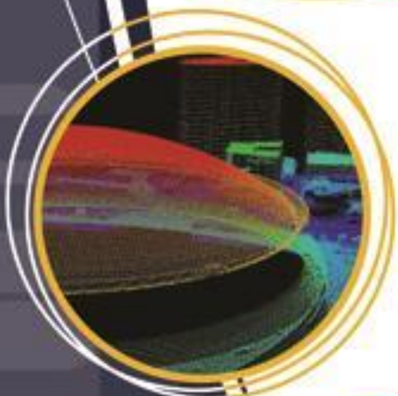
atlantic



Aerial Lidar Report

Jefferson County
Alabama

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Project Area

The project area encompasses Jefferson County located in the state of Alabama. The total area of the project is approximately 1,124 square miles or 2,911 square kilometers.

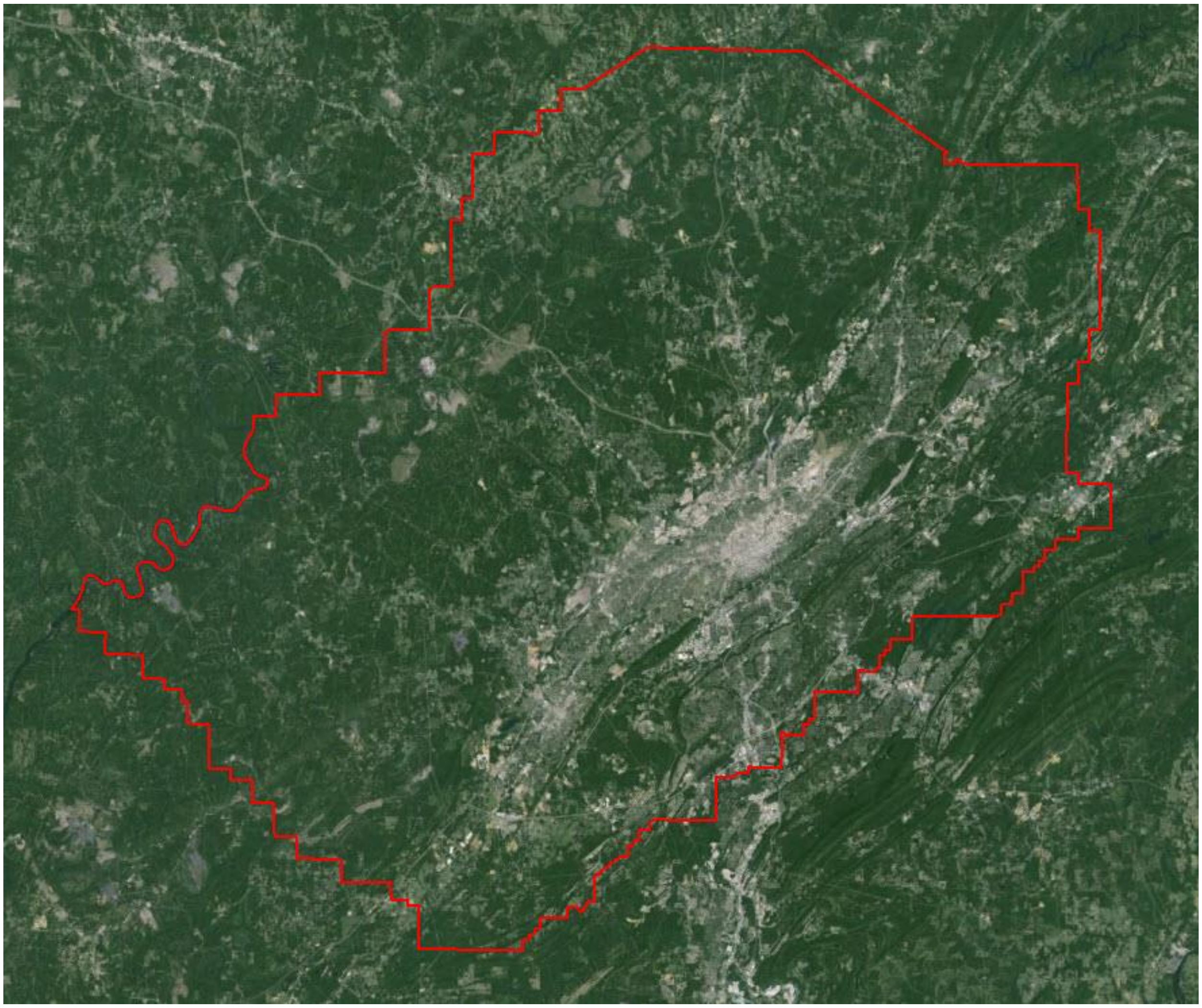


Figure 1: Project Area

Acquisition Dates

The Lidar survey was conducted between March 13th, 2013 and April 7th, 2013. An additional supplemental coverage flight was conducted on August 27, 2013.

Datum Reference

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

Horizontal Datum:	North American Datum of 1983
Vertical Datum:	North American Vertical Datum of 1988
Coordinate System:	State Plane Alabama West (FIPS 0102)
Units:	U.S. Survey Feet
Geoid Model:	Geoid 03

Lidar Acquisition Details

Atlantic acquired sixty three (63) passes for the project area as a series of parallel flight lines with cross flight lines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, 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.
- 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 were investigated so that required permissions could be obtained in a timely manner with respect to schedule. Additionally, Atlantic Group files all 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 accessed 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 Fayetteville Municipal Airport (FYM) in Fayetteville, TN are periodically checked and adjusted to minimize corrections at project sites.

Acquisition Equipment

Atlantic operated a Piper Navajo (Tail # N732JE) outfitted with a Leica ALS70-HP Lidar system during the collection of the project area. Table 1 represents a list of the features and characteristics for the Leica ALS70-HP Lidar system:

Atlantic's Sensor Characteristics		
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 adaptive, °)	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 Sensor Characteristics

Lidar System Parameters

Table 2 illustrates Atlantic's system parameters for Lidar acquisition on this project.

Lidar System Acquisition Parameters	
Item	**Parameter**
System	Leica ALS-70 HP
Altitude (AGL meters)	2000
Approx. Ground Speed (kts)	140
Laser Firing Rate (kHz)	270.4
Scan Frequency (hz)	32.9
Swath width (m)	1456
Swath Overlap (%)	30
Line Spacing (m)	982
Pass heading (degree)	55
Field of View (degree)	40
Points per meter^2 (m)	2.6
Scan Pattern	Sine

Table 2: Lidar System Acquisition Parameters

Lidar Acquisition Control

A total of two (2) NGS monuments and one (1) set point were used to control the lidar acquisition for the Jefferson County project area. The coordinates of each are provided in the table below in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

Acquisition Control Coordinates				
Name	**PID**	**Latitude (N)**	**Longitude (W)**	**Ellipsoid (meters)**
37 18	DH2734	33 47 19.66016	086 49 25.26613	122.710
37 25	DH2742	33 23 39.45046	086 57 16.53673	124.453
JEFF_1	N/A	33 18 48.08050	086 55 26.61380	183.217

Table 3: Acquisition Control Coordinates

Acquisition Status Report and Flightlines

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

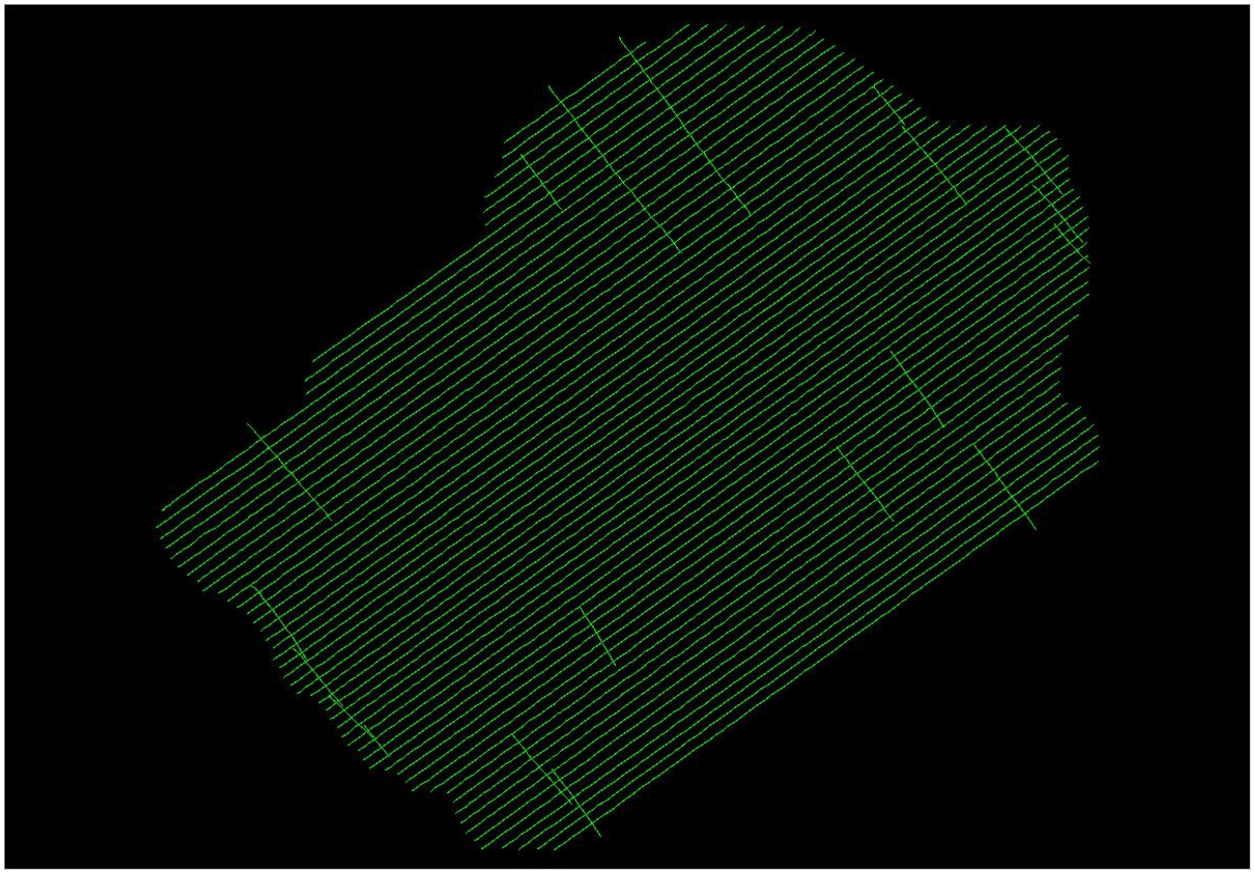


Figure 2: Trajectories as flown by Atlantic

Airborne GPS Kinematic

Airborne GPS data was processed using the Leica IPAS TC software. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 3. Distances from base station to aircraft were kept to a maximum of 40km.

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

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.

GPS processing reports for each mission are included in **Appendix A**.

Generation and Calibration of Laser Points (raw data)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete. Subsequently, the mission points are output using Leica's ALS Post Processor initially with default values from Leica or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within TerraScan using distance colored points to identify errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are output again and validated internally to ensure quality. Once validated each output mission is imported into the GeoCue software package. Here a project level supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

Figure 3: Lidar swath data showing complete coverage

Relative Accuracy

For effective data management, each imported mission is tiled out in GeoCue to a project specific tile scheme or index. Relative accuracy and internal quality are then checked using a number of carefully selected tiles in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed by the generation of Z-difference colored intensity orthos in GeoCue. The color scale of these orthos are 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. When available, surveyed control points are used to supplement and verify the calibration of the data.

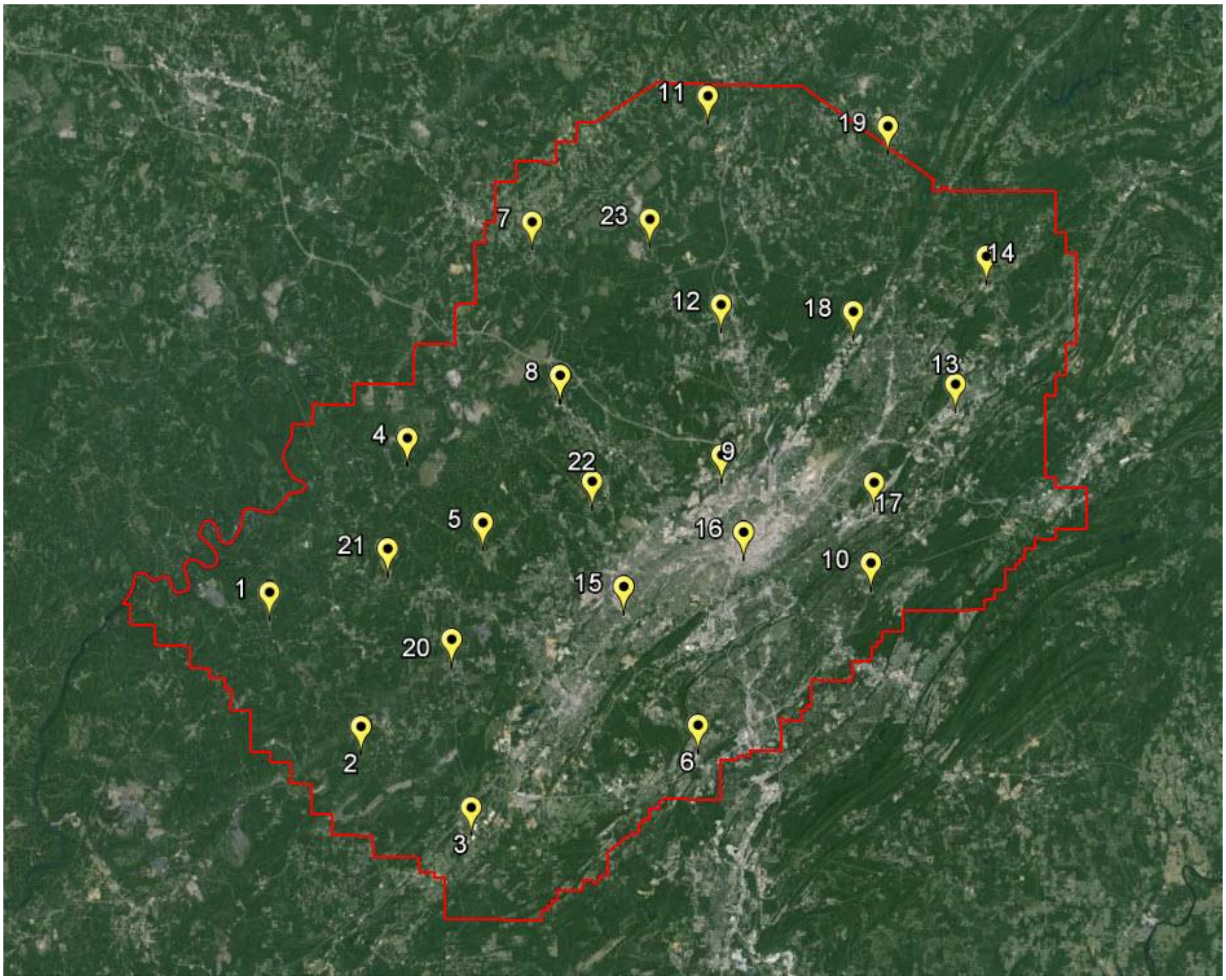


Figure 4: Control Point Distribution

For this project the specifications used are as follows:

Relative accuracy ≤0.230ft (7cm) $RMSD_Z$ within individual swaths and ≤0.328ft (10cm) $RMSD_Z$ or within swath overlap (between adjacent swaths).

Lidar Classification

The classification process begins with an initial classification macro that is applied through TerraScan. The macro uses a set of algorithms that classifies the Lidar point cloud into a specific classification scheme and serves as a starting base for the manual editing to begin. The following point cloud classification scheme is used at a minimum for each project.

Point Cloud Classification Scheme	
Code	**Description**
1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high; manually identified; if needed)
9	Water
10	Ignored Ground (breakline proximity)
11	Withheld (if the Withheld bit is not implemented in processing software)

Table 4: Point Cloud Classification Scheme

Manual classification is performed with the TerraSolid class tools (TerraScan) and surface representation tools (TerraModel). Real time shaded surfaces are used to identify classification anomalies and artifacts. Each tile is viewed for manual classification and quality assurance.

Breakline Collection

Hydro break line collection is performed manually in ESRI ArcMap using a combination of the classified lidar bare earth surface; Lidar derived intensity orthos, and a terrain dataset. Break lines are drawn at the intersection of the water line for all inland water bodies that are greater than two acres and all double line features that are greater than 30.5m (100ft) in width. Final break lines are the converted to a “3D” enabled shapefile to later hold elevation values of the surrounding lidar.

Hydro-Flattening

The LP360 ArcMap Extension allows break line conflation from lidar bare earth surface in real time display. The hydro break lines are used to classify any ground points that fall within the hydro feature and a buffer class is applied to all hydro features. The break lines are the conflated in LP360 and are given a vertical elevation value from the surrounding lidar points. Two types of conflation are performed in this process, one for closed features that uses a minimum “Z” value and another for double features that uses a “downhill” flowing value.

Bare-Earth DEM(s)

After hydro classification and conflation are complete the break lines are laid over the classified lidar data set along with the local tiling index. Bare Earth Digital Elevation Models (DEMs) are then processed using LP360 extension and are told to use previously conflated break line file to produce a “hydro flattened” DEM. The resulting final product is a 32 bit floating point (*.tif) image file for each corresponding tile in the designated project area. Each final DEM is viewed in Global Mapper to ensure proper flattening and downhill constraint.

Vertical Accuracy Assessment

An $RMSE_Z$ error check is performed by Atlantic at this stage of the project life cycle in the calibrated lidar data set against GPS static and kinematic data and compared to $RMSE_Z$ project specifications. Vertical Accuracy of the lidar data was assessed and reported in accordance with guidelines developed by the National Digital Elevation Program (NDEP) and subsequently adopted by the American Society for Photogrammetry and Remote Sensing (ASPRS). Guidelines are listed below in feet:

- Fundamental Vertical Accuracy (FVA)≤0.60ft ACC_Z, 95% $RMSE_Z$ (.30ft)
- Consolidated Vertical Accuracy (CVA)≤0.80ft ACC_Z, 95% $RMSE_Z$ (.41ft)
- Supplemental Vertical Accuracy (SVA)≤0.80ft ACC_Z, 95% $RMSE_Z$ (.41ft)

Guidelines are also listed below in meters:

- Fundamental Vertical Accuracy (FVA)≤18.13cm ACC_Z, 95% $RMSE_Z$ (9.25cm)
- Consolidated Vertical Accuracy (CVA)≤24.5cm ACC_Z, 95% $RMSE_Z$ (12.5cm)
- Supplemental Vertical Accuracy (SVA)≤24.5cm ACC_Z, 95% $RMSE_Z$ (12.5cm)

The following are the final statistics for the checkpoints used by Atlantic to verify vertical accuracy.

Check Point Validation								
100 % of Totals	RMSE (ft)	Mean (ft)	Median (ft)	Skew (ft)	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Open Terrain	0.275	-0.159	-0.175	0.098	0.242	20	-0.555	0.346
Urban	0.292	-0.189	-0.207	-0.082	0.229	20	-0.542	0.141
High Grass	0.293	0.025	-0.006	0.357	0.299	20	-0.491	0.555
Consolidated	0.287	-0.104	-0.104	0.447	0.262	60	-0.555	0.555

Table 5: Checkpoint Validation in Feet

Check Point Validation								
100 % of Totals	RMSE (m)	Mean (m)	Median (m)	Skew (m)	Std Dev (m)	# of Points	Min (m)	Max (m)
Open Terrain	0.084	-0.048	-0.053	0.030	0.074	20	-0.169	0.105
Urban	0.089	0.058	-0.063	-0.025	0.070	20	-0.165	0.043
High Grass	0.089	0.008	0.002	0.23	0.109	20	-0.150	0.169
Consolidated	0.087	0.08	-0.02	1.02	0.136	60	-0.169	0.169

Table 6: Checkpoint Validation in Meters

The figures below illustrate the distribution of each land cover category checkpoints throughout the project area.

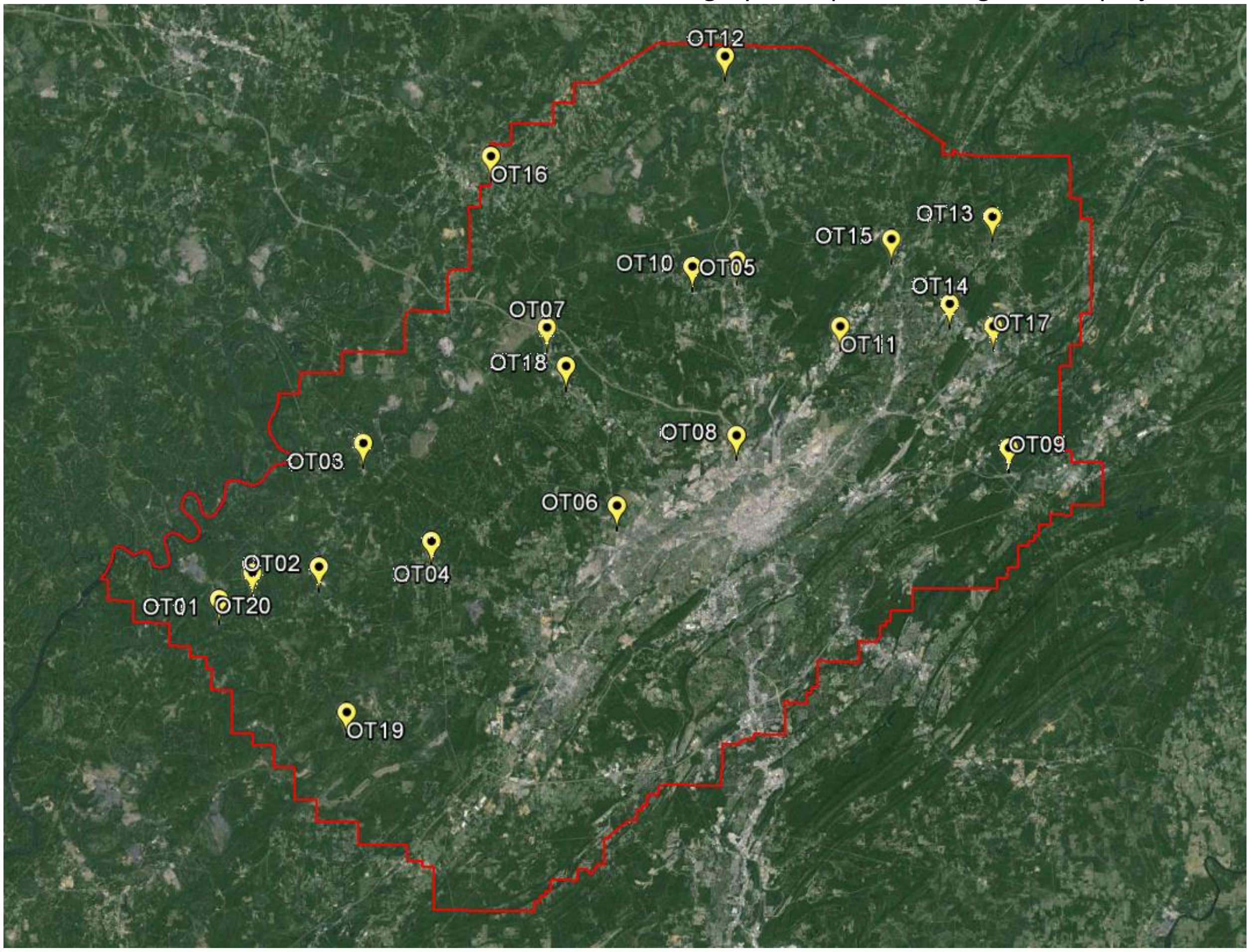


Figure 5: Open Terrain checkpoint Distribution

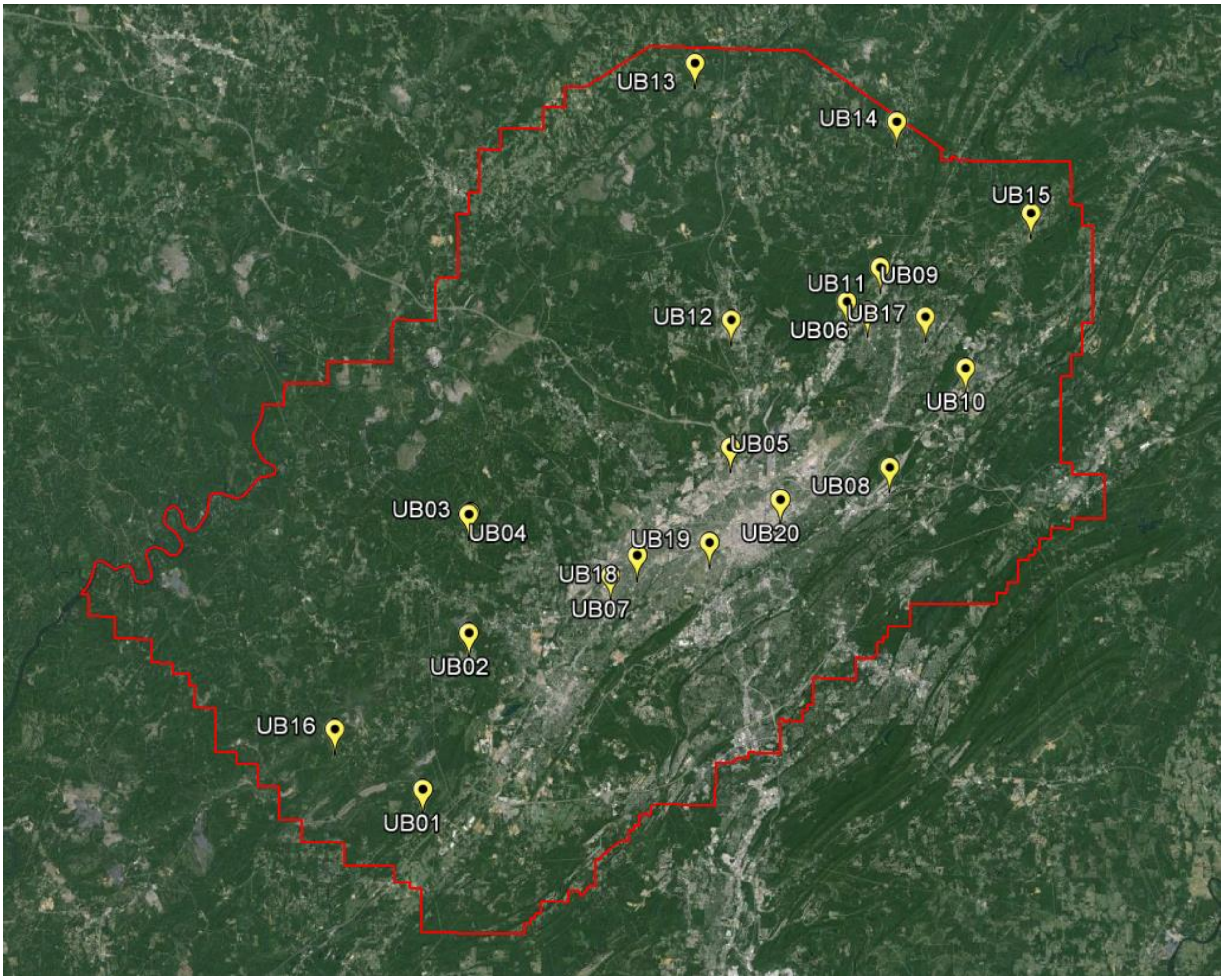


Figure 6: Urban Checkpoint Distribution

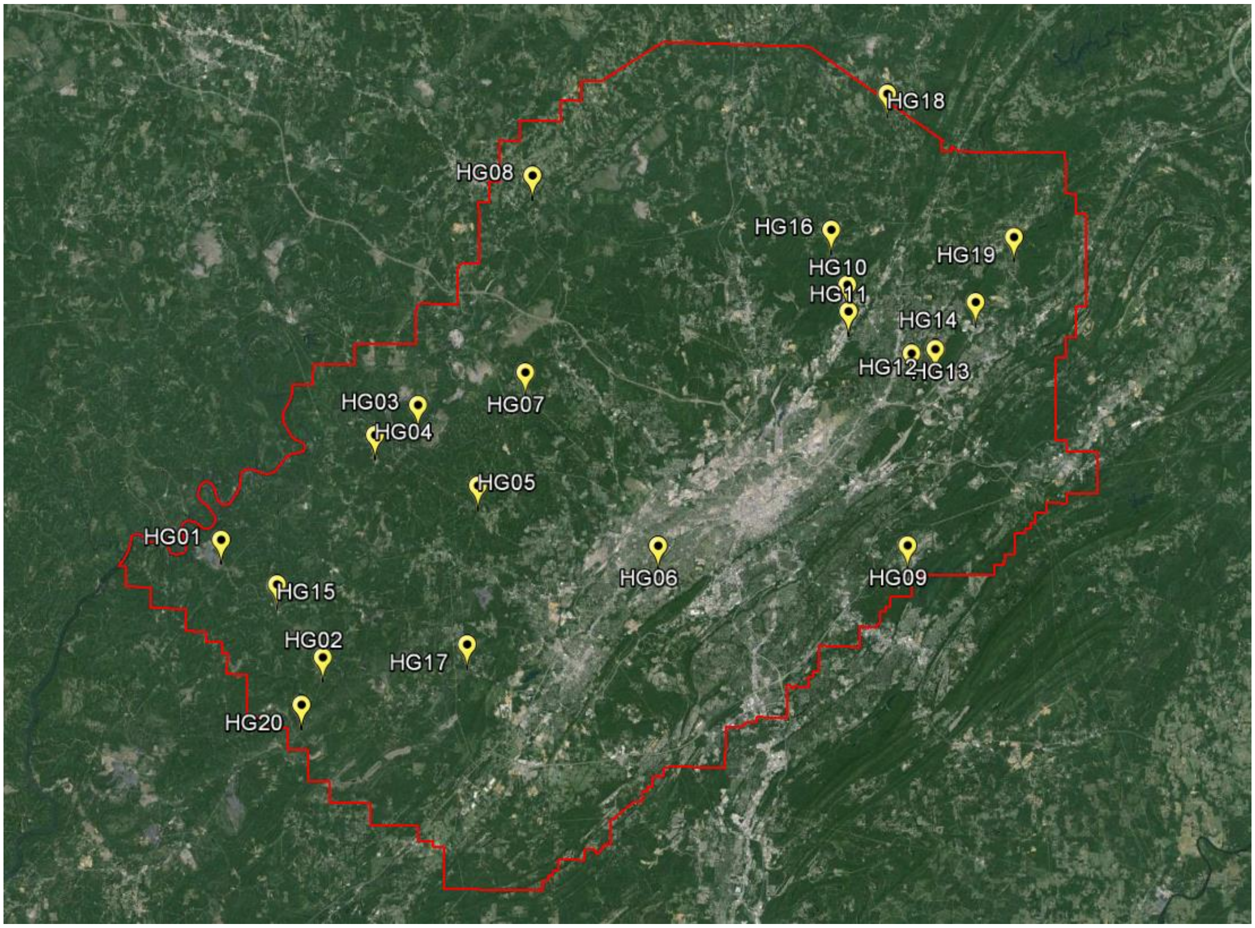


Figure 7: High Grass Checkpoint Distribution

As part of the vertical accuracy assessment the fully calibrated swath lidar data, including all returns and collected points, is examined in open, flat areas and assessed for fundamental vertical accuracy. The following are the statistics for the checkpoints used by Atlantic to verify the fundamental accuracy of the swath data.

Fundamental Vertical Accuracy of the LiDAR Point Data		
Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=0.60ft
Open Terrain	20	0.471

Table 7: Fundamental Vertical Accuracy of the Lidar Point Data in Feet

Fundamental Vertical Accuracy of the LiDAR Point Data		
Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=18.13cm
Open Terrain	20	14.36

Table 8: Fundamental Vertical Accuracy of the Lidar Point Data in Centimeters

The lidar digital elevation models are also examined in open, flat areas away from breaks and are assessed for fundamental vertical accuracy. The following are the final statistics for checkpoints used by Atlantic to verify the FVA, CVA, and SVA of the derived digital elevation model vertical accuracy.

Digital Elevation Model Vertical Accuracy				
Land Cover Category	**# of Points**	**FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=0.60ft**	**CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.80ft**	**SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.80ft**
Open Terrain	20	0.539		
Urban	20			0.126
High Grass	20			0.540
Consolidated	60		0.353	

Table 9: Digital Elevation Model Vertical Accuracy in Feet

Digital Elevation Model Vertical Accuracy				
Land Cover Category	**# of Points**	**FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=18.13cm**	**CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=24.5cm**	**SVA — Supplemental Vertical Accuracy (95th Percentile) Target=24.5cm**
Open Terrain	20	16.43		
Urban	20			3.84
High Grass	20			16.46
Consolidated	60		10.67	

Table 10: Digital Elevation Model Vertical Accuracy in Centimeters

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

Appendix A: GPS Processing Reports for Each Mission

Output Results for JD13072_1

Figure 1: Trajectory Map

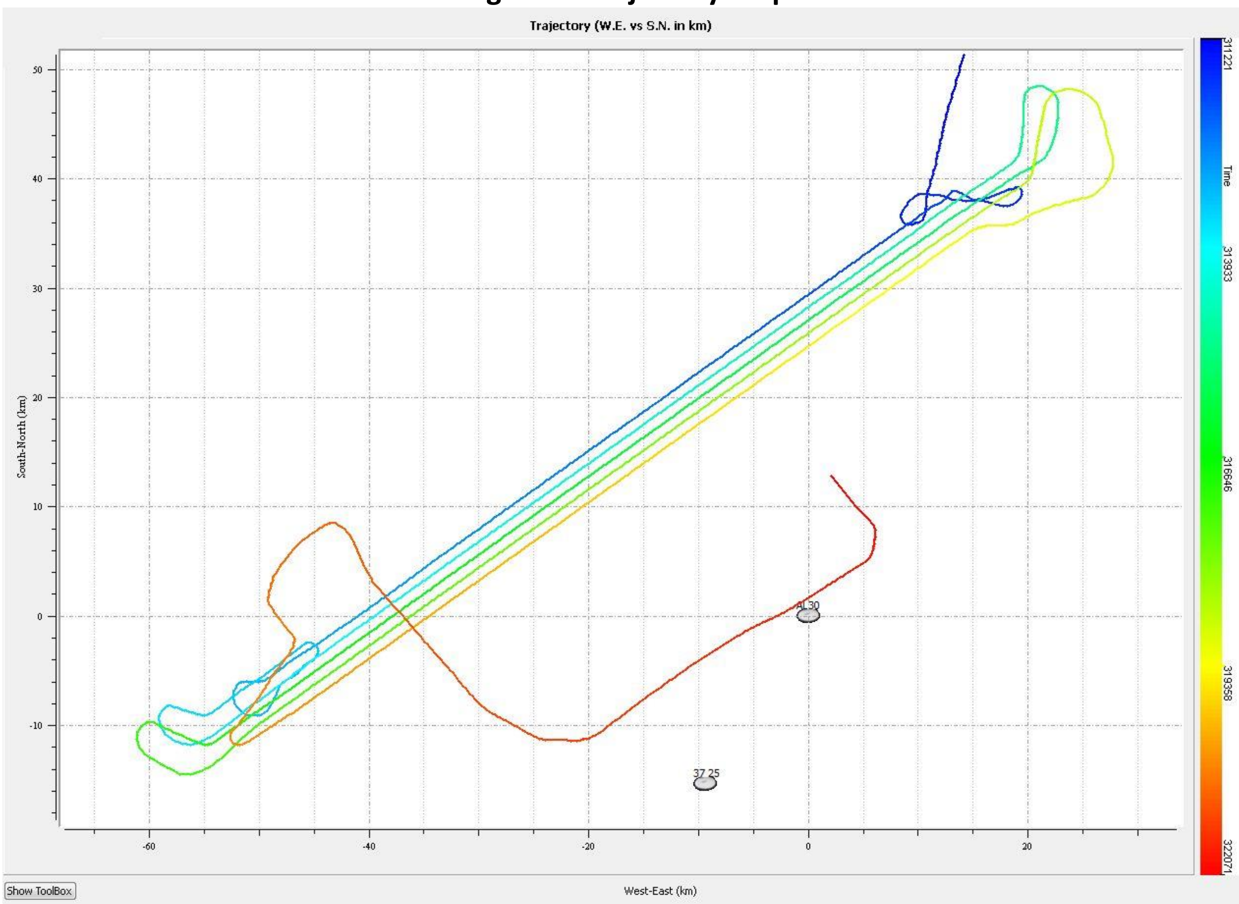


Figure 2: Forward/Reverse or Combined Separation Plot

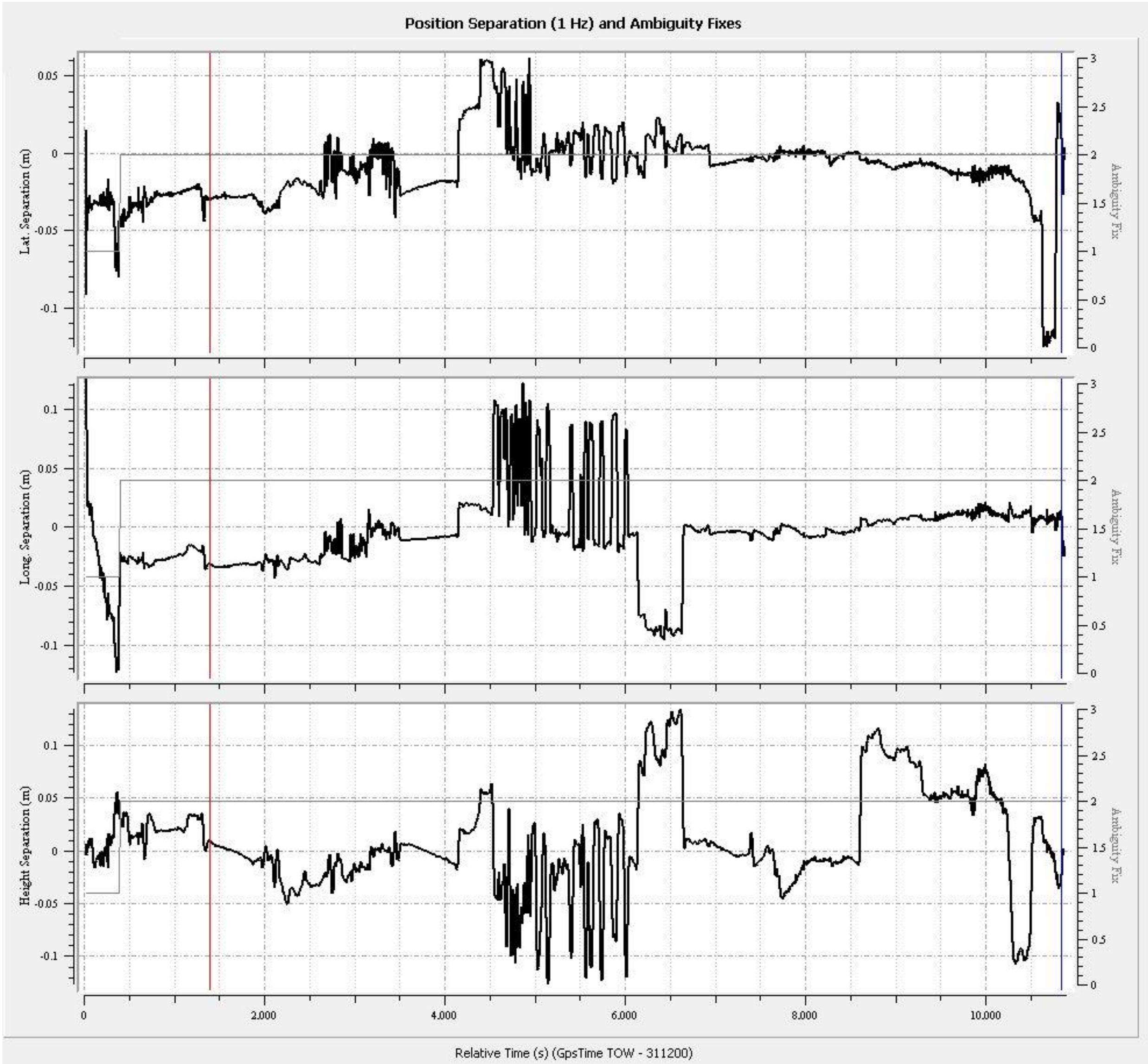


Figure 3: Attitude and Standard Deviation

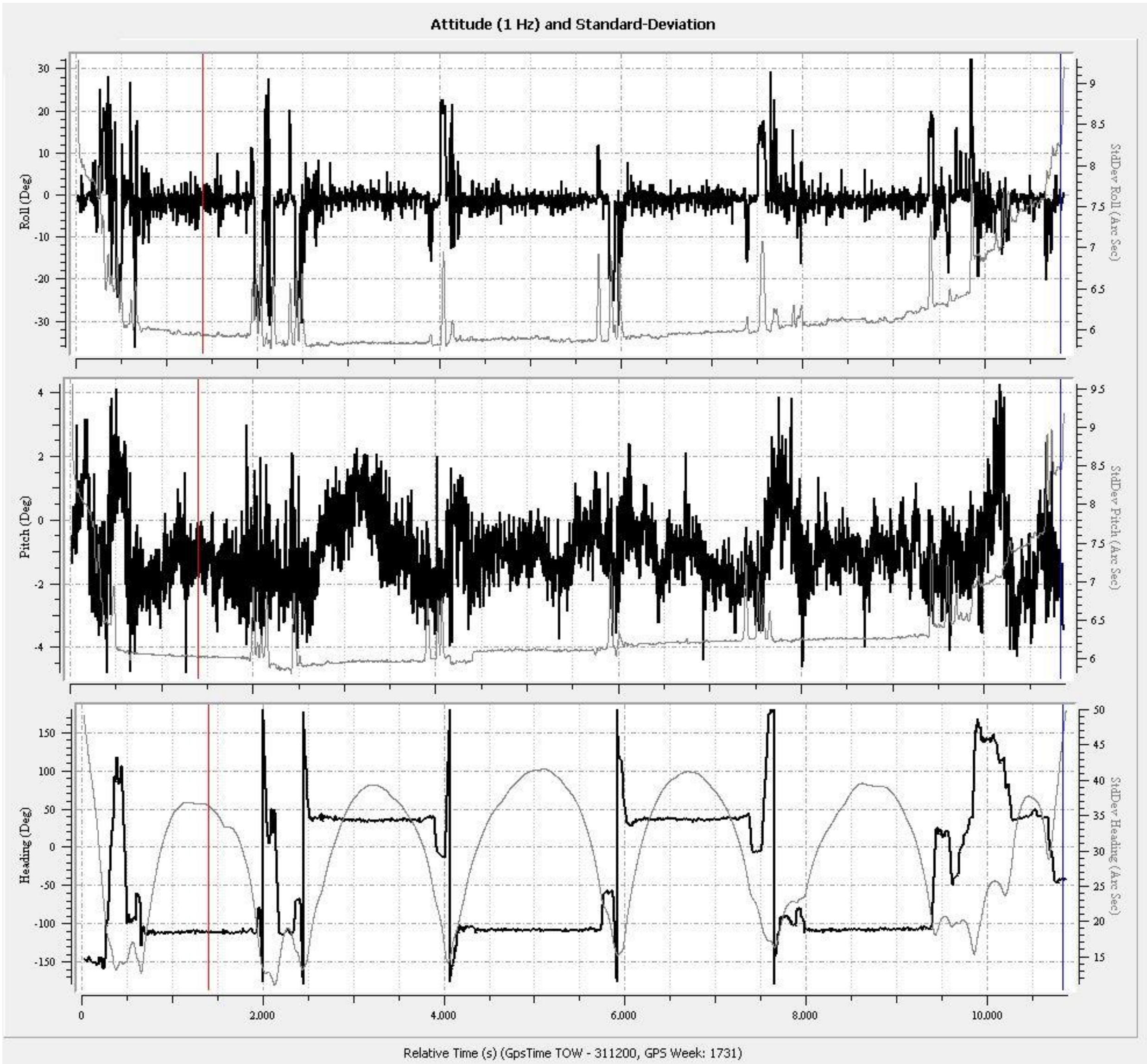


Figure 4: Position Accuracy and PDOP

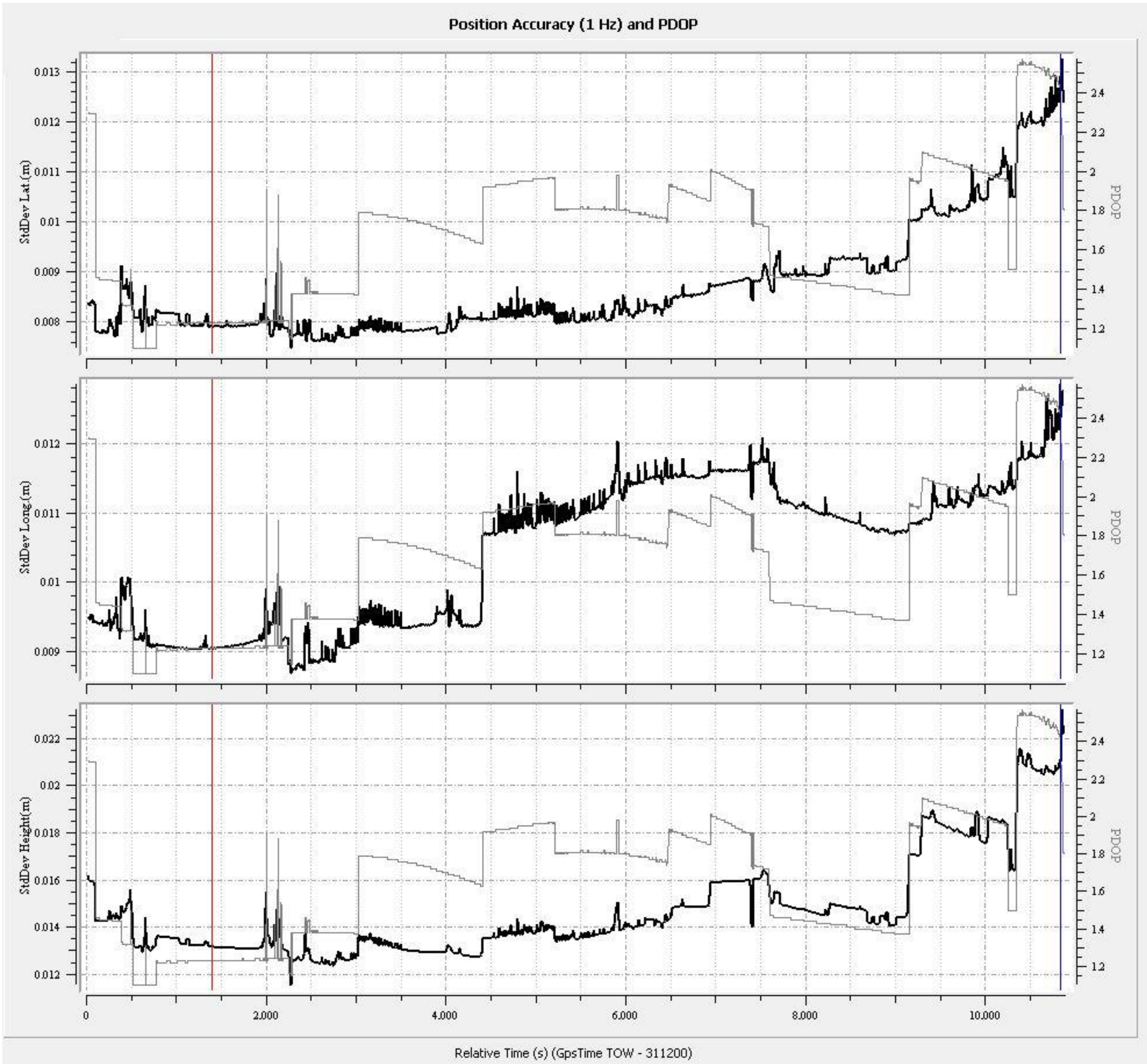
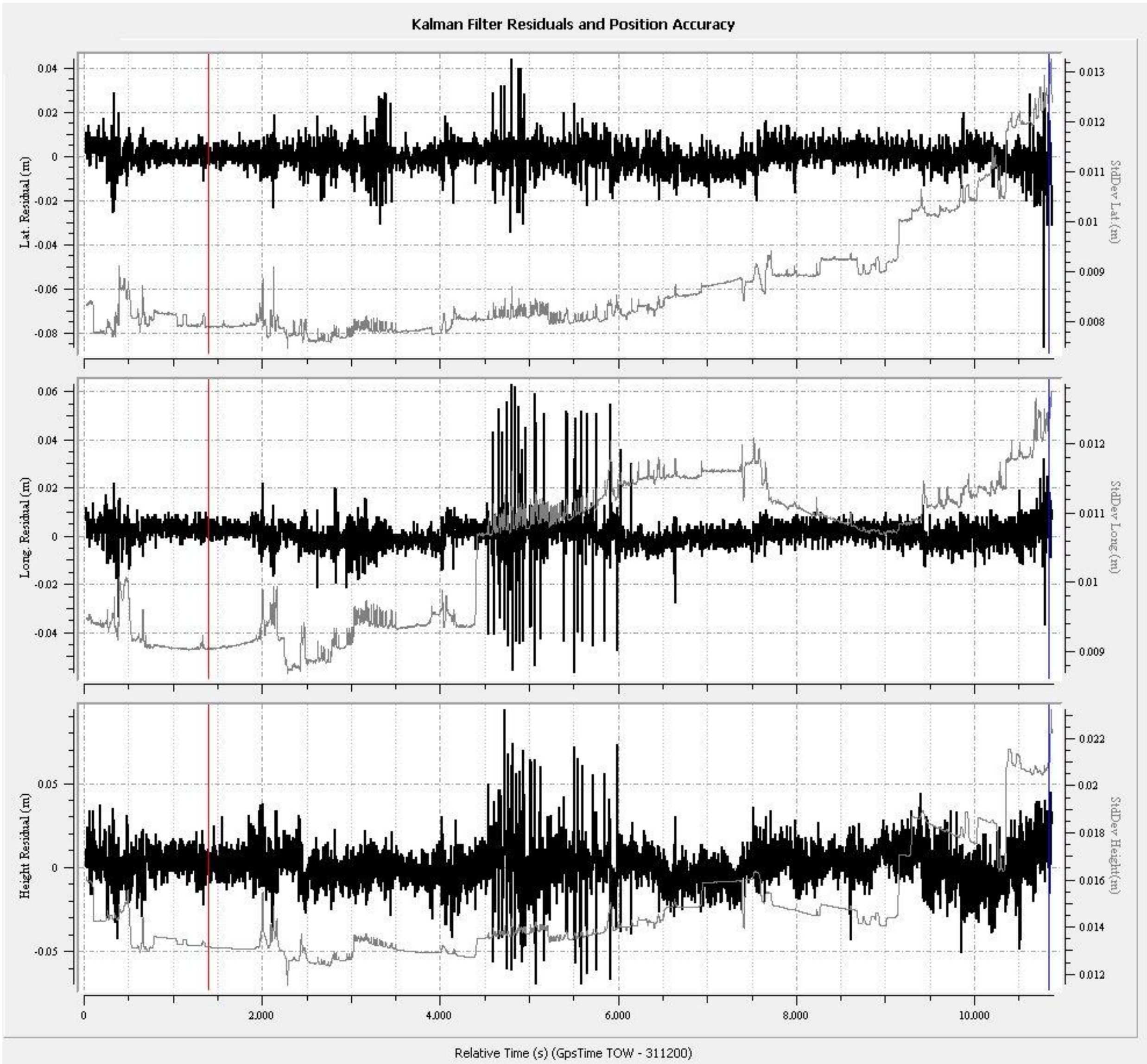


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13072_2

Figure 1: Trajectory Map

Figure 2: Forward/Reverse or Combined Separation Plot

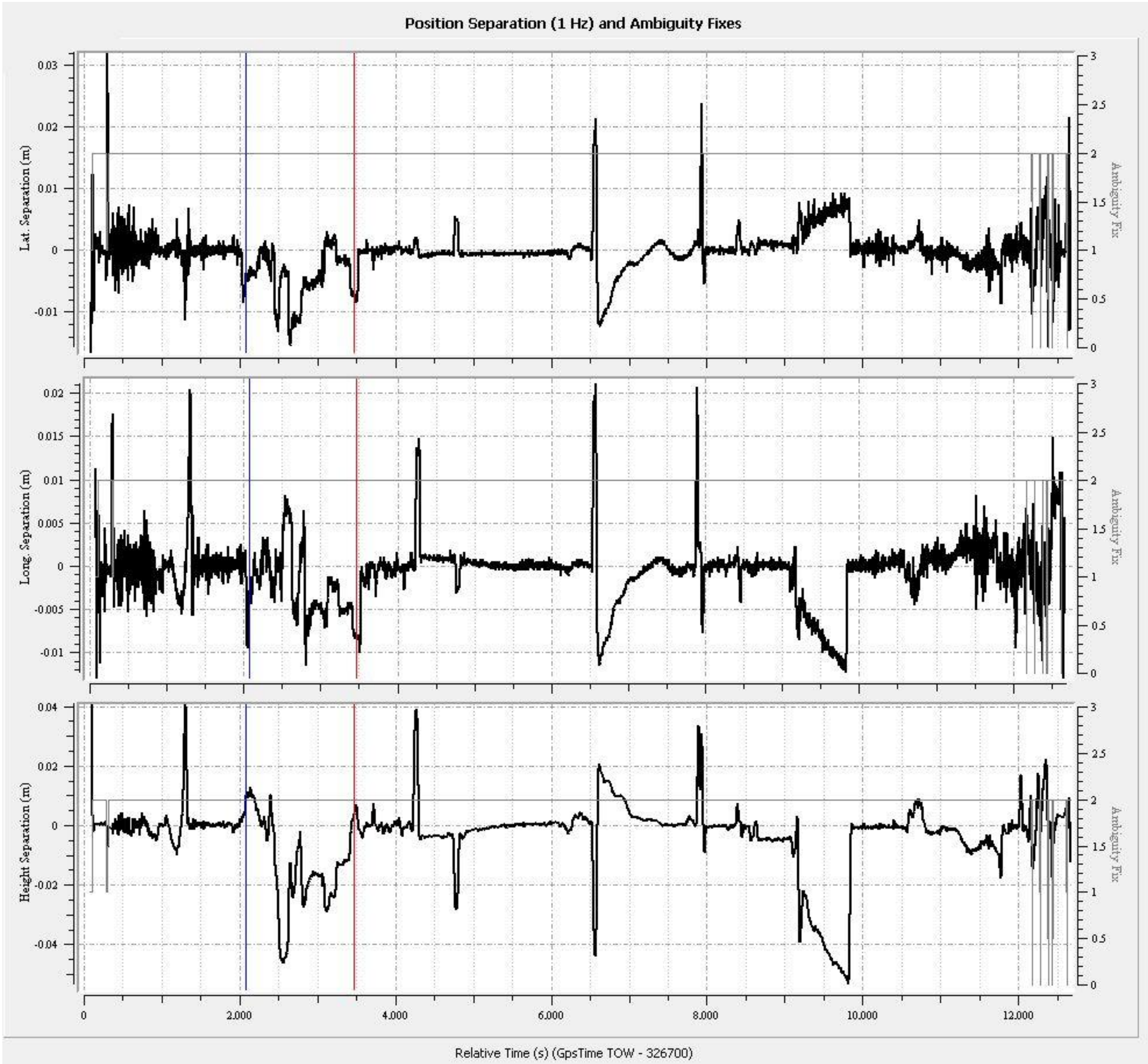


Figure 3: Attitude and Standard Deviation

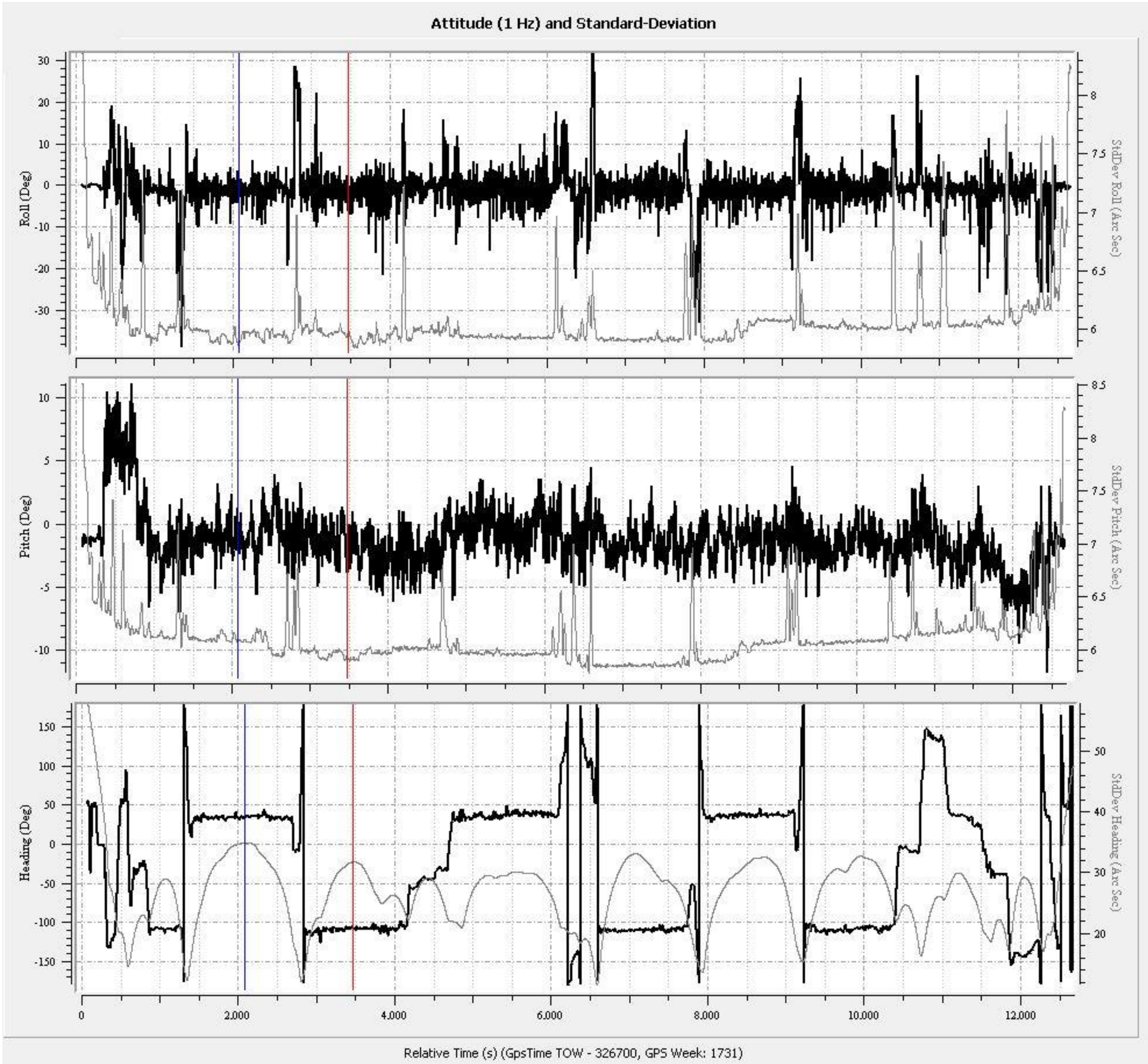


Figure 4: Position Accuracy and PDOP

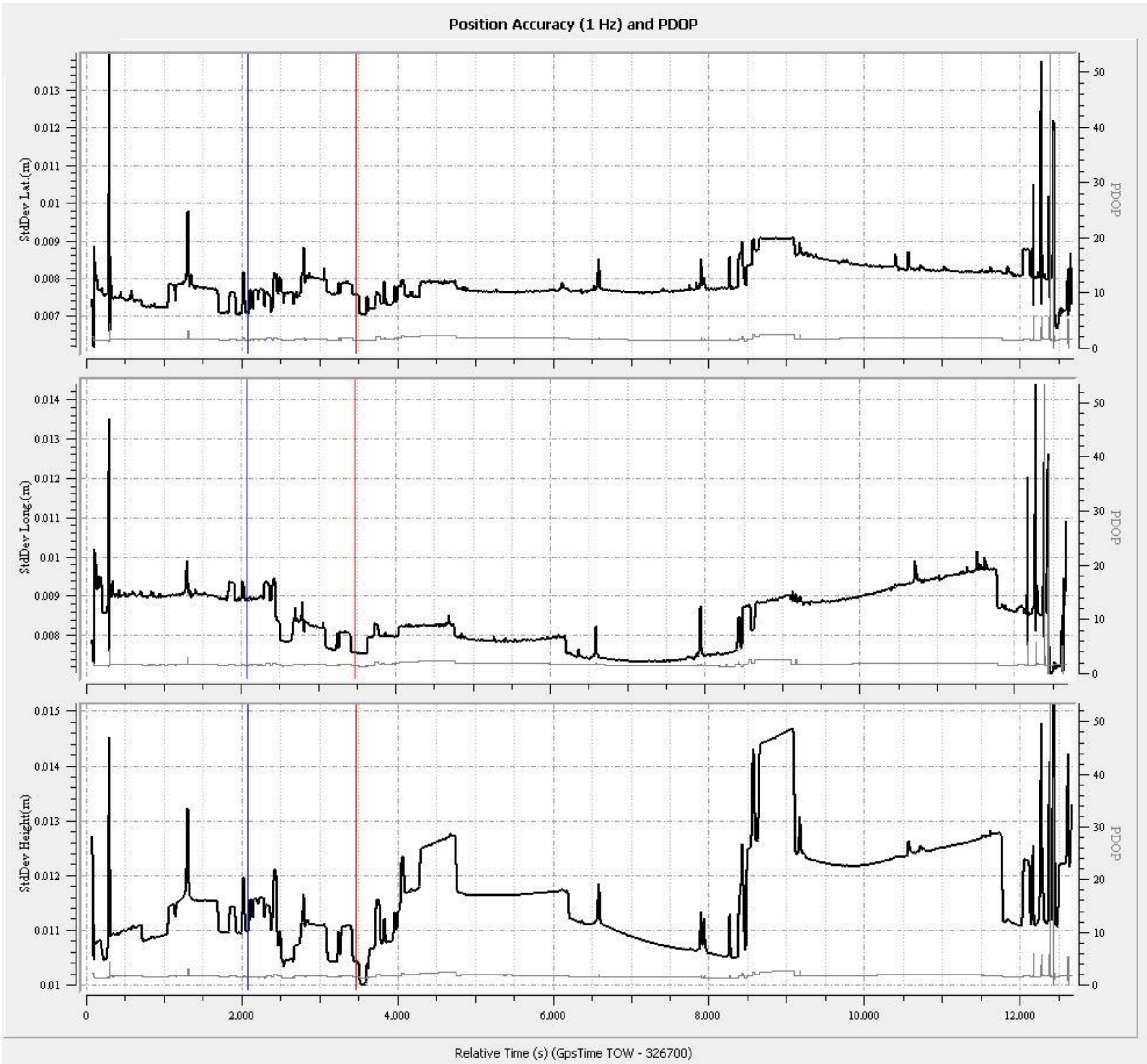
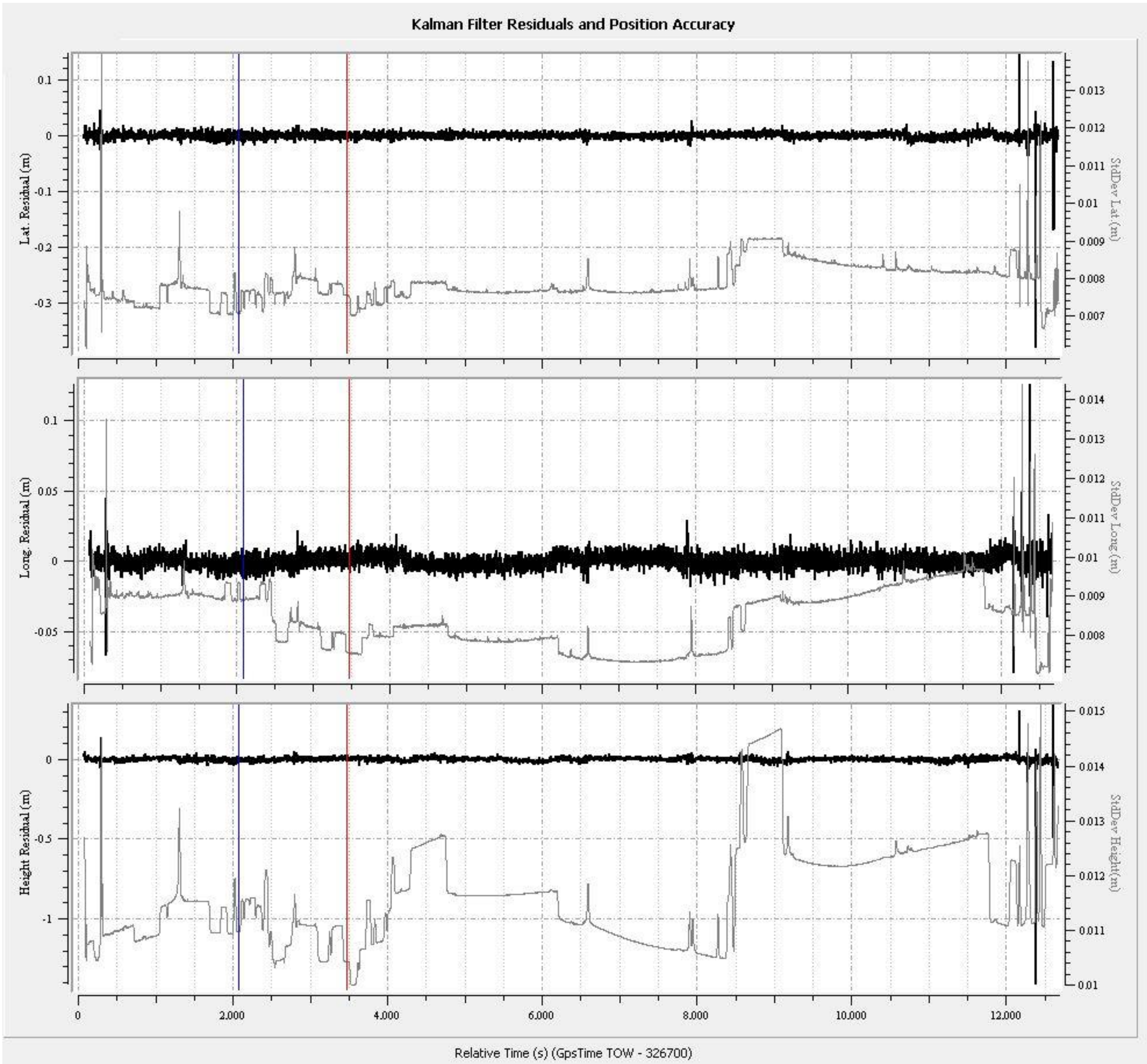


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13073_1

Figure 1: Trajectory Map

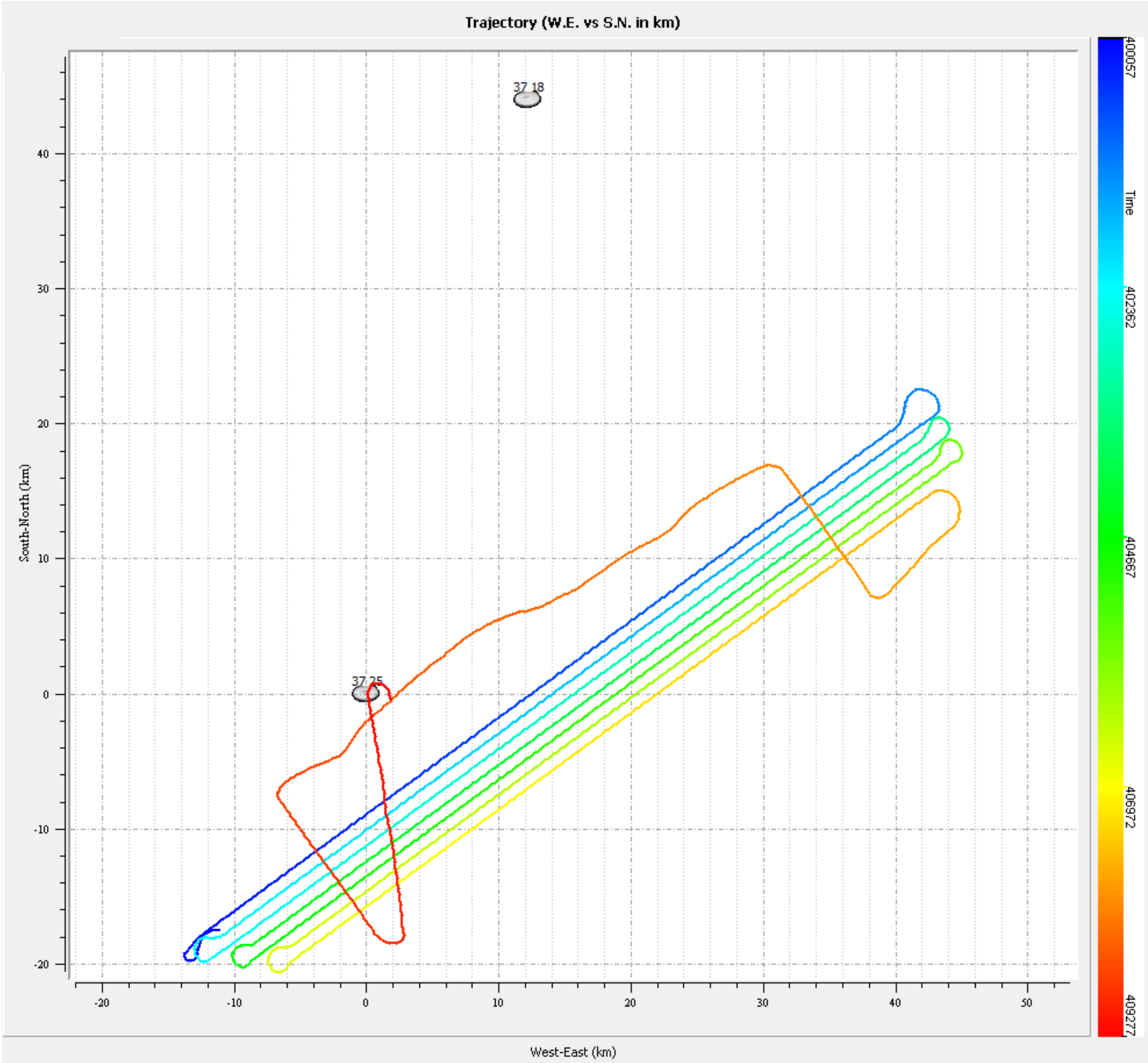


Figure 2: Forward/Reverse or Combined Separation Plot

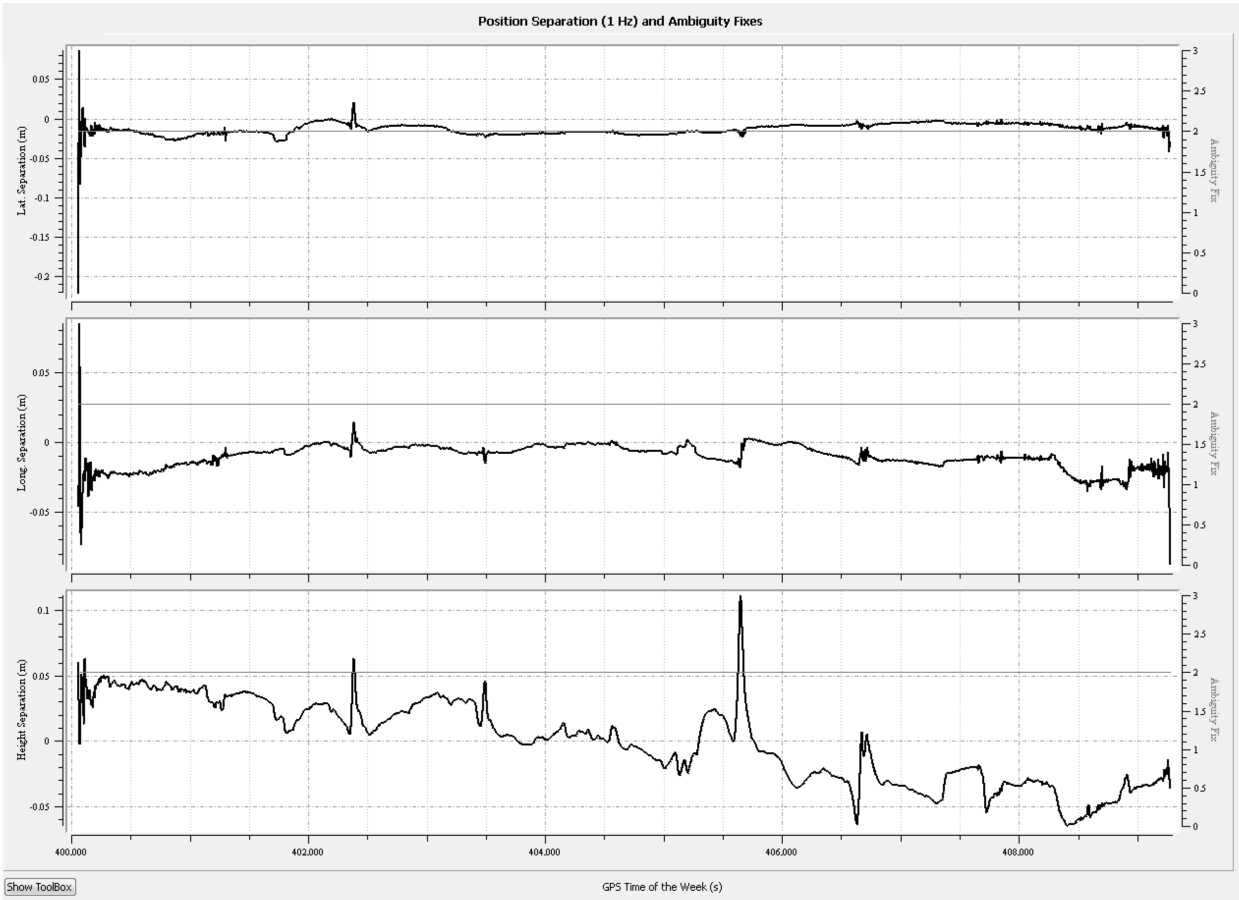


Figure 3: Attitude and Standard Deviation

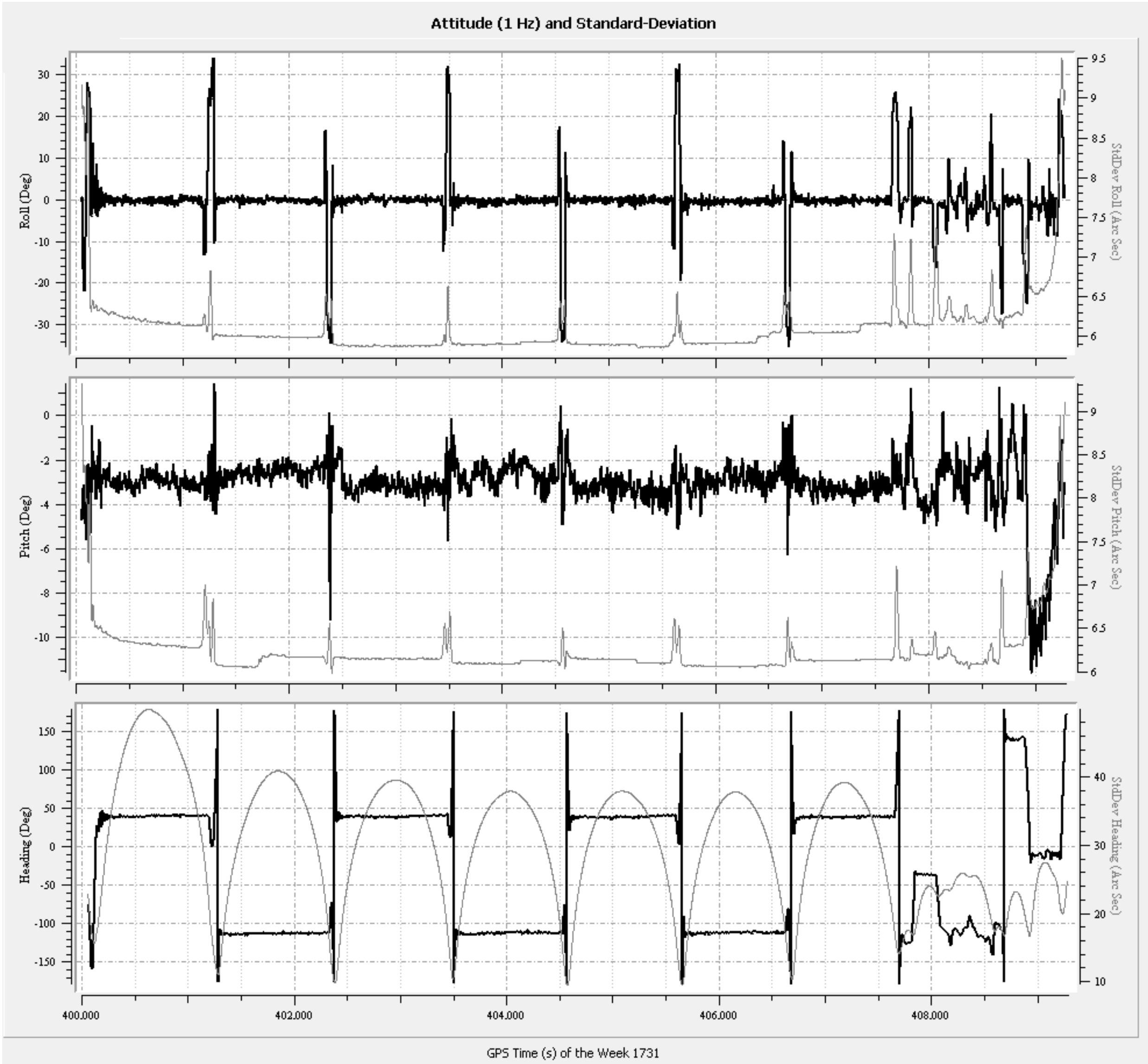


Figure 4: Position Accuracy and PDOP

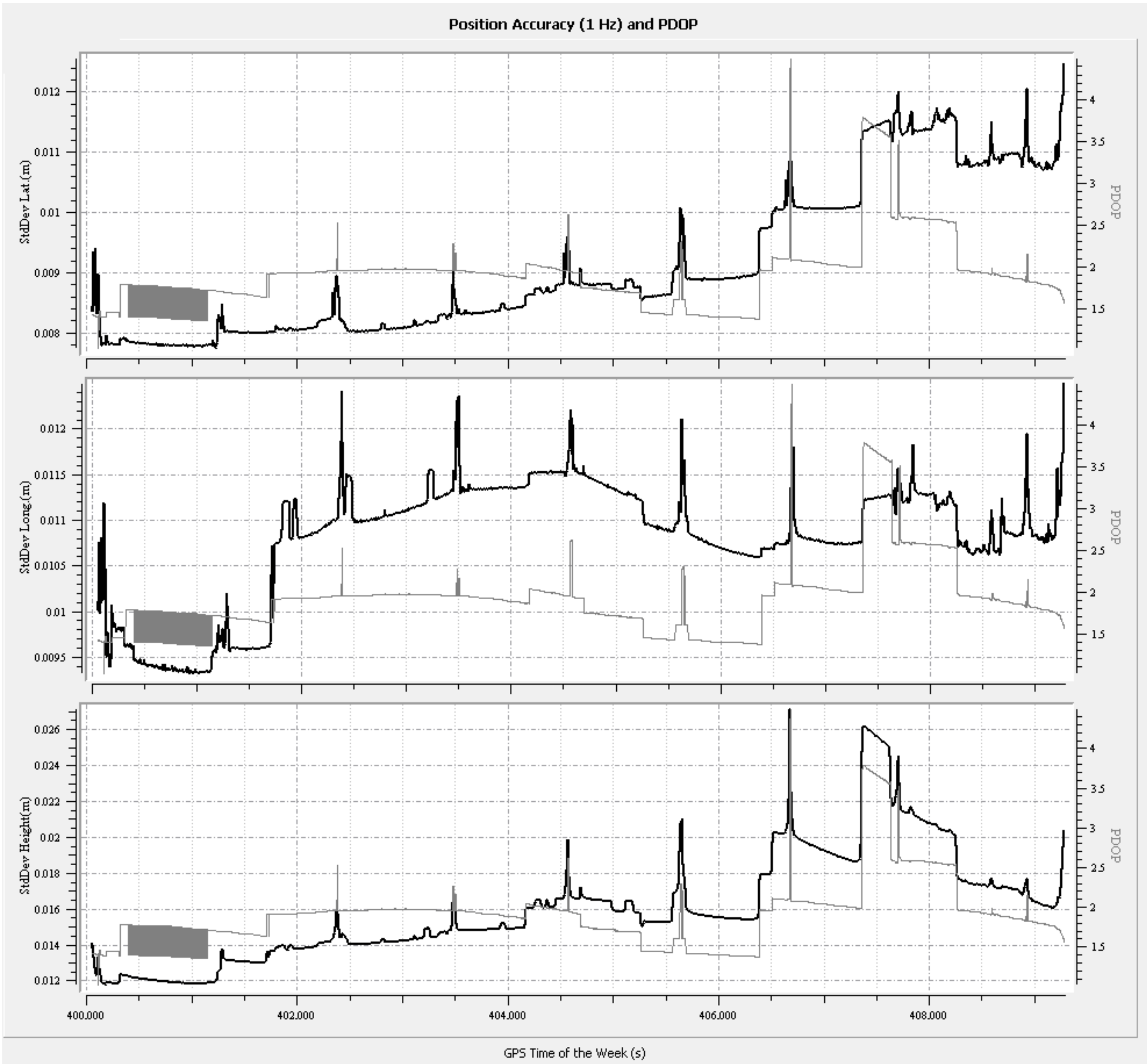
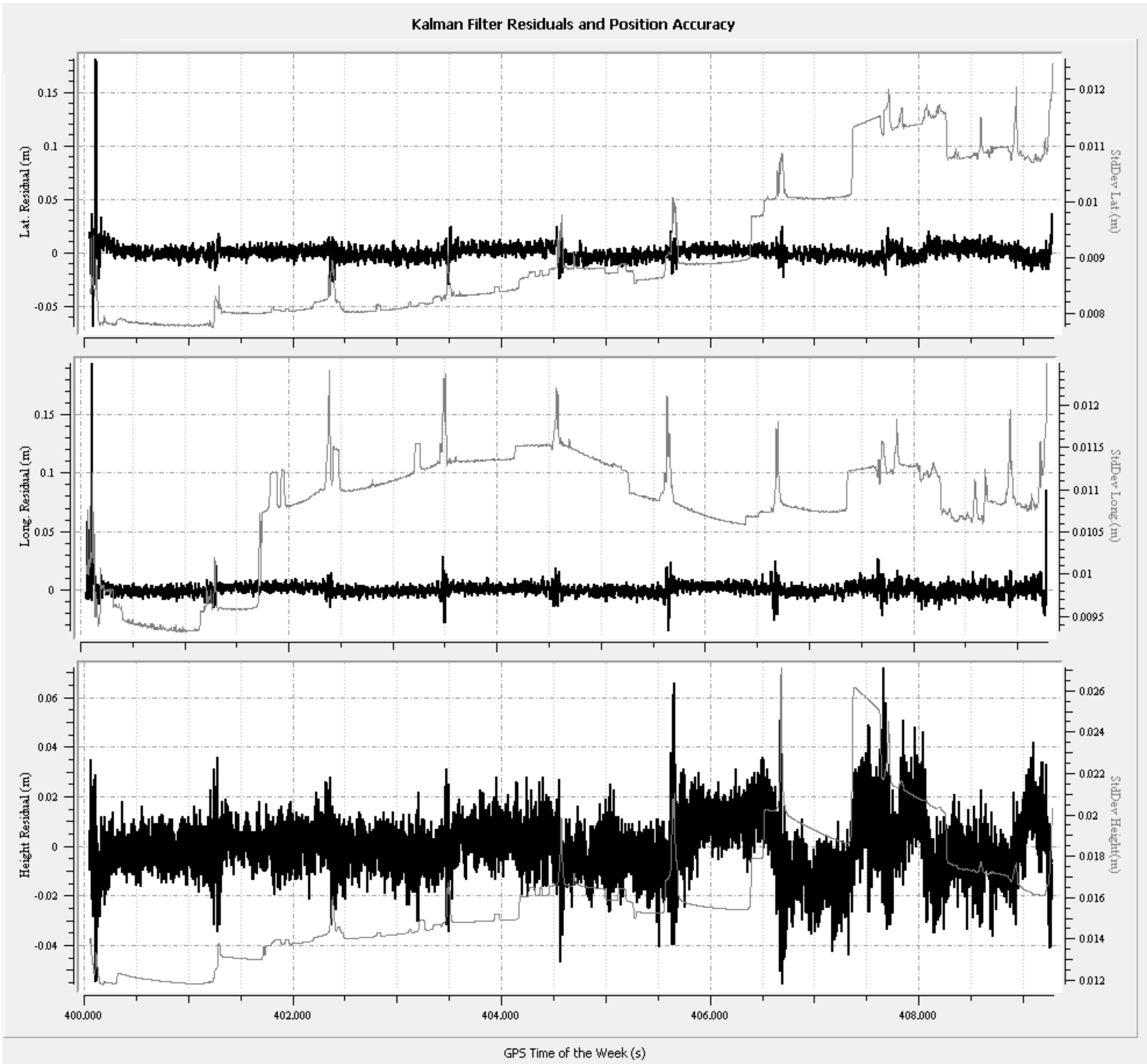


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13073_2

Figure 1: Trajectory Map

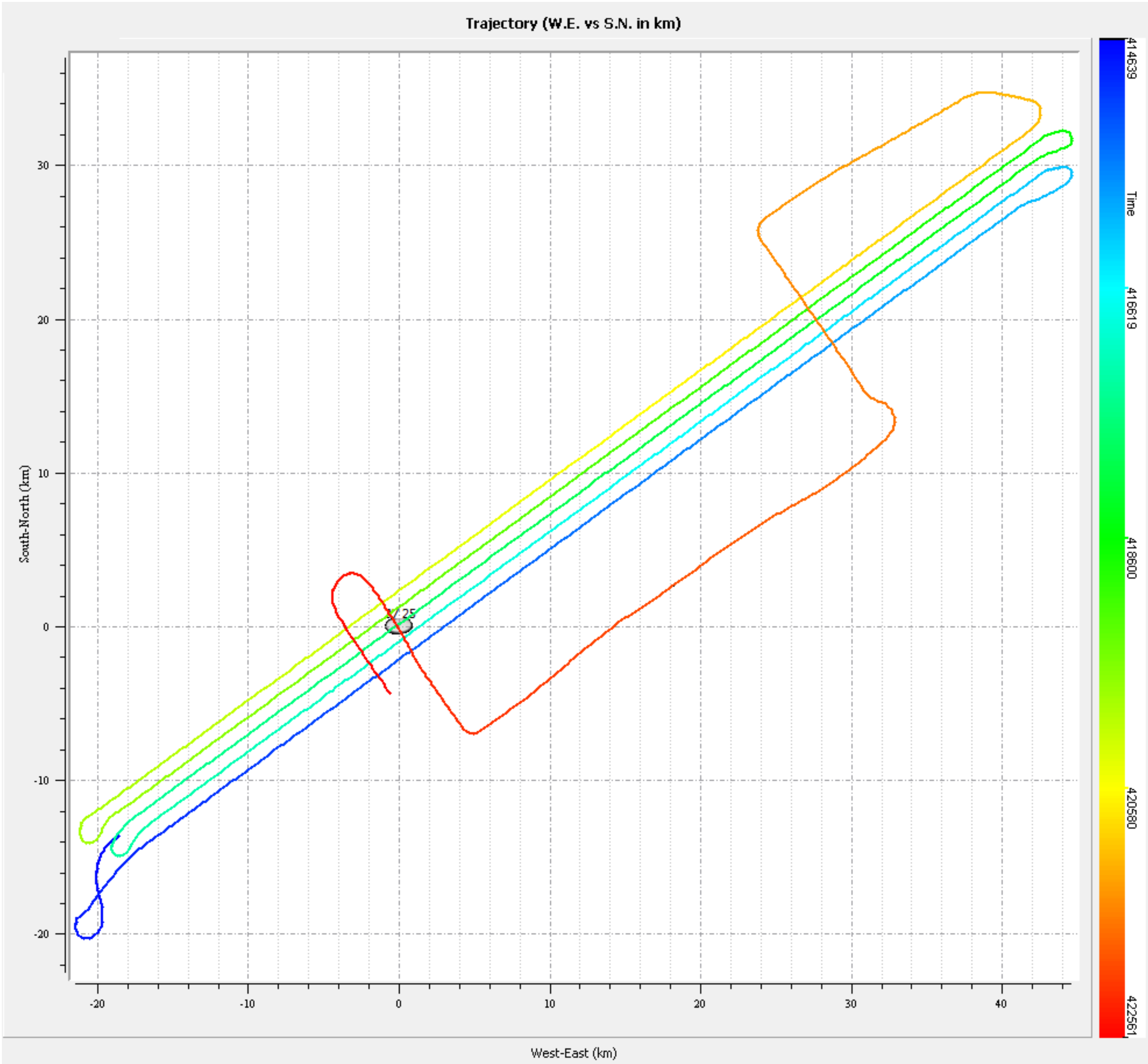


Figure 2: Forward/Reverse or Combined Separation Plot

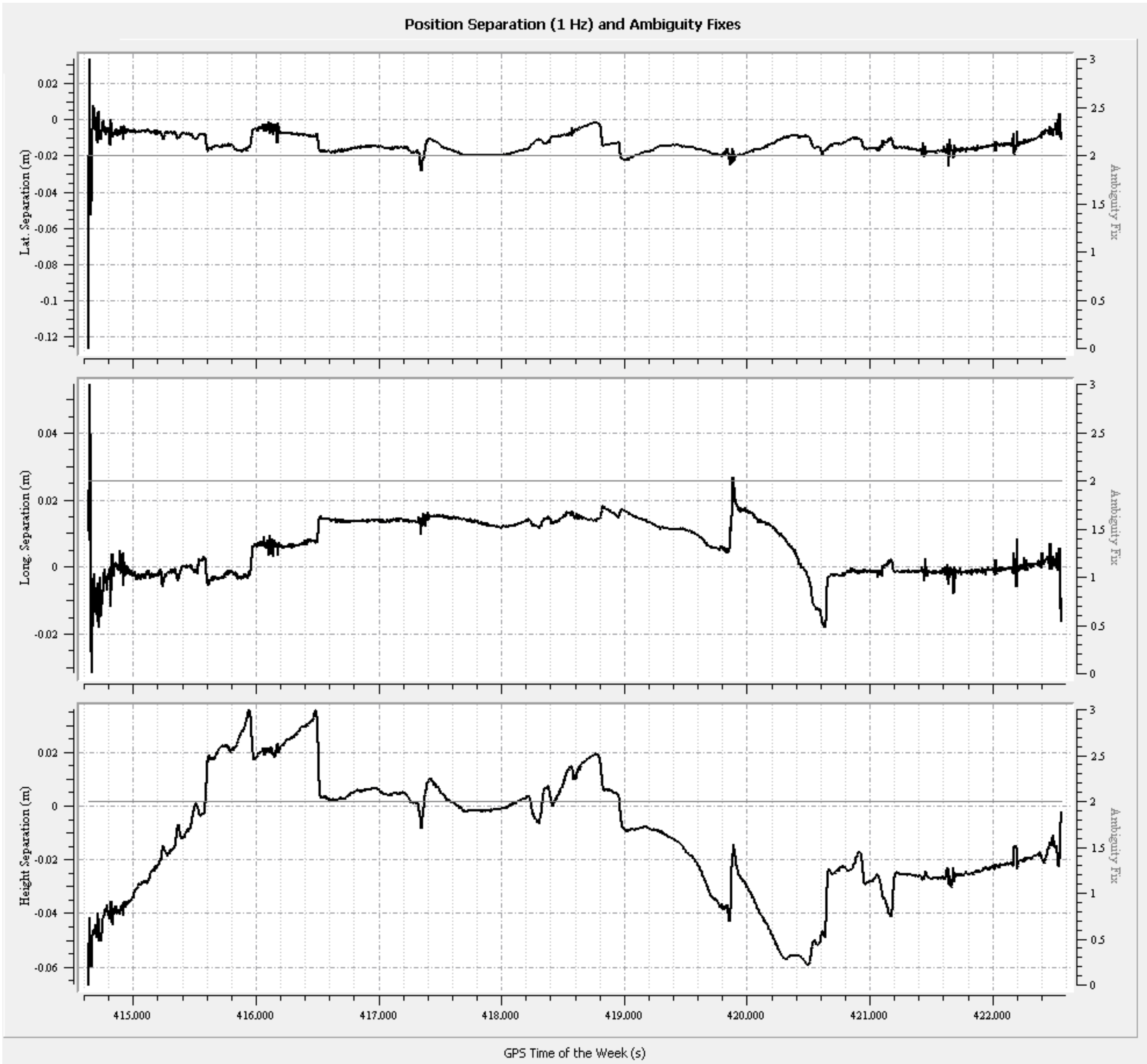


Figure 3: Attitude and Standard Deviation

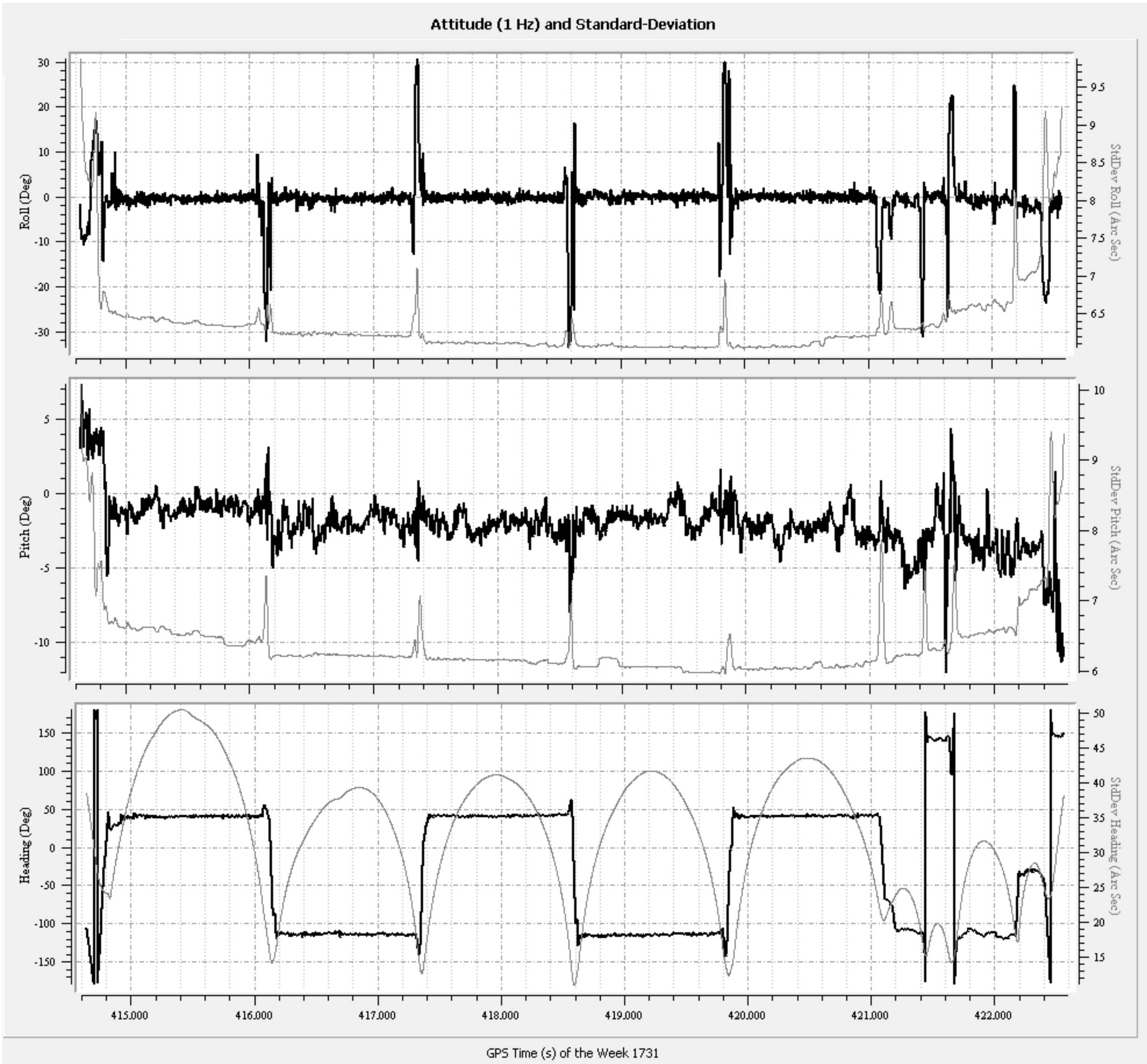


Figure 4: Position Accuracy and PDOP

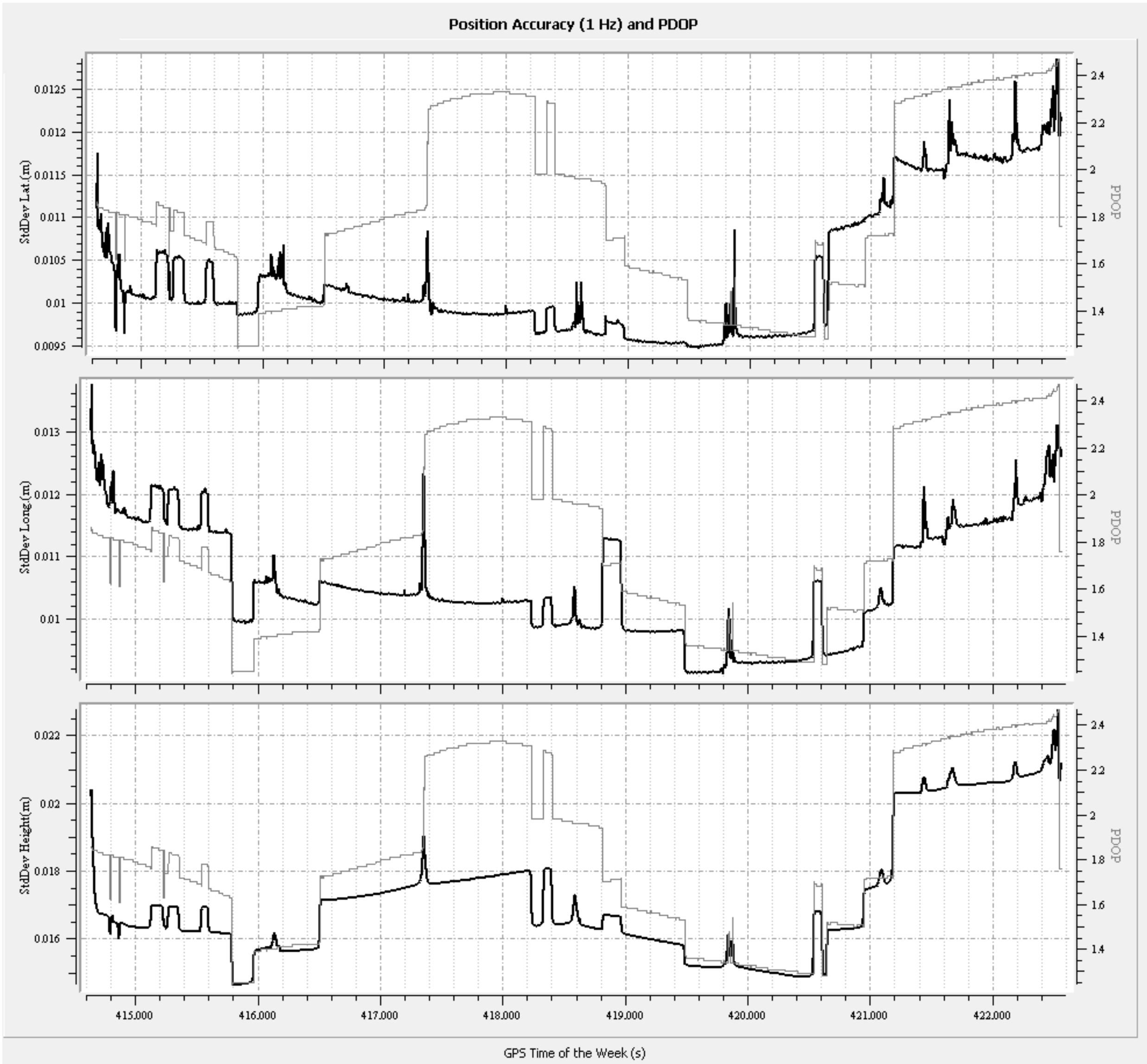
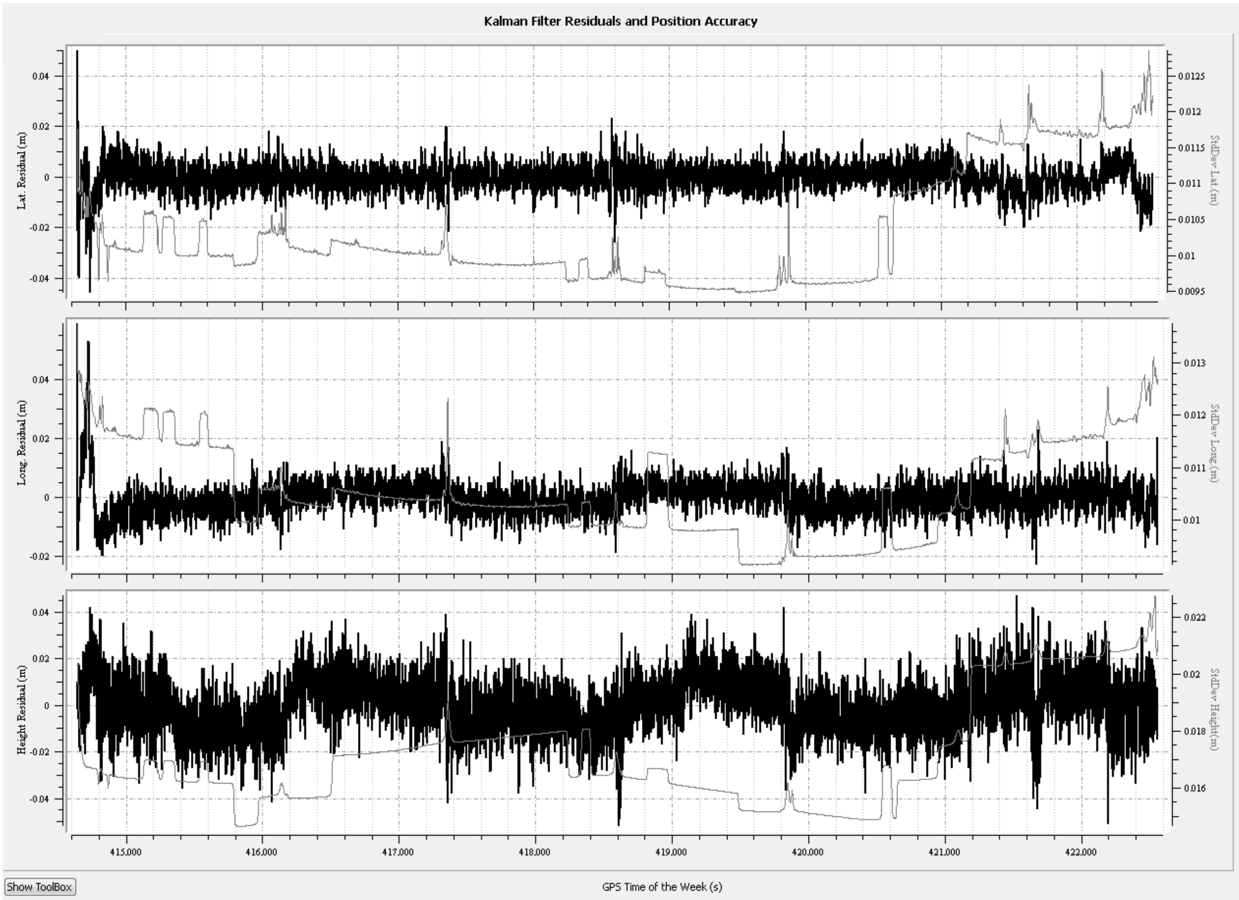


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13073_3

Figure 1: Trajectory Map

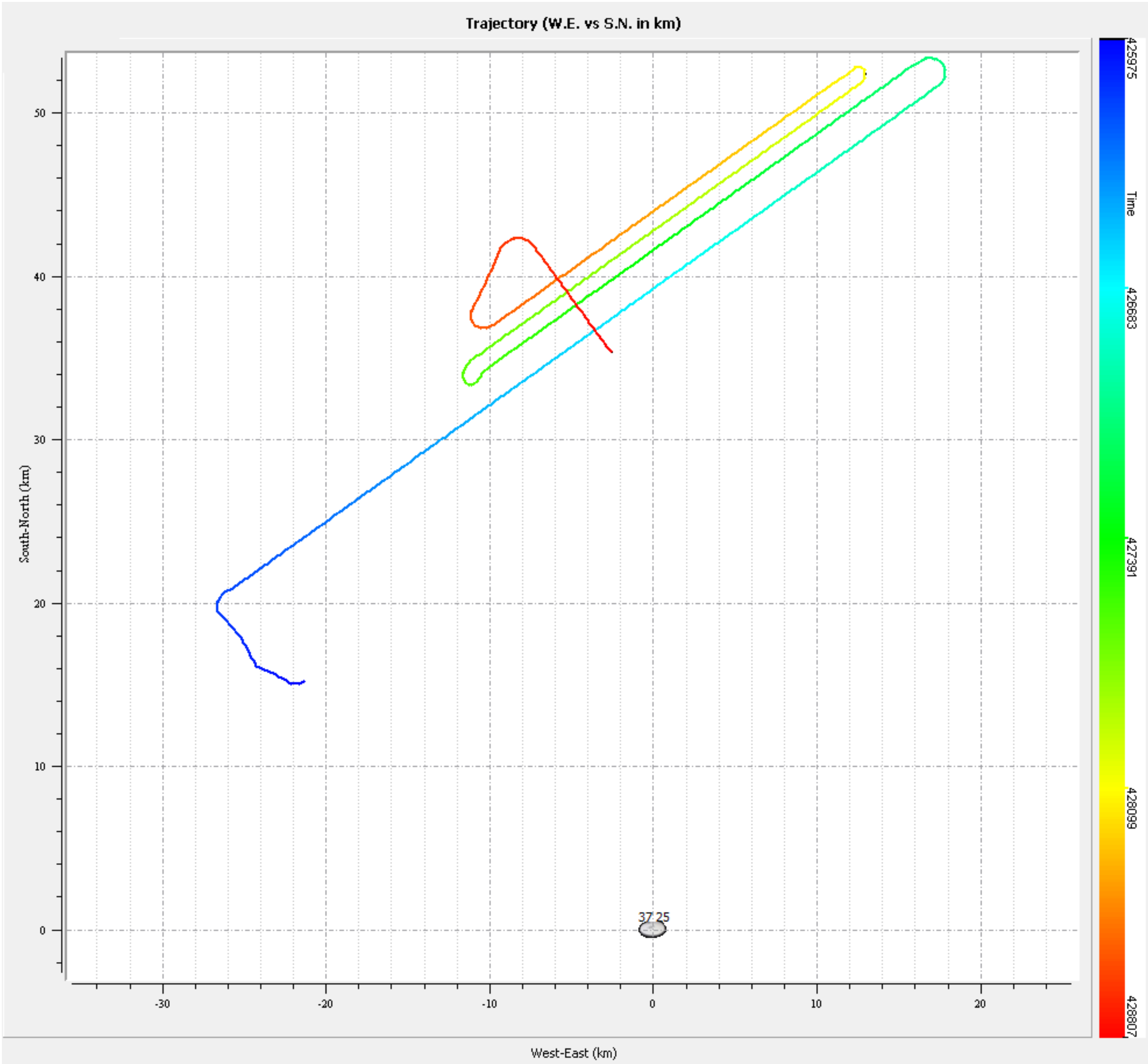


Figure 2: Forward/Reverse or Combined Separation Plot

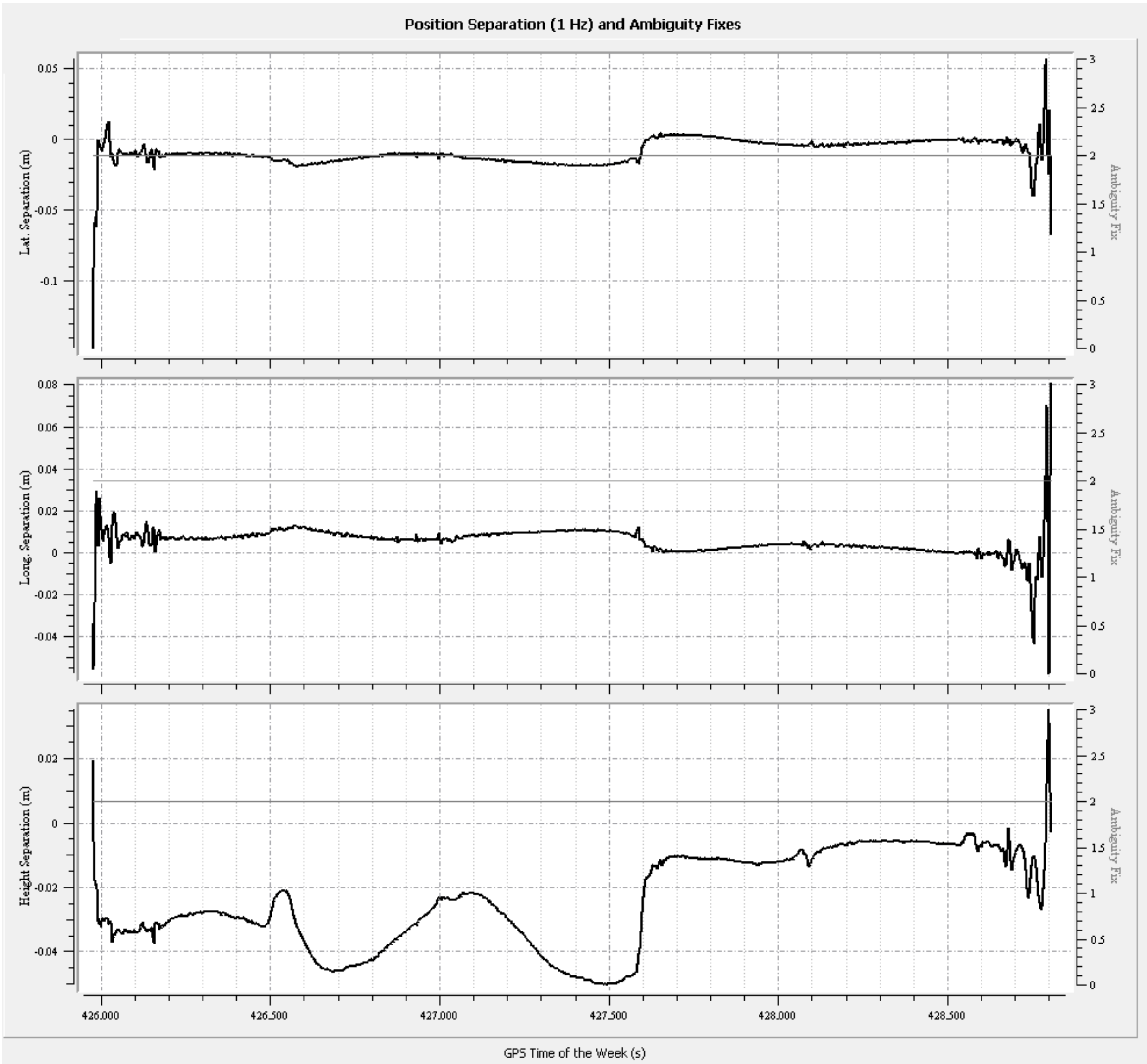


Figure 3: Attitude and Standard Deviation

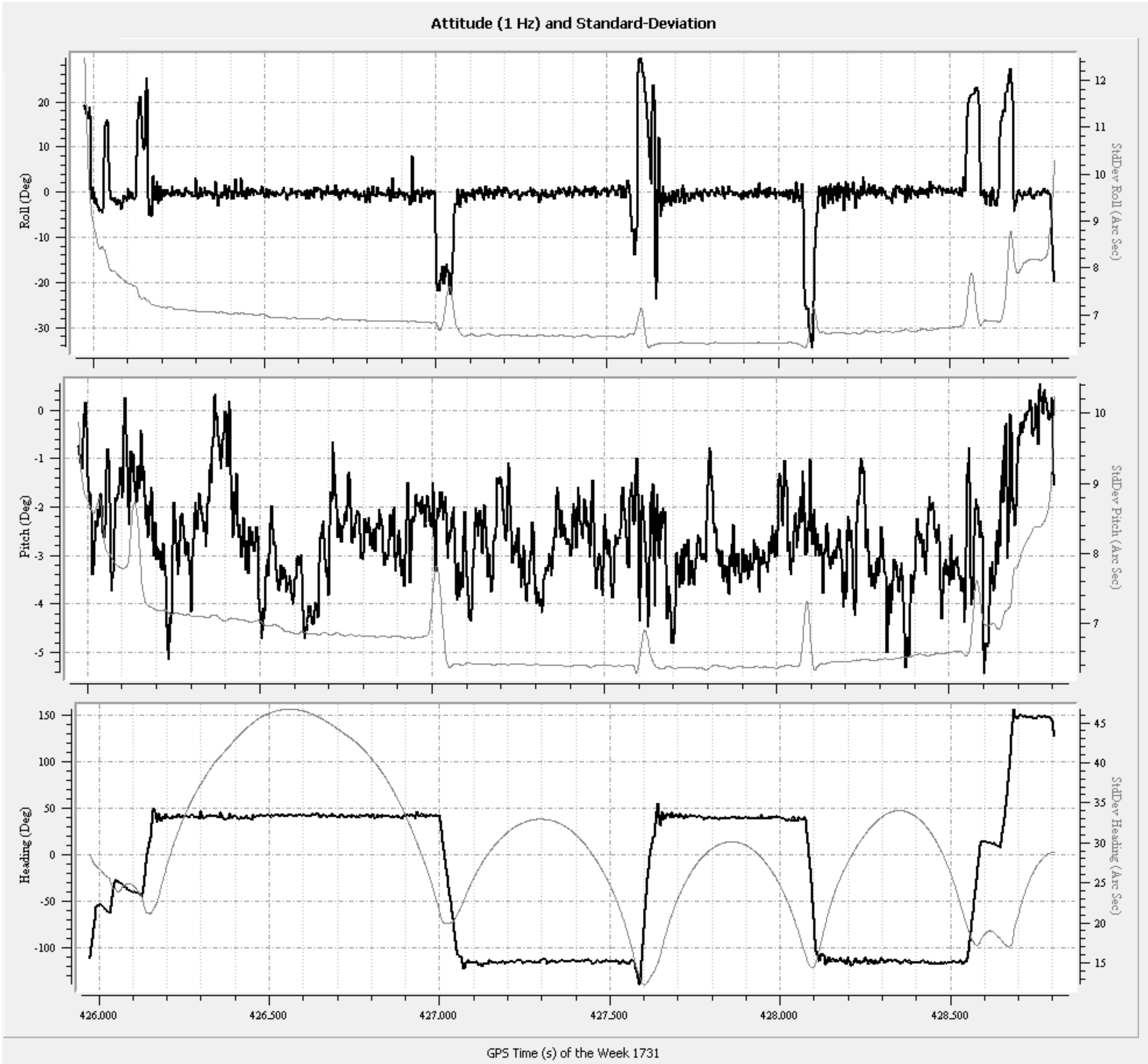


Figure 4: Position Accuracy and PDOP

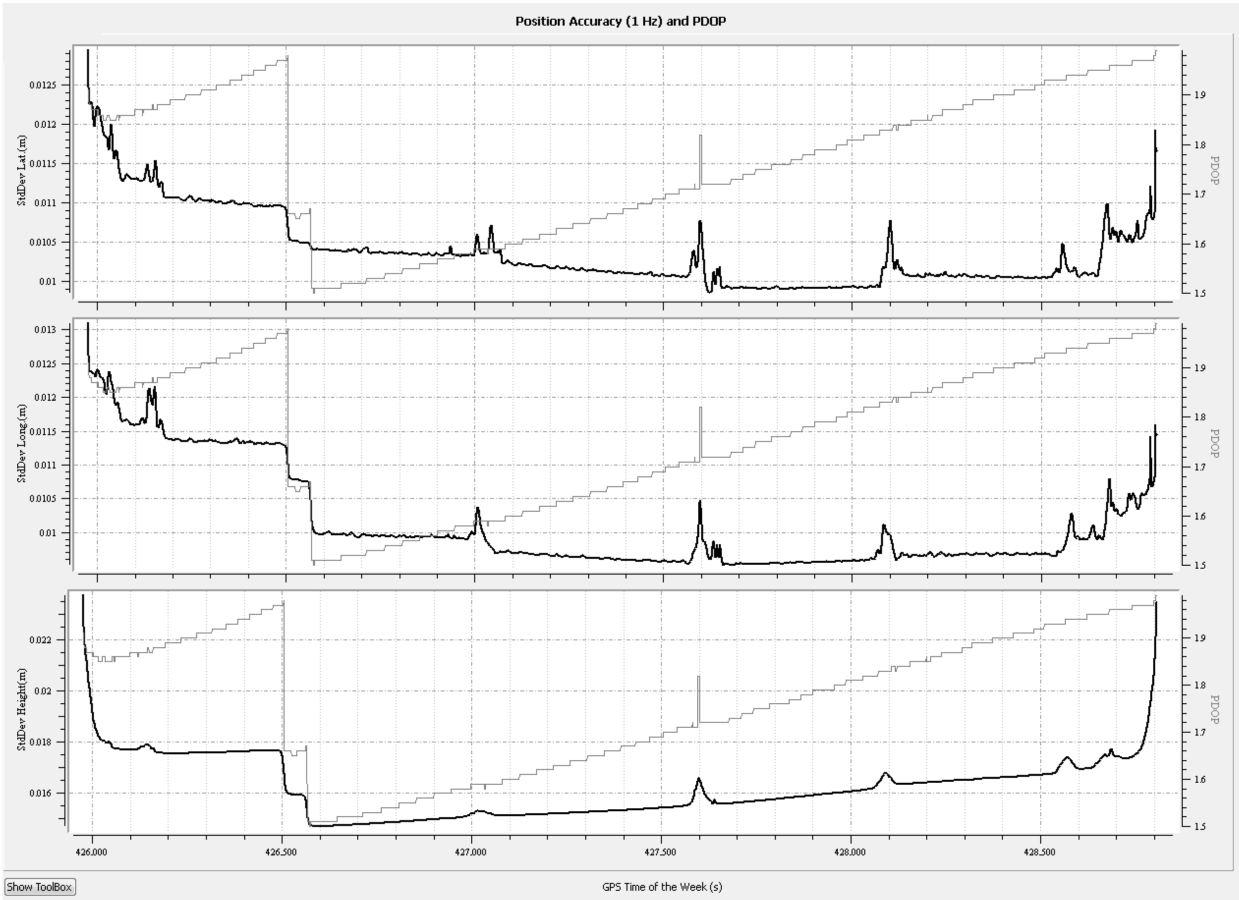
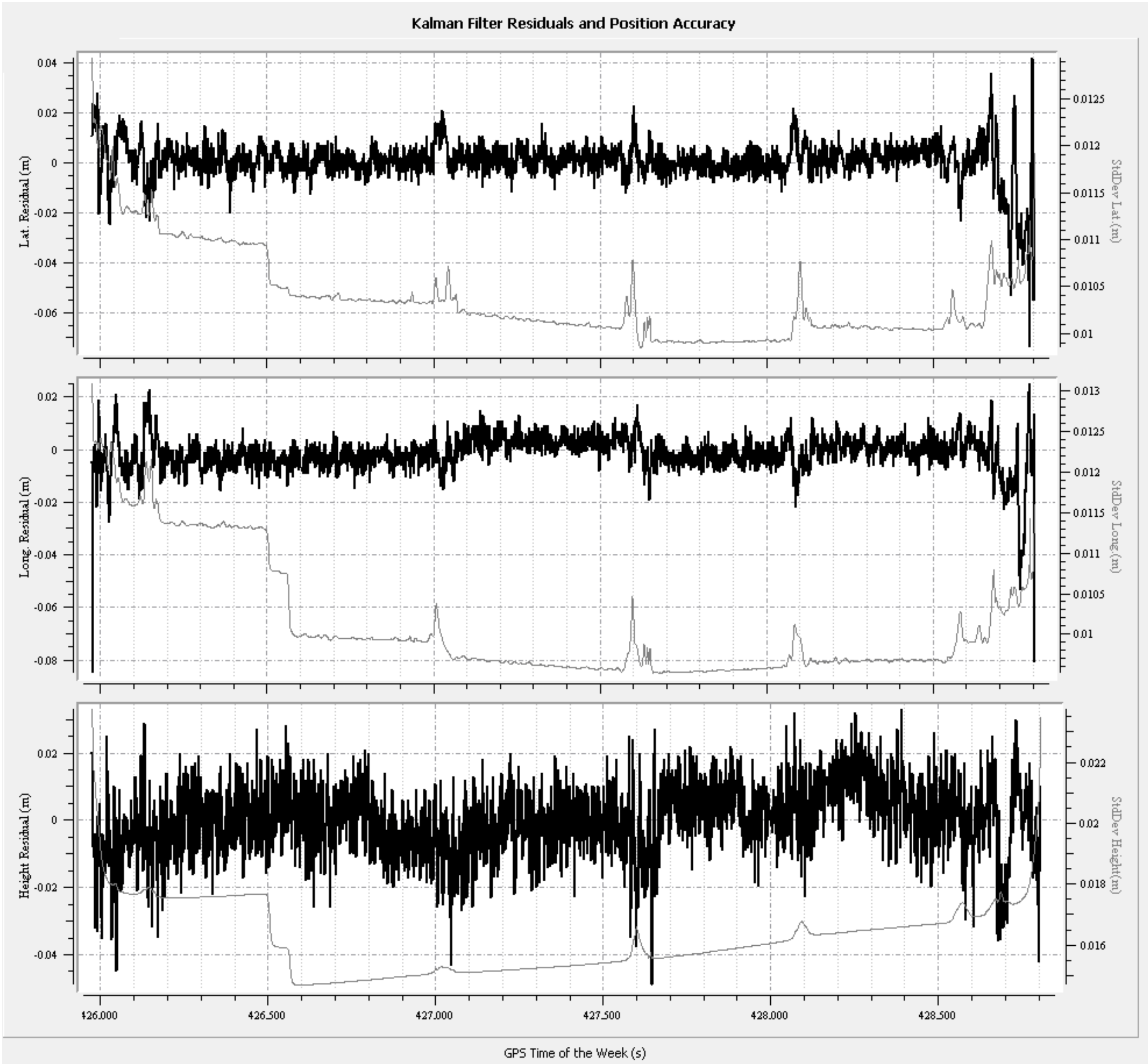


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13078_1

Figure 1: Trajectory Map

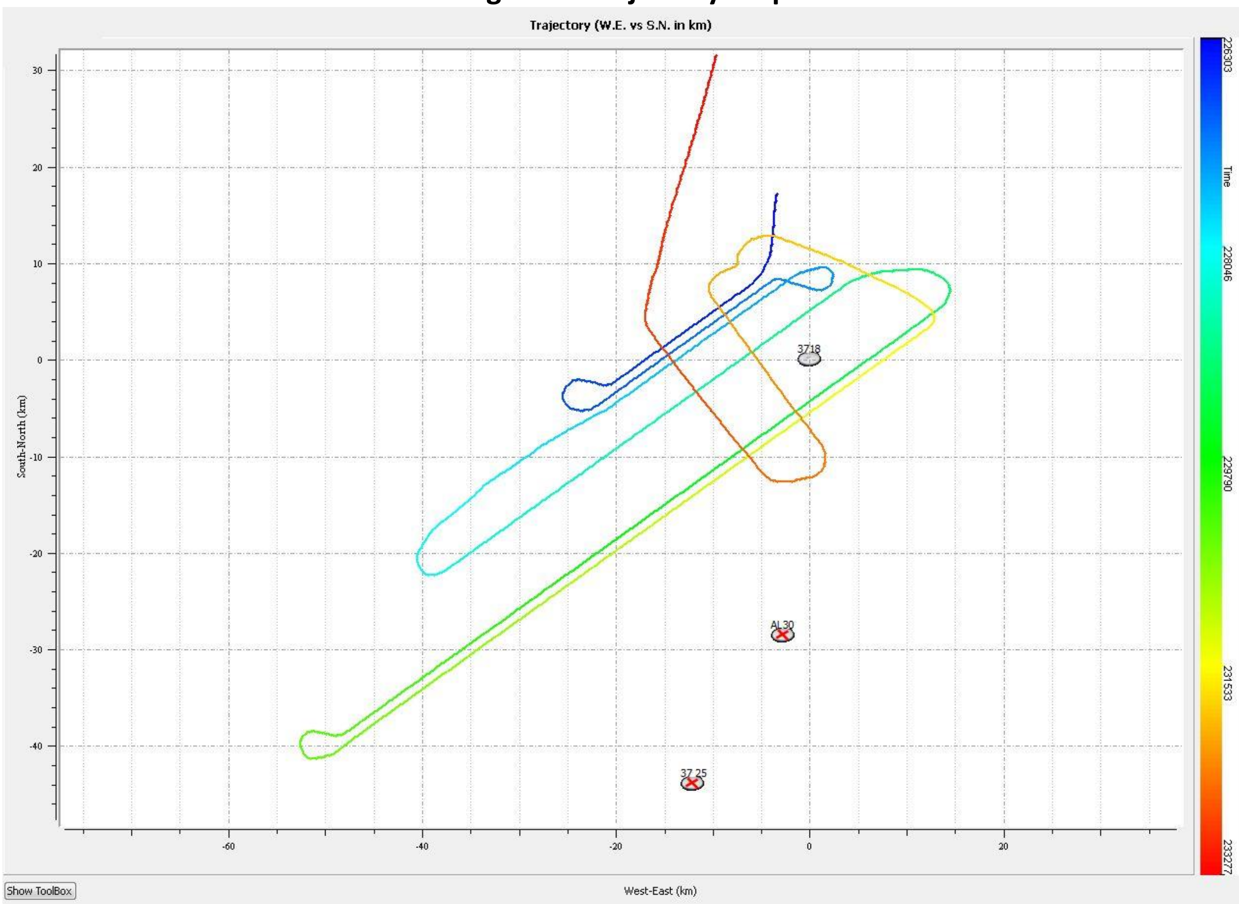


Figure 2: Forward/Reverse or Combined Separation Plot

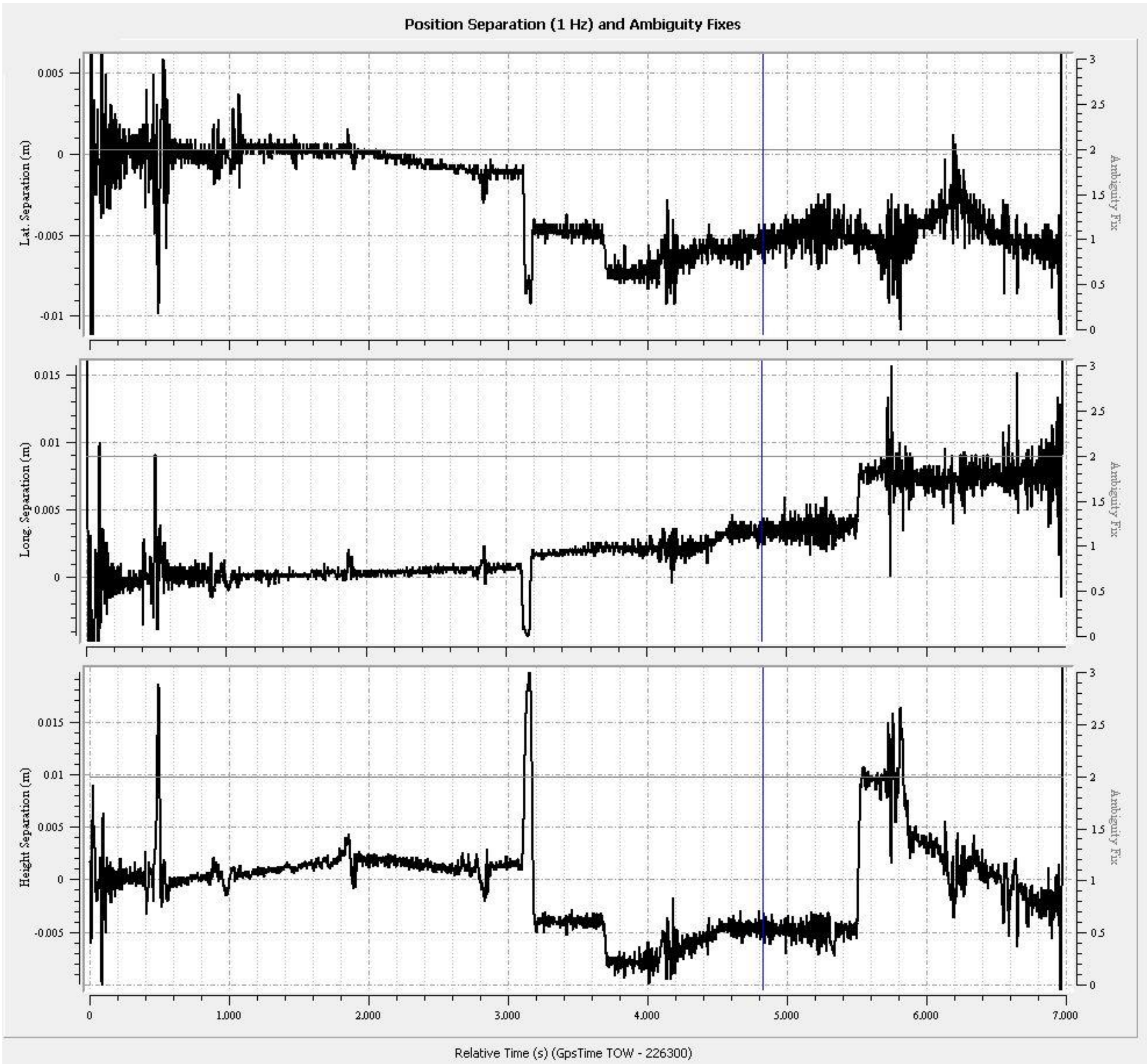


Figure 3: Attitude and Standard Deviation

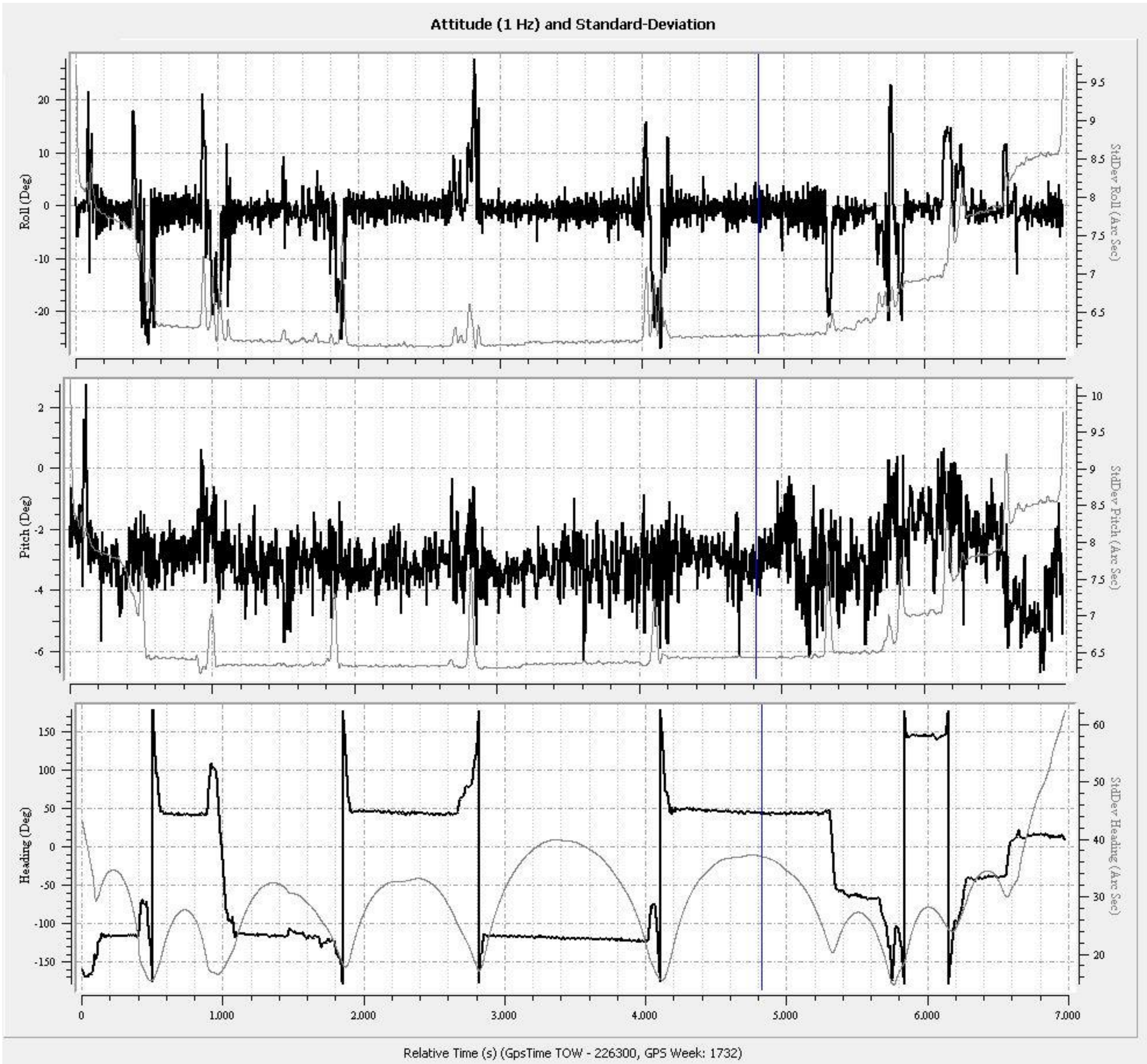


Figure 4: Position Accuracy and PDOP

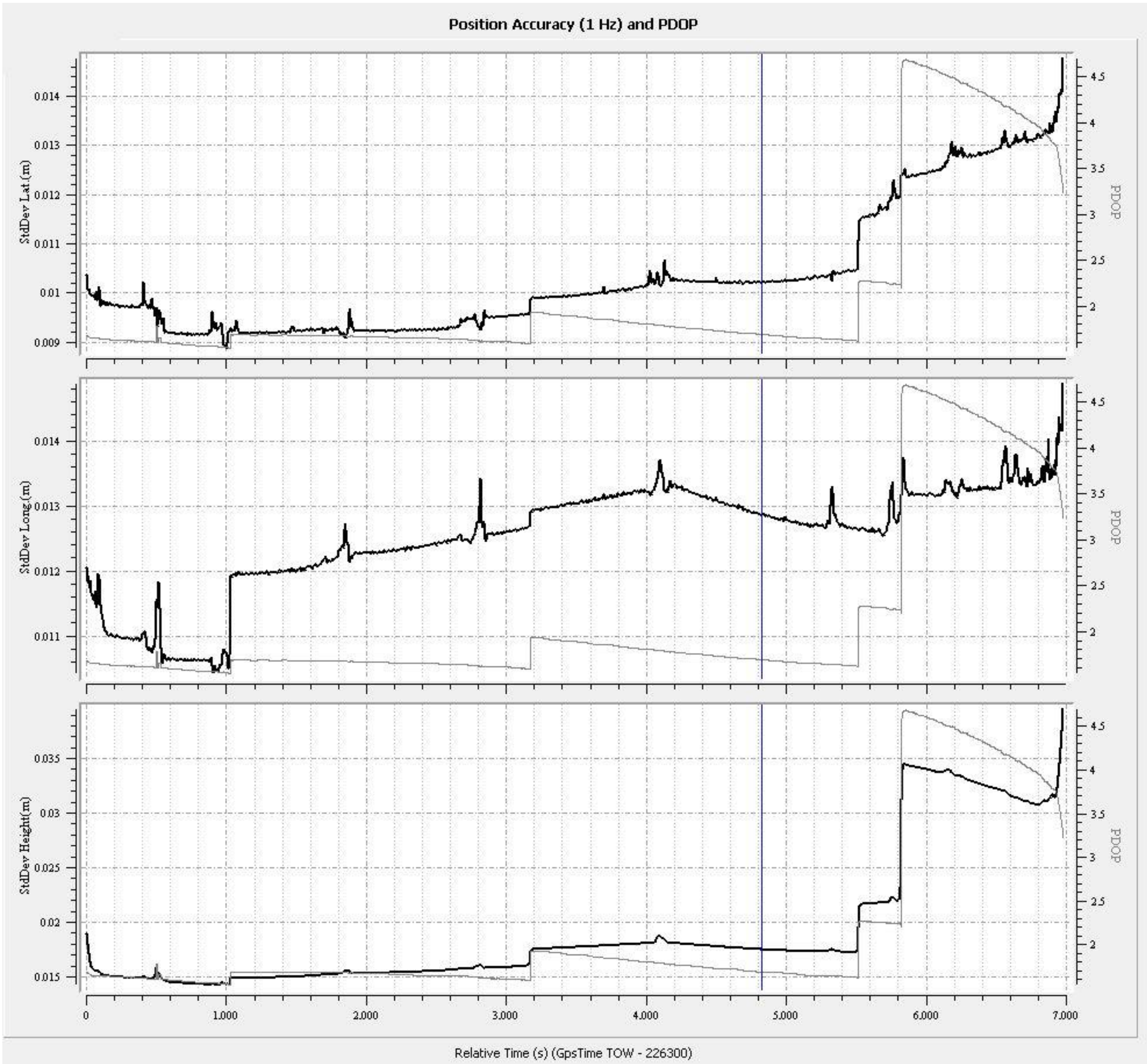
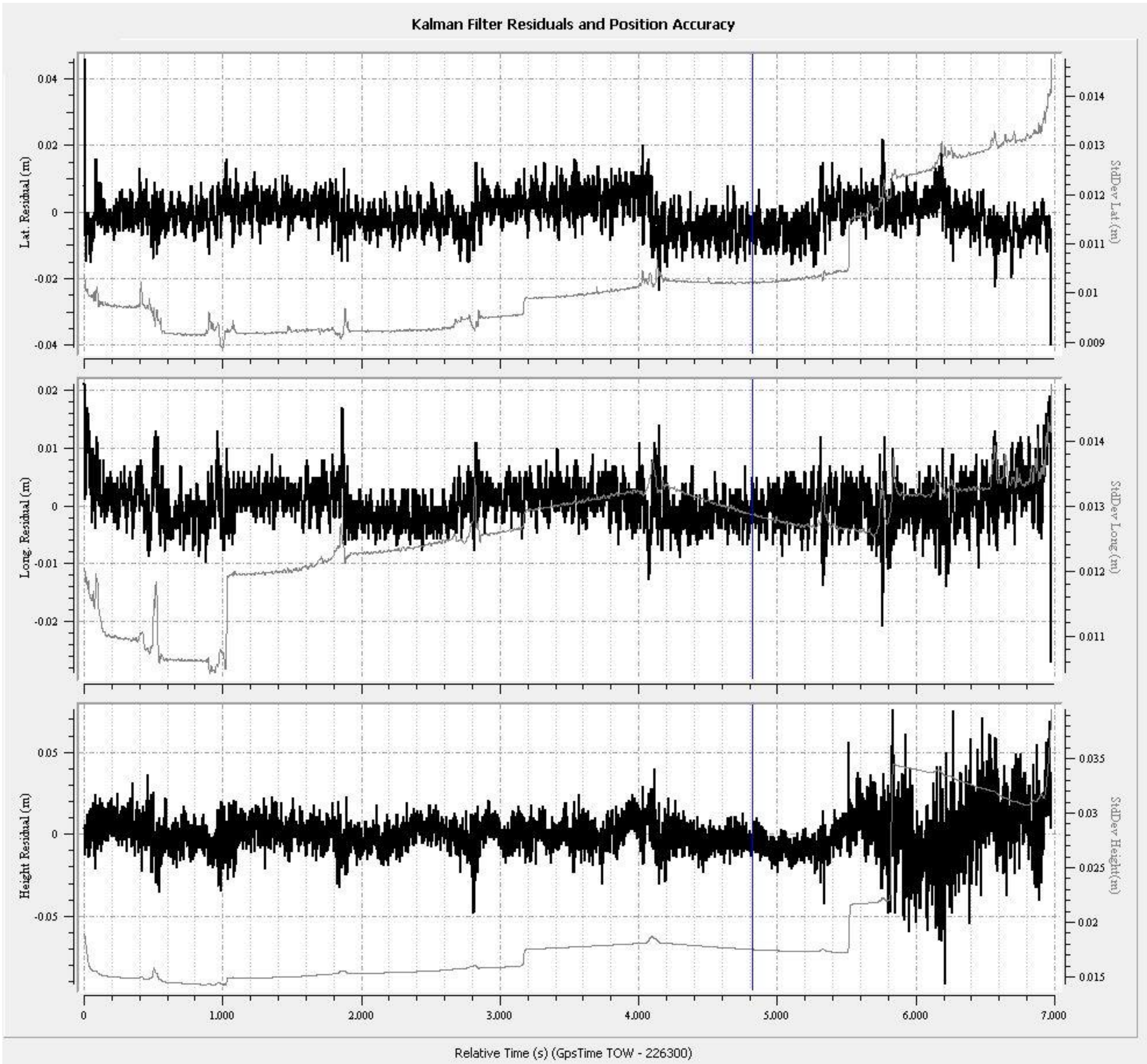


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13078_2

Figure 1: Trajectory Map

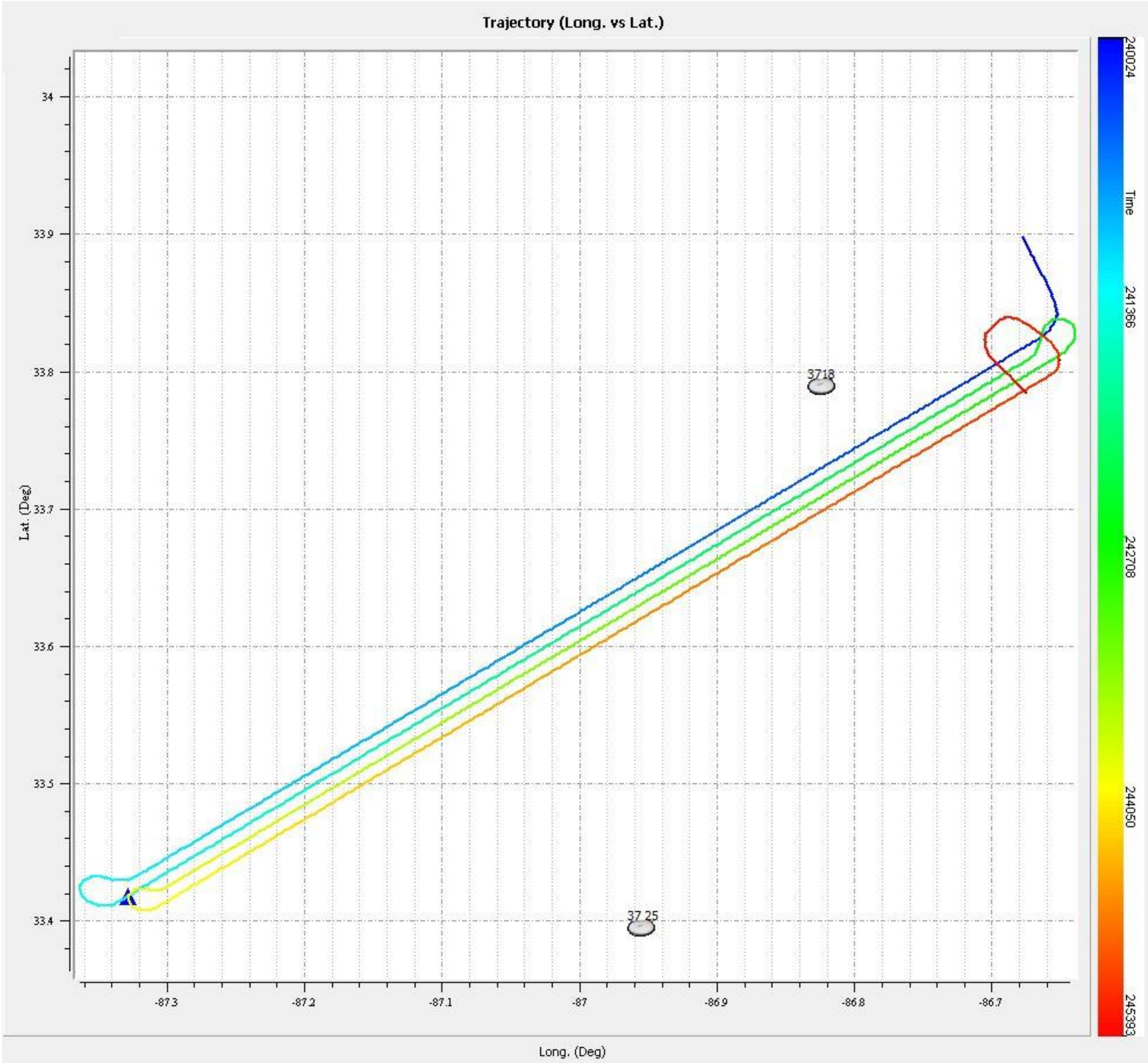


Figure 2: Forward/Reverse or Combined Separation Plot

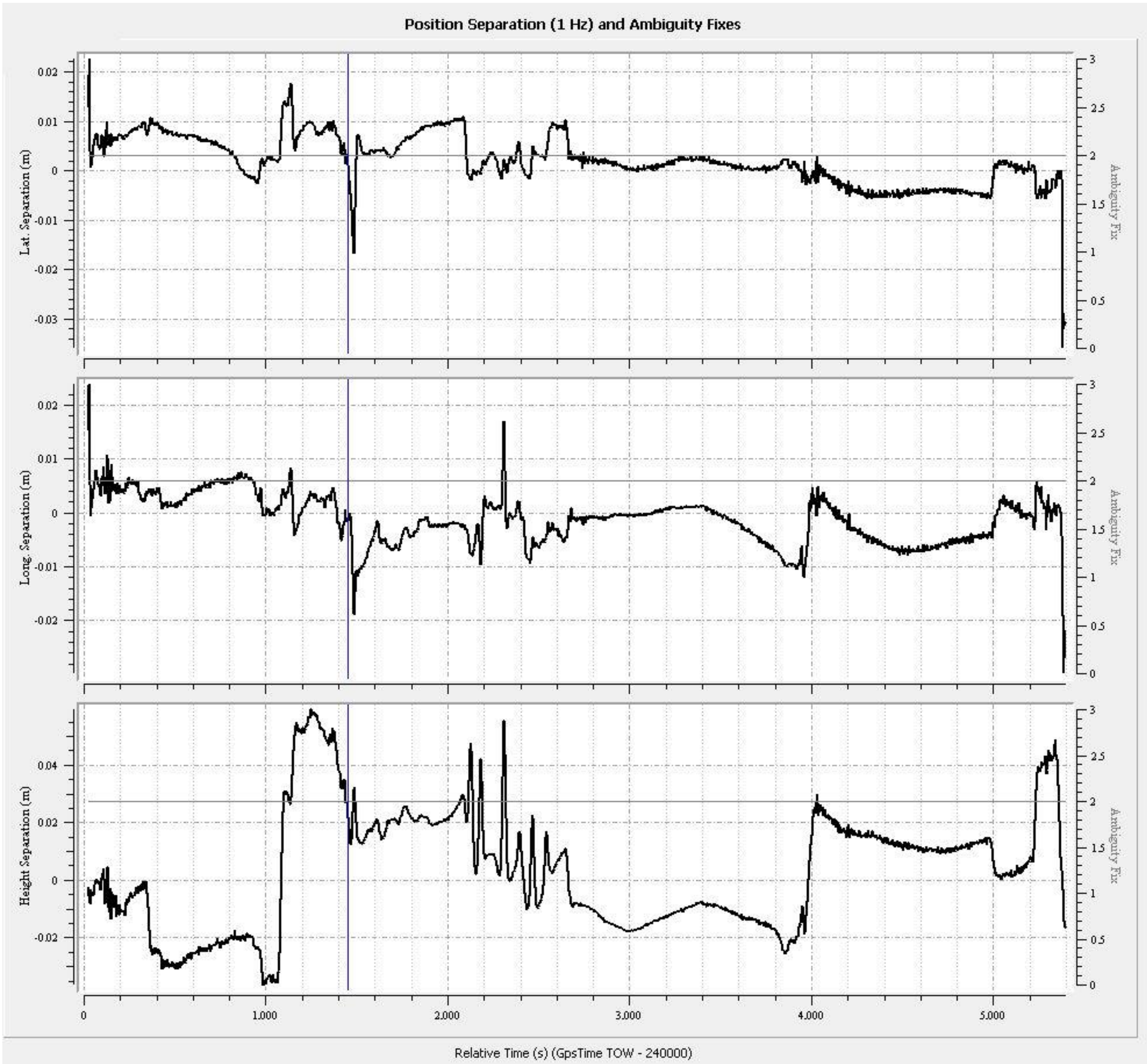


Figure 3: Attitude and Standard Deviation

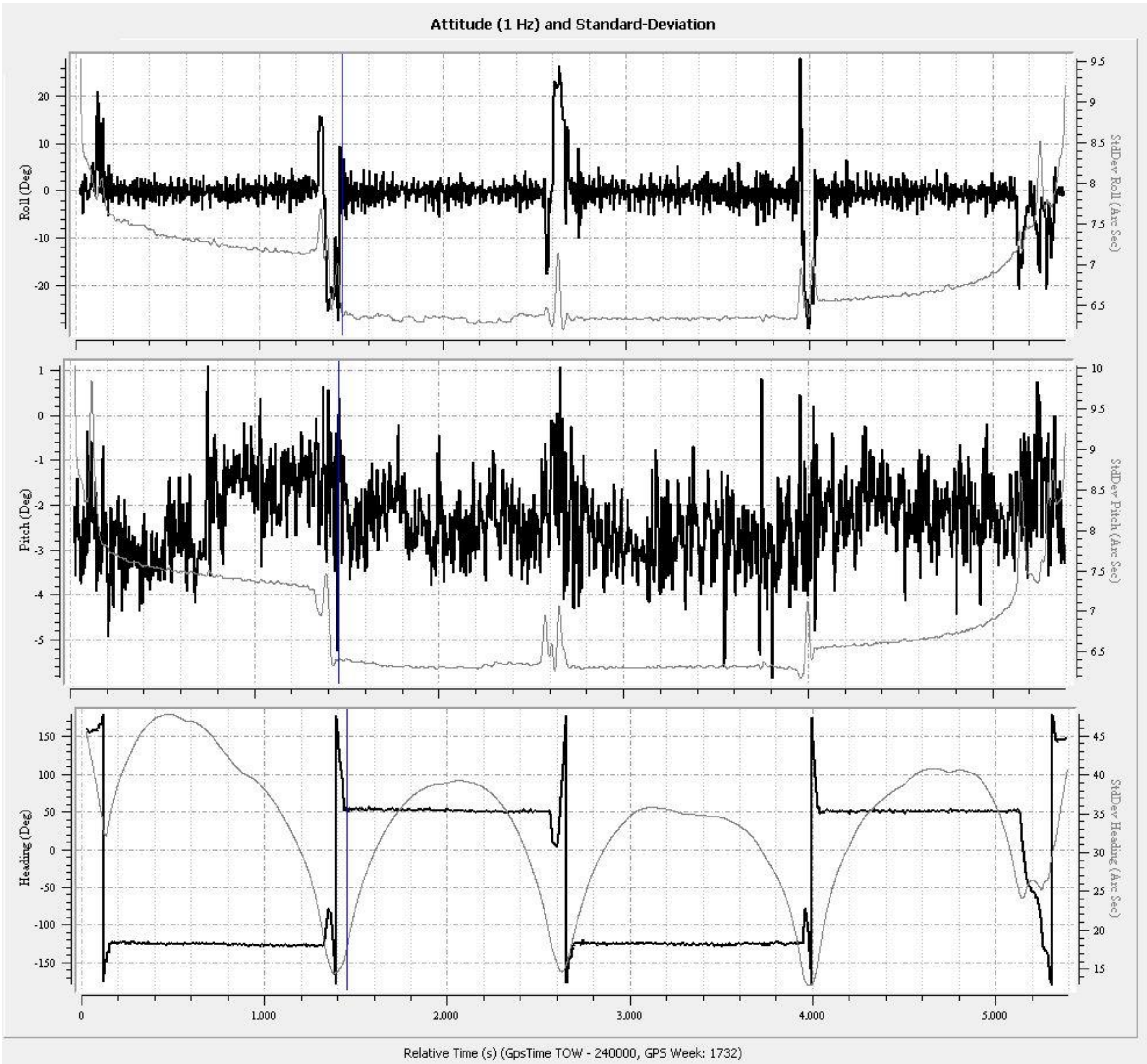


Figure 4: Position Accuracy and PDOP

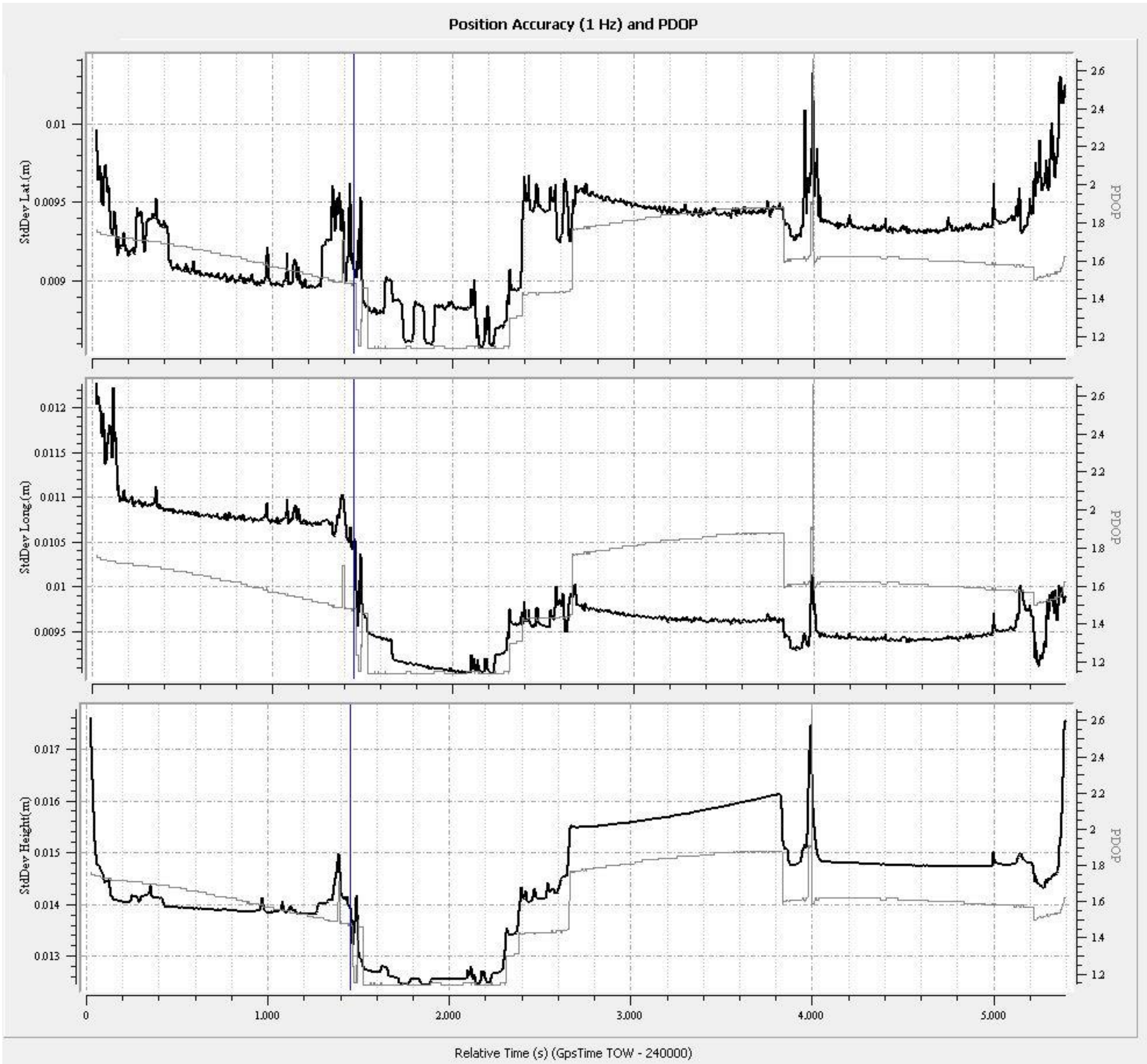
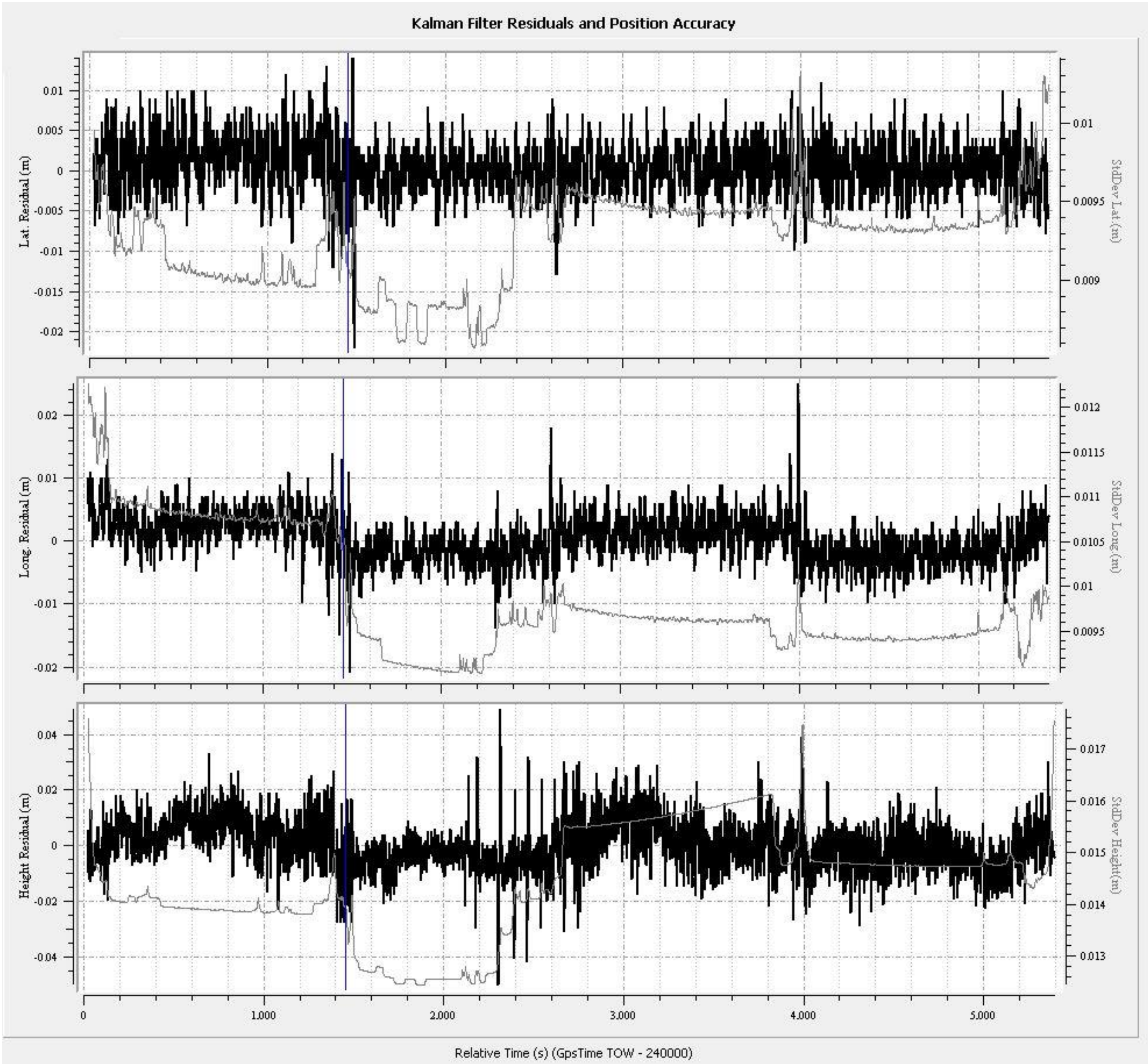


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13079_1

Figure 1: Trajectory Map

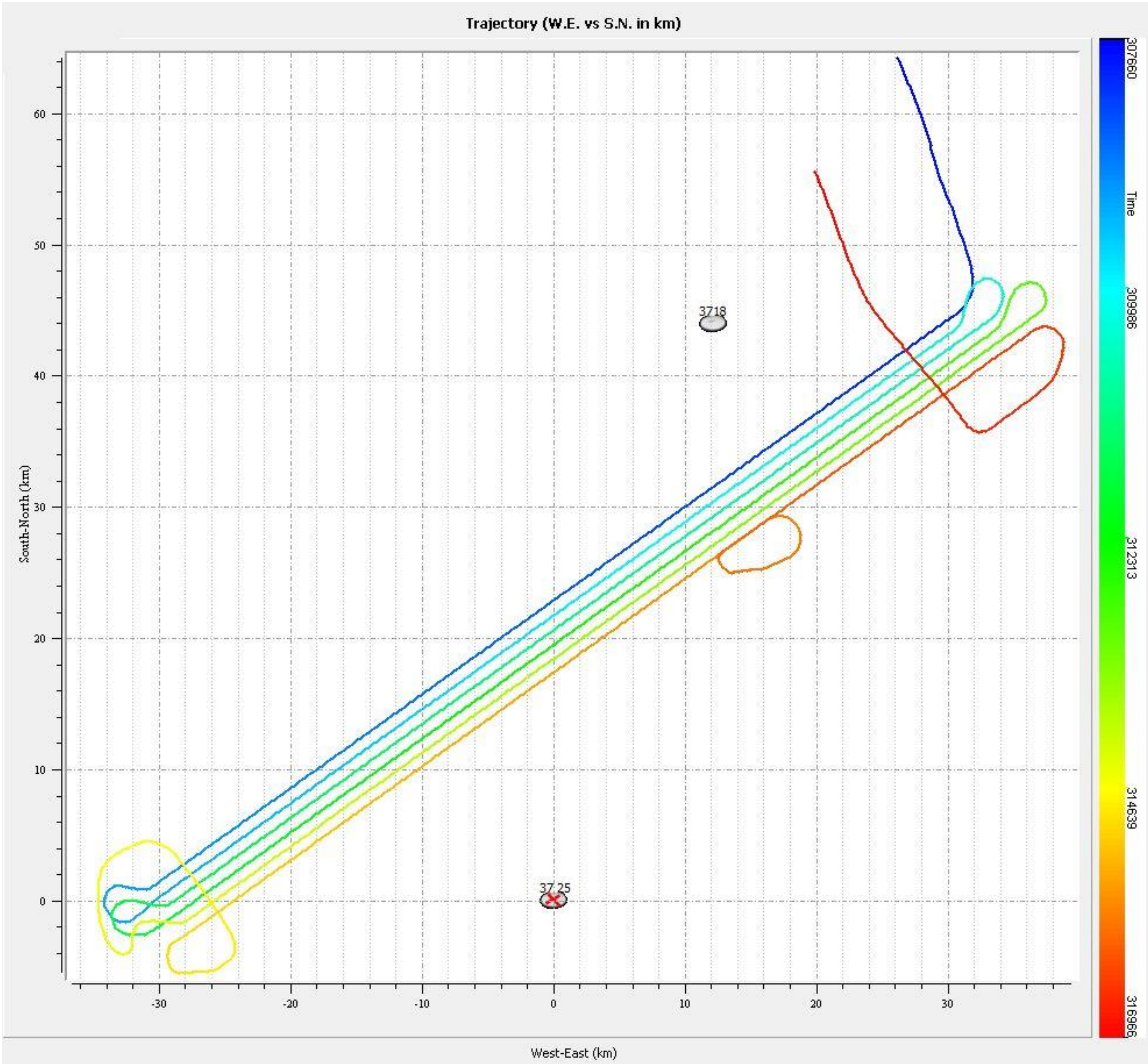


Figure 2: Forward/Reverse or Combined Separation Plot

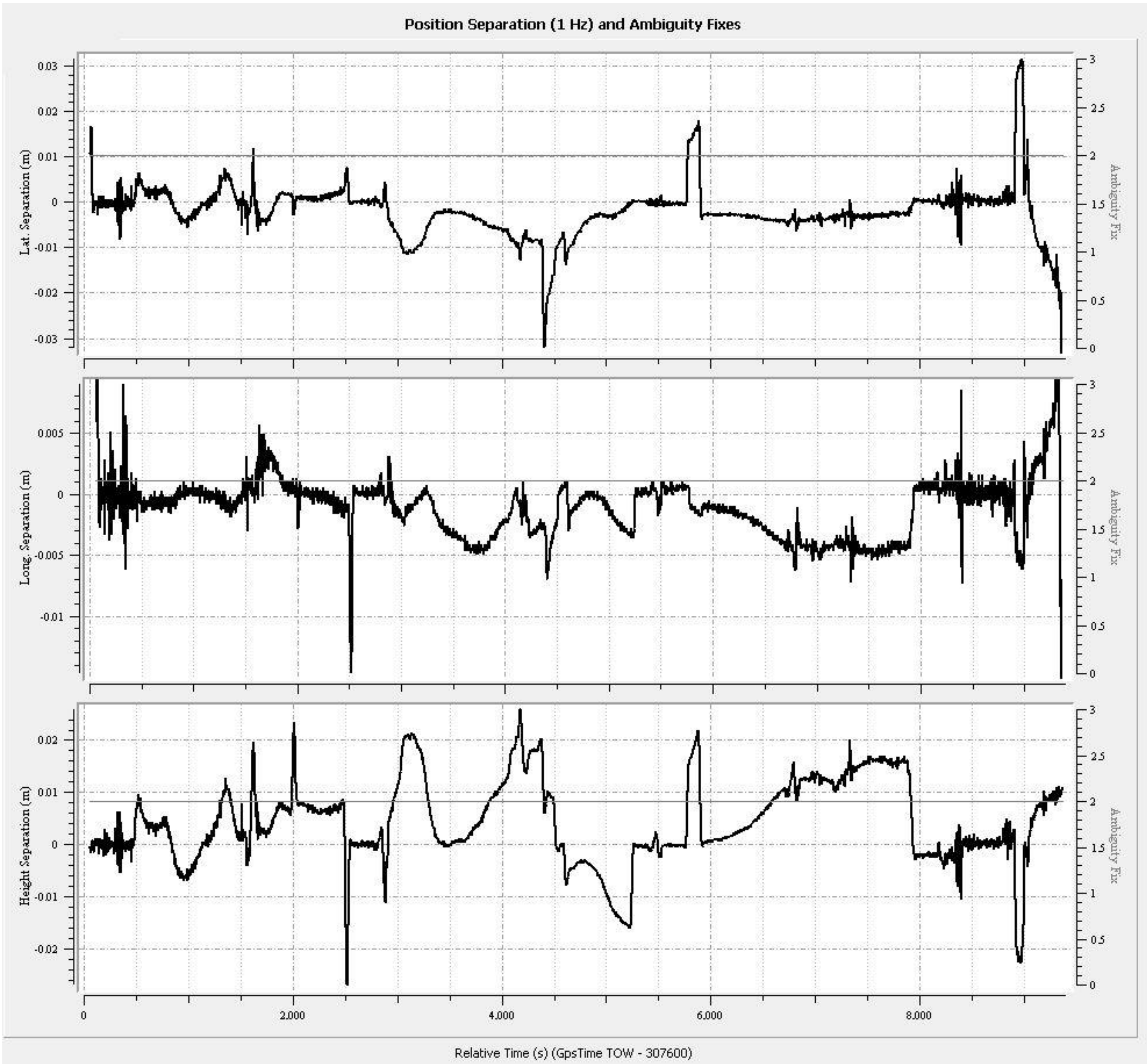


Figure 3: Attitude and Standard Deviation

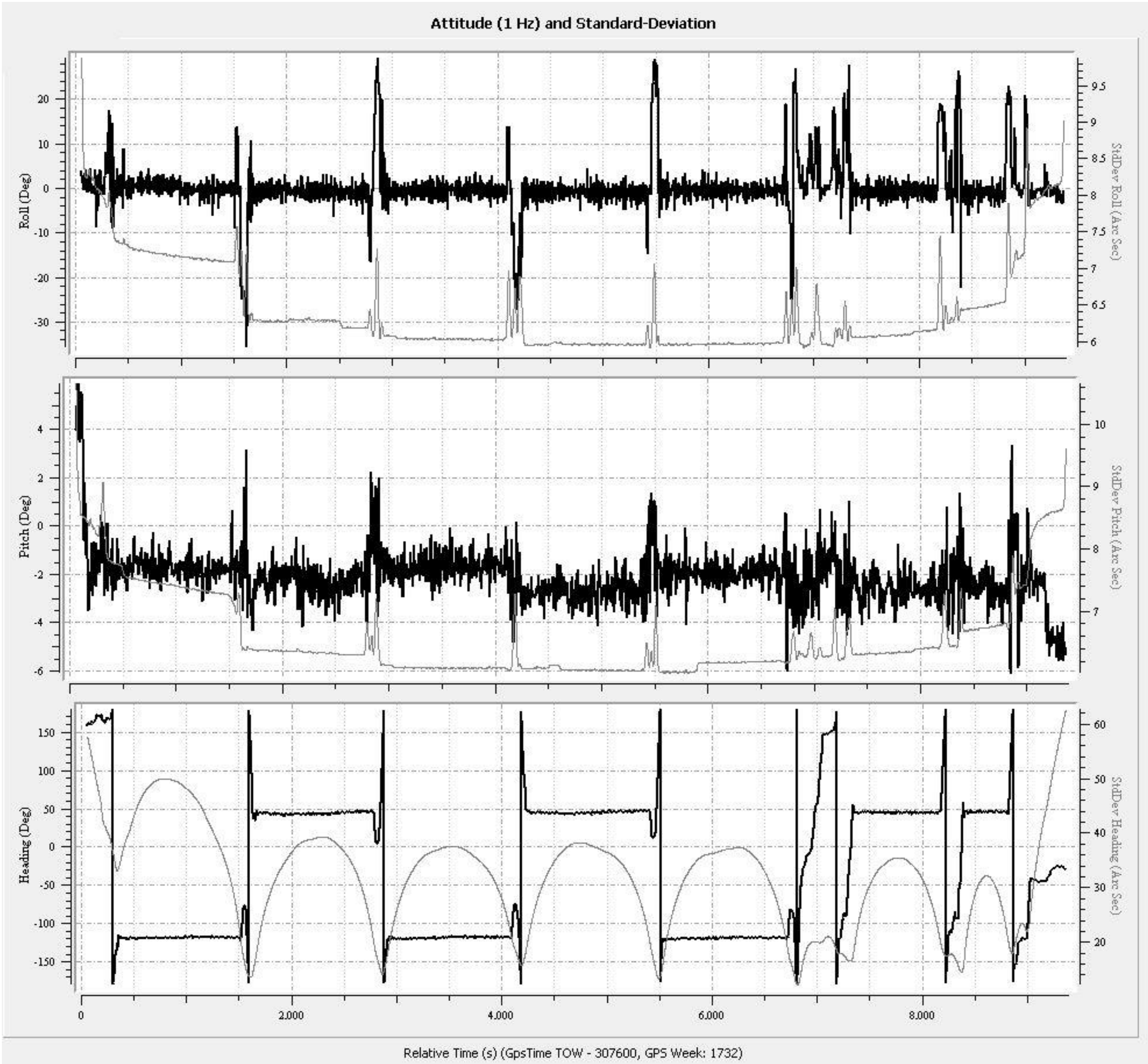


Figure 4: Position Accuracy and PDOP

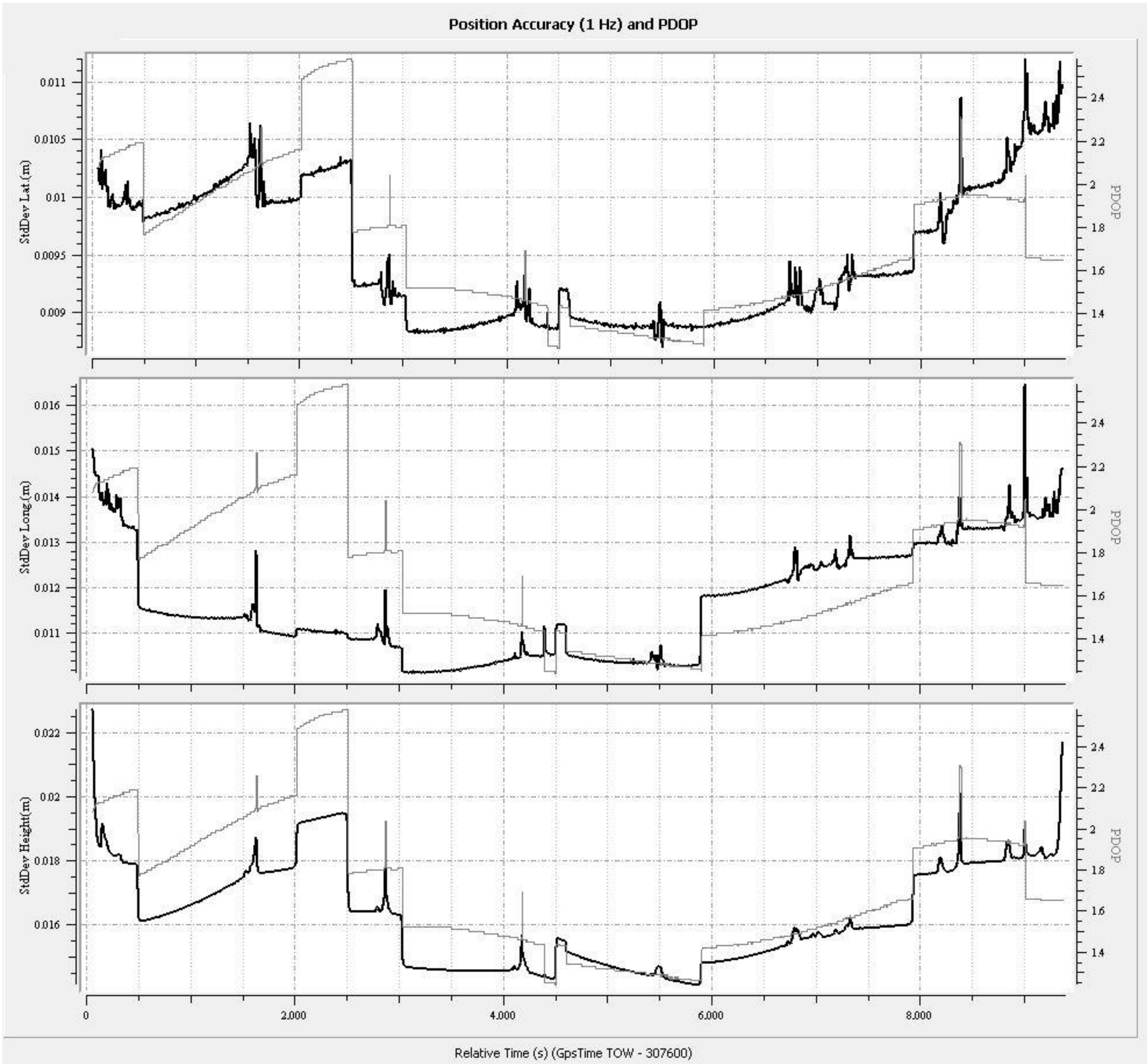
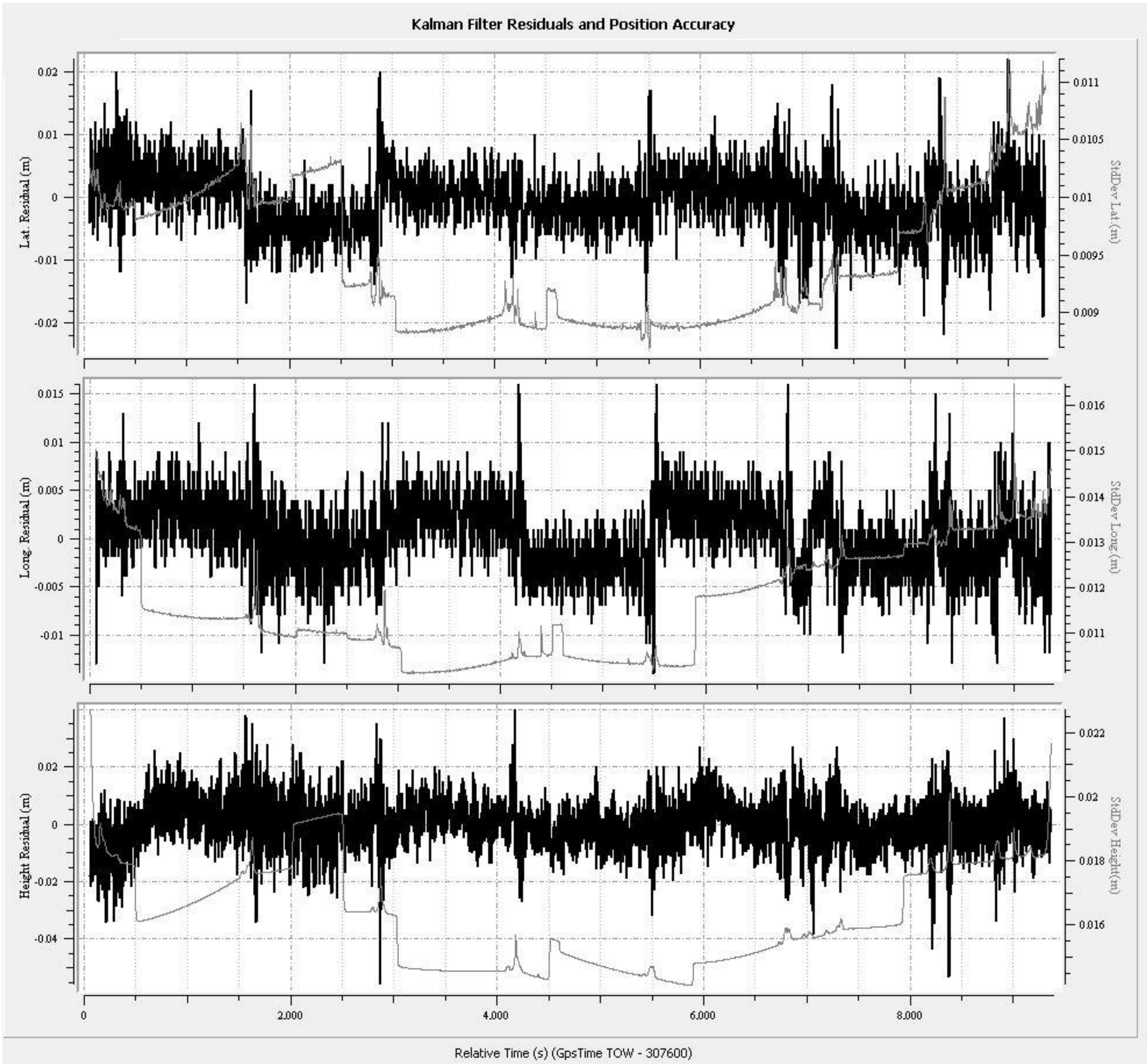


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13080_1

Figure 1: Trajectory Map

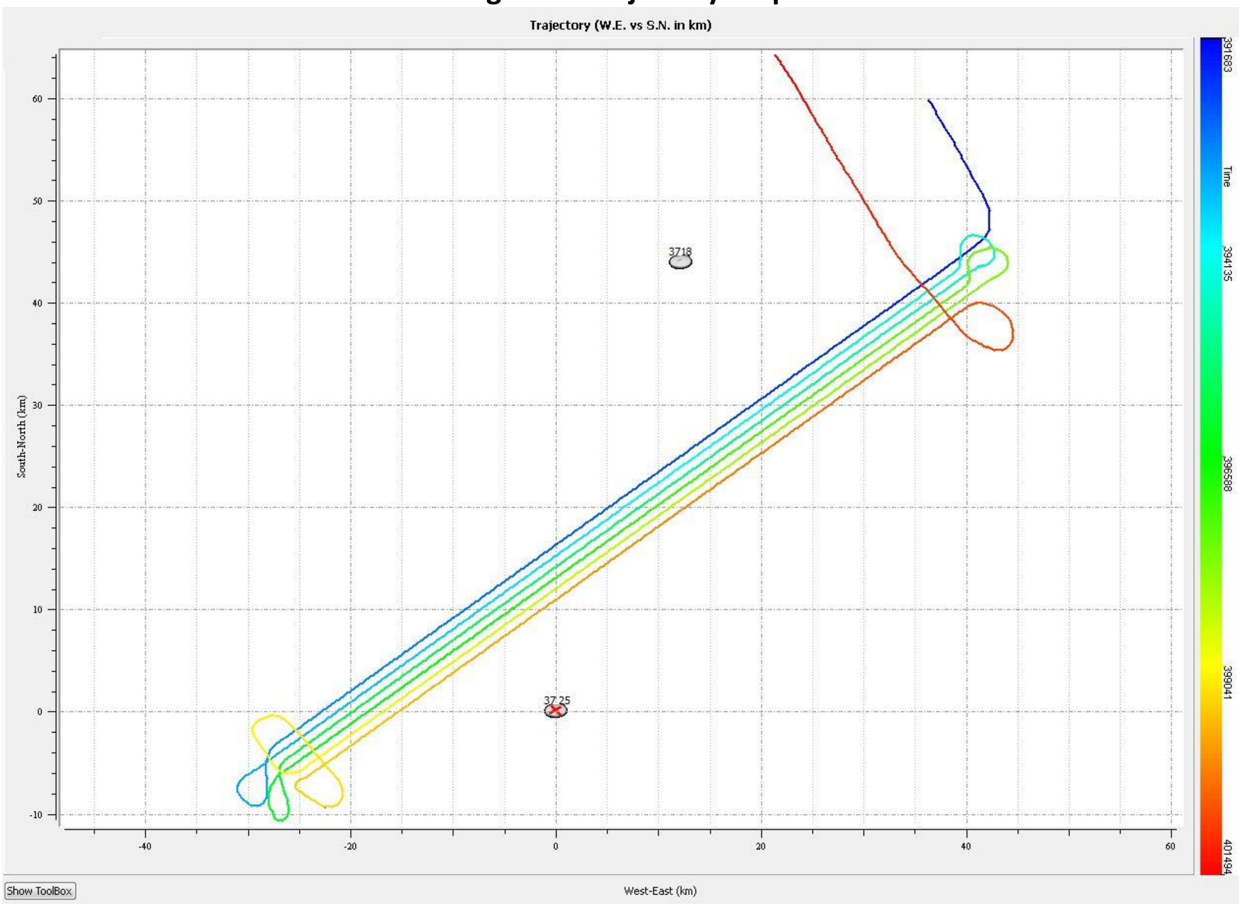


Figure 2: Forward/Reverse or Combined Separation Plot

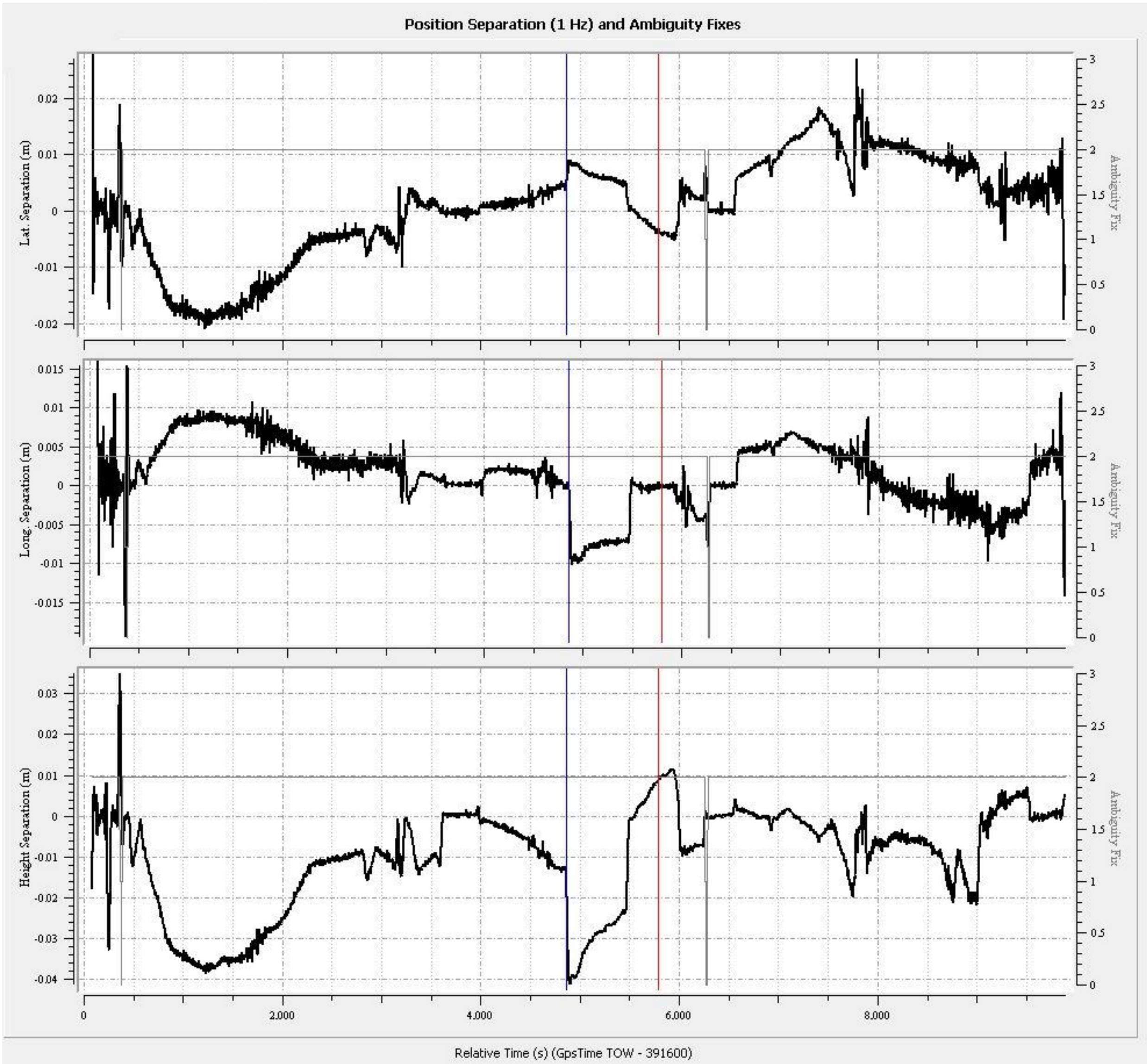


Figure 3: Attitude and Standard Deviation

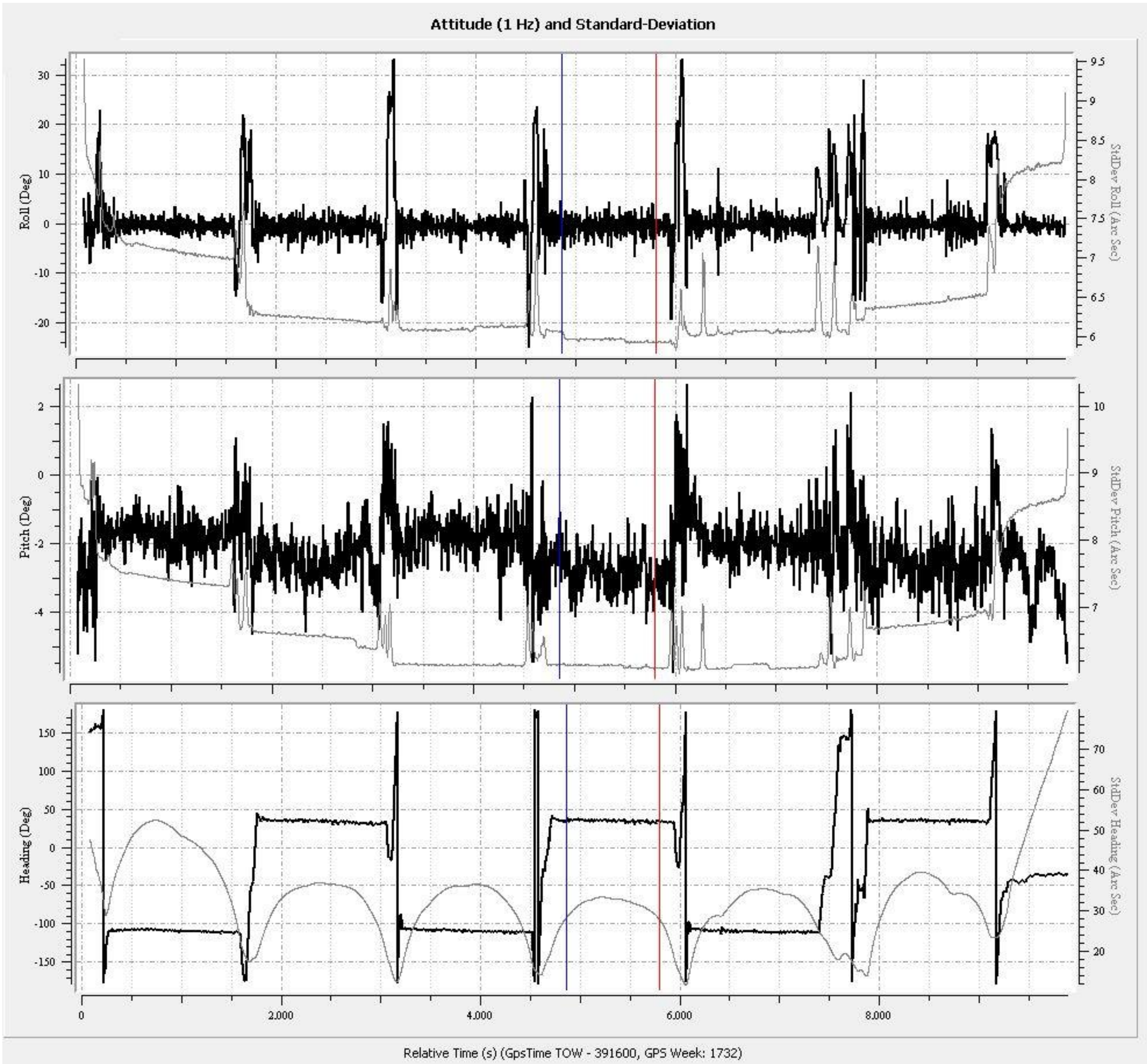


Figure 4: Position Accuracy and PDOP

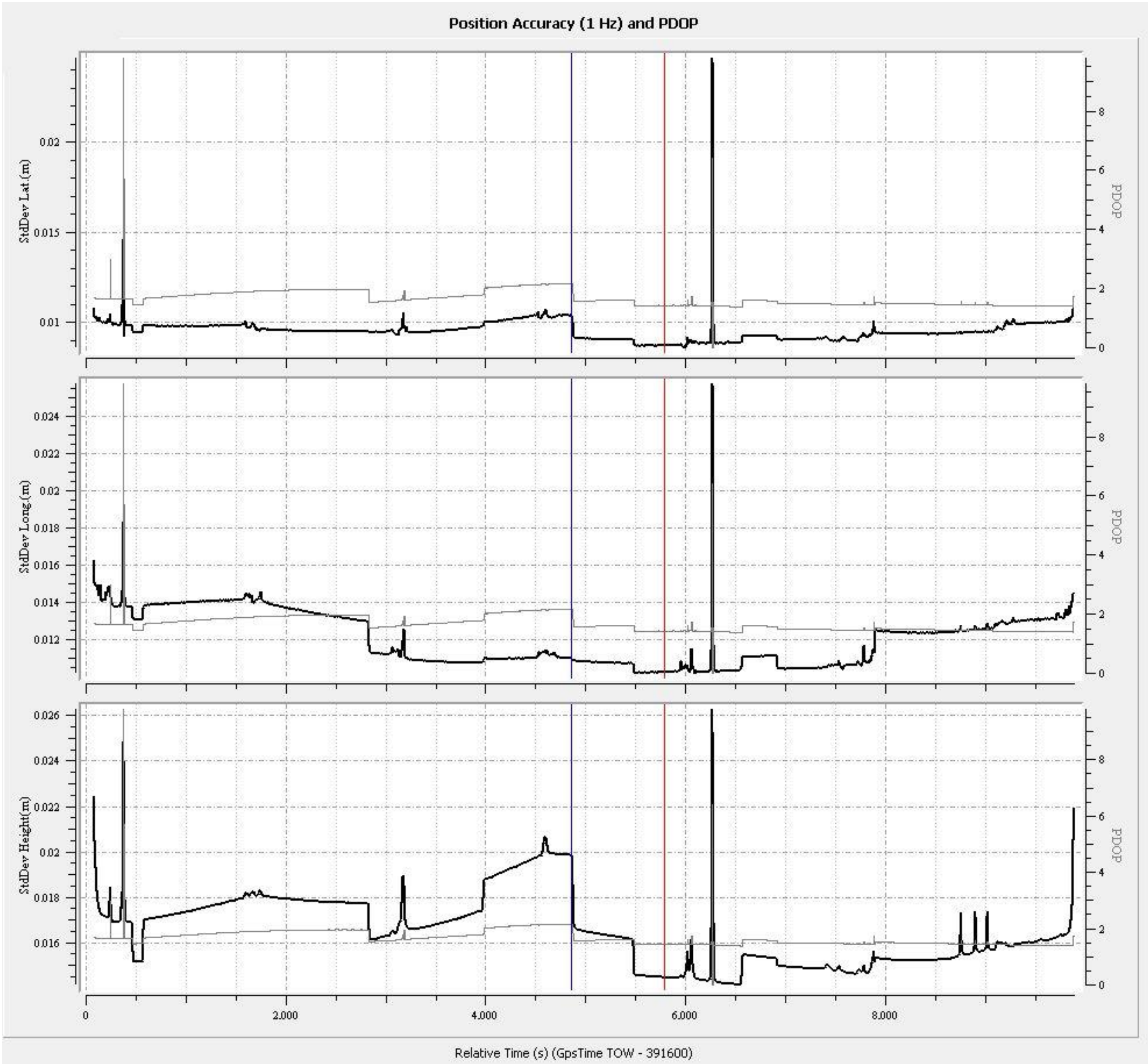
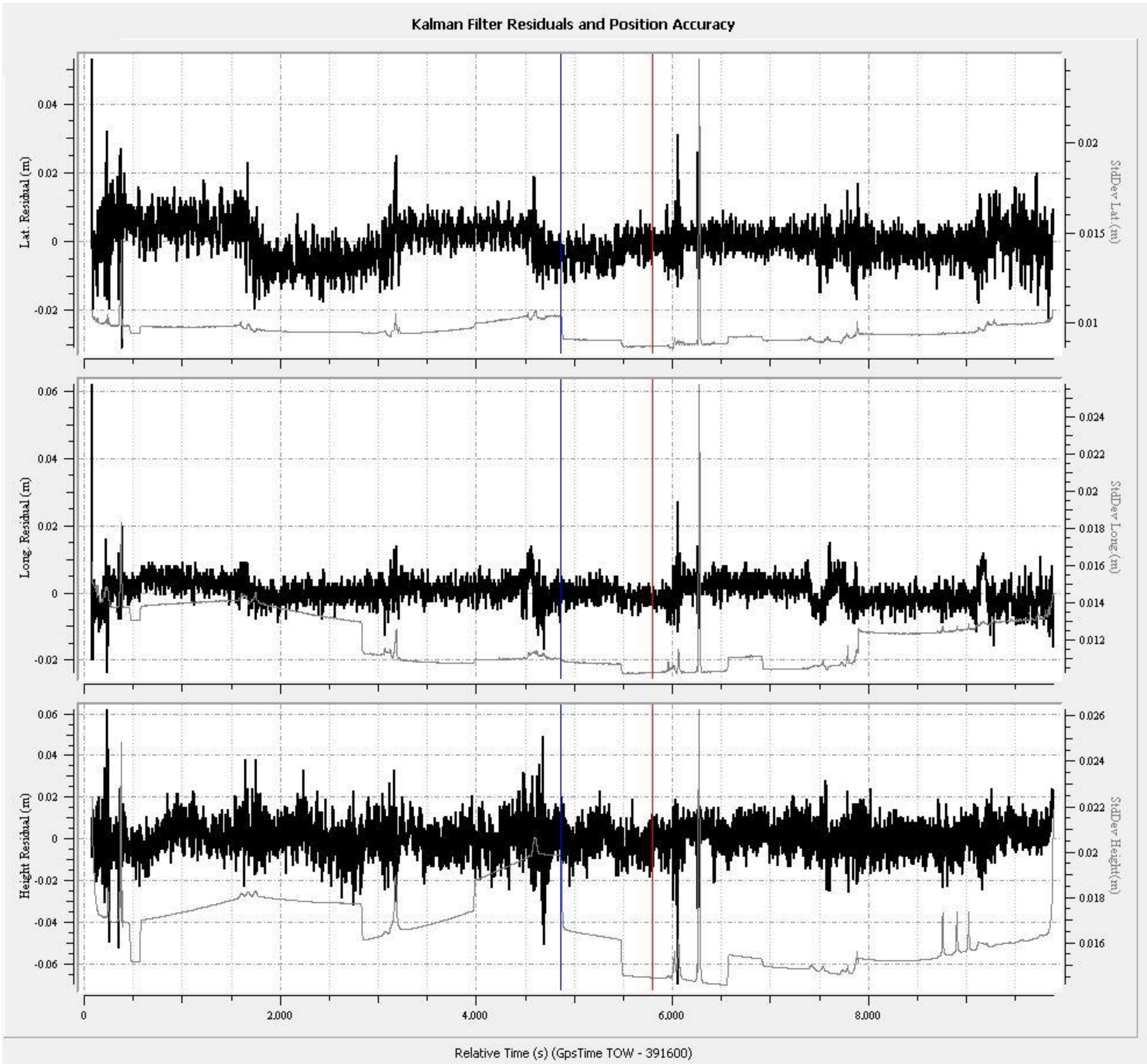


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13080_2

Figure 1: Trajectory Map

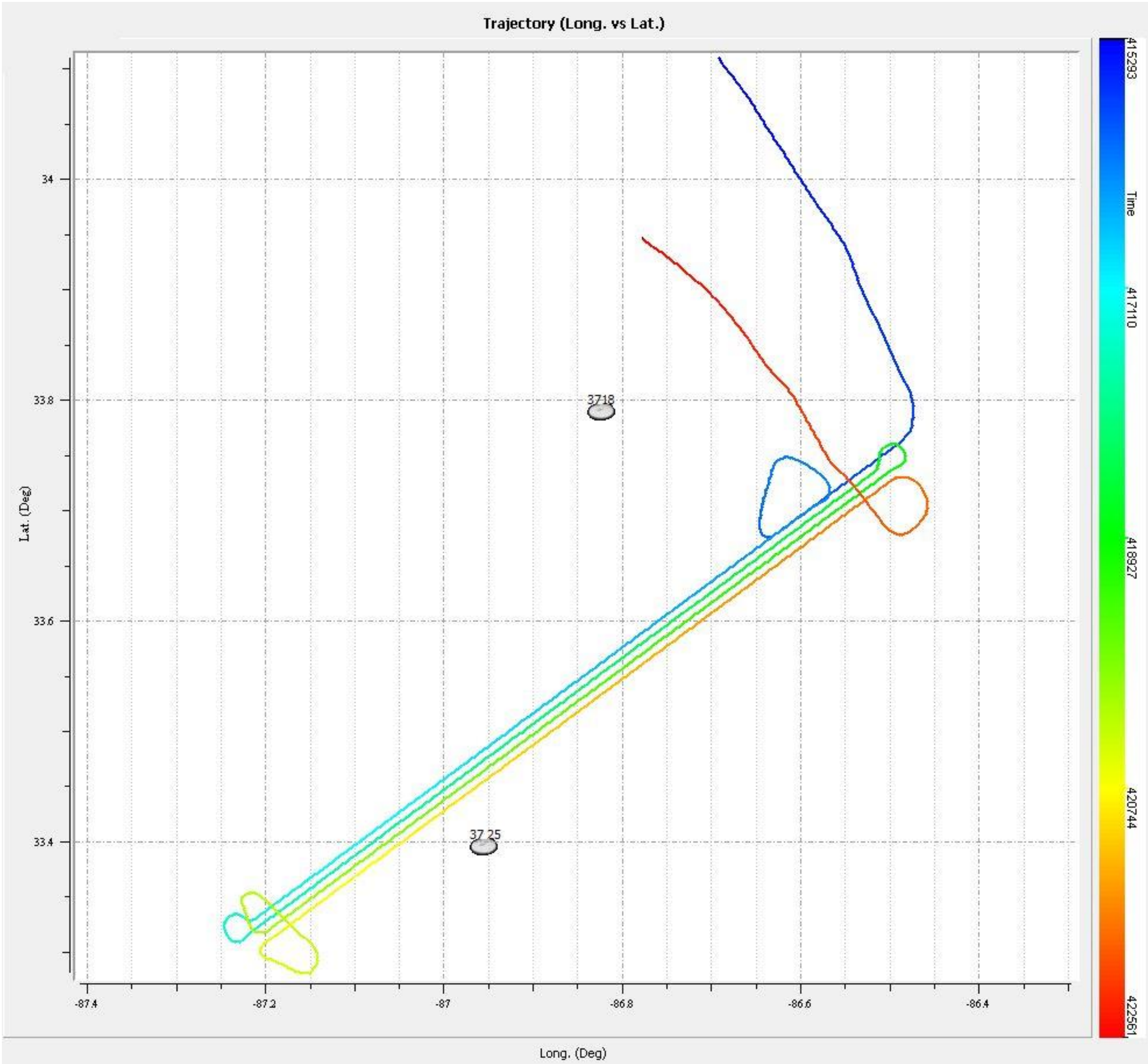


Figure 2: Forward/Reverse or Combined Separation Plot

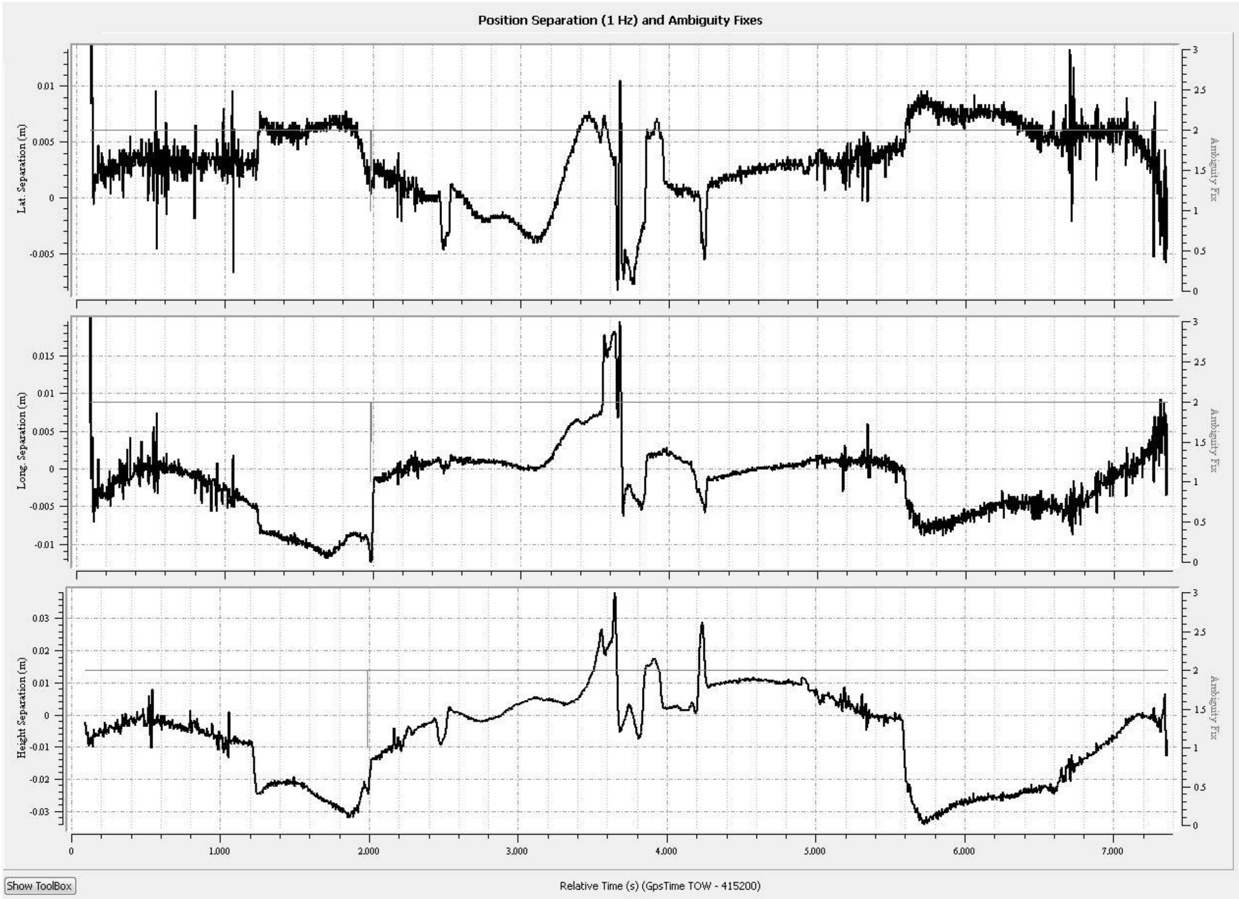


Figure 3: Attitude and Standard Deviation

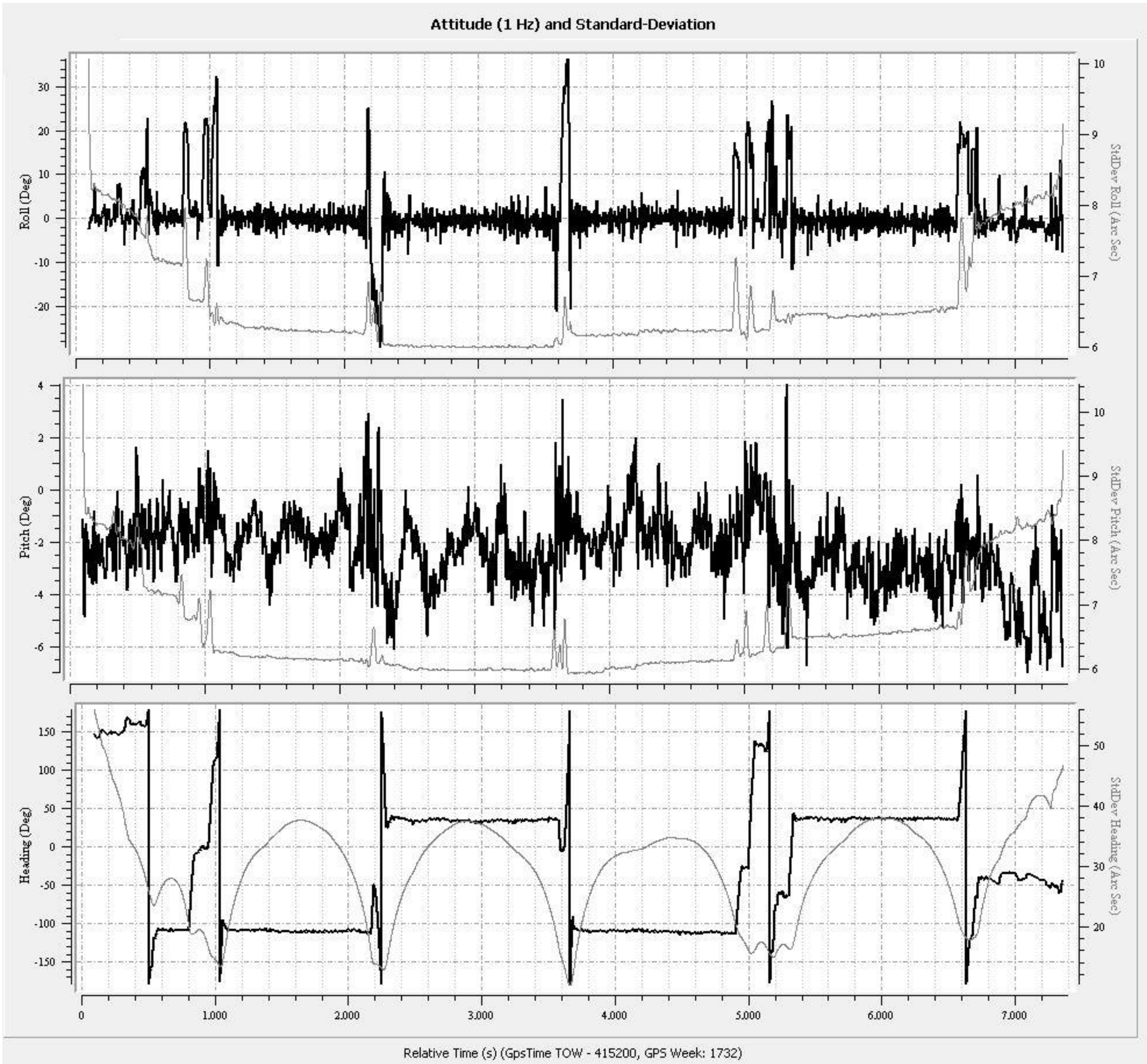


Figure 4: Position Accuracy and PDOP

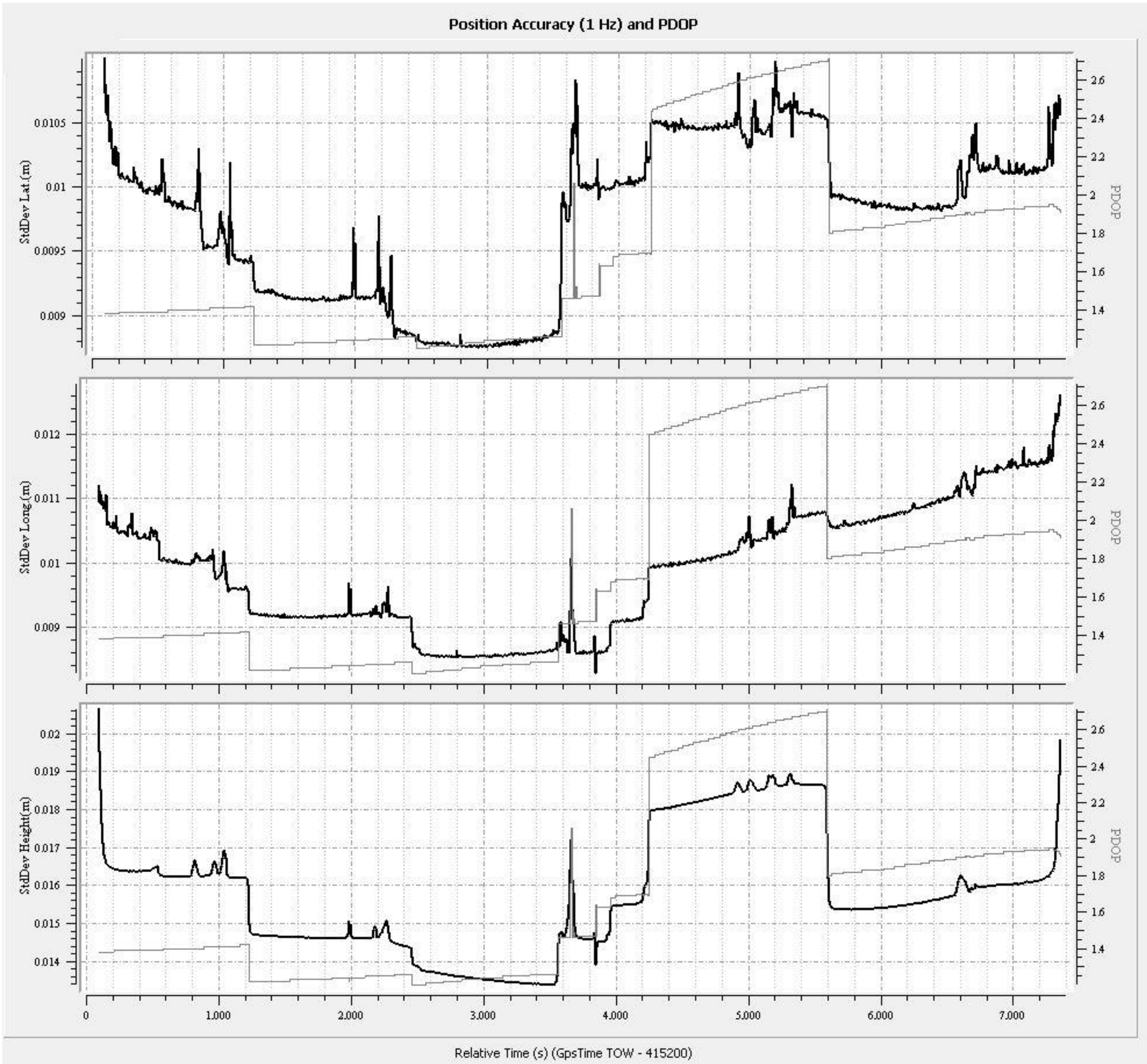
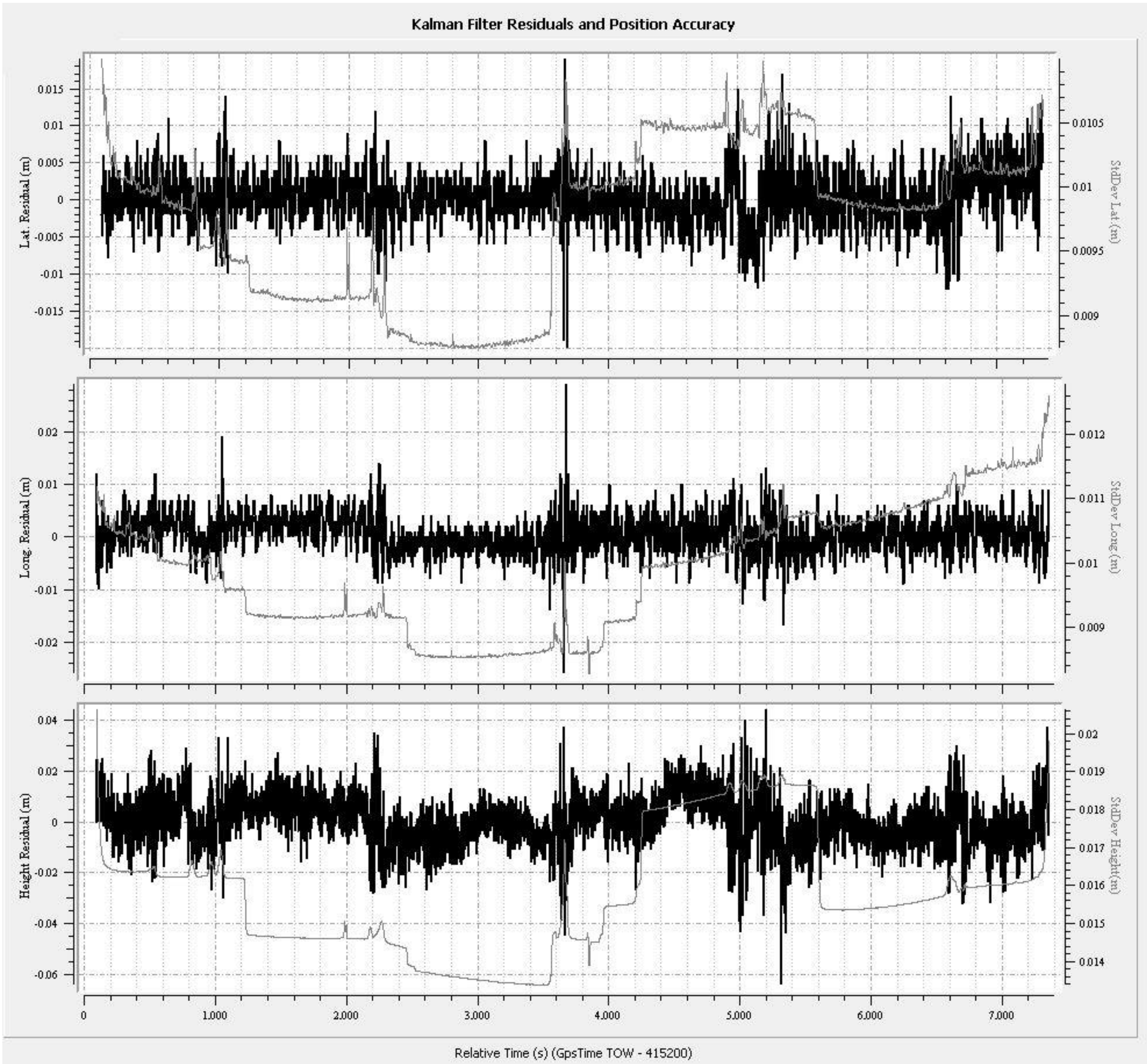


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13087_1

Figure 1: Trajectory Map

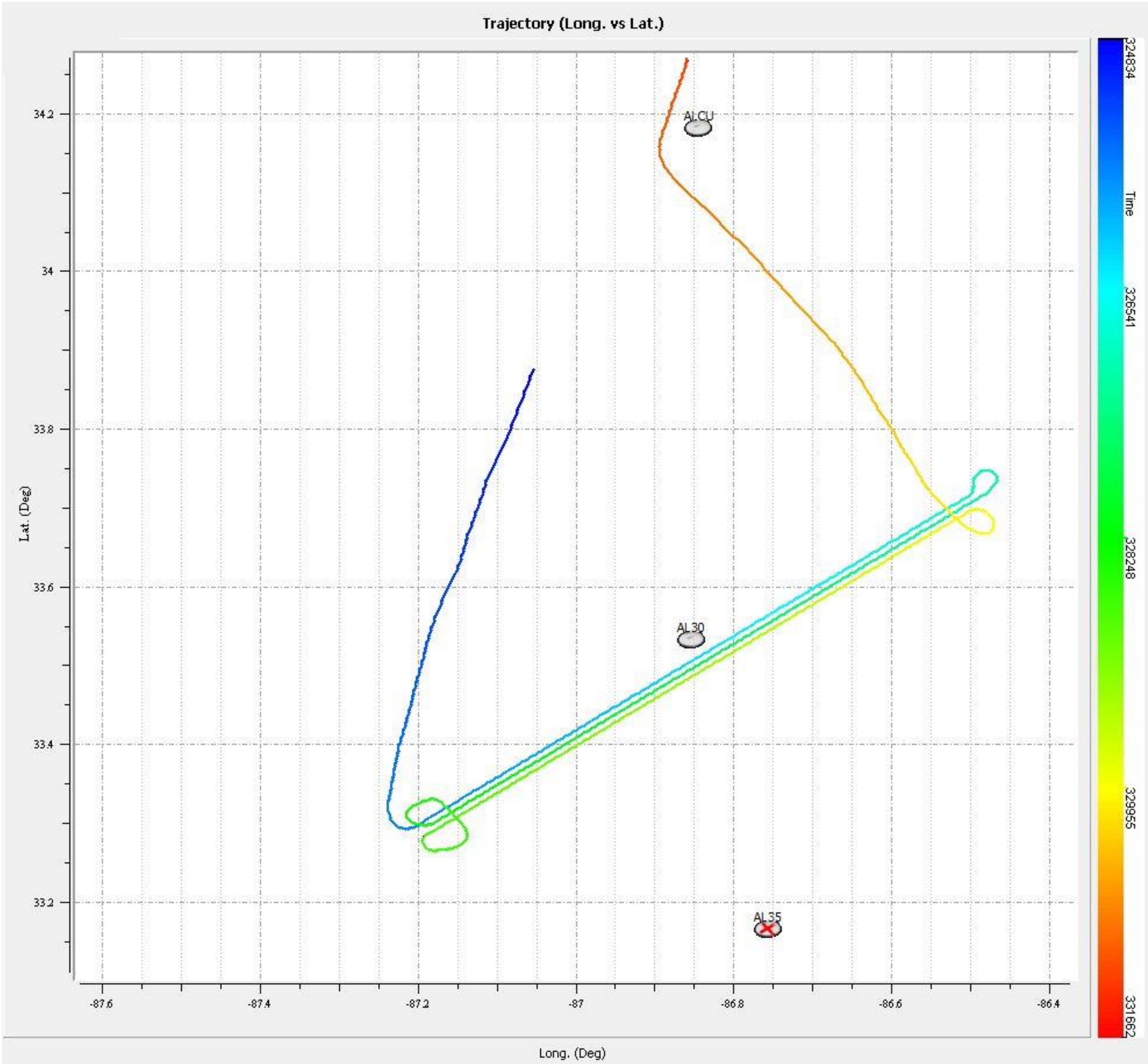


Figure 2: Forward/Reverse or Combined Separation Plot

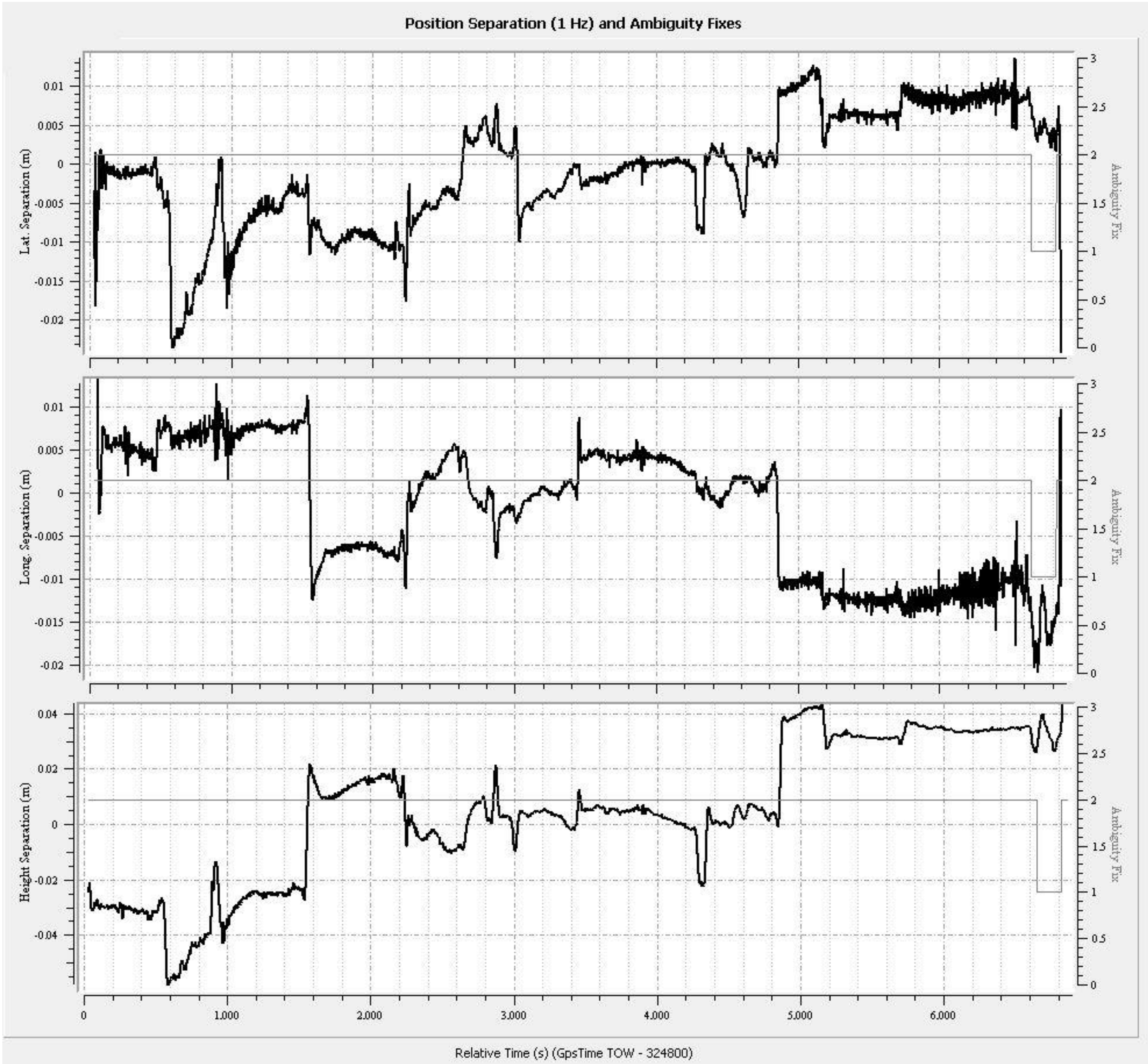


Figure 3: Attitude and Standard Deviation

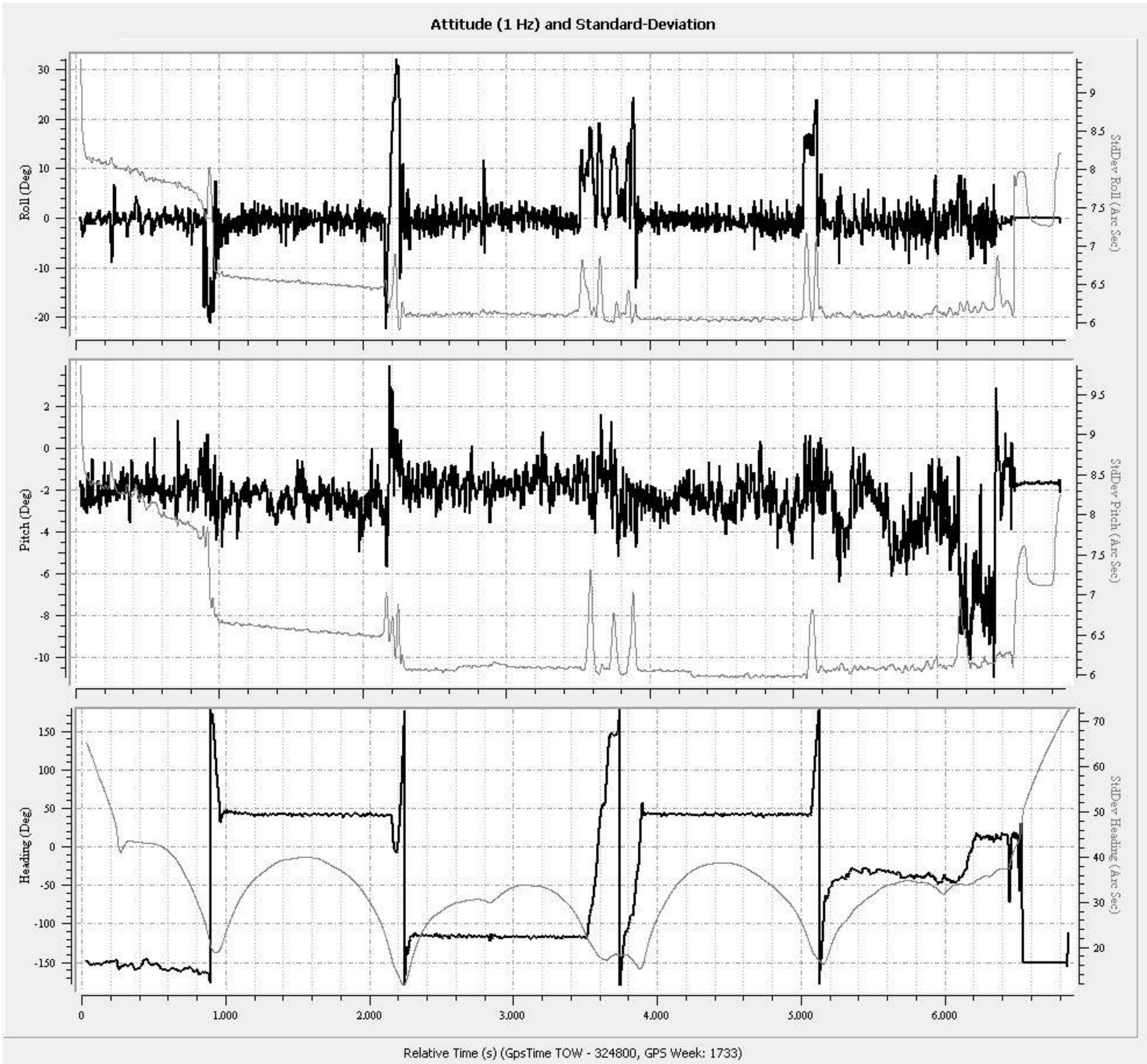


Figure 4: Position Accuracy and PDOP

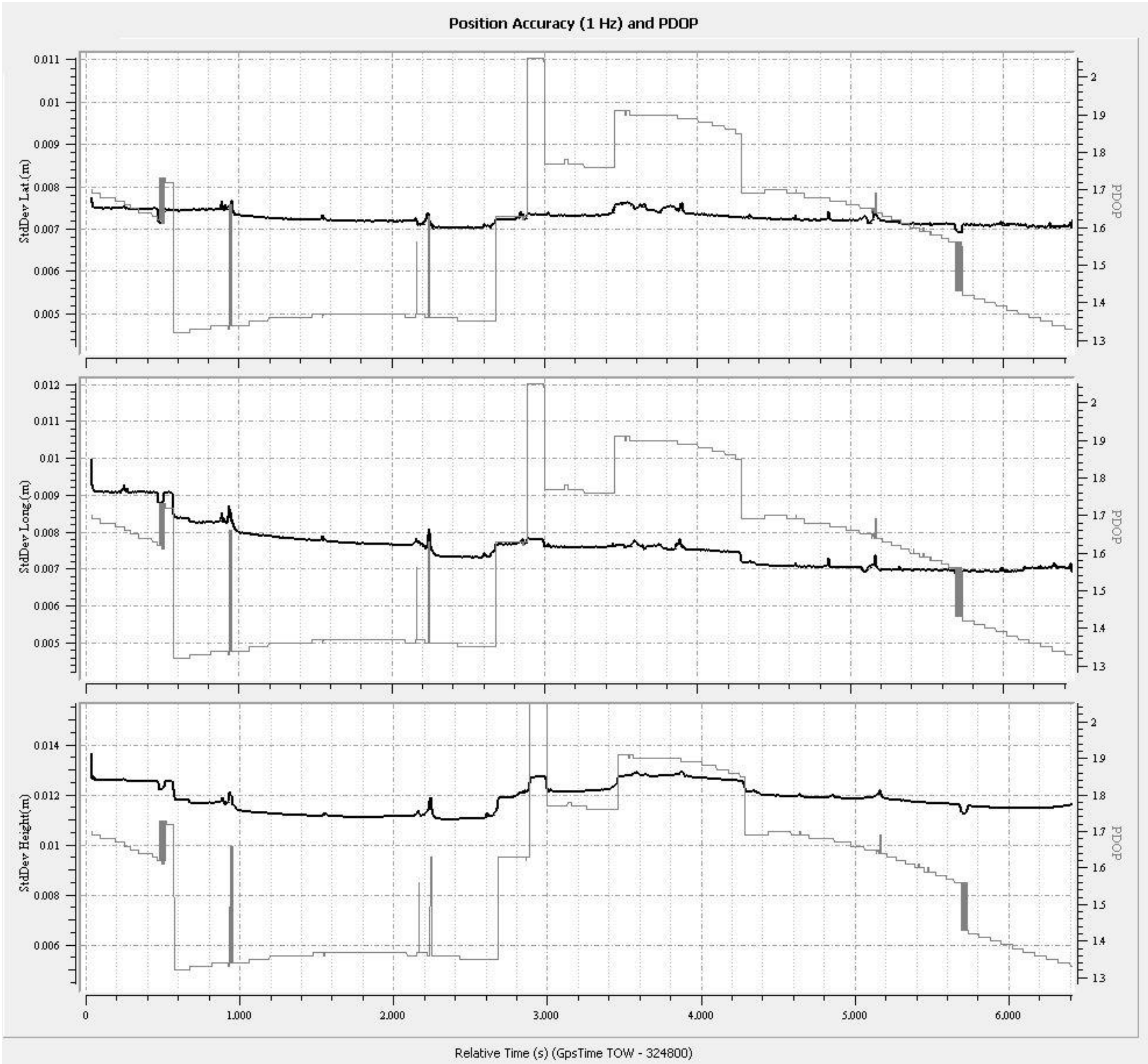
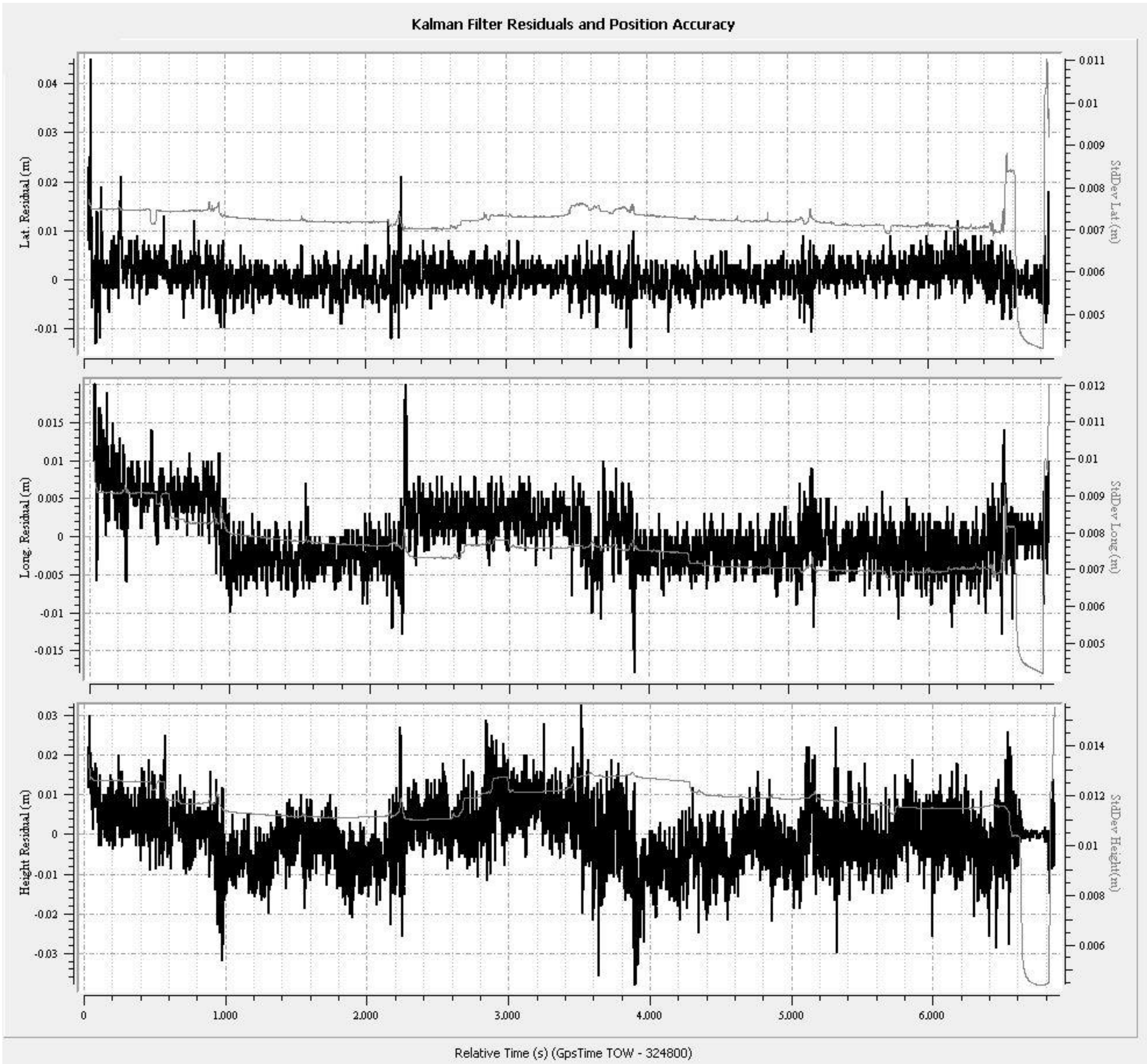


Figure 5: Kalman Filter Residuals and Position Accuracy



Output Result for JD13239_1

Figure 1: Trajectory Map

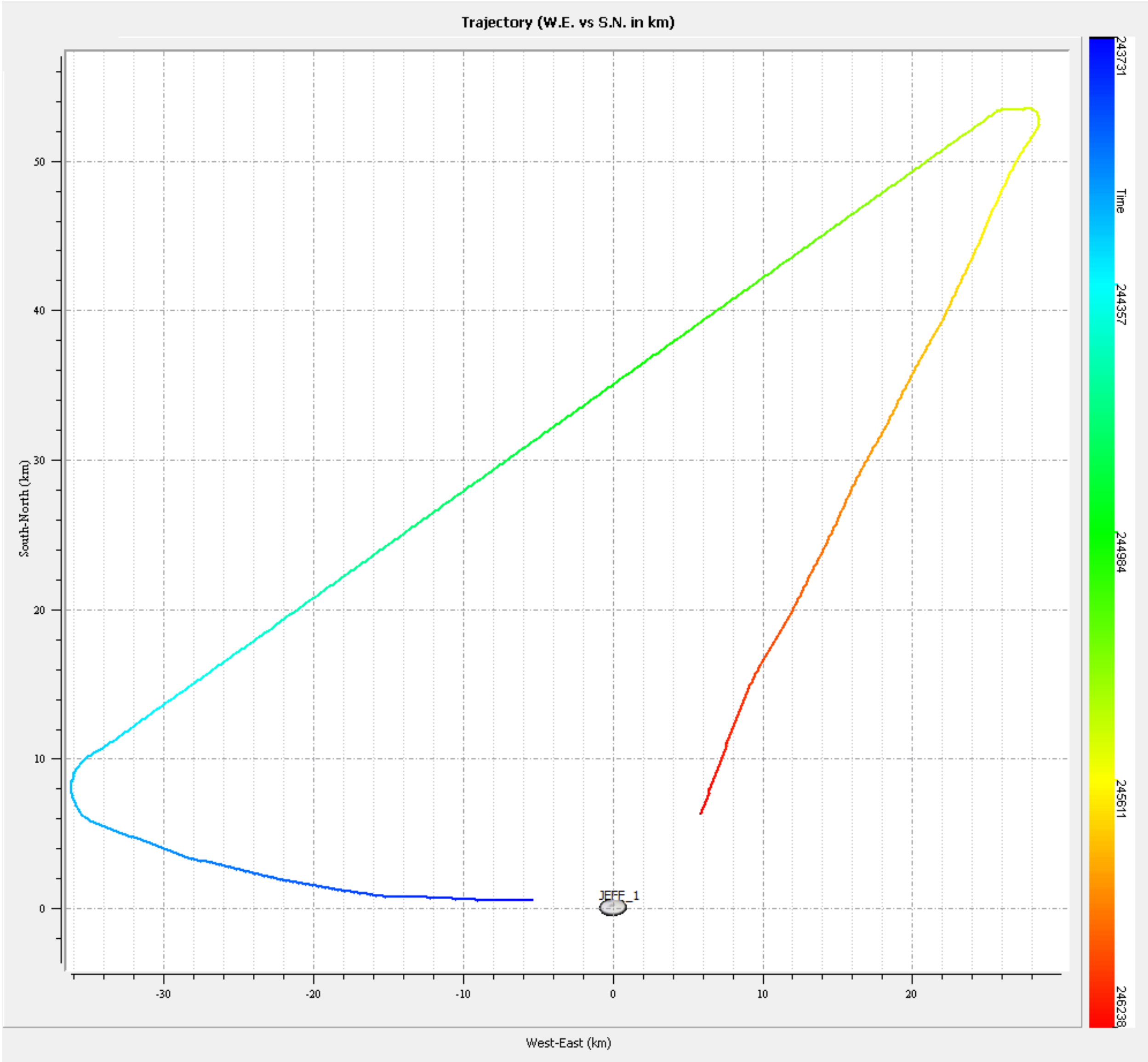


Figure 2: Forward/Reverse or Combined Separation Plot

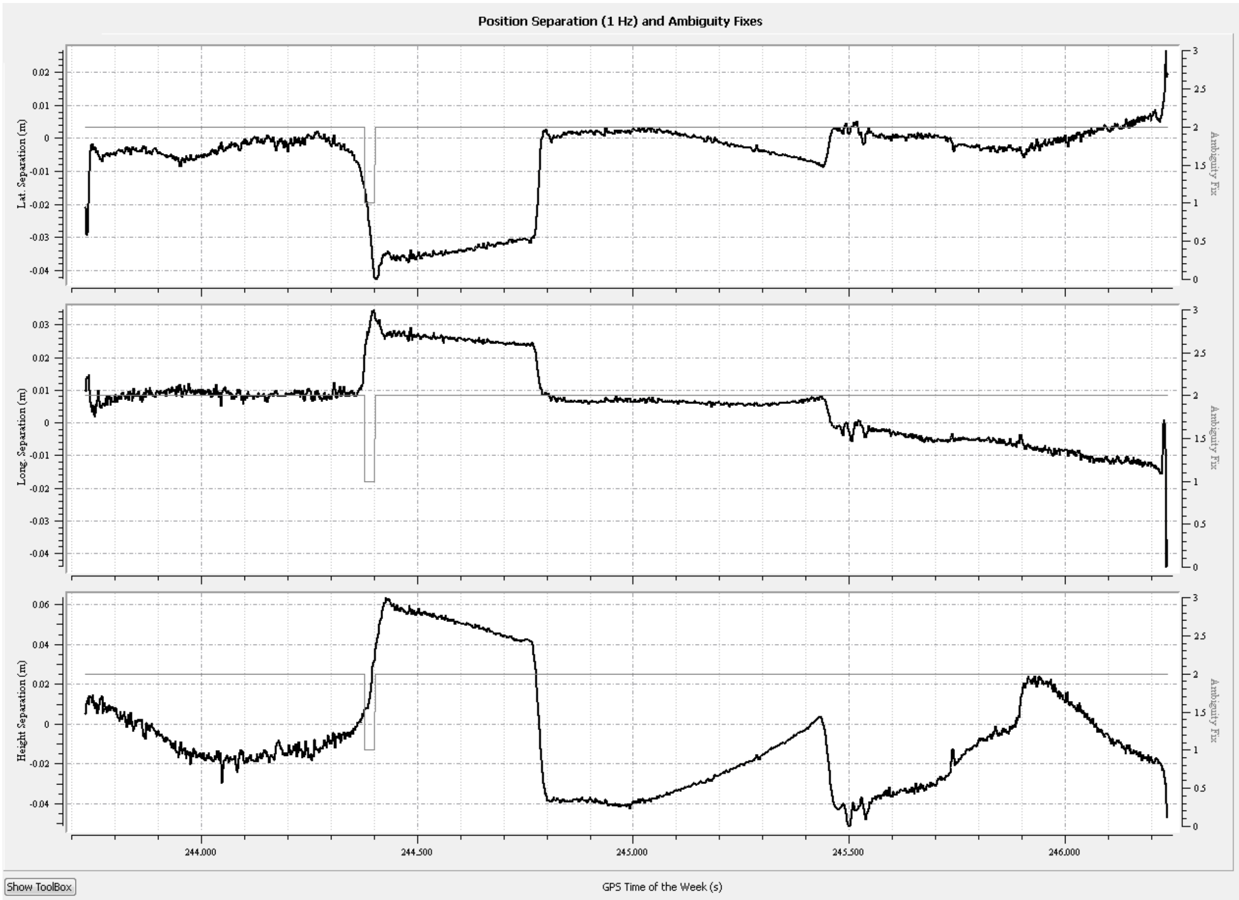


Figure 3: Attitude and Standard Deviation

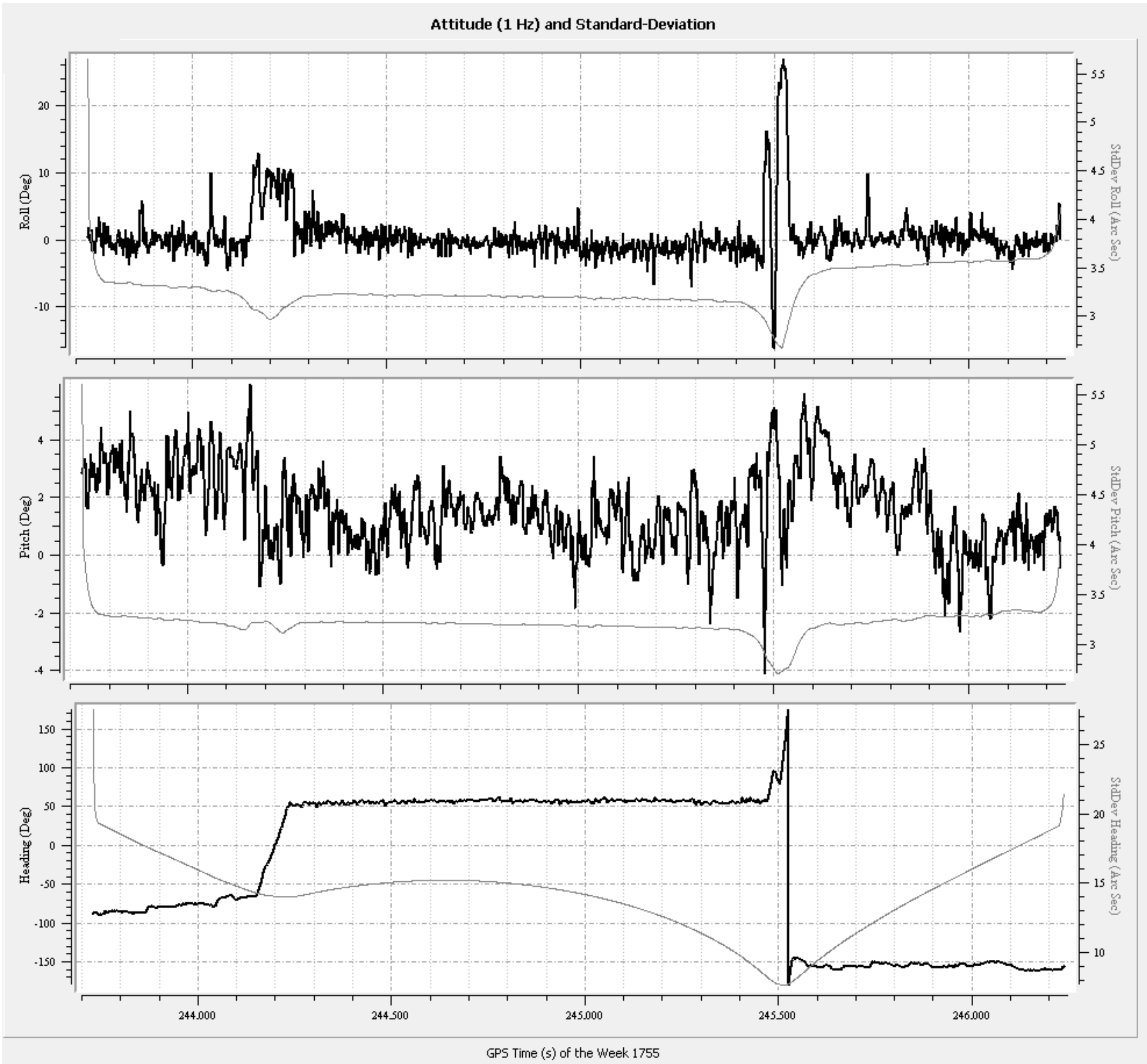


Figure 4: Position Accuracy and PDOP

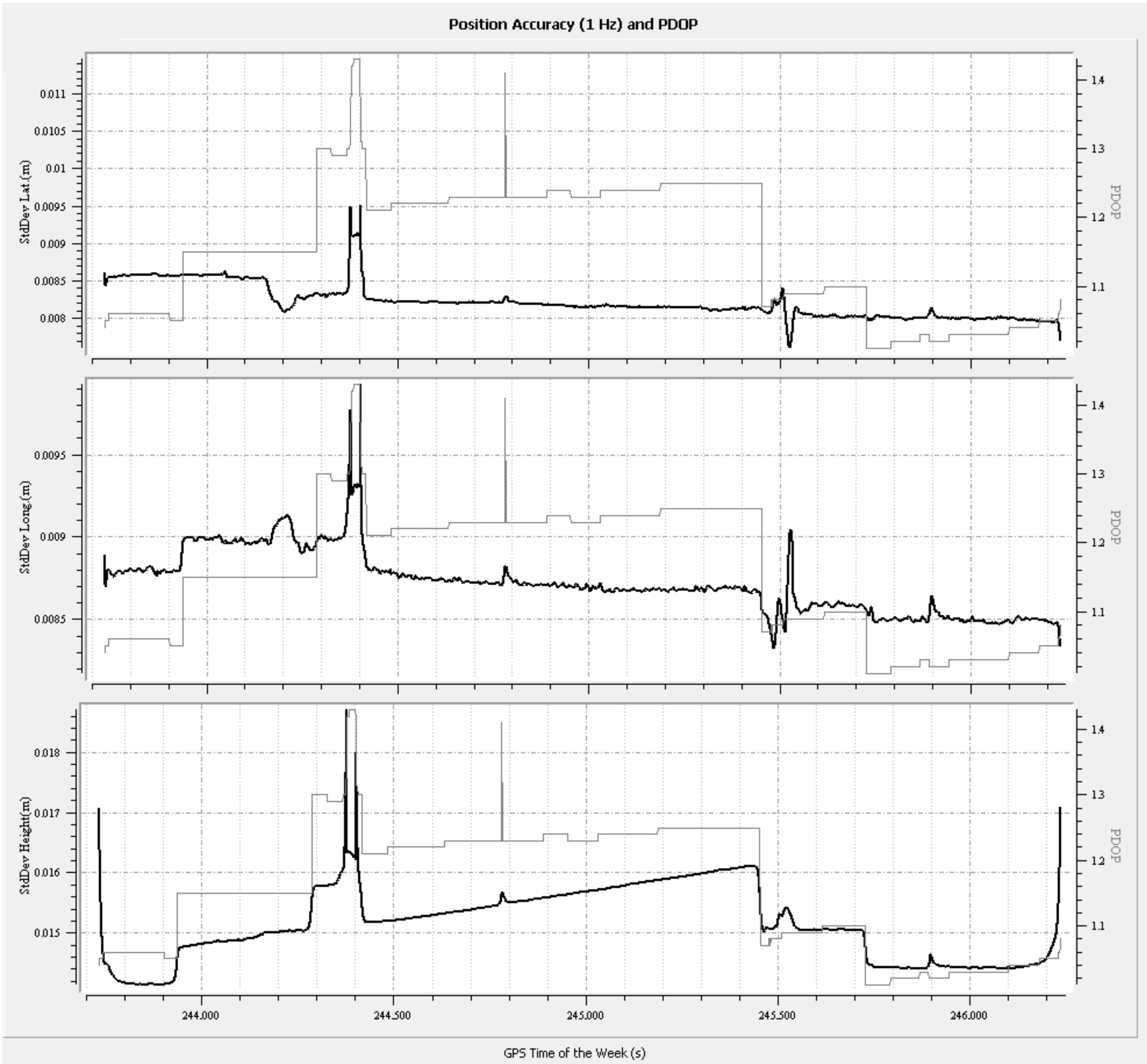


Figure 5: Kalman Filter Residuals and Position Accuracy