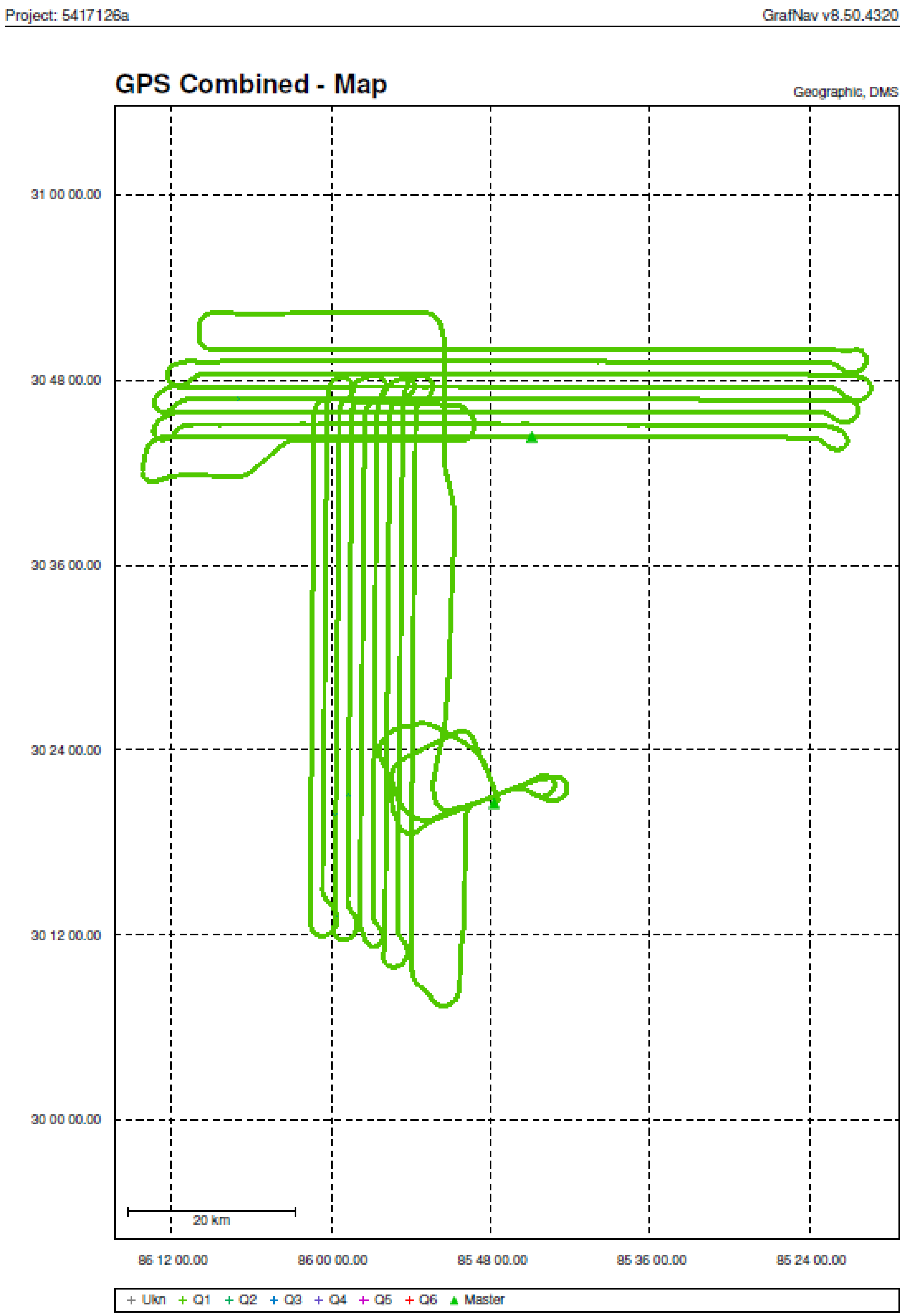

z accelerometer scale error (ppm)
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
344,000
346,000
348,000
350,000
352,000
Time (sec)


x gyro bias (deg/hr)
0.72
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
0.32
344,000
346,000
348,000
350,000
352,000
Time (sec)

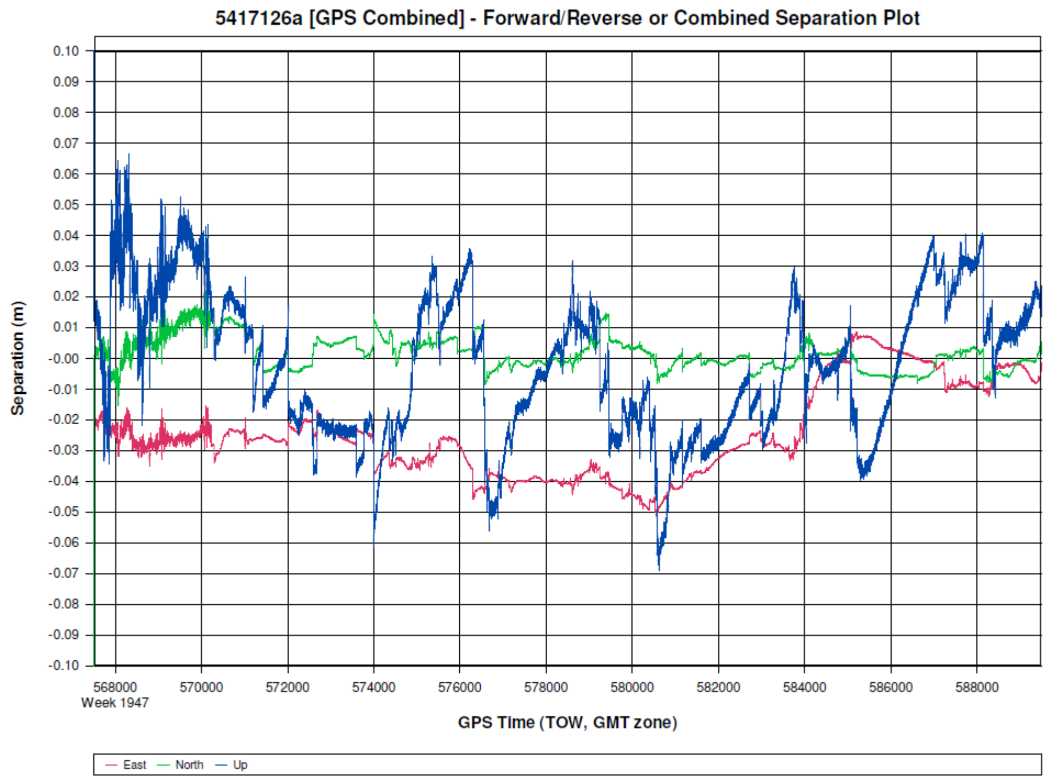

y gyro bias (deg/hr)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
344,000
346,000
348,000
350,000
352,000
Time (sec)


z gyro bias (deg/hr)
-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
344,000
346,000
348,000
350,000
352,000
Time (sec)

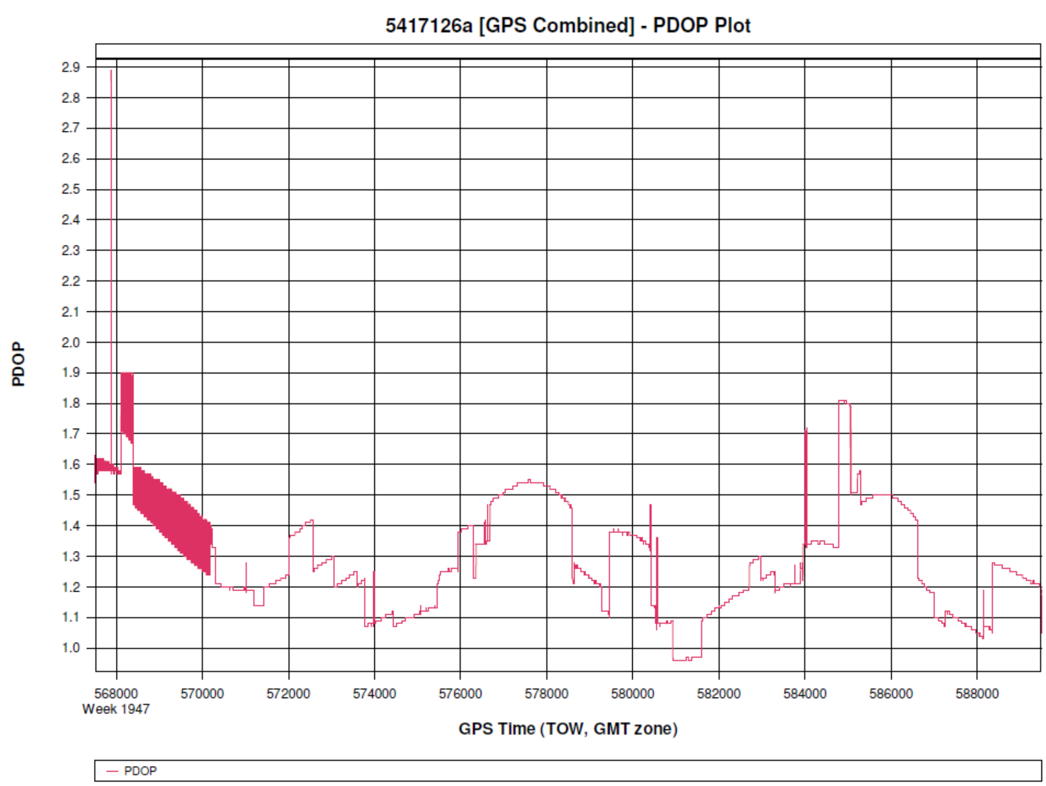
Mission 5 – 5417126a GNSS Processing



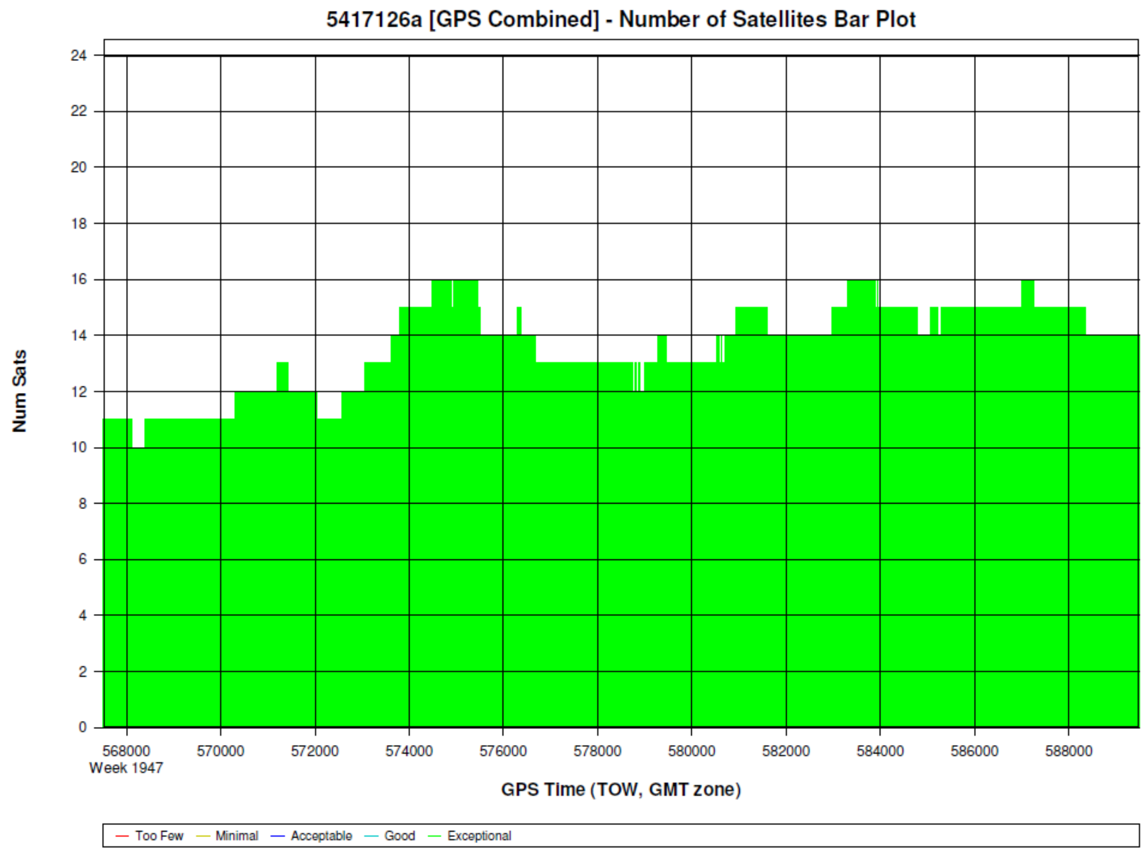
Project: 5417126a GrafNav v8.50.4320



Project: 5417126a GrafNav v8.50.4320



Project: 5417126a GrafNav v8.50.4320



Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417126a\05_INS-GPS_PROC\01_POS\5417126a\5417126a\GNSS\5417126a.gnv

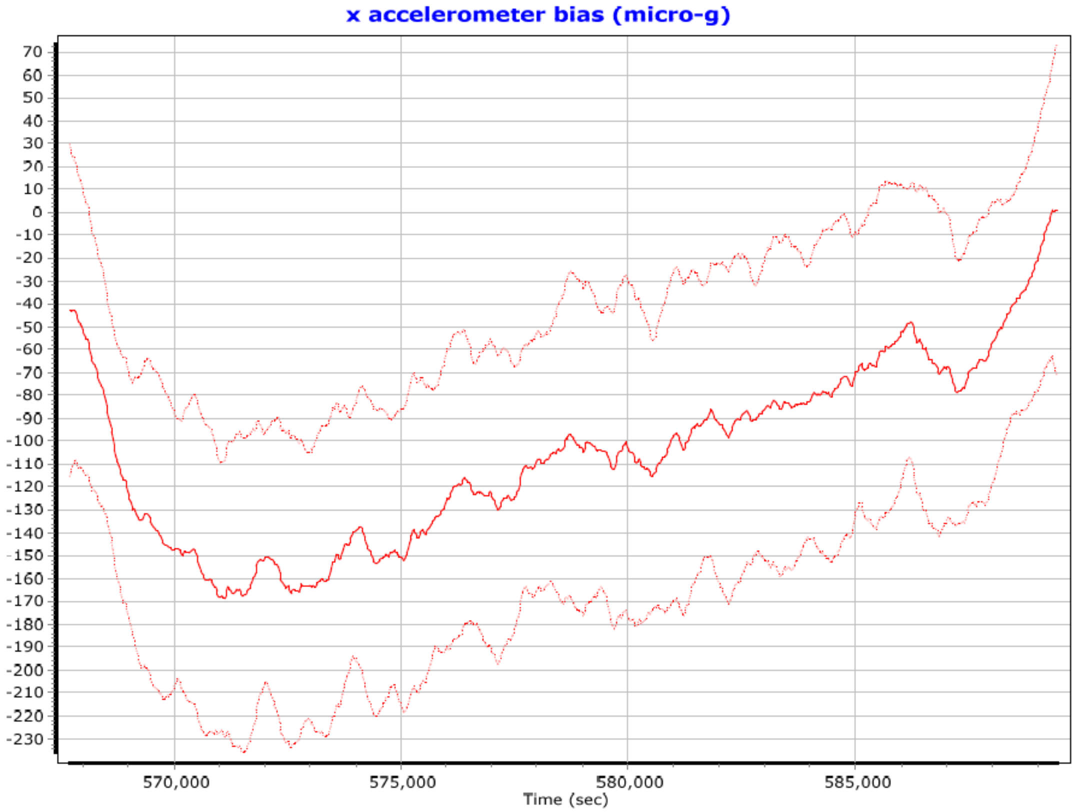
Solution Type: Combined

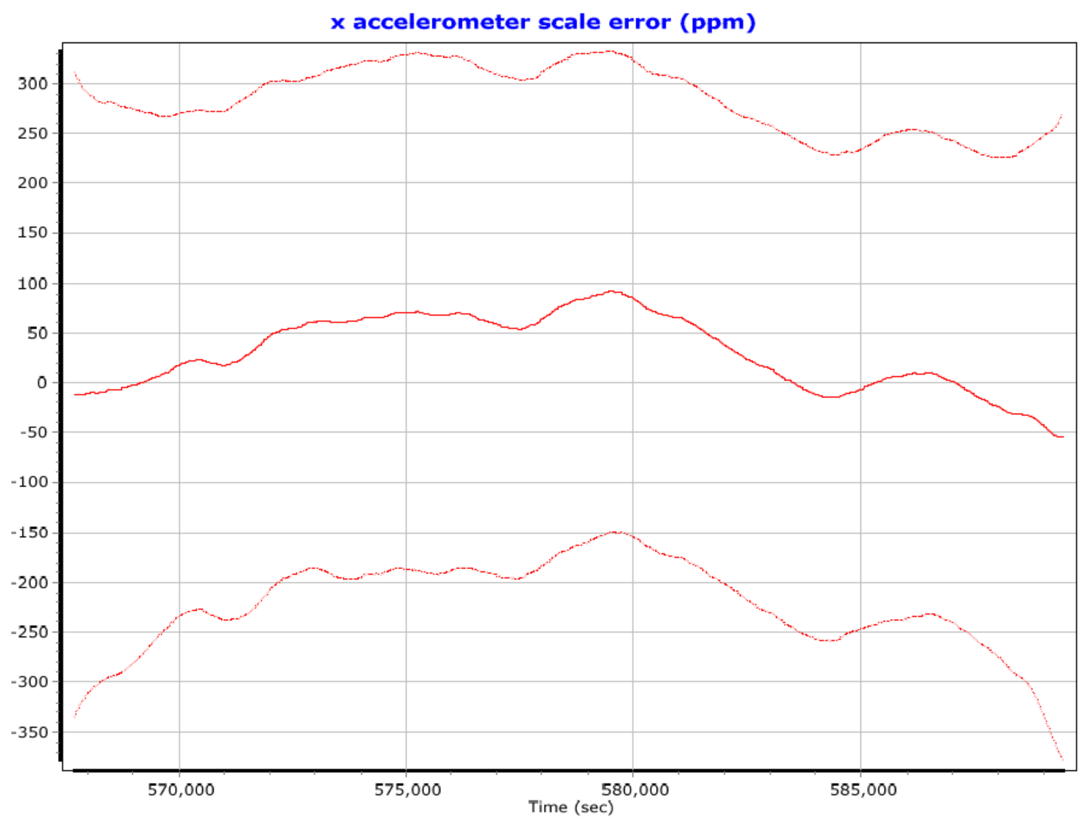
Number of Epochs:
- Total in GPB file: 22399
- No processed position: 400
- Missing Fwd or Rev: 3
- With bad C/A code: 0
- With bad L1 Phase: 0

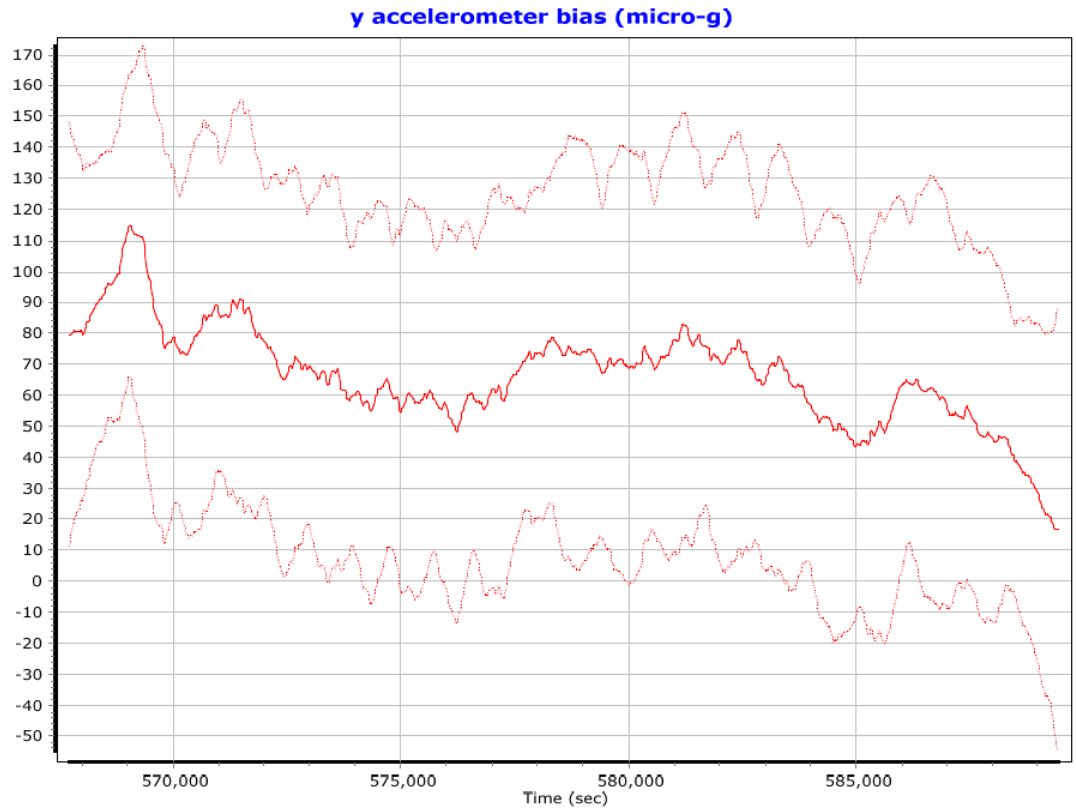
Measurement RMS Values:
- L1 Phase: 0.0209 (m)
- C/A Code: 0.77 (m)
- L1 Doppler: 0.782 (m/s)

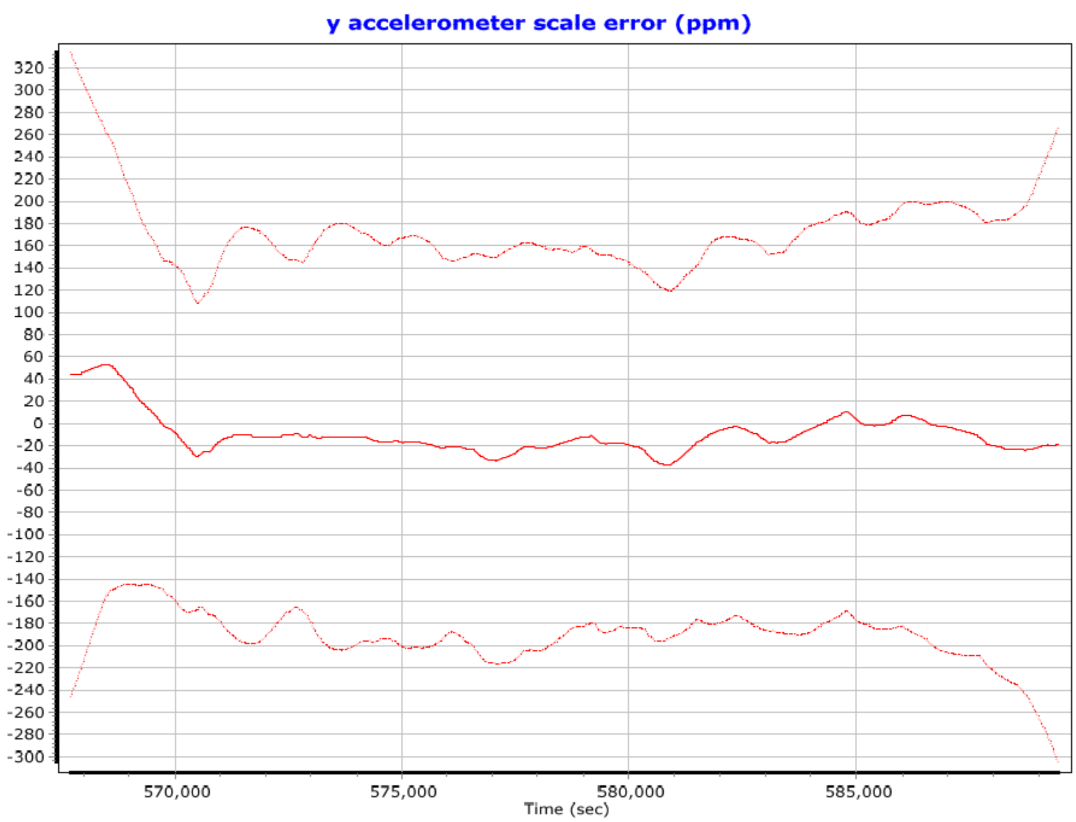
```
Fwd/Rev Separation RMS Values:
      East:        0.028 (m)
      North:       0.006 (m)
      Height:      0.024 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (21995 occurances):
      East:        0.028 (m)
      North:       0.006 (m)
      Height:      0.023 (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:          52.944 (km)
      Minimum:          7.649 (km)
      Average:          30.511 (km)
      First Epoch:      22.009 (km)
      Last Epoch:       21.782 (km)
```

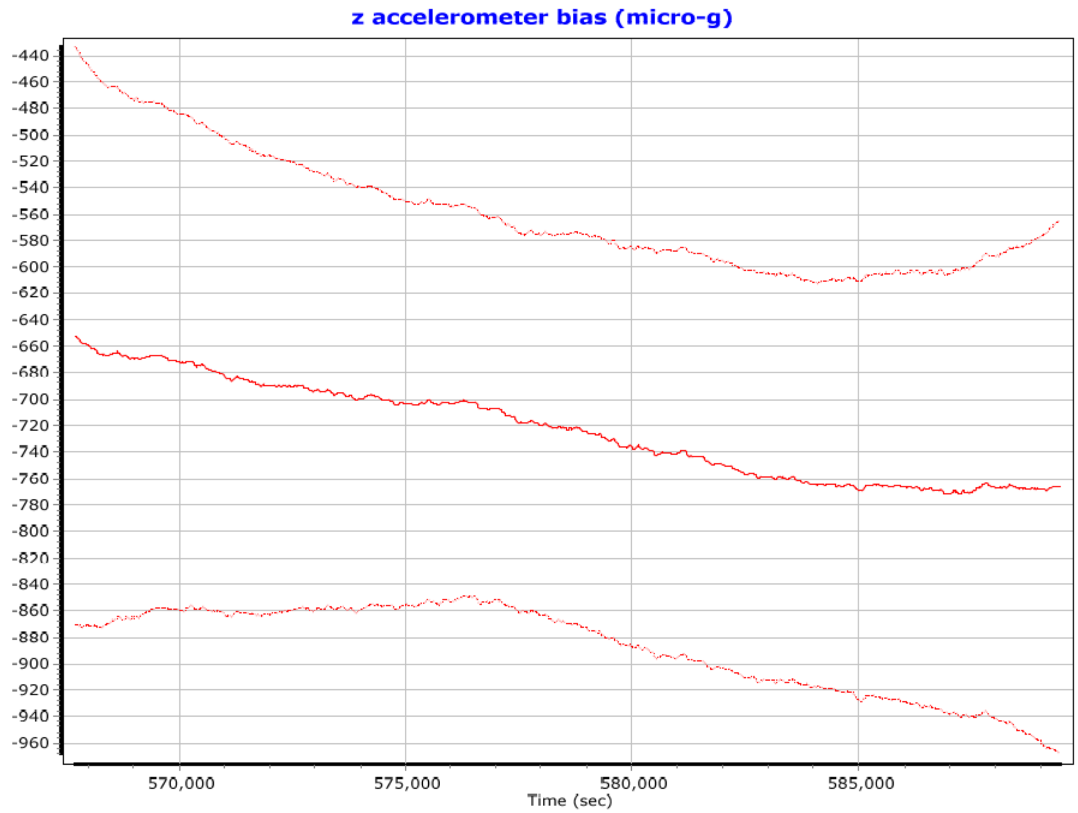
MISSION 5 – 5417126A SENSOR ERRORS

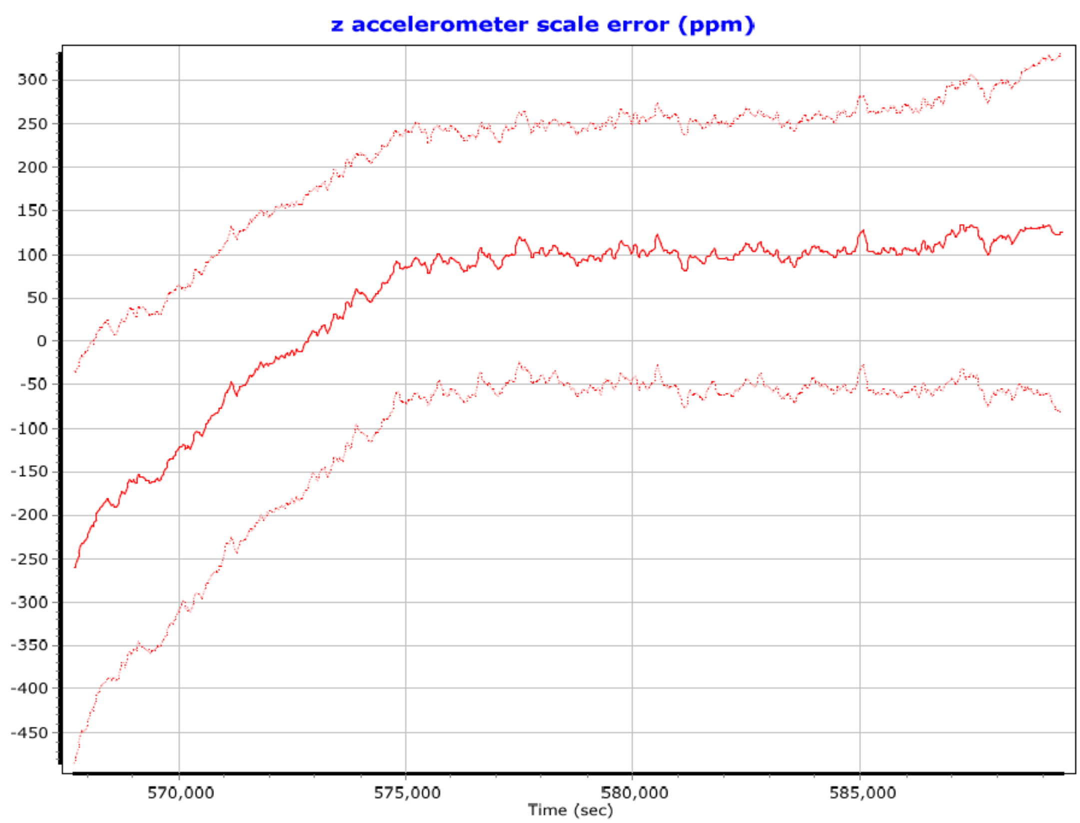


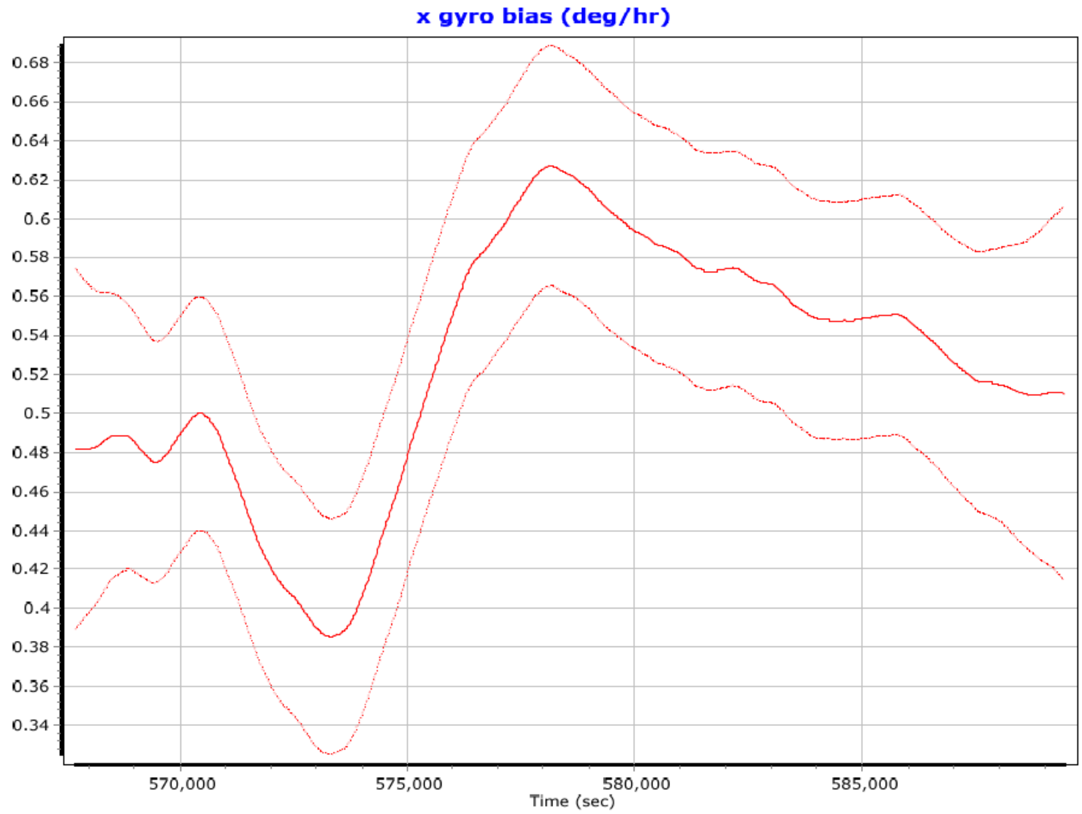


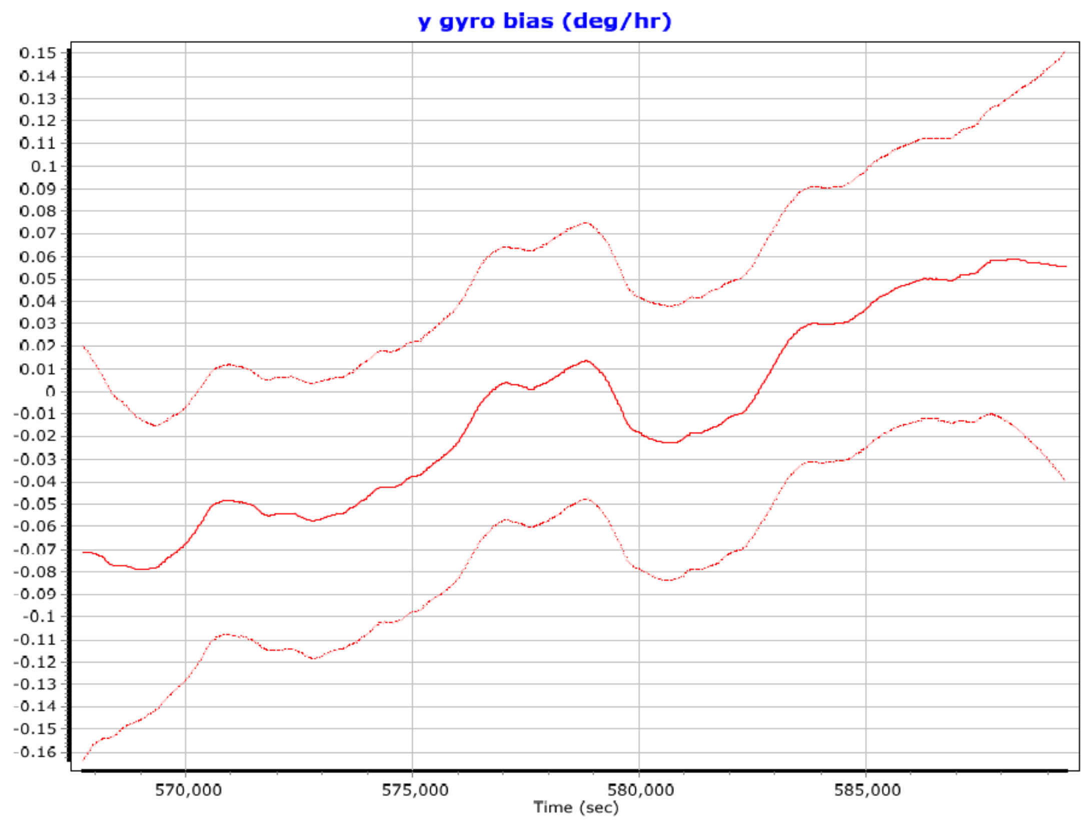

y accelerometer bias (micro-g)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
570,000
575,000
580,000
585,000
Time (sec)

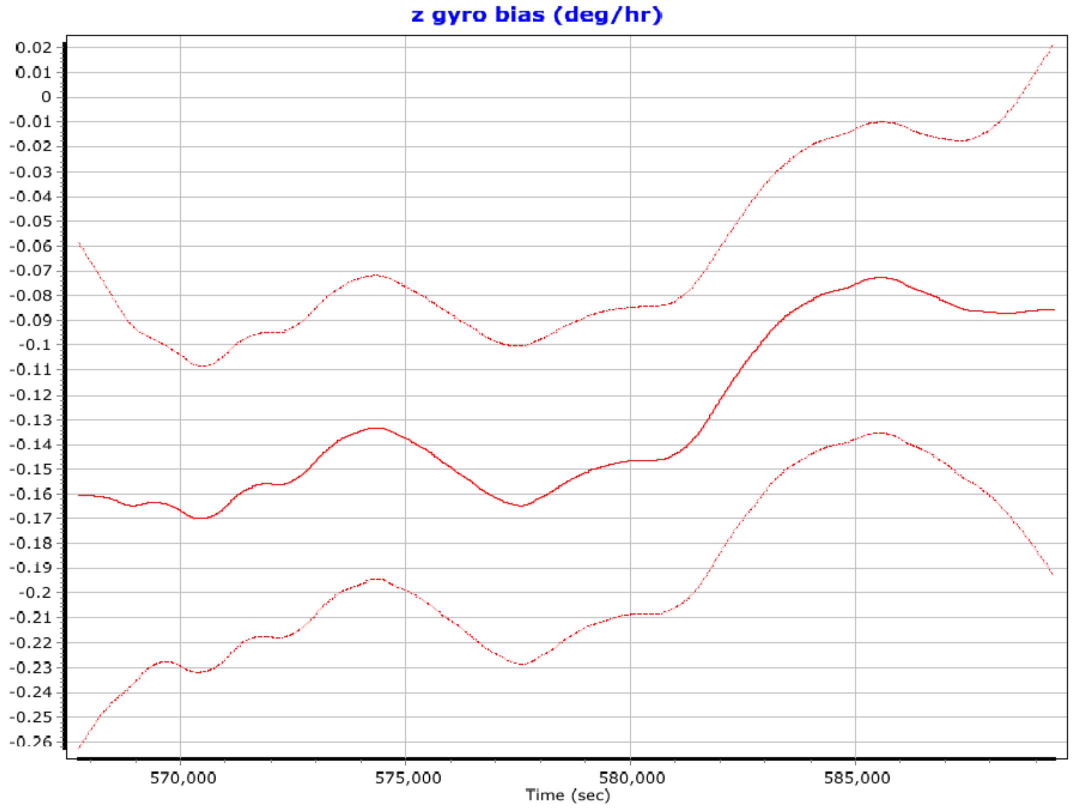

y accelerometer scale error (ppm)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
-300
570,000
575,000
580,000
585,000
Time (sec)


z accelerometer bias (micro-g)
-440
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
-920
-940
-960
570,000
575,000
580,000
585,000
Time (sec)

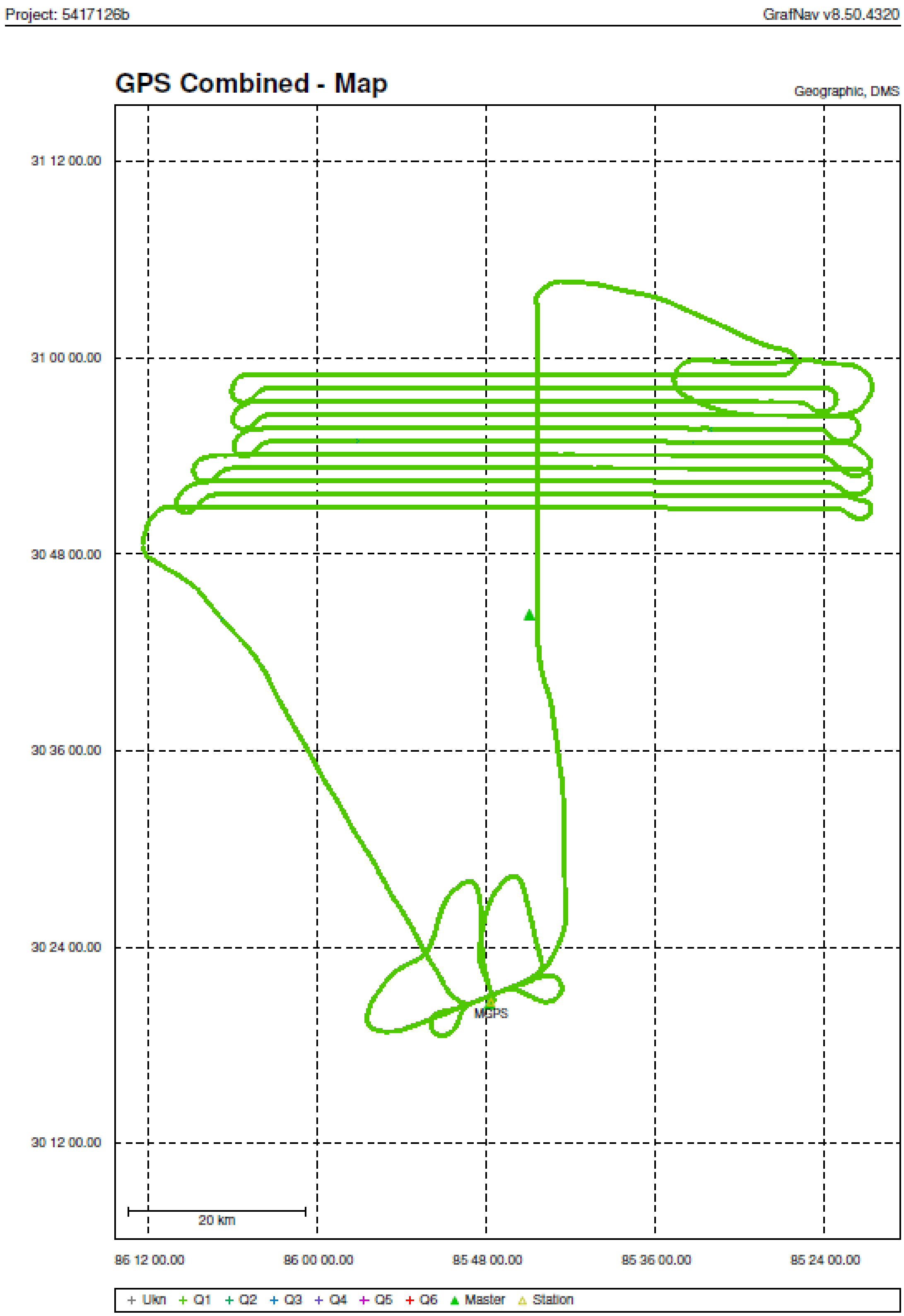

z accelerometer scale error (ppm)
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
570,000
575,000
580,000
585,000
Time (sec)

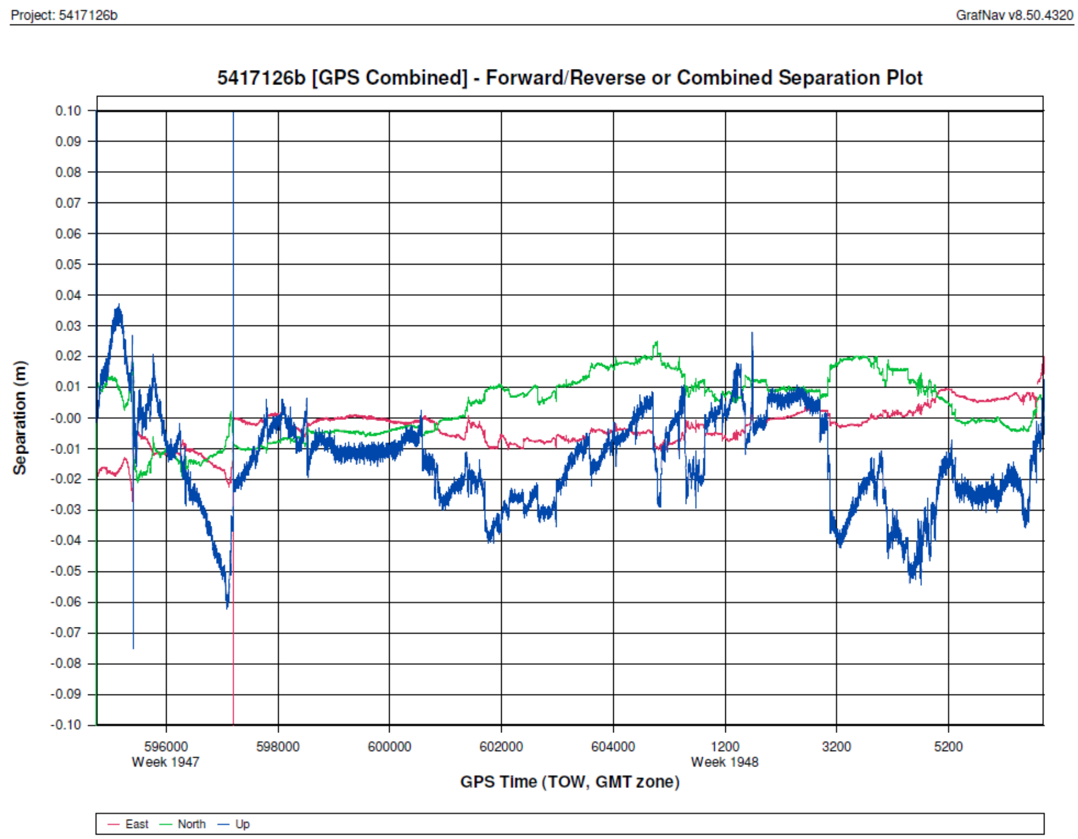

x gyro bias (deg/hr)
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
570,000
575,000
580,000
585,000
Time (sec)

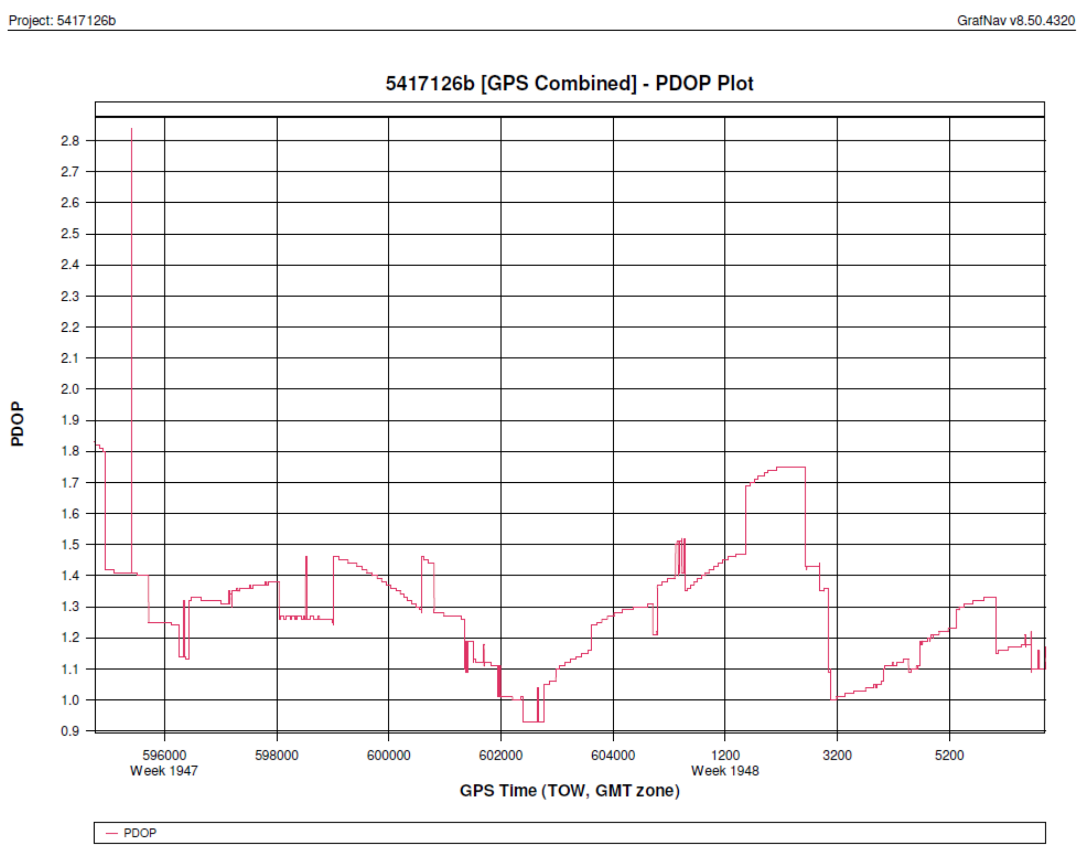

y gyro bias (deg/hr)
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
570,000
575,000
580,000
585,000
Time (sec)


z gyro bias (deg/hr)
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
-0.22
-0.23
-0.24
-0.25
-0.26
570,000
575,000
580,000
585,000
Time (sec)

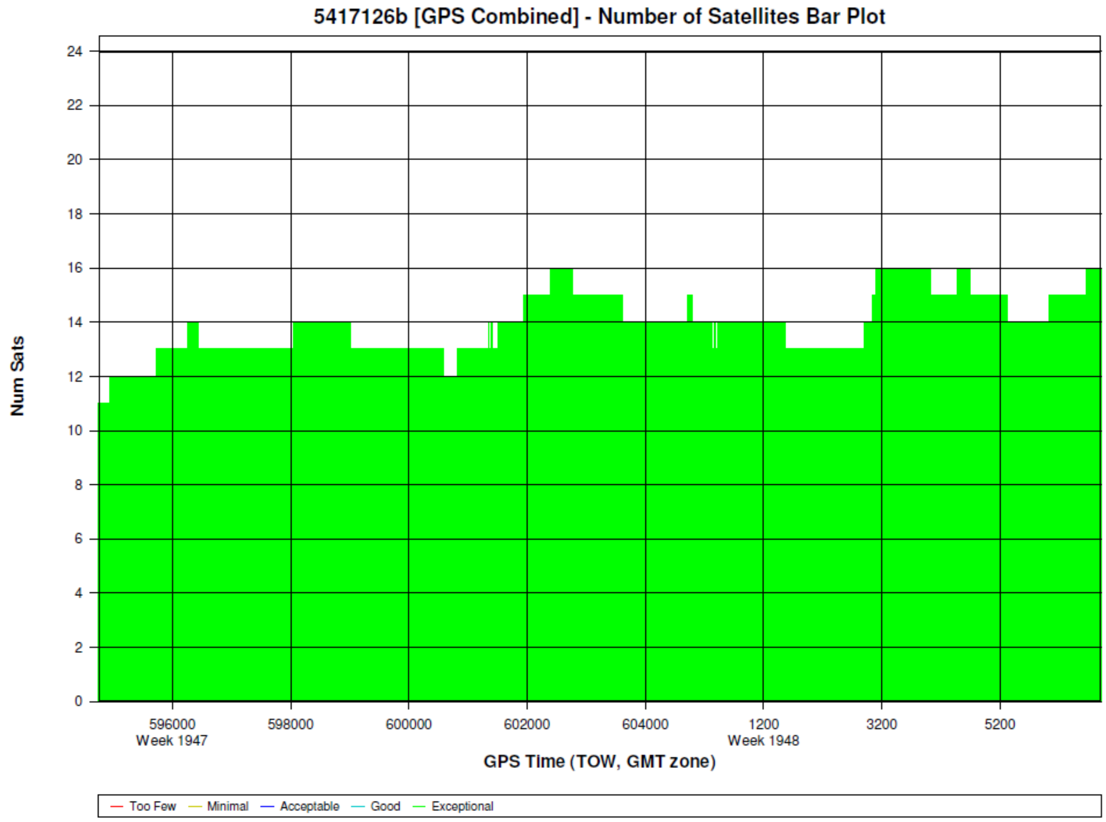
MISSION 6 – 5417126B GNSS PROCESSING




Project: 5417126b
GrafNav v8.50.4320
5417126b [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
596000
Week 1947
598000
600000
602000
604000
1200
Week 1948
3200
5200
GPS Time (TOW, GMT zone)
East
North
Up


Project: 5417126b
GrafNav v8.50.4320
5417126b [GPS Combined] - PDOP Plot
PDOP
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
596000
Week 1947
598000
600000
602000
604000
1200
Week 1948
3200
5200
GPS Time (TOW, GMT zone)
PDOP

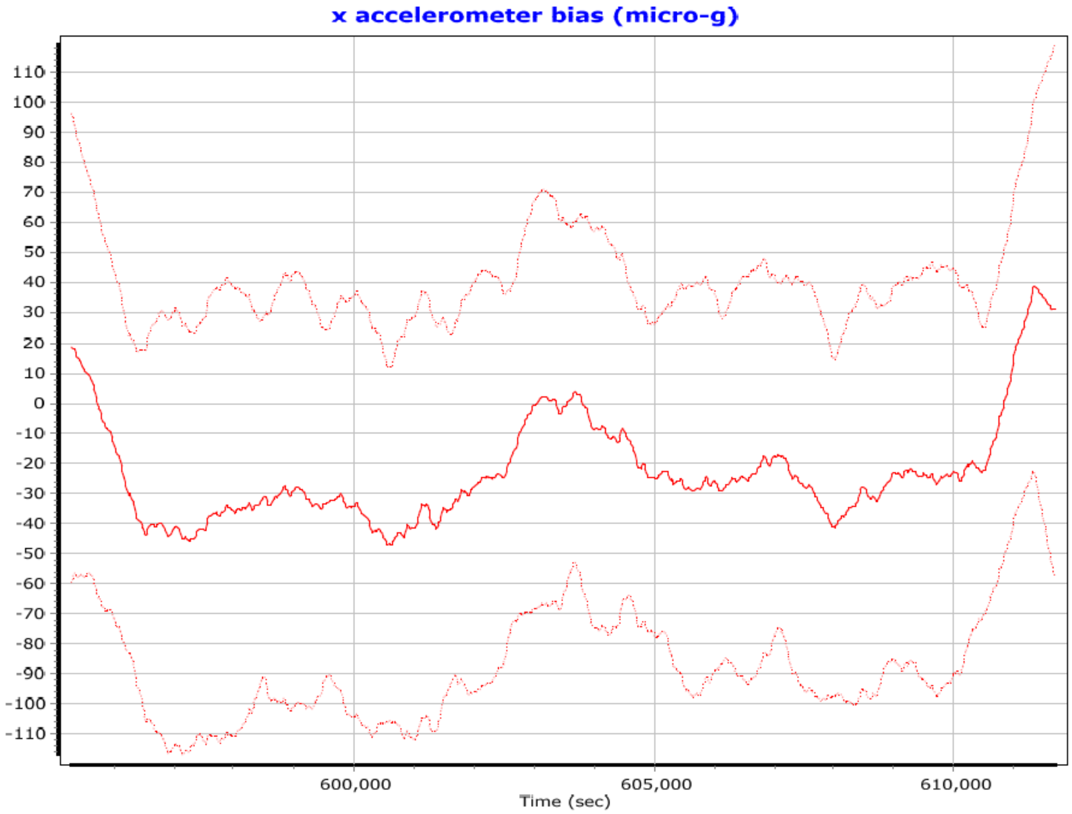
Project: 5417126b GrafNav v8.50.4320

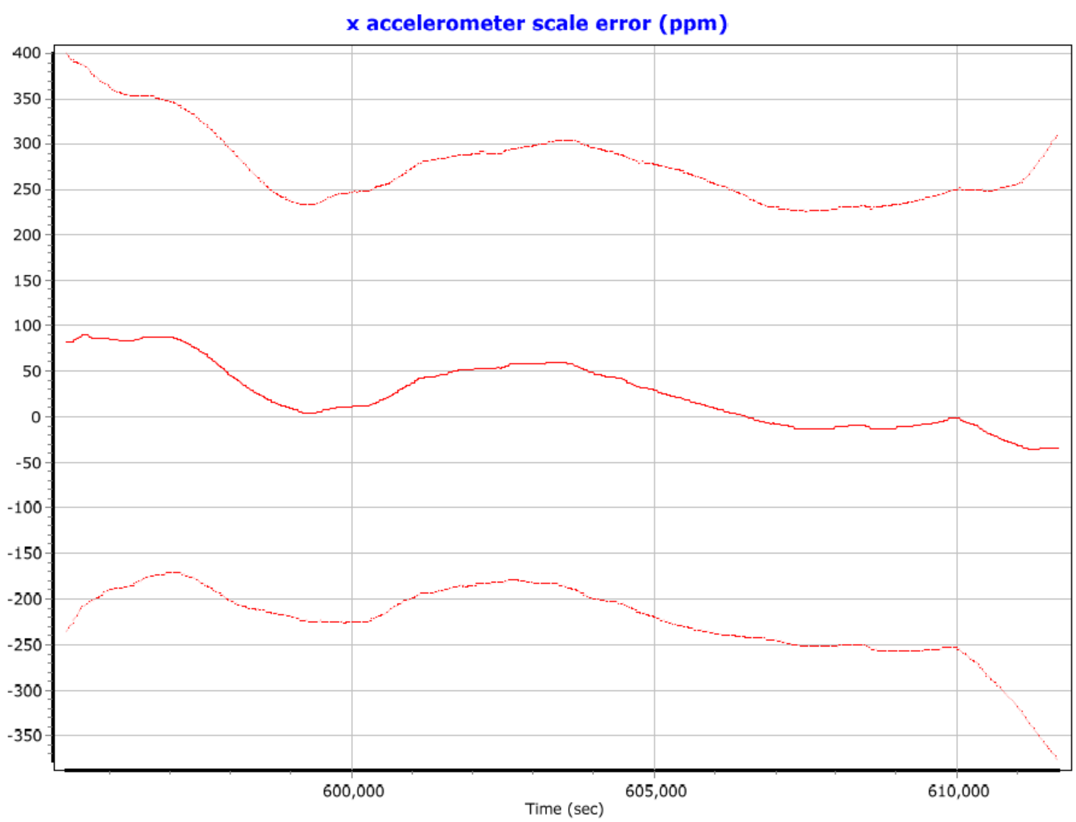


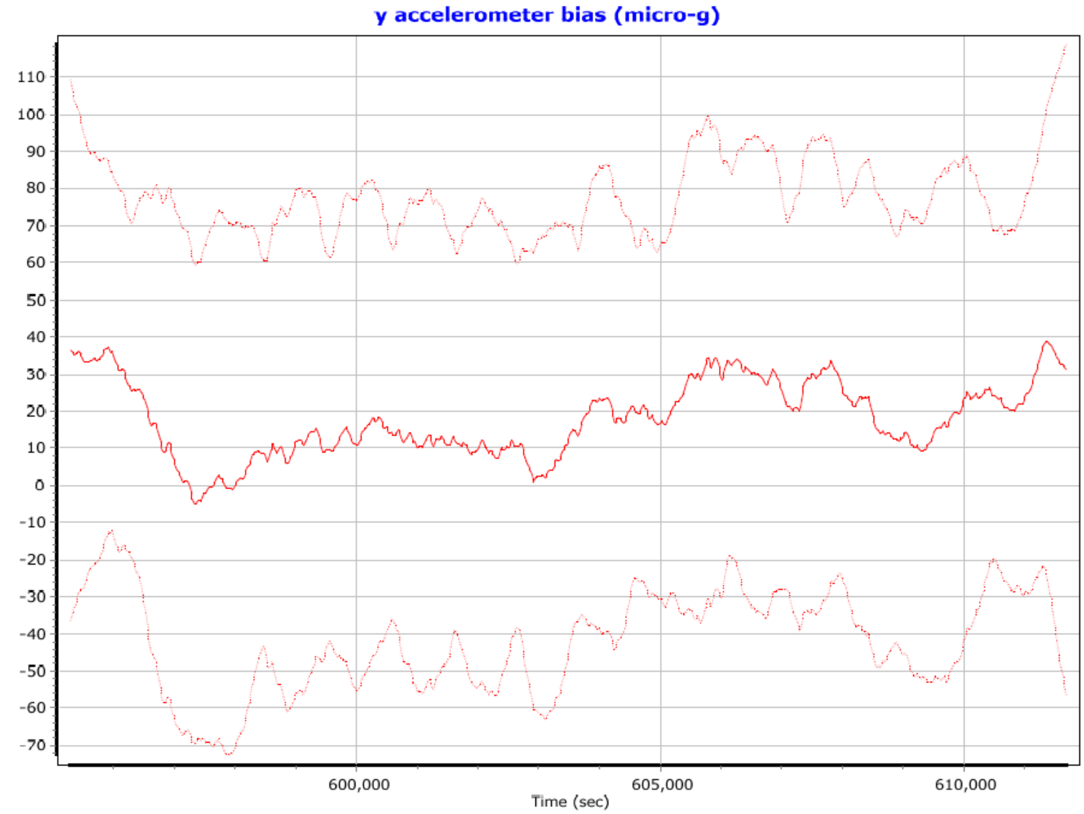

```
          Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417126b\05_INS-GPS_PROC\01_POS\5417126b\5417126b\GNSS\5417126b.gnv
Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      16973
      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:   0.0176 (m)
      C/A Code:   0.85 (m)
      L1 Doppler: 0.793 (m/s)

Fwd/Rev Separation RMS Values:
      East:       0.007 (m)
      North:      0.011 (m)
      Height:     0.028 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (16963 occurances):
      East:       0.007 (m)
```

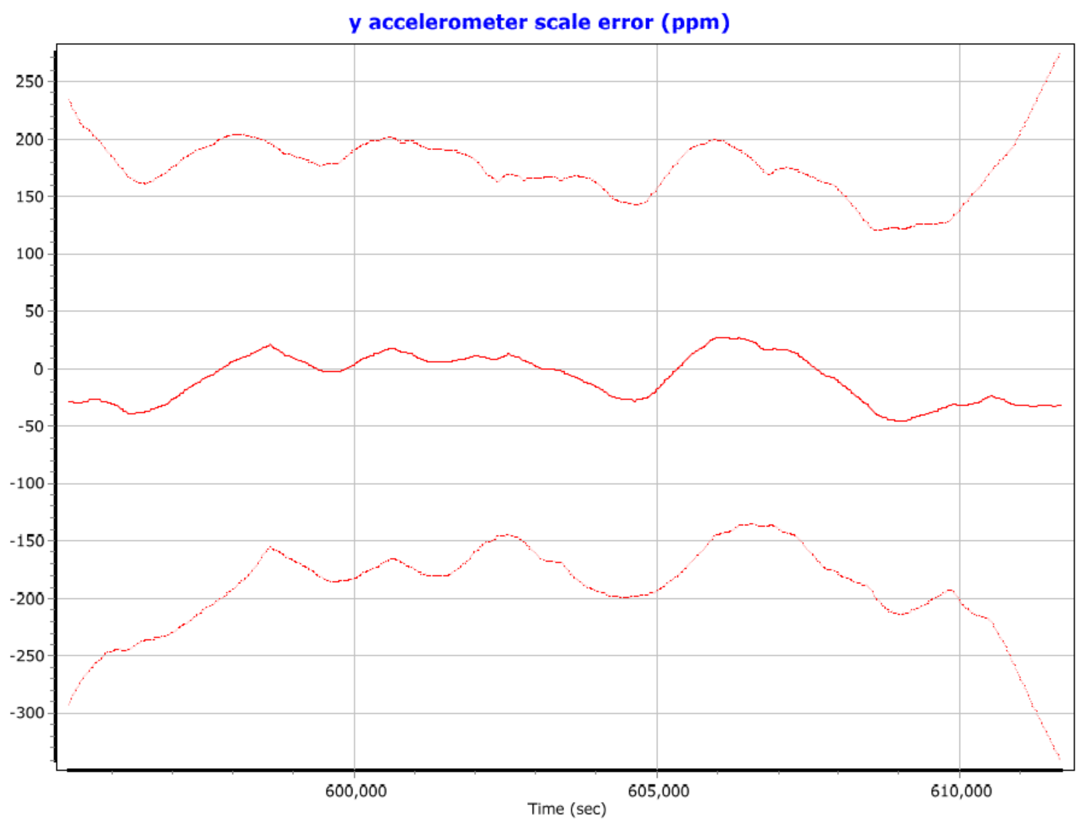
```
      North:       0.011 (m)
      Height:      0.021 (m)

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:          63.937 (km)
      Minimum:          6.050 (km)
      Average:          40.406 (km)
      First Epoch:      21.791 (km)
      Last Epoch:       21.785 (km)
```

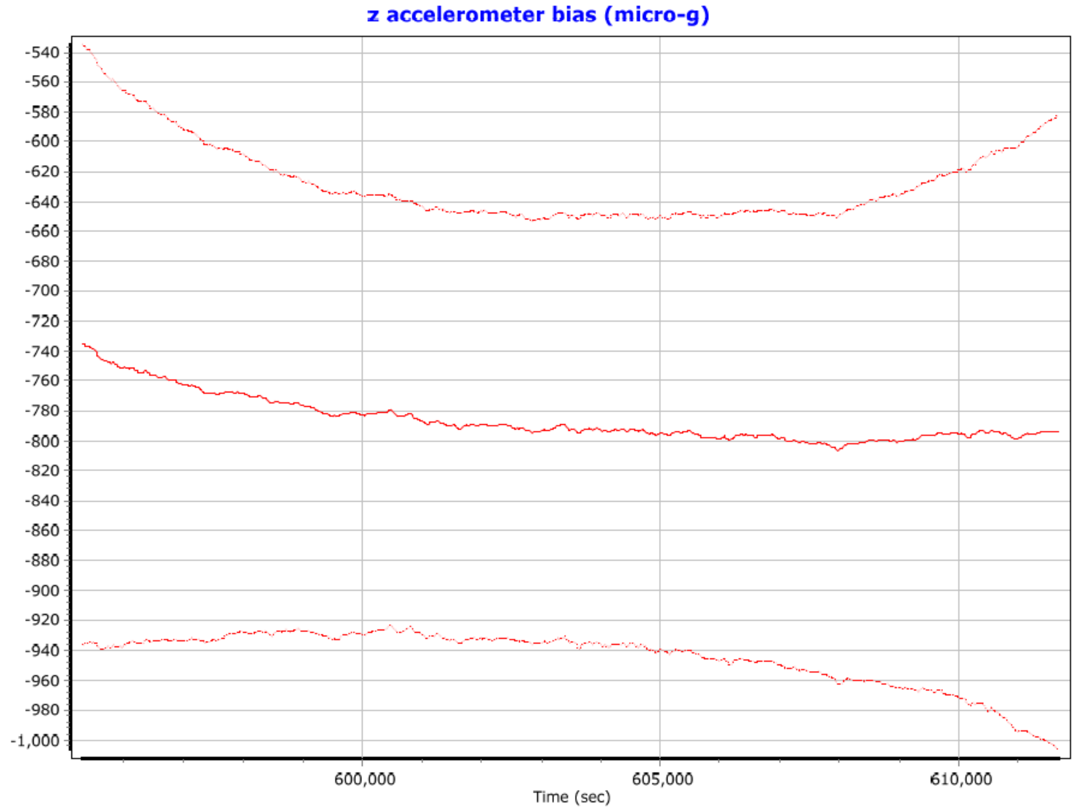
MISSION 6 – 5417126B SENSOR ERRORS

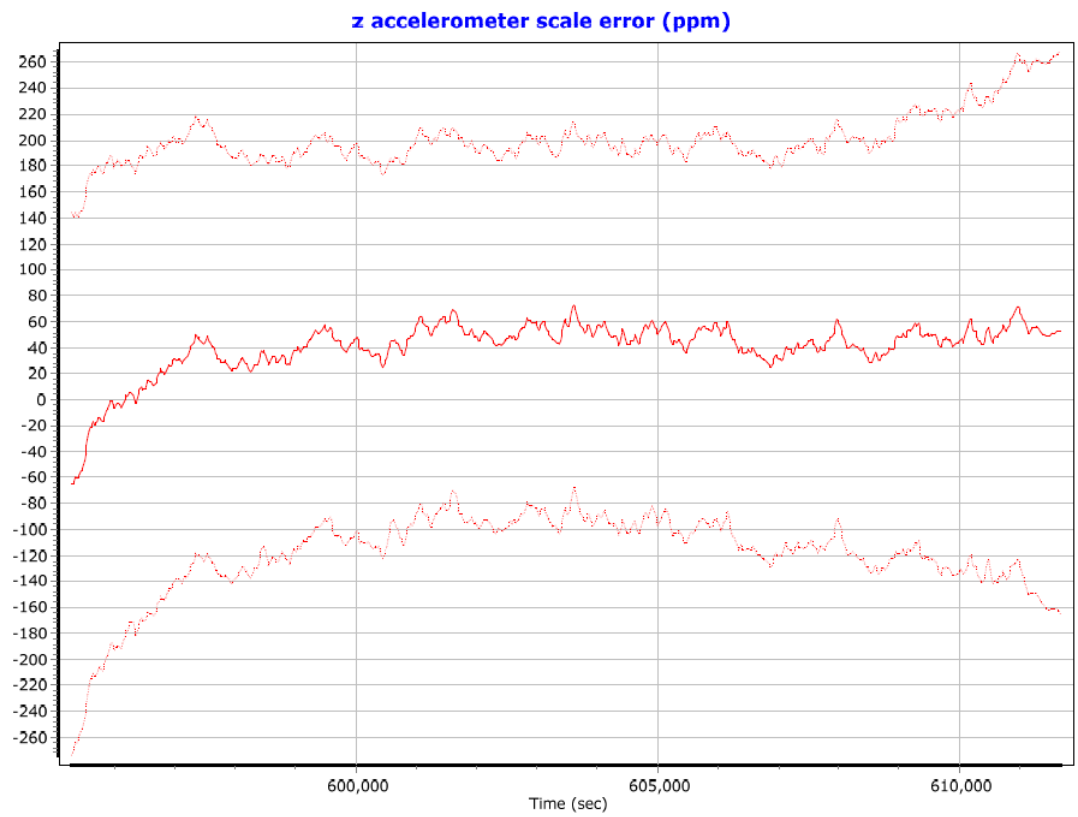


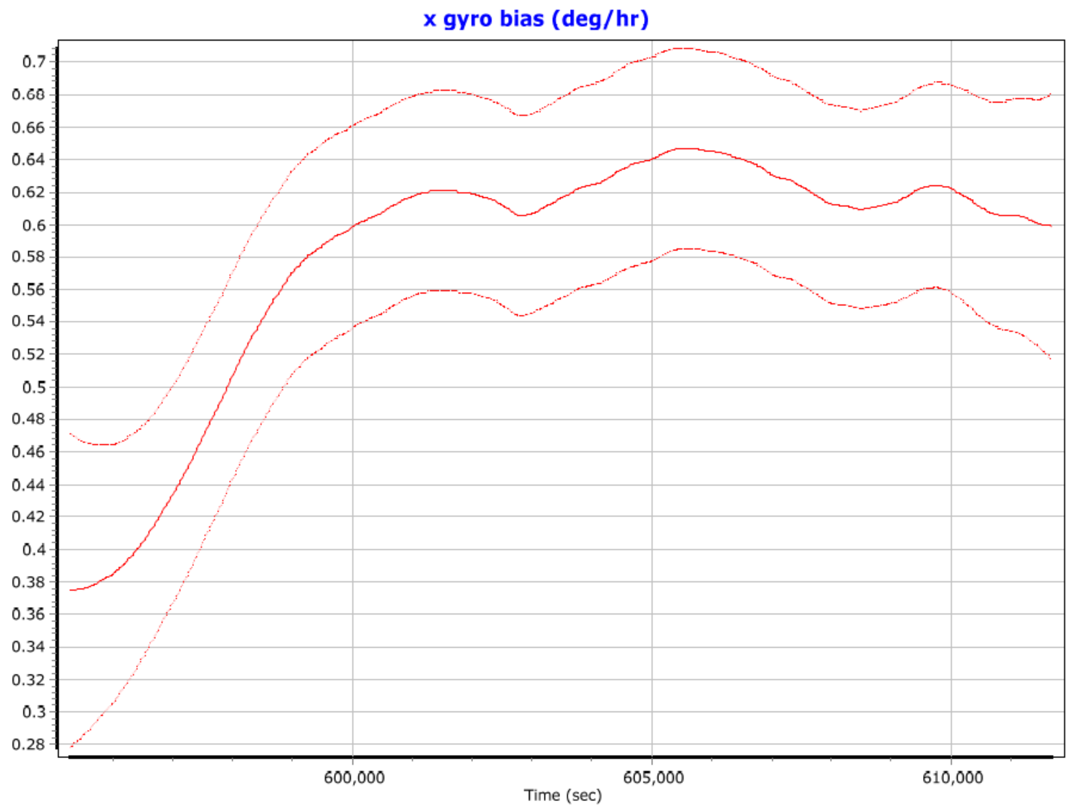


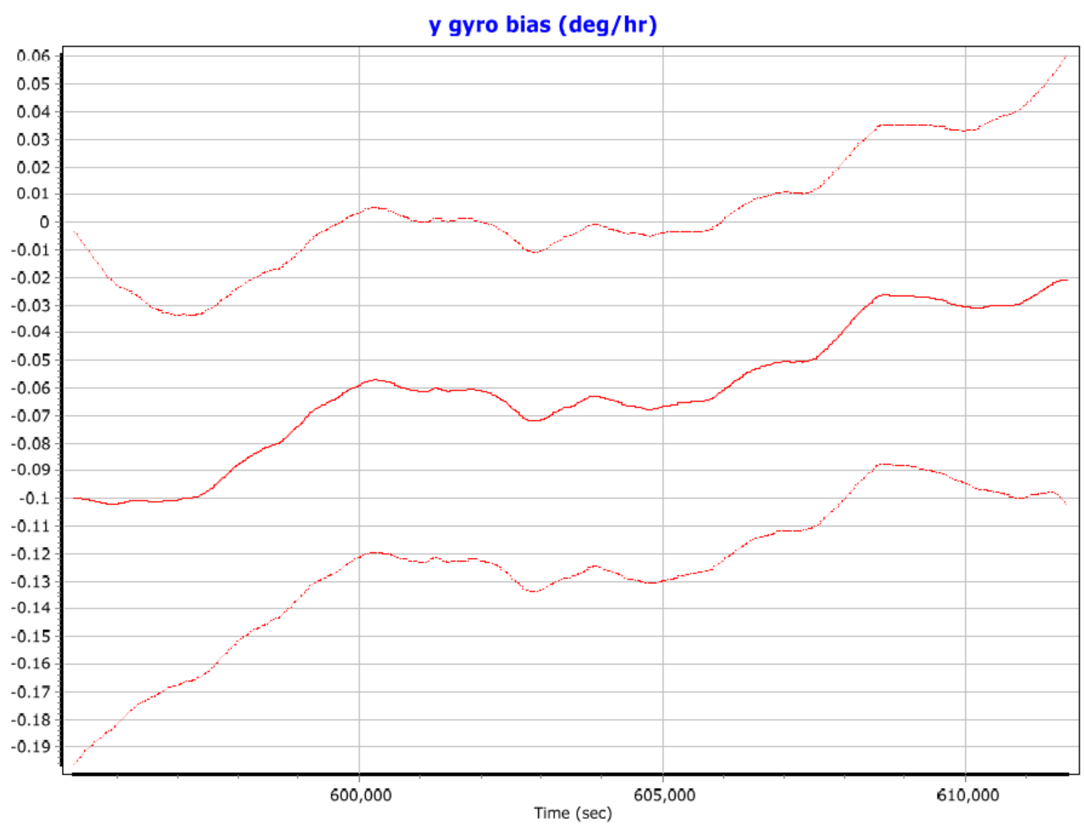

y accelerometer bias (micro-g)
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
600,000
605,000
610,000
Time (sec)

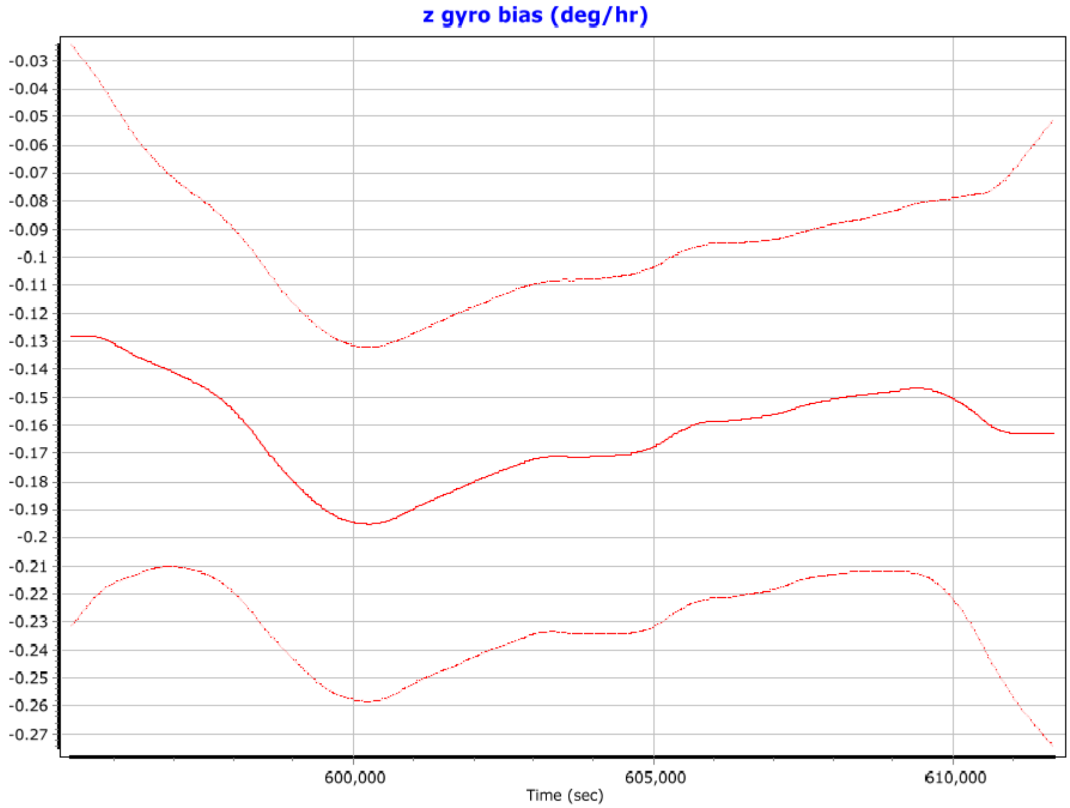

y accelerometer scale error (ppm)
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
600,000
605,000
610,000
Time (sec)


z accelerometer bias (micro-g)
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
-920
-940
-960
-980
-1,000
600,000
605,000
610,000
Time (sec)

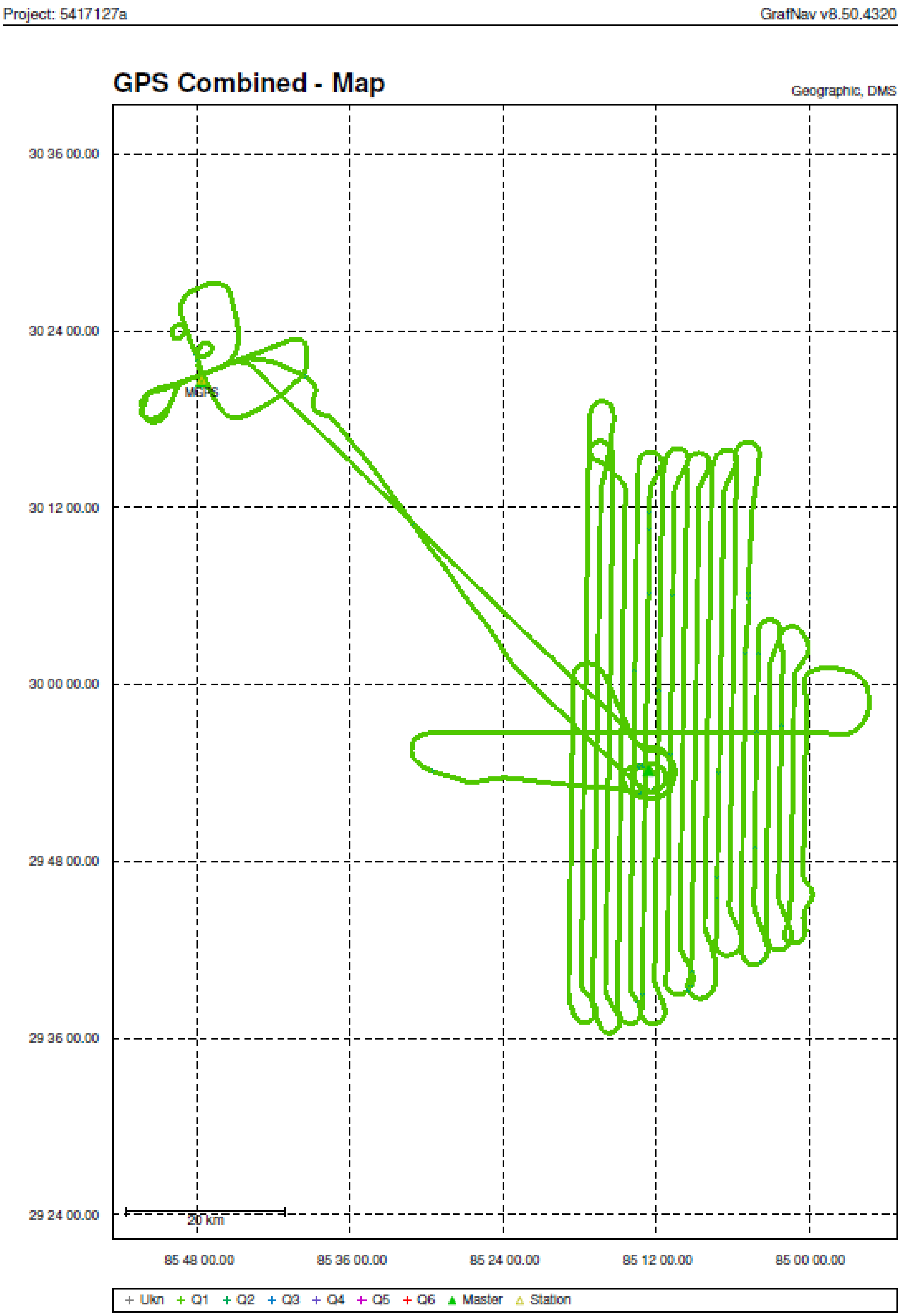

z accelerometer scale error (ppm)
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
600,000
605,000
610,000
Time (sec)


x gyro bias (deg/hr)
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
0.32
0.3
0.28
600,000
605,000
610,000
Time (sec)

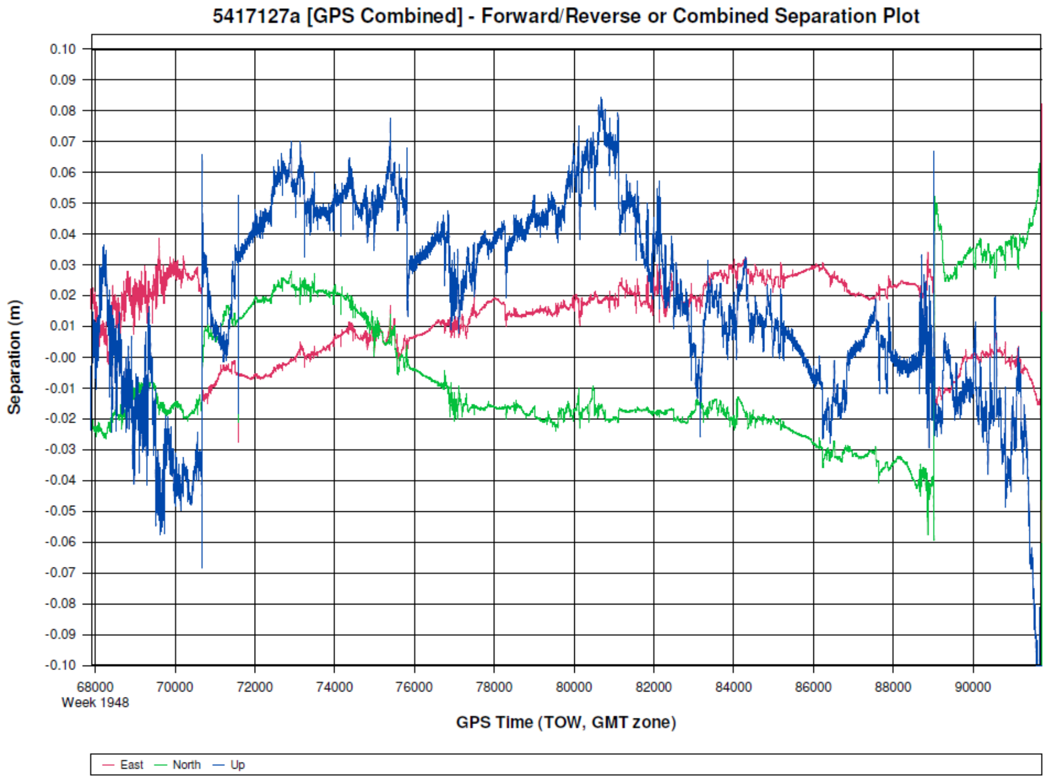

y gyro bias (deg/hr)
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
600,000
605,000
610,000
Time (sec)


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
600,000
605,000
610,000
Time (sec)

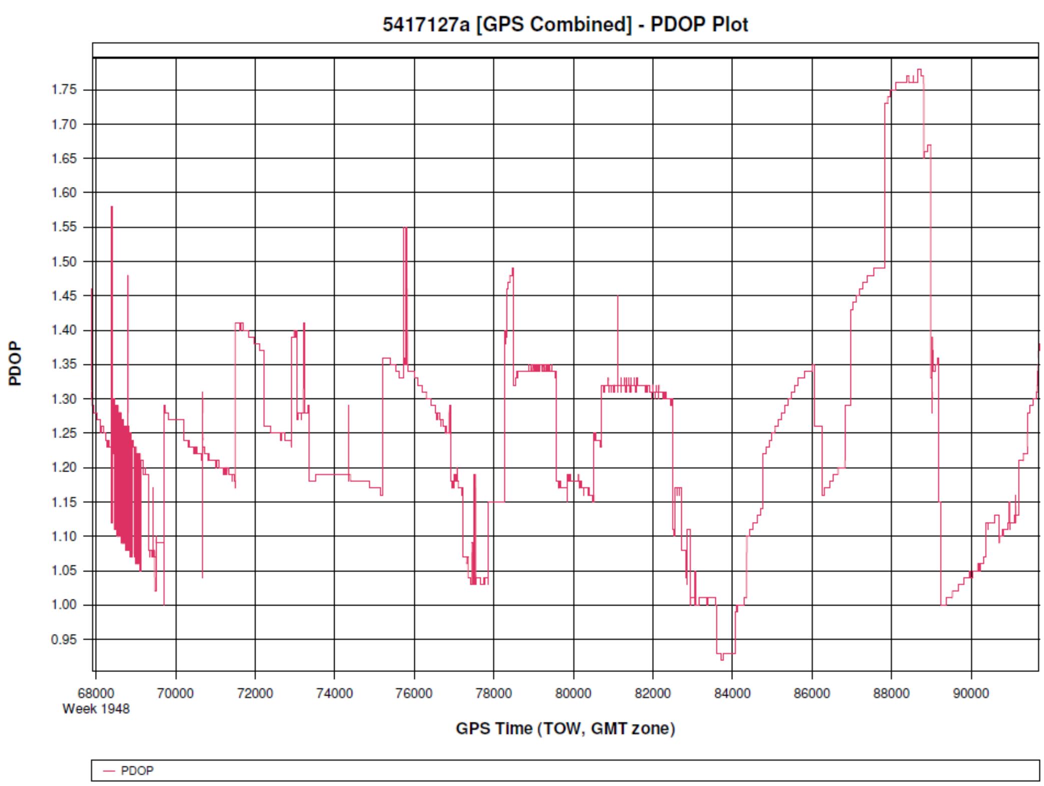
MISSION 7 – 5417127A GNSS PROCESSING



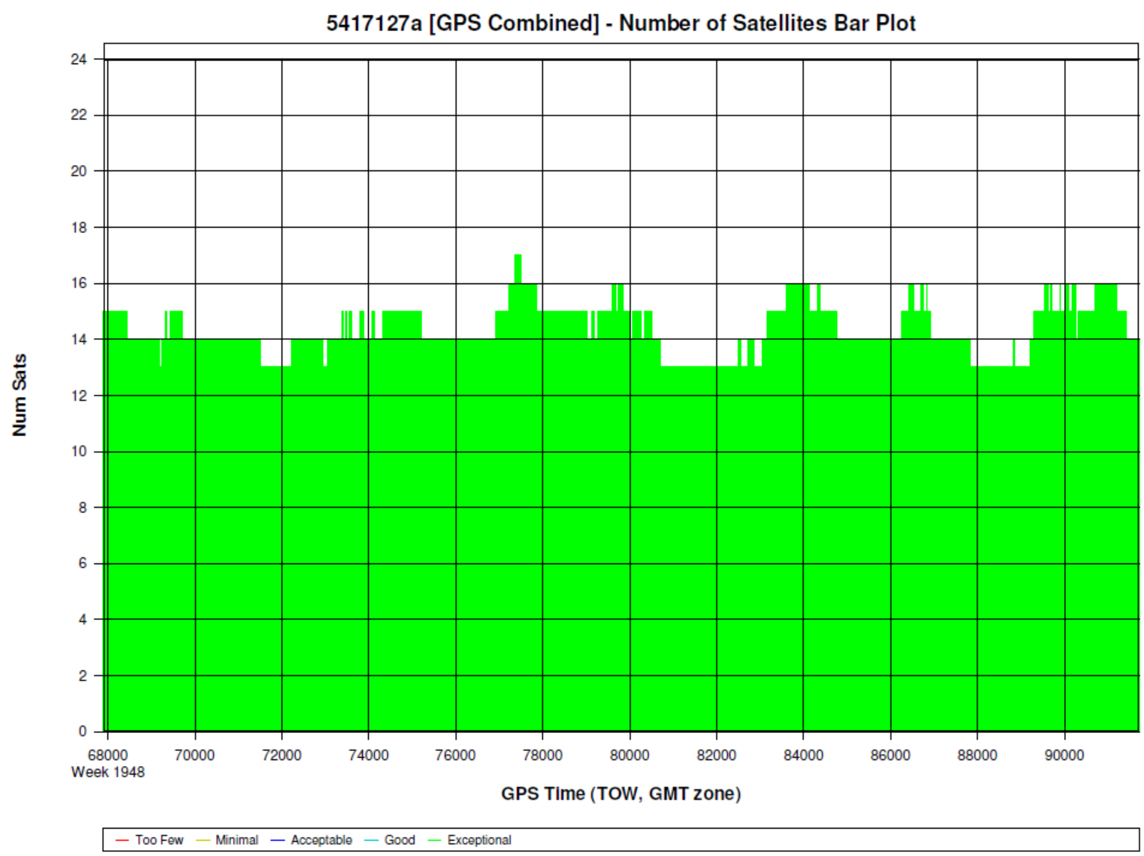
Project: 5417127a GrafNav v8.50.4320



Project: 5417127a GrafNav v8.50.4320



Project: 5417127a GrafNav v8.50.4320



Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417127a\05_INS-GPS_PROC\01_POS\5417127a\5417127a\GNSS\5417127a.gnv
Solution Type: Combined

Number of Epochs:
Total in GPB file: 23845
No processed position: 0
Missing Fwd or Rev: 6
With bad C/A code: 0
With bad L1 Phase: 0

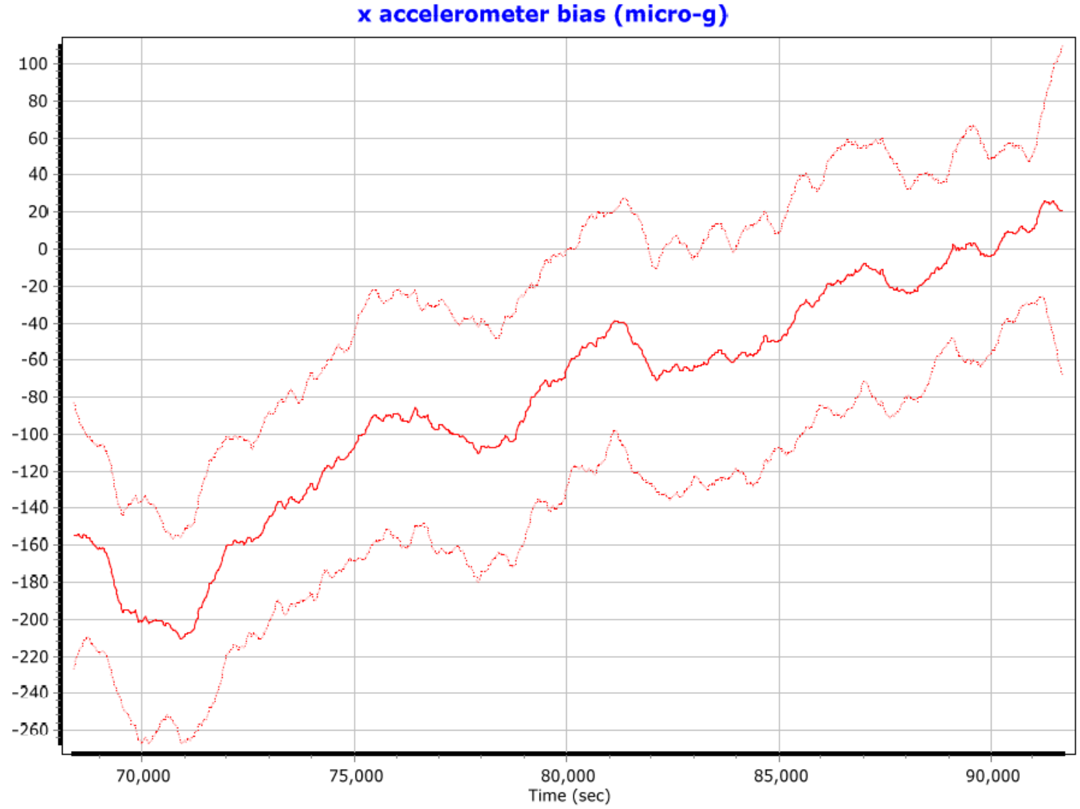
Measurement RMS Values:
L1 Phase: 0.0197 (m)
C/A Code: 0.91 (m)
L1 Doppler: 0.673 (m/s)

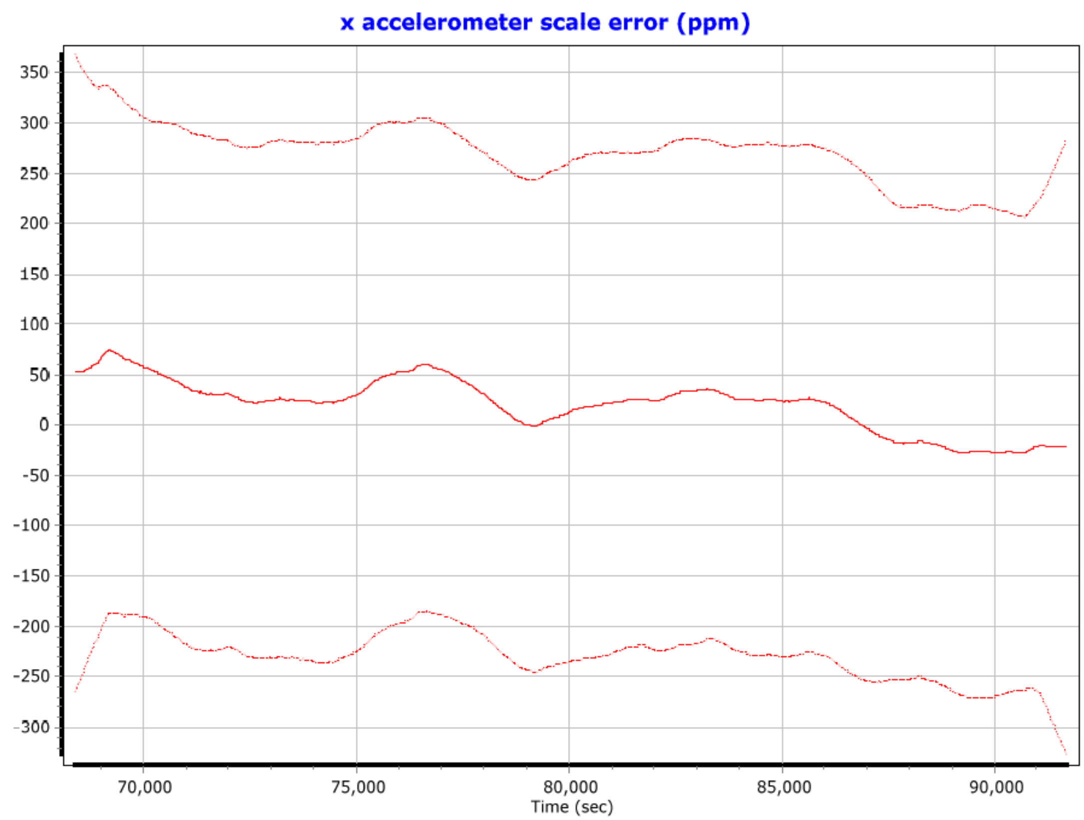
Fwd/Rev Separation RMS Values:
East: 0.018 (m)
North: 0.025 (m)
Height: 0.066 (m)

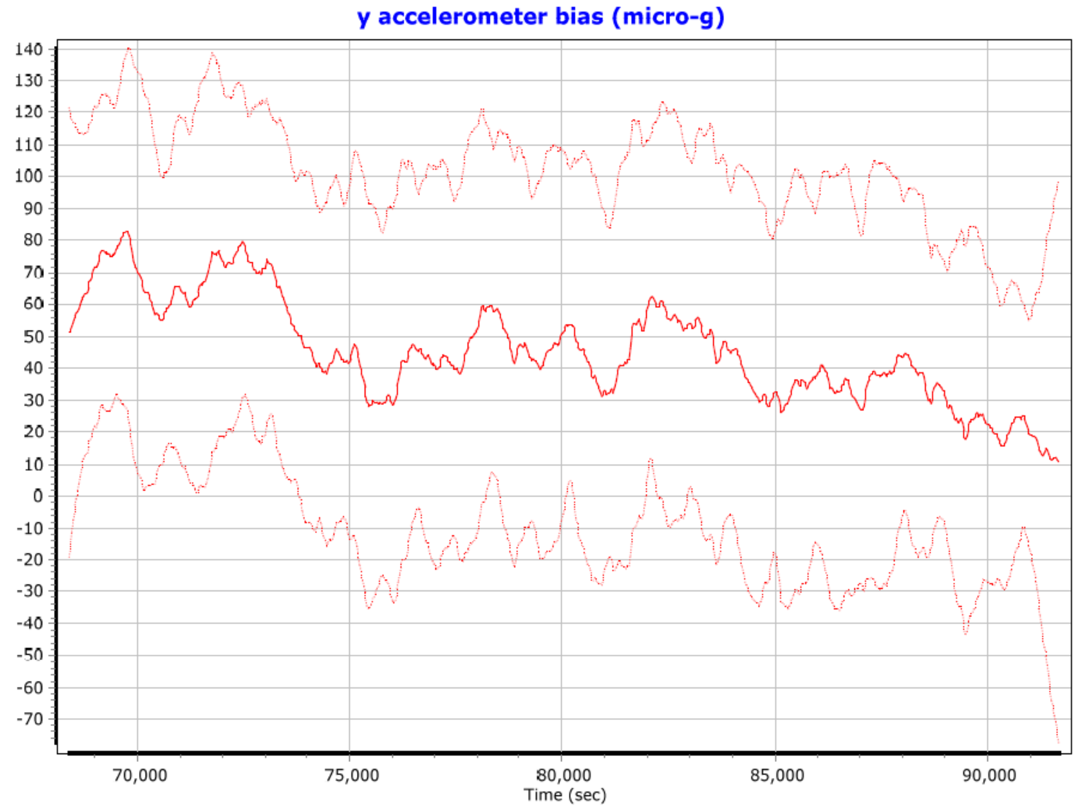
Fwd/Rev Sep. RMS for dual FWD/REV fixes (23805 occurances):

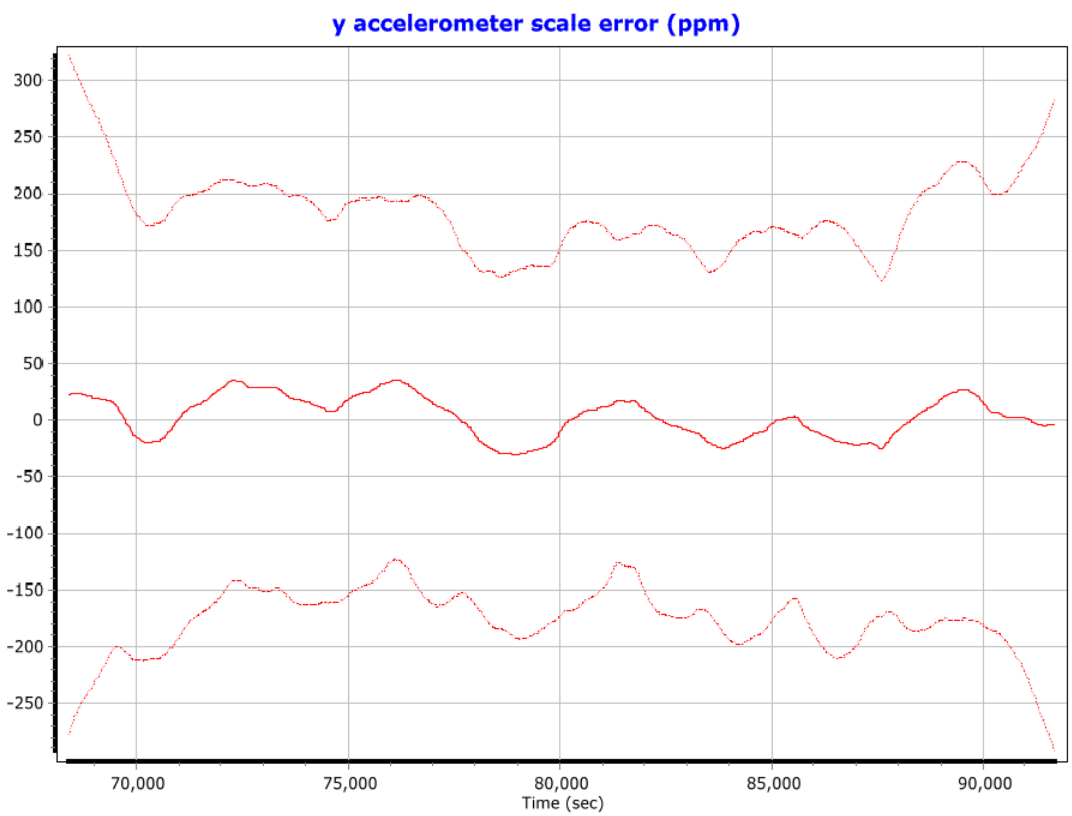
```
      East:        0.017 (m)
      North:       0.023 (m)
      Height:      0.036 (m)

Quality Number Percentages:
      Q 1:  99.4 %
      Q 2:   0.6 %
      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:          74.585 (km)
      Minimum:          3.975 (km)
      Average:          41.329 (km)
      First Epoch:      33.593 (km)
      Last Epoch:       37.104 (km)
```

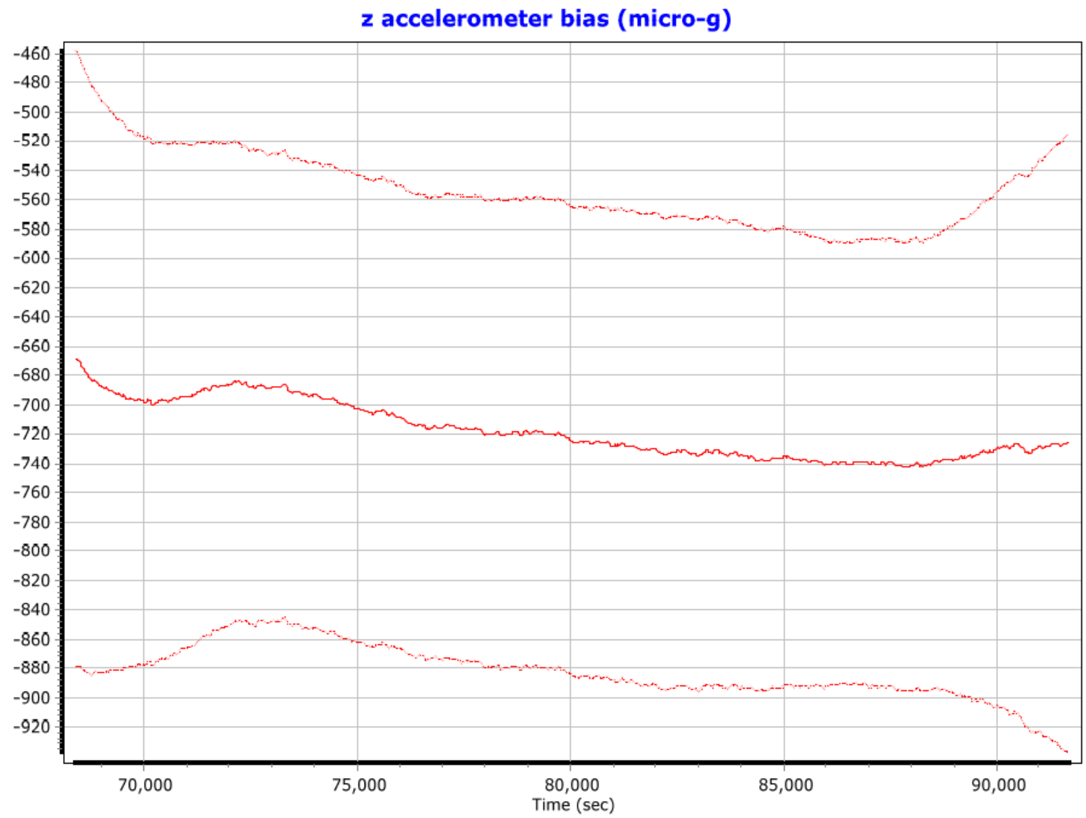
MISSION 7 – 5417127A SENSOR ERRORS

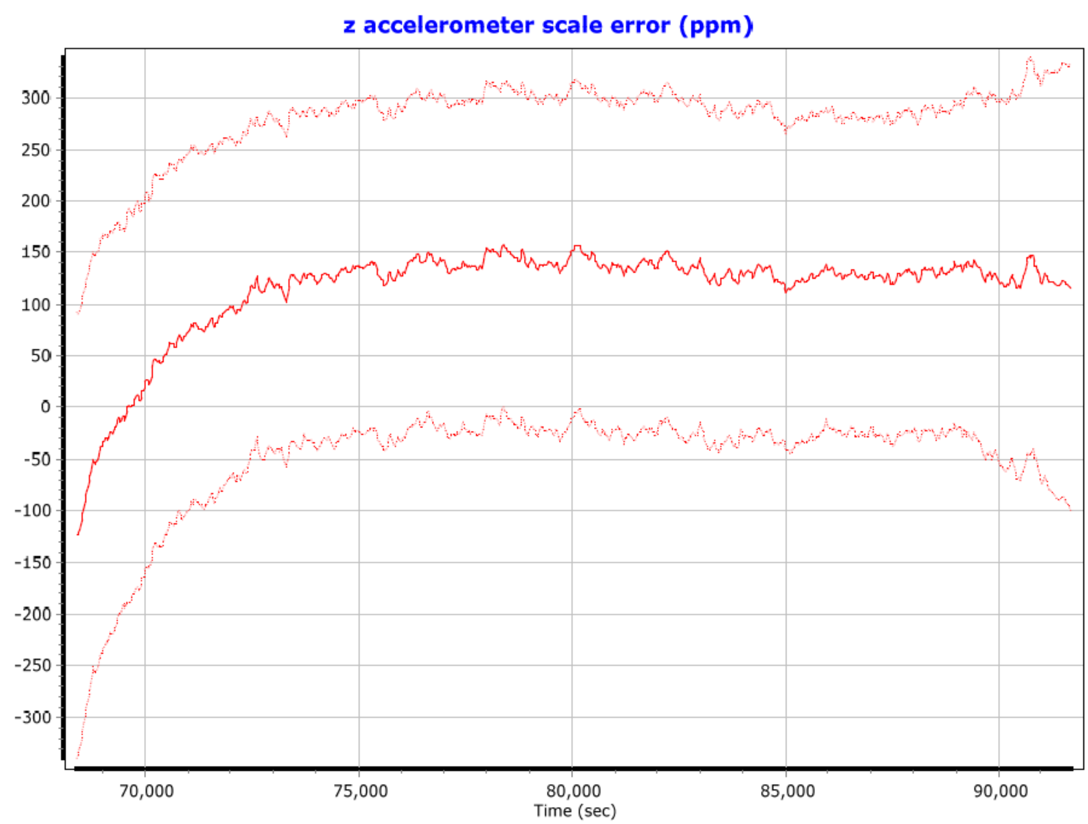


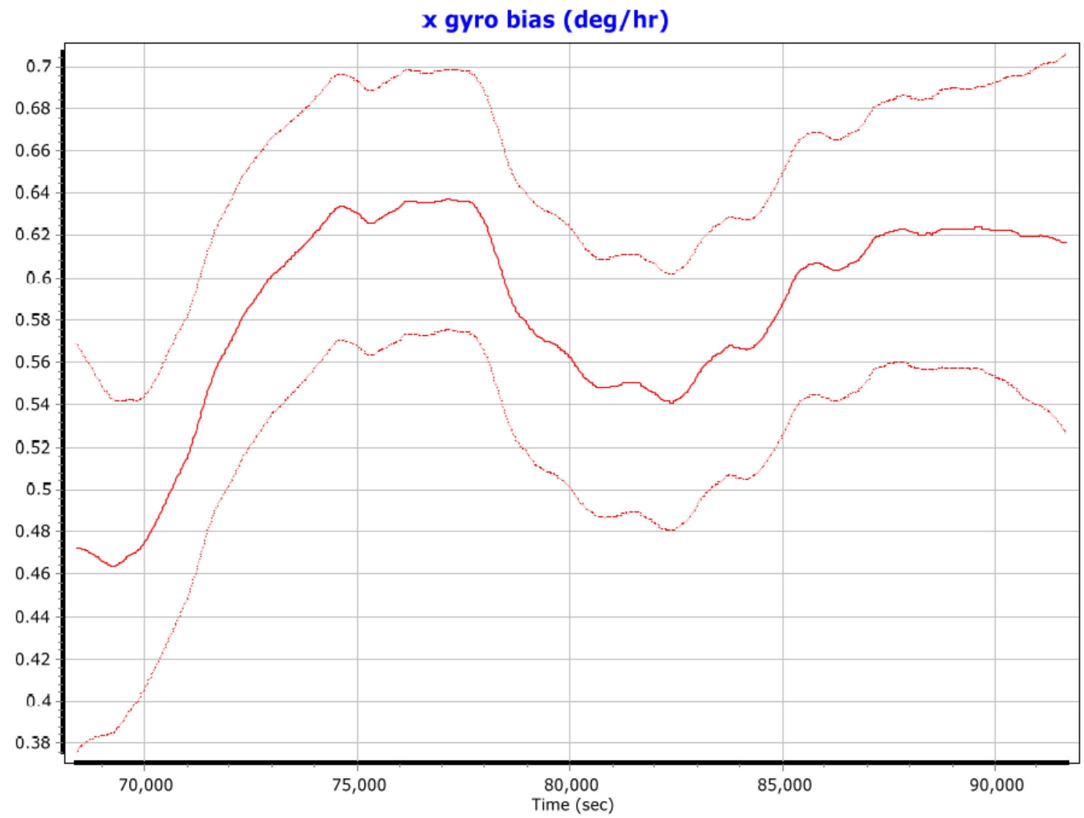


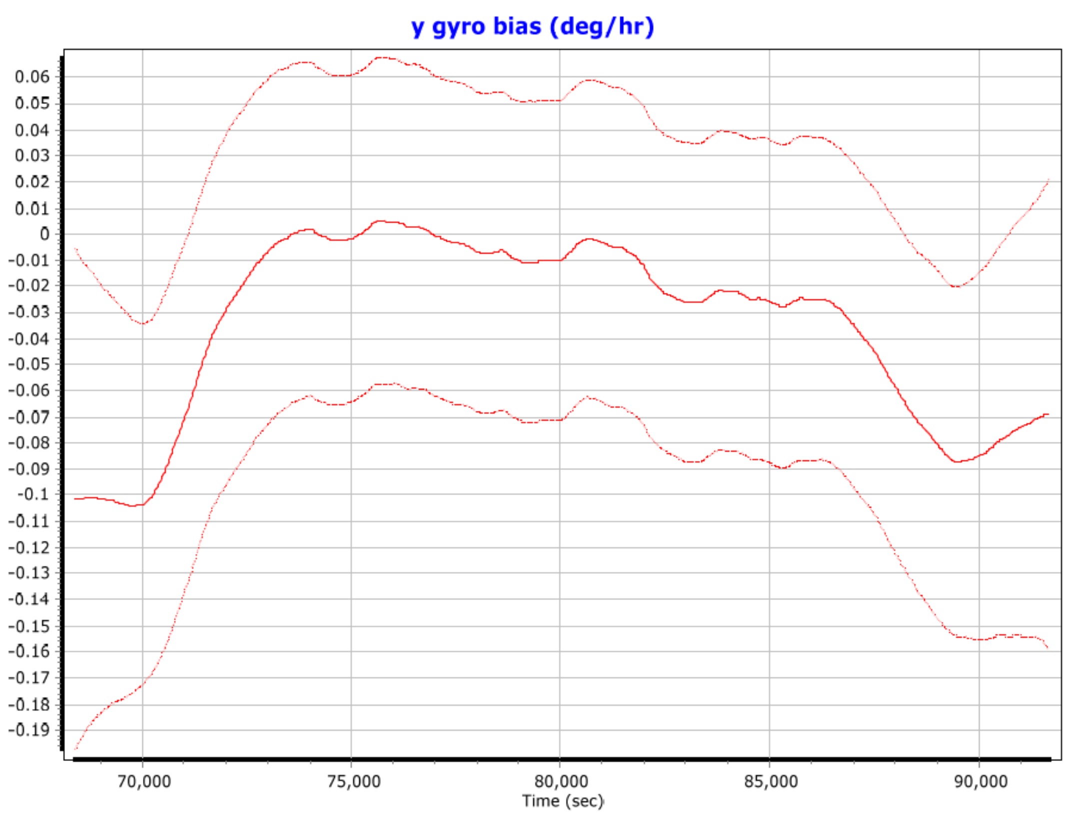

y accelerometer bias (micro-g)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
70,000
75,000
80,000
85,000
90,000
Time (sec)

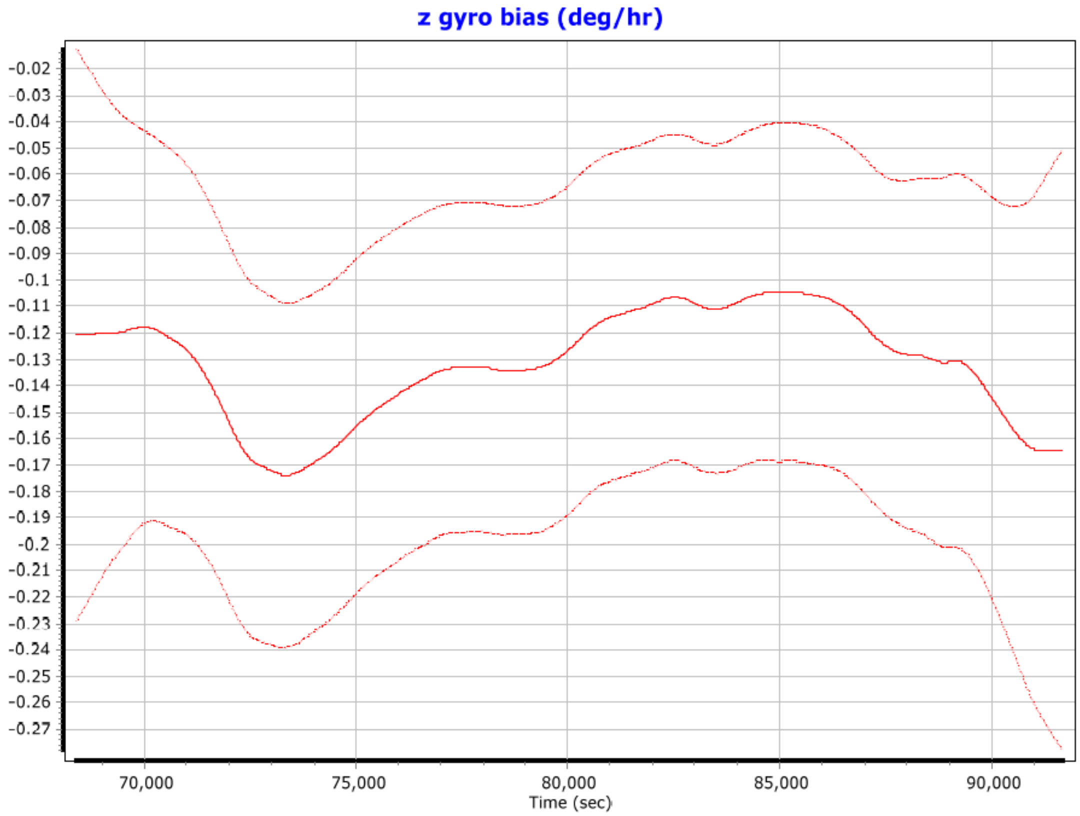

y accelerometer scale error (ppm)
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
70,000
75,000
80,000
85,000
90,000
Time (sec)


z accelerometer bias (micro-g)
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
-920
70,000
75,000
80,000
85,000
90,000
Time (sec)

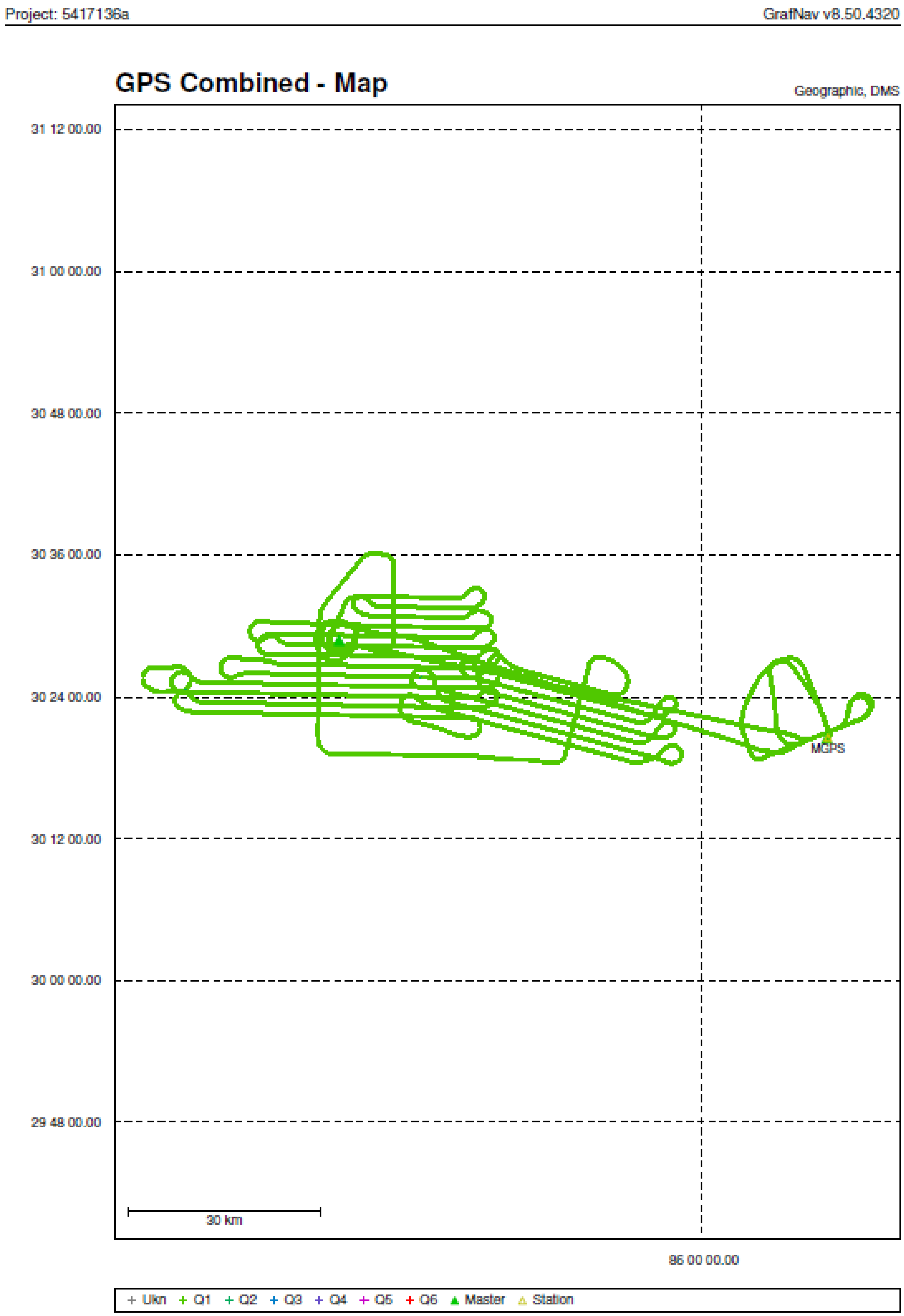

z accelerometer scale error (ppm)
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
70,000
75,000
80,000
85,000
90,000
Time (sec)


x gyro bias (deg/hr)
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
70,000
75,000
80,000
85,000
90,000
Time (sec)

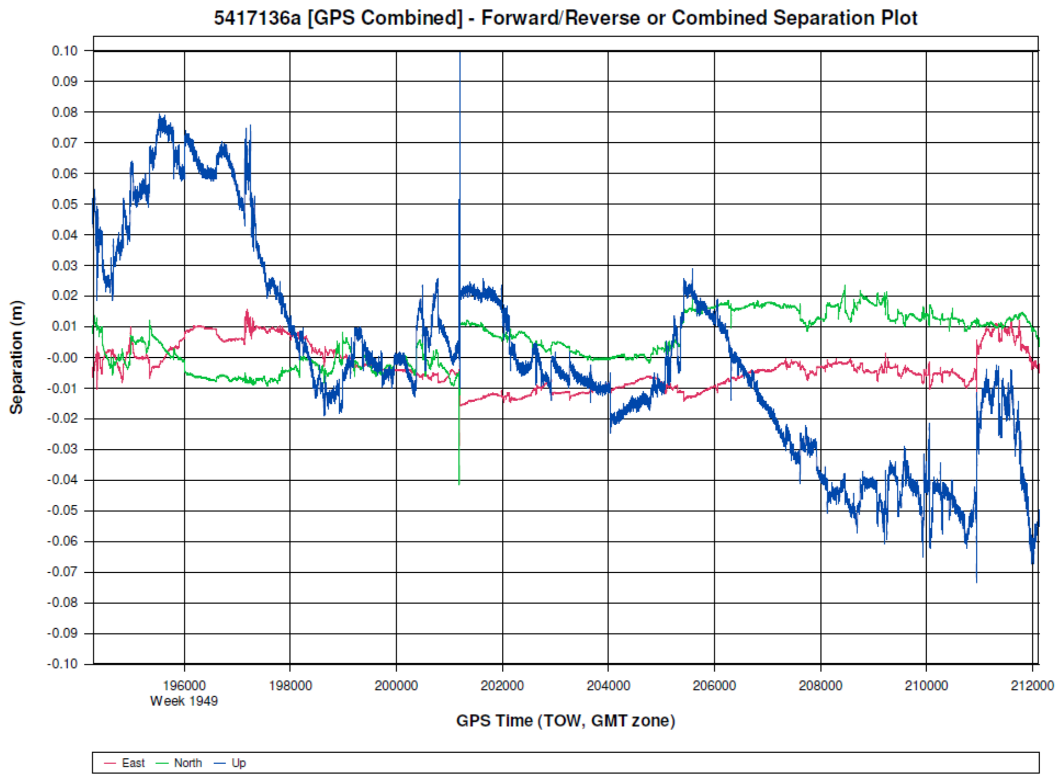

y gyro bias (deg/hr)
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
70,000
75,000
80,000
85,000
90,000
Time (sec)


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
70,000
75,000
80,000
85,000
90,000
Time (sec)

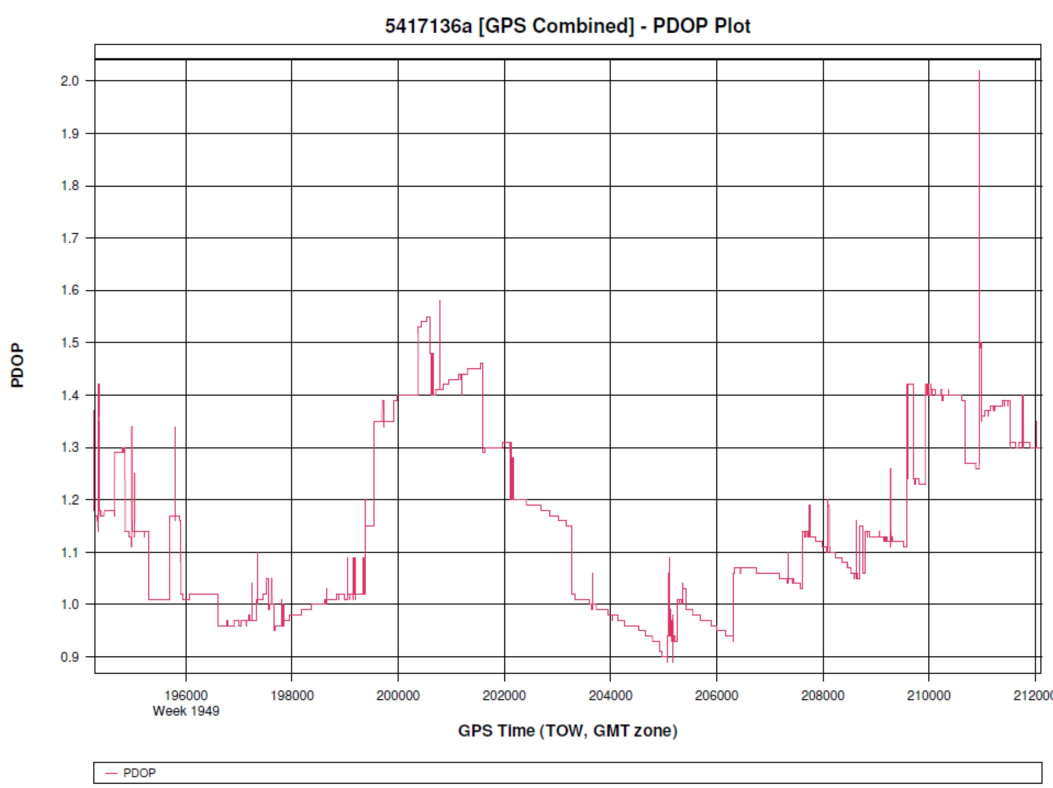
MISSION 8 – 5417136A GNSS PROCESSING



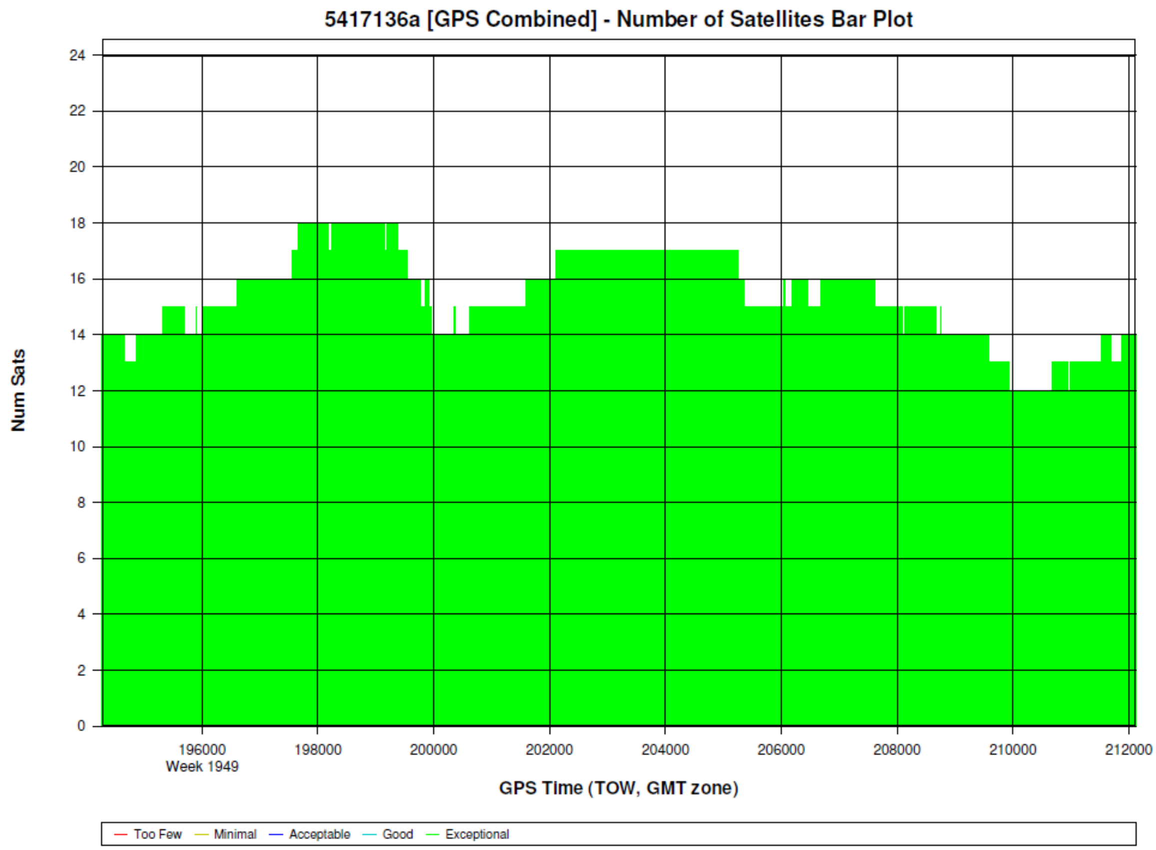
Project: 5417136a GrafNav v8.50.4320



Project: 5417136a GrafNav v8.50.4320



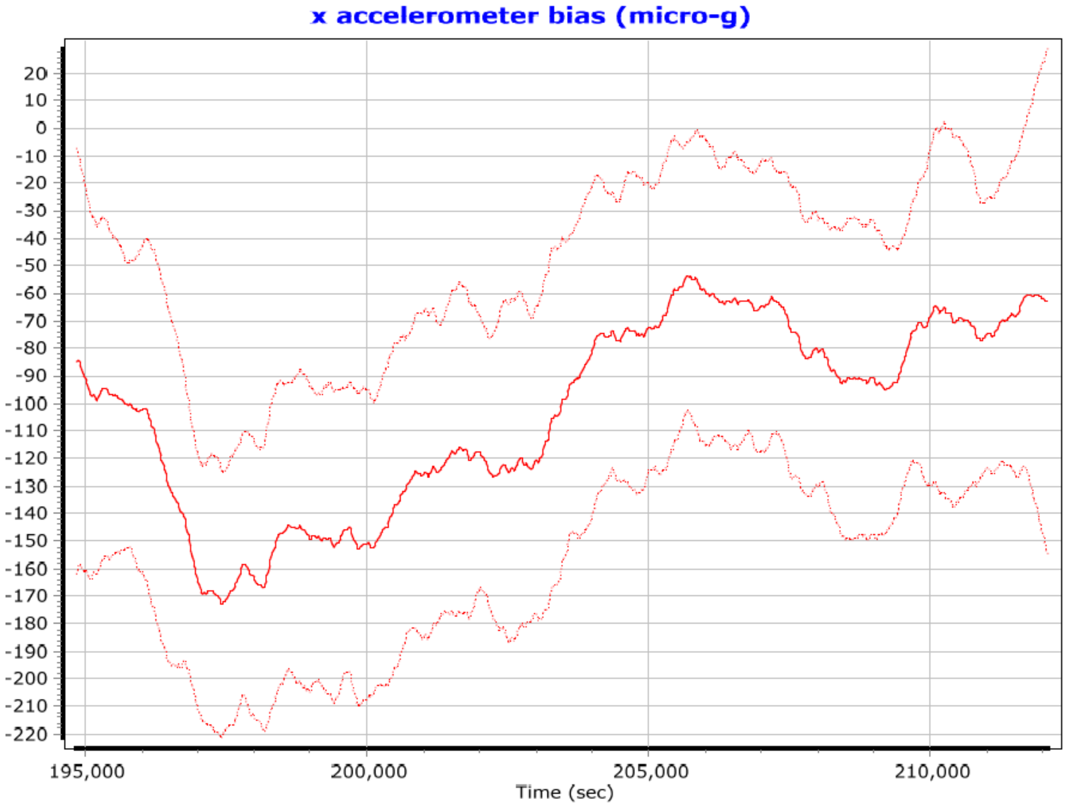
Project: 5417136a GrafNav v8.50.4320

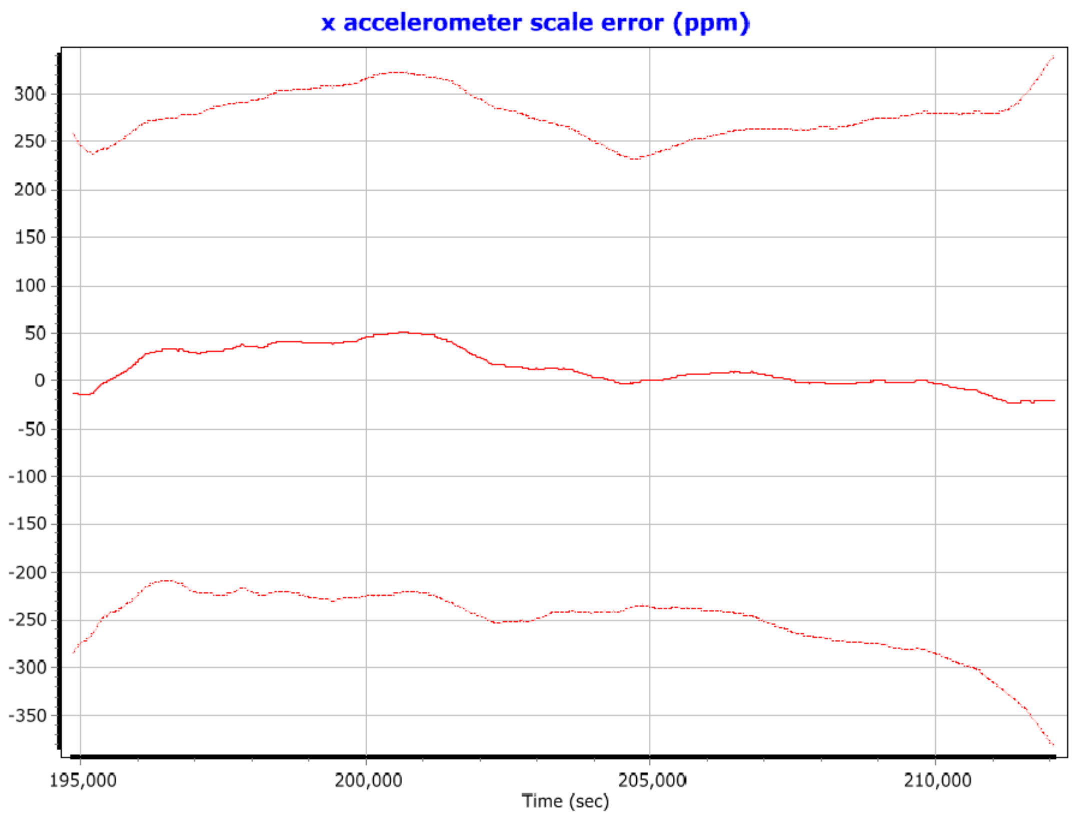


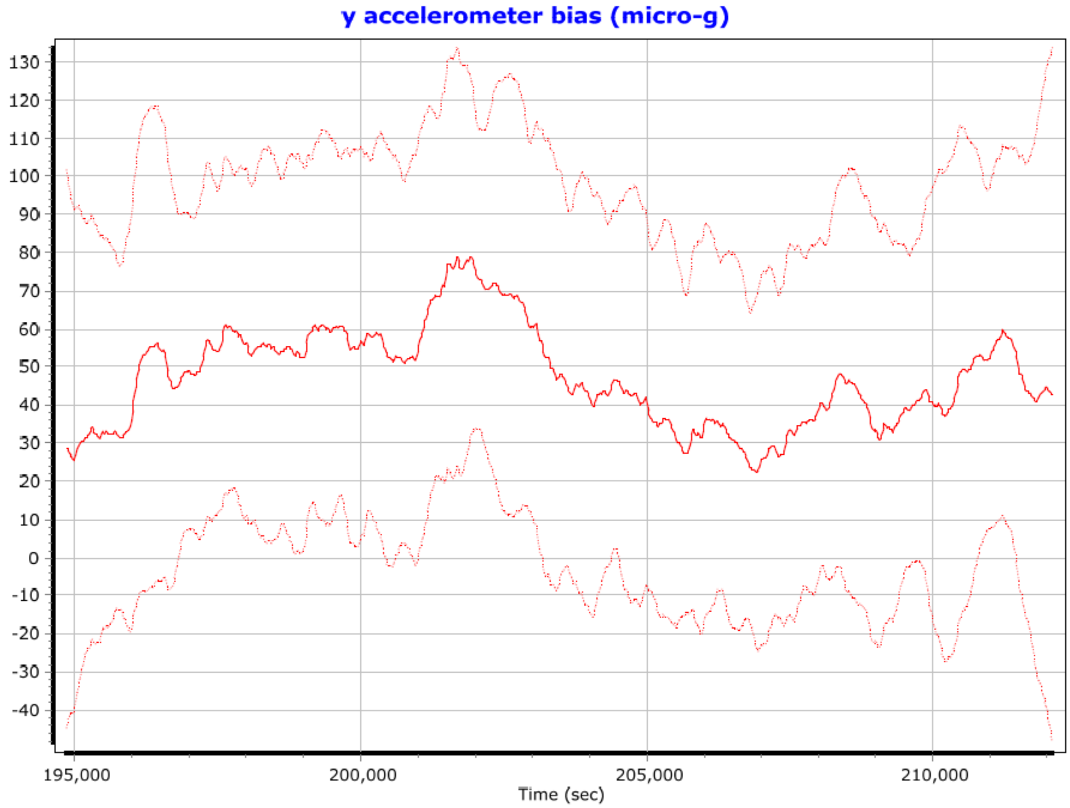

```
          Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417136a\05_INS-
GPS_PROC\01_POS\5417136a\5417136a\GNSS\5417136a.gnv
Solution Type:    Combined

Number of Epochs:
      Total in GPB file:      17863
      No processed position:  0
      Missing Fwd or Rev:     6
      With bad C/A code:      0
      With bad L1 Phase:      0

Measurement RMS Values:
      L1 Phase:   0.0187 (m)
      C/A Code:   0.72 (m)
      L1 Doppler: 0.762 (m/s)

Fwd/Rev Separation RMS Values:
      East:       0.008 (m)
      North:      0.010 (m)
      Height:     0.037 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (17856 occurances):
      East:       0.008 (m)
```

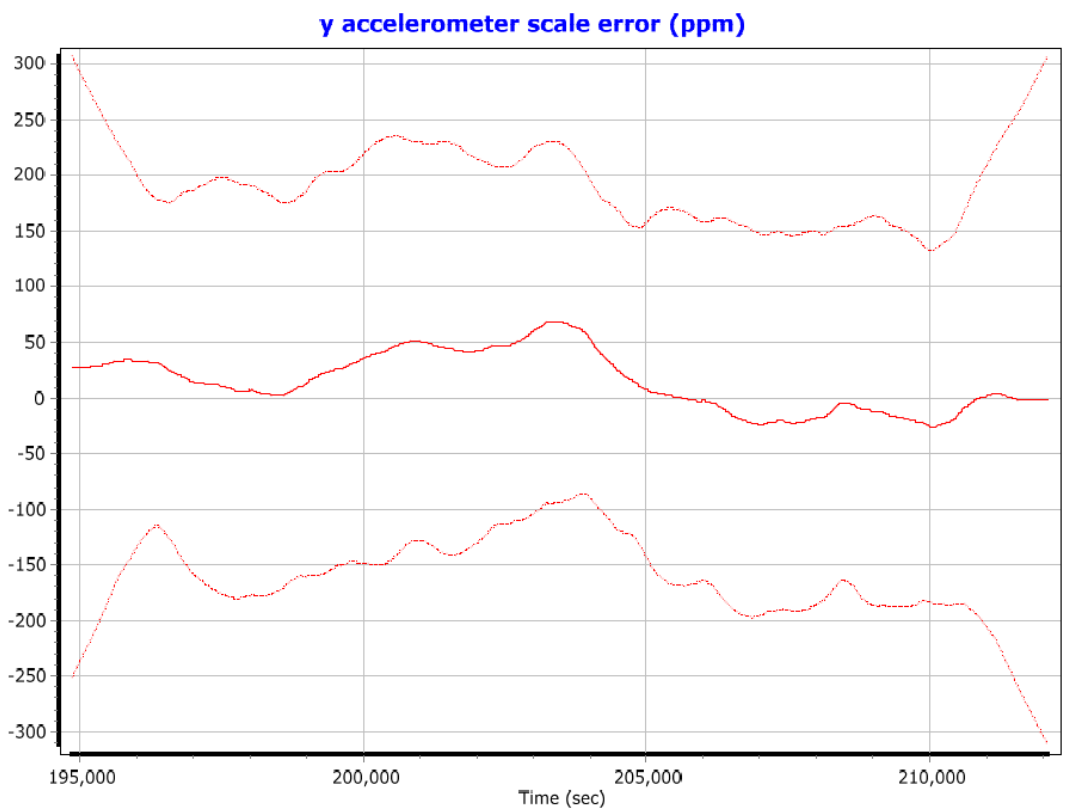
```
      North:      0.010 (m)
      Height:     0.033 (m)

Quality Number Percentages:
      Q 1:  99.8 %
      Q 2:   0.2 %
      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:          68.899 (km)
      Minimum:          2.104 (km)
      Average:          29.399 (km)
      First Epoch:      30.615 (km)
      Last Epoch:       39.001 (km)
```

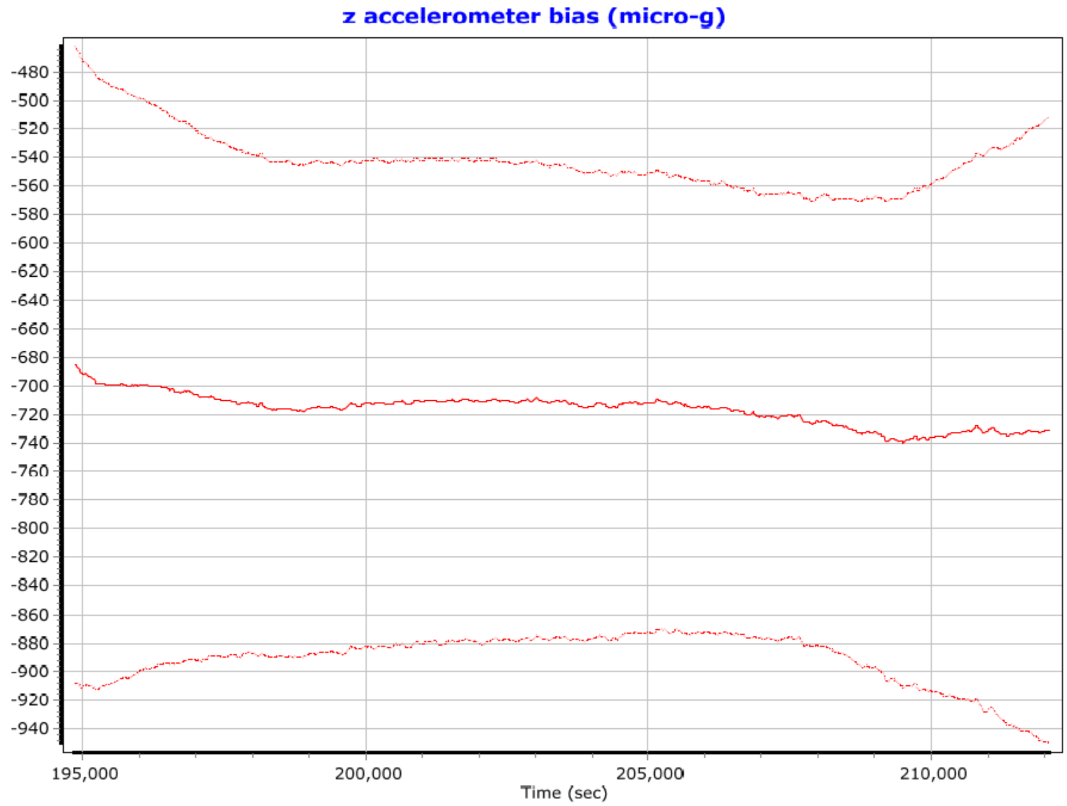
MISSION 8 – 5417136A SENSOR ERRORS

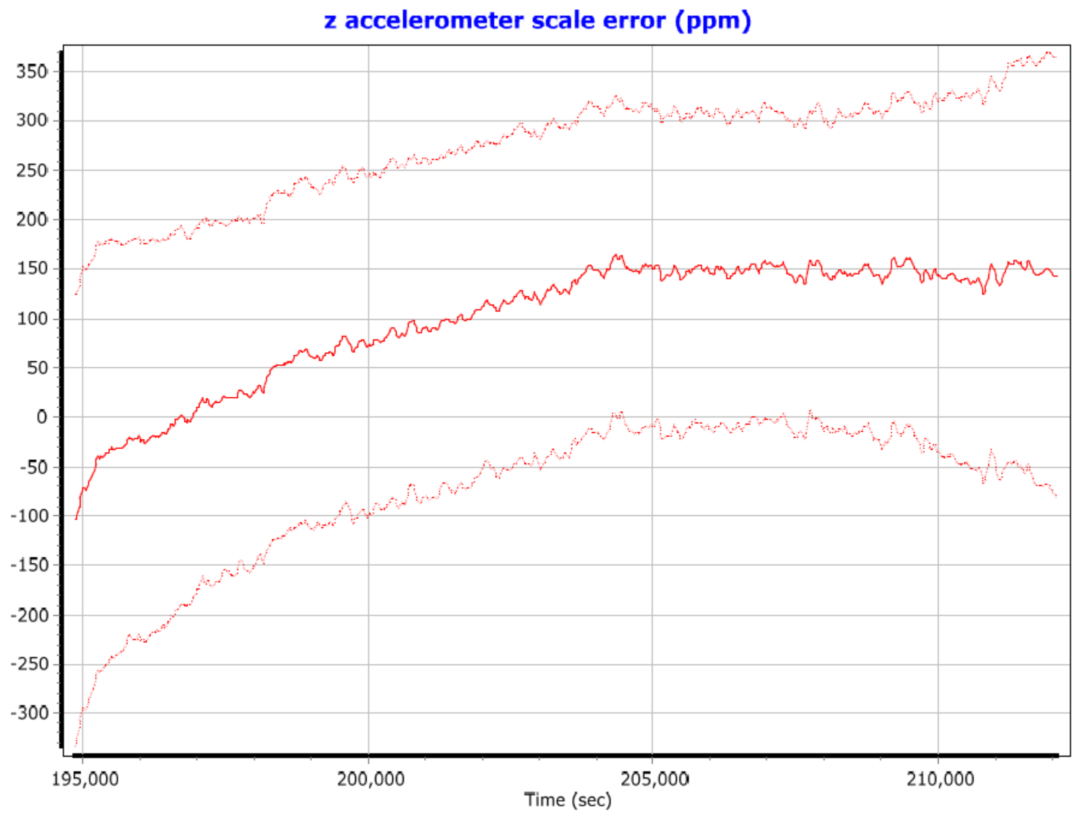


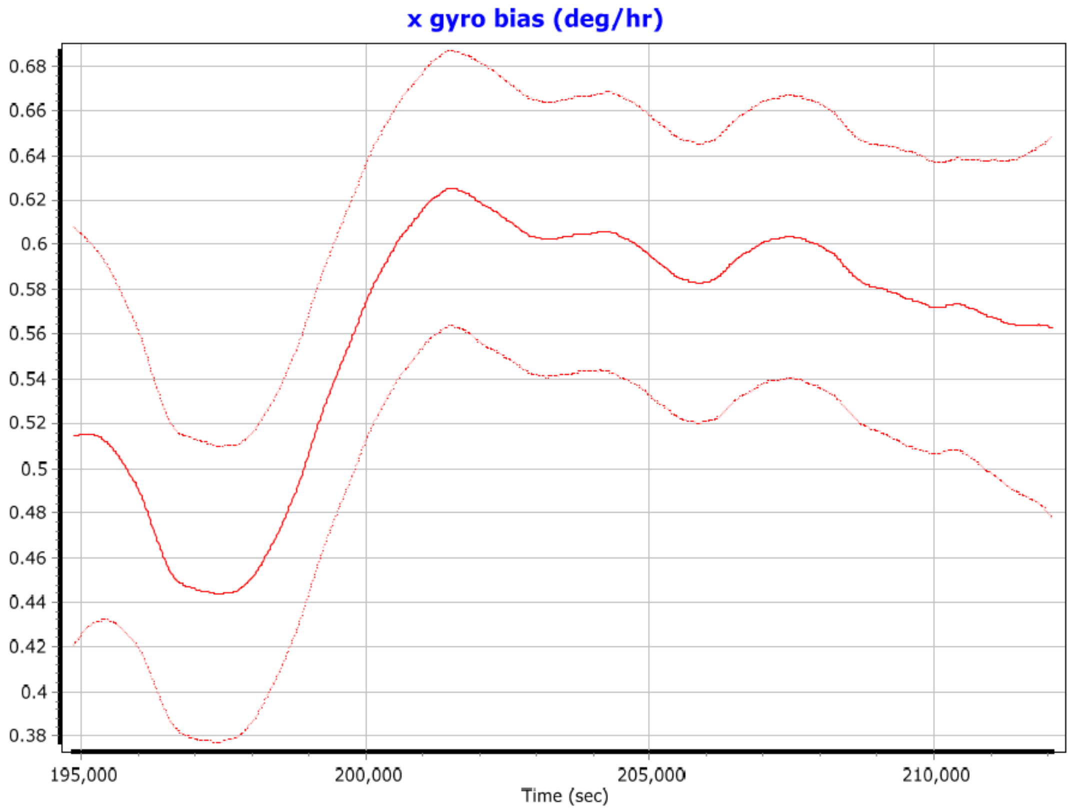


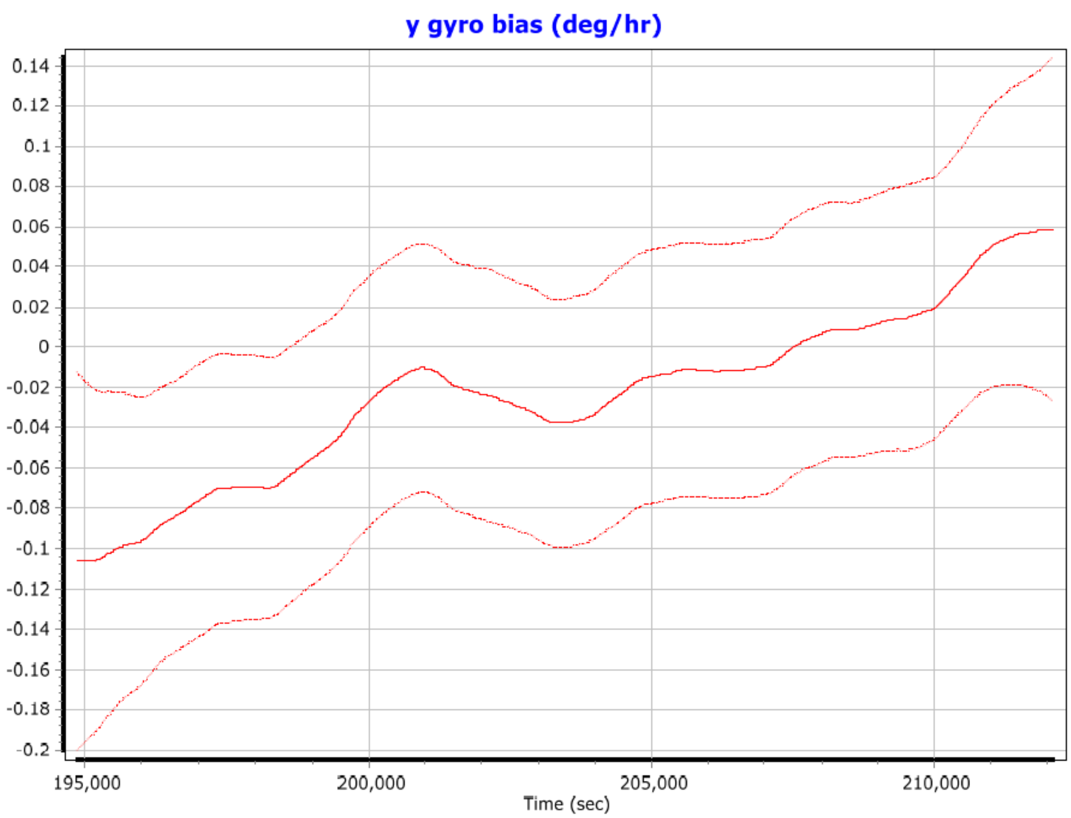

y accelerometer bias (micro-g)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
195,000
200,000
205,000
210,000
Time (sec)

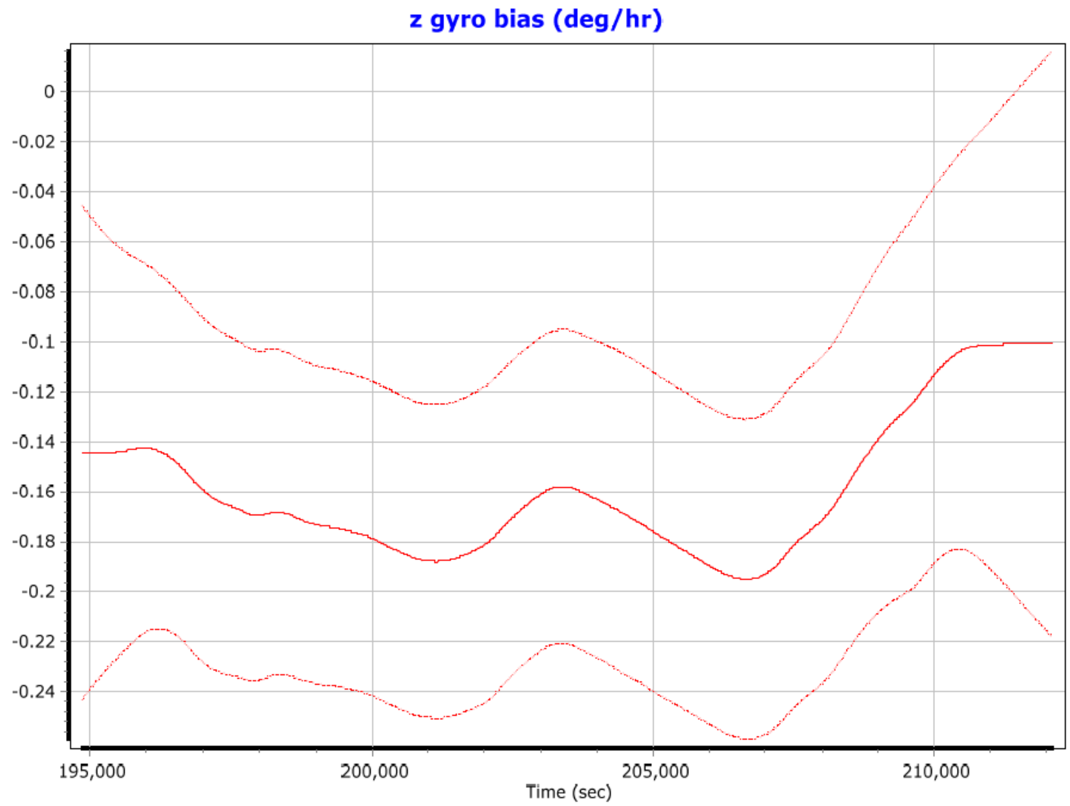

y accelerometer scale error (ppm)
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
195,000
200,000
205,000
210,000
Time (sec)


z accelerometer bias (micro-g)
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
-920
-940
195,000
200,000
205,000
210,000
Time (sec)

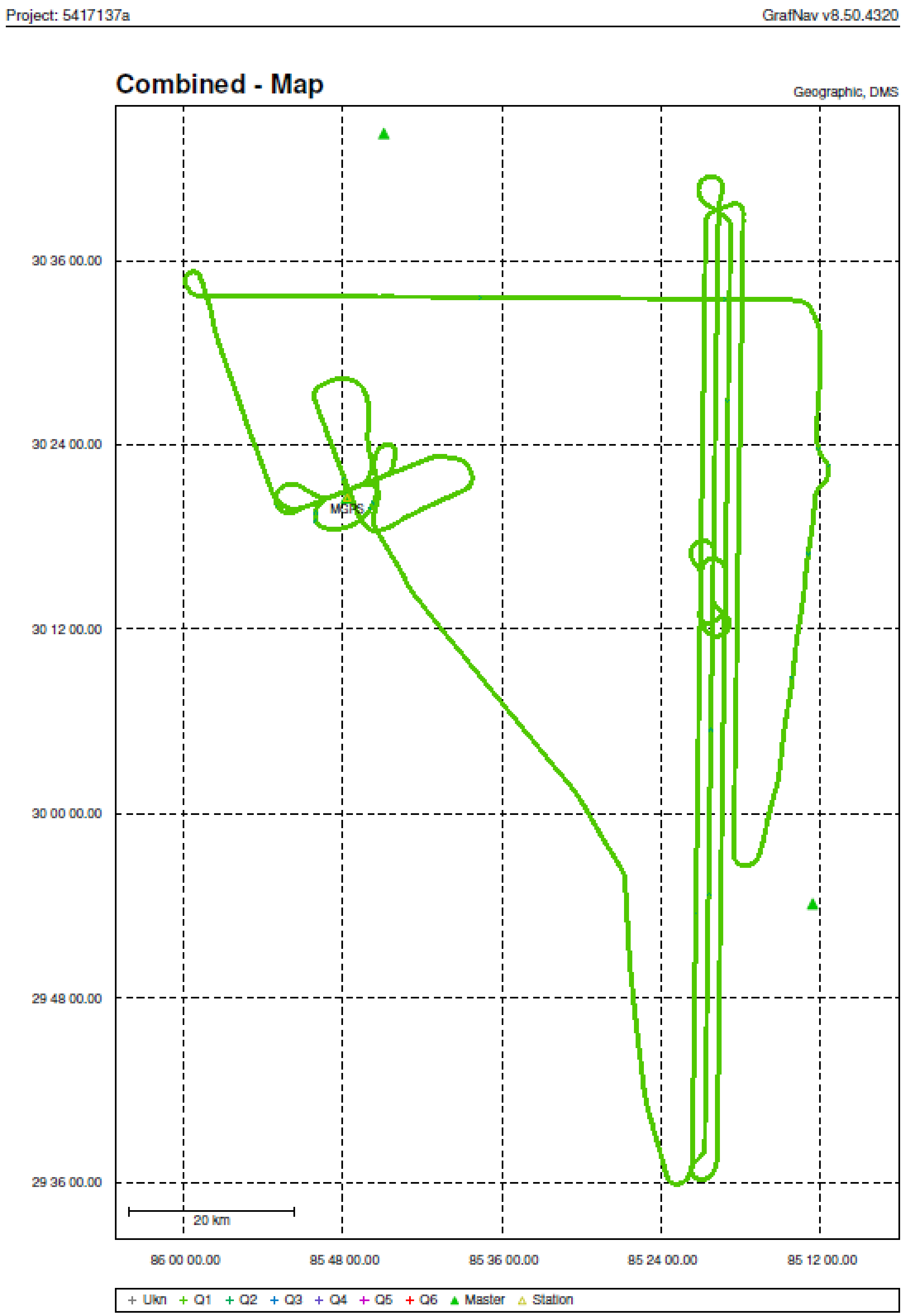

z accelerometer scale error (ppm)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
195,000
200,000
205,000
210,000
Time (sec)


x gyro bias (deg/hr)
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
195,000
200,000
205,000
210,000
Time (sec)

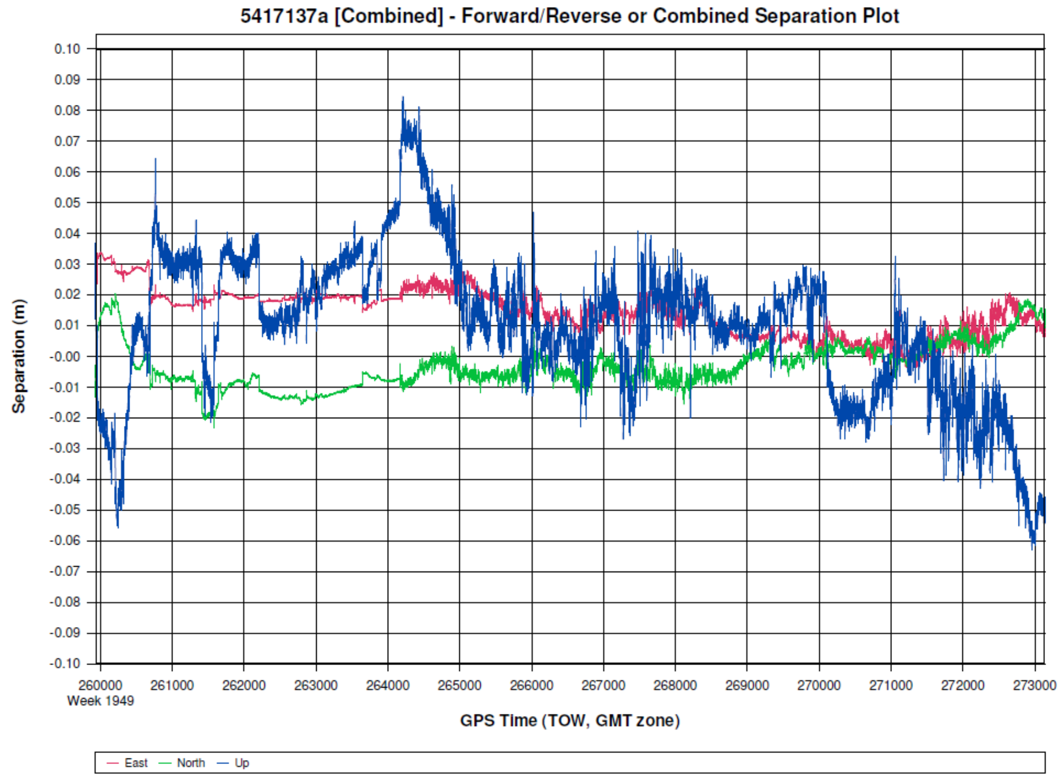

y gyro bias (deg/hr)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
195,000
200,000
205,000
210,000
Time (sec)


z gyro bias (deg/hr)
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
-0.22
-0.24
195,000
200,000
205,000
210,000
Time (sec)

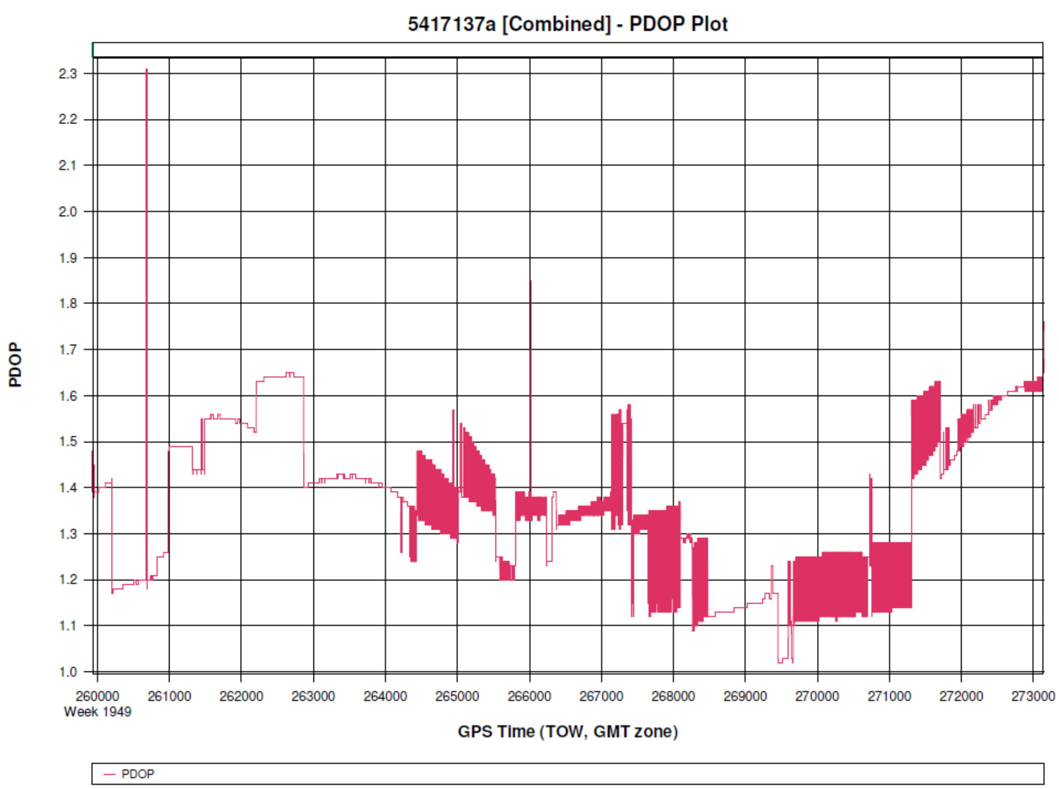
MISSION 9 – 5417137A GNSS PROCESSING



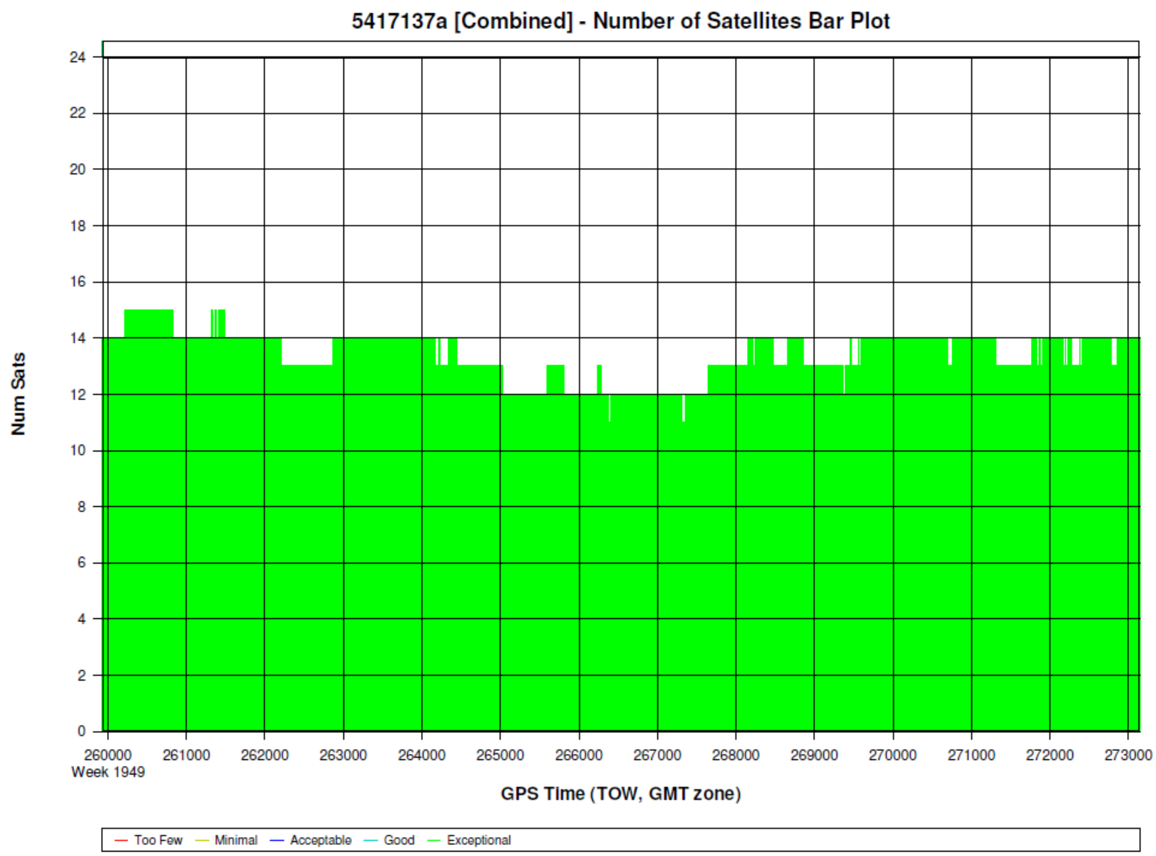
Project: 5417137a GrafNav v8.50.4320



Project: 5417137a GrafNav v8.50.4320



Project: 5417137a GrafNav v8.50.4320



Processing Summary Information
Program: GrafNav
Version: 8.50.4320
Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417137a\05_INS-GPS_PROC\01_POS\5417137a\5417137a\GNSS\5417137a.gnv
Solution Type: Combined

Number of Epochs:
Total in GPB file: 13225
No processed position: 0
Missing Fwd or Rev: 5
With bad C/A code: 0
With bad L1 Phase: 0

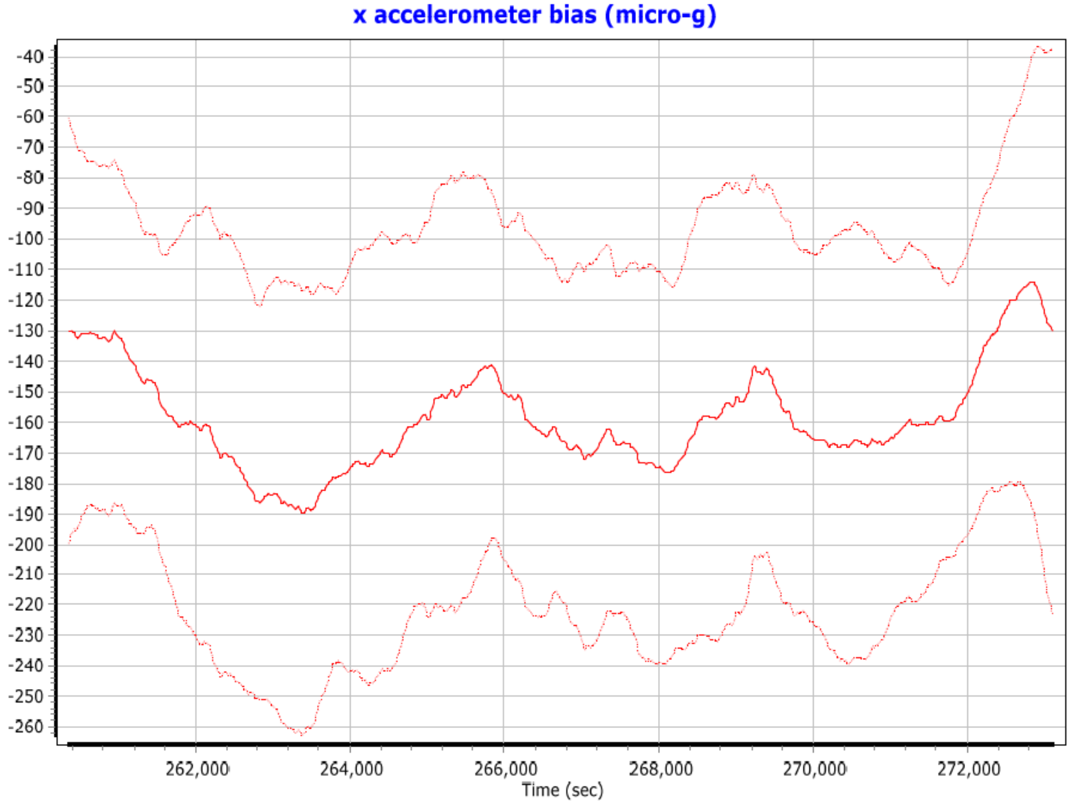
Measurement RMS Values:
L1 Phase: 0.0181 (m)
C/A Code: 0.87 (m)
L1 Doppler: 0.688 (m/s)

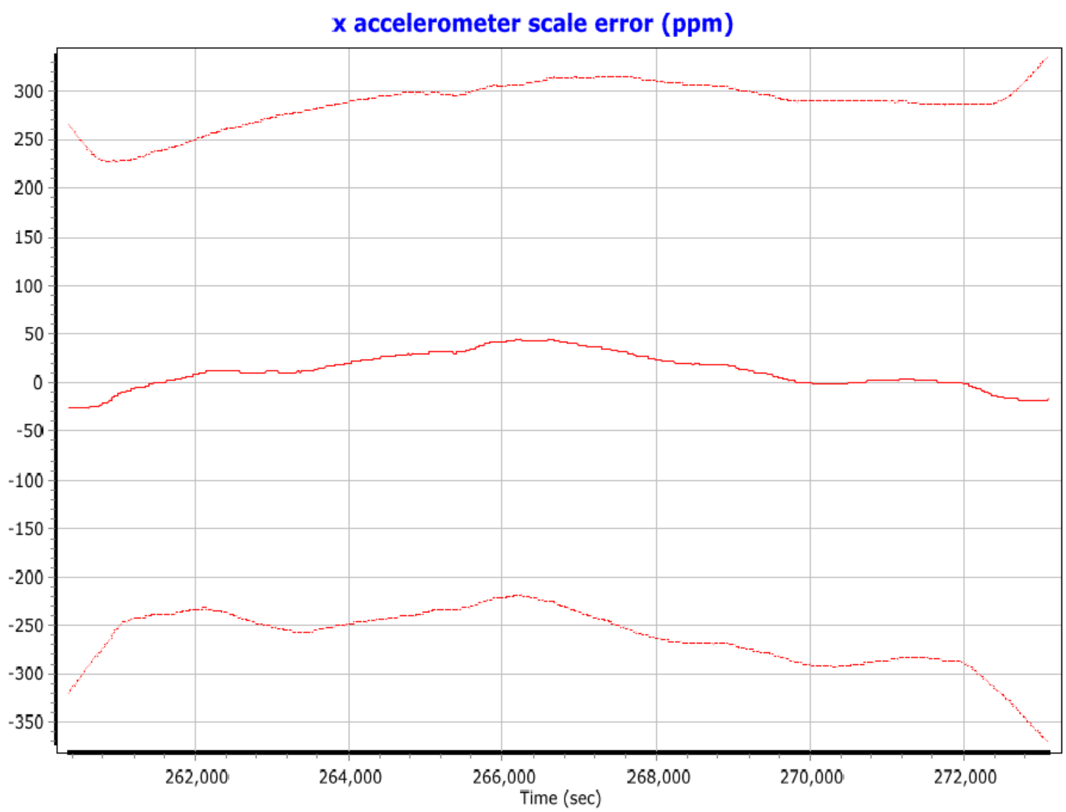
Fwd/Rev Separation RMS Values:
East: 0.016 (m)
North: 0.008 (m)
Height: 0.026 (m)

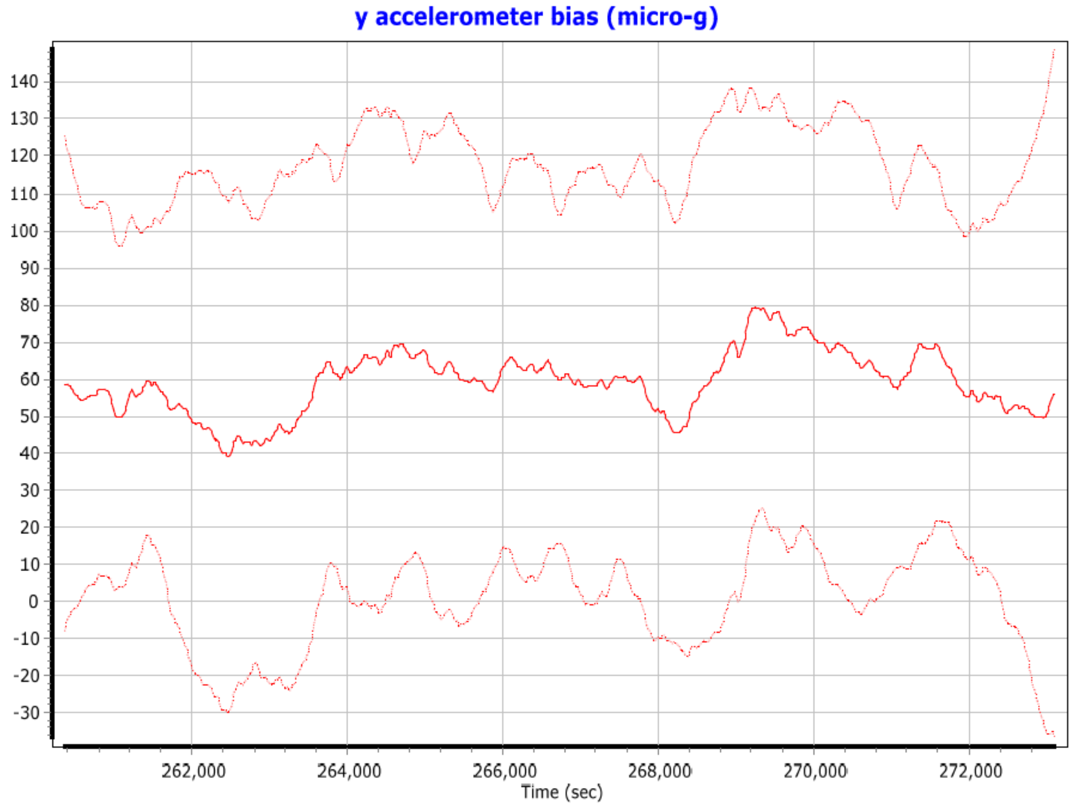
Fwd/Rev Sep. RMS for dual FWD/REV fixes (13220 occurances):
East: 0.016 (m)

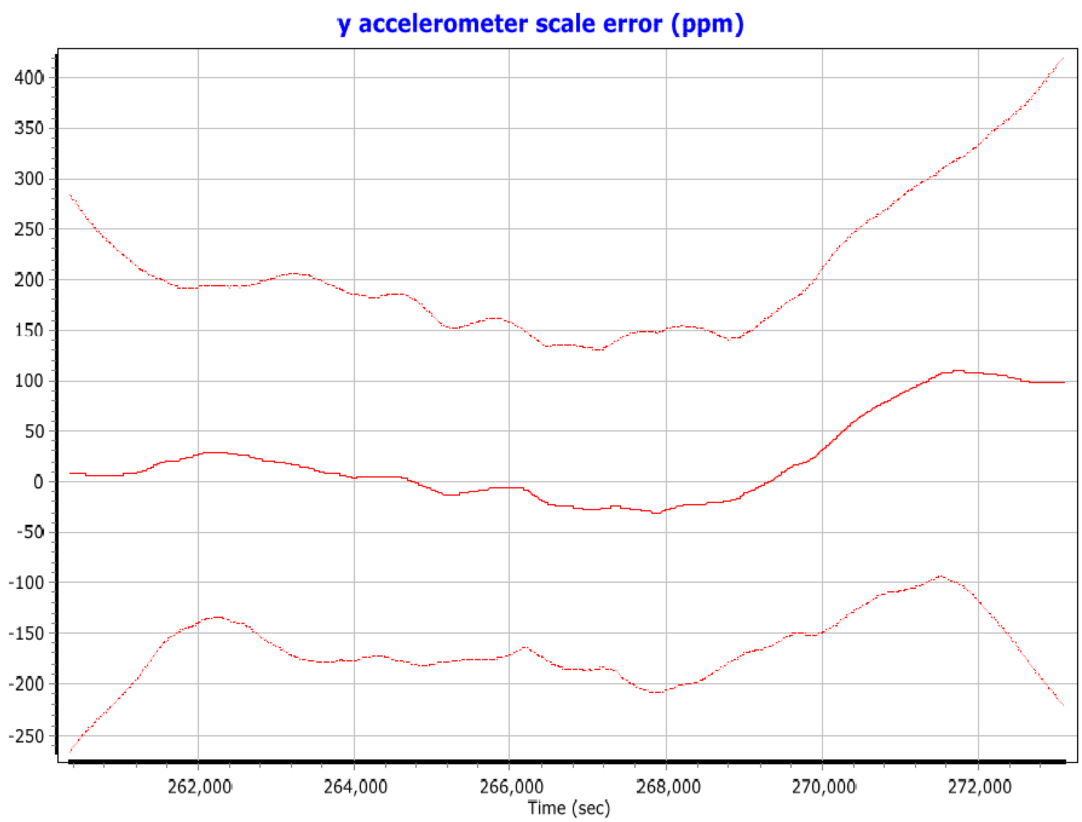
```
      North:       0.008 (m)
      Height:      0.026 (m)

Quality Number Percentages:
      Q 1:  99.5 %
      Q 2:   0.5 %
      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:          85.666 (km)
      Minimum:          7.531 (km)
      Average:          33.777 (km)
      First Epoch:      32.798 (km)
      Last Epoch:       19.592 (km)
```

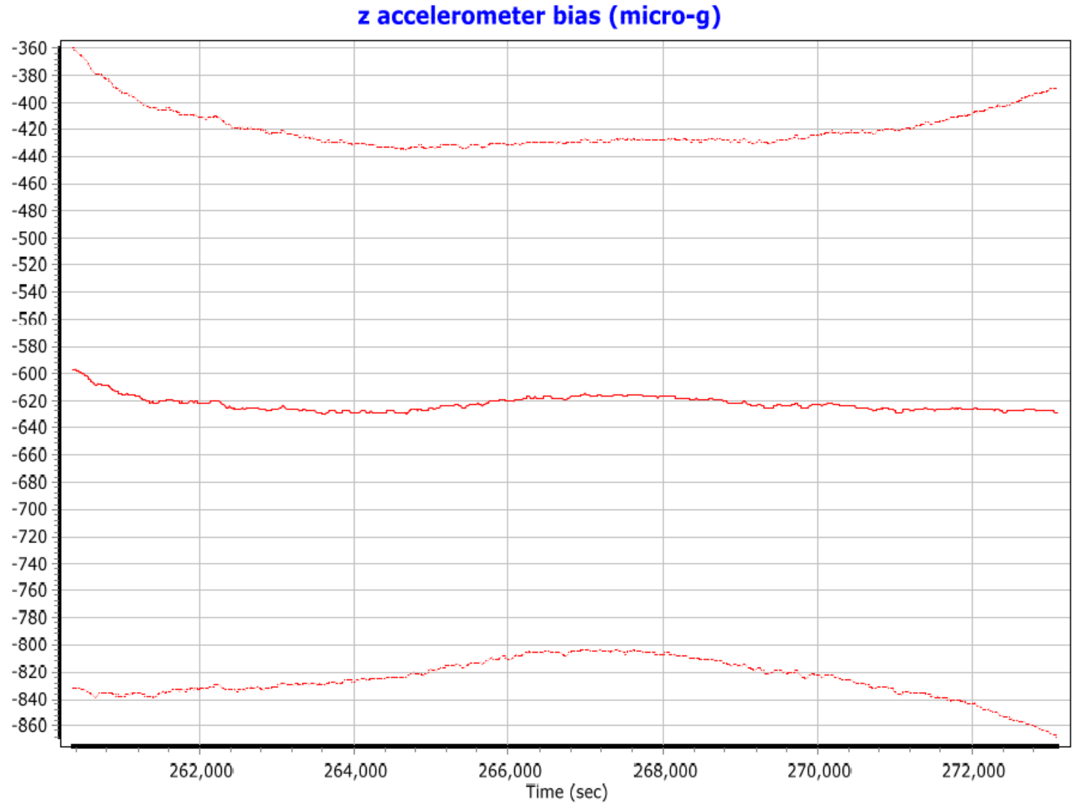
MISSION 9 – 5417137A SENSOR ERRORS

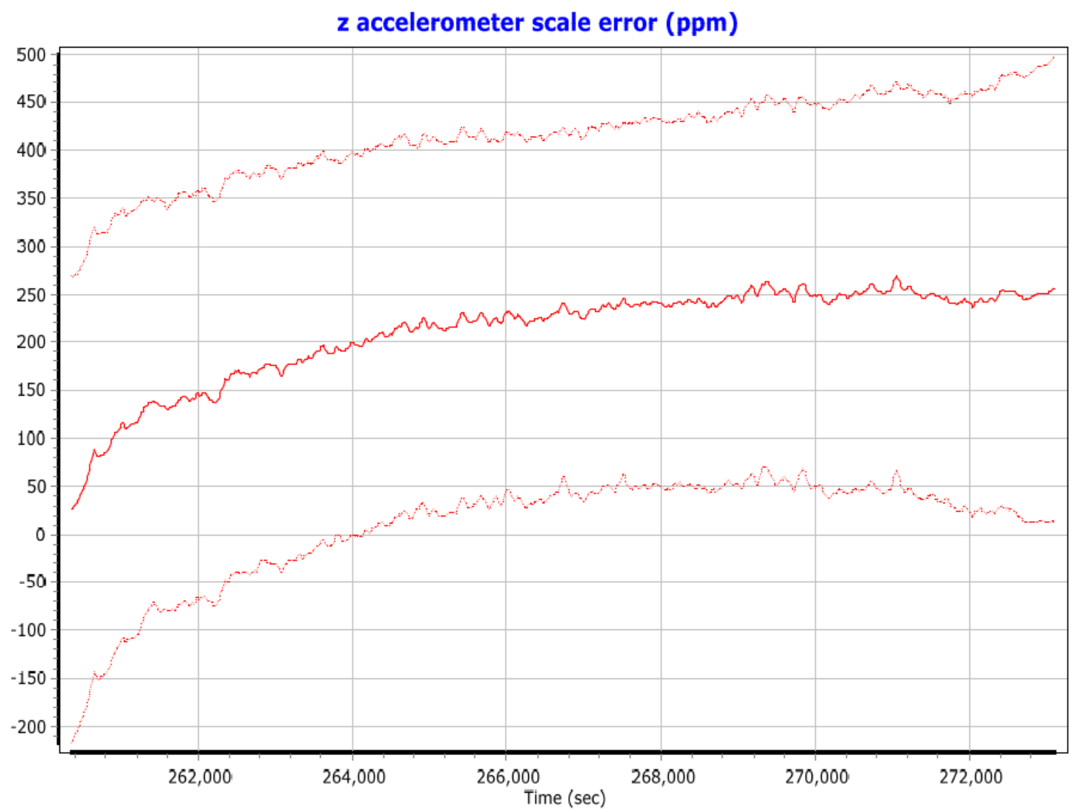


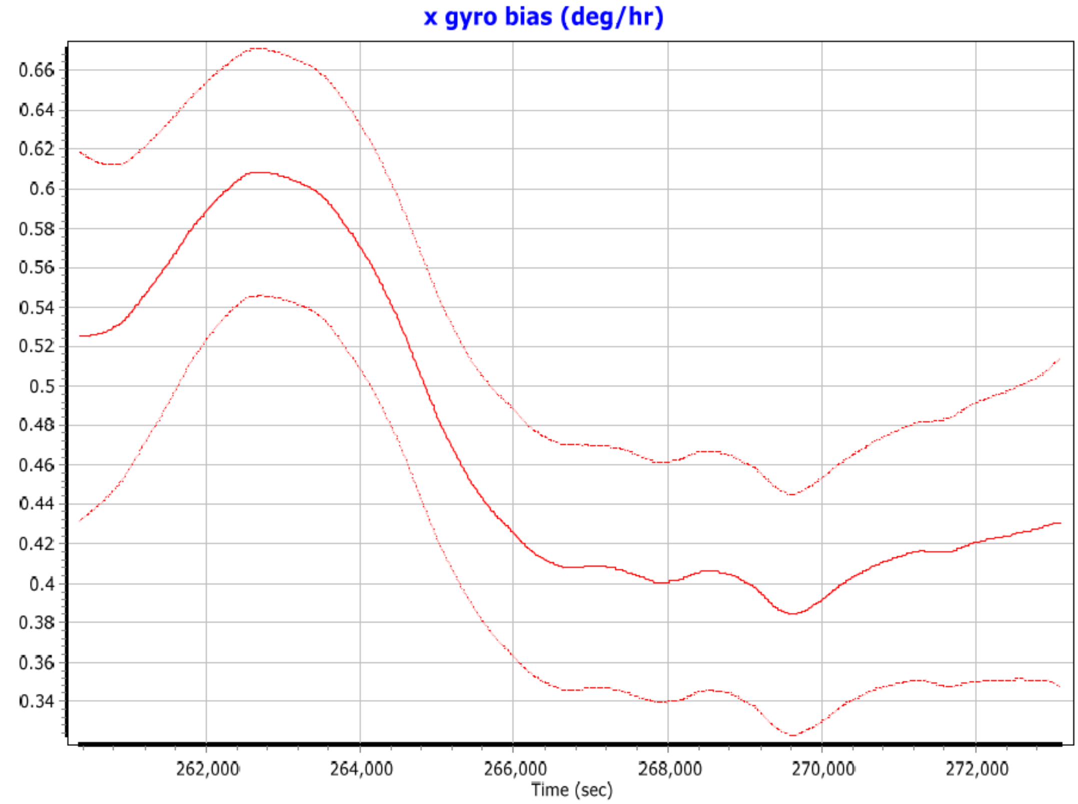


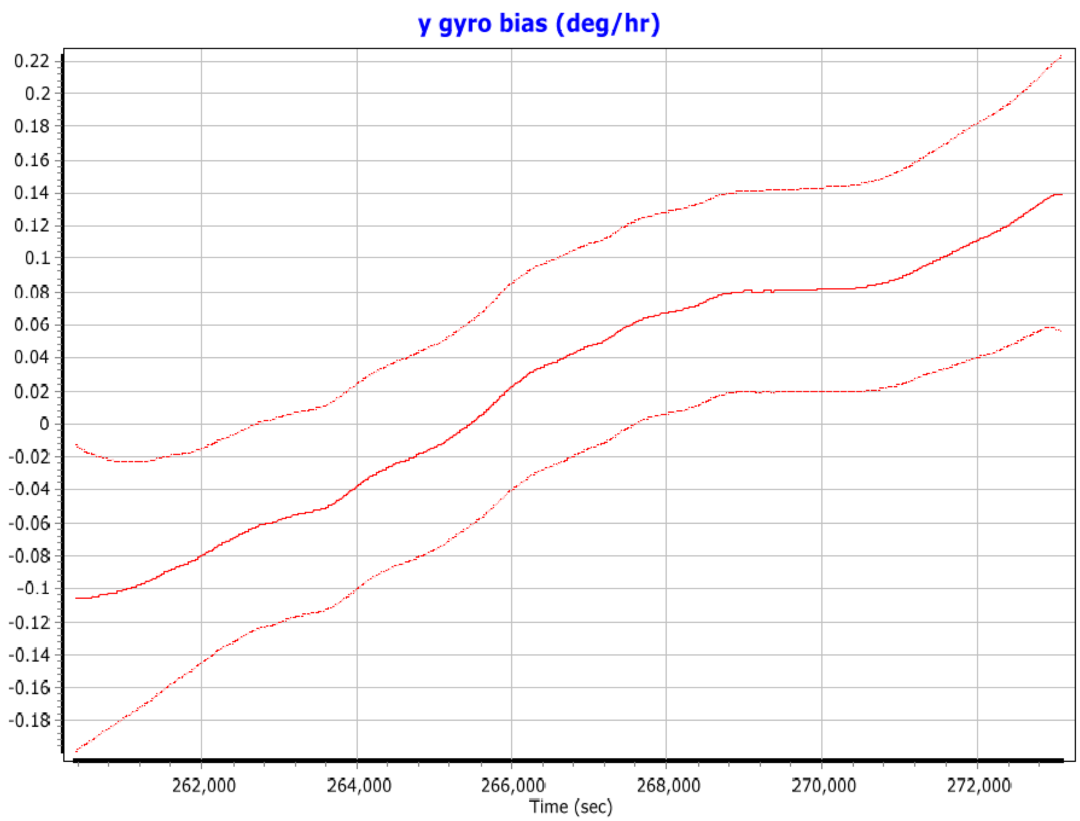

y accelerometer bias (micro-g)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)

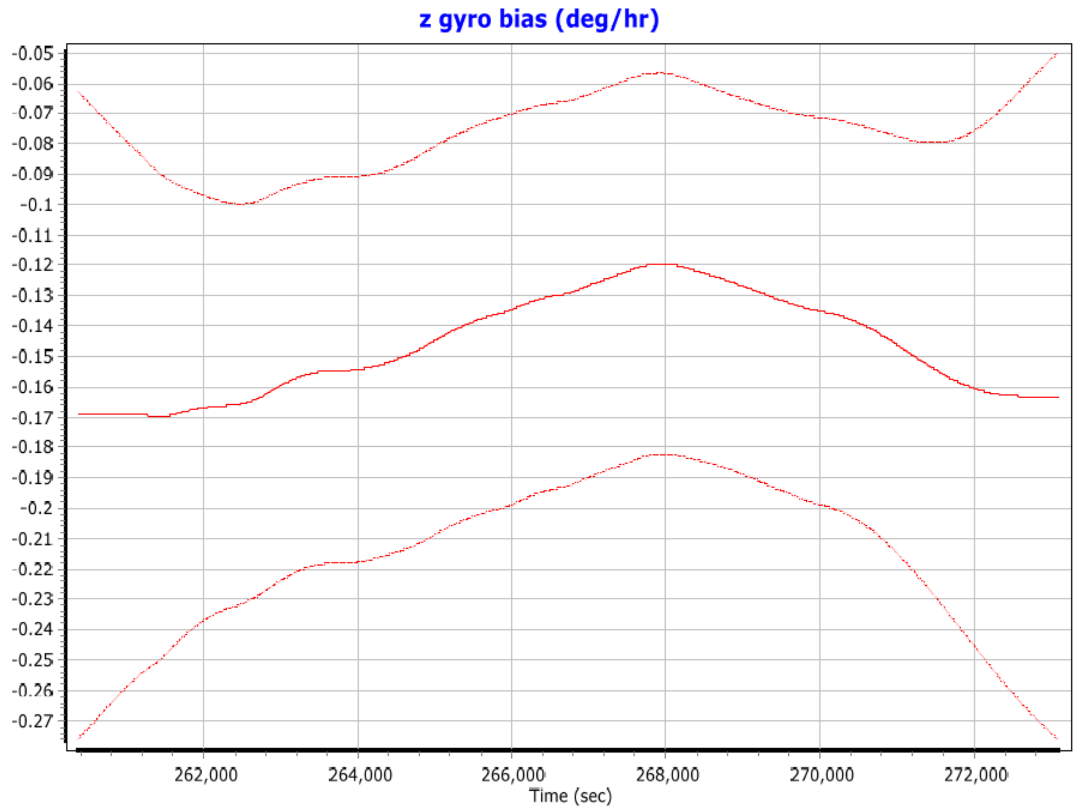

y accelerometer scale error (ppm)
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)


z accelerometer bias (micro-g)
-360
-380
-400
-420
-440
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)


z accelerometer scale error (ppm)
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)


x gyro bias (deg/hr)
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)


y gyro bias (deg/hr)
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)


z gyro bias (deg/hr)
-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
262,000
264,000
266,000
268,000
270,000
272,000
Time (sec)