

LiDAR Acquisition and Calibration Report

Report Date: 6/6/2017

SUBMITTED BY:

Dewberry

1000 North Ashley Drive Suite 801
Tampa, FL 33602
813.225.1325

SUBMITTED TO:

U.S. Geological Survey

1400 Independence Road
Rolla, MO 65401
573.308.3810

Overview

Dewberry elected to subcontract the LiDAR Acquisition and Calibration activities to Airborne Imaging Inc. A Clean Harbors Company (hereafter called Airborne Imaging). Airborne Imaging was responsible for providing LiDAR acquisition, calibration and delivery of LiDAR data files to Dewberry. Dewberry received calibrated swath data from Airborne Imaging on June 9th, 2017.

Project Area

The project area addressed by this report falls within the Florida counties of Okaloosa, Walton, Holmes, Jackson, Washington, Bay, Calhoun, and Gulf. The total size of the project is approximately 3,132 square miles plus a 100m buffer.

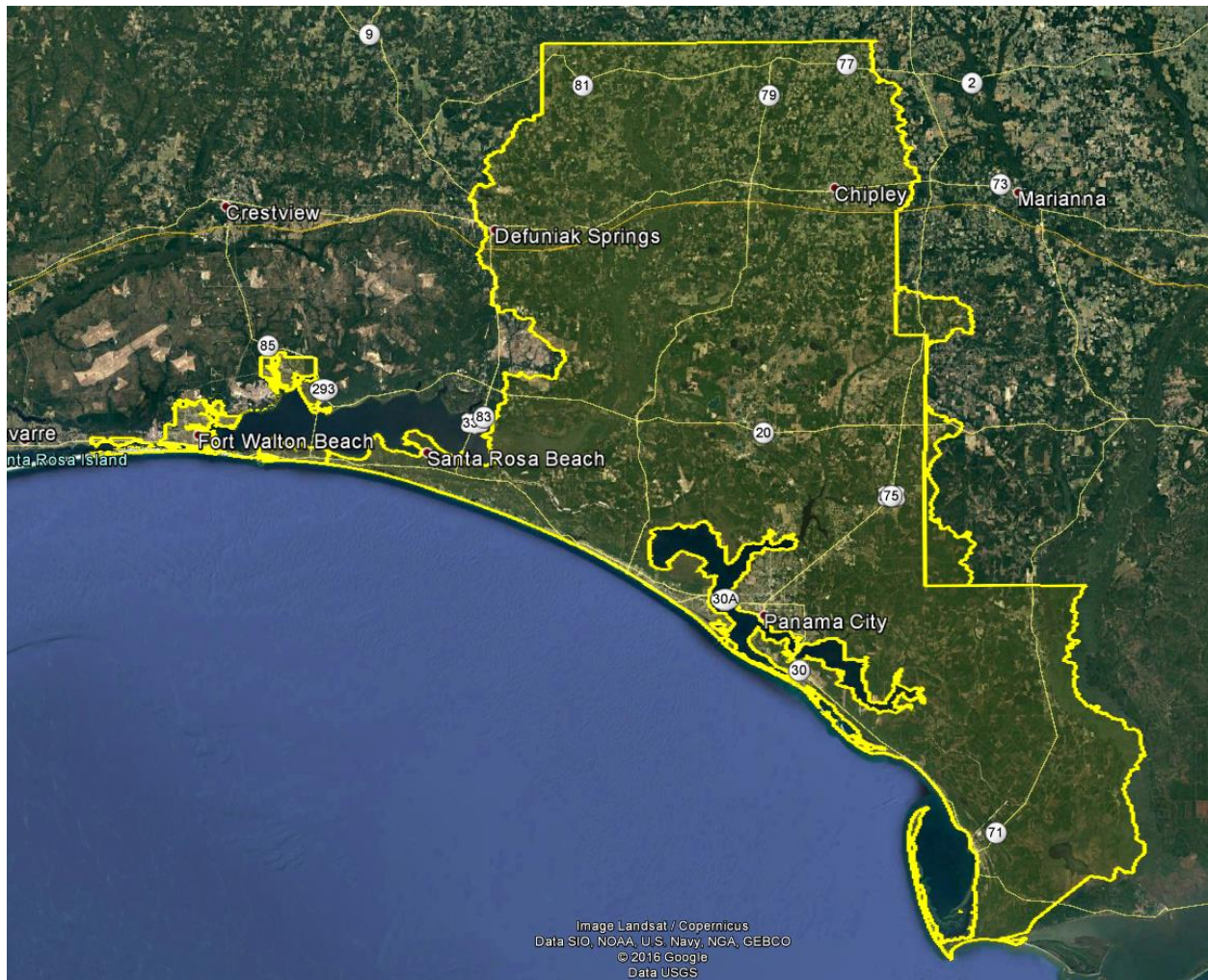


Figure 1 – Area of Interest

Acquisition Dates

The LiDAR survey was conducted between April 9th, 2017 and May 17th, 2017.

Datum Reference

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

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

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

Coordinate System: UTM Zone 16

Units: Lidar data is provided meters and U.S. Survey Feet

Geoid Model: Geoid12B (Geoid12B was used to convert ellipsoid heights to orthometric heights)

LiDAR Acquisition Details

Airborne Imaging planned 117 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, Airborne Imaging followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- 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, Airborne Imaging filed our flight plans as required by local Air Traffic Control (ATC) prior to each mission. Airborne Imaging 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 no snow, rain, fog, smoke, mist and low clouds. LiDAR systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Airborne Imaging accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

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

Airborne Imaging LiDAR sensors are calibrated at a designated site located at Red Deer, Alberta, Canada or St. Hubert, Quebec, Canada and are periodically checked and adjusted to minimize corrections at project sites.

LiDAR System parameters

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

TABLE 1 SENSOR COLLECTION PARAMETERS	
Item	Parameter
Sensor System	Riegl LMS-Q1560
Aircraft	Piper Navajo PA-31 Tail #: C-GKSX
Altitude (AGL)	2000m
Approx. Flight Speed (kts)	150
Scanner Pulse Rate (KhZ)	800 kHz (true) 533.3 kHz (effective)
Scan Frequency (lps)	185 Scanlines/s
Pulse Duration of the Scanner (microseconds)	3ns FWHM (0.003 us)
Pulse Width of the Scanner (m)	0.9m FWHM
Swath Width (m)	2309m
Central Wavelength of the Sensor Laser (nanometers)	1064nm
Will the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Laser Beam Divergence (milliradians)	0.25mrad (1/e ²)
Nominal Swath Width on the Ground (m)	2309m
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	60
Computed Along Track Spacing (m)	0.89 per channel
Computed Cross Track Spacing (m)	0.89 per channel
Nominal Pulse Spacing (single swath), (m)	0.632
Nominal Pulse Density (single swath) (ppsm), (m)	3.0 ppsm
Aggregate Nominal Pulse Spacing (m)	No less than .7 m
Maximum Number of Returns per Pulse	4
Line Spacing (m)	1491-1527
Maximum Baseline Length (mi)	20

Table 1 – Airborne Imaging LiDAR System Parameters

Acquisition Status Report and Flight Lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. LiDAR acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. LiDAR missions were flown only when no condition existed below the sensor that would affect the collection of data. The

pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows the combined trajectory of the flight lines.

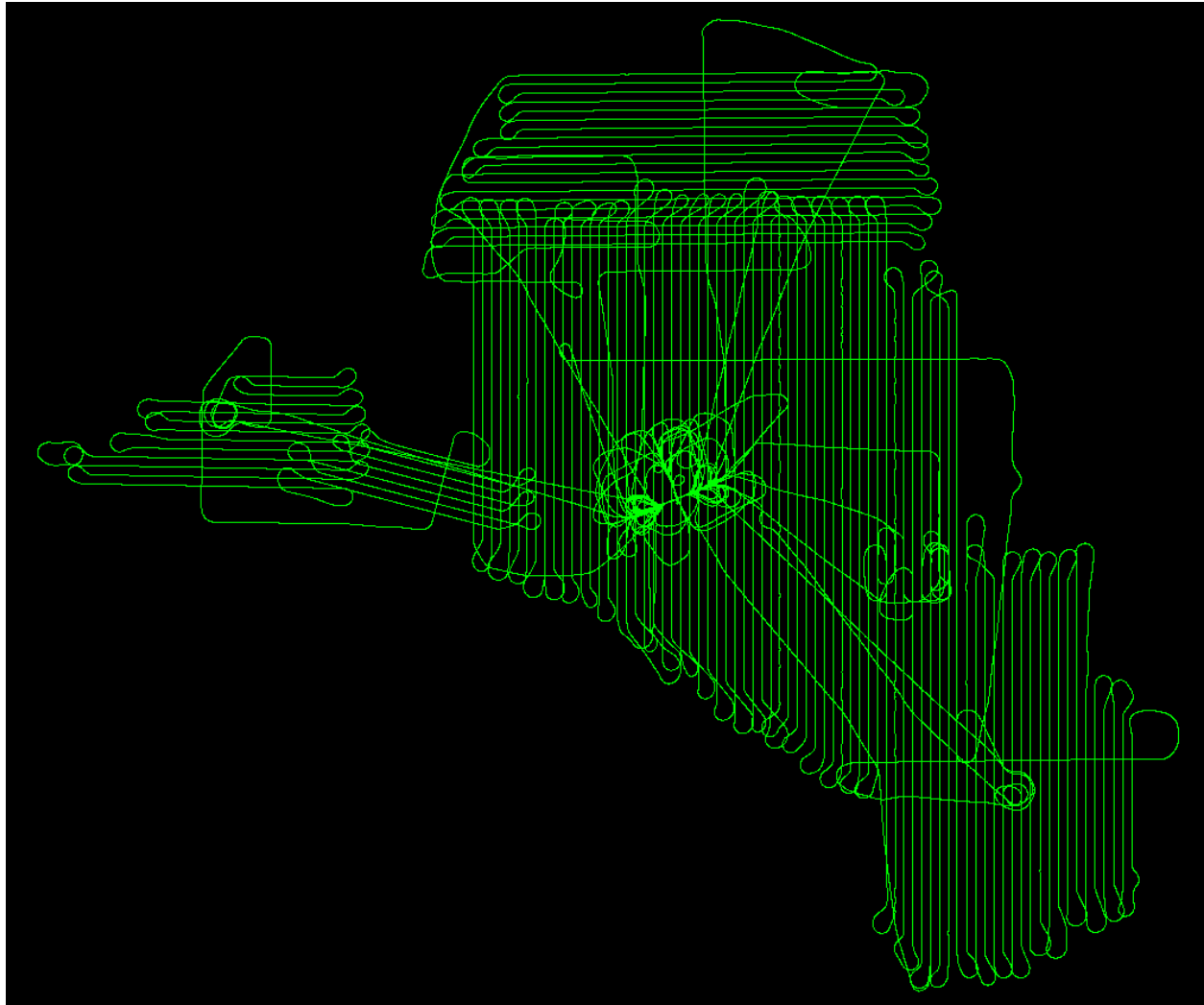


Figure 2 – Trajectories as flown by Airborne Imaging

LiDAR Control

Seven existing NGS monuments and six newly established base stations were used to control the LiDAR acquisition for the Choctawhatchee Walton LiDAR project area. The coordinates of all used base stations are provided in the table below.

Name	NAD83 UTM16		Ellipsoid Ht (m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
AS0886	681913.979	3317375.706	-22.369	5.148
B159	619846.104	3401350.025	-0.571	27.232
B160	672845.360	3309317.449	-21.597	5.797
B161	579293.765	3361938.111	-25.542	1.983
B162	615768.044	3357324.550	-11.587	16.229
B170	619823.783	3401252.405	0.967	28.771
B171	646616.757	3336475.978	-16.914	10.857
BE0841	642162.835	3321970.295	-21.678	5.906
BE2979	618998.107	3355844.172	-23.441	4.385
BE3768	614404.316	3391605.106	2.580	30.388
BG1452	584006.895	3393146.716	36.362	63.923
BG5044	538984.309	3371984.612	-25.041	2.326
TO06	628830.893	3419736.416	31.543	59.275

Table 2 – Base Stations used to control LiDAR acquisition

Airborne GNSS Kinematic

Airborne GNSS data was processed using the Applanix POSPac MMS software suite and Novatel’s GrafNav software. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from at least one base station to aircraft were kept to a maximum of 45km. For all flights, the GNSS data can be classified as excellent, with GNSS residuals of 3cm average or better but no larger than 10cm being recorded. GNSS 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 GNSS and Laser data against field notes and compile any data if not complete. Subsequently the mission points are output using Riegl’s RiProcess, initially with default values calibration for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch, and yaw corrections that need to be applied are calculated using Riegl’s Scan Data Adjustment within RiProcess. The Scan Data Adjustment utility uses plane matching to determine roll, pitch, and yaw corrections for each swath. 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 GNSS, aircraft trajectory, mission information, and ground control files are reviewed and archived. On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by field operations are present.

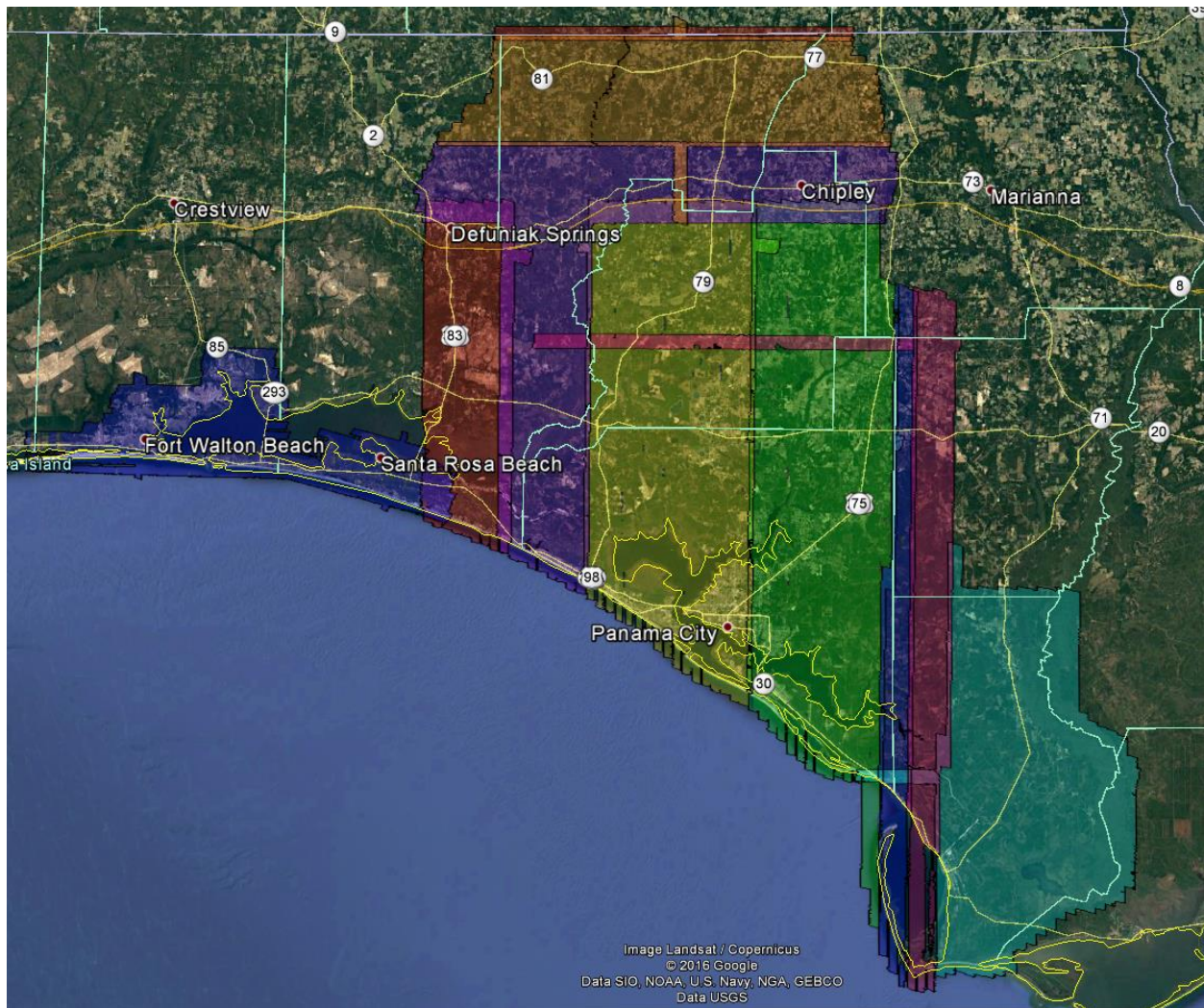


Figure 3 – LiDAR Swath output showing complete coverage.

Boresight and Relative accuracy

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GNSS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met. Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follows:

Relative accuracy ≤ 6 cm maximum differences within individual swaths and ≤ 8 cm RMSDz between adjacent and overlapping swaths.

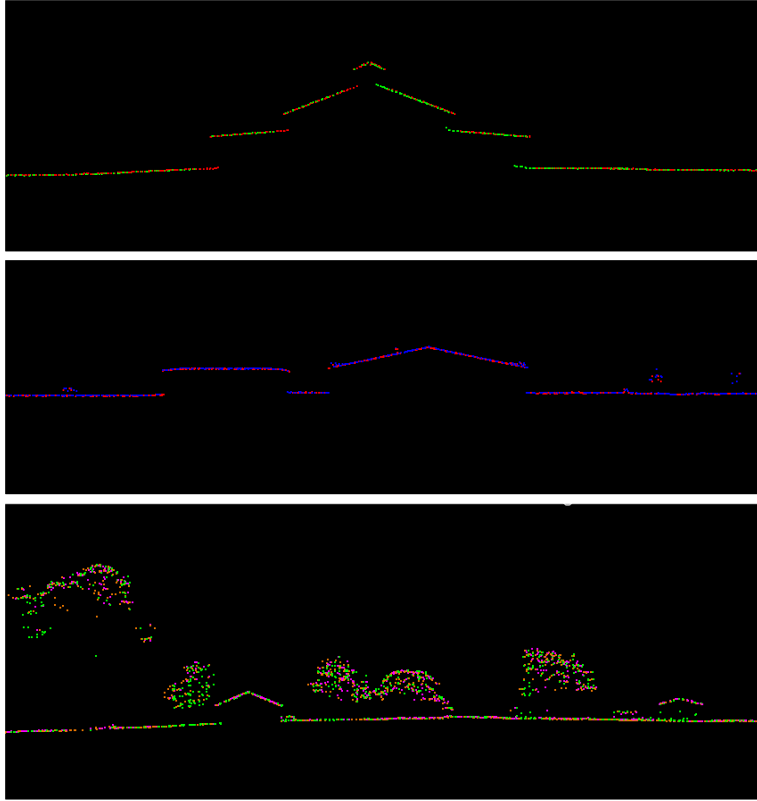


Figure 4 – Profile views showing correct roll and pitch adjustments.

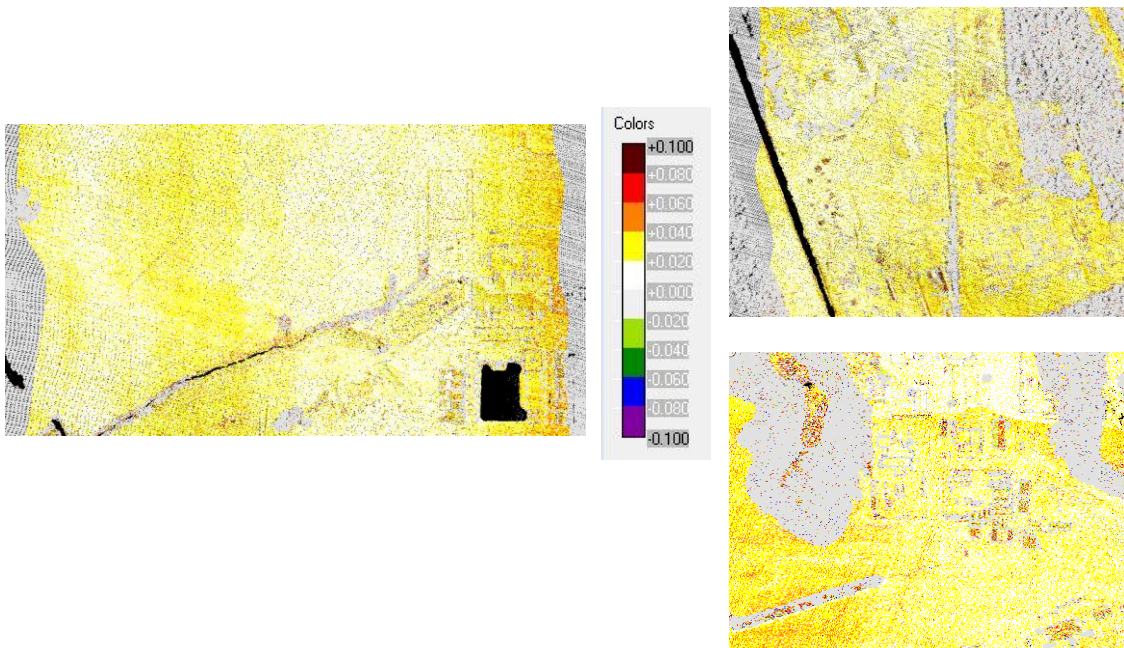


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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

Preliminary Vertical Accuracy Assessment

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

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements (RMSE_z ≤ 10 cm and Accuracy_z at the 95% confidence level ≤ 19.6 cm) when compared kinematic GNSS checkpoints.

Below is a summary for the test:

The calibrated Choctawhatchee Walton LiDAR dataset was tested to 0.094 m vertical accuracy at 95% confidence level based on RMSE_z (0.048 m x 1.9600) when compared to over 14500 GNSS kinematic check points. The following are the final statistics for the GNSS kinematic checkpoints used by Airborne Imaging to internally verify vertical accuracy.

100 % of Totals	# of Points	RMSE _z (nva) Spec=0.1 m	NVA at 95% Spec=0.196m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	14525	0.048	0.094	-0.001	0.048	-0.165	0.175

Table 3 – Kinematic GNSS Vertical Accuracy Results

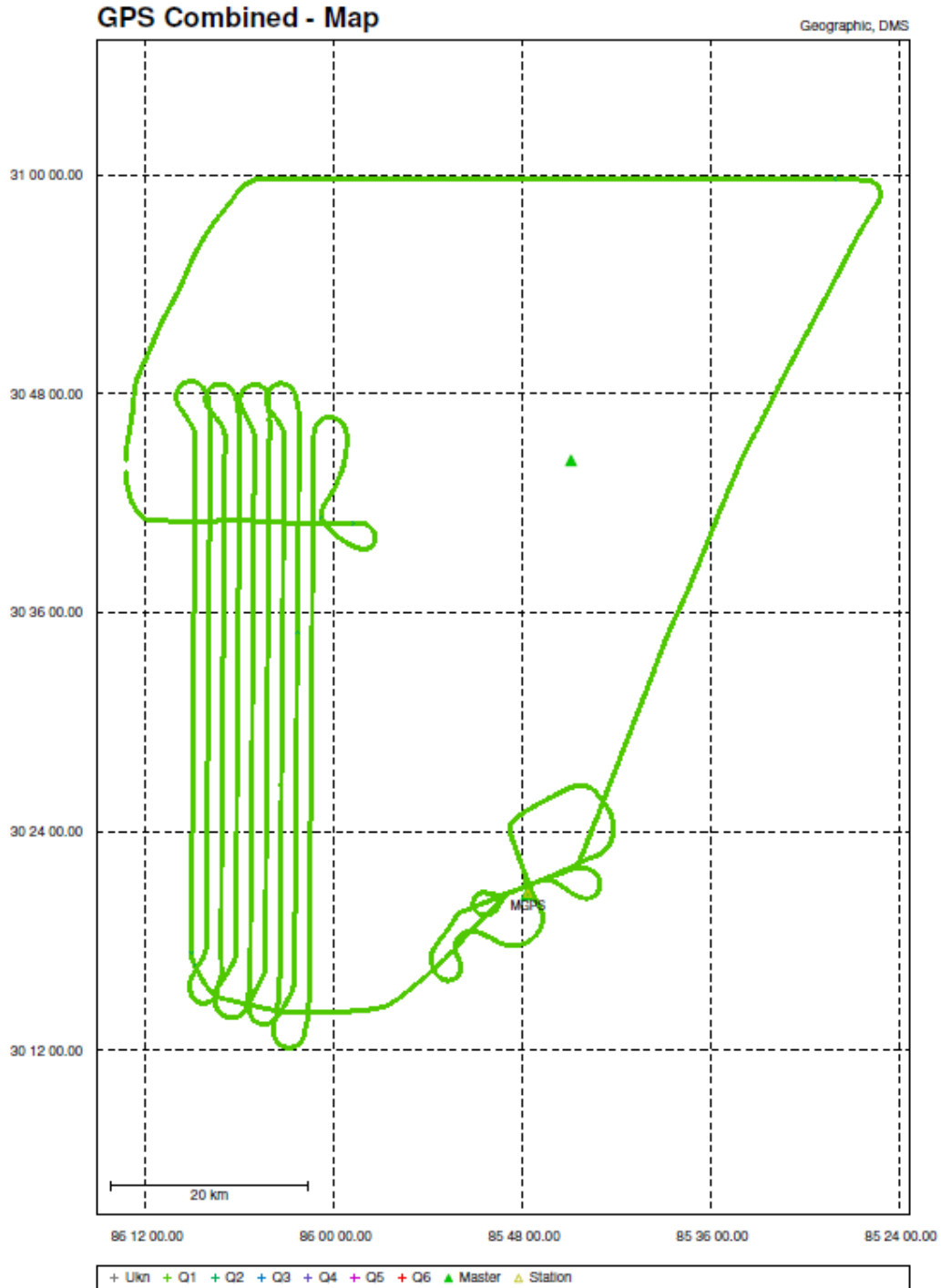
Overall the calibrated LiDAR data products collected by Airborne Imaging meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Airborne Imaging quality management program were adhered to throughout the acquisition stage for this project to ensure product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

Appendix A: GNSS and IMU Processing Reports for Each Mission

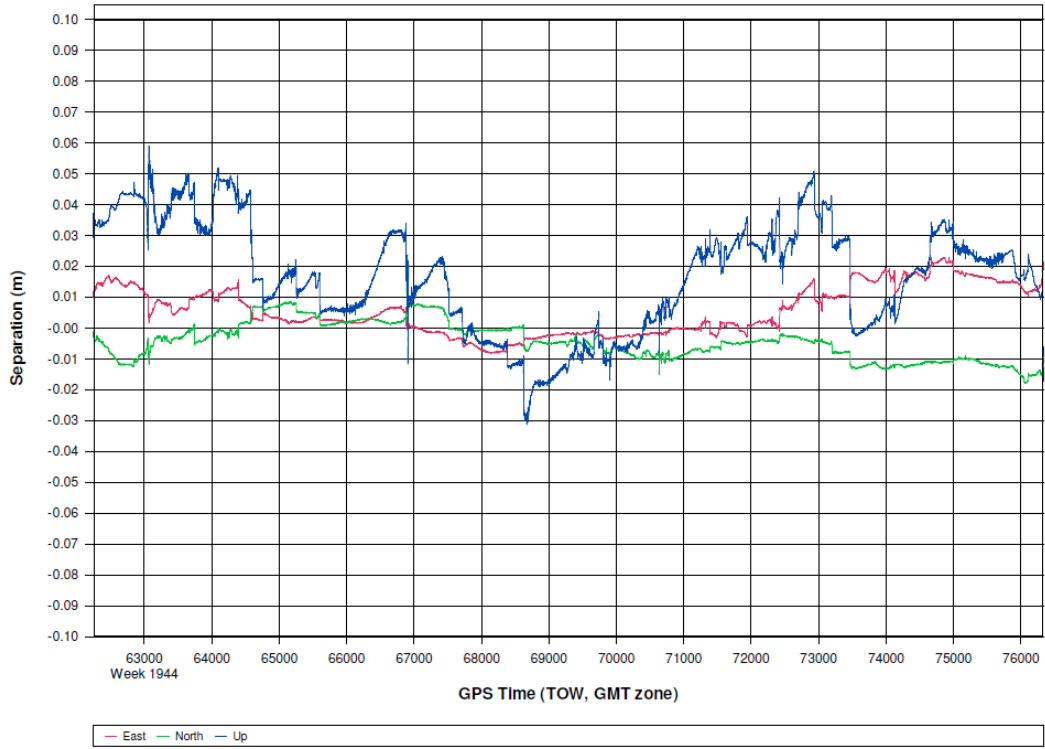
Mission 1 - 5417099a GNSS Processing

Project: 5417099a

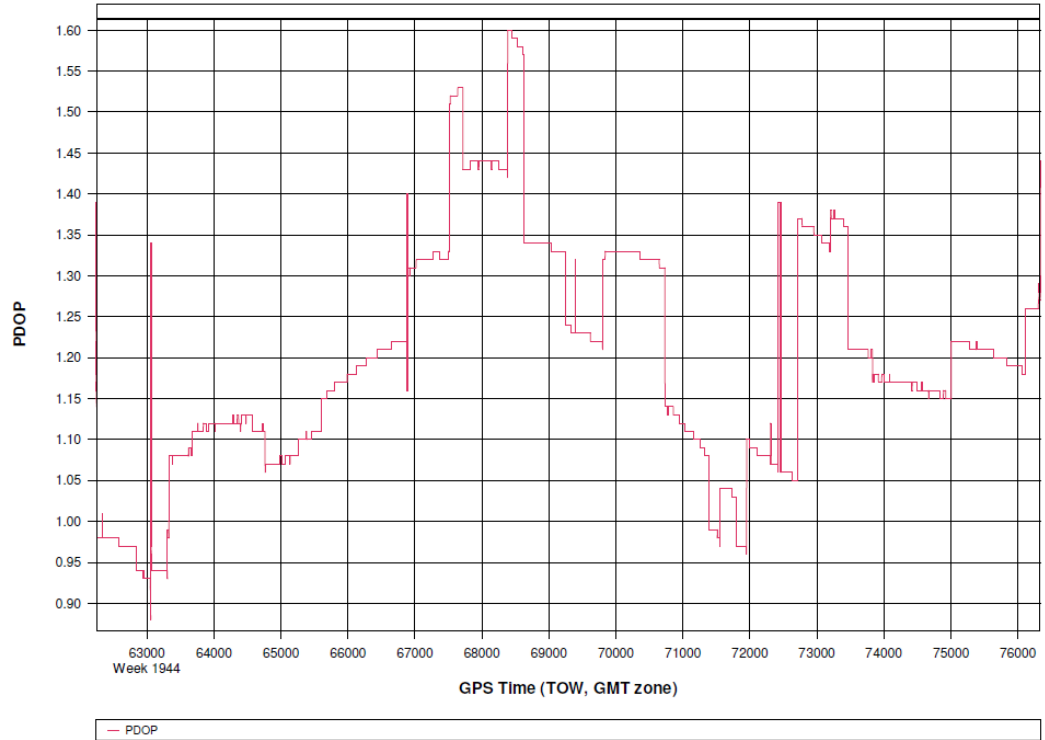
GrafNav v8.50.4320

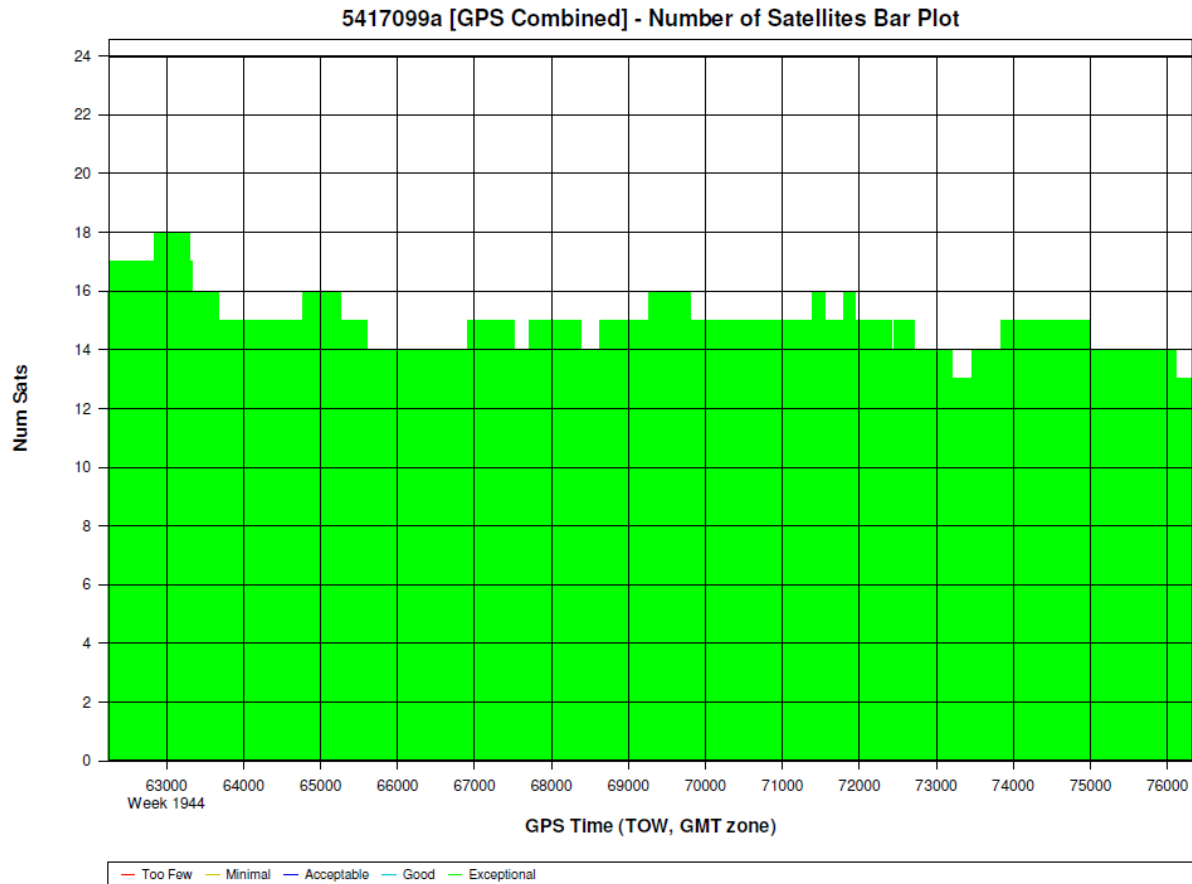


5417099a [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417099a [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417099a\05_INS-GPS_PROC\01_POS\5417099a\5417099a\GNSS\5417099a.gnv

Solution Type: Combined

Number of Epochs:

Total in GPB file:	14104
No processed position:	0
Missing Fwd or Rev:	5
With bad C/A code:	0
With bad L1 Phase:	0

Measurement RMS Values:

L1 Phase: 0.0185 (m)
C/A Code: 0.78 (m)
L1 Doppler: 0.037 (m/s)

Fwd/Rev Separation RMS Values:

East: 0.010 (m)
North: 0.007 (m)
Height: 0.024 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (14099 occurances):

East: 0.010 (m)
North: 0.007 (m)
Height: 0.024 (m)

Quality Number Percentages:

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

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

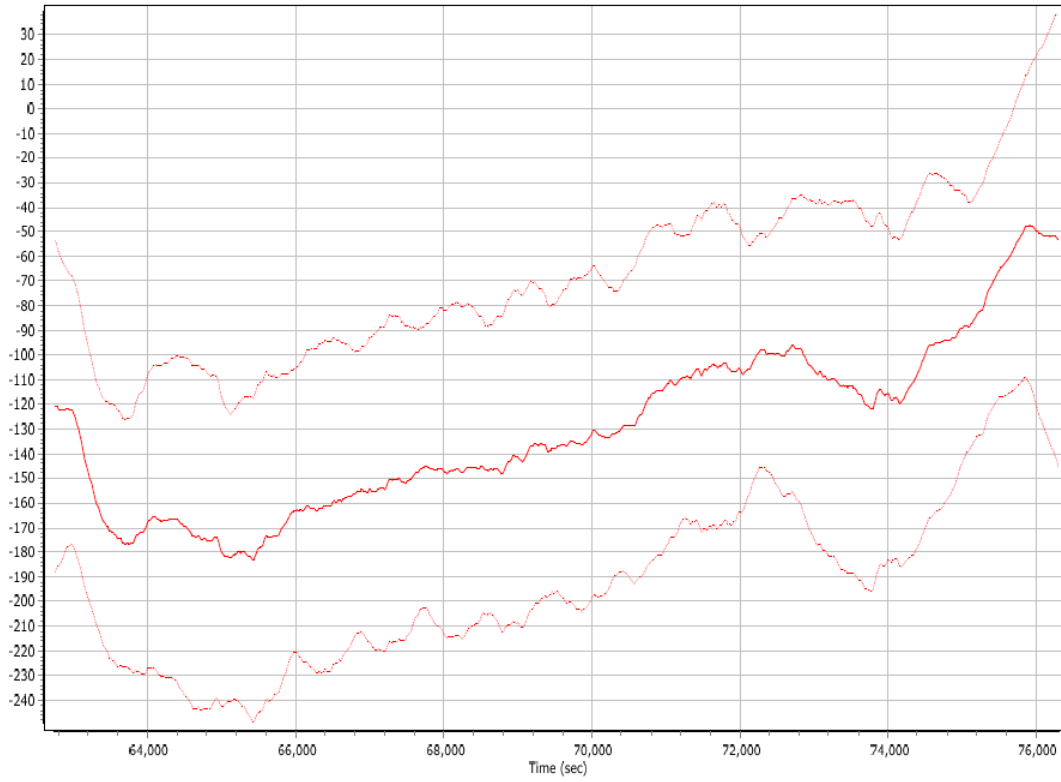
DOP over Tol: 0.0 %

Baseline Distances:

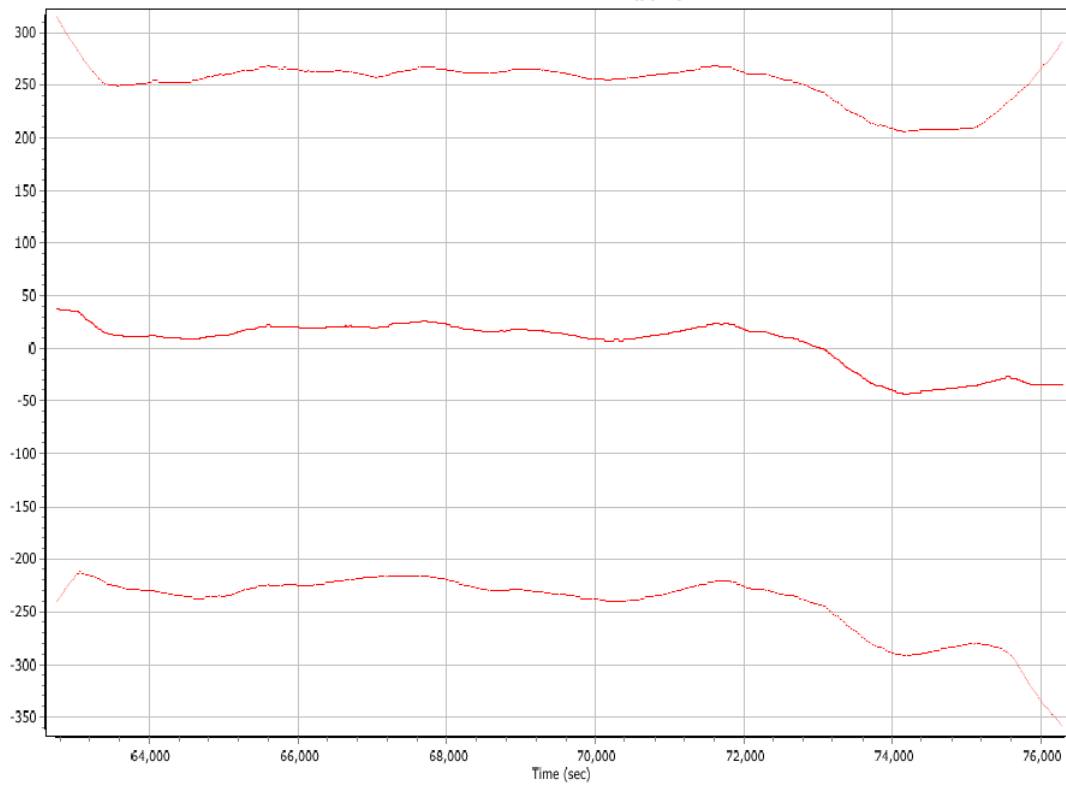
Maximum: 60.048 (km)
Minimum: 0.213 (km)
Average: 33.575 (km)
First Epoch: 21.483 (km)
Last Epoch: 0.213 (km)

Mission 1 - 5417099a Sensor Errors

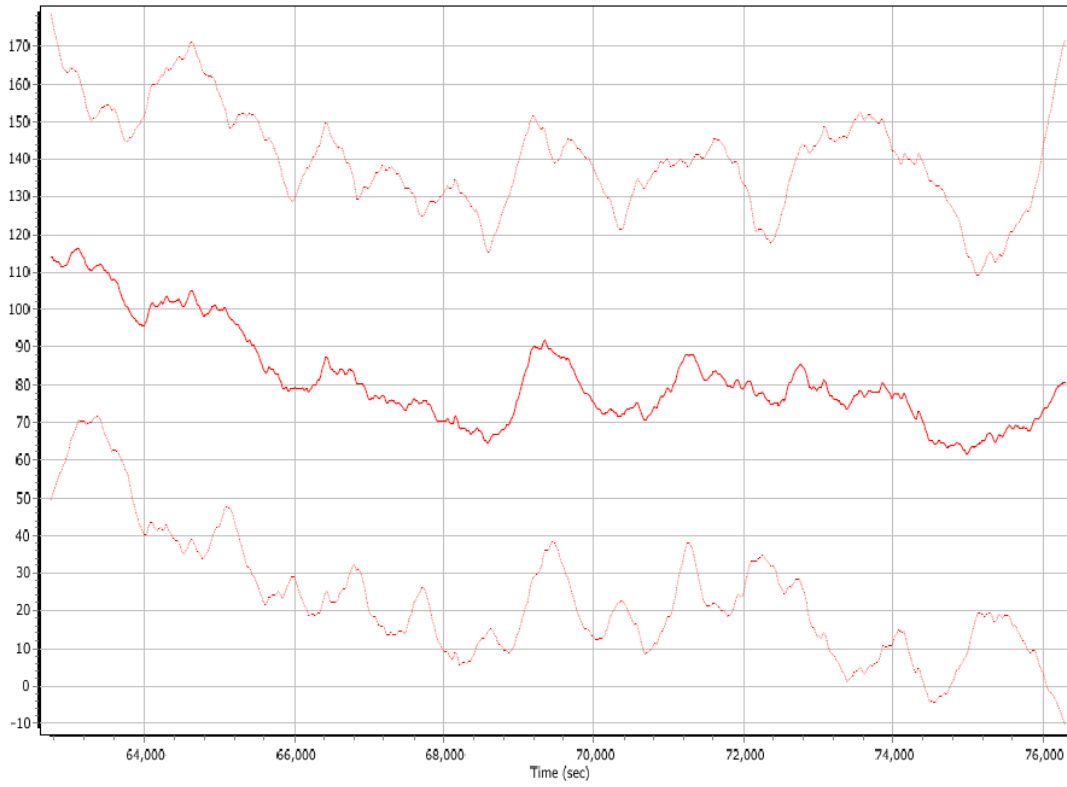
x accelerometer bias (micro-g)



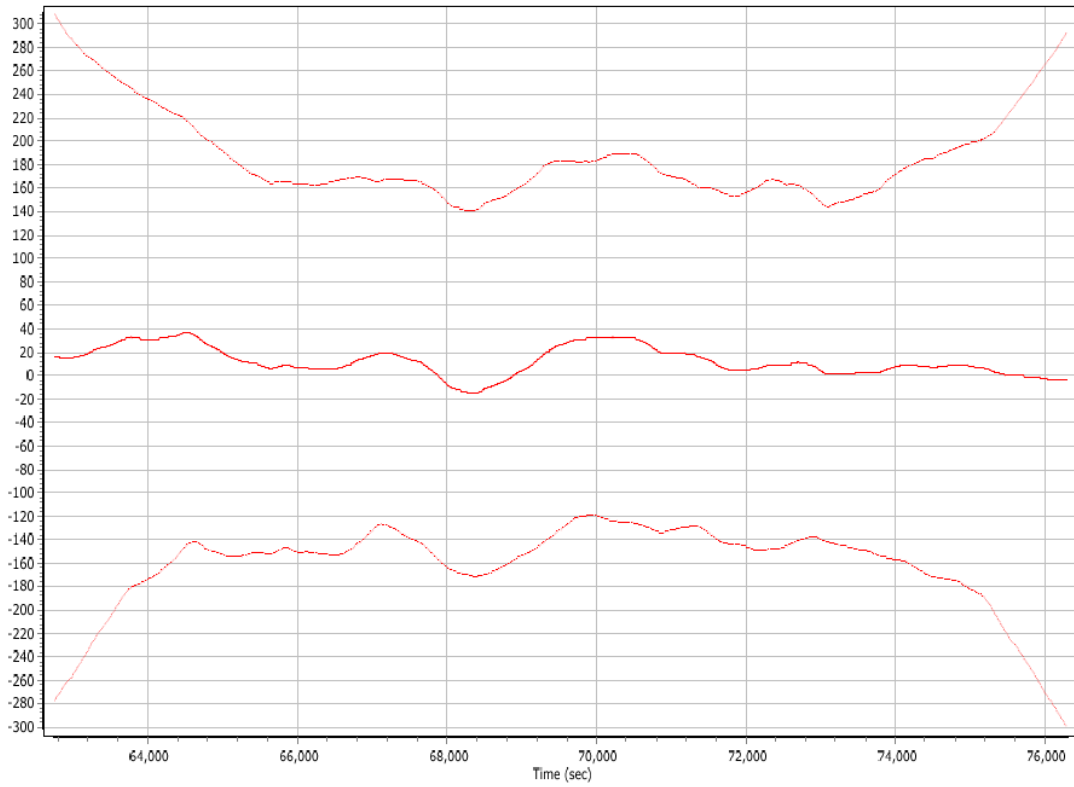
x accelerometer scale error (ppm)



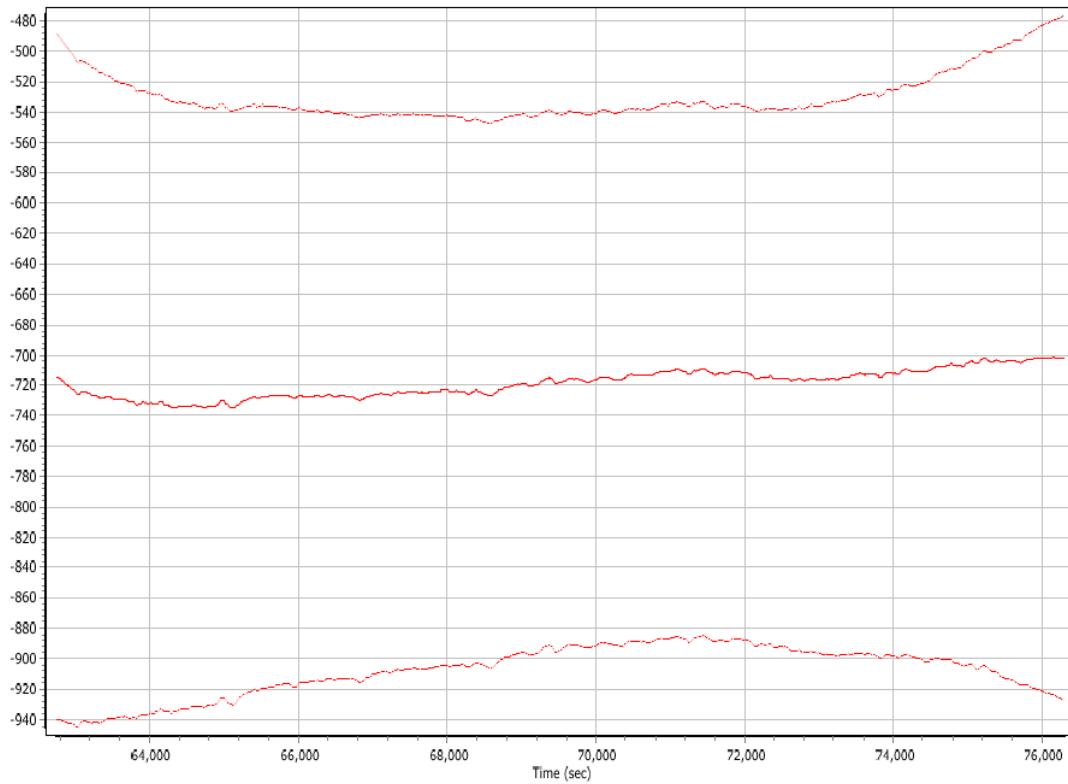
y accelerometer bias (micro-g)



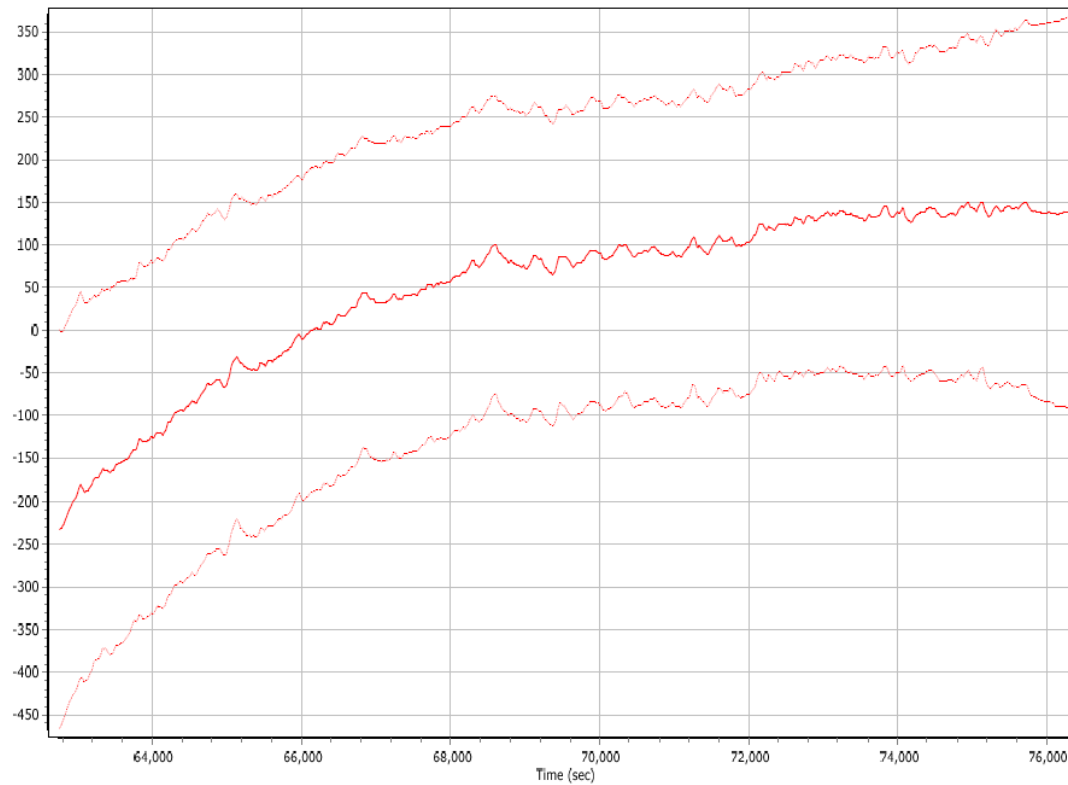
y accelerometer scale error (ppm)



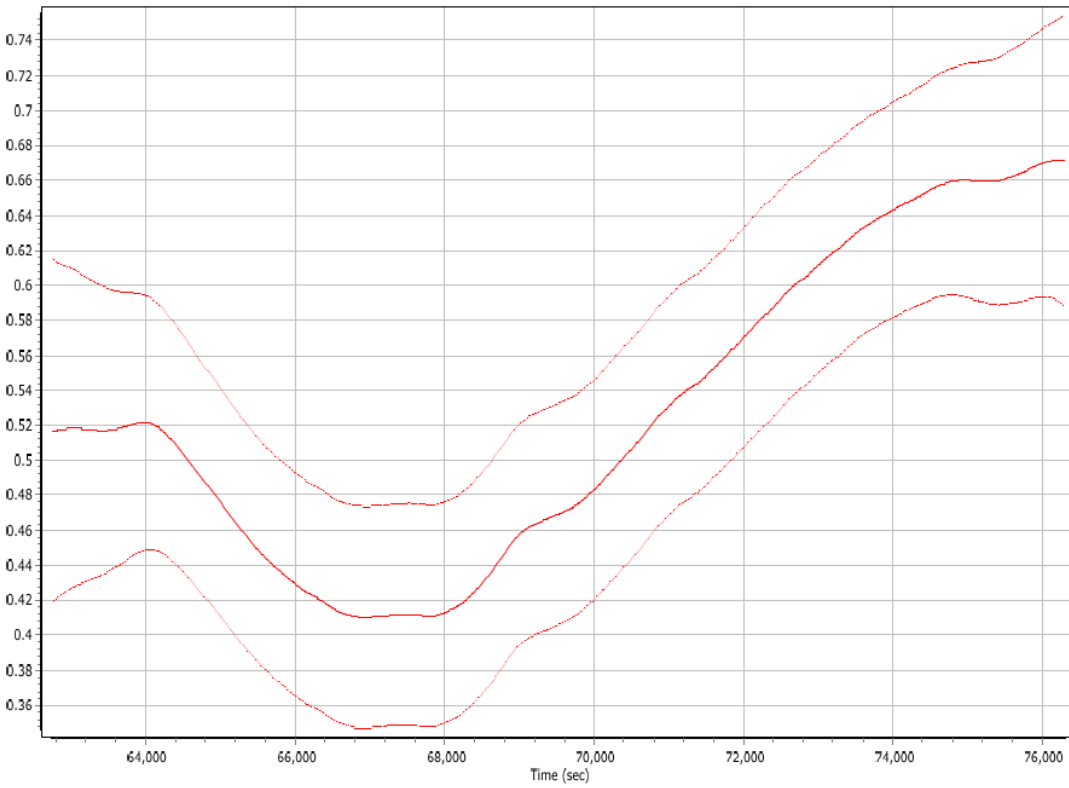
z accelerometer bias (micro-g)



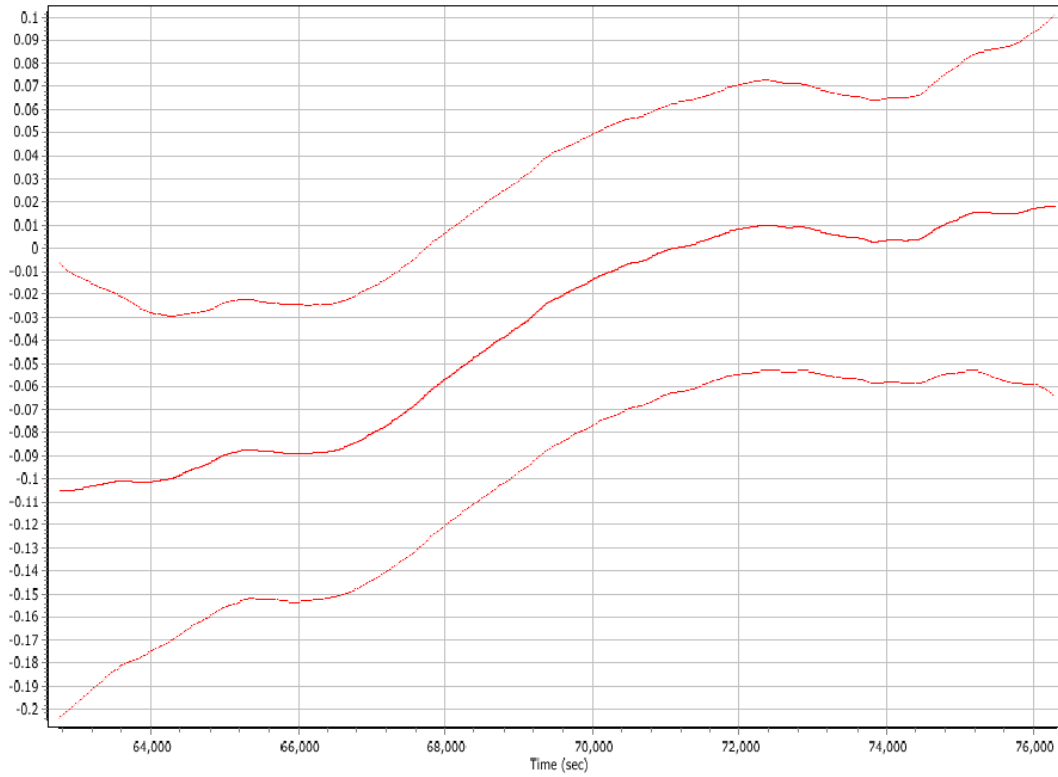
z accelerometer scale error (ppm)



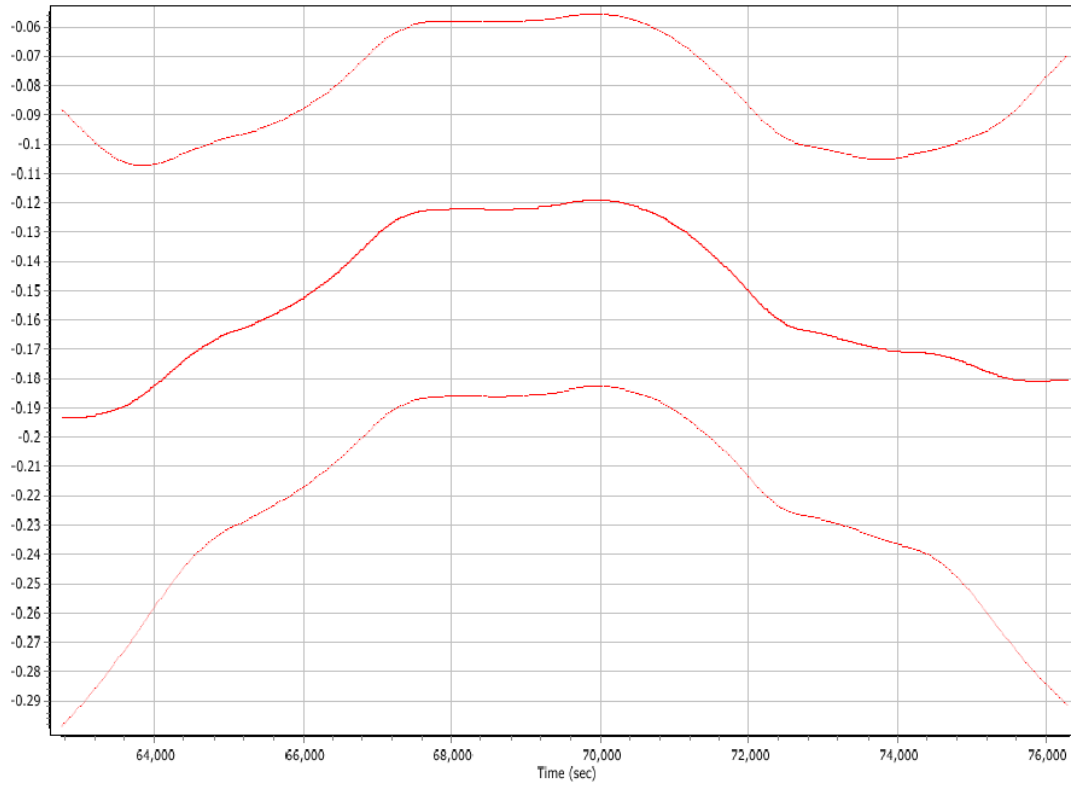
x gyro bias (deg/hr)



y gyro bias (deg/hr)



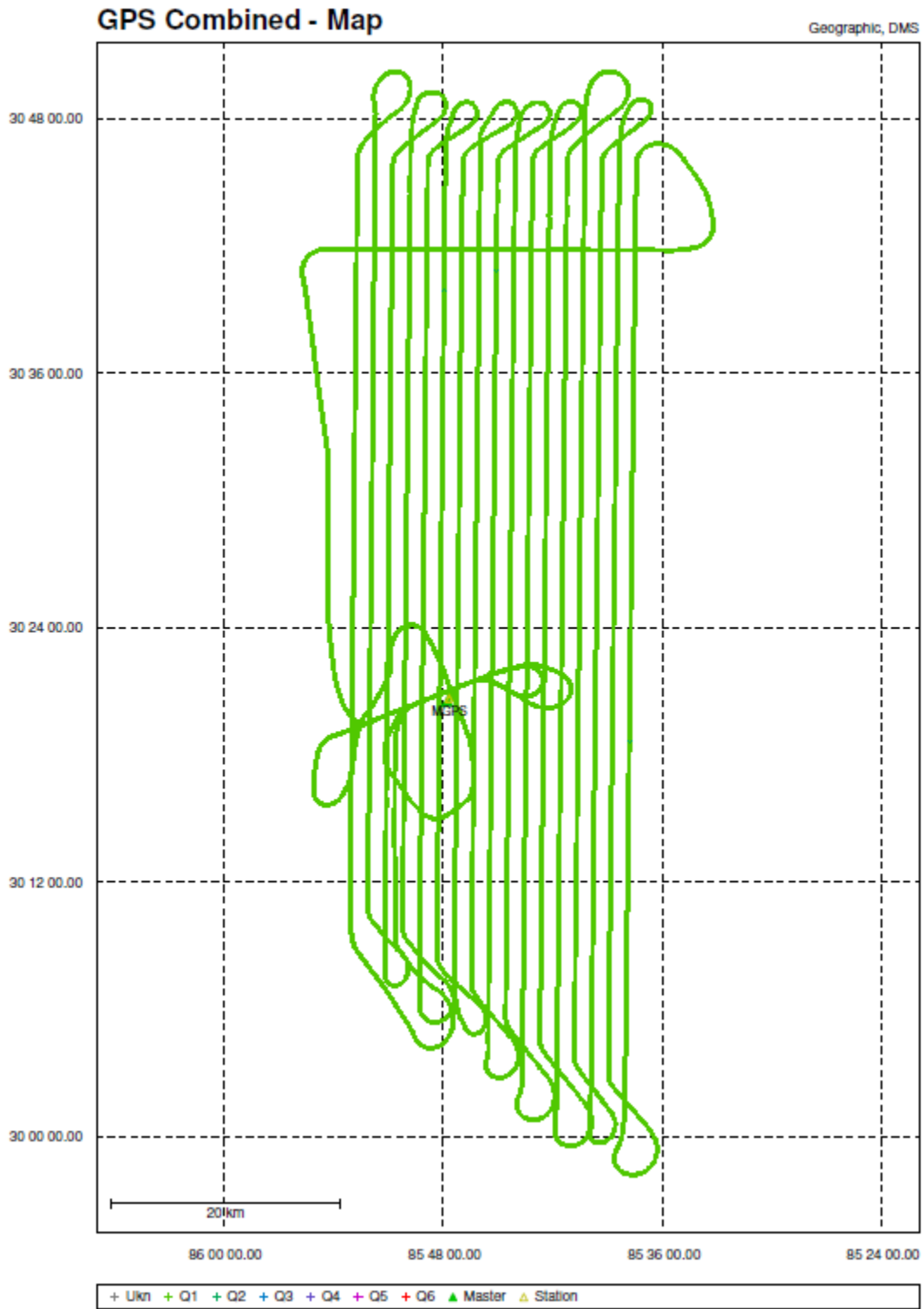
z gyro bias (deg/hr)



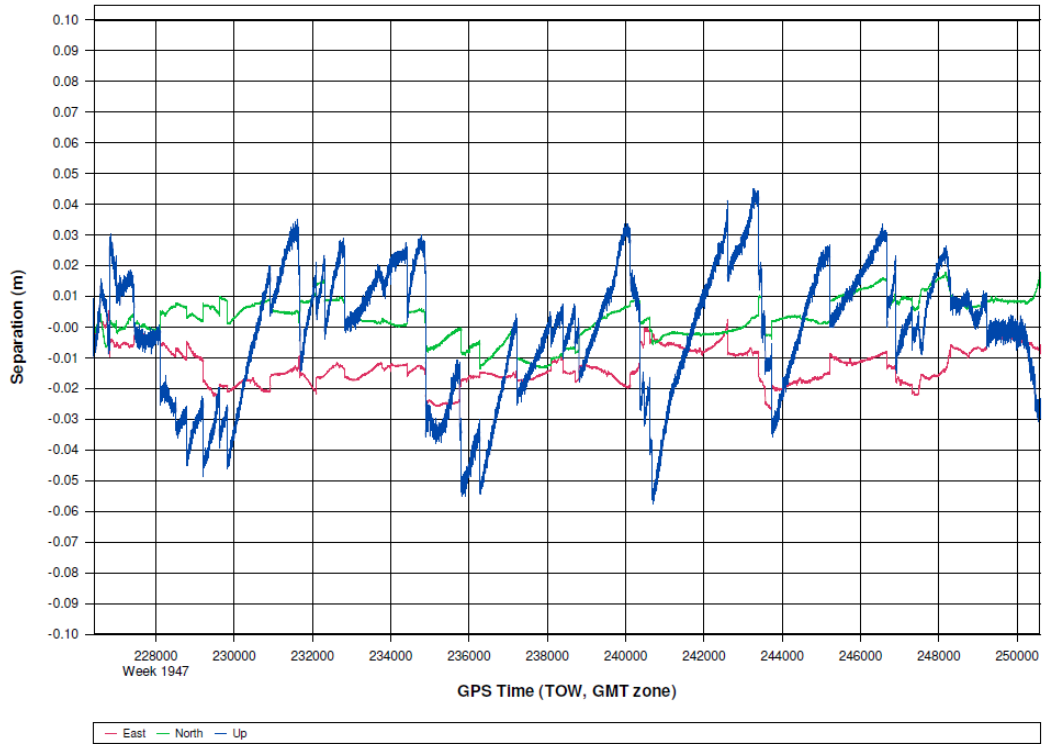
Mission 2 – 5417122a GNSS Processing

Project: 5417122a

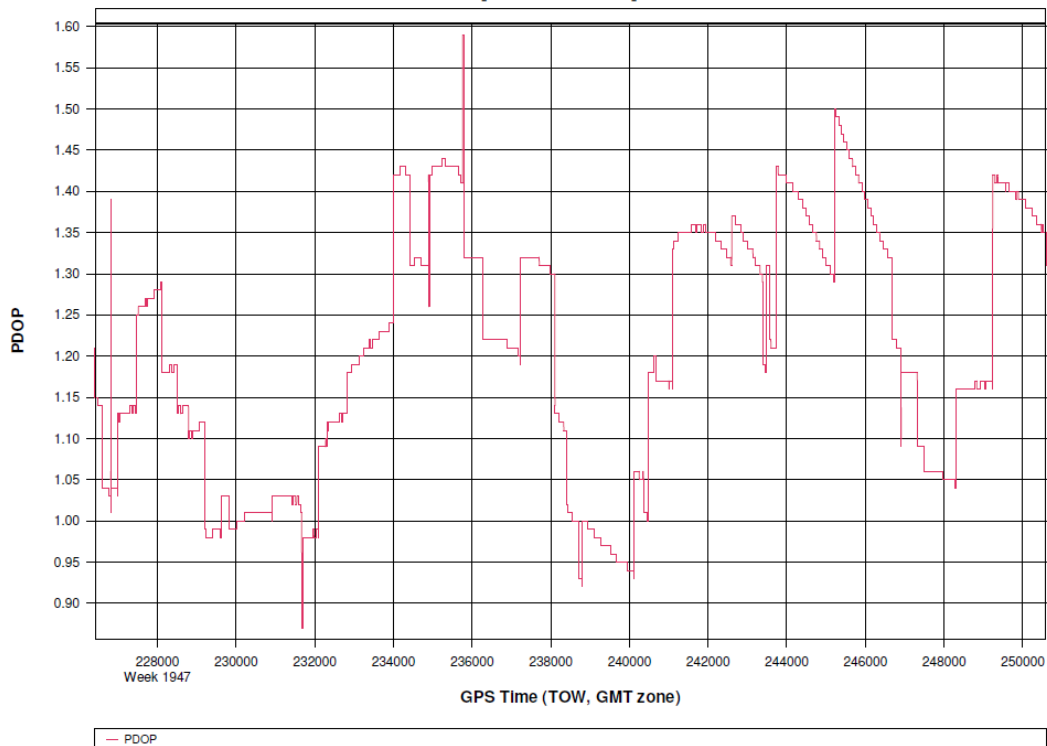
GrafNav v8.50.4320

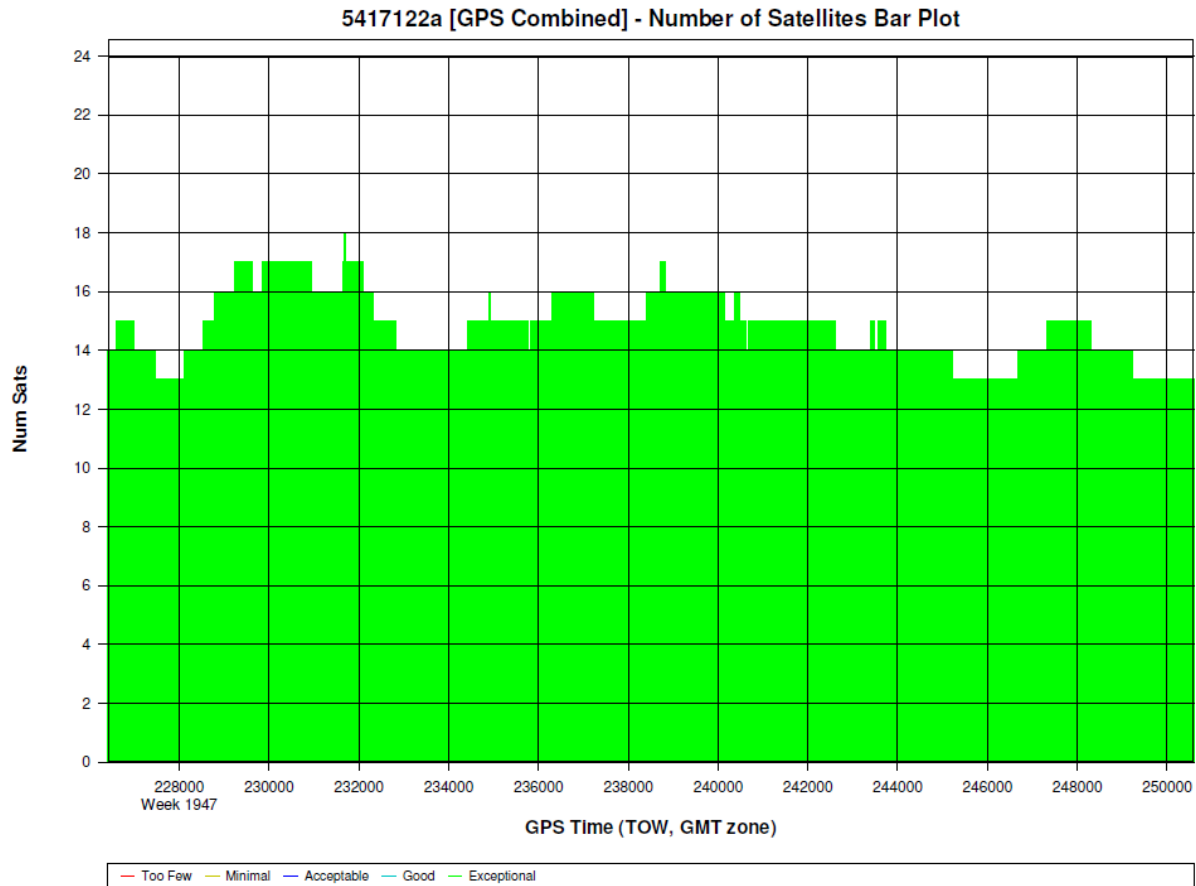


5417122a [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417122a [GPS Combined] - PDOP Plot





Processing Summary Information

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

Solution Type: Combined

Number of Epochs:

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

Measurement RMS Values:

L1 Phase:	0.0210 (m)
C/A Code:	0.74 (m)
L1 Doppler:	0.806 (m/s)

Fwd/Rev Separation RMS Values:

East: 0.014 (m)
North: 0.007 (m)
Height: 0.021 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (24205 occurrences):

East: 0.014 (m)
North: 0.007 (m)
Height: 0.021 (m)

Quality Number Percentages:

Q 1: 100.0 %
Q 2: 0.0 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

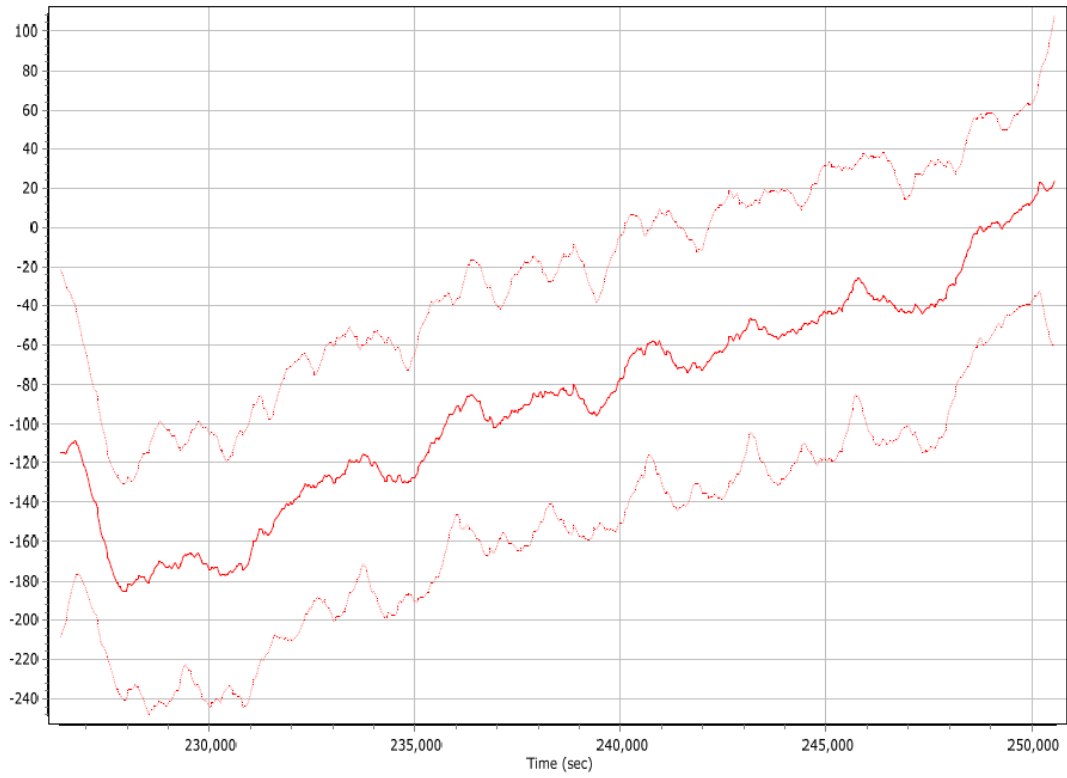
DOP over Tol: 0.0 %

Baseline Distances:

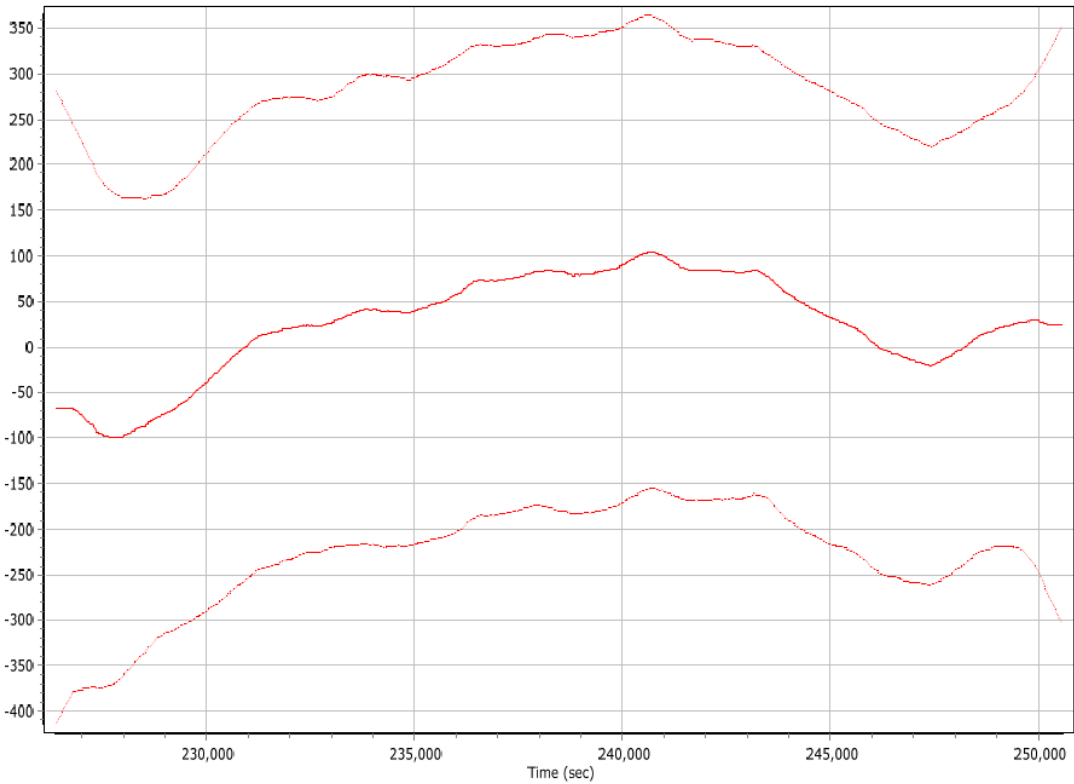
Maximum: 56.740 (km)
Minimum: 0.257 (km)
Average: 23.396 (km)
First Epoch: 0.327 (km)
Last Epoch: 0.263 (km)

Mission 2 - 5417122a Sensor Errors

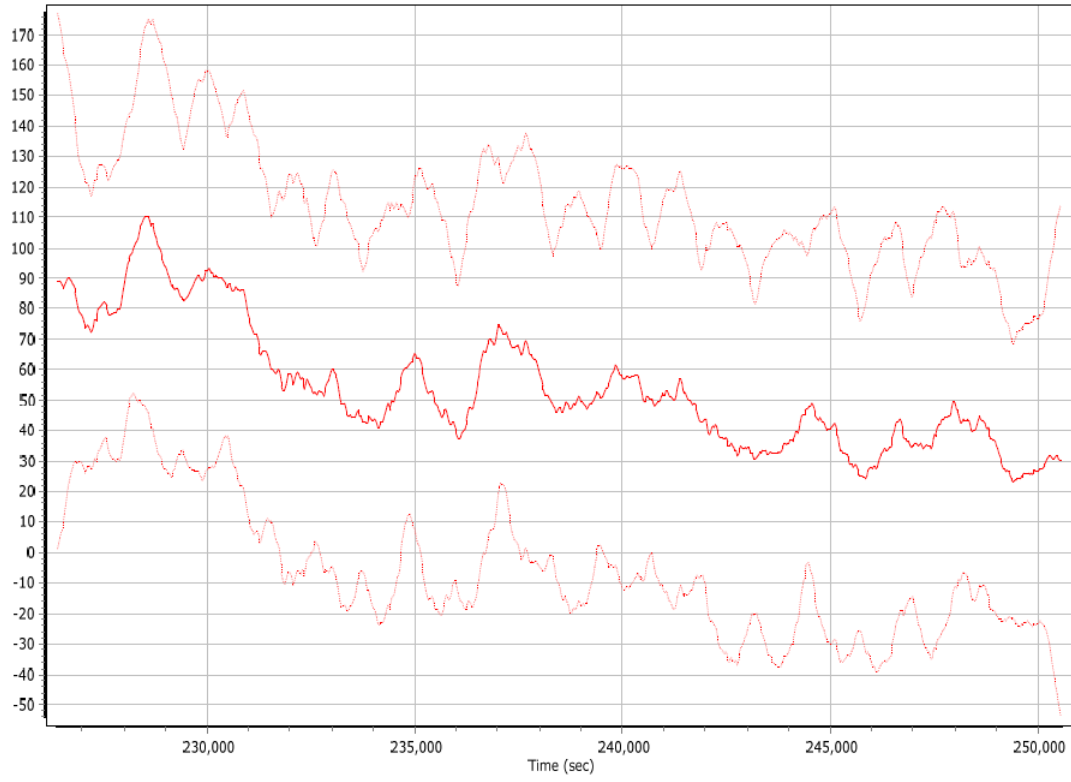
x accelerometer bias (micro-g)



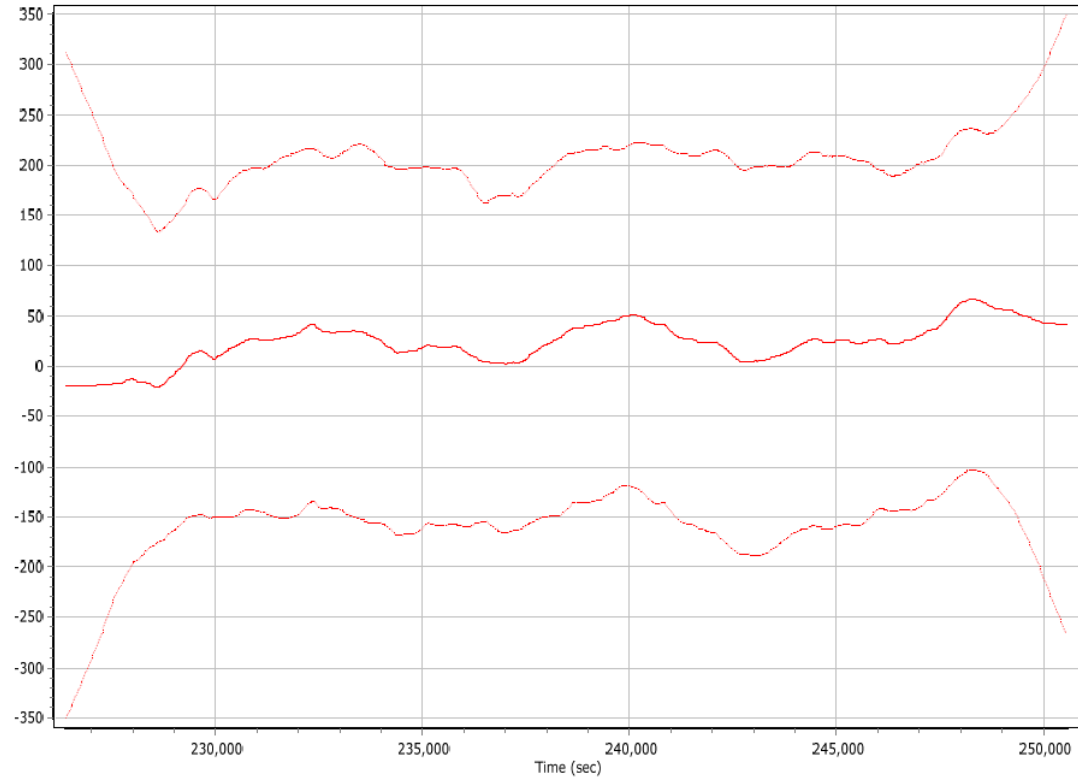
x accelerometer scale error (ppm)



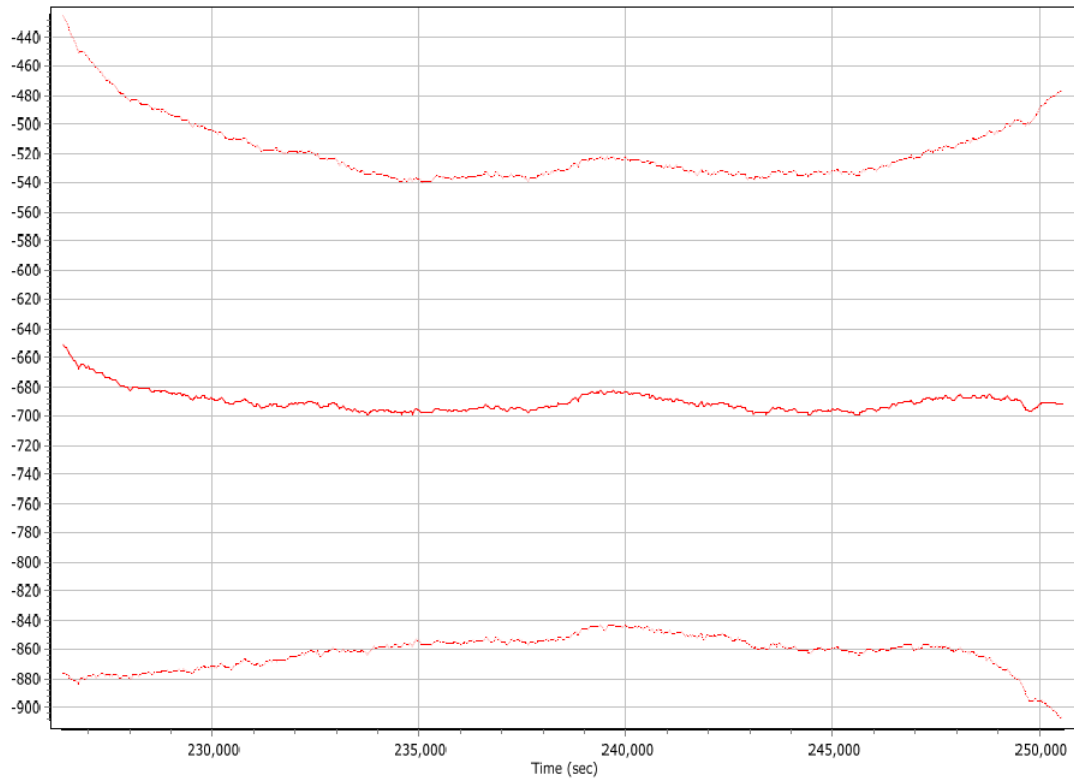
y accelerometer bias (micro-g)



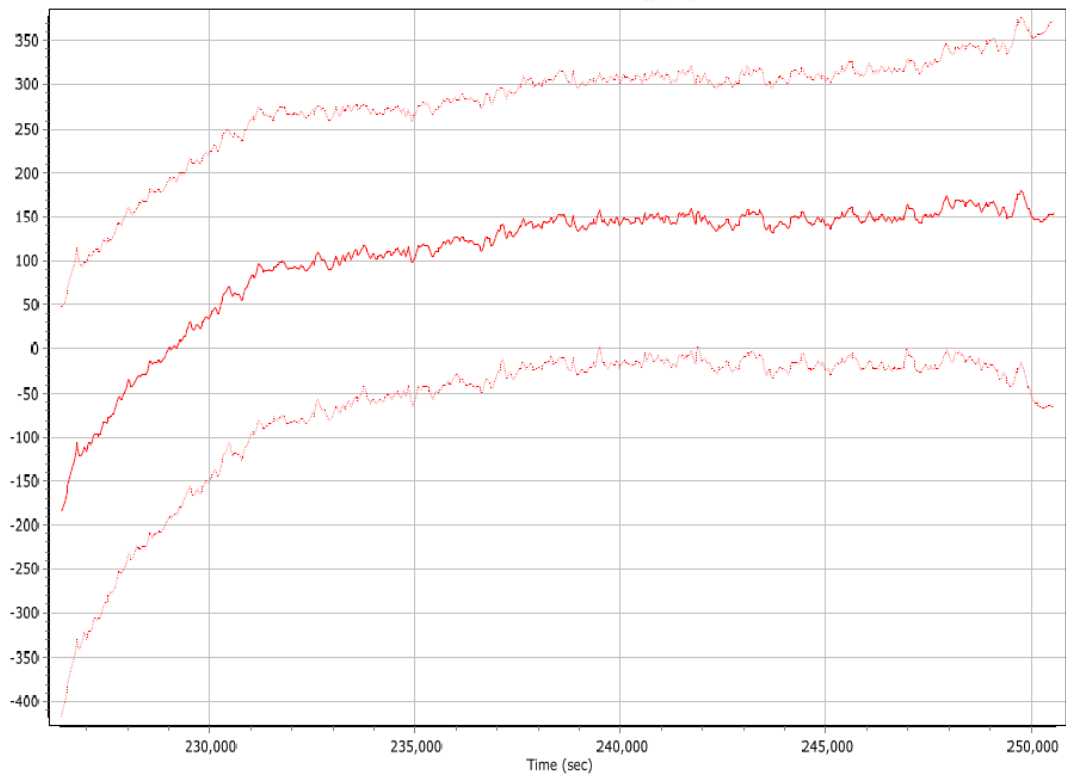
y accelerometer scale error (ppm)



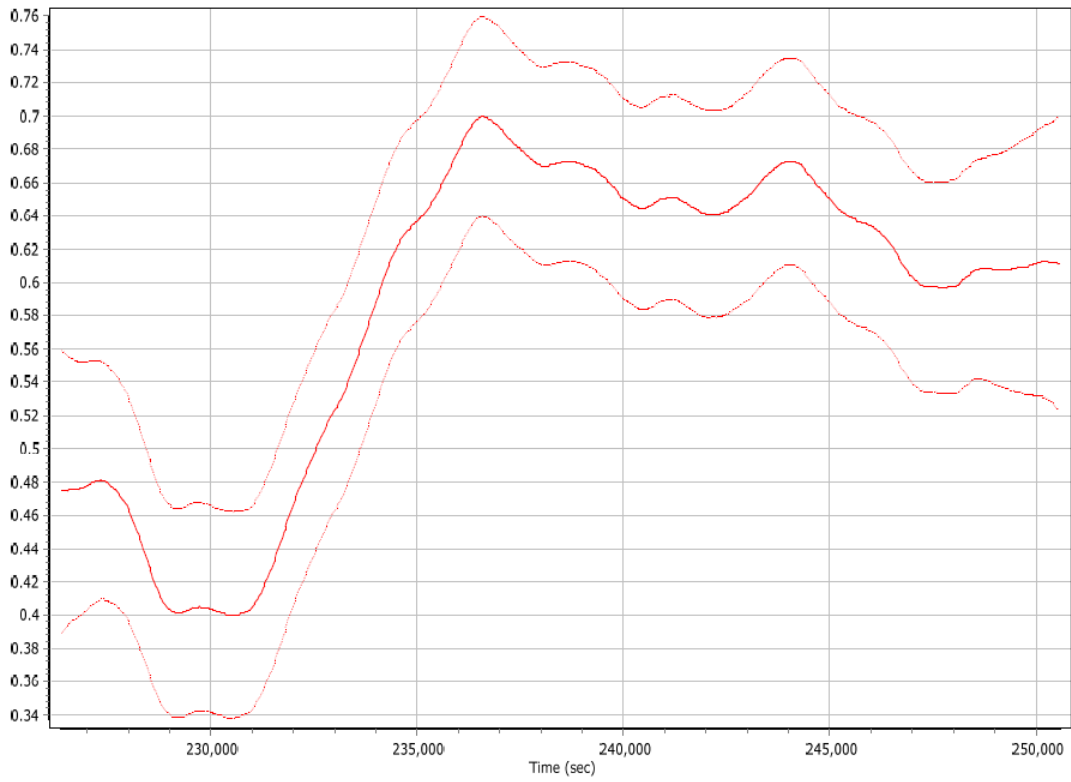
z accelerometer bias (micro-g)



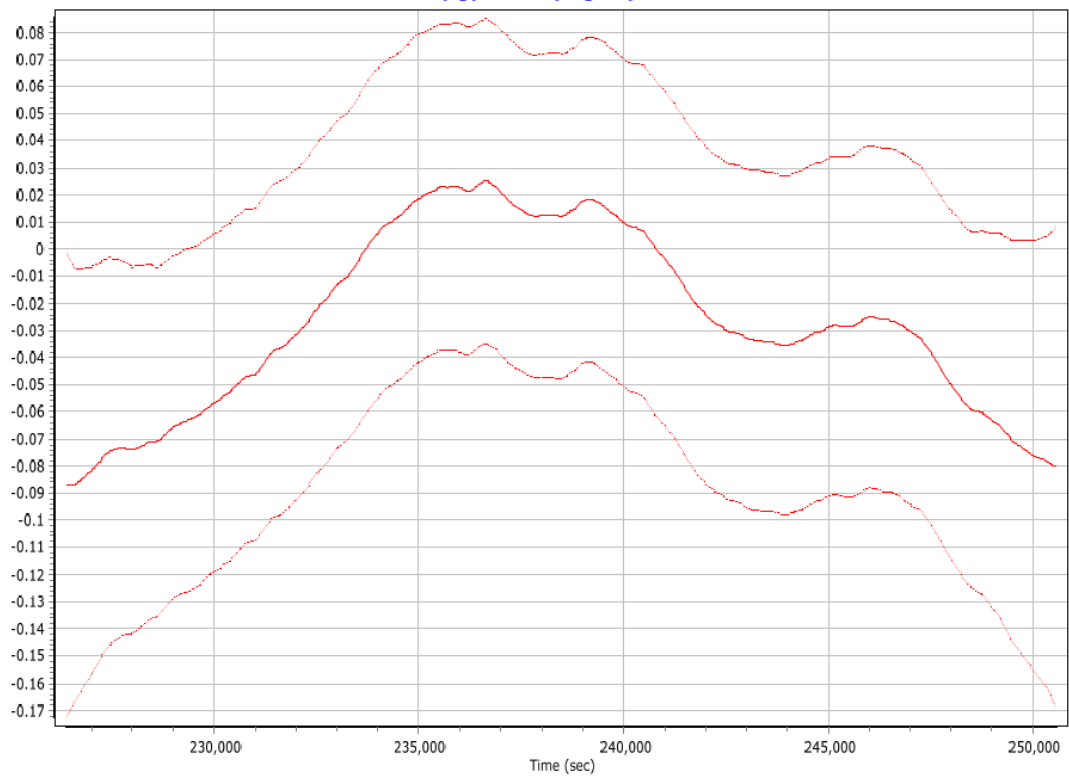
z accelerometer scale error (ppm)



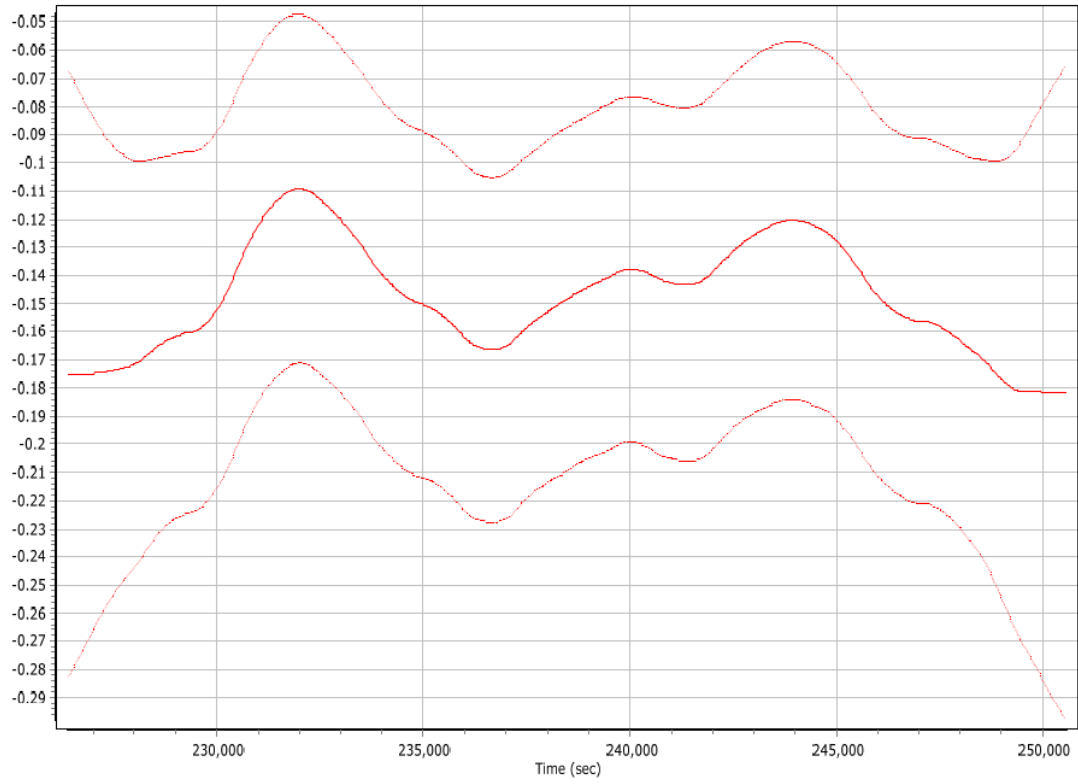
x gyro bias (deg/hr)



y gyro bias (deg/hr)



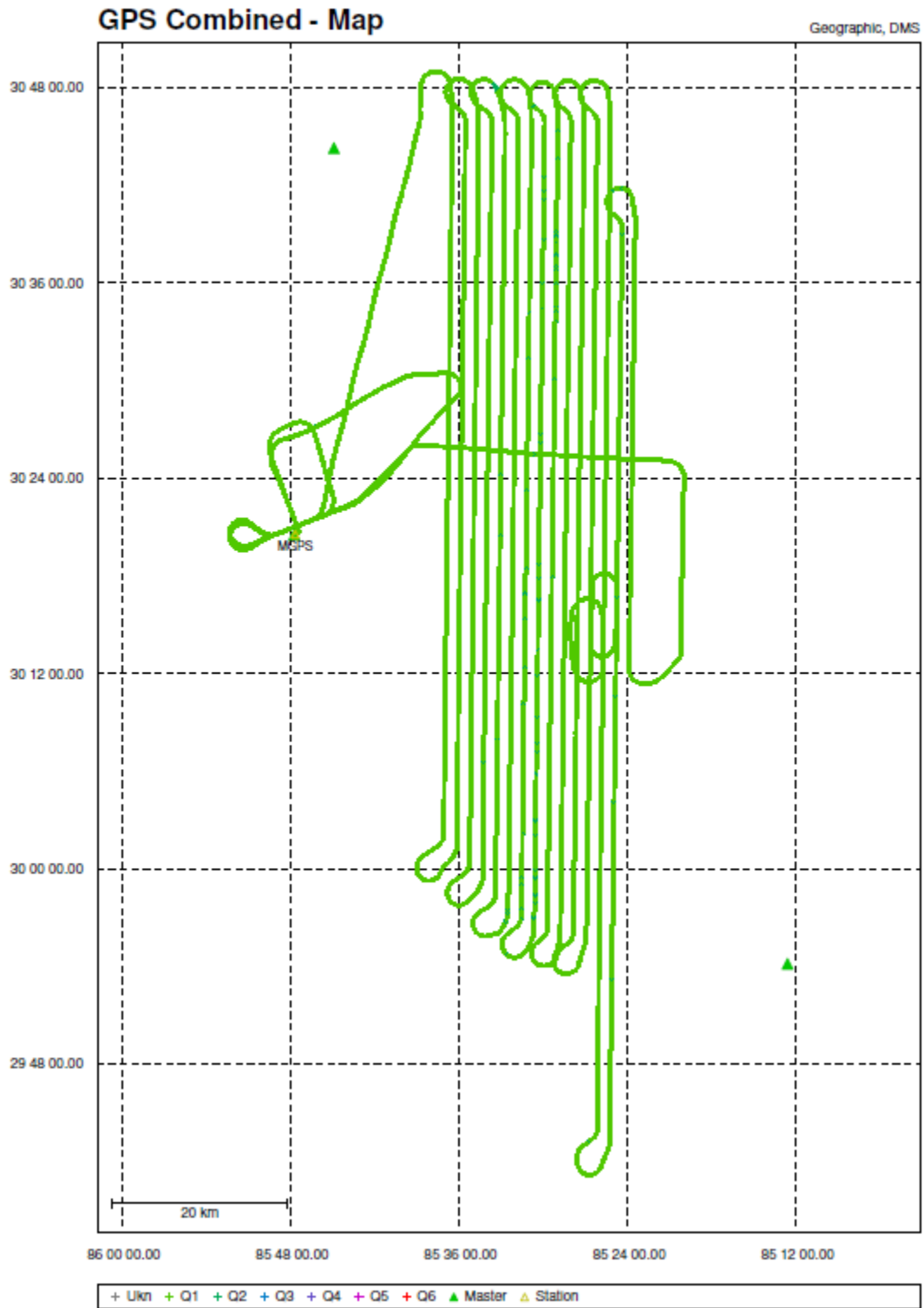
z gyro bias (deg/hr)



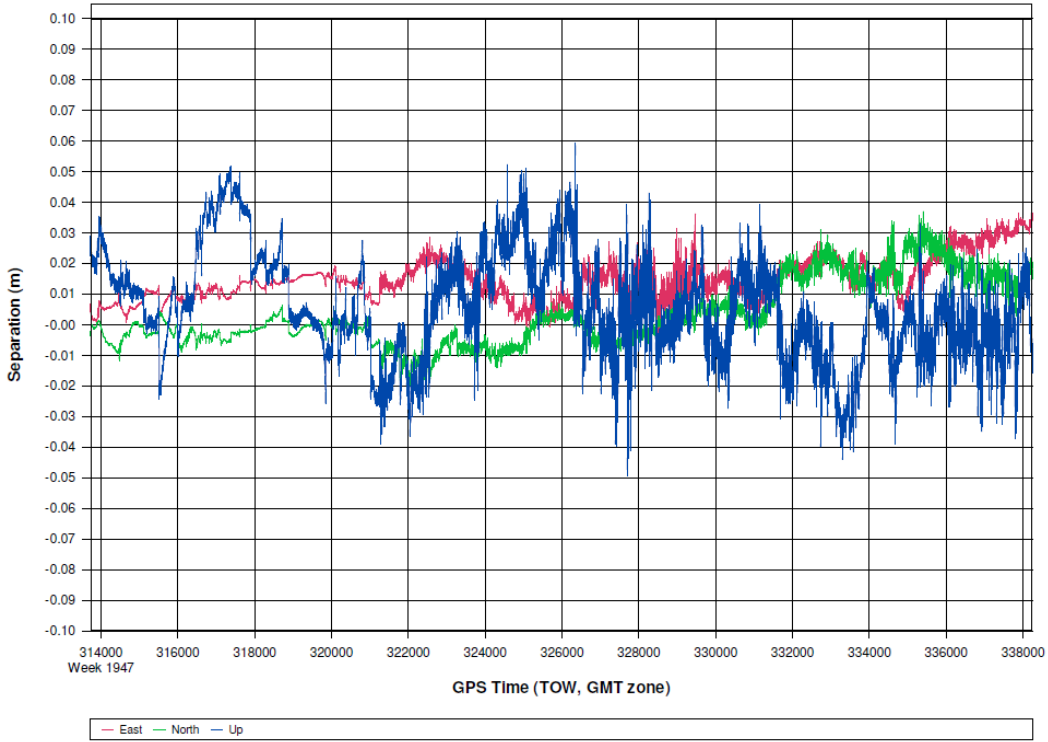
Mission 3 – 5417123a GNSS Processing

Project: 5417123a

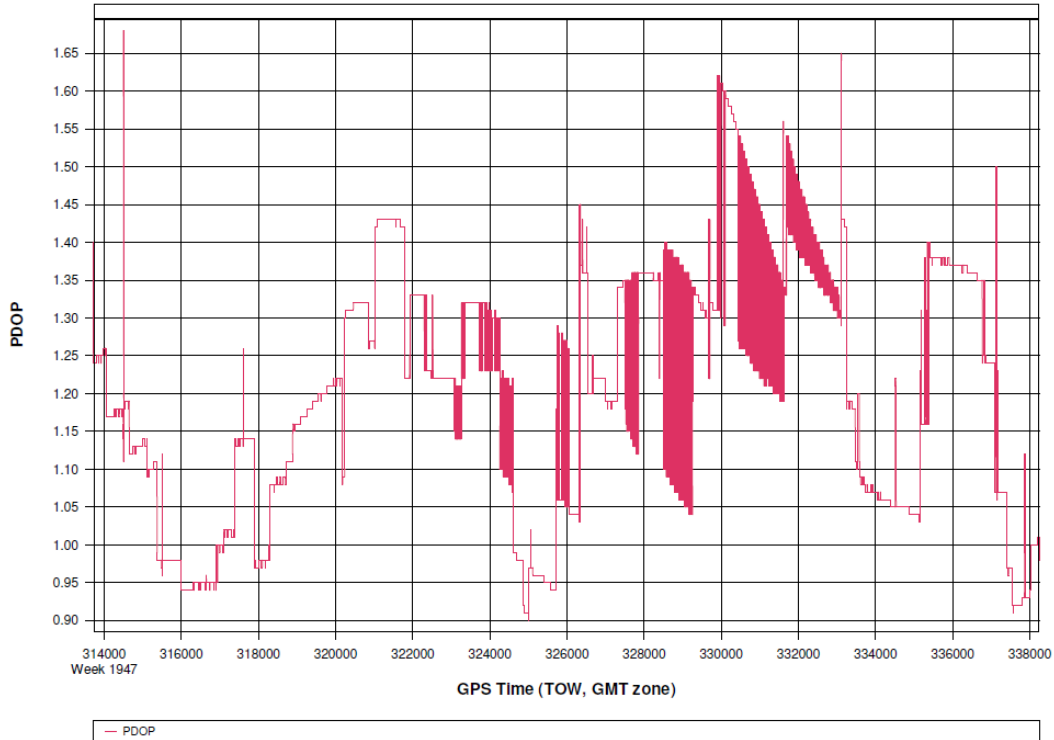
GrafNav v8.50.4320

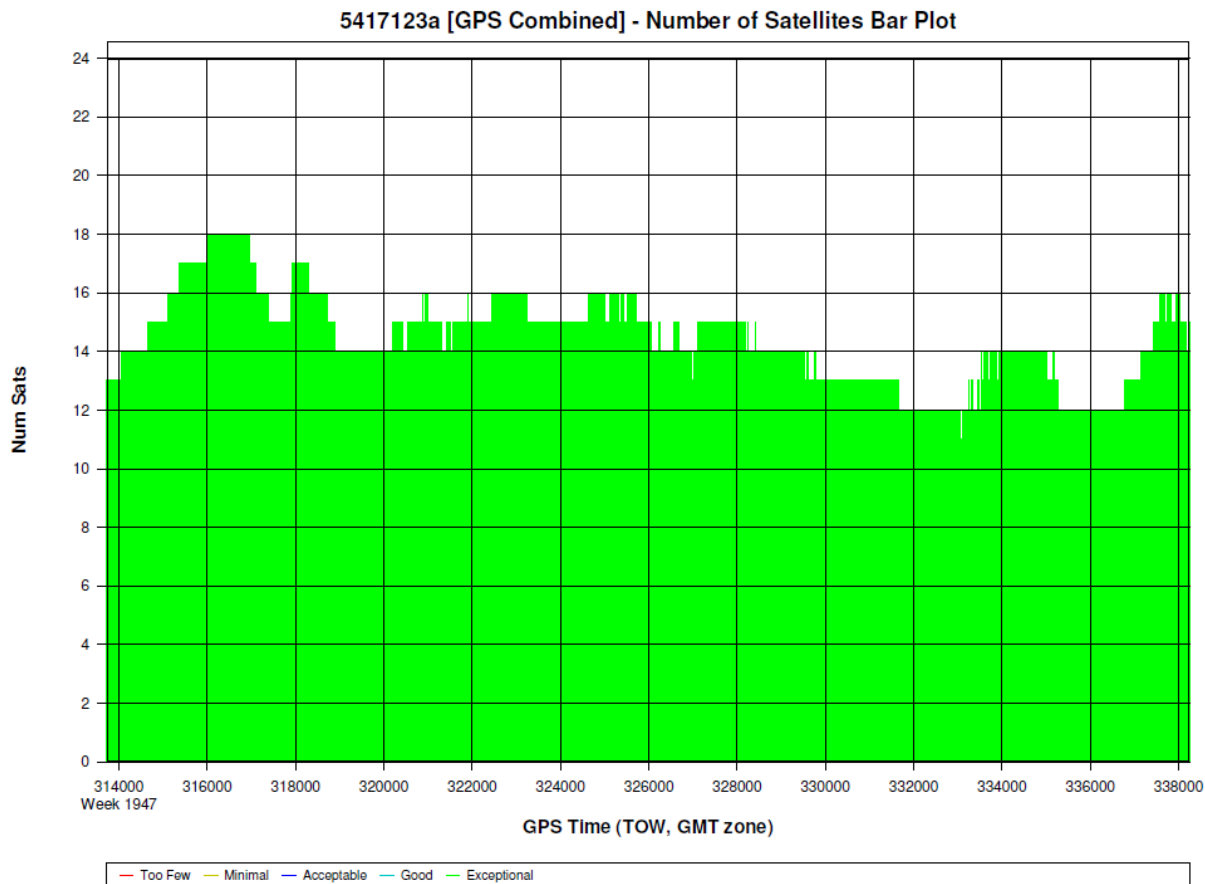


5417123a [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417123a [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417123a\05_INS-GPS_PROC\01_POS\5417123a\5417123a\GNSS\5417123a.gnv

Solution Type: Combined

Number of Epochs:

Total in GPB file:	24546
No processed position:	0
Missing Fwd or Rev:	5
With bad C/A code:	0
With bad L1 Phase:	0

Measurement RMS Values:

L1 Phase: 0.0209 (m)
C/A Code: 0.84 (m)
L1 Doppler: 0.719 (m/s)

Fwd/Rev Separation RMS Values:

East: 0.016 (m)
North: 0.011 (m)
Height: 0.018 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (24541 occurances):

East: 0.016 (m)
North: 0.011 (m)
Height: 0.018 (m)

Quality Number Percentages:

Q 1: 99.1 %
Q 2: 0.9 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

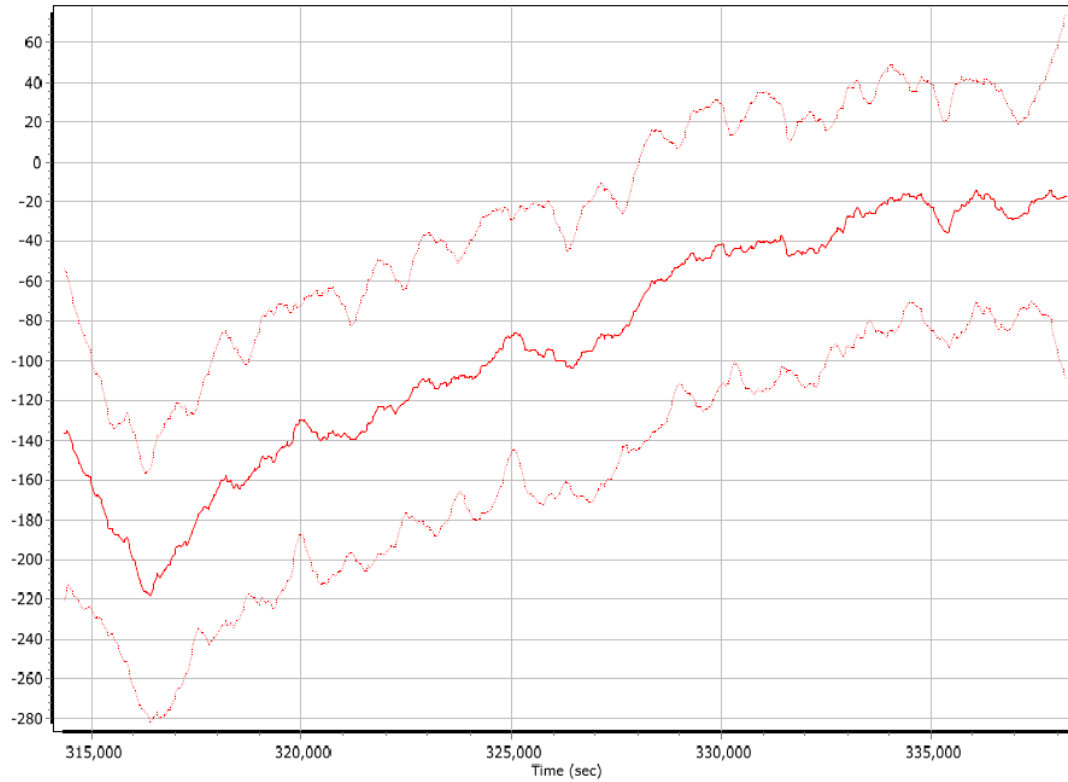
DOP over Tol: 0.0 %

Baseline Distances:

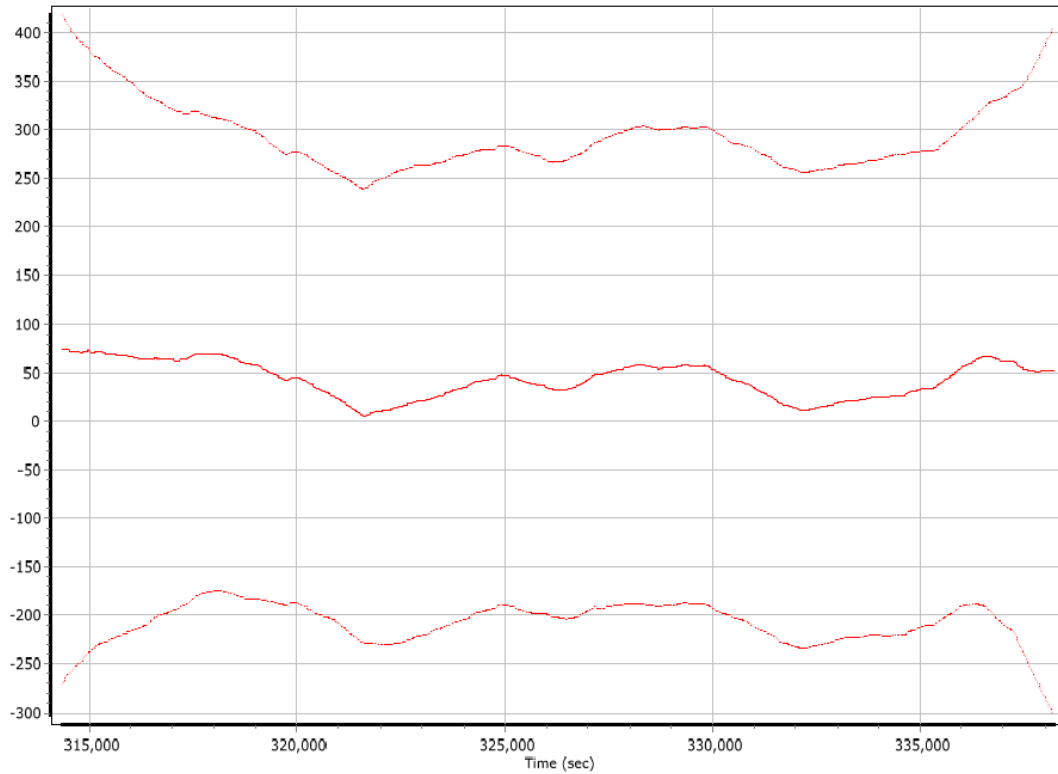
Maximum: 76.349 (km)
Minimum: 4.701 (km)
Average: 28.586 (km)
First Epoch: 21.732 (km)
Last Epoch: 17.061 (km)

Mission 3 - 5417123a Sensor Errors

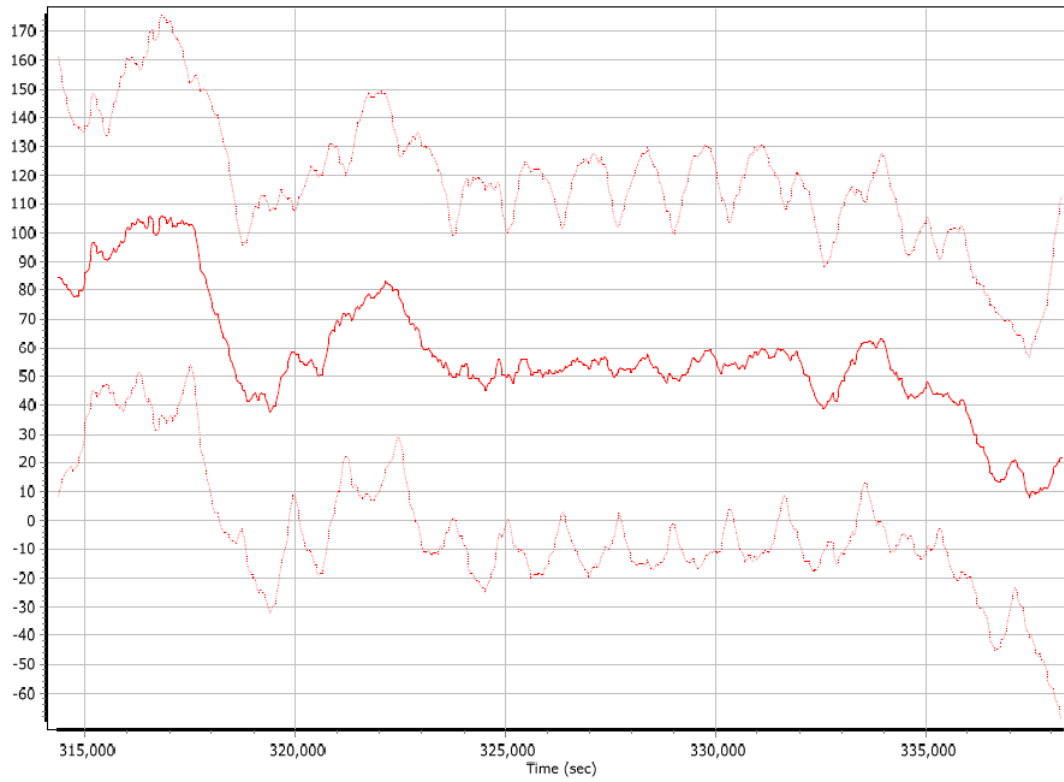
x accelerometer bias (micro-g)



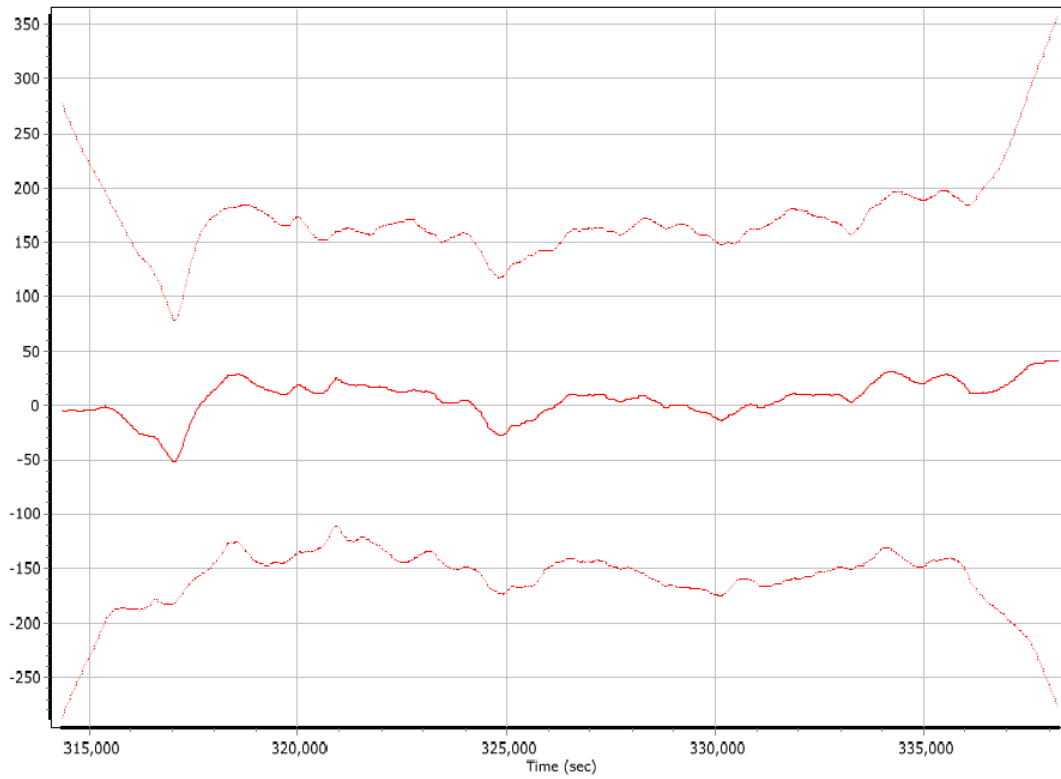
x accelerometer scale error (ppm)



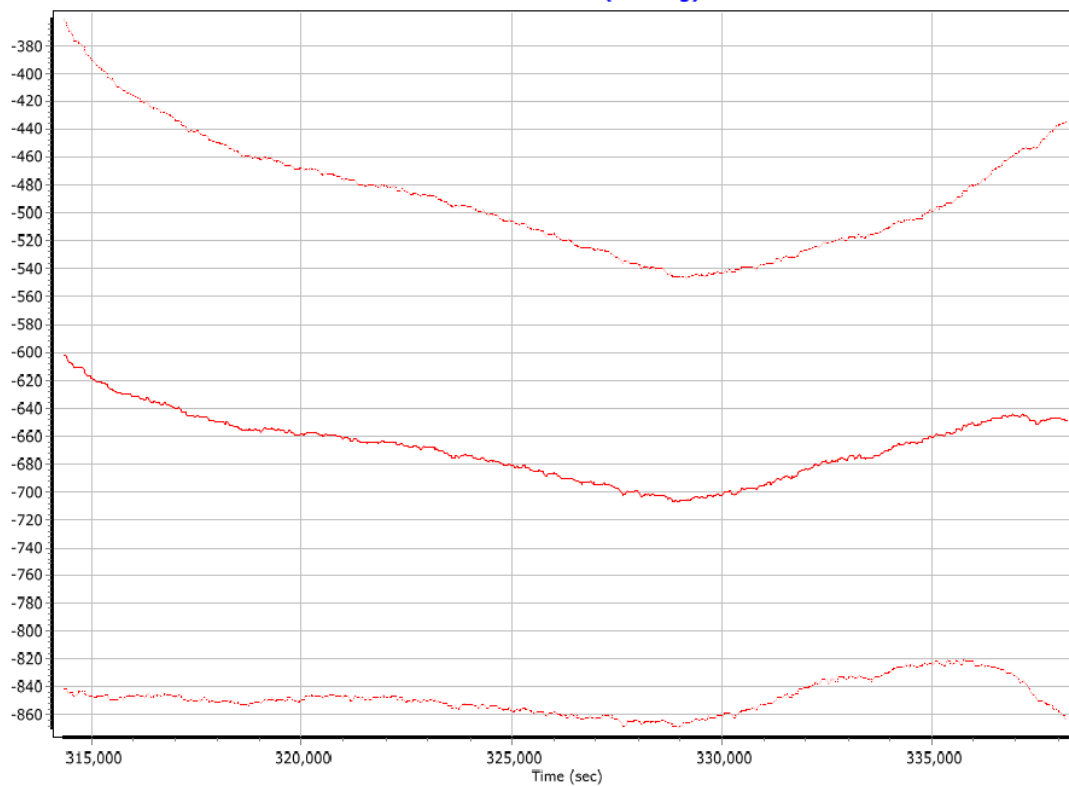
y accelerometer bias (micro-g)



y accelerometer scale error (ppm)



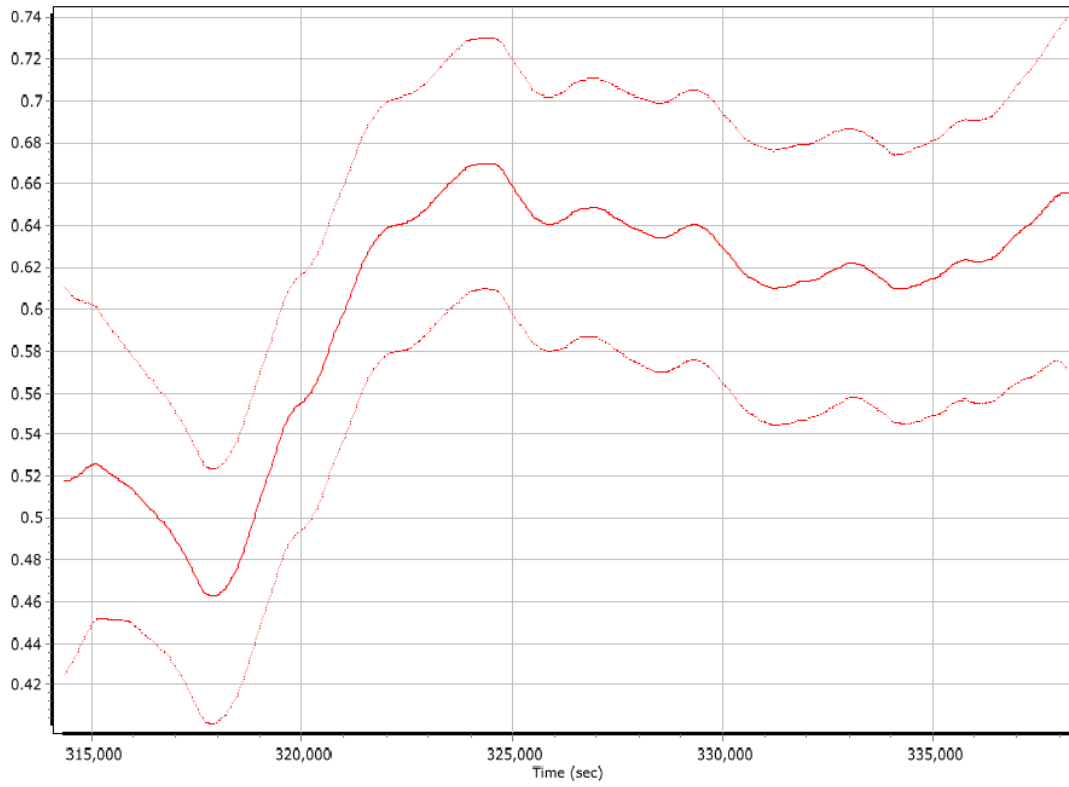
z accelerometer bias (micro-g)



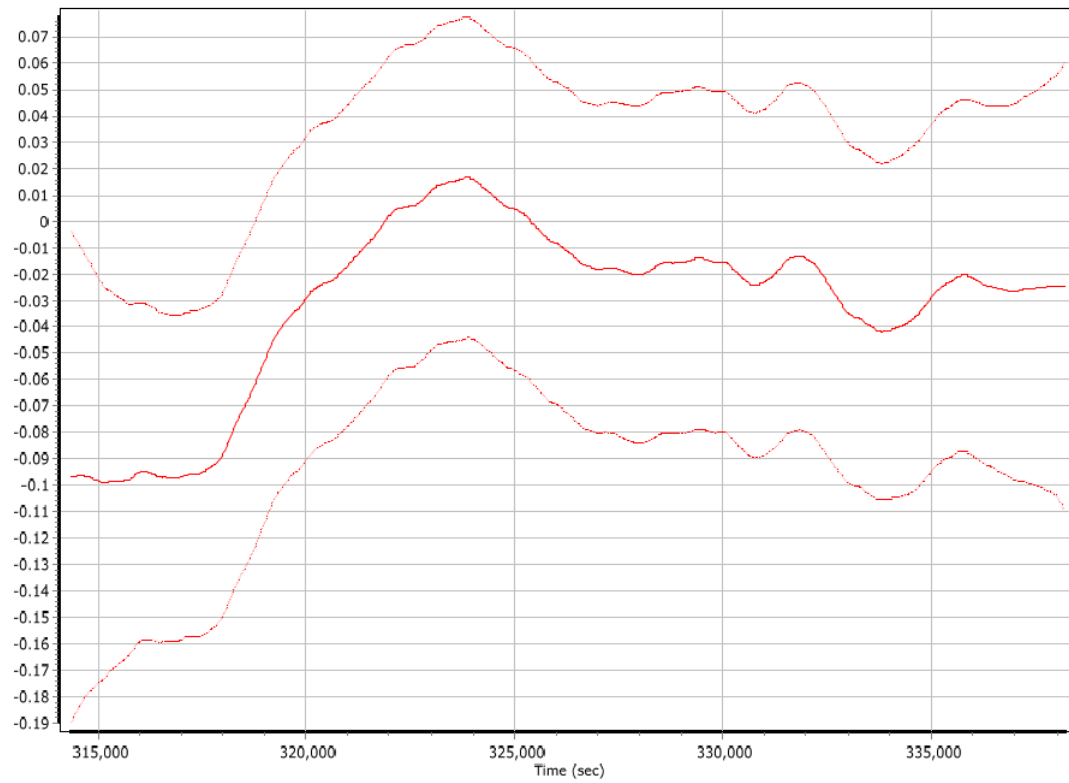
z accelerometer scale error (ppm)



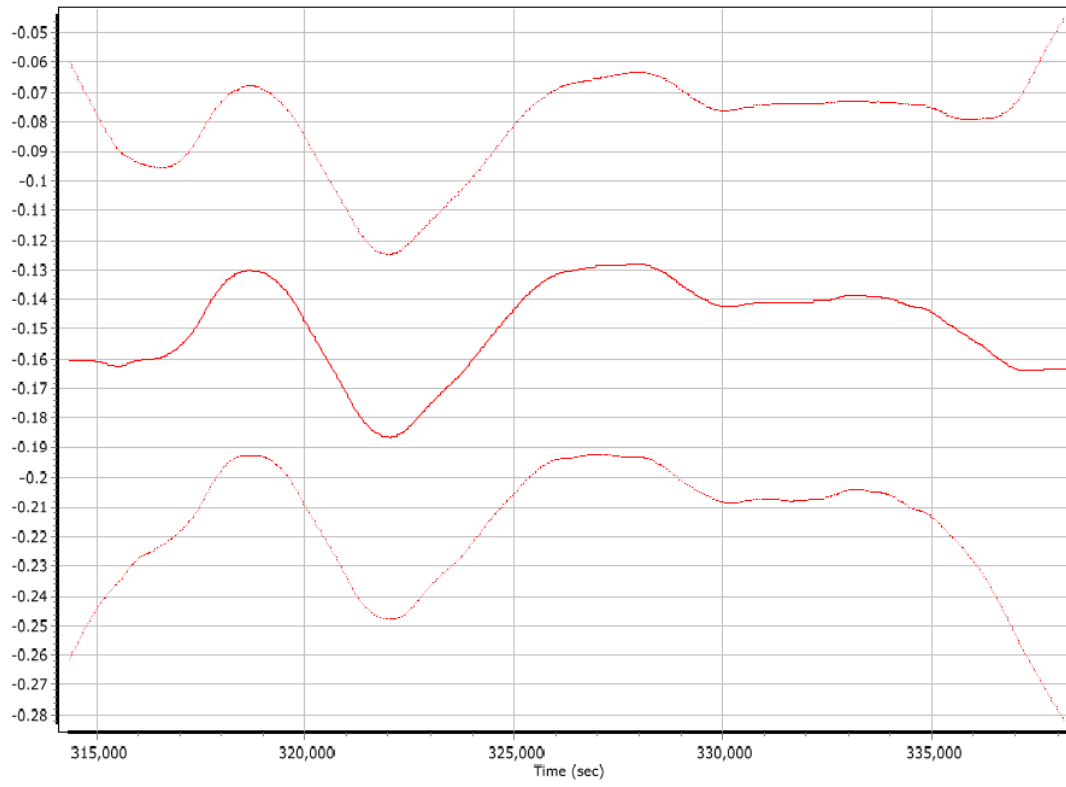
x gyro bias (deg/hr)



y gyro bias (deg/hr)



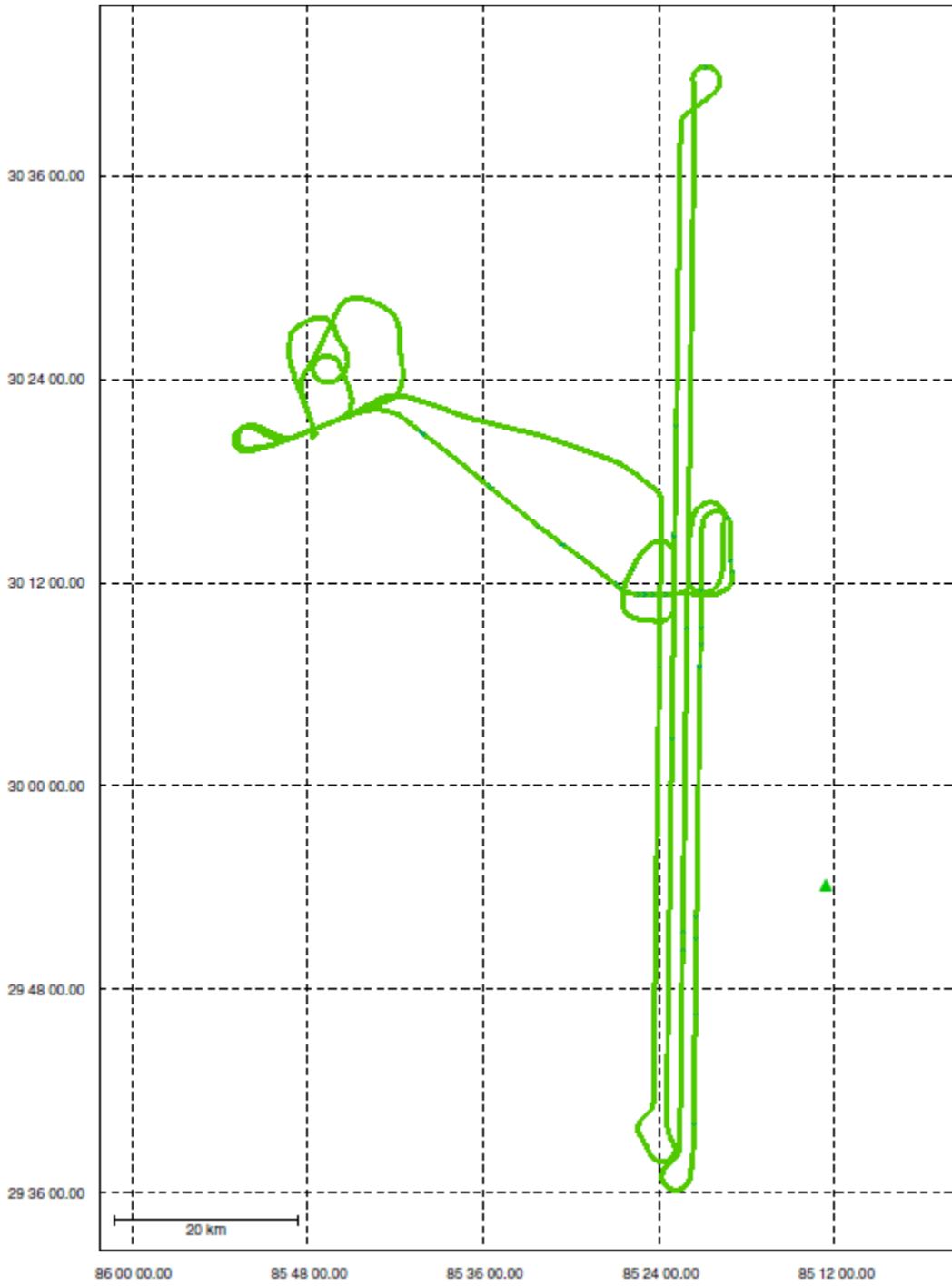
z gyro bias (deg/hr)



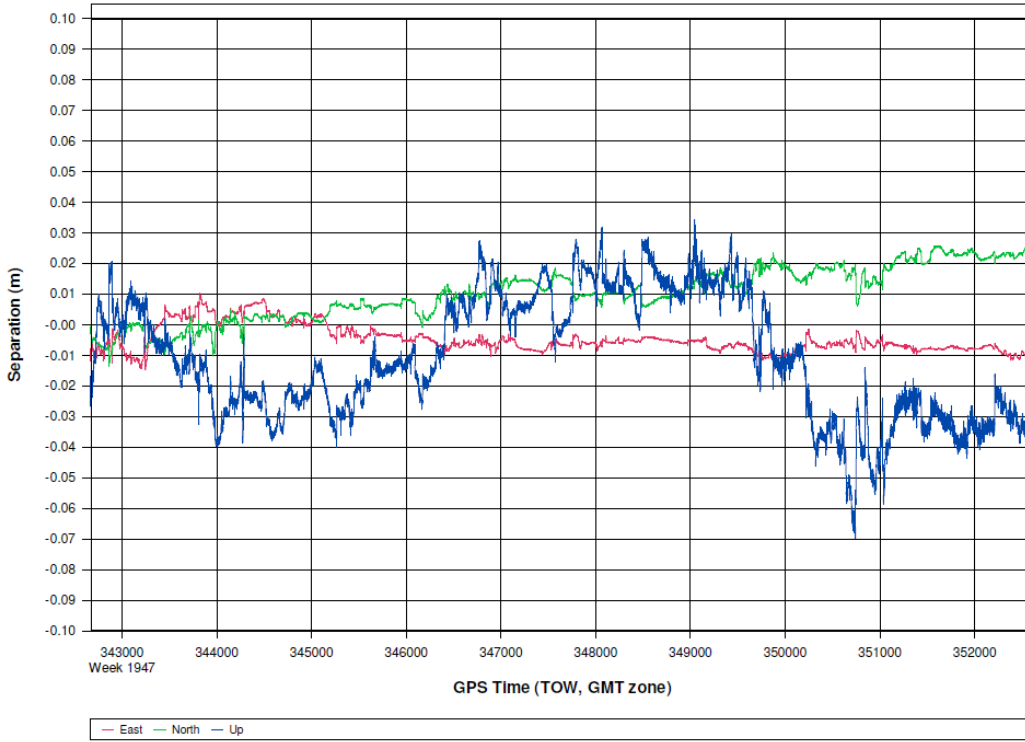
Mission 4 - 5417123b GNSS Processing

Project: 5417123b

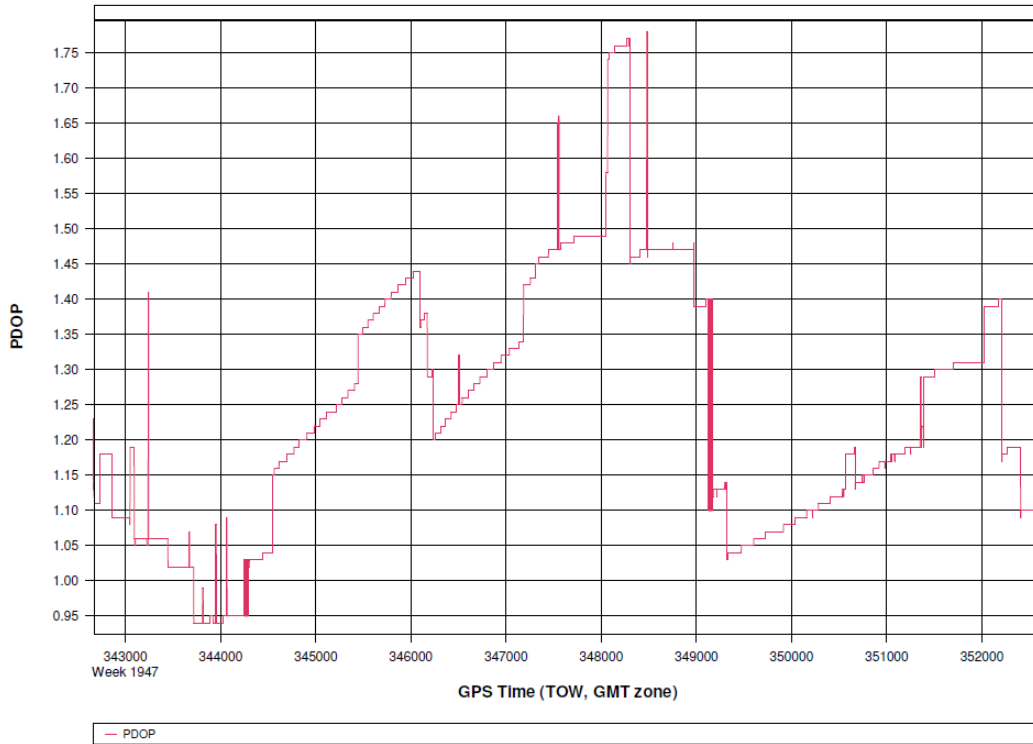
GrafNav v8.50.4320

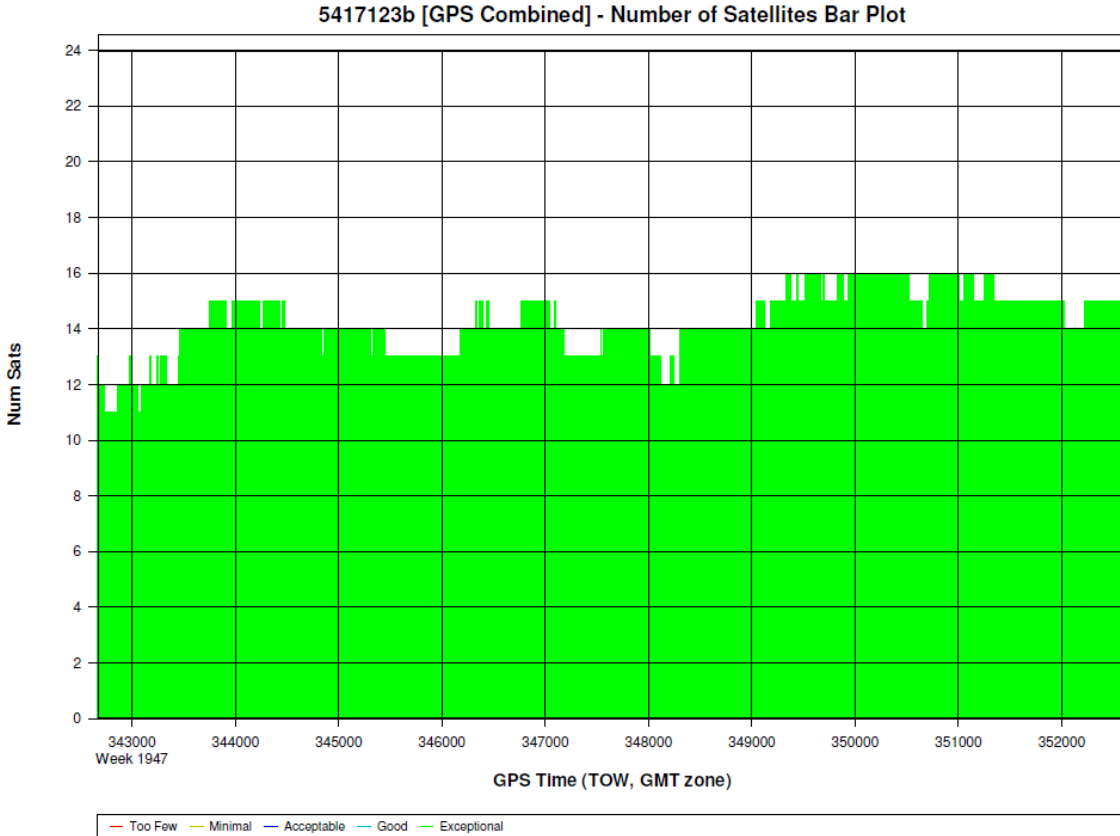


5417123b [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417123b [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417123b\05_INS-GPS_PROC\01_POS\5417123b\5417123b\GNSS\5417123b.gnv

Solution Type: Combined

Number of Epochs:

Total in GPB file:	9977
No processed position:	0
Missing Fwd or Rev:	5
With bad C/A code:	0
With bad L1 Phase:	0

Measurement RMS Values:

L1 Phase:	0.0209 (m)
C/A Code:	1.01 (m)
L1 Doppler:	0.775 (m/s)

Fwd/Rev Separation RMS Values:

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

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

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

Quality Number Percentages:

Q 1: 98.7 %
Q 2: 1.3 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

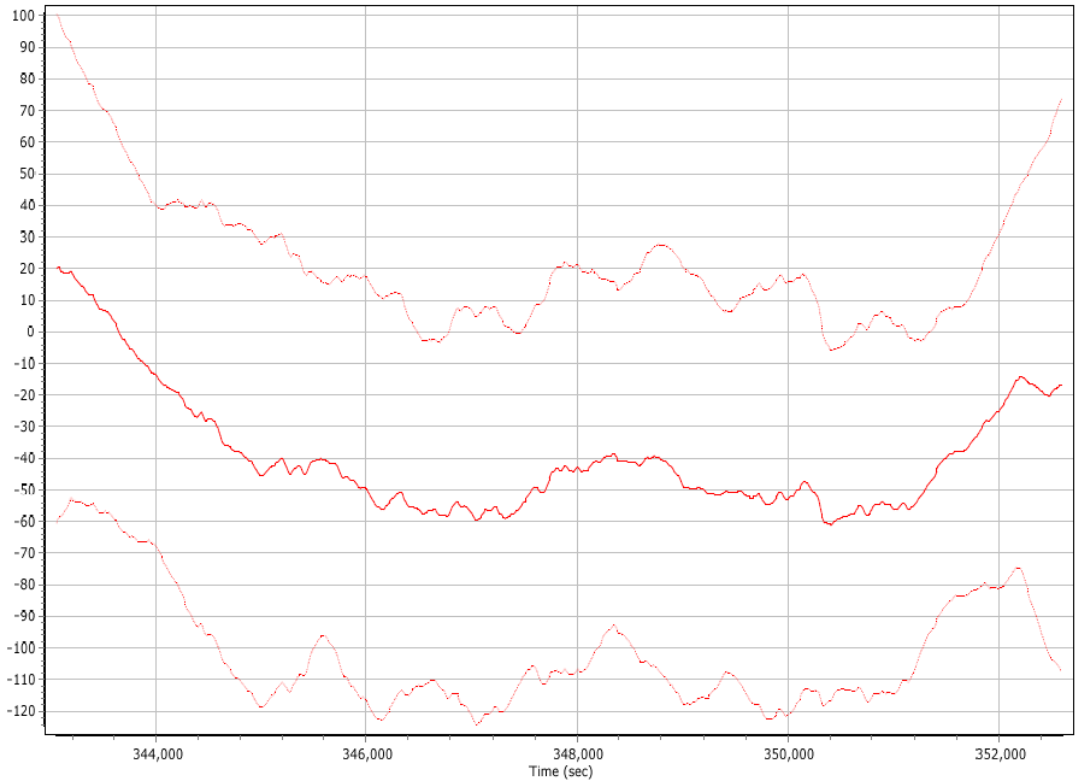
DOP over Tol: 0.0 %

Baseline Distances:

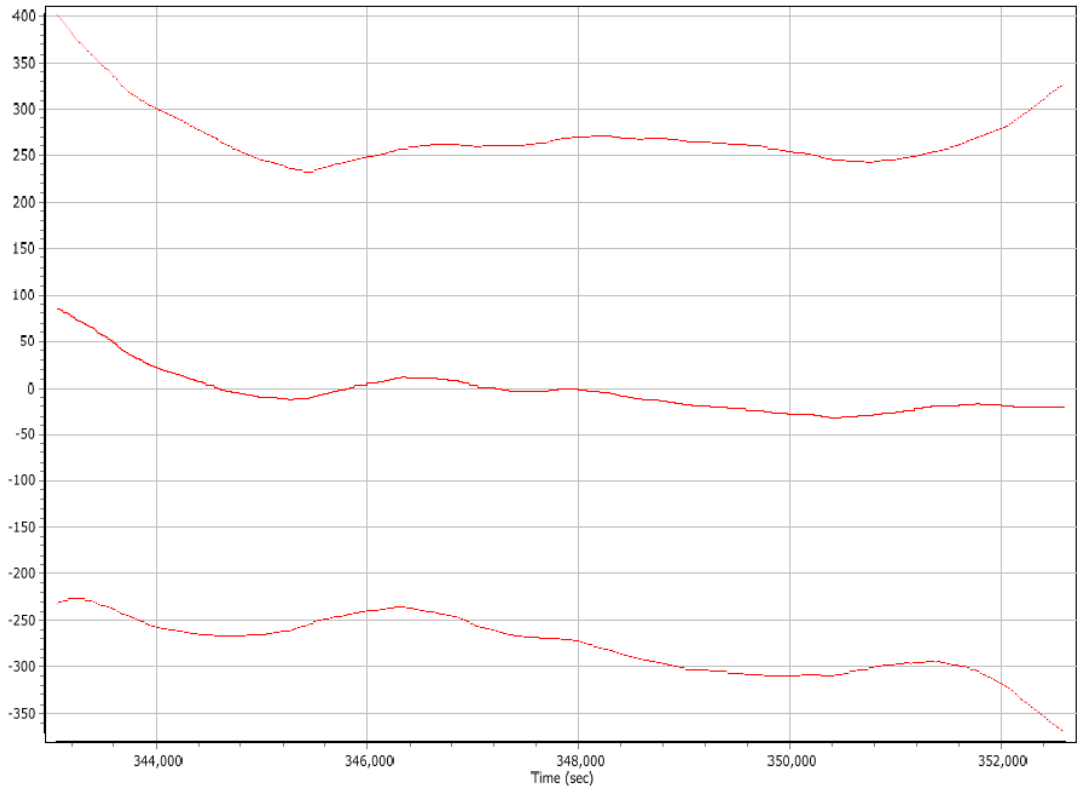
Maximum: 90.847 (km)
Minimum: 2.628 (km)
Average: 33.138 (km)
First Epoch: 15.534 (km)
Last Epoch: 16.451 (km)

Mission 4 - 5417123b Sensor Errors

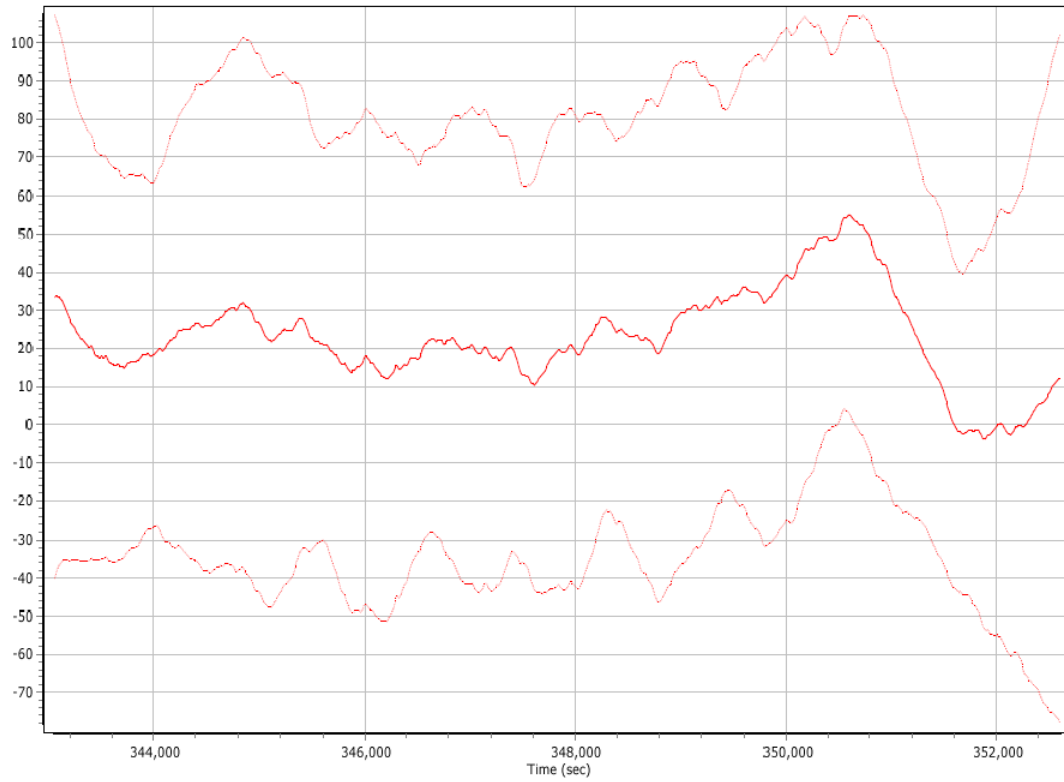
x accelerometer bias (micro-g)



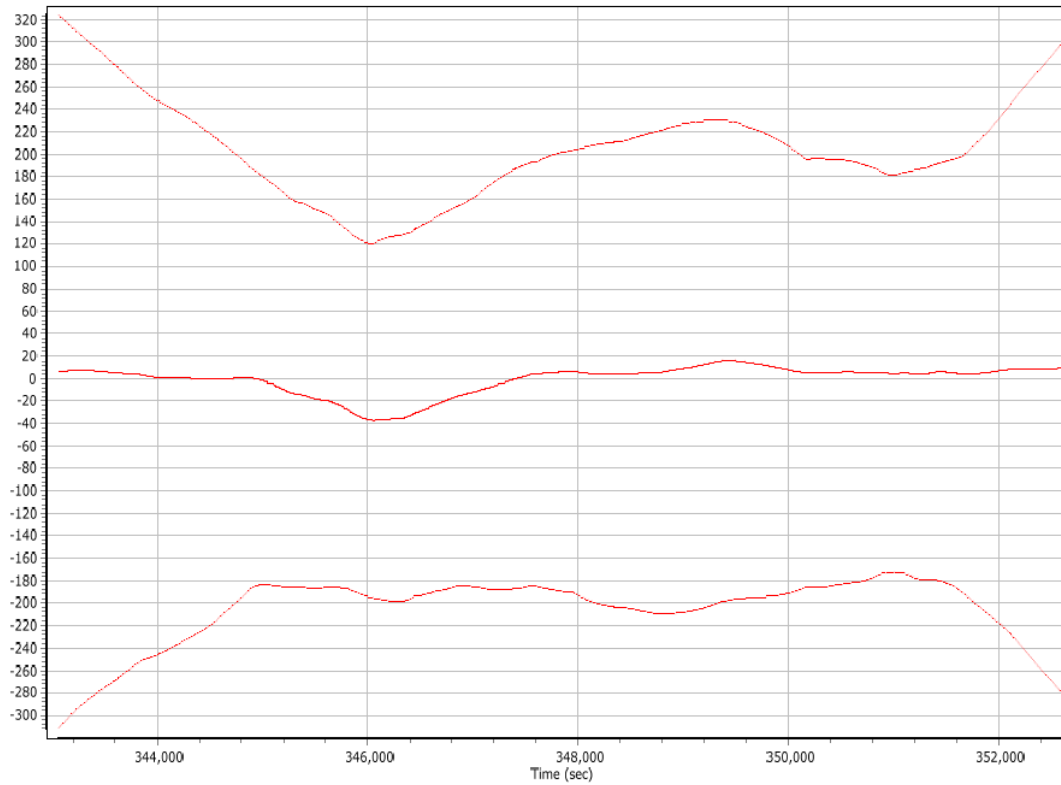
x accelerometer scale error (ppm)



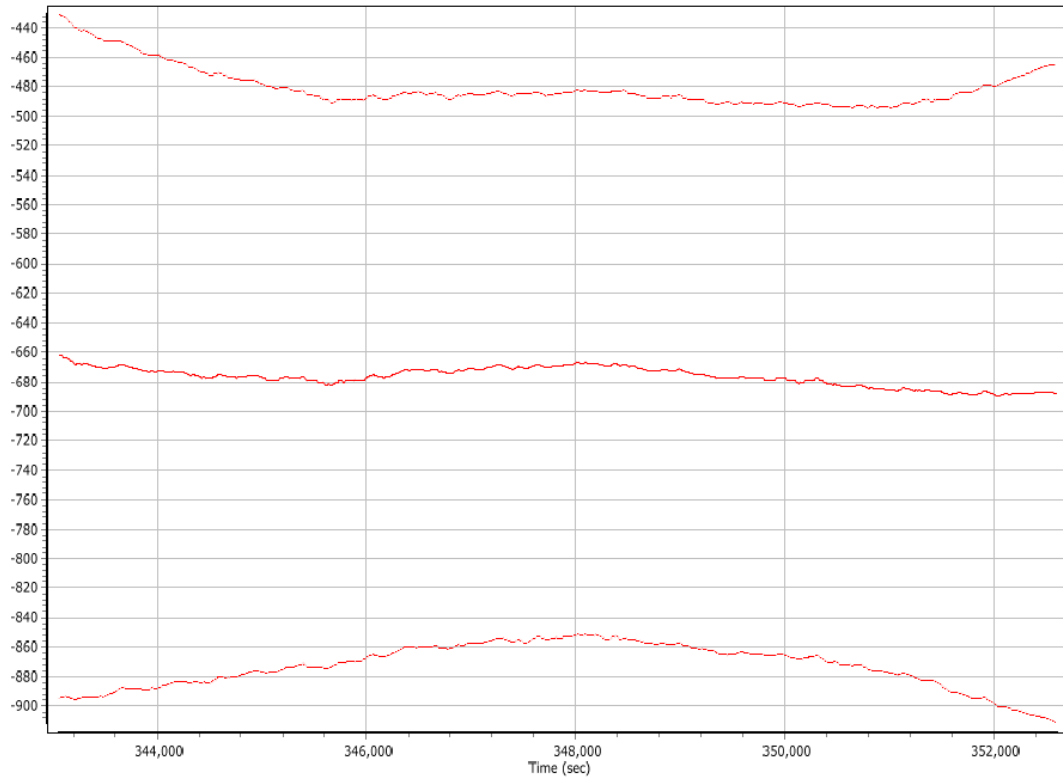
y accelerometer bias (micro-g)



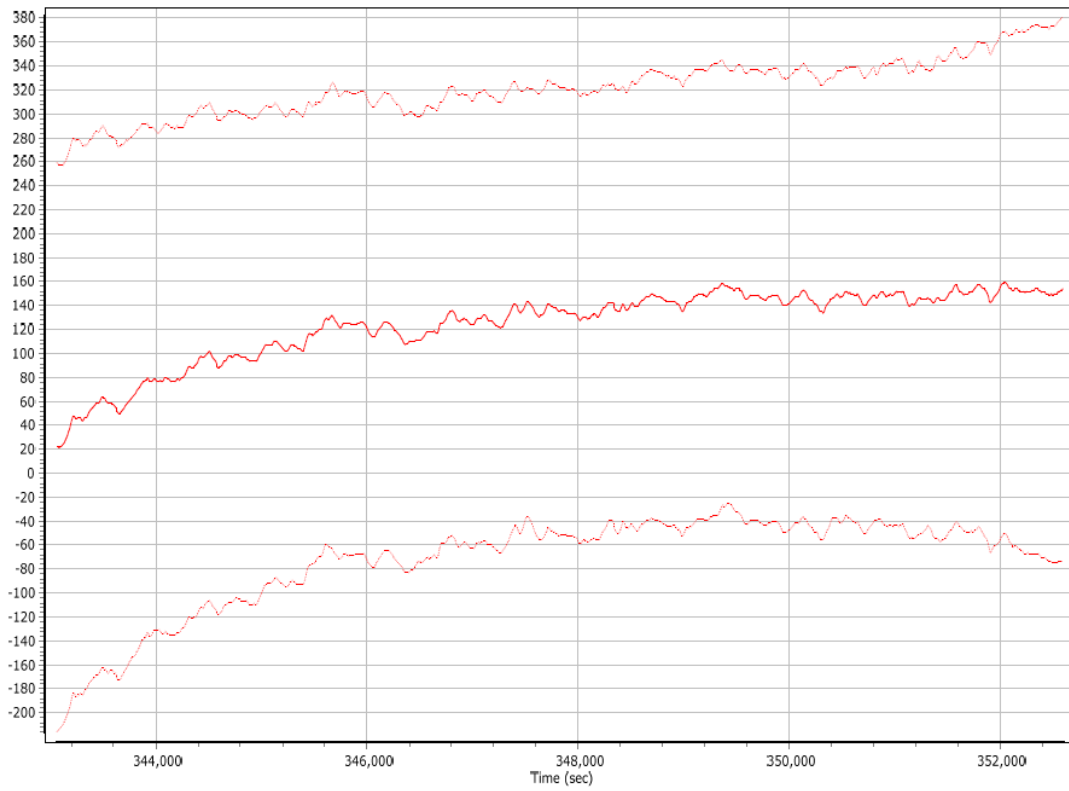
y accelerometer scale error (ppm)



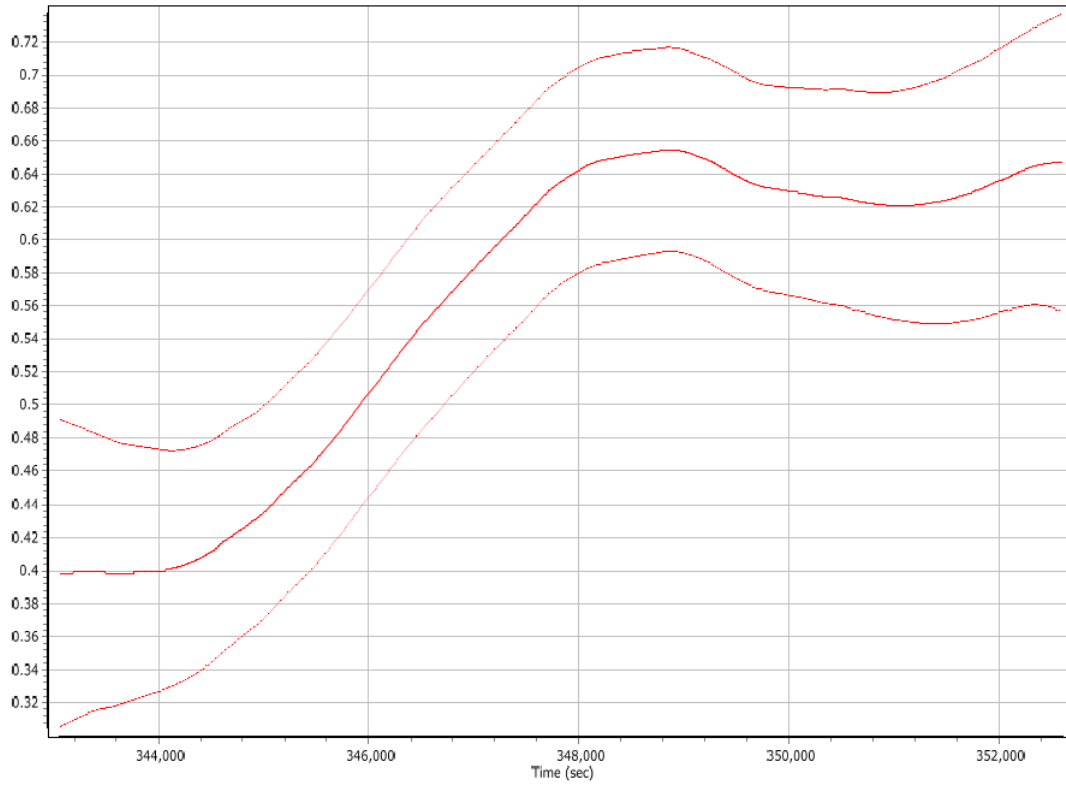
z accelerometer bias (micro-g)



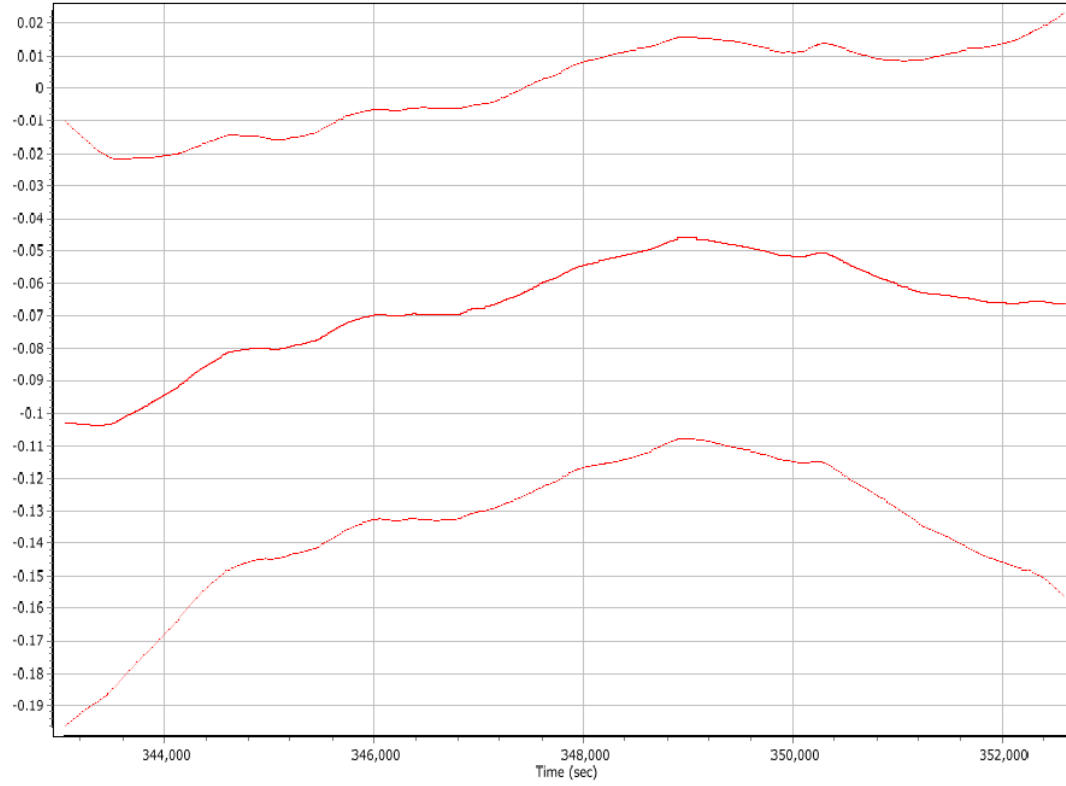
z accelerometer scale error (ppm)



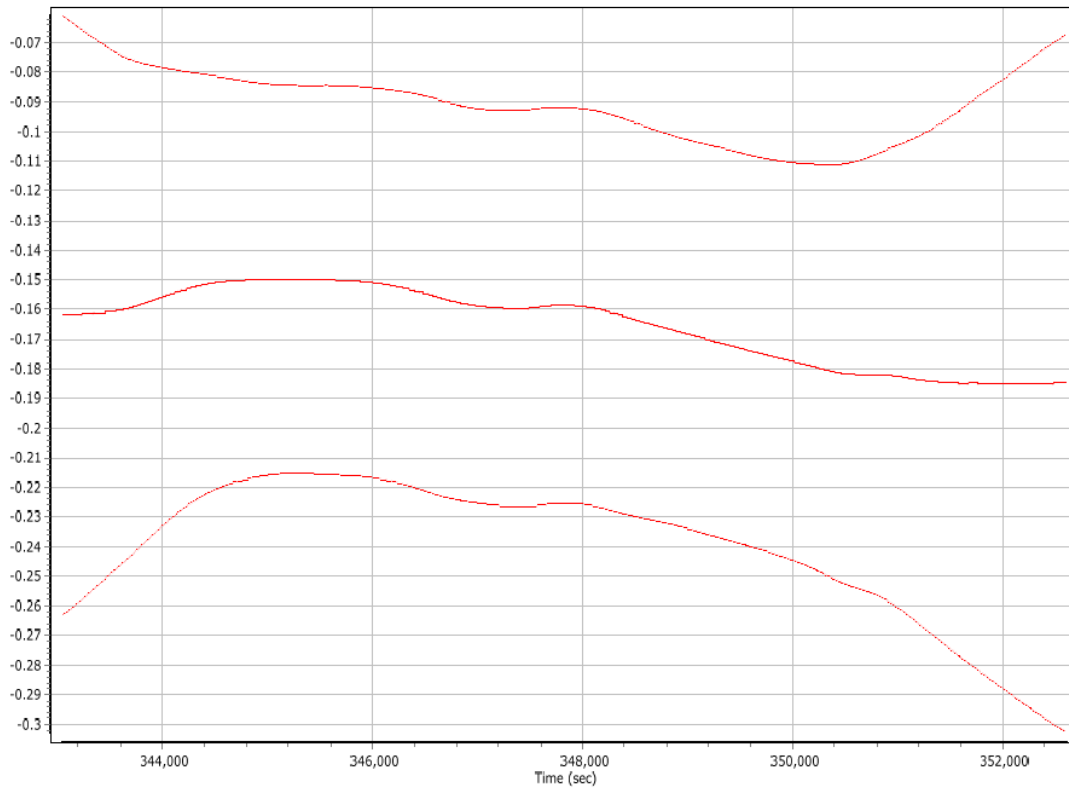
x gyro bias (deg/hr)



y gyro bias (deg/hr)



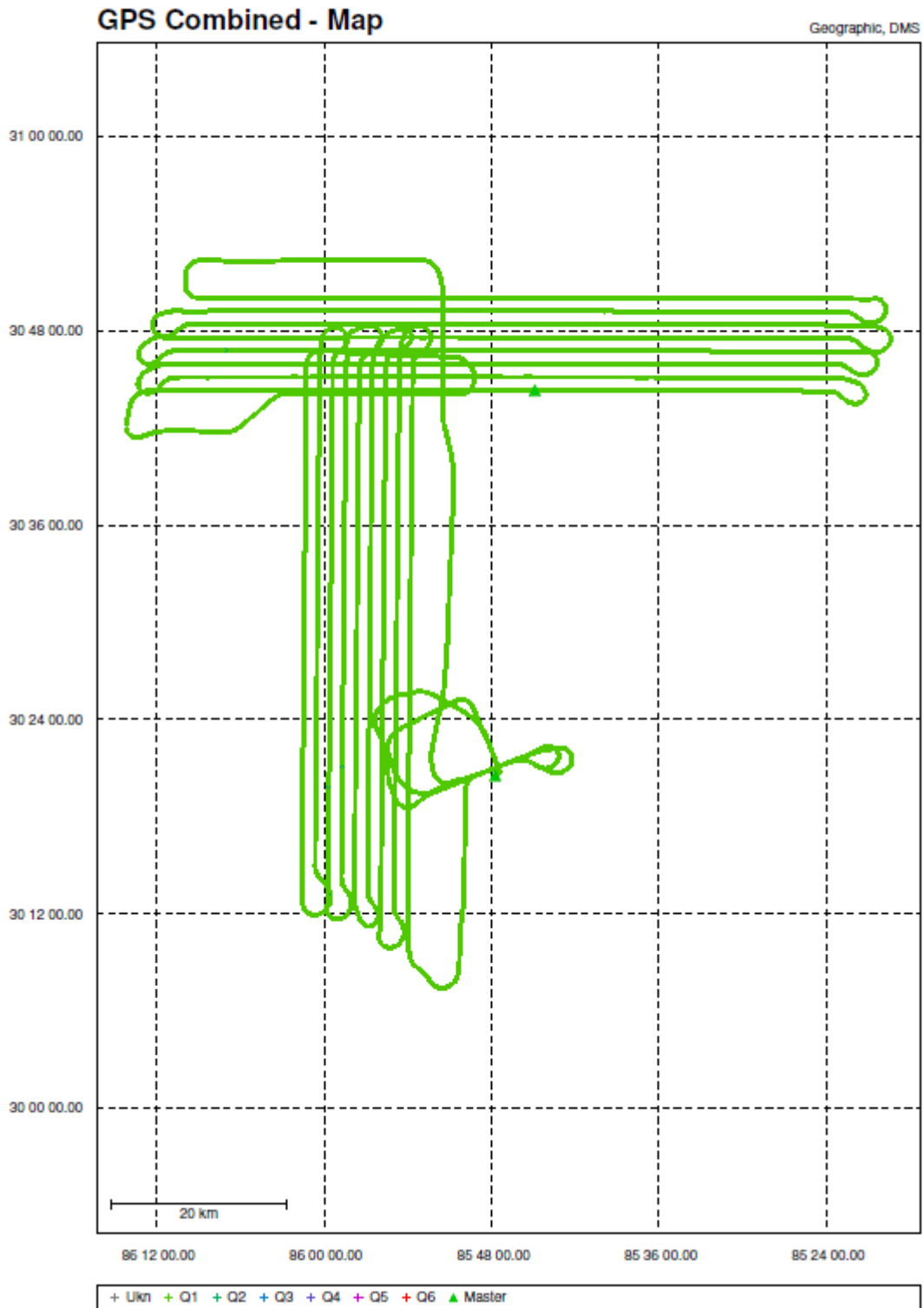
z gyro bias (deg/hr)



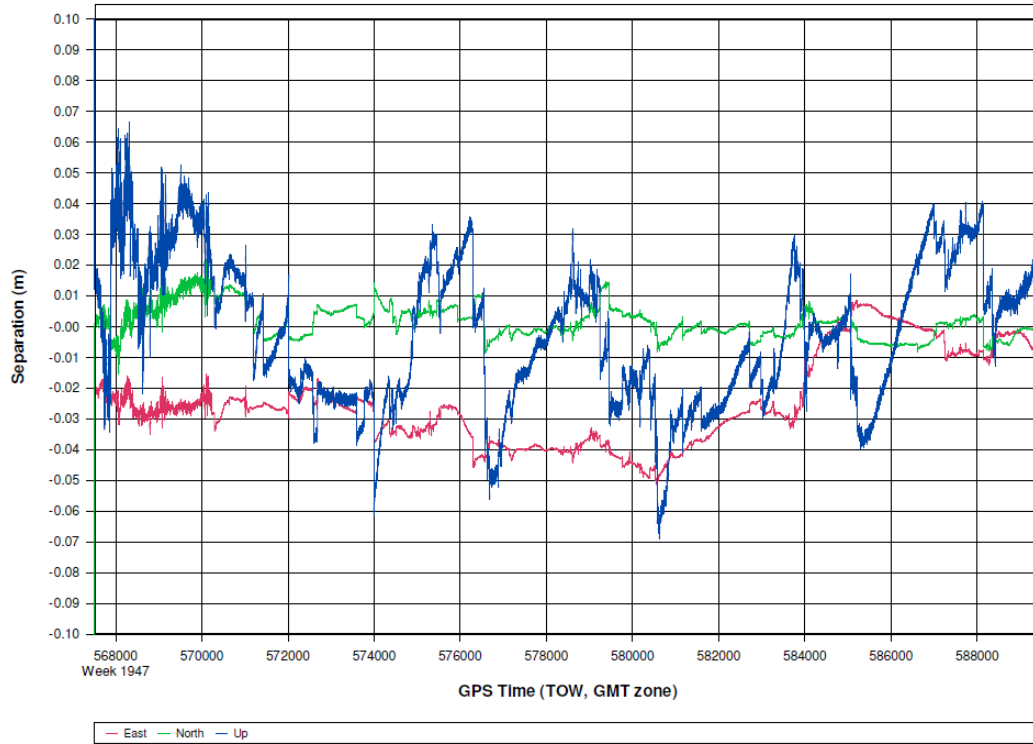
Mission 5 - 5417126a GNSS Processing

Project: 5417126a

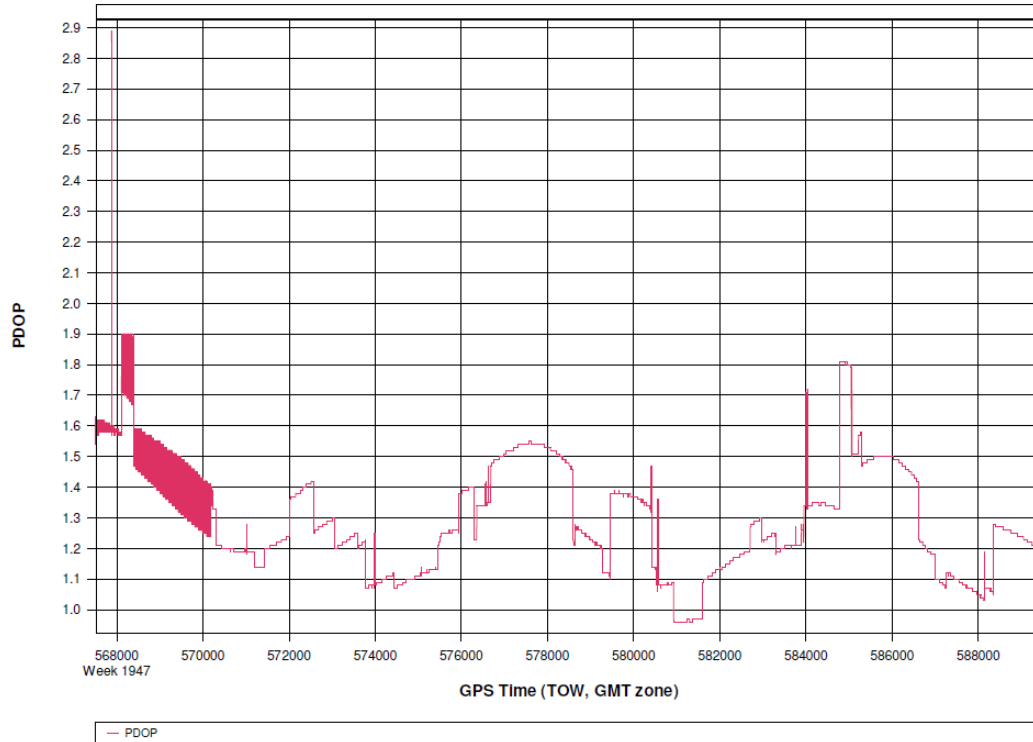
GrafNav v8.50.4320

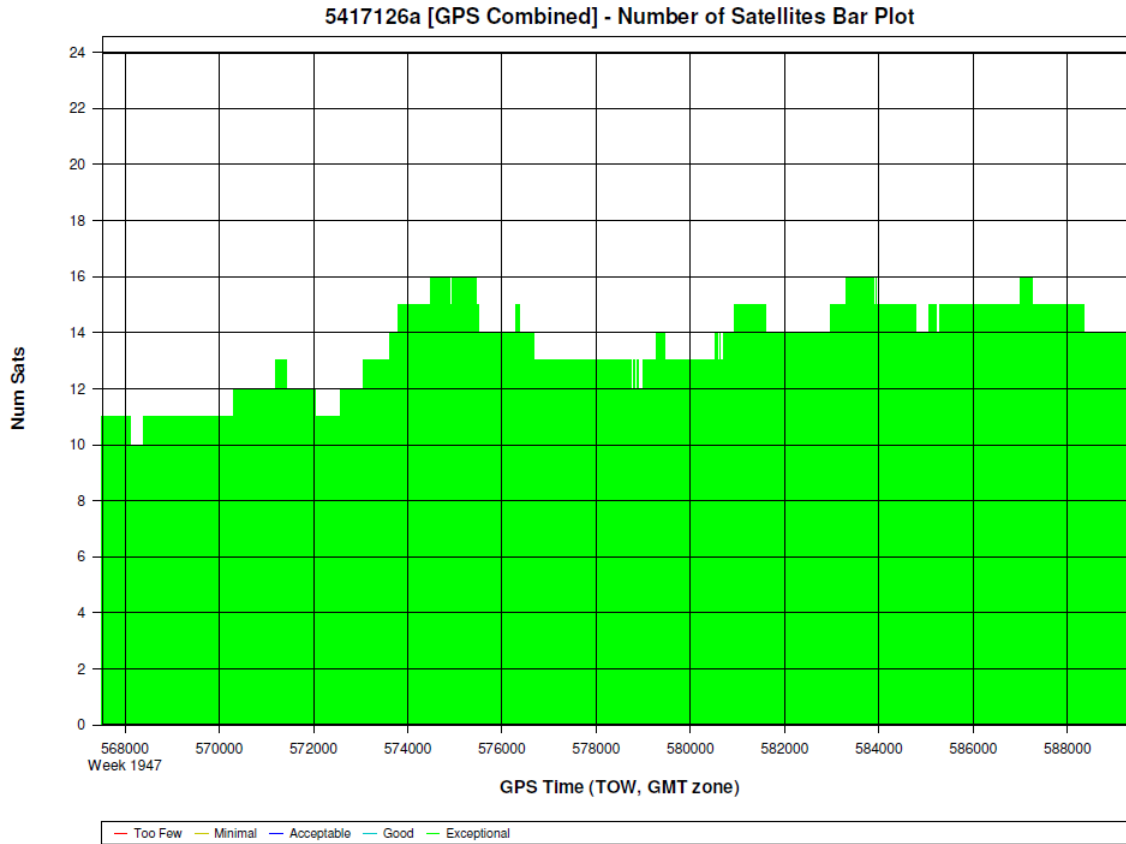


5417126a [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417126a [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

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

Solution Type: Combined

Number of Epochs:

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

Measurement RMS Values:

L1 Phase:	0.0209 (m)
C/A Code:	0.77 (m)
L1 Doppler:	0.782 (m/s)

Fwd/Rev Separation RMS Values:

East: 0.028 (m)
North: 0.006 (m)
Height: 0.024 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (21995 occurrences):

East: 0.028 (m)
North: 0.006 (m)
Height: 0.023 (m)

Quality Number Percentages:

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

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

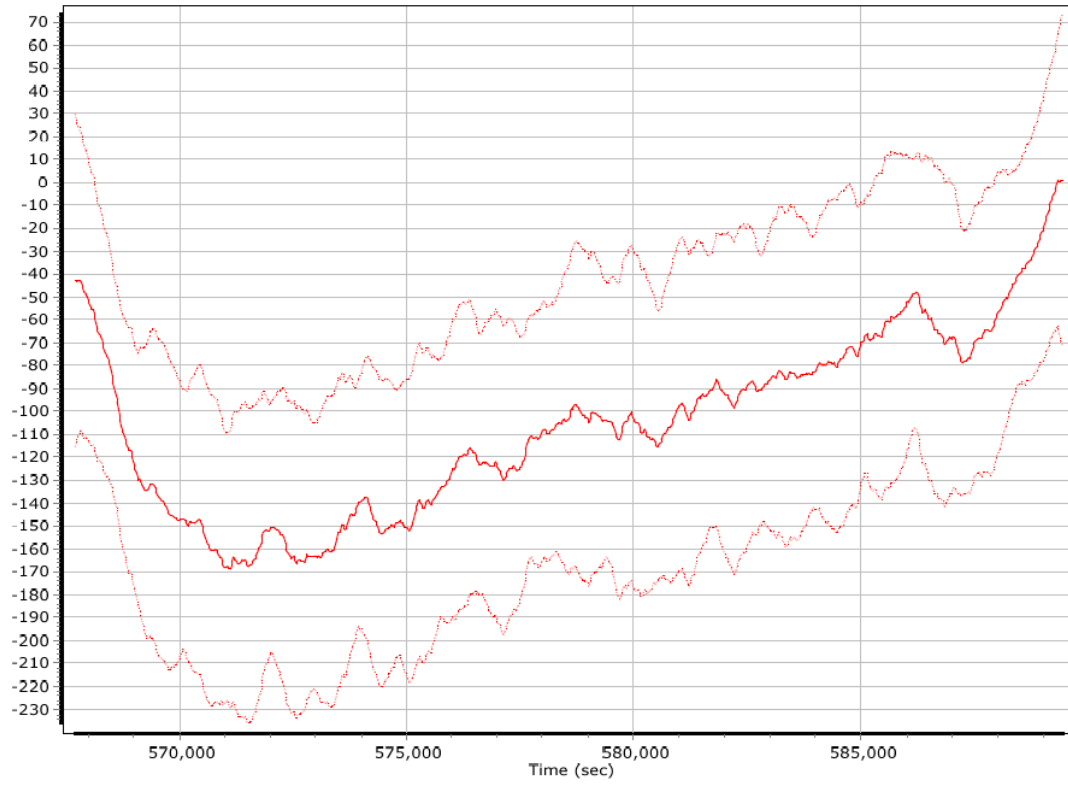
DOP over Tol: 0.0 %

Baseline Distances:

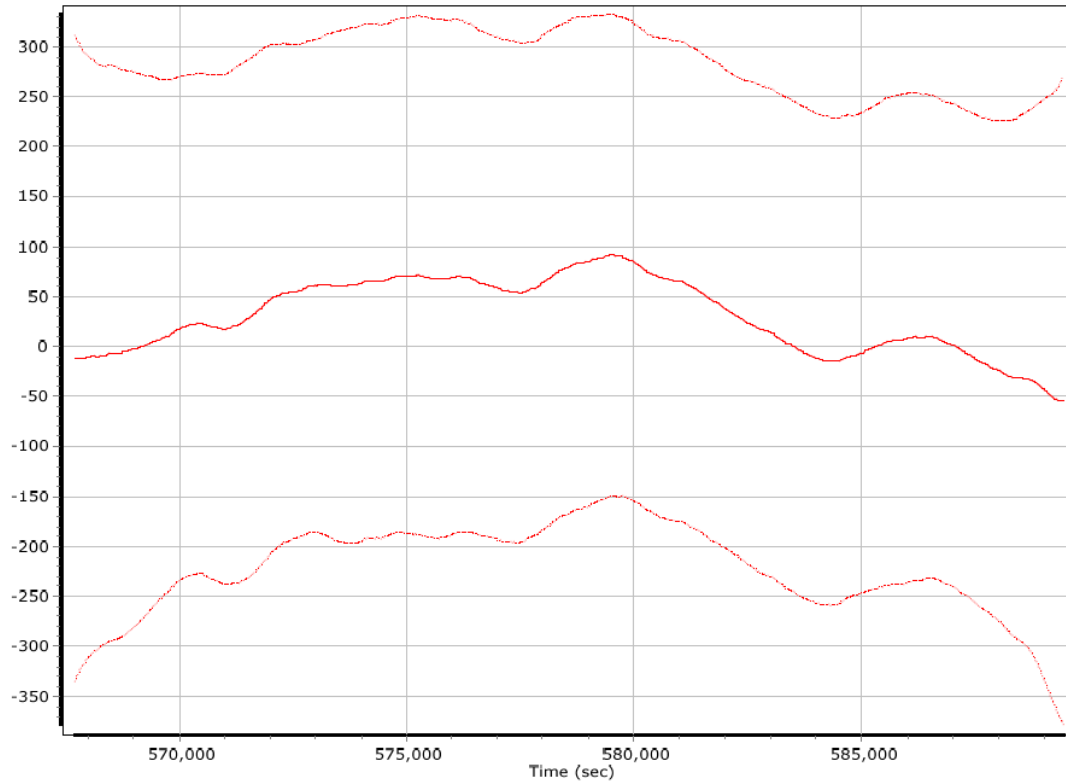
Maximum: 52.944 (km)
Minimum: 7.649 (km)
Average: 30.511 (km)
First Epoch: 22.009 (km)
Last Epoch: 21.782 (km)

Mission 5 - 5417126a Sensor Errors

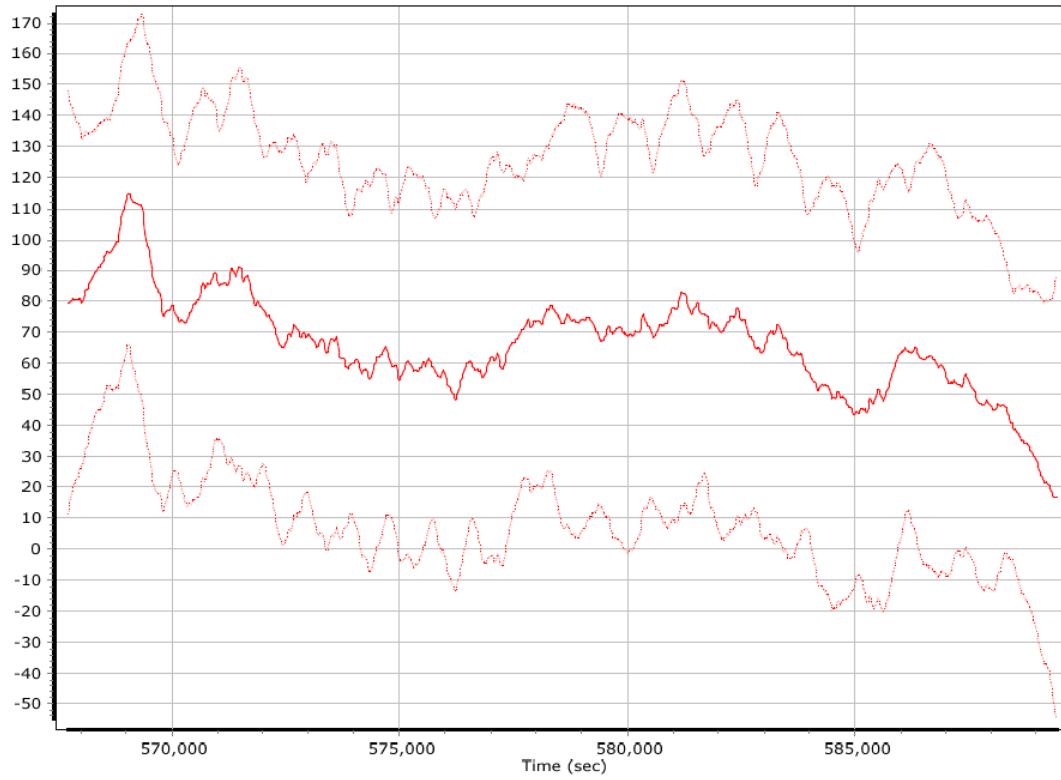
x accelerometer bias (micro-g)



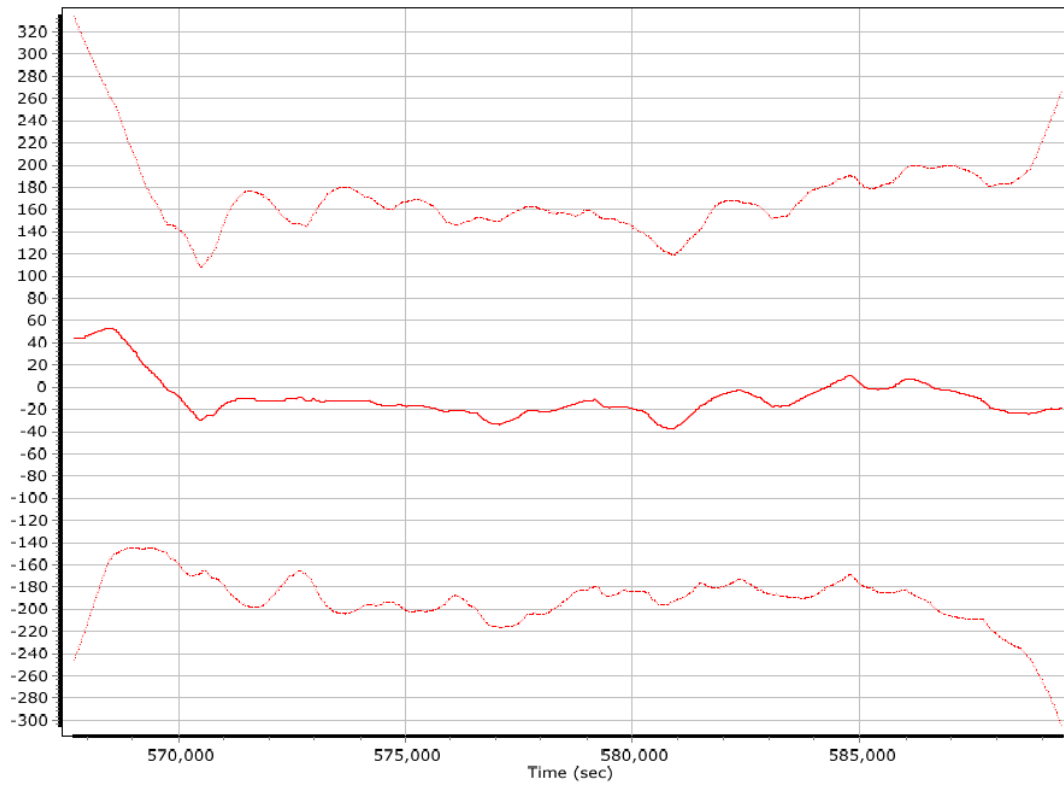
x accelerometer scale error (ppm)



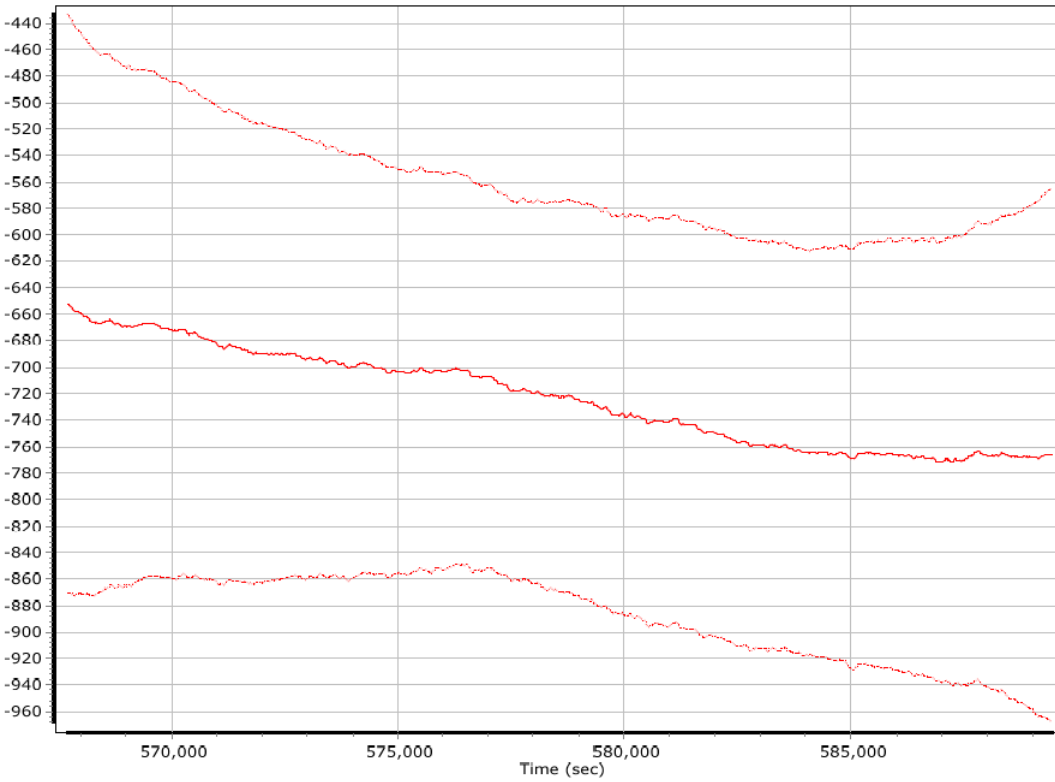
y accelerometer bias (micro-g)



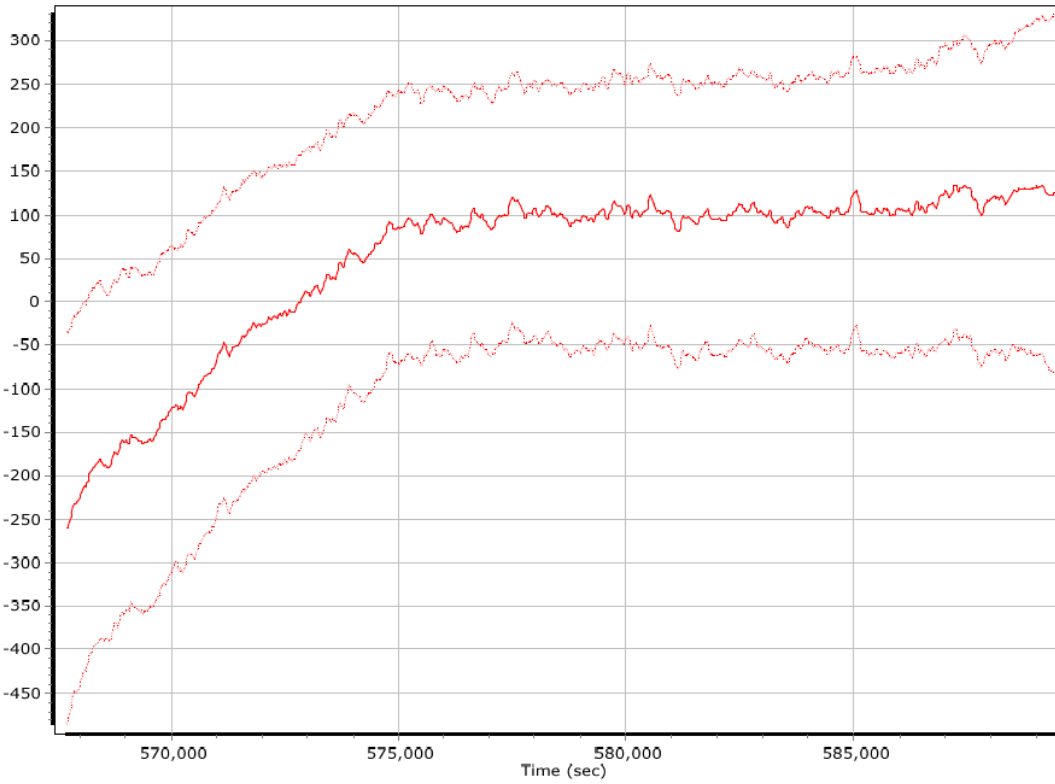
y accelerometer scale error (ppm)



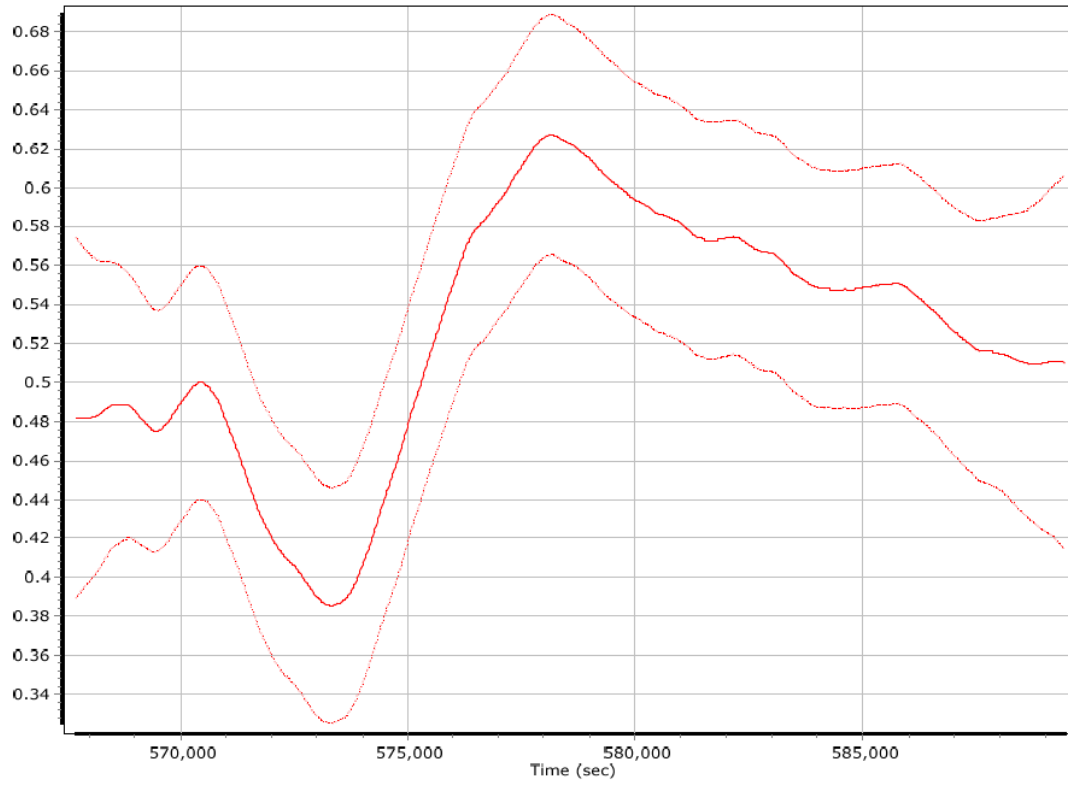
z accelerometer bias (micro-g)



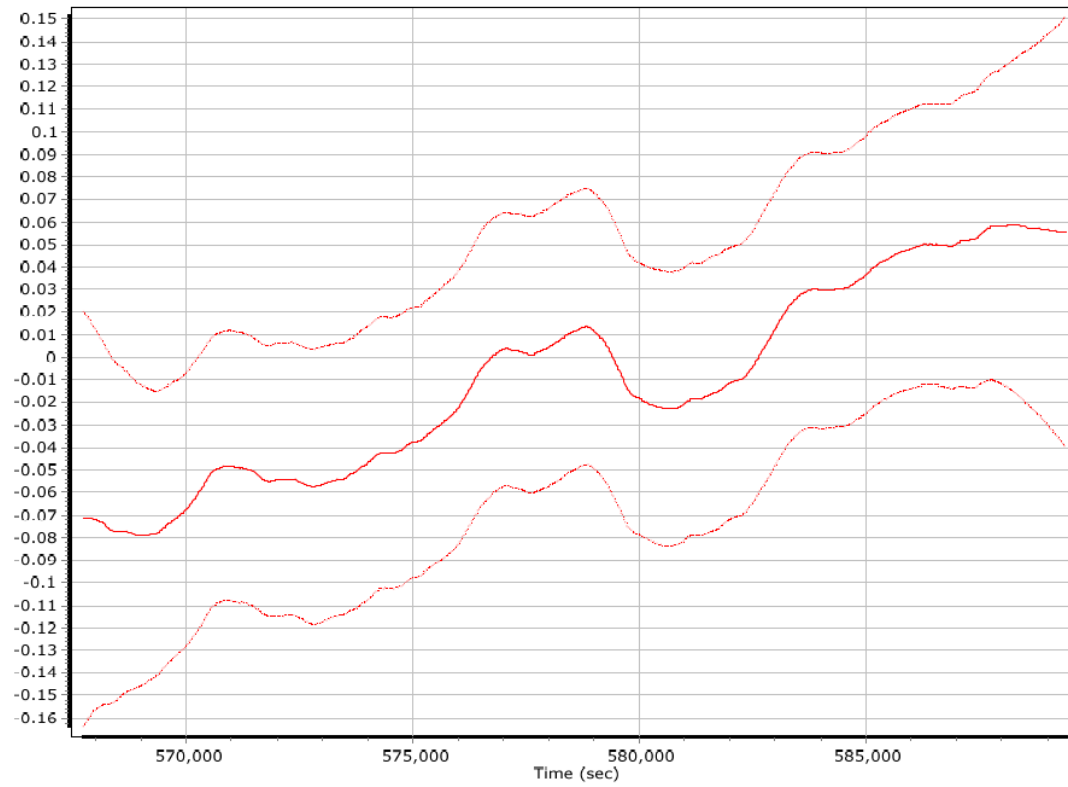
z accelerometer scale error (ppm)



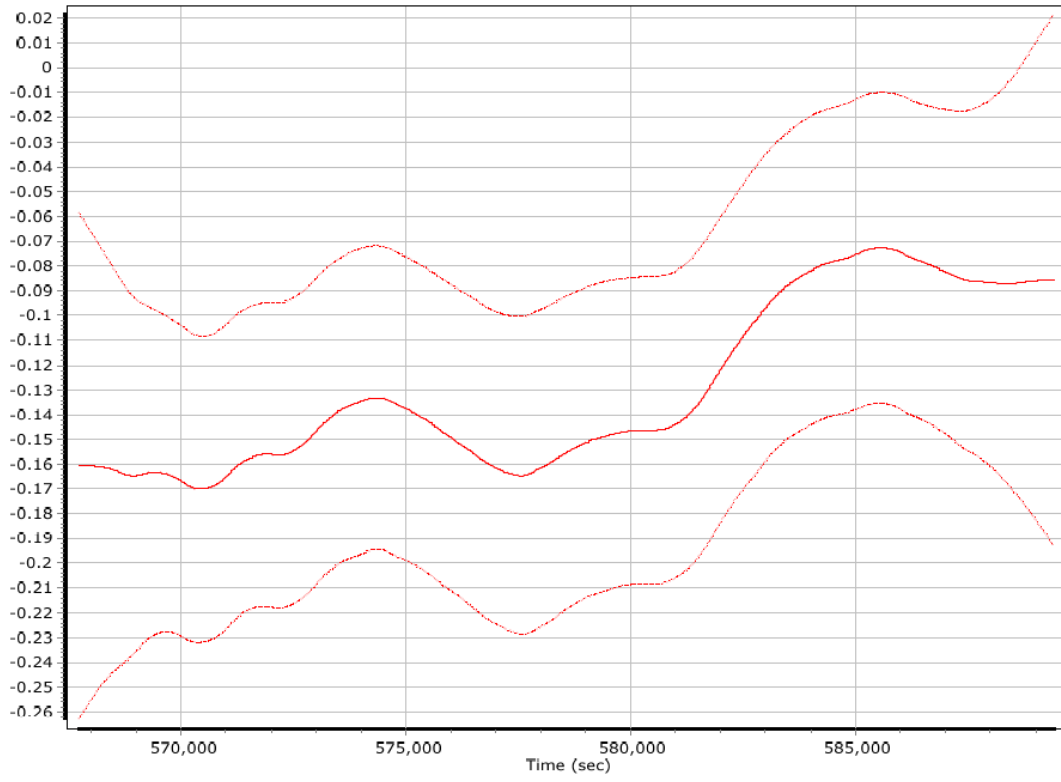
x gyro bias (deg/hr)



y gyro bias (deg/hr)



z gyro bias (deg/hr)



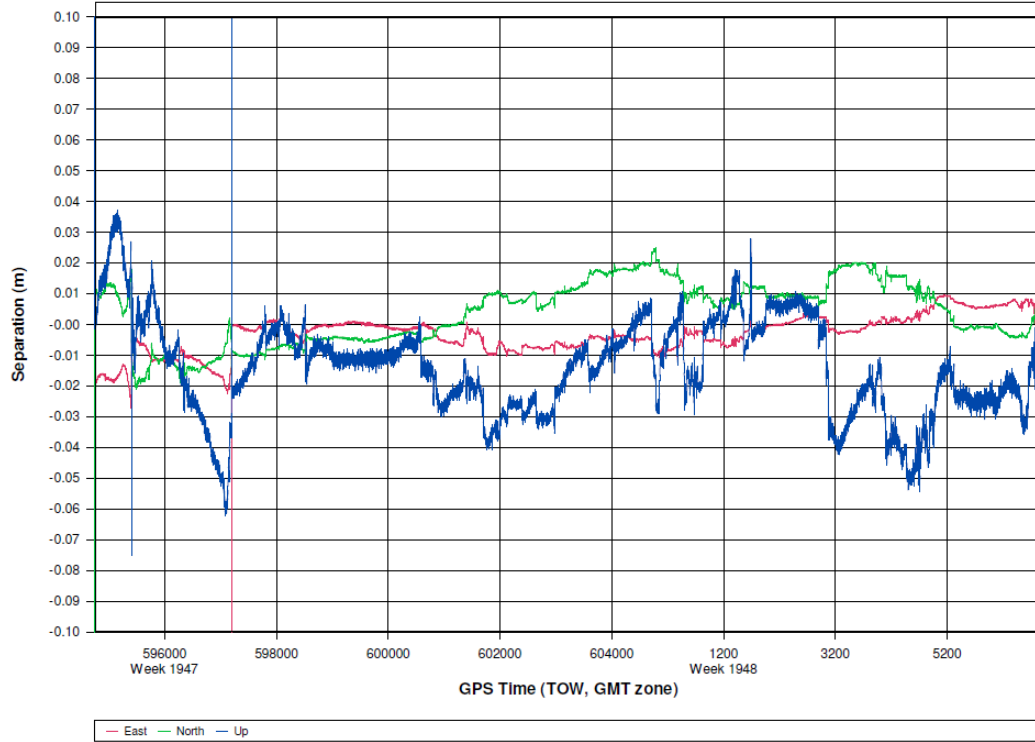
Mission 6 – 5417126b GNSS Processing

Project: 5417126b

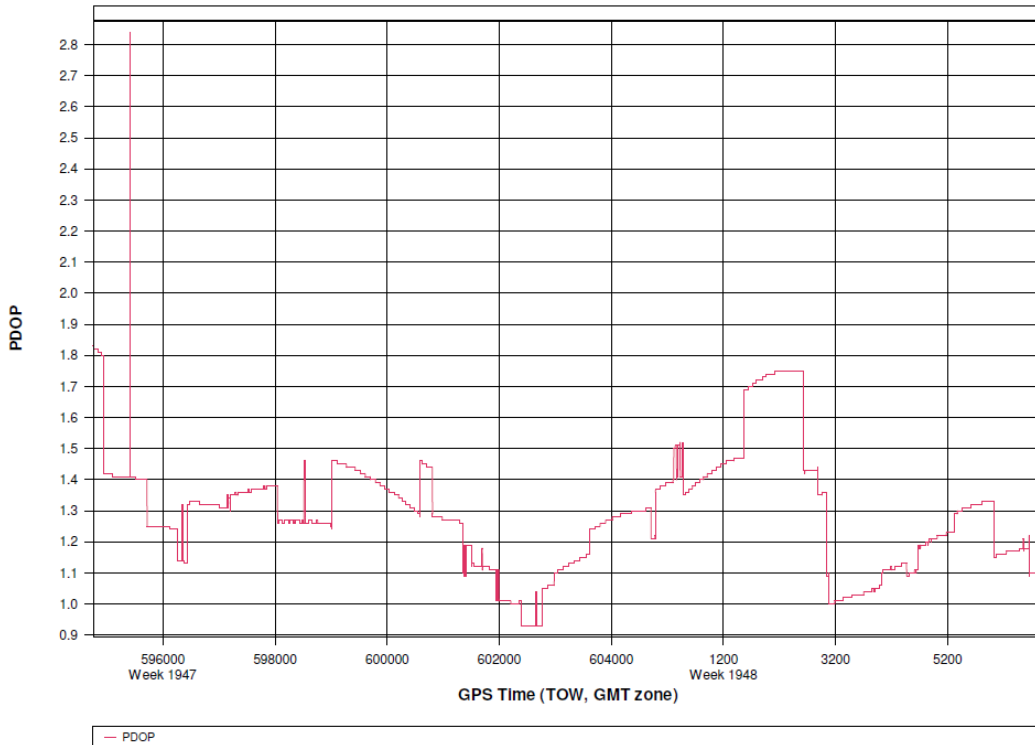
GrafNav v8.50.4320

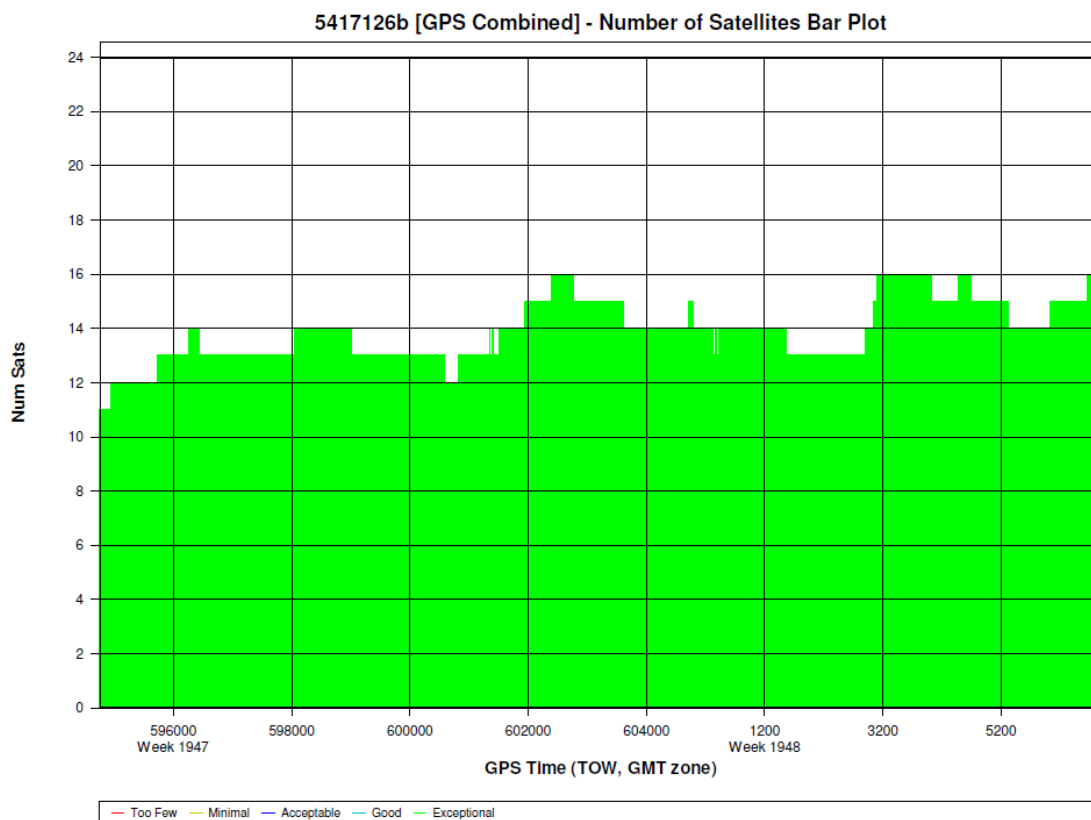


5417126b [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417126b [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

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

Solution Type: Combined

Number of Epochs:

Total in GPB file:	16973
No processed position:	0
Missing Fwd or Rev:	8
With bad C/A code:	0
With bad L1 Phase:	0

Measurement RMS Values:

L1 Phase:	0.0176 (m)
C/A Code:	0.85 (m)
L1 Doppler:	0.793 (m/s)

Fwd/Rev Separation RMS Values:

East: 0.007 (m)
North: 0.011 (m)
Height: 0.028 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (16963 occurrences):

East: 0.007 (m)
North: 0.011 (m)
Height: 0.021 (m)

Quality Number Percentages:

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

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

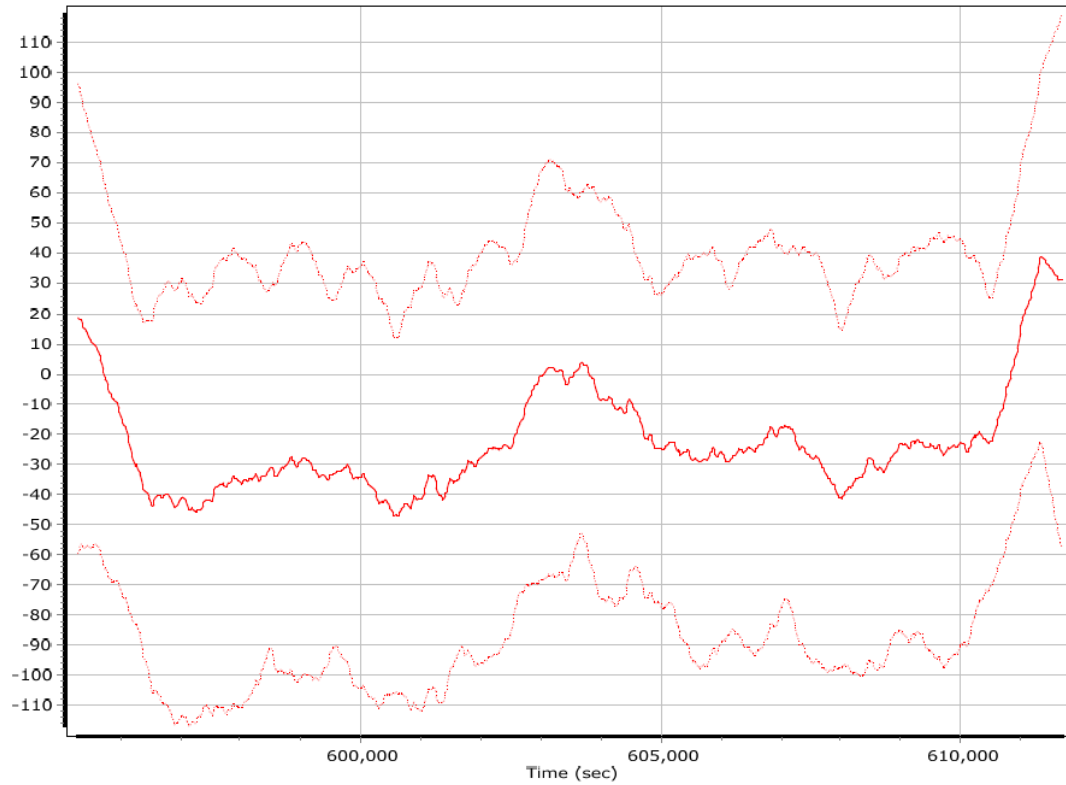
DOP over Tol: 0.0 %

Baseline Distances:

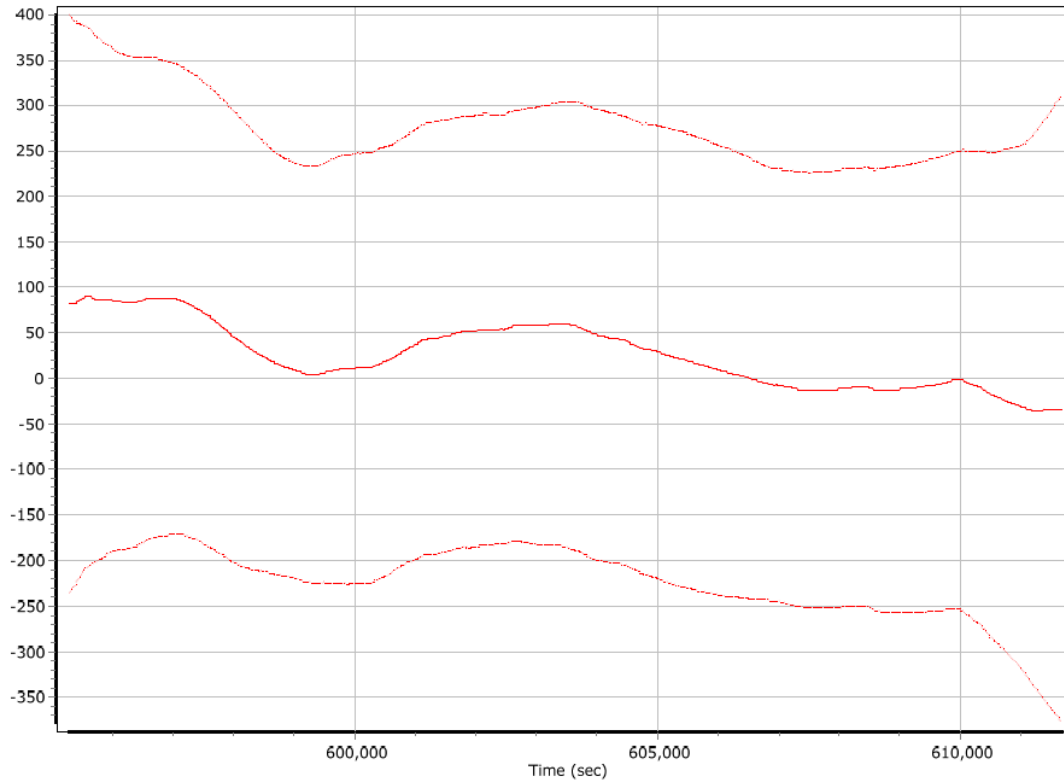
Maximum: 63.937 (km)
Minimum: 6.050 (km)
Average: 40.406 (km)
First Epoch: 21.791 (km)
Last Epoch: 21.785 (km)

Mission 6 - 5417126b Sensor Errors

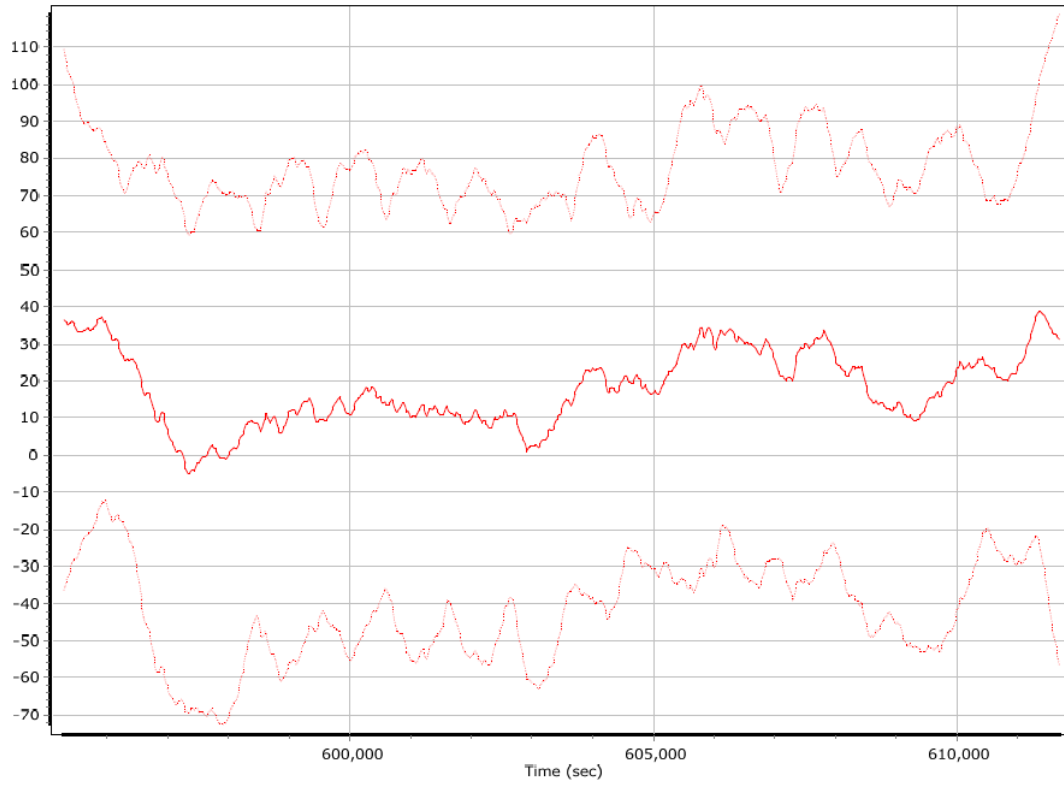
x accelerometer bias (micro-g)



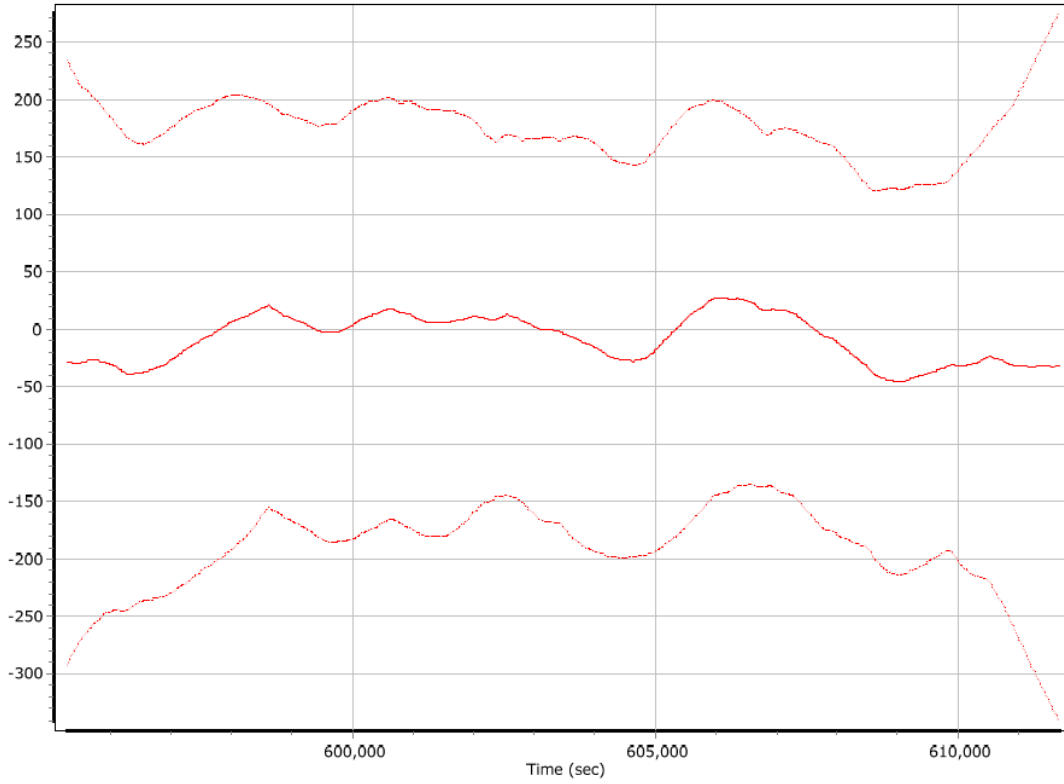
x accelerometer scale error (ppm)



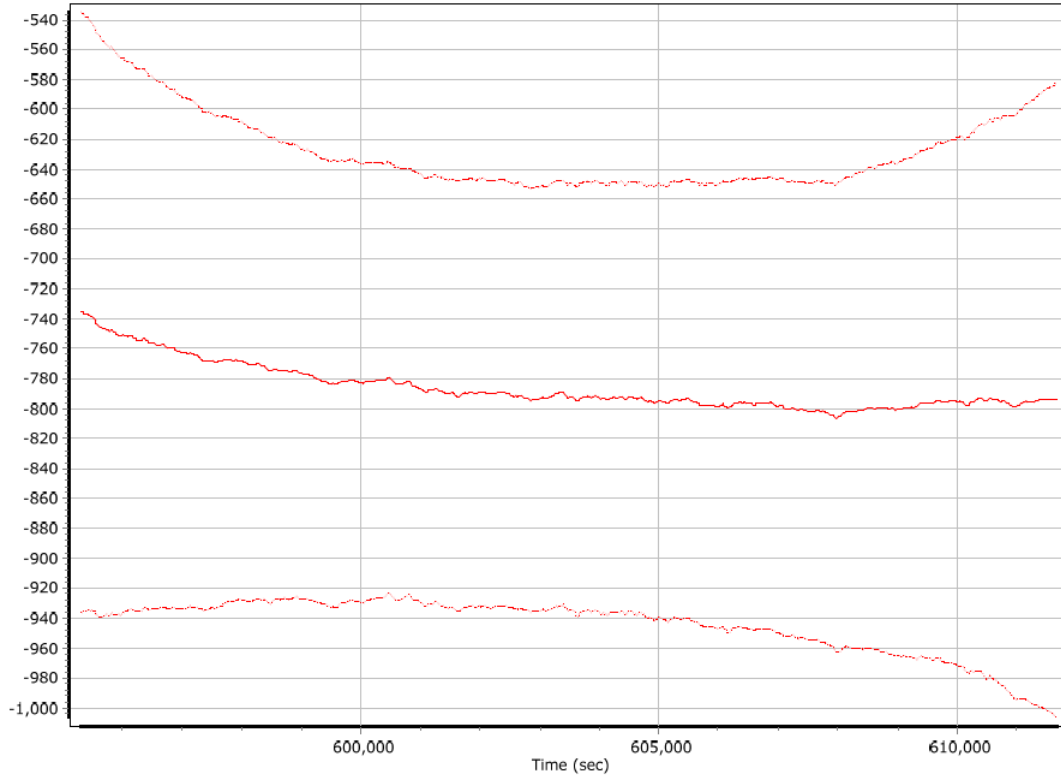
y accelerometer bias (micro-g)



y accelerometer scale error (ppm)



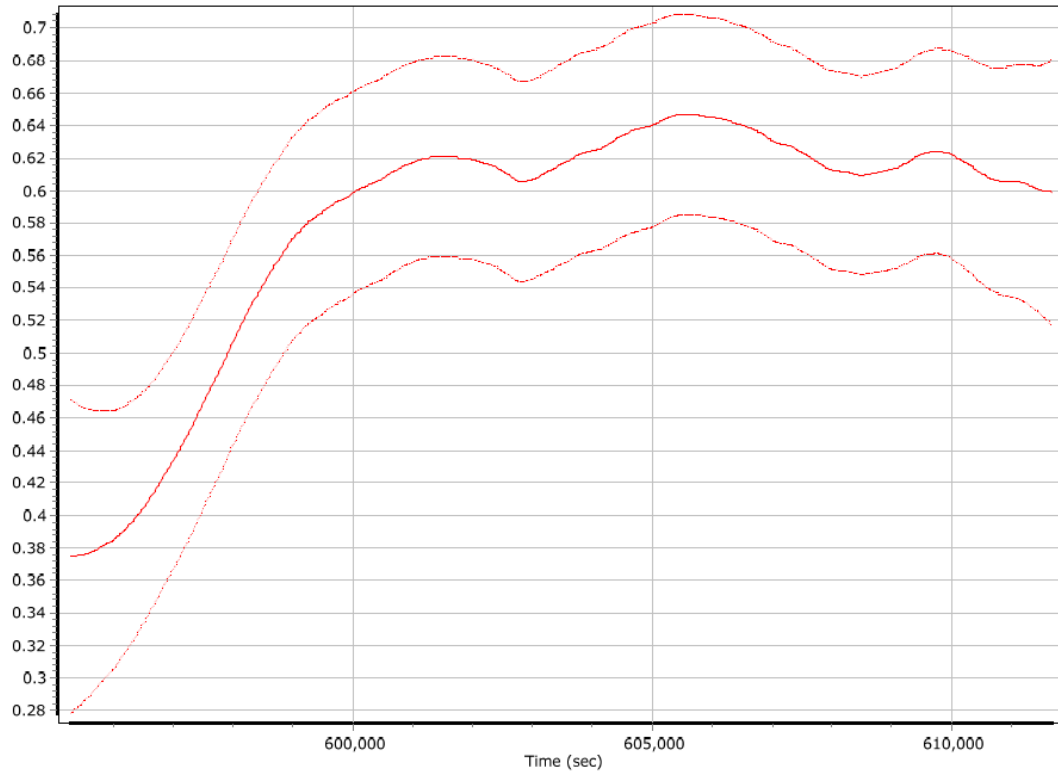
z accelerometer bias (micro-g)



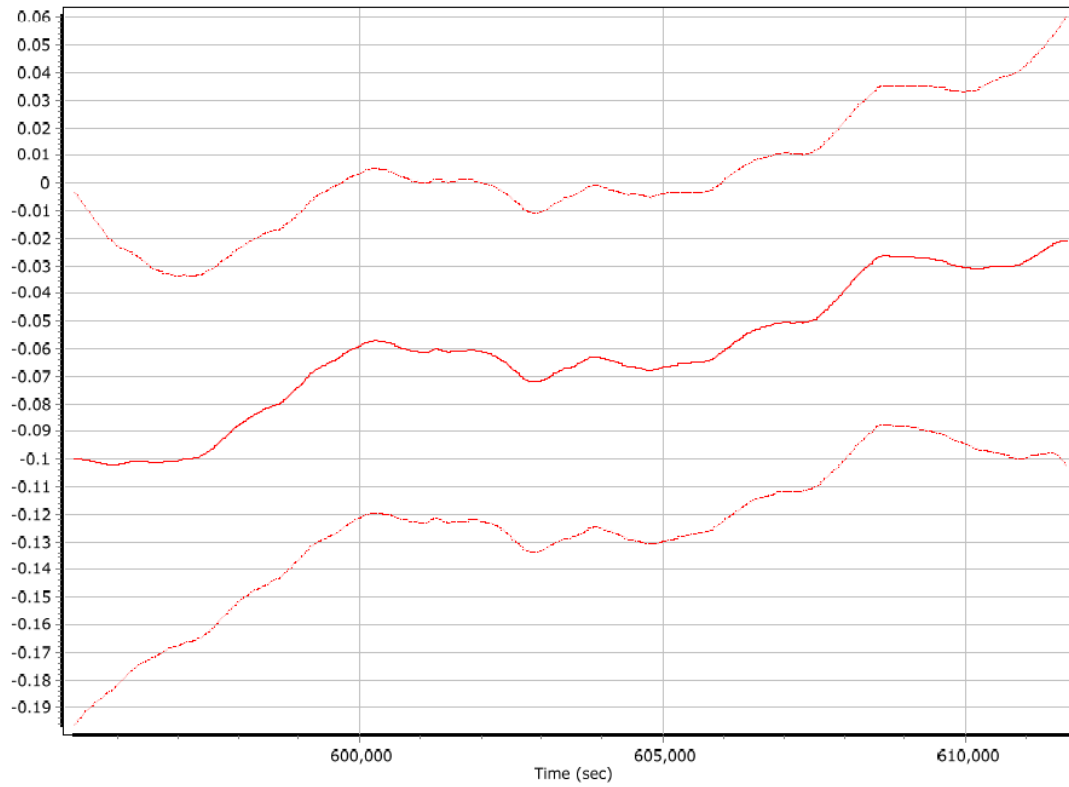
z accelerometer scale error (ppm)



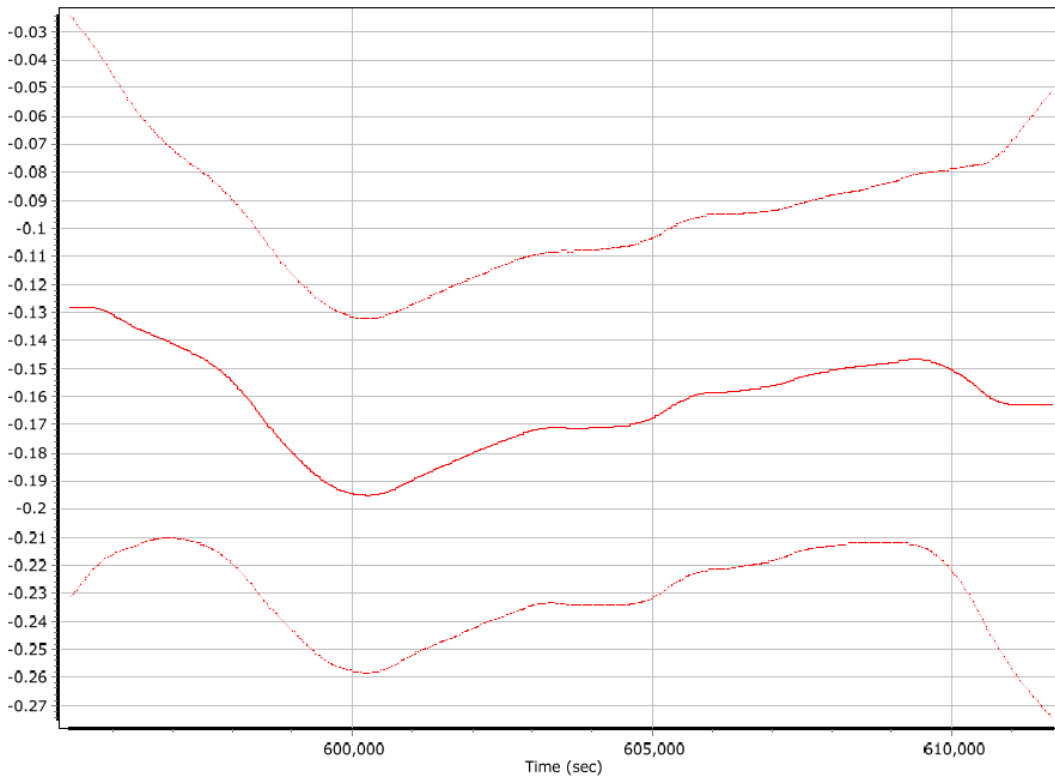
x gyro bias (deg/hr)



y gyro bias (deg/hr)



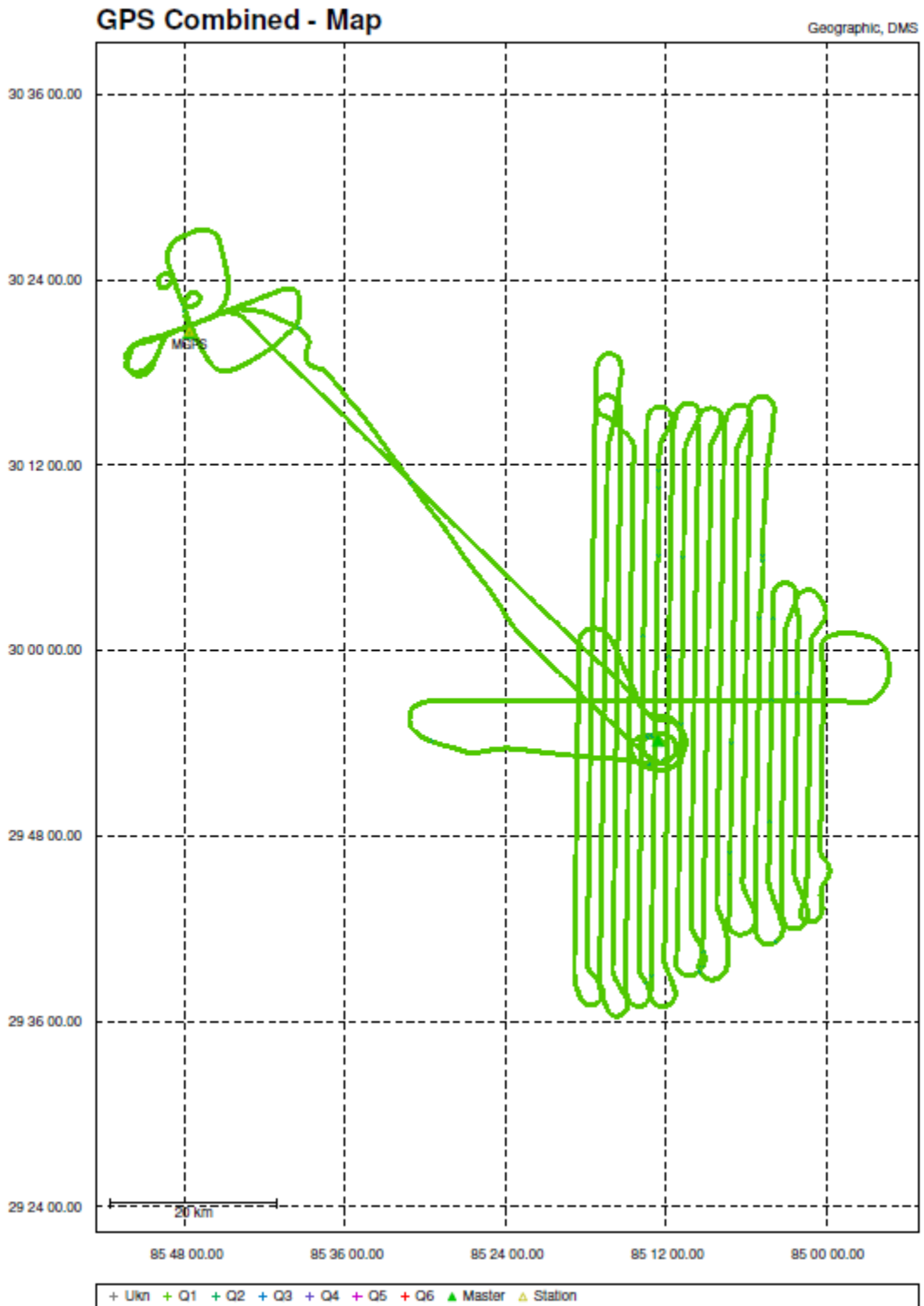
z gyro bias (deg/hr)



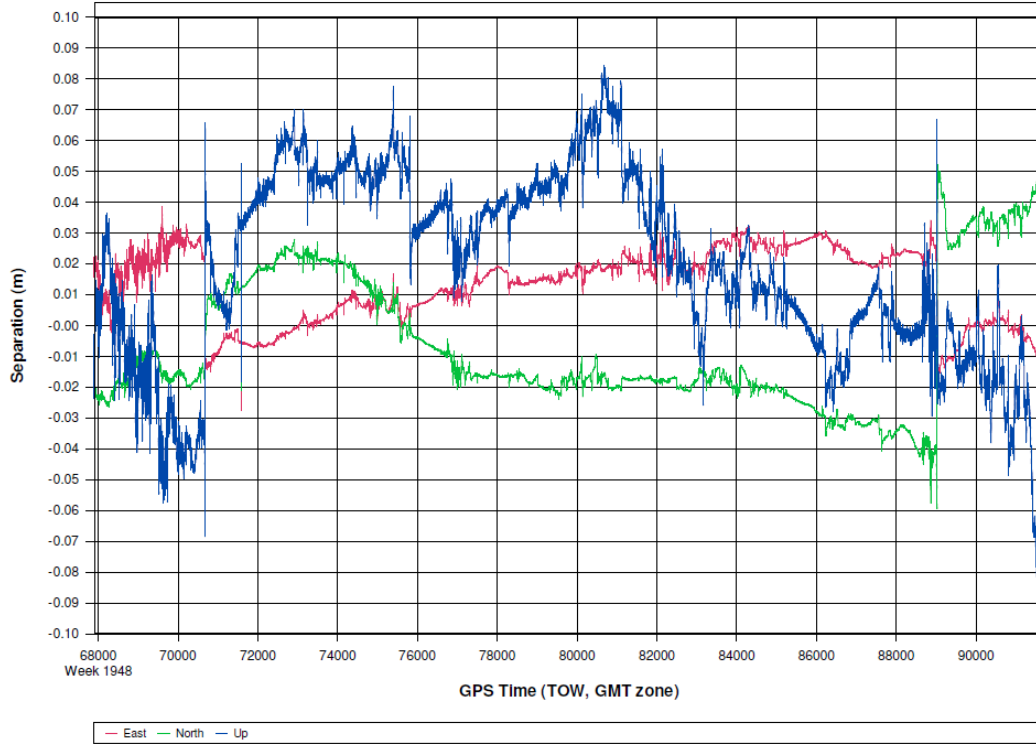
Mission 7 - 5417127a GNSS Processing

Project: 5417127a

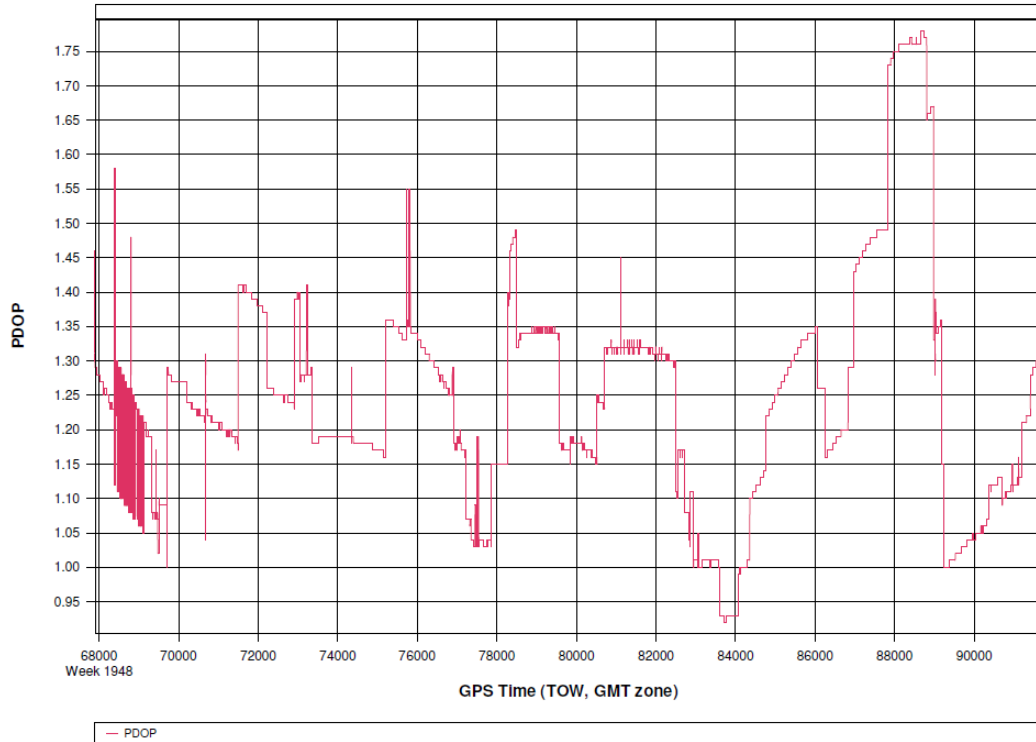
GrafNav v8.50.4320

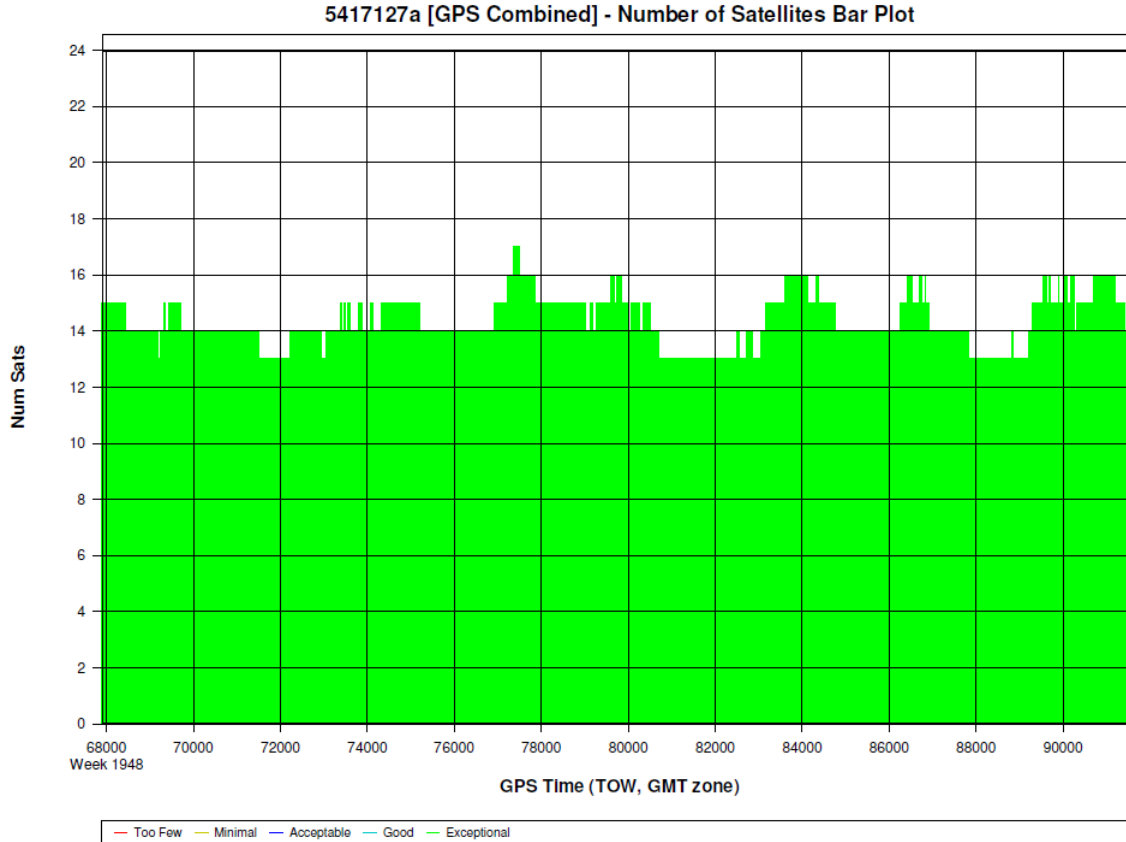


5417127a [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417127a [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417127a\05_INS-GPS_PROC\01_POS\5417127a\5417127a\GNSS\5417127a.gnv

Solution Type: Combined

Number of Epochs:

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

Measurement RMS Values:

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

Fwd/Rev Separation RMS Values:

East: 0.018 (m)
North: 0.025 (m)
Height: 0.066 (m)

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

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

Quality Number Percentages:

Q 1: 99.4 %
Q 2: 0.6 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

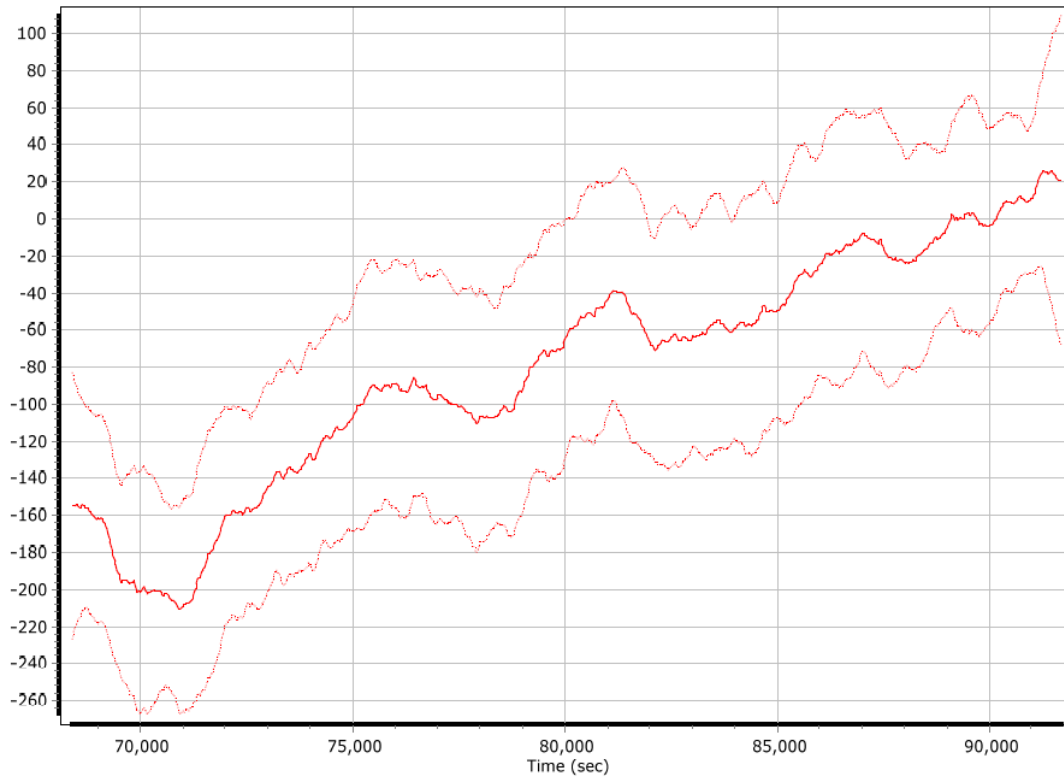
DOP over Tol: 0.0 %

Baseline Distances:

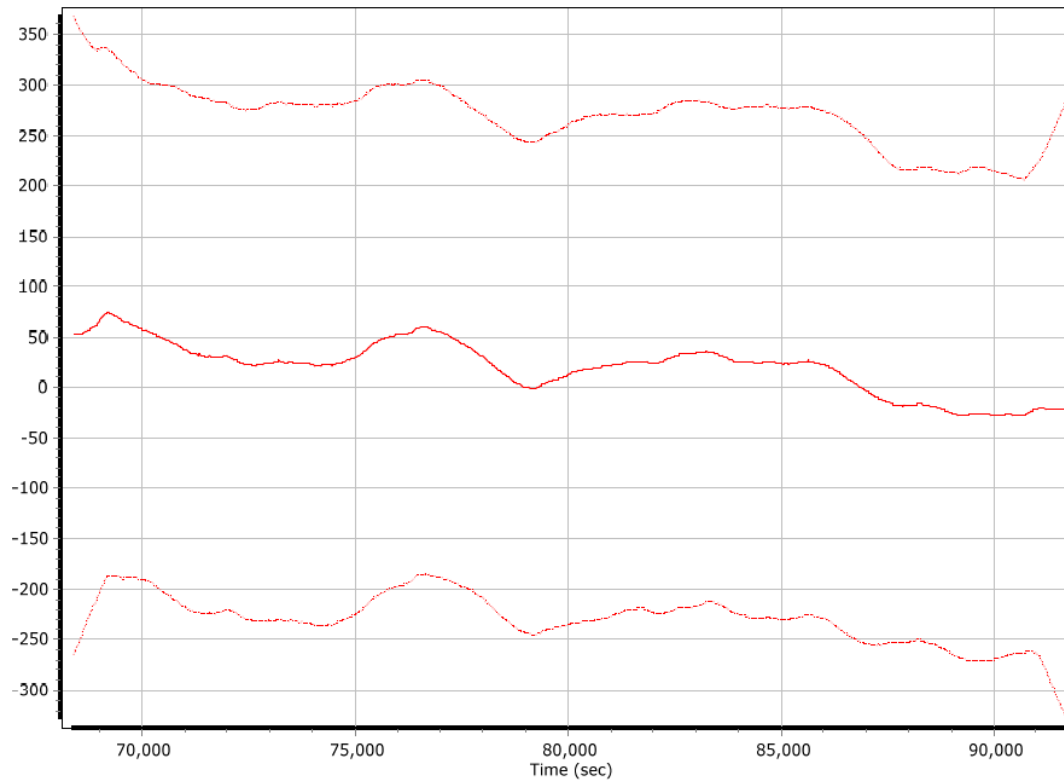
Maximum: 74.585 (km)
Minimum: 3.975 (km)
Average: 41.329 (km)
First Epoch: 33.593 (km)
Last Epoch: 37.104 (km)

Mission 7 - 5417127a Sensor Errors

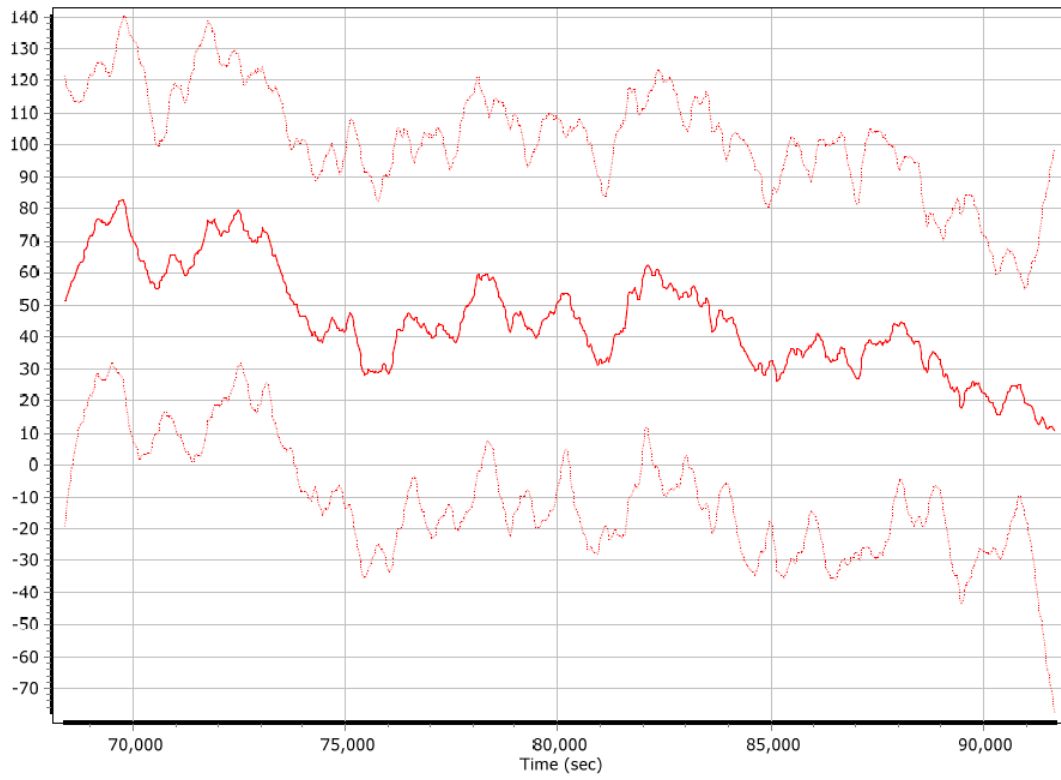
x accelerometer bias (micro-g)



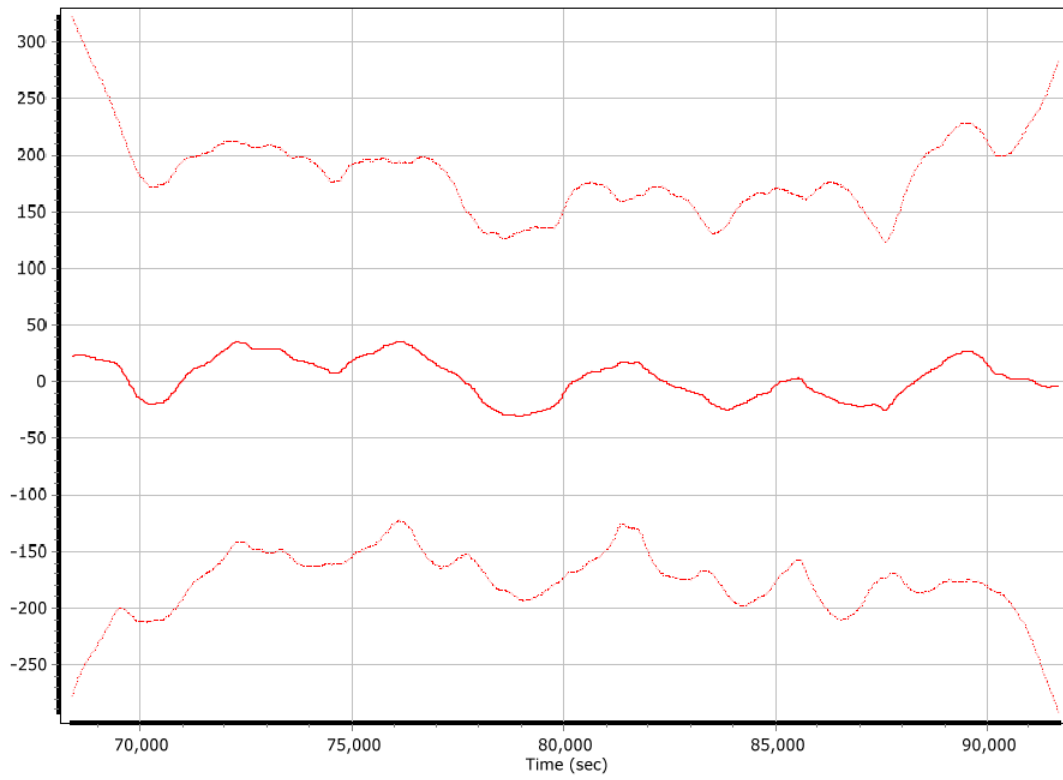
x accelerometer scale error (ppm)



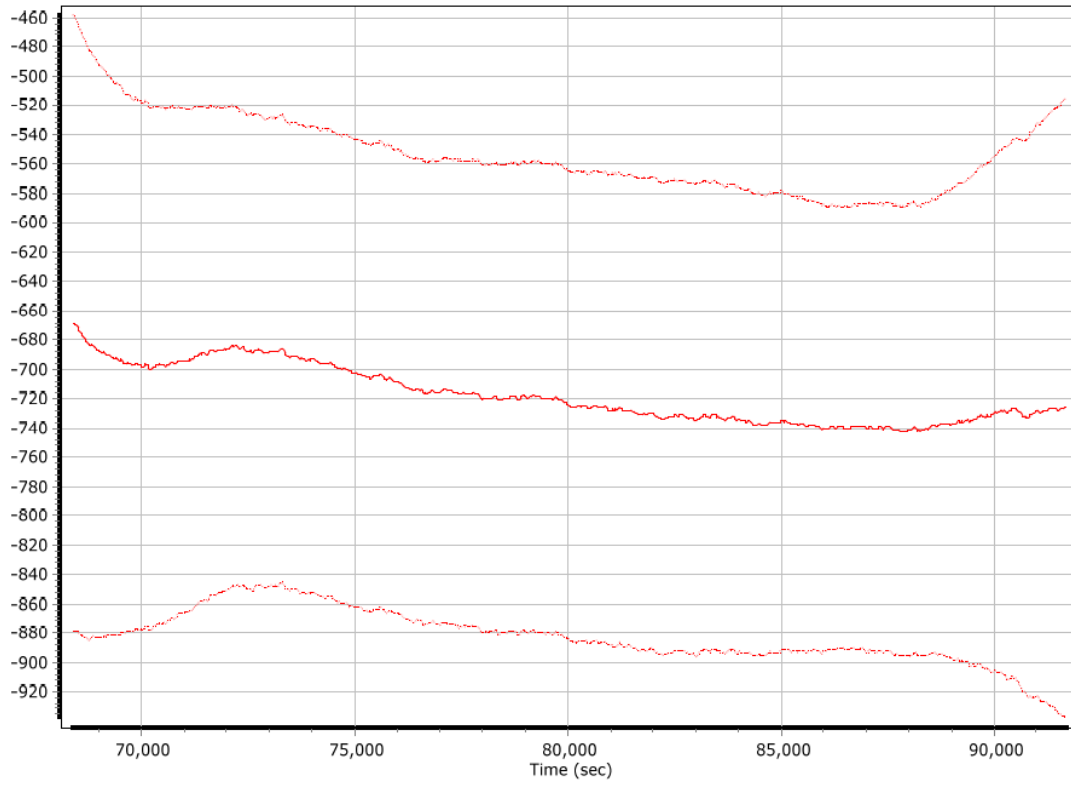
y accelerometer bias (micro-g)



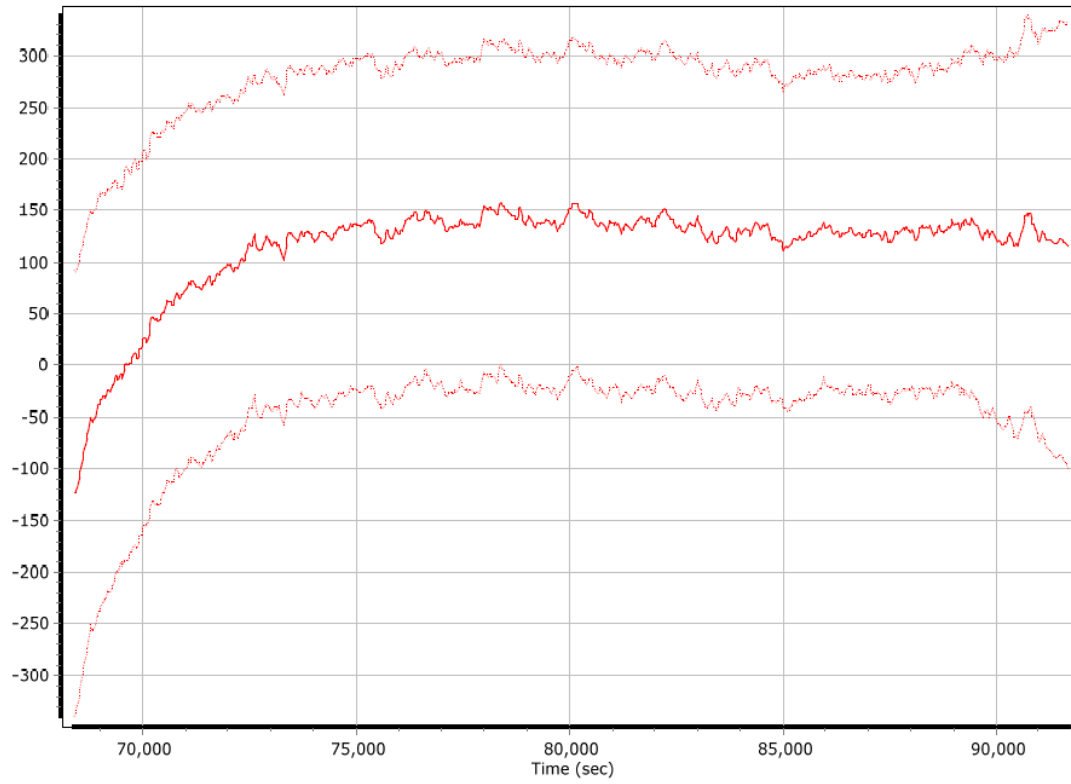
y accelerometer scale error (ppm)



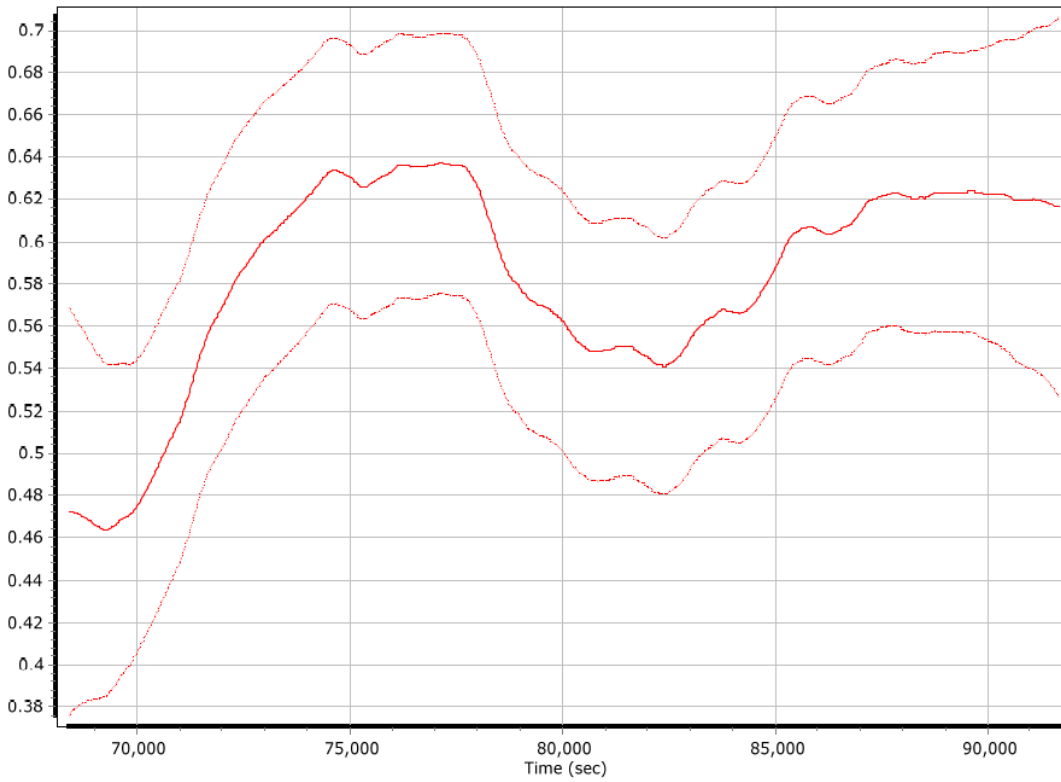
z accelerometer bias (micro-g)



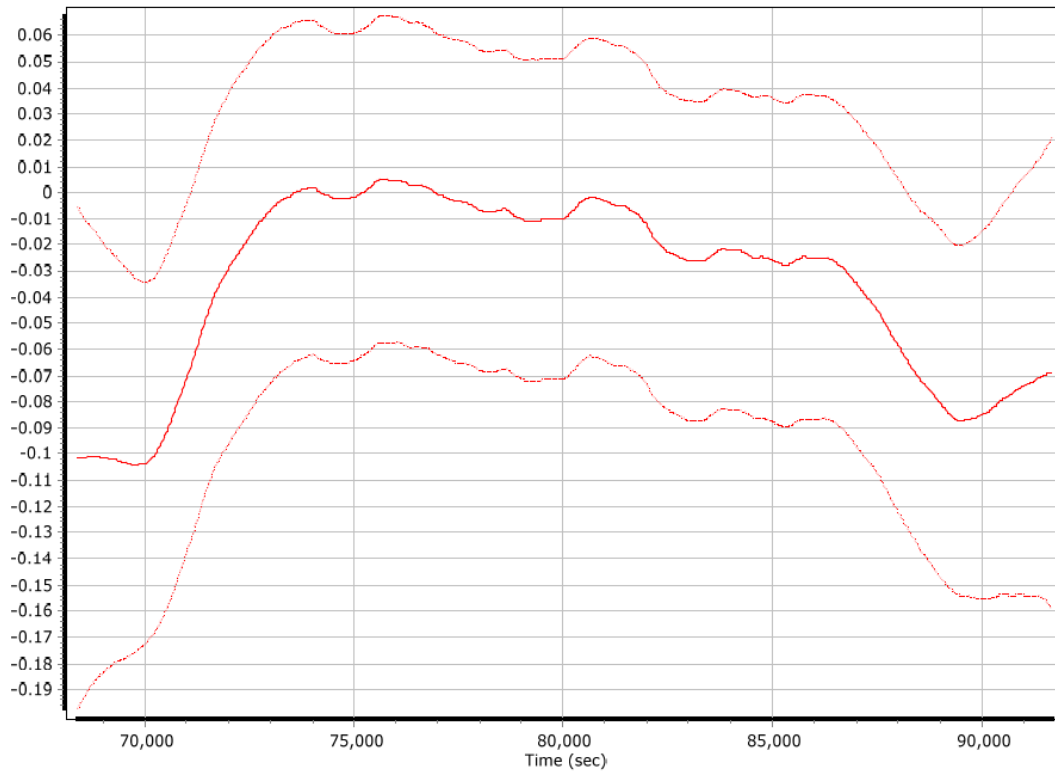
z accelerometer scale error (ppm)



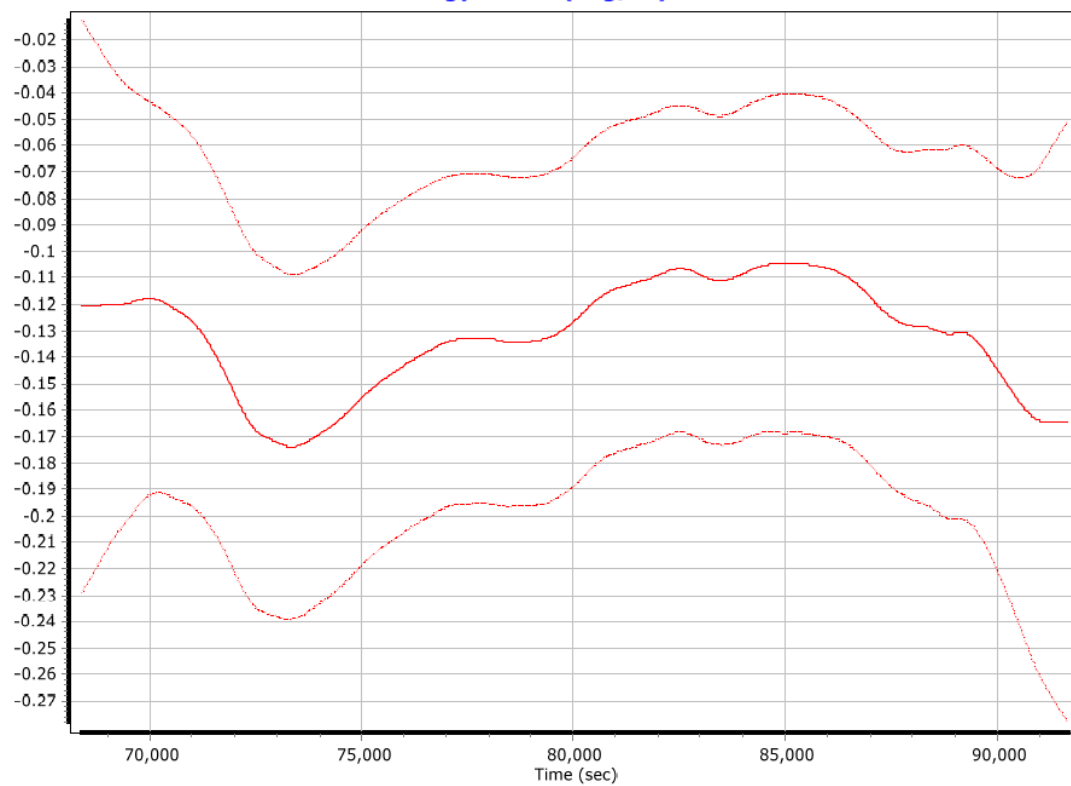
x gyro bias (deg/hr)



y gyro bias (deg/hr)



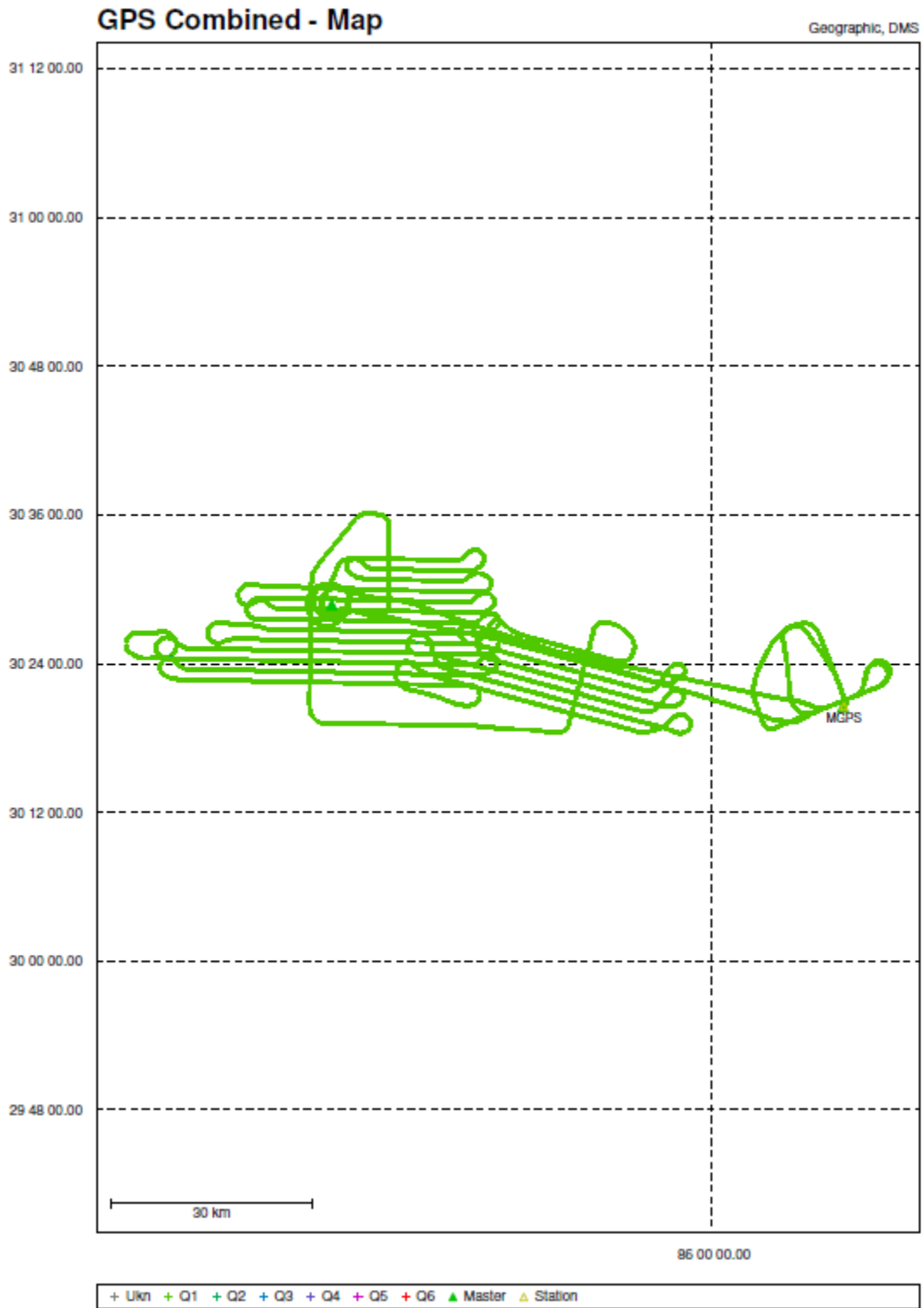
z gyro bias (deg/hr)



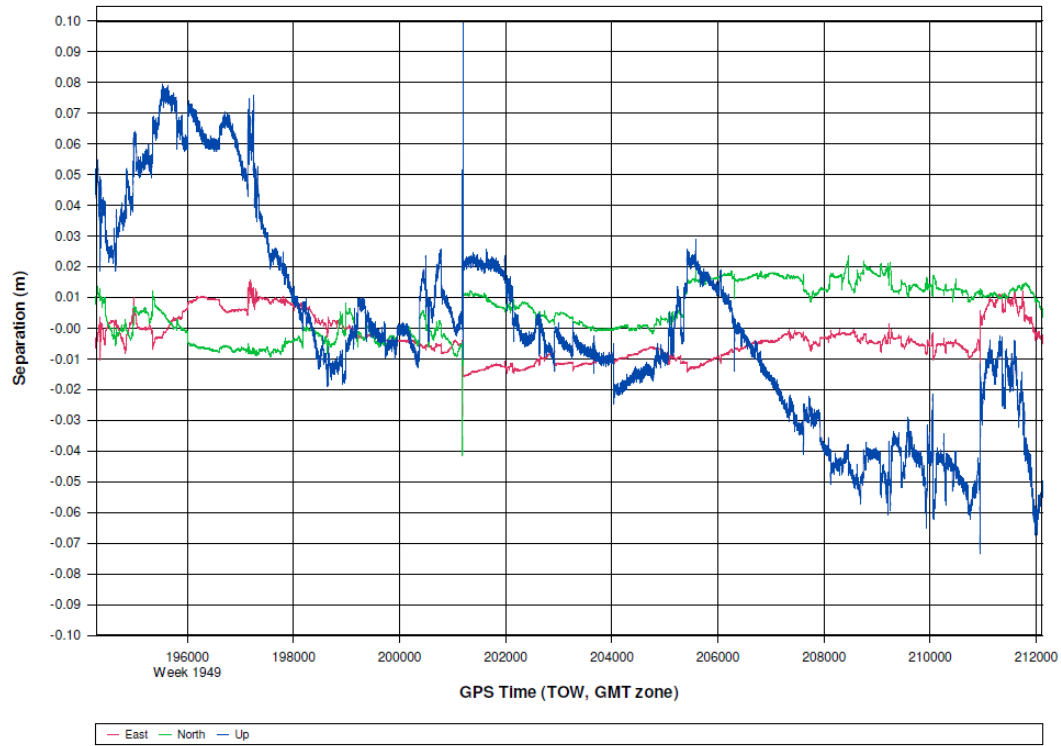
Mission 8 – 5417136a GNSS Processing

Project: 5417136a

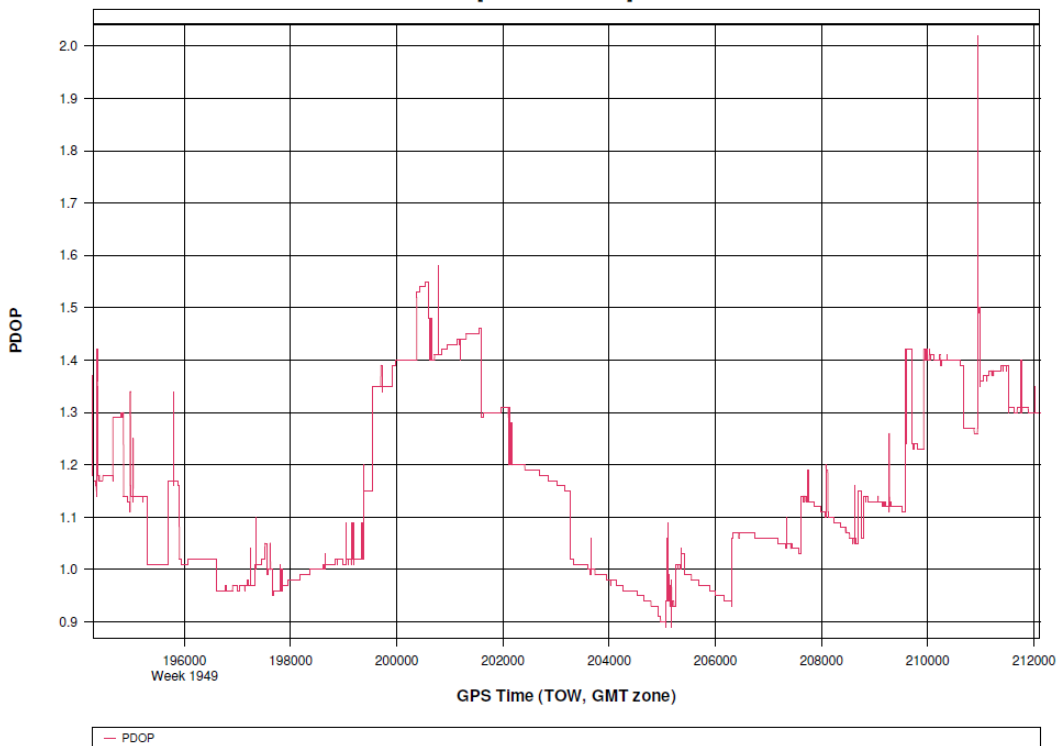
GrafNav v8.50.4320

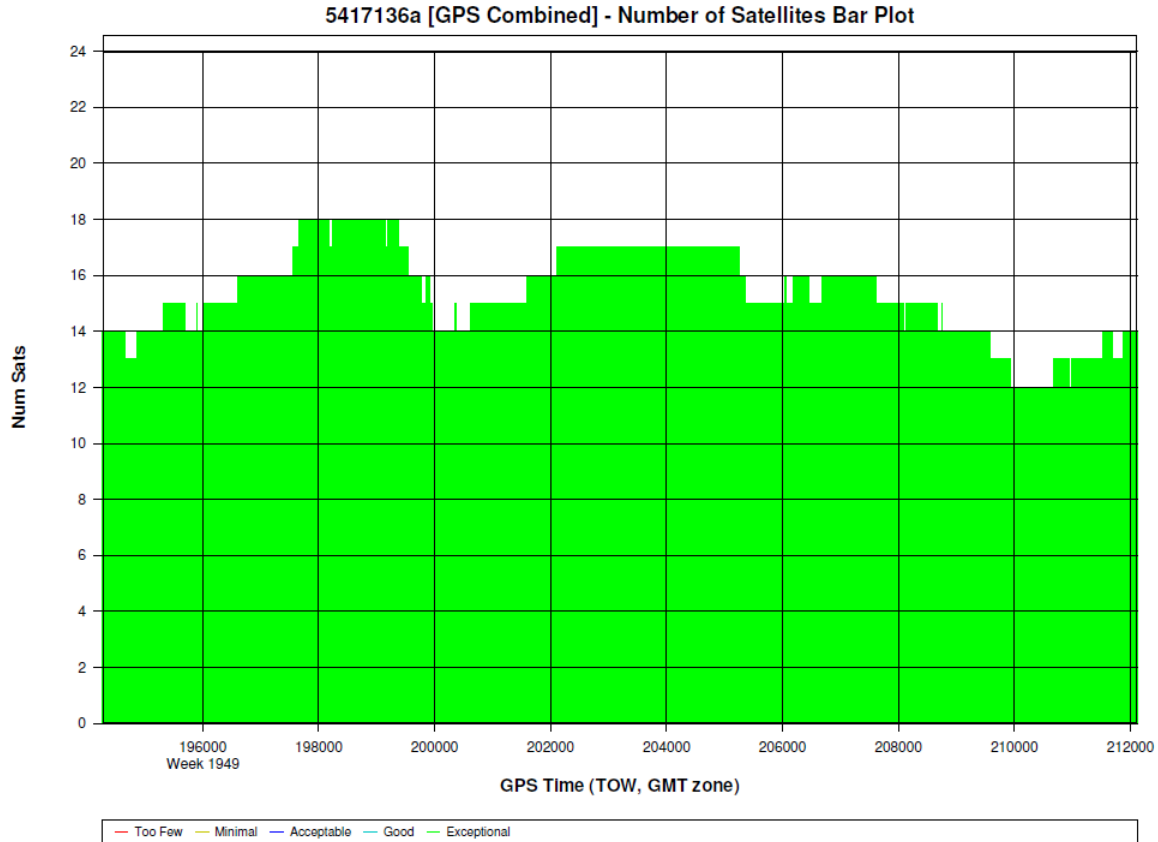


5417136a [GPS Combined] - Forward/Reverse or Combined Separation Plot



5417136a [GPS Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417136a\05_INS-GPS_PROC\01_POS\5417136a\5417136a\GNSS\5417136a.gnv

Solution Type: Combined

Number of Epochs:

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

Measurement RMS Values:

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

Fwd/Rev Separation RMS Values:

East: 0.008 (m)
North: 0.010 (m)
Height: 0.037 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (17856 occurrences):

East: 0.008 (m)
North: 0.010 (m)
Height: 0.033 (m)

Quality Number Percentages:

Q 1: 99.8 %
Q 2: 0.2 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

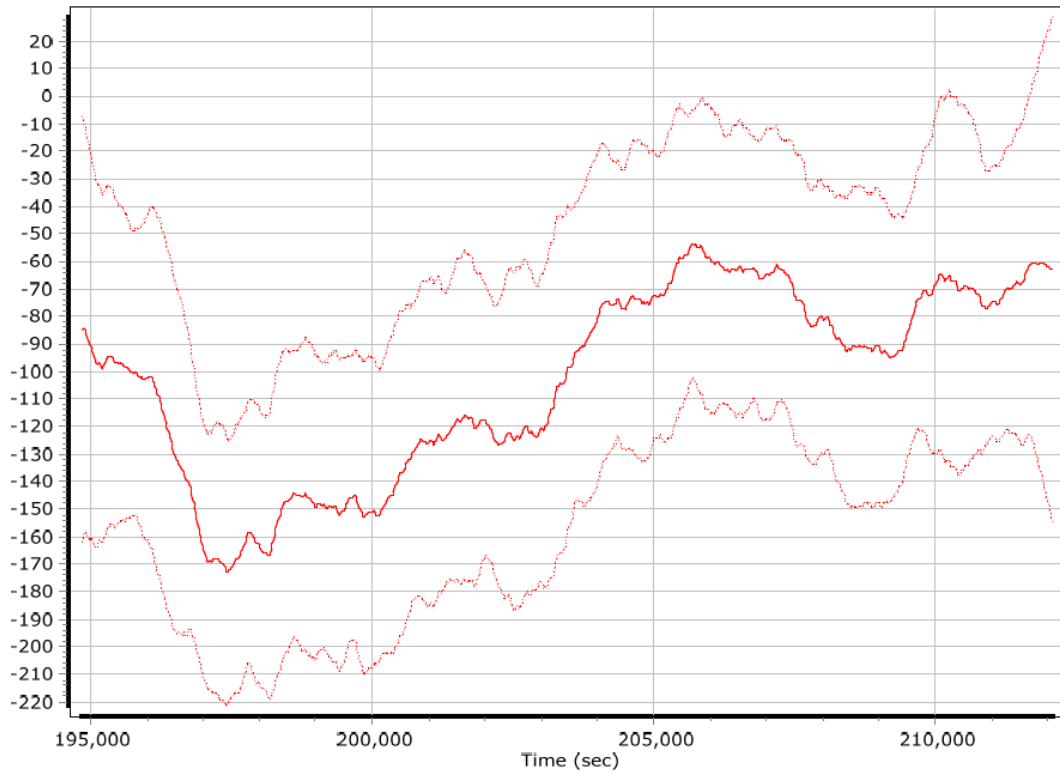
DOP over Tol: 0.0 %

Baseline Distances:

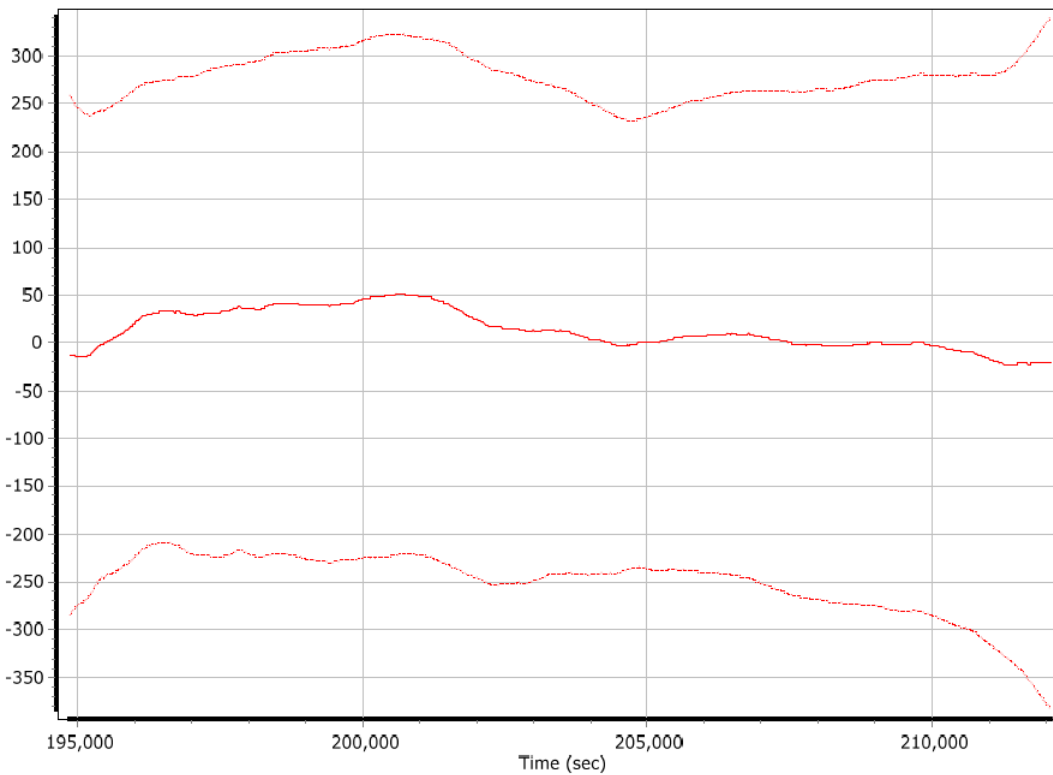
Maximum: 68.899 (km)
Minimum: 2.104 (km)
Average: 29.399 (km)
First Epoch: 30.615 (km)
Last Epoch: 39.001 (km)

Mission 8 - 5417136a Sensor Errors

x accelerometer bias (micro-g)



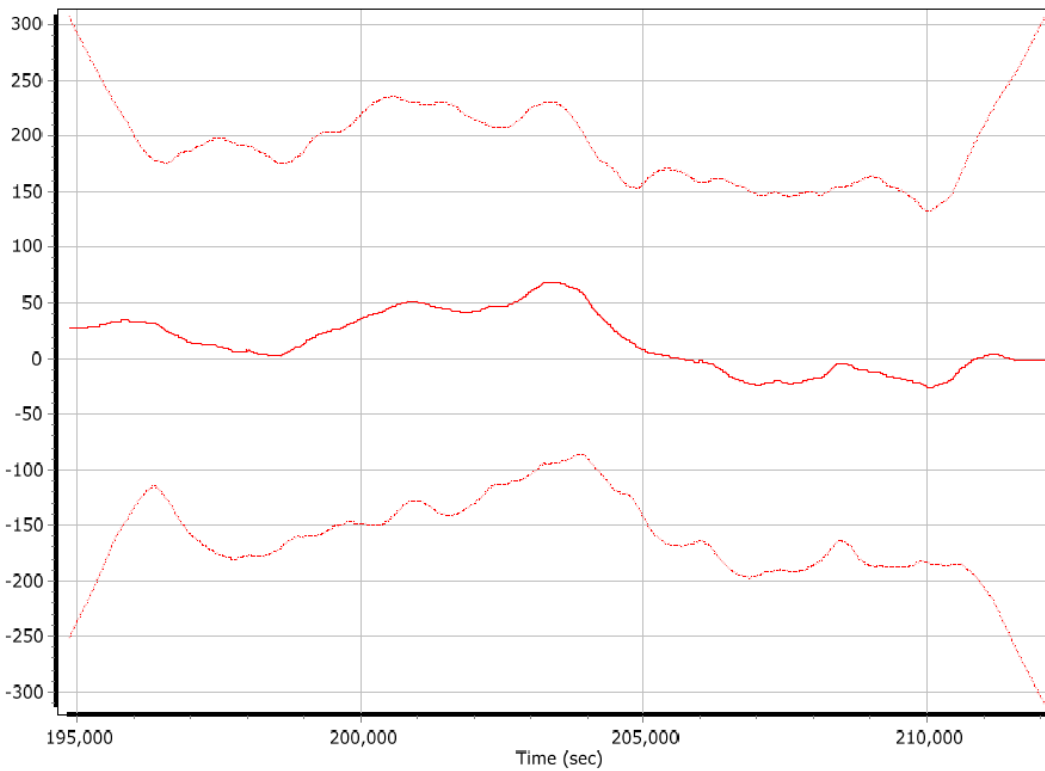
x accelerometer scale error (ppm)



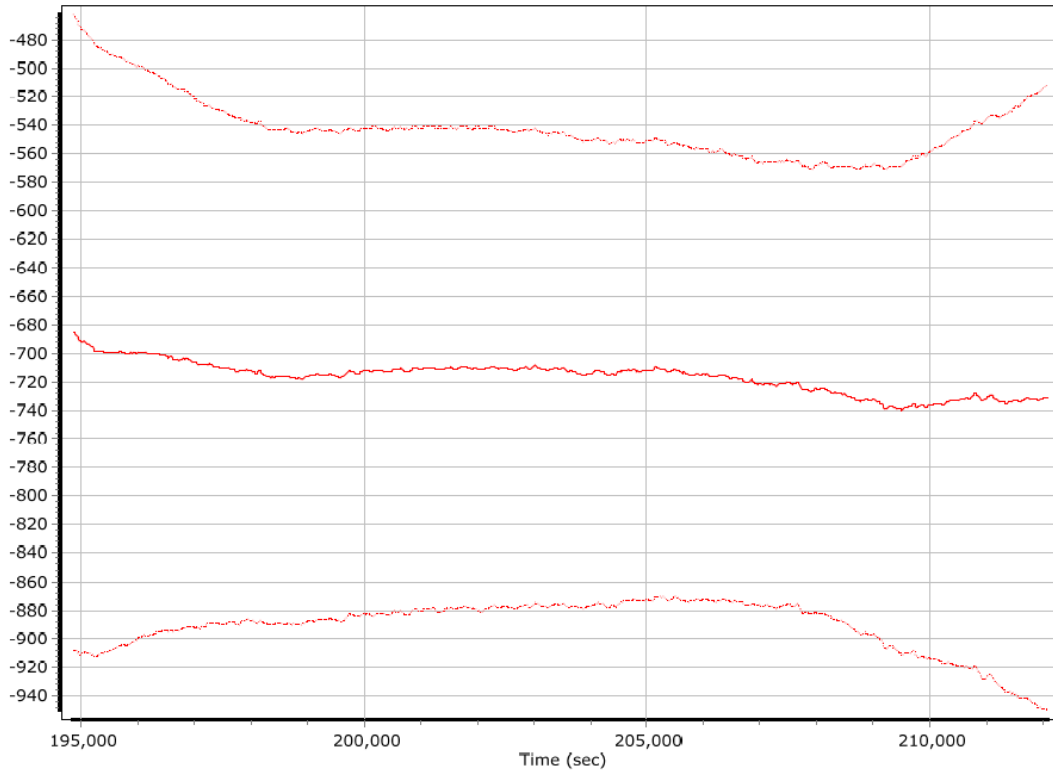
y accelerometer bias (micro-g)



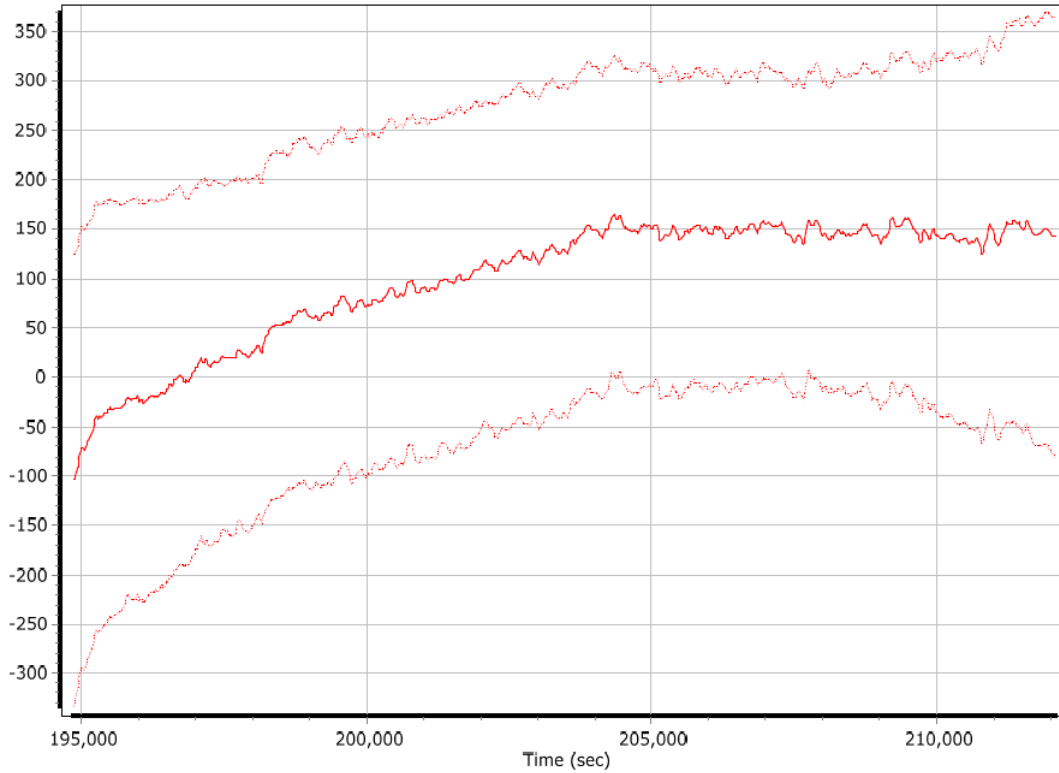
y accelerometer scale error (ppm)



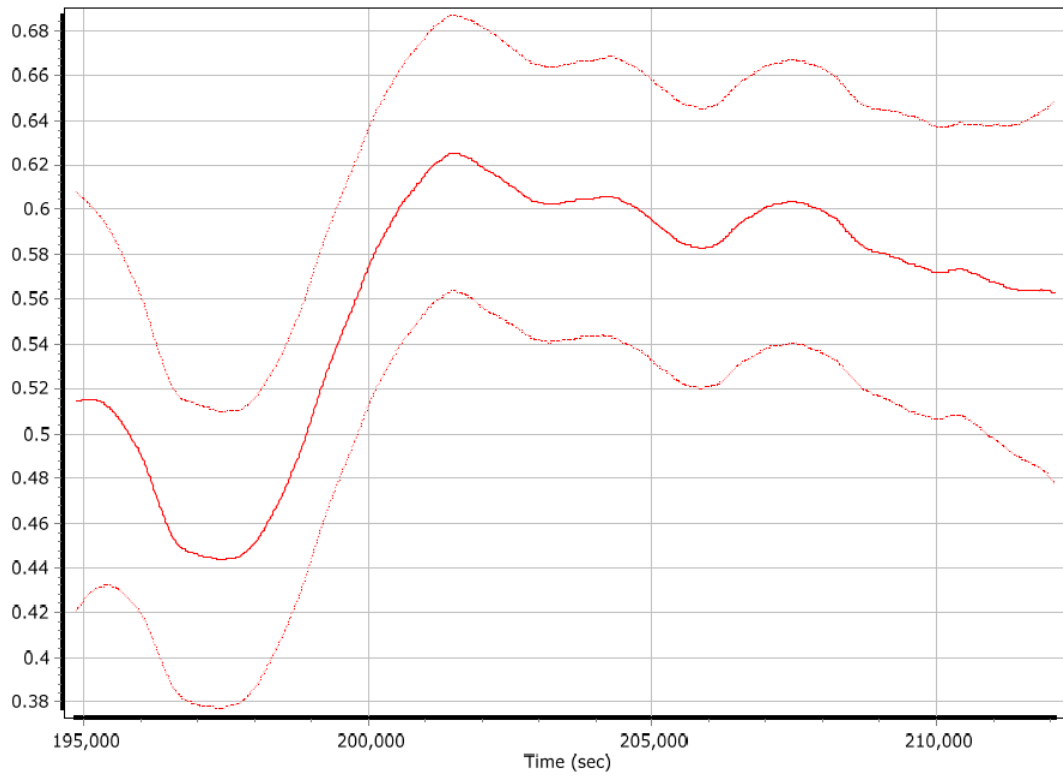
z accelerometer bias (micro-g)



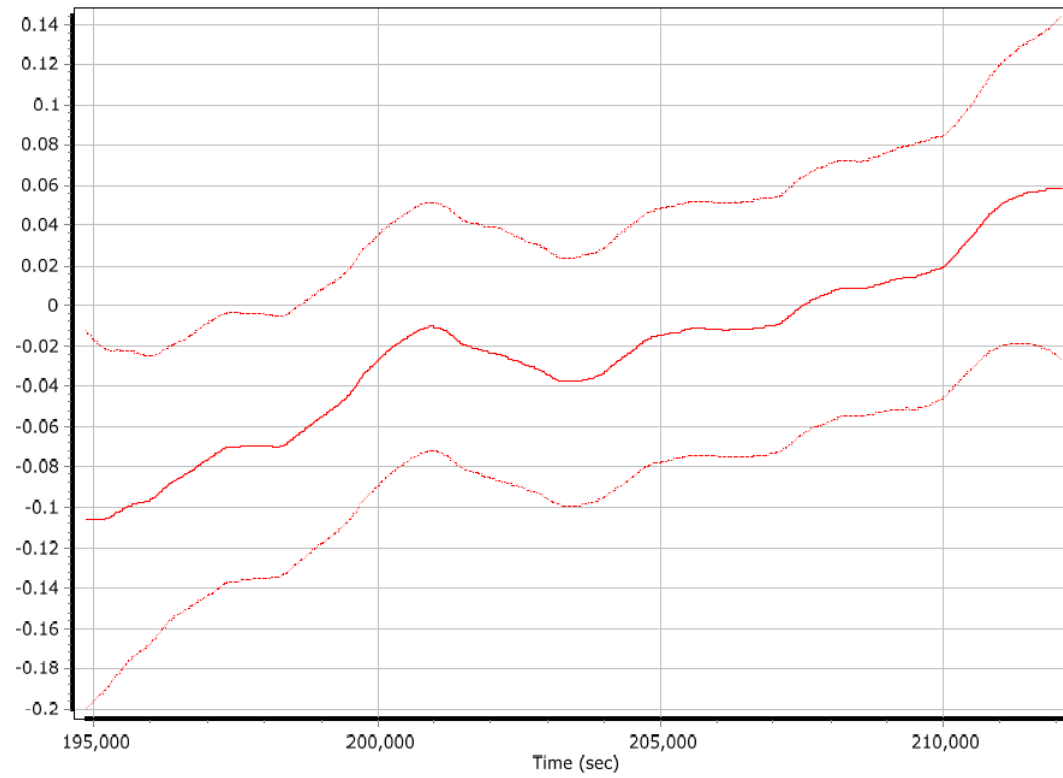
z accelerometer scale error (ppm)



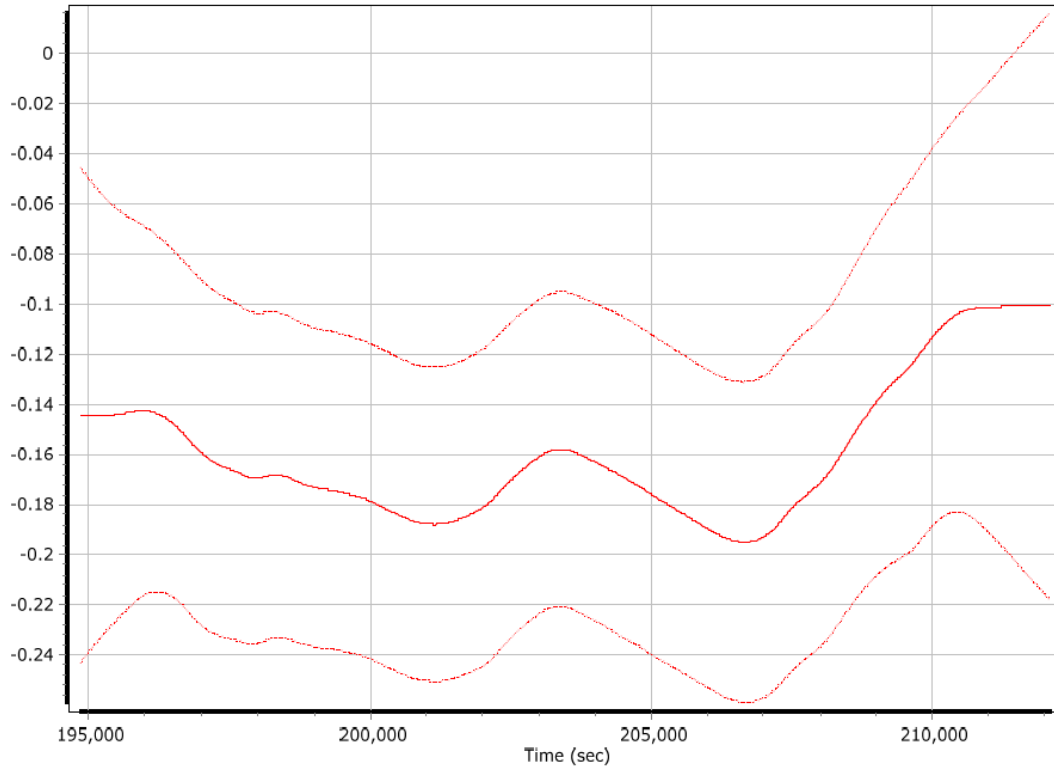
x gyro bias (deg/hr)



y gyro bias (deg/hr)



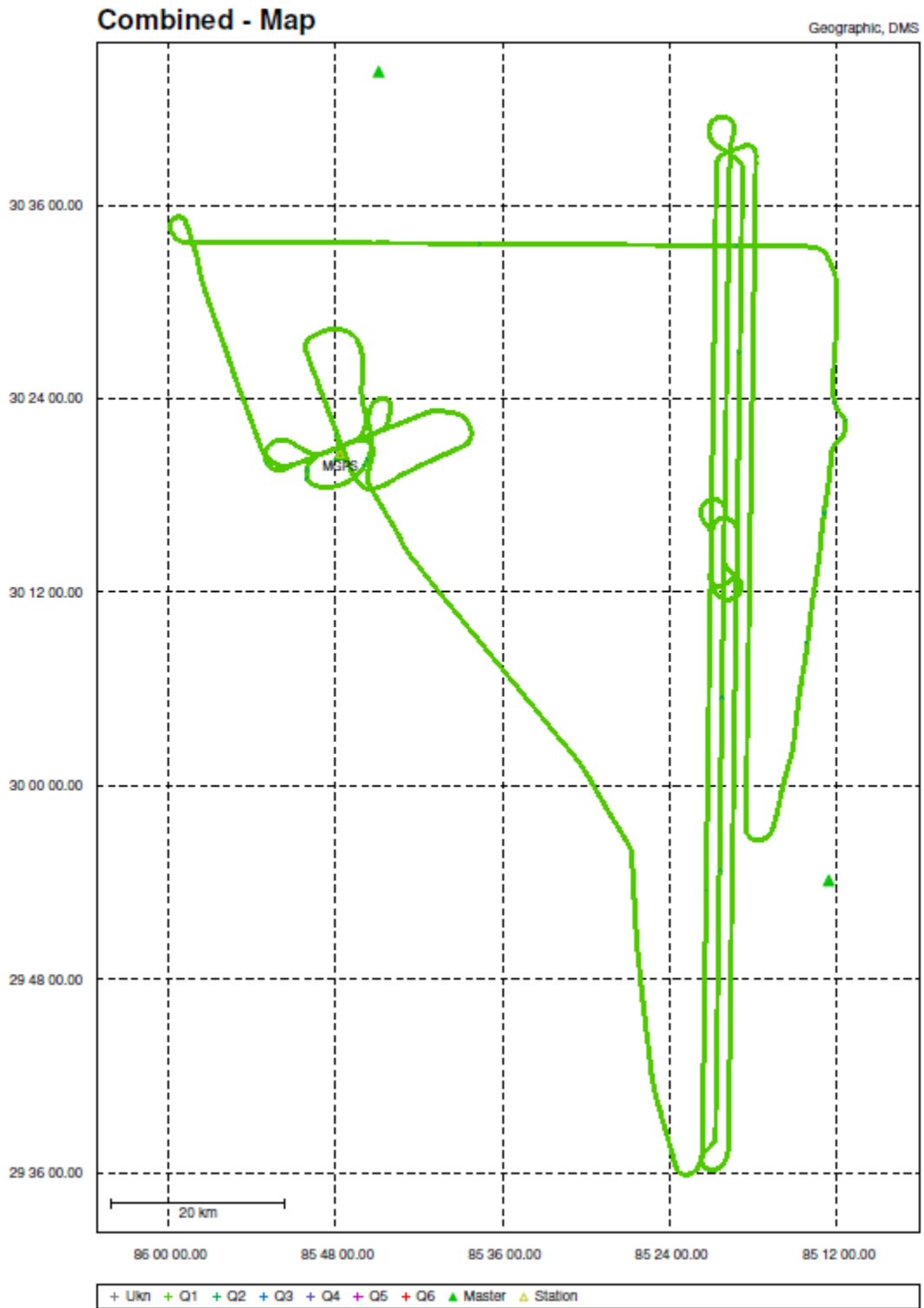
z gyro bias (deg/hr)



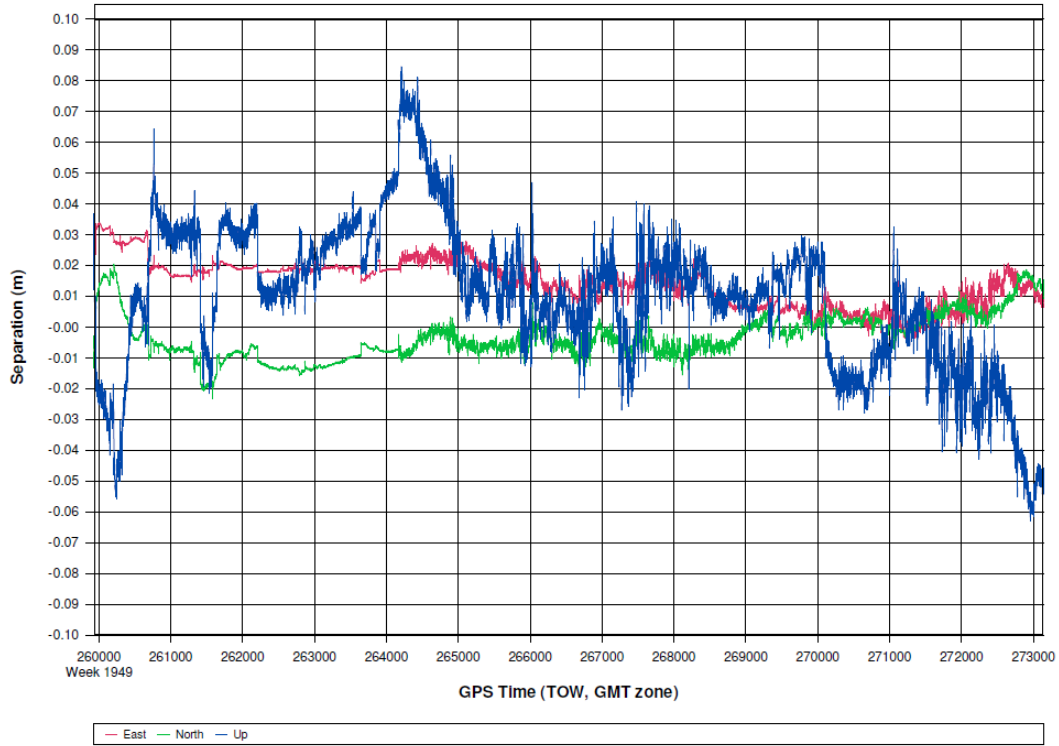
Mission 9 – 5417137a GNSS Processing

Project: 5417137a

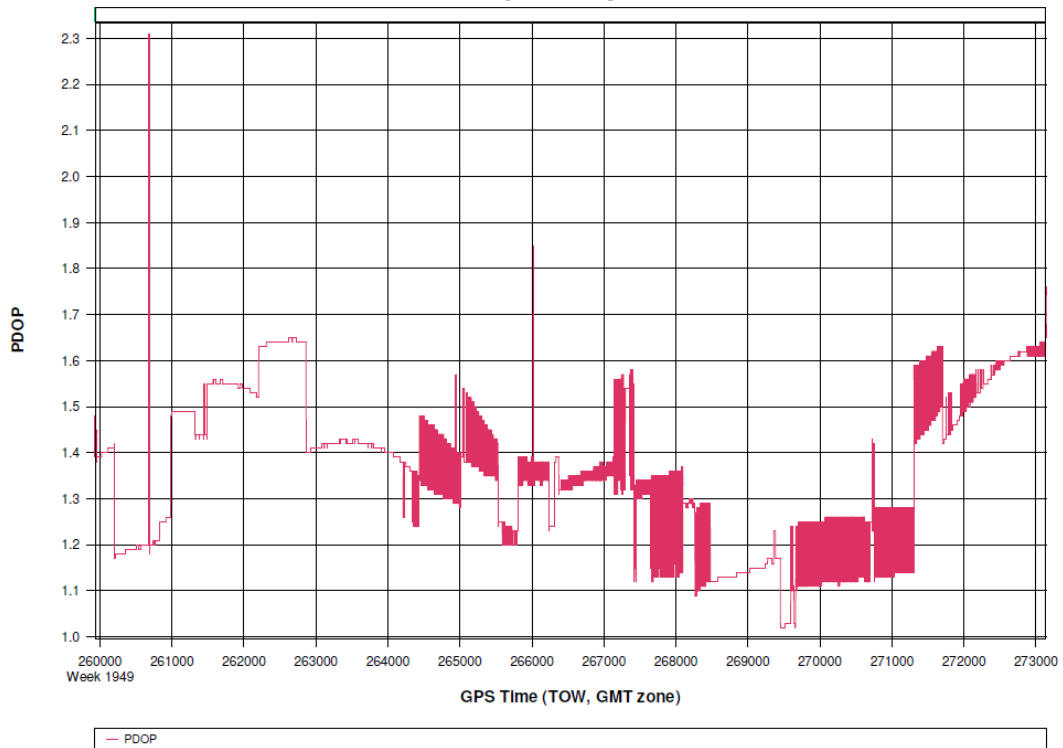
GrafNav v8.50.4320

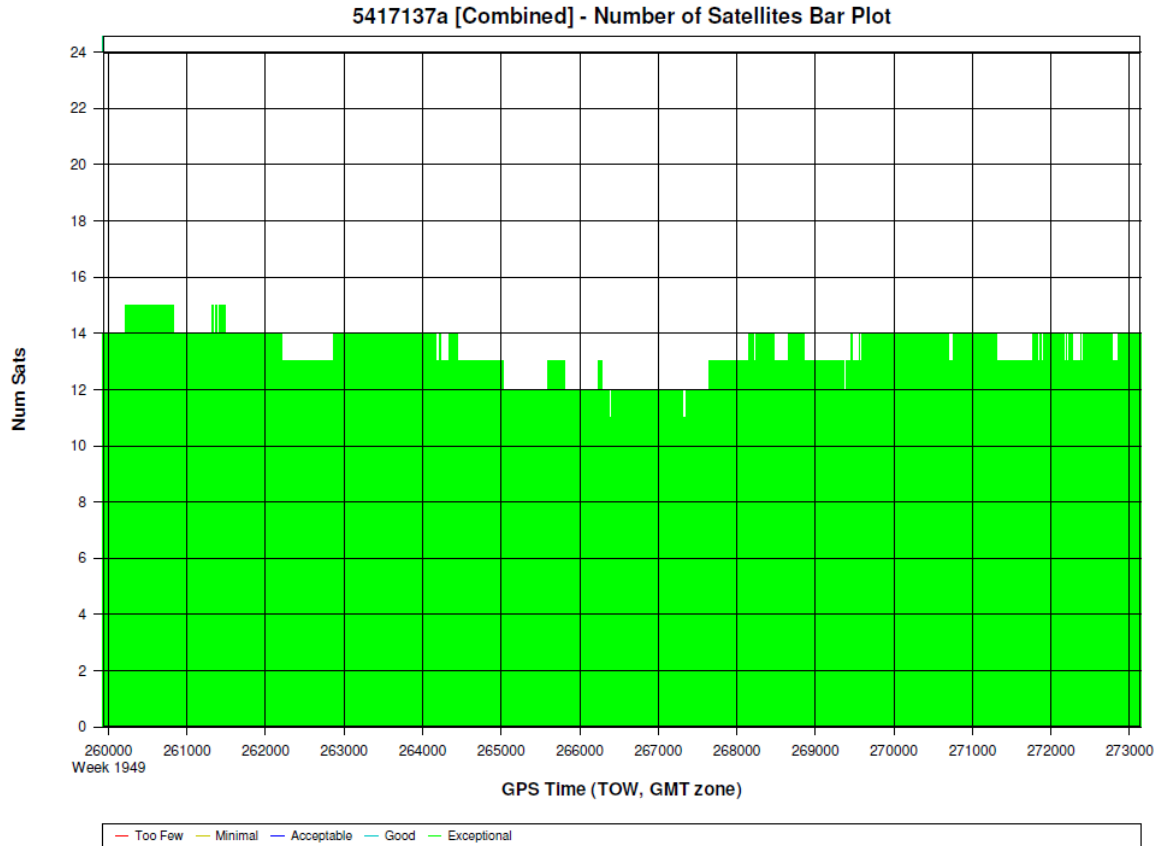


5417137a [Combined] - Forward/Reverse or Combined Separation Plot



5417137a [Combined] - PDOP Plot





Processing Summary Information

Program: GrafNav

Version: 8.50.4320

Project: F:\Projects\3123_ChoctawacheeWalton\LiDAR\5417137a\05_INS-GPS_PROC\01_POS\5417137a\5417137a\GNSS\5417137a.gnv

Solution Type: Combined

Number of Epochs:

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

Measurement RMS Values:

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

Fwd/Rev Separation RMS Values:

East: 0.016 (m)
North: 0.008 (m)
Height: 0.026 (m)

Fwd/Rev Sep. RMS for dual FWD/REV fixes (13220 occurrences):

East: 0.016 (m)
North: 0.008 (m)
Height: 0.026 (m)

Quality Number Percentages:

Q 1: 99.5 %
Q 2: 0.5 %
Q 3: 0.0 %
Q 4: 0.0 %
Q 5: 0.0 %
Q 6: 0.0 %

Position Standard Deviation Percentages:

0.00 - 0.10 m: 100.0 %
0.10 - 0.30 m: 0.0 %
0.30 - 1.00 m: 0.0 %
1.00 - 5.00 m: 0.0 %
5.00 m + over: 0.0 %

Percentages of epochs with DD_DOP over 10.00:

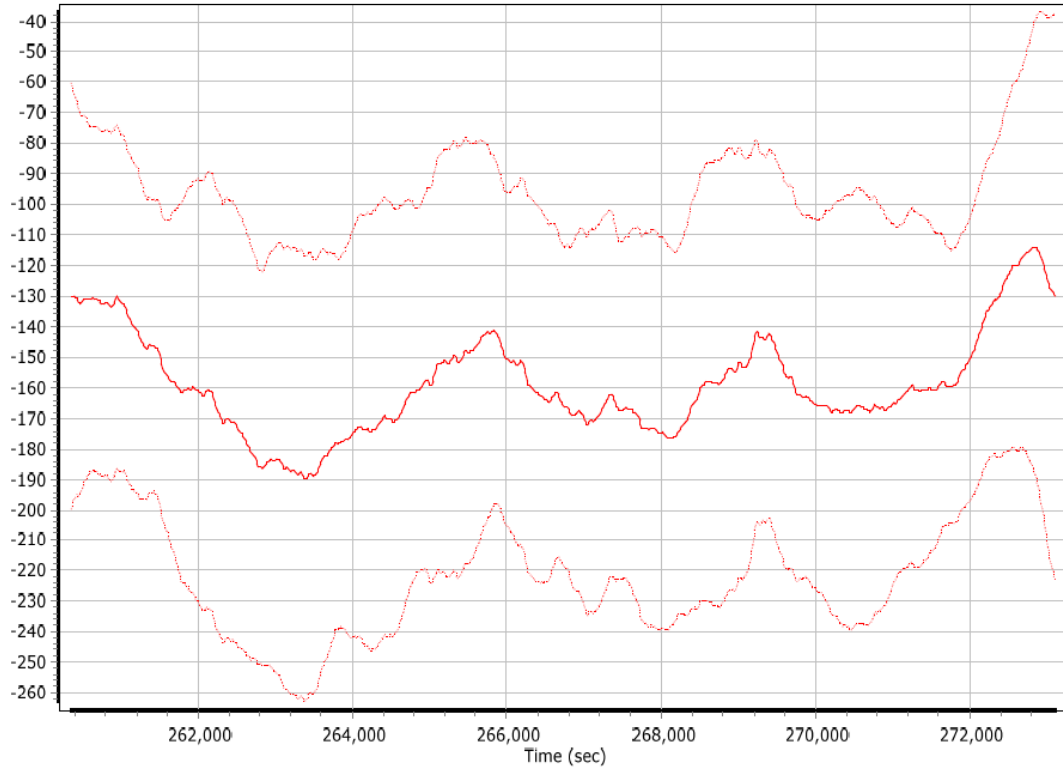
DOP over Tol: 0.0 %

Baseline Distances:

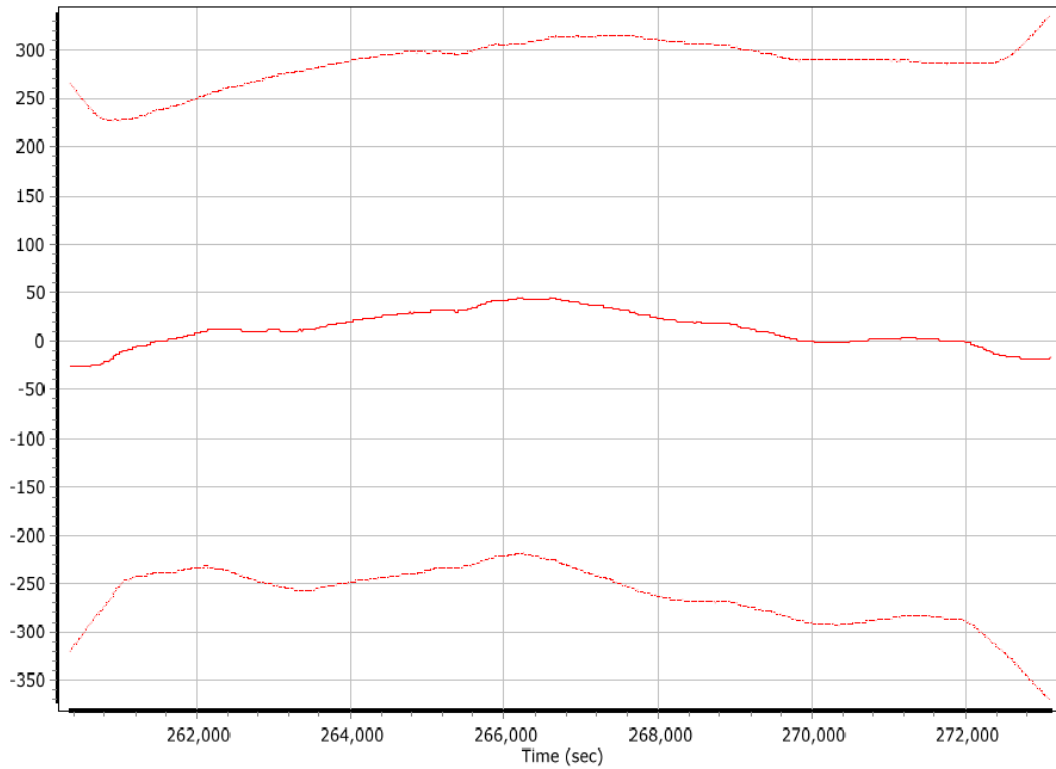
Maximum: 85.666 (km)
Minimum: 7.531 (km)
Average: 33.777 (km)
First Epoch: 32.798 (km)
Last Epoch: 19.592 (km)

Mission 9 - 5417137a Sensor Errors

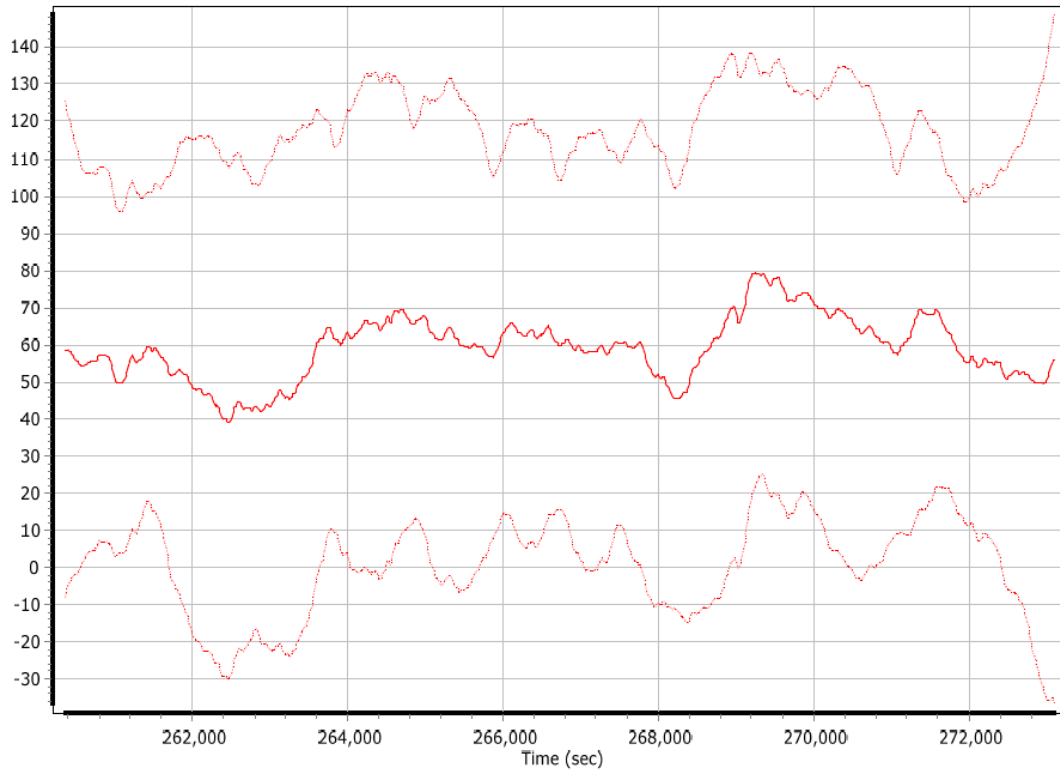
x accelerometer bias (micro-g)



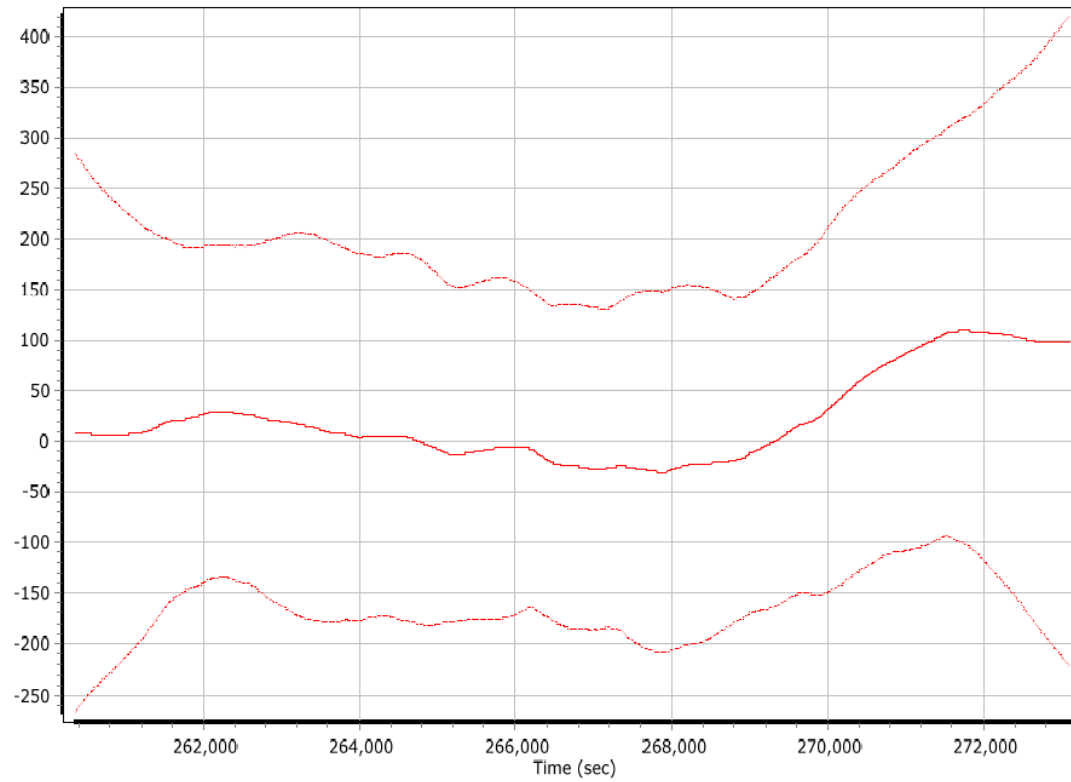
x accelerometer scale error (ppm)



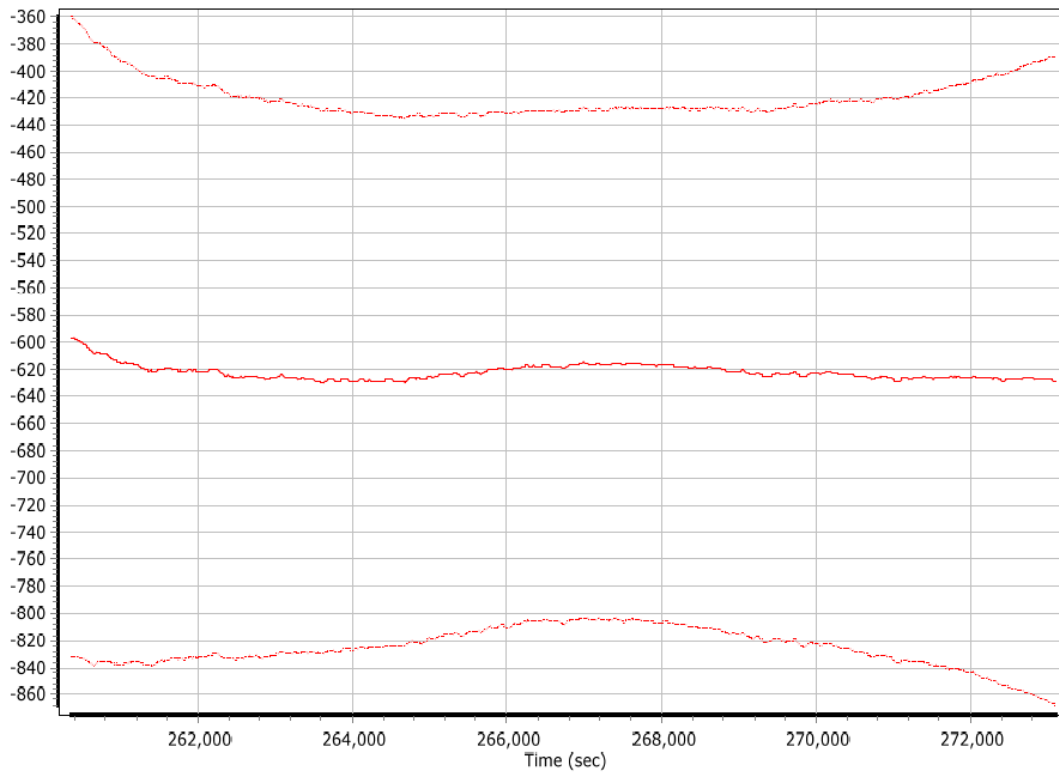
y accelerometer bias (micro-g)



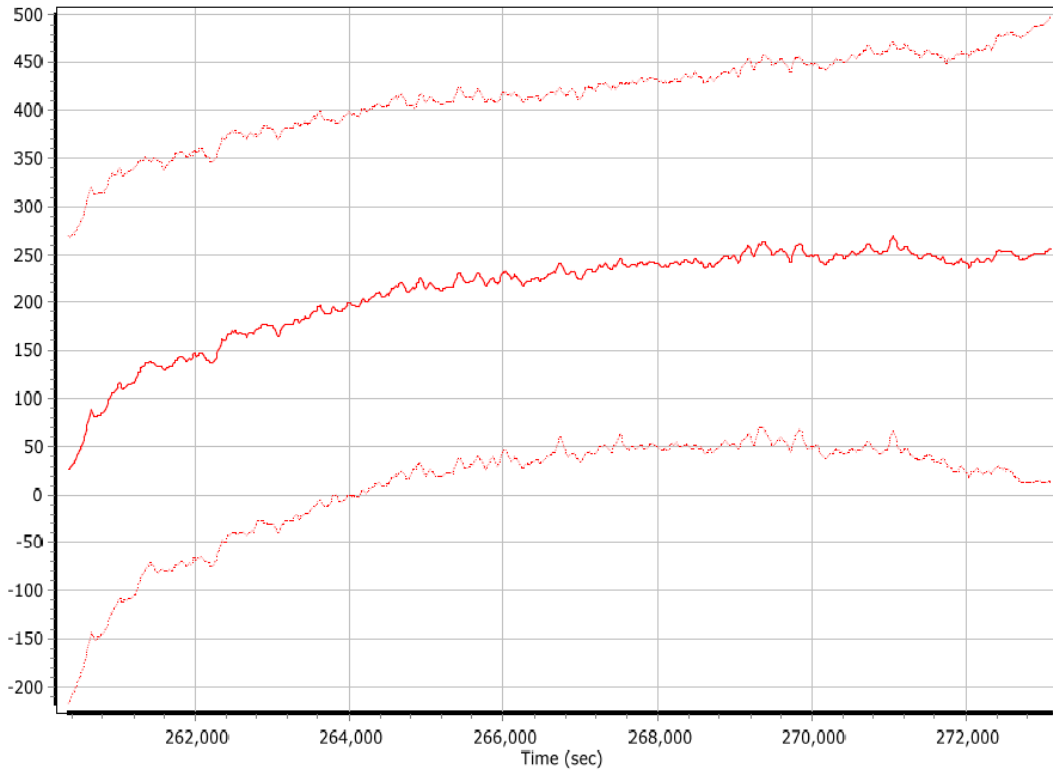
y accelerometer scale error (ppm)



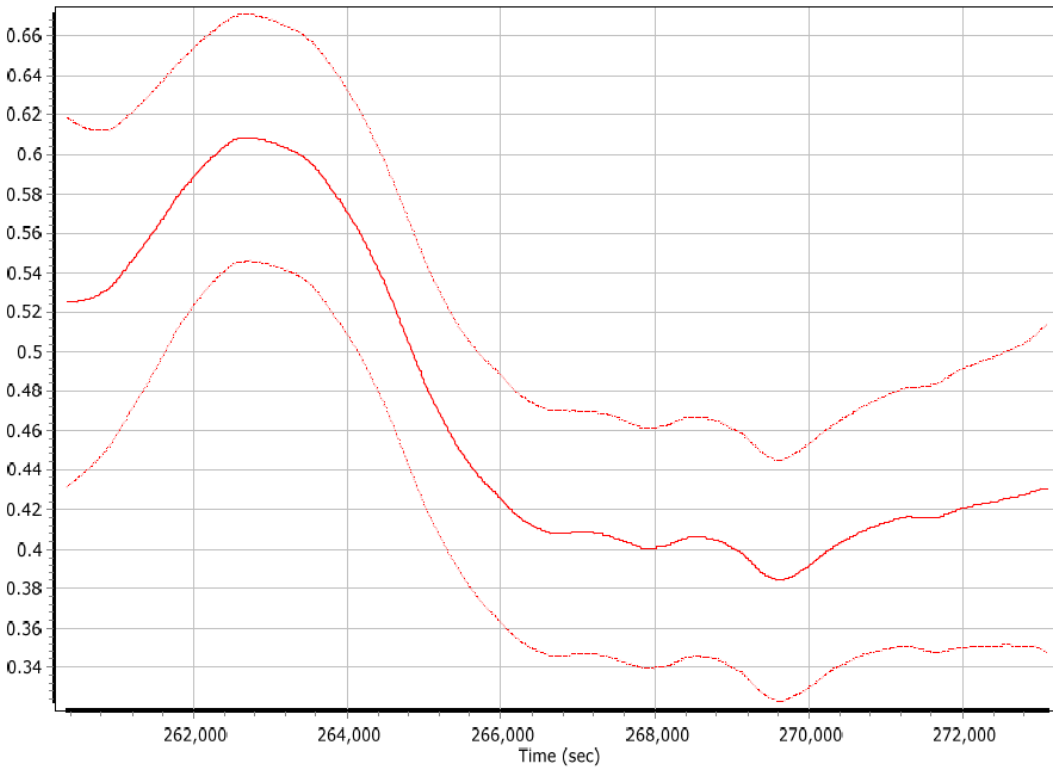
z accelerometer bias (micro-g)



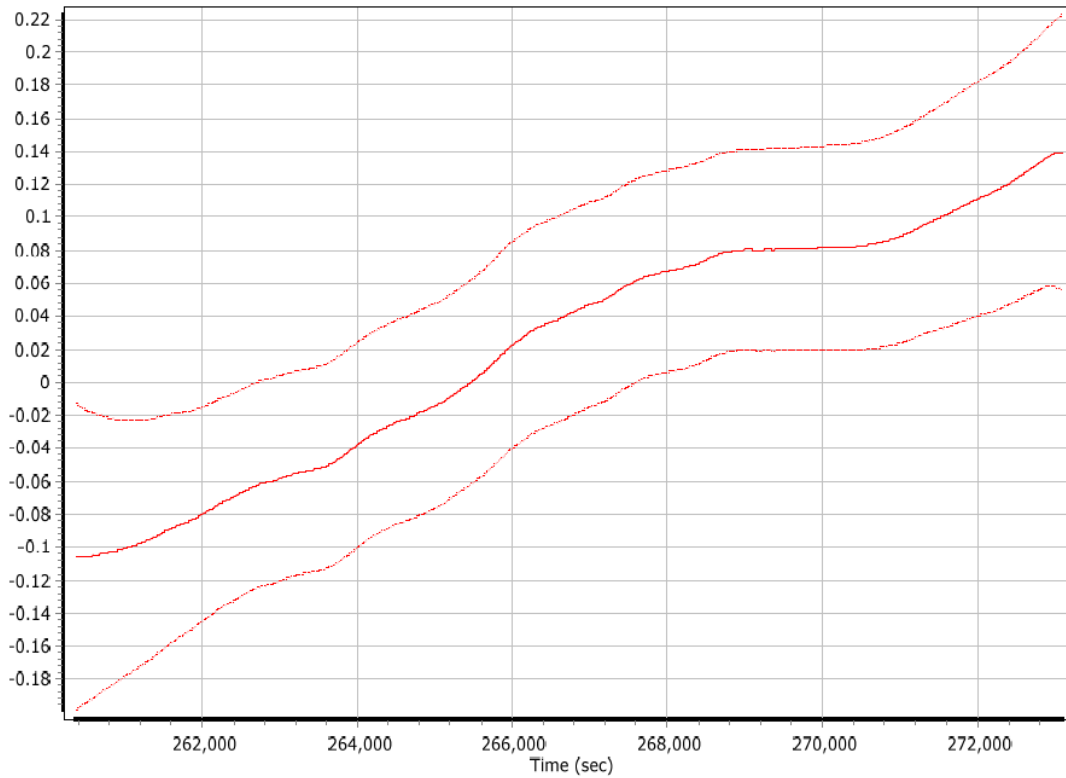
z accelerometer scale error (ppm)



x gyro bias (deg/hr)



y gyro bias (deg/hr)



z gyro bias (deg/hr)

