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USGS Norfolk, VA LiDAR

Report Produced for U.S. Geological Survey

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Table of Contents

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 USGS Norfolk, Virginia Project Area.

The LiDAR data were processed to a bare-earth digital terrain model (DTM). Detailed breaklines, 3D buildings, 2D buildings, forest polygons, tree points, bare-earth digital elevation models (DEMs), first return digital surface models, and last return digital surface models were produced for the project area. Deliverables were produced in both UTM and State Plane coordinates. Data was formatted according to tiles with each UTM tile covering an area of 1,500 meters by 1,500 meters and each State Plane tile covering an area of 5,000 feet by 5,000 feet. A total of 1,458 UTM tiles and 1,400 State Plane tiles were produced for the project encompassing an area of approximately 1,130 sq. miles.

THE PROJECT TEAM

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

Dewberry's Matthew Rudolph 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. He also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Laser Mapping Specialist, Inc (LMSI) and The Atlantic Group (Atlantic) completed LiDAR data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Virginia counties of Chesapeake, Hampton, James City, Newport News, Norfolk, Poquoson City, Portsmouth, Suffolk, Virginia Beach, Williamsburg, and York as well as portions of the North Carolina counties of Camden and Currituck.

DATE OF SURVEY

The LiDAR aerial acquisition for the Southern portion of the project was conducted from March 25, 2013 thru April 5, 2013. The LiDAR aerial acquisition for the Northern portion of the project was conducted from March 21, 2013 thru March 31, 2013.

DATUM REFERENCE

Data produced for the project were delivered in both of the following reference systems.

> **Horizontal Datum:** The horizontal datum for the project is North American Datum of 1983 (NAD 83)
> **Vertical Datum:** The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
> **Coordinate System:** UTM Zone 18
> **Units:** Horizontal units are in meters, Vertical units are in meters.

Geiod Model: Geoid12A

Horizontal Datum: North American Datum of 1983 HARN (NAD83 HARN)
Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
Coordinate System: Virginia State Plane South
Units: Horizontal units are in U.S. Survey feet, Vertical units are in feet.
Geoid Model: Geoid12A

LIDAR VERTICAL ACCURACY

For the Norfolk, Virginia LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.066 m** compared with the 0.092 m specification; and the FVA of the classified LiDAR data computed using $RMSE_z$ x 1.9600 was equal to **0.129 m**, compared with the 0.181 m specification.

For the Norfolk, Virginia LiDAR Project, the tested CVA of the classified LiDAR data computed using the 95th percentile was equal to **0.194 m,** compared with the 0.269 m 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) in UTM coordinates
2. Control & Accuracy Checkpoint Report & Points in UTM coordinates
3. Project Report (Acquisition, Processing, QC)
4. Classified Point Cloud Data (Tiled)in both UTM and State Plane coordinates
5. First Return Surface (Raster DSM – IMG Format) in both UTM and State Plane coordinates
6. Last Return Surface (Raster DSM – IMG Format) in both UTM and State Plane coordinates
7. Bare Earth Surface (Raster DEM – IMG Format) in both UTM and State Plane coordinates
8. Intensity Images (8-bit gray scale, tiled, GeoTIFF format) in both UTM and State Plane coordinates
9. Breakline Data (File GDB) in both UTM and State Plane coordinates
10. 3D and 2D buildings (File GDB) in both UTM and State Plane coordinates
11. Forest polygons (File GDB) in both UTM and State Plane coordinates
12. Tree points (File GDB) in both UTM and State Plane coordinates
13. Metadata
14. Project Extents in both UTM and State Plane coordinates, including a shapefile derived from the LiDAR Deliverable

PROJECT TILING FOOTPRINT

One thousand four hundred and fifty-eight (1,458) UTM tiles were delivered for the project. Each UTM tile's extent is 1,500 meters by 1,500 meters. One thousand four hundred (1400) State Plane tiles were delivered for the project. Each State plane tiles extent is 5,000 ft by 5,000 ft (see Appendix B for a complete listing of delivered tiles).

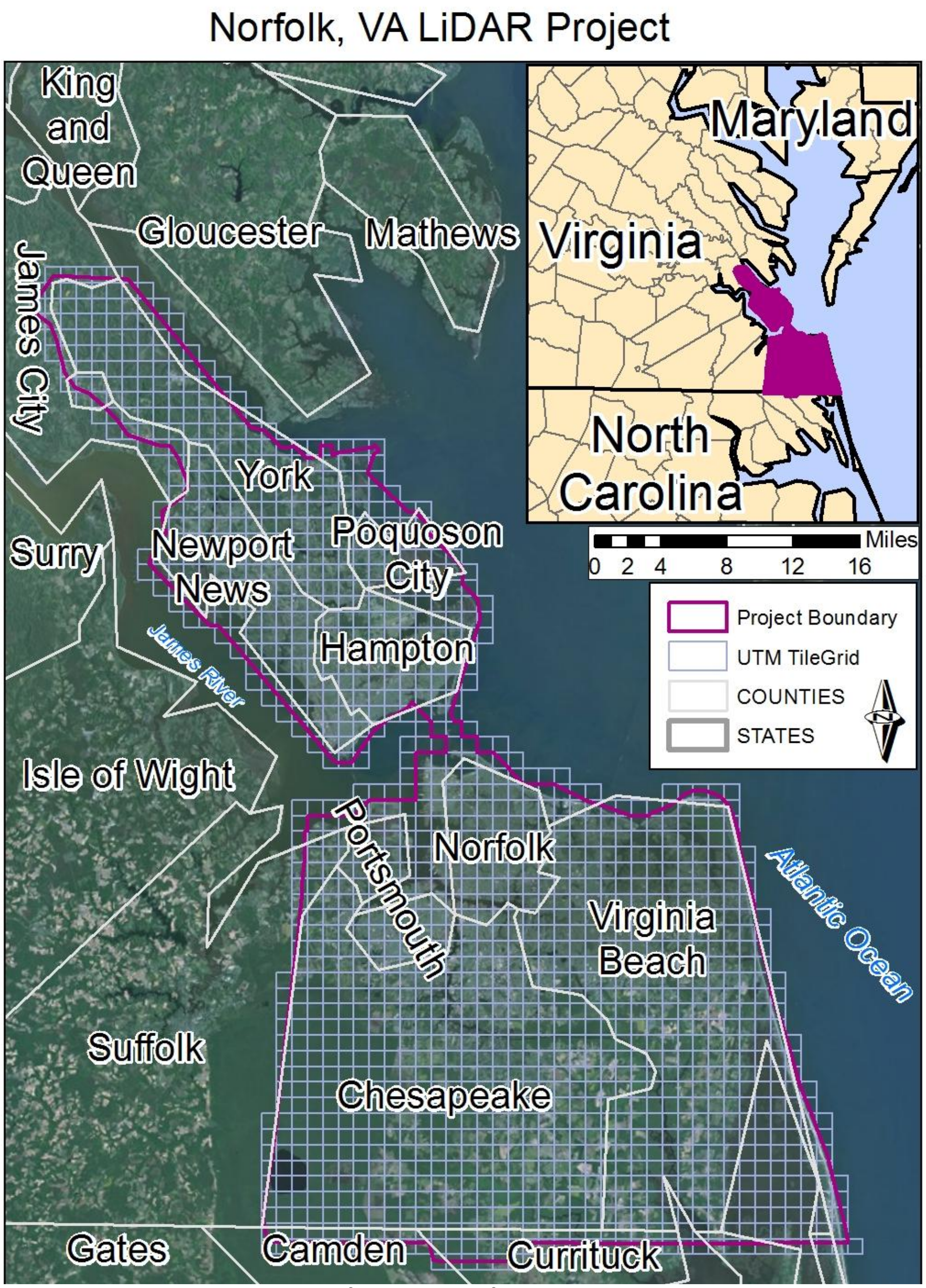


Figure 1 - Project Map

LiDAR Acquisition Report

Dewberry elected to subcontract the LiDAR Acquisition and Calibration activities to The Atlantic Group (Atlantic) and Laser Mapping Specialist Inc (LMSI). Atlantic and LMSI were responsible for providing LiDAR acquisition, calibration and delivery of LiDAR data files to Dewberry.

Dewberry received high accuracy, calibrated multiple return swath data from Atlantic on May 21, 2013 and from LMSI on June 5, 2013. Data was collected and delivered in compliance with the "U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 13 – ILMF 2010."

ACQUISITION EQUIPMENT

Atlantic operated a Cessna T-210 (Tail # N732JE) outfitted with a LEICA ALS70-HP LiDAR system during the collection of the Southern portion of the study area. Table 1 represents a list of the features and characteristics for the LEICA ALS70-HP LiDAR system:

Leica ALS70-HP		
Manufacturer	Leica	
Model	ALS70 - HP	
Platform	Fixed-wing	
Scan Pattern	sine, triangle, raster	
Maximum Scan rate (Hz)	sine	200
	triangle	158
	raster	120
Field of view (°)	0 - 75 (full angle, user adjustable)	
Maximum Pulse rate (kHz)	500	
Maximum Flying height (m AGL)	3500	
Number of returns	unlimited	
Number of intensity measurements	3 (first, second, third)	
Roll stabilization (automatic adative, °)	75 - active FOV	
Storage media	removable 500 GB SSD	
Storage capacity (hours @ max pulse rate)	6	
size (cm)	Scanner	37 W x 68 L x 26 H
	Control Electronics	45 W x 47 D x 36 H
Weight (kg)	Scanner	43
	Control Electronics	45
Operating Temperature	0 - 40 °C	
Flight Management	FCMS	
Power Consumption	927 W @ 22.0 - 30.3 VDC	

Table 1: Atlantic's LEICA Sensor Characteristic

LMSI operated an Optech 3100 EA LiDAR system during the collection of the Northern portion of the study area. Table 2 represents a list of the features and characteristics for the Optech 3100 EA LiDAR system:

Optech 3100 EA		
Manufacturer	Optech	
Model	3100EA	
Platform	Fixed-wing	
Maximum Scan rate (Hz)	0 to 70 Hz (>70 Hz optional)	
Field of view (°)	0 - 75 (full angle, user adjustable)	
Maximum Pulse rate (kHz)	100	
Maximum Flying height (m AGL)	3500	
Number of returns	Up to 4 range measurements, including 1^{st}, 2^{nd}, 3^{rd}, last returns	
Number of intensity measurements	12-bit dynamic range. Measurements for all recorded returns, including last return.	
Roll stabilization (automatic adative, °)	±5°; more compensation available if FOV reduced. Programmable in ±1° increments	
Storage media	Ruggedized removable SCSI hard disks	
size (cm)	Scanner	26cm W x 19cm L x 57 cm H
	Control Electronics	65 cm W x 59 cm D x 49 cm H
Weight (kg)	Scanner	23.4 kg
	Control Electronics	53.2 kg
Operating Temperature	Control rack: +10°C to 35 °C Sensor head: -10 °C to +35 °C	
Power Consumption	28 V 35 A (peak)	

Table 2: LMSI's Optech Sensor Characteristic

LIDAR SYSTEM PARAMETERS

Table 3 illustrates Atlantic's system parameters for LiDAR acquisition on this project.

Item	Parameter
System	Leica ALS-70 HP
Altitude (AGL meters)	1700
Approx. Ground Speed (kts)	120
Laser Firing Rate (kHz)	316.2
Scan Frequency (hz)	42.3
Swath width (m)	1237
Swath Overlap (%)	15%
Line Spacing (m)	858
Pass heading (degree)	164

Item	Parameter
Field of View (degree)	40
Computed Down Track spacing (m) per beam	0.73
Computed Cross Track Spacing (m) per beam	0.73
Average point spacing (m) per beam	0.7
Point Spacing density at Nadir	3.8
Points per meter^2 (m)	2.4
Gain up/Down	3
Scan Pattern	Triangle

Table 3: Atlantics LiDAR System Parameters

Table 4 illustrates LMSI's system parameters for LiDAR acquisition on this project.

Item	Parameter
System	Optech 3100 EA
Altitude (AGL meters)	880
Approx. Ground Speed (kts)	110
Laser Firing Rate (kHz)	70
Scan Frequency (hz)	40
Swath width (m)	612
Swath Overlap (%)	25%
Line Spacing (m)	275
Field of View (degree)	38
Computed Down Track spacing (m)	0.5
Computed Cross Track Spacing (m)	0.5
Points per meter^2 (m)	2

Table 4: LMSI's LiDAR System Parameters

DATUM REFERENCE

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83)
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 18
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12A

ATLANTIC LIDAR ACQUISITION DETAILS

Atlantic planned 64 passes for the Southern portion of 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, Atlantic followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO flight design software for direct integration into the aircraft flight navigation system.

- Planned flight lines; flight line numbers; and coverage area.
- LiDAR coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Atlantic Group will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Atlantic 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. Atlantic 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, Atlantic 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.
Atlantic LiDAR sensors are calibrated at a designated site located at the Lawrence County Airport in Courtland, Alabama and are periodically checked and adjusted to minimize corrections at project sites.

ACQUISITION FLIGHT LOGS, DATES, 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.

The table below shows the flight missions to acquire the laser data including flight dates, daily missions, number of lines, tidal information, and comments for each flight.

Date	Mission #	Lines Flown
3/25/13 to 3/29/13	5	1-43
3/31/13 to 4/5/13	5	44-66

Table 5: Flight Lines and Acquisition Dates

The figure below illustrates Atlantic's final trajectories.

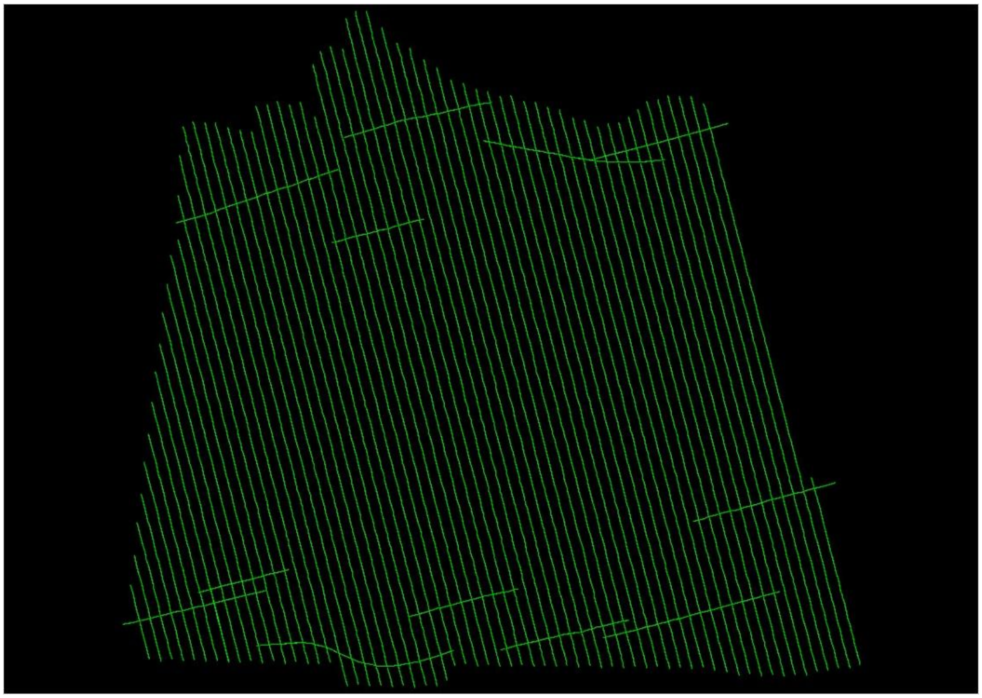


Figure 2: Trajectories as flown by Atlantic LiDAR Control

All surveys were performed to Federal Geodetic Control Subcommittee (FGCS) FGCS guidelines. Atlantic Group maximized existing NGS control and the ALDOT CORS stations to provide the control network, designed with proper redundancies, session occupation times, and time between sessions according to the applicable NOS technical standards. GPS observations were conducted using Federal Geodetic Control Committee (FGCC) approved dual frequency GPS receivers. A minimum of two fixed-height tripods were used as ground base stations running at a one (1.0) second epoch collection rate during every mission, typically at a minimum of four hours. The control locations are planned to ensure a 28km baseline distance from the furthest flight line distance. All mission collections were conducted with a PDOP of 3.2 or lower. Also, the KP index is considered prior to mission collection and no collection occurred when the KP index was at or above 4. During acquisition the following ground control points where used.

Station	Latitude	Longitude	Northing	Easting	Elevation	PID
CEM1	36 44 42.01674	76 06 26.52957	4067157.092	401140.823	5.000m	
CPK1	36 39 56.13139	76 19 19.36753	4058590.483	381853.335	4.185m	DN7636

Table 6 – Base Stations used to control LiDAR acquisition

Station	Julian Day	Receiver Model	Antenna Model	Height (m)	Start Date/Time	Stop Date/Time
CPK1	87	TOPCON	TPSHIPER_V	1.374	3/28/13 22:20	3/28/13 15:00
CEM1	88	TOPCON	TPSHIPER_V	1.391	3/29/13 11:15	3/29/13 11:43
CPK1	88	TOPCON	TPSHIPER_V	1.374	3/29/13	3/29/13

					2:30	17:33
CEM1	89	TOPCON	TPSHIPER_V	1.389	3/30/13 11:20	3/30/13 22:38
CPK1	89	TOPCON	TPSHIPER_V	1.374	3/30/13 15:22	3/30/13 20:02
CEM1	90	TOPCON	TPSHIPER_V	1.389	3/31/13 10:45	3/30/13 11:30
CPK1	90	TOPCON	TPSHIPER_V	1.374	3/31/13 4:15	3/31/13 8:30
CEM1	91	TOPCON	TPSHIPER_V	1.390	4/1/13 11:45	4/1/13 24:00
CPK1	91	TOPCON	TPSHIPER_V	1.373	4/1/13 5:15	4/1/13 20:30

Table 7 – Site Observations

Airborn GPS Kinematic
LEICA IPAS TC was used to post process the airborne solutions for the mission. IGS08 (EPOCH:2013.1011) coordinates from the OPUS solutions was used in the post processing.

Generation and Calibration of Laser Points (raw data)
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 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.

LMSI LIDAR ACQUISITION DETAILS

LMSI planned 90 passes for the Northern portion of 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, LMSI followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using ALTM-NAV flight management 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 LMSI will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

LMSI 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. LMSI 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, LMSI 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.

ACQUISITION DATES AND FLIGHTLINES

Table 8 shows the flight missions to acquire the laser data including flight dates, daily missions, number of lines, tidal information, and comments for each flight.

Date	Mission #	Lines Flown	Mission Time	Tidal Window	Mission Notes
3/21/13	1	1-18	10:23-1:30	9:36-1:36	
3/22/13	2	19-23, 23-25	11:21-12:33, 1:34-2:22	10:22-2:22	Had mechanical issue, fixed, went back up
3/23/13	0				Laser maint/ground control
3/24/13	0				Weather/ground control
3/25/13	0				Weather/ground control
3/26/13	0				Ground Control/laser maint
3/27/13	0				Ground Control
3/28/13	1	26-31	4:55-6:25	2:41-6:41	
3/29/13	2	32-54	3:37-7:10a, 3:57-7:16p	3:18-7:18a, 3:26-7:16p	
3/30/13	2	55-90	4:20-8:05am, 4:16-6:23p	4:07-8:07a, 4:13-8:13p	
3/31/13	1	26-31	5:05-6:41a	4:58-8:58a	reflights

Table 8: Flight Lines and Acquisition Dates

The figure below illustrates LMSI's final trajectories.

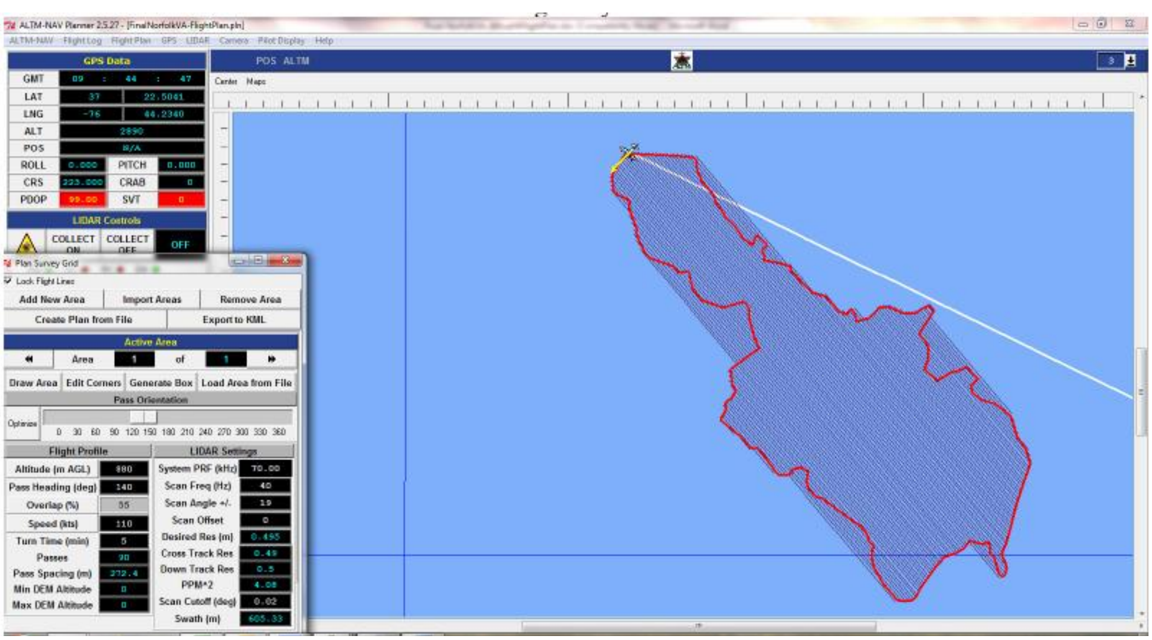


Figure 4: Trajectories as flown by LMSI LiDAR Control

Two base stations were utilized. The base station coordinates are set forth below.

Latitude	Longitude	Elevation
37 11 46.65724	76 29 28.13126	-18.135m
37 07 27.35080	76 25 12.73298	-33.312m

Table 9 – Base Stations used to control LiDAR acquisition Airborne GPS Kinematic

All airborne GPS trajectories were processed and checked on site. All trajectories were very high quality with forward/reverse separation between 2cm-5cm.

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.

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.

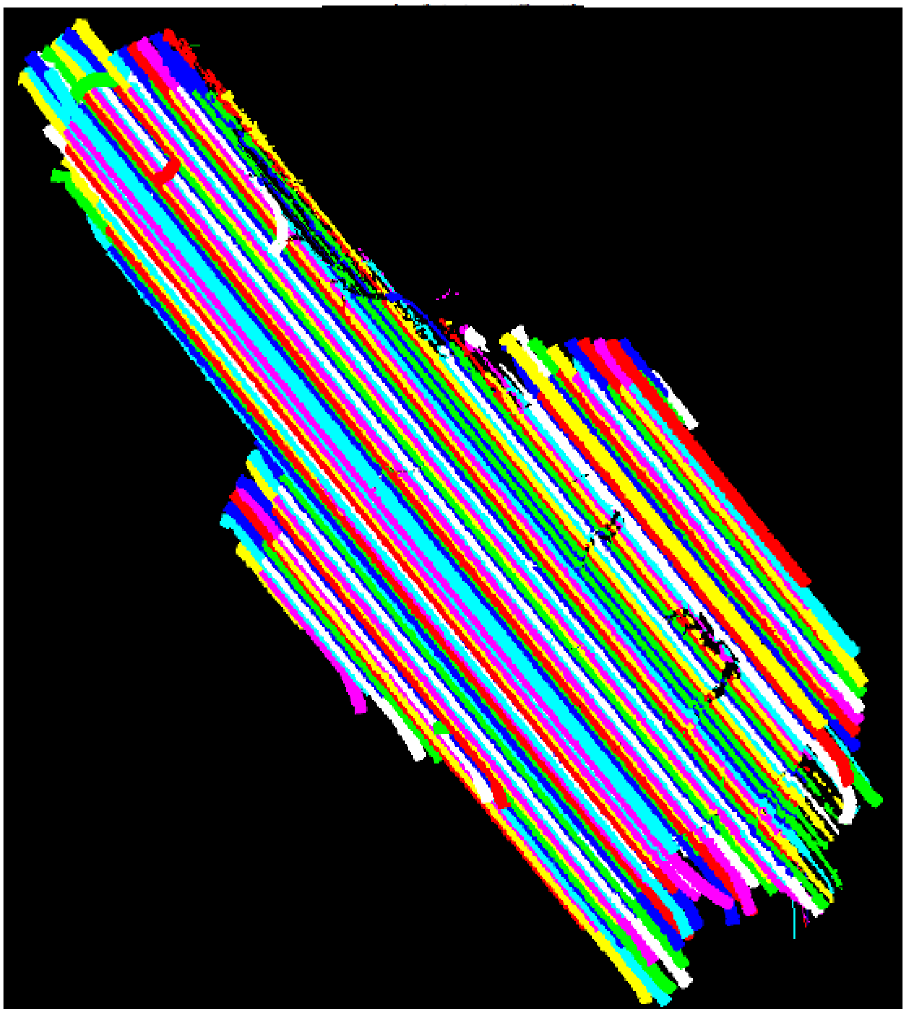


Figure 5 – LiDAR Swath output showing complete coverage. Boresight and Relative accuracy

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.

COMBINED SWATH VERTICAL ACCURACY ASSESSMENT

Dewberry tested the vertical accuracy of the open terrain swath data upon receipt of the calibrated data from Atlantic and LMSI. Dewberry tested the vertical accuracy of the swath data using the eighteen open terrain independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in open terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in open 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. Project specifications require a FVA of 0.181 m based on the $RMSE_z$ (0.0925 m) x 1.96. The dataset for the Norfolk, VA LiDAR Project satisfies these criteria. The raw LiDAR swath data tested 0.163 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.083m) x 1.9600. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	$RMSE_z$ (m) Open Terrain Spec=0.0925m	FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Open Terrain	0.083	0.163	0.058	0.025	0.963	0.077	18	-0.109	0.248

Table 10: FVA at 95% Confidence Level for Raw Swaths

Based on the initial vertical accuracy testing conducted by Dewberry, the calibrated data received from Atlantic and LMSI for the Norfolk, VA LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

LiDAR Processing & Qualitative Assessment

DATA CLASSIFICATION AND EDITING

LiDAR mass points were produced to LAS 1.2 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, or 11, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Noise, low and high points
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity.
- Class 11 = Withheld, Points with scan angles exceeding +/- 20 degrees.

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 outliers in the dataset to class 7 and points with scan angles exceeding +/- 20 degrees to class 11. After points that could negatively affect the ground are removed from class

1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

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

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.003 meter precision), Northing (0.003 meter precision), Elevation (0.003 meter precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header that defines the projection, datums, and units.

Once the initial ground routine has been performed on the data, Dewberry creates Delta Z (DZ) orthos to check the relative accuracy of the LiDAR data. These orthos compare the elevations of LiDAR points from overlapping flight lines on a 1 meter pixel cell size basis. If the elevations of points within each pixel are within 10 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 10 cm and 20 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 20 cm in difference, the pixel is colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. DZ orthos can be created using the full point cloud or ground only points and are used to review and verify the calibration of the data is acceptable. Some areas are expected to show sections or portions of red, including terrain variations, slope changes, and vegetated areas or buildings if the full point cloud is used. However, 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. The DZ orthos for Norfolk, VA showed that the data was calibrated correctly with no issues that would affect its usability. The figure below shows an example of the DZ orthos.

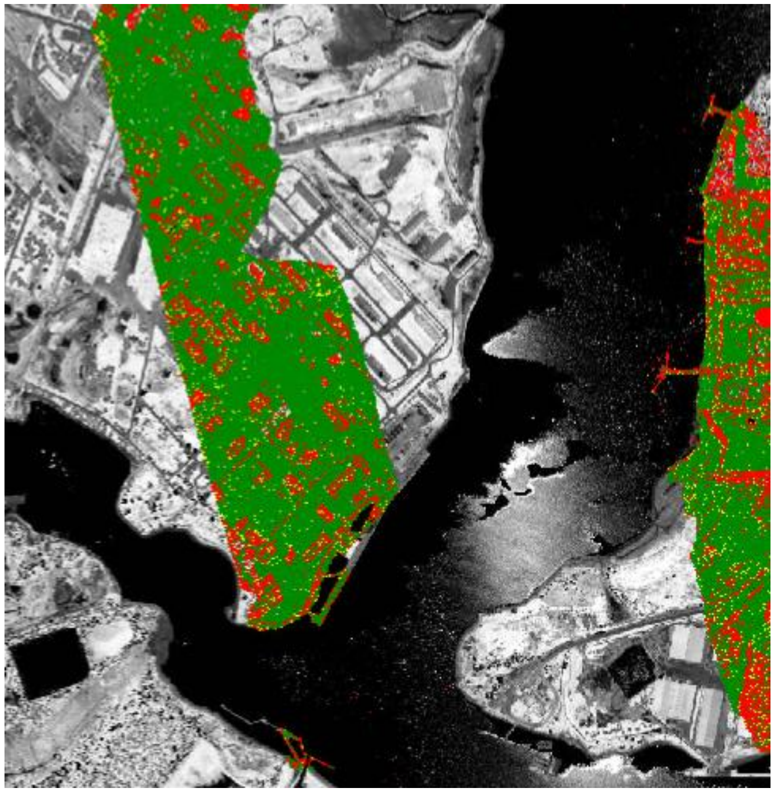


Figure 6 - DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, on buildings, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Once the calibration and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The LAS dataset was imported into GeoCue task management software for processing in Terrascan. Each tile was 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. 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. The final classification routine applied to the dataset selects ground points within a specified distance of the water breaklines and classifies them as class 10, ignored ground due to breakline proximity.

QUALITATIVE ASSESSMENT

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model.

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

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

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR nominal point spacing for this project is 1 point per 0.7 square meters. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional elevation mapping technologies and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the dataset is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified with DZ orthos. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

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

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

ANALYSIS

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

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the Norfolk, VA LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Norfolk, VA LiDAR project conform to the specifications outlined below.

- Format, Echos, Intensity
    - LAS format 1.2
    - Point data record format 1
    - Multiple returns (echos) per pulse
    - Intensity values populated for each point
- ASPRS classification scheme
    - Class 1 – unclassified
    - Class 2 – Bare-earth ground
    - Class 7 – Noise
    - Class 9 – Water
    - Class 10 – Ignored Ground due to breakline proximity
    - Class 11 – Withheld due to scan angles exceeding +/- 20 degrees
- Projections
    - Datum – North American Datum 1983
    - Projected Coordinate System – UTM Zone 18
    - Linear Units – Meters
    - Vertical Datum – North American Vertical Datum 1988, Geoid 12A
    - Vertical Units – Meters
    - Datum – North American Datum 1983 HARN (NAD83 HARN)
    - Projected Coordinate System – Virginia State Place South
    - Linear Units – U.S. Survey Feet
    - Vertical Datum – North American Vertical Datum 1988, Geoid 12A
    - Vertical Units – Feet
- LAS header information:
    - Class (Integer)
    - Adjusted GPS Time (0.0001 seconds)
    - Easting (0.003 meters)
    - Northing (0.003 meters)
    - Elevation (0.003 meters)
    - Echo Number (Integer 1 to 4)
    - Echo (Integer 1 to 4)

- Intensity (8 bit integer)
- Flight Line (Integer)
- Scan Angle (Integer degree)

2. *Data density, data voids:* The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" 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. For the Norfolk, VA LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 0.7 square meters.

    a. 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. These are considered to be acceptable voids. No unacceptable voids are present in the Norfolk, VA LiDAR project.

3. *Bare earth quality:* Dewberry reviewed the cleanliness of the bare earth to ensure the ground has correct definition, meets the project requirements, there is correct classification of points, and there are less than 5% residual artifacts.

    a. *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.

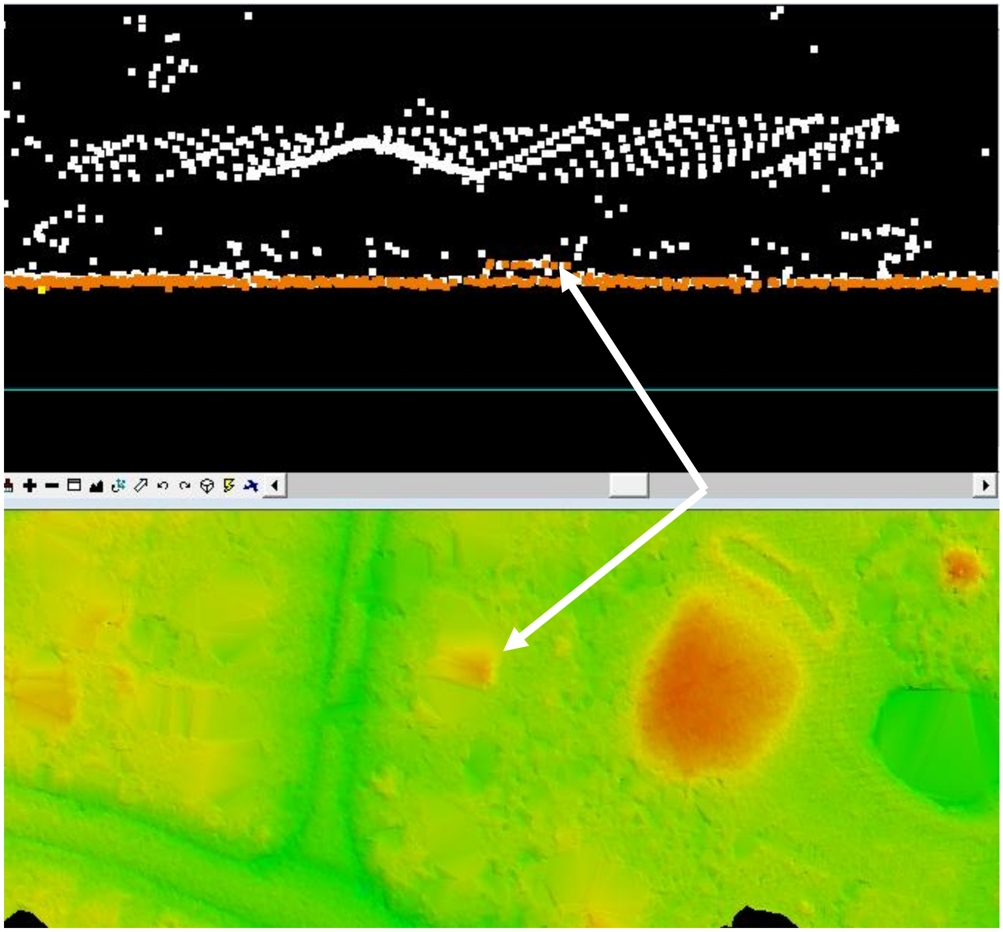


Figure 7 – Tile number 18SVF020755. Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and a model of the surface is shown in the bottom view. The arrow identifies low structure or vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

b. *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 triangulate across a bridge opening from legitimate ground points on either side of the actual bridge. This can cause visual artifacts or "saddles." These "artifacts" are only visual and do not exist in the LiDAR points or breaklines.

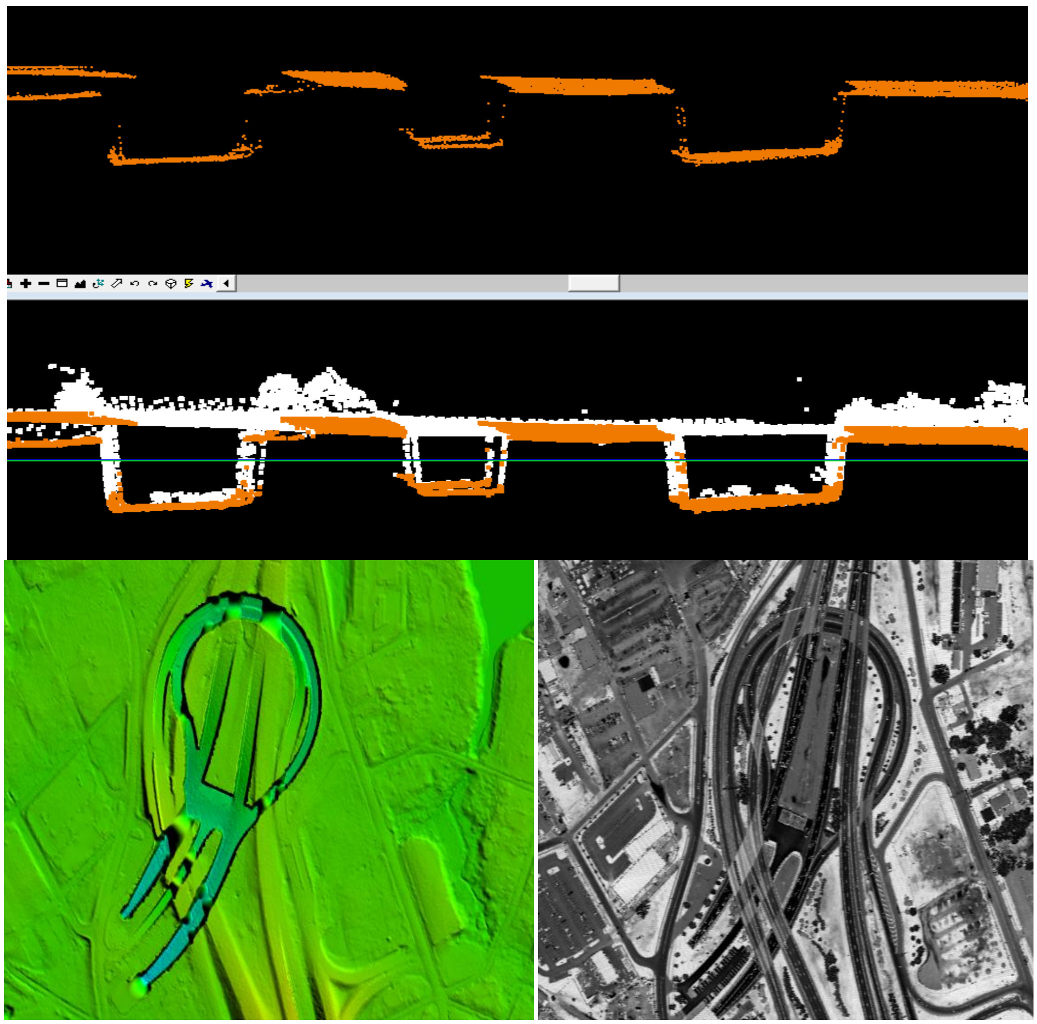


Figure 8 – Tile number 18SUF840770. The DEM in the bottom left view shows visual artifacts because the surface model is interpolated from the ground points on the slope leading from the tops of the overpasses and bridges to the lower ground points on either side of the overpasses and bridges. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts when there are features with large elevation differences. The profiles in the top two views show the LiDAR points of this particular feature colored by class. All overpass and bridge points have been removed from ground (orange) and are unclassified (white). There are no ground points that can be modified to correct these visual artifacts.

c. *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.

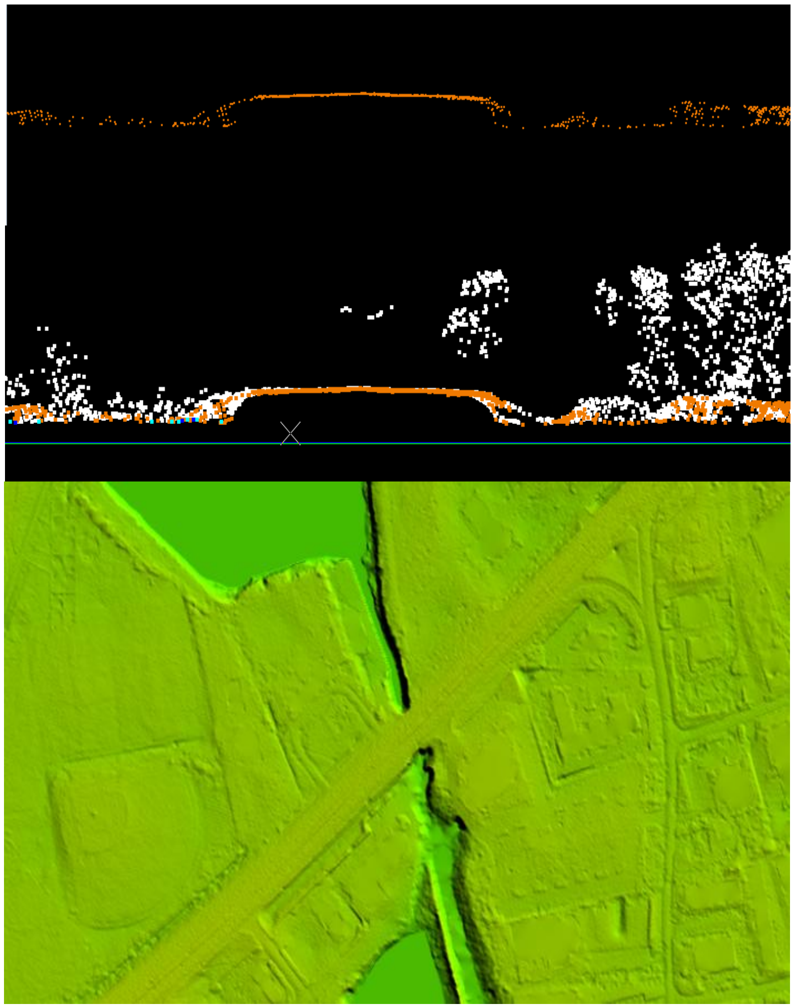


Figure 9– Tile number 18SUF885725. Profile with points colored by class (class 1=white, class 2=orange, class 9=blue) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

d. *In Ground Structures:* In ground structures exist within the project area. These types of structures occur mainly on military bases and in facilities designed for munitions testing and storage. These features are correctly included in the ground classification.

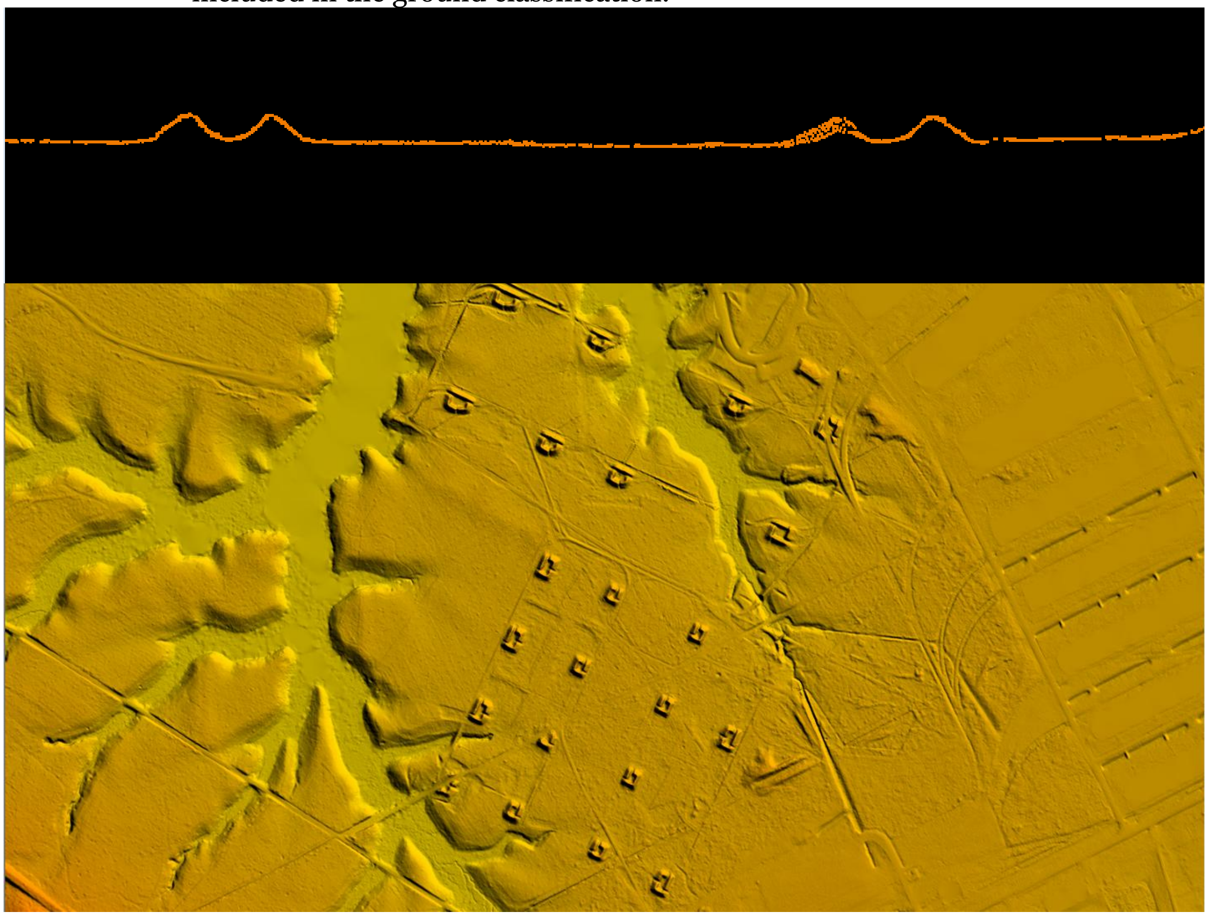


Figure 10 – Tile 18SUG555265. Profile with the points colored by class (class 1=white, class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

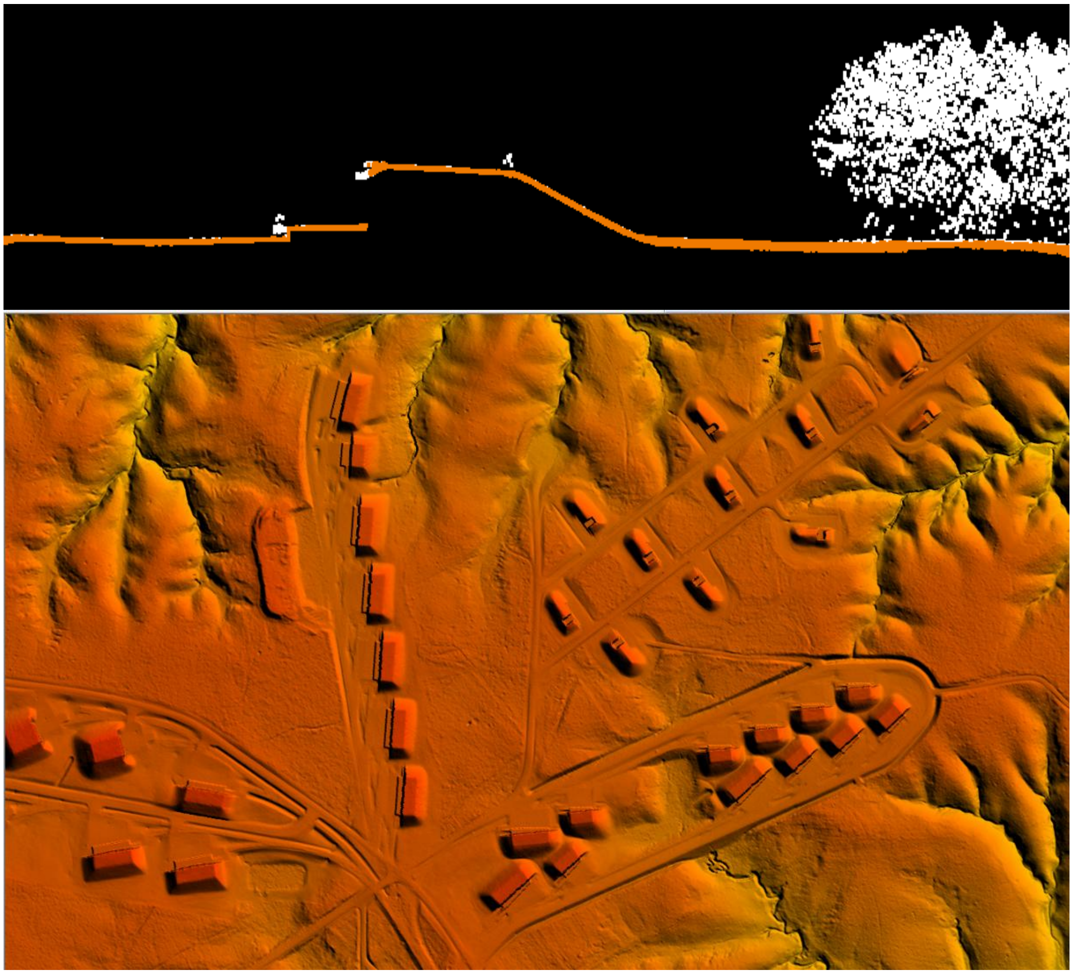


Figure 11 – Tiles 18SUG570220. Profile with the points colored by class (class 1=white, class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

e. *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.

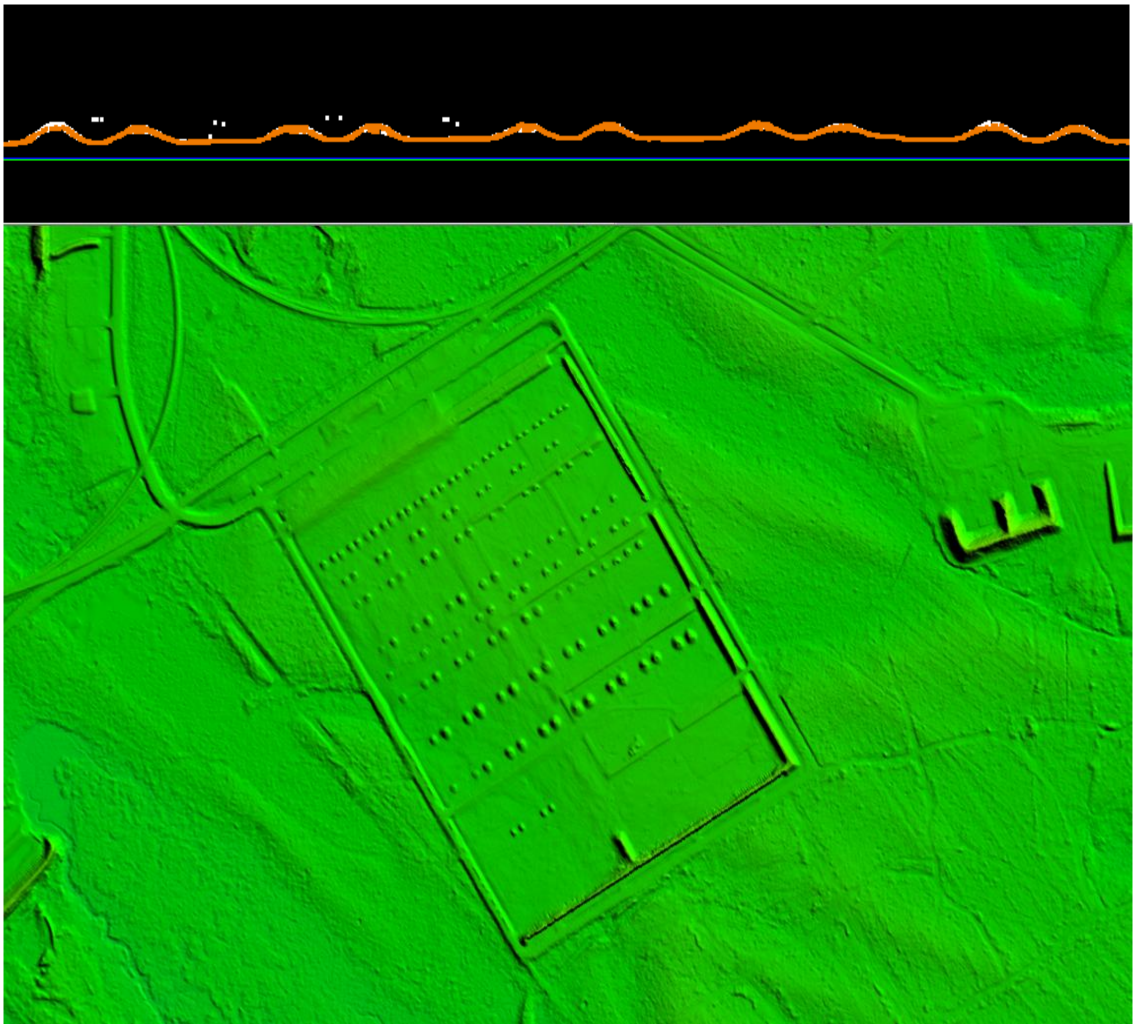


Figure 12 - Tile 18SUG585070. Profile with the points colored by class (class 1=white, class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

f. *Elevation Change Within Breaklines:* While water bodies are flattened in the final DEMs, other features such as linear hydrographic features can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Significant changes in elevation are also present in tidally influenced areas which are located throughout the Norfolk, VA Project area. Dewberry has reviewed the DEMs to ensure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. An example is shown below.

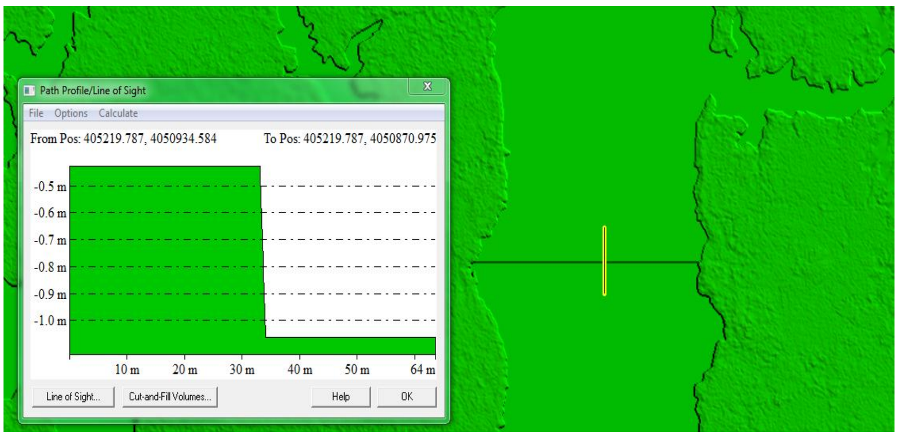


Figure 13 – Tile number 18SVF050500. Significant drops in elevation occur in the tidally influenced areas. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.

g. *Shipyards and Dry Docks*: Large dry docks are located throughout the Norfolk, VA project area. Newport News Shipbuilding is one of the largest in the world and has dry docks that can hold over 100 million gallons of water when flooded. Large vessels such as aircraft carriers were being actively constructed within most of the dry docks during the time of acquisition. Other dry docks were empty resulting in large crater like artifacts in the final bare earth DEMs. There are no ground points that can be modified to correct these visual artifacts. Examples are shown below.

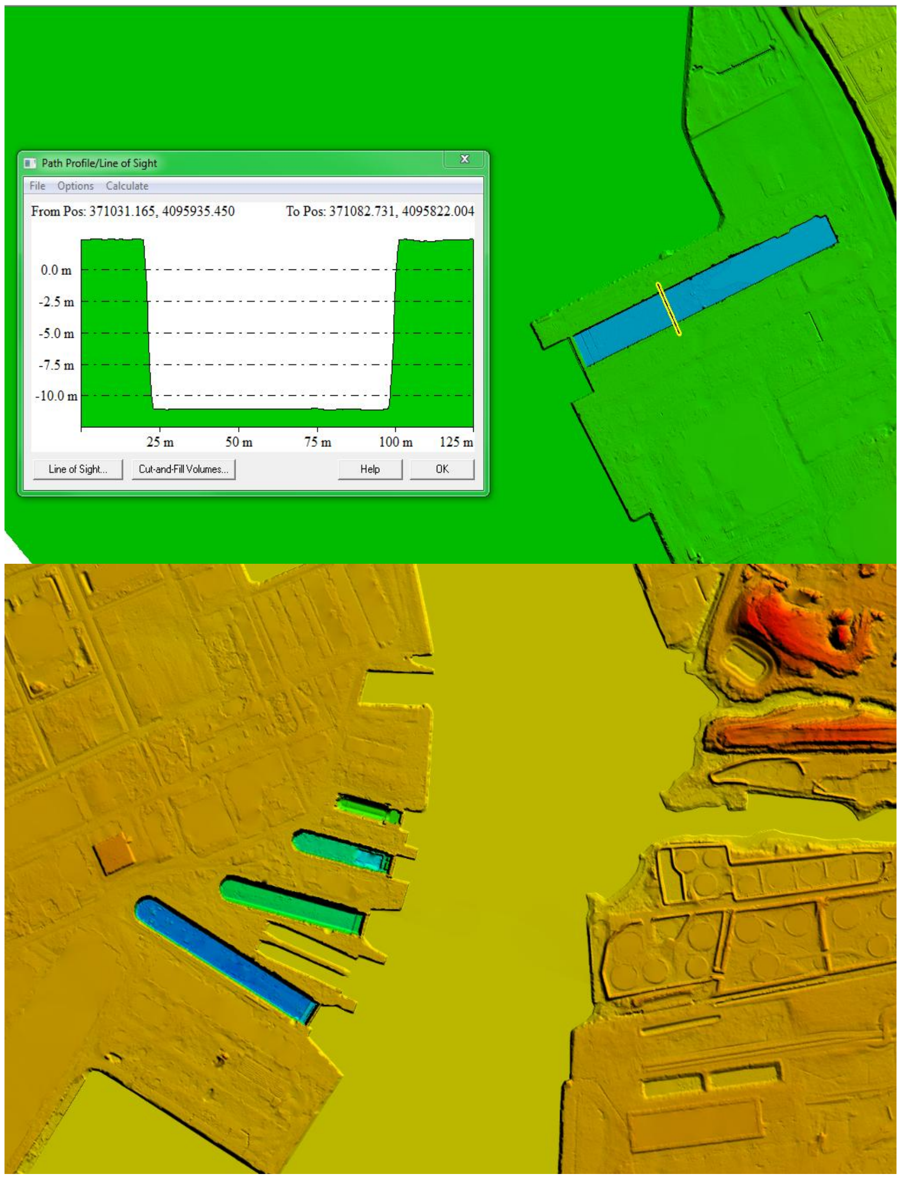


Figure 14– Tile 18SUF705950 in the top view and tile 18SUF840755 in the bottom view. The DEMs show visual artifacts because the surface model is interpolated from the ground points on the slope leading from the tops of the dry docks to the lower ground points within the dry docks. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts when there are features with large elevation differences.

h. *Canal Locks*: Great Bridge Lock, often closed by the Army Corp. due to flooding, was open at the time of acquisition. Dewberry collected it as a water body and it was hydro flattened along with the rest of the hydro mask in the final DEMs. Examples are shown below.

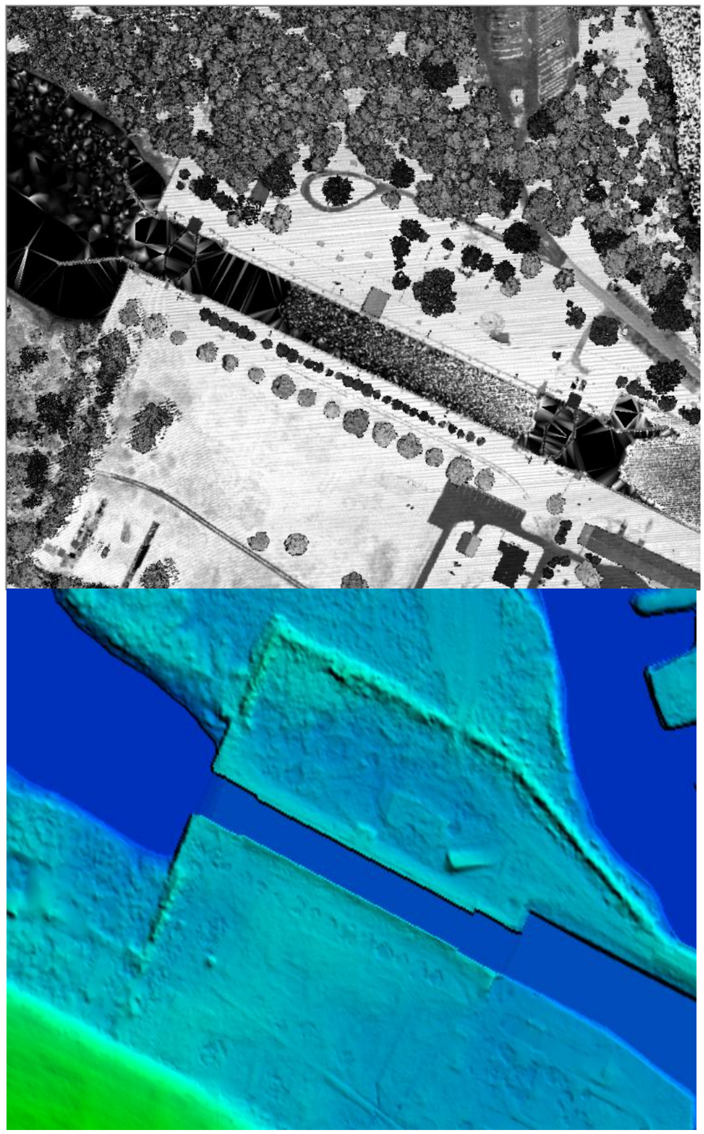


Figure 15 – Tile 18SUF885635. Great Bridge Lock was open and full of water at the time of acquisition. Dewberry included the lock in the hydro mask to avoid artifacts in the final DEM model shown above in the bottom view.

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

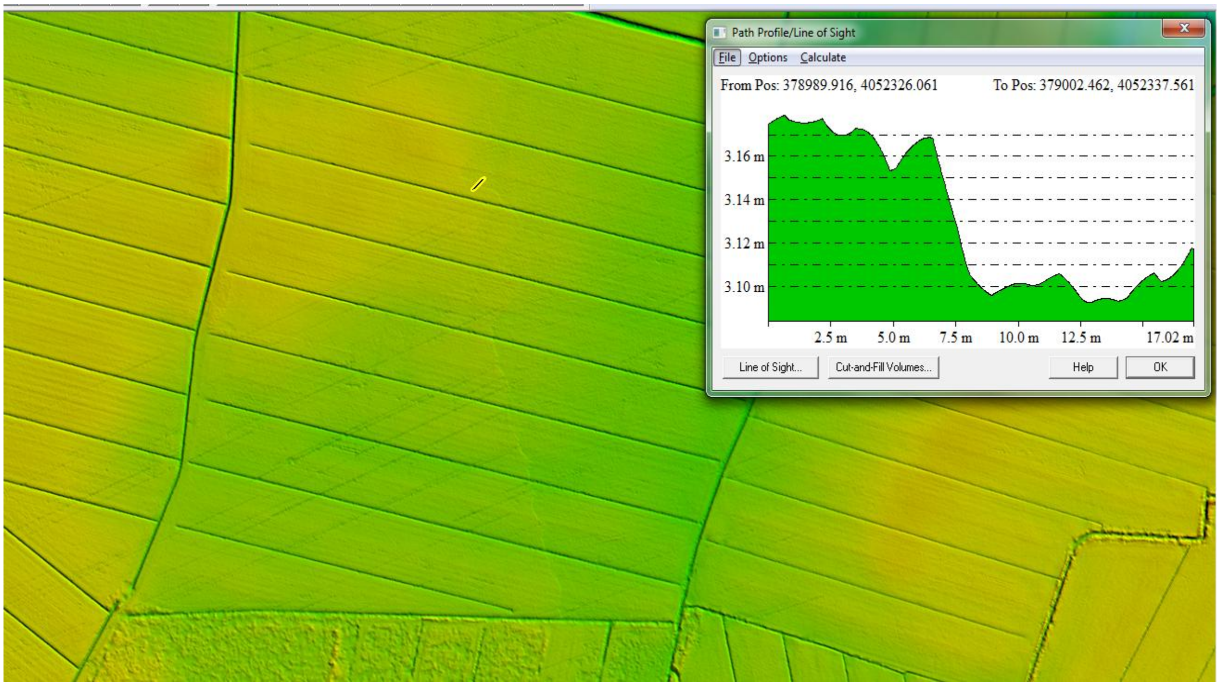


Figure 16– Tile number 18SUF780515. The flight line ridge is less than 8 cm. Overall, the FEMA Norfolk, VA LiDAR data meets the project specifications for 10 cm RMSE relative accuracy.

DERIVATIVE LIDAR PRODUCTS

Building Footprint Shapefiles

Dewberry generated 2D and 3D building footprints through the use of a semi-automated approach. This approach is semi automated in that the initial development of the features is conducted through the automated processing of the LiDAR data using proprietary tools and completed through manual review and editing of the features to ensure that the product meets the specifications.

Dewberry developed an automated processing algorithm that identified the planar surfaces in the LiDAR data and generated polygons from the indentified areas. Once the surfaces were identified and the initial polygons had been extracted, a secondary process preformed a best-fit line surrounding the initial polygons to square and finish the buildings.

While the automated portion of the process successfully extracts the majority of features, there are instances where features will not be accurately captured. Dewberry identified and manually added features that were visible in the LiDAR but were missed by the automated collect, separated buildings that were collected as a single footprint due to proximity, and reshaped complex features in the final processing steps.

a. *Missed or Inaccurately Generated Features:* The automated building footprints are based on LiDAR points that were classified based on size, elevation and angular relationships between the points. Occasionally, features were missed or inaccurately generated due to tree cover or certain properties not meeting the automated classification parameters. Dewberry added or modified these features as needed during the manual portion of the process. Examples are shown below.

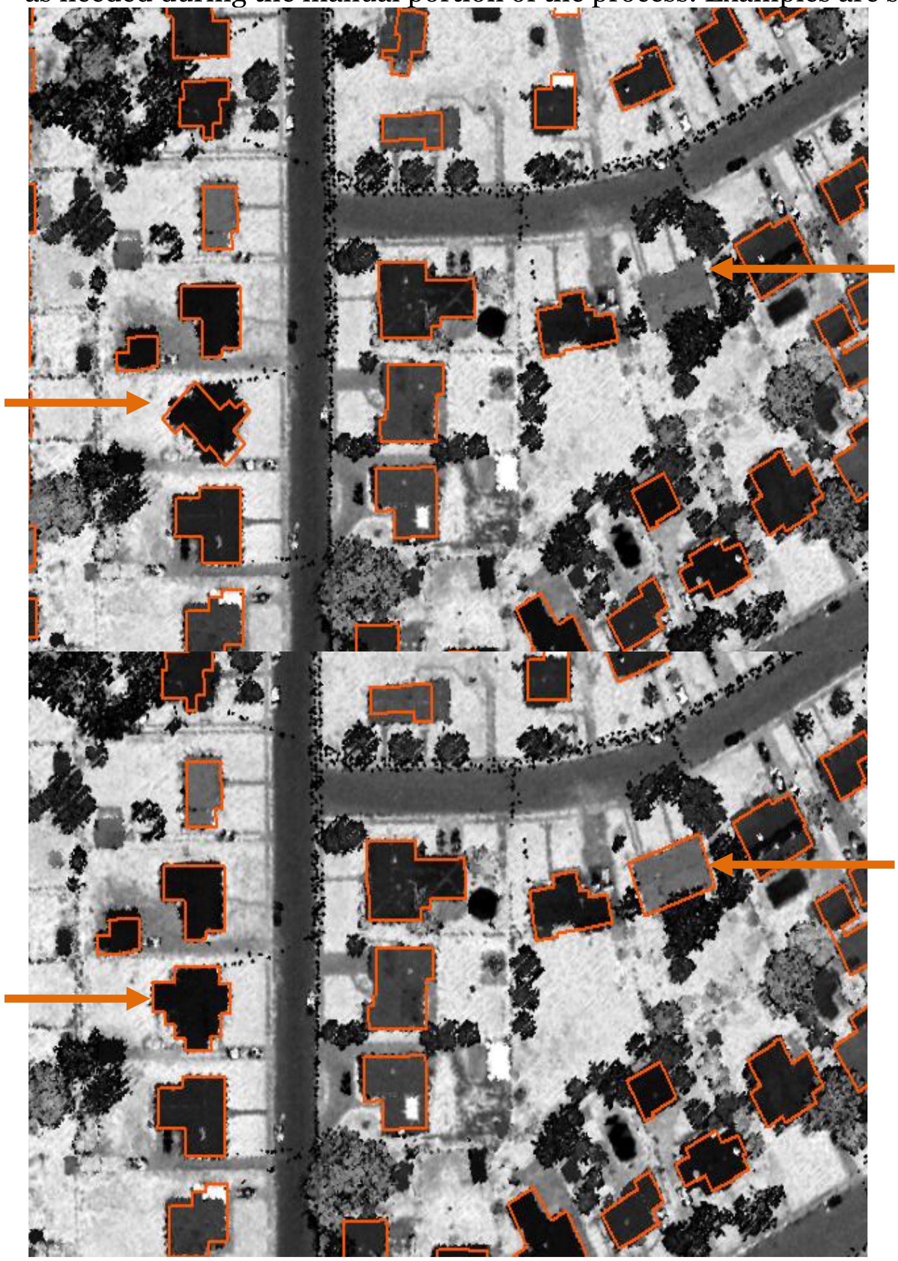


Figure 17 – Tiles 18SUF795950 and 18SUF795965. The top image shows the automated portion of the process missed a feature and did not accurately capture a second feature. Dewberry corrected these types of errors during the manual review as shown in the bottom image.

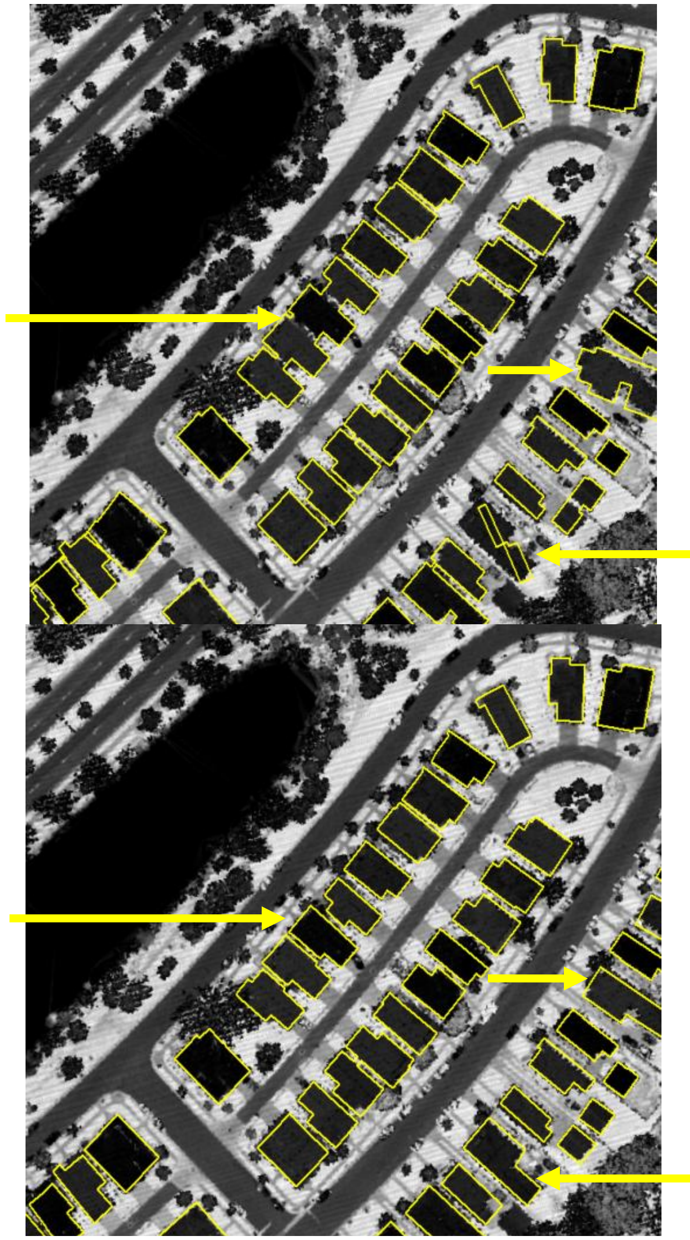


Figure 19 – Tile 18SUF795725. The top image shows the automated portion of the process did not accurately capture and separate individual features that were in close proximity. Dewberry corrected these types of errors during the manual review as shown in the bottom image.

Dewberry completed the buildings by programmatically adding the attributes for length, width, area, building top elevation, building base elevation, median height of building, and rooftype.

The positional accuracy of the features are equal to 1.5 meters relative to the LiDAR data. This accuracy allows for the fact that the roof line will not be completely accurate due to the density of points on the feature.

Vegetation Shapefiles

Forest polygons were developed using automated processes in eCognition software. This software allowed the input of the surface models and intensity imagery to determine vegetation stands as well as individual points. Upon completion of the automated extraction buildings and hydrographic features were erased from the vegetation polygons as required in the specifications.

Dewberry determined the predominant height of the stand, the average stem spacing, and the type of tree using GIS tools. Stand height was calculated using the mean surface model elevation for each tree stand. Average stem spacing was calculated using the mean Euclidean distance of the tree points within each stand. Tree type was assigned by first correlating forest landcover types from NOAA's Coastal Change Analysis Program (C-CAP) 2006 landcover dataset to coincident forest polygons. Then, the remaining forest polygons that were not coincident to the C-CAP forest landcover were classified manually.

Along with the forest polygons, Dewberry generated point records for each tree within the project area that exceeds the 4 meter height requirement. Trees were collected both inside and outside of the vegetation polygons. Dewberry used eCognition to segment the intensity and surface models into likely candidates for individual trees. These segments were converted to a centroid and attributed as a tree point. Dewberry performed a review of the dataset to ensure that no significant errors are present. However, it should be noted that the individual tree points will be best estimates for the trees and not necessarily the absolute location of an individual tree.

Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of one hundred (100) checkpoints were surveyed for the USGS Norfolk, VA LiDAR Project.

Point ID	NAD83 UTM Zone 18		NAVD88
	Easting X (m)	Northing Y (m)	Elevation (m)
BLT	351760.734	4127850.10	18.183
BLT	381578.163	4078664.26	0.747
BLT	393248.624	4072438.86	5.015
BLT	402227.485	4071563.33	3.332
BLT	392360.215	4067495.23	4.073
BLT	381270.904	4060371.47	4.561
BLT	400675.21	4061689.79	3.101
BLT	418260.165	4058718.15	0.336
BLT	381142.027	4051271.05	0.508
BLT	391753.707	4051529.69	3.966
BLT	410587.042	4049846.41	0.215
BLT	354157.693	4124969.35	26.867

BLT	393929.901	4045956.46	1.760
BLT	374985.334	4116934.63	1.681
BLT	377113.574	4112722.61	1.301
BLT	363984.403	4105501.27	5.313
BLT	376746.304	4101703.52	3.508
BLT	387491.887	4091258.47	0.708
BLT	376730.499	4083420.21	5.063
BLT	409359.513	4083180.74	1.461
FO	370349.672	4073223.38	6.550
FO	372583.785	4071595.18	5.275
FO	415396.475	4067053.56	0.702
FO	397607.018	4068185.83	2.955
FO	376505.026	4067499.95	4.395
FO	395910.233	4060914.70	2.597
FO	410438.562	4055125.18	0.440
FO	380102.698	4056043.02	4.959
FO	396807.306	4049602.58	2.637
FO	403948.268	4045614.94	2.244
FO	350327.179	4136365.61	24.911
FO	391454.574	4046723.48	4.048
FO	360028.768	4126241.51	9.111
FO	366402.057	4118875.45	16.648
FO	372250.758	4112572.97	4.076
FO	362705.508	4108269.85	9.253
FO	381648.883	4101531.90	2.403
FO	372274.821	4096033.45	5.794
FO	399373.443	4084210.27	5.089
FO	400375.322	4078421.85	3.415
GWC	393746.948	4078316.06	1.982
GWC	375676.882	4072545.39	4.983
GWC	409067.175	4073011.62	5.377
GWC	403954.911	4067042.59	4.174
GWC	377981.16	4066255.19	3.710
GWC	392212.252	4061512.70	6.443
GWC	402351.116	4055382.32	2.440
GWC	386220.44	4056359.55	5.163
GWC	386712.905	4049194.93	3.966
GWC	409971.276	4046257.13	2.111
GWC	344779.087	4134125.52	35.999
GWC	376541.932	4046741.63	4.160
GWC	360405.124	4118838.76	13.727
GWC	373059.394	4119343.90	1.280
GWC	381475.24	4109732.52	0.319
GWC	376178.523	4107208.36	2.294
GWC	376137.546	4096625.80	4.989
GWC	365940.986	4114829.51	17.938
GWC	393786.442	4082613.86	6.043

GWC	404973.792	4084165.95	4.738
OT	348684.803	4133416.99	25.196
OT	387312	4078657.57	2.843
OT	387581.462	4072616.49	5.679
OT	409482.049	4066448.20	2.486
OT	381818.542	4067562.41	2.601
OT	378660.721	4061599.98	4.475
OT	409784.125	4060963.64	1.461
OT	397899.773	4055461.44	3.726
OT	376373.978	4051531.89	5.106
OT	385337.999	4049989.79	4.067
OT	399629.715	4045755.10	2.509
OT	365374.175	4120908.93	19.117
OT	389710.031	4046832.73	3.427
OT	360651.125	4113702.12	10.775
OT	385773.135	4105404.72	1.142
OT	365920.251	4107753.53	9.598
OT	371637.805	4101773.55	6.314
OT	382129.104	4097123.06	2.298
OT	383472.444	4086525.63	3.377
OT	404011.498	4078298.89	4.043
UT	350036.421	4130867.11	21.875
UT	376920.293	4079299.32	3.214
UT	381584.308	4073036.02	3.282
UT	398962.242	4072060.25	3.235
UT	387116.242	4067549.67	5.267
UT	386392.045	4061538.34	5.179
UT	417183.163	4061728.53	0.768
UT	407222.046	4055014.76	3.243
UT	392295.391	4055820.66	5.854
UT	403094.607	4049572.58	2.671
UT	407107.901	4049321.39	3.256
UT	386772.849	4046143.79	5.127
UT	366296.531	4122275.22	1.749
UT	365989.527	4112855.29	16.213
UT	360182.785	4110977.45	9.528
UT	371528.482	4107289.80	8.882
UT	365947.433	4102065.18	9.063
UT	375440.462	4094026.89	1.167
UT	388018.935	4084249.17	3.177
UT	410043.225	4077444.67	4.977

Table 11: Norfolk, VA LiDAR surveyed accuracy checkpoints

LiDAR Vertical Accuracy Statistics & Analysis

BACKGROUND

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For quantitative assessment (i.e. vertical accuracy assessment), one hundred (100) check points were surveyed for the project and are located within bare earth/open terrain, urban, grass/weeds/crops, brush lands/tress, and forested/fully grown land cover categories. The checkpoints were surveyed for the project using RTK survey methods. 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.

VERTICAL ACCURACY TEST PROCEDURES

FVA (Fundamental Vertical Accuracy) is determined with check points located only in the open terrain (grass, dirt, sand, and/or rocks) land cover category, where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the Norfolk, VA LiDAR project, vertical accuracy must be 0.181 meters or less based on an $RMSE_z$ of 0.0925 meters x 1.9600.

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The Norfolk, VA LiDAR Project CVA standard is 0.269 meters based on the 95th percentile. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each land cover category. The Norfolk, VA LiDAR Project SVA target is 0.269 meters based on the 95th percentile. Target specifications are given for SVA's as one individual land cover category may exceed this target value as long as the overall CVA is within specified tolerances. Again, $Accuracy_z$ differs from SVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas SVA 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 the table below.

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only using $RMSE_z$ *1.9600	0.181 meters (based on $RMSE_z$ (0.0925 meters) * 1.9600)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined at the 95% confidence level	0.269 meters (based on combined 95^{th} percentile)
Supplemental Vertical Accuracy (SVA) in each land cover category separately at the 95% confidence level	0.269 meters (based on 95^{th} percentile for each land cover category)

Table 12 — Acceptance Criteria

VERTICAL ACCURACY TESTING STEPS

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 FVA, CVA, and SVA values.
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.

The figure below shows the location of the QA/QC checkpoints within the project area.

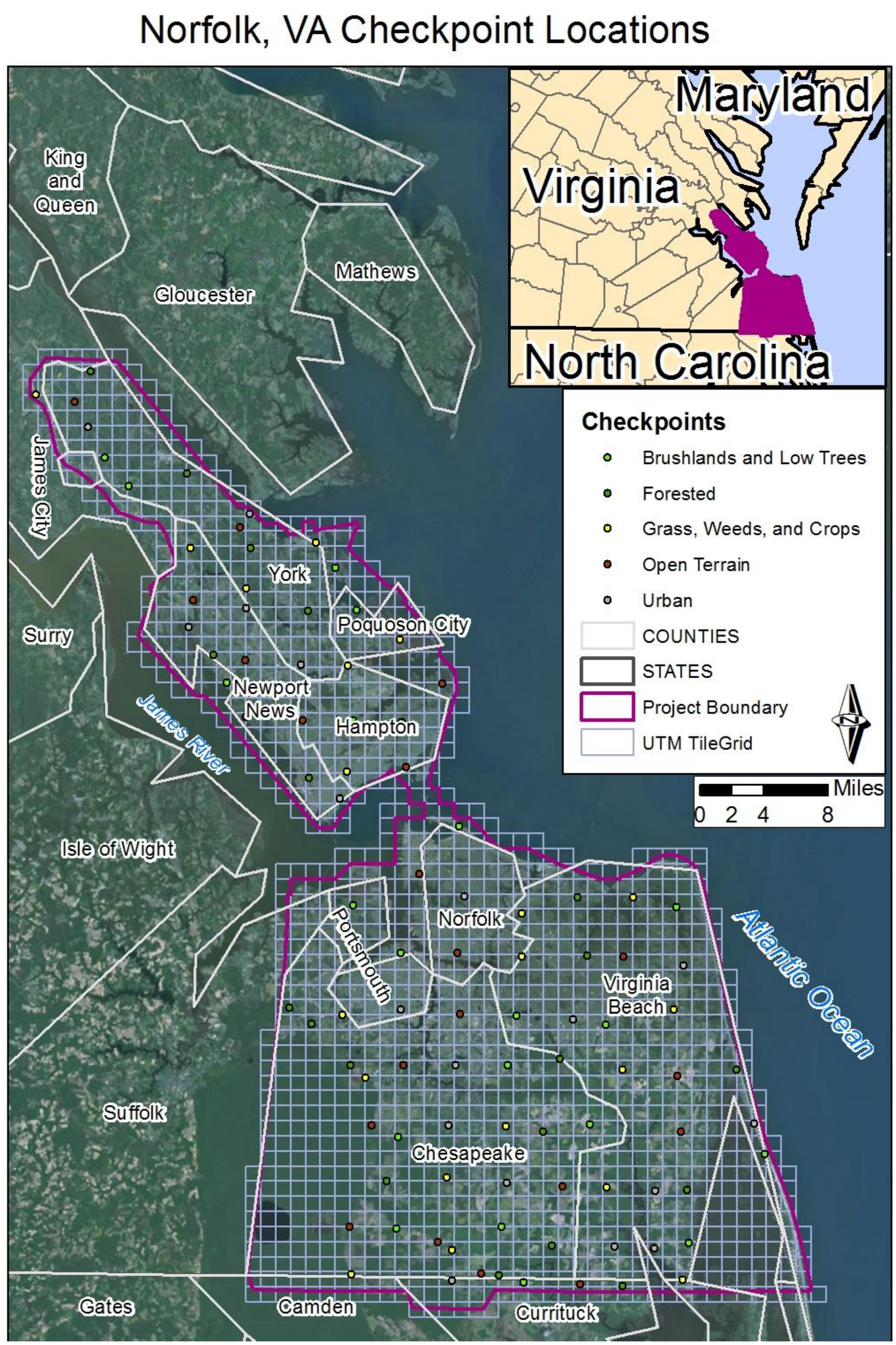


Figure 20 – Location of QA/QC Checkpoints

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	FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181 m	CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m	SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m
Consolidated	100		0.194	
Bare Earth-Open Terrain	20	0.129		
Grass, Weeds and Crops	20			0.198
Forest	20			0.163
Urban	20			0.196
Brush Land and Trees	20			0.196

Table 13 – FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.066 meters, within the target criteria of 0.092 meters. Compared with the 0.181 meters specification, the FVA tested 0.129 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.194 meters based on the 95^{th} percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the urban land cover category tested 0.196 meters based on the 95^{th} percentile, checkpoints in the grass, weeds and crops land cover category tested 0.198 meters based on the 95^{th} percentile, checkpoints in the forested land cover category tested 0.163 meters based on the 95^{th} percentile, and checkpoints in the brush land and trees land cover category tested 0.196 meters based on the 95^{th} 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 +/- 0.15 meters of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to +0.23 meters.

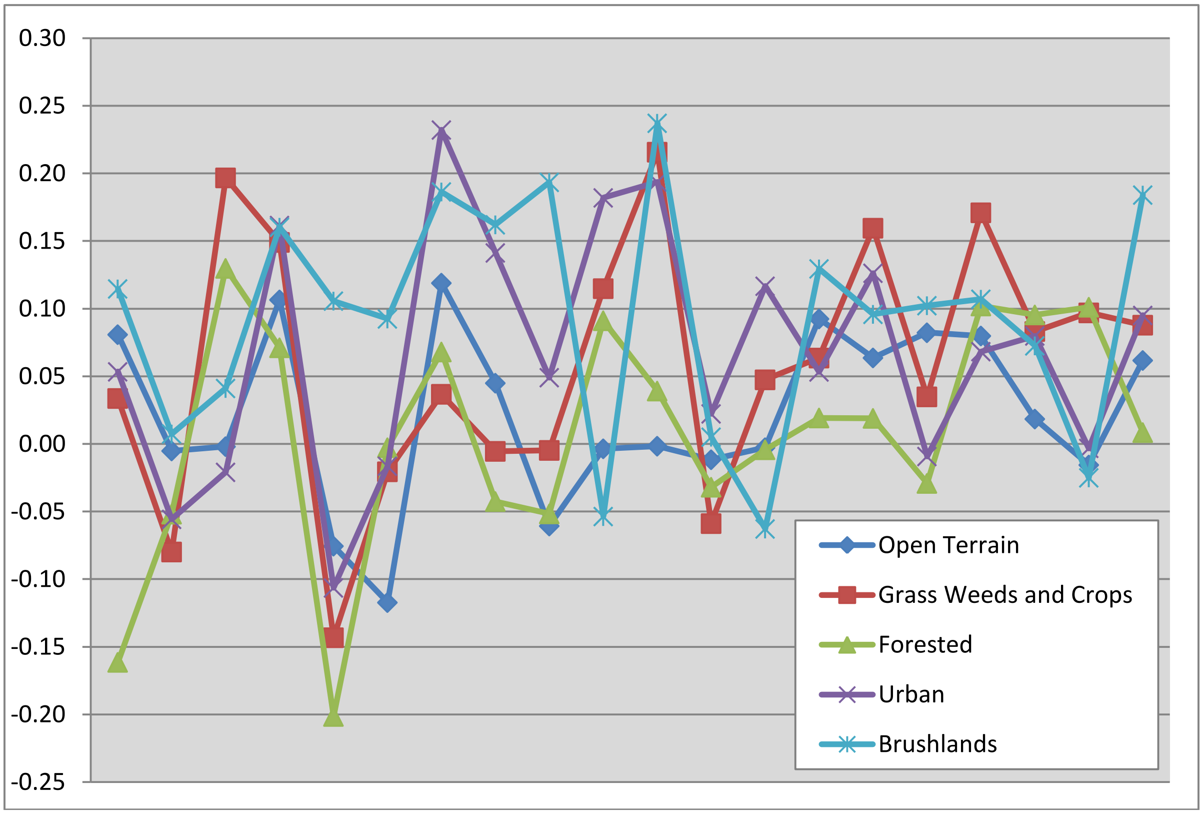


Figure 21 – Magnitude of elevation discrepancies per land cover category

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

Point ID	NAD83 UTM Zone 18		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
BLT	410587.042	4049846.41	0.215	0.4522	0.24	0.24
FO	376505.026	4067499.95	4.395	4.1936	-0.20	0.20
GWC	409067.175	4073011.62	5.377	5.5738	0.20	0.20
GWC	344779.087	4134125.52	35.999	36.2148	0.22	0.22
UT	417183.163	4061728.53	0.768	1.0002	0.23	0.23

Table 14 – 5% Outliers

Table 15 provides overall descriptive statistics.

100 % of Totals	RMSE$_z$ (m) Open Terrain Spec=0.0925m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.050	0.053	-0.197	0.088	100	-0.201	0.237
Open Terrain	0.066	0.023	0.008	-0.428	0.064	20	-0.117	0.119
Grass, Weeds and Crops		0.059	0.056	-0.256	0.095	20	-0.201	0.216
Forest		0.008	0.014	-0.884	0.086	20	-0.201	0.130
Urban		0.068	0.061	-0.005	0.089	20	-0.106	0.232
Brush land and Trees		0.093	0.104	-0.349	0.085	20	-0.063	0.237

Table 15 — 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 -0.201 meters and a high of +0.237 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 -0.15 meters to +0.15 meters.

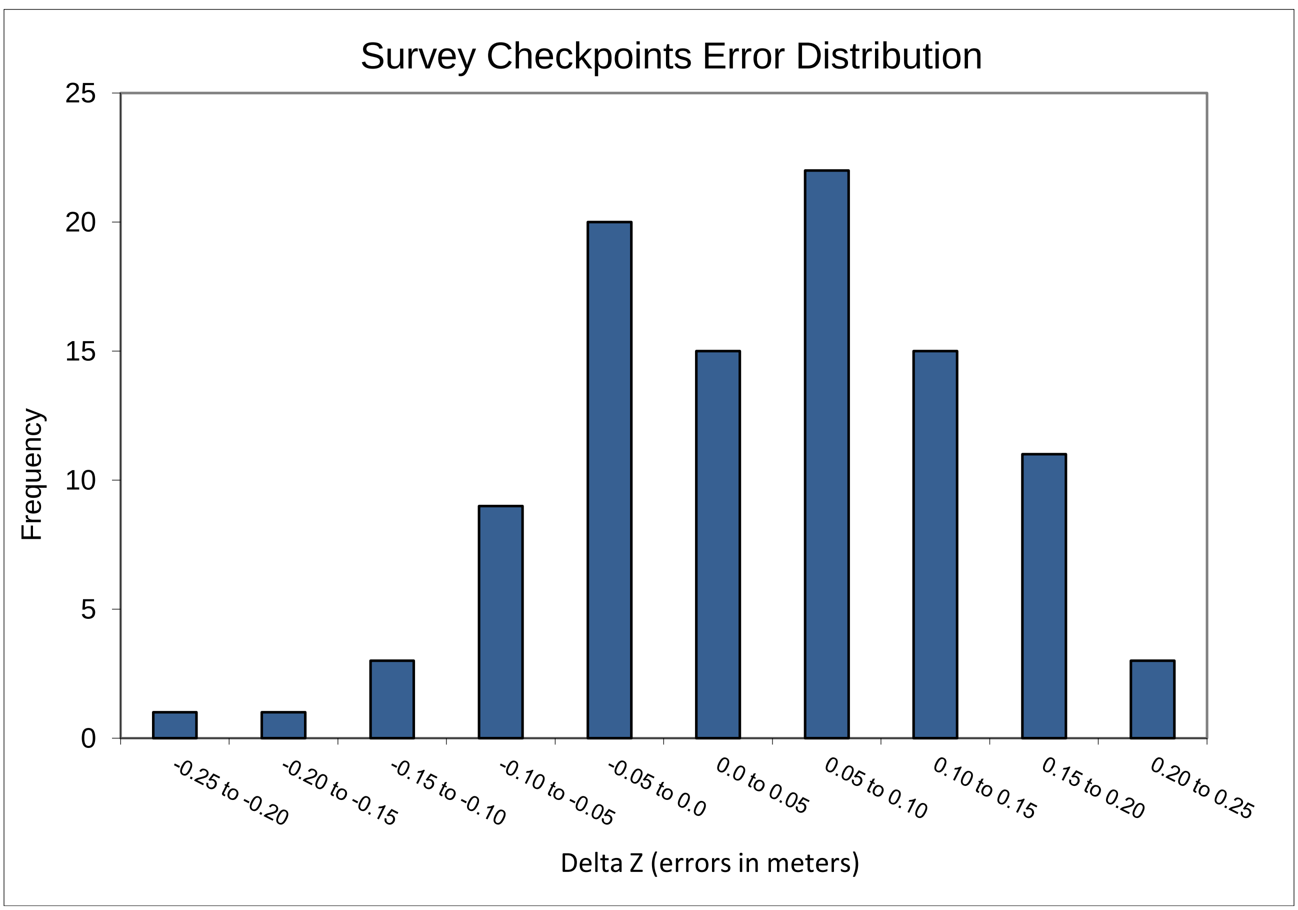


Figure 22 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the Norfolk, VA LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

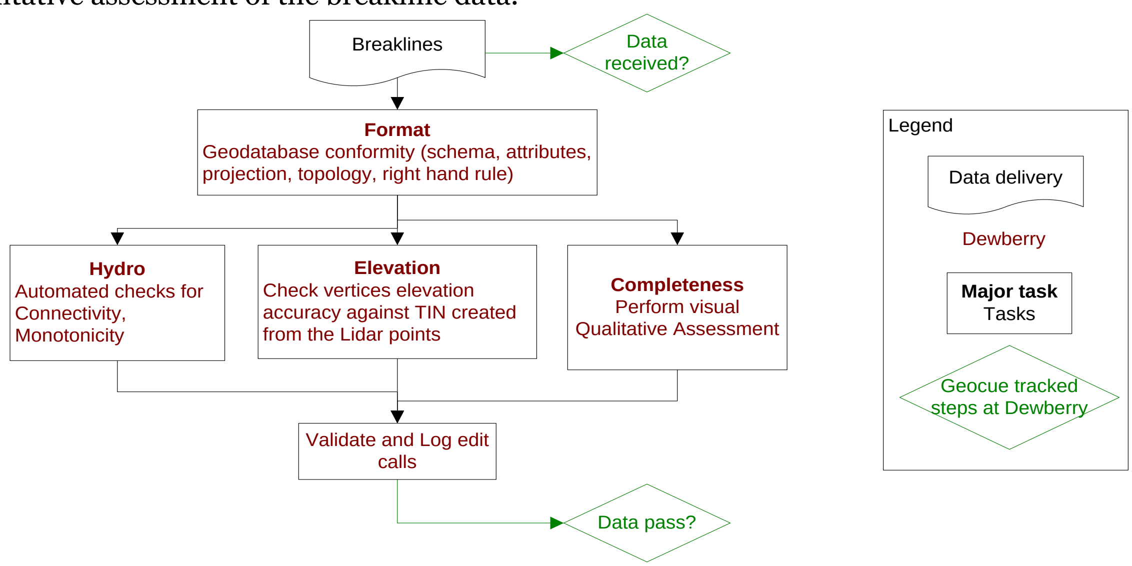
BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of the Norfolk, VA LiDAR 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 developed by Dewberry to stereo-compile the three types of hard breaklines in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are reviewed in stereo and the lowest elevation is applied to the entire waterbody.

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.



BREAKLINE TOPOLOGY RULES

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

The next step is to compare the elevation of the breakline vertices against the 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.

Dewberry's final check for the breaklines was to perform a full qualitative analysis. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations. The quality control steps taken by Dewberry are outlined in the QA Checklist below.

BREAKLINE QA/QC CHECKLIST

Project Number/Description: TO G13PD00279 USGS Norfolk, VA LiDAR

Date:______1/29/2014____

Overview

☒ All Feature Classes are present in GDB

☒ All features have been loaded into the geodatabase correctly. Ensure feature classes with subtypes are domained correctly.

☒ The breakline topology inside of the geodatabase has been validated. See Data Dictionary for specific rules

☒ Projection/coordinate system of GDB is accurate with project specifications

Perform Completeness check on breaklines using either intensity or ortho imagery

☒ Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency (See Data Dictionary for specific collection rules). Features should be collected consistently across tile bounds within a dataset as well as be collected consistently between datasets.

☒ Check to make sure breaklines are compiled to correct tile grid boundary and there is full coverage without overlap

☒ Check to make sure breaklines are correctly edge-matched to adjoining datasets if applicable. Ensure breaklines from one dataset join breaklines from another dataset that are coded the same and all connecting vertices between the two datasets match in X,Y, and Z (elevation). There should be no breaklines abruptly ending at dataset boundaries and no discrepancies of Z-elevation in overlapping vertices between datasets.

Compare Breakline Z elevations to LiDAR elevations

☒ Using a terrain created from LiDAR ground points and water points, drape breaklines on terrain to compare Z values. Breakline elevations should be at or below the elevations of the immediately surrounding terrain. This should be performed before other breakline checks are completed.

Perform automated data checks using ESRI's Data Reviewer
The following data checks are performed utilizing ESRI's Data Reviewer extension. These checks allow automated validation of 100% of the data. Error records can either be written to a table for future correction, or browsed for immediate correction. Data Reviewer checks should always be performed on the full dataset.

☒ Perform "adjacent vertex elevation change check" on the Inland Ponds feature class (Elevation Difference Tolerance=.001 meters). This check will return Waterbodies whose vertices are not all identical. This tool is found under "Z Value Checks."

☒ Perform "unnecessary polygon boundaries check" on Inland Ponds and Lakes, Tidal Waters, and Islands (if delivered as a separate feature class) feature classes. This tool is found under "Topology Checks."

☒ Perform "different Z-Value at intersection check" (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) (Elevation Difference Tolerance= .01 meters Minimum, 200 meters Maximum, Touches). This tool is found under "Z Value Checks." Please note that polygon feature classes will need to be converted to lines for this check.

☒ Perform "duplicate geometry check" on (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal Waters to Tidal Waters), (Islands to Islands-if delivered as a separate shapefile), (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is crosses, attributes do not need to be checked. This tool is found under "Feature on Feature Checks." Please note that "crosses" only works with line feature classes and not polygons. If the inputs are polygons, they will need to be converted to a line prior to running this tool.

☒ Perform “geometry on geometry check (Tidal Waters to Islands), and (Inland Ponds and Lakes to Islands), (Inland Streams and Rivers to Islands). Spatial relationship is contains, attributes do not need to be checked. This tool is found under “Feature on Feature Checks.”

☒ Perform “geometry on geometry check” (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is intersect, attributes do not need to be checked. This tool is found under “Feature on Feature Checks.” Please note that false positives may be returned with this tool but that this tool may identify issues not found with “crosses.”

☒ Perform “polygon overlap/gap is sliver check” on (Tidal Waters to Tidal Waters), (Island to Island), (Island to Inland Ponds and Lakes) and (Inland Ponds and Lakes to Inland Ponds and Lakes), (Inland Ponds and Lakes to Tidal Waters). Maximum Polygon Area is not required. This tool is found under “Feature on Feature Checks.”

Perform Dewberry Proprietary Tool Checks

☒ Perform monotonicity check on (Inland Streams and Rivers) and (Tidal Waters to Tidal Waters if they are not a constant elevation) using “A3_checkMonotonicityStreamLines.” This tool looks at line direction as well as elevation. Features in the output shapefile attributed with a “d” are correct monotonically, but were compiled from low elevation to high elevation. These features are ok and can be ignored. Features in the output shapefile attributed with an “m” are not correct monotonically and need elevations to be corrected. Input features for this tool need to be in a geodatabase and must be a line. If features are a polygon they will need to be converted to a line feature. Z tolerance is 0.01 meters.

☒ Perform connectivity check between (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) using the tool “07_CheckConnectivityForHydro.” The input for this tool needs to be in a geodatabase. The output is a shapefile showing the location of overlapping vertices from the polygon features and polyline features that are at different Z-elevation.

Metadata

☒ Each XML file (1 per feature class) is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc. Content should be consistent across all feature classes.

Completion Comments: Complete – Approved

Data Dictionary

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983, Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12A shall be used to convert ellipsoidal heights to orthometric heights.

COORDINATE SYSTEM AND PROJECTION

All data shall be projected to UTM Zone 18, Horizontal Units in Meters and Vertical Units in Meters.

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 1/2 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. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1/2 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.

2D BUILDINGS

Feature Dataset: Buildings
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Buildings_2D
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This 2D polygon feature class will depict at least 98% of all buildings larger than 200 square meters and at least 95% of all buildings larger than 100 square meters. The positional accuracy of the collected features will be equal to 1.5 meters relative to the LiDAR data.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
Id	Double	Yes						Polygon ID number for the building substructure assigned by user
ARA2d	Double	Yes						Area of the 2D sub structure calculated by software
LEN2d	Double	Yes						Length of the 2D polygon calculated by software
WID2d	Double	Yes						Width of the 2D polygon calculated by software
HGT2d	Double	Yes						Median height of the building substructure above ground level based on the difference between the DSM and the Bare Earth model calculated 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
2D Buildings	2D buildings will include the majority of structures larger than 100 square meters. The positional accuracy of the collected features will be equal to 1.5 meters relative to the LiDAR data.	The roofs of some buildings or structures may be offset from the true footprint in the imagery. Care should be taken to collect the actual or true footprint of each structure by collecting the base of the structure. All building footprints should be captured in 2D, but should still show correct topology.

3D BUILDINGS

Feature Dataset: Buildings
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Buildings_3D
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This 3D polygon feature class will depict at least 98% of all buildings larger than 200 square meters and at least 95% of all buildings larger than 100 square meters. The positional accuracy of the collected features will be equal to 1.5 meters relative to the LiDAR data.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
Id	Double	Yes						Polygon ID number for the building substructure assigned by user
BldgId	Double	Yes						ID number of the entire building footprint assigned by user
TopElev3D	Double	Yes						Elevation of the top of the bulding subsection. This is the arithmetic median of all LiDAR points within the polygon calculated by software
BaseElev3D	Double	Yes						Base elevation of the building subsection. This is the arithmetic minimum of all bare earth elevation points within the polygon calculated by software
ARA3D	Double	Yes						Area of the 3D substructure calculated by software
LEN3D	Double	Yes						Length of the 3D polygon calculated by software
WID3D	Double	Yes						Width of the 3D polygon calculated by software
HGT3D	Double	Yes						Median height of building substructure above ground level based on the difference between

								the DSM and the bare earth model calculated by software
SSR	Double	Yes						Classified roof type identified in the NGA FACC coding schema. Flat=41, pitched=42 and complex(other)=999 assigned by user
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
3D Buildings	3D buildings will include the majority of structures larger than 100 square meters. The positional accuracy of the collected features will be equal to 1.5 meters relative to the LiDAR data.	The roofs of some buildings or structures may be offset from the true footprint in the imagery. Care should be taken to collect the actual or true footprint of each structure by collecting the base of the structure. All building footprints should correct topology.

FOREST POLYGONS

Feature Dataset: Vegetation
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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

Description

This 2D polygon feature class will be delineated in areas where vegetation greater than 2m in height is predominant over a contiguous area 5,000 square meters or larger. Forests shall be de-conflicted from identifiable open water greater than 15 meters wide.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
Id	Double	Yes						Polygon ID number assigned by user
ARA	Double	Yes						Area calculated by software
PHT	Double	Yes						Predominant height of stand calculated by software
TSC	Double	Yes						Average stem spacing distance for stand, in decimeters calculated by software
Type	Double	Yes						Tree type (deciduous or coniferous) assigned by user
SHAPE_LENGTH	Double	Yes						Calculated by Software
SHAPE_AREA	Double	Yes						Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Forest polygons	Areas of vegetation greater than 2m in height that are predominant over a contiguous area 5,000 square meters or larger will be included in the collect. Forests shall be de-conflicted from identifiable open water greater than 15 meters wide. .	All polygons should have the correct topology.

TREE POINTS

Feature Dataset: Vegetation
Feature Type: Point
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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

Description

This point feature class will be extracted from identified vegetated areas that exceed 4 meters in height relative to the bare earth model.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
Id	Double	Yes						Point ID number assigned by user
HGT	Double	Yes						The height of the tree calculated by software
BaseElev	Double	Yes						Base height of the tree calculated by software
Type	Double	Yes						Tree type (deciduous or coniferous) assigned by user
SHAPE_LENGTH	Double	Yes						Calculated by Software
SHAPE_AREA	Double	Yes						Calculated by Software

Feature Definition

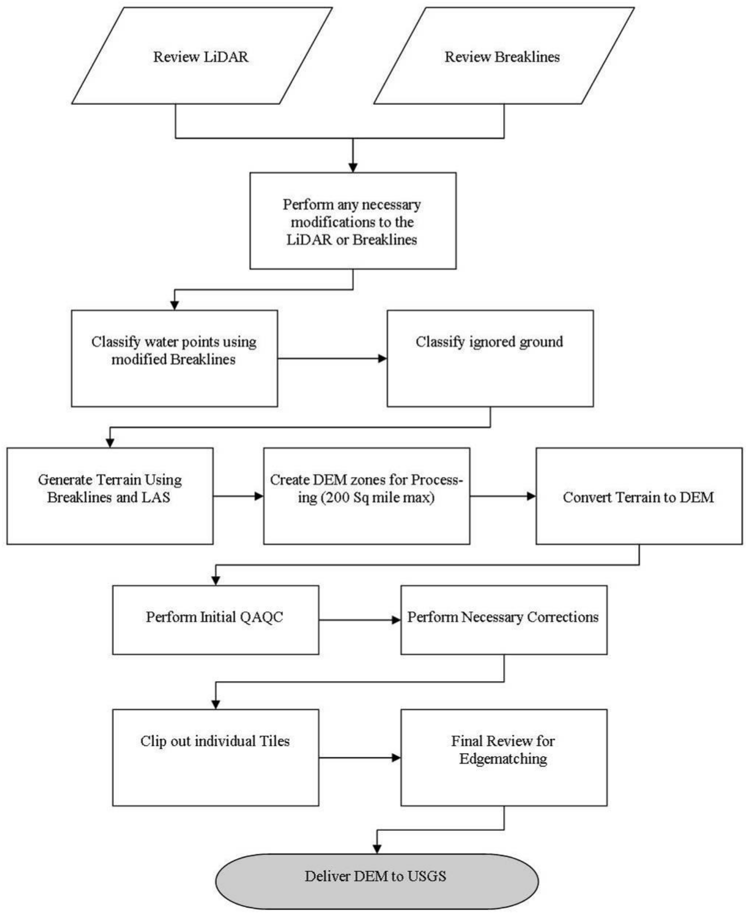
Description	Definition	Capture Rules
Tree Points	This point feature class will extracted from identified vegetated areas that exceed 4 meters in height relative to the bare earth model. .	All points should have the correct topology.

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.

Dewberry Hydro-Flattening Workflow



1. Classify Water Points: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.
2. Classify Ignored Ground Points: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as no more than 1x the nominal point spacing on the landward side of the breakline.
3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File.
4. Create DEM Zones for Processing: Create DEM Zones that are buffered around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones too large for processing. Dewberry will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.
5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 4. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.

7. Correct Issues on Zones: Dewberry will perform corrections on zones following Dewberry's correction process.
8. Extract Individual Tiles: Dewberry will extract individual tiles from the zones utilizing a Dewberry proprietary tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

The creation of first and last return DSMs follow a similar workflow as outlined above, except that breaklines are not used to enforce the first and last return terrains. Additionally, rather than ground only data, the first or last return of all point classes, except for noise-class 7, are used to create the multipoint files and subsequent terrains.

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 and first return DSM of the same tile.

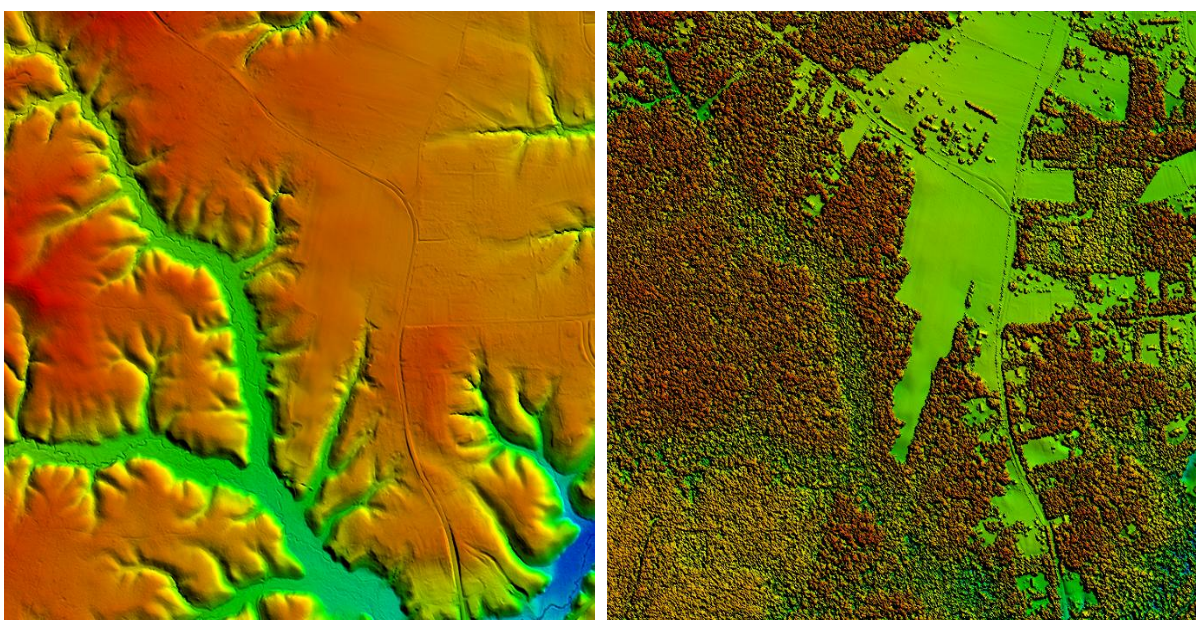


Figure 21-Tile 18SUG480340. The bare earth DEM is shown on the left while the first return DSM is shown on the right

DEM VERTICAL ACCURACY RESULTS

The same 100 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.

Table 16 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m
Consolidated	100		0.197	
Bare Earth-Open Terrain	20	0.135		
Grass Weeds and Crops	20			0.194
Forest	20			0.168
Urban	20			0.216
Brush Land and Trees	20			0.211

Table 16 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.069 meters, within the target criteria of 0.092 meters. Compared with the 0.181 meters specification, the FVA tested 0.135 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.197 meters based on the 95th percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the grass weeds and crops land cover category tested 0.194 meters based on the 95th percentile, checkpoints in the forested and fully grown land cover category tested 0.168 meters based on the 95th percentile, checkpoints in the brush and small trees land cover category tested 0.211 meters based on the 95th percentile, and checkpoints in the urban land cover category tested 0.216 meters based on the 95th percentile.

Table 17 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 18		NAVD88	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
BLT_17	381142.027	4051271.05	0.508	0.718	0.21	0.21
BLT_19	410587.042	4049846.41	0.215	0.432	0.22	0.22

FO_14B	376505.026	4067499.95	4.395	4.199	-0.20	0.20
GWC_1CHK	344779.087	4134125.52	35.999	36.215	0.22	0.22
UT_15CHK	417183.163	4061728.53	0.768	1.016	0.25	0.25

Table 17 — 5% Outliers

Table 18 provides overall descriptive statistics.

100 % of Totals	RMSE$_z$ (m) Open Terrain Spec=0.092m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.051	0.059	-0.224	0.089	100	-0.196	0.248
Open Terrain	0.069	0.021	0.032	-0.880	0.067	20	-0.155	0.119
Grass, Weeds and Crops		0.062	0.065	-0.186	0.090	20	-0.196	0.216
Forest		0.011	0.013	-0.862	0.089	20	-0.196	0.125
Urban		0.068	0.071	0.141	0.091	20	-0.099	0.248
Brush Land and Trees		0.092	0.095	-0.386	0.085	20	-0.069	0.217

Table 18 — Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: TO G13PD00279 USGS Norfolk, VA LiDAR
Date:_______1/29/2014______

Overview

☒ Correct number of files are delivered and all files are in ERDAS IMG format
☒ Verify Raster Extents
☒ Verify Projection/Coordinate System

Review

☒ Manually review bare-earth DEMs in Arc with a hillshade to check for issues with the hydro-flattening process or any general anomalies that may be present. Specifically, water should be flowing downhill, water features should NOT be floating above surrounding terrain and bridges should NOT be present in bare-earth DEM. Hydrologic breaklines should be overlaid during review of DEMs.
☒ Manually review first return DSMs with a hillshade to check for processing issues or coverage issues.
☒ Manually review last return DSMs with a hillshade to check for processing issues or coverage issues.
☒ DEM cell size is 1 meter
☒ Perform all necessary corrections in Arc using Dewberry's proprietary correction workflow.
☒ Review all corrections in Global Mapper
☒ Perform final overview on tiled data in Global Mapper to ensure seamless product.

Metadata

☒ Project level DEM metadata XML file is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc.

Completion Comments: Complete – Approved

Appendix A: Survey Report

Check Point Survey Report
"Norfolk, VA LiDAR Task Order"
USGS Contract: G10PC00013
Task Order Number: G13PD000279

Prepared by:

Dewberry Engineers Inc.
Charlotte, North Carolina, 282269
Phone: 704.509.9918
Fax: 704.509.9937

INTRODUTION

Project Summary

Dewberry Engineers Inc. is under contract to United States Geodetic Survey to provide 100 QA Check Points for 933 square miles in Chesapeake, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Virginia Beach, and York Counties in Virginia. Under the above USGS Task Order, Dewberry is tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As a part of this work Dewberry staff will complete checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR.

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

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

Final horizontal coordinates are referenced to UTM Zone 18 North, NAD83, in meters. Final Vertical elevations are referenced to NAVD88, in meters.

Points of Contact

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

Dewberry Engineers Inc.
Matthew Rudolph
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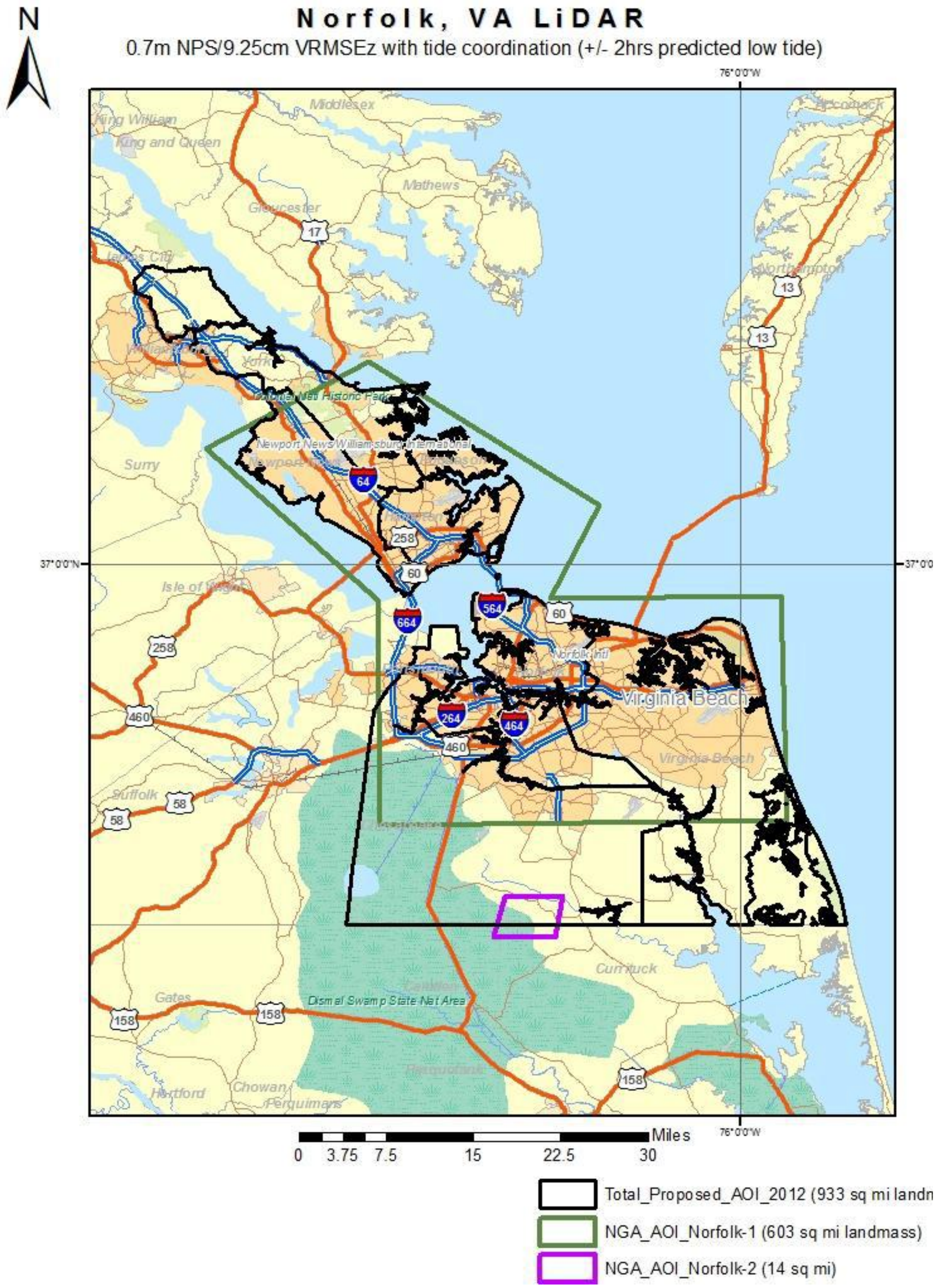
Suite 150
Charlotte, NC 20269
(704)264-1257direct
(704)509-9937

1.3 Project Area



PROJECT DETAILS

Survey Equipment

In performing the GPS observations, Trimble R-8 GNSS receiver/antenna attached to a 2 meter fixed height pole with a Trimble TSC2 Data Collector to collect GPS raw data were used to perform the field surveys.

Survey Point Detail

The 100 Check Points were well distributed throughout the project area so as to cover as many flight lines as possible using "dispersed method" of placement.

A "Ground Control Point Documentation Report" sheet was used to show the placement of the nail and a sketch for each of the points surveyed.

Network Design

The GPS survey performed by Dewberry Engineers Inc. located in Charlotte,NC was tied to a Real Time Network (RTN) managed by KeyNetGPS inc. KeyNetGPS is a series of continuously operating, high precision GNSS reference stations. These reference stations have all been linked together using Trimble VRS3Net App software, creating a Virtual Reference Station System (VRS).

Field Survey Procedures and Analysis

Dewberry Engineers Inc. used Trimble R-8 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerances of 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately three (3) minutes in duration and measured to at least 180 epochs.

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

Ten existing NGS monuments listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network. Some of these monuments were used as Horizontal and Vertical control checks. Some monuments were used as Horizontal or Vertical checks only as shown in the table below.

	AS SURVEYED(m)			AS PUBLISHED(m)						
NGS PT. ID	NORTHING	EASTING	ELEV	NORTHING	EASTING	ELEV	Δ N	Δ E	Δ ELEV	CHK TYPE
DOUGLAS CHK	4075440.488	380599.04	3.73	4,075,440.59	380,599.12	3.75	-0.103	-0.084	-0.020	VERT.
STATION 509	4100627.566	384554.955	2.124	4,100,627.56	384,554.95	2.3	0.010	0.007	X	HORIZ.
STATION 537	4098672.971	376462.99	3.503	4,098,672.96	376,463.00	4	0.008	-0.006	X	HORIZ.
STATION 538	4097985.036	375769.747	2.108	4,097,985.03	375,769.74	2	0.004	0.007	X	HORIZ.

F-455	4096857.383	376079.277	3.927	X	X	3.957	X	X	-0.030	VERT.
MON 007	4135651.82	349236.942	23.259	4,135,651.79	349,236.96	23.5	0.031	-0.022	X	HORIZ.
124	4107886.234	372228.771	8.579	4,107,886.28	372,228.77	8.7	-0.048	0.003	X	HORIZ.
PASCALE	4071366.848	371222.946	5.515	4,071,366.85	371,222.94	5.6	-0.003	0.009	X	HORIZ.
PEAKE	4094521.001	376414.781	2.479	4,094,520.99	376,414.77	2.5	0.008	0.013	-0.021	VERT.
D 470	4076051.123	3999352.192	3.401	X	X	3.447	X	X	-0.046	VERT.

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

Data Processing Procedures

After field data is collected the information is downloaded from the data collectors into the office software. The software programs used Trimble Business Center and Arc Map 10.

Downloaded data is run through the Trimble Business Center program to obtain the following reports; points report, point comparison, and a point detail report. The reports are reviewed for point accuracy and precision.

After review of the point data an “ASCII” or “txt” file is created. Point files are loaded into Arc Map 10(GIS software) to make a visual check of the point data to make sure it also checks with the “Ground Control Point Documentation Report” sketch and description as well as the Pt#, Coordinates, and Elevation.

FINAL COORDINATES

The final coordinate system for checkpoints is as follows:

Coord System = UTM
UTM Zone = Zone 18
Horiz Datum = NAD83
Vert Datum = NAVD88
Units = both in Meters
Geoid Model = GEOID12A

BRUSHLAND and LOW TREES			
BLT-1	4127850.095	351760.734	18.183
BLT-2	4124969.354	354157.693	26.867
BLT-3	4116934.625	374985.334	1.681
BLT-4	4112722.605	377113.574	1.301
BLT-5	4105501.265	363984.403	5.313
BLT-6	4101703.518	376746.304	3.508
BLT-7	4091258.47	387491.887	0.708
BLT-8	4083420.214	376730.499	5.063
BLT-9	4083180.738	409359.513	1.461
BLT-10	4078664.264	381578.163	0.747

BLT-11	4072438.855	393248.624	5.015
BLT-12	4071563.329	402227.485	3.332
BLT-13	4067495.229	392360.215	4.073
BLT-14	4060371.467	381270.904	4.561
BLT-15	4061689.787	400675.21	3.101
BLT-16	4058718.15	418260.165	0.336
BLT-17	4051271.046	381142.027	0.508
BLT-18	4051529.692	391753.707	3.966
BLT-19	4049846.406	410587.042	0.215
BLT-20	4045956.462	393929.901	1.76
FORESTED			
FO-1	4136323.776	350228.113	23.871
FO-2	4126211.091	360014.272	8.932
FO-3	4118875.446	366402.057	16.648
FO-4	4112572.968	372250.758	4.076
FO-5	4108269.849	362705.508	9.253
FO-6	4101531.898	381648.883	2.403
FO-7	4096033.448	372274.821	5.794
FO-8	4084210.274	399373.443	5.089
FO-9	4078442.28	400259.407	3.628
FO-10	4073199.529	370329.394	6.472
FO-11	4071580.897	372624.23	4.829
FO-12	4067053.555	415396.475	0.702
FO-13	4068198.754	397579.131	2.607
FO-14	4067550.12	376314.026	4.690
FO-15	4060962.236	395885.204	2.266
FO-16	4055125.178	410438.562	0.44
FO-17	4056004.221	380058.909	4.986
FO-18	4049656.47	396892.944	2.857
FO-19	4045705.789	403974.708	1.817
FO-20	4046751.378	391556.197	3.545
GRASS,WEEDS,and CROPS			
GWC-1	4134125.481	344779.064	35.965
GWC-2	4118838.763	360405.124	13.727
GWC-3	4119343.897	373059.394	1.28
GWC-4	4109732.524	381475.24	0.319
GWC-5	4107208.362	376178.523	2.294
GWC-6	4096625.795	376137.546	4.989
GWC-7	4114829.507	365940.986	17.938
GWC-8	4082613.859	393786.442	6.043

GWC-9	4084165.948	404973.792	4.738
GWC-10	4078316.06	393746.948	1.982
GWC-11	4072545.385	375676.882	4.983
GWC-12	4073011.615	409067.175	5.377
GWC-13	4067042.59	403954.911	4.174
GWC-14	4066255.187	377981.16	3.71
GWC-15	4061512.702	392212.252	6.443
GWC-16	4055382.316	402351.116	2.44
GWC-17	4056359.548	386220.44	5.163
GWC-18	4049194.933	386712.905	3.966
GWC-19	4046257.13	409971.276	2.111
GWC-20	4046741.634	376541.932	4.16
OPEN			
OT-1	4133416.989	348684.803	25.196
OT-2	4120908.932	365374.175	19.117
OT-3	4113702.121	360651.125	10.775
OT-4	4105404.702	385773.144	1.138
OT-5	4107753.528	365920.254	9.605
OT-6	4101773.558	371637.824	6.304
OT-7	4097123.061	382129.104	2.298
OT-8	4086525.625	383472.444	3.377
OT-9	4078298.891	404011.498	4.043
OT-10	4078657.569	387312	2.843
OT-11	4072616.492	387581.48	5.668
OT-12	4066448.202	409482.049	2.486
OT-13	4067562.414	381818.542	2.601
OT-14	4061599.984	378660.721	4.475
OT-15	4060963.643	409784.125	1.461
OT-16	4055461.44	397899.773	3.726
OT-17	4051531.896	376373.966	5.115
OT-18	4049989.779	385337.991	4.057
OT-19	4045755.088	399629.718	2.501
OT-20	4046832.726	389710.031	3.427
URBAN			
UT-1	4130867.113	350036.421	21.875
UT-2	4122275.214	366296.536	1.73
UT-3	4112855.286	365989.516	16.203
UT-4	4110977.445	360182.785	9.528
UT-5	4107289.791	371528.47	8.849
UT-6	4102065.181	365947.433	9.063

UT-7	4094026.888	375440.462	1.167
UT-8	4046143.784	386772.856	5.124
UT-9	4046143.784	386772.856	5.124
UT-10	4046143.784	386772.856	5.124
UT-11	4046143.784	386772.856	5.124
UT-12	4046143.784	386772.856	5.124
UT-13	4046143.784	386772.856	5.124
UT-14	4046143.784	386772.856	5.124
UT-15	4046143.784	386772.856	5.124
UT-16	4046143.784	386772.856	5.124
UT-17	4046143.784	386772.856	5.124
UT-18	4046143.784	386772.856	5.124
UT-19	4046143.784	386772.856	5.124
UT-20	4046143.784	386772.856	5.124

GPS OBSERVATIONS

NORFOLK, VA LiDAR 2013					
POINT ID	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBSERV. DATE	RE-OBSERV TIME
BRUSHLANDS AND LOW TREES					
BLT-1	5/6/2013	239	8:13	N/A	N/A
BLT-2	5/5/2013	240	12:15	N/A	N/A
BLT-3	5/5/2013	240	10:14	N/A	N/A
BLT-4	5/5/2013	240	8:58	N/A	N/A
BLT-5	5/4/2013	241	13:42	N/A	N/A
BLT-6	5/4/2013	241	11:22	N/A	N/A
BLT-7	5/4/2013	241	7:22	N/A	N/A
BLT-8	5/2/2013	243	14:53	N/A	N/A
BLT-9	5/3/2013	242	12:29	N/A	N/A
BLT-10	5/2/2013	243	15:28	N/A	N/A
BLT-11	5/2/2013	243	10:52	N/A	N/A
BLT-12	5/2/2013	243	19:30	N/A	N/A
BLT-13	5/1/2013	244	12:52	N/A	N/A
BLT-14	5/1/2013	244	16:45	5/22/2013	12:03
BLT-15	5/1/2013	244	11:15	N/A	N/A
BLT-16	4/30/2013	245	17:18	N/A	N/A
BLT-17	4/29/2013	246	12:18	N/A	N/A
BLT-18	4/29/2013	246	15:32	N/A	N/A

BLT-19	4/30/2013	245	12:07	N/A	N/A
BLT-20	4/29/2013	246	15:07	N/A	N/A
FORESTED					
FO-1	5/6/2013	239	9:35	N/A	N/A
FO-2	5/5/2013	240	13:43	N/A	N/A
FO-3	5/5/2013	240	11:00	N/A	N/A
FO-4	5/5/2013	240	9:26	N/A	N/A
FO-5	5/4/2013	241	14:05	N/A	N/A
FO-6	5/4/2013	241	9:54	N/A	N/A
FO-7	5/4/2013	241	11:55	N/A	N/A
FO-8	5/3/2013	242	15:08	N/A	N/A
FO-9	5/3/2013	242	14:19	N/A	N/A
FO-10	5/2/2013	243	13:16	N/A	N/A
FO-11	5/2/2013	243	12:32	N/A	N/A
FO-12	4/30/2013	245	16:14	N/A	N/A
FO-13	5/1/2013	244	12:01	N/A	N/A
FO-14	5/1/2013	244	15:28	N/A	N/A
FO-15	5/1/2013	244	9:57	N/A	N/A
FO-16	4/30/2013	245	12:36	N/A	N/A
FO-17	4/29/2013	246	17:47	N/A	N/A
FO-18	4/30/2013	245	7:23	N/A	N/A
FO-19	4/30/2013	245	9:41	N/A	N/A
FO-20	4/29/2013	246	14:25	N/A	N/A
GRASS,WEEDS,and CROPS					
GWC-1	5/6/2013	239	9:08	5/6/2013	10:42
GWC-2	5/5/2013	240	14:38	5/22/2013	17:15
GWC-3	5/5/2013	240	10:34	5/5/2013	17:53
GWC-4	5/5/2013	240	8:27	N/A	N/A
GWC-5	5/4/2013	241	15:31	N/A	N/A
GWC-6	5/4/2013	241	8:49	N/A	N/A
GWC-7	5/5/2013	240	16:04	5/22/2013	16:50
GWC-8	5/2/2013	243	18:02	5/3/2013	10:24
GWC-9	5/3/2013	242	13:09	5/22/2013	7:30
GWC-10	5/2/2013	243	18:26	N/A	N/A
GWC-11	5/2/2013	243	12:01	5/3/2013	7:52
GWC-12	5/3/2013	242	11:24	5/3/2013	17:04
GWC-13	5/1/2013	244	11:39	5/22/2013	8:36

GWC-14	5/1/2013	244	15:08	5/22/2013	12:40
GWC-15	5/1/2301	244	19:21	N/A	N/A
GWC-16	4/30/2013	245	10:51	N/A	N/A
GWC-17	4/29/2013	246	16:10	5/22/2013	11:31
GWC-18	4/29/2013	246	12:52	N/A	N/A
GWC-19	4/30/2013	245	11:25	N/A	N/A
GWC-20	4/29/2013	246	11:52	4/29/2013	17:20
OPEN					
OT-1	5/6/2013	239	10:31	5/22/2013	17:40
OT-2	5/5/2013	240	13:15	5/5/2013	17:24
OT-3	5/5/2013	240	14:58	5/22/2013	16:22
OT-4	5/4/2013	241	10:50	5/4/2013	17:48
OT-5	5/4/2013	241	14:44	5/22/2013	15:10
OT-6	5/4/2013	241	12:39	5/4/2013	16:46
OT-7	5/4/2013	241	9:37	5/4/2013	18:07
OT-8	5/2/2013	243	16:57	5/3/2013	9:59
OT-9	5/3/2013	242	14:01	5/22/2013	7:58
OT-10	5/2/2013	243	16:16	5/3/2013	9:27
OT-11	5/2/2013	243	11:16	5/3/2013	9:07
OT-12	4/30/2013	245	15:52	5/22/2013	9:02
OT-13	5/1/2013	244	14:44	5/2/2013	8:51
OT-14	5/1/2013	244	16:18	5/22/2013	12:23
OT-15	4/30/2013	245	15:36	5/1/2031	8:05
OT-16	4/30/2013	245	18:49	5/1/2013	9:28
OT-17	4/29/2013	246	11:25	4/29/2013	17:30
OT-18	4/29/2013	246	12:35	4/29/2013	17:03
OT-19	4/30/2013	245	8:53	N/A	N/A
OT-20	4/29/2013	246	14:04	5/22/2013	10:49
URBAN					
UT-1	5/6/2013	239	8:38	N/A	N/A
UT-2	5/5/2013	240	11:45	5/5/2013	17:34
UT-3	5/5/2013	240	15:43	5/6/2013	11:41
UT-4	5/5/2013	240	15:23	5/22/2013	15:48
UT-5	5/4/2013	241	15:08	5/6/2013	12:53
UT-6	5/4/2013	241	13:15	5/22/2013	14:35
UT-7	5/4/2013	241	8:04	5/4/2013	17:15

UT-8	5/2/2013	243	17:24	5/3/2013	9:43
UT-9	5/3/2013	242	11:51	5/3/2013	16:45
UT-10	5/2/2013	243	14:14	5/3/2013	8:18
UT-11	5/2/2013	243	11:38	5/3/2013	8:43
UT-12	5/2/2013	243	19:02	5/3/2013	10:54
UT-13	5/1/2013	244	14:18	5/2/2013	8:26
UT-14	5/1/2013	244	13:46	5/2/2013	9:11
UT-15	4/30/2013	245	17:01	5/22/2013	9:27
UT-16	4/30/2013	245	13:26	5/1/2013	8:27
UT-17	4/29/2013	246	15:47	5/6/2013	16:30
UT-18	4/30/2013	245	9:25	5/1/2013	7:10
UT-19	4/30/2013	245	11:43	5/1/2013	8:46
UT-20	4/29/2013	246	13:40	4/29/2013	13:45

POINT COMPARISON

LiDAR QA				
PT ID	CHK PT	DELTA N	DELTA E	DELTA EL
BLT-14	BLT-14CHK3	0.007	-0.002	0.022
GWC-1	GWC-1CHK	-0.036	-0.023	-0.034
GWC-2	GWC-2CHK2	-0.018	0.021	-0.029
GWC-3	GWC-3CHK	-0.013	-0.007	0.051
GWC-7	GWC-7CHK2	-0.008	-0.031	0.002
GWC-8	GWC-8CHK	0.02	0.018	-0.001
GWC-9	GWC-9CHK2	-0.024	0.005	0.016
GWC-11	GWC-11CHK	-0.023	0.022	0.004
GWC-12	GWC-12CHK	0.001	-0.016	0.002
GWC-13	GWC-13CHK	0.012	-0.028	-0.026
GWC-14	GWC-14CHK2	-0.009	0.006	0.012
GWC-17	GWC-17CHK2	0.021	-0.024	0.016
GWC-20	GWC-20CHK	0	0.002	-0.008
OT-1	OT-1CHK2	-0.008	-0.015	0.017
OT-2	OT-2CHK	0.003	0.002	-0.012
OT-3	OT-3CHK2	-0.022	0.003	-0.045
OT-4	OT-4CHK	-0.019	0.009	-0.004
OT-5	OT-5CHK2	-0.014	-0.011	-0.043
OT-6	OT-6CHK	0.007	0.004	0.002
OT-7	OT-7CHK	-0.042	0.016	0.07
OT-8	OT-8CHK	-0.001	0.011	-0.008

OT-9	OT-9CHK2	-0.008	0.006	-0.007
OT-10	OT-10CHK	-0.002	0.001	-0.015
OT-11	OT-11CHK	-0.002	0.018	-0.011
OT-12	OT-12CHK2	-0.018	0.007	0.006
OT-13	OT-13CHK	-0.012	0.014	-0.007
OT-14	OT-14CHK2	0.002	0.026	0.025
OT-15	OT-15CHK	0.005	0.007	0.007
OT-16	OT-16CHK	-0.009	-0.007	0.072
OT-17	OT-17CHK	0.003	-0.012	0.009
OT-18	OT-18CHK	-0.01	-0.008	-0.01
OT-19	OT-19CHK	-0.012	0.003	-0.008
OT-20	OT-20CHK	0	-0.002	0.041
UT-2	UT-2CHK	-0.003	0.005	-0.019
UT-3	UT-3CHK2	-0.007	-0.011	-0.01
UT-4	UT-4CHK2	-0.018	-0.034	-0.047
UT-5	UT-5CHK2	-0.007	-0.012	-0.033
UT-6	UT-6CHK2	0.011	0.012	-0.046
UT-7	UT-7CHK	-0.015	-0.008	0.019
UT-8	UT-8CHK	0.003	-0.004	0.005
UT-9	UT-9CHK	-0.012	-0.004	0.011
UT-10	UT-10CHK	0.007	0	-0.021
UT-11	UT-11CHK	0.001	0.023	0.012
UT-12	UT-12CHK	0.013	-0.023	0.031
UT-13	UT-13CHK	-0.012	0.007	0.001
UT-14	UT-14CHK	-0.015	-0.002	0.027
UT-15	UT-15CHK2	0.01	0.007	-0.011
UT-16	UT-16CHK	-0.003	0.01	0.019
UT-17	UT-17CHK2	-0.038	0.006	-0.004
UT-18	UT-18CHK	0.007	0.009	-0.016
UT-19	UT-19CHK	0.009	0.02	0.03
UT-20	UT-20CHK	-0.004	0.007	-0.003

Appendix B: Complete List of Delivered Tiles

UTM TILES (1,458):

18SUF825425
18SUF840425
18SUF855425
18SUF870425
18SUF885425
18SUF900425
18SUF660440
18SUF675440
18SUF690440
18SUF705440
18SUF720440
18SUF735440
18SUF750440
18SUF765440
18SUF780440
18SUF795440
18SUF810440
18SUF825440
18SUF840440
18SUF855440
18SUF870440
18SUF885440
18SUF900440
18SUF915440
18SUF930440
18SUF945440
18SUF960440
18SUF975440
18SUF990440
18SVF005440
18SVF020440
18SVF035440
18SVF050440
18SVF065440
18SVF080440
18SVF095440
18SVF110440
18SVF125440
18SVF140440
18SVF155440
18SVF170440
18SVF185440
18SVF200440
18SVF215440
18SVF230440
18SUF660455
18SUF675455
18SUF690455
18SUF705455
18SUF720455
18SUF735455
18SUF750455
18SUF765455
18SUF780455
18SUF795455
18SUF810455
18SUF825455
18SUF840455
18SUF855455
18SUF870455
18SUF885455
18SUF900455
18SUF915455
18SUF930455
18SUF945455
18SUF960455
18SUF975455
18SUF990455
18SVF005455
18SVF020455
18SVF035455
18SVF050455
18SVF065455
18SVF080455
18SVF095455
18SVF110455
18SVF125455
18SVF140455
18SVF155455
18SVF170455
18SVF185455
18SVF200455
18SVF215455
18SUF660470
18SUF675470
18SUF690470
18SUF705470
18SUF720470
18SUF735470
18SUF750470
18SUF765470
18SUF780470
18SUF795470
18SUF810470
18SUF825470
18SUF840470
18SUF855470
18SUF870470
18SUF885470
18SUF900470
18SUF915470
18SUF930470
18SUF945470
18SUF960470
18SUF975470
18SUF990470
18SVF005470
18SVF020470
18SVF035470
18SVF050470
18SVF065470
18SVF080470
18SVF095470
18SVF110470
18SVF125470
18SVF140470
18SVF155470
18SVF170470
18SVF185470
18SVF200470
18SVF215470
18SUF660485
18SUF675485
18SUF690485
18SUF705485
18SUF720485
18SUF735485
18SUF750485
18SUF765485
18SUF780485
18SUF795485
18SUF810485
18SUF825485
18SUF840485
18SUF855485
18SUF870485
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18SUF900485
18SUF915485
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18SUF945485
18SUF960485
18SUF975485
18SUF990485
18SVF005485
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18SVF095485
18SVF110485
18SVF125485
18SVF140485
18SVF155485
18SVF170485
18SVF185485
18SVF200485
18SVF215485
18SUF660500
18SUF675500
18SUF690500
18SUF705500
18SUF720500
18SUF735500
18SUF750500
18SUF765500
18SUF780500
18SUF795500
18SUF810500
18SUF825500
18SUF840500
18SUF855500
18SUF870500
18SUF885500
18SUF900500

18SUF915500
18SUF930500
18SUF945500
18SUF960500
18SUF975500
18SUF990500
18SVF005500
18SVF020500
18SVF035500
18SVF050500
18SVF065500
18SVF080500
18SVF095500
18SVF110500
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18SVF140500
18SVF155500
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18SVF185500
18SVF200500
18SVF215500
18SUF660515
18SUF675515
18SUF690515
18SUF705515
18SUF720515
18SUF735515
18SUF750515
18SUF765515
18SUF780515
18SUF795515
18SUF810515
18SUF825515
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18SUF870515
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18SVF020515
18SVF035515
18SVF050515
18SVF065515
18SVF080515
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18SVF200515
18SUF660530
18SUF675530
18SUF690530
18SUF705530
18SUF720530
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18SUF750530
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18SVF200530
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18SUF675545
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18SUF945575

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18SUF990575	18SVF170590	18SUF840620	18SVF035635
18SVF005575	18SVF185590	18SUF855620	18SVF050635
18SVF020575	18SUF675605	18SUF870620	18SVF065635
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18SVF065575	18SUF720605	18SUF915620	18SVF110635
18SVF080575	18SUF735605	18SUF930620	18SVF125635
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18SVF125575	18SUF780605	18SUF975620	18SVF170635
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18SUF735590	18SUF915605	18SVF110620	18SUF795650
18SUF750590	18SUF930605	18SVF125620	18SUF810650
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18SVF080680
18SVF095680
18SVF110680
18SVF125680
18SVF140680
18SVF155680
18SUF675695
18SUF690695
18SUF705695
18SUF720695
18SUF735695
18SUF750695
18SUF765695
18SUF780695
18SUF795695
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18SUF825695
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DO_S23_2348_10

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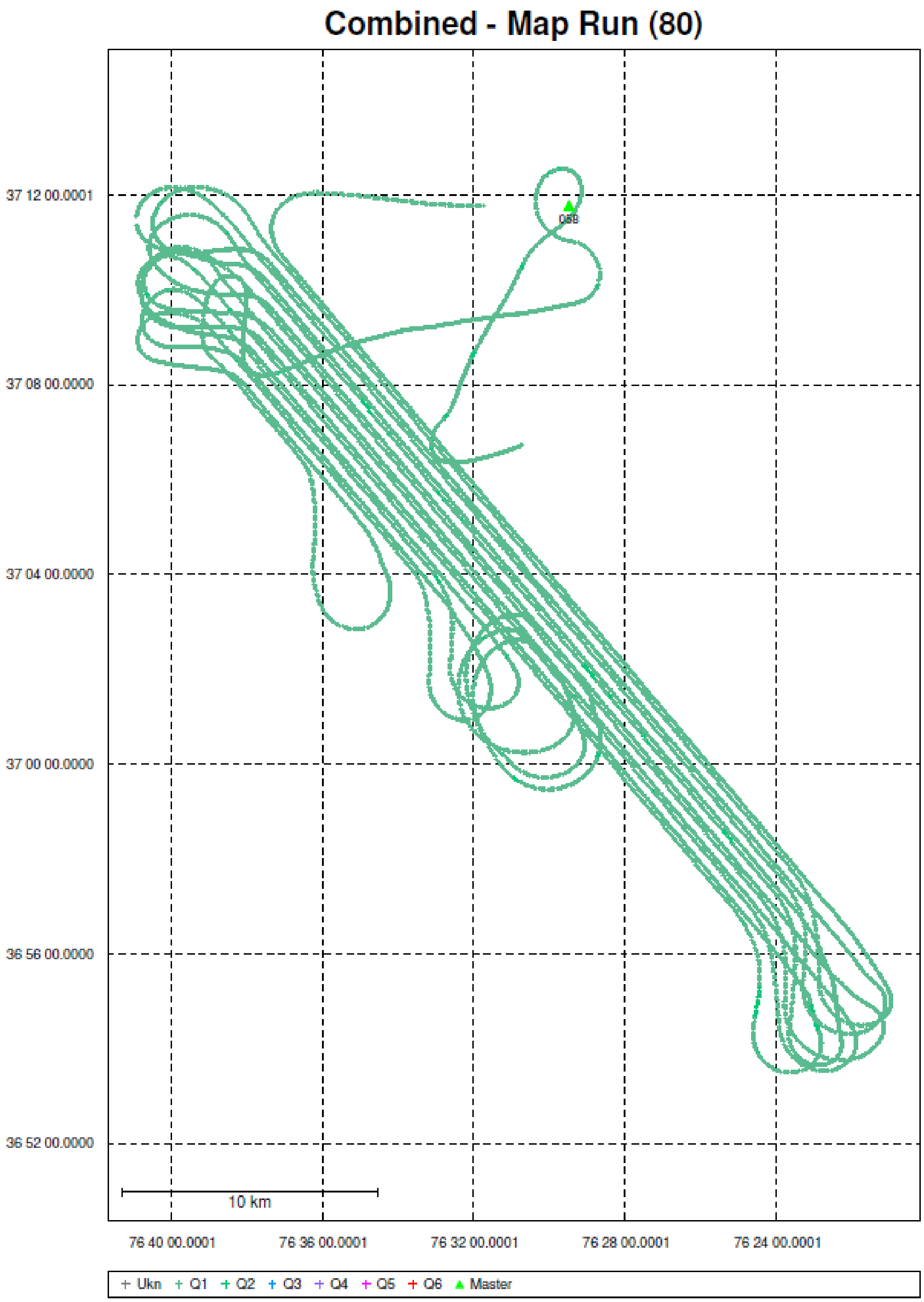
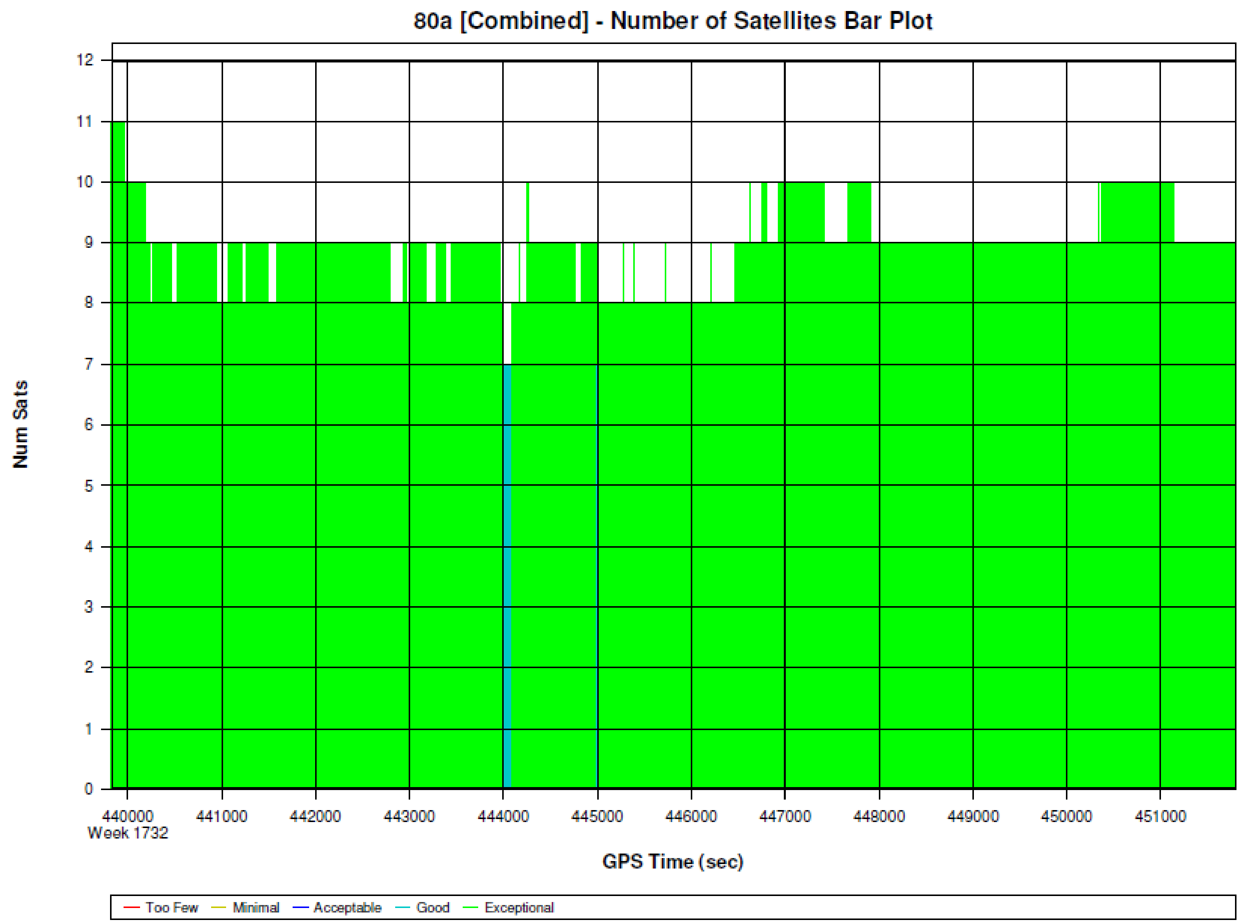
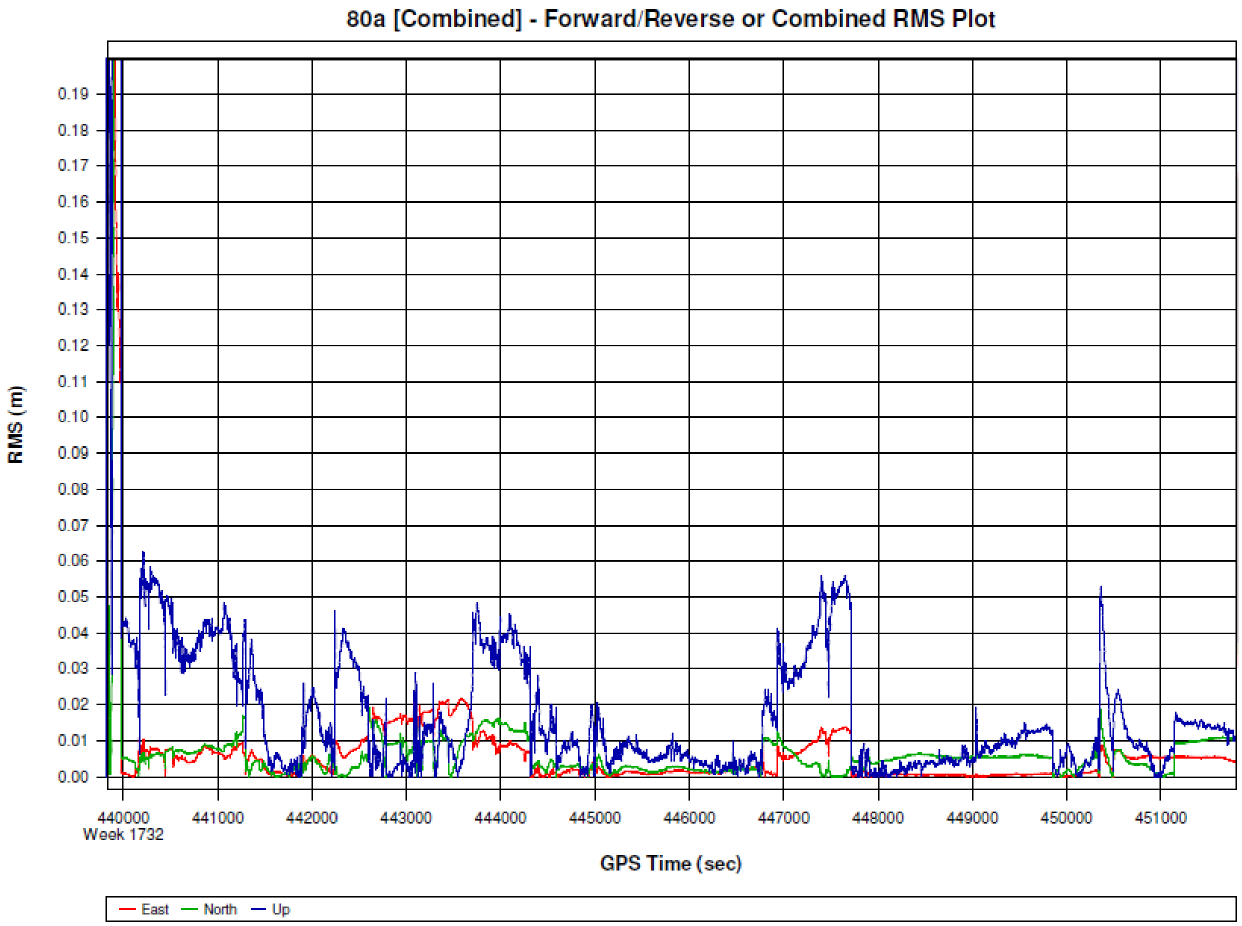
DO_S23_2440_10	DO_S23_2358_40	DO_S23_1345_20	DO_S23_1509_20
DO_S23_2440_40	DO_S23_2357_10	DO_S23_1345_30	DO_S23_1600_10
DO_S23_2440_30	DO_S23_2357_20	DO_S23_1346_40	DO_S23_1512_30
DO_S23_2349_10	DO_S23_2357_40	DO_S23_1356_10	DO_S23_1512_40
DO_S23_2349_40	DO_S23_2357_30	DO_S23_2427_40	DO_S23_1511_20

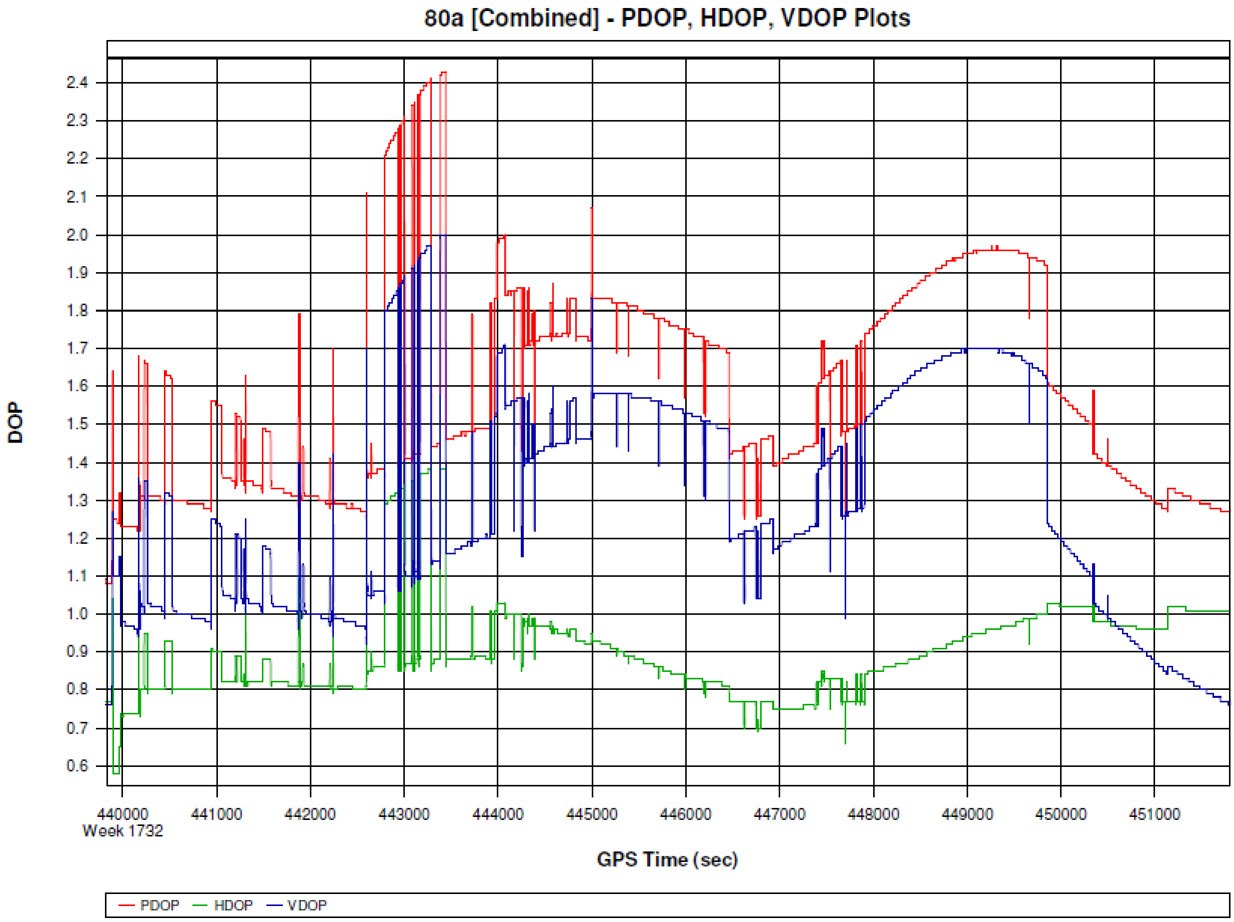
Appendix C: GPS Processing Reports for Each Mission

LASER MAPPING SPECIALISTS (LMSI)


Combined - Map Run (80)
37 12 00.0001
37 08 00.0000
37 04 00.0000
37 00 00.0000
36 56 00.0000
36 52 00.0000
76 40 00.0001
76 36 00.0001
76 32 00.0001
76 28 00.0001
76 24 00.0001
10 km
Ukn
Q1
Q2
Q3
Q4
Q5
Q6
Master

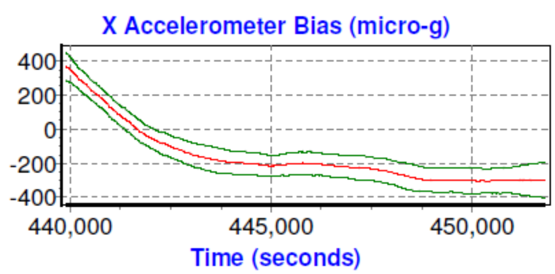

80a [Combined] - Number of Satellites Bar Plot
Num Sats
0
1
2
3
4
5
6
7
8
9
10
11
12
440000
Week 1732
441000
442000
443000
444000
445000
446000
447000
448000
449000
450000
451000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

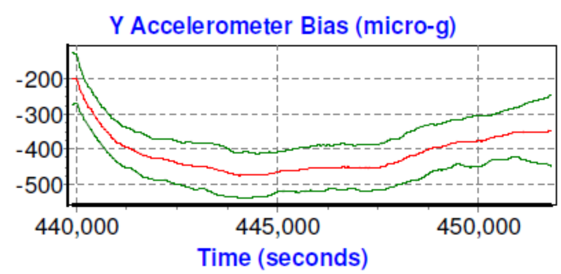

80a [Combined] - Forward/Reverse or Combined RMS Plot
RMS (m)
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
440000
Week 1732
441000
442000
443000
444000
445000
446000
447000
448000
449000
450000
451000
GPS Time (sec)
East
North
Up

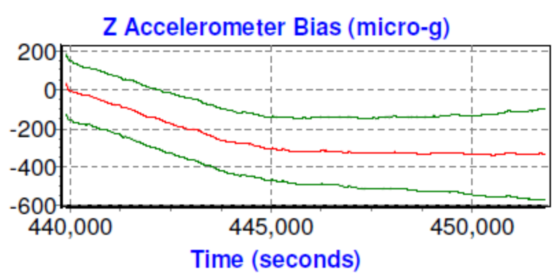


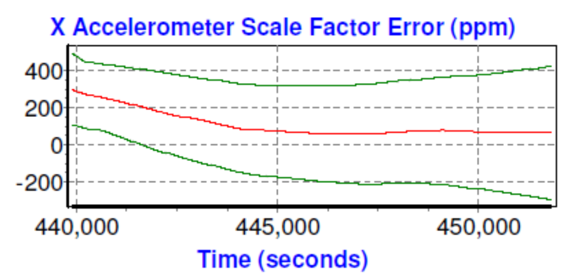
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13080a\pos\GPS\80a.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 135984
No processed position: 123996
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0300 (m)
C/A Code: 1.04 (m)
L1 Doppler: 0.020 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.042 (m)
North: 0.033 (m)
Height: 0.158 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (11827 occurances):
East: 0.010 (m)

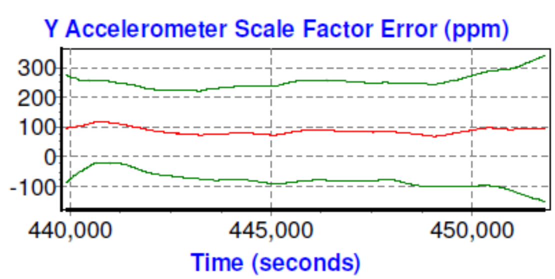
North: 0.009 (m)
Height: 0.031 (m)
Quality Number Percentages:
Q 1: 99.0 %
Q 2: 1.0 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 0.0 %
Baseline Distances:
Maximum: 35.259 (km)
Minimum: 0.925 (km)
Average: 17.735 (km)
First Epoch: 9.509 (km)
Last Epoch: 3.478 (km)

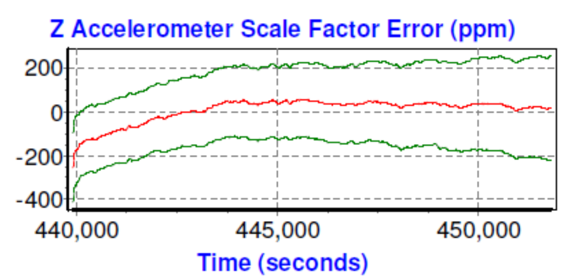


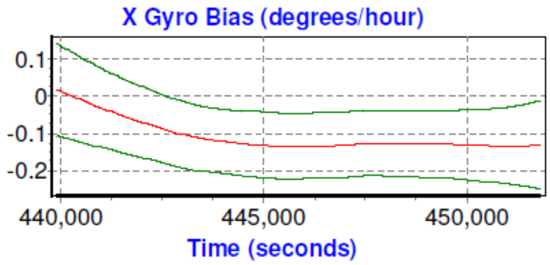


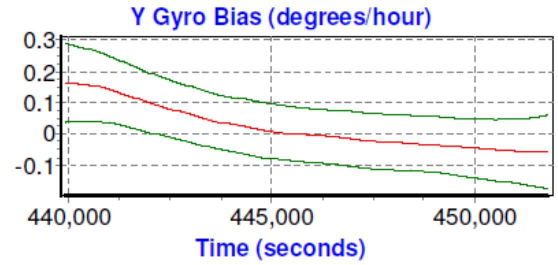


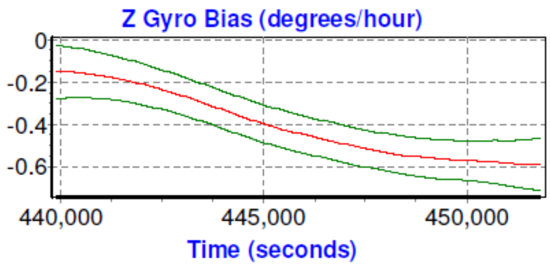


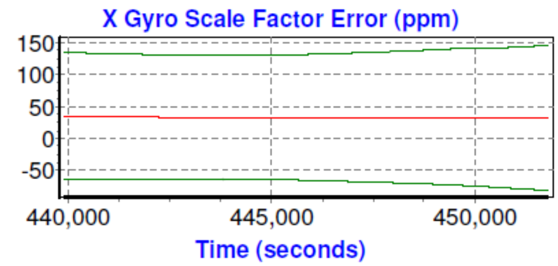


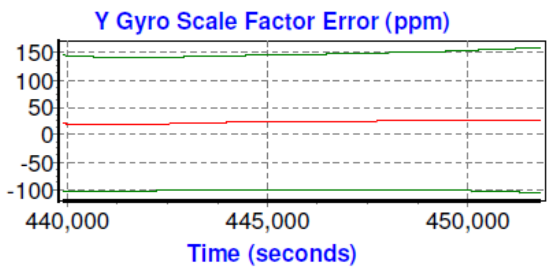


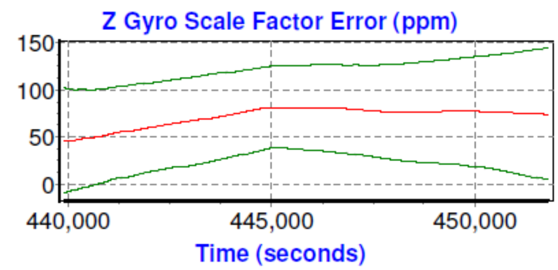

X Gyro Bias (degrees/hour)
0.1
0
-0.1
-0.2
440,000
445,000
450,000
Time (seconds)

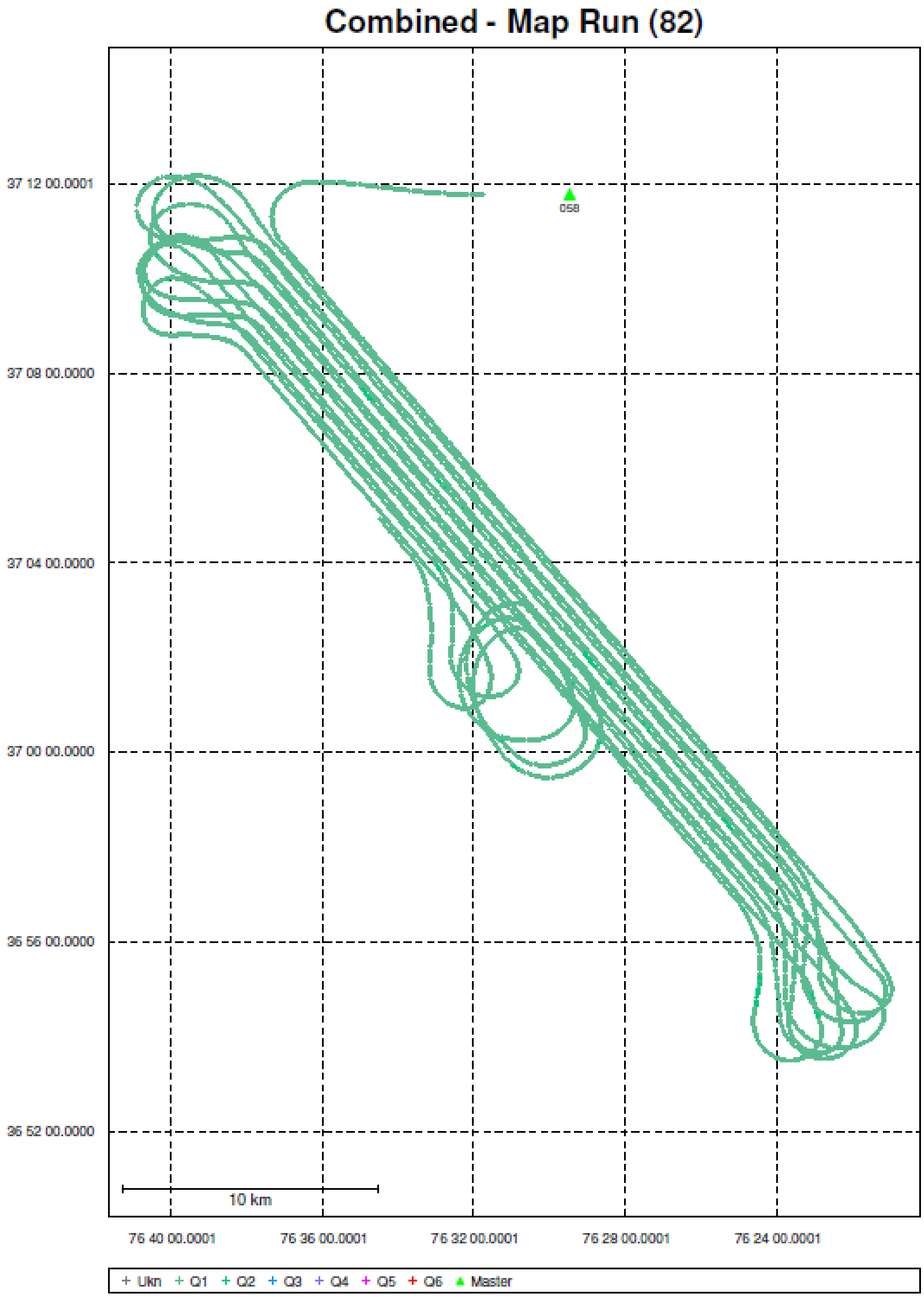

Y Gyro Bias (degrees/hour)
0.3
0.2
0.1
0
-0.1
440,000
445,000
450,000
Time (seconds)

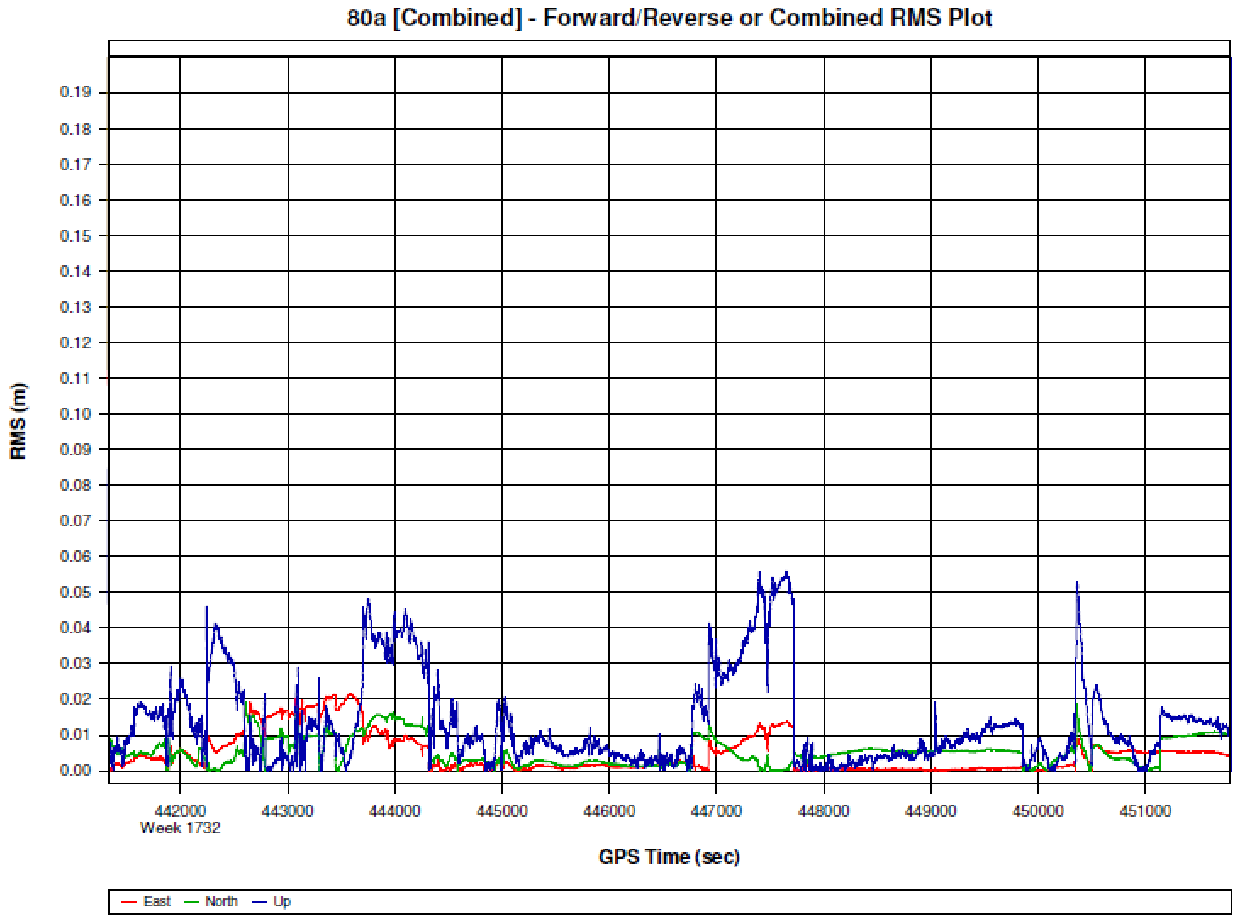

Z Gyro Bias (degrees/hour)
0
-0.2
-0.4
-0.6
440,000
445,000
450,000
Time (seconds)

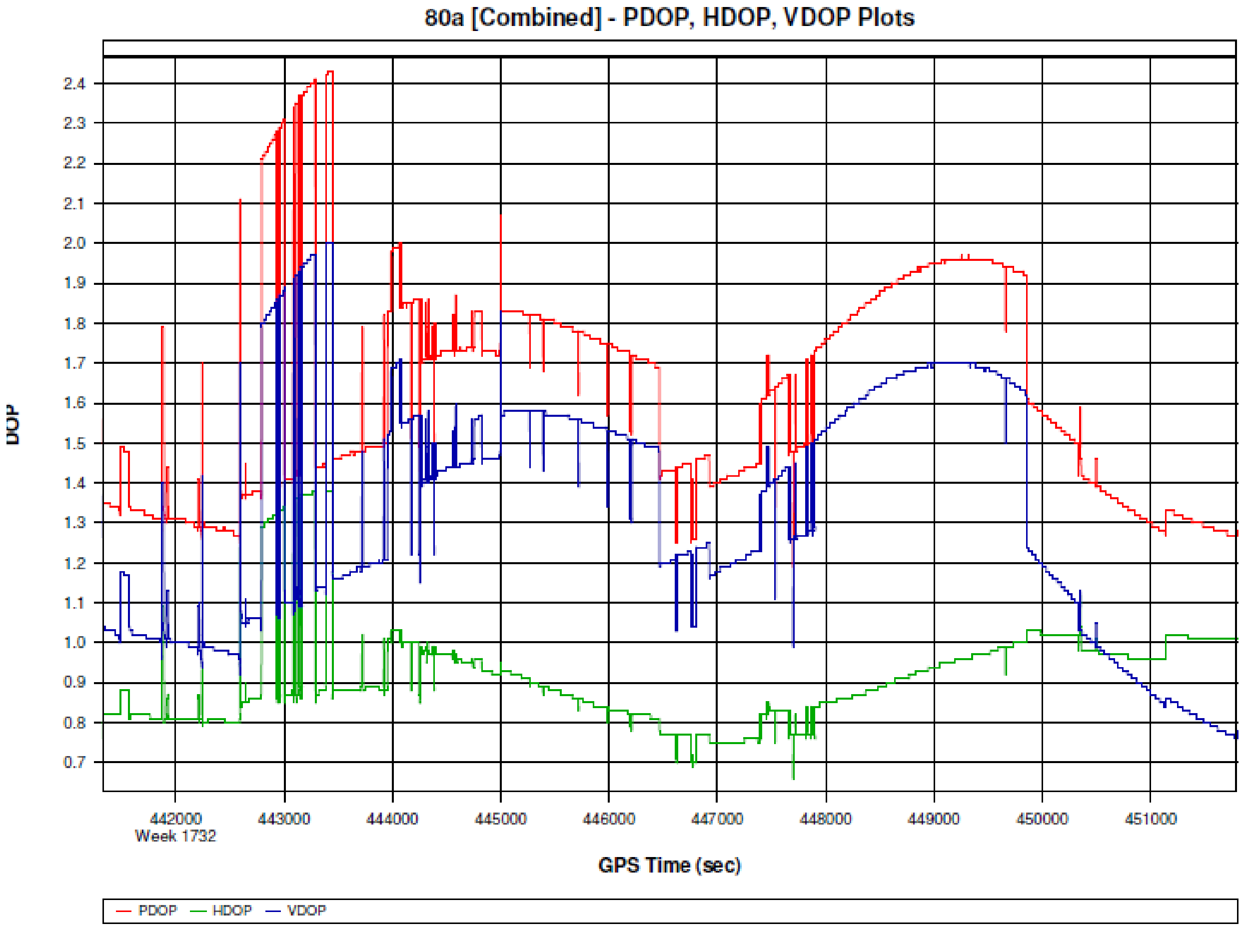

X Gyro Scale Factor Error (ppm)
150
100
50
0
-50
440,000
445,000
450,000
Time (seconds)

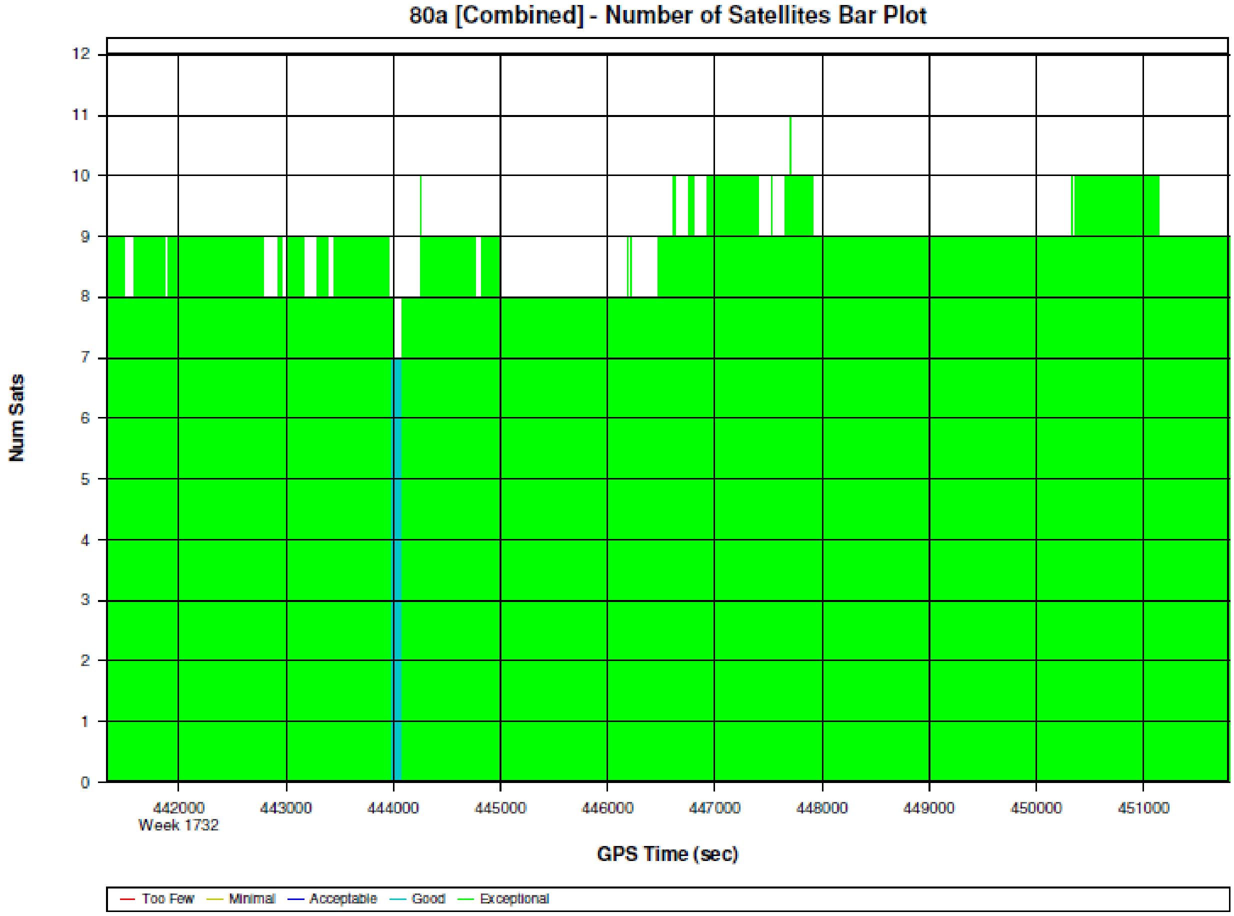

Y Gyro Scale Factor Error (ppm)
150
100
50
0
-50
-100
440,000
445,000
450,000
Time (seconds)


Z Gyro Scale Factor Error (ppm)
150
100
50
0
440,000
445,000
450,000
Time (seconds)


Combined - Map Run (82)
37 12 00.0001
37 08 00.0000
37 04 00.0000
37 00 00.0000
36 56 00.0000
36 52 00.0000
76 40 00.0001
76 36 00.0001
76 32 00.0001
76 28 00.0001
76 24 00.0001
058
10 km
+ Ukn + Q1 + Q2 + Q3 + Q4 + Q5 + Q6 ▲ Master

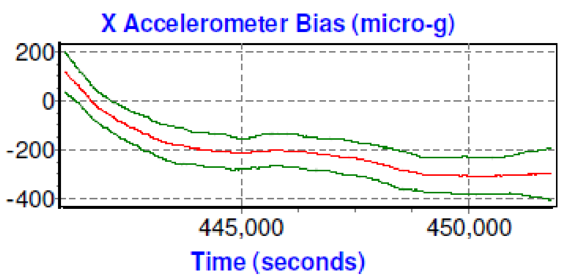

80a [Combined] - Forward/Reverse or Combined RMS Plot
RMS (m)
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
442000
Week 1732
443000
444000
445000
446000
447000
448000
449000
450000
451000
GPS Time (sec)
East
North
Up

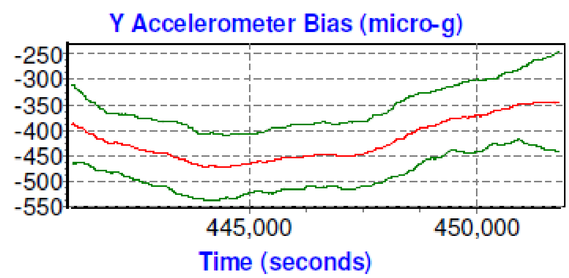

80a [Combined] - PDOP, HDOP, VDOP Plots
DOP
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
442000
Week 1732
443000
444000
445000
446000
447000
448000
449000
450000
451000
GPS Time (sec)
PDOP
HDOP
VDOP

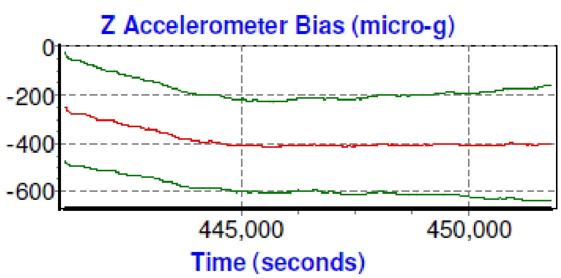


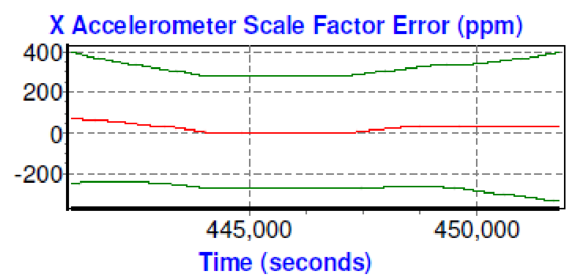
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13080a\pos\GPS\80a.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 135984
No processed position: 125507
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0298 (m)
C/A Code: 1.02 (m)
L1 Doppler: 0.019 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.013 (m)
North: 0.011 (m)
Height: 0.026 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (10471 occurances):
East: 0.010 (m)
North: 0.009 (m)

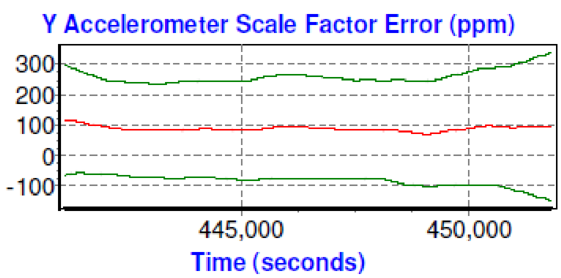
Height: 0.026 (m)
Quality Number Percentages:
Q 1: 99.1 %
Q 2: 0.9 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 0.0 %
Baseline Distances:
Maximum: 35.259 (km)
Minimum: 3.478 (km)
Average: 18.685 (km)
First Epoch: 14.725 (km)
Last Epoch: 3.478 (km)

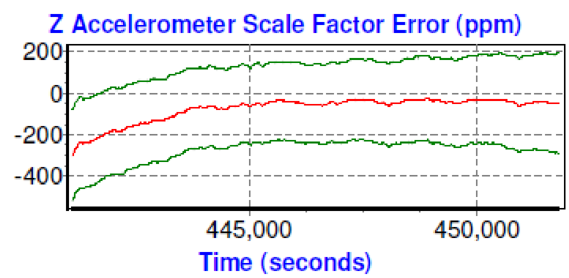


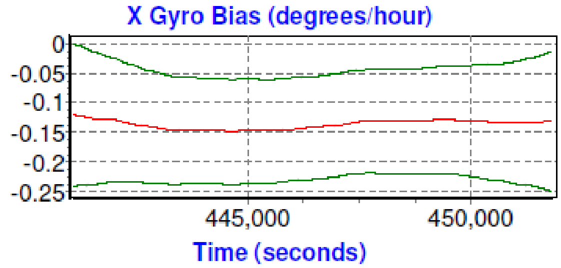


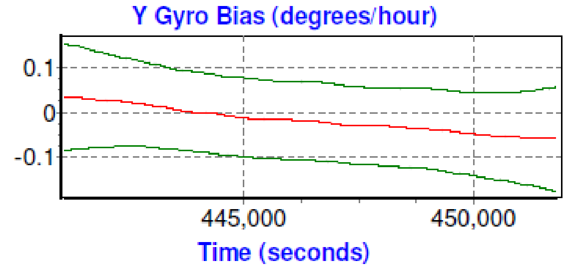


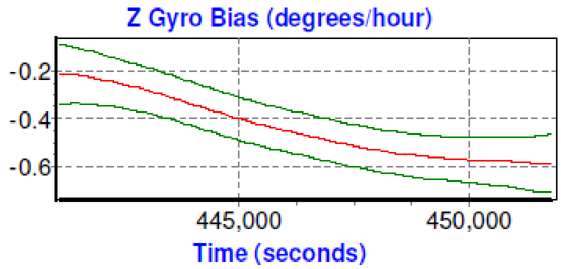


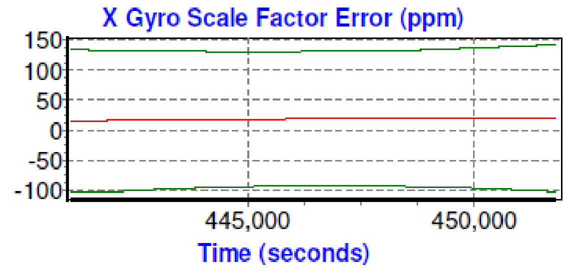


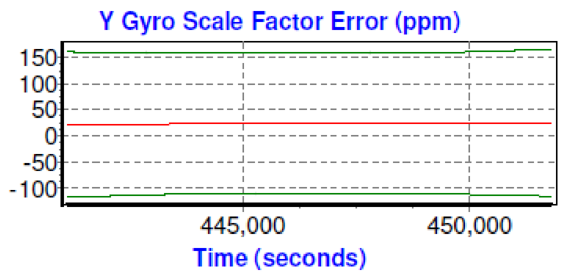


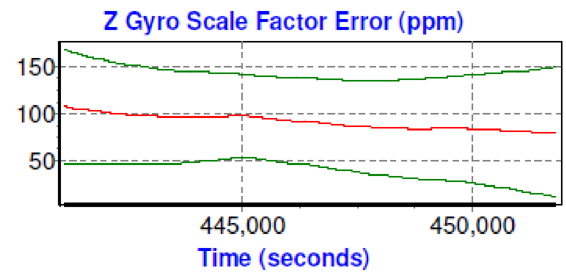

X Gyro Bias (degrees/hour)
0
-0.05
-0.1
-0.15
-0.2
-0.25
445,000
450,000
Time (seconds)

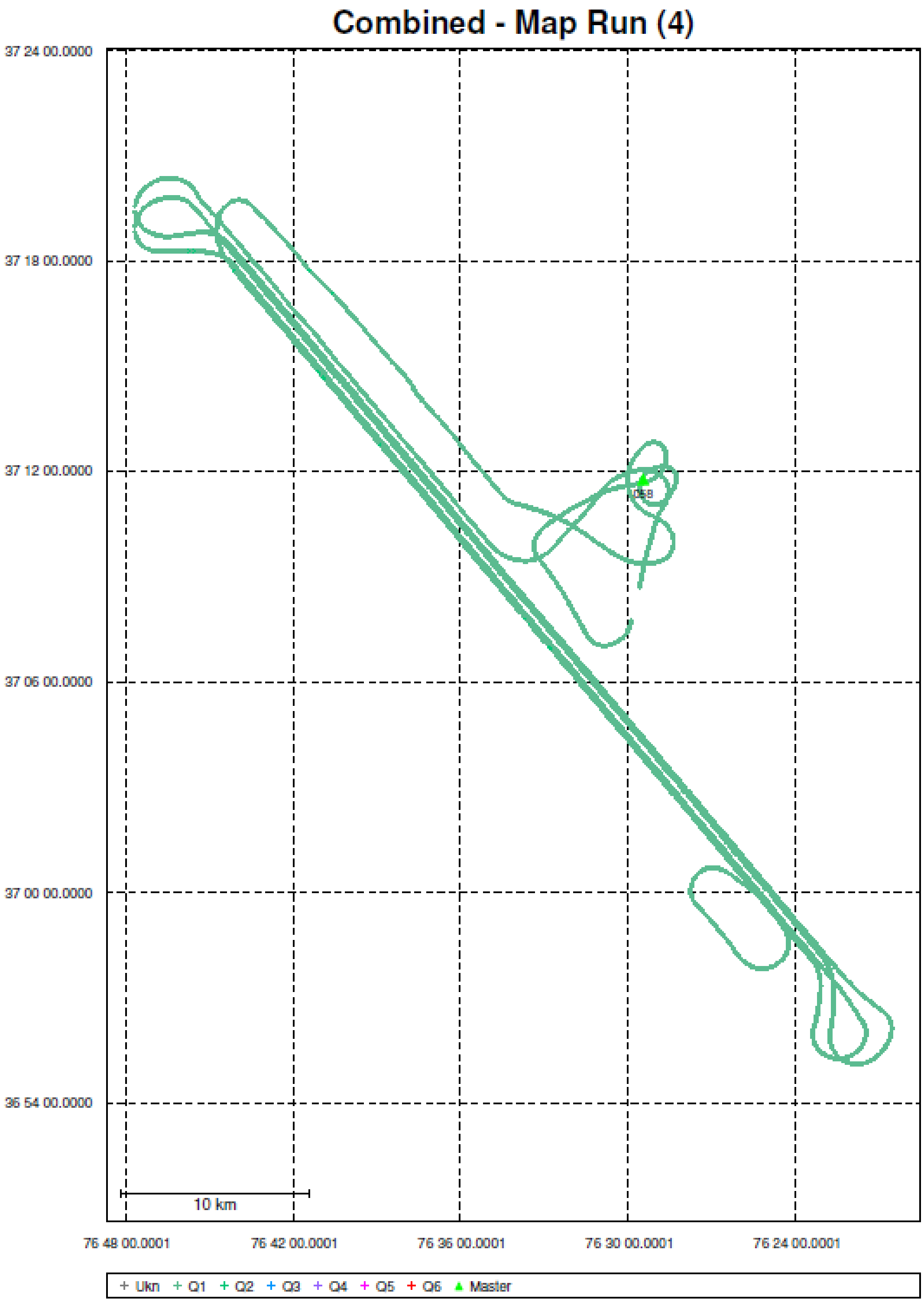

Y Gyro Bias (degrees/hour)
0.1
0
-0.1
445,000
450,000
Time (seconds)

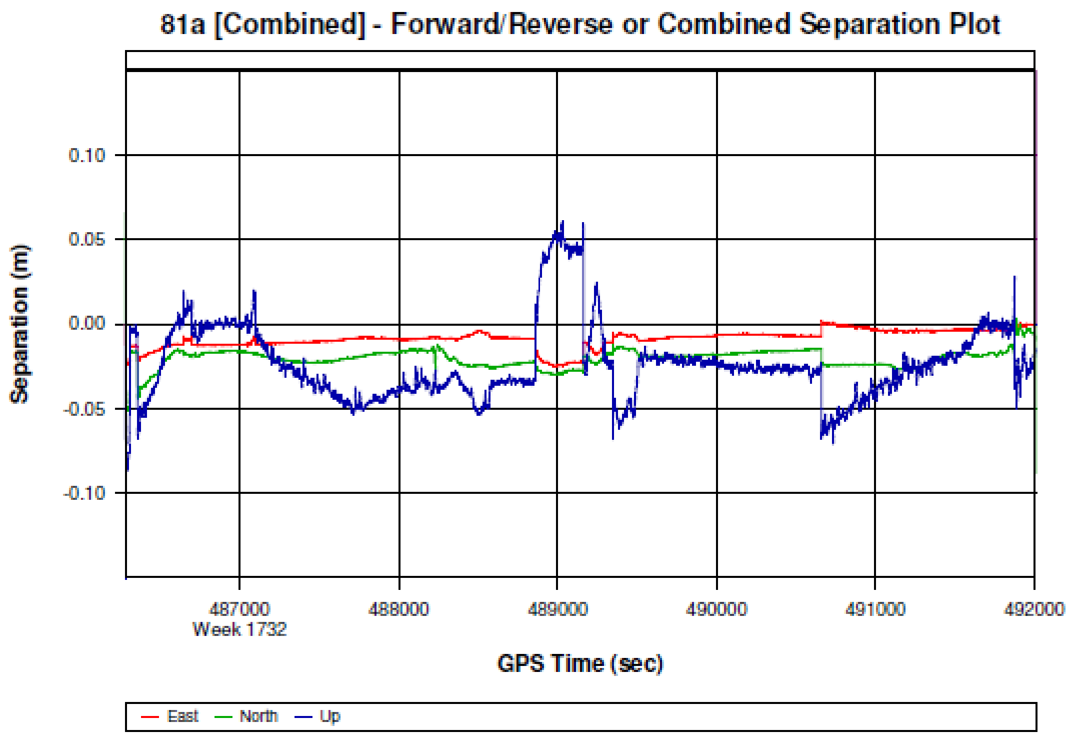

Z Gyro Bias (degrees/hour)
-0.2
-0.4
-0.6
445,000
450,000
Time (seconds)

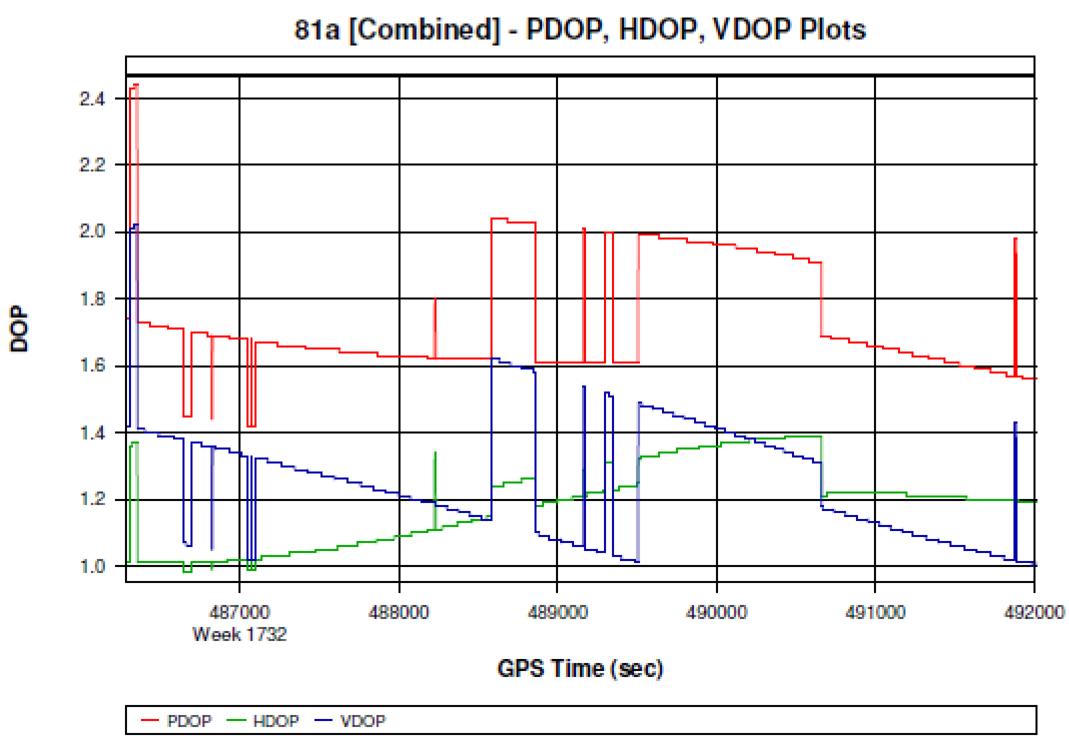

X Gyro Scale Factor Error (ppm)
150
100
50
0
-50
-100
445,000
450,000
Time (seconds)

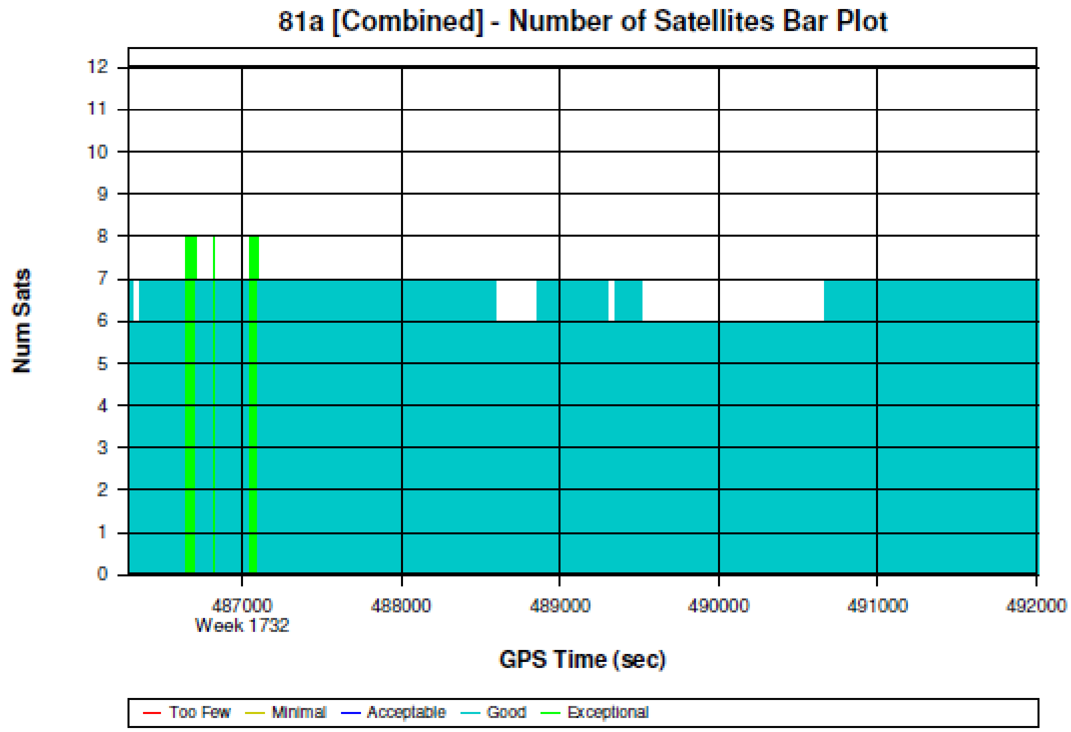

Y Gyro Scale Factor Error (ppm)
150
100
50
0
-50
-100
445,000
450,000
Time (seconds)

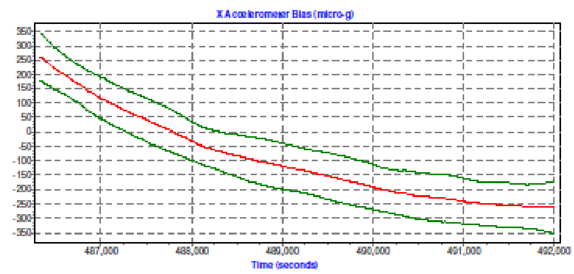

Z Gyro Scale Factor Error (ppm)
150
100
50
445,000
450,000
Time (seconds)

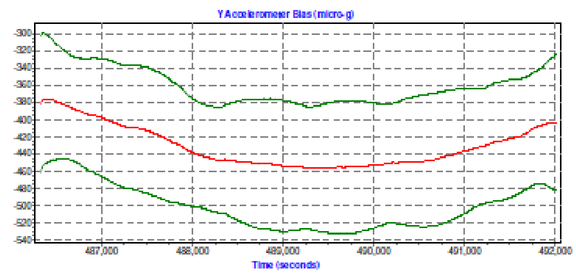

Combined - Map Run (4)
37 24 00.0000
37 18 00.0000
37 12 00.0000
37 06 00.0000
37 00 00.0000
36 54 00.0000
76 48 00.0001
76 42 00.0001
76 36 00.0001
76 30 00.0001
76 24 00.0001
10 km
058
Ukn
Q1
Q2
Q3
Q4
Q5
Q6
Master

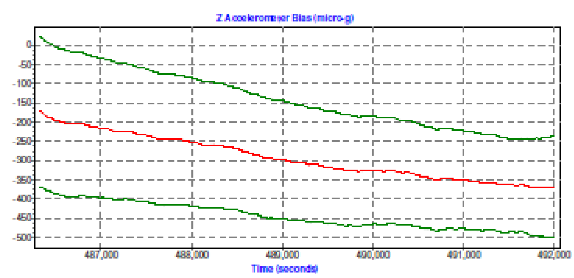

81a [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.10
0.05
0.00
-0.05
-0.10
487000
Week 1732
488000
489000
490000
491000
492000
GPS Time (sec)
East
North
Up

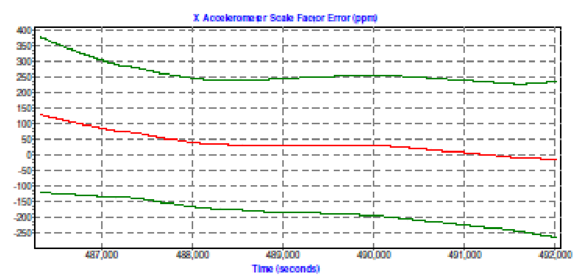

81a [Combined] - PDOP, HDOP, VDOP Plots
DOP
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
487000
Week 1732
488000
489000
490000
491000
492000
GPS Time (sec)
PDOP
HDOP
VDOP

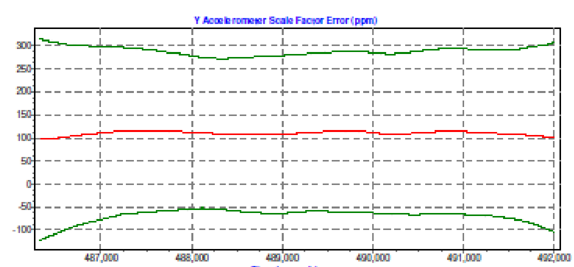

81a [Combined] - Number of Satellites Bar Plot
Num Sats
12
11
10
9
8
7
6
5
4
3
2
1
0
487000
Week 1732
488000
489000
490000
491000
492000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

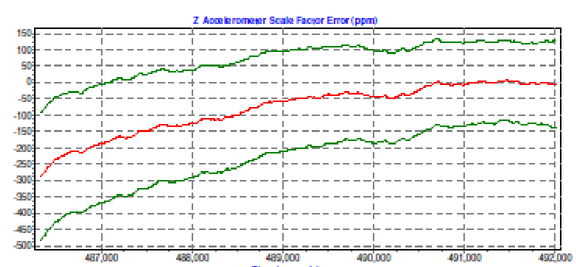

X Accelerometer Bias (micro-g)
Time (seconds)

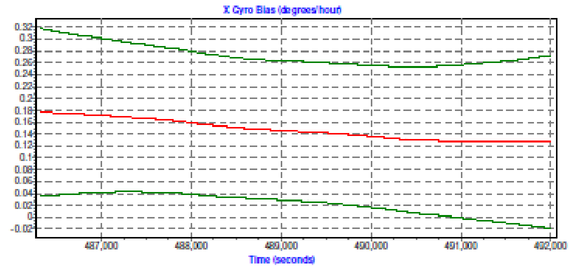

Y Accelerometer Bias (micro-g)
Time (seconds)

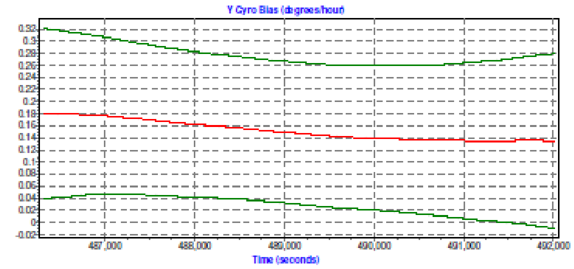

Z Accelerometer Bias (micro-g)
Time (seconds)

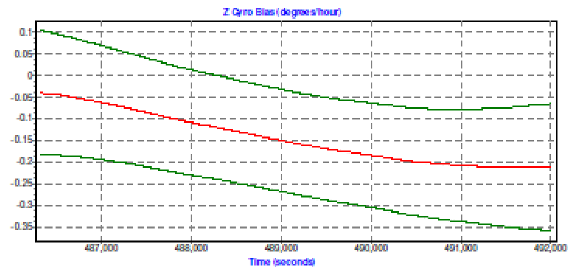

X Accelerometer Scale Factor Error (ppm)
Time (seconds)

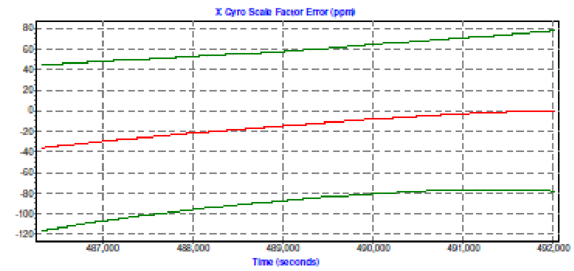

Y Accelerometer Scale Factor Error (ppm)
Time (seconds)

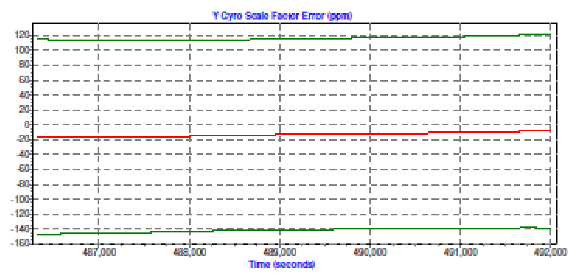

Z Accelerometer Scale Factor Error (ppm)
Time (seconds)

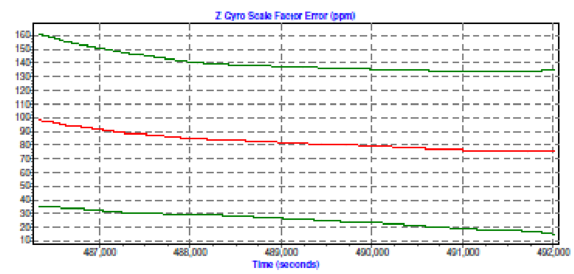






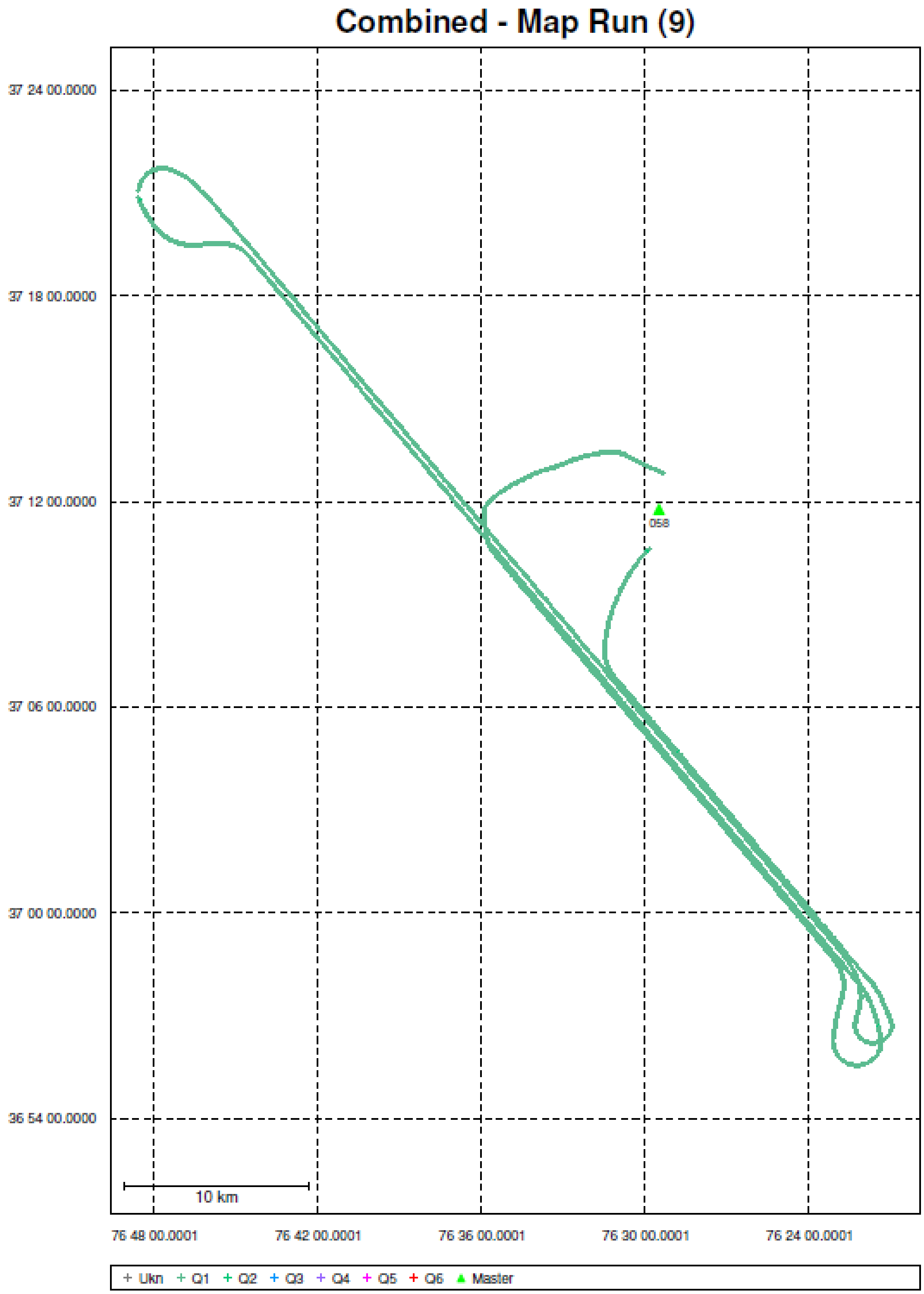


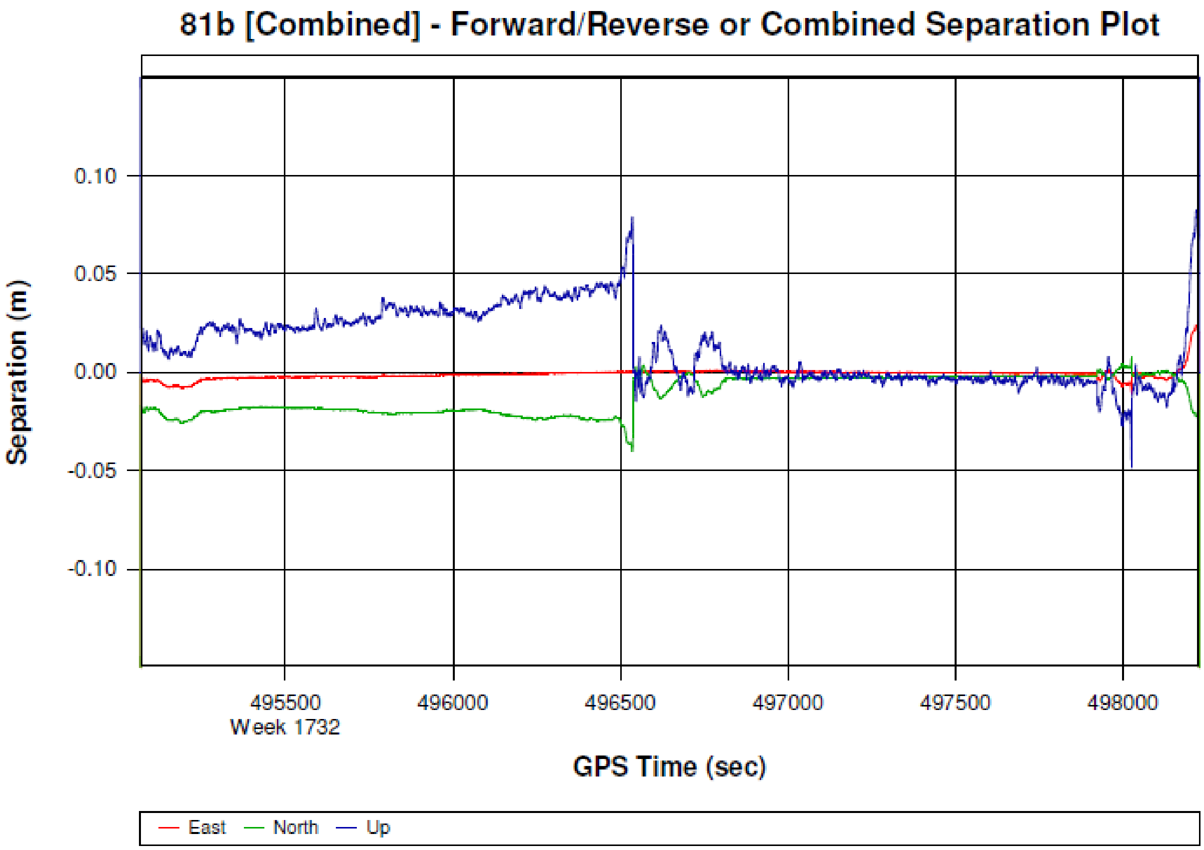


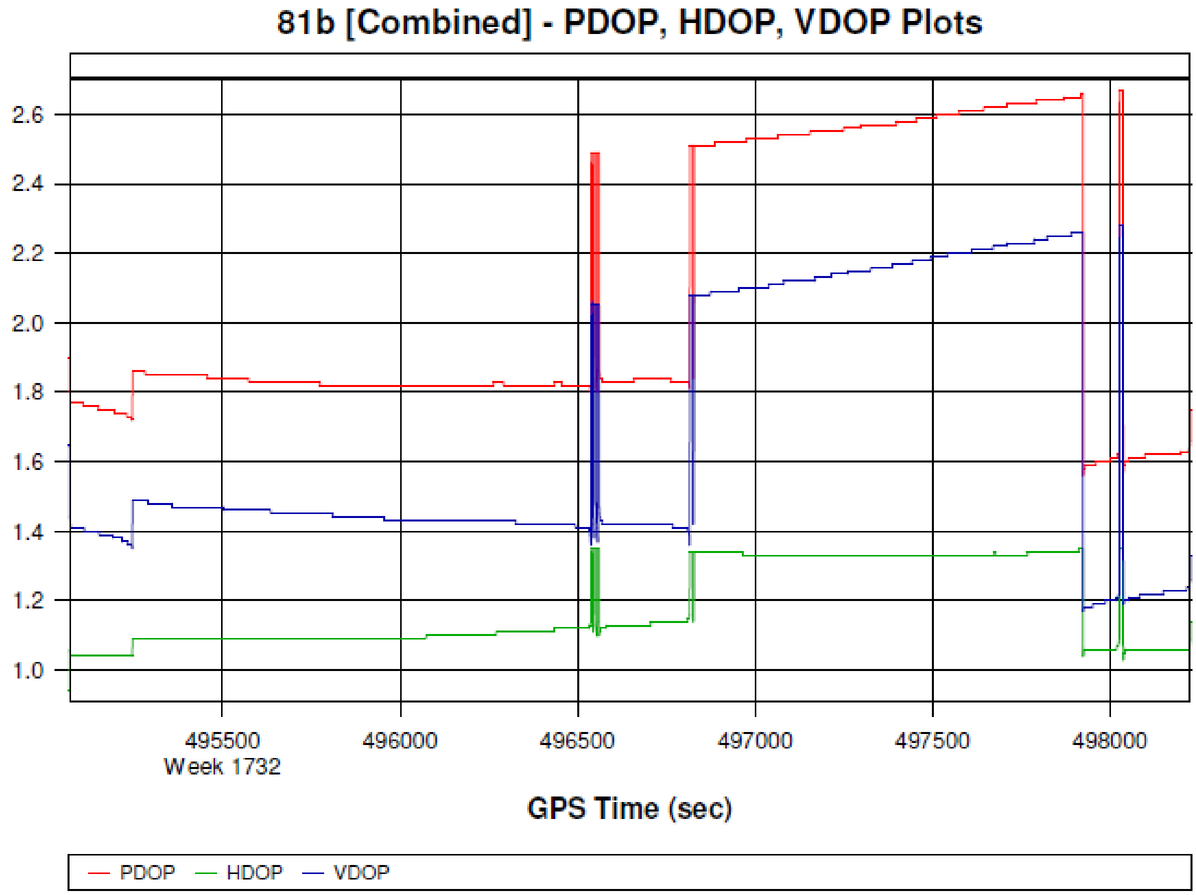


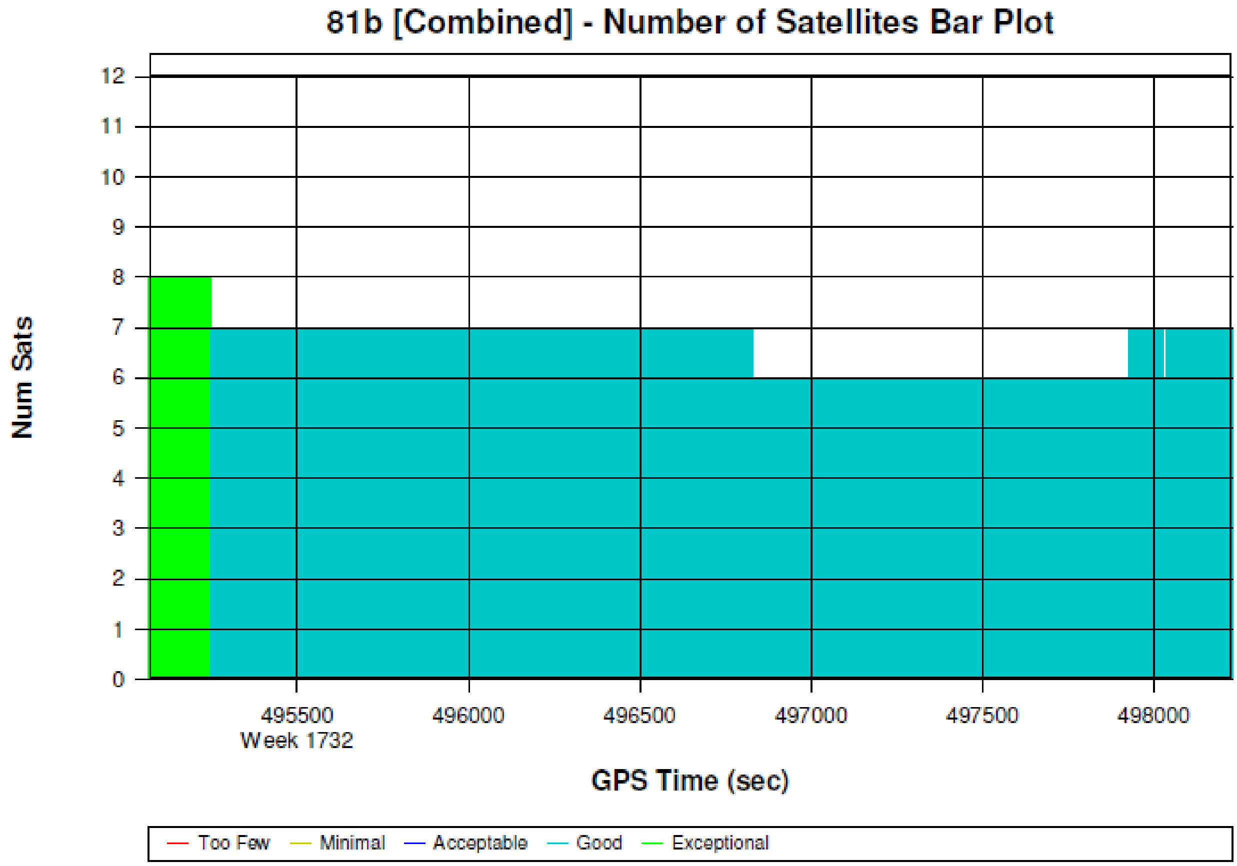
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13081a\pos\GPS\81a.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 70958
No processed position: 65227
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0228 (m)
C/A Code: 1.12 (m)
L1 Doppler: 0.031 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.010 (m)
North: 0.021 (m)
Height: 0.040 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (5725 occurances):
East: 0.010 (m)
North: 0.021 (m)
Height: 0.033 (m)
Quality Number Percentages:

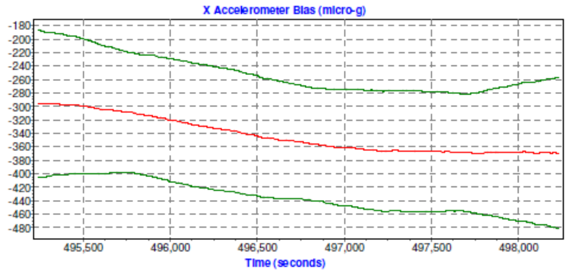
Q 1: 99.4 %
Q 2: 0.6 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 0.0 %
Baseline Distances:
Maximum: 32.953 (km)
Minimum: 0.656 (km)
Average: 16.175 (km)
First Epoch: 7.473 (km)
Last Epoch: 5.691 (km)

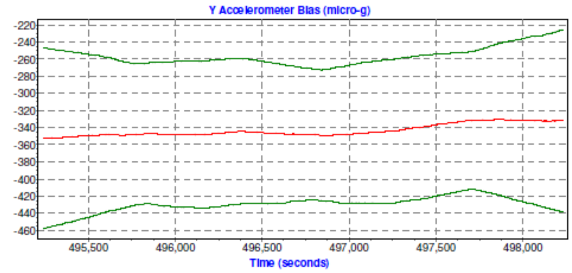

Combined - Map Run (9)
37 24 00.0000
37 18 00.0000
37 12 00.0000
37 06 00.0000
37 00 00.0000
36 54 00.0000
058
10 km
76 48 00.0001
76 42 00.0001
76 36 00.0001
76 30 00.0001
76 24 00.0001
+ Ukn + Q1 + Q2 + Q3 + Q4 + Q5 + Q6 ▲ Master

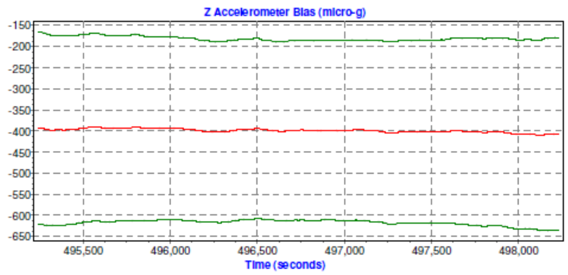

81b [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.10
0.05
0.00
-0.05
-0.10
495500
Week 1732
496000
496500
497000
497500
498000
GPS Time (sec)
East
North
Up

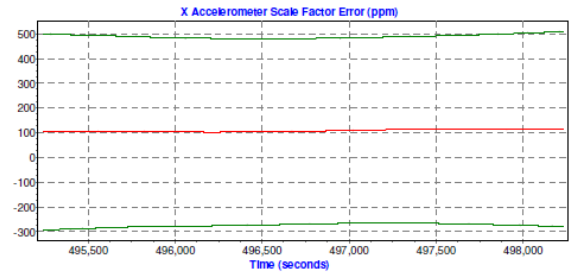

81b [Combined] - PDOP, HDOP, VDOP Plots
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
495500
Week 1732
496000
496500
497000
497500
498000
GPS Time (sec)
PDOP
HDOP
VDOP

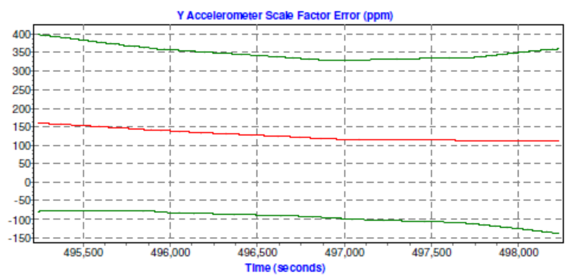

81b [Combined] - Number of Satellites Bar Plot
Num Sats
12
11
10
9
8
7
6
5
4
3
2
1
0
495500
Week 1732
496000
496500
497000
497500
498000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

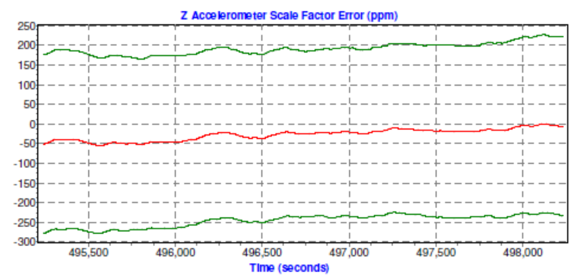

X Accelerometer Bias (micro-g)
-180
-200
-220
-240
-260
-280
-300
-320
-340
-360
-380
-400
-420
-440
-460
-480
495,500
496,000
496,500
497,000
497,500
498,000
Time (seconds)

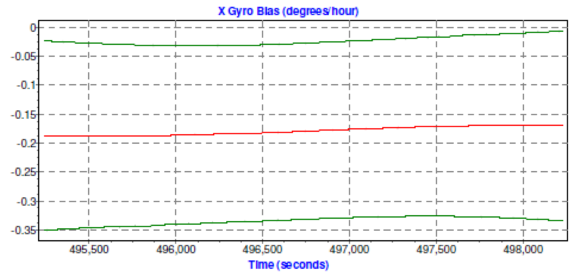

Y Accelerometer Bias (micro-g)
-220
-240
-260
-280
-300
-320
-340
-360
-380
-400
-420
-440
-460
495,500
496,000
496,500
497,000
497,500
498,000
Time (seconds)

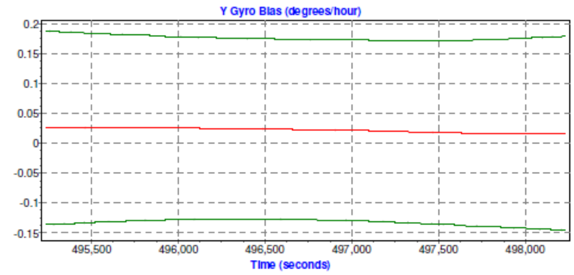

Z Accelerometer Bias (micro-g)
-150
-200
-250
-300
-350
-400
-450
-500
-550
-600
-650
495,500
496,000
496,500
497,000
497,500
498,000
Time (seconds)

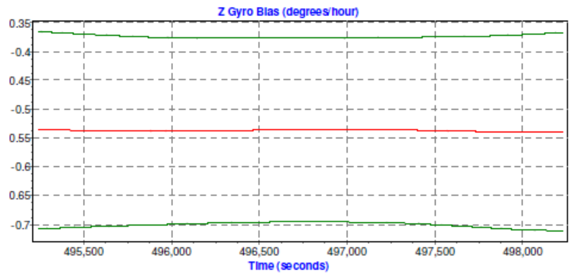

X Accelerometer Scale Factor Error (ppm)
500
400
300
200
100
0
-100
-200
-300
495,500
496,000
496,500
497,000
497,500
498,000
Time (seconds)

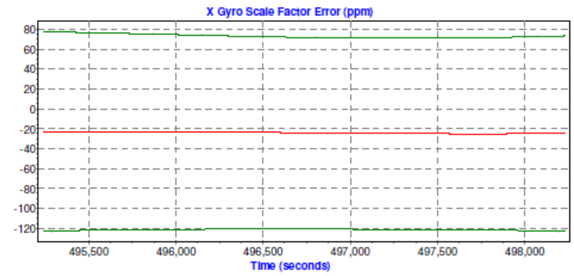

Y Accelerometer Scale Factor Error (ppm)
400
350
300
250
200
150
100
50
0
-50
-100
-150
495,500
496,000
496,500
497,000
497,500
498,000
Time (seconds)

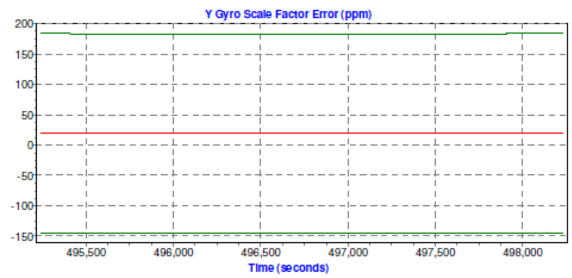

Z Accelerometer Scale Factor Error (ppm)
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
495,500
496,000
496,500
497,000
497,500
498,000
Time (seconds)

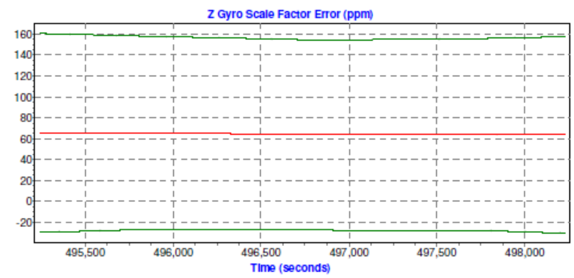








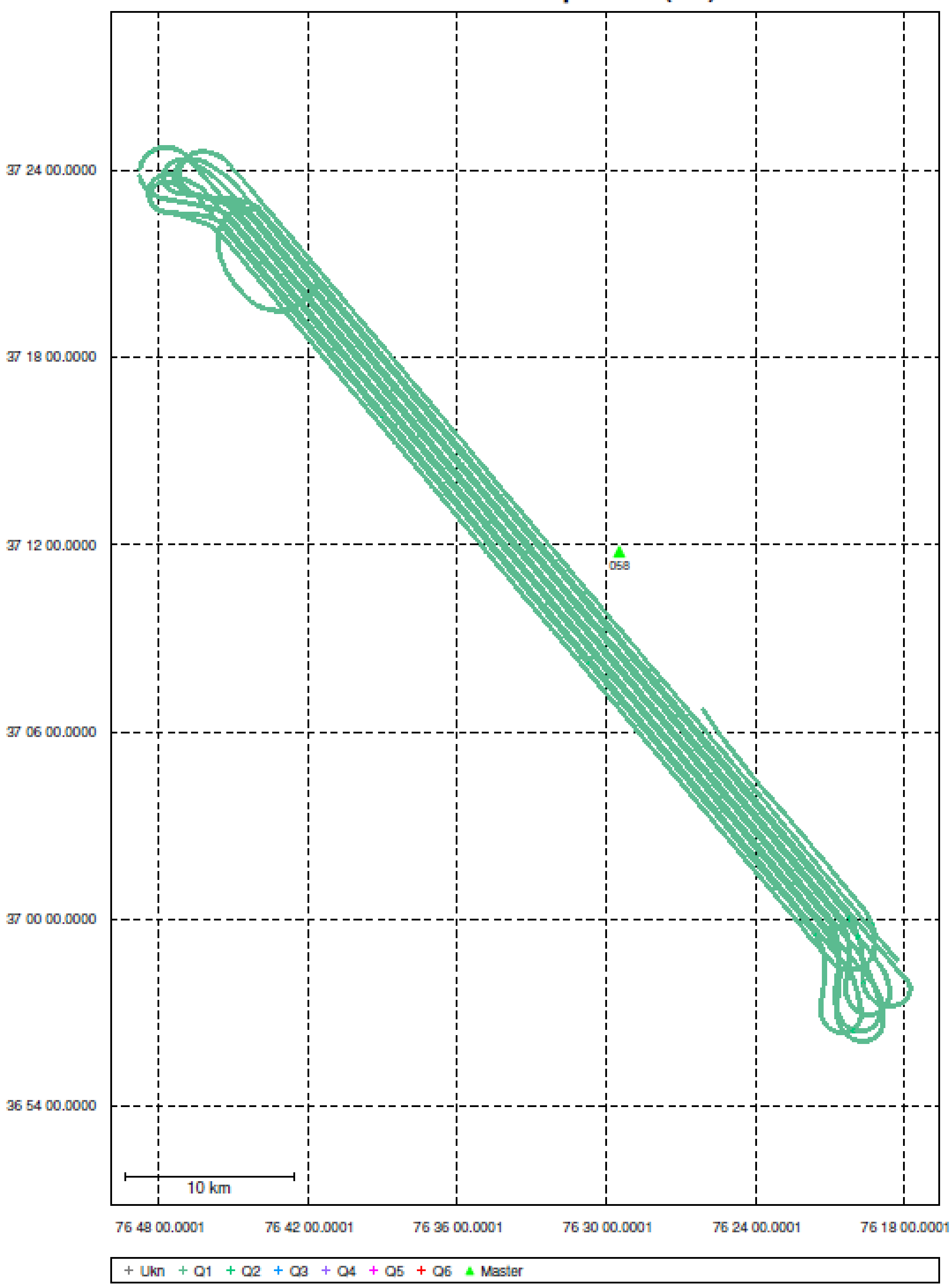




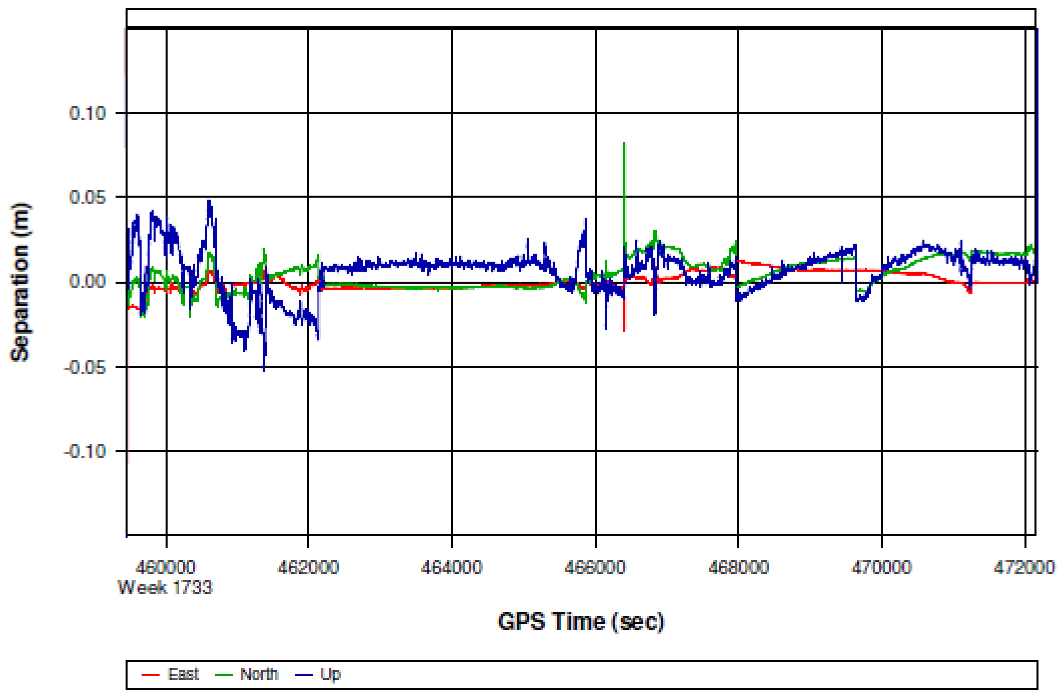
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13081b\pos\GPS\81b.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 48966
No processed position: 45922
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0227 (m)
C/A Code: 1.15 (m)
L1 Doppler: 0.029 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.015 (m)
North: 0.028 (m)
Height: 0.044 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (3038 occurances):
East: 0.003 (m)
North: 0.014 (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: 33.176 (km)
Minimum: 2.361 (km)
Average: 17.860 (km)
First Epoch: 6.556 (km)
Last Epoch: 2.361 (km)

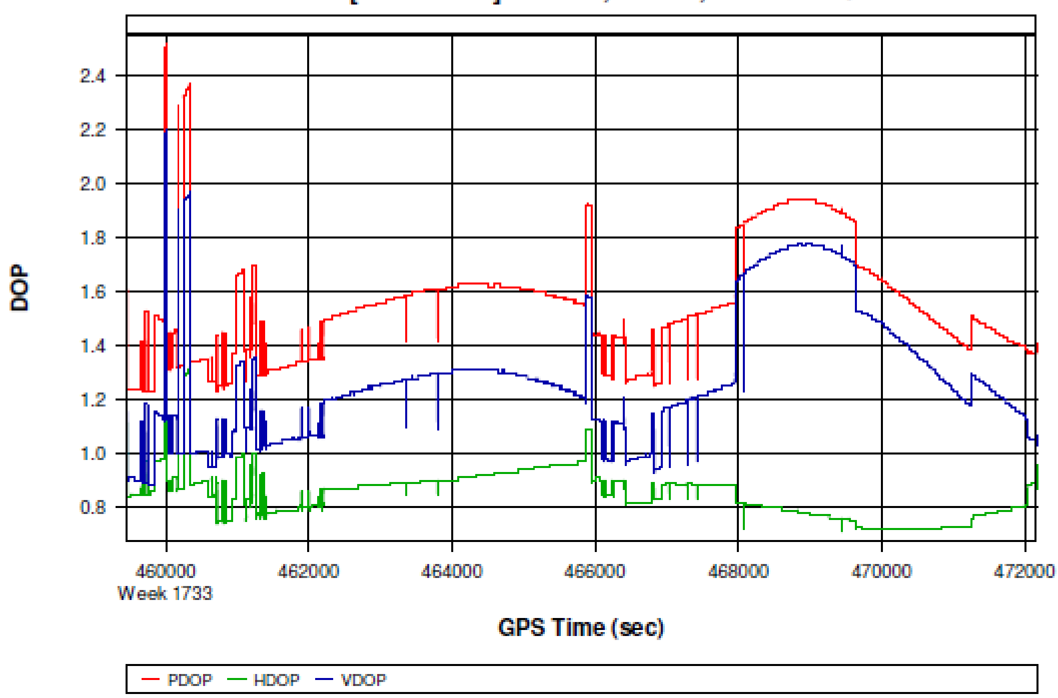
Combined - Map Run (27)

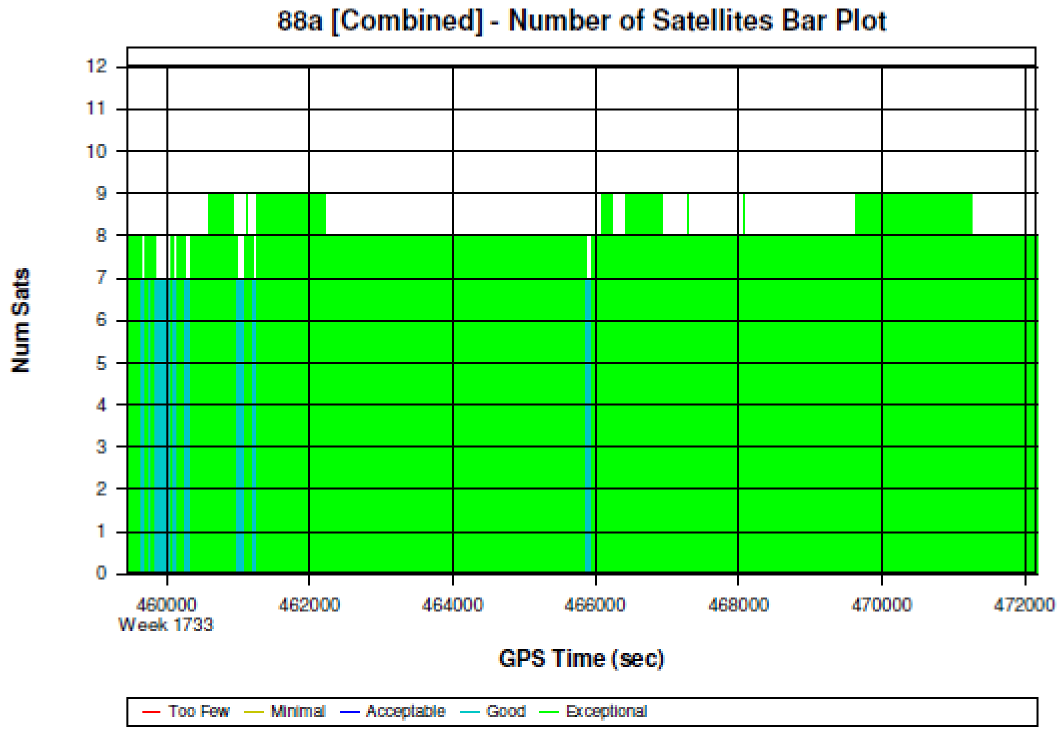


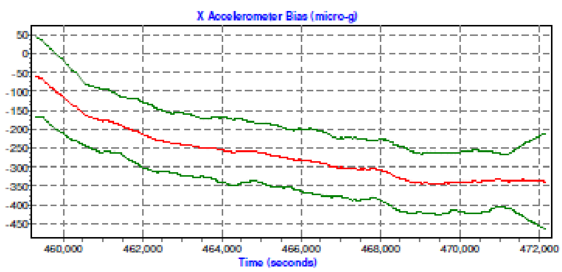
88a [Combined] - Forward/Reverse or Combined Separation Plot

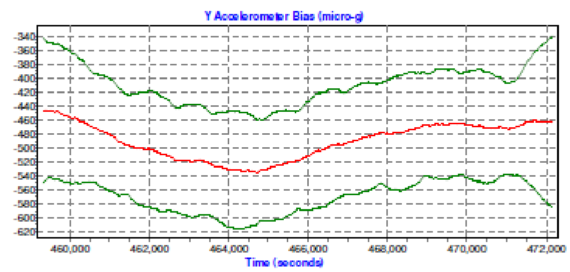


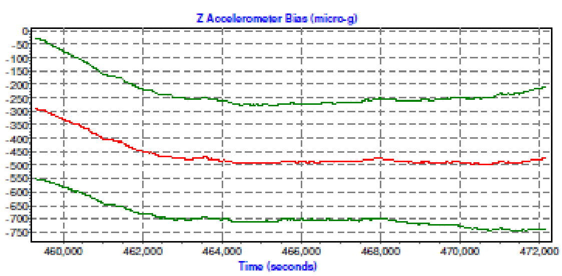
88a [Combined] - PDOP, HDOP, VDOP Plots

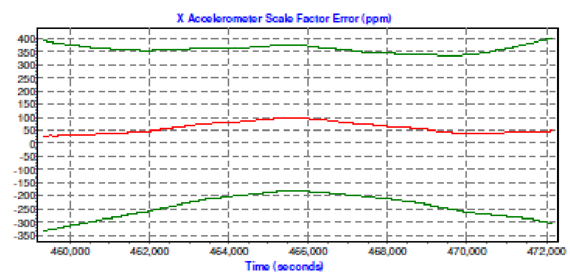


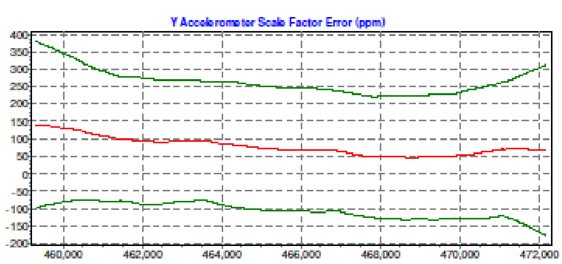

88a [Combined] - Number of Satellites Bar Plot
Num Sats
GPS Time (sec)
Week 1733
Too Few
Minimal
Acceptable
Good
Exceptional

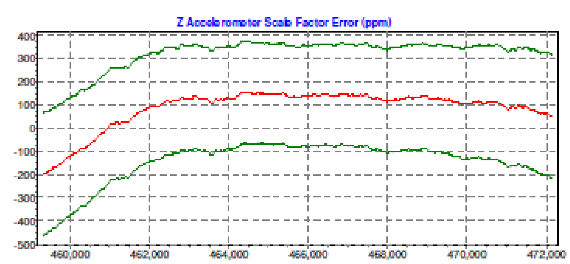

X Accelerometer Bias (micro-g)
Time (seconds)

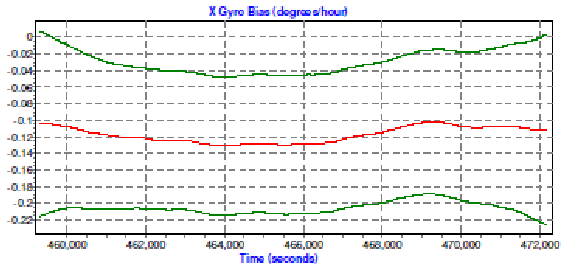

Y Accelerometer Bias (micro-g)
Time (seconds)

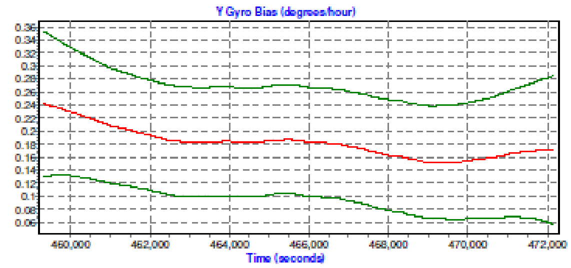

Z Accelerometer Bias (micro-g)
Time (seconds)

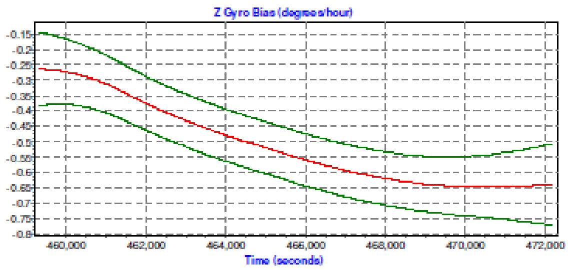

X Accelerometer Scale Factor Error (ppm)
Time (seconds)

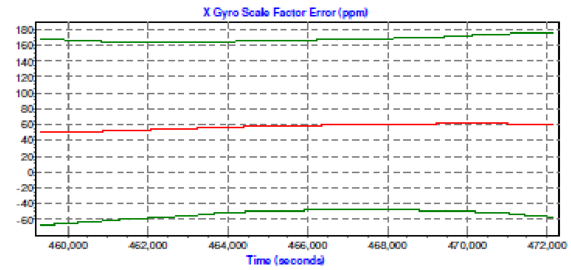

Y Accelerometer Scale Factor Error (ppm)
Time (seconds)

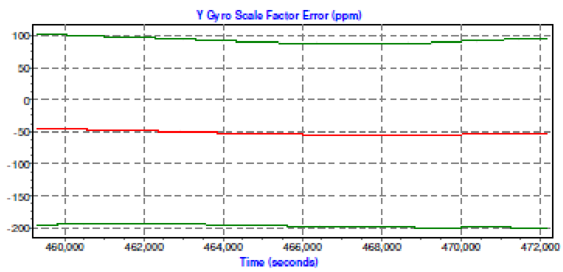

Z Accelerometer Scale Factor Error (ppm)
Time (seconds)

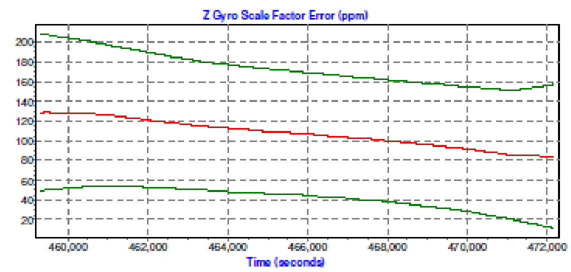








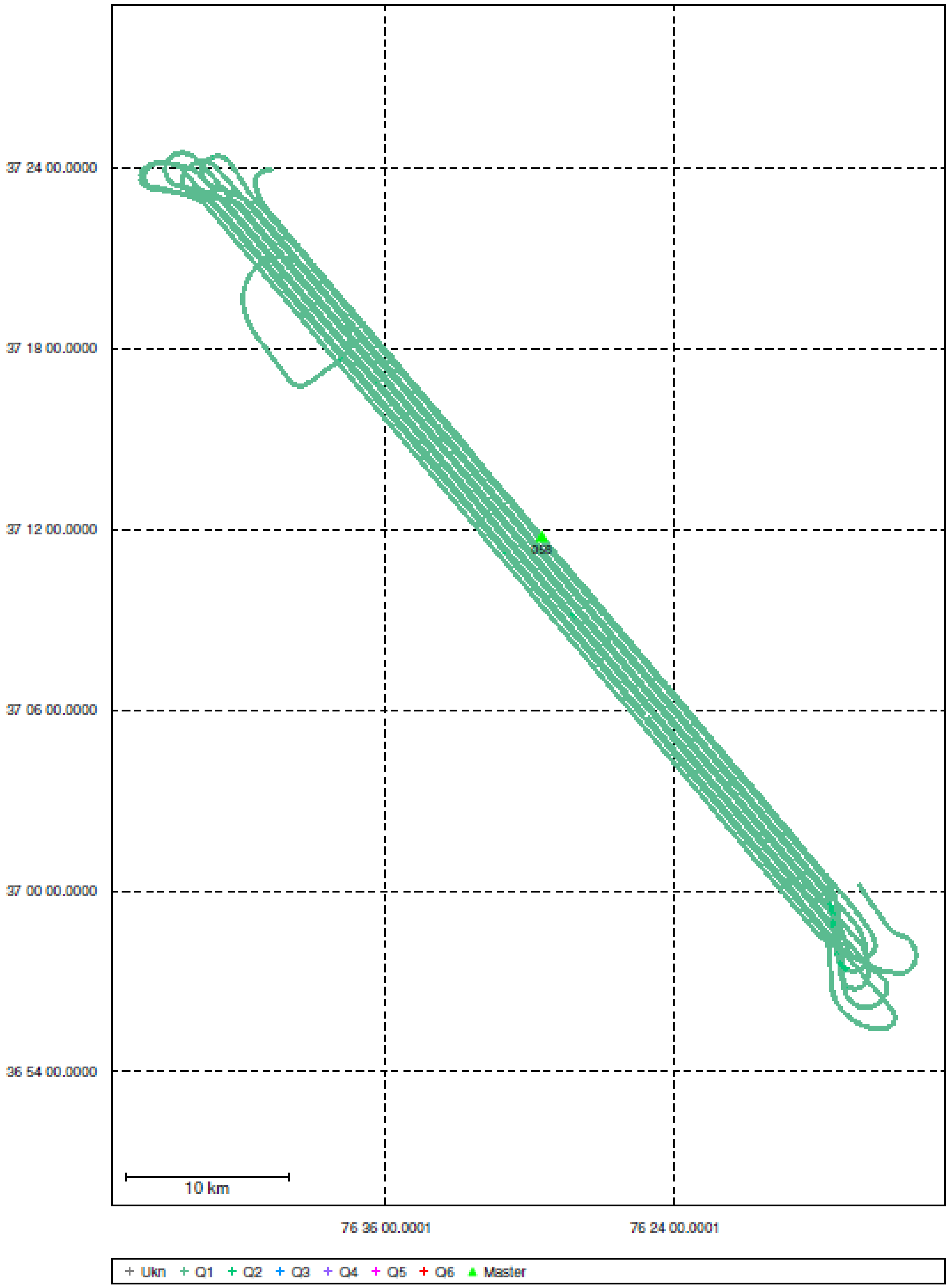


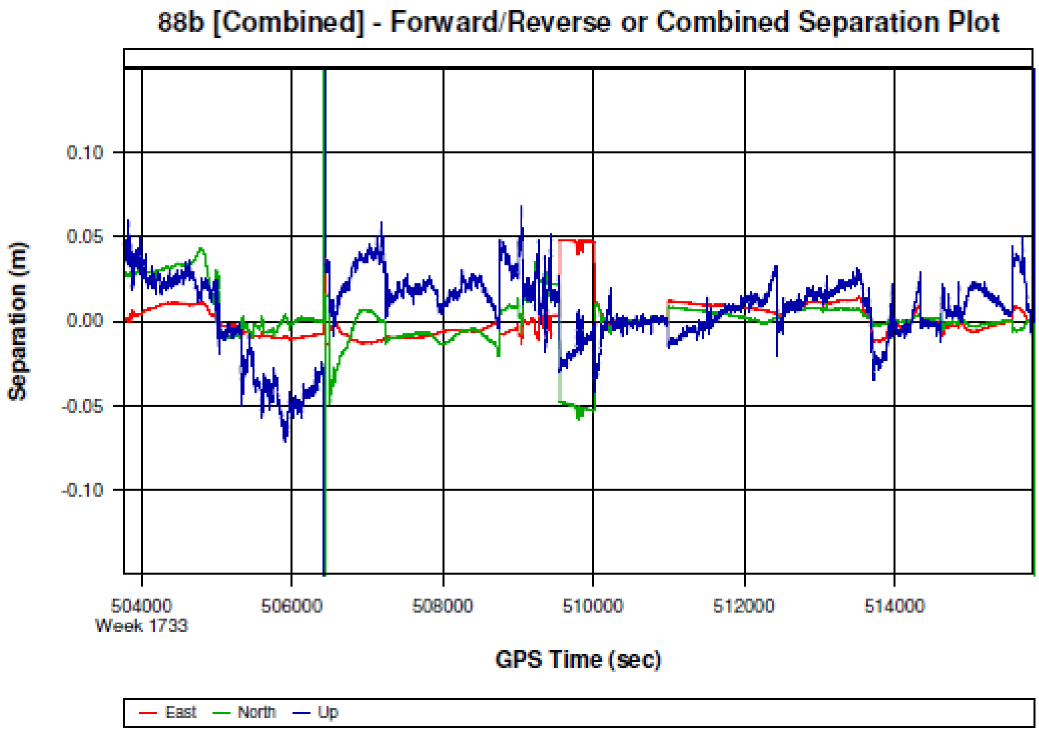


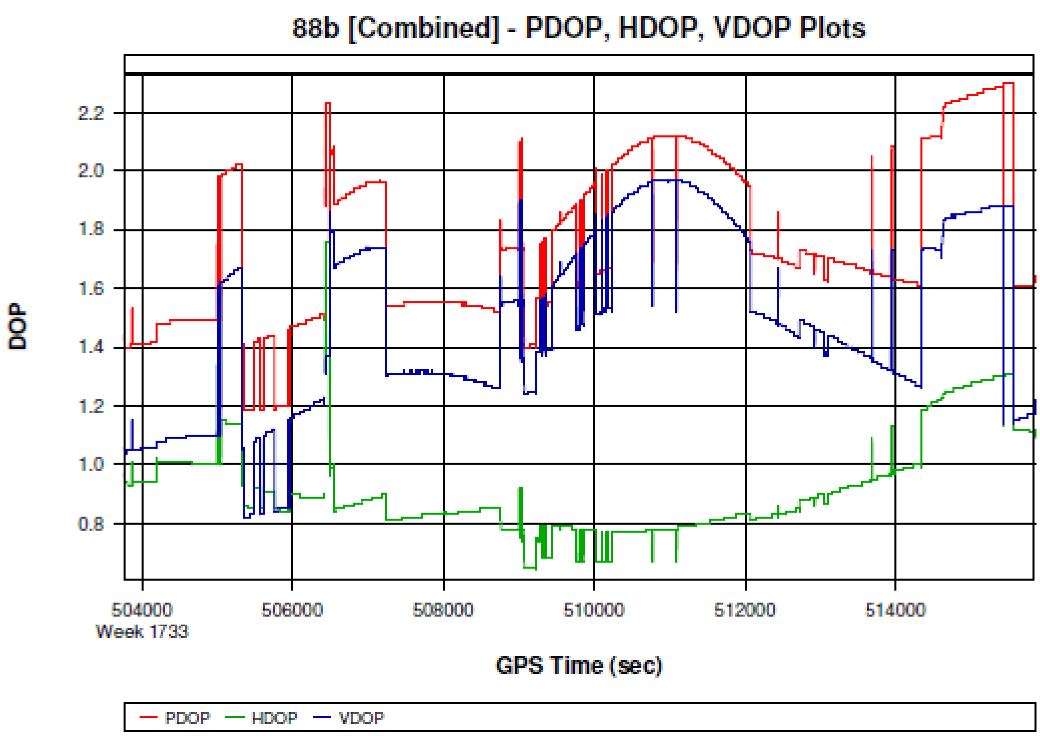
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13088a\pos\GPS\88a.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 155168
No processed position: 142444
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0260 (m)
C/A Code: 1.10 (m)
L1 Doppler: 0.018 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.006 (m)
North: 0.013 (m)
Height: 0.021 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (12708 occurances):
East: 0.005 (m)
North: 0.010 (m)
Height: 0.014 (m)
Quality Number Percentages:

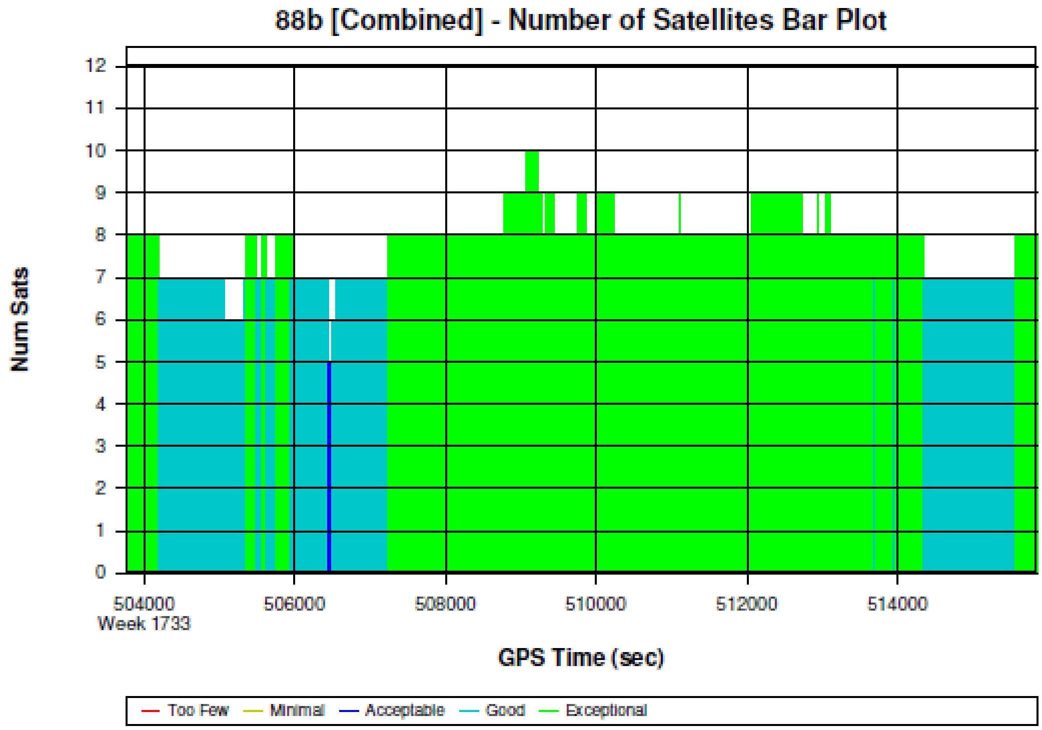
Q 1: 99.5 %
Q 2: 0.5 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 0.0 %
Baseline Distances:
Maximum: 36.679 (km)
Minimum: 3.087 (km)
Average: 18.294 (km)
First Epoch: 28.454 (km)
Last Epoch: 29.355 (km)

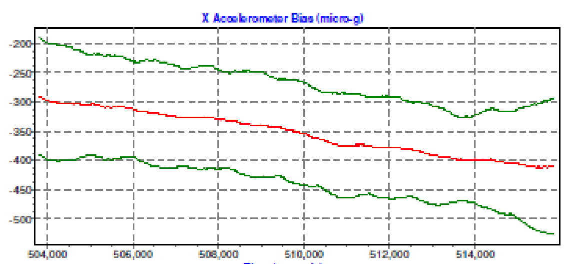
Combined - Map Run (37)

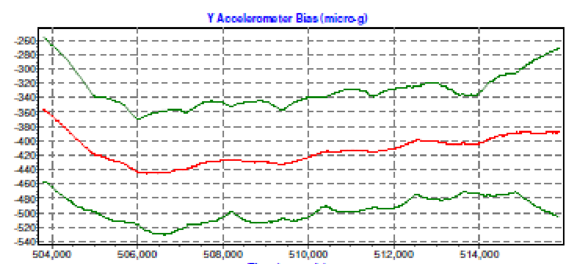


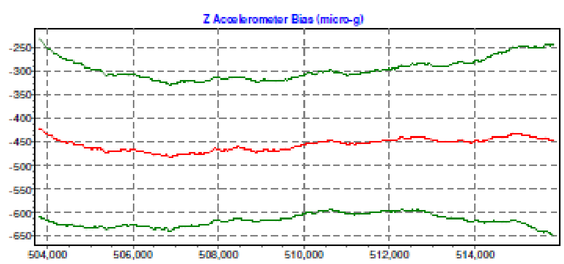

88b [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.10
0.05
0.00
-0.05
-0.10
504000
Week 1733
506000
508000
510000
512000
514000
GPS Time (sec)
East
North
Up

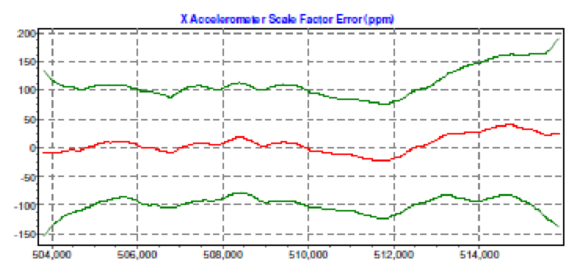

88b [Combined] - PDOP, HDOP, VDOP Plots
DOP
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
504000
Week 1733
506000
508000
510000
512000
514000
GPS Time (sec)
PDOP
HDOP
VDOP

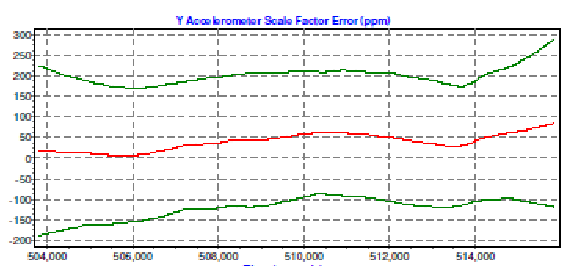

88b [Combined] - Number of Satellites Bar Plot
Num Sats
0
1
2
3
4
5
6
7
8
9
10
11
12
504000
Week 1733
506000
508000
510000
512000
514000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

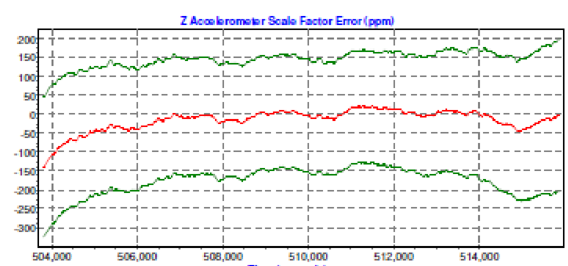

X Accelerometer Bias (micro-g)
Time (seconds)

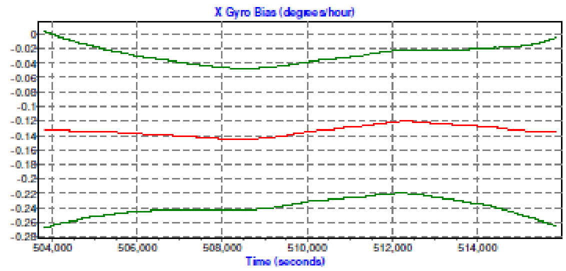

Y Accelerometer Bias (micro-g)
Time (seconds)

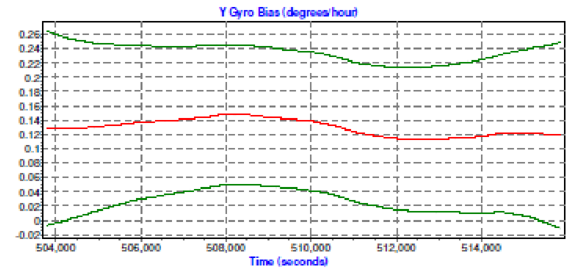

Z Accelerometer Bias (micro-g)
Time (seconds)

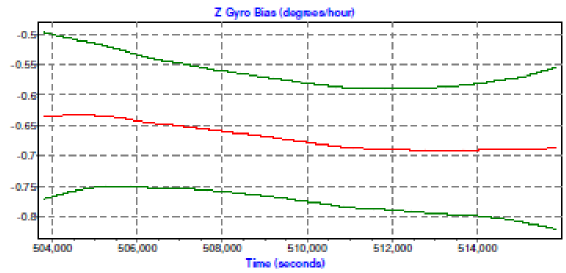

X Accelerometer Scale Factor Error (ppm)
Time (seconds)

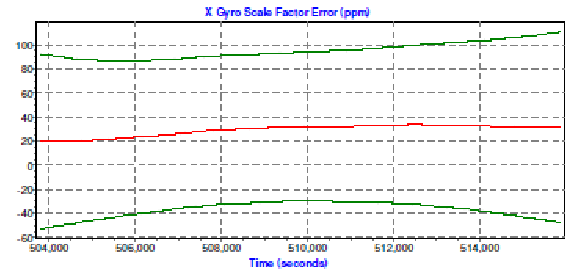

Y Accelerometer Scale Factor Error (ppm)
Time (seconds)


Z Accelerometer Scale Factor Error (ppm)
Time (seconds)





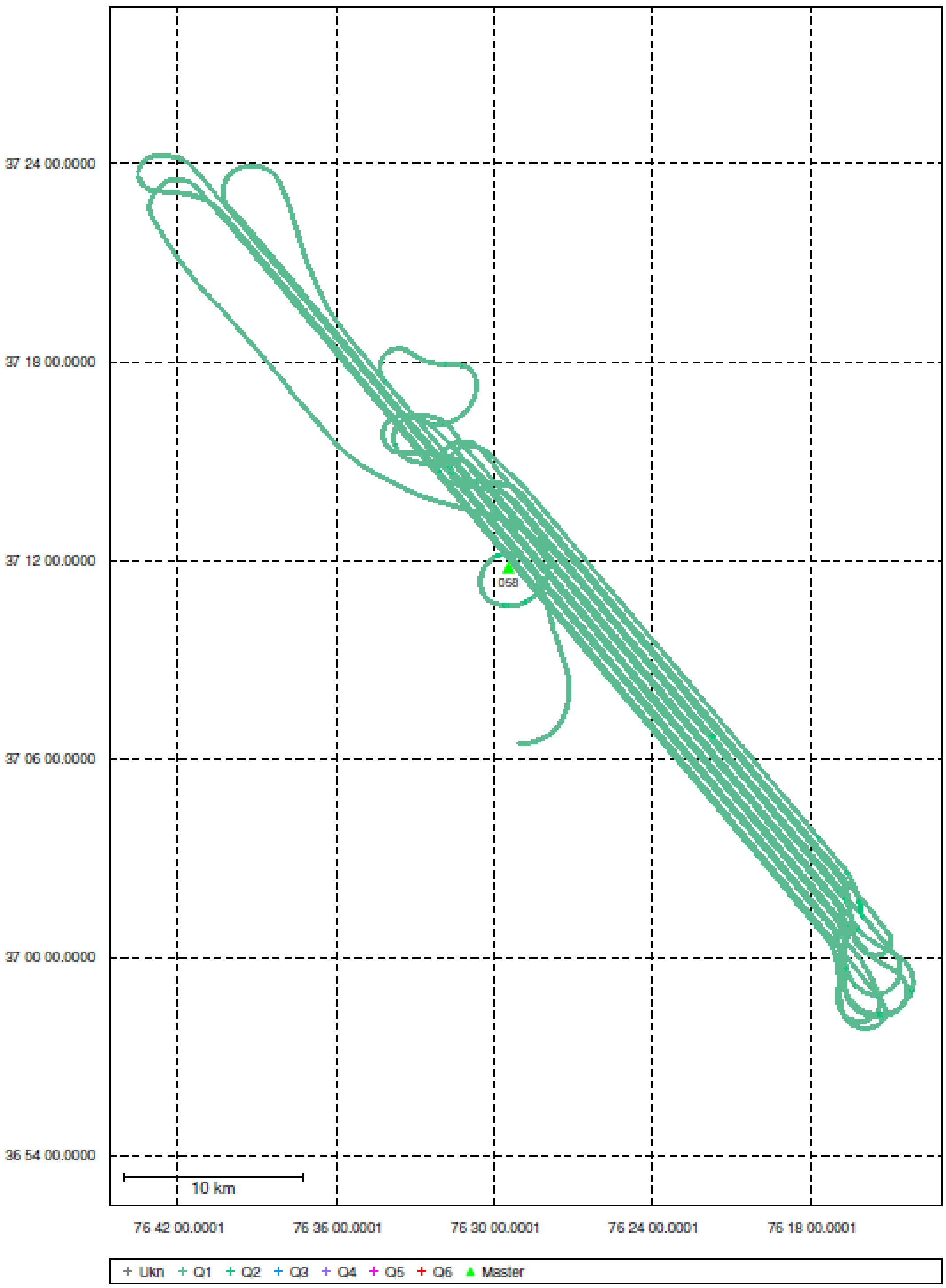


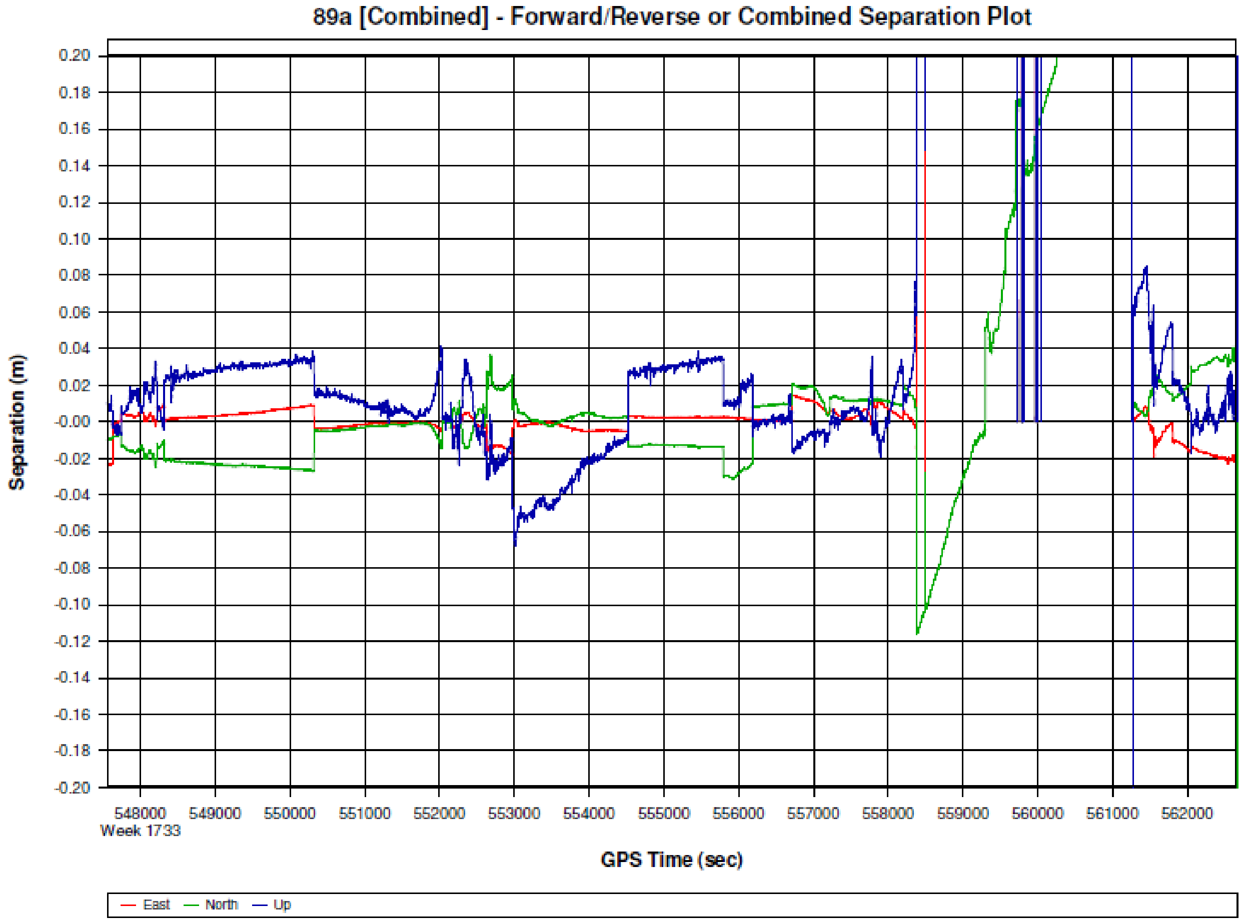


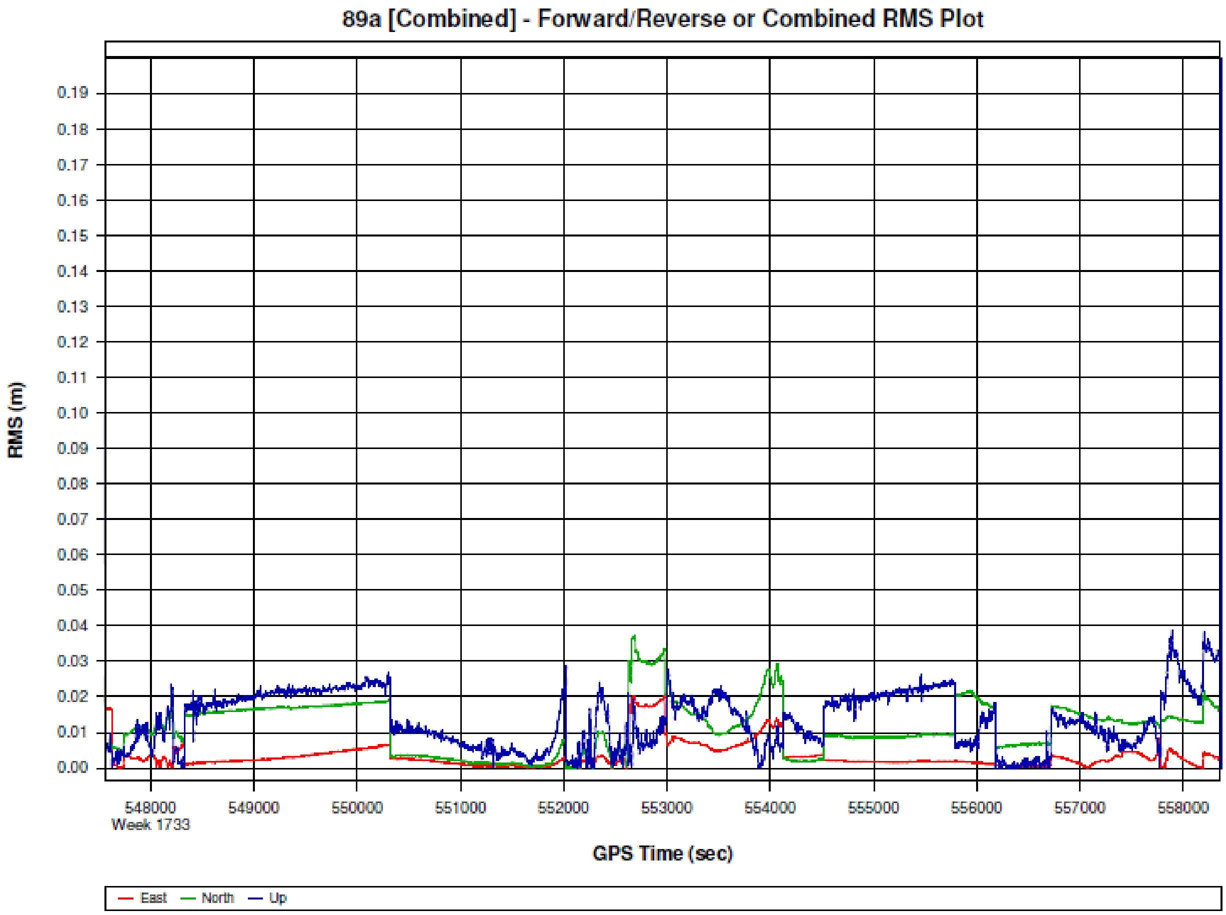
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13088b\pos\GPS\88b.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 155934
No processed position: 143849
Missing Fwd or Rev: 8
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0265 (m)
C/A Code: 1.12 (m)
L1 Doppler: 0.027 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.011 (m)
North: 0.021 (m)
Height: 0.030 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (12073 occurances):
East: 0.010 (m)
North: 0.020 (m)
Height: 0.029 (m)

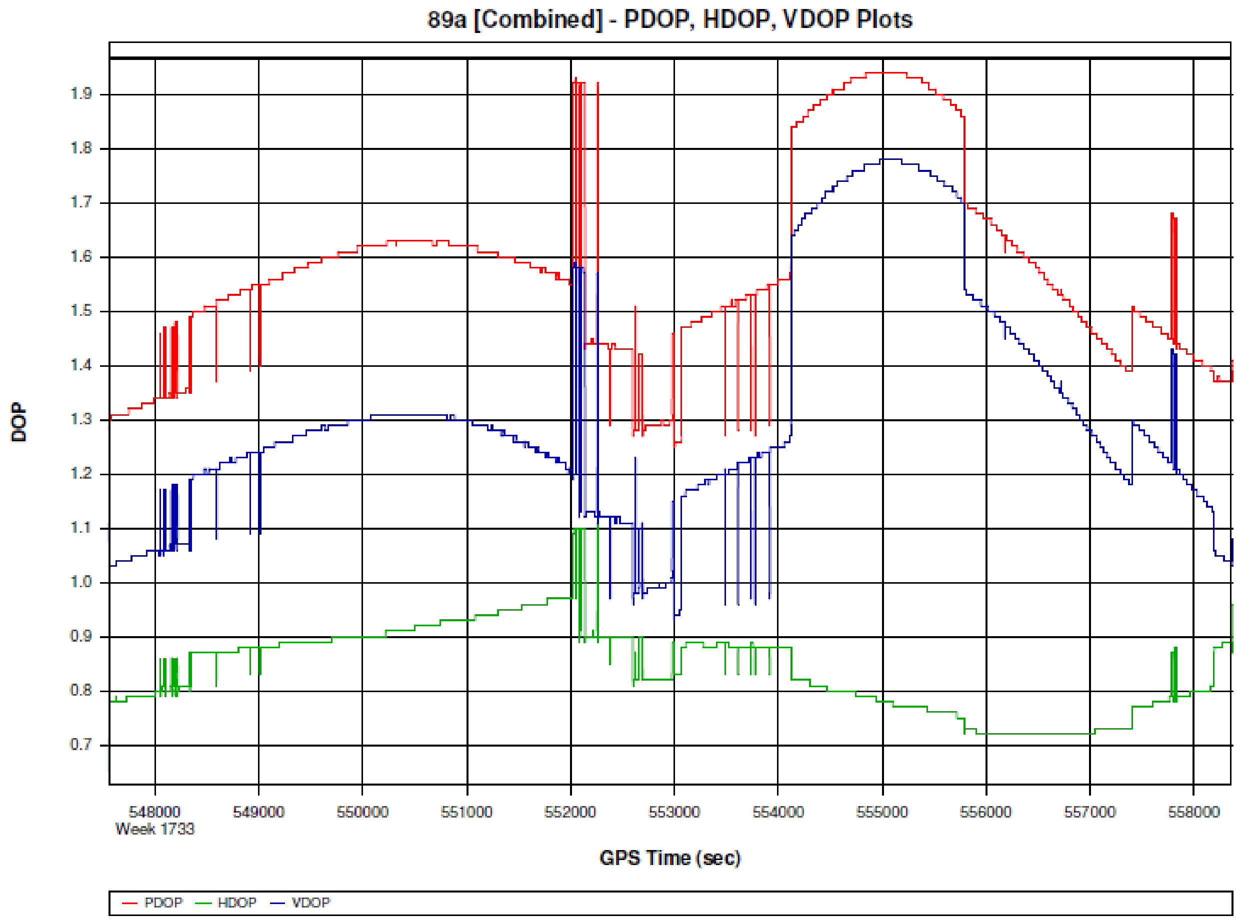
Quality Number Percentages:
Q 1: 99.0 %
Q 2: 1.0 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 88.9 %
0.10 - 0.30 m: 11.1 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 0.0 %
Baseline Distances:
Maximum: 37.012 (km)
Minimum: 0.926 (km)
Average: 17.514 (km)
First Epoch: 29.014 (km)
Last Epoch: 28.011 (km)

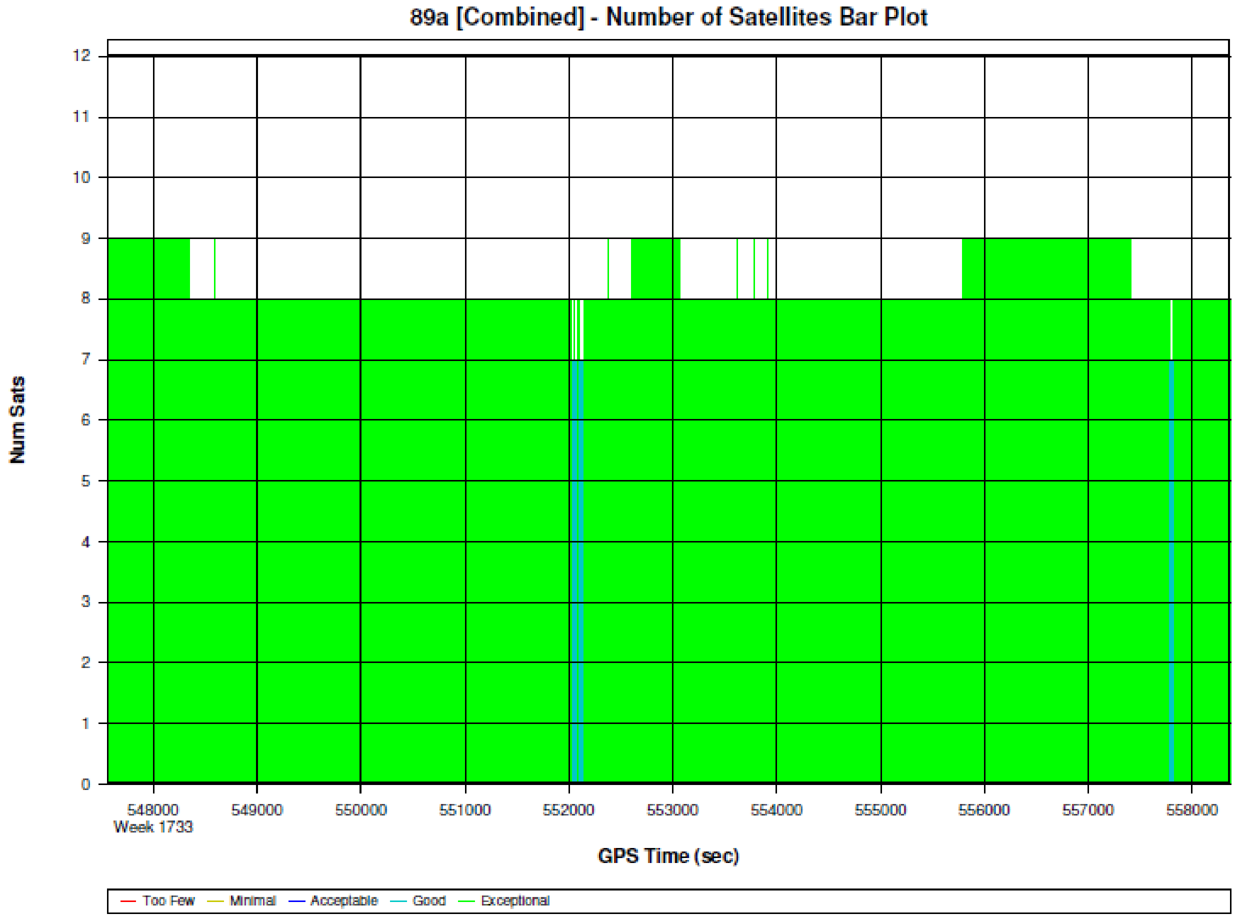
Combined - Map Run (51)




89a [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
-0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
548000
Week 1733
549000
550000
551000
552000
553000
554000
555000
556000
557000
558000
559000
560000
561000
562000
GPS Time (sec)
East
North
Up

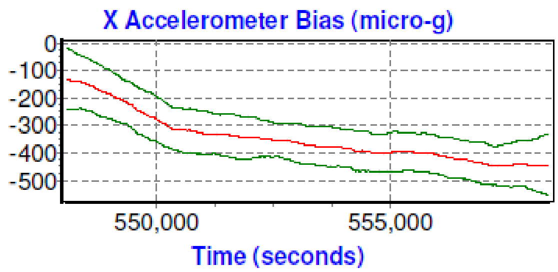

89a [Combined] - Forward/Reverse or Combined RMS Plot
RMS (m)
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
548000
Week 1733
549000
550000
551000
552000
553000
554000
555000
556000
557000
558000
GPS Time (sec)
East
North
Up

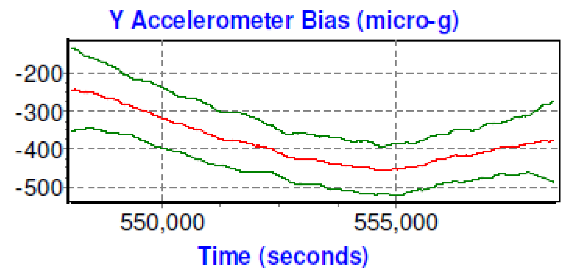

89a [Combined] - PDOP, HDOP, VDOP Plots
DOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
548000
Week 1733
549000
550000
551000
552000
553000
554000
555000
556000
557000
558000
GPS Time (sec)
PDOP
HDOP
VDOP

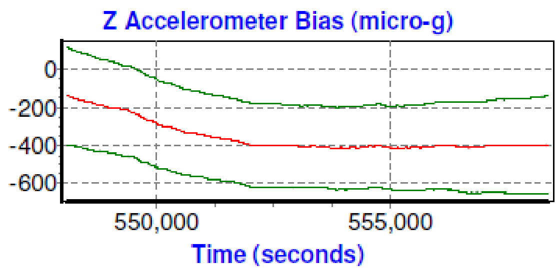


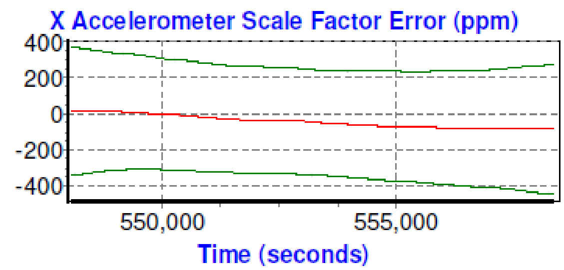
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13089a\pos\GPS\89a.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 162207
No processed position: 151395
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0298 (m)
C/A Code: 1.10 (m)
L1 Doppler: 0.018 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.008 (m)
North: 0.019 (m)
Height: 0.026 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (10806 occurances):
East: 0.007 (m)
North: 0.019 (m)

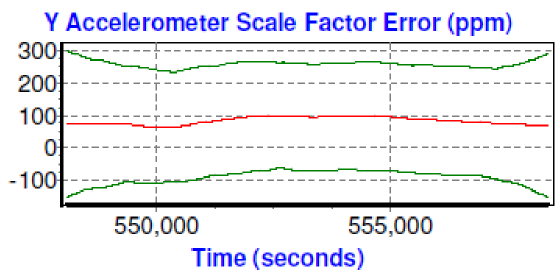
Height: 0.022 (m)
Quality Number Percentages:
Q 1: 99.1 %
Q 2: 0.9 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 0.0 %
Baseline Distances:
Maximum: 33.051 (km)
Minimum: 0.954 (km)
Average: 14.602 (km)
First Epoch: 9.799 (km)
Last Epoch: 27.866 (km)

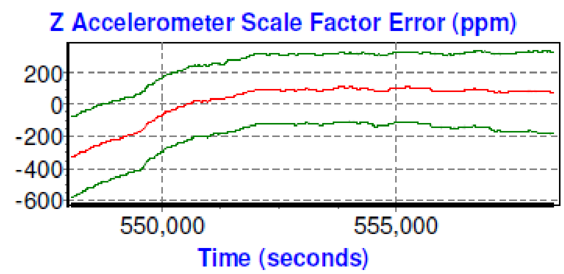


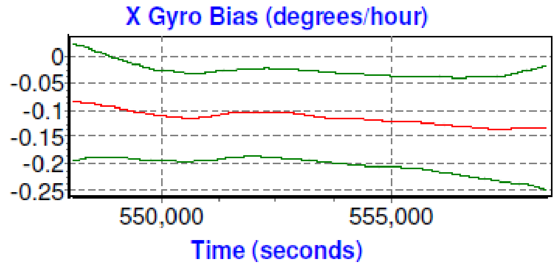


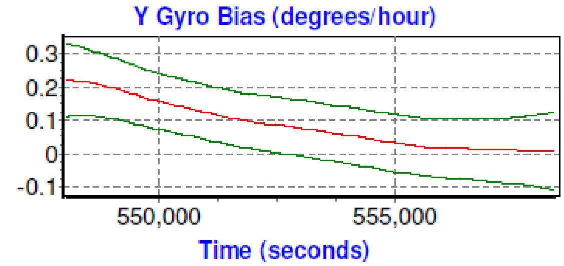


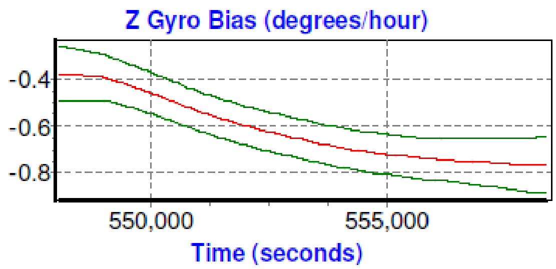


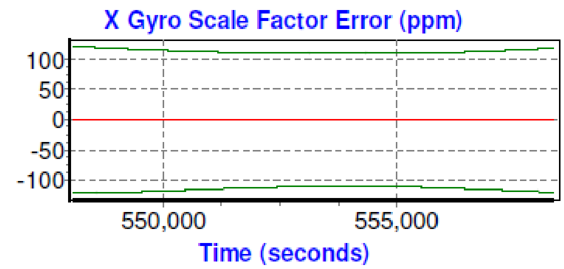


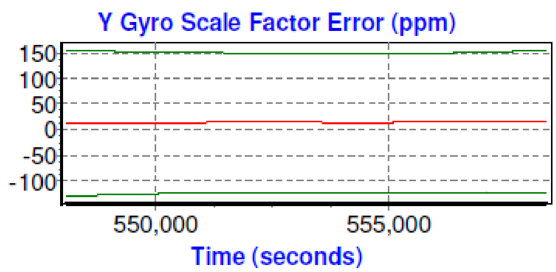


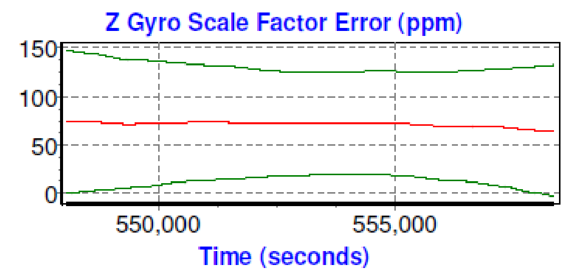

X Gyro Bias (degrees/hour)
0
-0.05
-0.1
-0.15
-0.2
-0.25
550,000
555,000
Time (seconds)

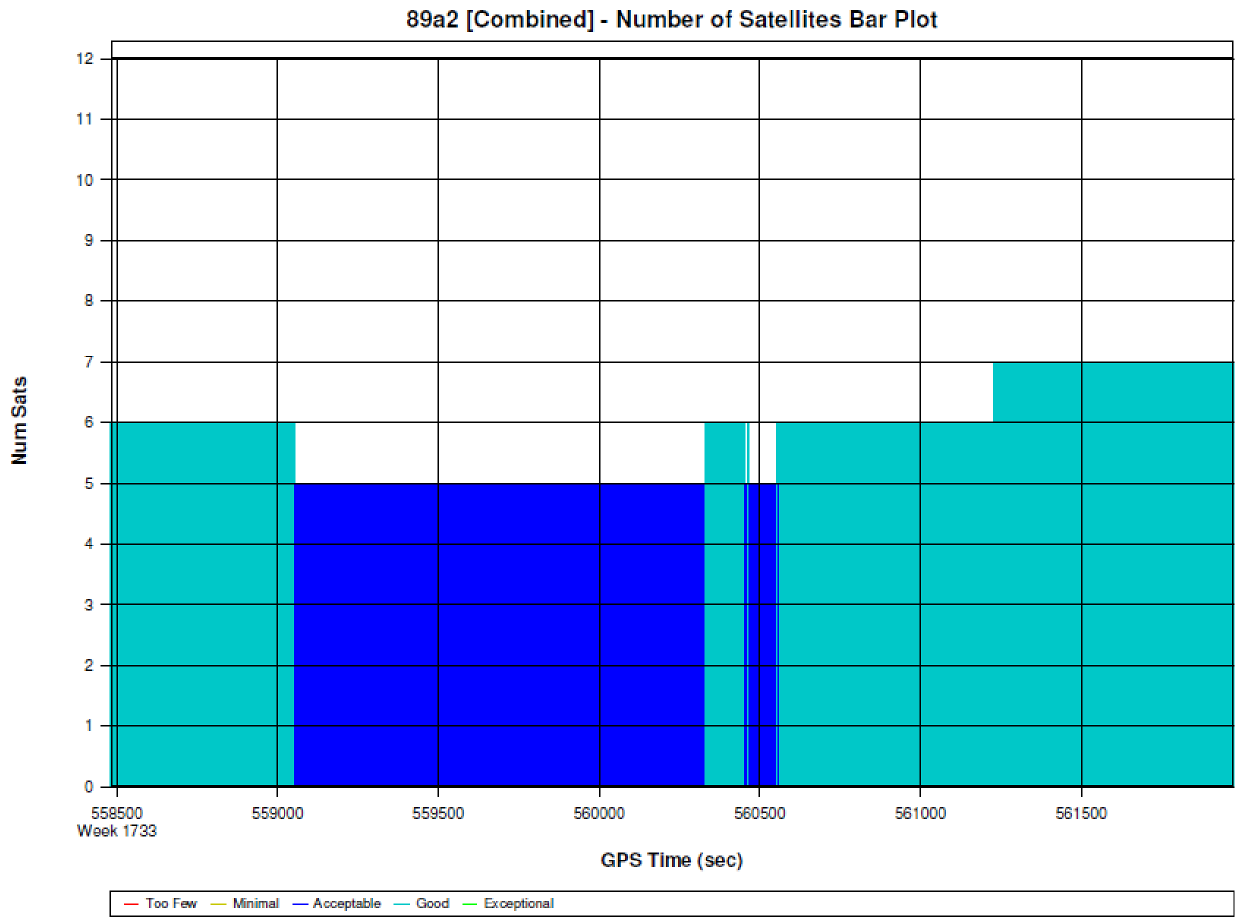

Y Gyro Bias (degrees/hour)
0.3
0.2
0.1
0
-0.1
550,000
555,000
Time (seconds)

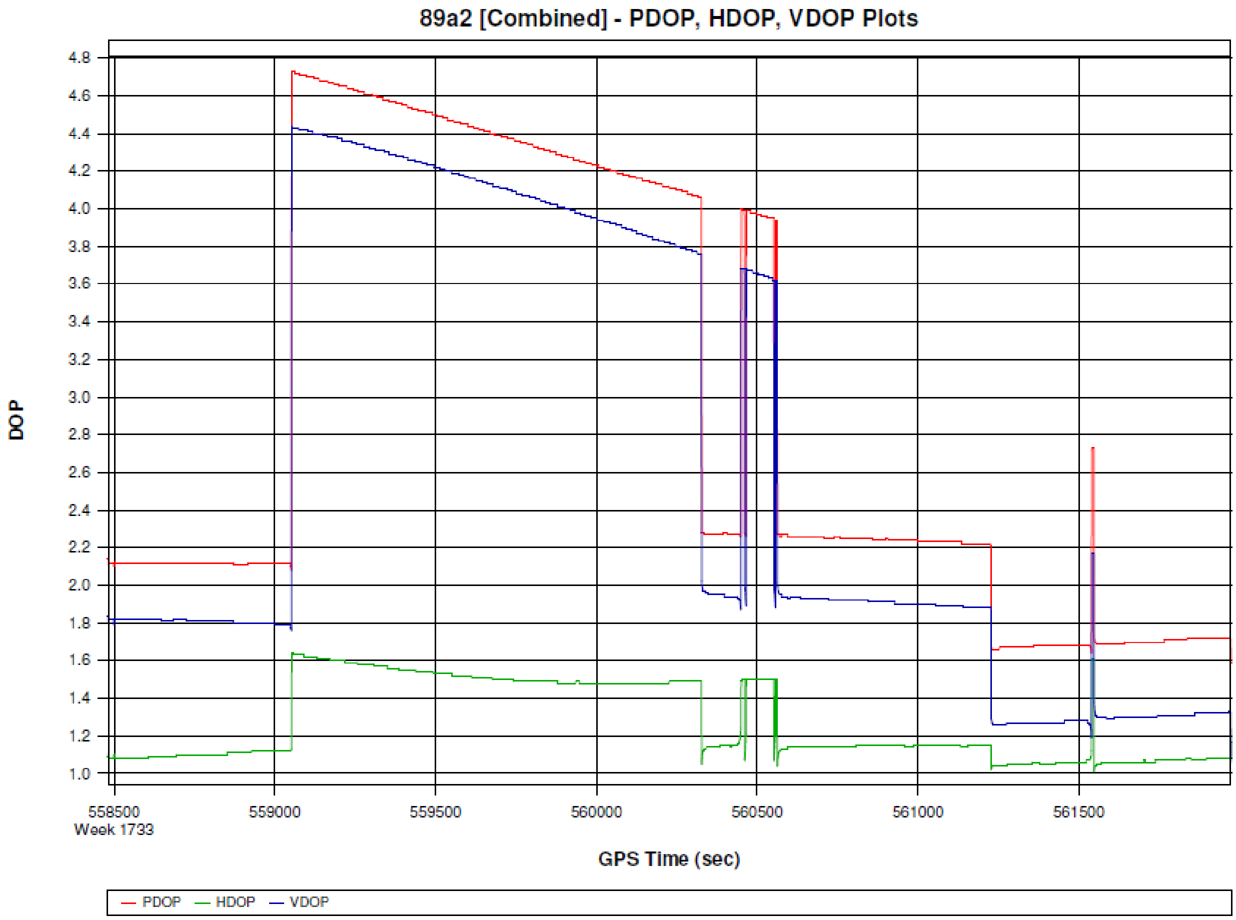

Z Gyro Bias (degrees/hour)
-0.4
-0.6
-0.8
550,000
555,000
Time (seconds)


X Gyro Scale Factor Error (ppm)
100
50
0
-50
-100
550,000
555,000
Time (seconds)

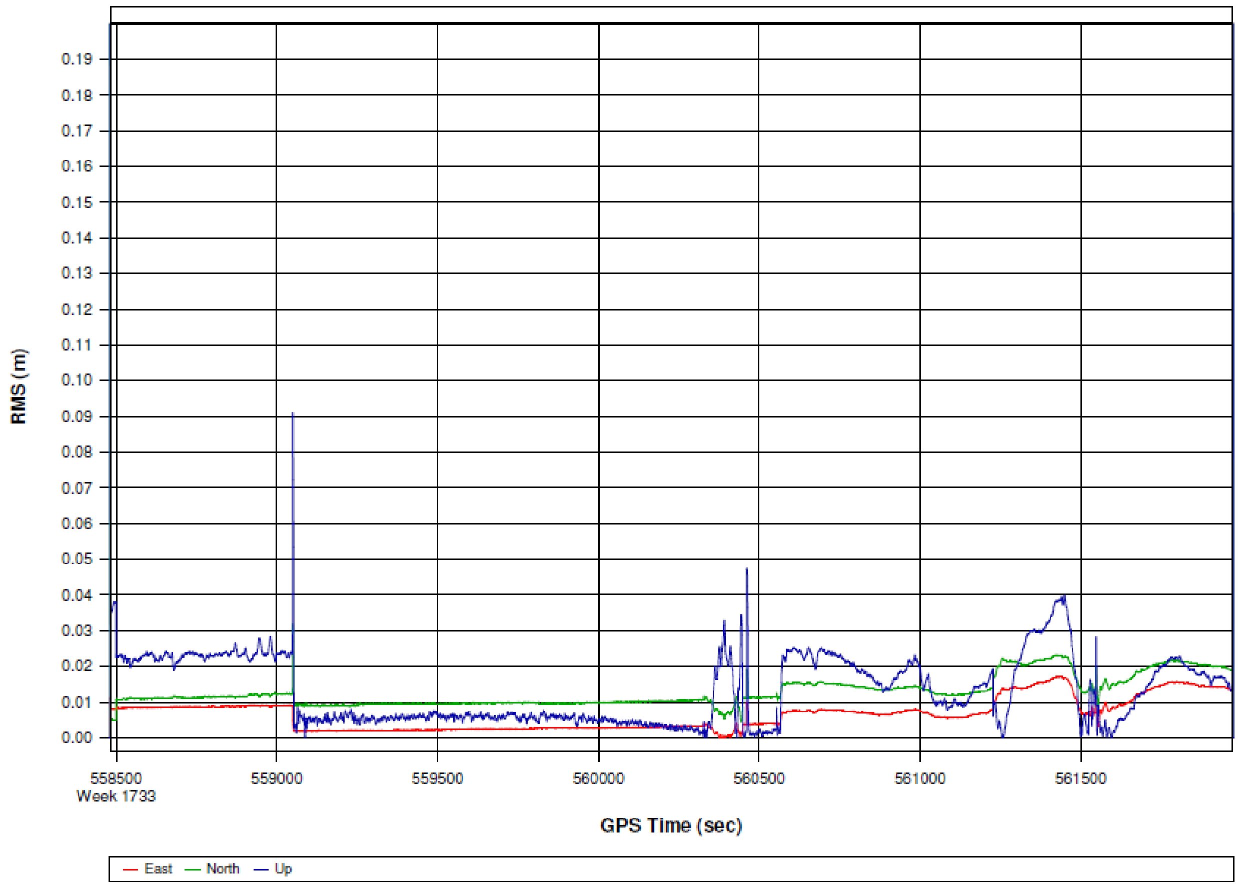

Y Gyro Scale Factor Error (ppm)
150
100
50
0
-50
-100
550,000
555,000
Time (seconds)

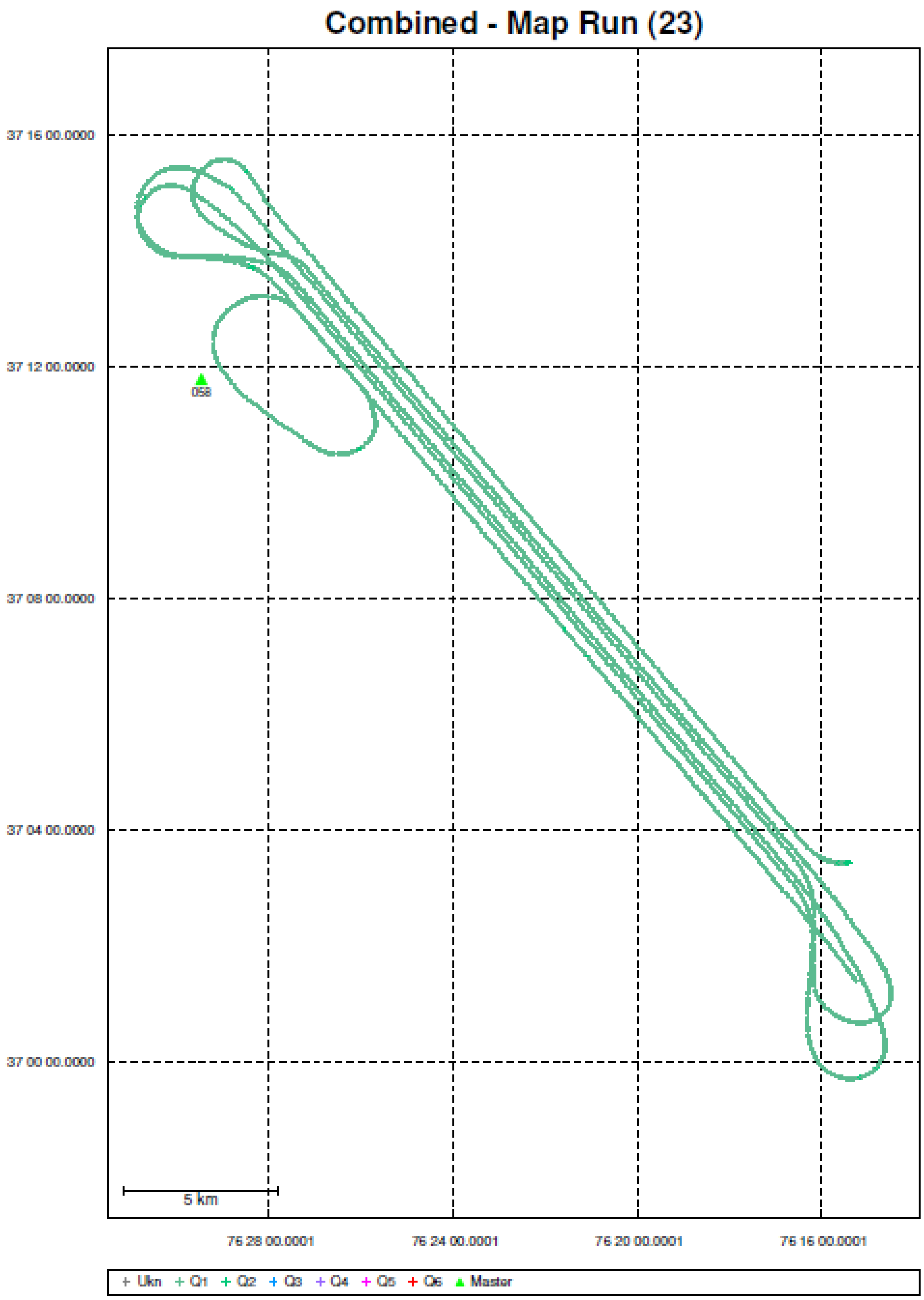

Z Gyro Scale Factor Error (ppm)
150
100
50
0
550,000
555,000
Time (seconds)

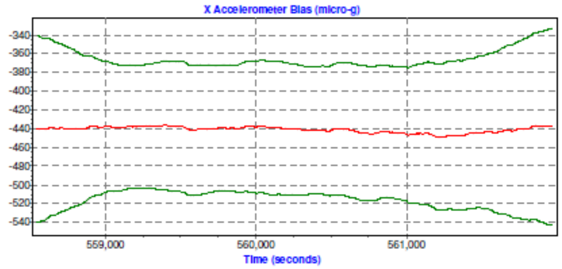

89a2 [Combined] - Number of Satellites Bar Plot
Num Sats
12
11
10
9
8
7
6
5
4
3
2
1
0
558500
Week 1733
559000
559500
560000
560500
561000
561500
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

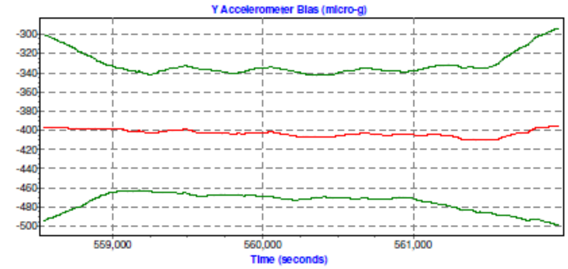

89a2 [Combined] - PDOP, HDOP, VDOP Plots
DOP
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
558500
Week 1733
559000
559500
560000
560500
561000
561500
GPS Time (sec)
PDOP
HDOP
VDOP

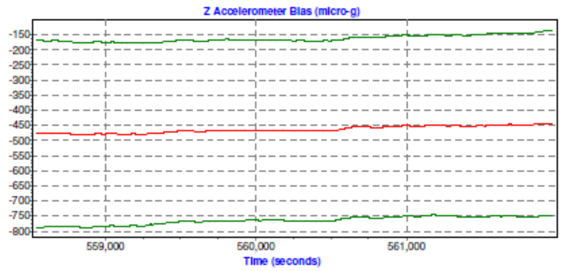
89a2 [Combined] - Forward/Reverse or Combined RMS Plot

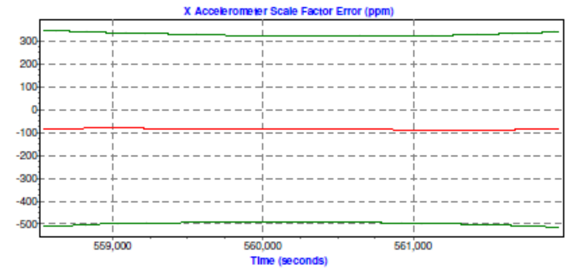


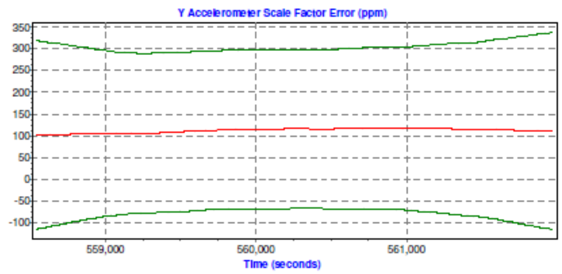

Combined - Map Run (23)
37 16 00.0000
37 12 00.0000
37 08 00.0000
37 04 00.0000
37 00 00.0000
058
5 km
76 28 00.0001
76 24 00.0001
76 20 00.0001
76 16 00.0001
+ Ukn + Q1 + Q2 + Q3 + Q4 + Q5 + Q6 ▲ Master

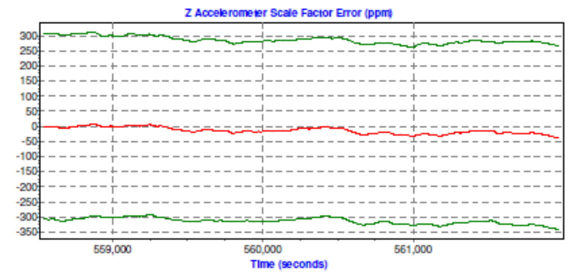

X Accelerometer Bias (micro-g)
Time (seconds)

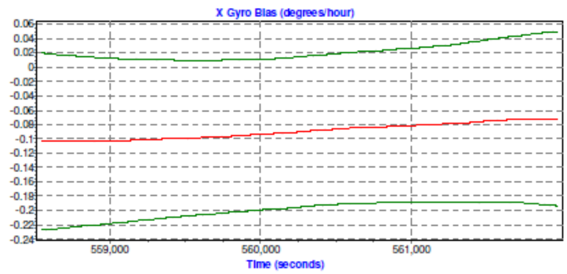

Y Accelerometer Bias (micro-g)
Time (seconds)

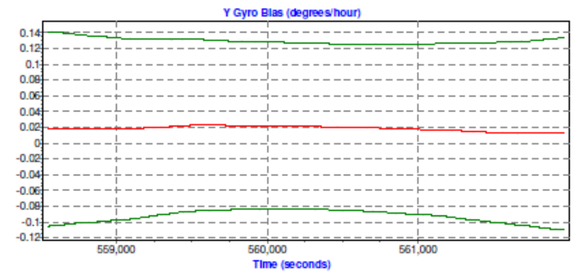

Z Accelerometer Bias (micro-g)
Time (seconds)

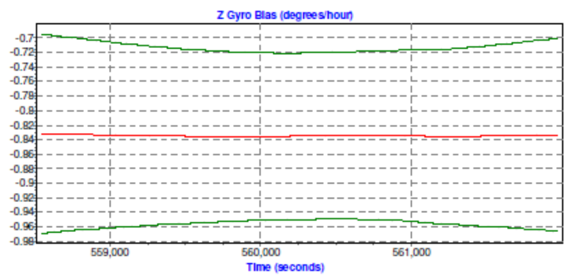

X Accelerometer Scale Factor Error (ppm)
Time (seconds)

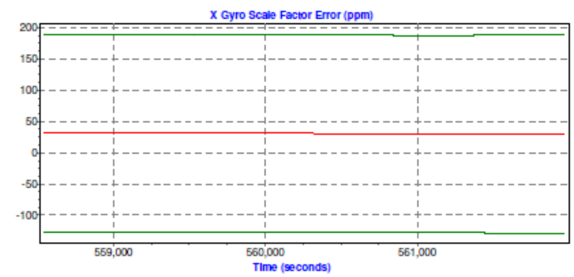

Y Accelerometer Scale Factor Error (ppm)
Time (seconds)

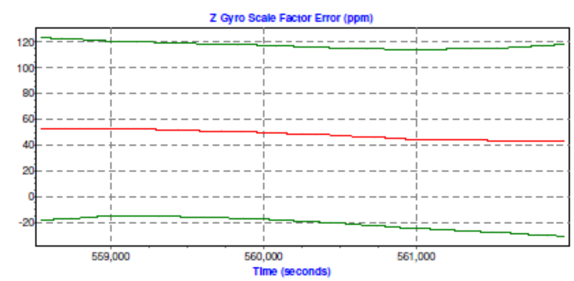

Z Accelerometer Scale Factor Error (ppm)
Time (seconds)







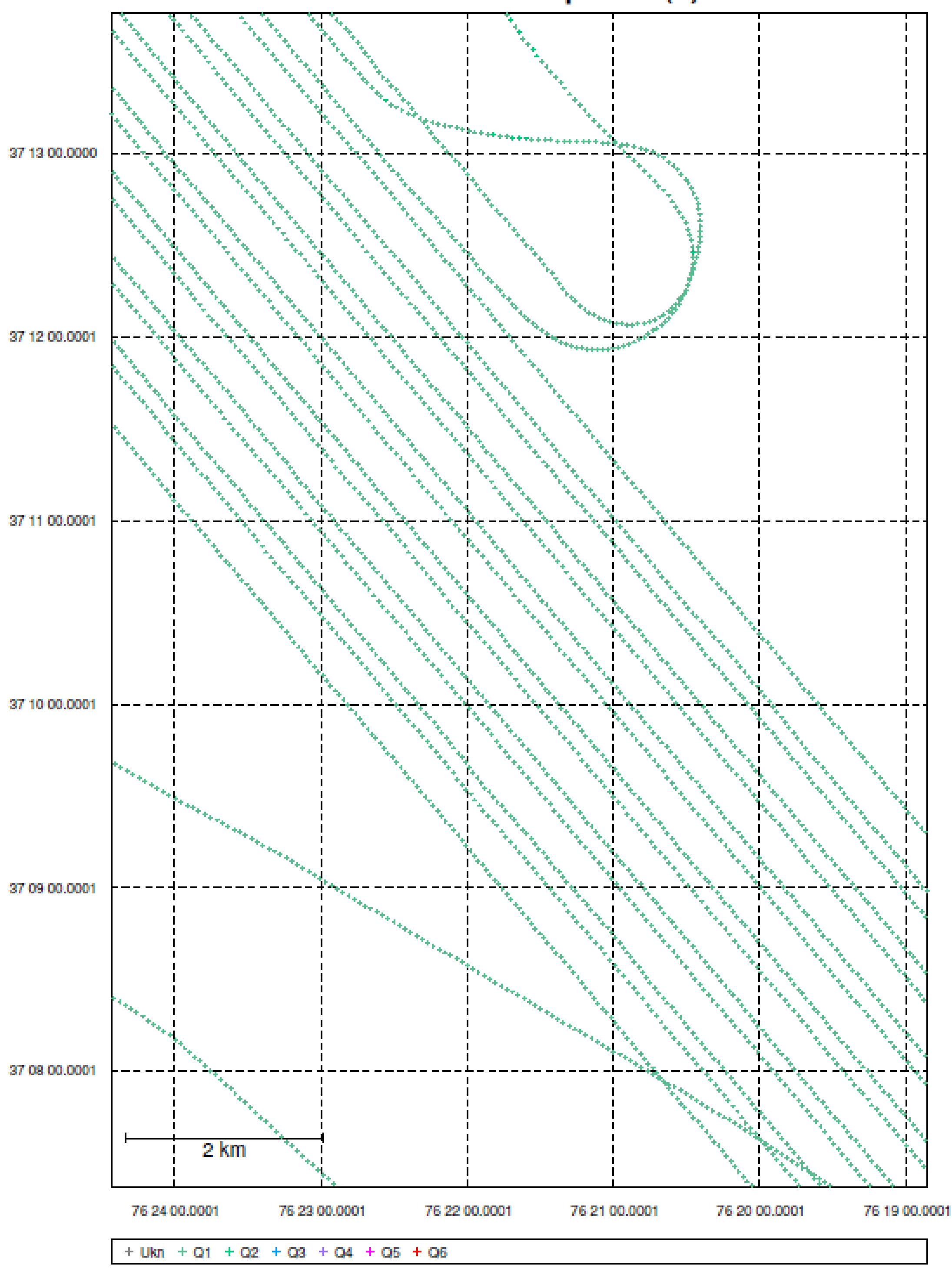


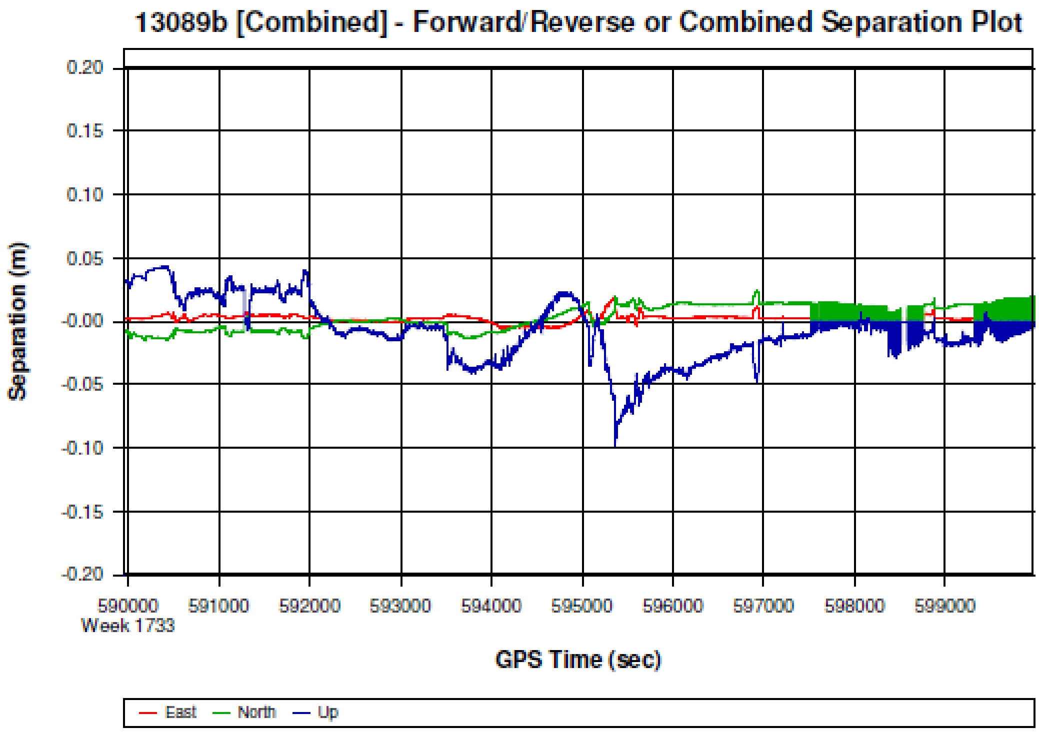


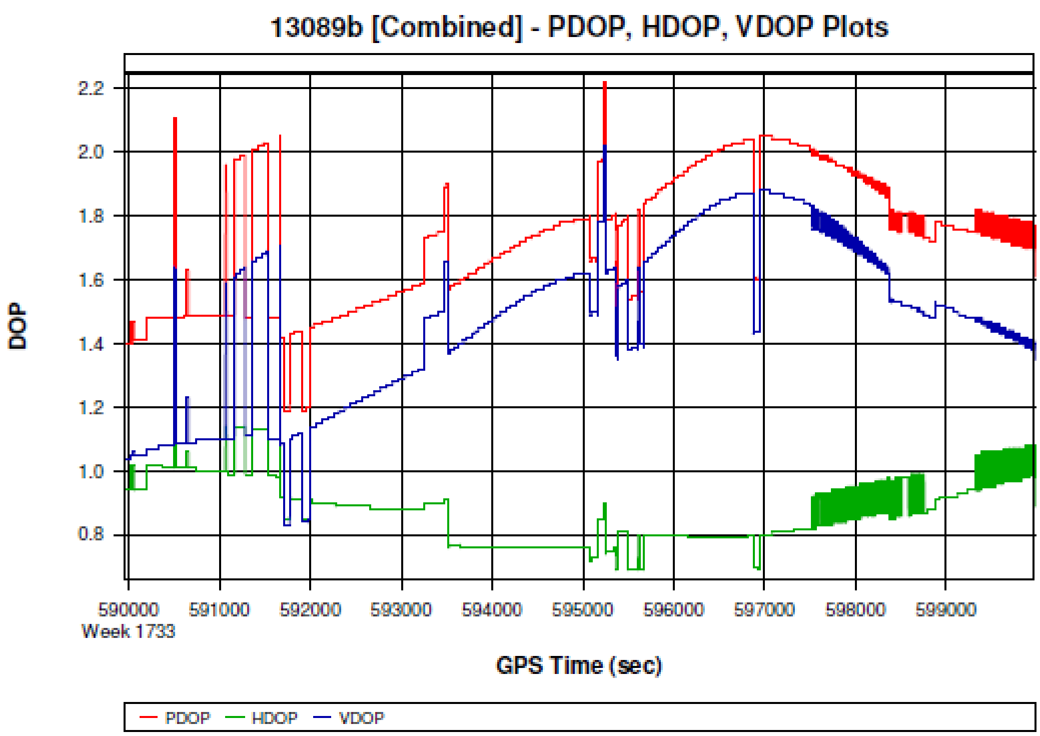
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: D:\Projects\Dewberry\Va\Norfolk_2013\13089a\pos2\GPS\89a2.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 162207
No processed position: 158711
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0247 (m)
C/A Code: 1.35 (m)
L1 Doppler: 0.019 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.016 (m)
North: 0.024 (m)
Height: 0.055 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (3489 occurances):
East: 0.011 (m)
North: 0.019 (m)
Height: 0.023 (m)

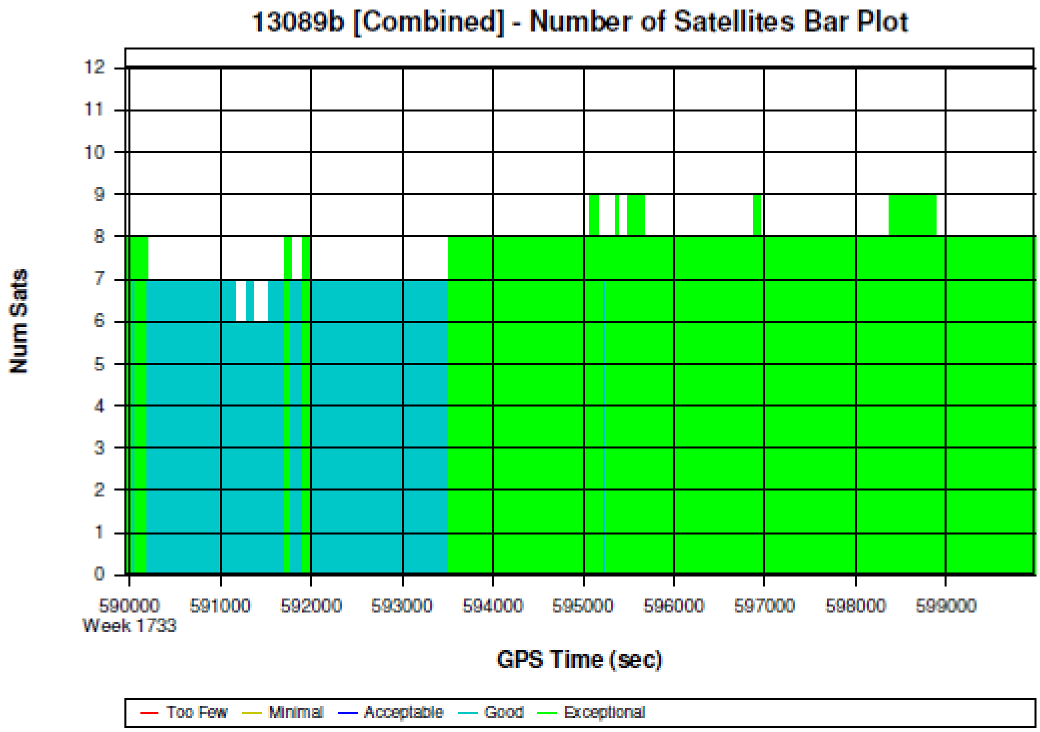
Quality Number Percentages:
Q 1: 99.5 %
Q 2: 0.5 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 60.5 %
0.10 - 0.30 m: 39.5 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 39.4 %
Baseline Distances:
Maximum: 30.893 (km)
Minimum: 1.152 (km)
Average: 13.398 (km)
First Epoch: 28.490 (km)
Last Epoch: 25.968 (km)

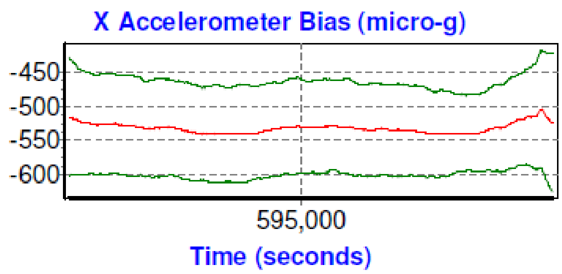
Combined - Map Run (2)

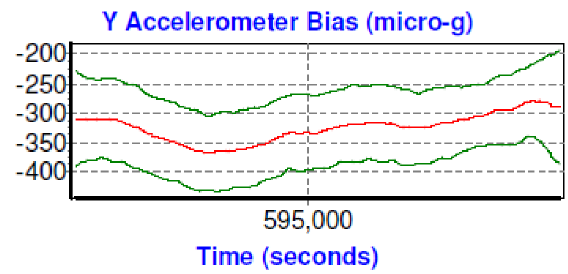


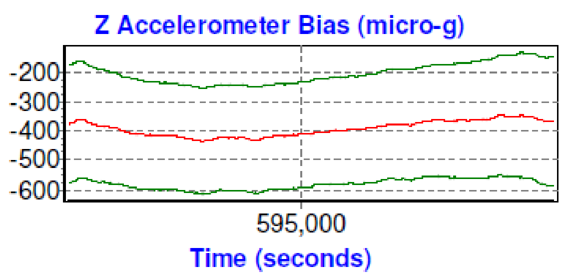

13089b [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
-0.20
590000
Week 1733
591000
592000
593000
594000
595000
596000
597000
598000
599000
GPS Time (sec)
East
North
Up

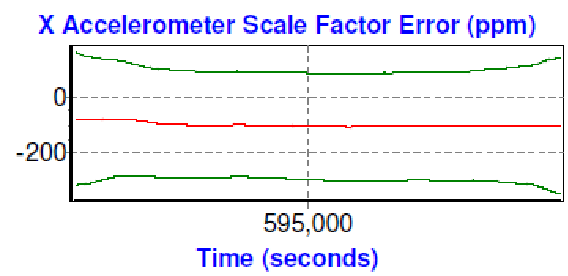

13089b [Combined] - PDOP, HDOP, VDOP Plots
DOP
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
590000
Week 1733
591000
592000
593000
594000
595000
596000
597000
598000
599000
GPS Time (sec)
PDOP
HDOP
VDOP

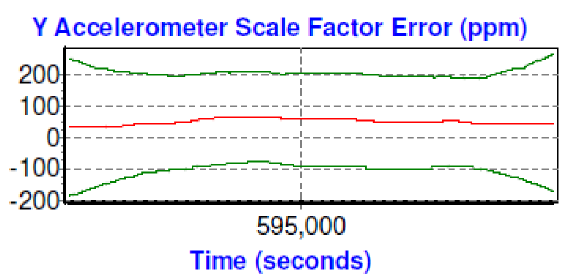

13089b [Combined] - Number of Satellites Bar Plot
Num Sats
0
1
2
3
4
5
6
7
8
9
10
11
12
590000
Week 1733
591000
592000
593000
594000
595000
596000
597000
598000
599000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

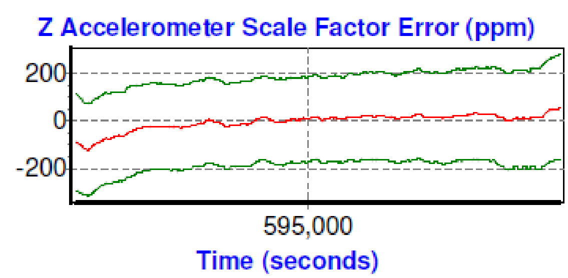

X Accelerometer Bias (micro-g)
-450
-500
-550
-600
595,000
Time (seconds)

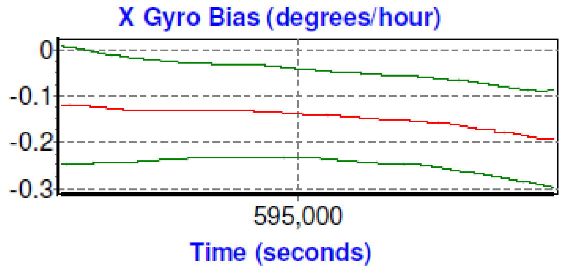

Y Accelerometer Bias (micro-g)
-200
-250
-300
-350
-400
595,000
Time (seconds)

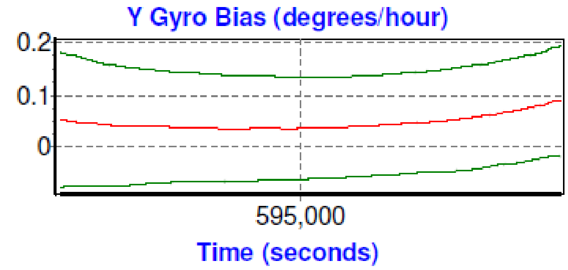

Z Accelerometer Bias (micro-g)
-200
-300
-400
-500
-600
595,000
Time (seconds)

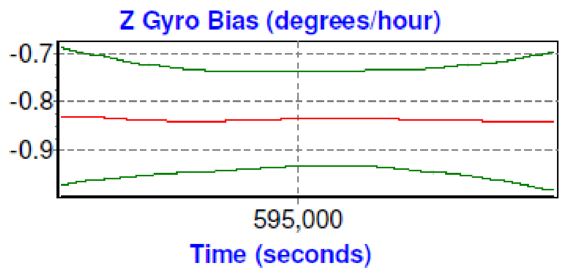

X Accelerometer Scale Factor Error (ppm)
0
-200
595,000
Time (seconds)

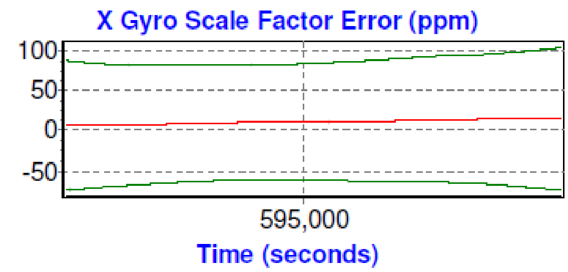

Y Accelerometer Scale Factor Error (ppm)
200
100
0
-100
-200
595,000
Time (seconds)

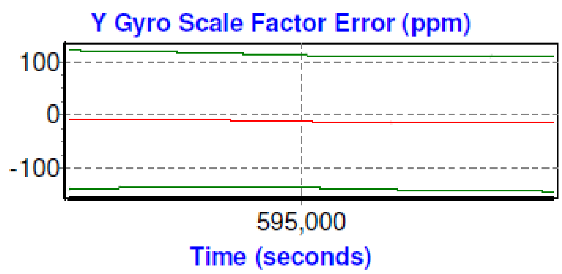

Z Accelerometer Scale Factor Error (ppm)
200
0
-200
595,000
Time (seconds)

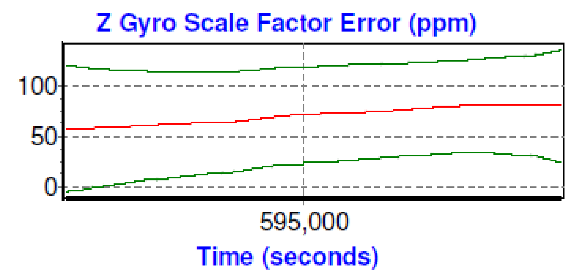

X Gyro Bias (degrees/hour)
0
-0.1
-0.2
-0.3
595,000
Time (seconds)


Y Gyro Bias (degrees/hour)
0.2
0.1
0
595,000
Time (seconds)

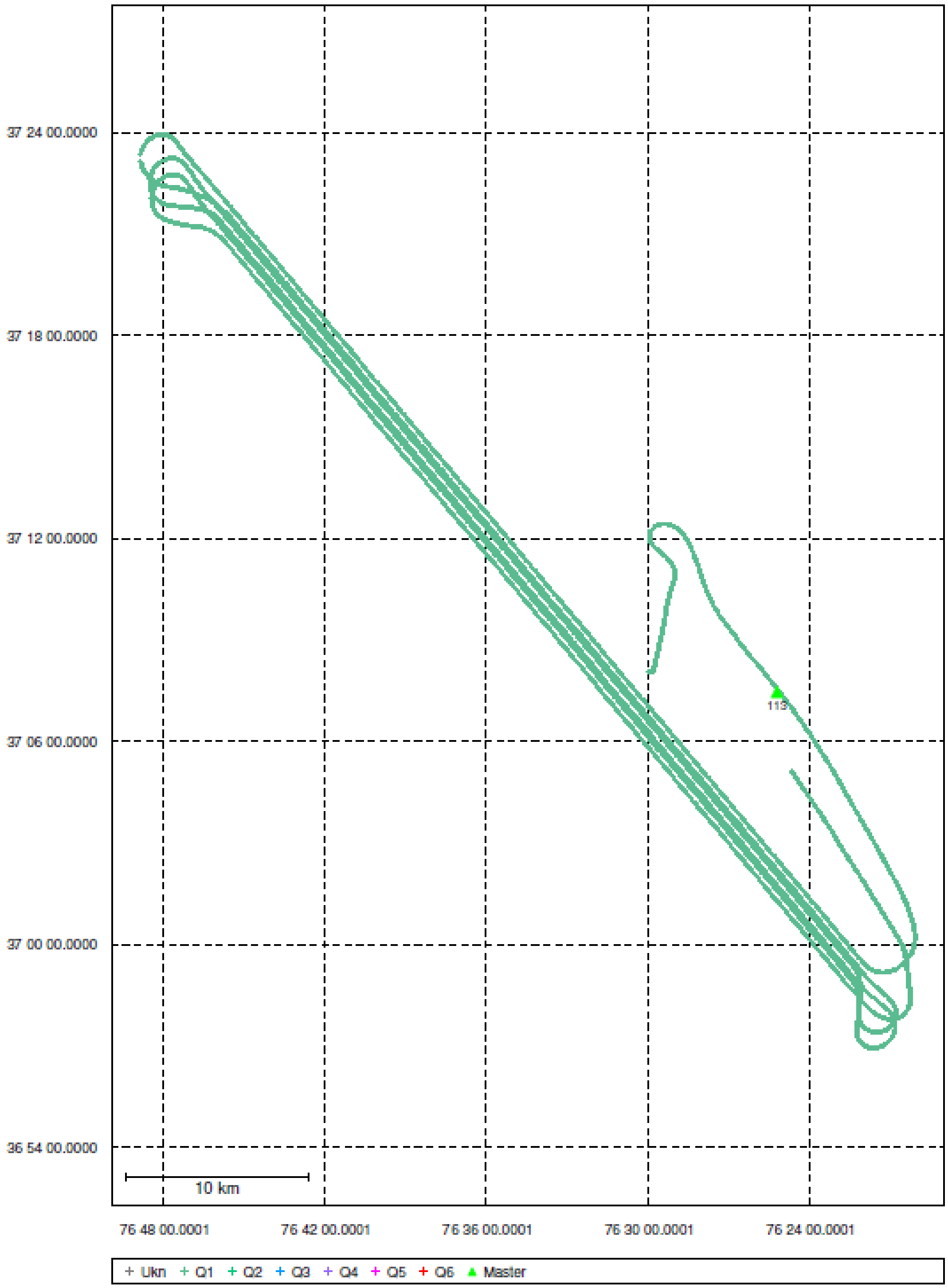

Z Gyro Bias (degrees/hour)
-0.7
-0.8
-0.9
595,000
Time (seconds)

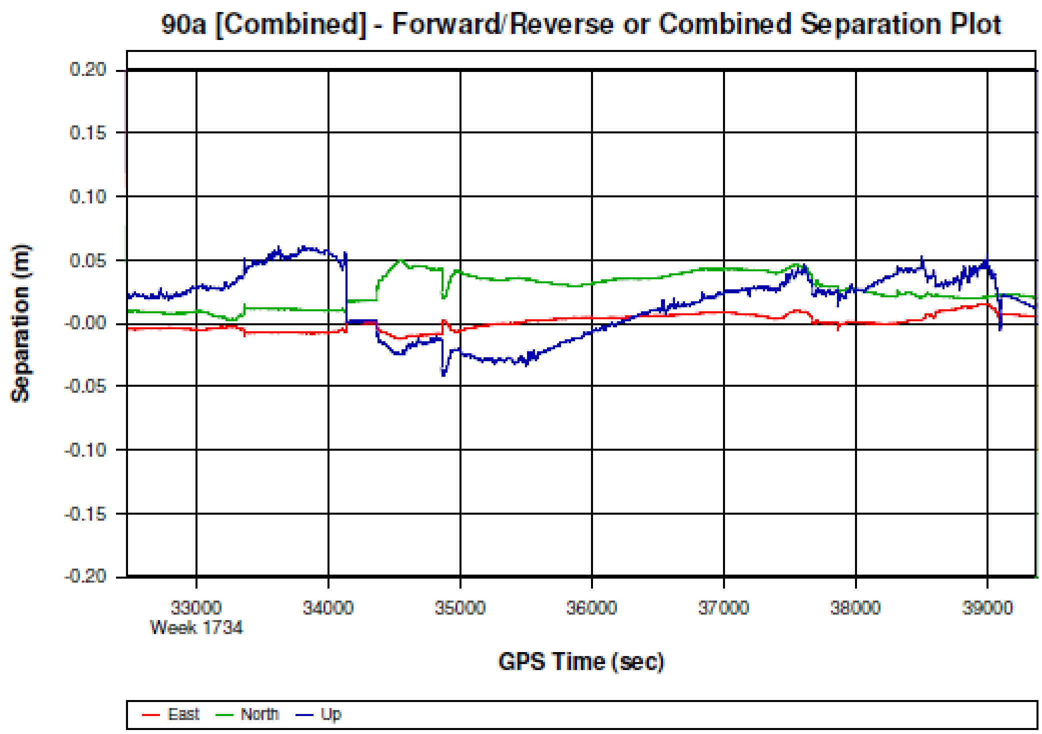

X Gyro Scale Factor Error (ppm)
100
50
0
-50
595,000
Time (seconds)

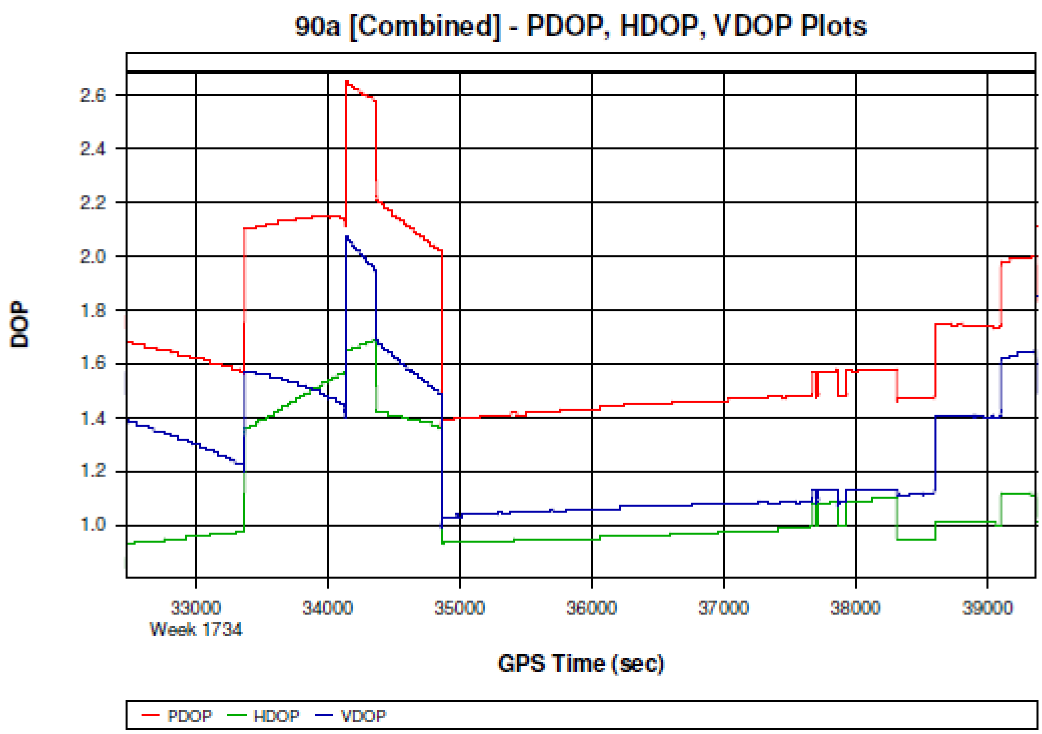

Y Gyro Scale Factor Error (ppm)
100
0
-100
595,000
Time (seconds)

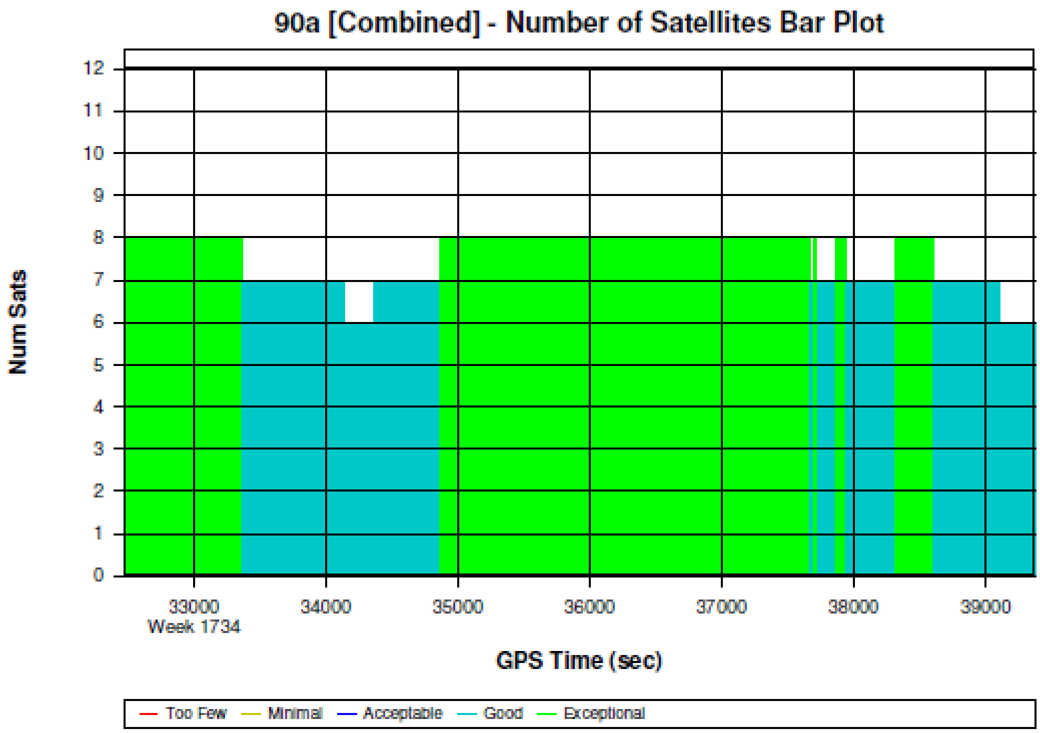

Z Gyro Scale Factor Error (ppm)
100
50
0
595,000
Time (seconds)

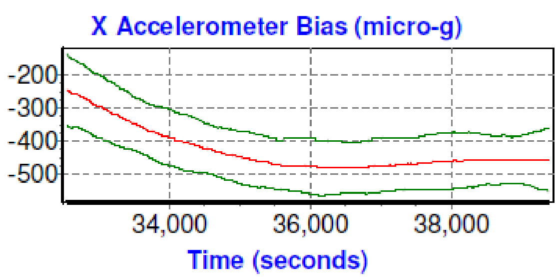
Combined - Map Run (8)

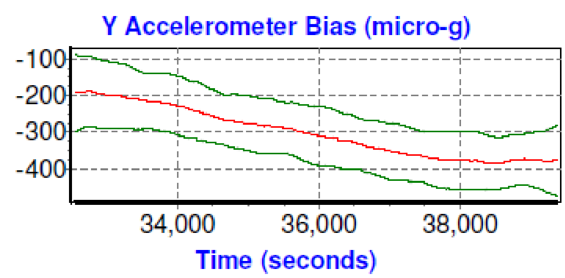


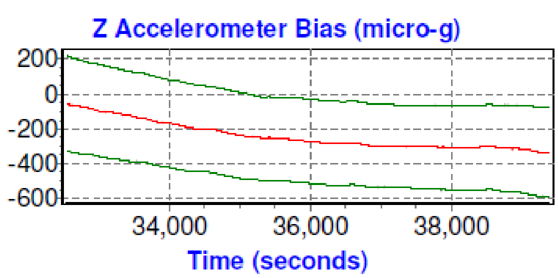

90a [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
-0.20
33000
Week 1734
34000
35000
36000
37000
38000
39000
GPS Time (sec)
East
North
Up

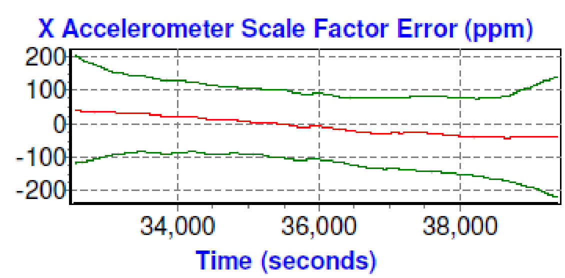

90a [Combined] - PDOP, HDOP, VDOP Plots
DOP
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
33000
Week 1734
34000
35000
36000
37000
38000
39000
GPS Time (sec)
PDOP
HDOP
VDOP

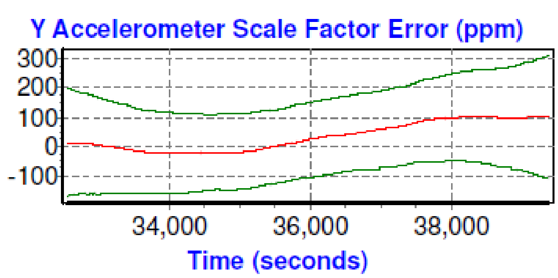

90a [Combined] - Number of Satellites Bar Plot
Num Sats
12
11
10
9
8
7
6
5
4
3
2
1
0
33000
Week 1734
34000
35000
36000
37000
38000
39000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

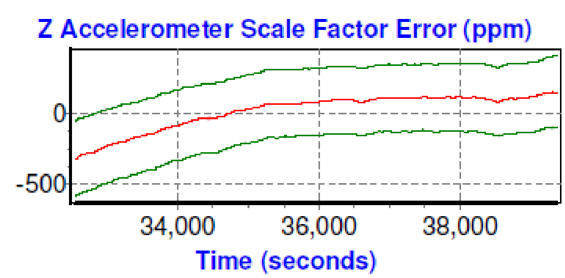

X Accelerometer Bias (micro-g)
-200
-300
-400
-500
34,000
36,000
38,000
Time (seconds)

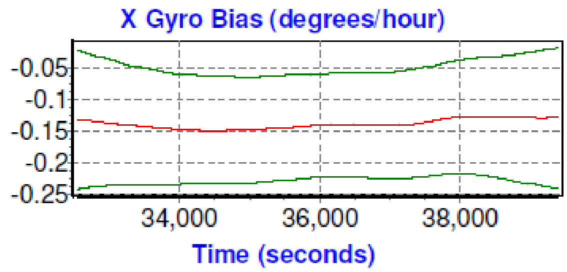

Y Accelerometer Bias (micro-g)
-100
-200
-300
-400
34,000
36,000
38,000
Time (seconds)

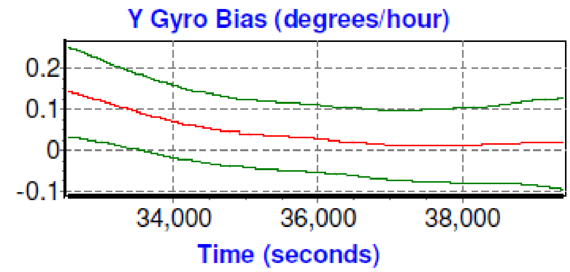

Z Accelerometer Bias (micro-g)
200
0
-200
-400
-600
34,000
36,000
38,000
Time (seconds)

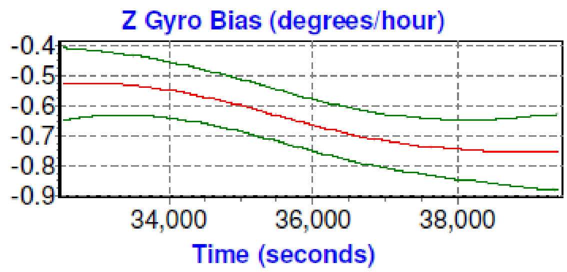

X Accelerometer Scale Factor Error (ppm)
200
100
0
-100
-200
34,000
36,000
38,000
Time (seconds)

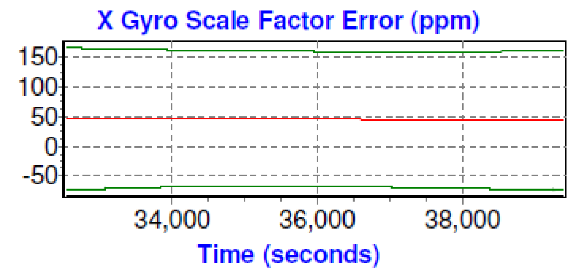

Y Accelerometer Scale Factor Error (ppm)
300
200
100
0
-100
34,000
36,000
38,000
Time (seconds)

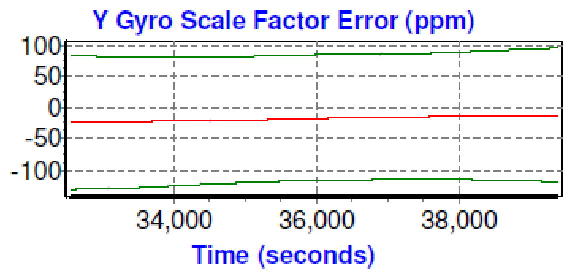

Z Accelerometer Scale Factor Error (ppm)
0
-500
34,000
36,000
38,000
Time (seconds)

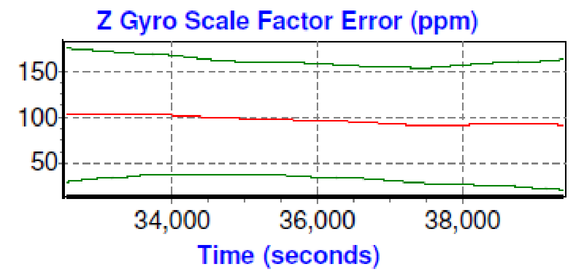

X Gyro Bias (degrees/hour)
-0.05
-0.1
-0.15
-0.2
-0.25
34,000
36,000
38,000
Time (seconds)

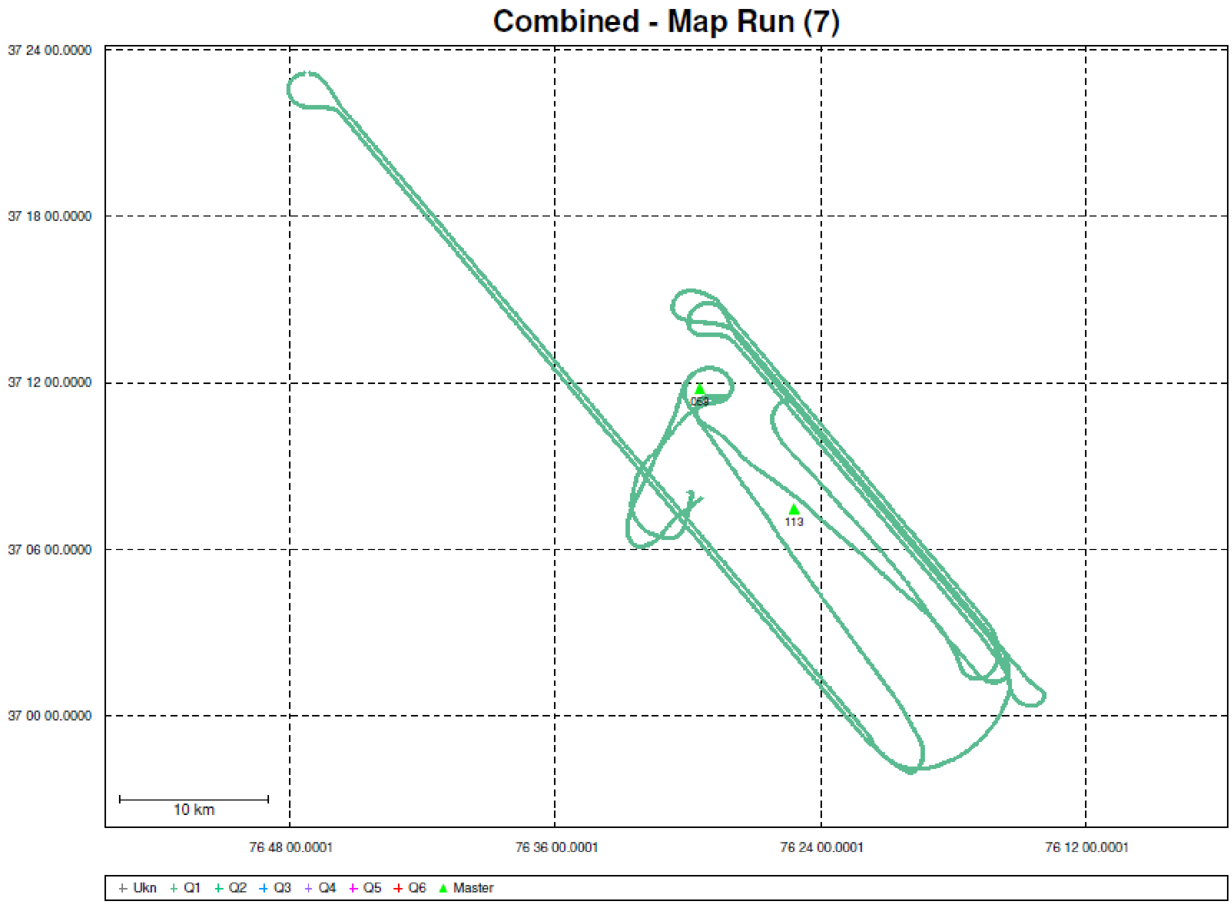

Y Gyro Bias (degrees/hour)
0.2
0.1
0
-0.1
34,000
36,000
38,000
Time (seconds)

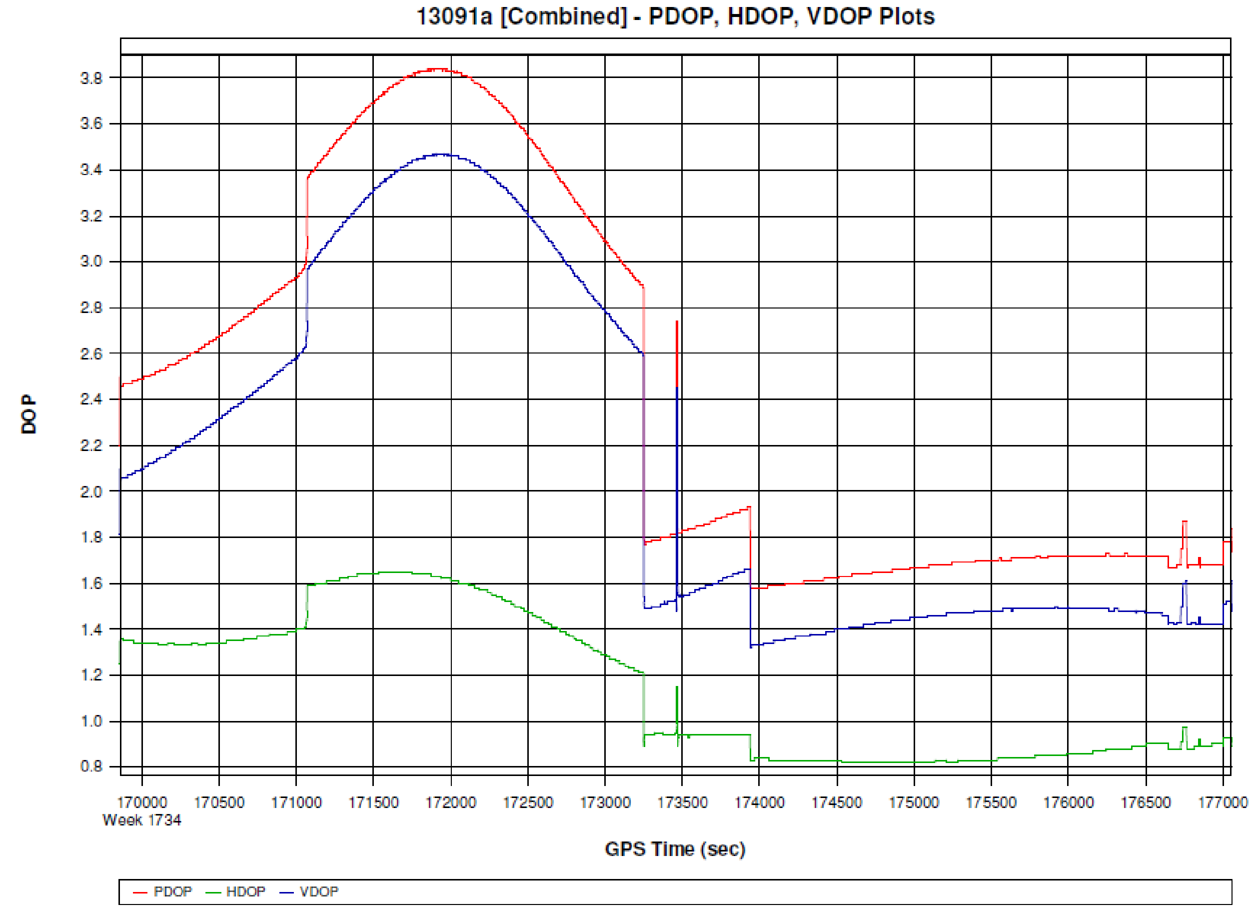

Z Gyro Bias (degrees/hour)
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
34,000
36,000
38,000
Time (seconds)

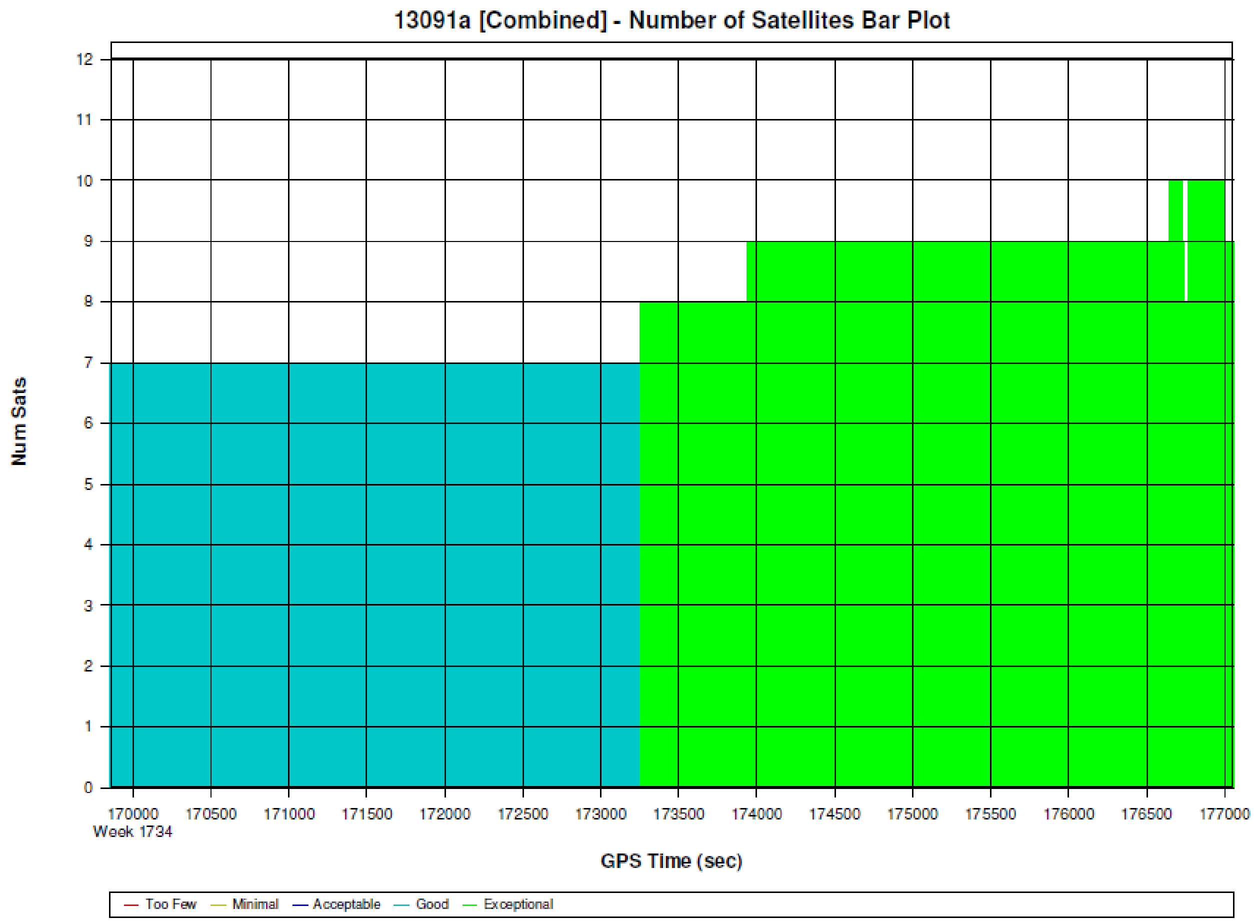

X Gyro Scale Factor Error (ppm)
150
100
50
0
-50
34,000
36,000
38,000
Time (seconds)

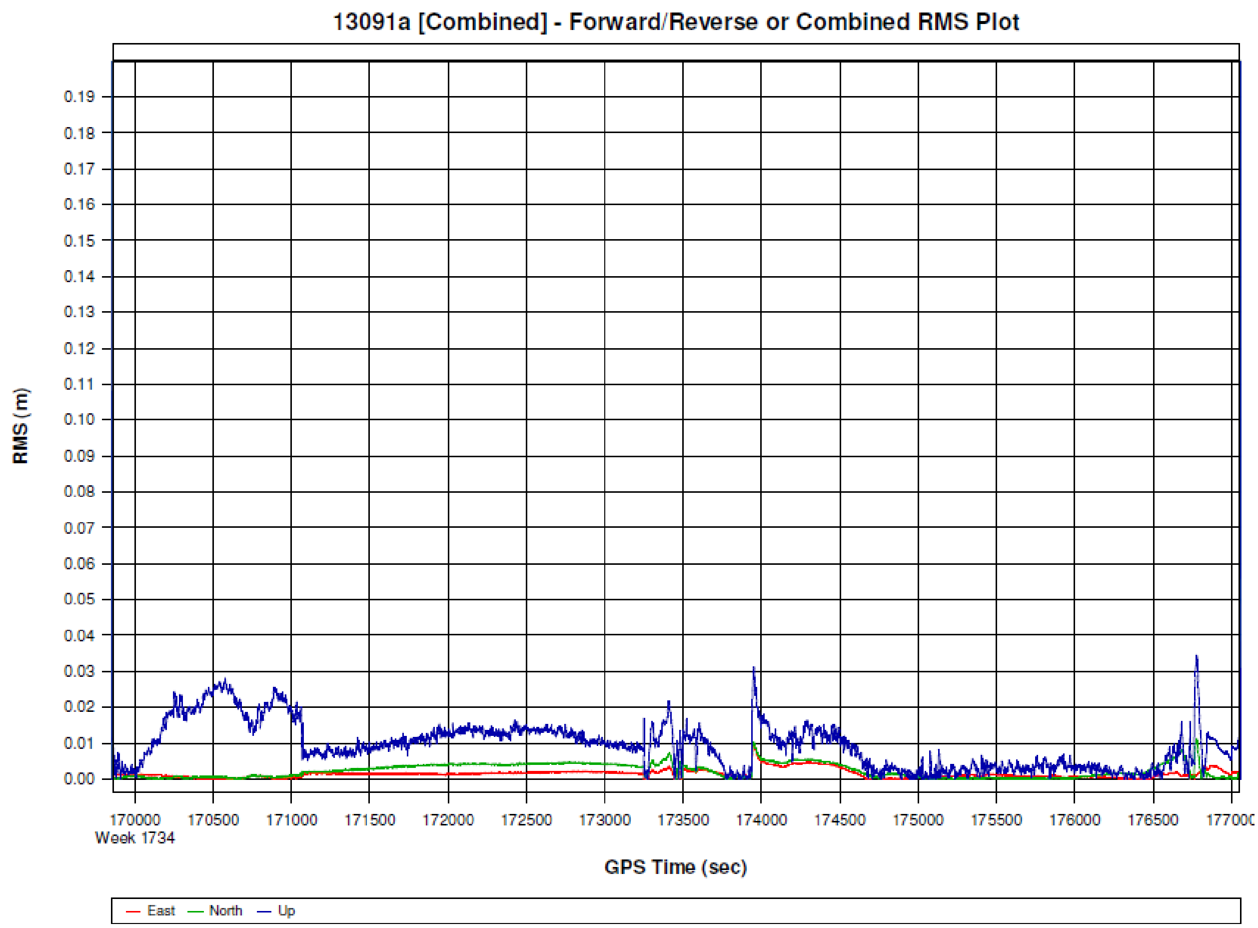

Y Gyro Scale Factor Error (ppm)
100
50
0
-50
-100
34,000
36,000
38,000
Time (seconds)


Z Gyro Scale Factor Error (ppm)
150
100
50
34,000
36,000
38,000
Time (seconds)


Combined - Map Run (7)
37 24 00.0000
37 18 00.0000
37 12 00.0000
37 06 00.0000
37 00 00.0000
76 48 00.0001
76 36 00.0001
76 24 00.0001
76 12 00.0001
10 km
113
Ukn
Q1
Q2
Q3
Q4
Q5
Q6
Master

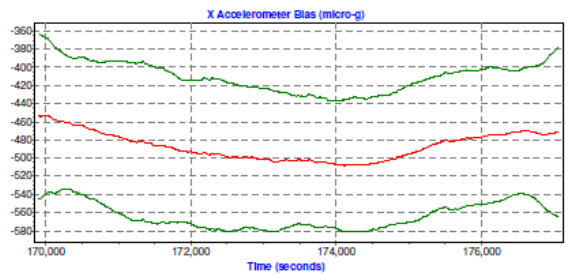

13091a [Combined] - PDOP, HDOP, VDOP Plots
DOP
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
170000
Week 1734
170500
171000
171500
172000
172500
173000
173500
174000
174500
175000
175500
176000
176500
177000
GPS Time (sec)
PDOP
HDOP
VDOP

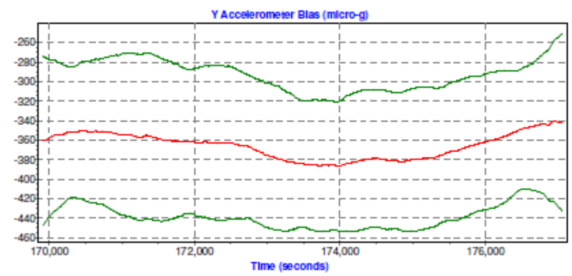

13091a [Combined] - Number of Satellites Bar Plot
Num Sats
0
1
2
3
4
5
6
7
8
9
10
11
12
170000
Week 1734
170500
171000
171500
172000
172500
173000
173500
174000
174500
175000
175500
176000
176500
177000
GPS Time (sec)
Too Few
Minimal
Acceptable
Good
Exceptional

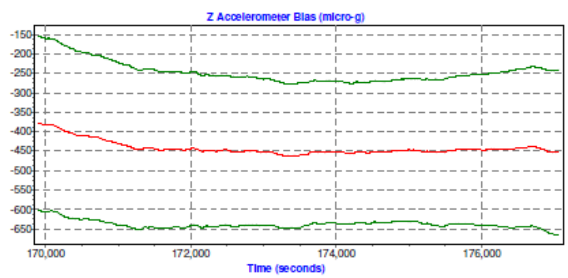


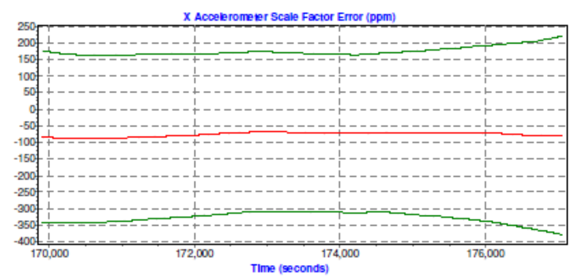
Processing Summary Information
Program: POSGPS
Version: 4.30.3108
Project: C:\Projects\VA\Norfolk\13091a\pos\GPS\13091a.gnv
Solution Type: Combined Fwd/Rev
Number of Epochs:
Total in GPB file: 78684
No processed position: 71478
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0
Measurement RMS Values:
L1 Phase: 0.0192 (m)
C/A Code: 0.97 (m)
L1 Doppler: 0.020 (m/s)
Fwd/Rev Separation RMS Values:
East: 0.004 (m)
North: 0.009 (m)
Height: 0.017 (m)
Fwd/Rev Sep. RMS for 25%-75% weighting (7200 occurances):
East: 0.003 (m)
North: 0.004 (m)

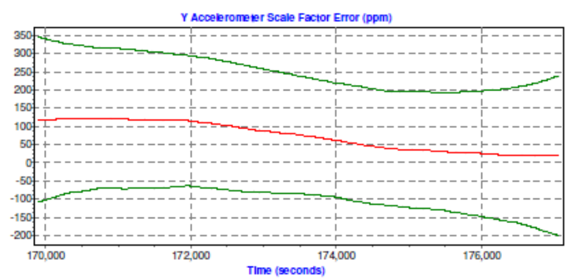
Height: 0.016 (m)
Quality Number Percentages:
Q 1: 100.0 %
Q 2: 0.0 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %
Position Standard Deviation Percentages:
0.00 - 0.10 m: 77.8 %
0.10 - 0.30 m: 22.2 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %
Percentages of epochs with DD_DOP over 10.00:
DOP over Tol: 10.0 %
Baseline Distances:
Maximum: 34.181 (km)
Minimum: 1.104 (km)
Average: 14.521 (km)
First Epoch: 7.294 (km)
Last Epoch: 6.917 (km)

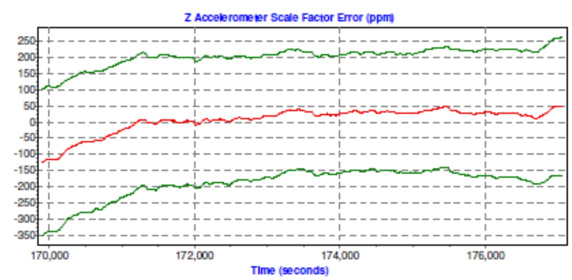


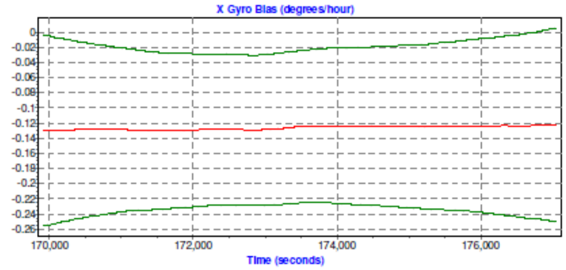


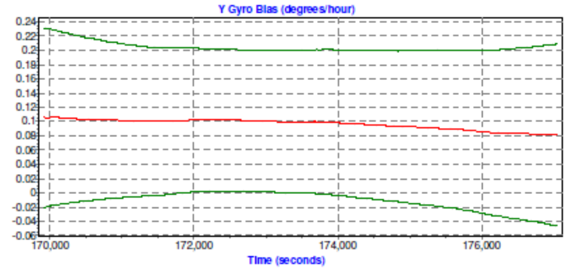


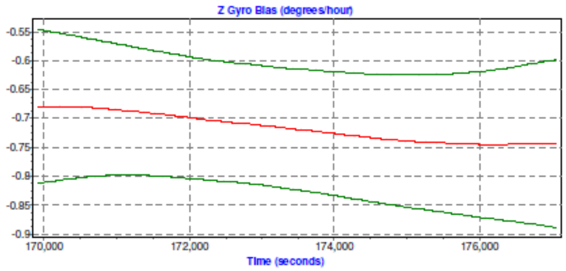


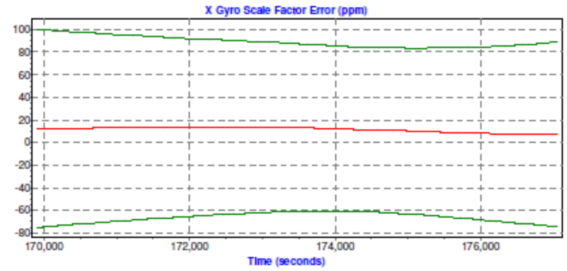


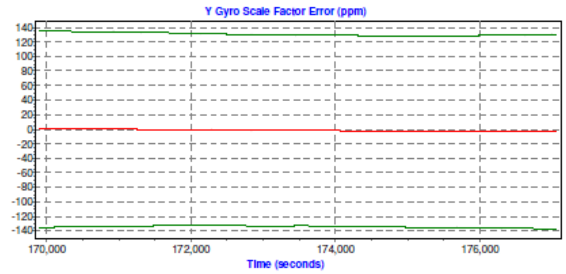


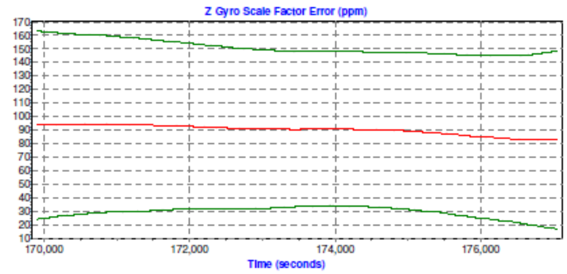

X Gyro Bias (degrees/hour)
Time (seconds)


Y Gyro Bias (degrees/hour)
Time (seconds)


Z Gyro Bias (degrees/hour)
Time (seconds)


X Gyro Scale Factor Error (ppm)
Time (seconds)


Y Gyro Scale Factor Error (ppm)
Time (seconds)


Z Gyro Scale Factor Error (ppm)
Time (seconds)

THE ATLANTIC GROUP

Output Results for JD13087_1

Figure 1: Trajectory Map

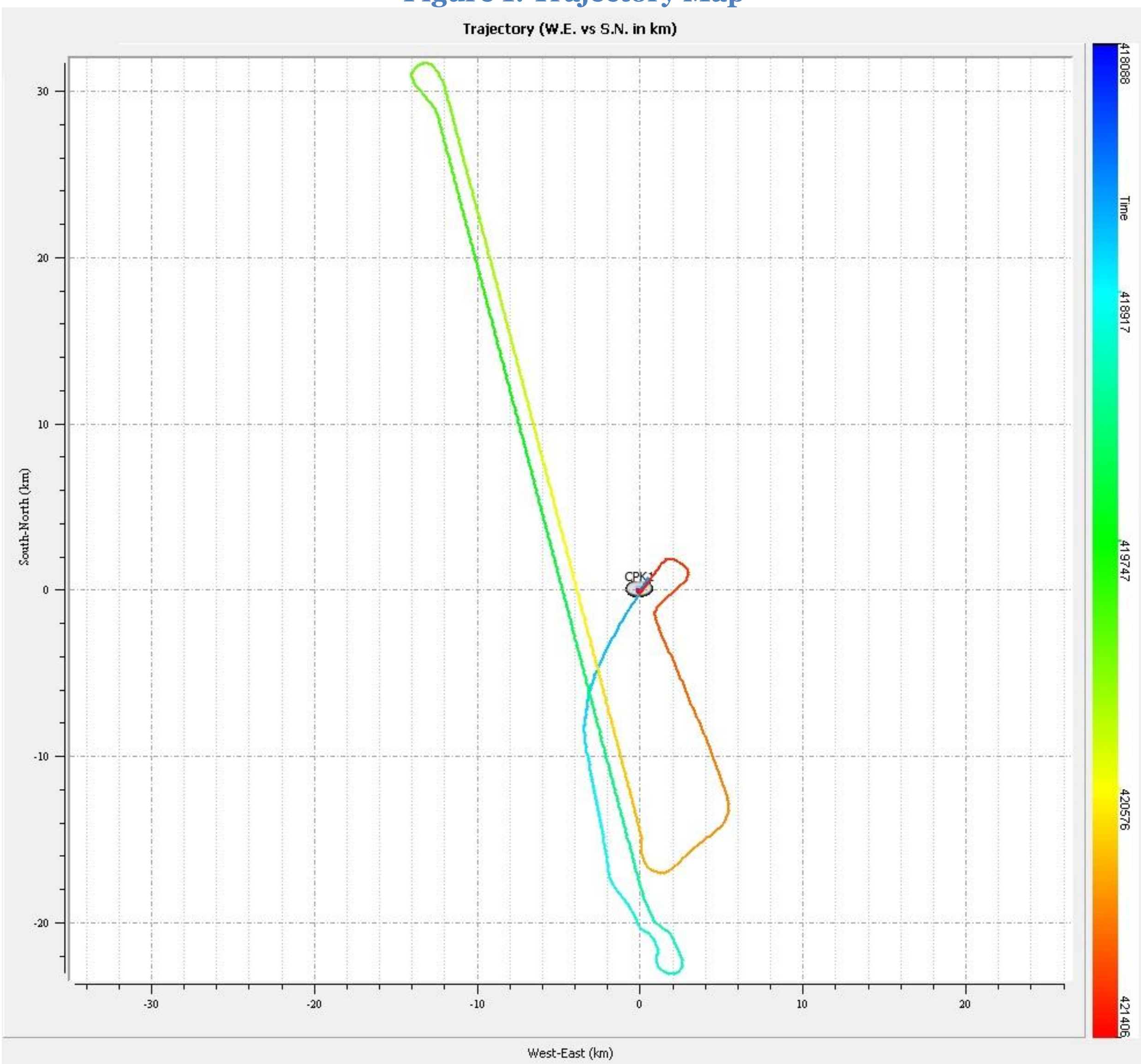


Figure 2: Position and Standard Deviation

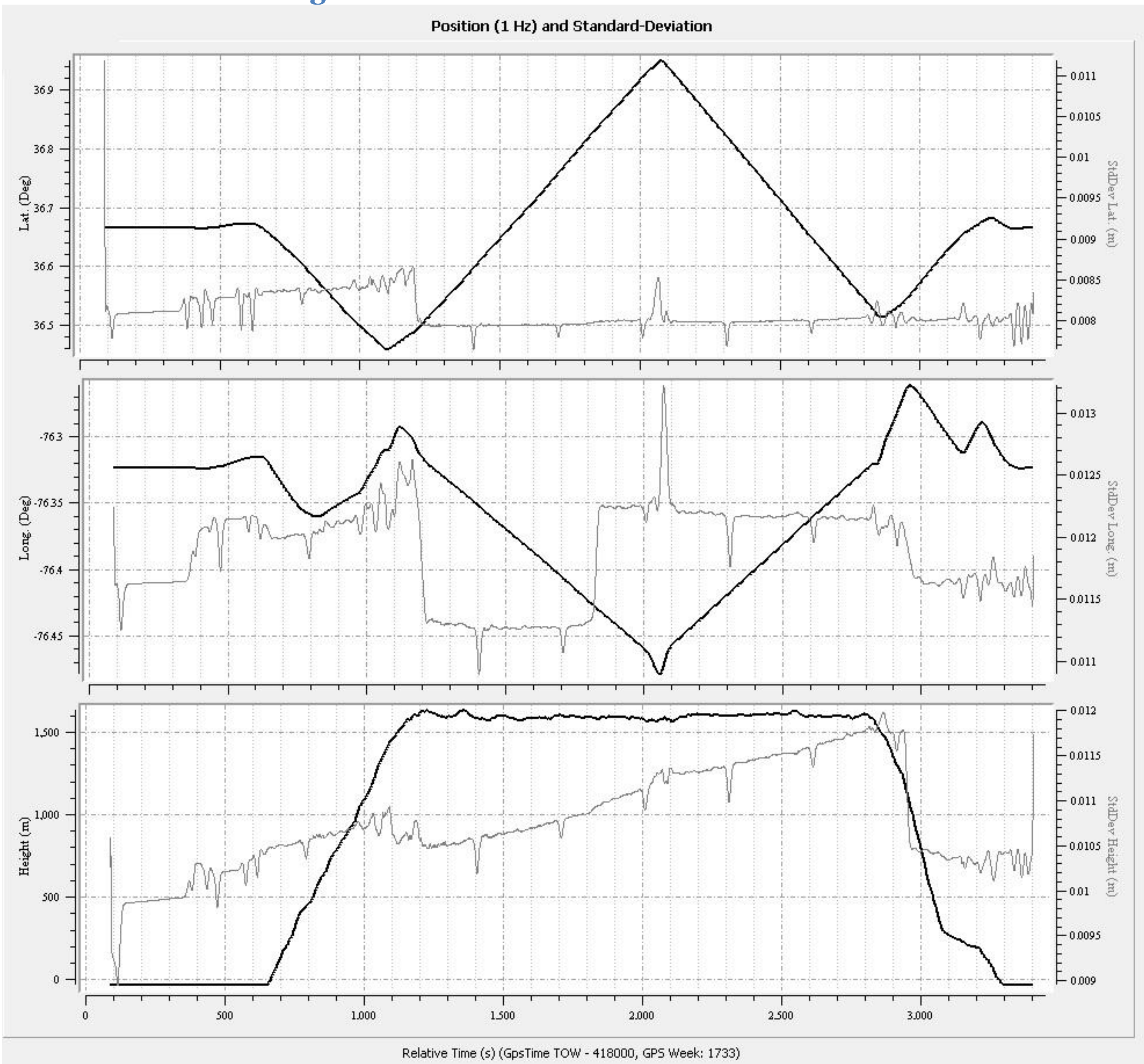


Figure 3: Velocity and Standard Deviation

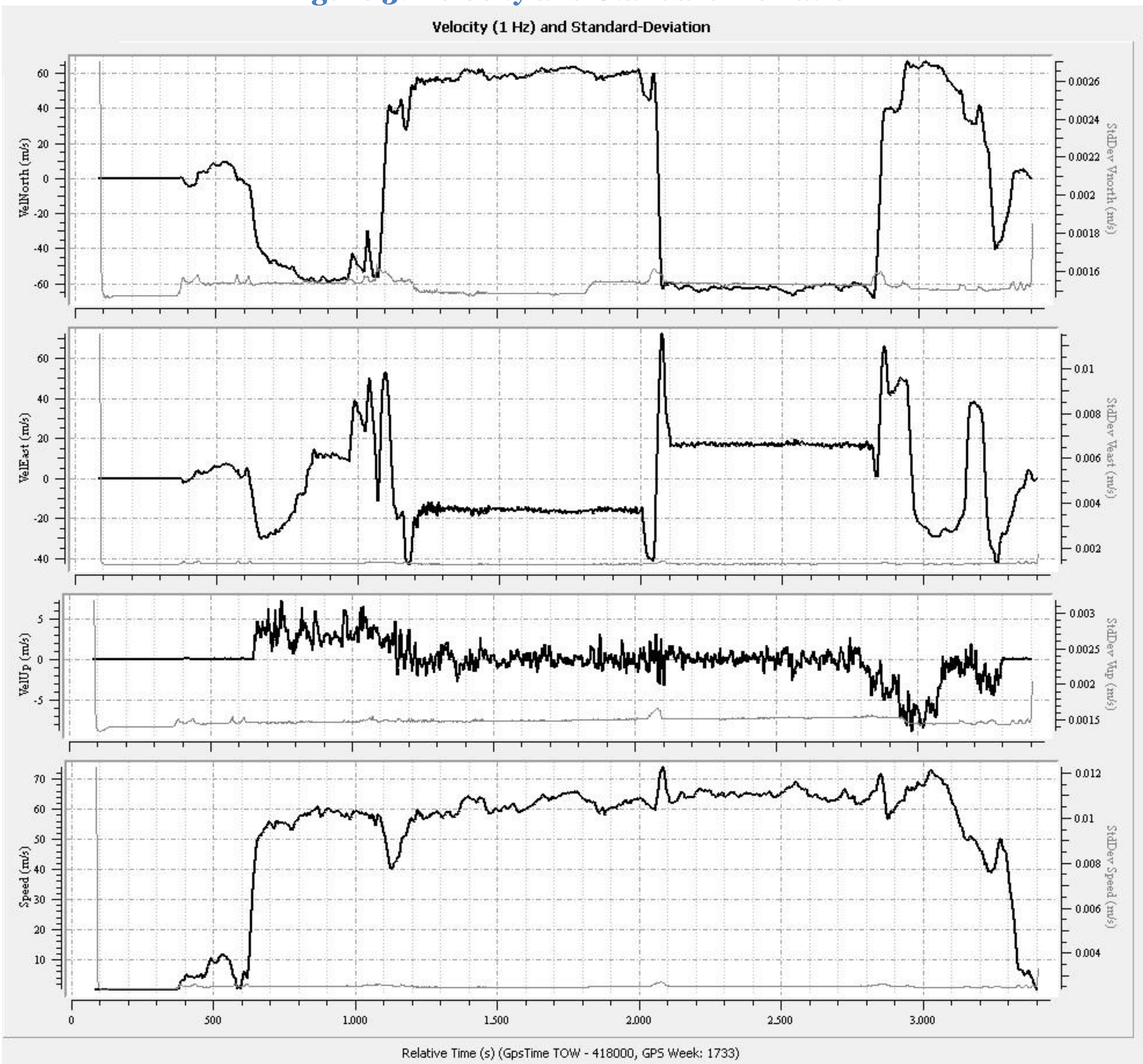


Figure 4: Forward/Reverse or Combined Separation Plot

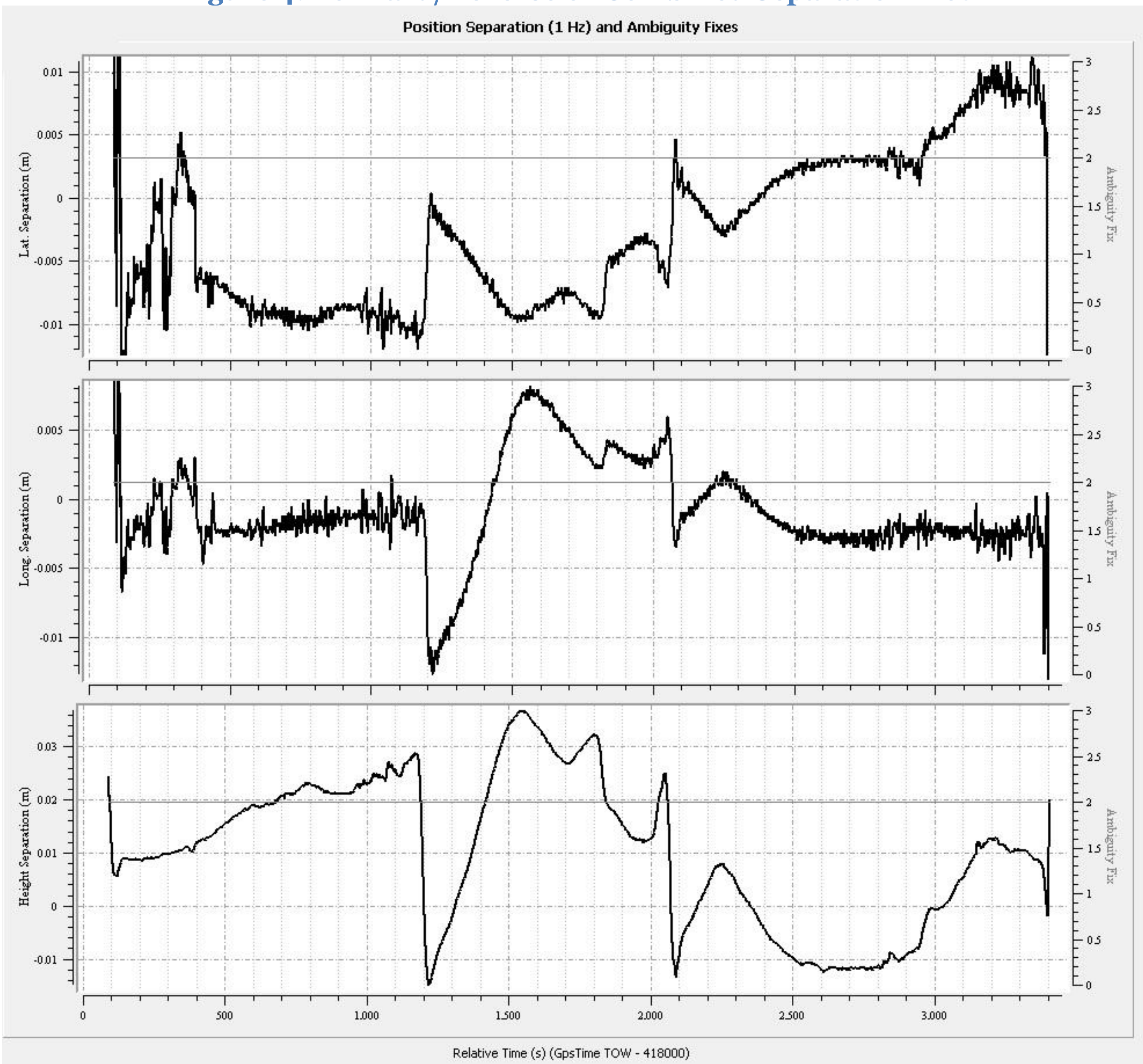


Figure 5: Attitude and Standard Deviation

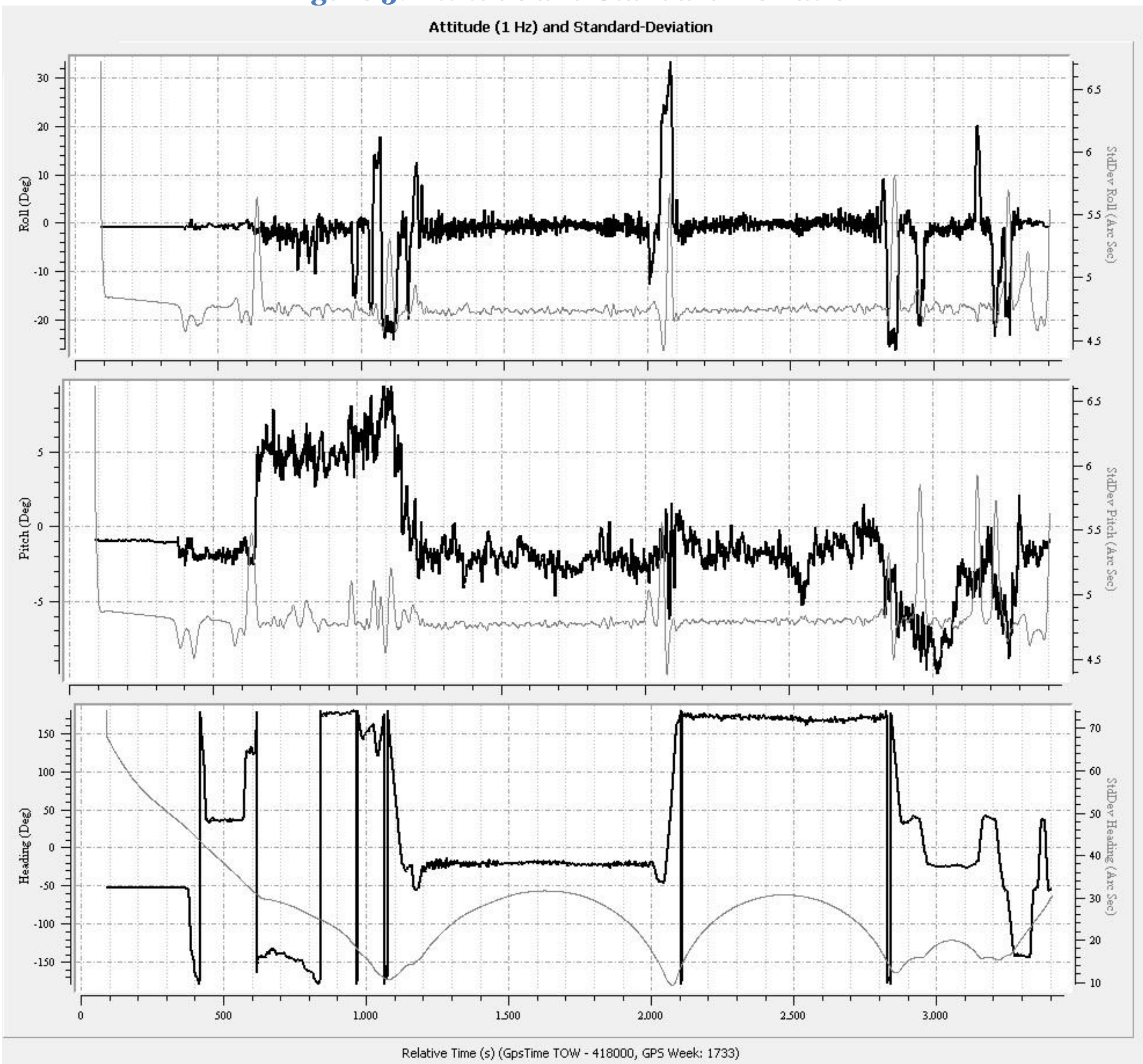


Figure 6: Position Accuracy and PDOP

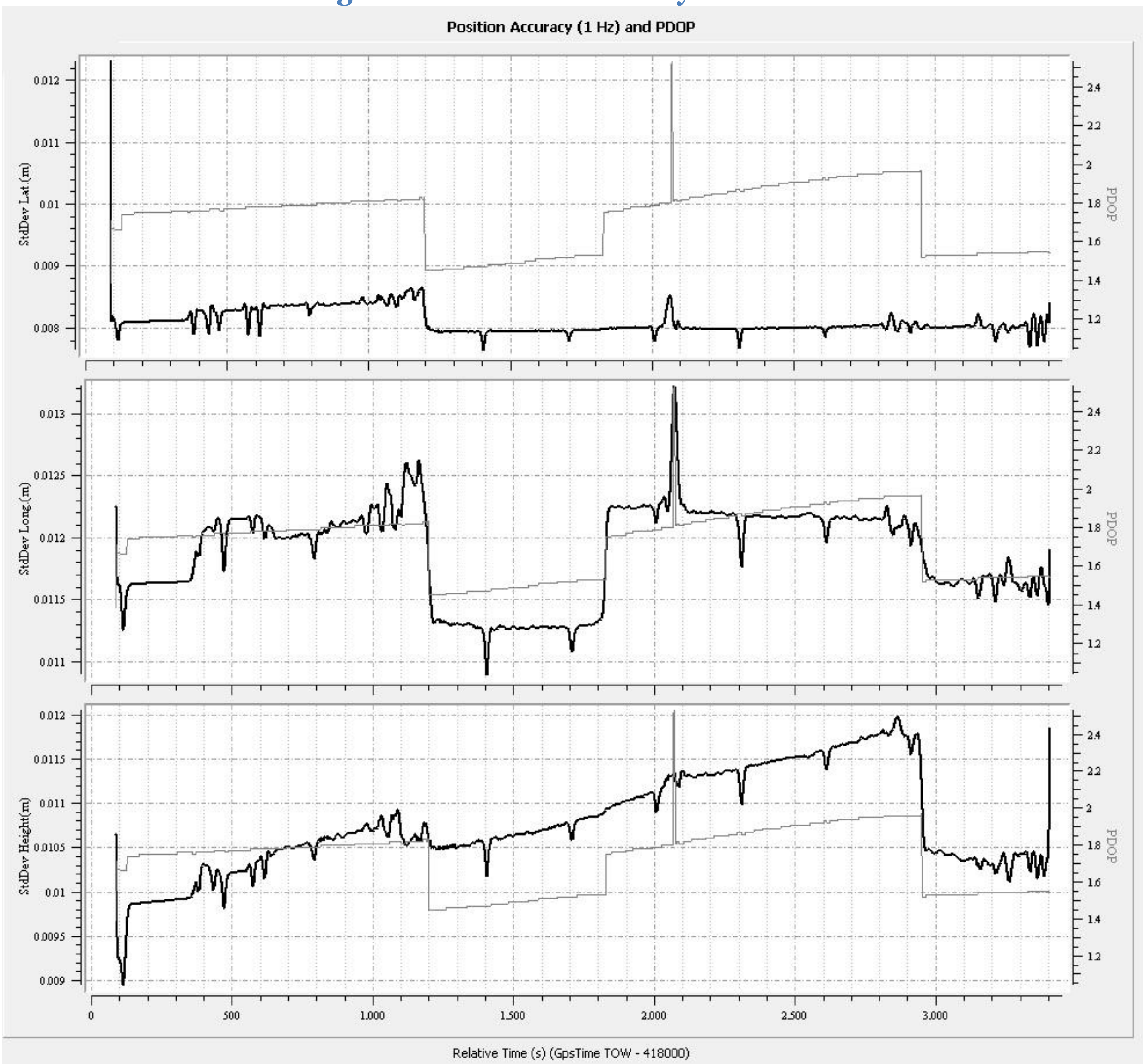


Figure 7: Accelerometer Bias Estimation

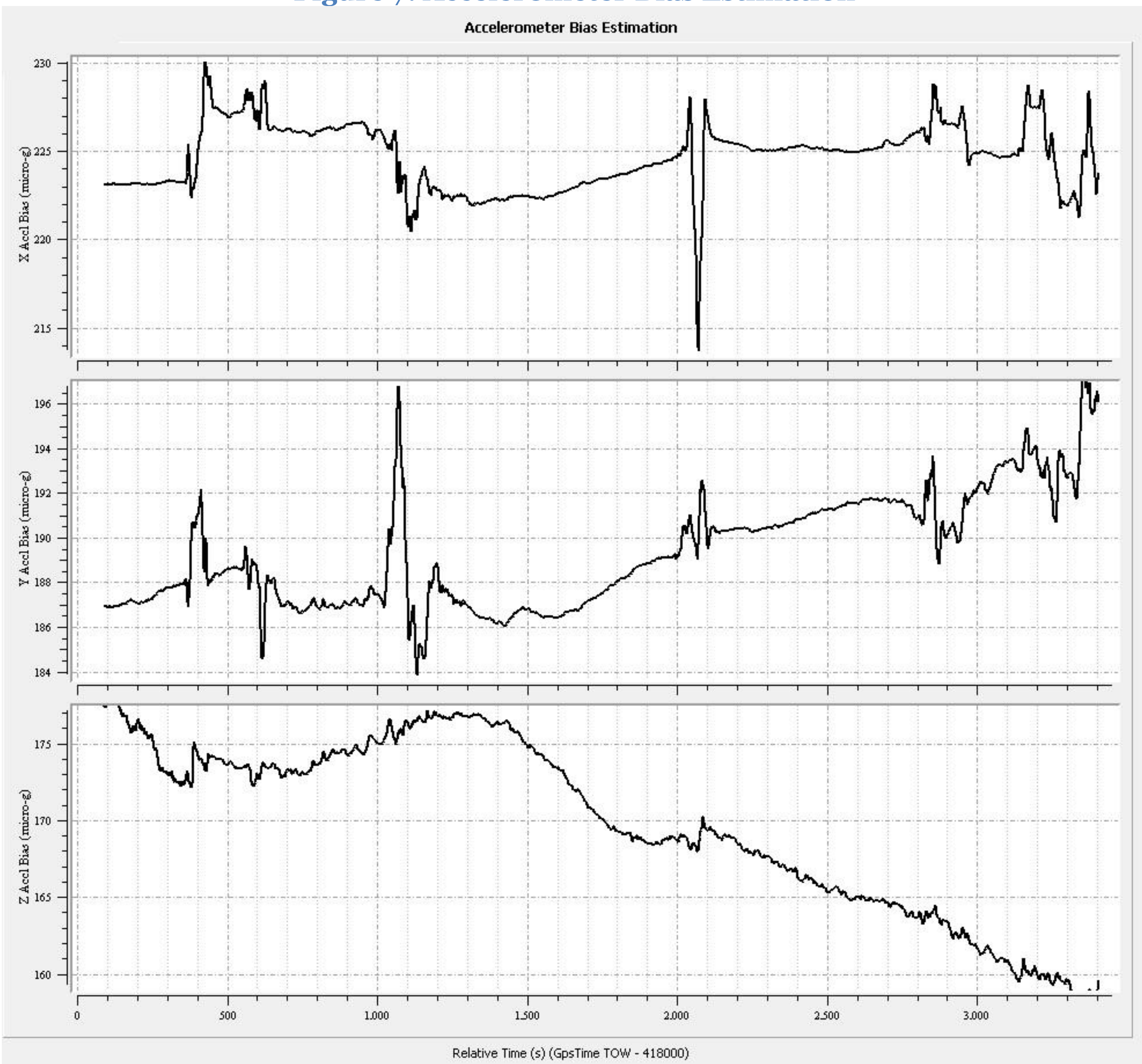


Figure 8: Kalman Filter Residuals and Position Accuracy

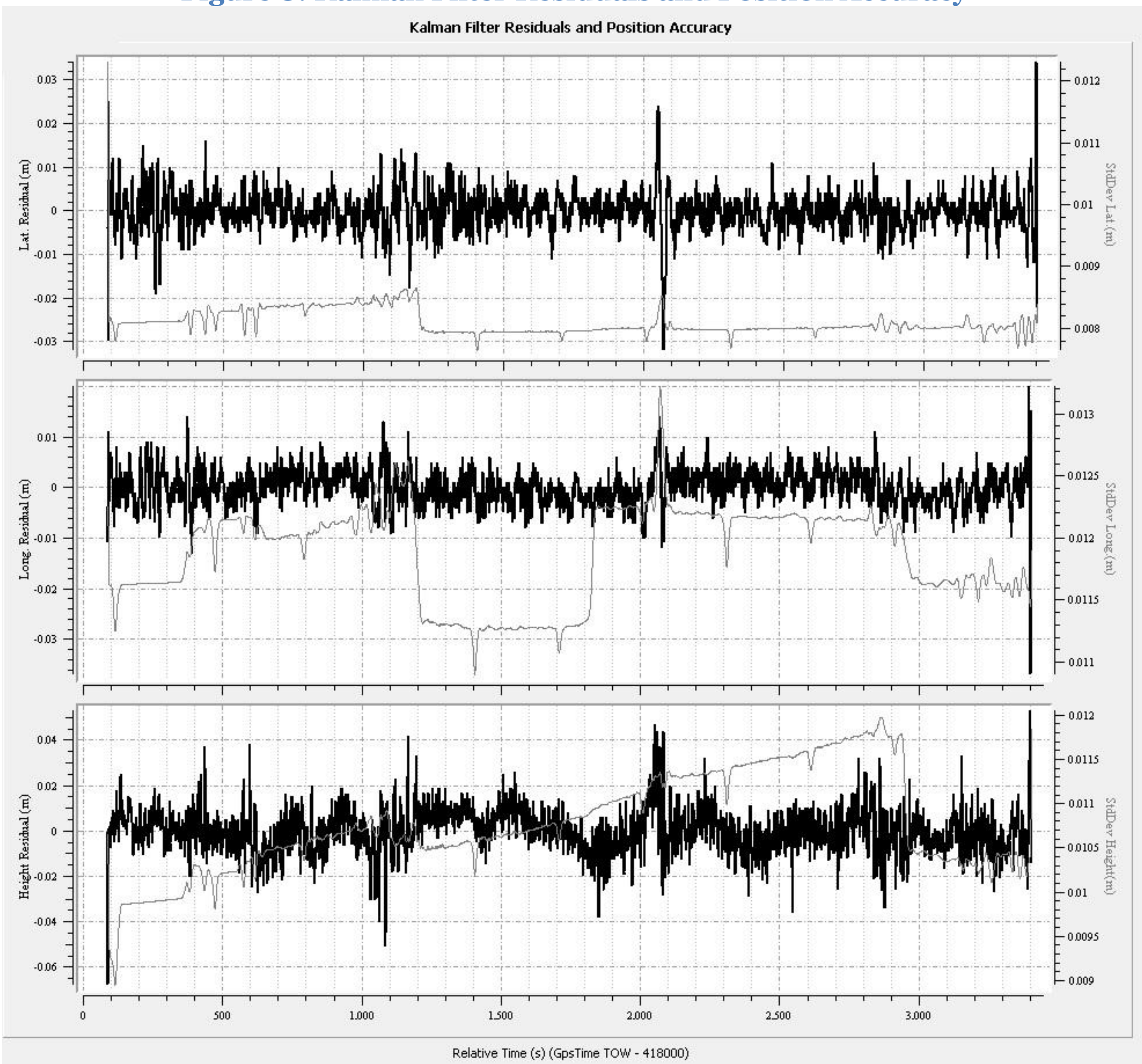
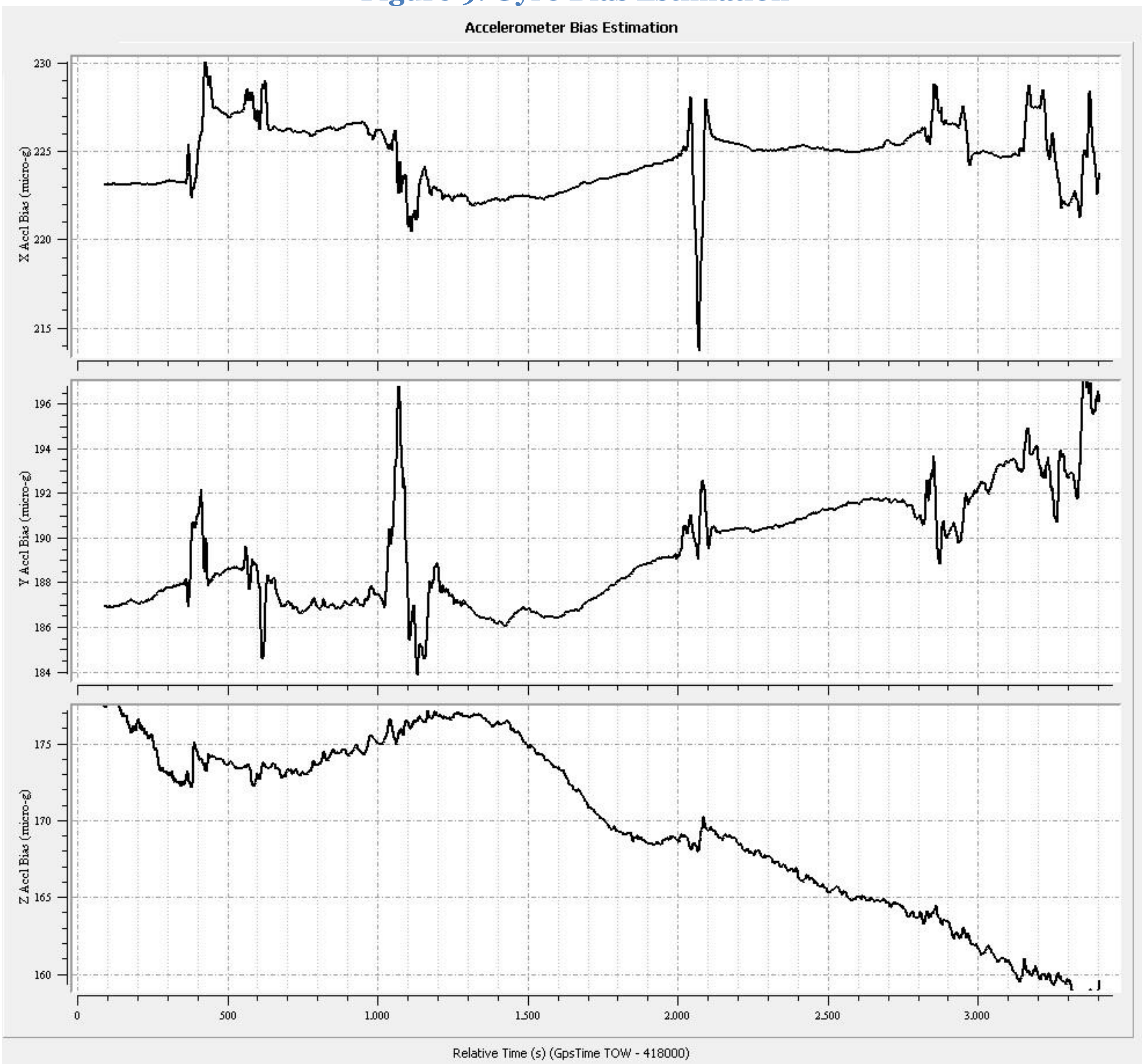


Figure 9: Gyro Bias Estimation



Output Result for JD13088_1

Figure 1: Trajectory Map

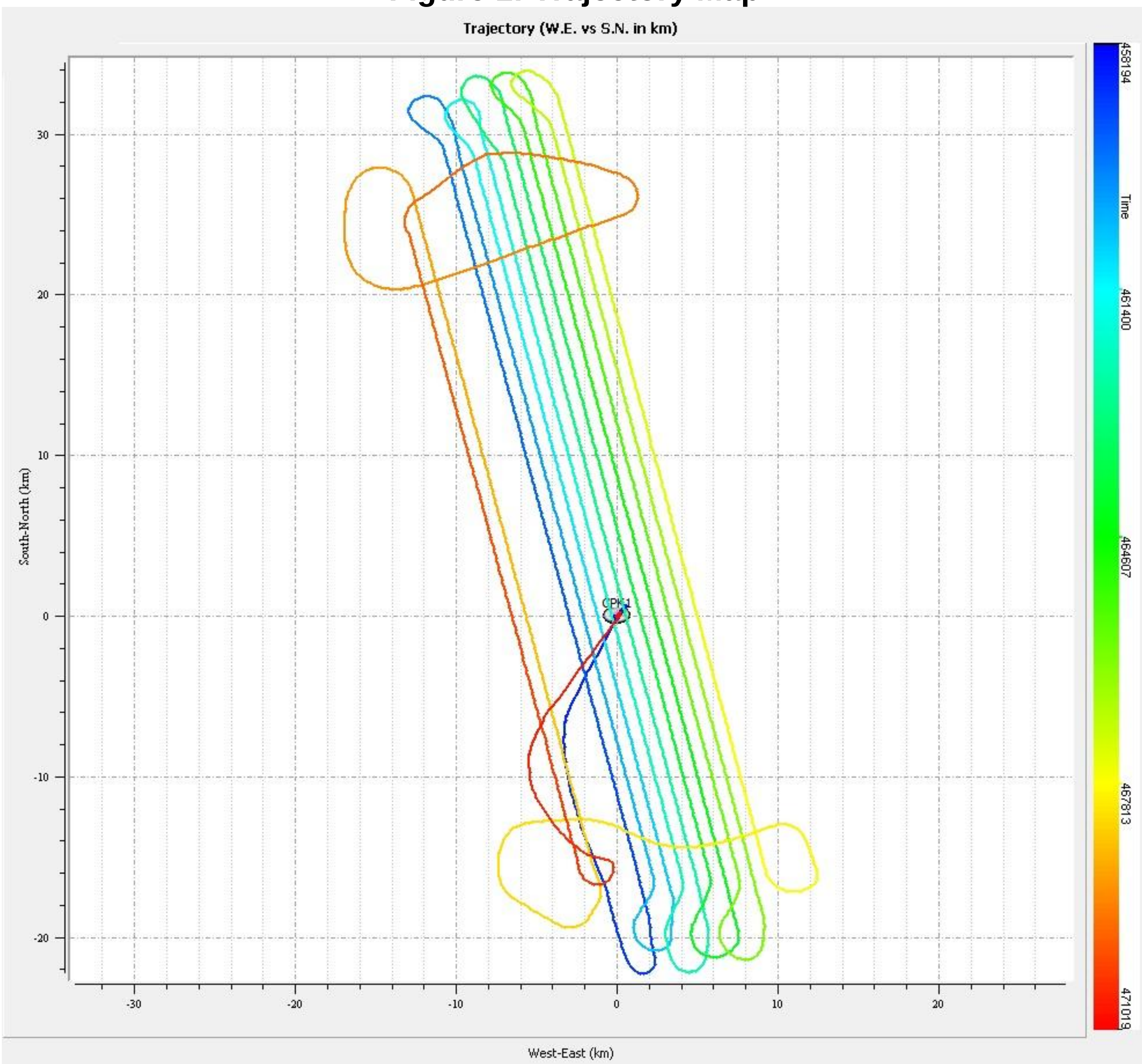


Figure 2: Position and Standard Deviation

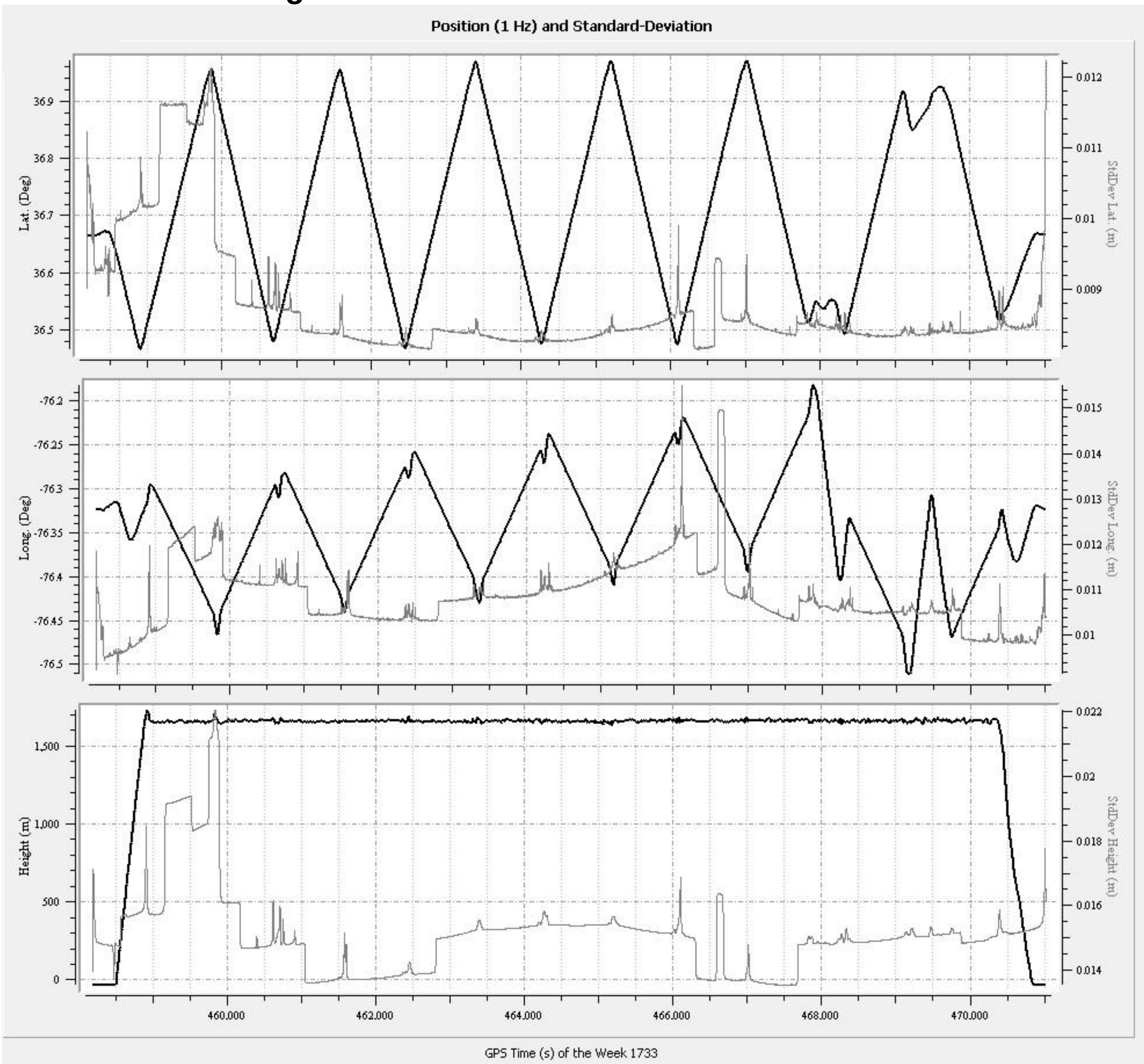


Figure 3: Velocity and Standard Deviation

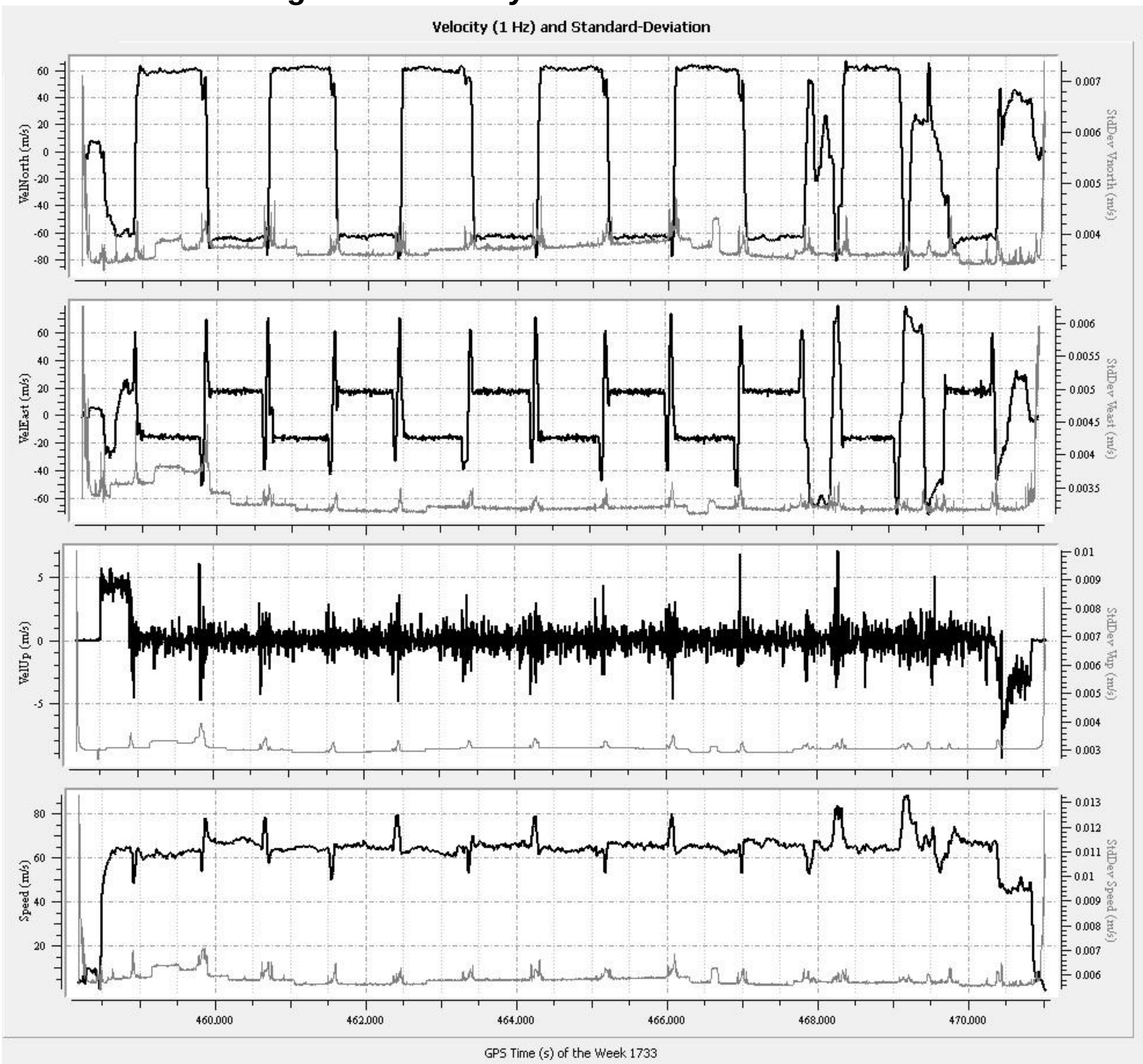


Figure 4: Forward/Reverse or Combined Separation Plot

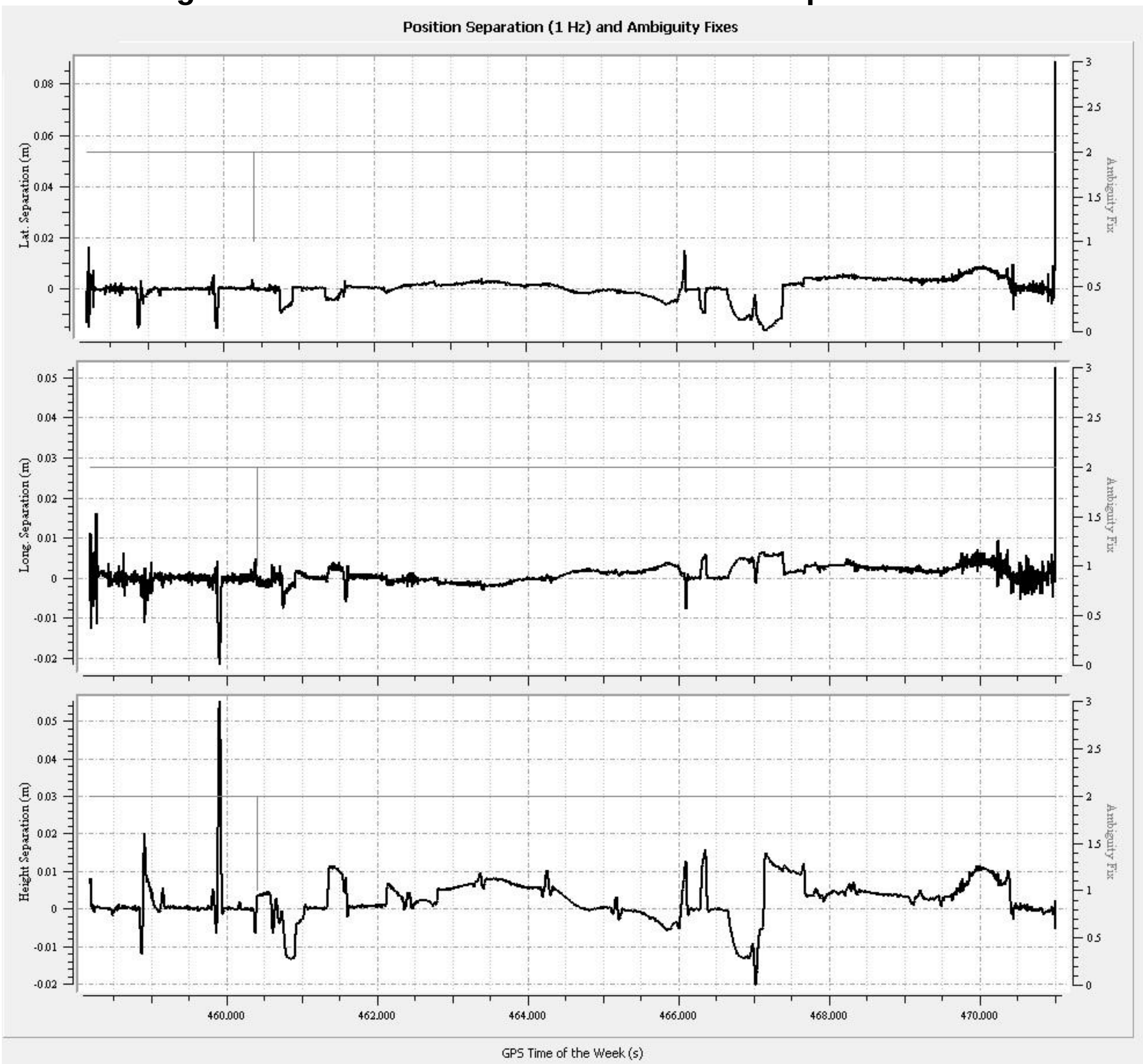


Figure 5: Attitude and Standard Deviation

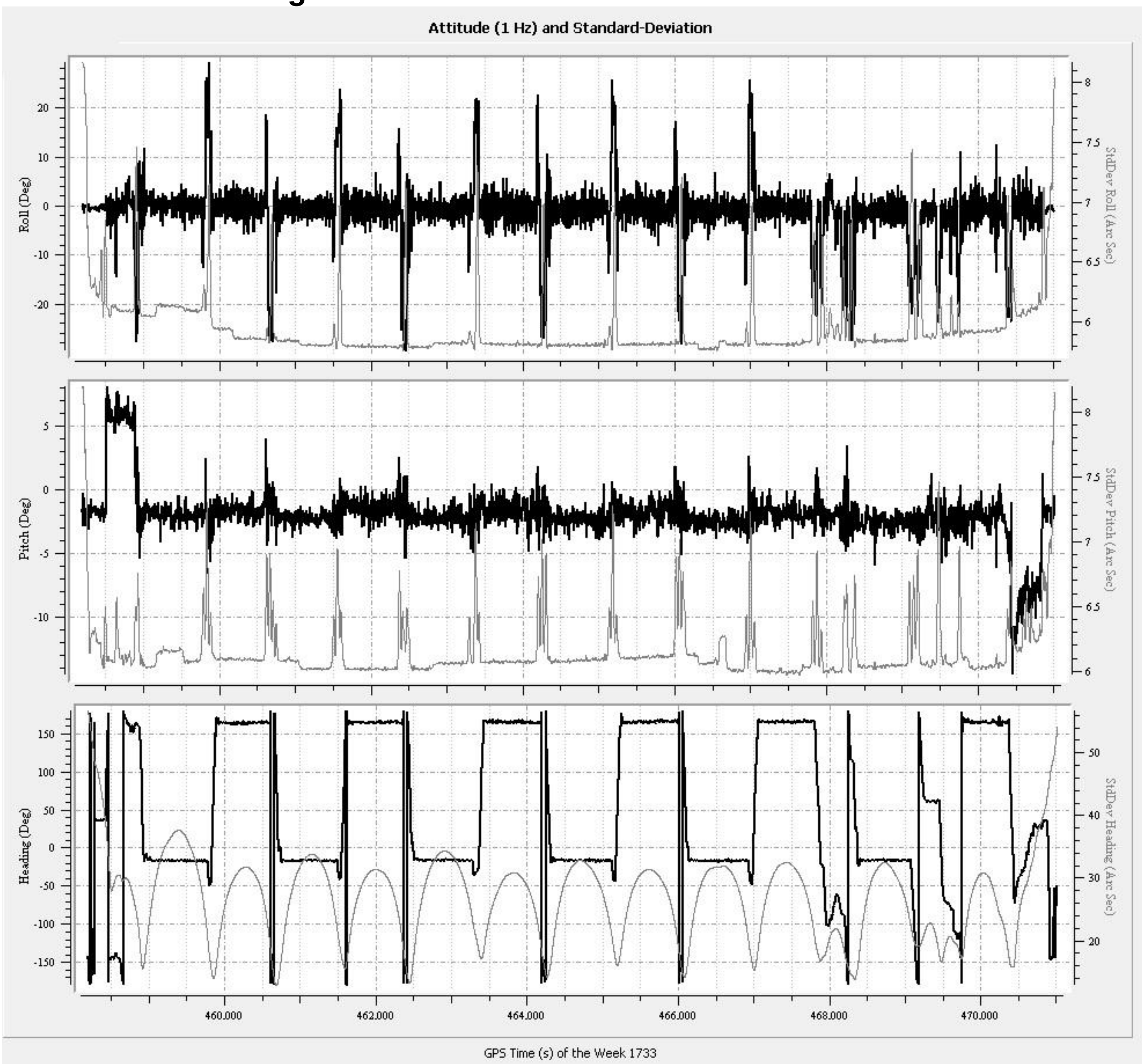


Figure 6: Position Accuracy and PDOP

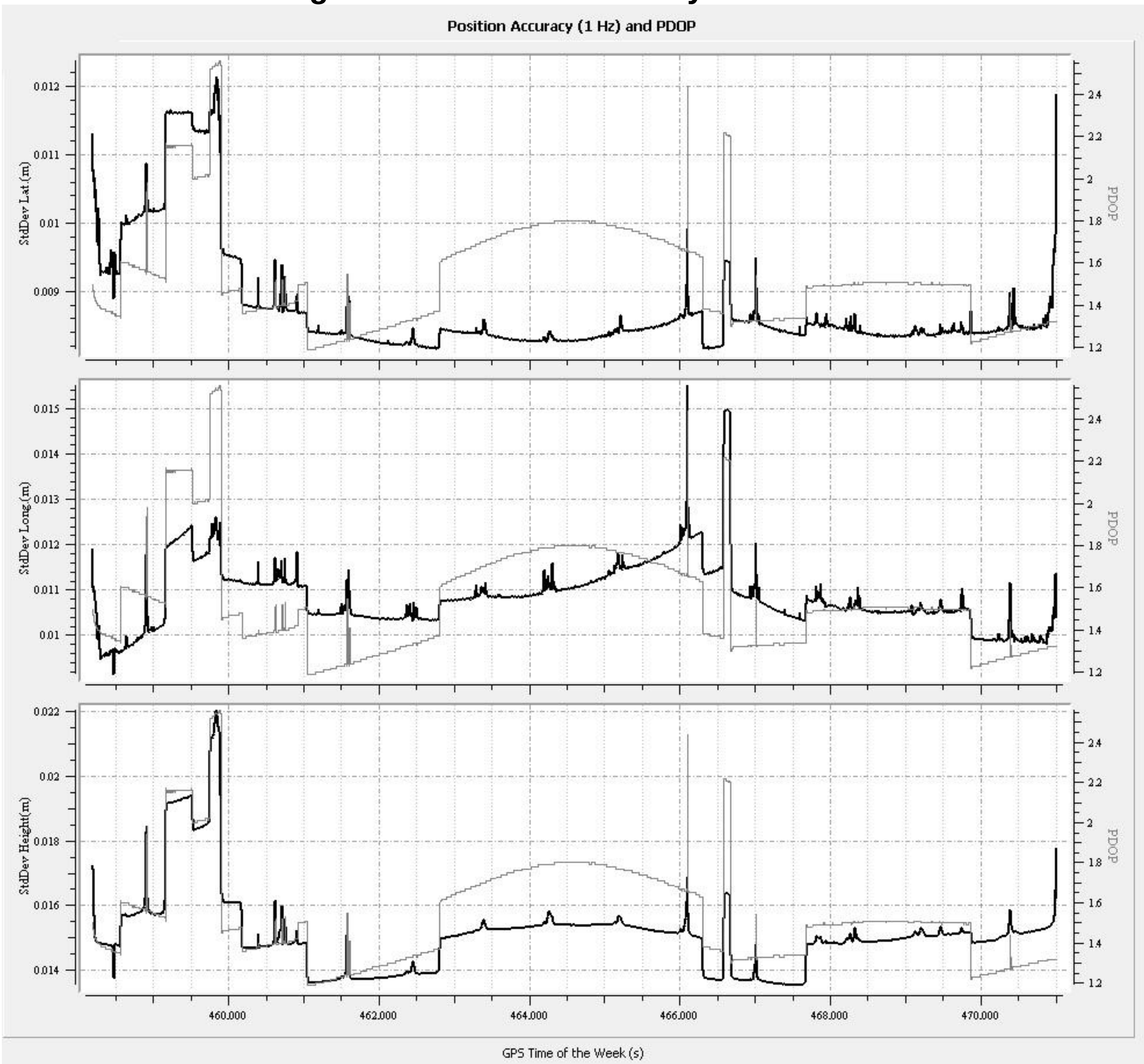


Figure 7: Accelerometer Bias Estimation

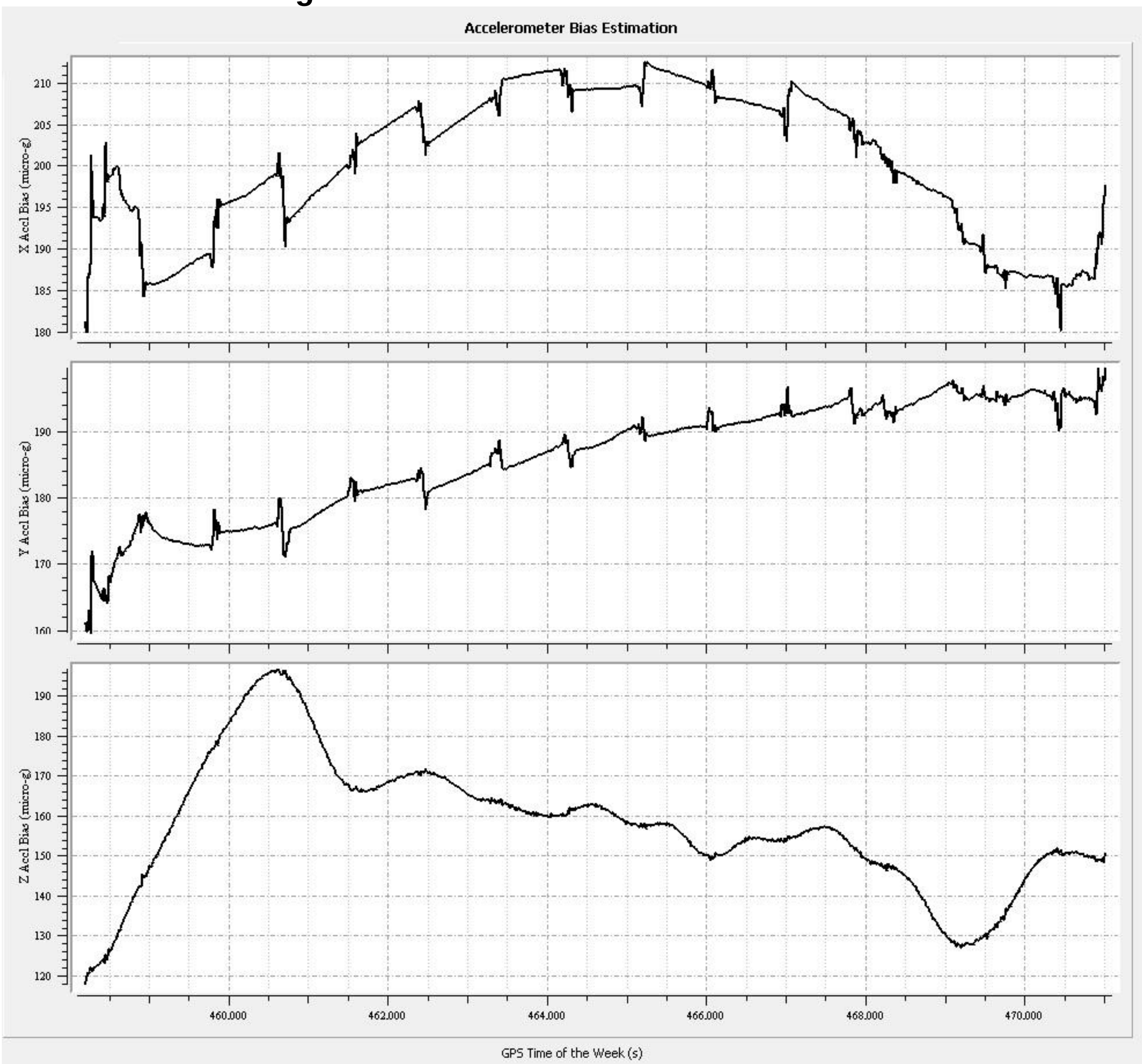


Figure 8: Kalman Filter Residuals and Position Accuracy

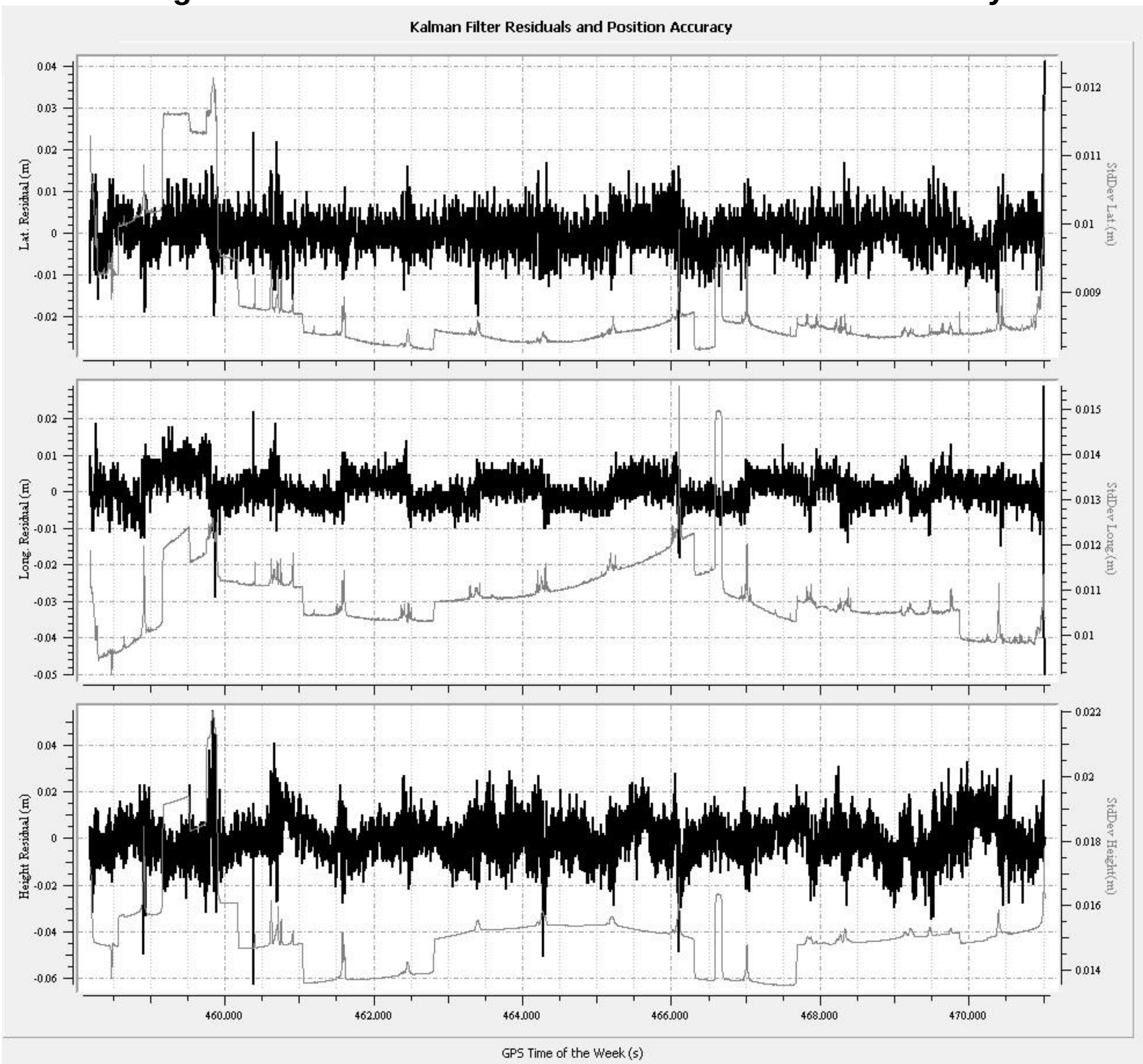
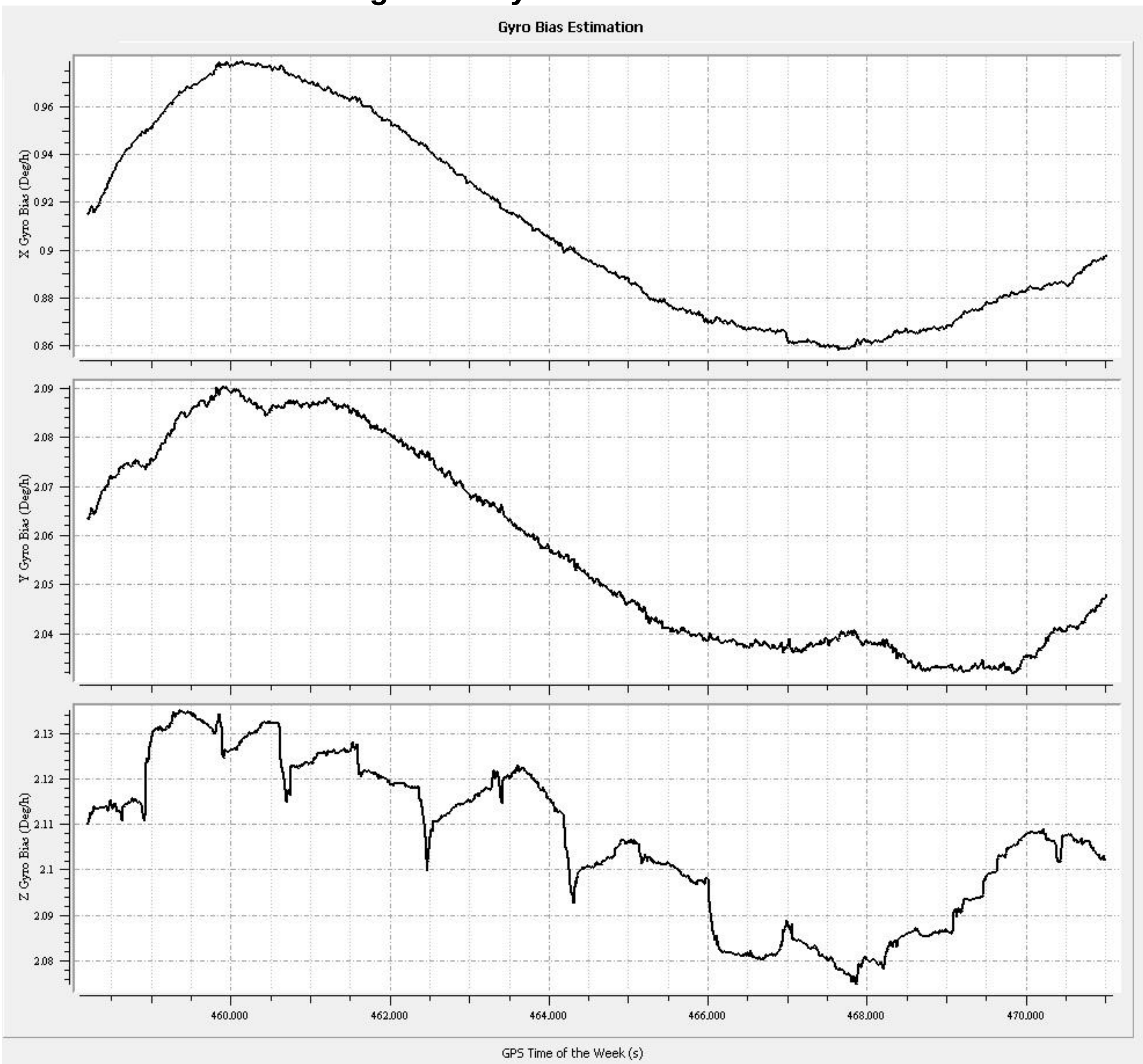


Figure 9: Gyro Bias Estimation



Output Result for JD13088_2

Figure 1: Trajectory Map

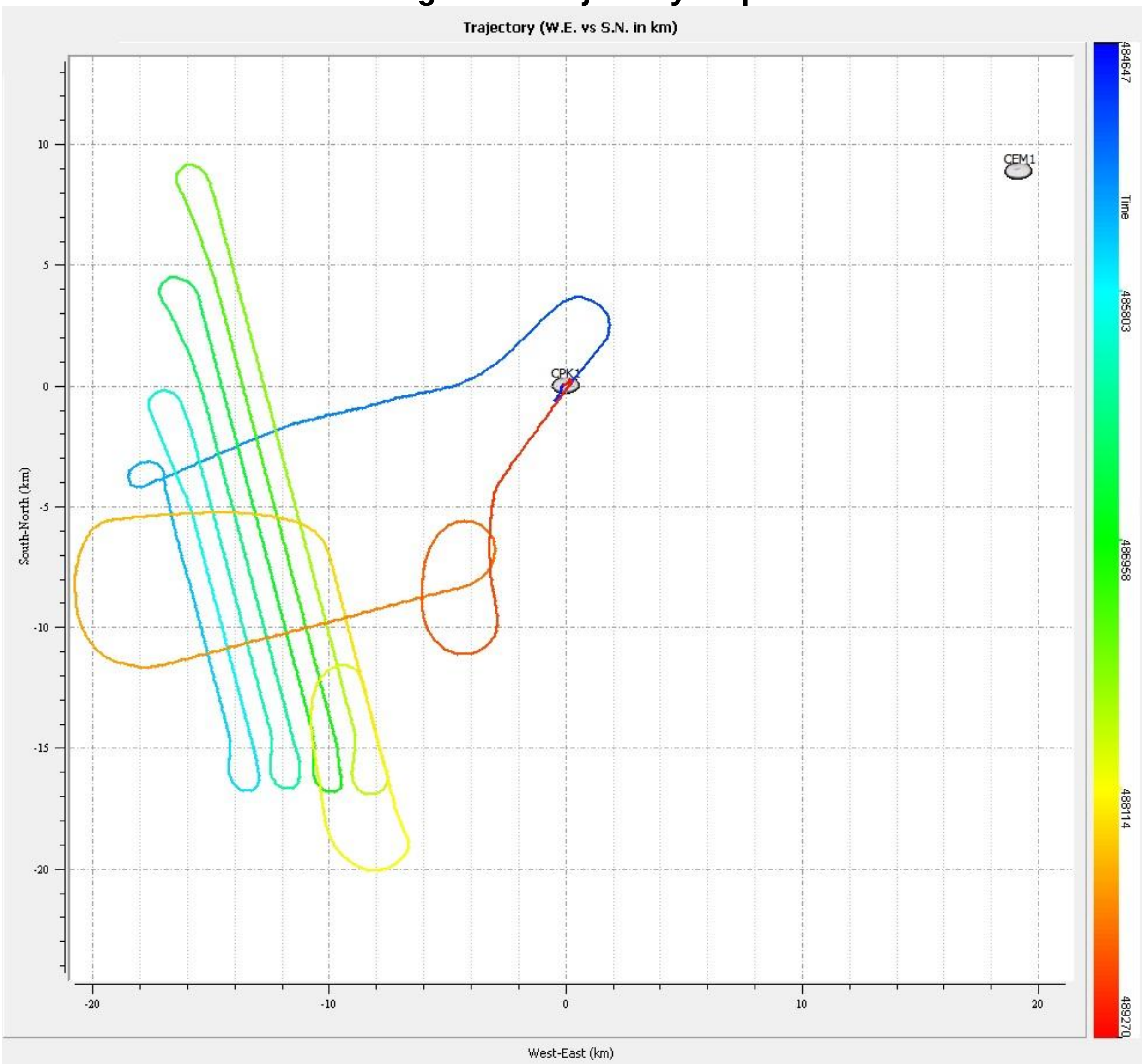


Figure 2: Position and Standard Deviation

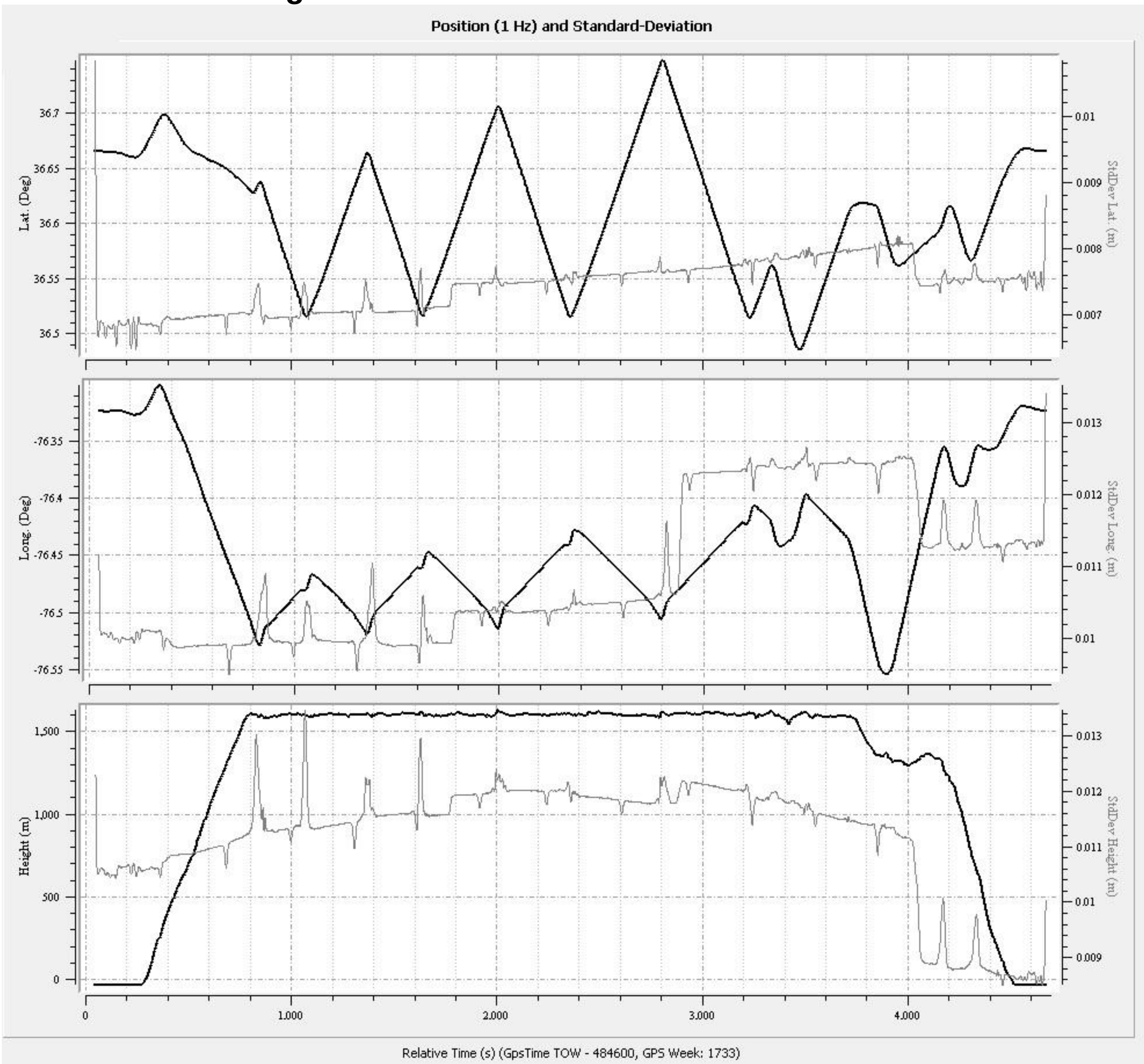


Figure 3: Velocity and Standard Deviation

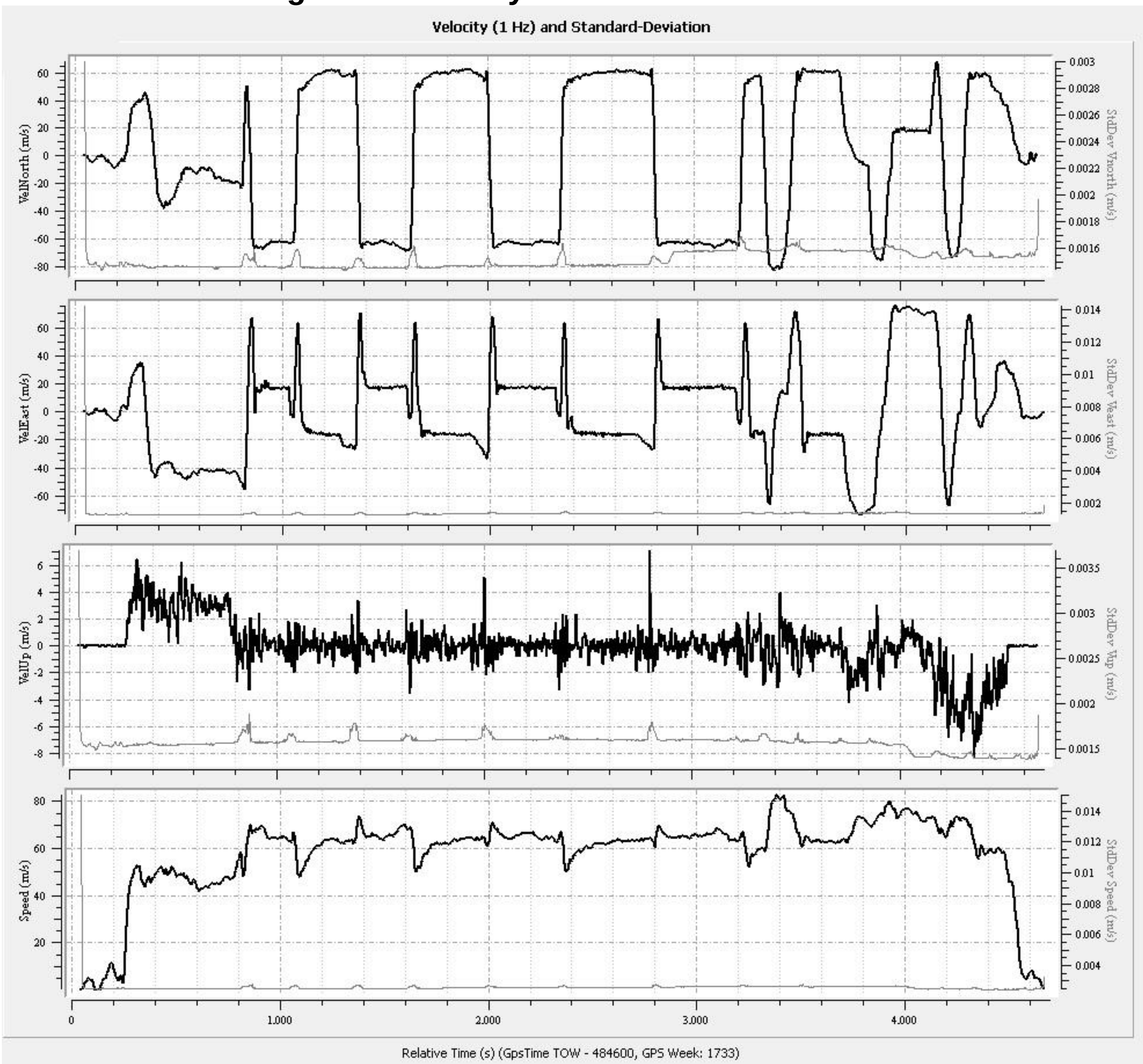


Figure 4: Forward/Reverse or Combined Separation Plot

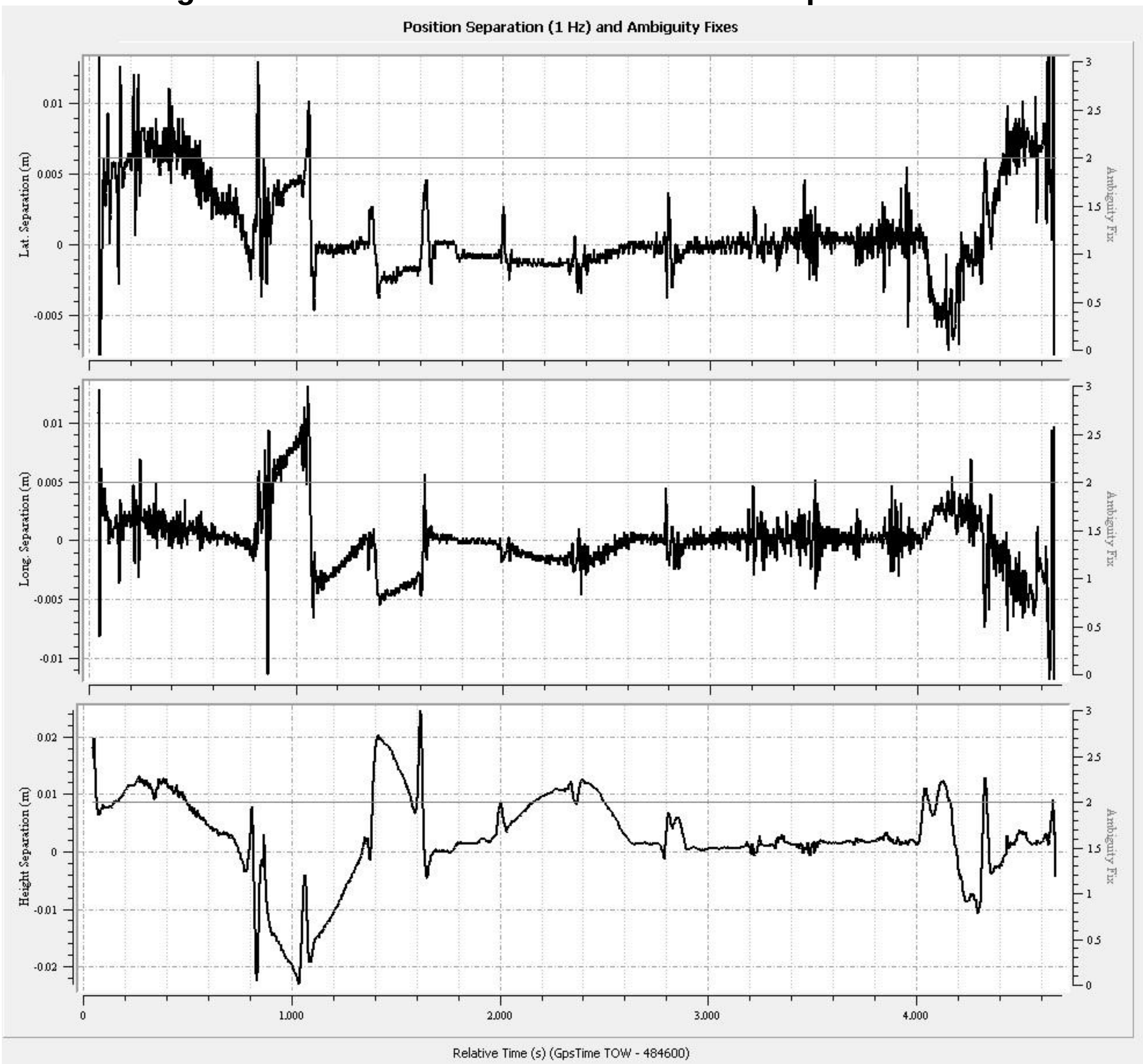


Figure 5: Attitude and Standard Deviation

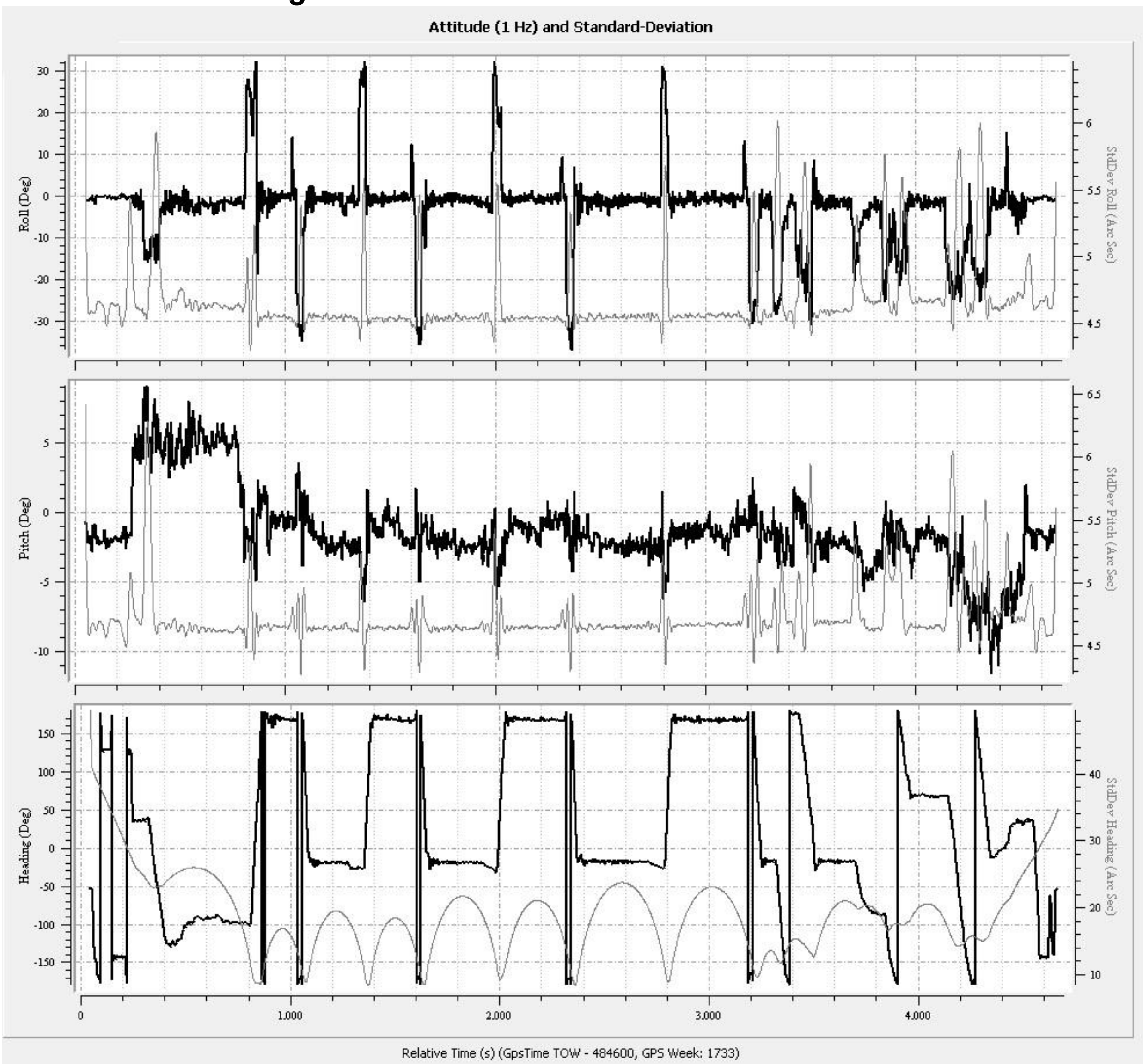


Figure 6: Position Accuracy and PDOP

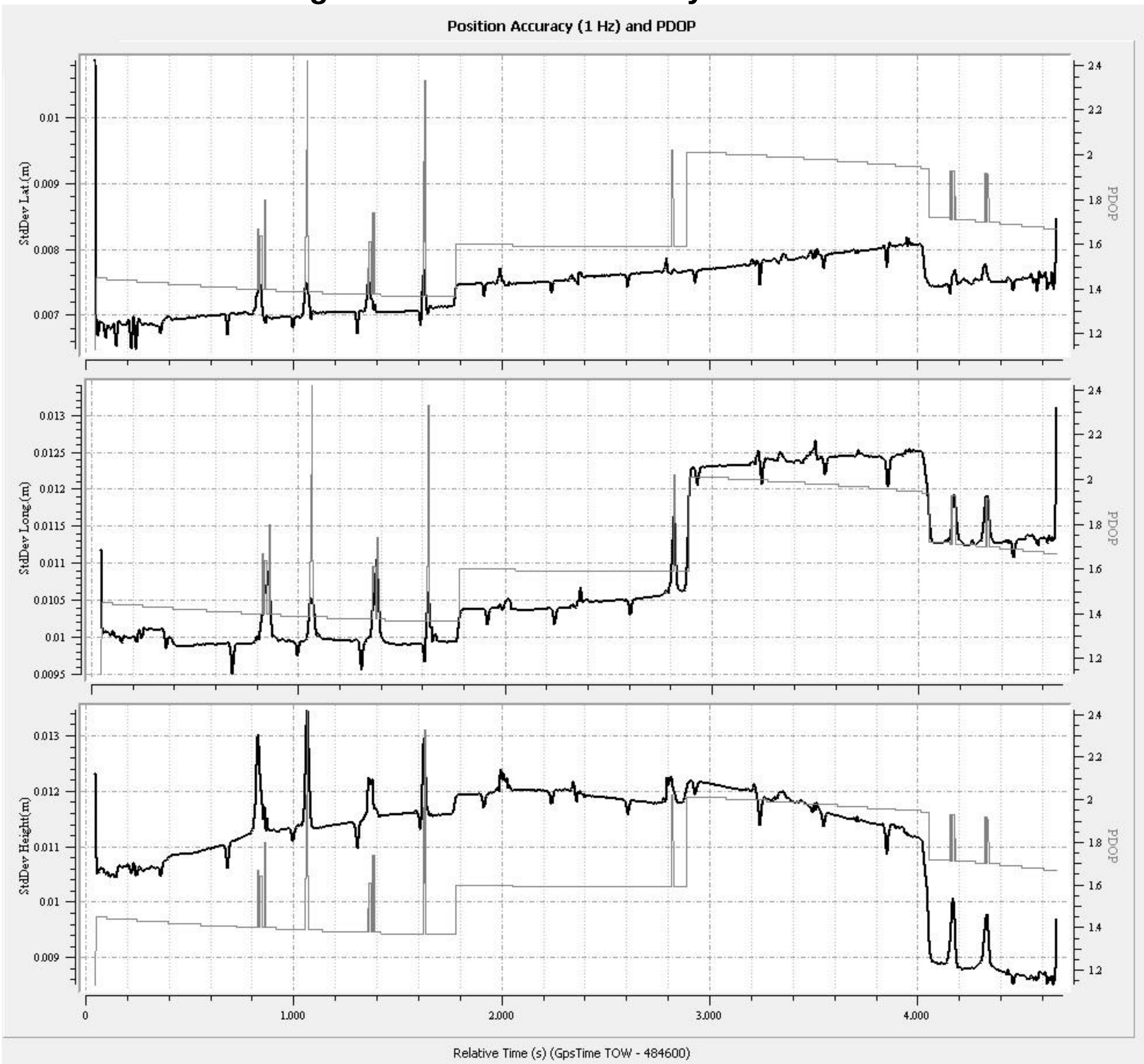


Figure 7: Accelerometer Bias Estimation

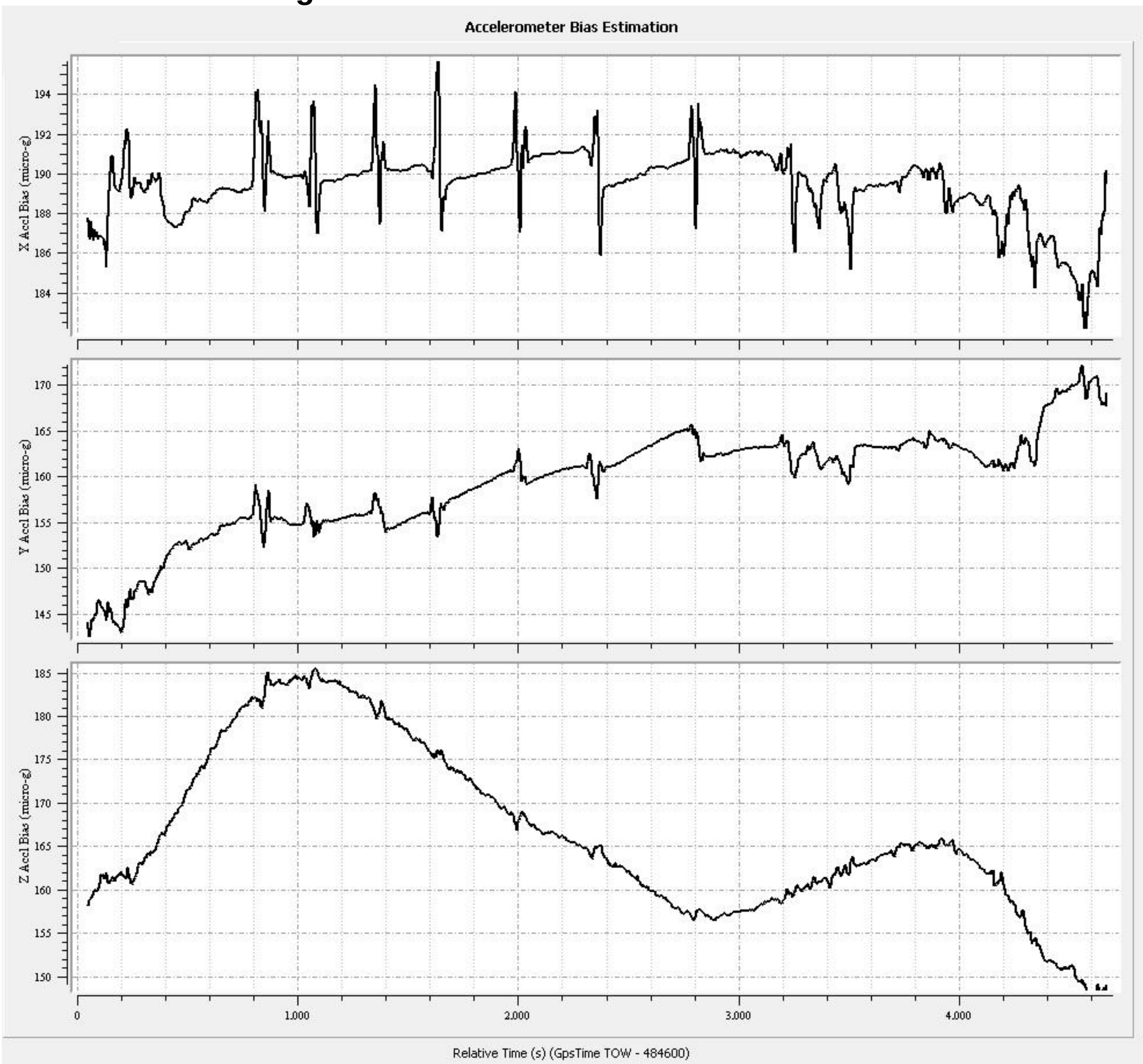


Figure 8: Kalman Filter Residuals and Position Accuracy

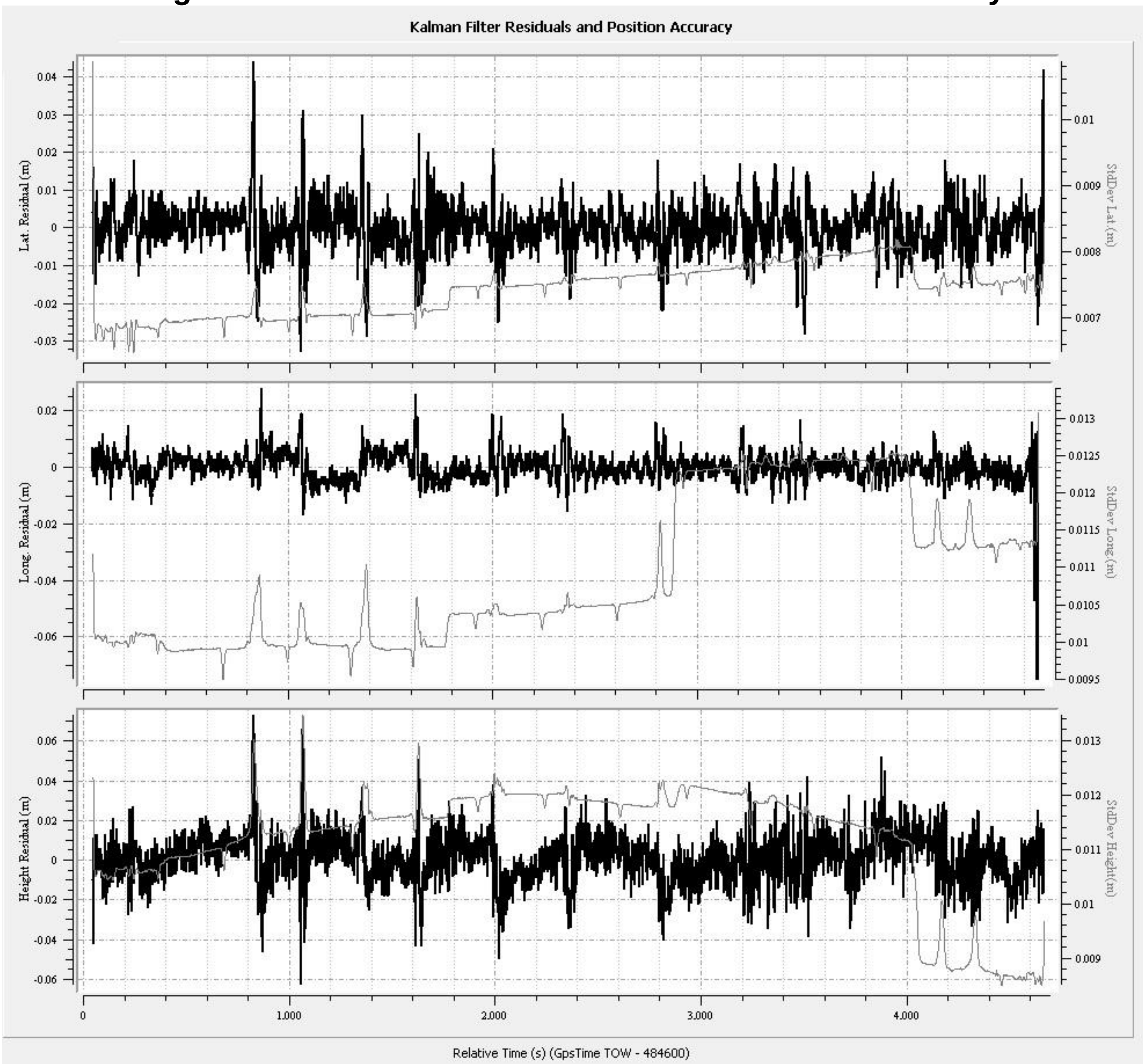
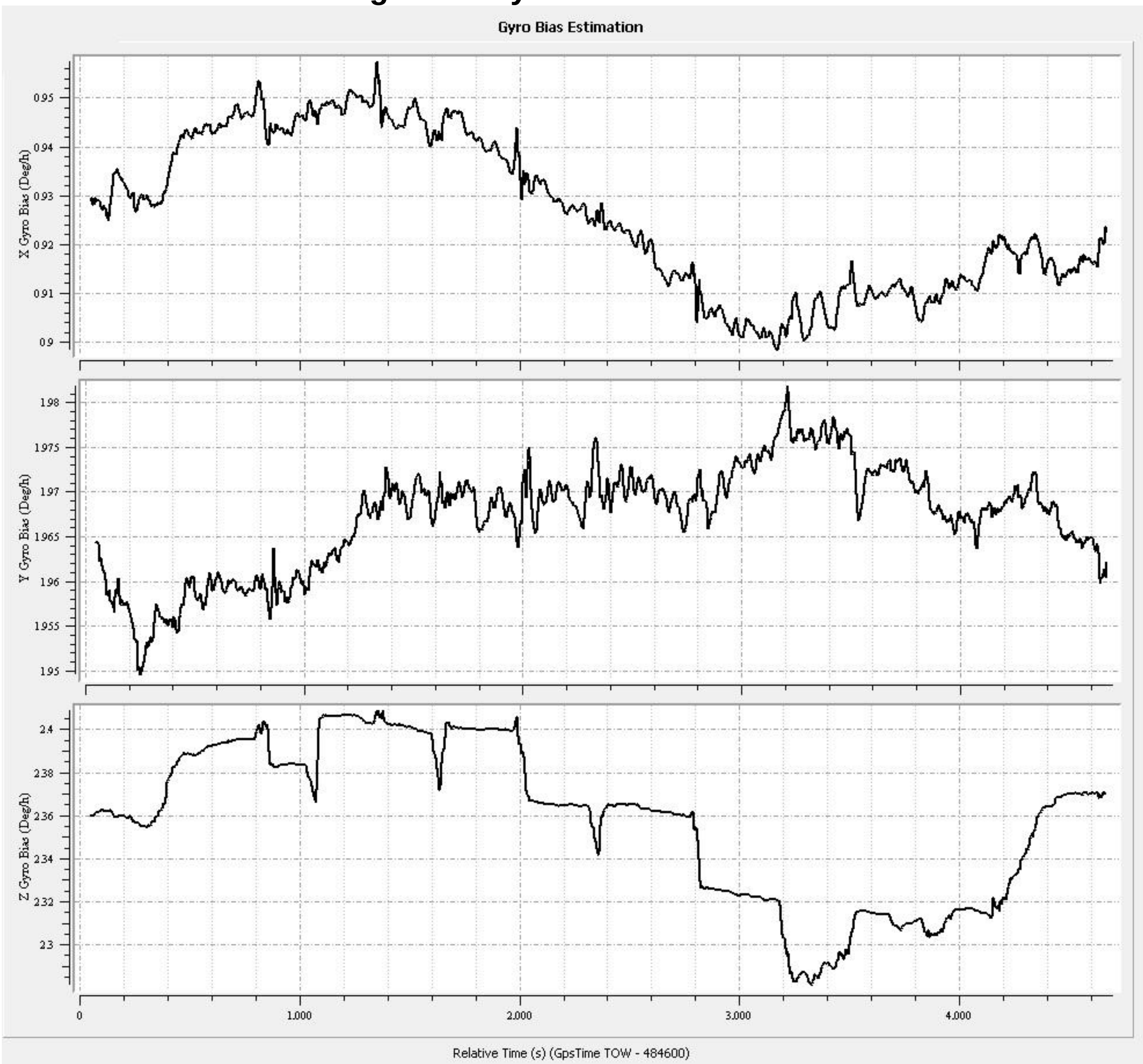


Figure 9: Gyro Bias Estimation



Output Results for JD13088_3

Figure 1: Trajectory Map

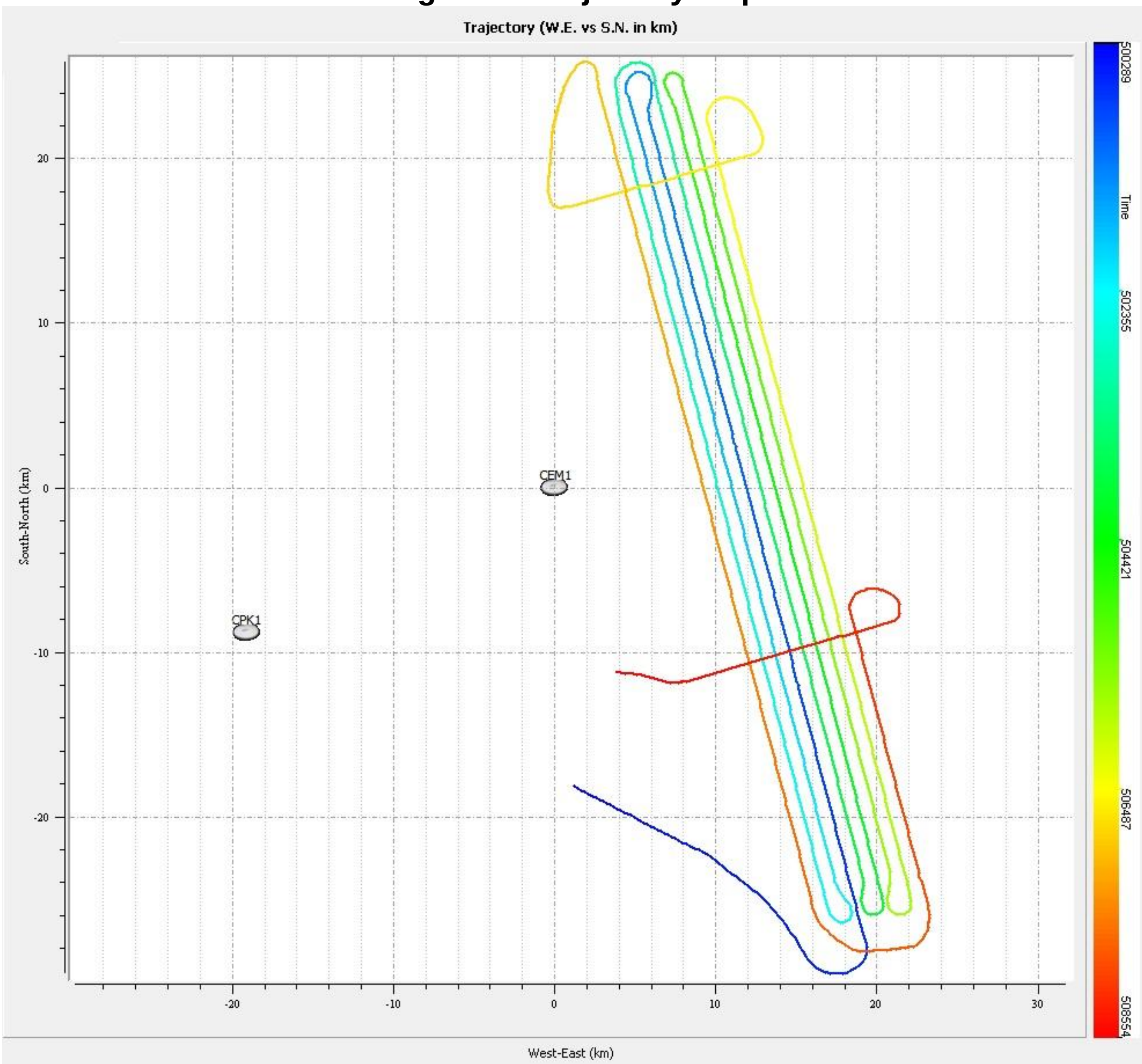


Figure 2: Position and Standard Deviation

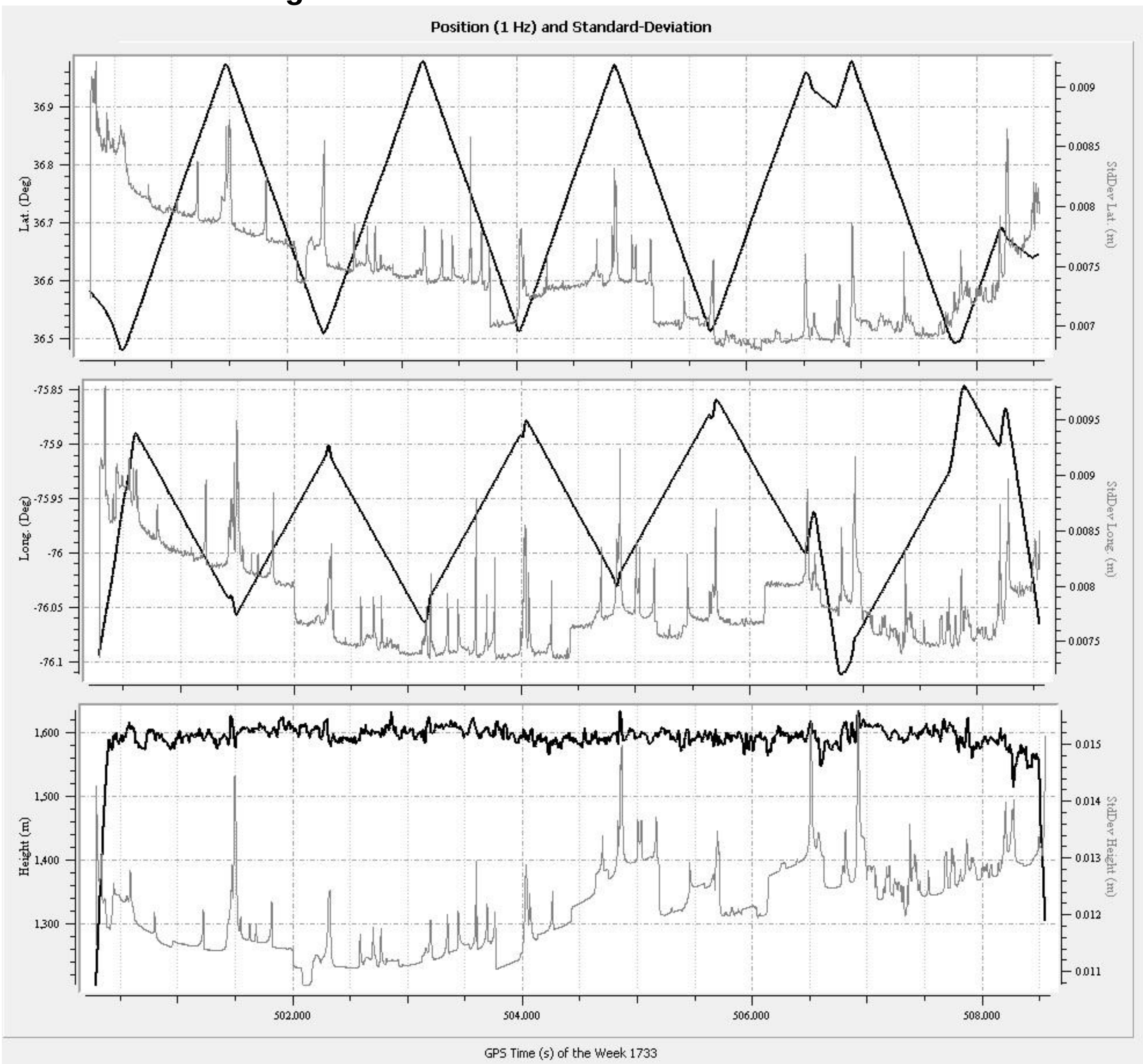


Figure 3: Velocity and Standard Deviation

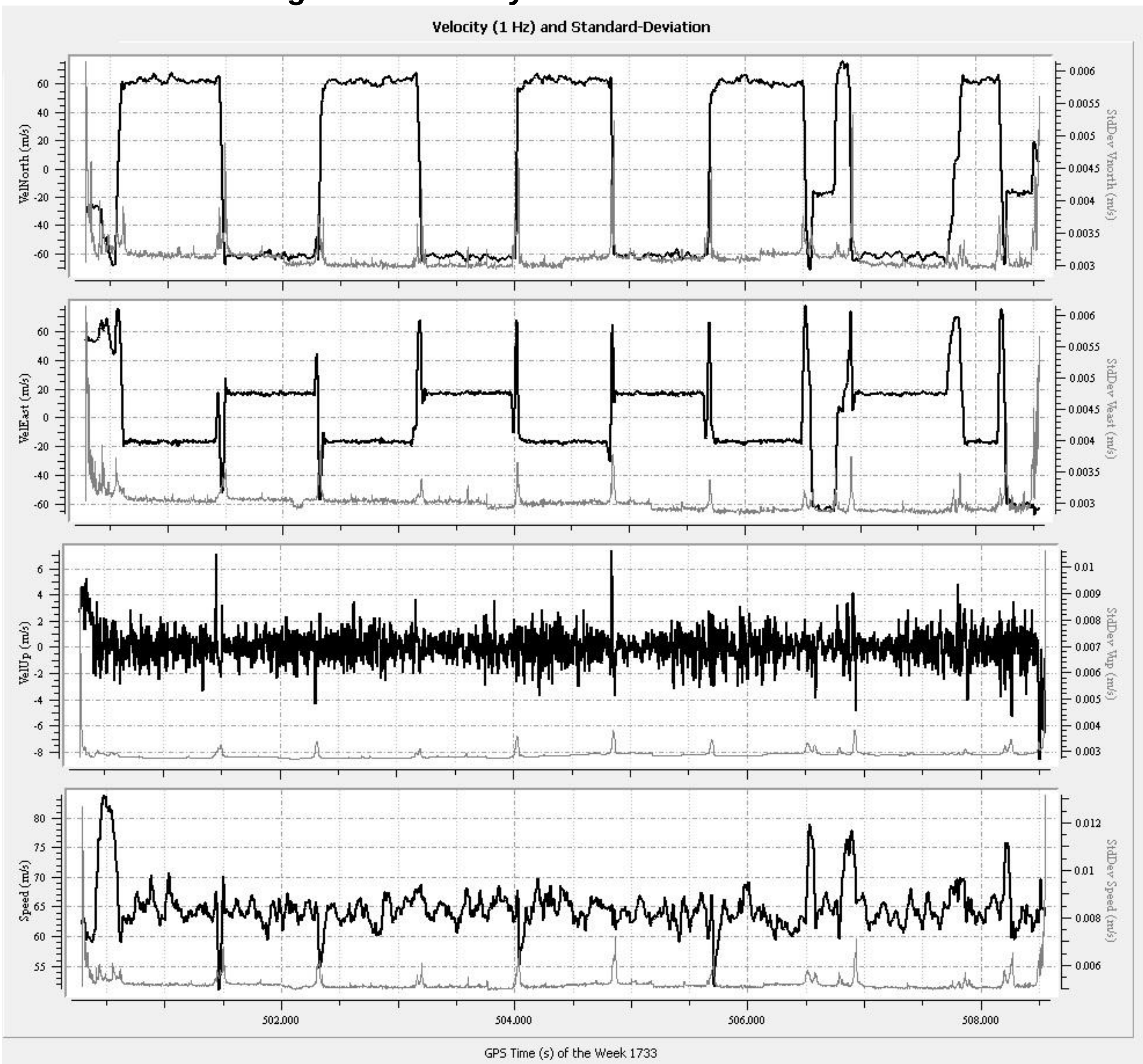


Figure 4: Forward/Reverse or Combined Separation Plot

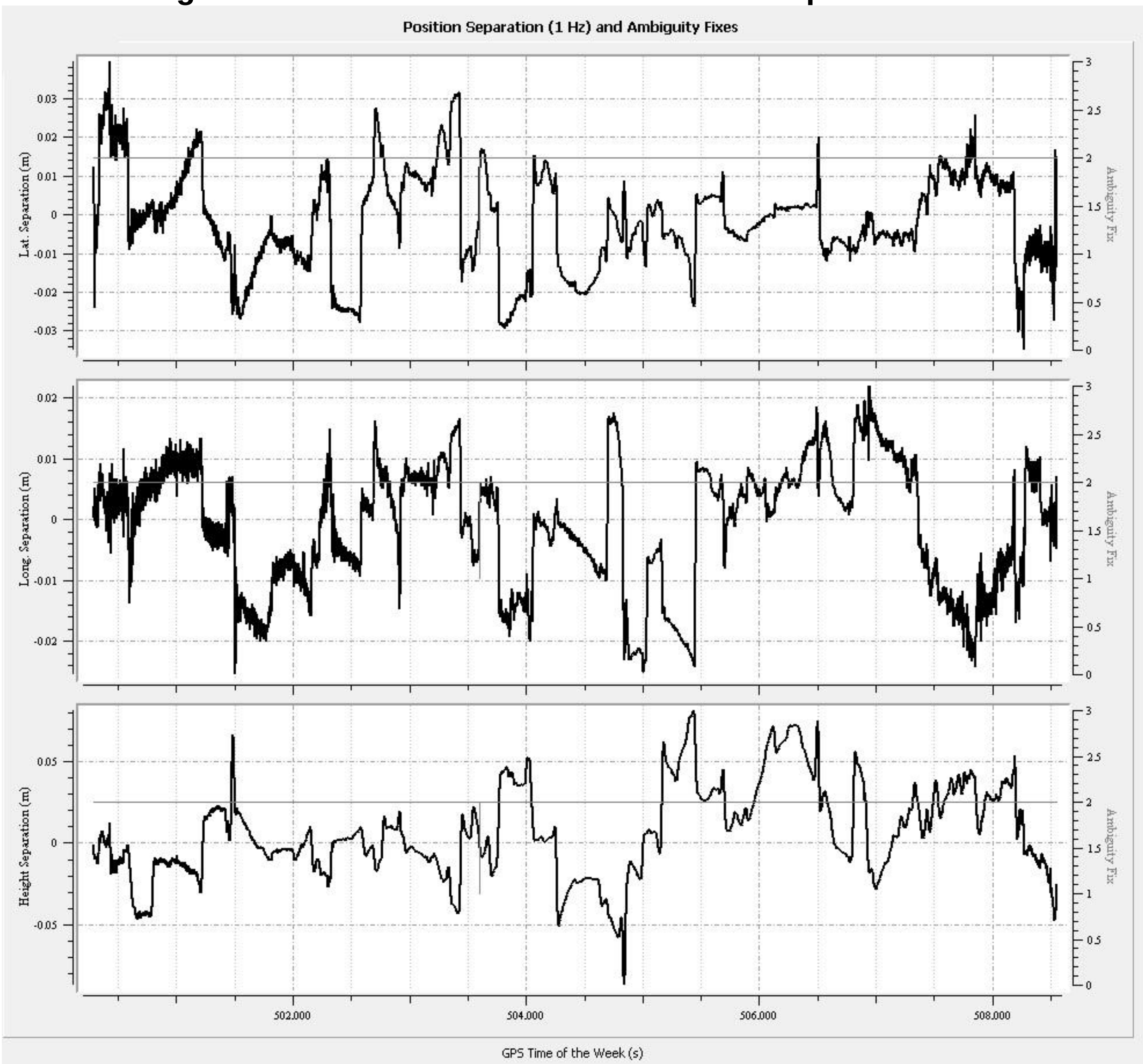


Figure 5: Attitude and Standard Deviation

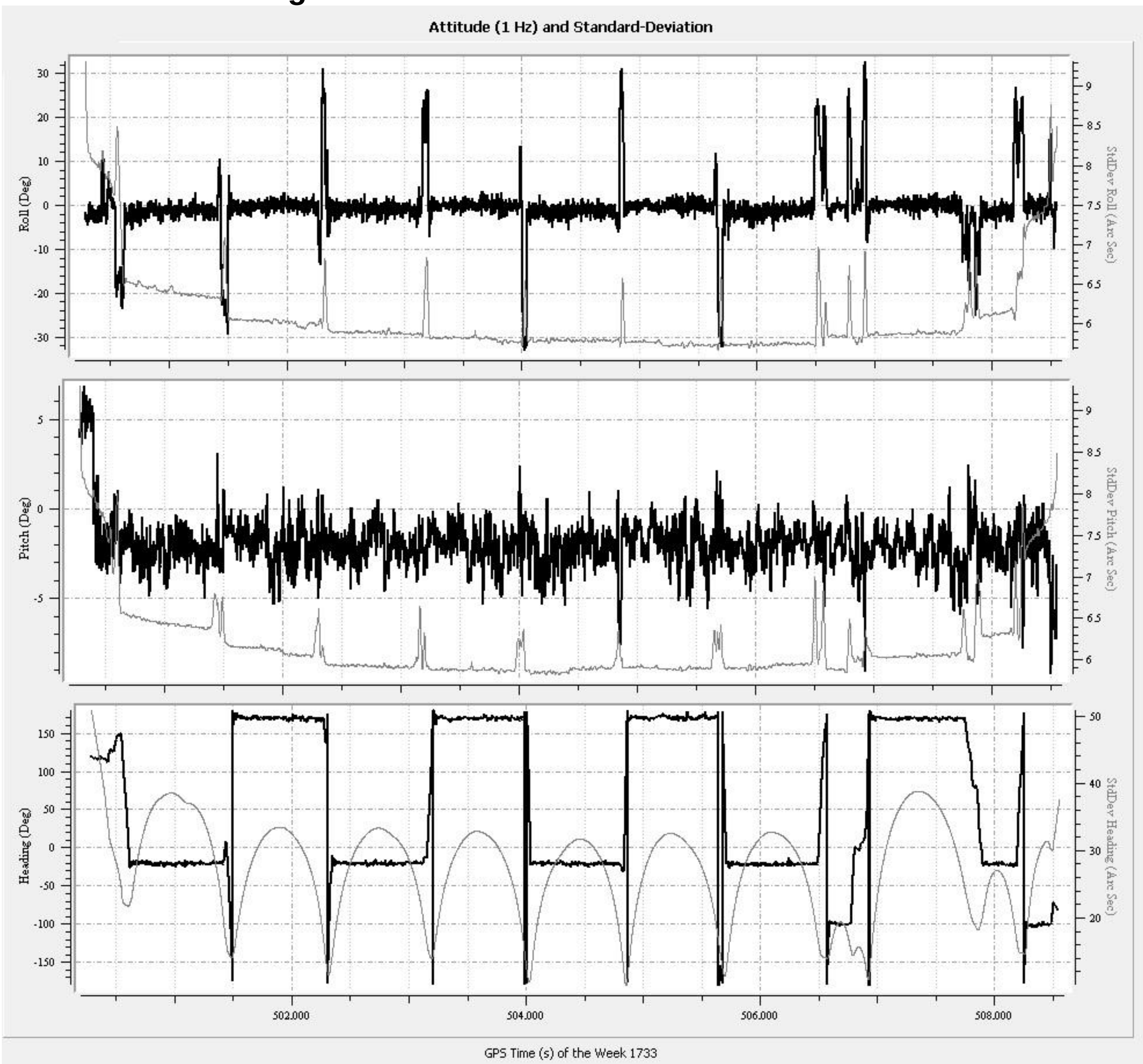


Figure 6: Position Accuracy and PDOP

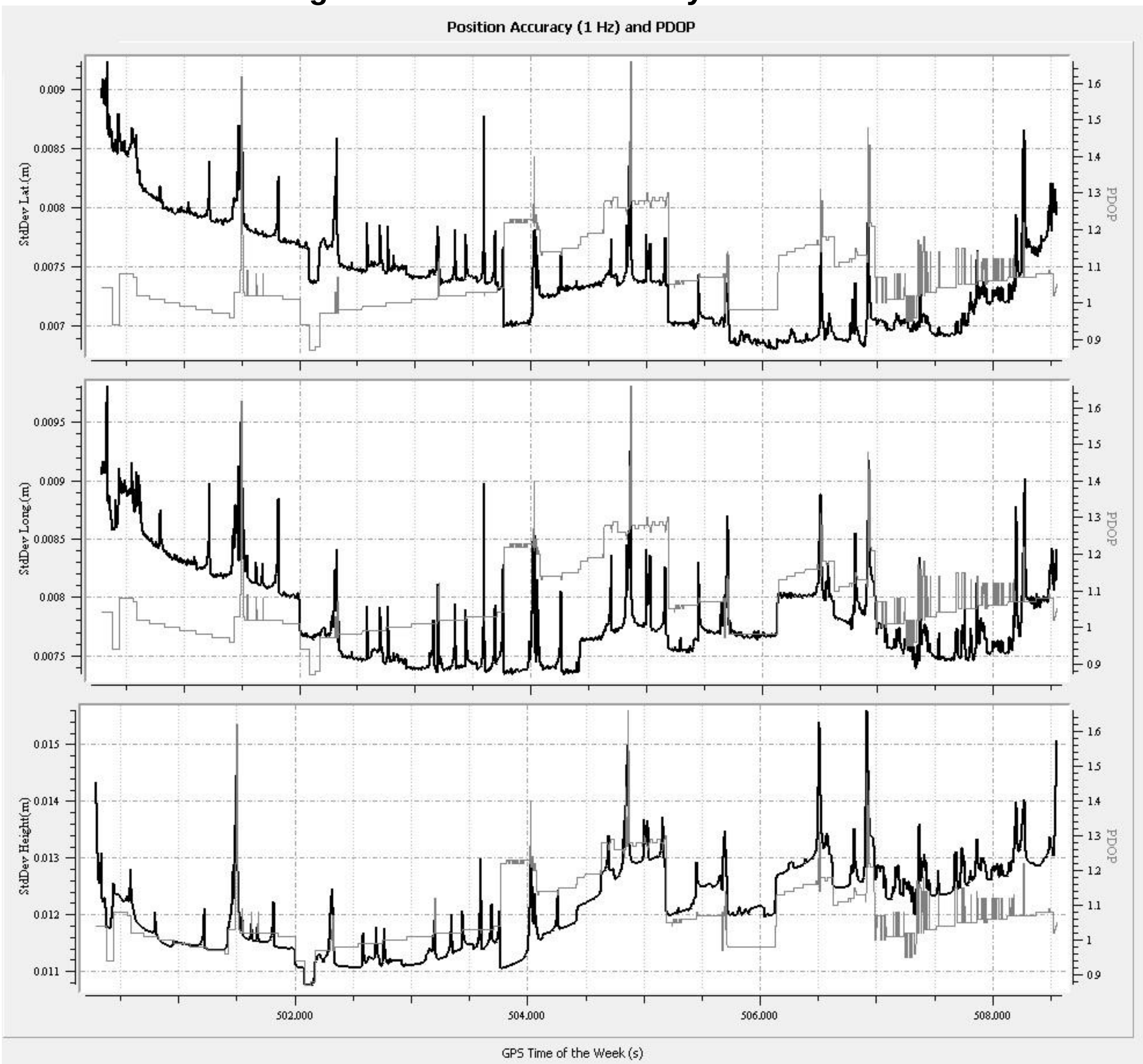


Figure 7: Accelerometer Bias Estimation

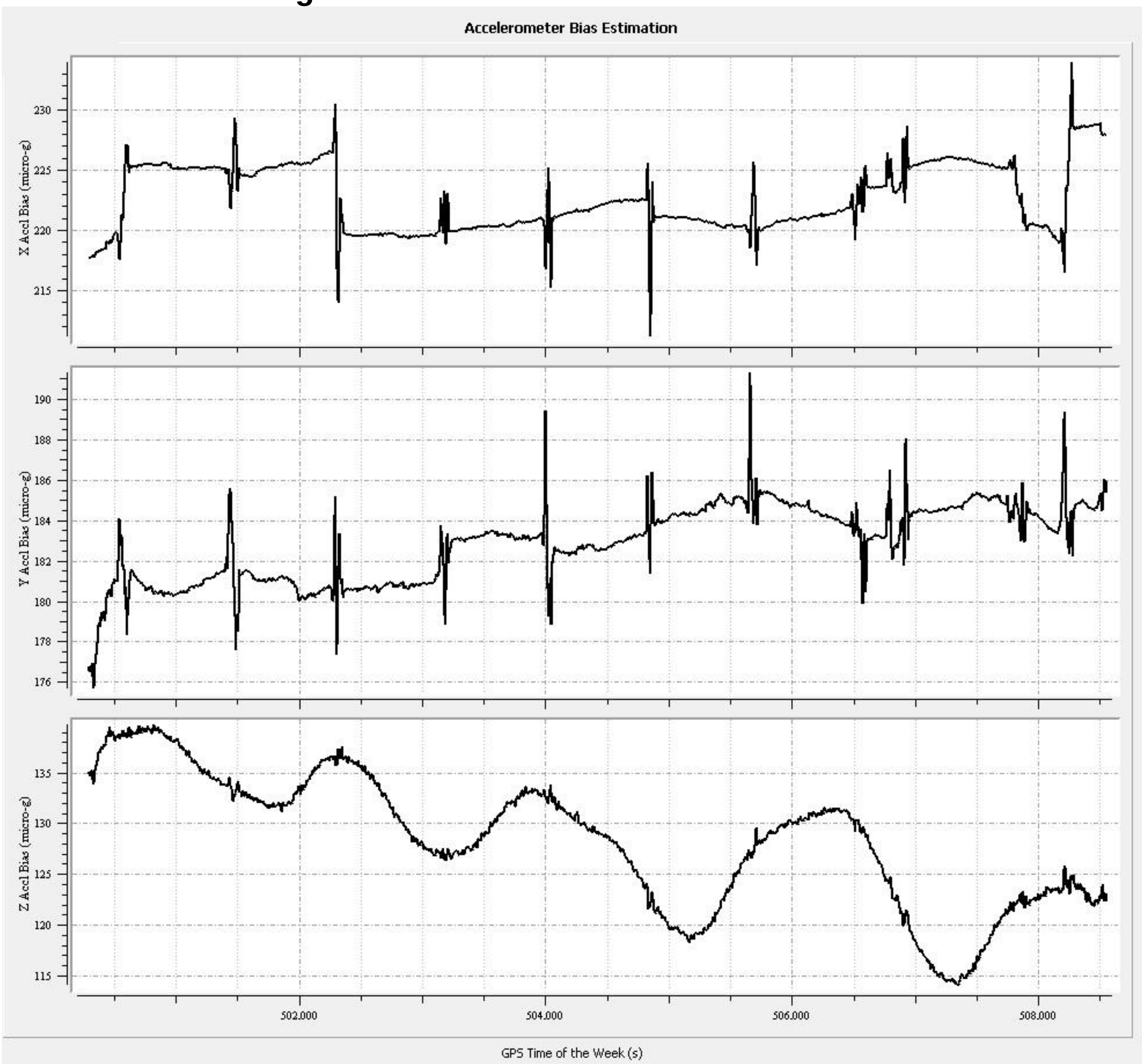


Figure 8: Kalman Filter Residuals and Position Accuracy

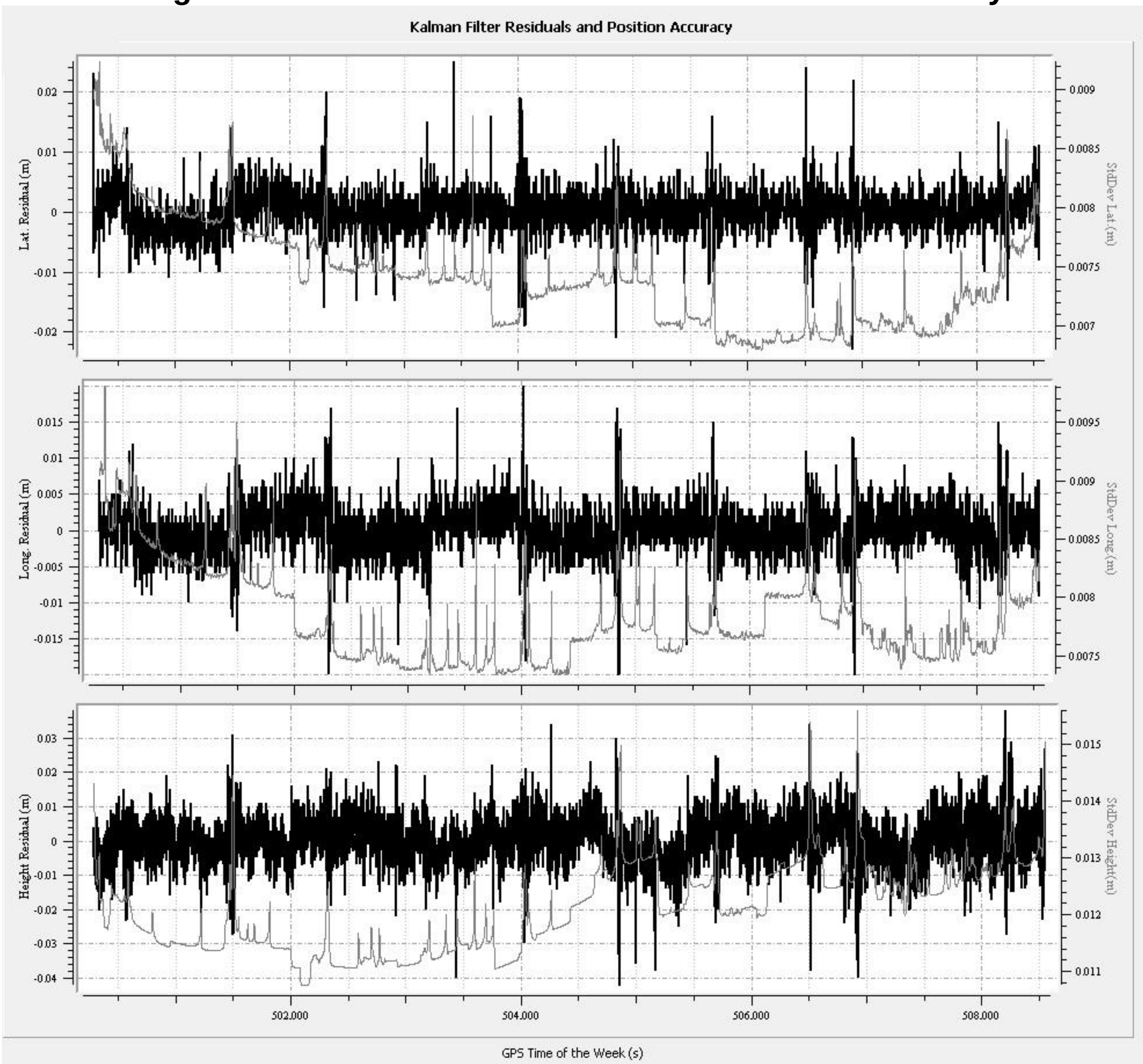
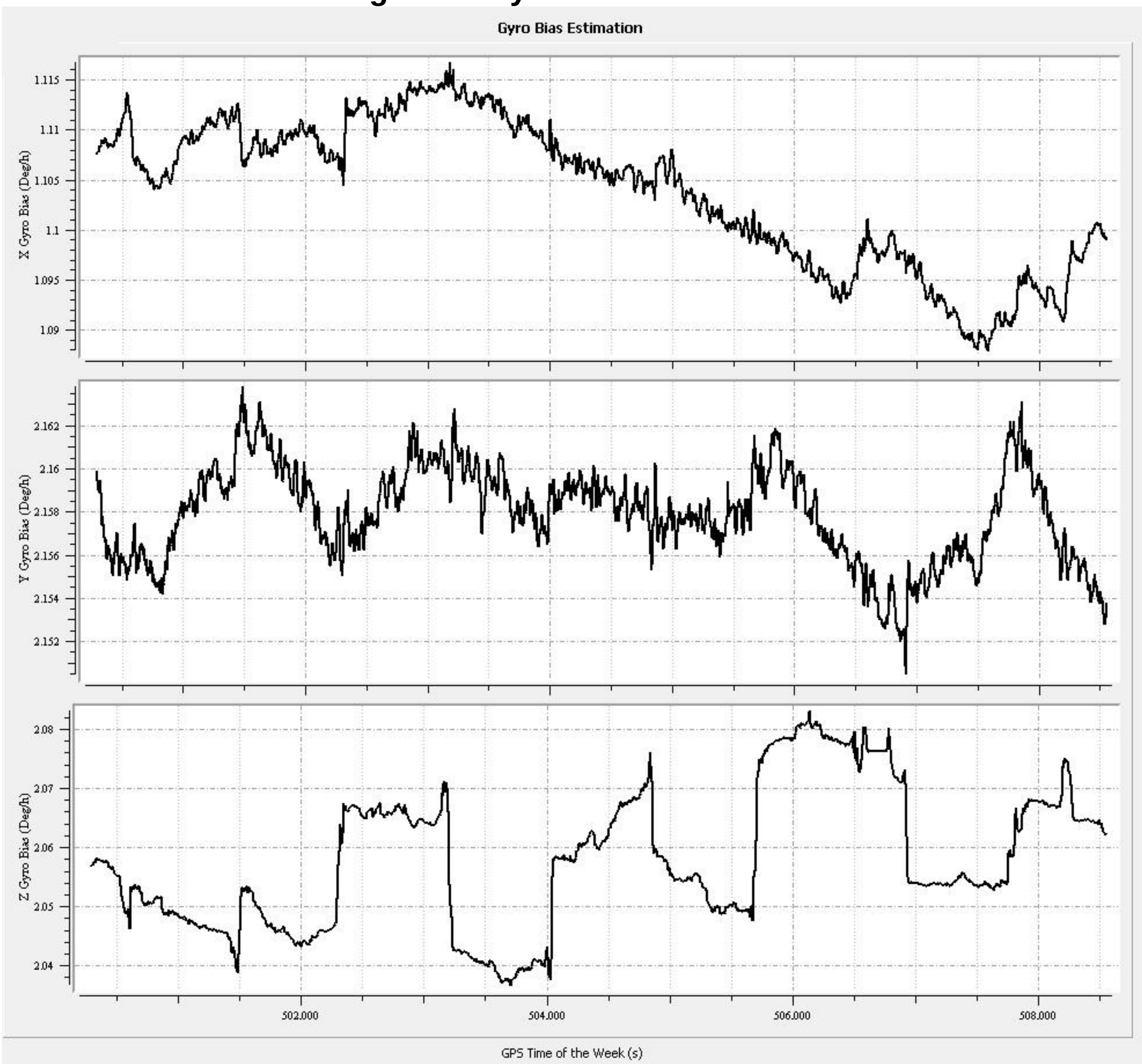


Figure 9: Gyro Bias Estimation



Output Results for JD13089_1

Figure 1: Trajectory Map

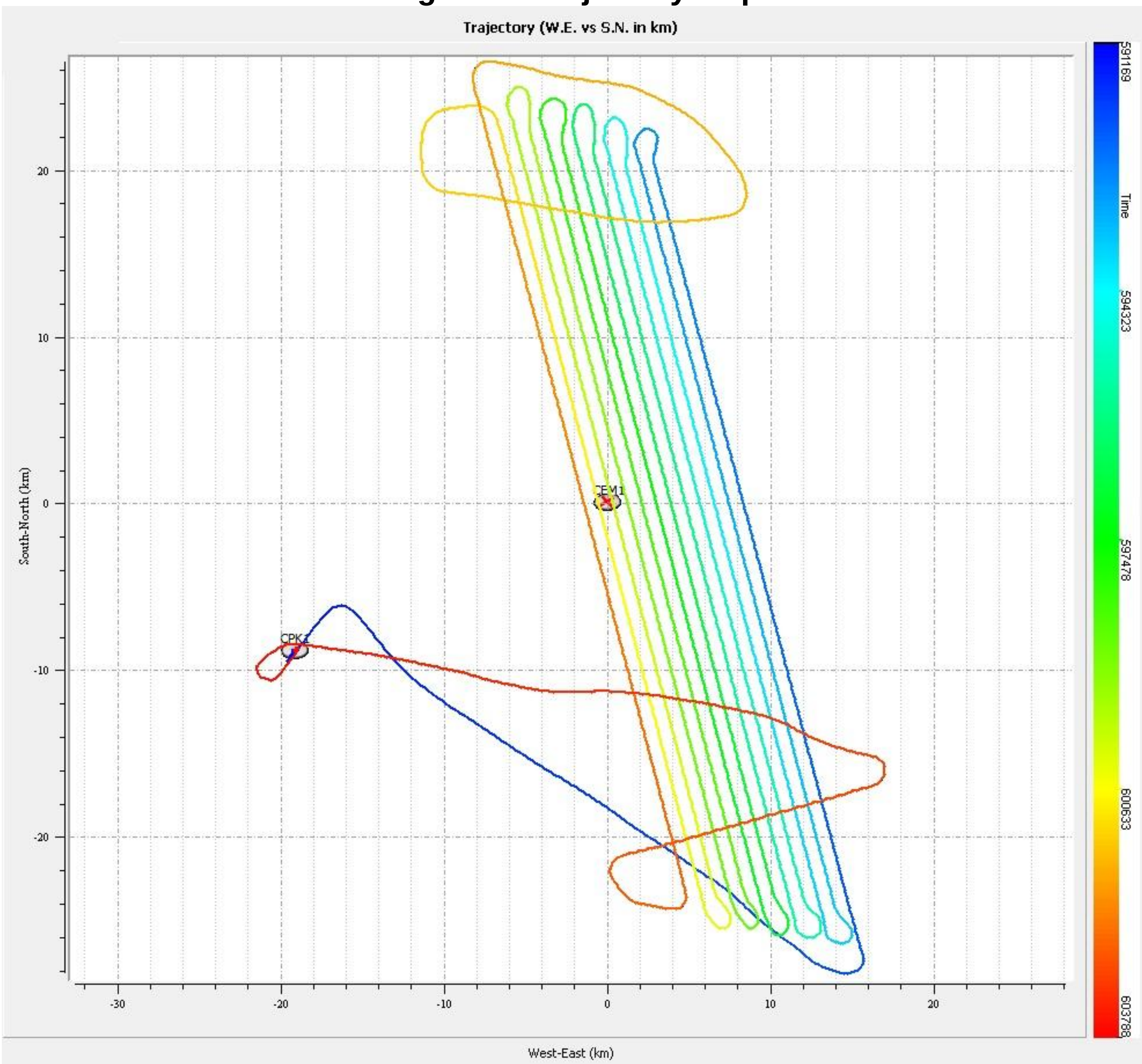


Figure 2: Position and Standard Deviation

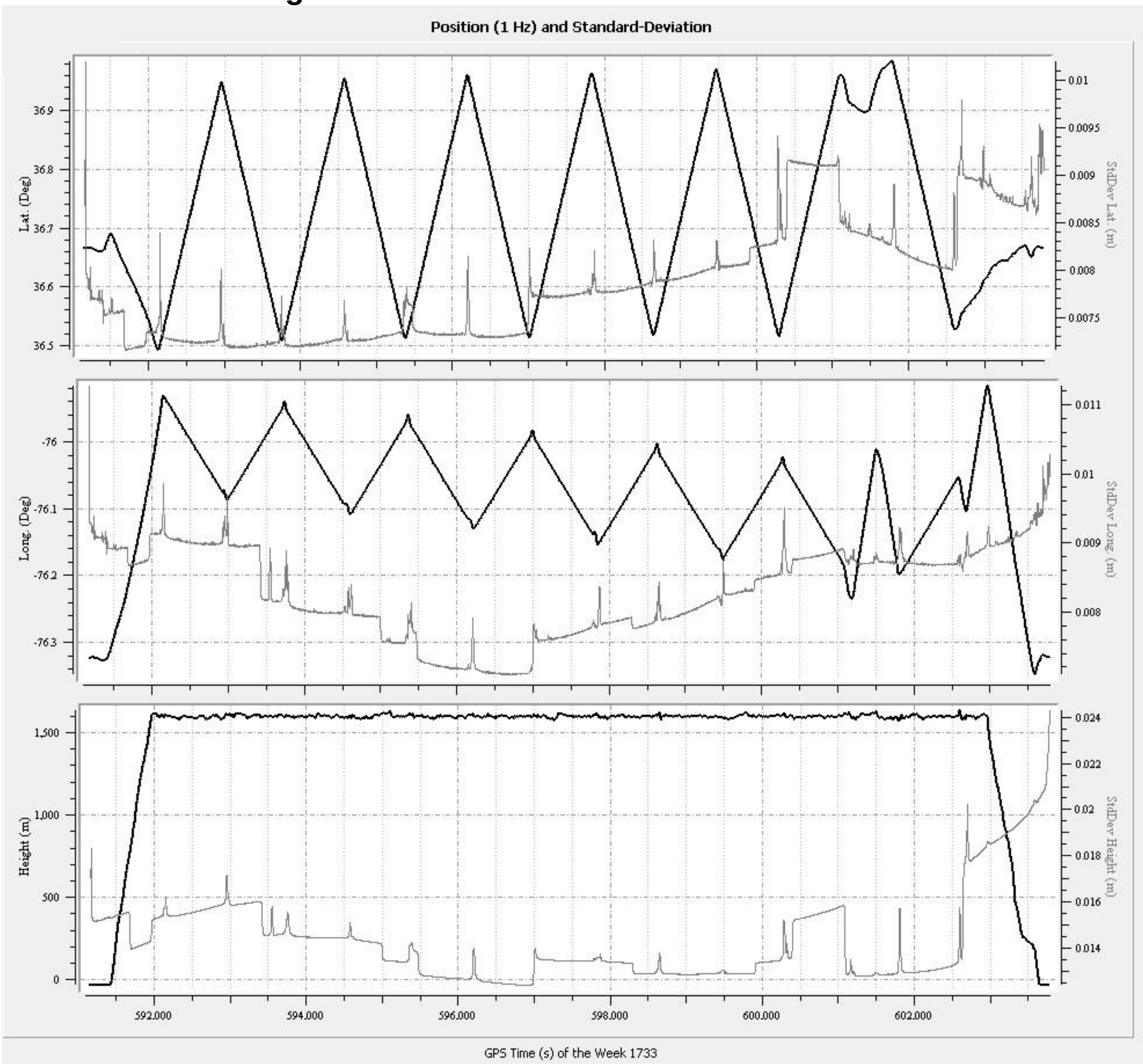


Figure 3: Velocity and Standard Deviation

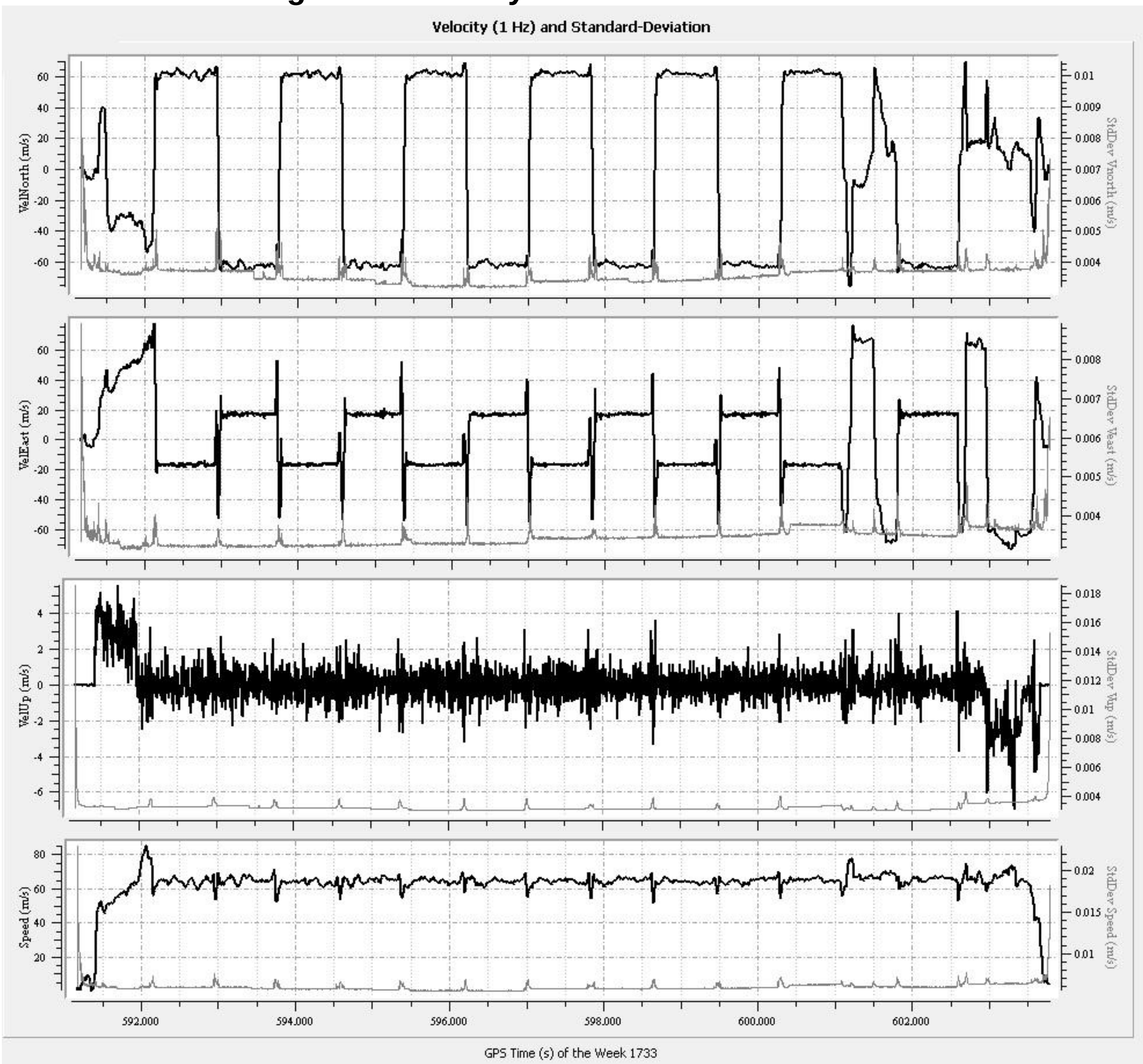


Figure 4: Forward/Reverse or Combined Separation Plot

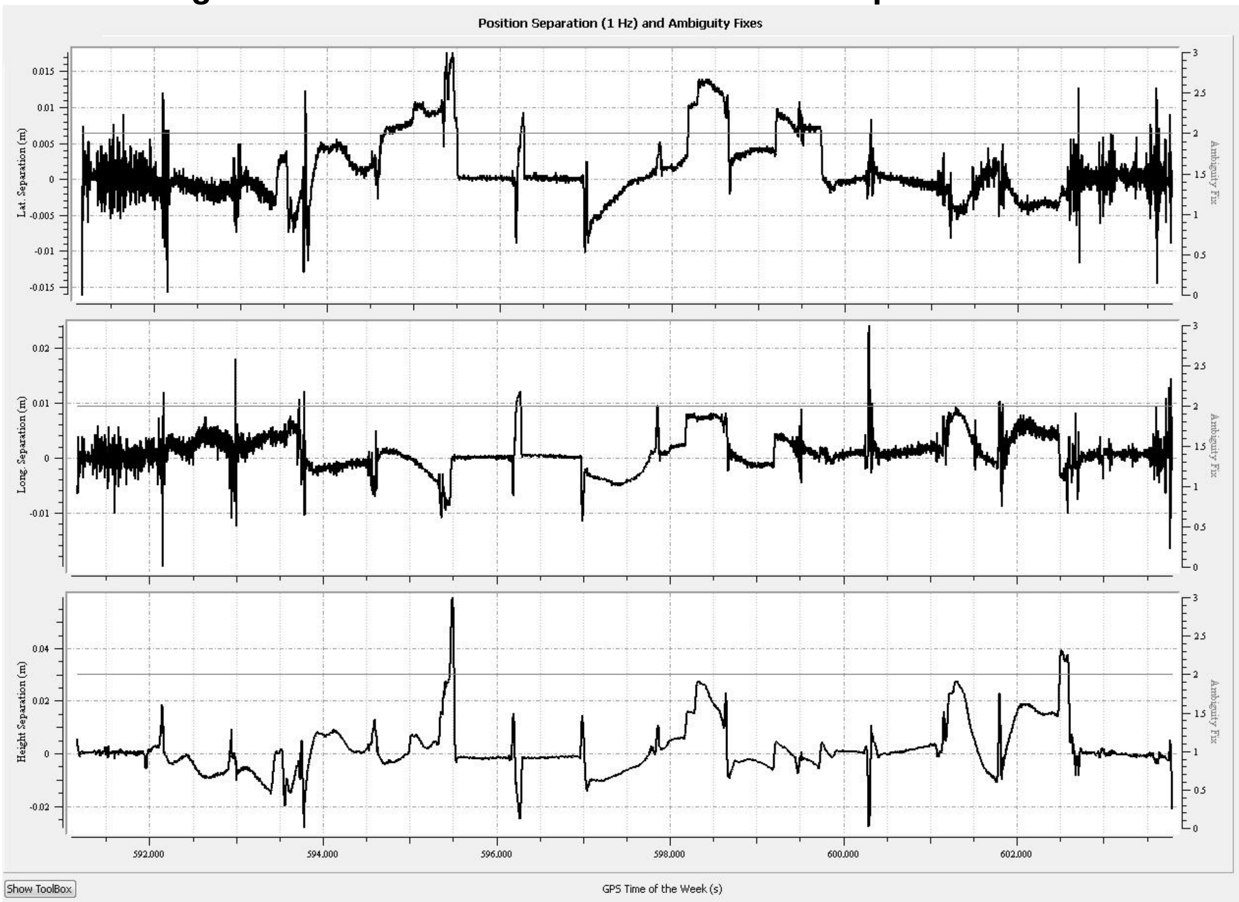


Figure 5: Attitude and Standard Deviation

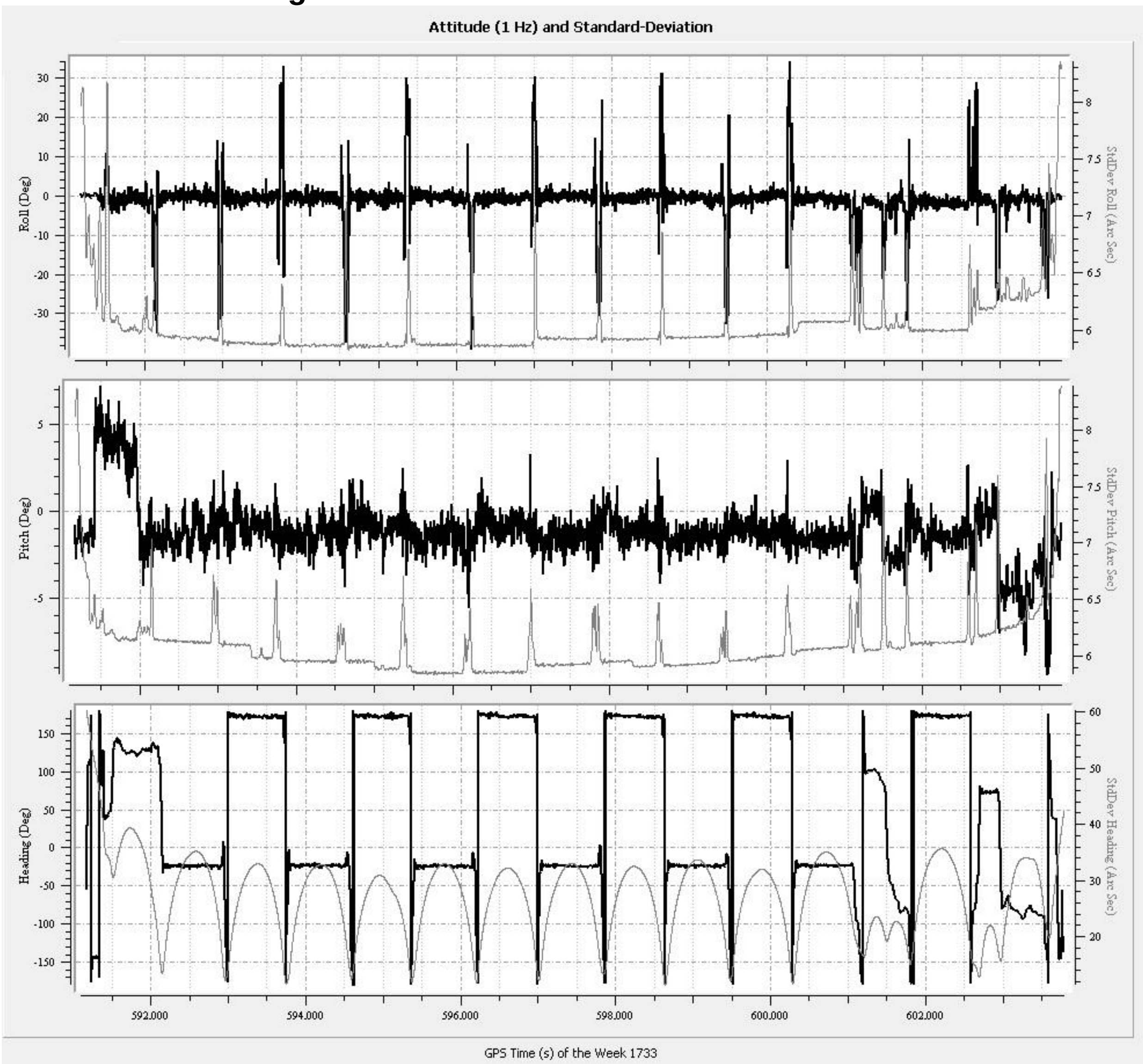


Figure 6: Position Accuracy and PDOP

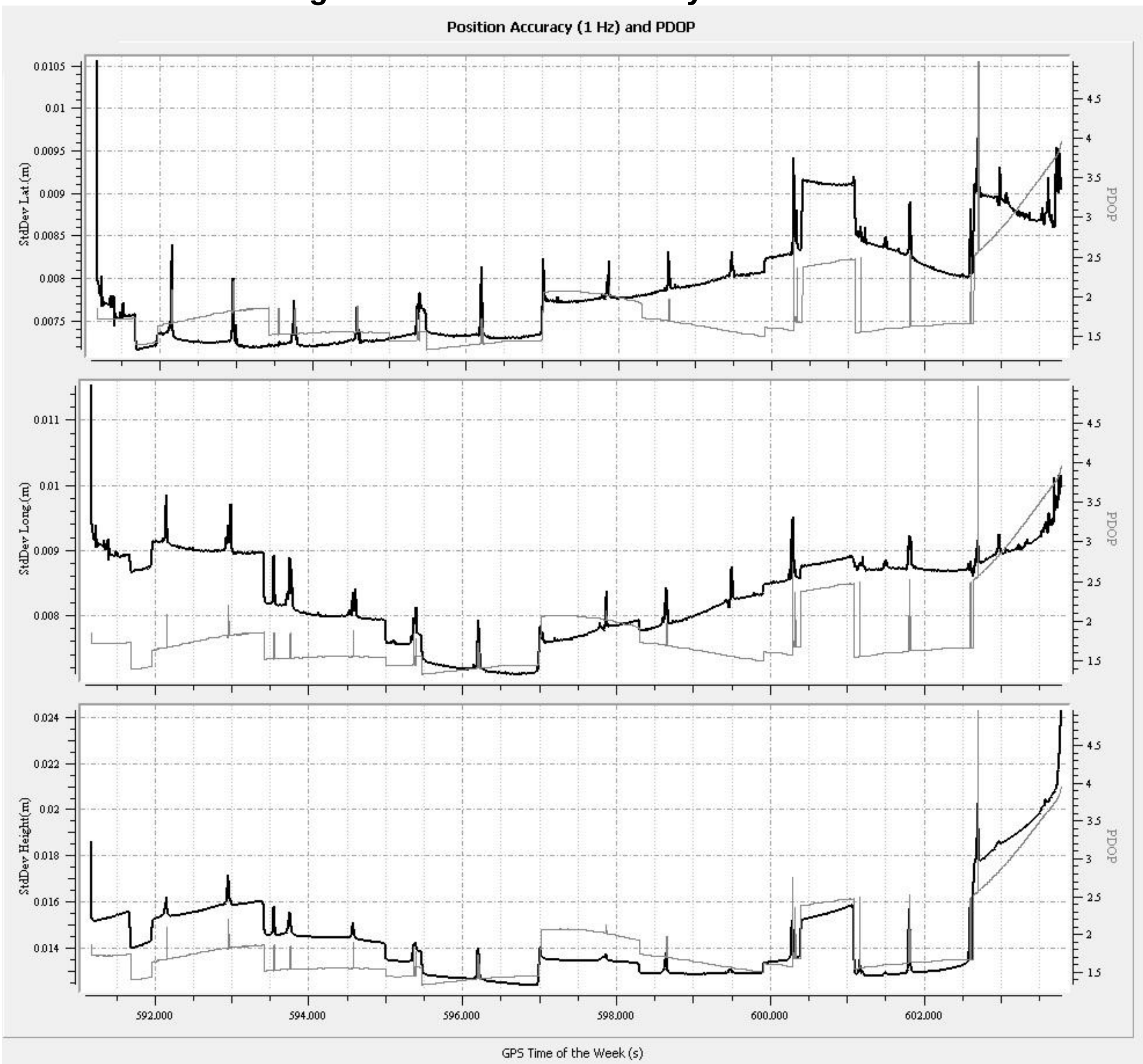


Figure 7: Accelerometer Bias Estimation

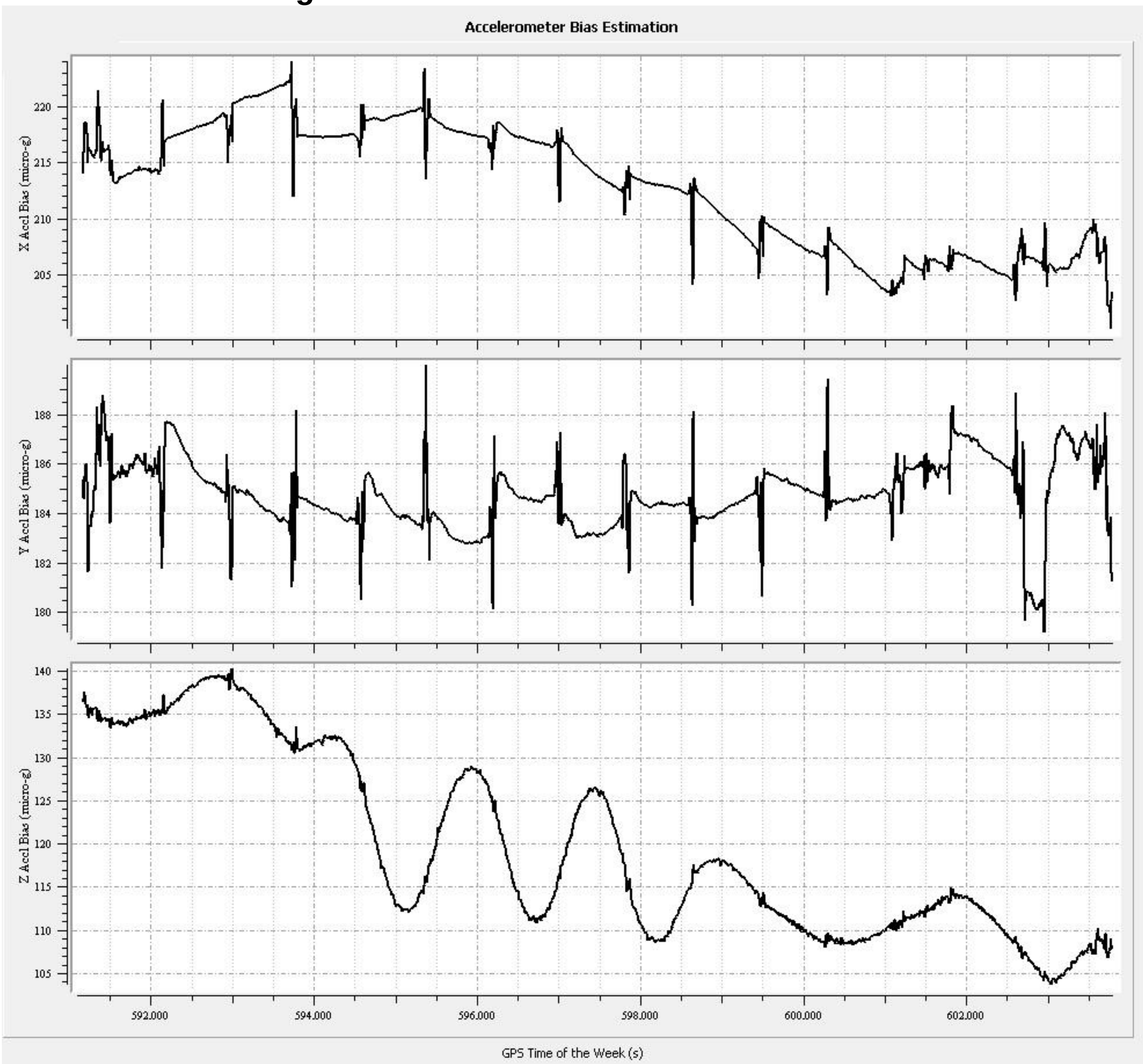


Figure 8: Kalman Filter Residuals and Position Accuracy

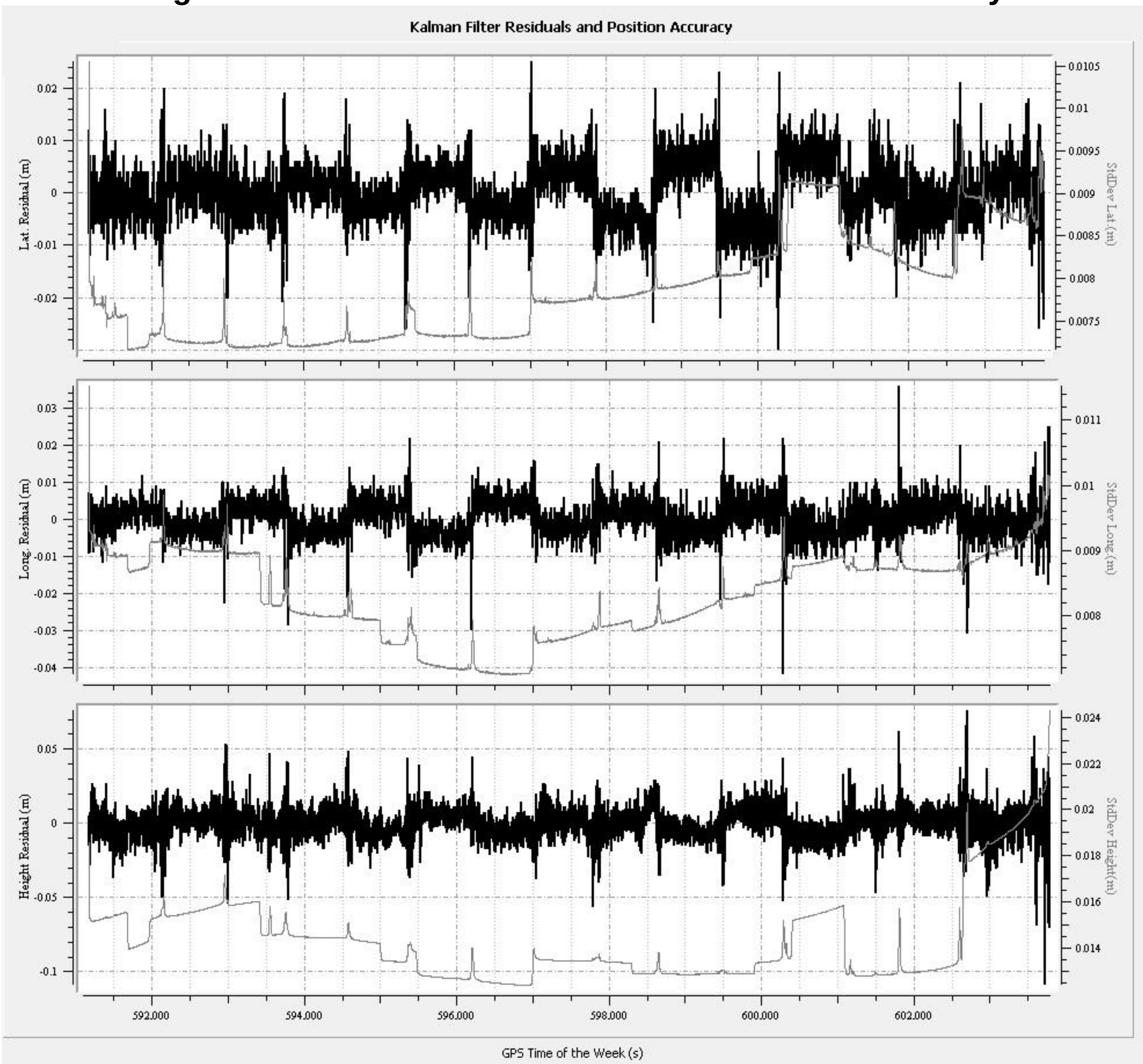
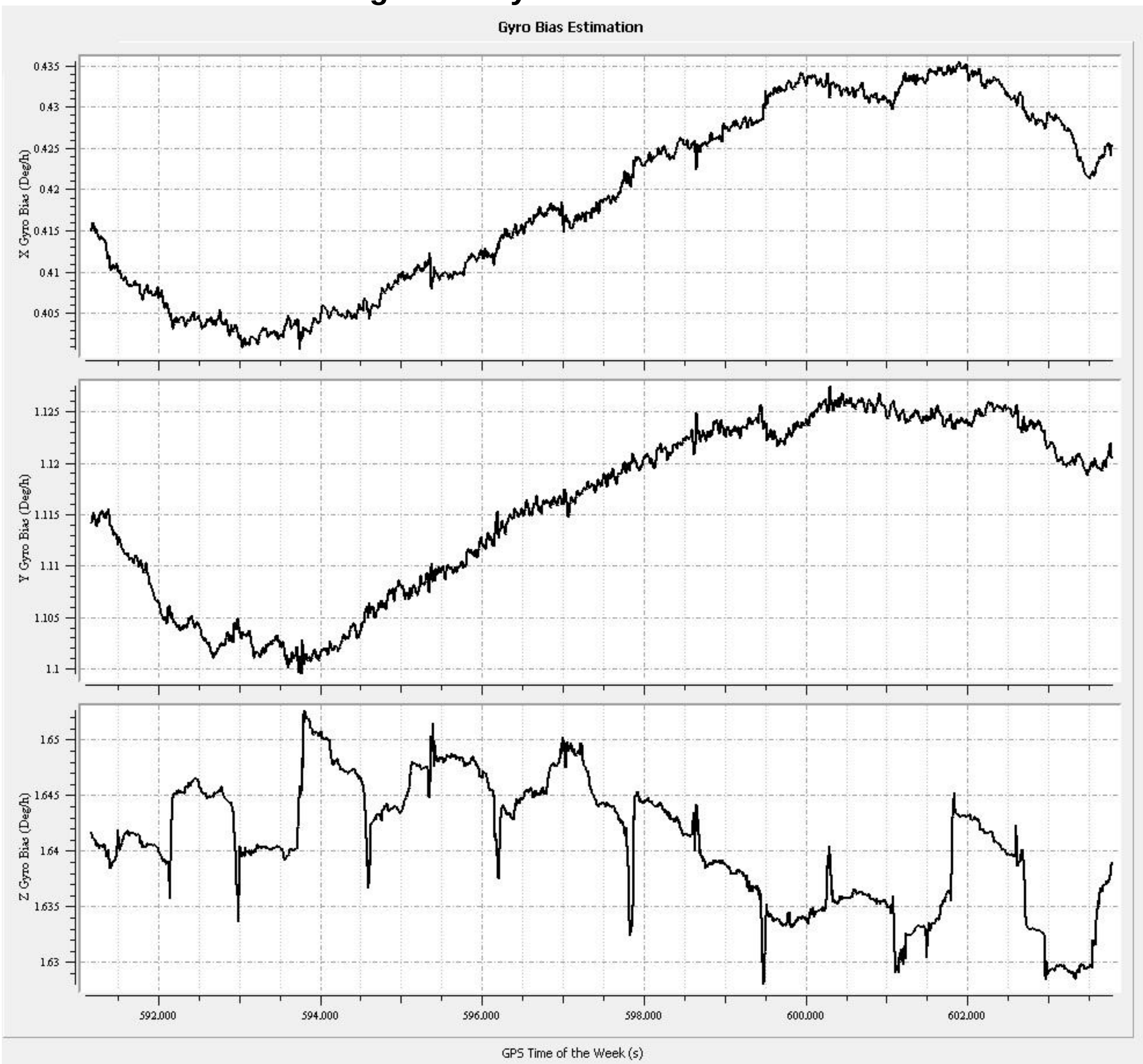


Figure 9: Gyro Bias Estimation



Output Results for JD13090_1

Figure 1: Trajectory Map

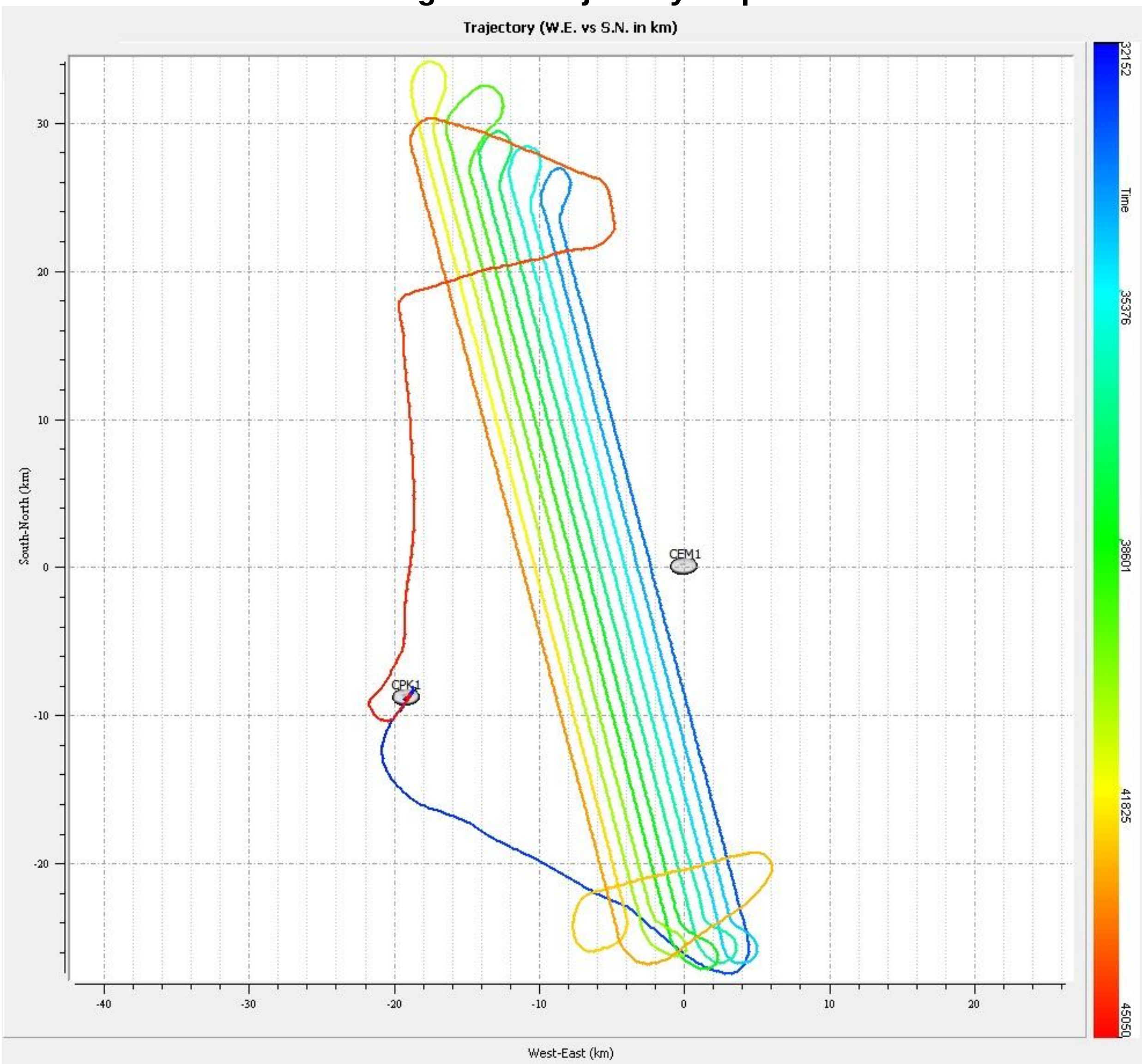


Figure 2: Position and Standard Deviation

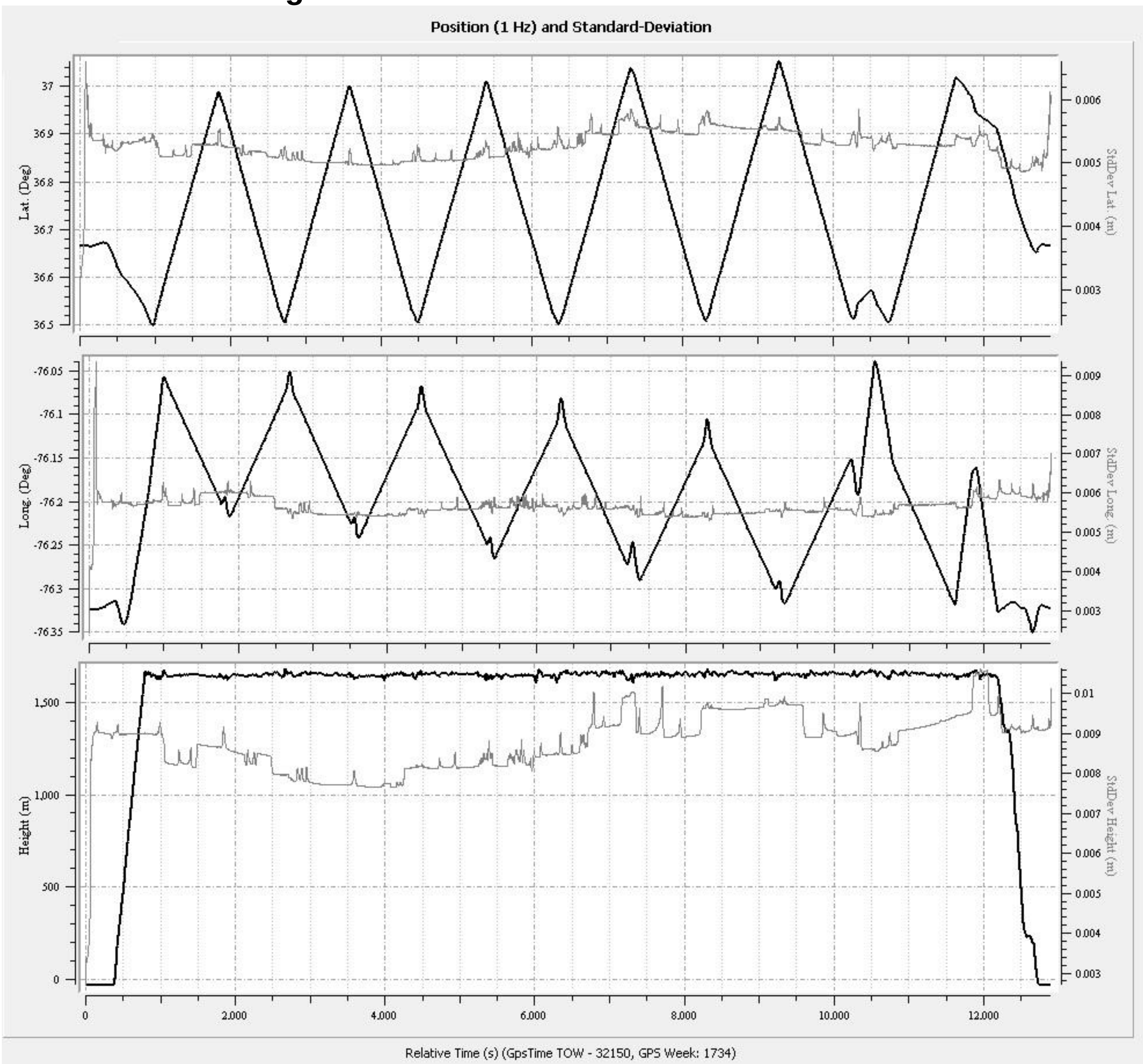


Figure 3: Velocity and Standard Deviation

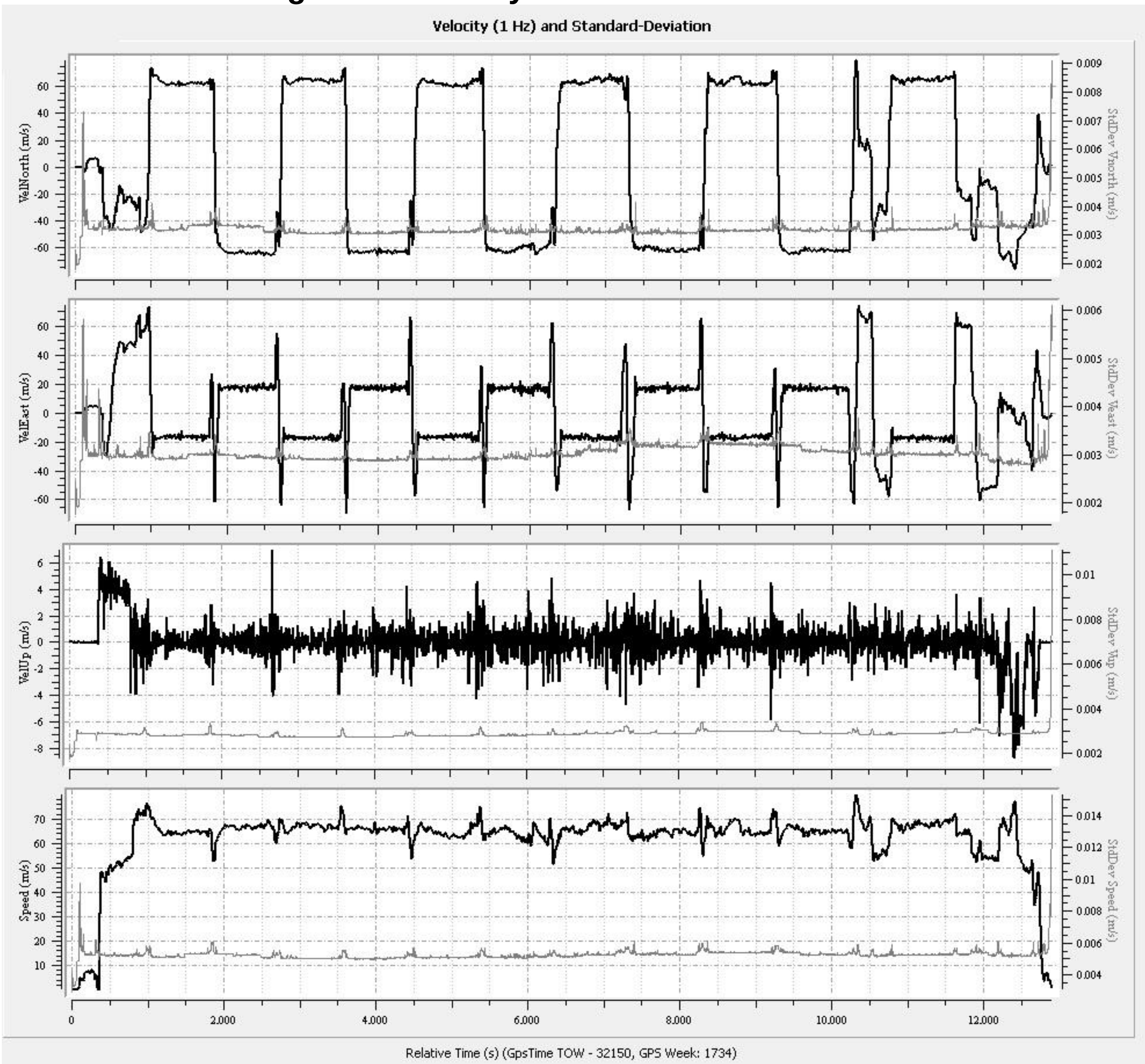


Figure 4: Forward/Reverse or Combined Separation Plot

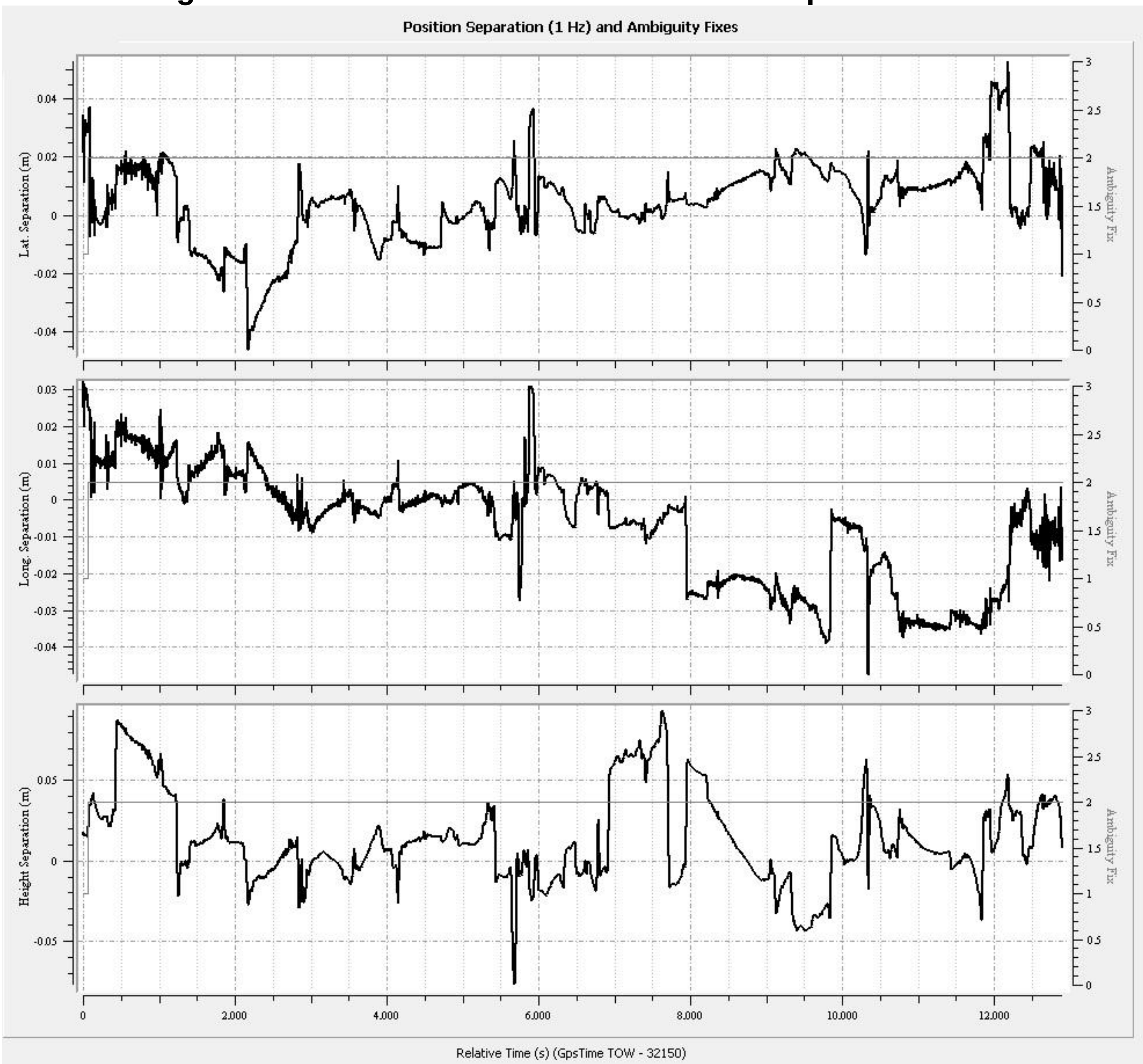


Figure 5: Attitude and Standard Deviation

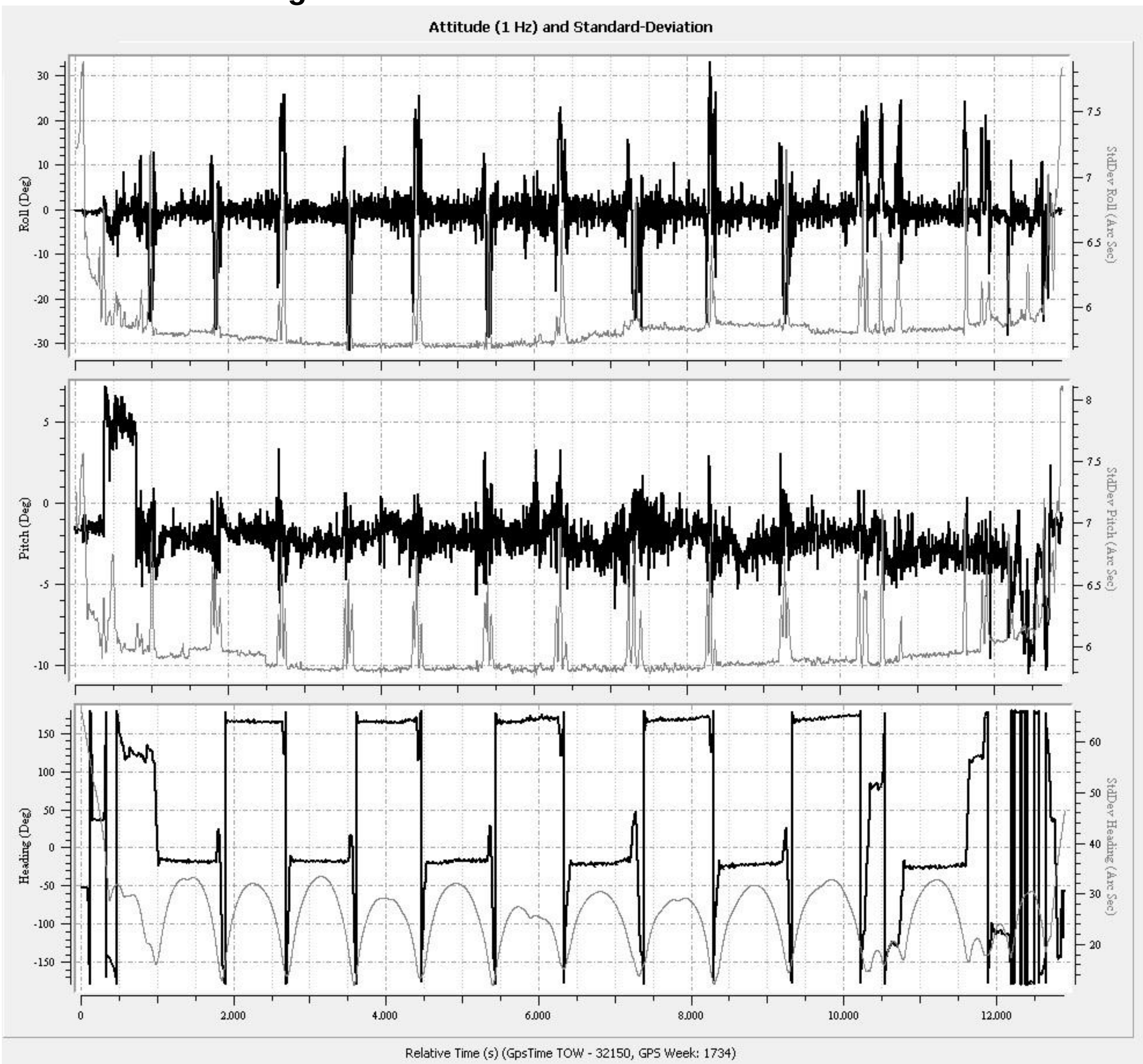


Figure 6: Position Accuracy and PDOP

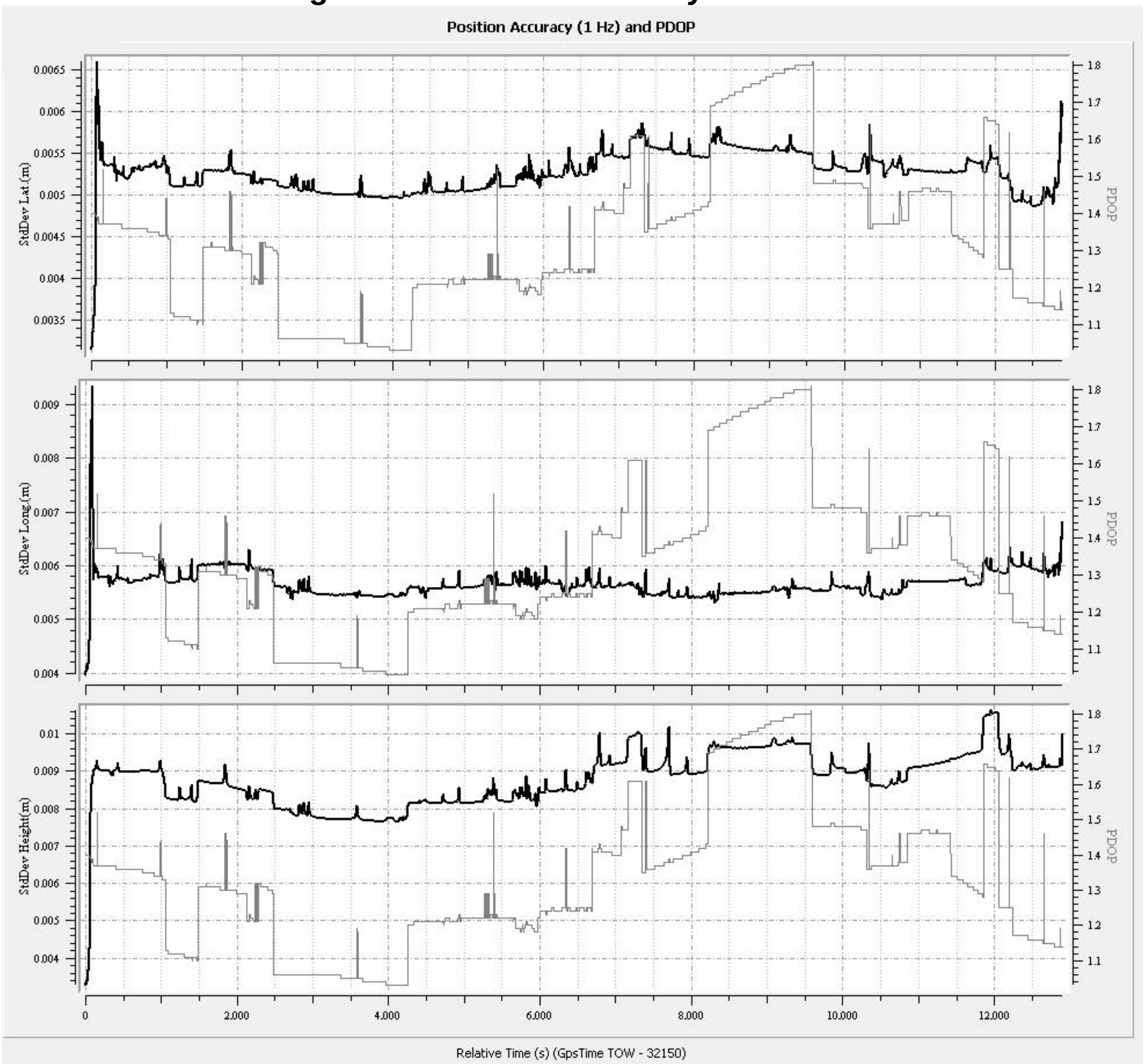


Figure 7: Accelerometer Bias Estimation

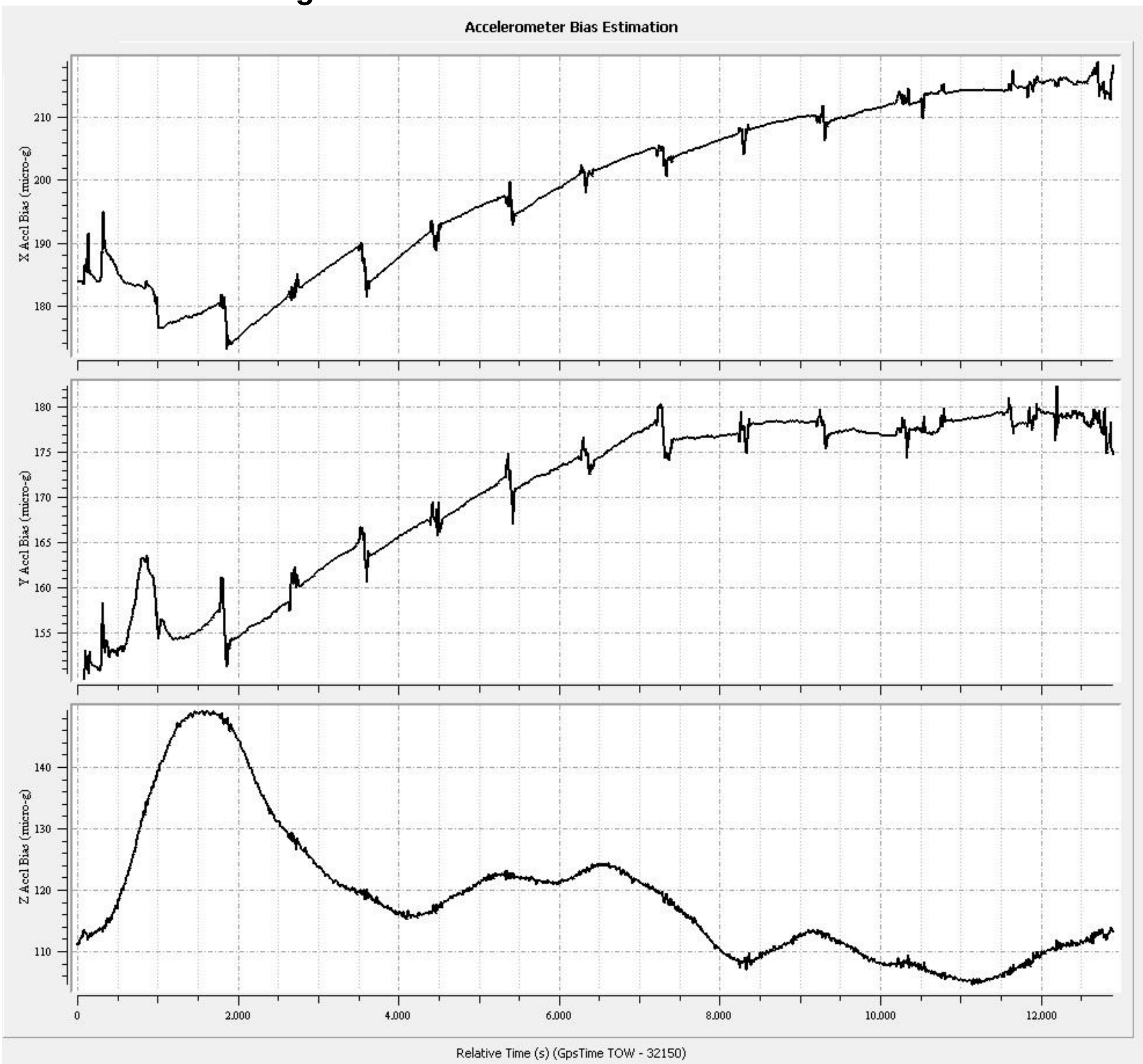


Figure 8: Kalman Filter Residuals and Position Accuracy

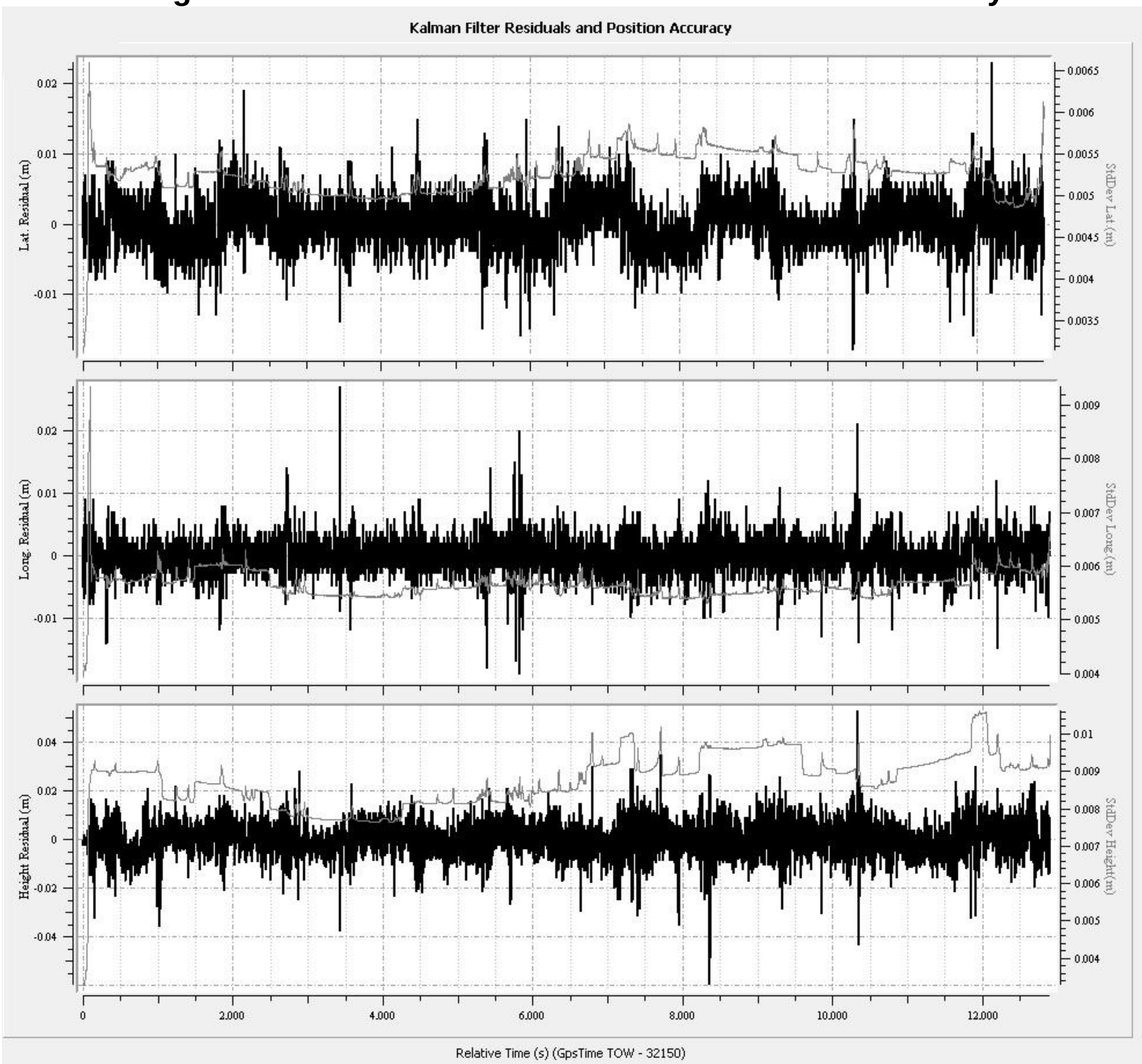
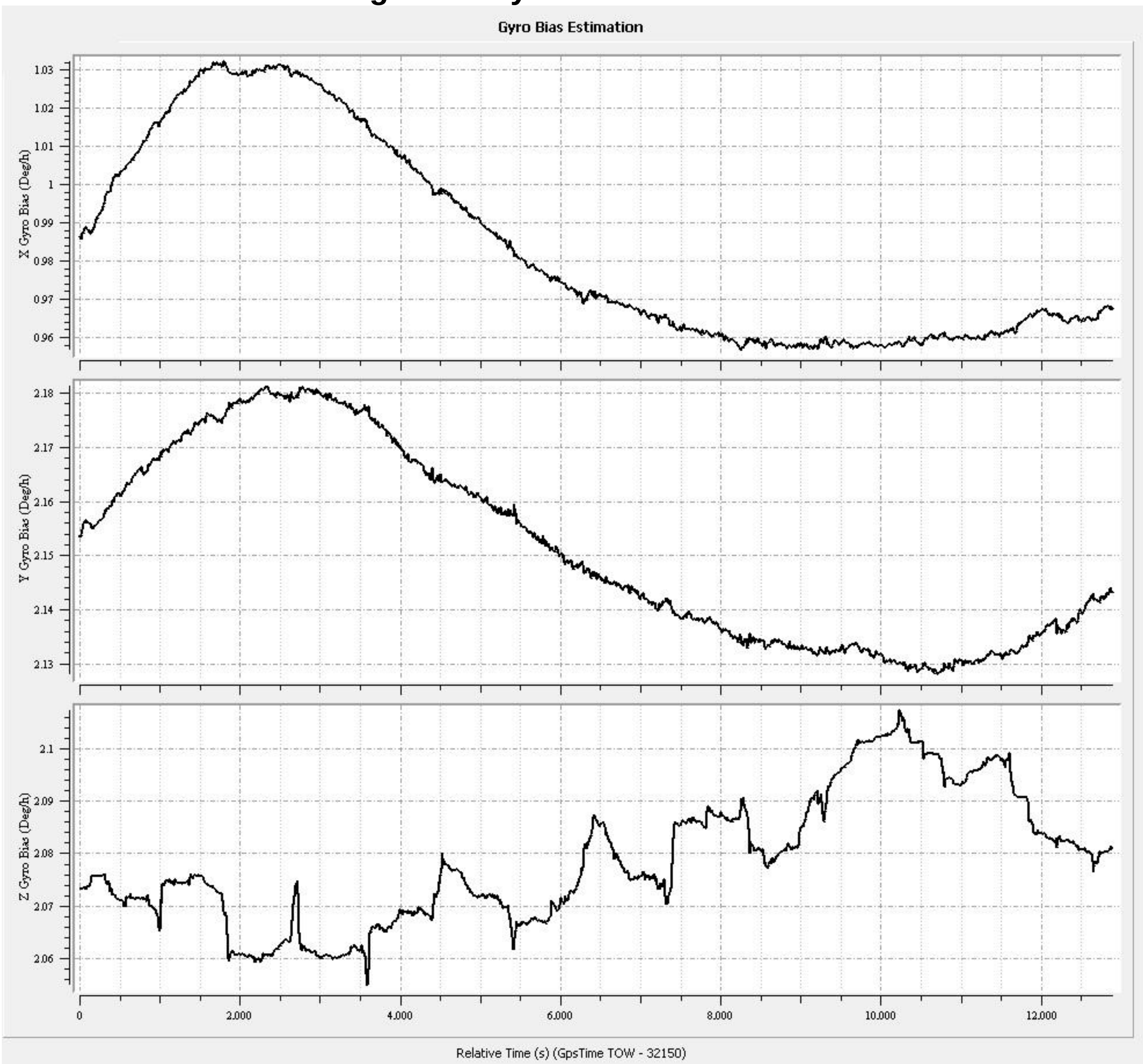


Figure 9: Gyro Bias Estimation



Output Results for JD13091_1

Figure 1: Trajectory Map

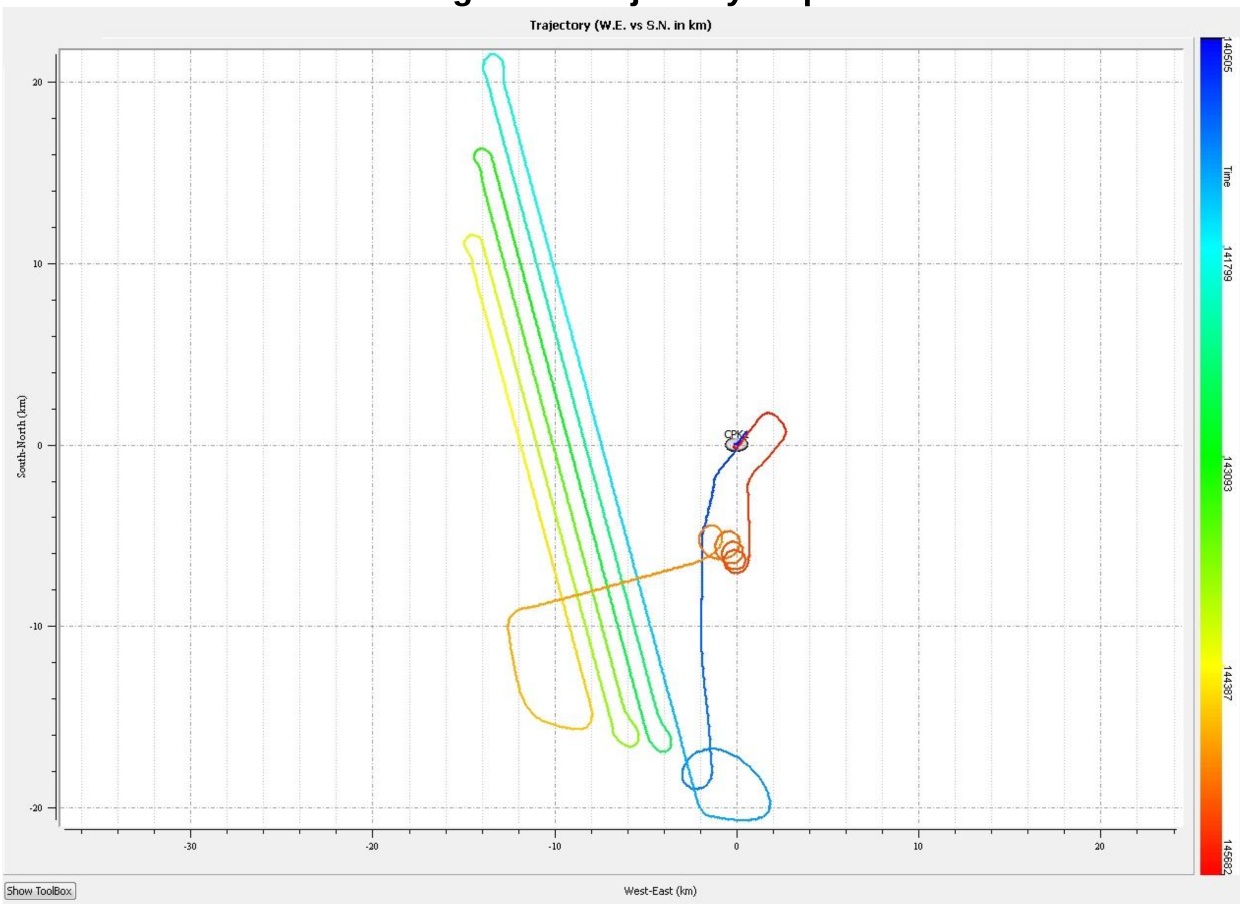


Figure 2: Position and Standard Deviation

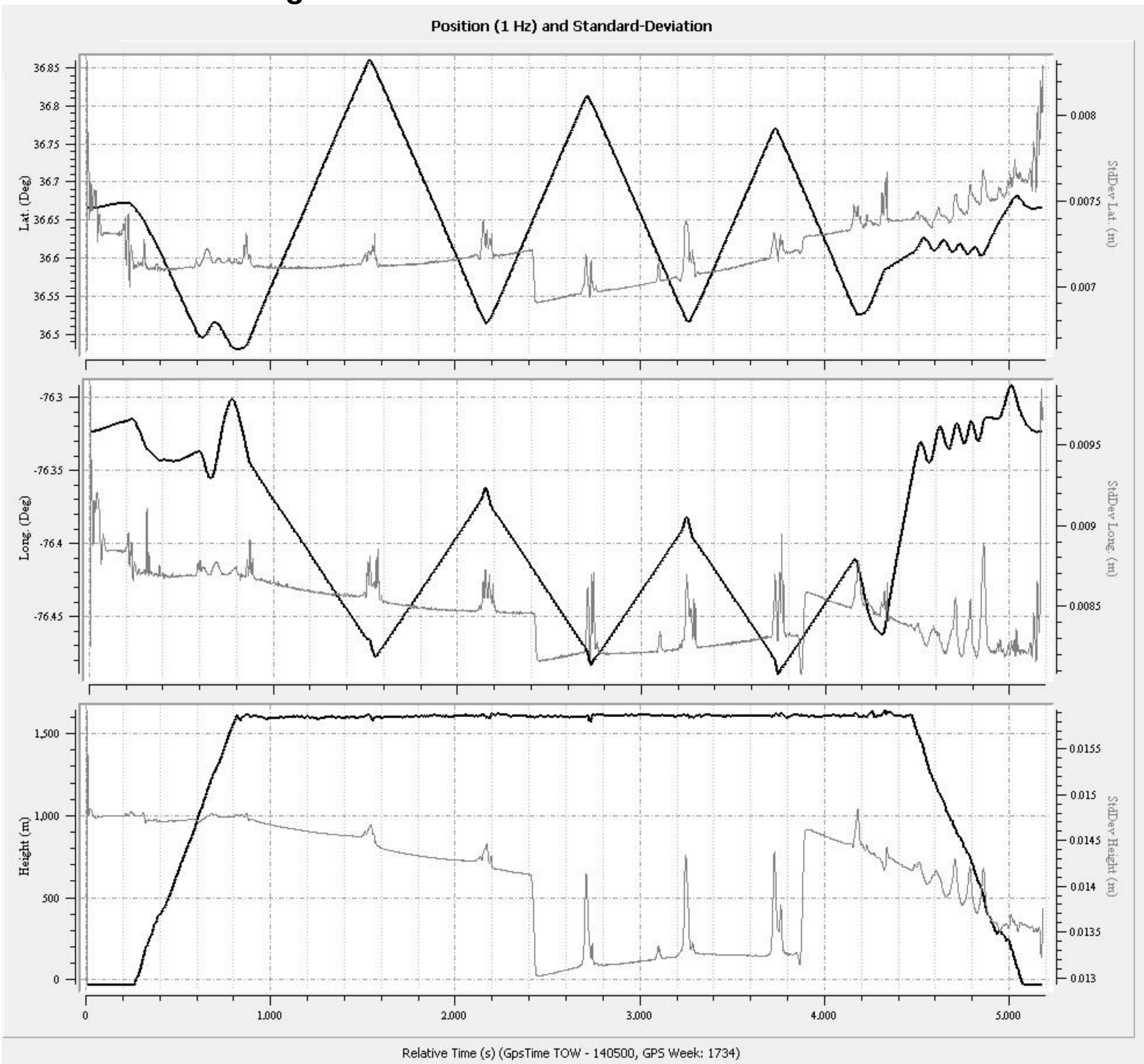


Figure 3: Velocity and Standard Deviation

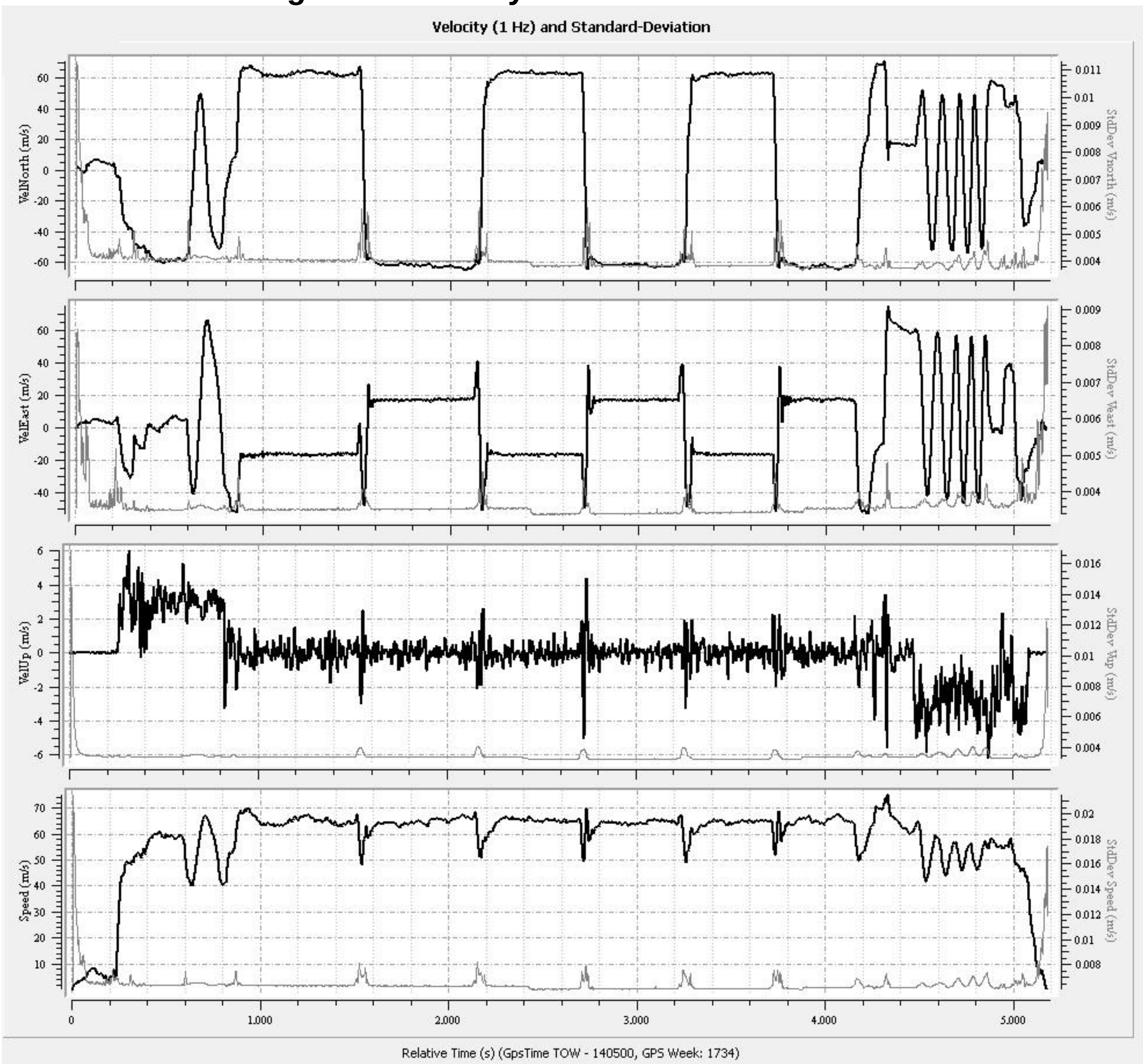


Figure 4: Forward/Reverse or Combined Separation Plot

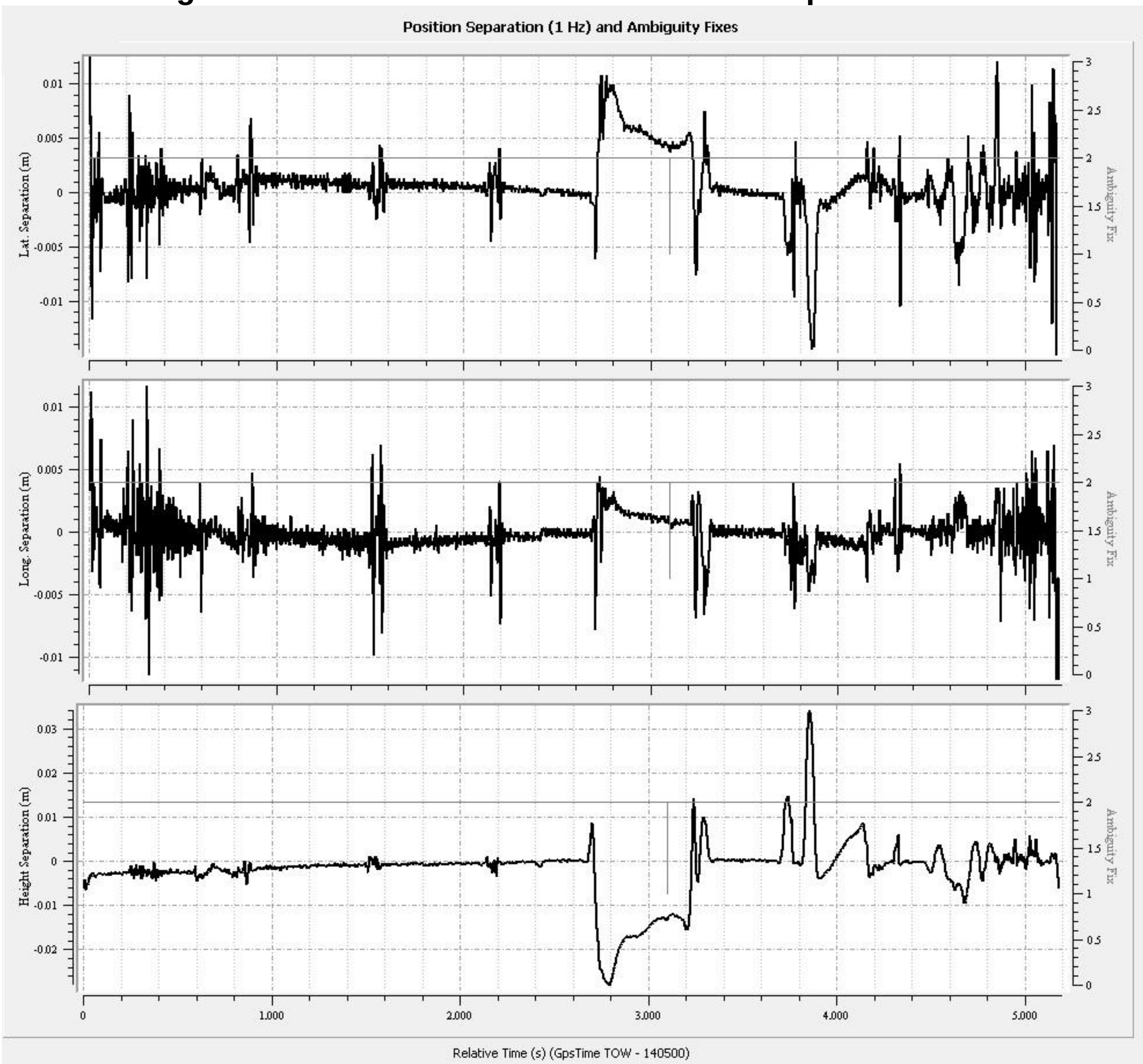


Figure 5: Attitude and Standard Deviation

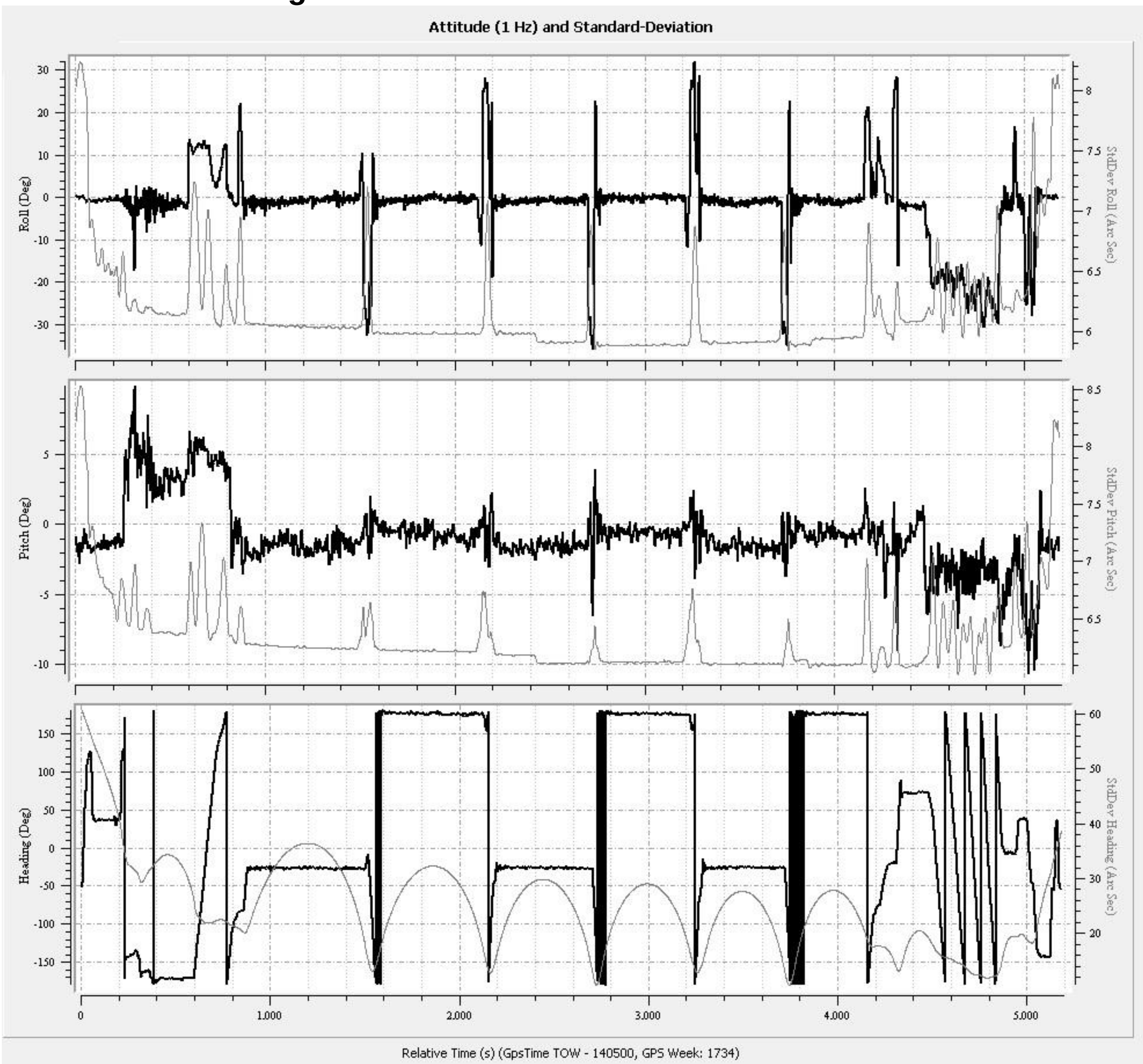


Figure 6: Position Accuracy and PDOP

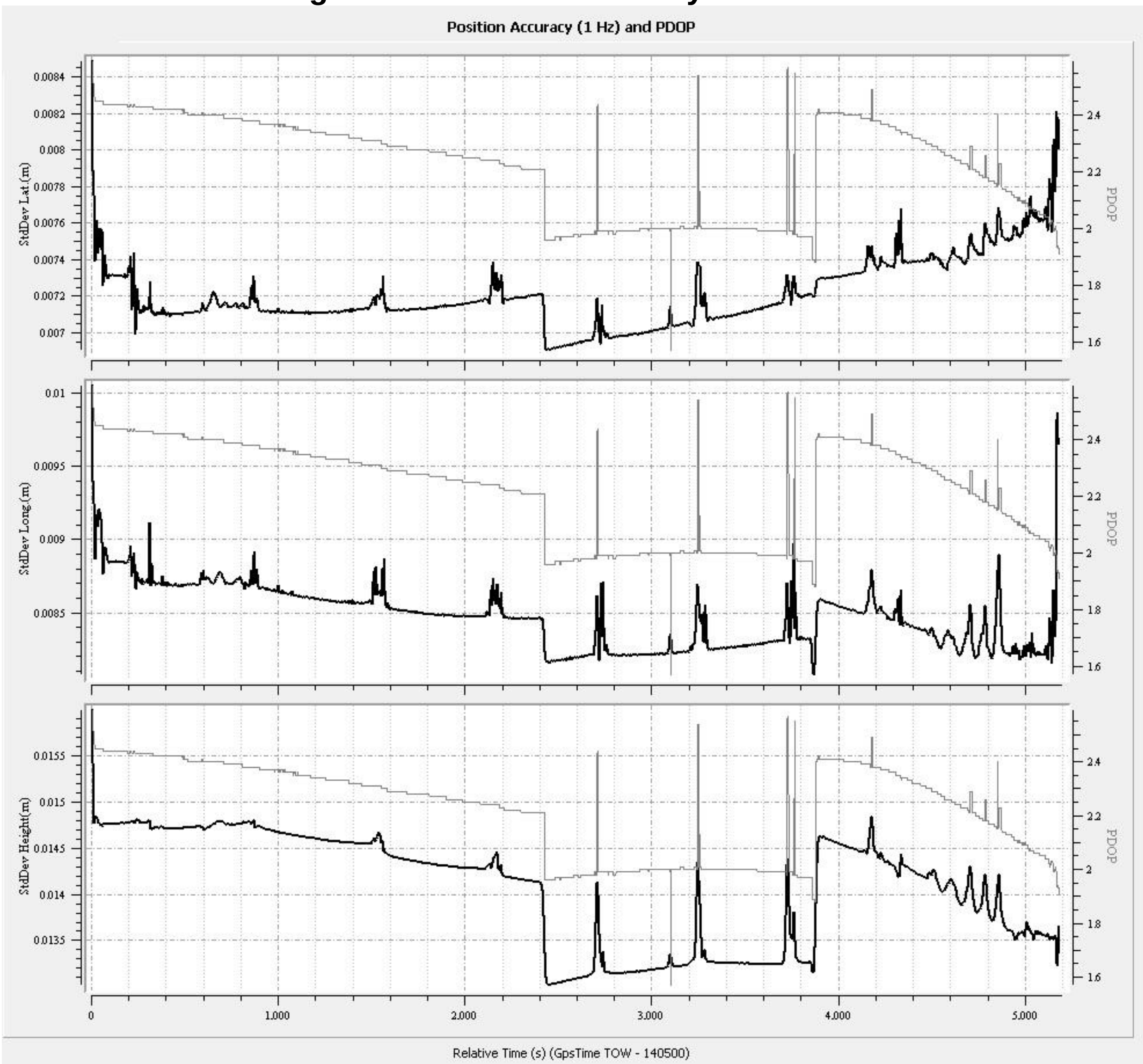


Figure 7: Accelerometer Bias Estimation

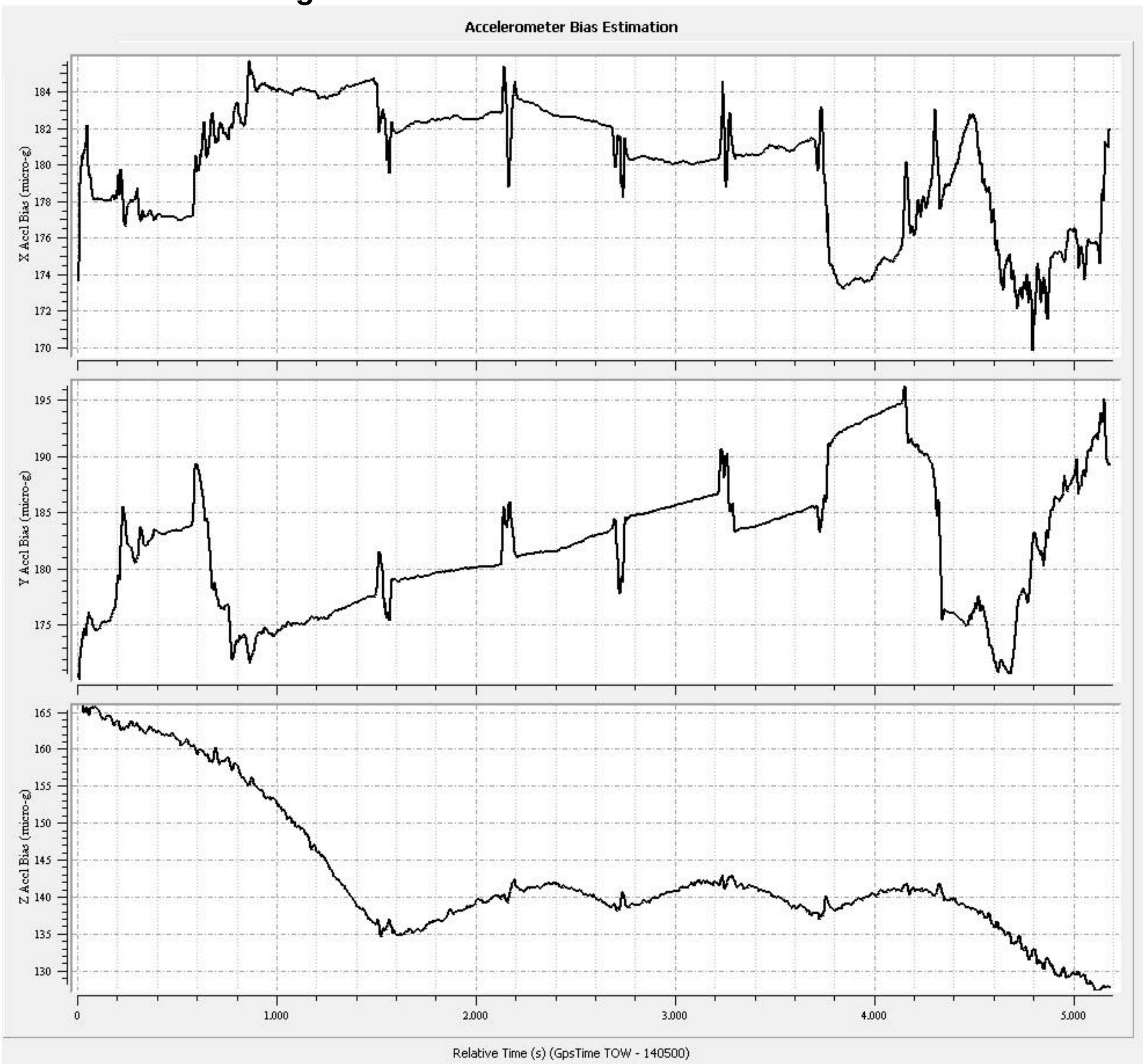


Figure 8: Kalman Filter Residuals and Position Accuracy

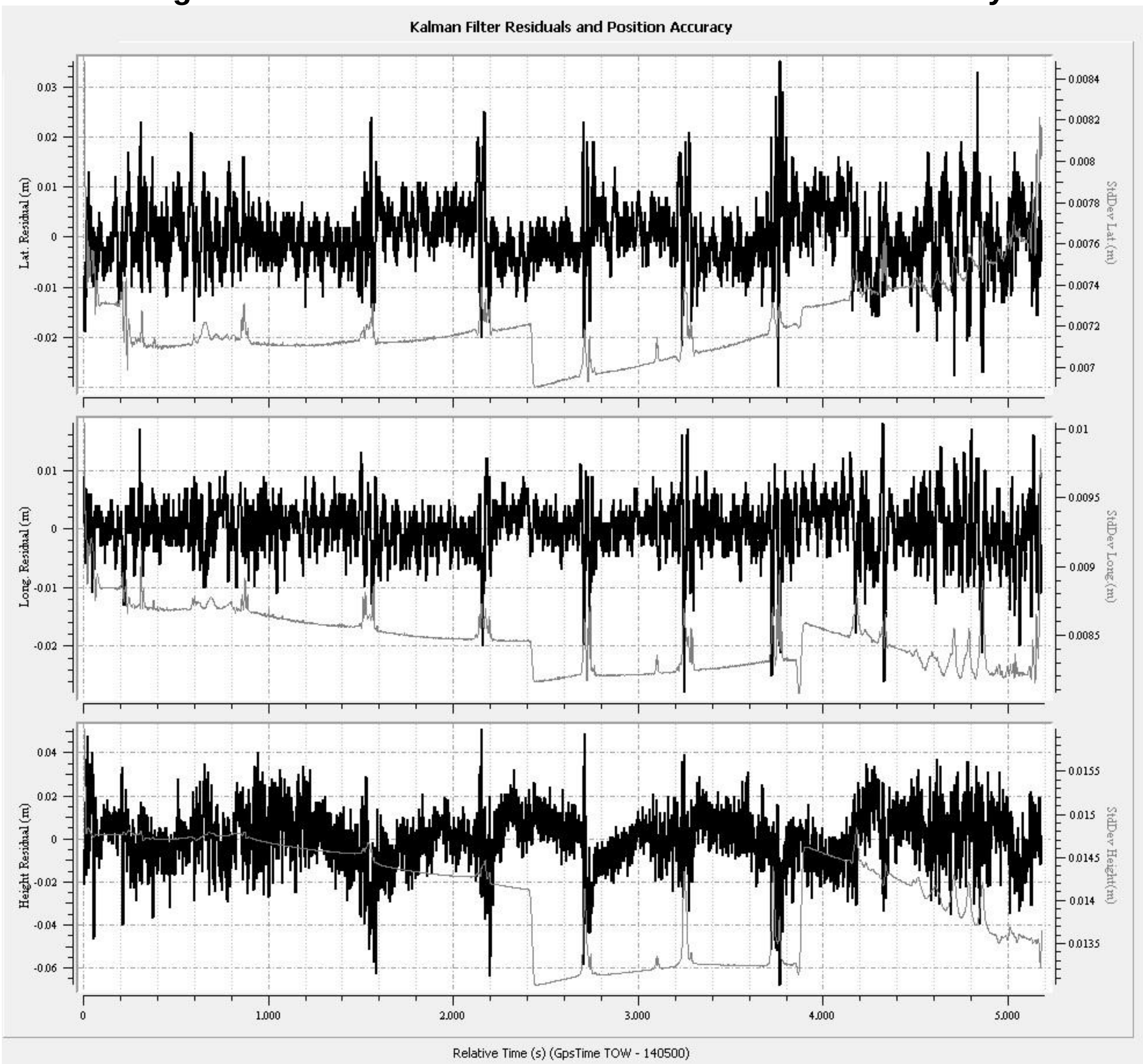
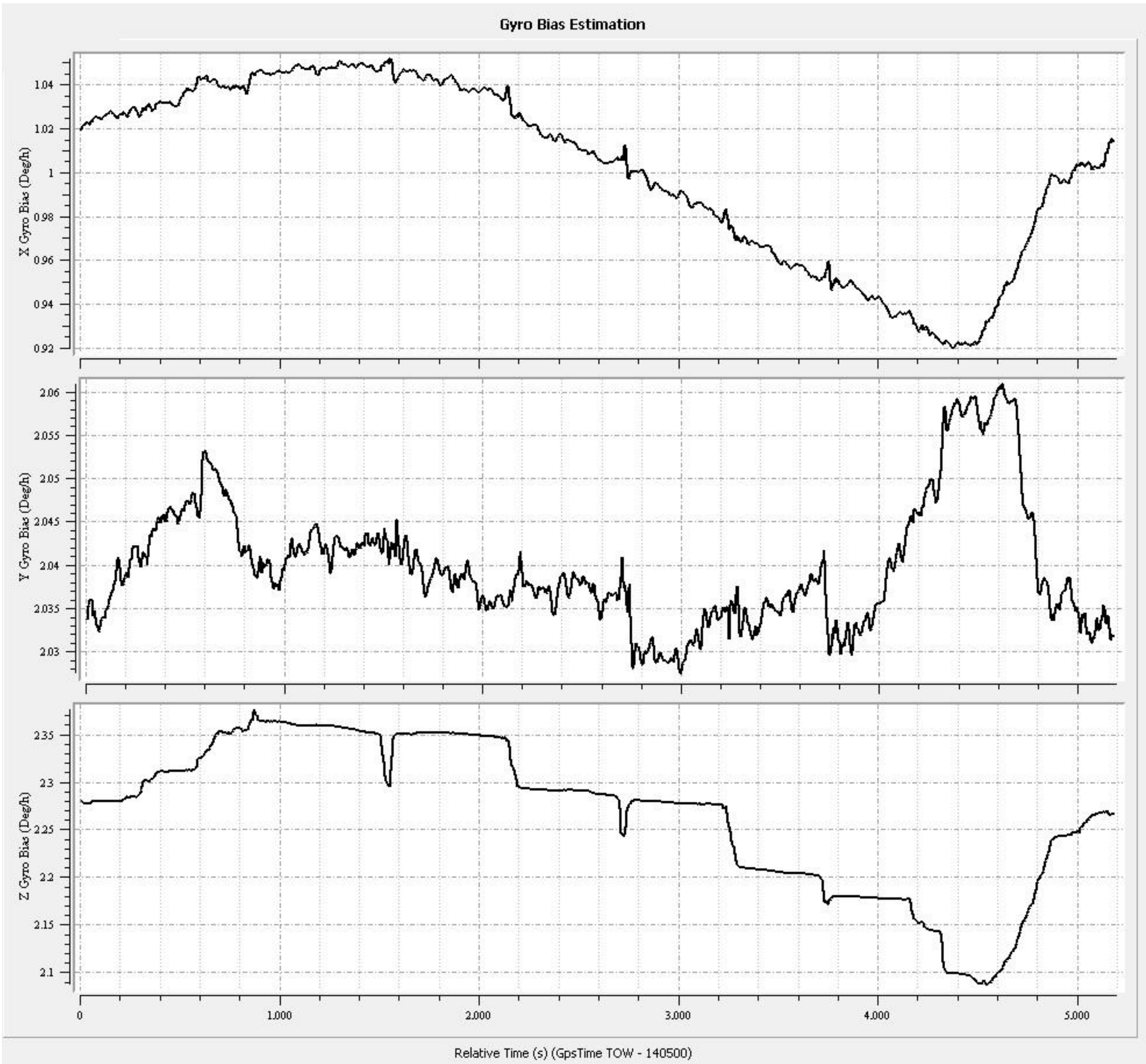


Figure 9: Gyro Bias Estimation



Output Results for JD13091_2

Figure 1: Trajectory Map

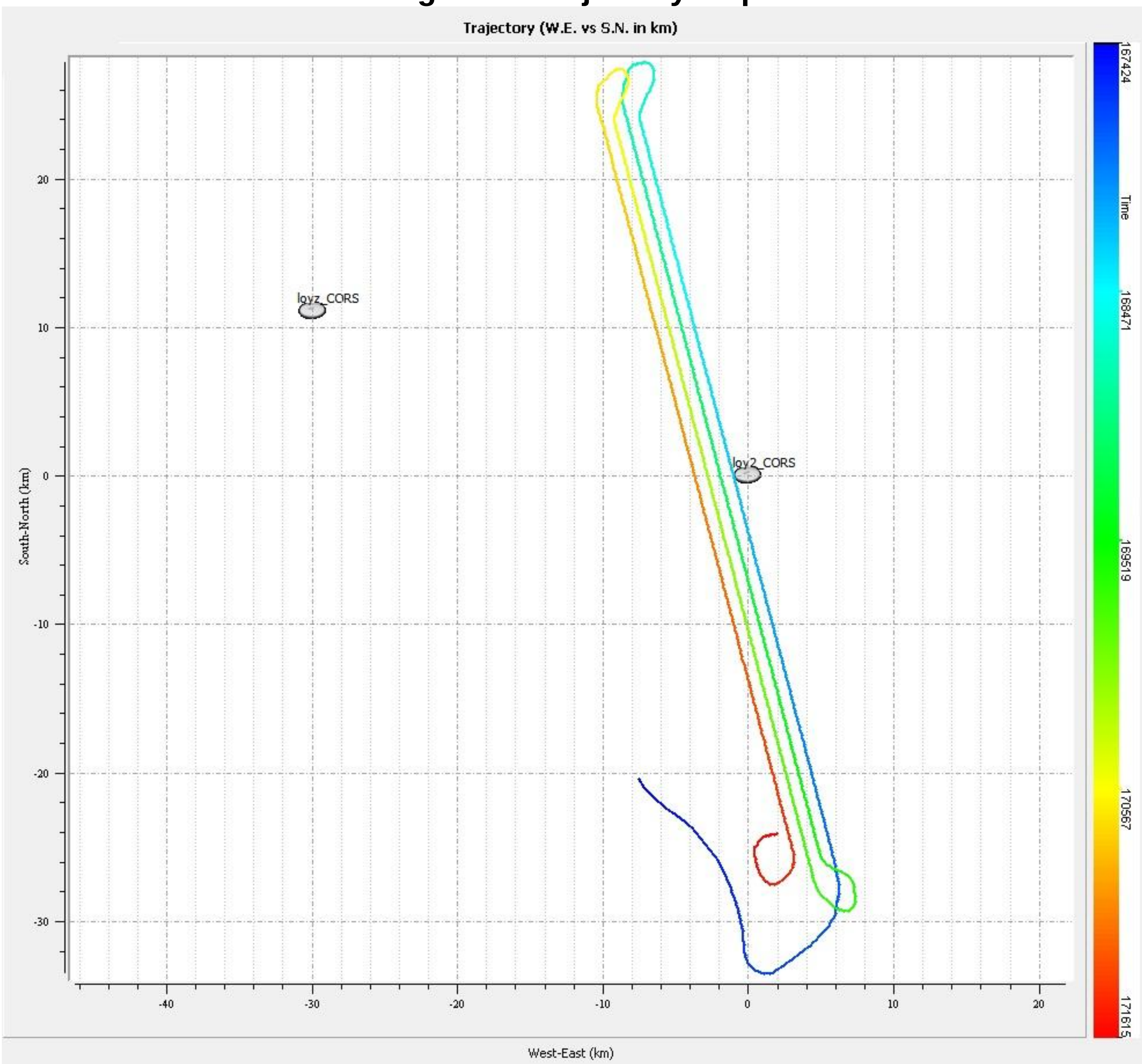


Figure 2: Position and Standard Deviation

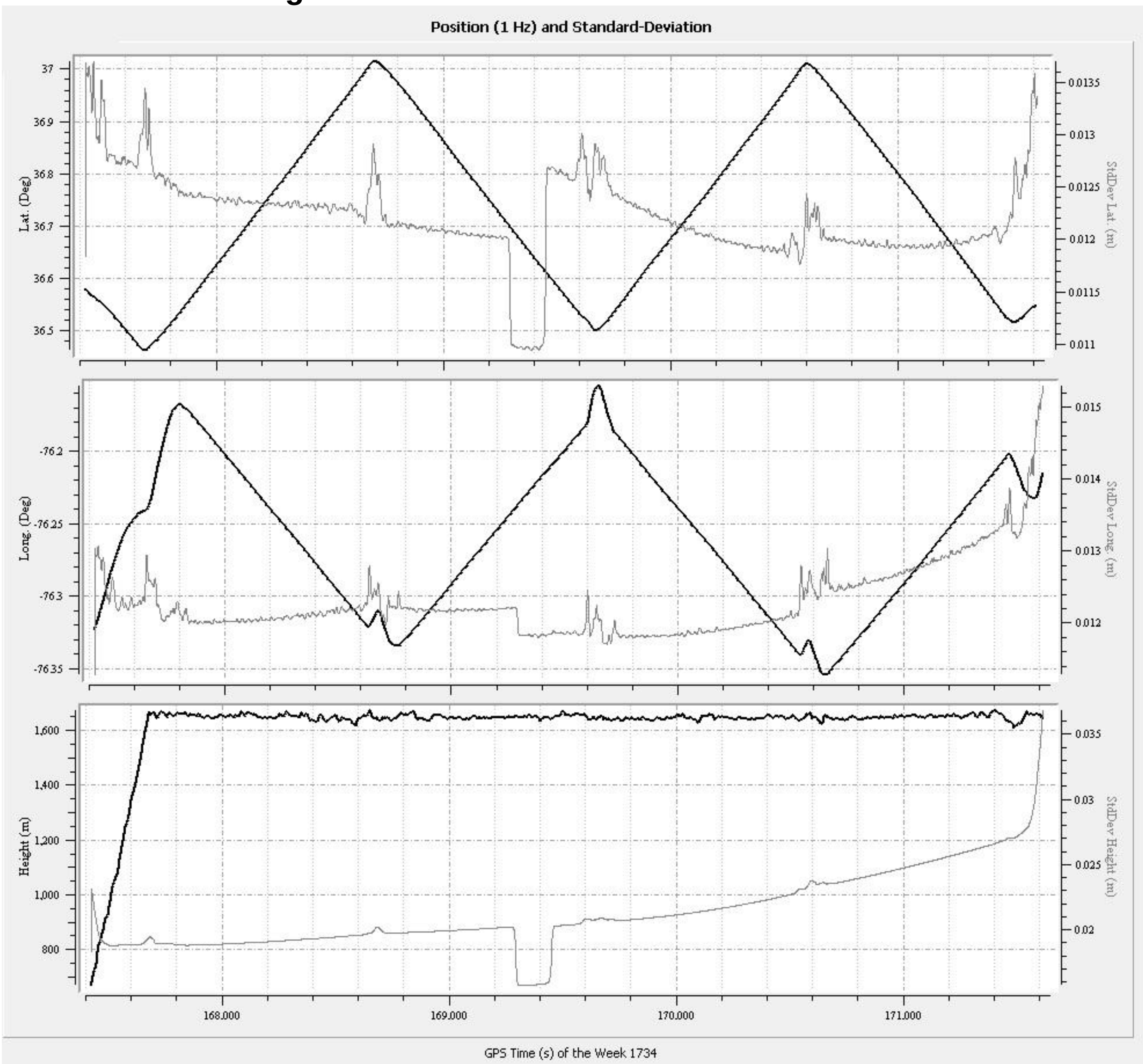


Figure 3: Velocity and Standard Deviation

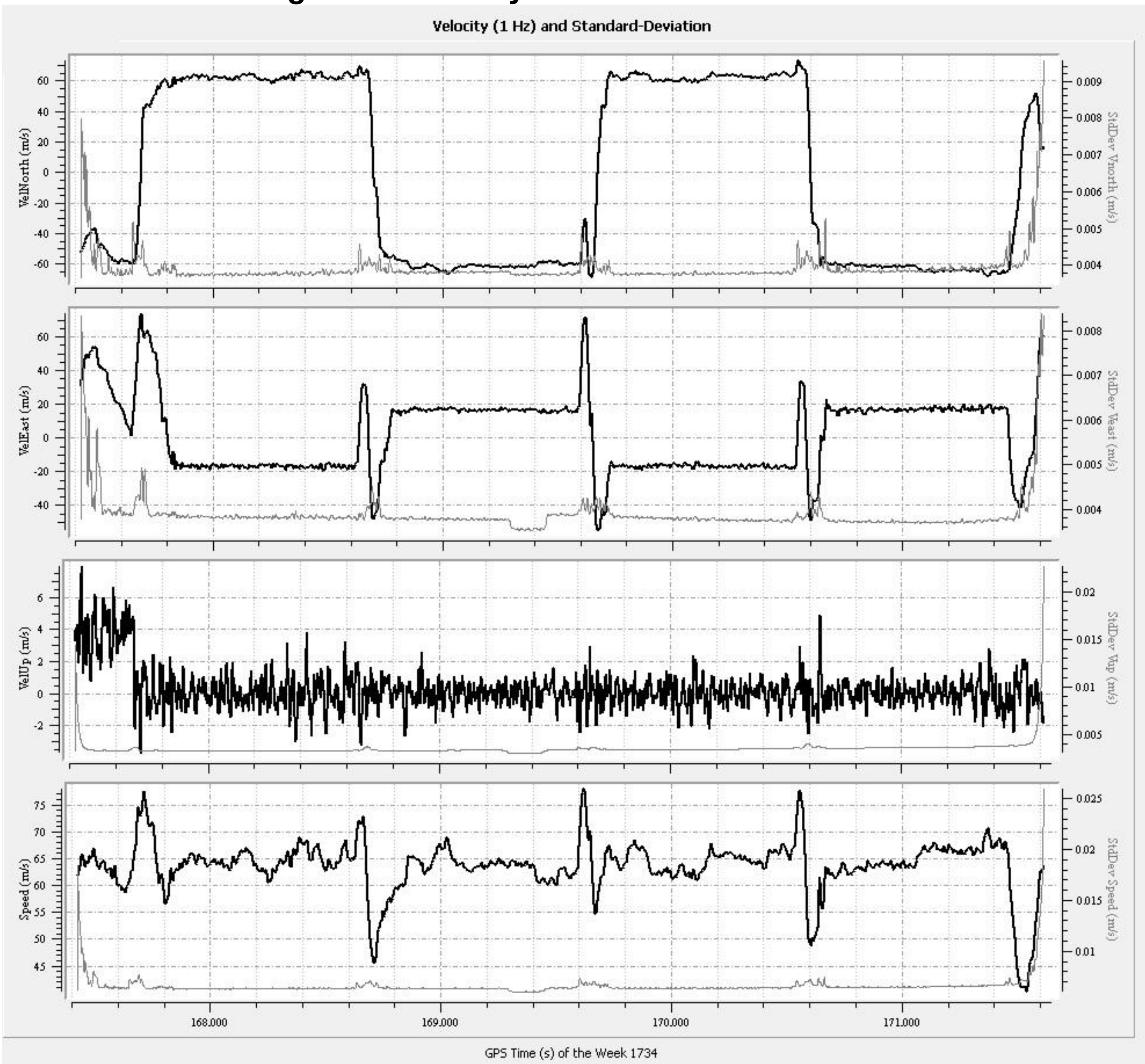


Figure 4: Forward/Reverse or Combined Separation Plot

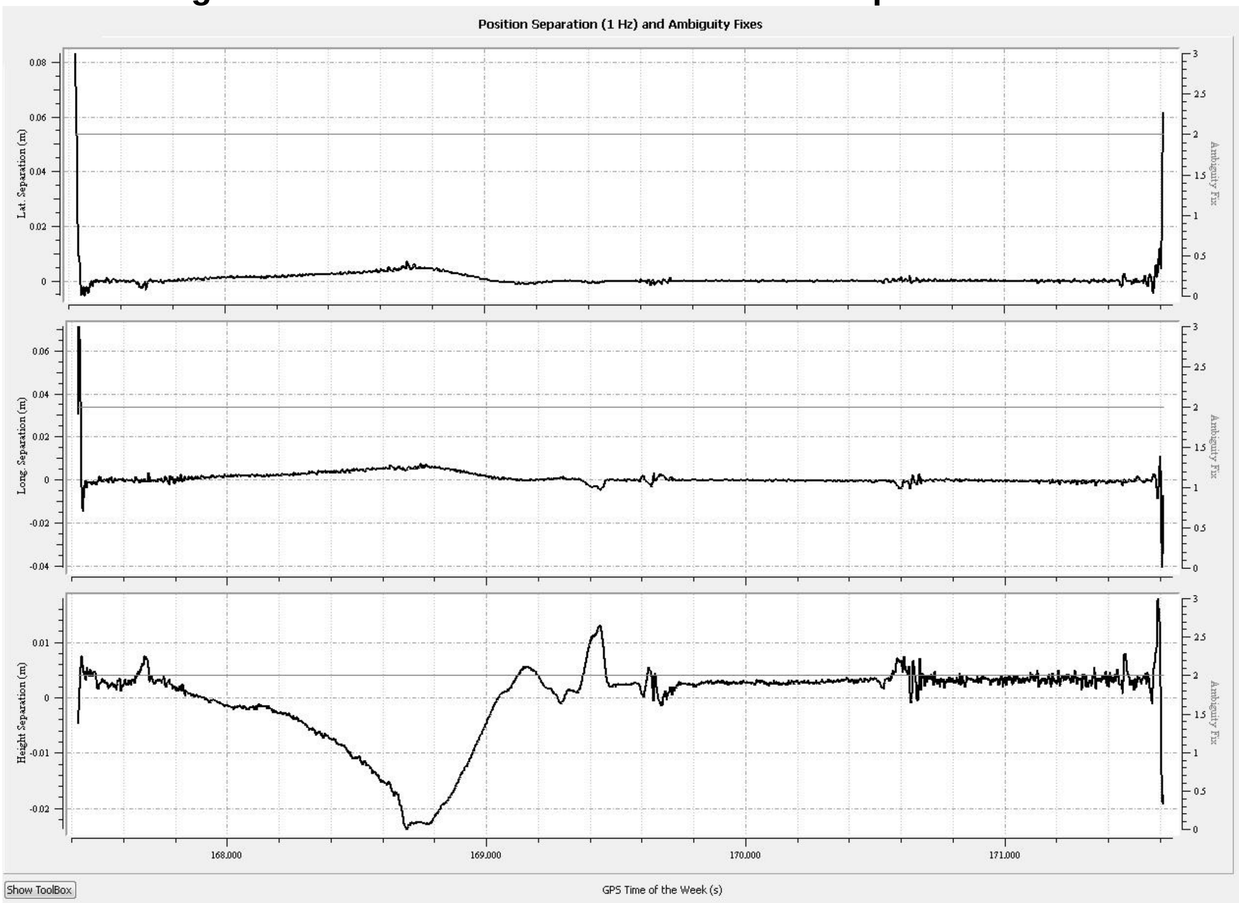


Figure 5: Attitude and Standard Deviation

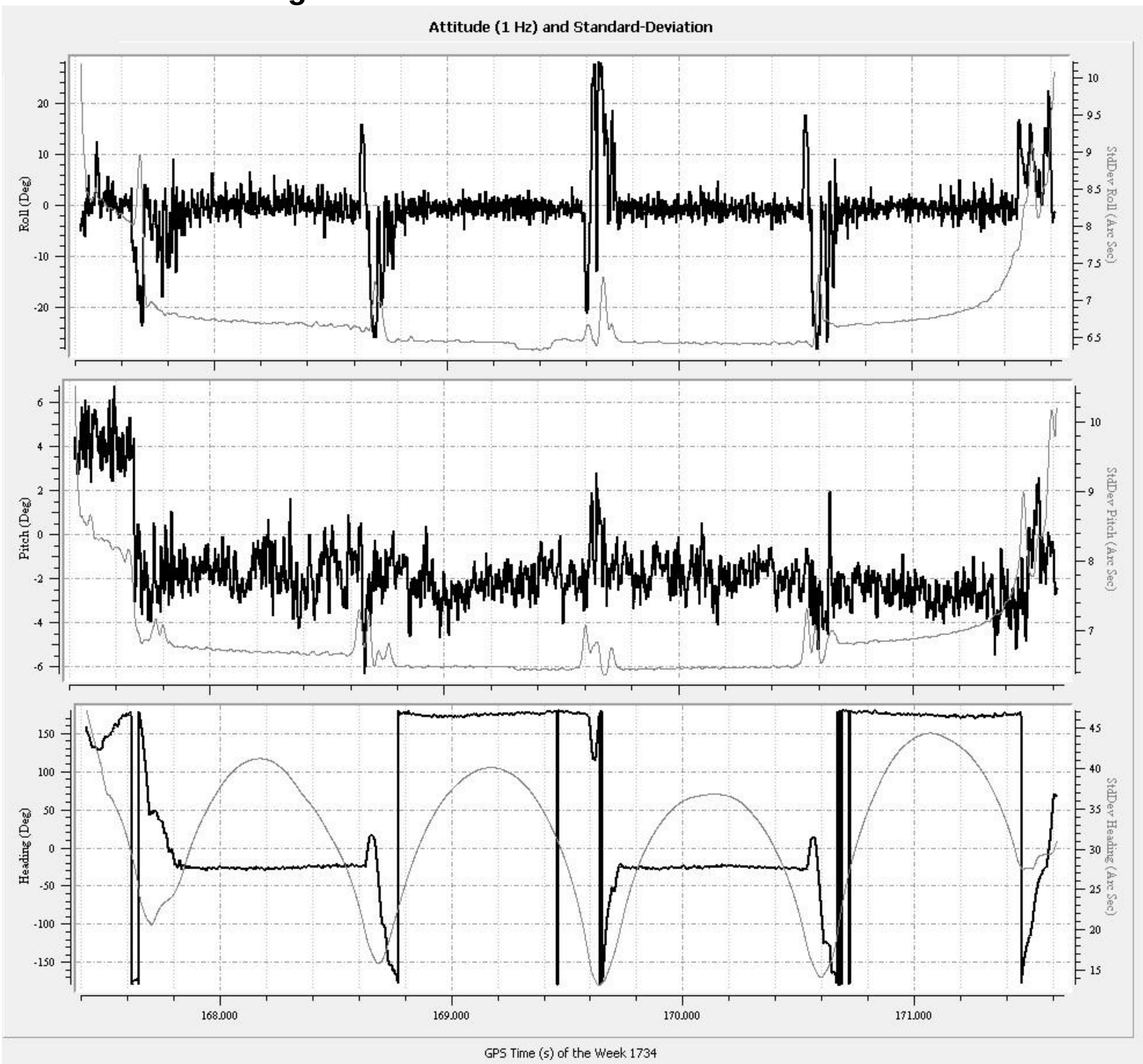


Figure 6: Position Accuracy and PDOP

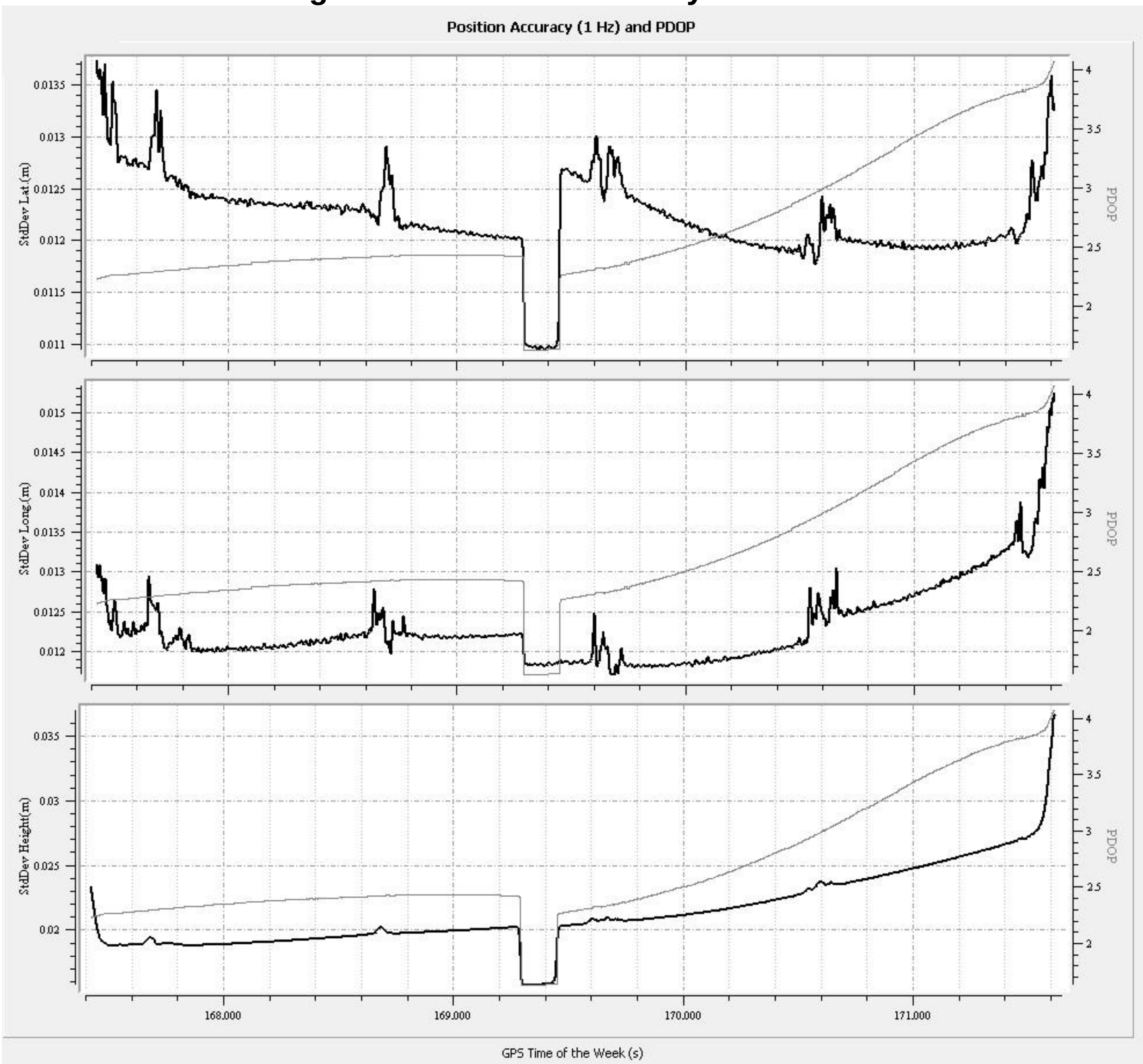


Figure 7: Accelerometer Bias Estimation

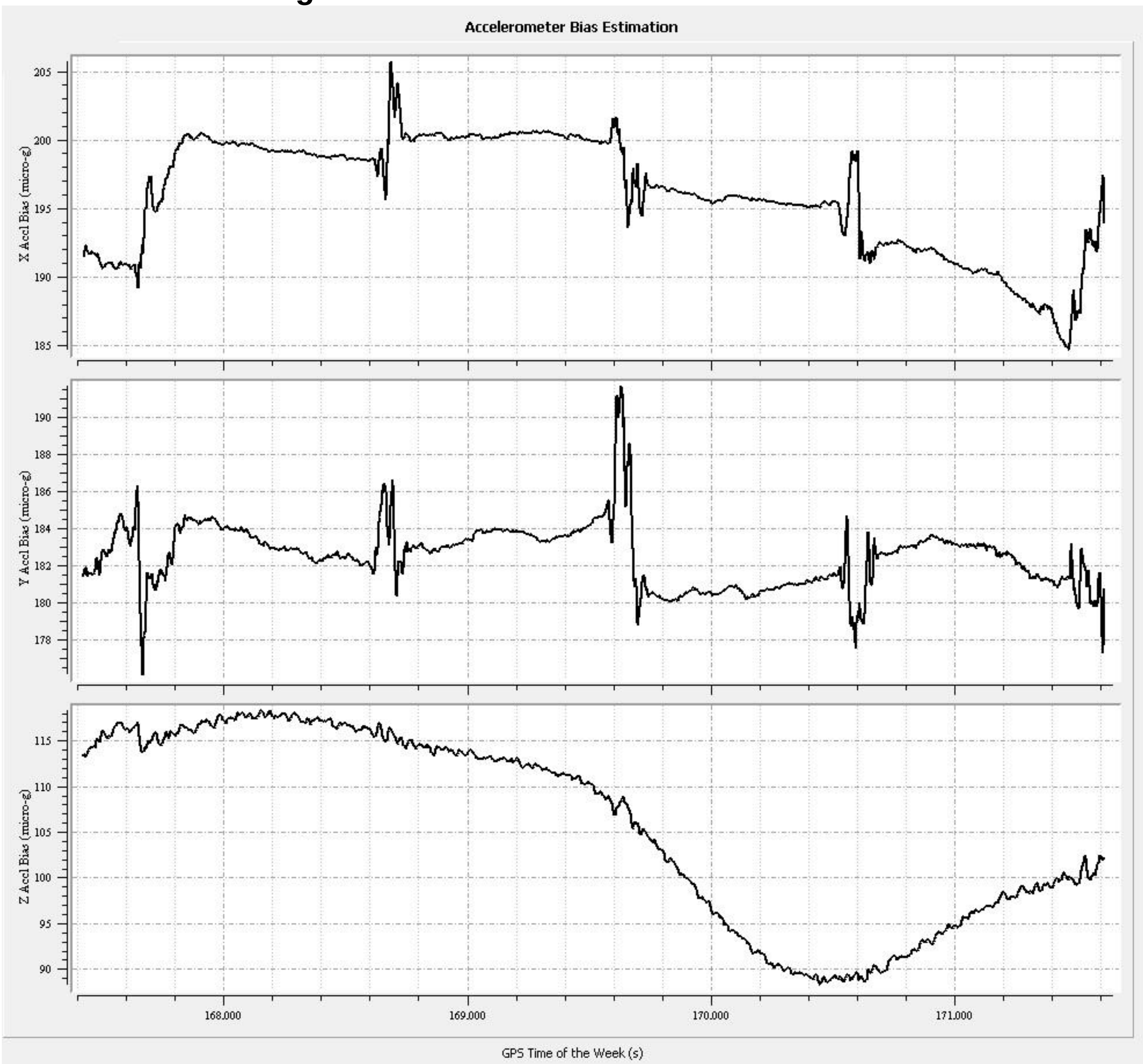


Figure 8: Kalman Filter Residuals and Position Accuracy

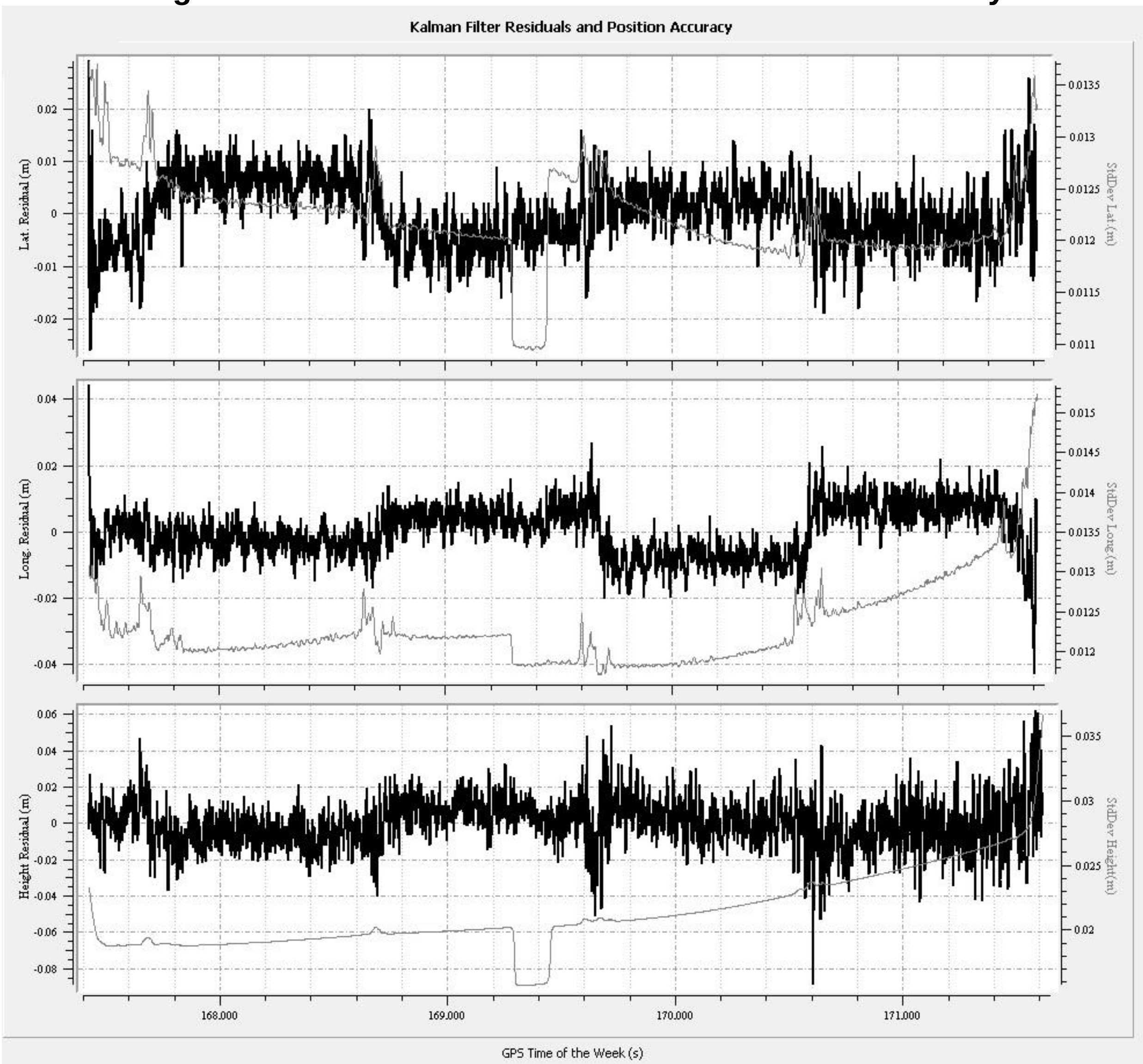
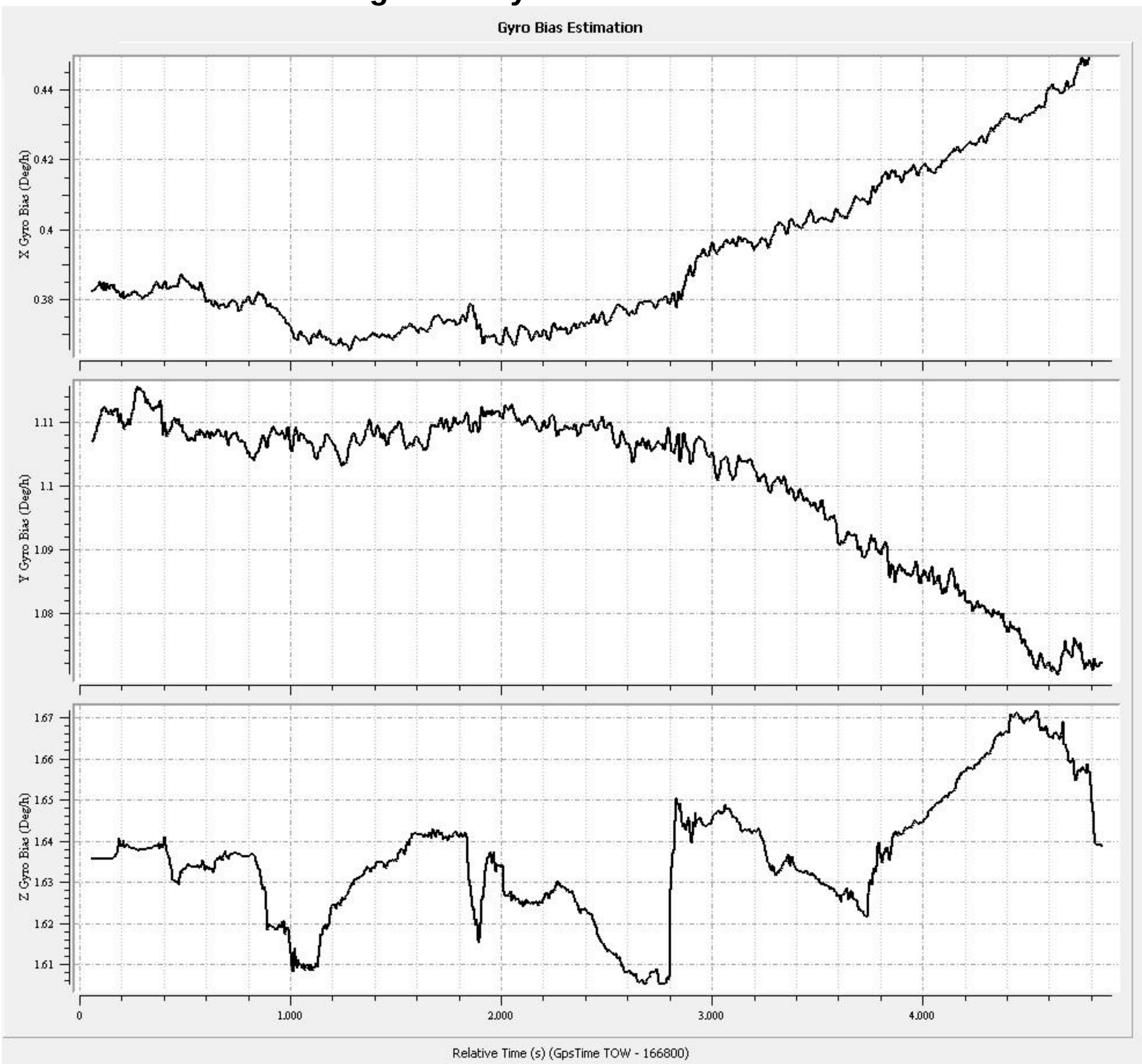


Figure 9: Gyro Bias Estimation



Output Result for JD13091_3

Figure 1: Trajectory Map

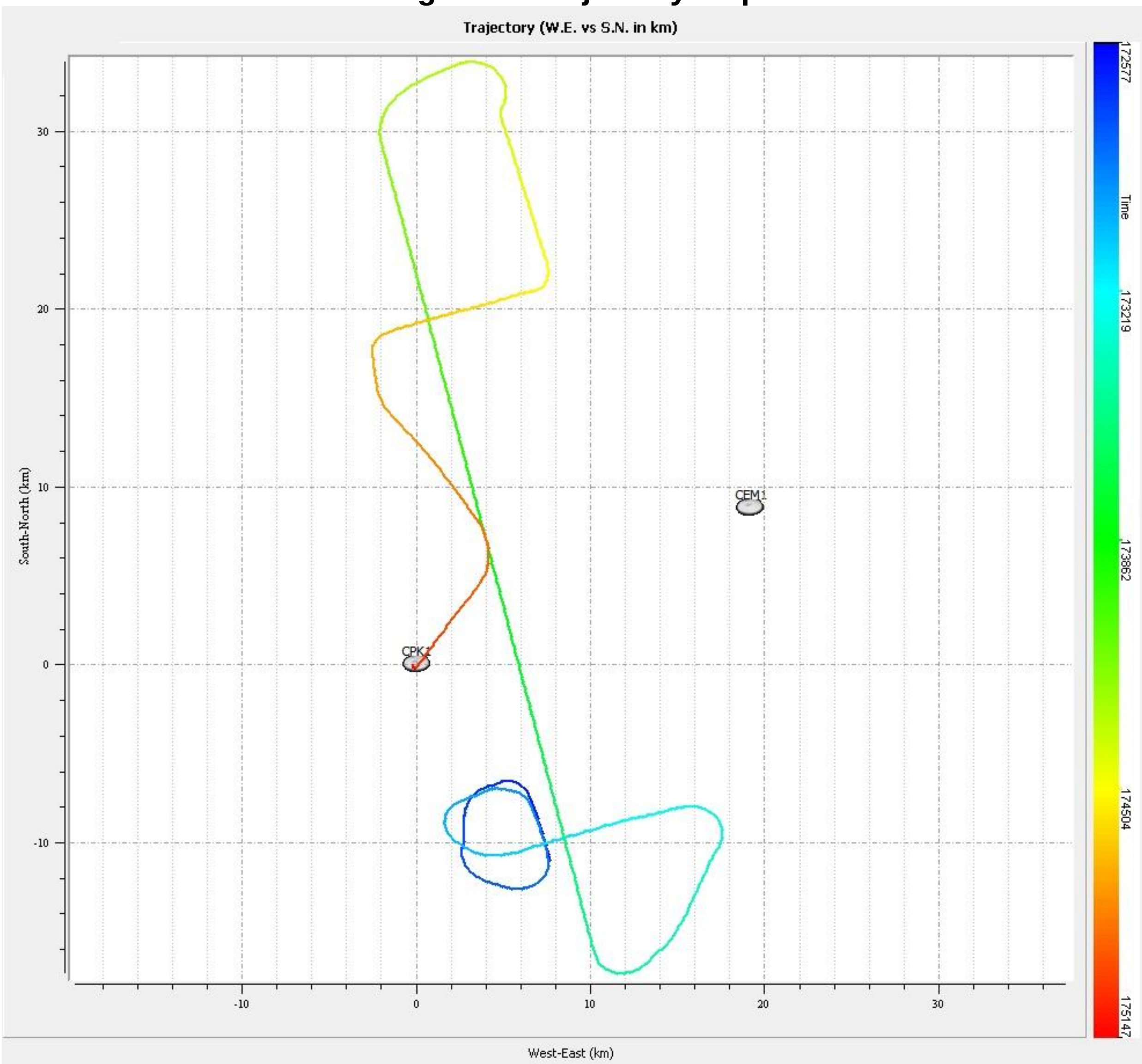


Figure 2: Position and Standard Deviation

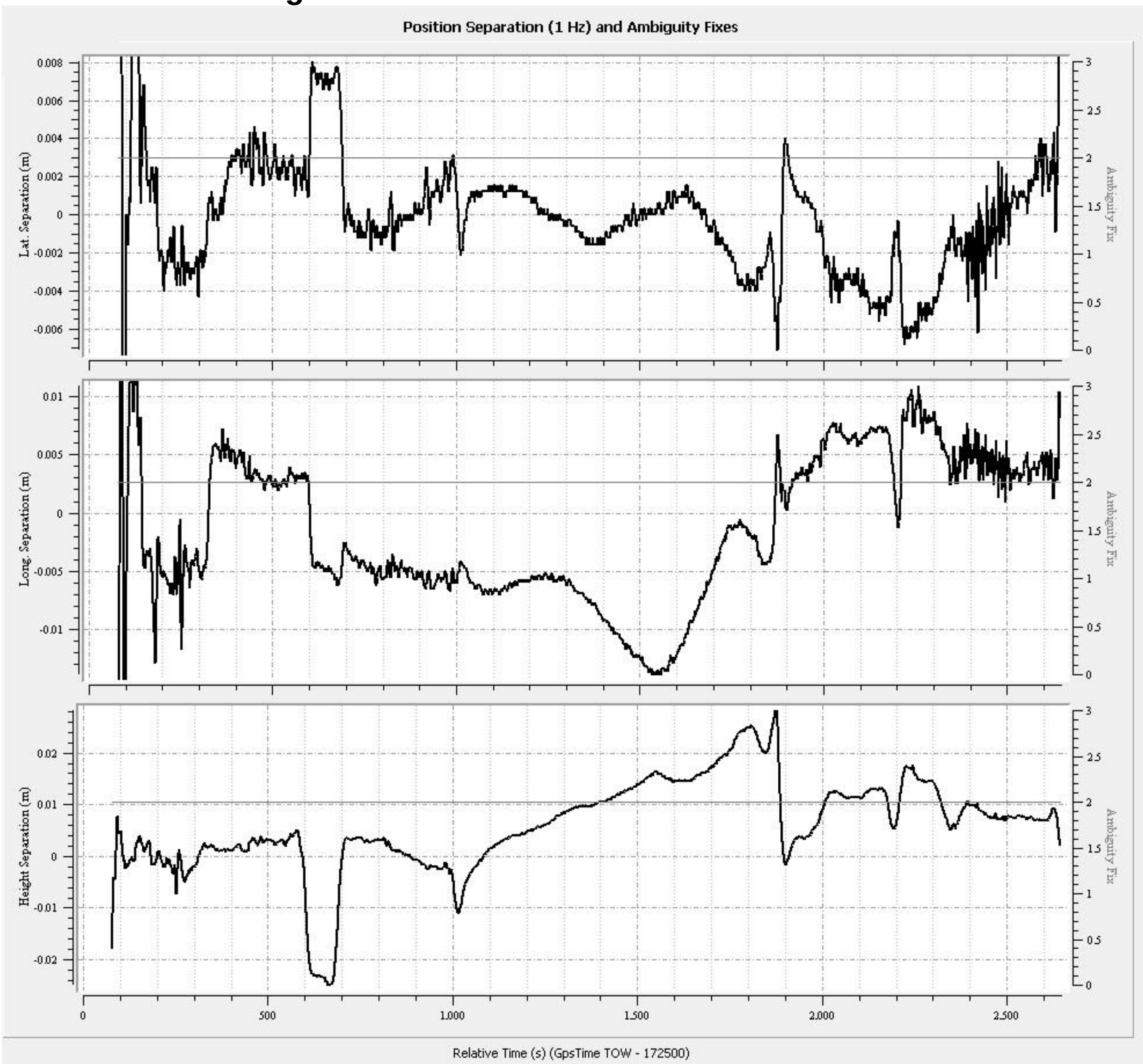


Figure 3: Velocity and Standard Deviation

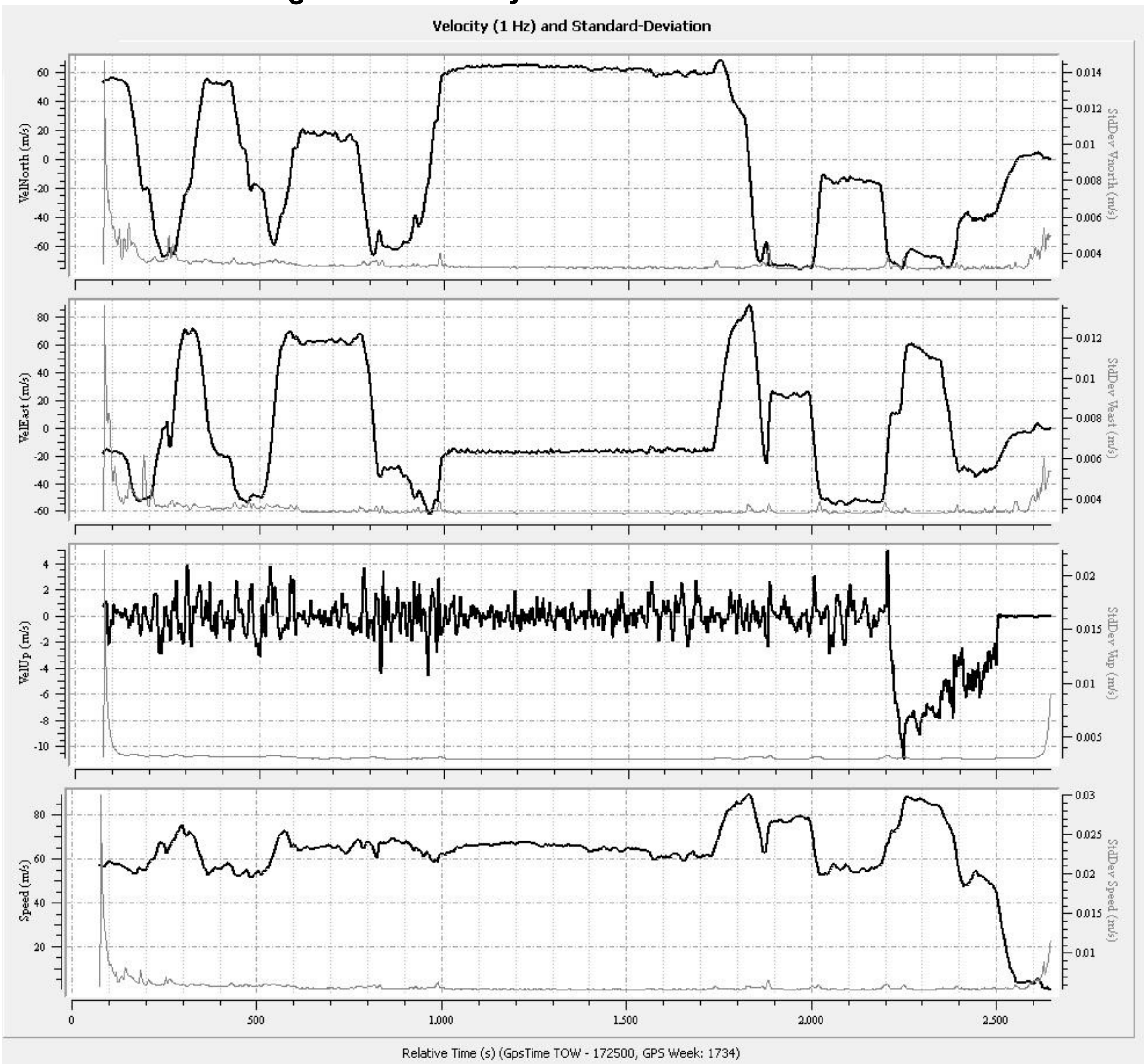


Figure 4: Forward/Reverse or Combined Separation Plot

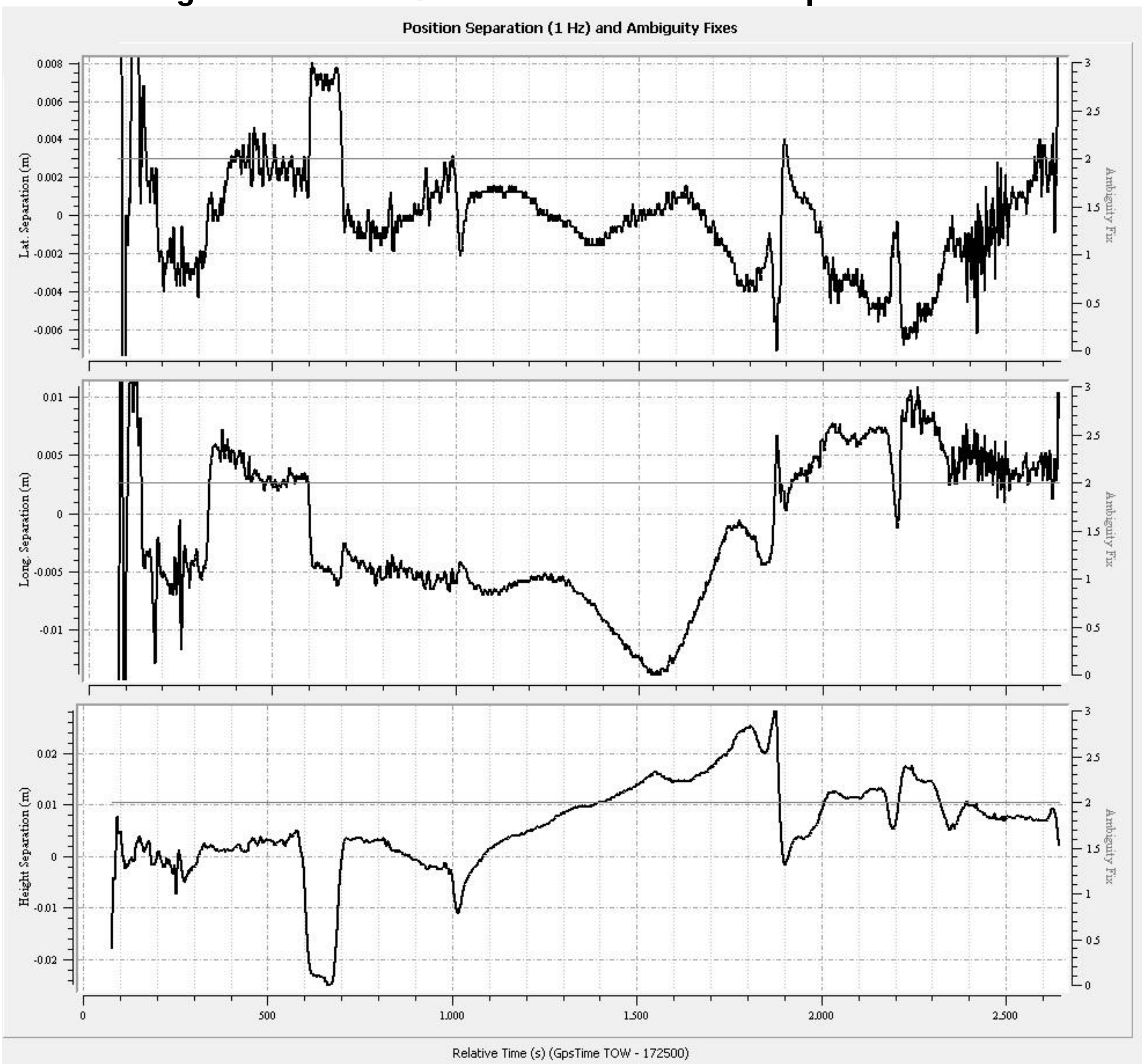


Figure 5: Attitude and Standard Deviation

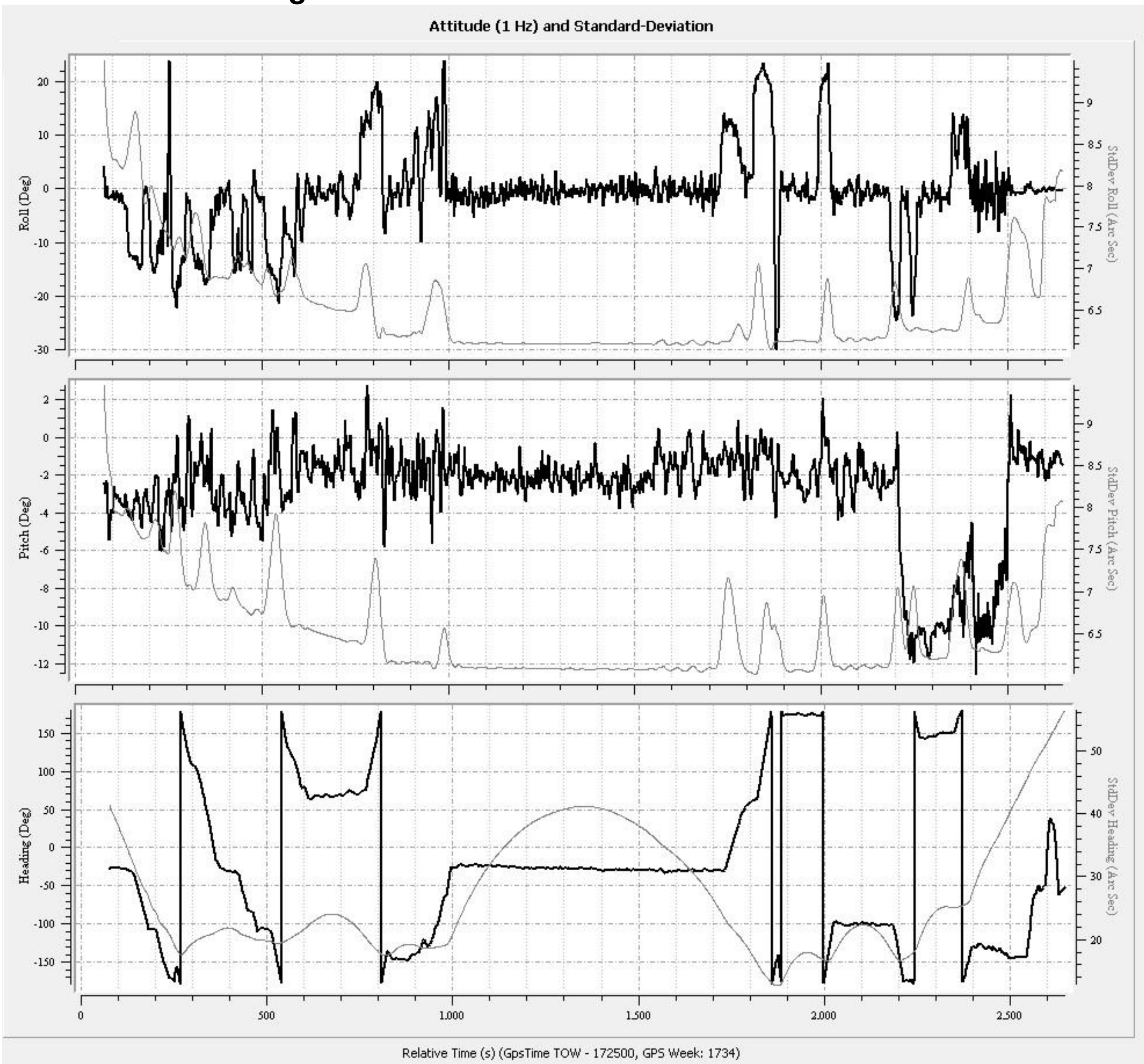


Figure 6: Position Accuracy and PDOP

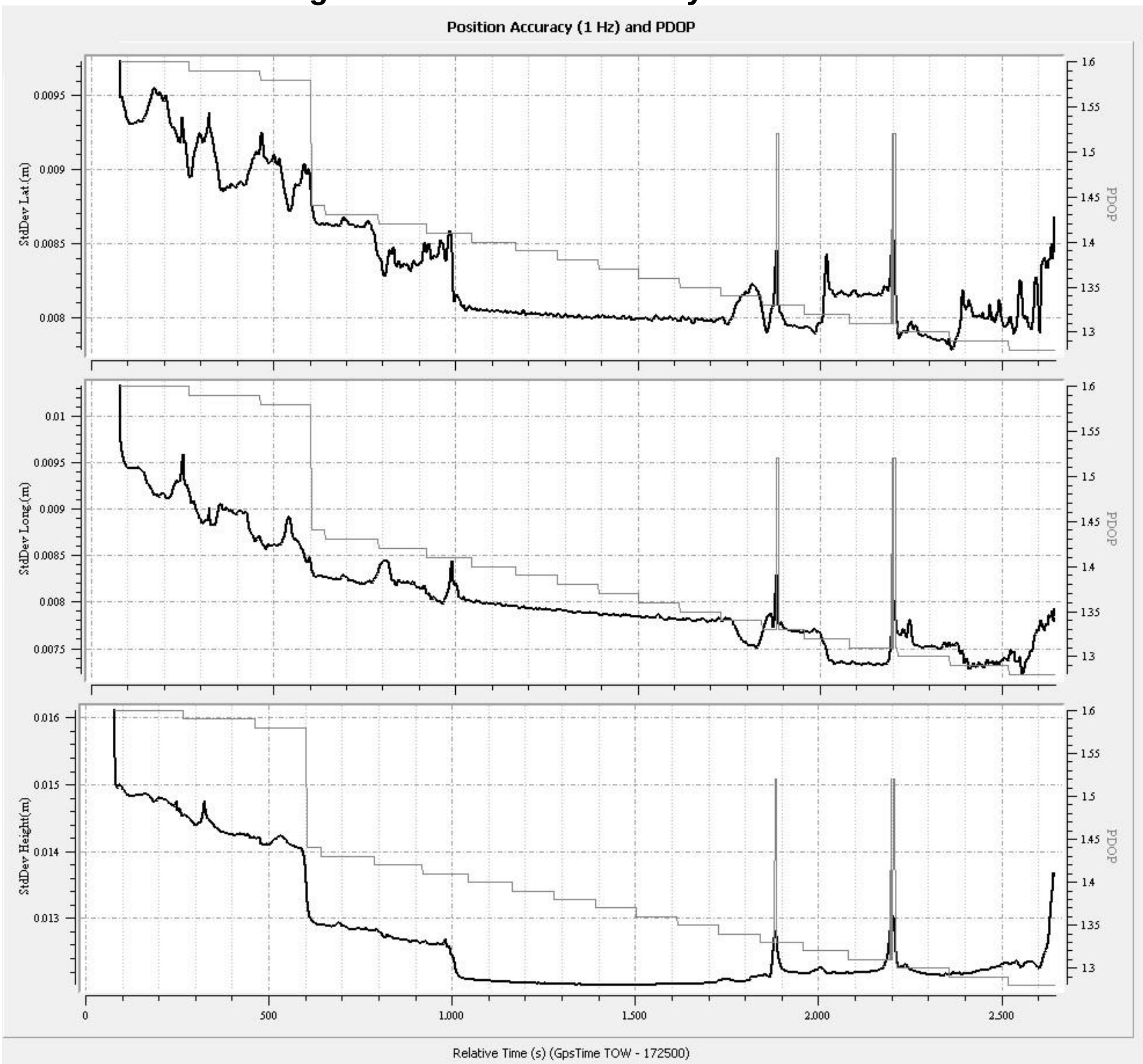


Figure 7: Accelerometer Bias Estimation

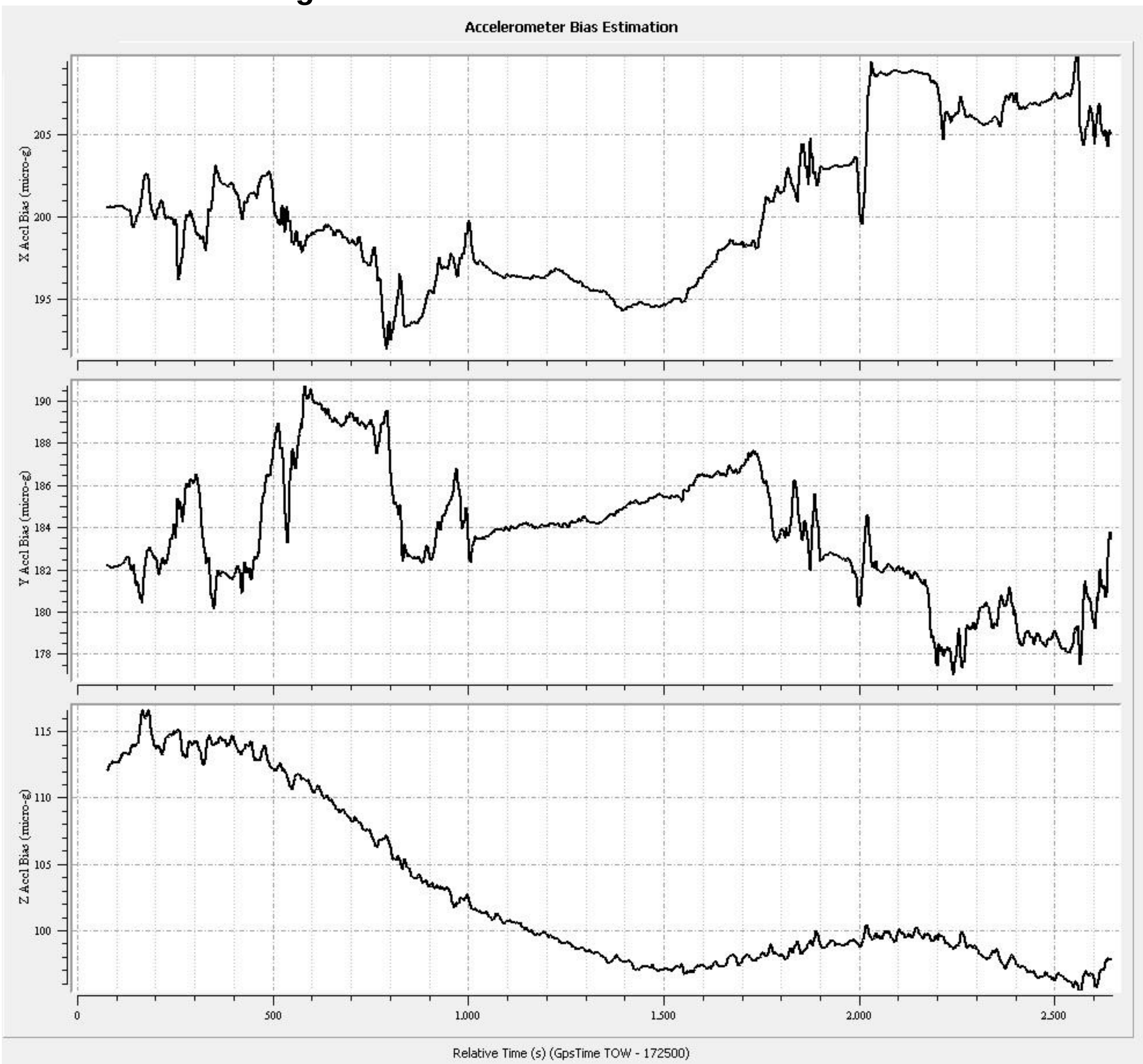


Figure 8: Kalman Filter Residuals and Position Accuracy

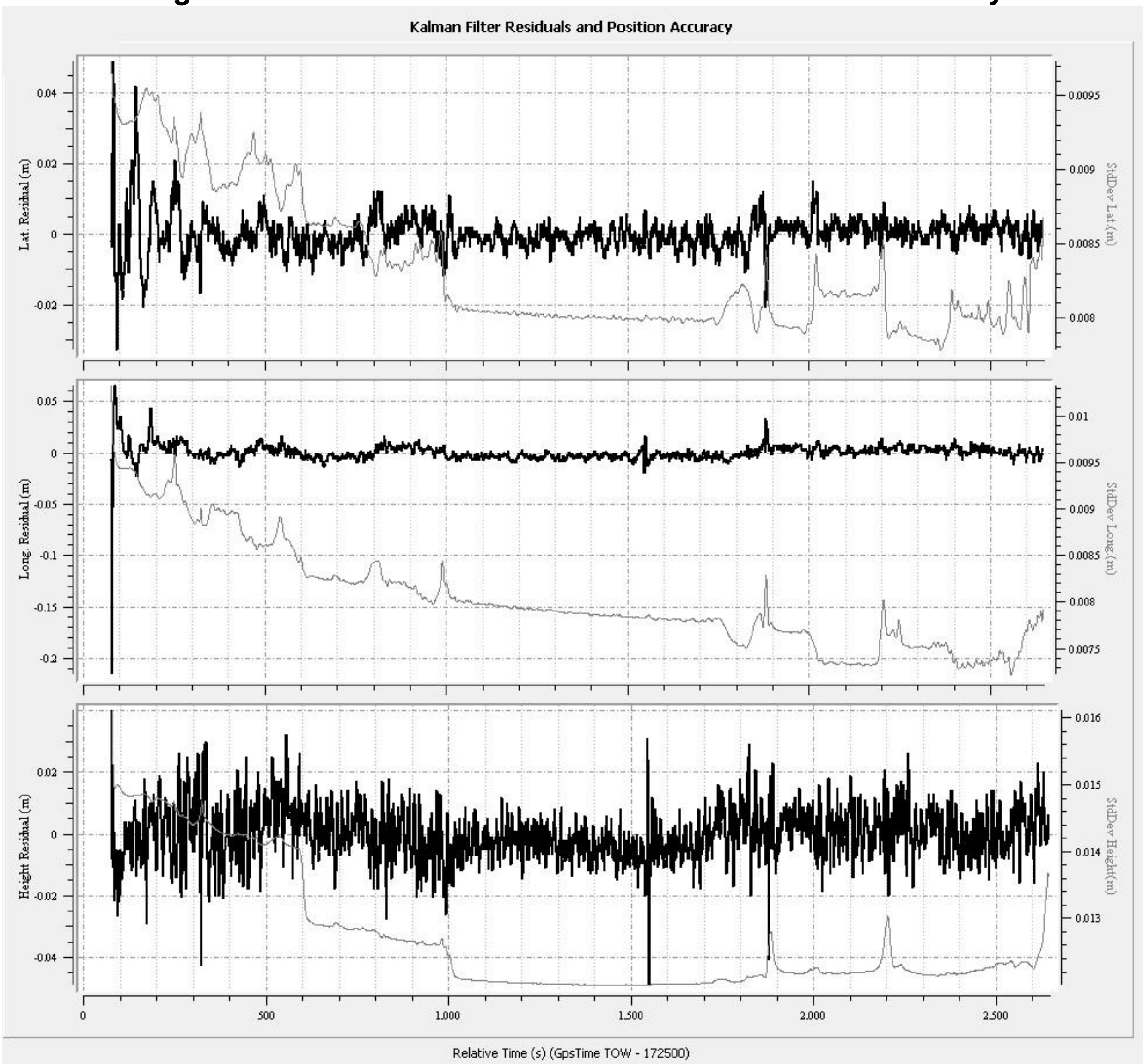


Figure 9: Gyro Bias Estimation