Everglades National Park Lidar

Report Produced for U.S. Geological Survey

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Executive Summary

Dewberry was tasked with developing a consistent and accurate topographic and bathymetric (topobathymetric) elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the USGS Everglades National Park (ENP) in Florida.

The lidar data were processed and classified according to project specifications. Topobathymetric Digital Elevation Models (DEMs) were produced for the project area. Data were formatted according to tiles with each tile covering an area of 1000 m by 1000 m. A total of 3,320 tiles were produced for the project encompassing an area of approximately 1,211 sq. miles.

THE PROJECT TEAM

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

Dewberry's William D. Donley completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints and ground control points for the project. Surveyed checkpoints were acquired to use in independent testing of the vertical accuracy of the lidar-derived model and surveyed ground control points were acquired to use for lidar calibration processes. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see Appendices A and B to view the separate Survey Reports that were created for this portion of the project.

SURVEY AREA

The project area addressed by this report falls within Florida Everglades National Park, located in the counties of Monroe and Miami-Dade.

DATE OF SURVEY

The lidar aerial acquisition was conducted from April 19, 2017 to June 12, 2017.

COORDINATE REFERENCE SYSTEM

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

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 17
Units: Horizontal units are in meters, Vertical units are in meters.
Geoid Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Everglades National Park Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **3.6 cm** compared with the 10 cm specification;

and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **7 cm**, compared with the 19.6 cm specification.

For the Everglades National Park Lidar Project, the Bathymetric Vertical Accuracy of the classified lidar was not a testing requirement. Survey checkpoints identified as bathymetric were delivered for testing. Dewberry used these points for internal production processing, however the points were not survey grade and were not used for bathymetric vertical accuracy testing.

For the Everglades National Park Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to **35 cm,** compared with the 29.4 cm specification.

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

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Project Extents, including buffered boundary, tile grid, and a shapefile derived from the lidar deliverable (Shapefiles)
2. Breakline Data (GDB and Shapefiles)
3. Classified Point Cloud Data (Tiled)
4. Bare Earth Surface Tiled Topobathymetric DEMs with voids enforced (IMG)
5. Digital Surface Models (IMG)
6. Intensity Images for Green Sensor Data and NIR Sensor Data (Tiled, GeoTIFF)
7. Low Confidence polygons (Shapefile)
8. Raw color imagery frames (GeoTIFF)
9. Independent Survey Checkpoint Data (Report, Photos, Point Shapefile, & Coordinates Spreadsheet)
10. Calibration Points (Report, Photos, Point Shapefile, & Coordinates Spreadsheet)
11. Metadata (XML)
12. Final Project Report (Acquisition, Processing, QC)

PROJECT TILING FOOTPRINT

Three thousand three hundred twenty (3,320) tiles were delivered for the project. Each tile's extent is 1,000 meters by 1,000 meters (see Appendix C for a complete listing of delivered tiles).

Figure 1 – Project Map

OVERVIEW OF CLASSIFICATION

The classification schema used during manual editing and also the schema used for the final LAS delivered to USGS as required by the project's scope of work in conjunction with ASPRS standards for bathymetric classification is listed below.

Lidar Classification – Manual Editing and Final Deliverables	
Class	**Description**
Class 1	Processed, but unclassified (includes buildings and vegetation)
Class 2	Bare-earth ground
Class 7	Low Noise
Class 9	Water
Class 17	Bridge Decks
Class 18	High Noise
Class 40	Bathymetric Bottom
Class 41	Water Surface
Class 45	No bathymetric bottom found (water column)

Table 1 - Final lidar classification schema

Lidar Acquisition Report

Dewberry elected to perform the lidar acquisition and calibration activities. Dewberry was responsible for performing lidar acquisition and calibration of lidar data files.

LIDAR ACQUISITION DETAILS

Dewberry planned 124 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Dewberry followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Riegl ALS 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, Dewberry will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Dewberry 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. Dewberry accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensors to maximize successful data acquisition. Due to flight restrictions in Everglades National Park, no missions were conducted during night hours.

Within 72-hours prior to the planned day(s) of acquisition, Dewberry 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.

Dewberry lidar sensors are calibrated at a designated site in Kissimmee, Florida and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Dewberry operated a Navajo Aircraft (Tail # C-GKCN) outfitted with a Riegl VQ820G and Riegl LMS Q680i duel lidar system configuration during the collection of the study area. Table 2 illustrates Dewberry system parameters for lidar acquisition on this project.

Item	Parameter	Parameter
System	Riegl VQ820G	Riegl LMS Q680i
Altitude (AGL meters)	400	400
Approx. Flight Speed (knots)	130	130
Scanner Pulse Rate (kHz)	522	400
Scan Frequency (hz)	200	191
Pulse Duration of the Scanner (nanoseconds)	1.2	3
Pulse Width of the Scanner (m)	0.36	0.9
Swath width (m)	307	462
Central Wavelength of the Sensor Laser (nanometers)	532	1550
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes	Yes
Beam Divergence (milliradians)	1	1
Nominal Swath Width on the Ground (m)	307	462
Swath Overlap (%)	30	30
Total Sensor Scan Angle (degree)	60	60
Computed Down Track spacing (m) per beam	0.45	0.63
Computed Cross Track Spacing (m) per beam	0.25	0.18
Nominal Pulse Spacing (single swath), (m)	0.35	0.35
Nominal Pulse Density (single swath) (ppsm), (m)	8	8
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.35	0.35
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	8	8
Maximum Number of Returns per Pulse	Unlimited	Unlimited

Table 2 - Dewberry lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

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

Figure 2 shows the combined trajectory of the flightlines.

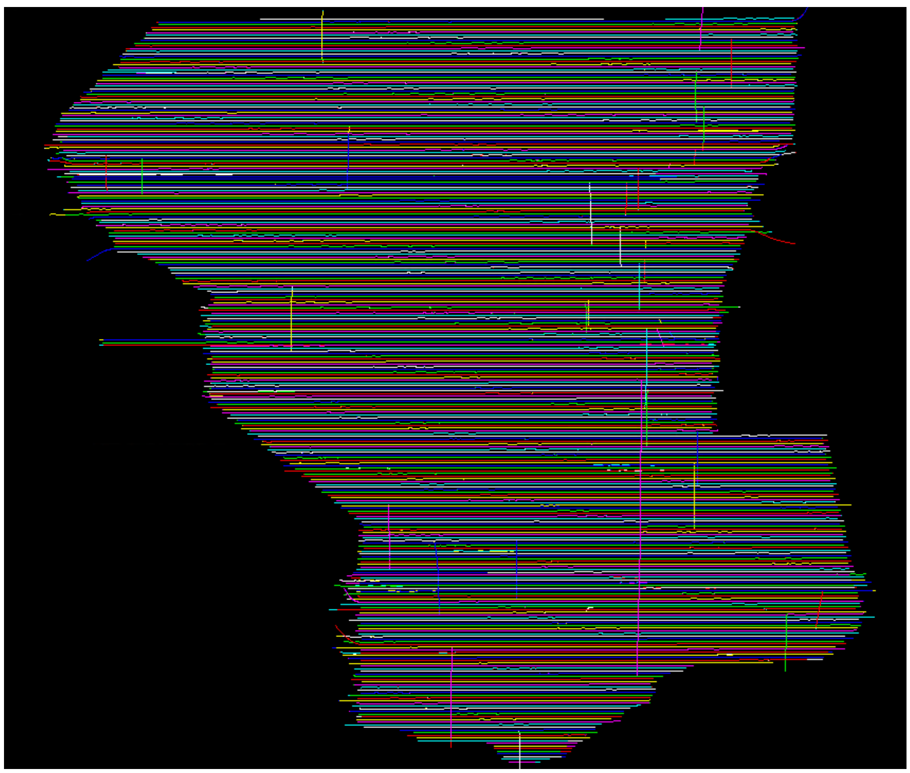


Figure 2: Trajectories as flown by Dewberry

LIDAR CONTROL

Dewberry deployed static GPS base stations during the acquisition of the Everglades National Park. Considerations were made for location access and clear visibility of the horizon. Additionally these static sessions were recorded at 1 Hz samples for the highest quality post processed solution. These static base sessions were then incorporated during the kinematic post-processing of aircraft position. These base stations were either set on existing control monumentation, or new benchmarks established. The coordinates of these base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	NAD83 (2011) UTM 17		Ellipsoid Ht (NAD83 (2011), m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
7119	545250.45	2820522.10	-22.868	1.795
AC0526	518658.29	2849337.17	-20.758	3.405
Home	545211.71	2820507.07	-19.138	5.527

Table 3 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the PosPac kinematic On-The-Fly (OTF) software suite. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40 km.

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

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

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

Subsequently the mission points are output using Riegl RiProcess, initially with default values from Riegl or the last mission calibrated 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 scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

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

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

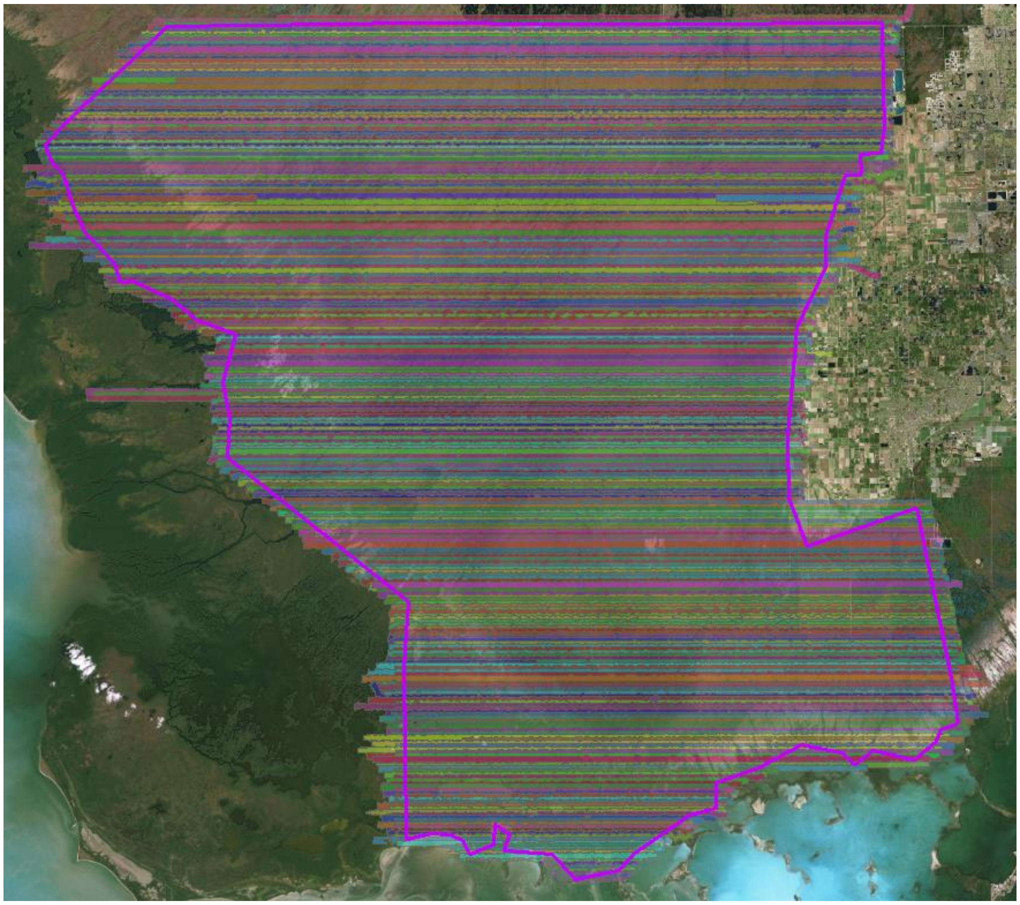


Figure 3 – Lidar swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

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

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

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

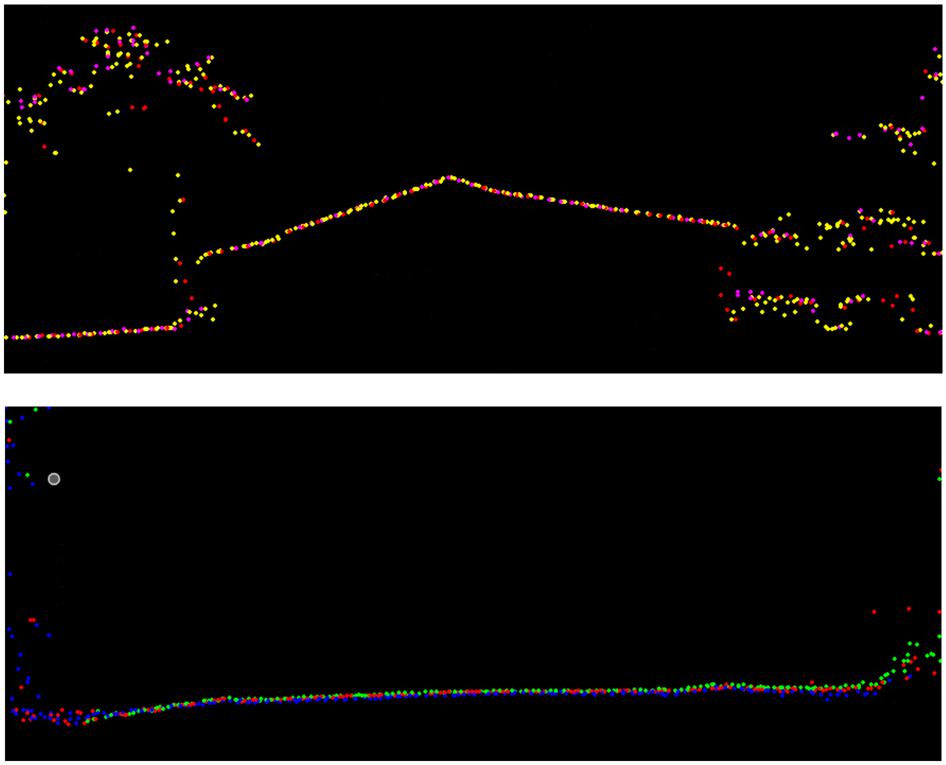


Figure 4 – Profile views showing correct roll and pitch adjustments.

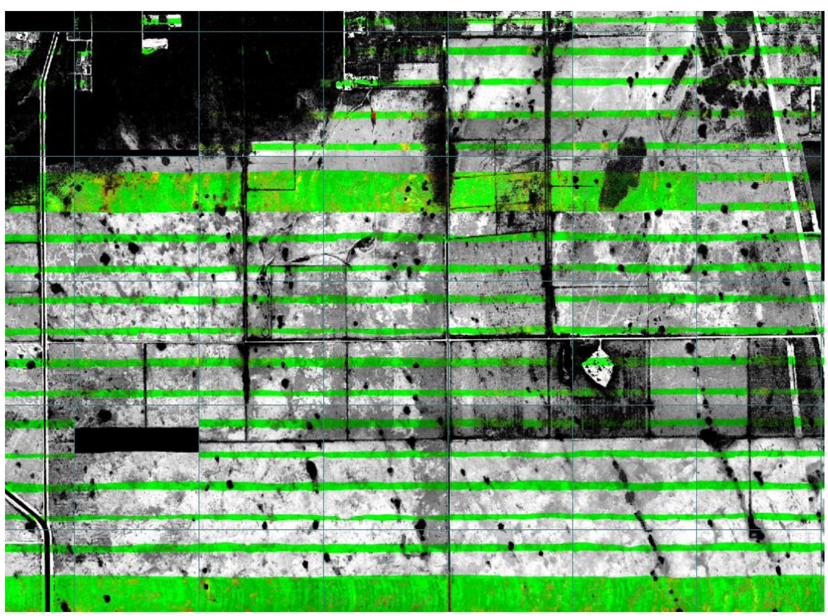


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

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

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

The calibrated Everglades National Park lidar dataset was tested to 0.064 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.10 m x 1.9600) when compared to 47 GPS static check points.

The following are the final statistics for the GPS static ground control points used by Dewberry to internally verify vertical accuracy.

Number	NAD83 (2011) UTM 17N		NAVD88 (Geoid 12B)	Laser Z (m)	Delta Z
	Easting X (m)	Northing Y (m)	Known Z (m)		
GCP-300	513849.390	2788034.780	1.100	1.060	-0.040
GCP-302	518915.380	2791439.940	1.050	1.010	-0.040
GCP-303	520299.670	2794732.580	0.900	0.920	0.020
GCP-304	520299.110	2798228.870	0.970	0.990	0.020
GCP-305	518645.760	2802768.080	1.030	1.030	0.000
GCP-306	518949.930	2807015.560	0.970	0.940	-0.030
GCP-307	521261.730	2809820.740	1.170	1.190	0.020
GCP-309	528070.620	2812364.740	0.810	0.850	0.040
GCP-311	534577.490	2809133.990	1.570	1.560	-0.010
GCP-312	539248.840	2807455.320	1.400	1.370	-0.030
GCP-313	541739.320	2808653.000	1.400	1.440	0.040
GCP-314	552212.710	2806533.260	1.300	1.310	0.010
GCP-315	541273.100	2811431.220	2.350	2.310	-0.040
GCP-316	541219.440	2816117.060	2.530	2.520	-0.010
GCP-317	542820.030	2820364.800	3.500	3.510	0.010
GCP-318	542771.510	2825889.070	3.520	3.550	0.030
GCP-320	542606.380	2833991.360	2.400	2.440	0.040
GCP-321	547852.700	2800345.880	0.780	0.770	-0.010
GCP-322	550992.590	2798878.540	1.050	1.020	-0.030
GCP-324	541989.340	2849188.480	2.180	2.160	-0.020
GCP-325	539660.340	2849260.110	2.490	2.510	0.020
GCP-326	537386.870	2849255.010	2.460	2.410	-0.050
GCP-327	535988.080	2849251.580	2.460	2.460	0.000
GCP-328	533629.880	2849246.620	2.450	2.490	0.040
GCP-330	523464.490	2849095.840	2.390	2.370	-0.020
GCP-333	522635.970	2849301.040	3.160	3.190	0.030

GCP-334	521065.030	2849215.860	2.800	2.720	-0.080
GCP-335	520419.130	2849316.390	3.890	3.890	0.000
GCP-336	519210.430	2849207.620	2.730	2.710	-0.020
GCP-338	517230.220	2849196.130	2.810	2.820	0.010
GCP-341	513797.780	2849175.990	2.610	2.590	-0.020
GCP-344	510105.450	2849252.510	2.150	2.220	0.070
GCP-345	508084.220	2849245.260	2.570	2.590	0.020
GCP-346	506542.610	2848187.160	2.100	2.120	0.020
GCP-347	504289.630	2847731.780	2.450	2.430	-0.020
GCP-348	499416.890	2849144.440	2.070	2.070	0.000
GCP-349	493187.810	2849145.990	1.880	1.860	-0.020
GCP-400	538008.760	2806640.440	0.710	0.770	0.060
GCP-401	547760.570	2807599.480	1.850	1.840	-0.010
GCP-405	551014.160	2802738.790	1.460	1.430	-0.030
GCP-406	550284.180	2840759.170	4.380	4.380	0.000
GCP-407	550420.700	2846100.710	4.630	4.600	-0.030
GCP-408	523526.740	2848815.620	2.720	2.680	-0.040
GCP-409	532830.820	2840670.720	3.540	3.590	0.050
GCP-410	532865.020	2845038.190	3.810	3.830	0.020
GCP-411	550298.640	2849283.860	2.930	3.000	0.070
GCP-412	496428.720	2846318.480	0.980	0.970	-0.010

Table 4 - Static GPS Ground Control Points

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	NVA at 95% Spec=0.196 m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	47	0.033	0.064	0.001	0.033	-0.080	0.070

Table 5 - Static GPS Ground Control Vertical Accuracy Results

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

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

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

Refraction Correction

Bathymetric data must have a refraction correction applied, which corrects the horizontal and vertical (depth) positions of each data point by accounting for the change in direction and speed of light as it enters and travels through water. The refraction correction was performed by Dewberry using the proprietary tool Dewberry's Lidar Processor (DLP).

Final Swath Vertical Accuracy Assessment

Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the sixty (60) non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the Florida Everglades National Park Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 4.3 cm, equating to +/- 8.5 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	RMSEz NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy (RMSEz x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	60	0.043	0.085	0.016	0.017	0.005	0.040	-0.084	0.104	-0.204

Table 6 - NVA at 95% Confidence Level for Raw Swaths

One checkpoint (NVA-151) was removed from the raw swath vertical accuracy testing due to its location underneath a parked vehicle. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While NVA-151 is located in open terrain, the parked vehicle is modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing so this point was removed from the final calculations. Once the data underwent the classification process, the car was removed from the final ground classification and this point could be used in the final vertical accuracy testing for the fully classified lidar data. Table 7, below, provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. Table 8, below, provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 6, below, shows a side profile of the lidar point cloud and the location of the checkpoint beneath the parked vehicle in the survey photo.

Point ID	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA-151	544035.935	2849277.208	2.608	3.720	1.112	1.112

Table 7 - Checkpoint removed from raw swath vertical accuracy testing

Point ID	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA-151	544035.935	2849277.208	2.608	2.580	-0.028	0.028

Table 8 - Final tested vertical accuracy for NVA-151 post ground classification

Figure 6 – Survey photo of NVA checkpoint 151 (left image) and profile view of the lidar with point location (right image). Checkpoint 151 is located underneath a parked vehicle. This point was removed from raw swath vertical accuracy testing because above ground features, including vehicles, have not been separated from the ground classification yet.

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL1 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. Bathymetric areas may be yellow or red due to varying elevations of returns within the water column. Large or continuous sections of yellow or red pixels following flight line patterns and not the terrain, vegetation, or bathymetric areas 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 Florida Everglades National Park Lidar Project are shown in the figure below; this project meets inter-swath relative accuracy specifications.

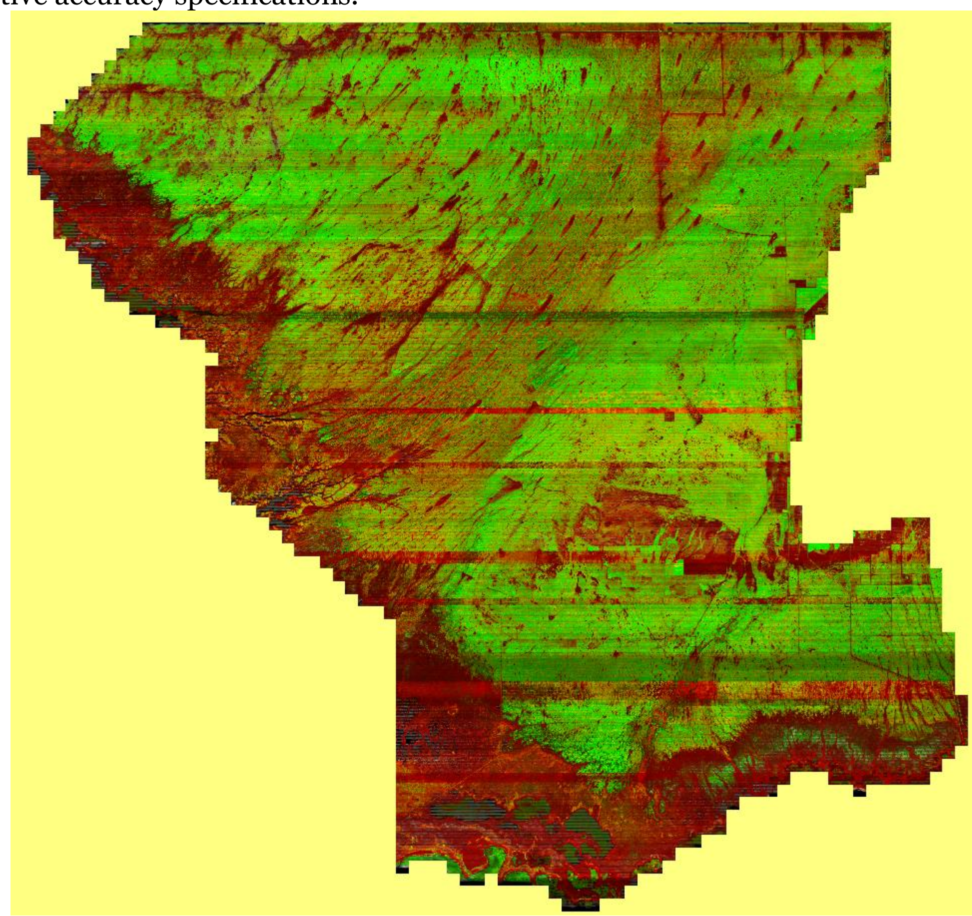


Figure 7 – Single return DZ Orthos (combined green and near infrared sensors) for the Florida Everglades National Park Lidar Project. Offsets between flight lines of 0-8 cm are green, 8-16 cm are yellow, and above 16 cm are red. Larger offsets in vegetated and bathymetric areas are expected as different returns from water column and vegetation can occur between different flight lines. Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL1 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The image below shows two examples of the intra-swath relative accuracy of Everglades National Park Lidar project; this project meets intra-swath relative accuracy specifications.

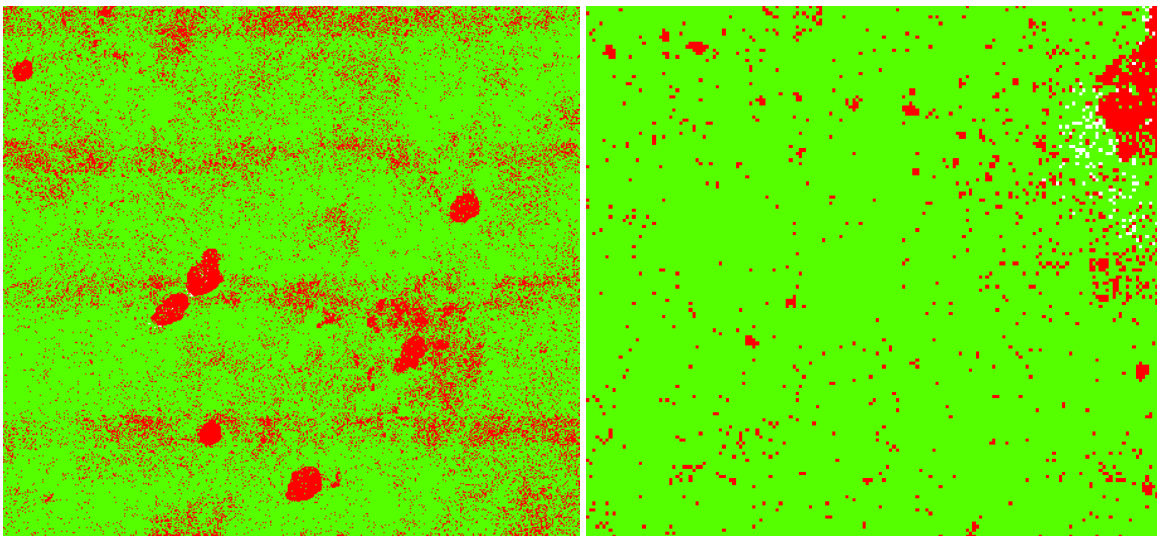


Figure 8 – Intra-swath relative accuracy. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of tree islands (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

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

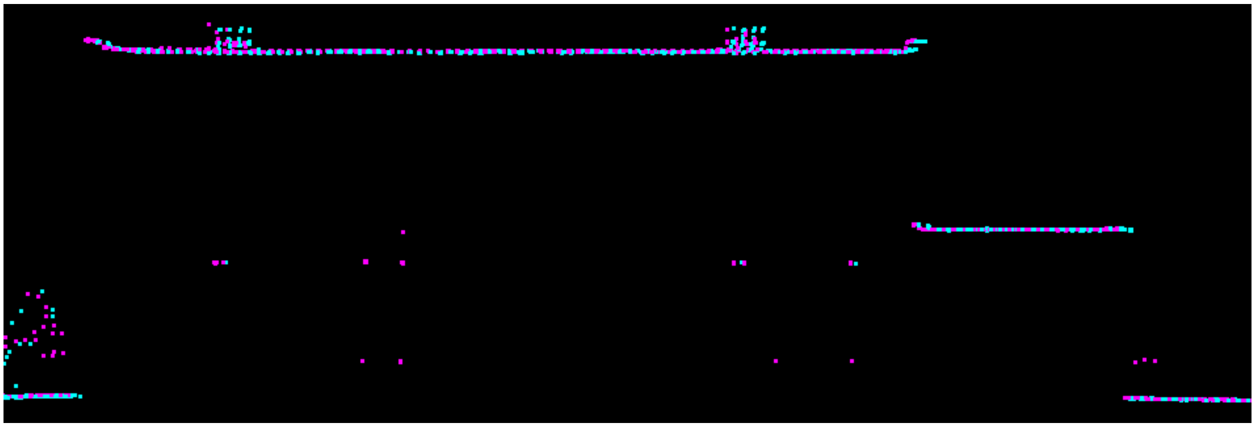


Figure 9 – Horizontal Alignment. Two separate flight lines differentiated by color (Teal/Purple) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

For topographic areas, the required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.35 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 8 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have a combined topobathy ANPS of 0.22 meters or an ANPD of 21.15 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 8 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

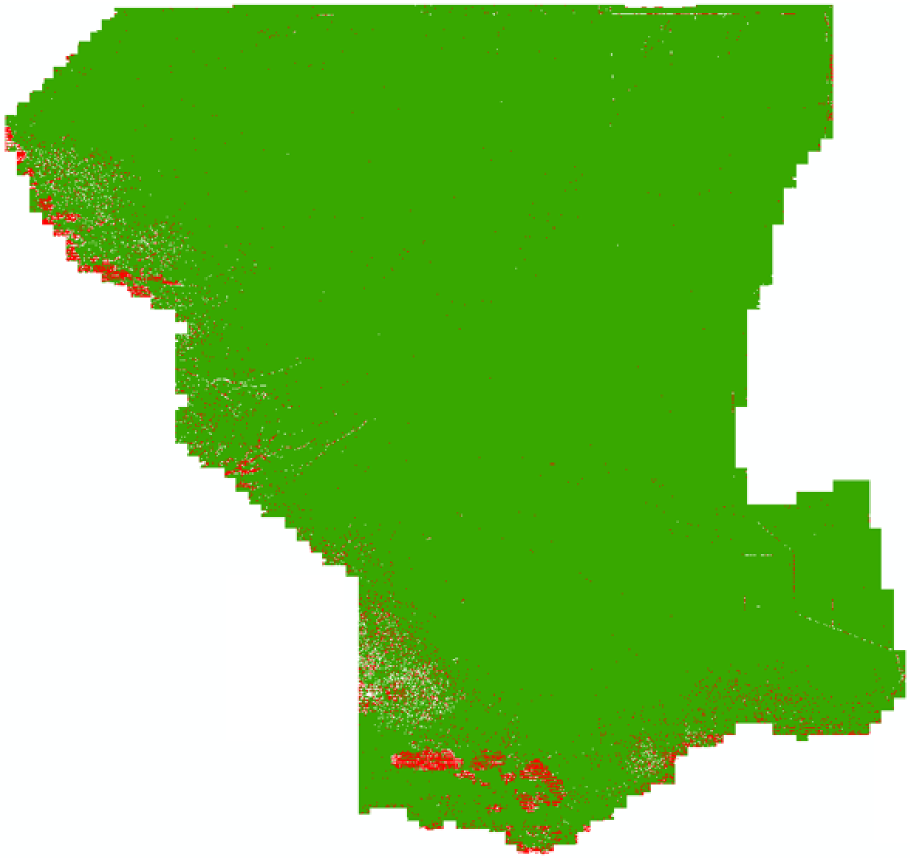


Figure 10 – 1-square meter density grid. There are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 8 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

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

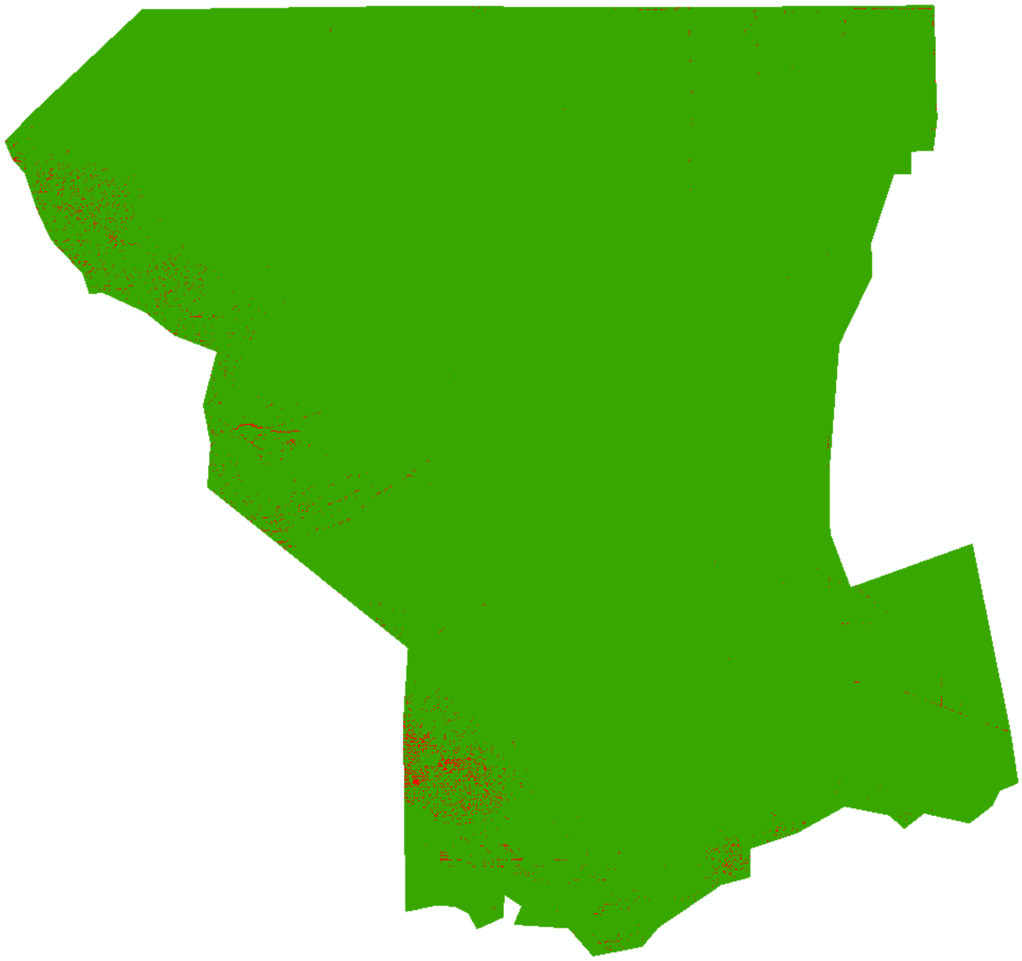


Figure 11 – Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point are colored red. 99.5% of cells contain at least one lidar point.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry used 2D digitization to collect breaklines for this project. Green sensor intensity imagery, near infrared (NIR) intensity imagery, bare earth ground models, LAS datasets, and density models were produced to assist with breakline delineation. Breaklines were collected following USGS Base Specifications for collection – inland ponds and lakes 2 acres or greater surface area, and inland streams and rivers 100 feet nominal width.

Hydrologic features meeting collection size requirements were determined using the near infrared intensity imagery, which identifies wet features at the time of data collection. Green intensity imagery was used to determine where bathymetric data was present, along with drawing profiles using the lidar point cloud.

Refraction requirements were determined between Dewberry and the client. Hydrologic features meeting USGS collection size requirements and also containing bathymetric data deeper than 50 cm were refracted. Bathymetric data within locations of refraction follow the ASPRS topographic-bathymetric point classification schema.

Hydrographic breaklines are delivered in three feature classes/shapefiles. They are discussed below. Bridge saddle breaklines were also collected where necessary and are discussed in the DEM Qualitative Review section of this report.

Inland Water Voids

These polygons are located where no bathymetric data were found in the lidar. Any points within these polygons that were grounded by the initial grounding macro were reclassified to point class 9: water. In the final topobathy DEMs, these locations are represented as voids and set to No Data.

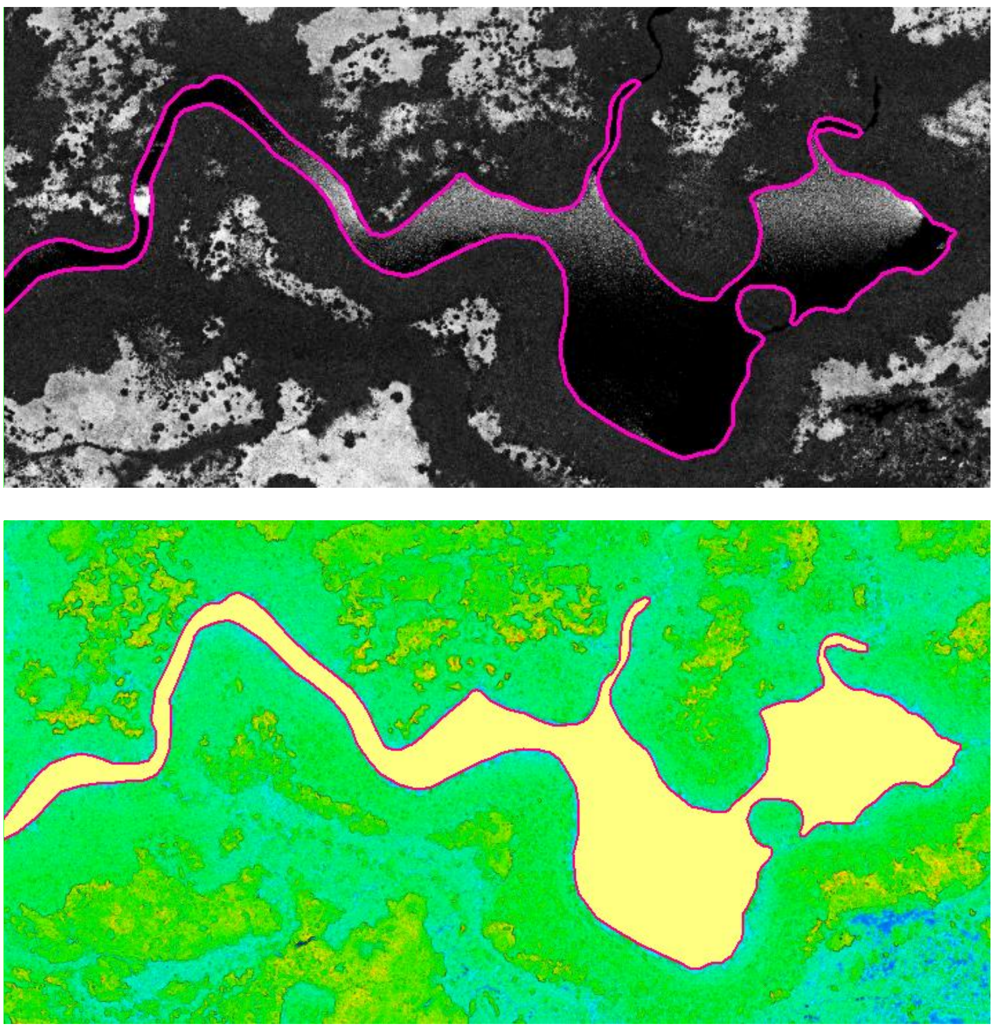
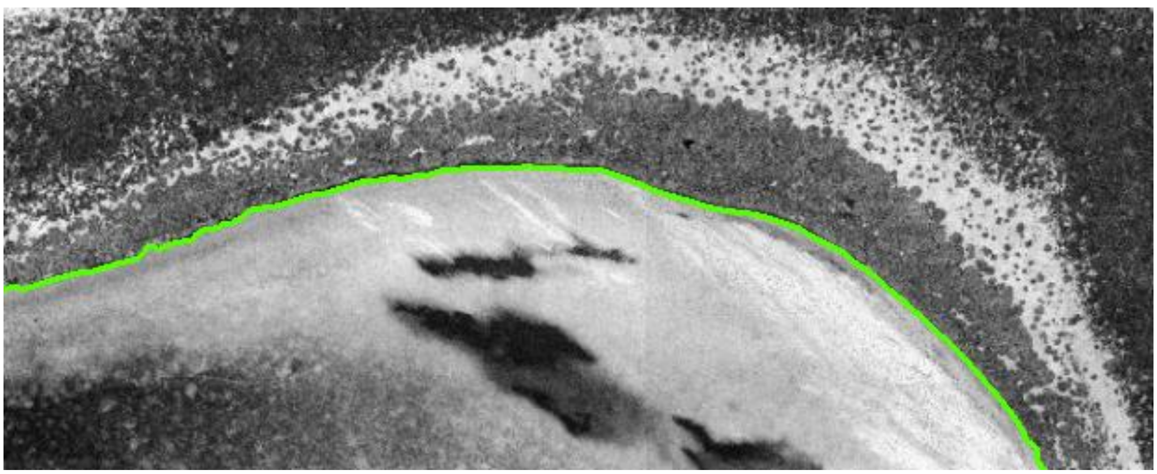


Figure 12 - Tiles 17RMJ980210 and 17RMJ980200. Near infrared intensity image and inland water void (pink) representing hydrologic feature where no bathymetric data were found (top image). The initial ground points were reclassified to class 9: water, and are represented as No Data voids in the topobathy DEMs (bottom image).

Land/Water Interface

These polygons are located where bathymetric data were found in the lidar that is deep enough to require refraction (i.e. deeper than 50 cm). Dewberry's internal refraction tool corrects the horizontal and vertical (depth) positions of each data point by accounting for the change in the speed of light as it travels through water and the change in angle or direction as light enters the water. The refraction tool is applied to the Green sensor data. Because the LAS is a combination of the NIR and Green sensor data, Dewberry applied a topobathy classification schema to the NIR points within these polygons so all lidar points within these polygons follow the ASPRS topobathy classification schema.

Class 40 – Bathymetric point (submerged topography)
Class 41 – Water Surface (distinct from point class 9, which is used in topographic-only lidar and only designates "water", not "water surface")
Class 45 – No-bottom-found-at (bathymetric lidar point for which no detectable bottom return was received)



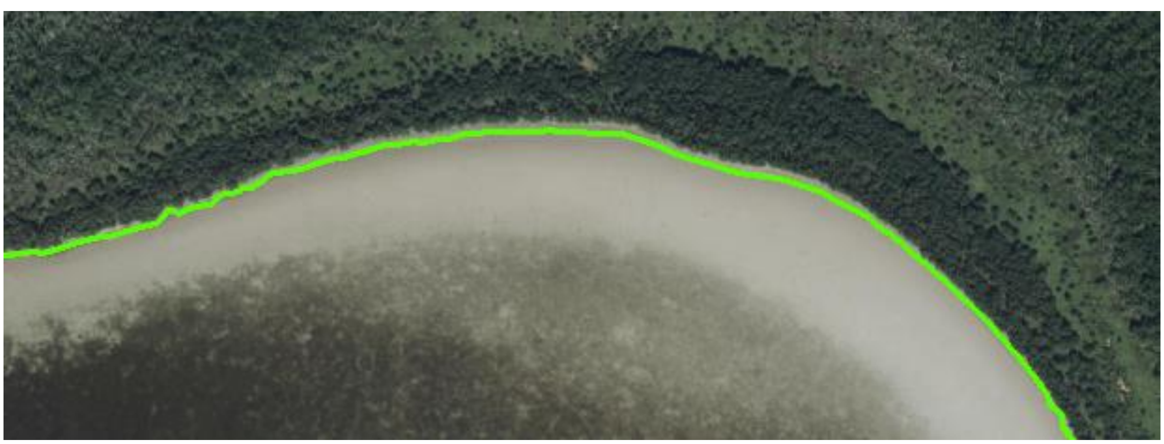


Figure 13 - Tiles 17RNH210830 and 17RNH220830. Green intensity image and land/water interface breakline (green) representing hydrologic feature where refraction correction was performed on bathymetric data (top image). Basemap with land/water interface (bottom image).

Topobathy Voids

These polygons are located within the land/water interface breaklines used for refraction, and are located where no submerged bottom data were found in the lidar. Points within these polygons follow the same classification schema used in the land/water interface breaklines. In the final topobathy DEMs, these locations are represented as voids and set to No Data.

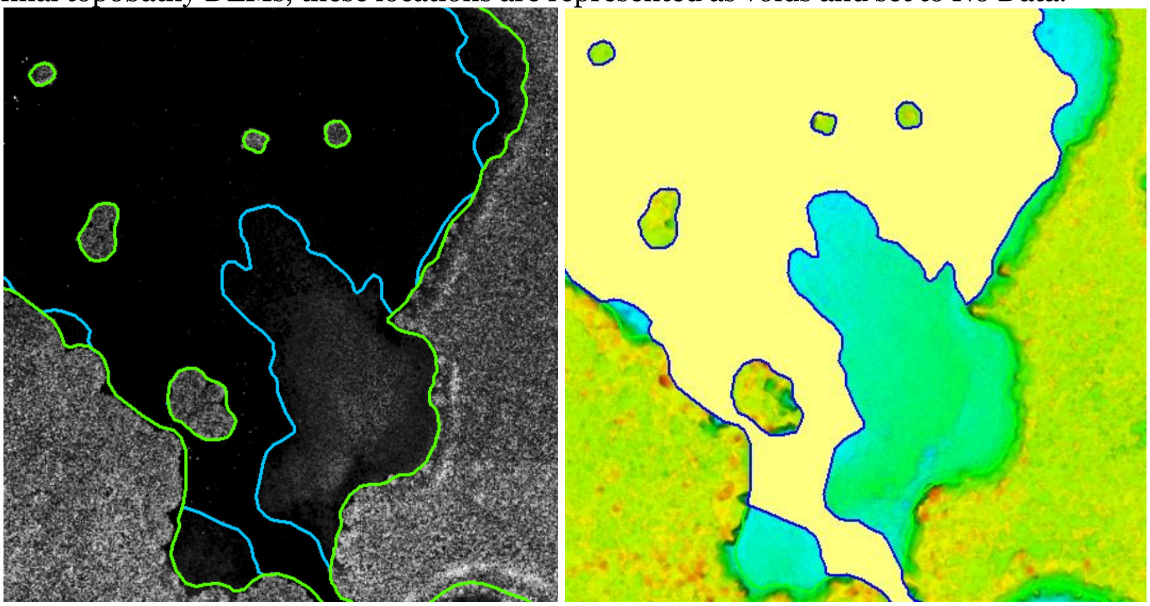


Figure 14 - Tile 17RNH400890. Green intensity image, land/water interface breakline (green), and topobathy voids (blue) representing hydrologic feature where refraction correction was performed on bathymetric data and locations with no bathymetric data were delineated as voids (left image). Locations where no bathymetric data are found are reclassified to class 45: no bottom found, and are represented as No Data voids in the topobathy DEMs (right image).

BREAKLINE CHECKLIST

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

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).
Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains.

Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Perform all Topology and Data Integrity Checks

Table 9 - A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. Data processing included breakline creation to define the land/water interface, automated and manual editing of the lidar tiles, QA/QC, and final formatting of the LAS files.

GeoCue and Terrascan Processing

Next 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 to create the initial automated ground and bathy bottom classifications, using the final project classification schema.

This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

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

The final breaklines defining the land/water interface are then used to perform refraction correction and classify "ground" points within the water breaklines as bathymetric bottom. The breaklines are also used as part of the classification routines to ensure water surface and water column points are classified correctly.

Each tile was then imported into Terrascan and a surface model was created to examine the ground (class 2) and bathy bottom (class 40) classification. 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 and that class 40 accurately represents submerged topography. Dewberry analysts visually reviewed the surface models and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Common errors in the bathymetric classification that were corrected by Dewberry include some of the issues outlined below.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise
- Class 40 = Bathymetric Bottom
- Class 41 = Water Surface
- Class 45 = No bathymetric bottom found (water column)

Special attention was given along shorelines or the land/water interface as no hard edges or seams should exist between ground and bathy bottom.

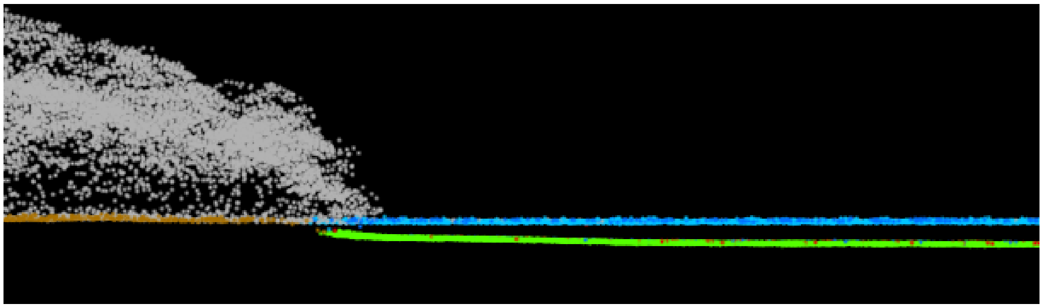


Figure 15 - The land water interface should be seamless with no hard edges or seamlines. The topobathy surface model is shown in the top image with a profile location overlaid. The LAS profile is shown in the bottom image where bathy bottom points are green, water surface points are blue, ground points are orange, and unclassified points are grey.

Areas of rapids or swift moving water may also need to be removed from the bathy bottom class as these may be surface or water column points and not bathy bottom points due to the water movement and stirring of sediment (increased turbidity). When possible, color orthos were used to help determine water clarity and likelihood of full penetration to the submerged bottom. Generally, editors looked for consistency in data, especially continuous topography (connecting the dots method to ensure channel geometry is reasonable).

Special attention was given in deeper areas where there may not be any true bathy bottom points, but the automated algorithm classified lower water column points as bathy bottom. When evaluating points to determine if they are low water column points or true bathy bottom, the following rules were used as guidelines to maintain accuracy and consistency:

1. Gradient consistency-if the points are part of consistent gradients or consistent channel geometry, they are more likely to be bathy bottom rather than low water column noise. Conversely, points that would cause abrupt changes or inconsistency in the overall gradient or channel geometry are less likely to be bathy bottom points, especially if the abrupt change would result in shallower (higher) bathy bottom points above lower bathy bottom points with a high confidence.

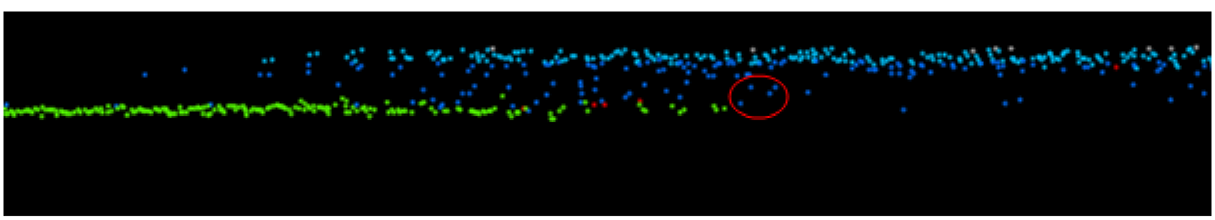


Figure 16 - Bathy Bottom points (green) are shown with water column (dark blue) and water surface points (light blue) in this profile. The four water column points circled in red would cause inconsistent and upward changes in the topobathy model if these points were classified to bathy bottom. These points should remain classified as water column.

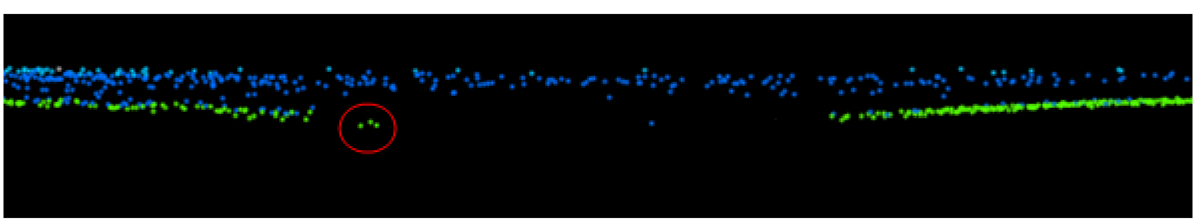


Figure 17 - Bathy Bottom points (green) are shown with water column (dark blue) and water surface points (light blue) in this profile. The bathy bottom points circled in red are isolated, but maintain a consistent gradient with other bathy bottom points to the east. These points should remain classified as bathy bottom.

Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

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

Submerged Objects

No submerged objects were identified during editing and review of the lidar data, therefore no points were classified to class 43 or class 44.

Temporal Changes

Changes in the bathymetric bottom surface can result from differences between collection periods due to factors such as currents moving sediment. However, Dewberry did not identify any significant temporal changes in this project.

Lidar Qualitative Assessment

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

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for the Everglades National Park lidar project.

NIR Depressions

Marsh areas within the project contain east-west strips of minimally "depressed" NIR data at nadir. The cause of these artifacts is due to incorrect range values due to highly reflective, extremely shallow water. This is evident in the NIR intensities – where this artifact occurs in the NIR intensity is very bright. This bright strip of nadir intensity is a typical signature of a wetter surface. Due to the extremely high intensity, the intensity based range corrections become less valid. Since the water has no depth, the green data is not lower than the NIR, thus the artifact appears. Dewberry minimized these NIR depressions by filtering based on the scan angle and intensity properties, the relationship of the NIR below the green dataset, and its isolation within a single flightline's points. An example is shown below.

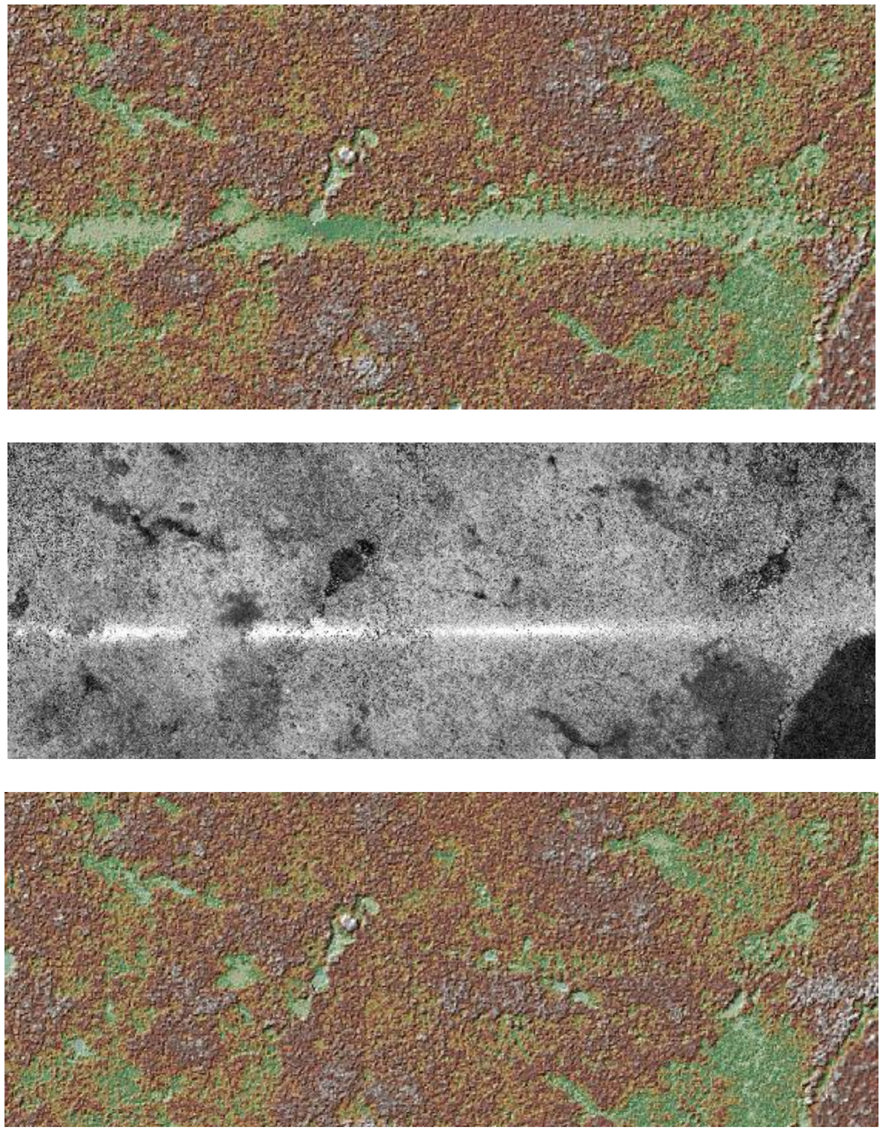
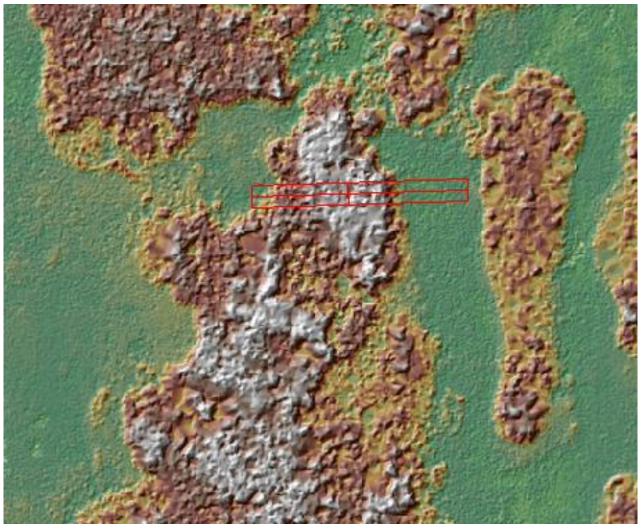


Figure 18 – Tile 17RNJ130080. NIR depressions originally identified in the initial ground DEMs (top image). These locations are represented by very bright strips in the NIR intensity imagery (middle image). Filtering methods resulted in minimized effects of the NIR depressions (bottom image).

Excessive Vegetation

Dewberry identified locations of very dense low-lying vegetation within the project area. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The higher points were removed from ground and the lower points were left as ground due to the difficulty of delineating where the true ground ended and the low-lying vegetation began. An example of this low-lying vegetation in the project area is shown below.



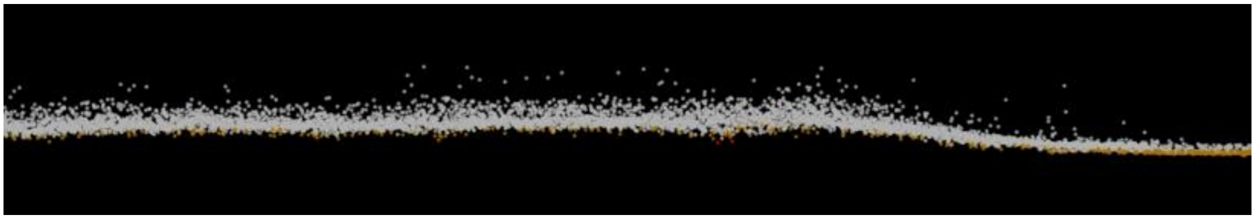
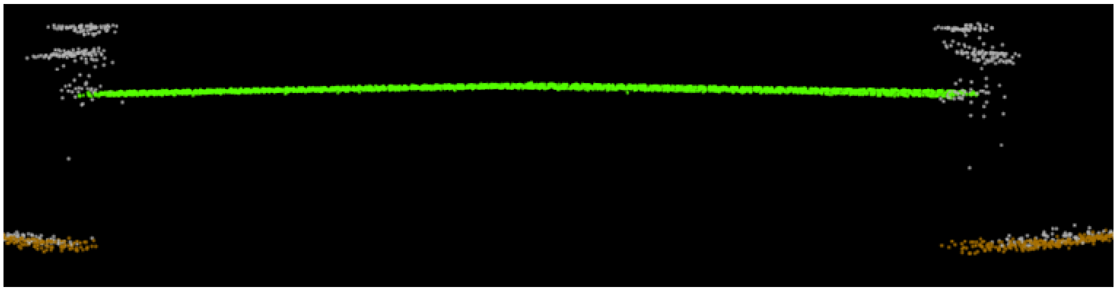


Figure 19 – Tile 17RNH340960. Bare earth topobathy DEM showing location of low-lying dense vegetation in Everglades National Park (top image). The LAS profile (bottom image) shows higher points were removed from ground and the lower points were left as ground in the final classification schema.

Bridge Removal Artifacts

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



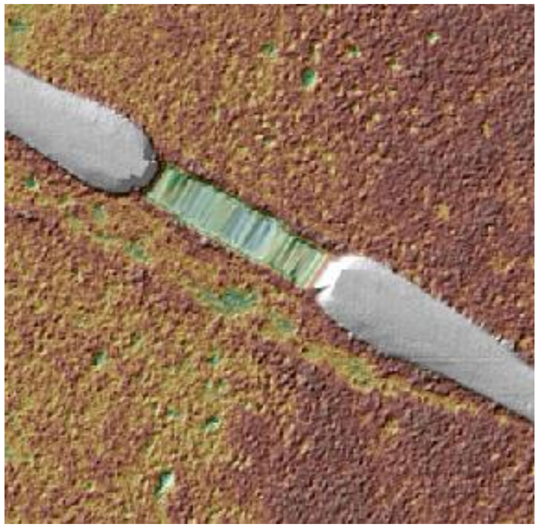
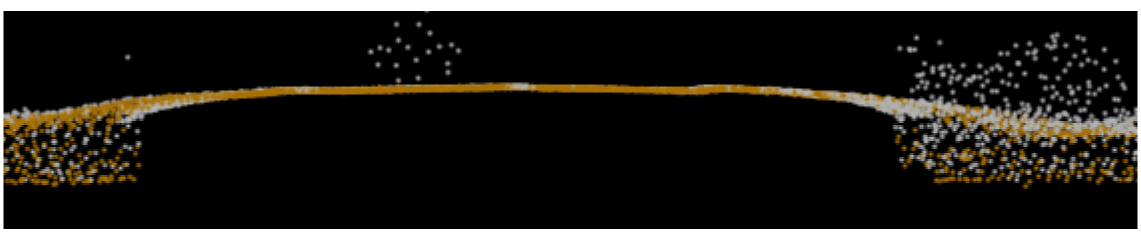


Figure 20 –Tile number 17RNJ390090. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points (green) have been removed from ground (orange) and are classified as bridge deck.

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.



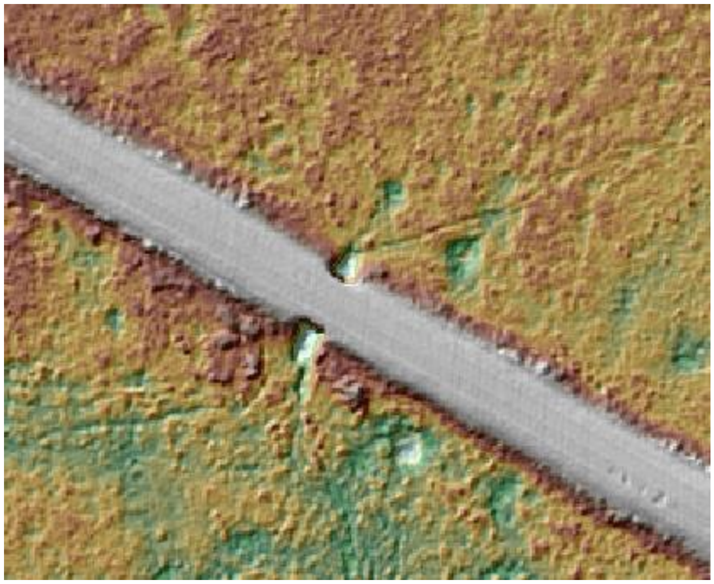


Figure 21 – Tile number 17RNJ390090. Profile with points colored by class (class 1=grey, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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.

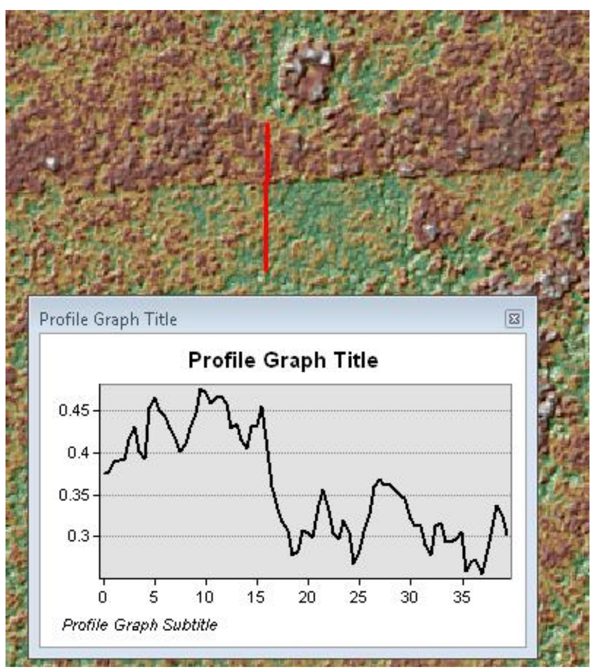


Figure 22 – Tile number 17RNJ200070. The flight line ridge is less than 8 cm. Overall, the Florida Everglades National Park lidar data meets the project specifications for 8 cm RMSE relative accuracy.

Formatting

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

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) UTM Zone 17N, meters and NAVD88 (Geoid 12B), meters in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 17: Bridge Deck Class 18: High Noise Class 40: Bathymetric Bottom Class 41: Water Surface Class 45: No bathymetric bottom found (water column)	Pass
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Derivative Lidar Products

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

INTENSITY IMAGERY

Full point cloud intensity images were generated in the GeoCue software of both the Green sensor and the Near Infrared (NIR) sensor data. Each image contains a respective world file to georeference the raster map image. Intensity images are delivered in 8-bit, 256 color gray scale, and GeoTIFF format.

The NIR intensity imagery contains strips of data drop-outs in localized areas. An example of this is shown below. These data drop-outs do not impact the usability of the final lidar data as these data are present in the Green lidar data; the full point cloud consists of data from both the NIR and Green lidar sensors.

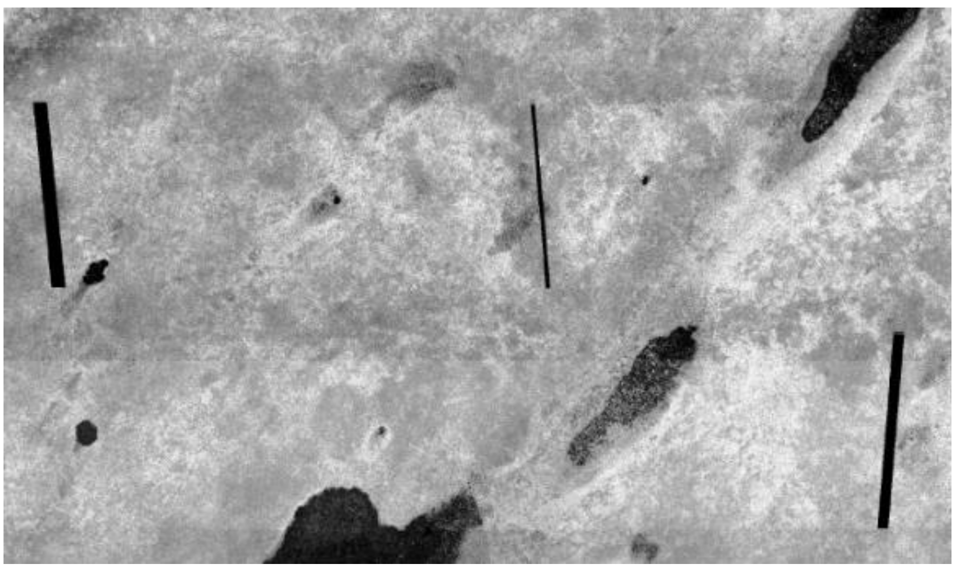


Figure 23 – The intensity imagery of the NIR sensor data contain small black strips in several localized areas. These strips are where drop-outs occurred during collection of the NIR data. This does not impact the coverage of the lidar and is only visible in the intensity imagery of the NIR sensor data. The Green sensor lidar data was combined with the NIR sensor lidar data to create complete coverage of the lidar point cloud. The combined data has been verified to meet project specifications. There are no detrimental effects to the DEM or any derivative products aside from the artifacts in the NIR intensity imagery.

LOW-CONFIDENCE POLYGONS

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

Lidar Positional Accuracy

BACKGROUND

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

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

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred thirty eight (138) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, forested/fully grown, and submerged topography land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

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

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

Point ID	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
100	543079.597	2836710.724	3.385

101	547314.001	2837248.061	1.607
102	546793.713	2835637.593	1.606
103	545750.175	2832407.957	2.17
104	542664.056	2832427.138	2.338
106	542756.182	2822474.292	3.203
107	542810.294	2817792.76	2.856
108	542866.728	2812729.445	1.818
118	520306.625	2800382.673	0.883
120	527594.236	2808089.378	0.34
122	533607.061	2808098.151	1.293
123	541002.767	2807498.292	0.887
124	543836.915	2805488.588	1.023
125	543714.578	2800572.493	1.19
126	547816.23	2804003.615	2.227
128	550898.076	2806522.064	1.086
129	553937.03	2806554.035	1.304
130	555680.231	2797122.754	0.655
131	550957.355	2799162.547	0.543
148	515034.473	2788702.555	0.862
150	520348.953	2793107.853	0.66
158	530381.44	2849373.802	3.25
161	523434.366	2837818.879	1.865
413	544411.242	2807928.587	2.233
414	546485.02	2806069.545	2.482
415	547771.676	2801713.161	2.099
417	538007.777	2806509.318	0.82
105	542686.165	2827526.839	2.288
109	543026.282	2809128.916	2.262
110	538851.84	2809933.277	1.318
111	535509.582	2811173.343	1.646
112	532162.45	2811832.531	1.669
113	528735.225	2813307.196	1.679
114	524791.751	2813000.11	1.27
115	523030.728	2812348.82	1.351
116	521825.291	2813724.038	1.082
117	518134.545	2805267.915	0.979
119	520171.164	2796284.377	0.952
121	531554.389	2806039.417	1.323
127	550179.266	2808610.684	0.809
132	514356.183	2849179.277	2.747
133	517304.704	2849334.301	4.19
134	519410.489	2849313.902	3.999
135	520397.028	2849187.798	2.967

136	522567.263	2849303.614	3.006
137	523518.875	2848795.892	3.015
143	506861.664	2848776.82	2.127
144	496434.481	2849026.74	2.45
145	500665.487	2849055.652	2.054
146	495246.924	2844988.406	0.798
147	512625.154	2787190.341	0.913
149	517775.761	2790677.638	0.951
151	544035.935	2849277.208	2.608
152	549985.732	2849319.656	2.931
153	525217.978	2849354.404	3.43
154	526026.249	2849358.576	3.372
155	527568.517	2849370.059	3.347
156	528720.247	2849370.459	3.373
157	529581.786	2849351.2	3.847
159	531651.615	2849371.261	3.774
160	532739.336	2849294.568	3.482
416	537995.121	2808117.983	1.811
138	512703.238	2843726.494	1.547
139	517995.585	2844025.513	1.771
140	521738.093	2843803.256	1.639
141	509960.513	2838598.562	0.797
142	514924.281	2838695.4	1.283
200	543237.474	2840111.177	1.381
201	550231.757	2840322.079	1.689
202	539299.42	2833878.331	1.422
203	534056.345	2831173.018	1.205
204	532428.572	2826333.015	1.193
205	538753.233	2826656.368	1.366
206	538665.872	2820200.088	1.058
207	534162.987	2819992.3	1.209
208	529540.564	2819935.575	0.936
209	523091.995	2819564.126	0.331
210	538659.449	2815534.591	1.168
211	520050.151	2808392.485	0.257
212	525060.416	2800464.228	0.045
213	529435.811	2800873.868	0.256
214	534339.091	2800656.344	-0.088
215	538619.367	2800661.432	0.119
216	548069.554	2796730.626	-0.382
217	543208.971	2795917.093	-0.383
218	537220.334	2794739.962	-0.324
219	531952.194	2794966.41	-0.46

220	529450.003	2790382.642	-0.452
221	524870.159	2794754.582	-0.369
222	520378.161	2838820.216	1.388
223	508007.545	2833812.838	0.283
224	514368.828	2834083.566	1
225	518816.481	2833409.753	1.043
226	503114.788	2828624.583	-0.155
227	509064.102	2828621.425	0.39
228	515997.196	2828393.11	0.759
229	499924.975	2824548.14	-0.181
230	508657.9	2824597.494	0.15
231	515466.944	2824466.811	0.433
232	505811.959	2820918.29	-0.186
233	505010.513	2844273.373	1.208
234	503130.446	2838283.069	0.407
235	495637.561	2839248.012	0.092
236	489696.599	2840072.175	-0.296
237	495068.279	2834814.668	-0.29
238	513115.321	2787735.451	-0.16
239	520415.845	2792098.225	-0.405
240	537823.674	2790559.953	-0.56
241	551893.47	2794082.512	-0.276
242	537786.183	2846853.293	1.439
243	543006.735	2845977.712	1.448
244	497670.07	2828390.52	-0.148
245	484791.681	2840655.307	-0.339
246	524886.565	2841735.417	1.417
247	531701.478	2840691.659	1.426
248	523019.874	2834496.691	1.144
249	532535.427	2835048.148	1.404
250	520898.525	2828596.78	0.781
251	527135.739	2827894.78	0.976
252	512772.221	2817421.751	-0.044
253	511048.181	2808496.606	-0.248
500	539946.127	2809333.181	-0.101
501	539720.076	2809443.736	-0.423
502	539281.652	2809708.186	-0.154
503	539060.758	2809809.728	-0.142
504	522668.671	2812703.647	0.003
505	522392.072	2812835.414	-0.057
506	522042.29	2813105.88	-0.182
507	522506.886	2811759.157	-0.172
508	518380.972	2805881.605	-0.32

509	519662.323	2791919.961	-0.46
510	537914.168	2806302.845	-0.115
511	537843.535	2806091.929	-0.045
512	537595.323	2805784.184	-0.193
513	537508.596	2805542.112	-0.148
514	537325.004	2805257.624	-0.625
515	542942.854	2806822.562	-0.139
516	542940.397	2806294.073	-0.25

Table 10 - USGS FL Everglades National Park lidar surveyed accuracy checkpoints.

One hundred and thirty-eight checkpoints were surveyed for vertical accuracy testing. One checkpoint (NVA-413) was removed from testing due to its location outside of the project boundary.

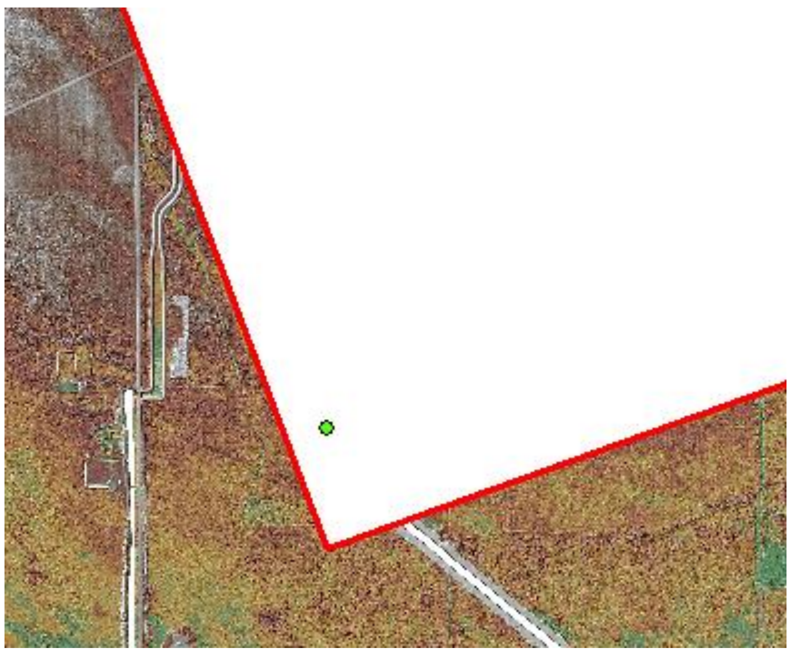


Figure 24 – Checkpoint NVA-413 (green) was removed from accuracy testing because it was located outside of the project boundary (red).

Project specifications do not require bathymetric accuracy testing. Seventeen (17) points were surveyed for bathymetric accuracy testing (Point ID 500 – 516). Dewberry used these checkpoints for internal production processing, however these points were not survey grade and were not used for final bathymetric accuracy testing in the project area. An example of a bathymetric point removed from accuracy testing is shown below.

Figure 25 – Survey photos of bathy checkpoint 501 shown above. Bathymetric checkpoints 500 through 516 were removed from accuracy testing because they were determined to not be survey grade.

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

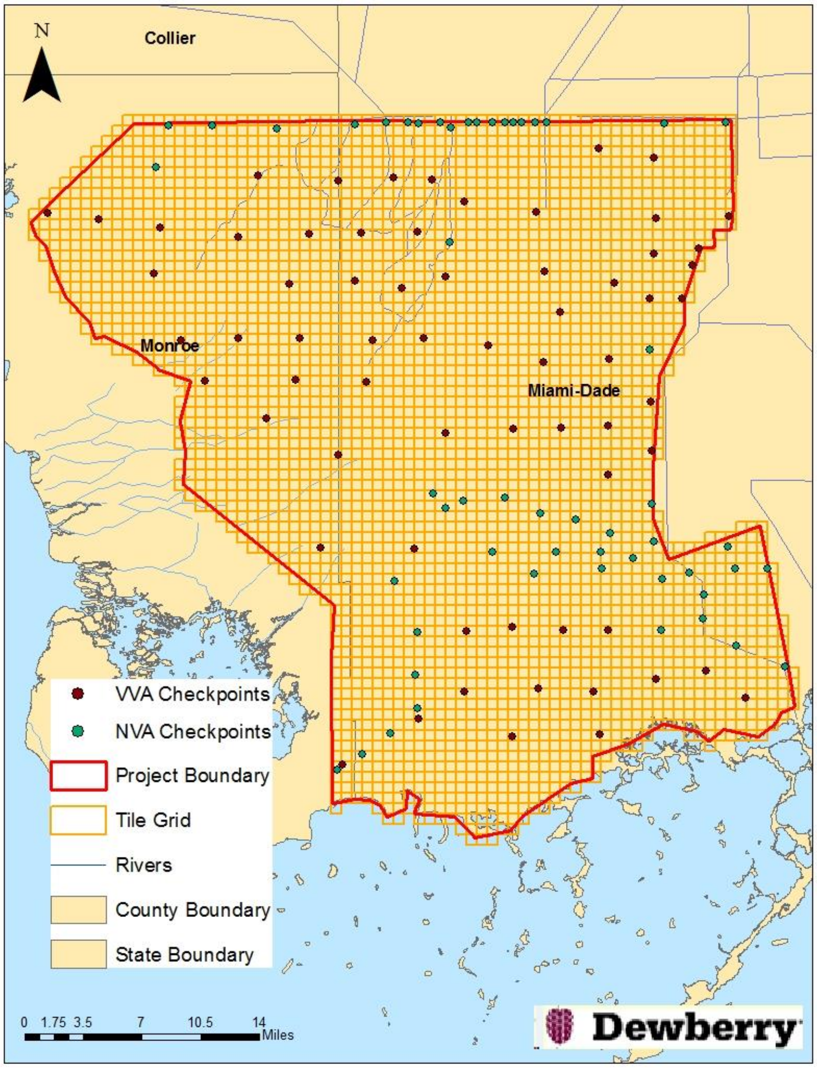


Figure 26 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

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

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95^{th}

percentile error for all checkpoints in all vegetated land cover categories combined. The Florida Everglades National Park Lidar Project VVA standard is 29.4 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 11.

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

Table 11 – Acceptance Criteria

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

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

VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	61	7	
VVA	59		35

Table 12 – Tested Vertical Accuracy

The topographic portion of this lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 3.6 cm, equating to +/- 7 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 35 cm at the 95th percentile. The bathymetric portion of this lidar dataset was not tested.

As a result of the failing final VVA accuracy calculation of 35 cm, Dewberry did an in-depth analysis of the checkpoints. Five (5) VVA checkpoints had high Delta Z values when compared to all of the VVA checkpoint Delta Z values from the lidar accuracy testing. They are shown in the table below, as well as some of the survey field photos. The survey field photos show that neither light nor lidar pulses can penetrate through some of the dense vegetation.

Point ID	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
214	534339.091	2800656.344	-0.088	0.230	0.318	0.318
216	548069.554	2796730.626	-0.382	0.110	0.492	0.492
217	543208.971	2795971.093	-0.383	-0.030	0.353	0.353
238	513115.321	2787735.451	-0.160	0.190	0.350	0.350
239	520415.845	2792098.225	-0.405	0.090	0.495	0.495

Table 13 — VVA checkpoints with high Delta Z values.

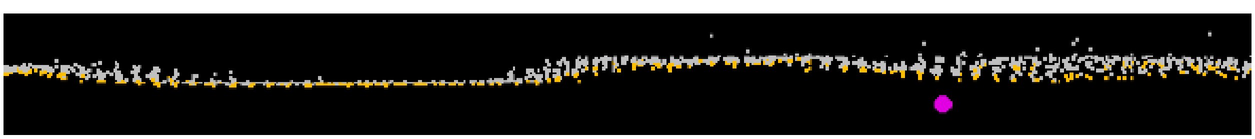


Figure 27 – VVA Point 216. The top two images show the dense vegetation at the survey tripod location. The lidar profile (bottom image) shows the lidar could not penetrate through the dense vegetation to the location of point 216 (pink).

Figure 28 – VVA Point 238. The two images show the dense vegetation at the survey tripod location.

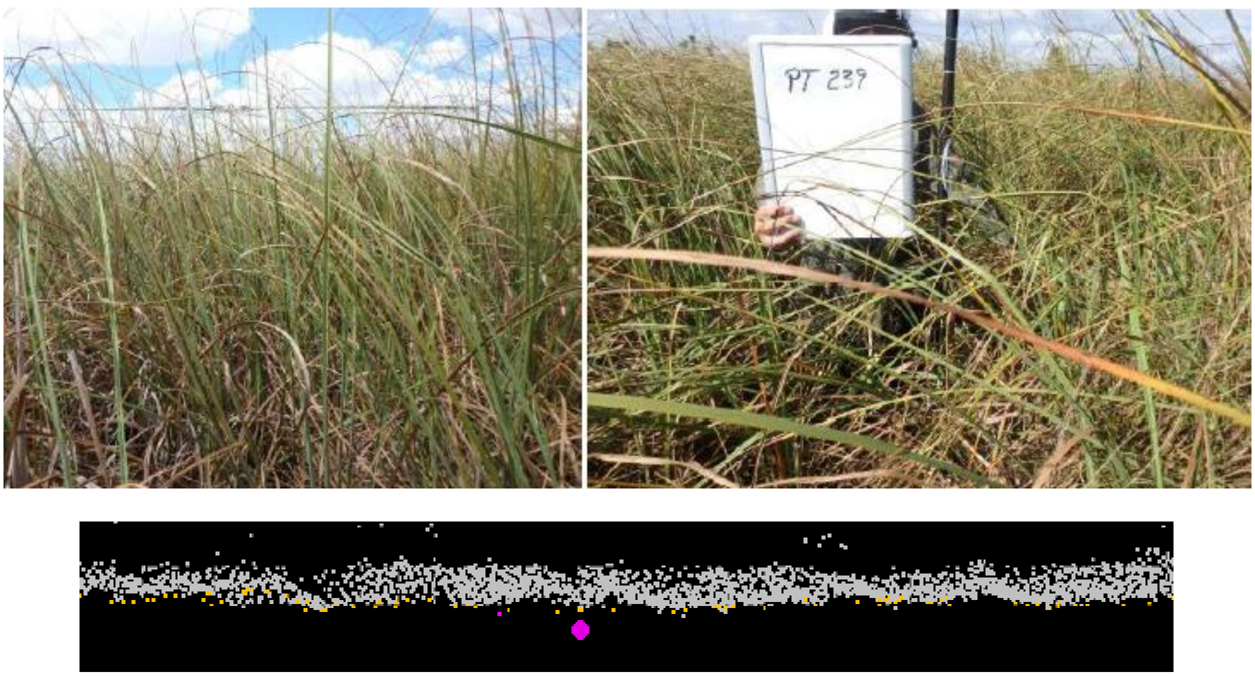


Figure 29 – VVA Point 239. The top two images show the dense vegetation at the survey tripod location. The lidar profile (bottom image) shows the lidar could not penetrate through the dense vegetation to the location of point 239 (pink).

The points identified above revealed a trend of points with high Delta Z values based on land cover type in Everglades National Park. Dewberry also performed a comparison of the topobathy raster elevations versus a plumb-bob survey covering the extents of the North AOI delivery. The plumb-bob survey points were provided by USGS and National Park Service. The results of this comparison also showed a trend of points with high Delta Z values based on land cover type. Further information can be found in the separate plumb-bob comparison report. Below is an image of the location of the plumb-bob survey points covering the extents of the North AOI.

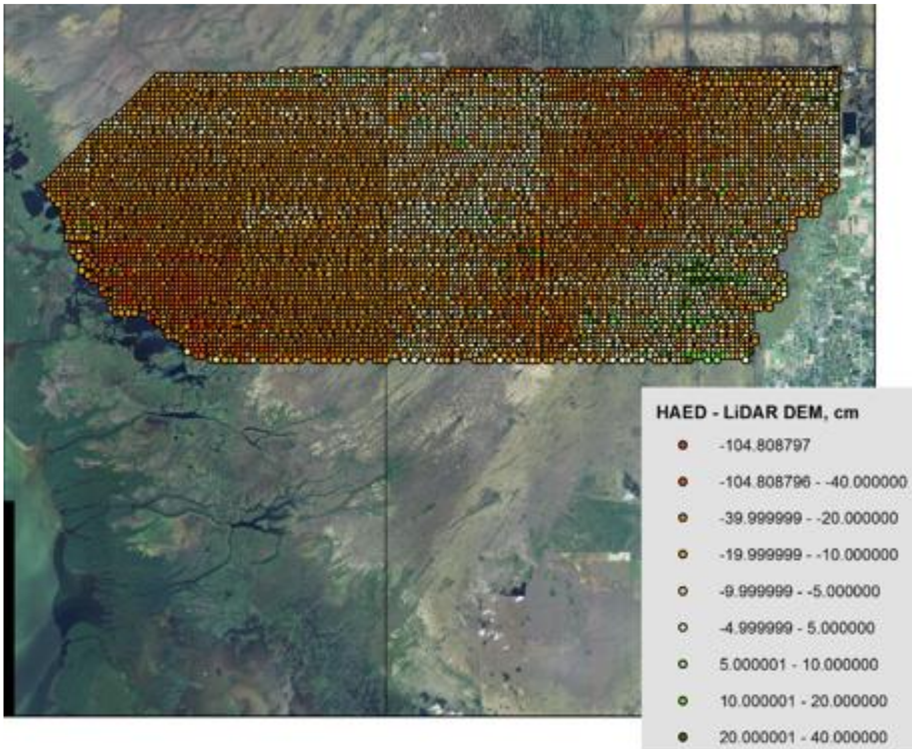


Figure 30 – Screenshot from the NPS of their comparison between HAED points elevations and the elevations of the delivered Everglades North AOI DEMs. Differences (DZ) are shown in centimeters.

Below is a statistics summary table from the plumb-bob comparison report, showing various land cover types in the North AOI and the corresponding accuracy values of the topobathy raster/plumb-bob point comparison.

	Shark River Slough	Coastal Mangroves	All Points without Slough and Mangroves	All Points Combined
# of Points	2659	998	5360	9017
RMSE	0.258	0.407	0.182	0.240
Mean	0.202	0.361	0.132	0.178
Median	0.176	0.330	0.119	0.152
Skew	0.529	0.692	0.425	0.882
Std Dev	0.160	0.188	0.125	0.161
Min	-0.376	-0.290	-0.481	-0.481
Max	0.945	1.012	0.973	1.012
Kurtosis	0.563	0.849	1.714	1.924
NVA (AccuracyZ)	0.505	0.799	0.356	0.470
VVA (95th Percentile)	0.495	0.732	0.345	0.473

Table 14 – Statistics summary of point distribution (meters) in the North AOI of the Everglades project.

Dewberry understood when entering this lidar project that vegetation coverage and density would provide a challenge for lidar in the environment of Everglades National Park.

The green wavelength topobathymetric lidar sensor while capable of mapping topography, is optimized for bathymetric measurements. Due to its larger beam divergence / spot size and scan pattern, in some areas it may have difficulty recording ground measurements through dense vegetation. The NIR topographic sensor is optimized for topographic surveying, and with its narrow beam divergence and multiple look angles is much more likely to penetrate dense vegetation. The combination of the two sensors leads to the ideal case of both recording shallow water bathymetric returns (where otherwise the NIR would record water surface elevation or no information at all), and penetrating dense vegetation.

The acquisition plan was optimized for bathymetric measurements. The above ground altitude (AGL) of 400m is not ideal for efficient broad area topographic collects due to the increased flight times, but it is optimal for achieving bathymetric results with the VQ-820G. Additionally this low altitude increases point densities for both scanners and thus increases the statistical likelihood of ground measurements.

Taking into account the sensor optimization parameters configured for the Florida Everglades National Lidar Project, the unique land cover types in the project area, and the VVA accuracy points with high Delta Z values, Dewberry determined the final VVA accuracy calculation of 35 cm to be justified. The NVA accuracy passes specifications for the project area, showing the usability of the lidar data is valid. The high Delta Z values are correlated to land cover types found in Everglades National Park. Dewberry plans to address the VVA accuracy by adjusting the standard operating procedures of the low-confidence polygons to account for these land cover types in the future. Further information on this discussion can be found in the separate plumb-bob comparison report.

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 +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +50 cm. The line graph below also shows a clear separation between NVA and VVA checkpoints, further illustrating the dataset achieves good vertical accuracy in non-vegetated areas but that the lidar had poorer penetration in dense vegetated areas.

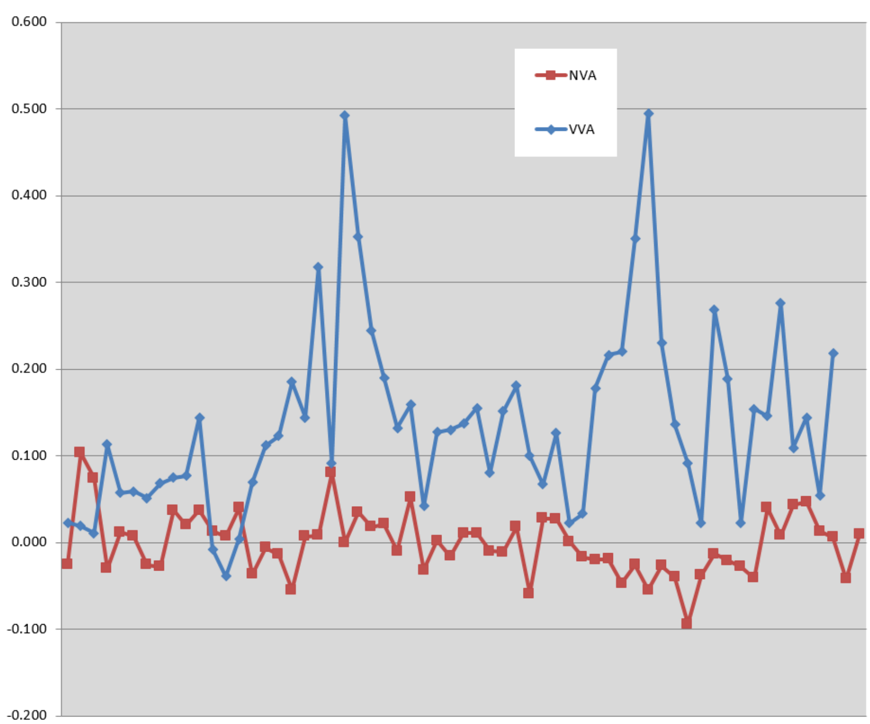


Figure 31 – Magnitude of elevation discrepancies per land cover category

Table 15 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
216	548069.554	2796730.626	-0.382	0.110	0.492	0.492
217	543208.971	2795971.093	-0.383	-0.030	0.353	0.353
239	520415.845	2792098.225	-0.405	0.090	0.495	0.495

Table 15 — 5% Outliers

Table 16 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) Spec=0.10 m NVA	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	61	0.036	-0.001	0.001	0.328	0.036	0.650	-0.094	0.103
VVA	59	N/A	0.138	0.127	1.306	0.110	2.309	-0.039	0.495

Table 16 — 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 -0.094 meters and a high of +0.495 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 -0.05 meters to +0.15 meters.

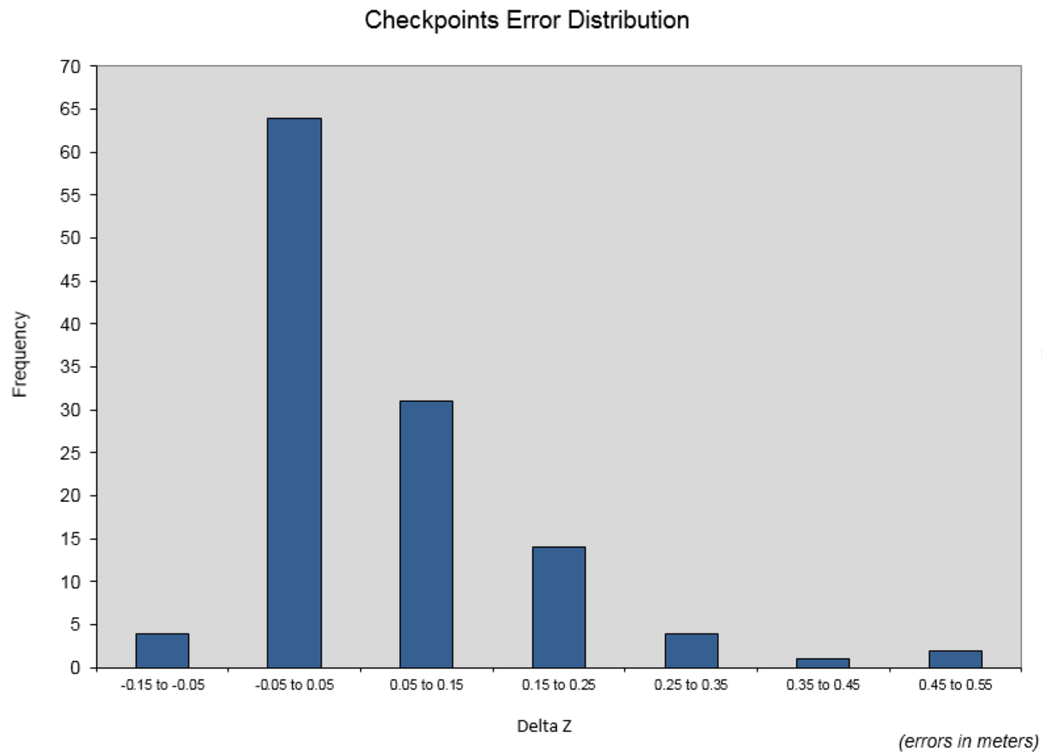


Figure 32 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS Florida Everglades National Park Lidar Project satisfies the project's pre-defined vertical accuracy criteria for the NVA testing. However, the VVA testing does not meet the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

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

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

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

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.

2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

No checkpoints were photo-identifiable in the intensity imagery, horizontal accuracy could not be tested on this dataset.

DEM Processing & Qualitative Assessment

The final topobathy DEMs are IMG format with 0.5 meter pixel cell size, tiled, named according to project specifications. Inland water voids and topobathy voids were enforced in the DEMs so that bathymetric areas where no bathymetry was collected are NoData in the DEMs.

DEM GENERATION

After the final void polygons (inland water voids and topobathy voids) are created and imported into the terrain GDB, a multipoint feature class was created from all lidar bathymetric bottom and bare earth ground points. Next, a terrain was created using the multipoint feature class and final void polygon layers. The void polygons are used in the terrain as “soft erase” features. This ensures that bathymetric areas where there are no bathymetric bottom points will be set as NoData in the DEM. After the terrain processed, the Arc tool Terrain to Raster was used to create the final topobathy DEM. The DEM is then split into individual tiles following the project tiling scheme.

The creation of first return DSMs follows a similar workflow as required for bare earth DEMs, except that void polygons are not applied to the first return terrain. Additionally, rather than ground only data, the first return of all point classes, except for low noise (class 7), high noise (class 18), bathy bottom (class 40), and water column (class 45), are used to create the multipoint file and subsequent terrain. Review of the DSMs includes looking for spikes, divots, or noise points not properly classified to the noise classes (class 7 and class 18), other lidar mis-classifications, and processing artifacts. As void polygons are not used in DSMs, DSMs are interpolated across hydrologic features. After corrections are applied, the DSM is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

DEM QUALITATIVE REVIEW

Dewberry performed a comprehensive qualitative assessment of the topobathy DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, formatting, 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, are formatted correctly, and contain the correct coordinate reference system information.

The final topobathy DEMs are then reviewed in Global Mapper at a 1:3000 scale. A review with the void polygons visible and another review without the void polygons visible was performed in order to ensure voids were enforced properly and there were no issues along the boundaries of the void layer. Special attention was given along the land/water interface to ensure there were no hard edges along the interface. Any remaining lidar issues and DEM artifacts were flagged by the reviewer and corrected by the editing team as necessary.

The images below show an example of a topobathy DEM and first return DSM of the same tile.

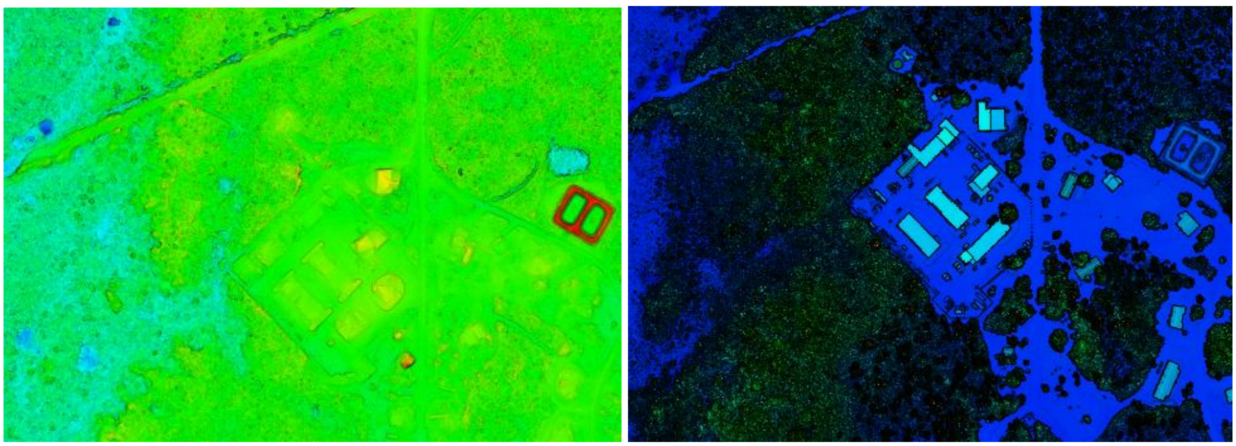


Figure 33 - Tile 17RNJ400070. The bare earth DEM is shown on the left while the first return DSM is shown on the right

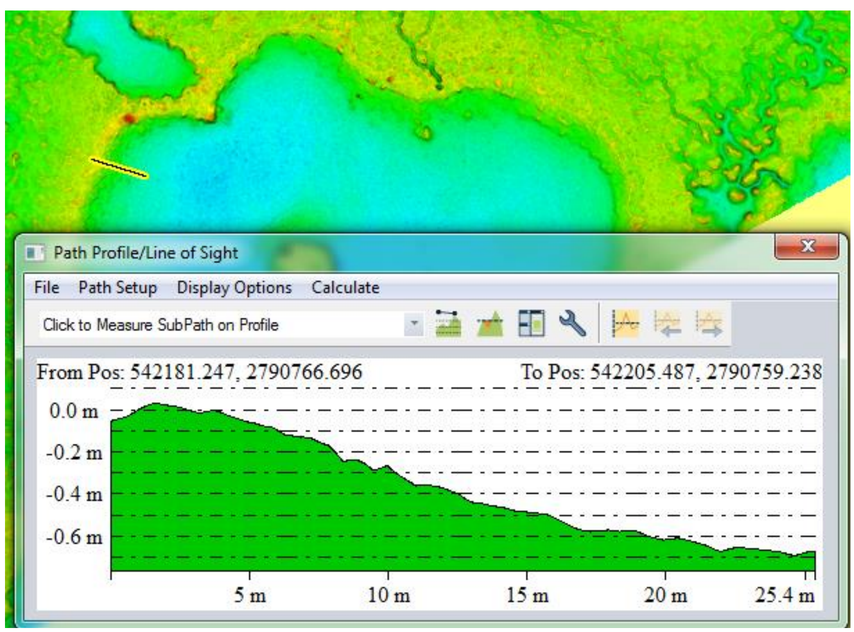


Figure 34 - DEM tile 17RNH420900. An example of the land-water interface is shown. No hard edges along the interface were identified during DEM QA/QC.

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

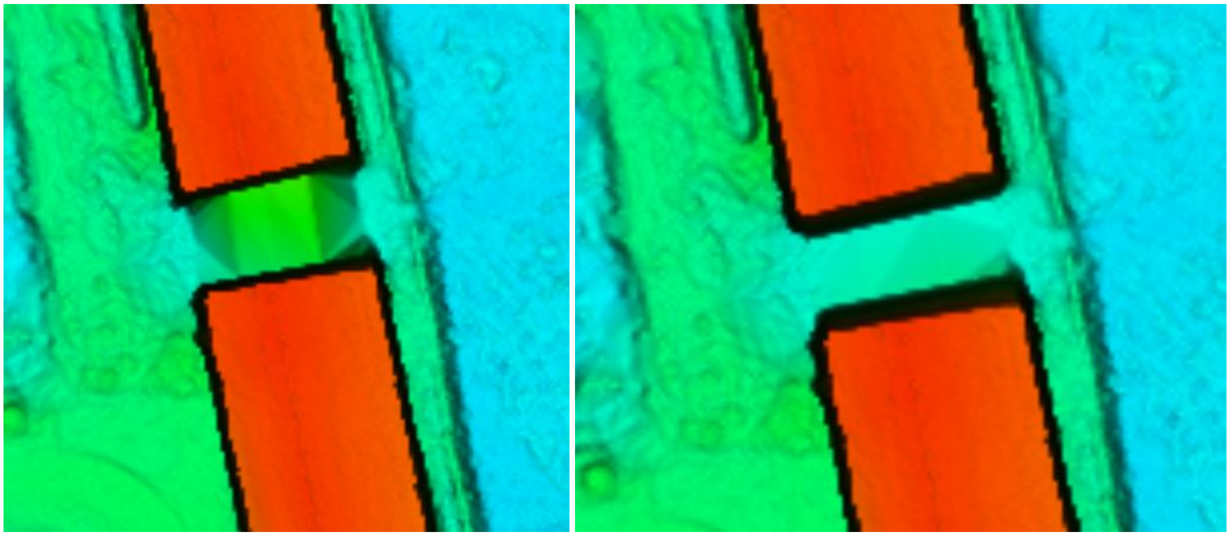


Figure 35 – Tiles 17RNJ530060 and 17RNJ540060. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM QUANTITATIVE ASSESSMENT

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

The survey checkpoints used to test this topobathymetric dataset are listed in the survey report included as Appendix A.

Table 17 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSE$_z$ x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	61	6.8	
VVA	59		34.8

Table 17 – DEM tested NVA and VVA

The topographic portion of this DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE$_z$ =3.5 cm, equating to +/- 6.8 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 34.8 cm at the 95th percentile. The bathymetric portion of this DEM dataset was not tested. A more in-depth analysis of the VVA accuracy testing results can be found in the lidar vertical accuracy section of this report.

Table 18 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
216	548069.554	2796730.626	-0.382	0.101	0.483	0.483
244	543208.971	2795917.093	-0.383	-0.028	0.355	0.355
239	520415.845	2792098.225	-0.405	0.093	0.498	0.498

Table 18 – 5% Outliers

Table 19 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) Spec=0.1 m NVA	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	61	0.035	-0.002	-0.001	0.449	0.035	0.327	-0.079	0.095
VVA	59	N/A	0.144	0.122	1.172	0.112	1.671	-0.032	0.498

Table 19 – Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS Florida Everglades National Park Lidar Project satisfies the project's pre-defined vertical accuracy criteria for the NVA testing. However, the VVA testing does not meet the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

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

Pass/Fail	Validation Step
Pass	Final void breakline polygons are created.
Pass	Masspoints (LAS to multipoint) are created from final ground and bathymetric bottom points.
Pass	Masspoints and void breakline polygons are used to create the final topobathymetric terrain.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size.
Pass	Manually review topobathymetric DEMs to check for issues.
Pass	Special attention should be paid along the land/water interface.
Pass	DEMs should be seamless across tile boundaries.
Pass	Bridges should NOT be present in final topobathy DEMs.
Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.
Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA and VVA Vertical Accuracy and other statistics.
Pass	Split the DEMs into tiles according to the project tiling scheme.
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs.
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 20 - A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Optical Imagery

During acquisition of the lidar data, Dewberry acquired optical imagery of the area of interest using a Nikon three-band (Red, Green, and Blue channels) D810 camera when possible throughout the project area. Dewberry performed the aerotriangulation, georeferencing, and conversion to Geotiff format. Dewberry and the client agreed to deliver usable optical imagery collected during acquisition in Geotiff format.

IMAGERY PROCESSING

Dewberry used Geomedia software to convert the image frames from their native sensor format to Geotiff format and to georeference the image frames. The three-band (RGB) imagery has the same coordinate reference system as the lidar data:

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Coordinate System: UTM Zone 17N
Units: Horizontal units are in meters.

Once Dewberry generated the image frames and world files, photo-center shapefiles were created and all images were verified to load correctly. Image frames found to be unusable after processing are not provided to the client. Below is an example of a set of usable Geotiff image frames for the Florida Everglades National Park Lidar Project.

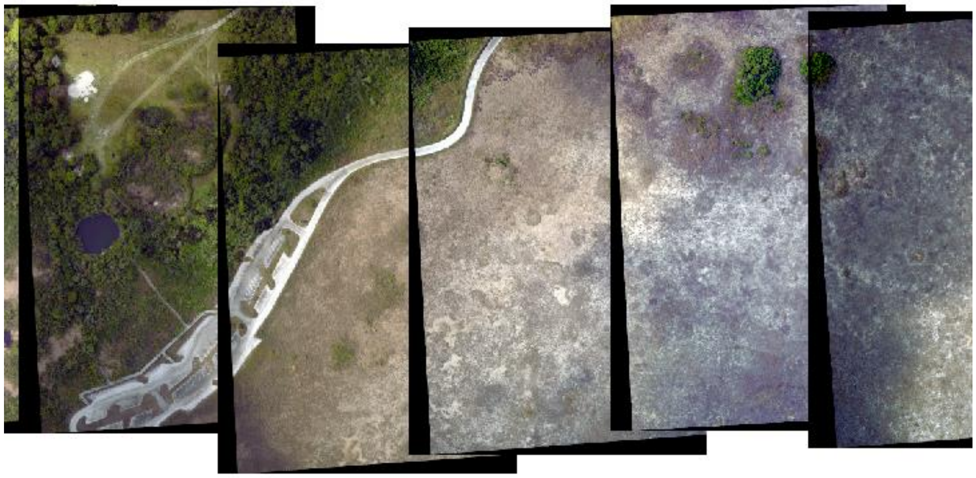


Figure 36 – A set of usable Geotiff imagery frames collected during acquisition of the project area.

Metadata

Project level metadata files were delivered in XML format for all project deliverables including lidar, DEMs, breaklines, and intensity imagery. All metadata files are FGDC compliant and were verified to be error-free according to the USGS MetaParser.

Appendix A: Checkpoint Survey Report

Please see the report included with this deliverable:
Appendix_A_Checkpoint_Survey_Report

Appendix B: Ground Control Survey Report

Please see the report included with this deliverable:
Appendix_B_Ground_Control_Survey_Report

Appendix C: Complete List of Delivered Tiles

17RNH250800	17RNH320830	17RNH280850	17RNH170870	17RNH300880
17RNH260800	17RNH120840	17RNH290850	17RNH180870	17RNH310880
17RNH270800	17RNH130840	17RNH300850	17RNH190870	17RNH320880
17RNH240810	17RNH140840	17RNH310850	17RNH200870	17RNH330880
17RNH250810	17RNH150840	17RNH320850	17RNH210870	17RNH340880
17RNH260810	17RNH160840	17RNH330850	17RNH220870	17RNH350880
17RNH270810	17RNH170840	17RNH340850	17RNH230870	17RNH360880
17RNH280810	17RNH180840	17RNH350850	17RNH240870	17RNH370880
17RNH290810	17RNH190840	17RNH120860	17RNH250870	17RNH380880
17RNH170820	17RNH200840	17RNH130860	17RNH260870	17RNH120890
17RNH180820	17RNH210840	17RNH140860	17RNH270870	17RNH130890
17RNH200820	17RNH220840	17RNH150860	17RNH280870	17RNH140890
17RNH210820	17RNH230840	17RNH160860	17RNH290870	17RNH150890
17RNH220820	17RNH240840	17RNH170860	17RNH300870	17RNH160890
17RNH230820	17RNH250840	17RNH180860	17RNH310870	17RNH170890
17RNH240820	17RNH260840	17RNH190860	17RNH320870	17RNH180890
17RNH250820	17RNH270840	17RNH200860	17RNH330870	17RNH190890
17RNH260820	17RNH280840	17RNH210860	17RNH340870	17RNH200890
17RNH270820	17RNH290840	17RNH220860	17RNH350870	17RNH210890
17RNH280820	17RNH300840	17RNH230860	17RNH360870	17RNH220890
17RNH290820	17RNH310840	17RNH240860	17RNH370870	17RNH230890
17RNH300820	17RNH320840	17RNH250860	17RNH120880	17RNH240890
17RNH120830	17RNH330840	17RNH260860	17RNH130880	17RNH250890
17RNH160830	17RNH120850	17RNH270860	17RNH140880	17RNH260890
17RNH170830	17RNH130850	17RNH280860	17RNH150880	17RNH270890
17RNH180830	17RNH140850	17RNH290860	17RNH160880	17RNH280890
17RNH190830	17RNH150850	17RNH300860	17RNH170880	17RNH290890
17RNH200830	17RNH160850	17RNH310860	17RNH180880	17RNH300890
17RNH210830	17RNH170850	17RNH320860	17RNH190880	17RNH310890
17RNH220830	17RNH180850	17RNH330860	17RNH200880	17RNH320890
17RNH230830	17RNH190850	17RNH340860	17RNH210880	17RNH330890
17RNH240830	17RNH200850	17RNH350860	17RNH220880	17RNH340890
17RNH250830	17RNH210850	17RNH360860	17RNH230880	17RNH350890
17RNH260830	17RNH220850	17RNH370860	17RNH240880	17RNH360890
17RNH270830	17RNH230850	17RNH120870	17RNH250880	17RNH370890
17RNH280830	17RNH240850	17RNH130870	17RNH260880	17RNH380890
17RNH290830	17RNH250850	17RNH140870	17RNH270880	17RNH390890
17RNH300830	17RNH260850	17RNH150870	17RNH280880	17RNH400890
17RNH310830	17RNH270850	17RNH160870	17RNH290880	17RNH410890

17RNH480890	17RNH140910	17RNH130920	17RNH550920	17RNH530930
17RNH120900	17RNH150910	17RNH140920	17RNH120930	17RNH540930
17RNH130900	17RNH160910	17RNH150920	17RNH130930	17RNH550930
17RNH140900	17RNH170910	17RNH160920	17RNH140930	17RNH560930
17RNH150900	17RNH180910	17RNH170920	17RNH150930	17RNH120940
17RNH160900	17RNH190910	17RNH180920	17RNH160930	17RNH130940
17RNH170900	17RNH200910	17RNH190920	17RNH170930	17RNH140940
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17RNH190900	17RNH220910	17RNH210920	17RNH190930	17RNH160940
17RNH200900	17RNH230910	17RNH220920	17RNH200930	17RNH170940
17RNH210900	17RNH240910	17RNH230920	17RNH210930	17RNH180940
17RNH220900	17RNH250910	17RNH240920	17RNH220930	17RNH190940
17RNH230900	17RNH260910	17RNH250920	17RNH230930	17RNH200940
17RNH240900	17RNH270910	17RNH260920	17RNH240930	17RNH210940
17RNH250900	17RNH280910	17RNH270920	17RNH250930	17RNH220940
17RNH260900	17RNH290910	17RNH280920	17RNH260930	17RNH230940
17RNH270900	17RNH300910	17RNH290920	17RNH270930	17RNH240940
17RNH280900	17RNH310910	17RNH300920	17RNH280930	17RNH250940
17RNH290900	17RNH320910	17RNH310920	17RNH290930	17RNH260940
17RNH300900	17RNH330910	17RNH320920	17RNH300930	17RNH270940
17RNH310900	17RNH340910	17RNH330920	17RNH310930	17RNH280940
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17RNH500900	17RNH500910	17RNH490920	17RNH470930	17RNH440940
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17RNH400990	17RNH380000	17RNJ360010	17RNJ340020	17RNJ320030
17RNH410990	17RNJ390000	17RNJ370010	17RNJ350020	17RNJ330030
17RNH420990	17RNH400000	17RNJ380010	17RNJ360020	17RNJ340030
17RNH430990	17RNH410000	17RNJ390010	17RNJ370020	17RNJ350030
17RNH440990	17RNH420000	17RNJ400010	17RNJ380020	17RNJ360030
17RNH450990	17RNJ430000	17RNJ410010	17RNJ390020	17RNJ370030
17RNH460990	17RNJ440000	17RNJ420010	17RNJ400020	17RNJ380030
17RNH470990	17RNJ450000	17RNJ430010	17RNJ410020	17RNJ390030
17RNH480990	17RNH460000	17RNJ440010	17RNJ420020	17RNJ400030
17RNH490990	17RNJ470000	17RNJ450010	17RNJ430020	17RNJ410030
17RNH500990	17RNJ480000	17RNJ460010	17RNJ440020	17RNJ420030
17RNH510990	17RNH490000	17RNJ470010	17RNJ450020	17RNJ430030
17RNH520990	17RNJ500000	17RNJ480010	17RNJ460020	17RNJ440030
17RNH530990	17RNJ510000	17RNJ490010	17RNJ470020	17RNJ450030
17RNH540990	17RNJ520000	17RNJ500010	17RNJ480020	17RNJ460030
17RNH550990	17RNJ530000	17RNJ510010	17RNJ490020	17RNJ470030
17RNJ120000	17RNJ540000	17RNJ520010	17RNJ500020	17RNJ480030
17RNJ130000	17RNJ550000	17RNJ530010	17RNJ510020	17RNJ490030
17RNJ140000	17RNJ120010	17RNJ540010	17RNJ520020	17RNJ500030
17RNJ150000	17RNJ130010	17RNJ550010	17RNJ530020	17RNJ510030
17RNJ160000	17RNJ140010	17RNJ120020	17RNJ540020	17RNJ520030
17RNJ170000	17RNJ150010	17RNJ130020	17RNJ110030	17RNJ530030
17RNH180000	17RNJ160010	17RNJ140020	17RNJ120030	17RNJ540030
17RNJ190000	17RNJ170010	17RNJ150020	17RNJ130030	17RNJ090040
17RNJ200000	17RNJ180010	17RNJ160020	17RNJ140030	17RNJ100040
17RNJ210000	17RNJ190010	17RNJ170020	17RNJ150030	17RNJ110040
17RNJ220000	17RNJ200010	17RNJ180020	17RNJ160030	17RNJ120040
17RNH230000	17RNJ210010	17RNJ190020	17RNJ170030	17RNJ130040
17RNH240000	17RNJ220010	17RNJ200020	17RNJ180030	17RNJ140040
17RNJ250000	17RNJ230010	17RNJ210020	17RNJ190030	17RNJ150040
17RNJ260000	17RNJ240010	17RNJ220020	17RNJ200030	17RNJ160040
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17RNJ360460
17RNJ370460
17RNJ380460
17RNJ390460
17RNJ400460
17RNJ410460
17RNJ420460
17RNJ430460
17RNJ440460
17RNJ450460

17RNJ460460
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17RNJ500460
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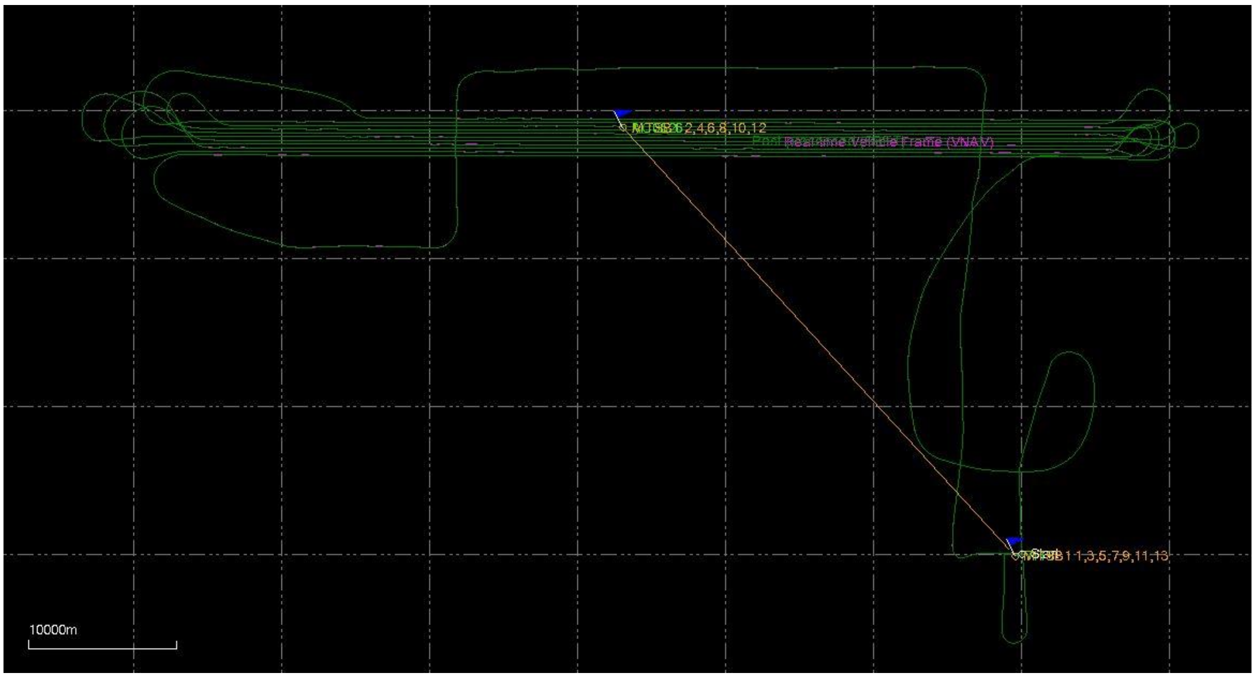
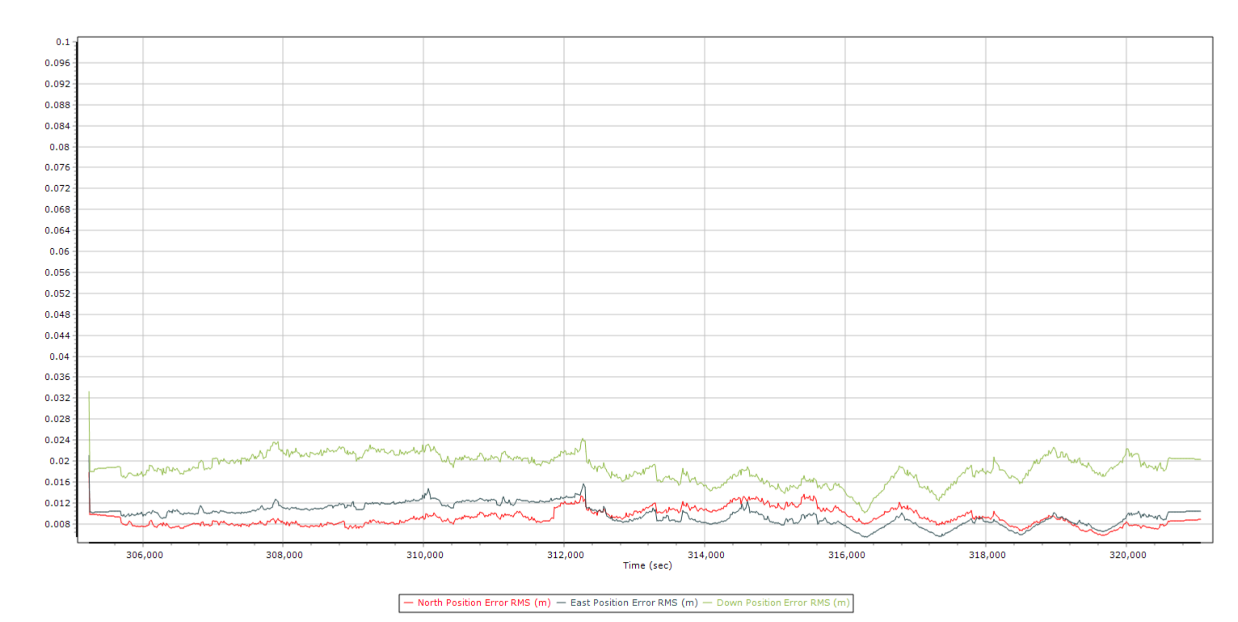
Appendix D: GPS Spatial Processing

Mission: 20170419_A

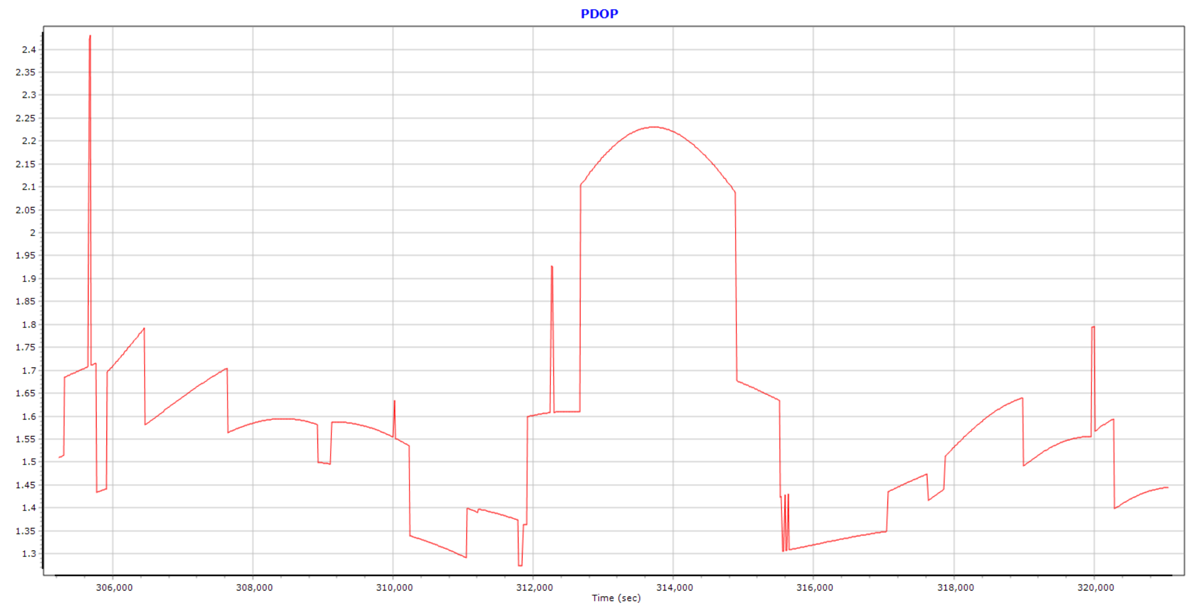
Mission Trajectory



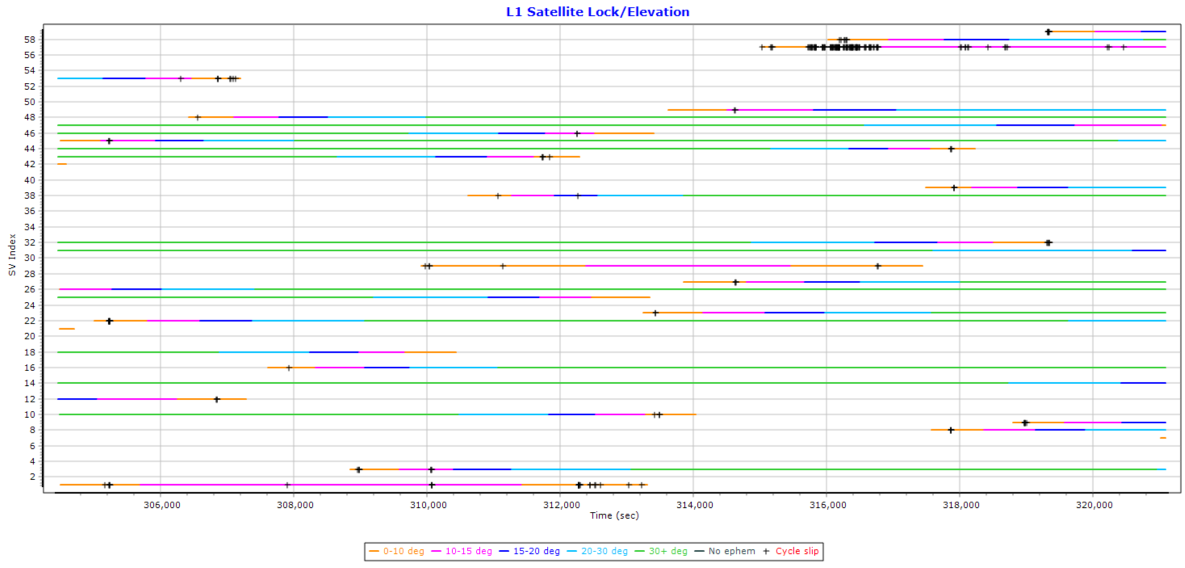
Smoothed Performance Metrics



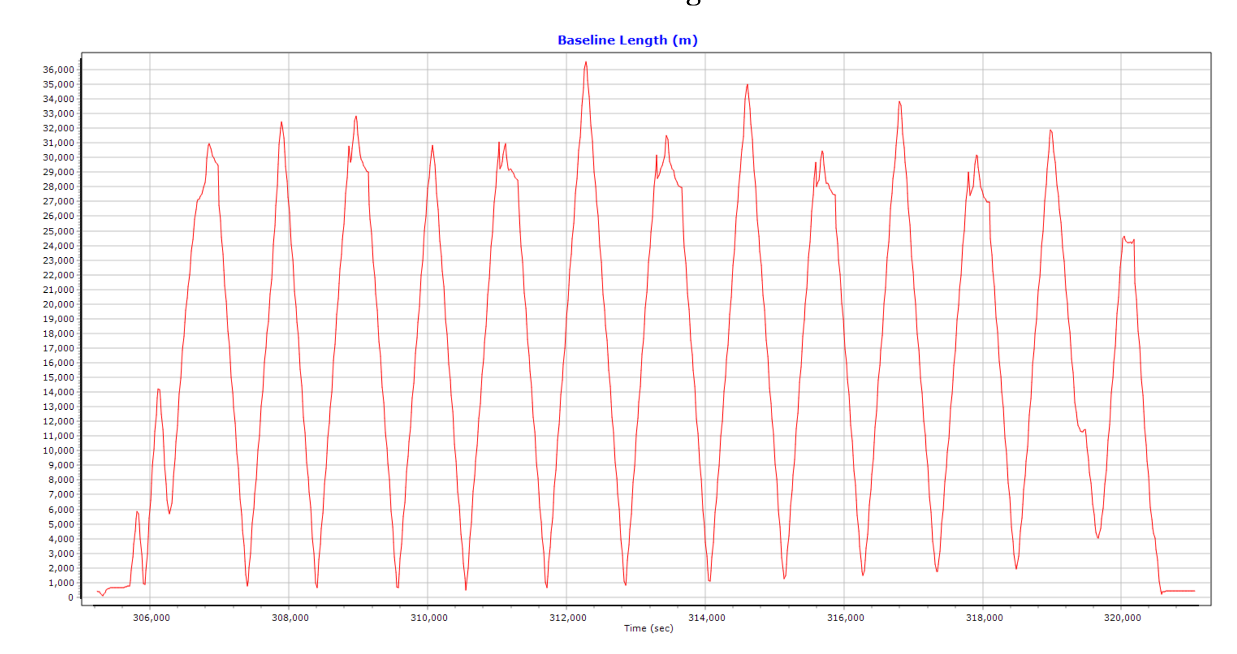
PDOP



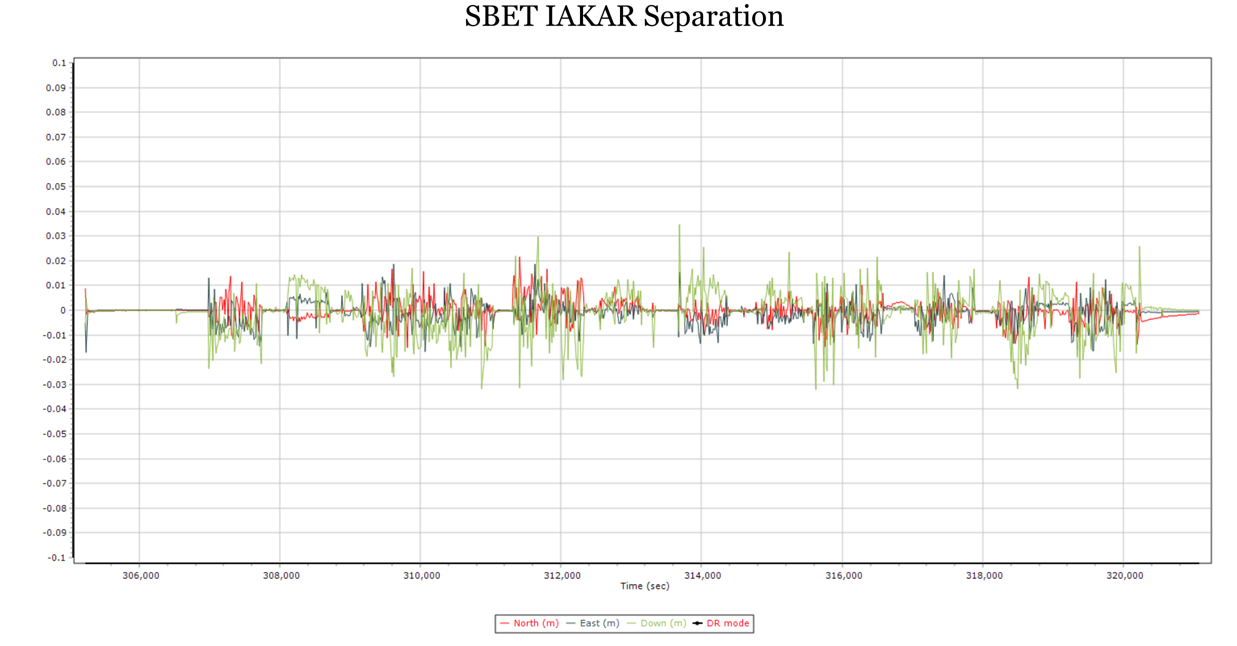
Satellite Lock and Elevation



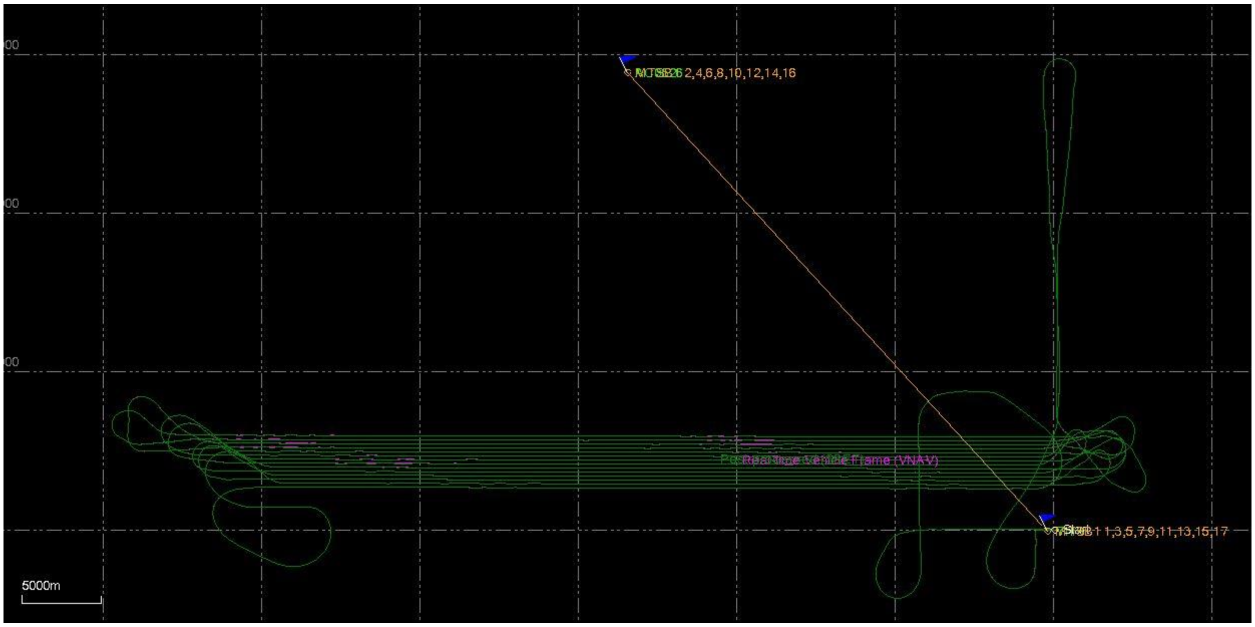
Baseline Length



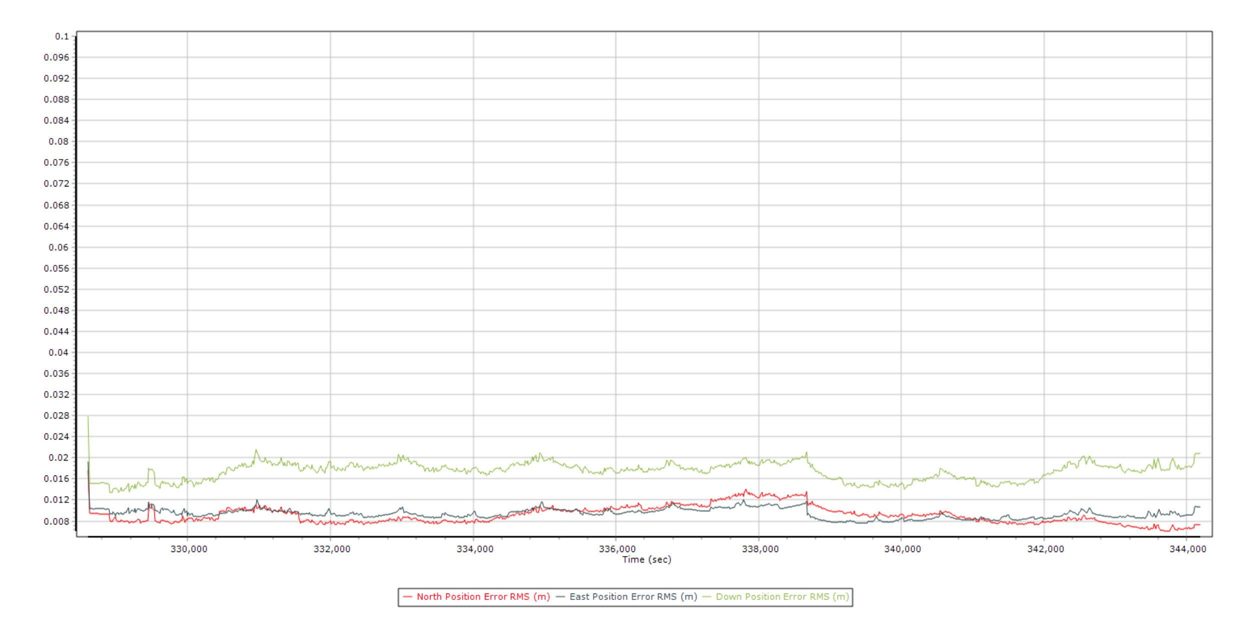
SBET IAKAR Separation

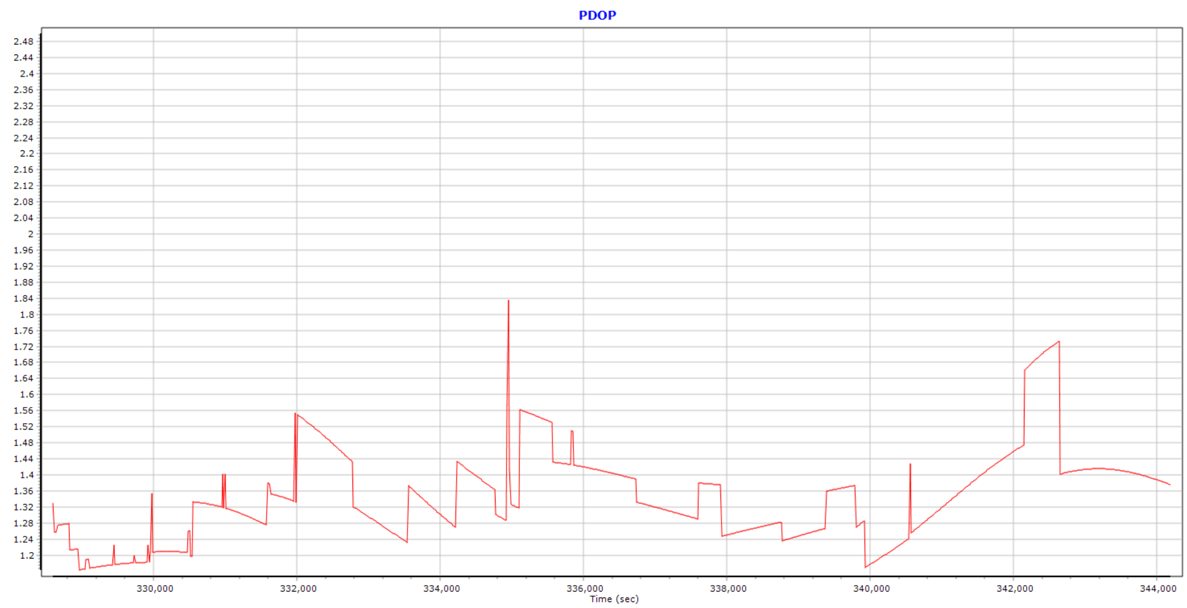


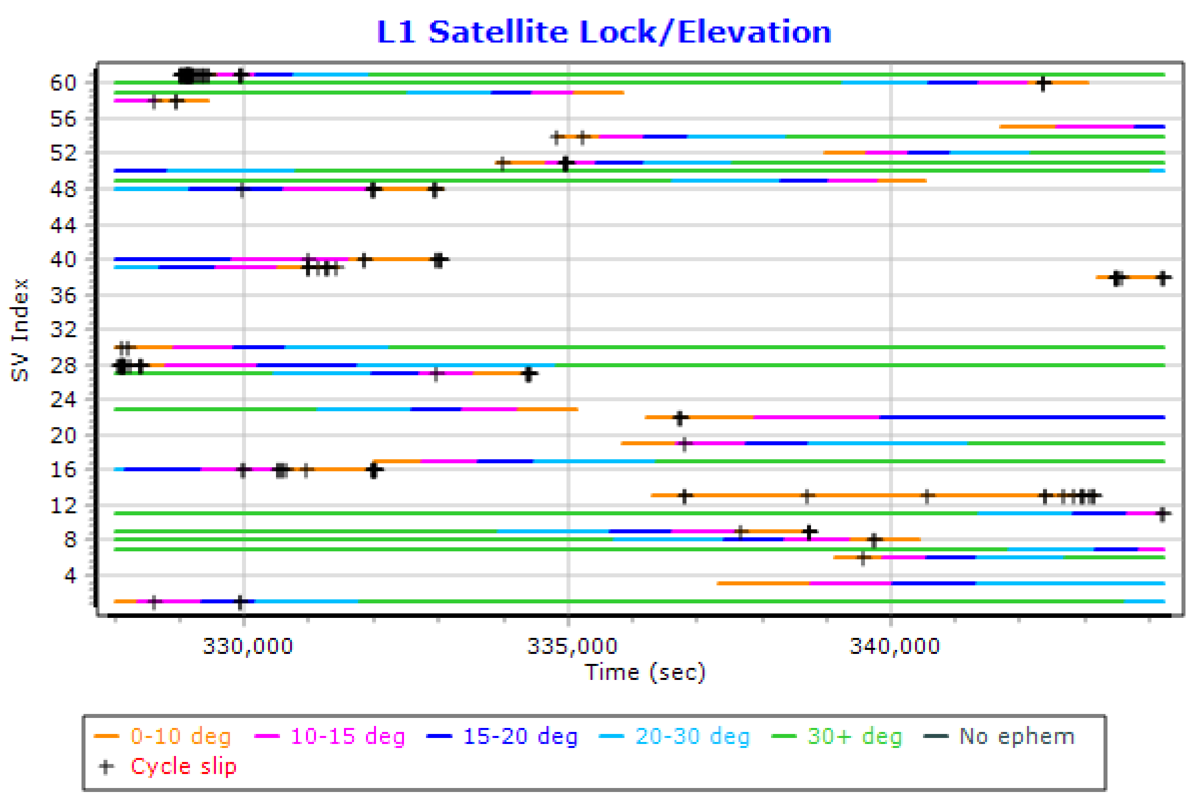
Mission:20170419_B
Trajectory:

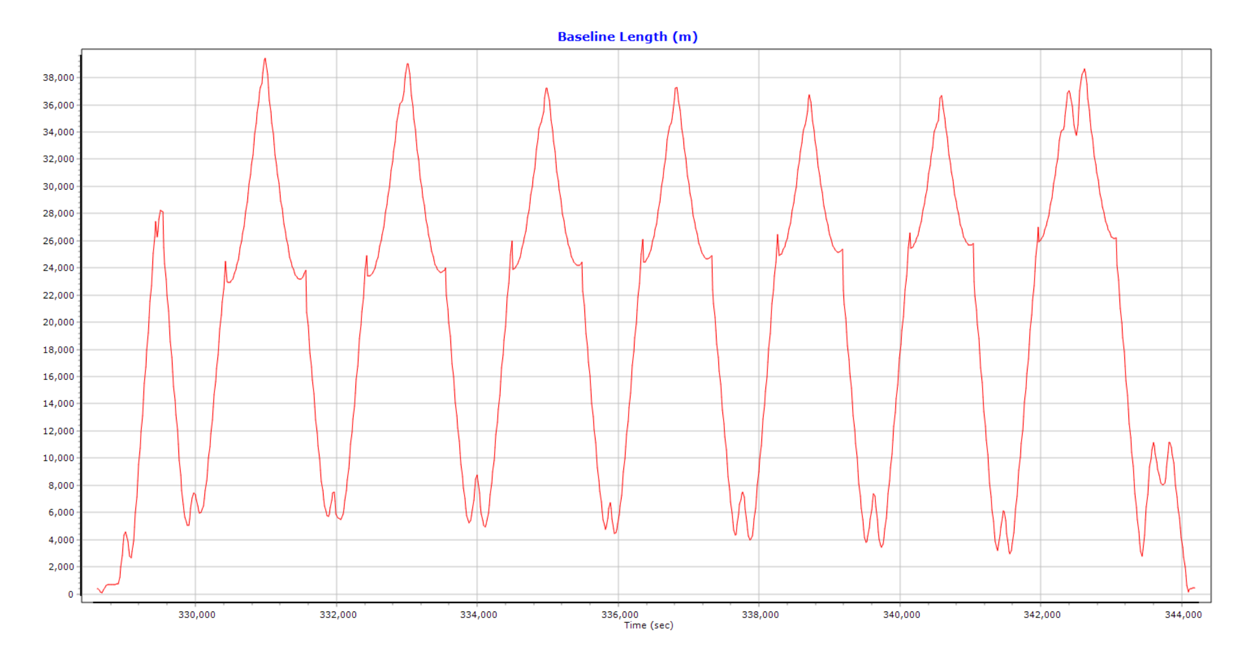


Smoothed Performance Metrics




PDOP
2.48
2.44
2.4
2.36
2.32
2.28
2.24
2.2
2.16
2.12
2.08
2.04
2
1.96
1.92
1.88
1.84
1.8
1.76
1.72
1.68
1.64
1.6
1.56
1.52
1.48
1.44
1.4
1.36
1.32
1.28
1.24
1.2
330,000
332,000
334,000
336,000
338,000
340,000
342,000
344,000
Time (sec)

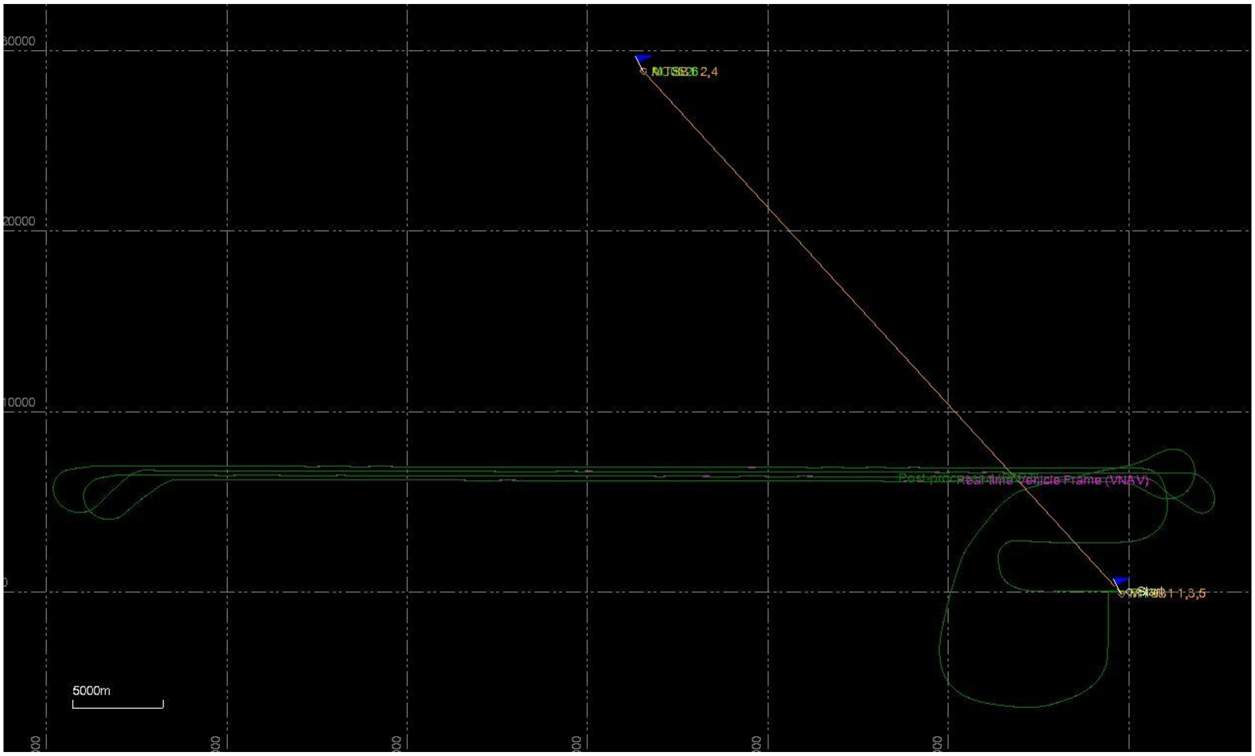

L1 Satellite Lock/Elevation
SV Index
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
330,000
335,000
340,000
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip



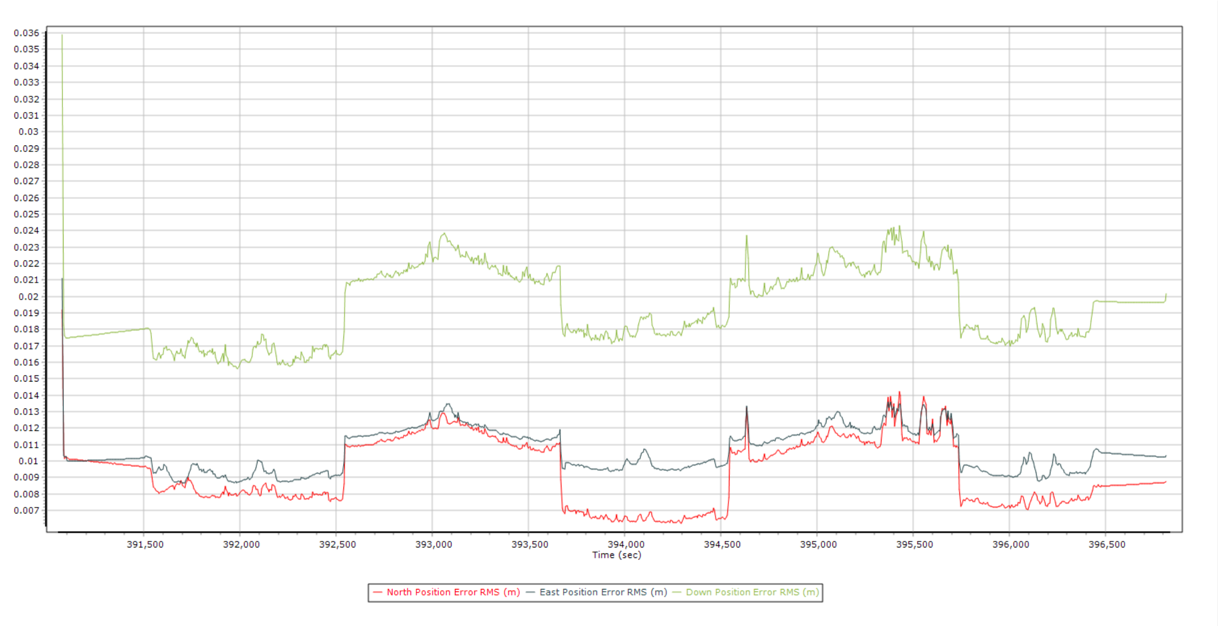
SBET IAKAR Separation

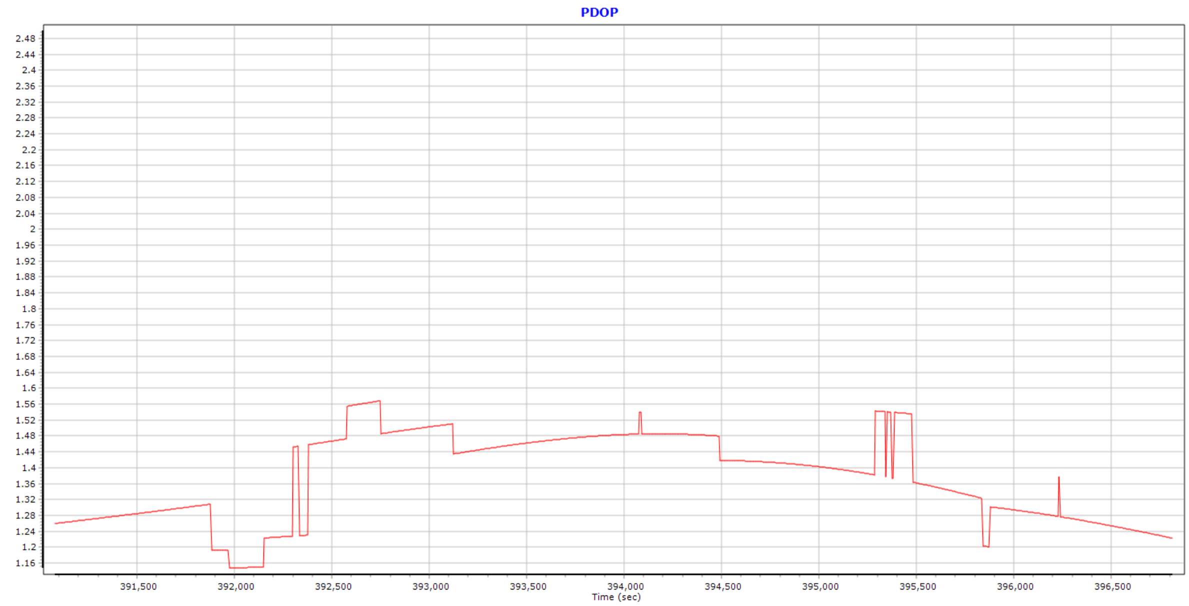
Mission: 20170420_A

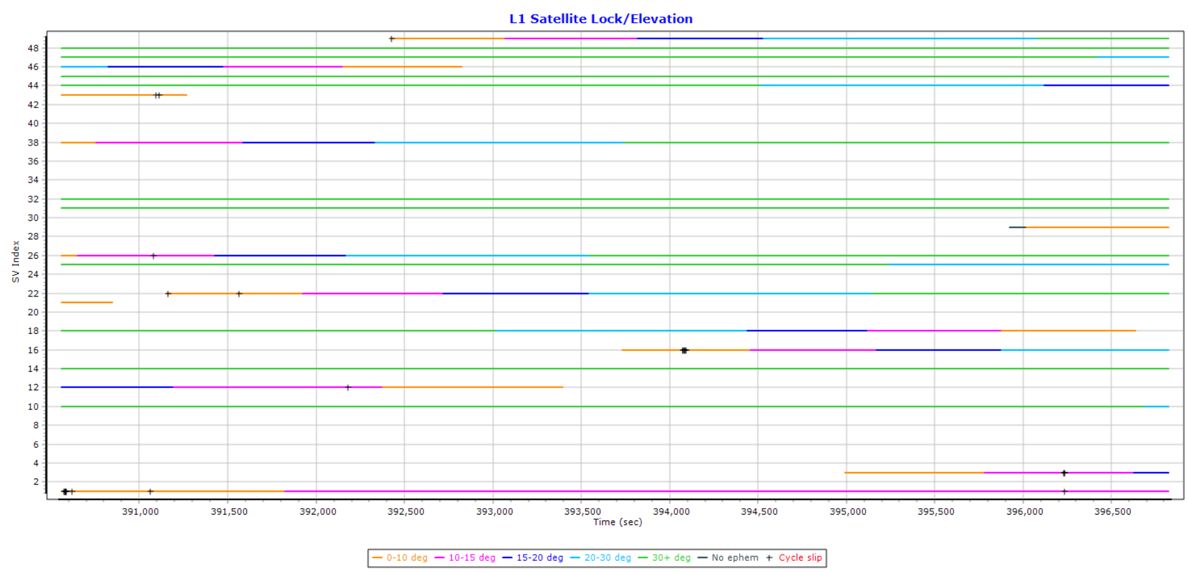
Trajectory

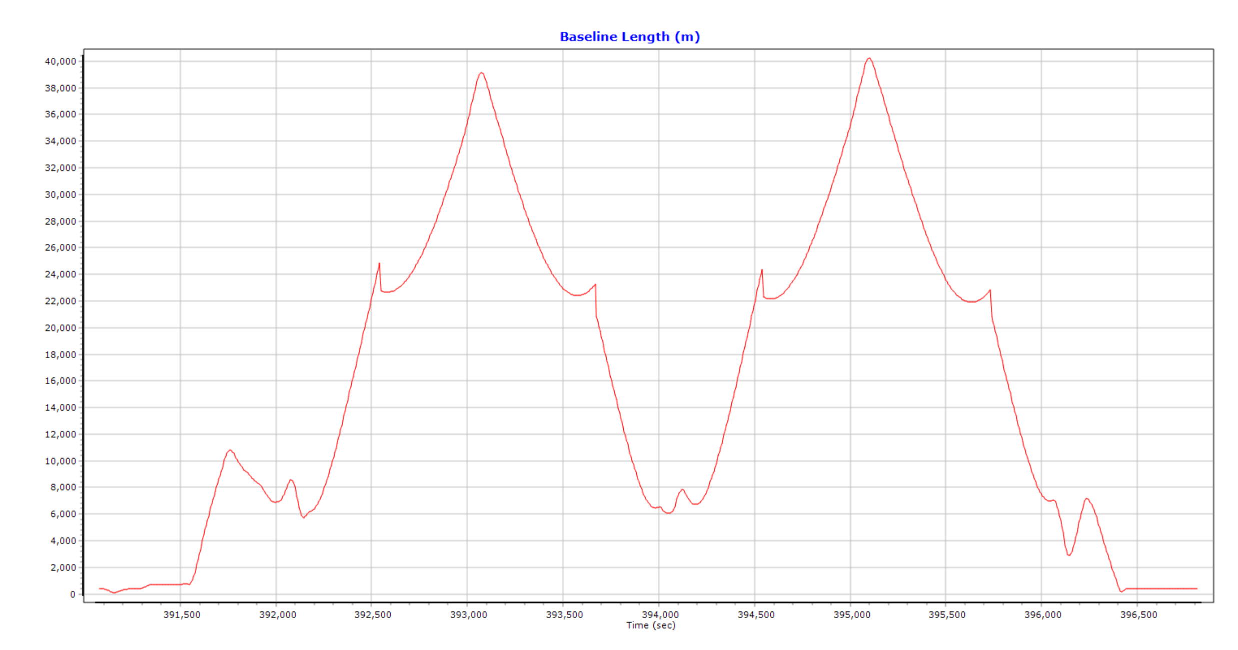


Smoothed Performance Metrics



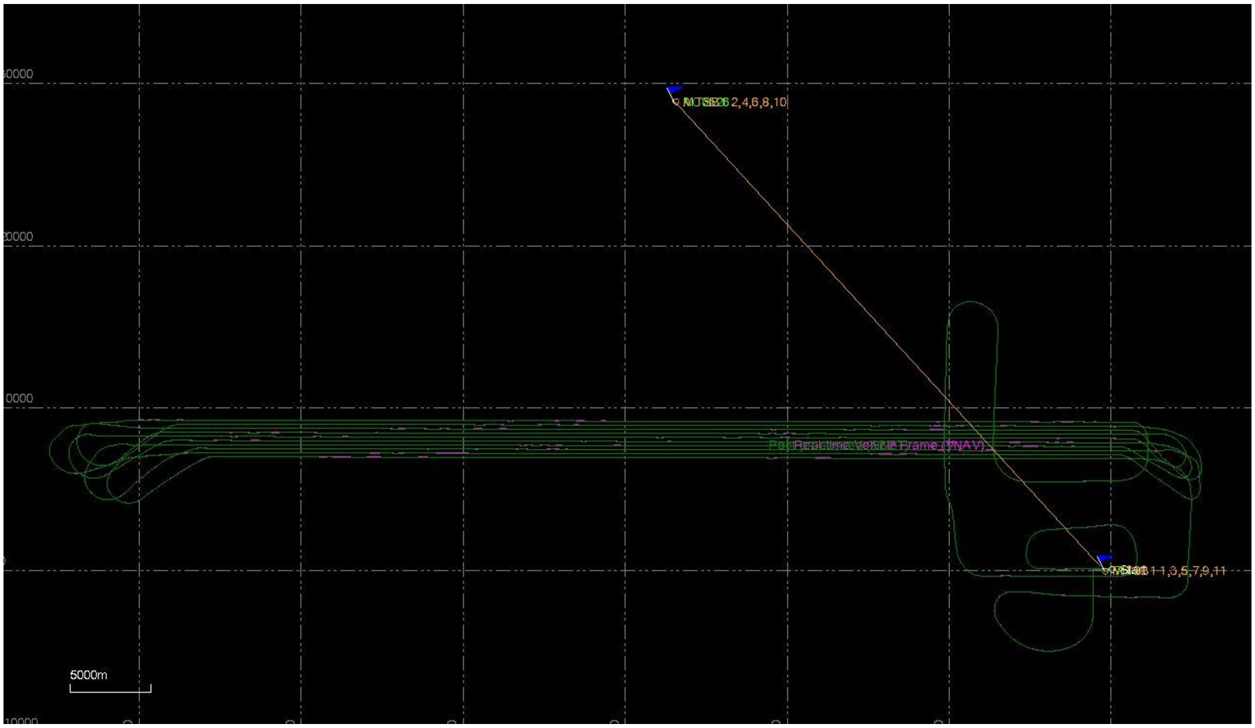

PDOP
Time (sec)


L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

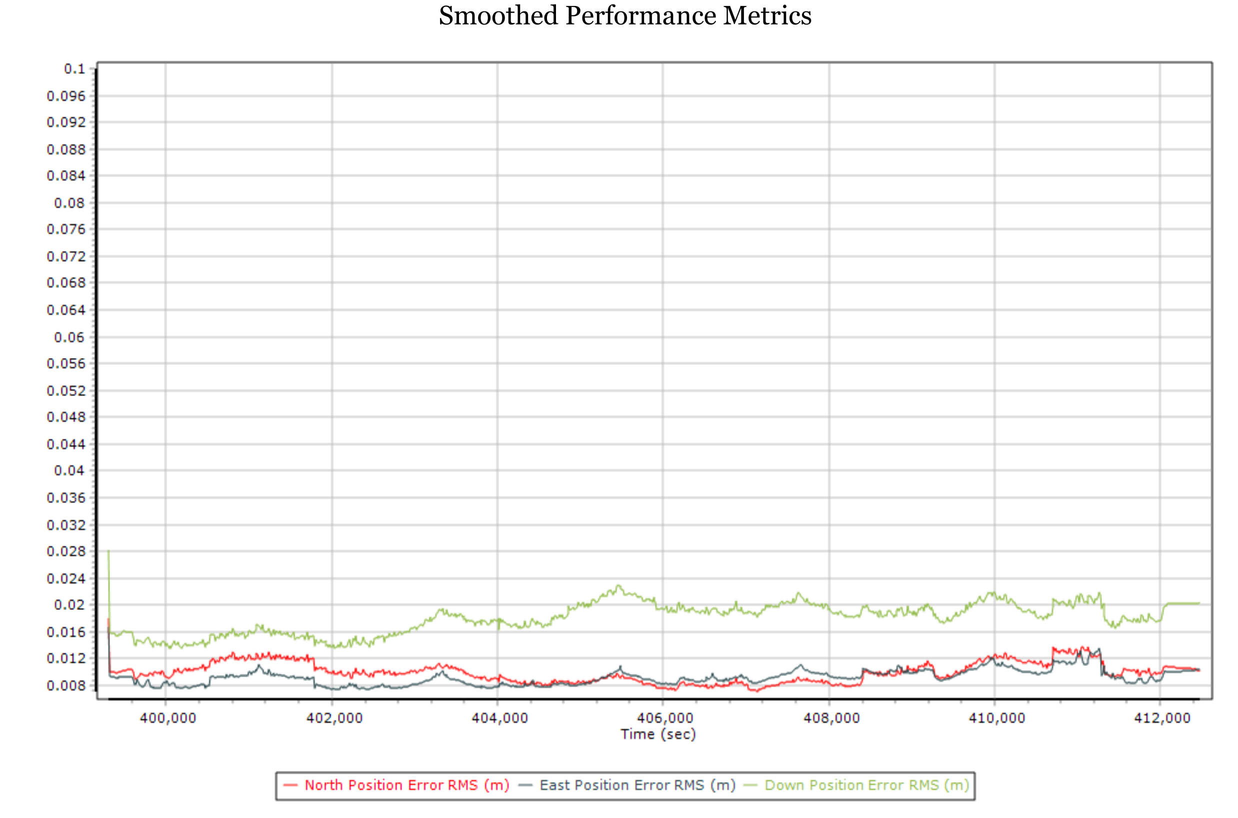


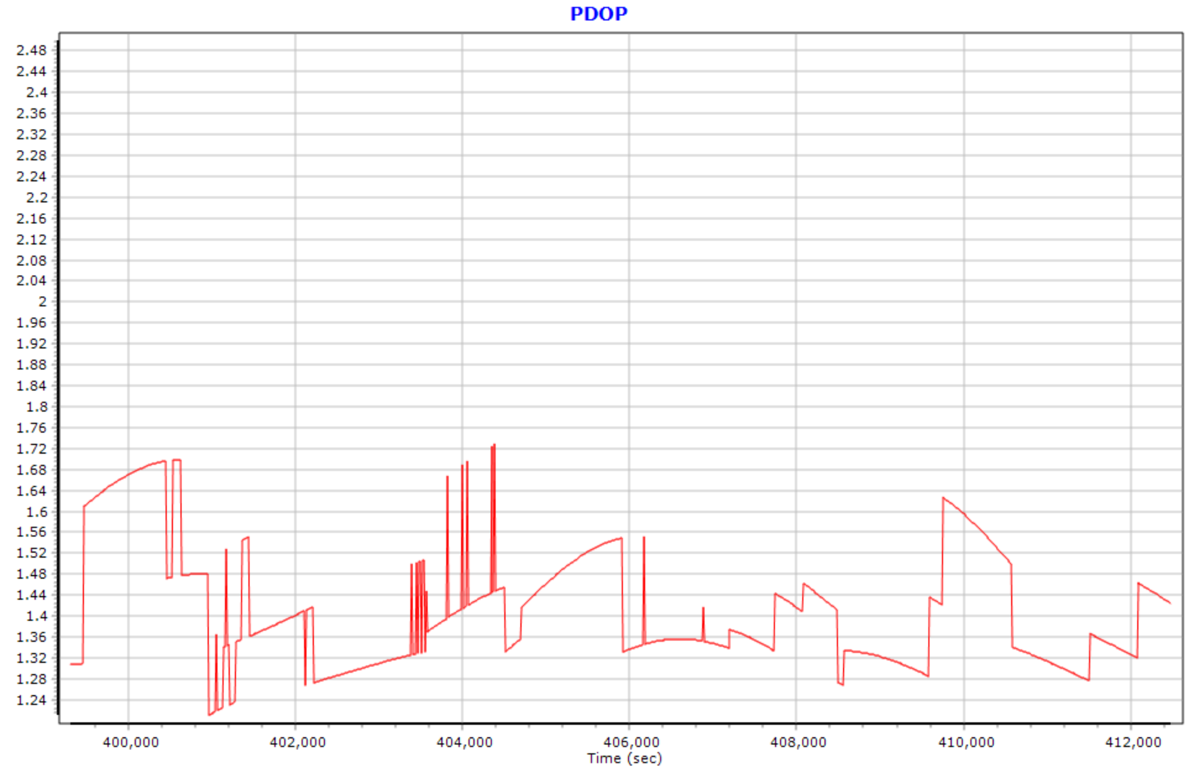
SBET IAKAR Separation

Mission: 20170420_B



Smoothed Performance Metrics




PDOP
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2.44
2.4
2.36
2.32
2.28
2.24
2.2
2.16
2.12
2.08
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2
1.96
1.92
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1.56
1.52
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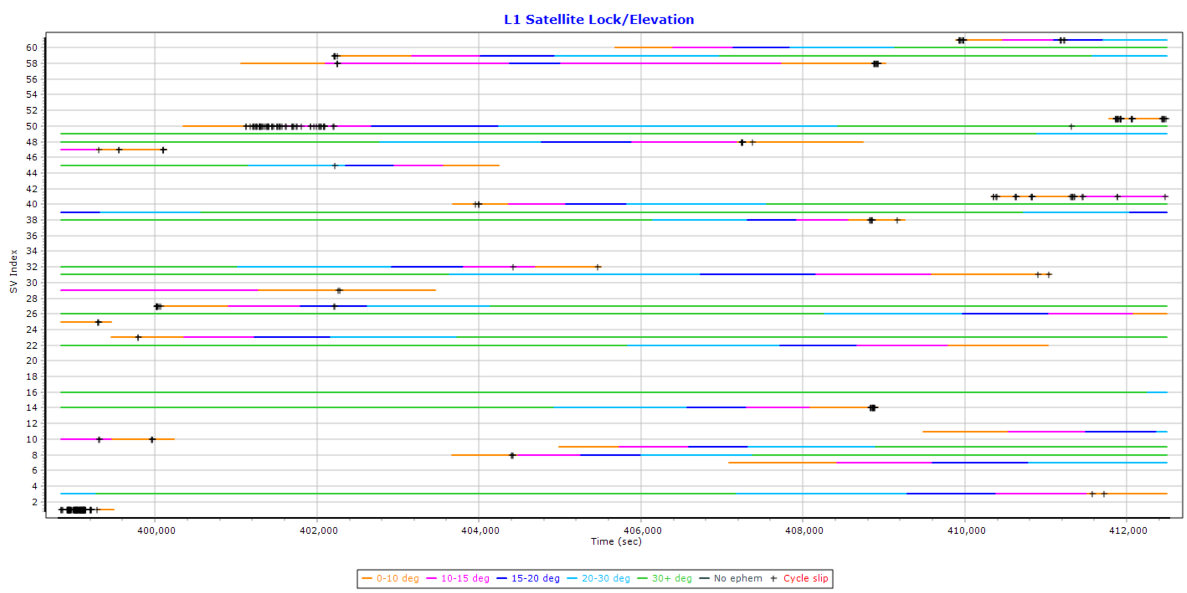
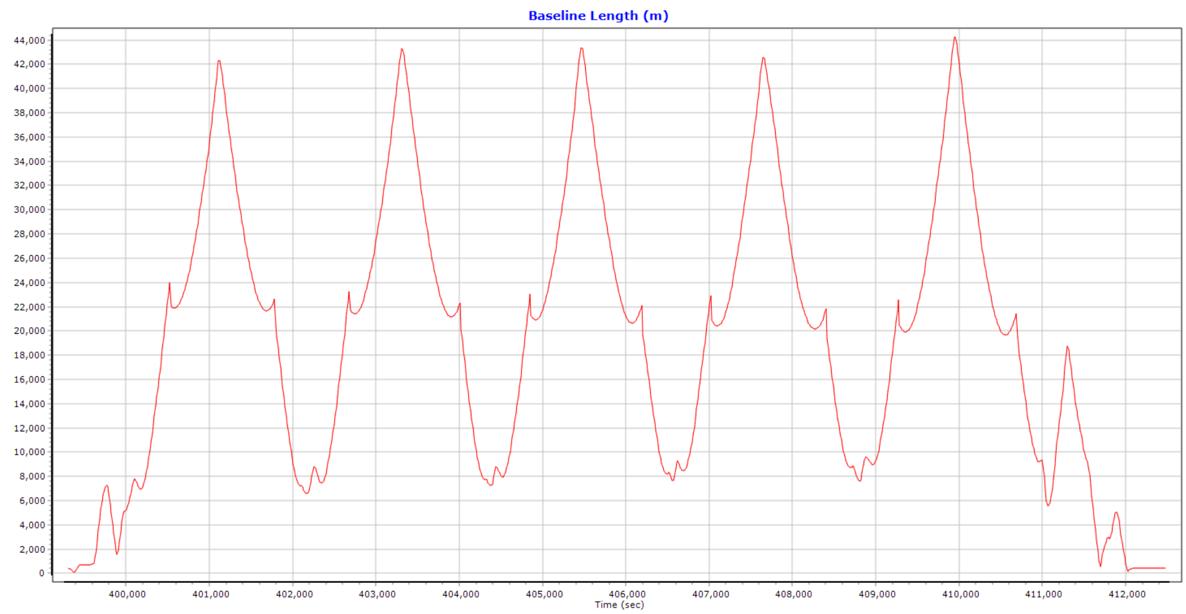
1.44
1.4
1.36
1.32
1.28
1.24
400,000
402,000
404,000
406,000
408,000
410,000
412,000
Time (sec)

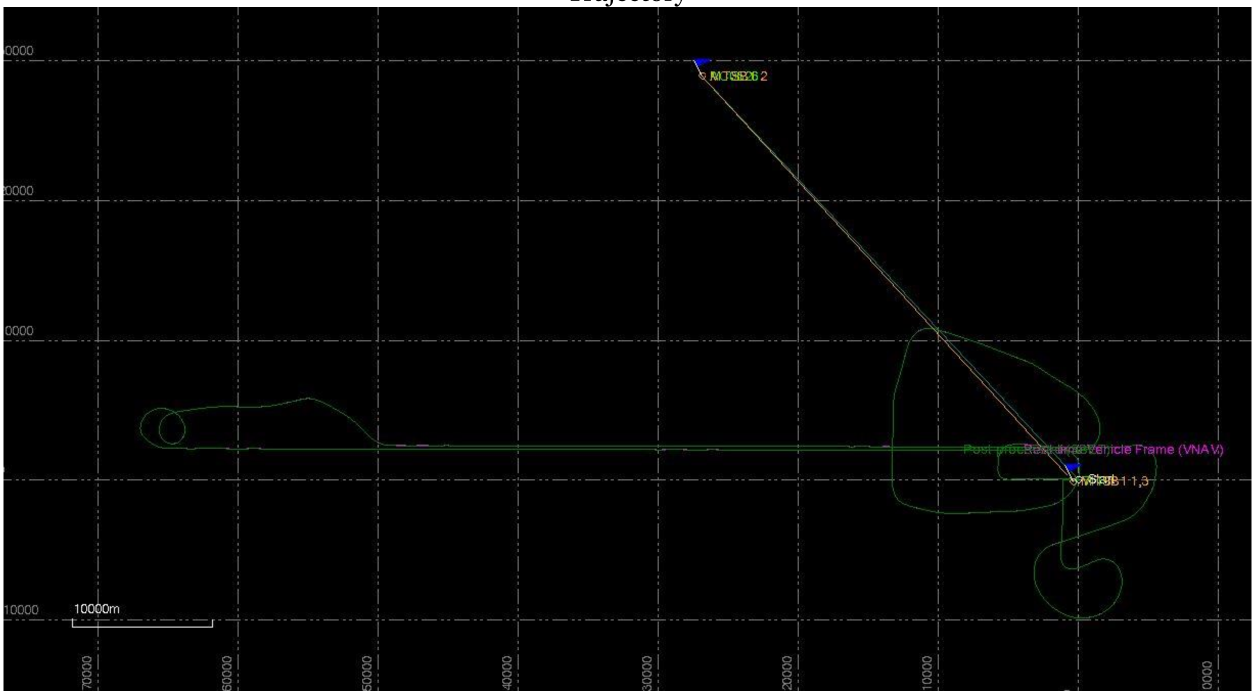

L1 Satellite Lock/Elevation
SV Index
400,000
402,000
404,000
406,000
408,000
410,000
412,000
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip



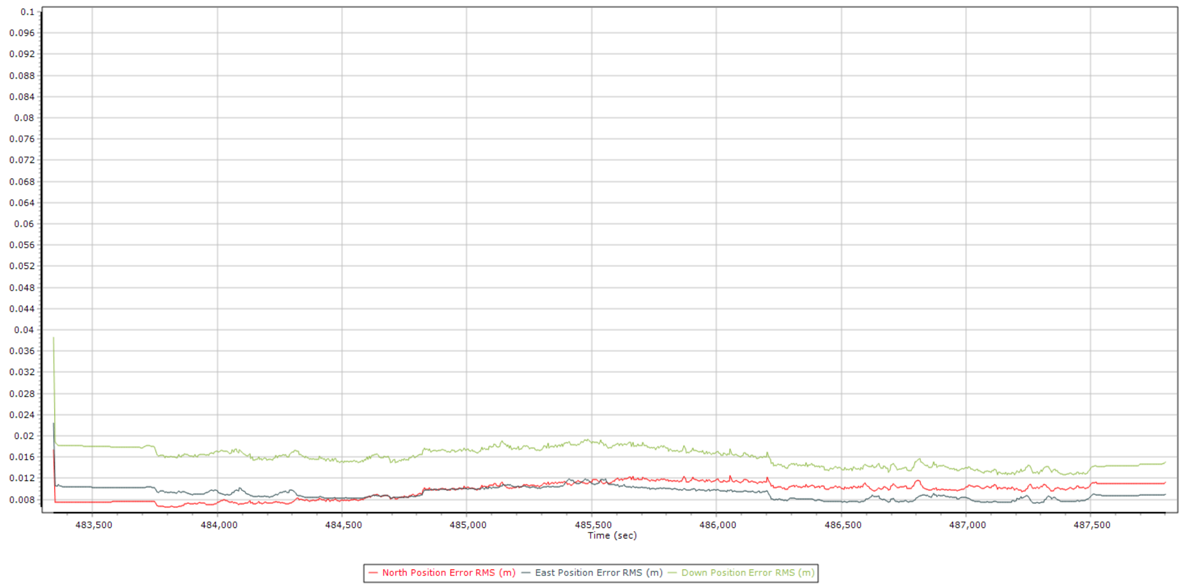
SBET IAKAR Separation

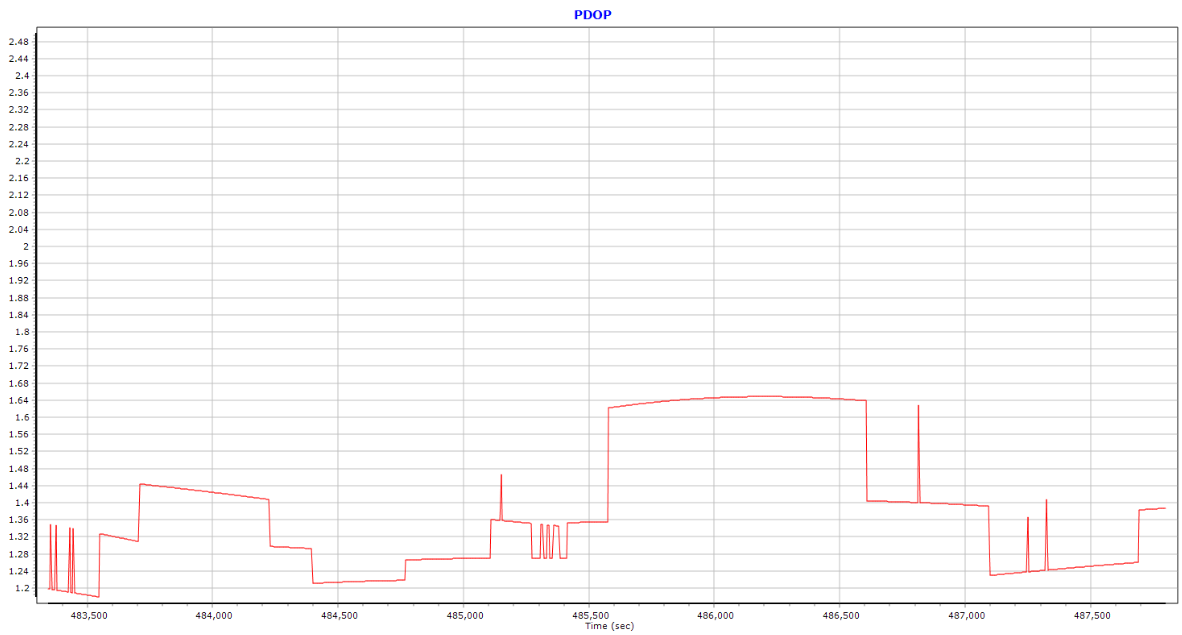
Mission: 20170421_A

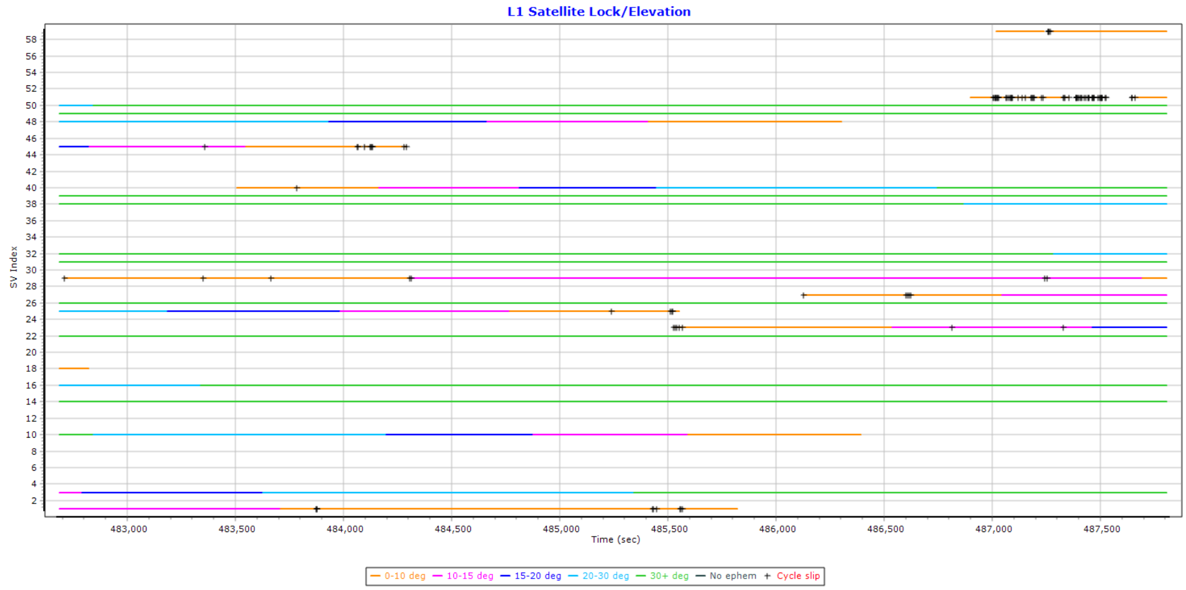
Trajectory

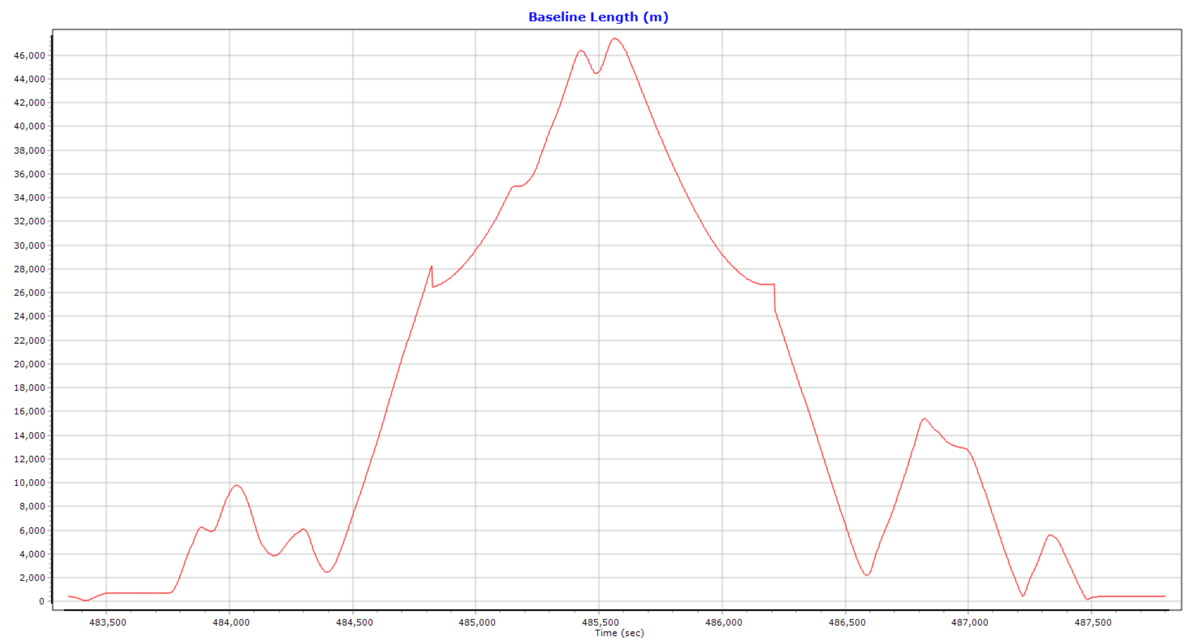


Smoothed Performance Metrics


Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

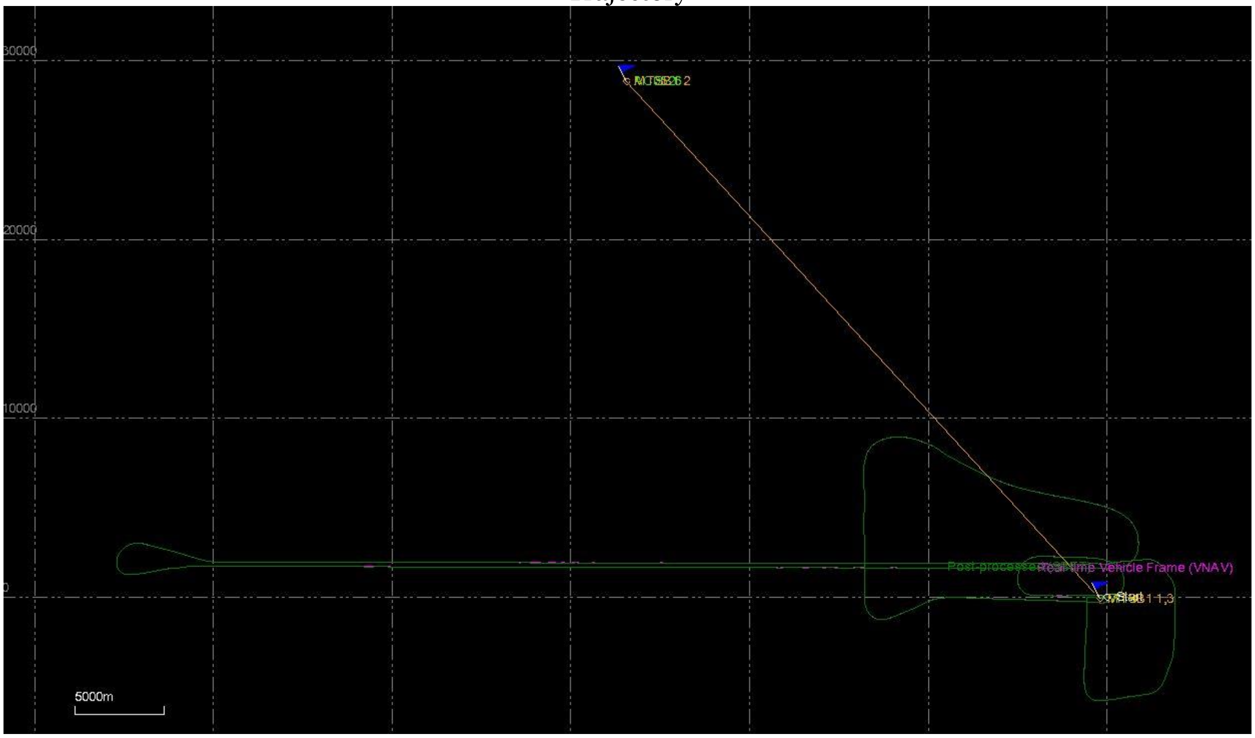

PDOP
Time (sec)


L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

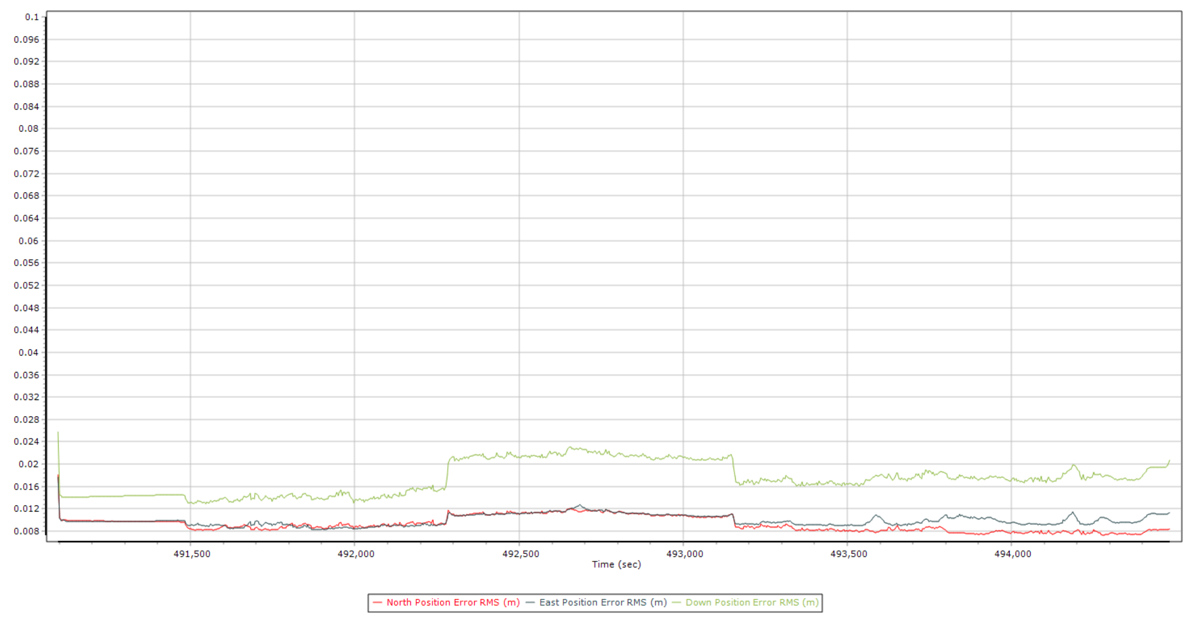

Baseline Length (m)
Time (sec)

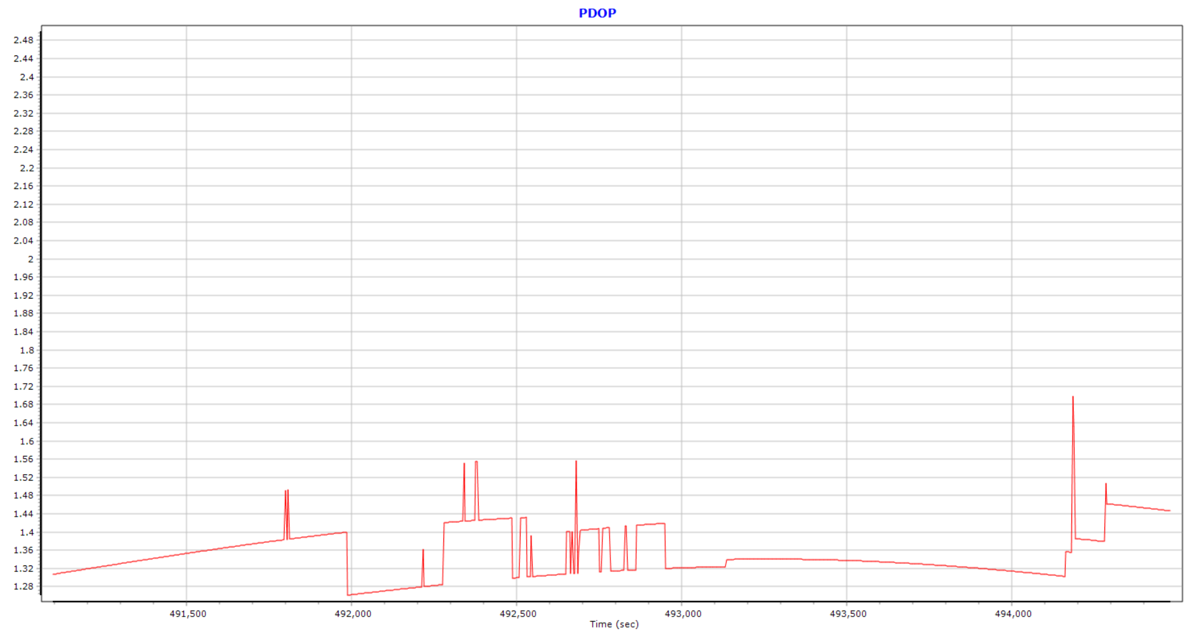
SBET IAKAR Separation

20170421_B
Trajectory



Smoothed Performance Metrics




PDOP
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2.4
2.36
2.32
2.28
2.24
2.2
2.16
2.12
2.08
2.04
2
1.96
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1.52
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1.28
491,500
492,000
492,500
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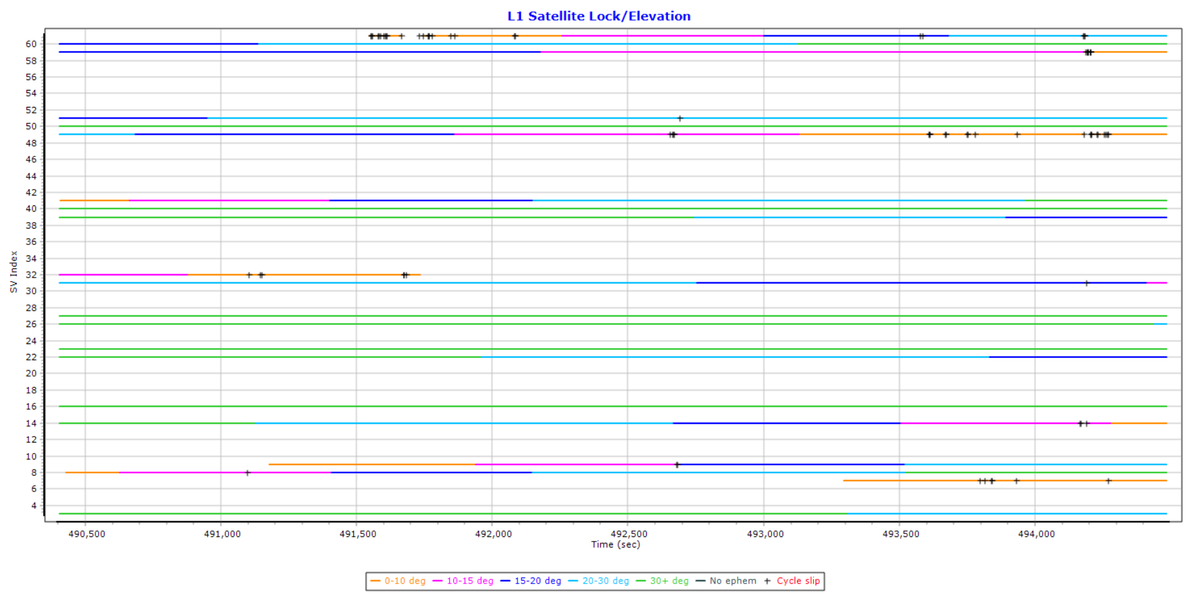
493,500
494,000
Time (sec)


L1 Satellite Lock/Elevation
SV Index
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
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22
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18
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14
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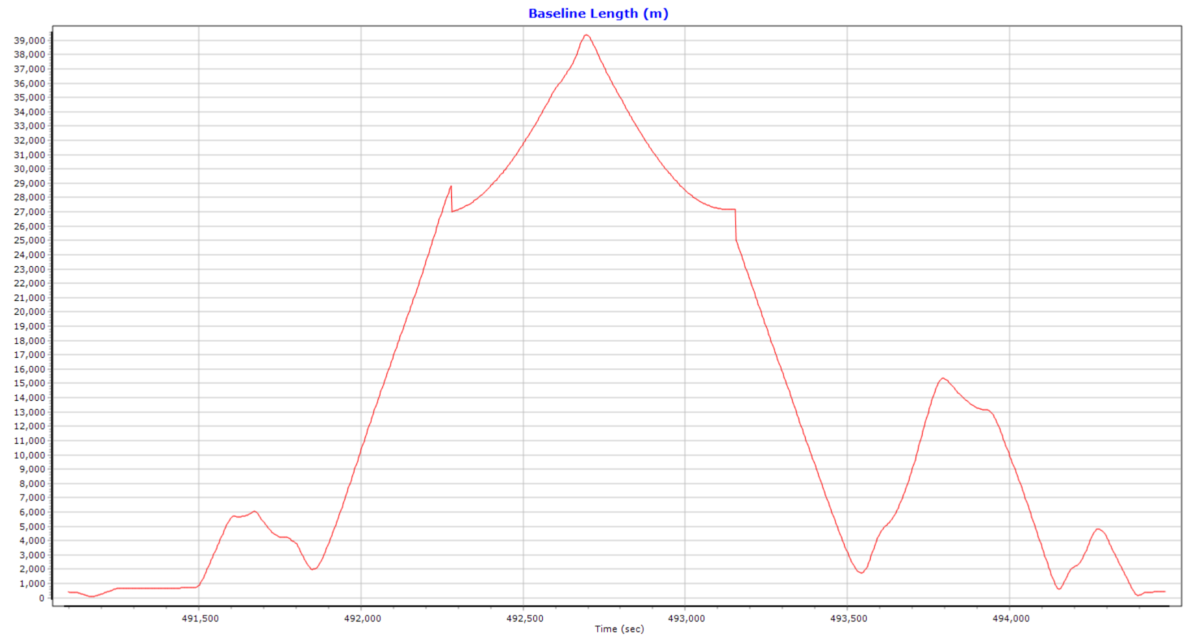
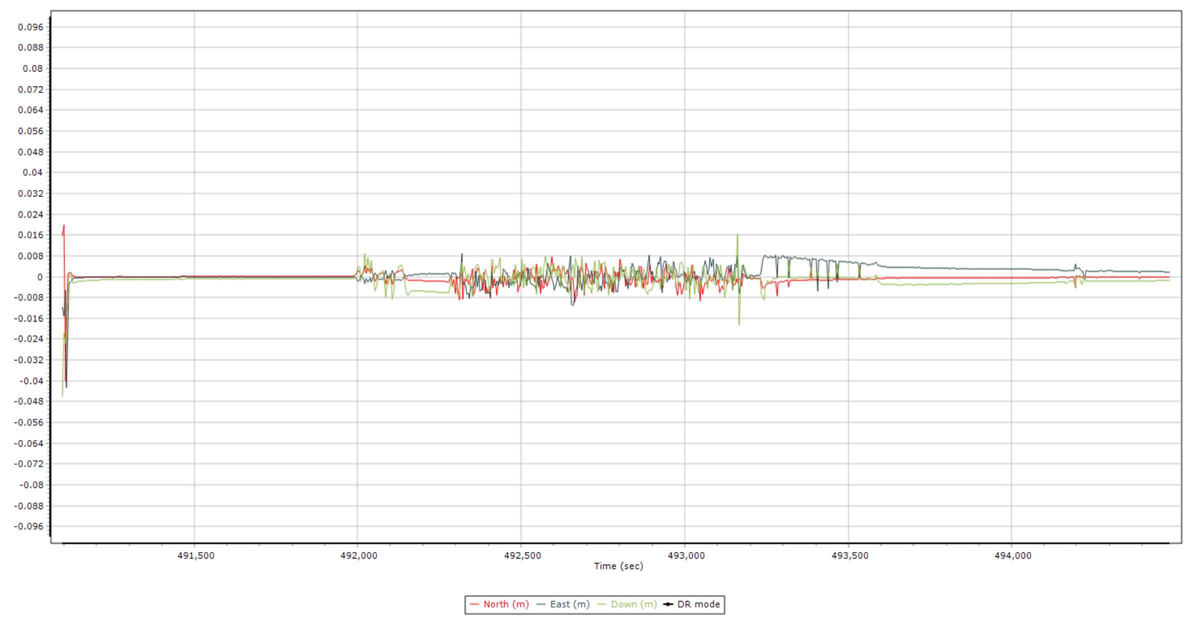
8
6
4
490,500
491,000
491,500
492,000
492,500
493,000
493,500
494,000
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

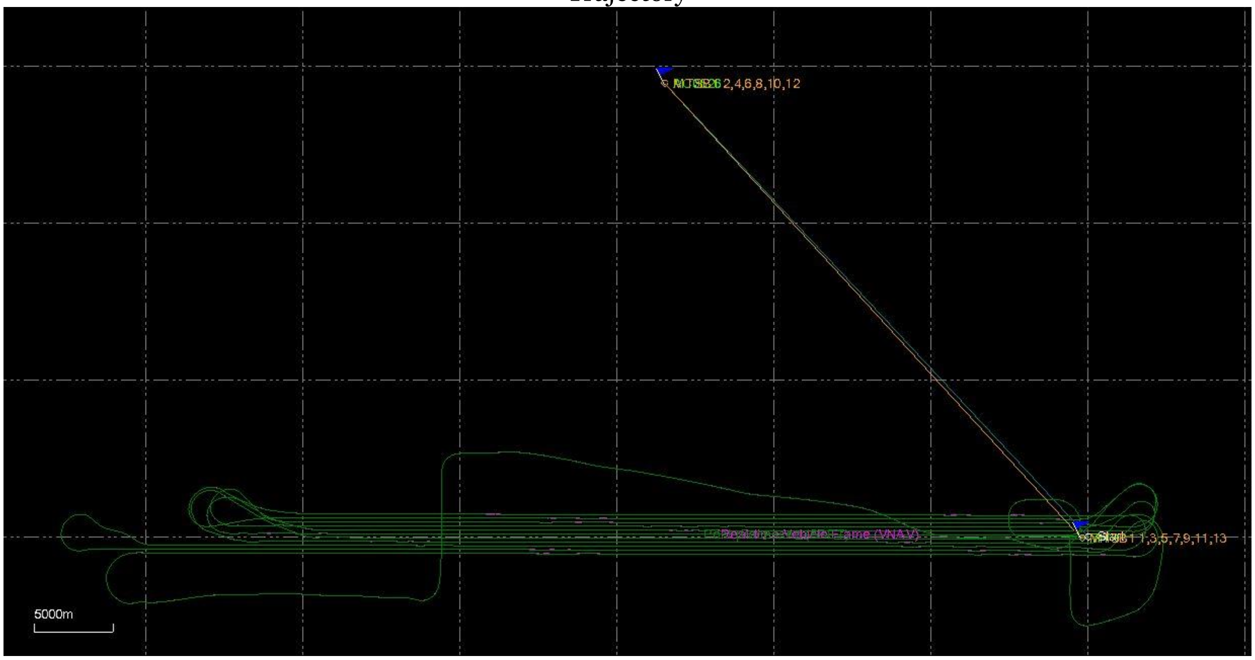


SBET IAKAR Separation

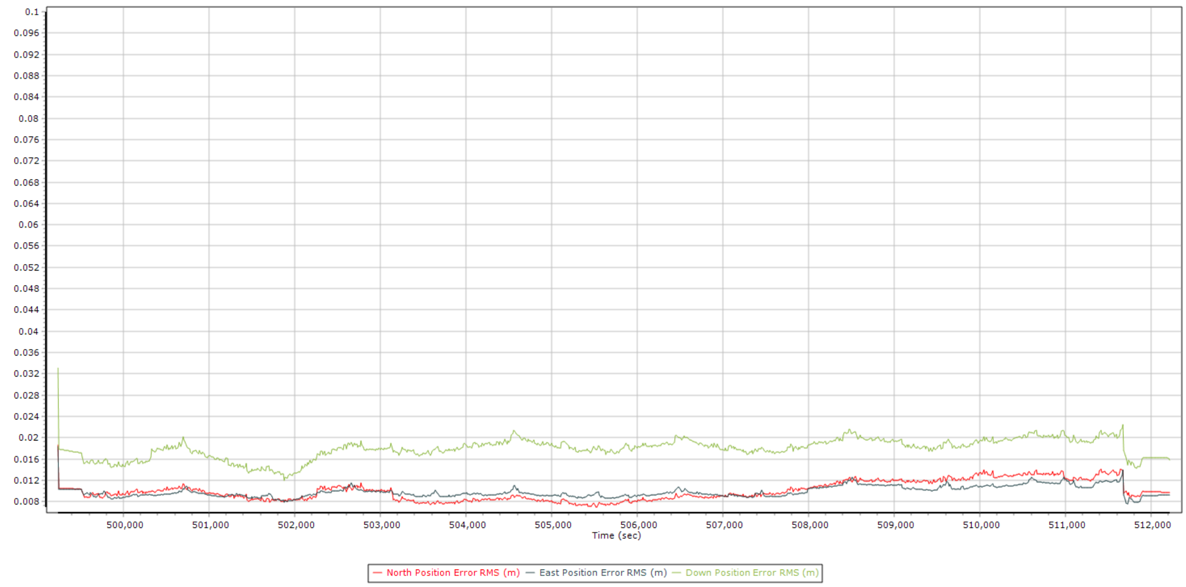


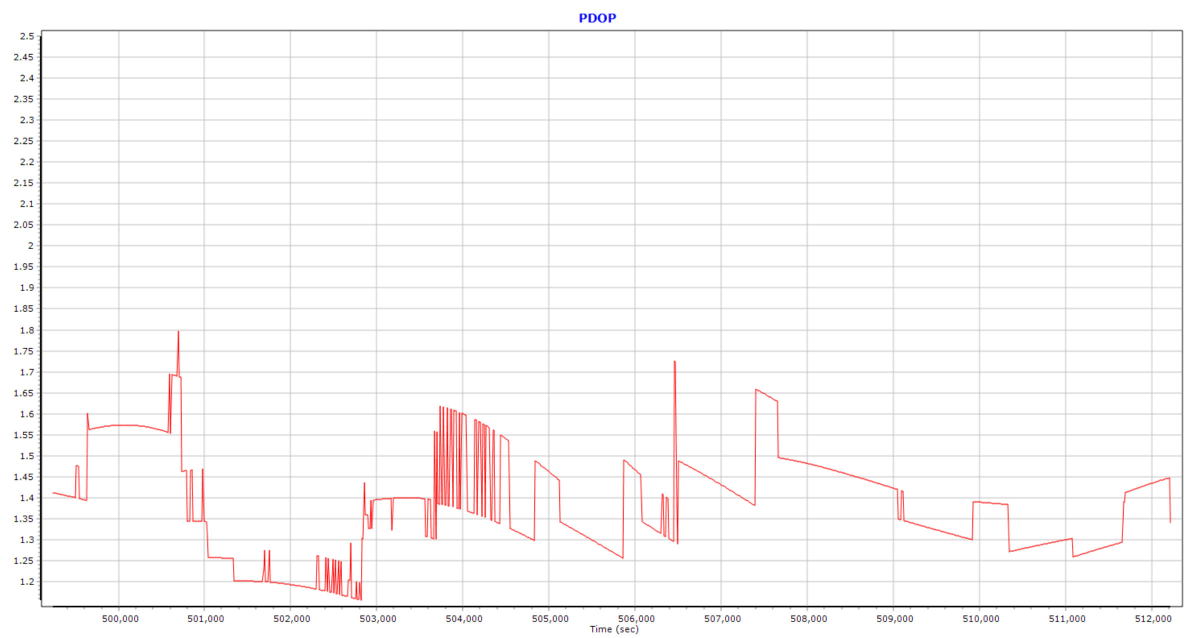
20170421_C

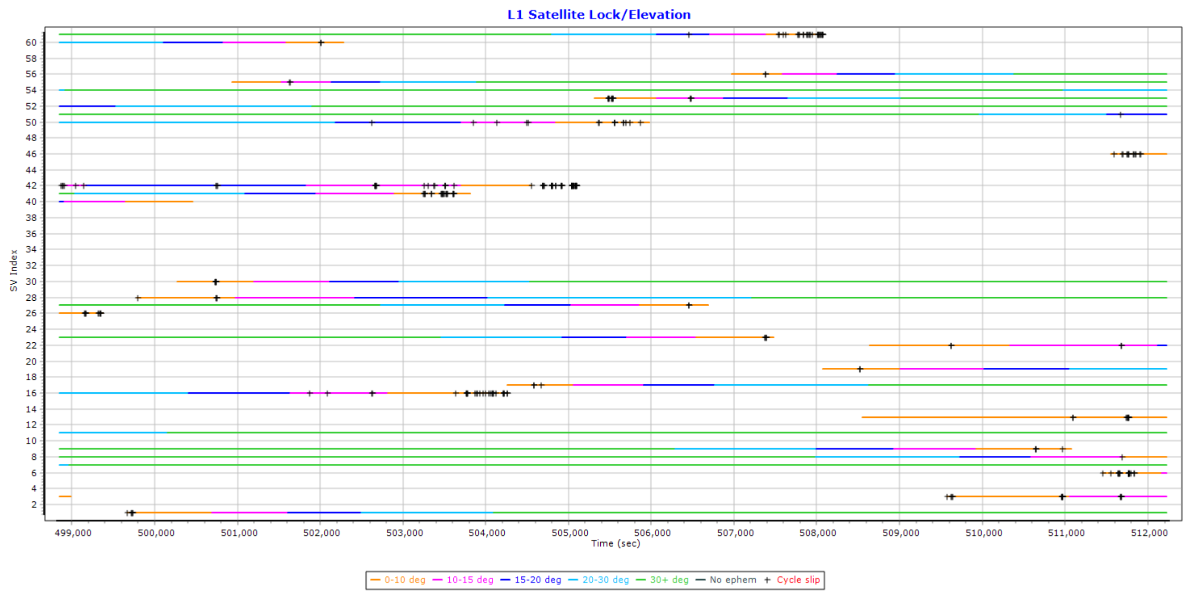
Trajectory

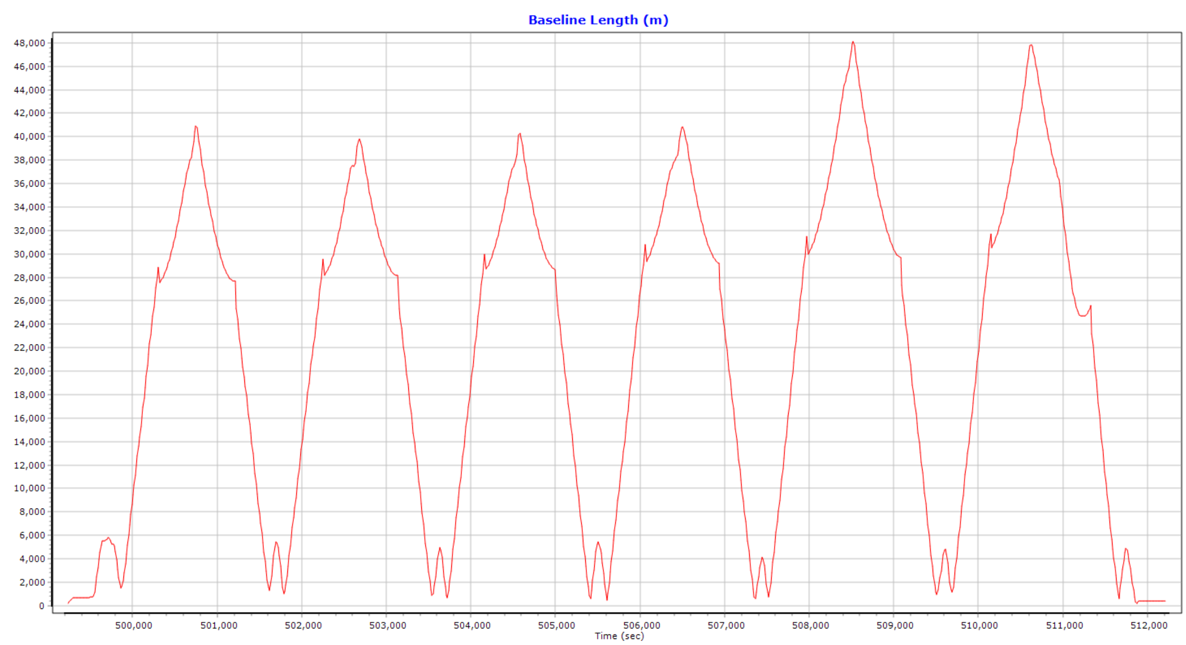


Smoothed Performance Metrics

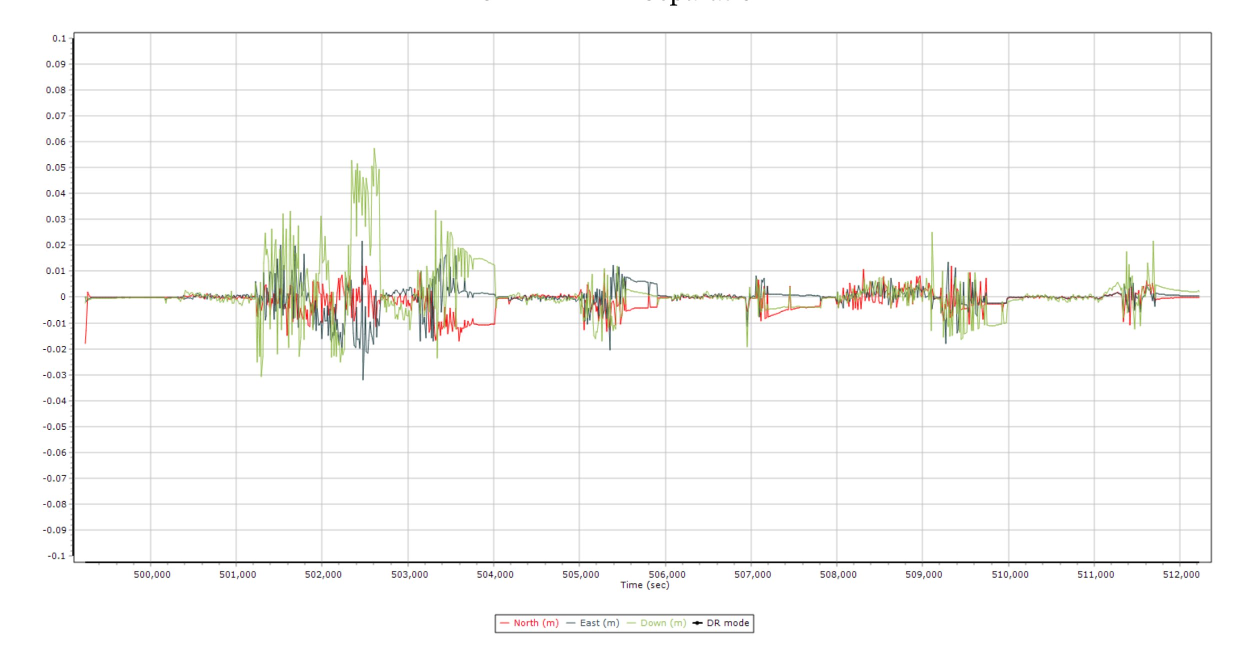

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


PDOP
Time (sec)


L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

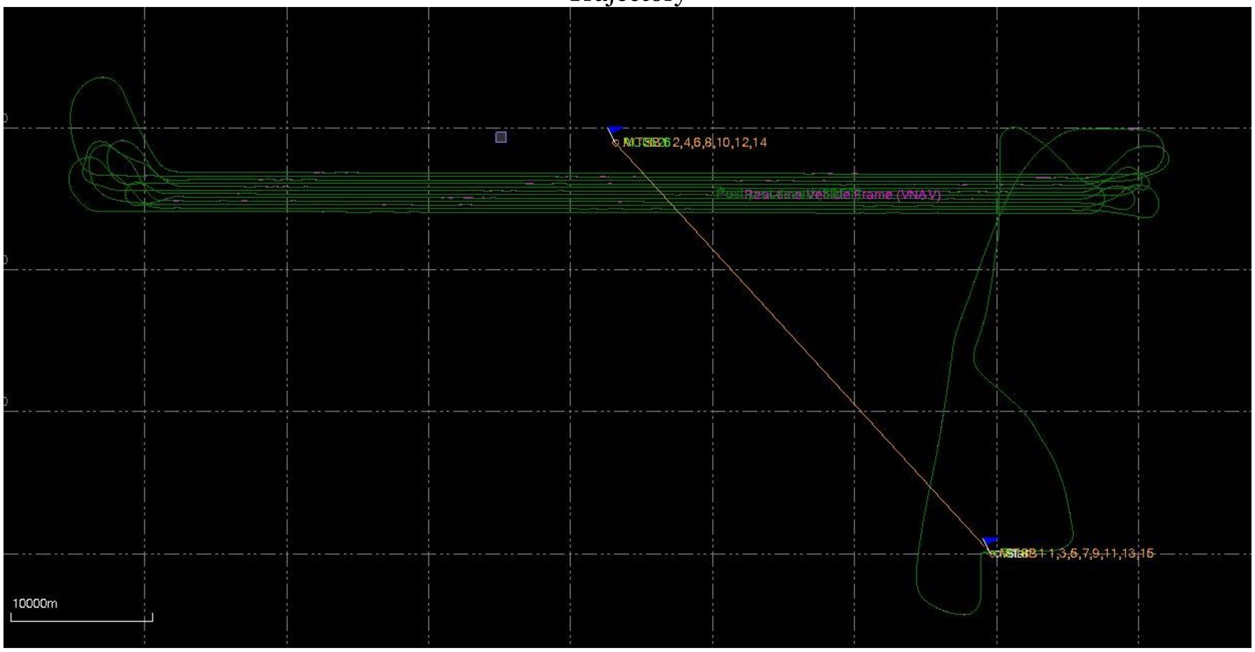

Baseline Length (m)
Time (sec)

SBET IAKAR Separation

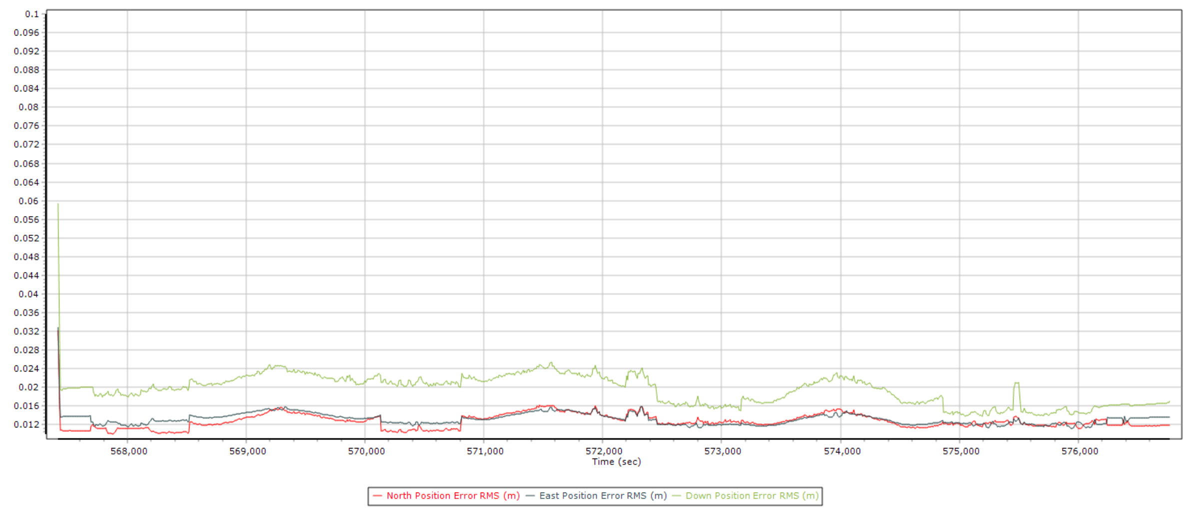


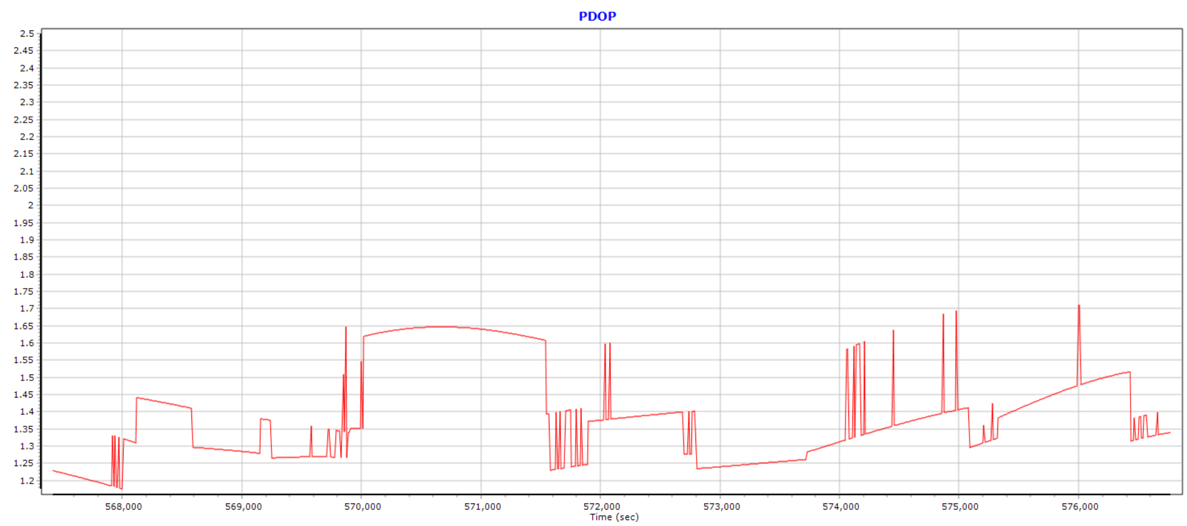
Mission: 20170424_A

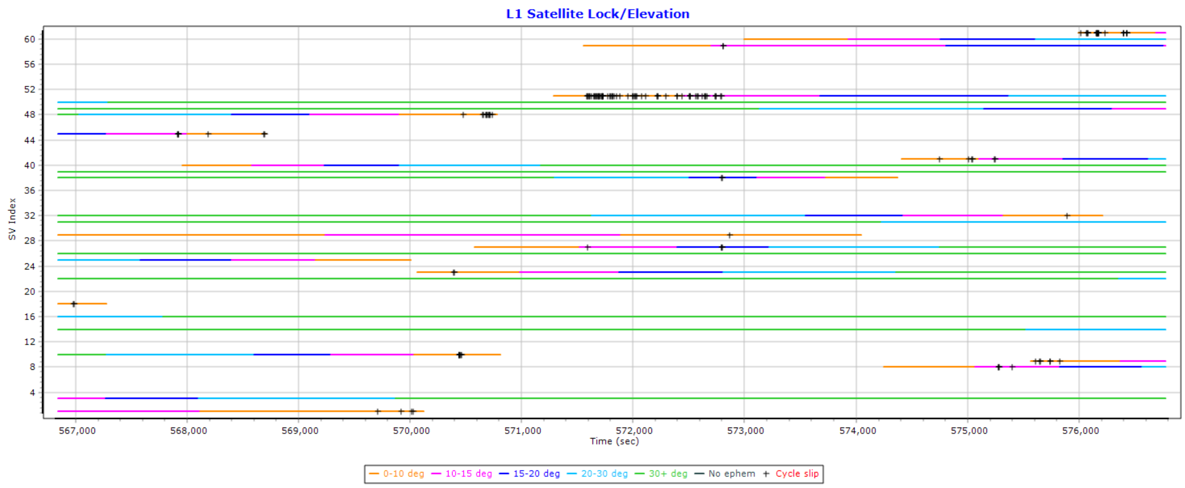
Trajectory

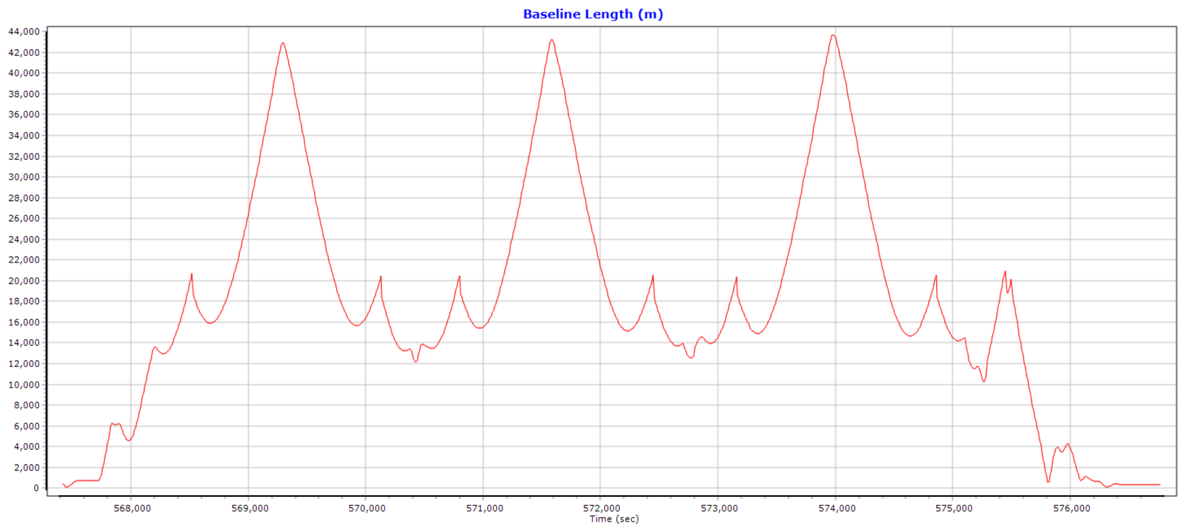


Smoothed Performance Metrics

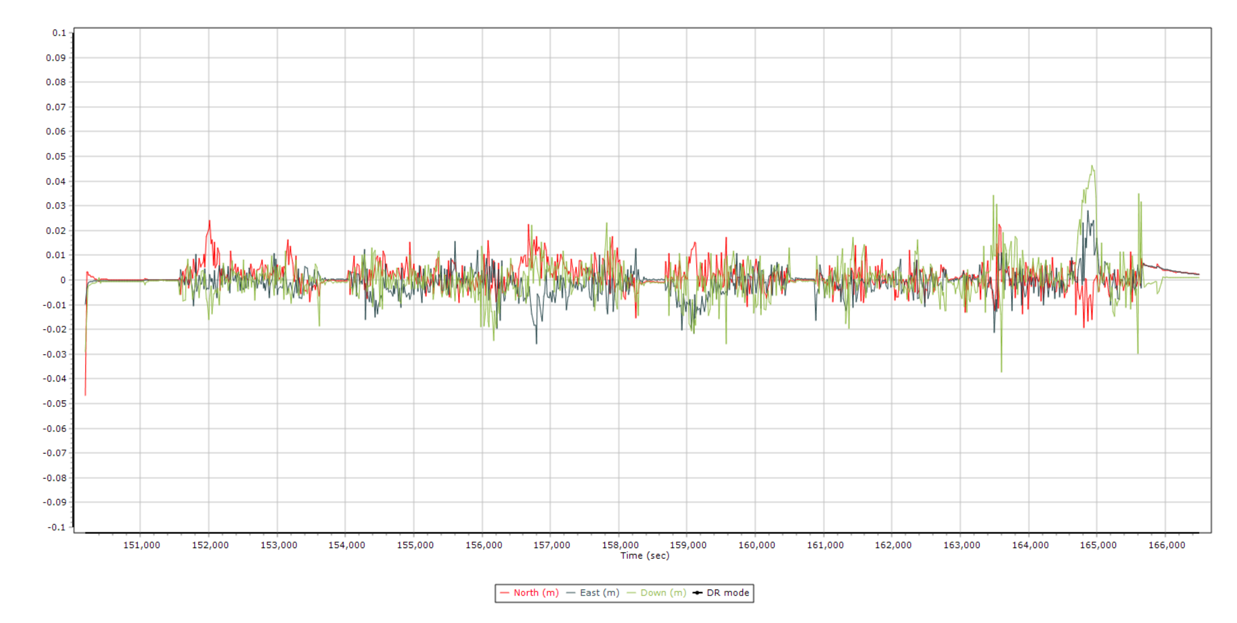

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


PDOP
Time (sec)

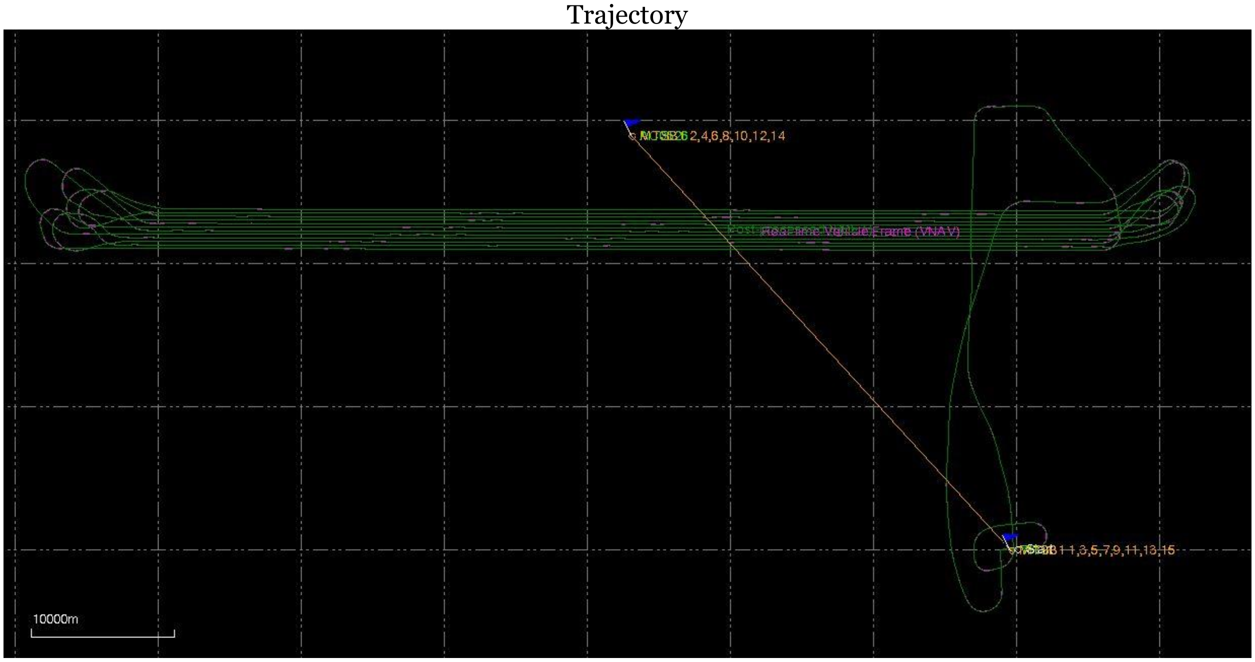




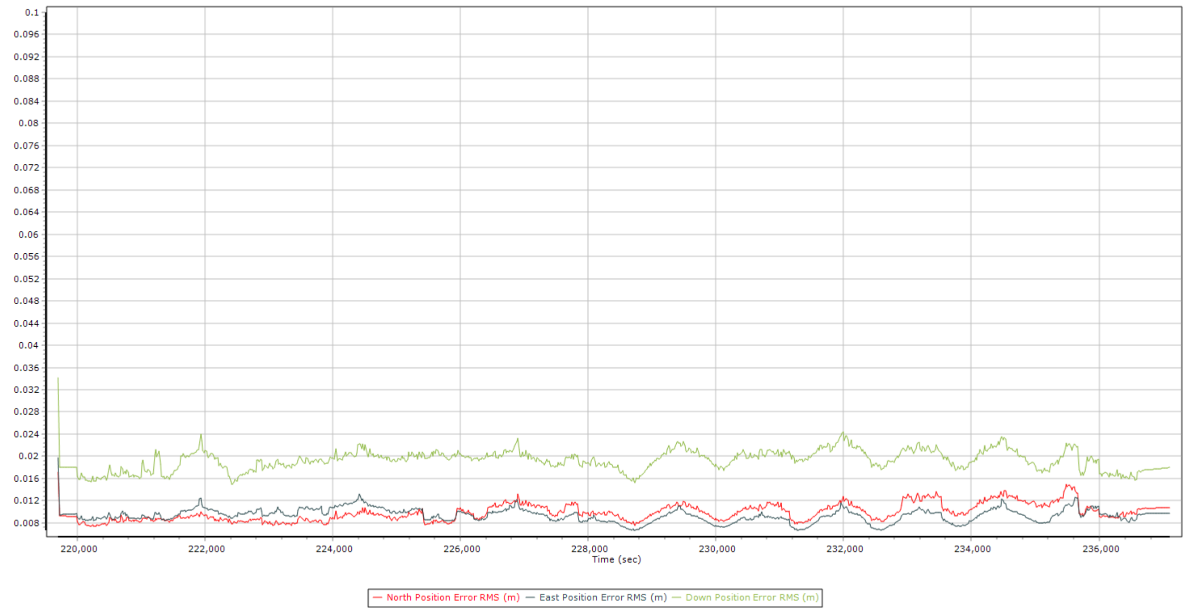
SBET IAKAR Separation

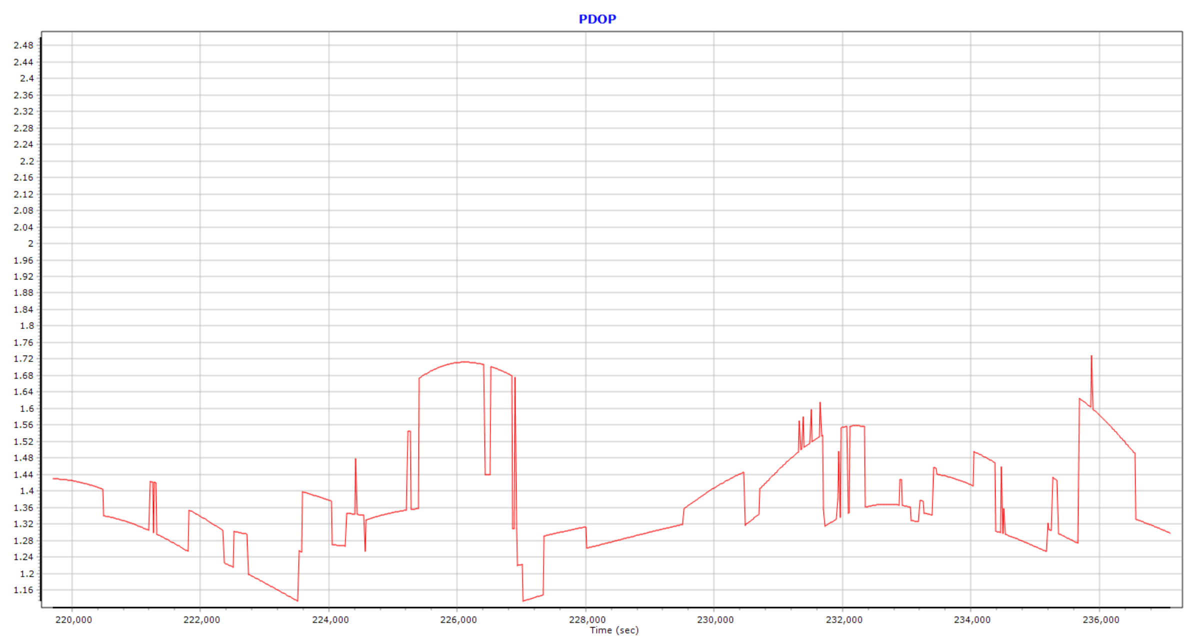


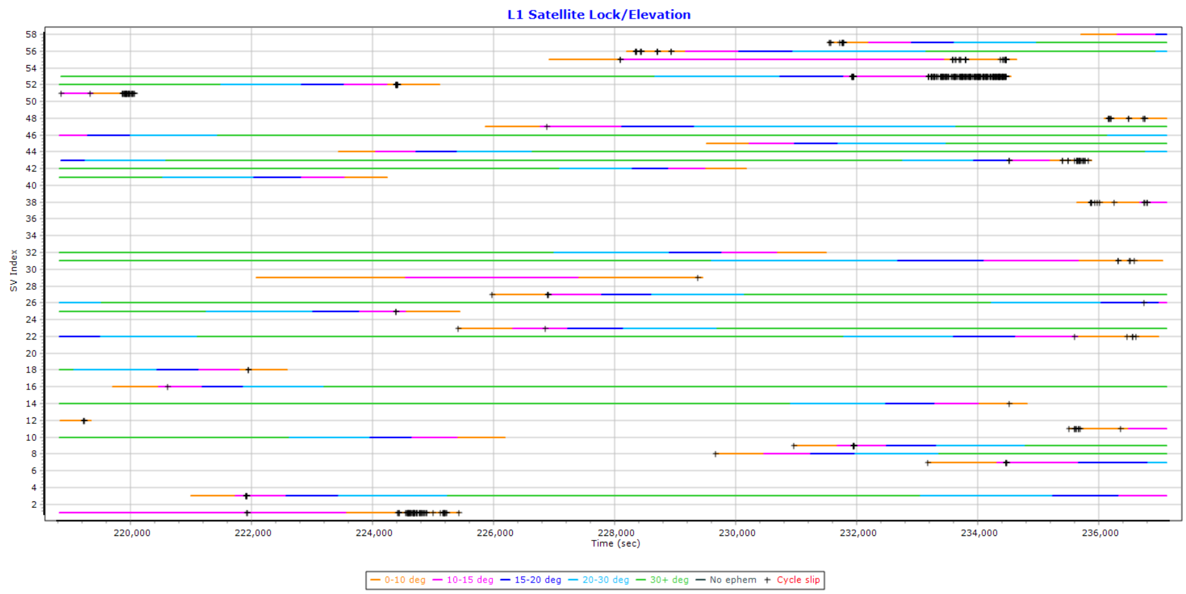
Mission:
20170425_A
Trajectory

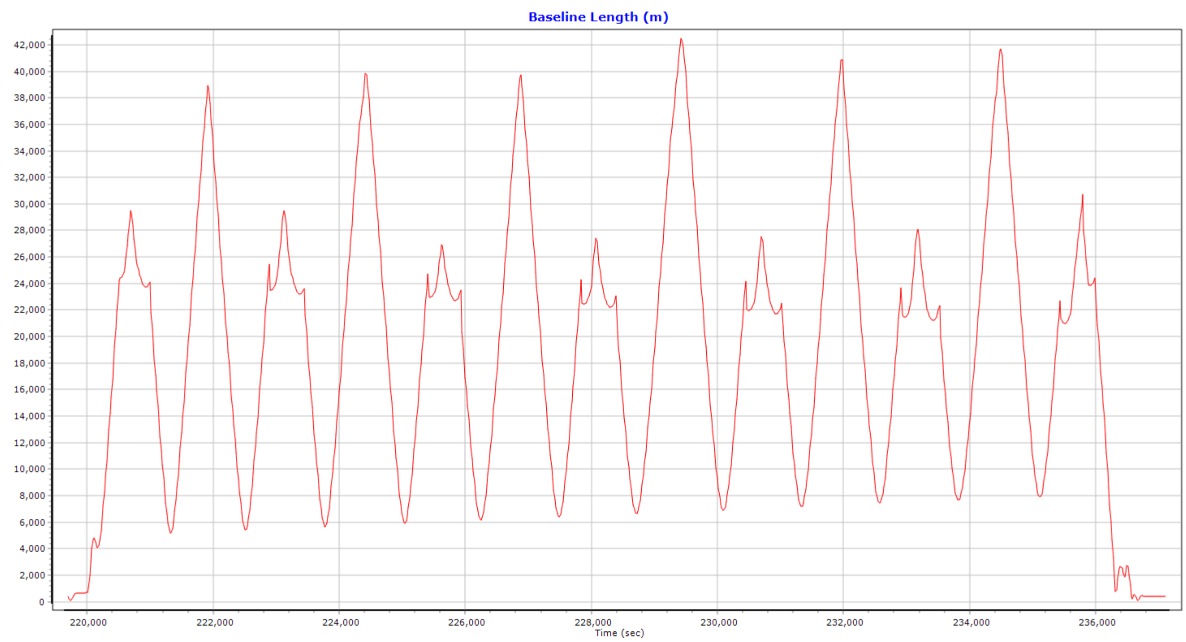


Smoothed Performance Metrics





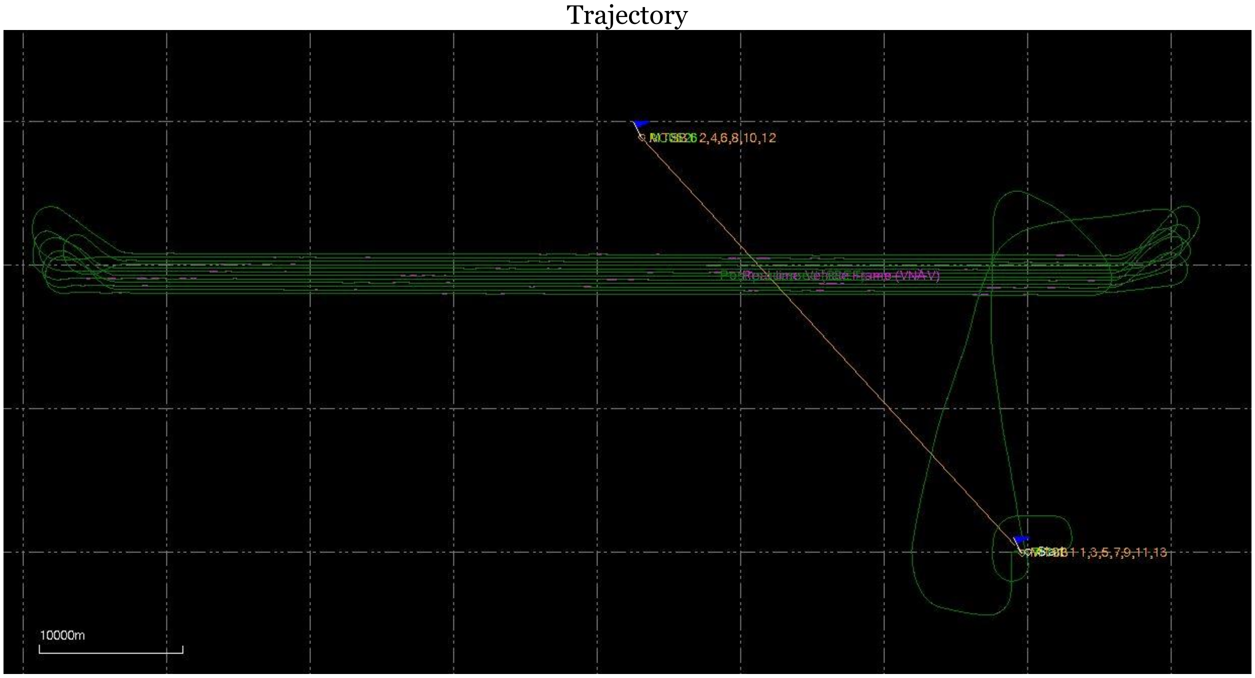




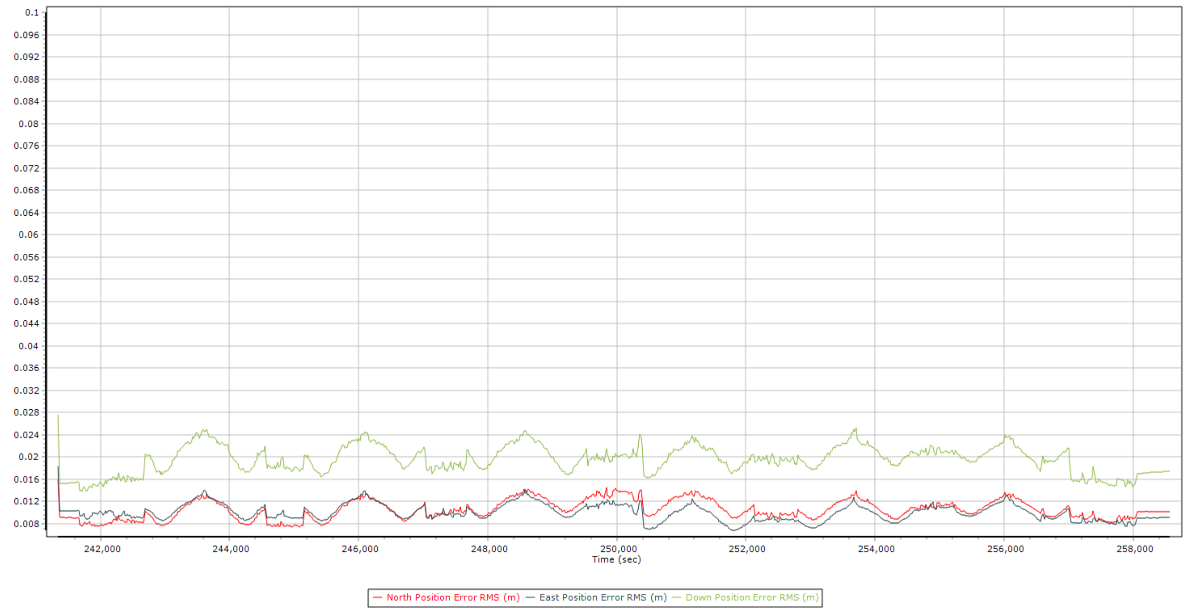
SBET IAKAR Separation

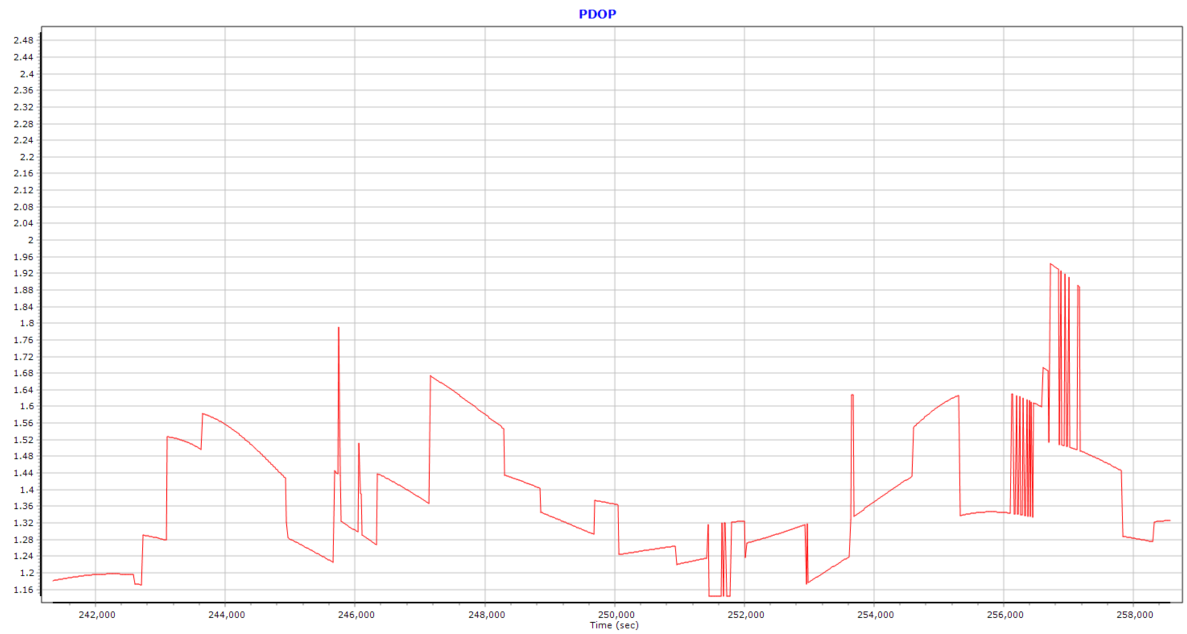
Mission: 20170425_B

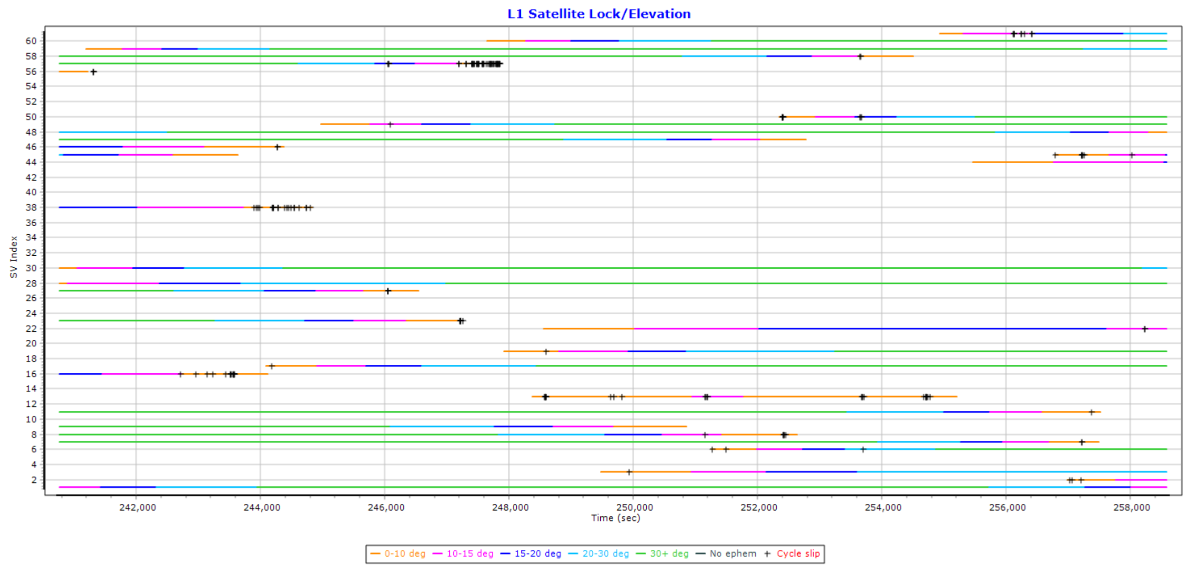
Trajectory

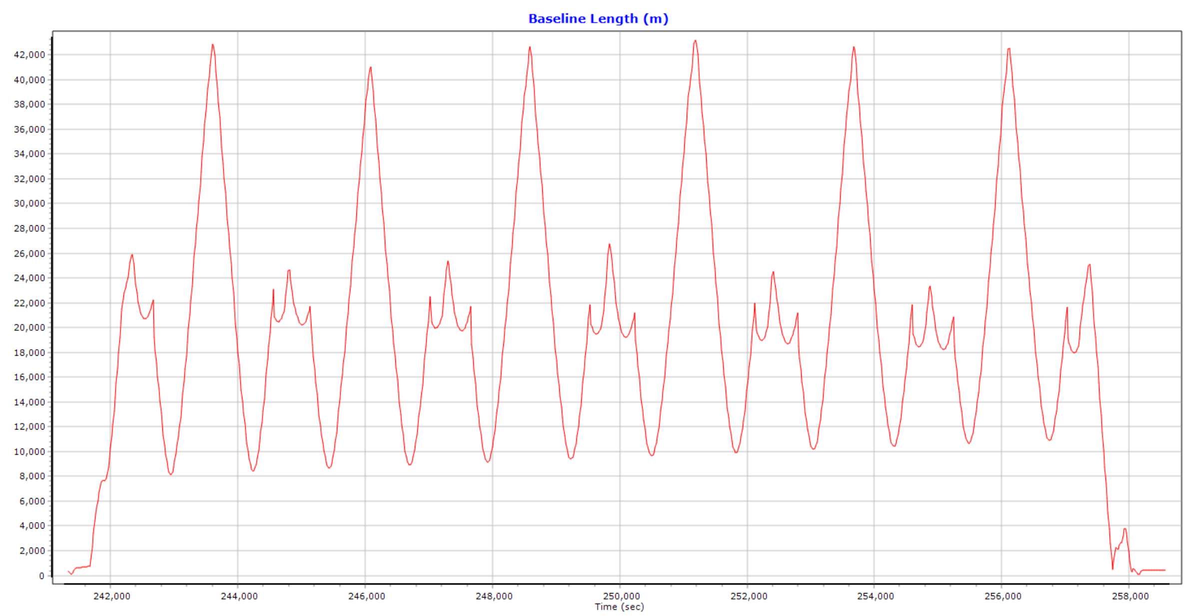


Smoothed Performance Metrics



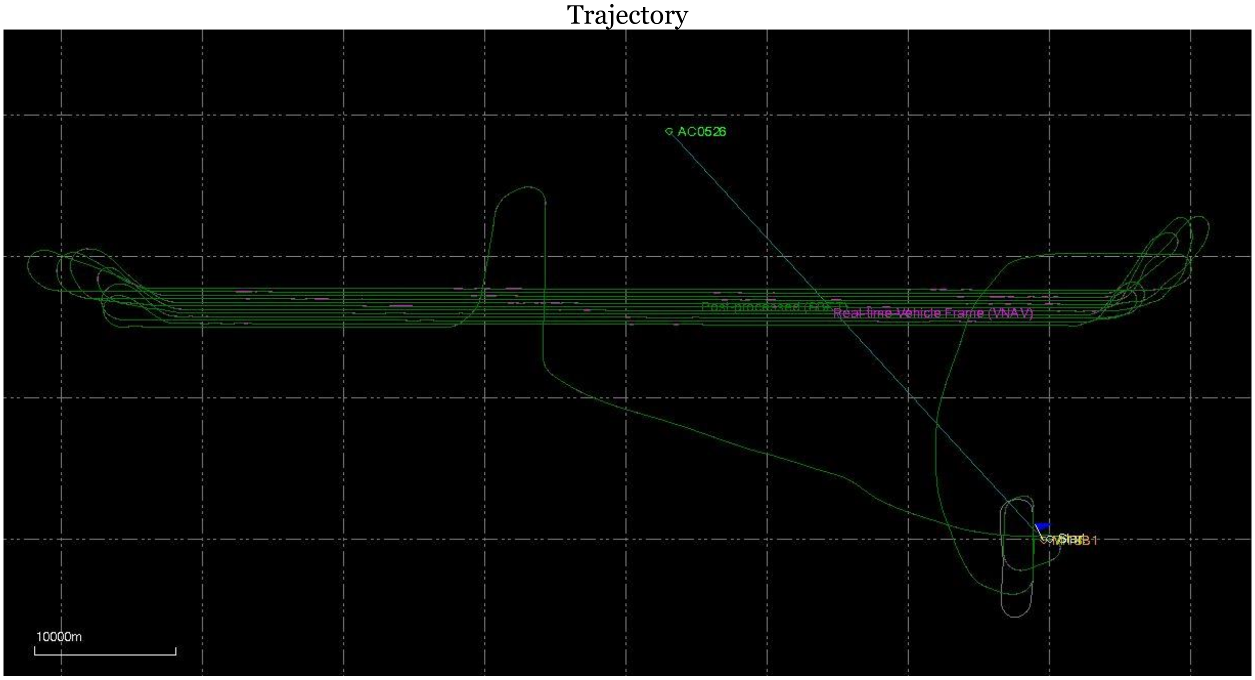



L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

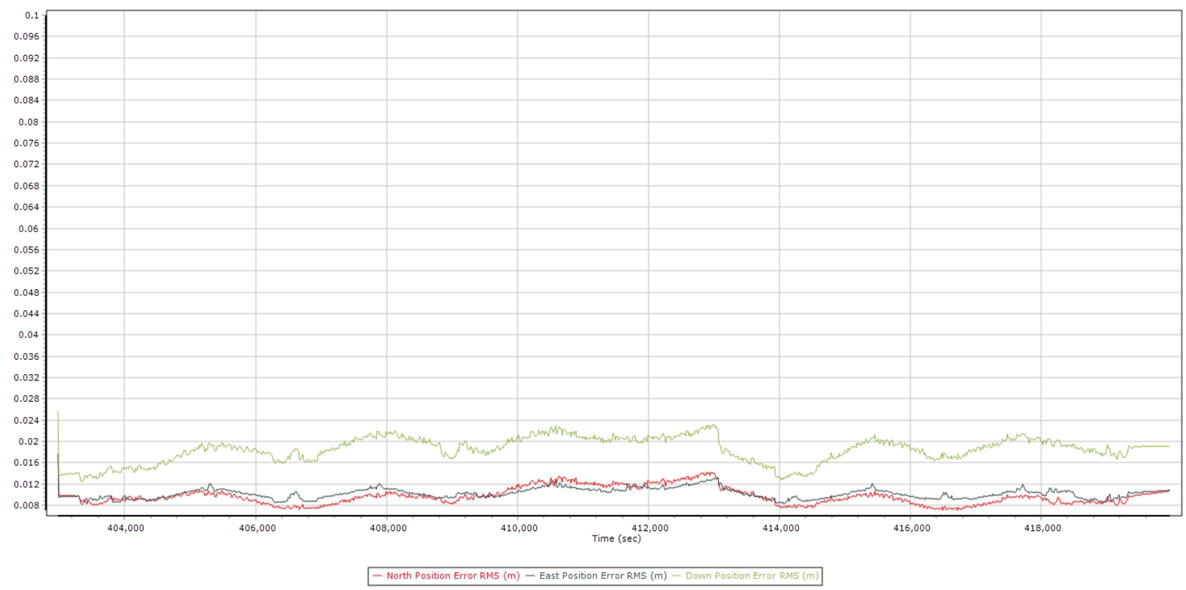

Baseline Length (m)
Time (sec)

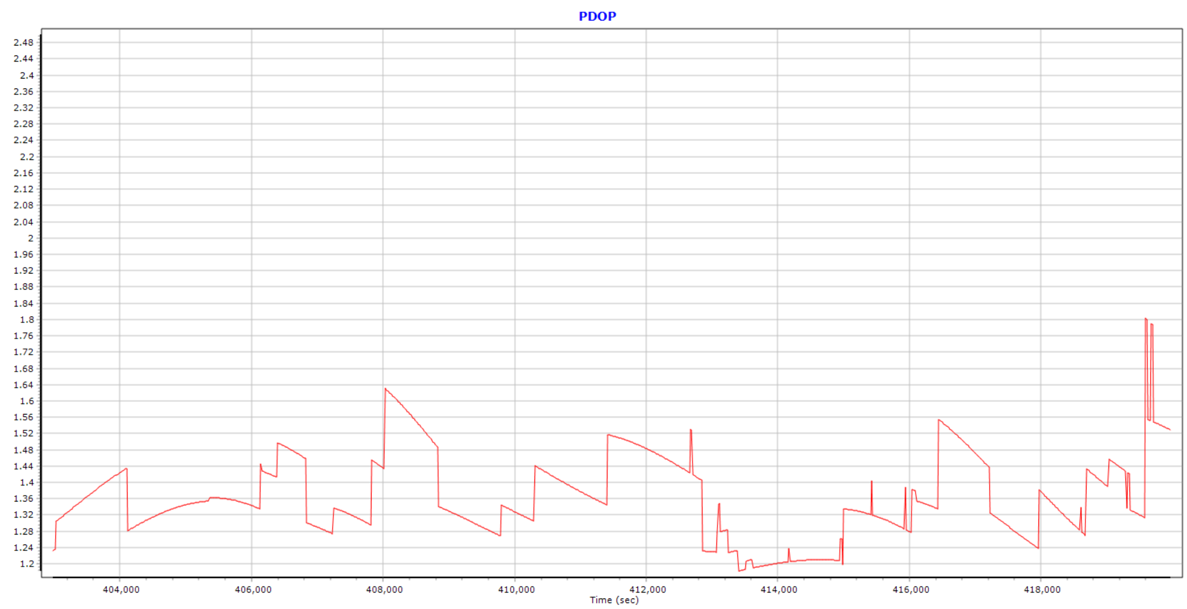
Mission:20170427_A

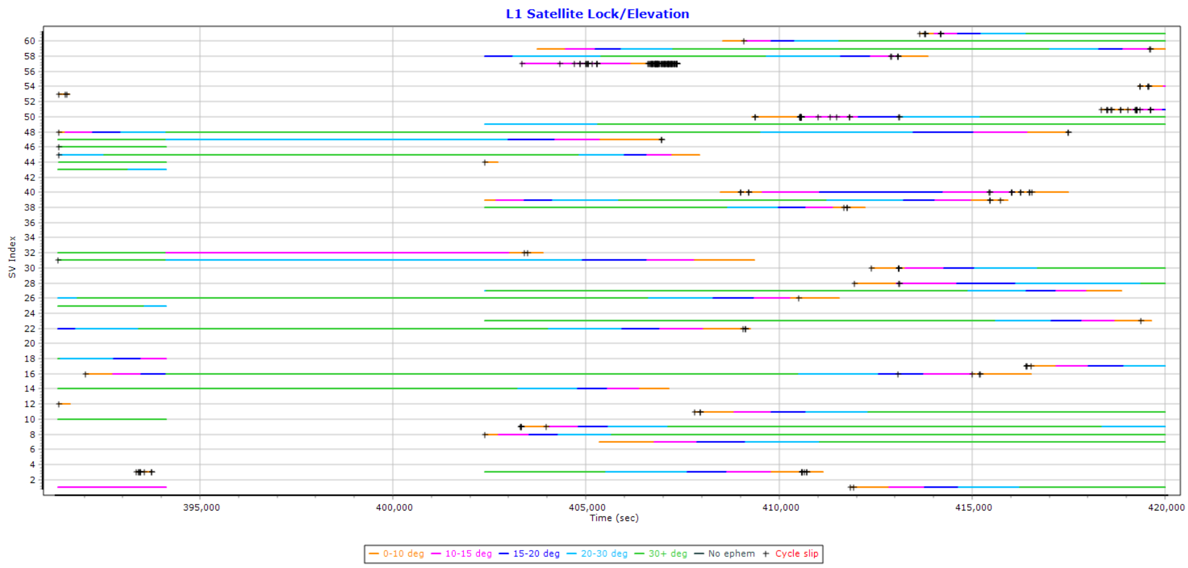
Trajectory

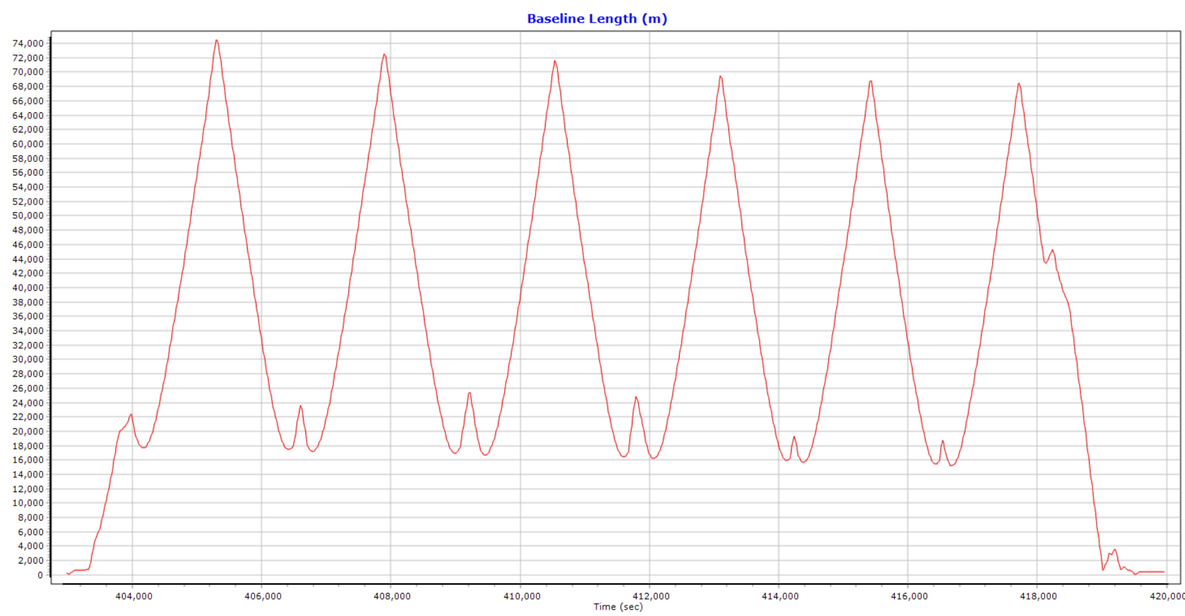


Smoothed Performance Metrics





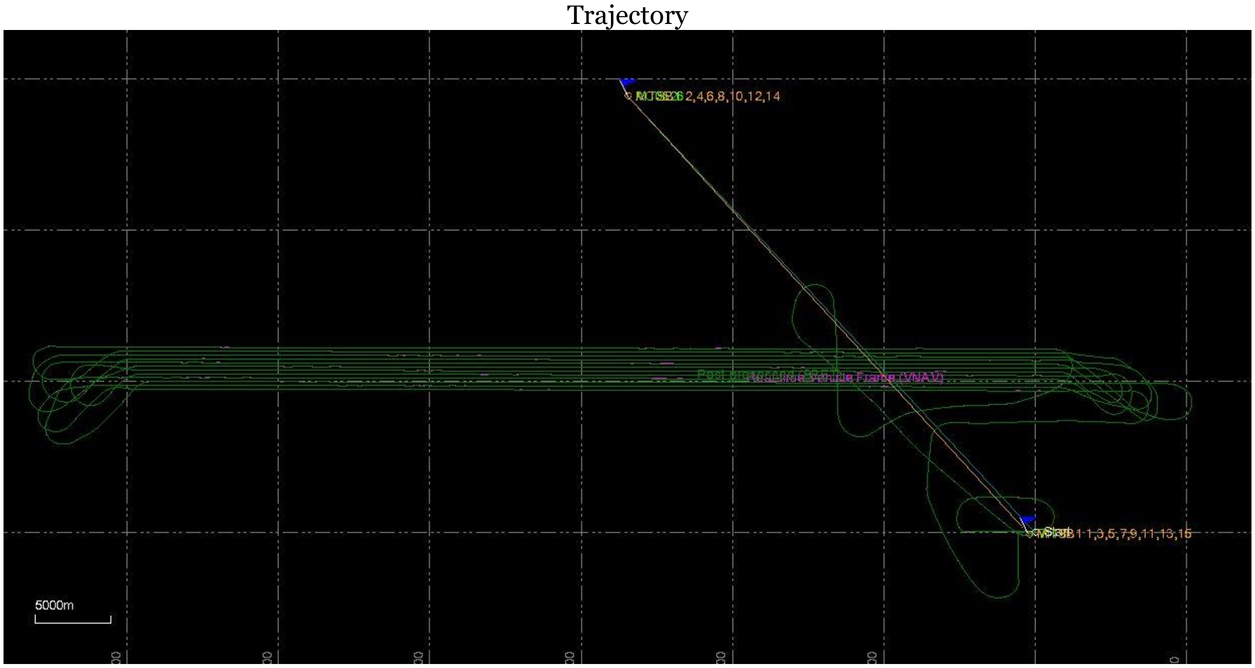

L1 Satellite Lock/Elevation
SV Index
Time (sec)
395,000
400,000
405,000
410,000
415,000
420,000
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip


Baseline Length (m)
Time (sec)
404,000
406,000
408,000
410,000
412,000
414,000
416,000
418,000
420,000

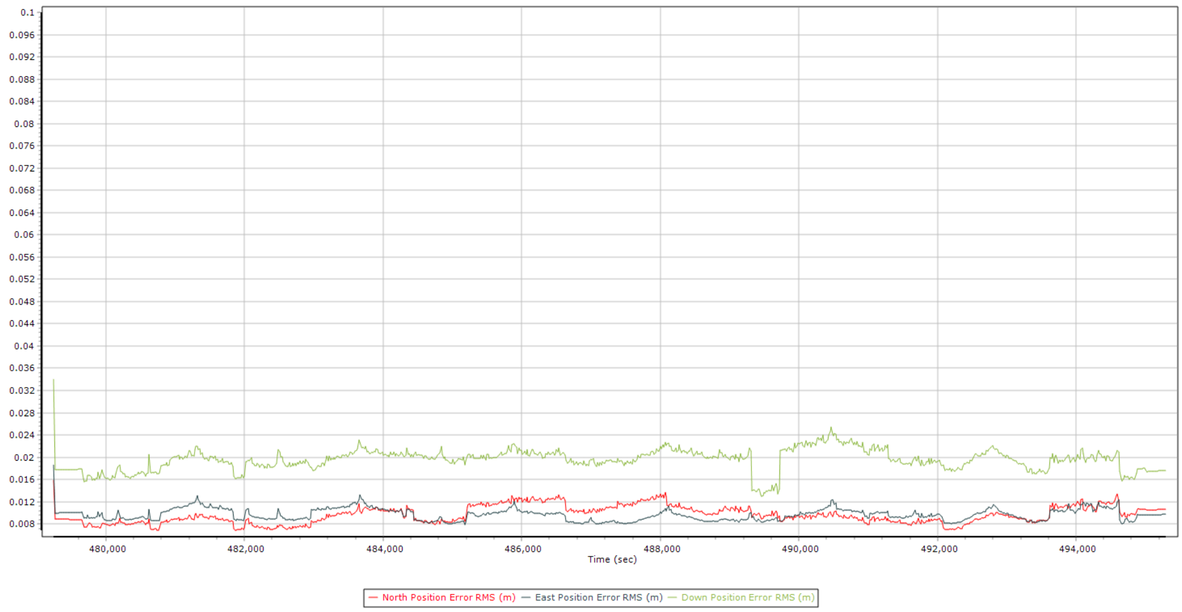
SBET IAKAR Separation

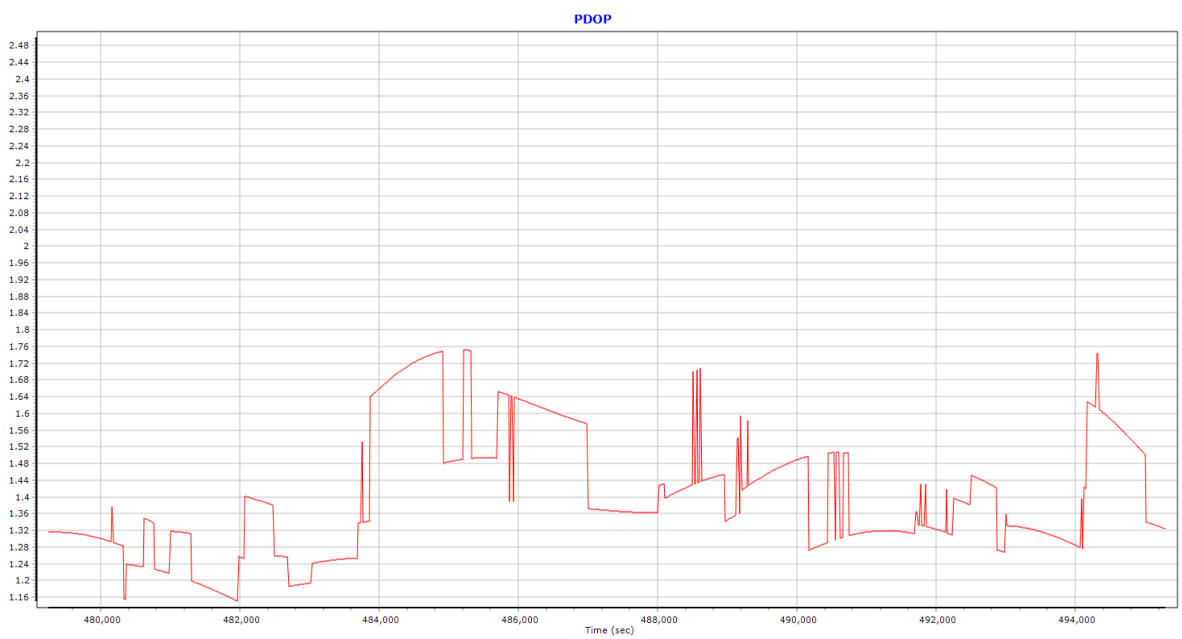
Mission: 20170428_A

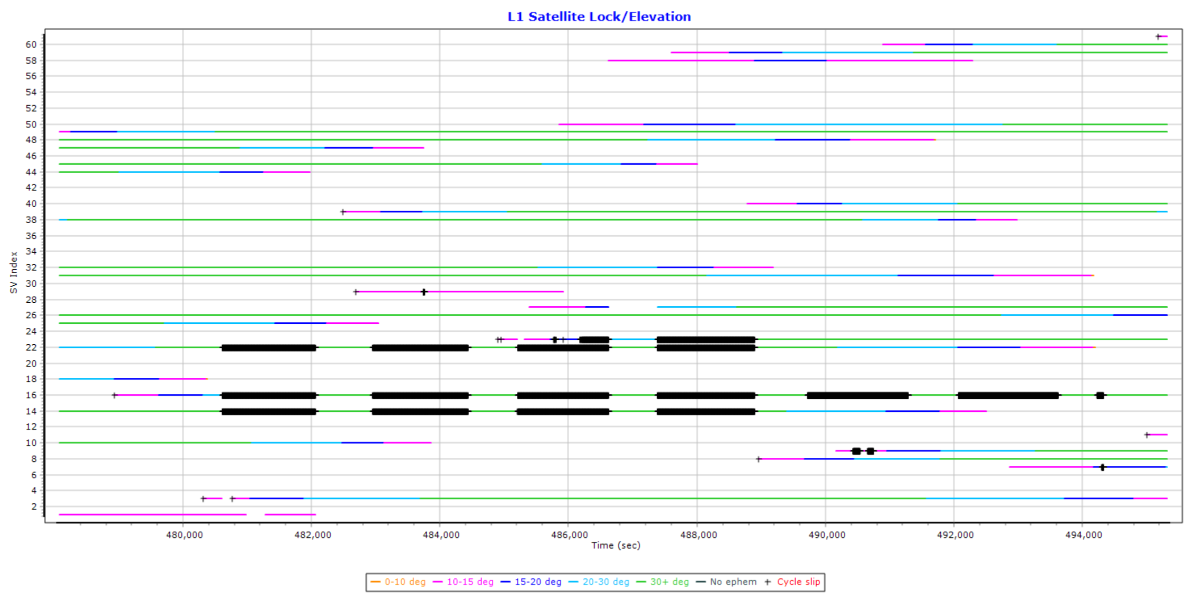
Trajectory

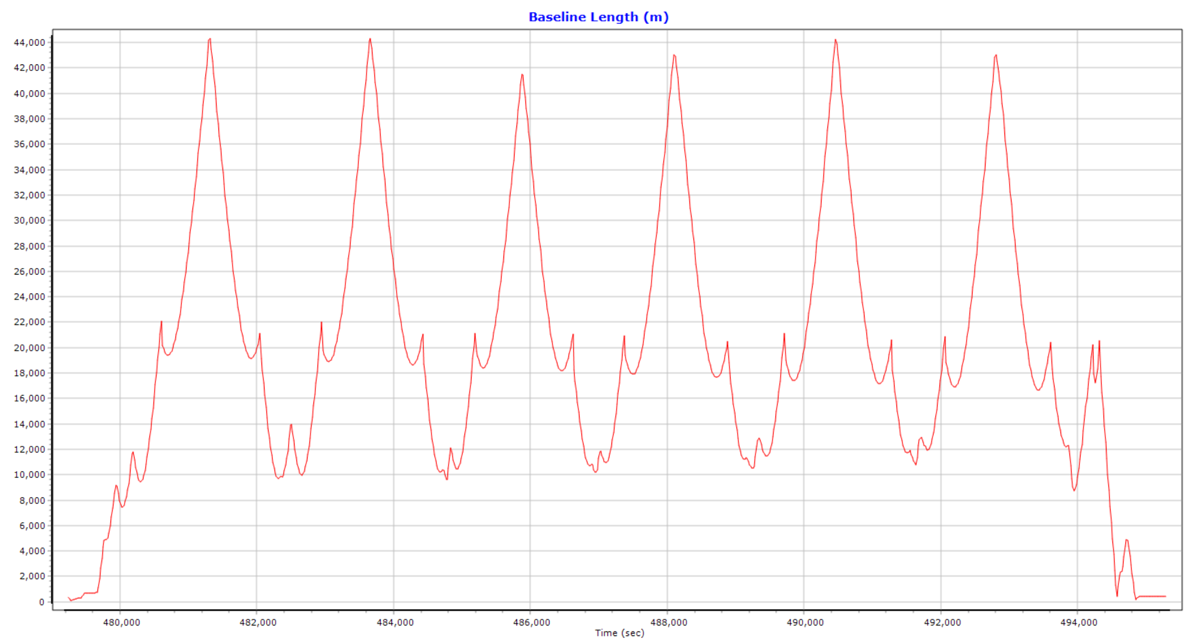


Smoothed Performance Metrics

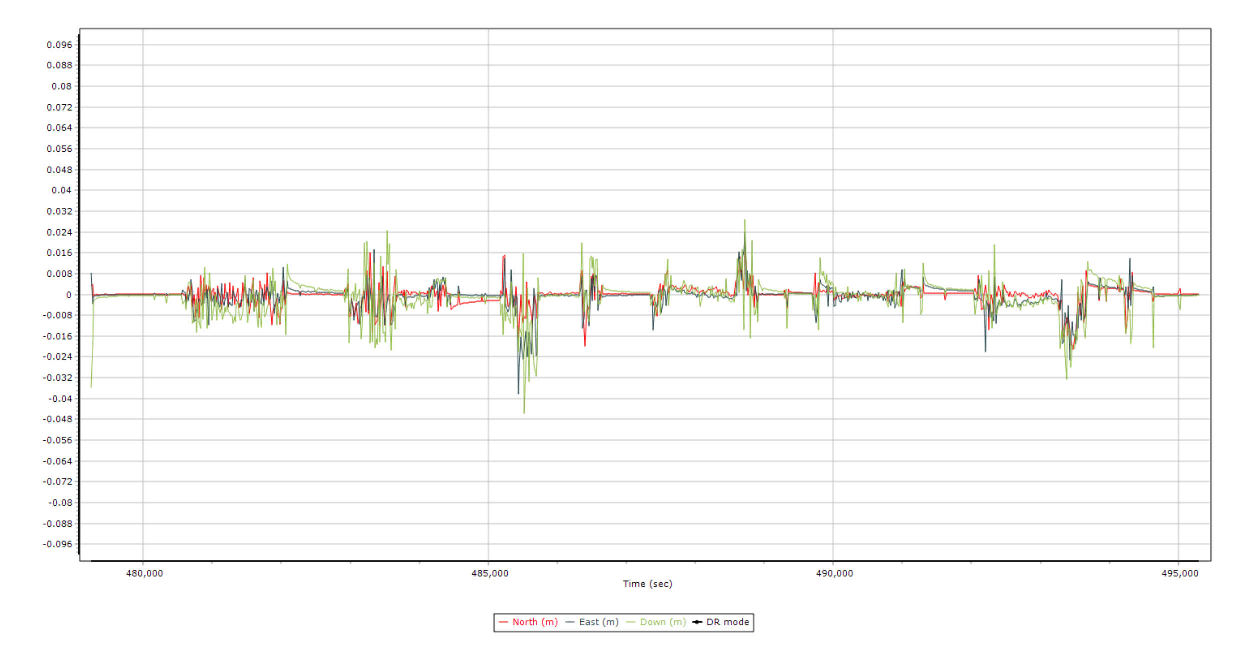






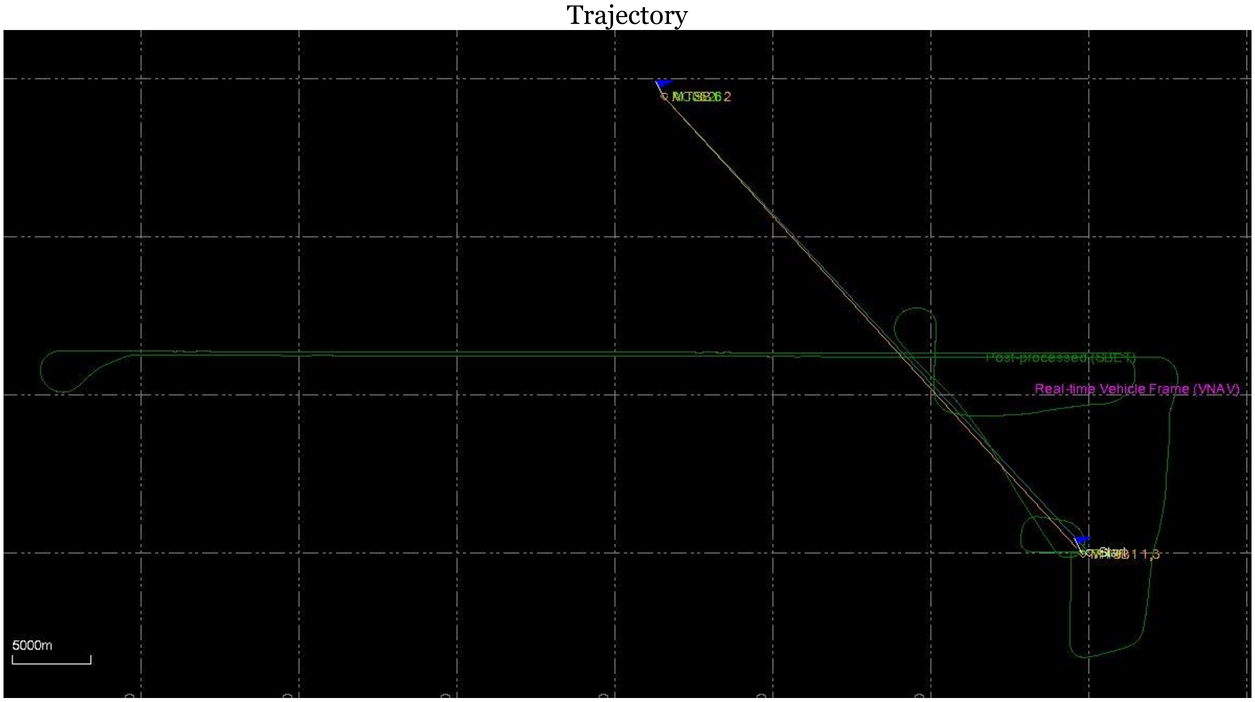


SBET IAKAR Separation

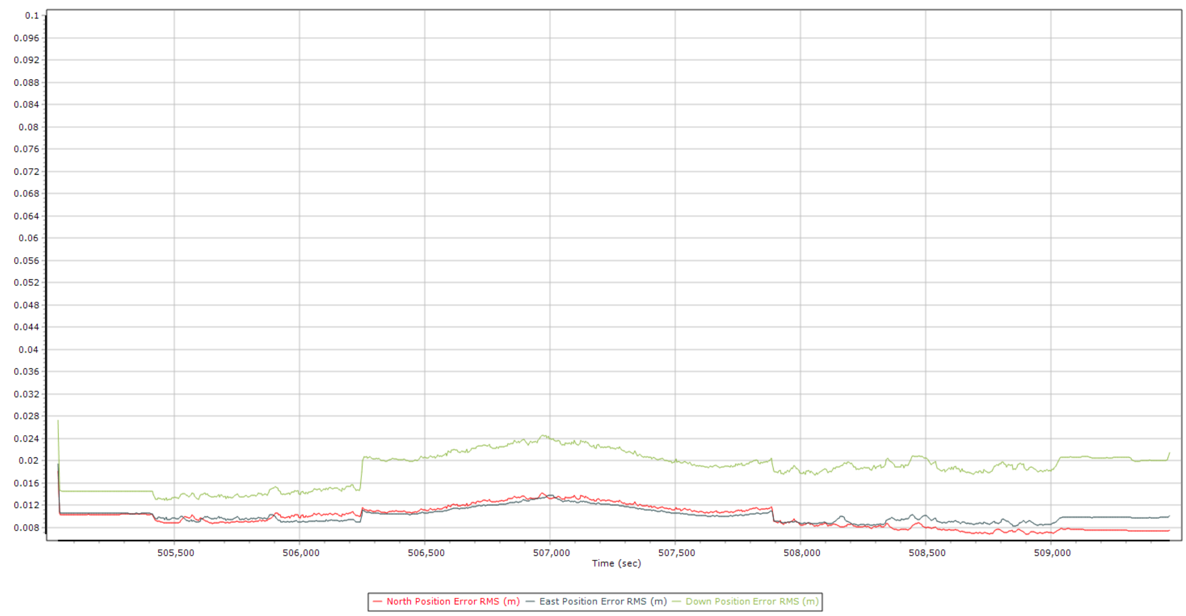


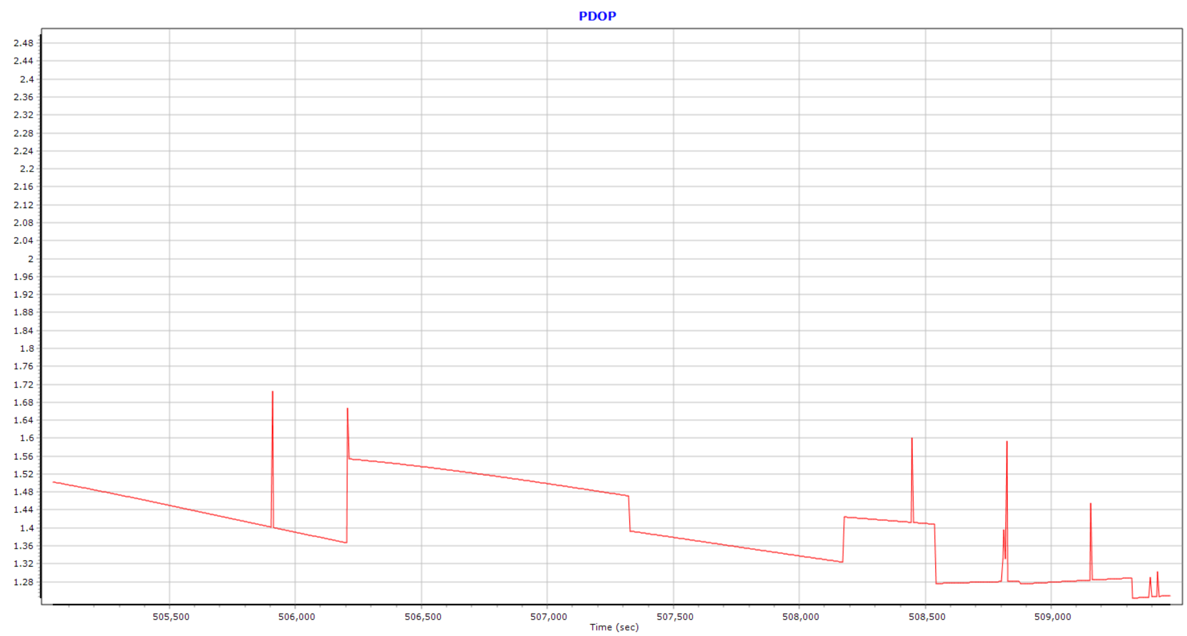
Mission: 20170428_B

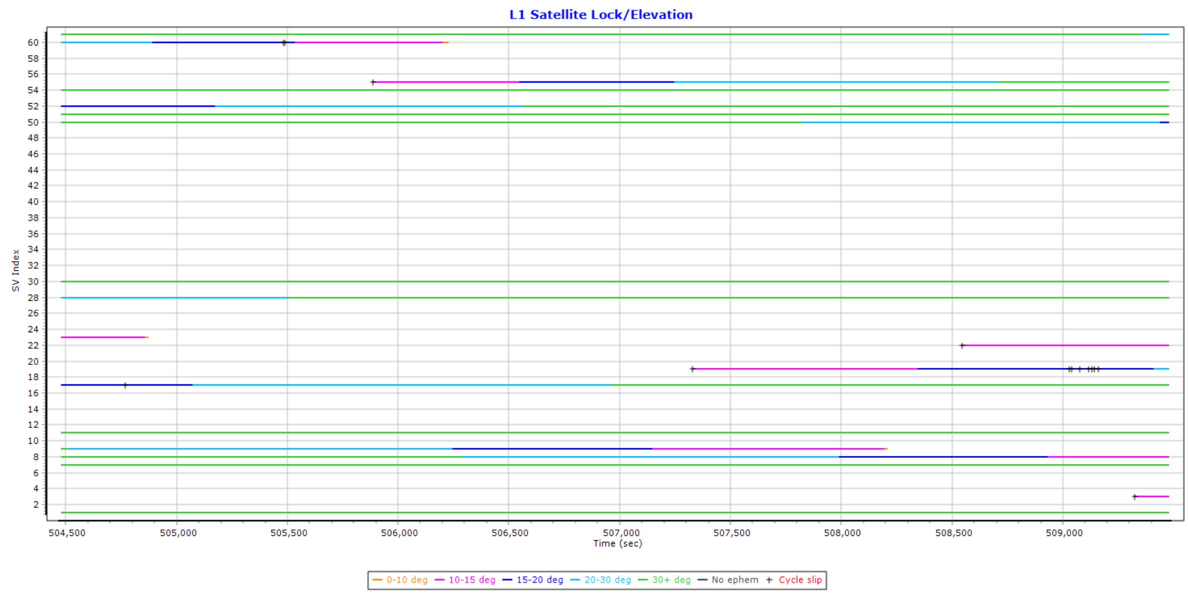
Trajectory

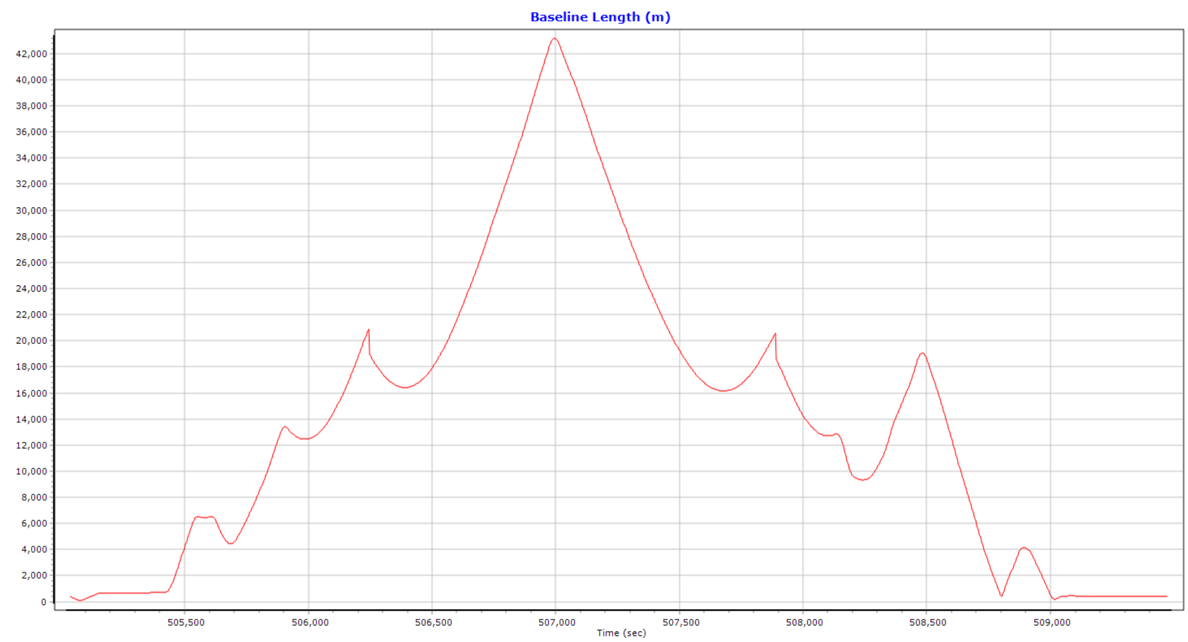


Smoothed Performance Metrics

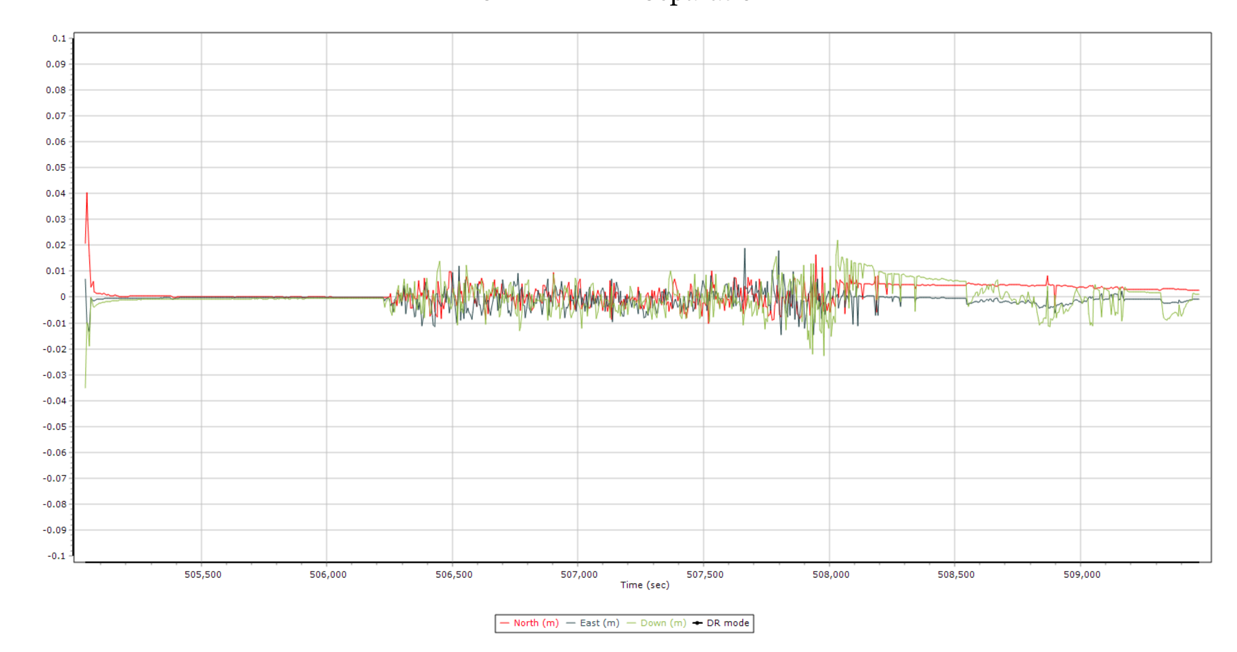





L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

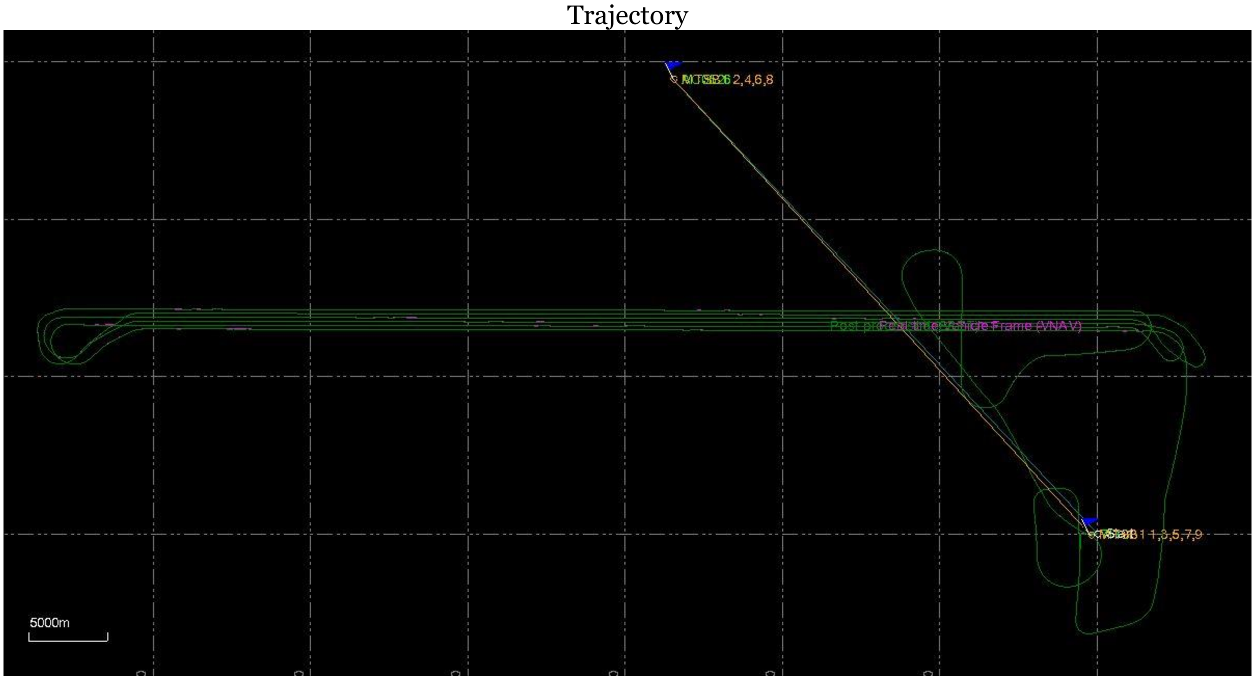

Baseline Length (m)
Time (sec)

SBET IAKAR Separation

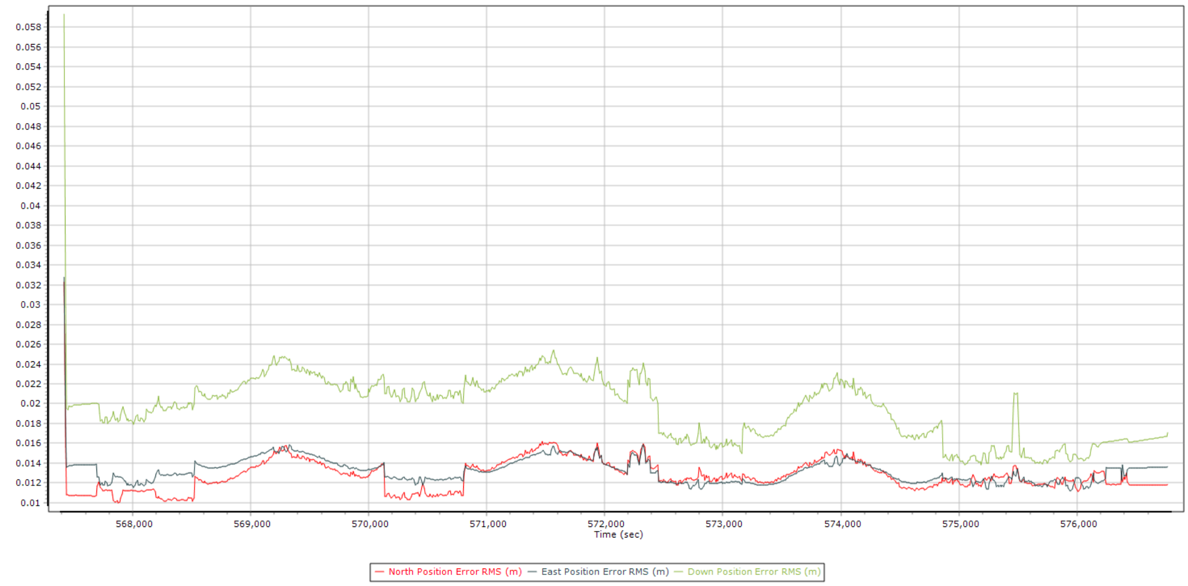


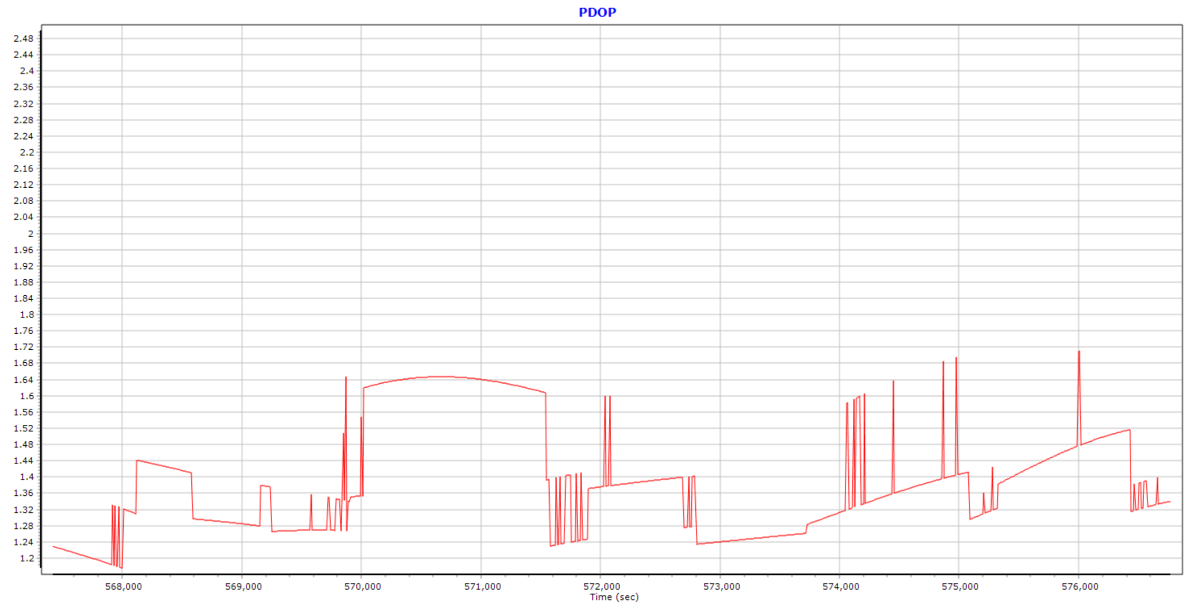
Mission: 20170429

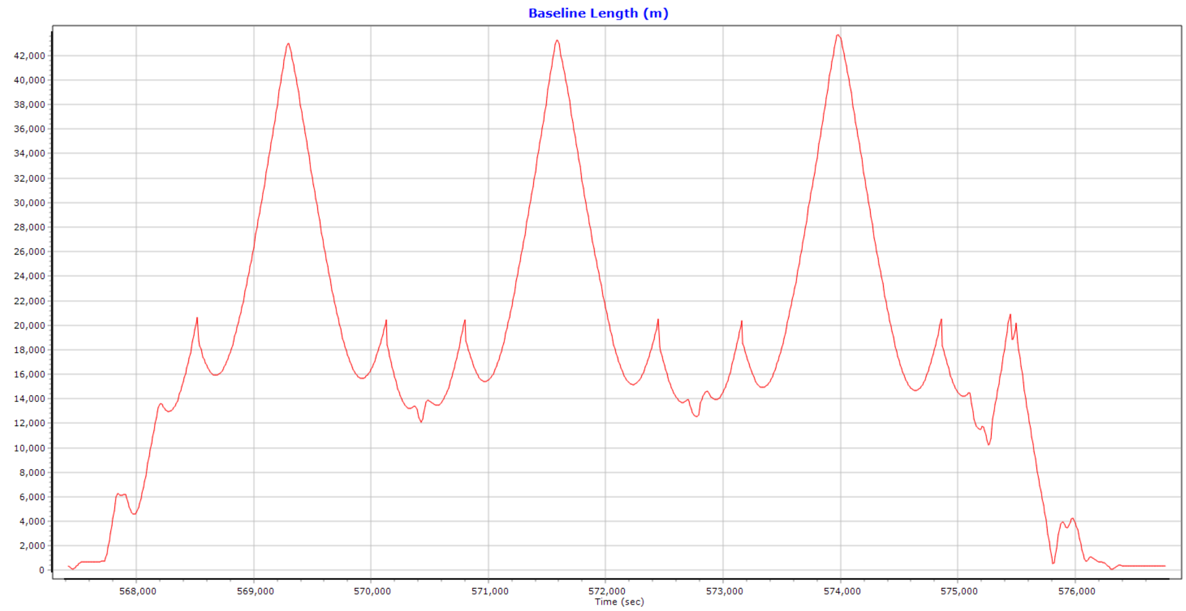
Trajectory



Smoothed Performance Metrics

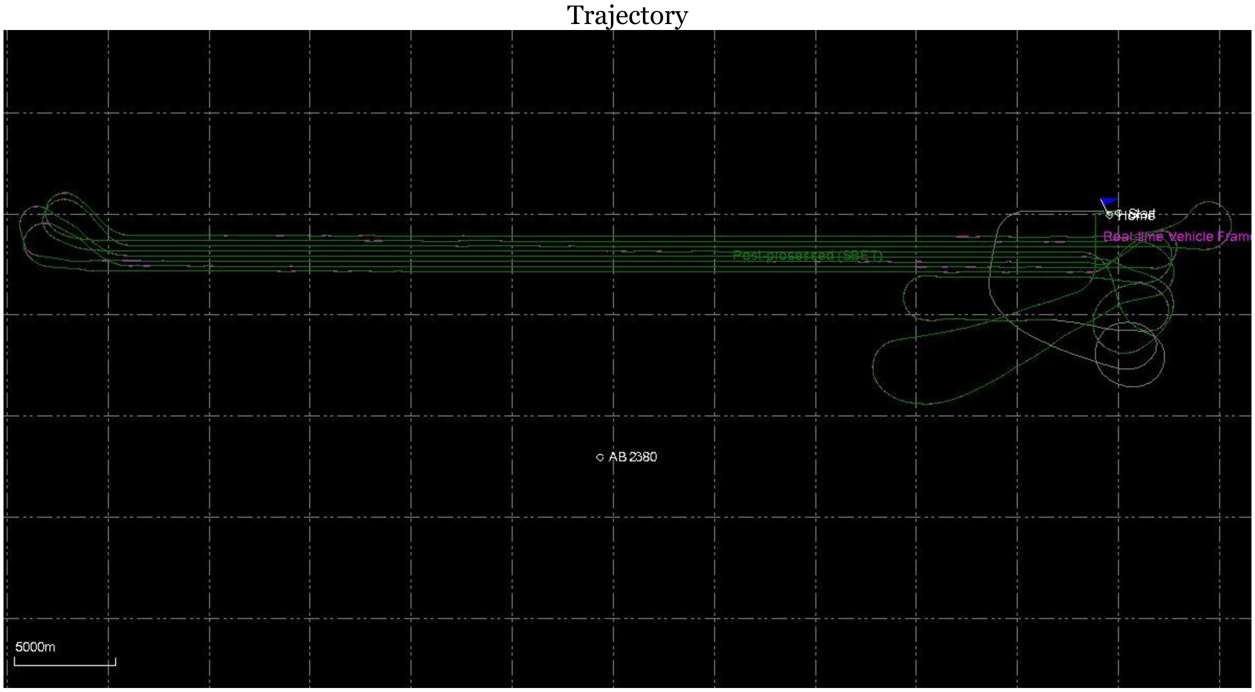



PDOP
Time (sec)

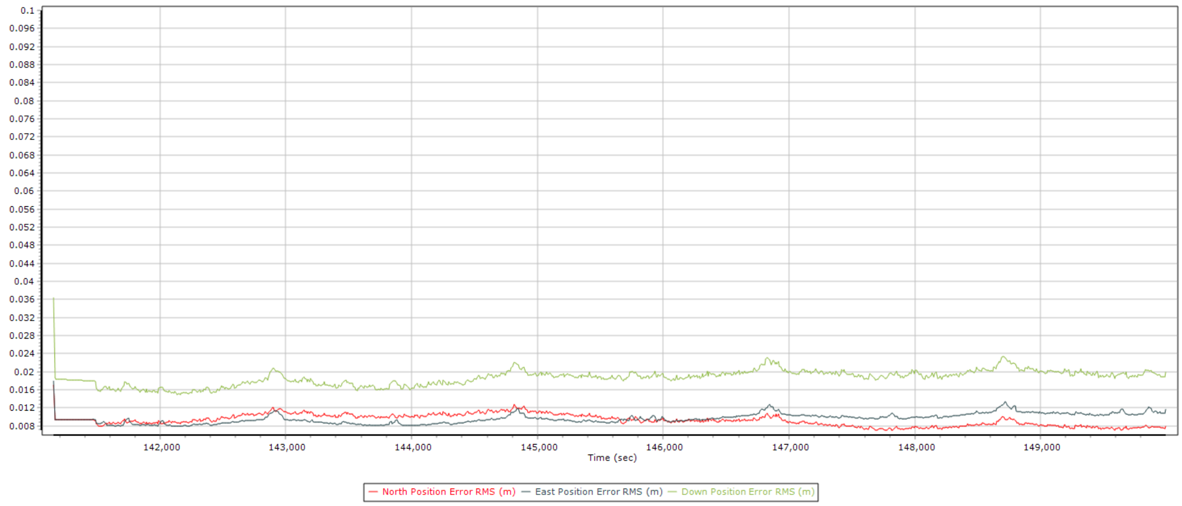

Baseline Length (m)
Time (sec)

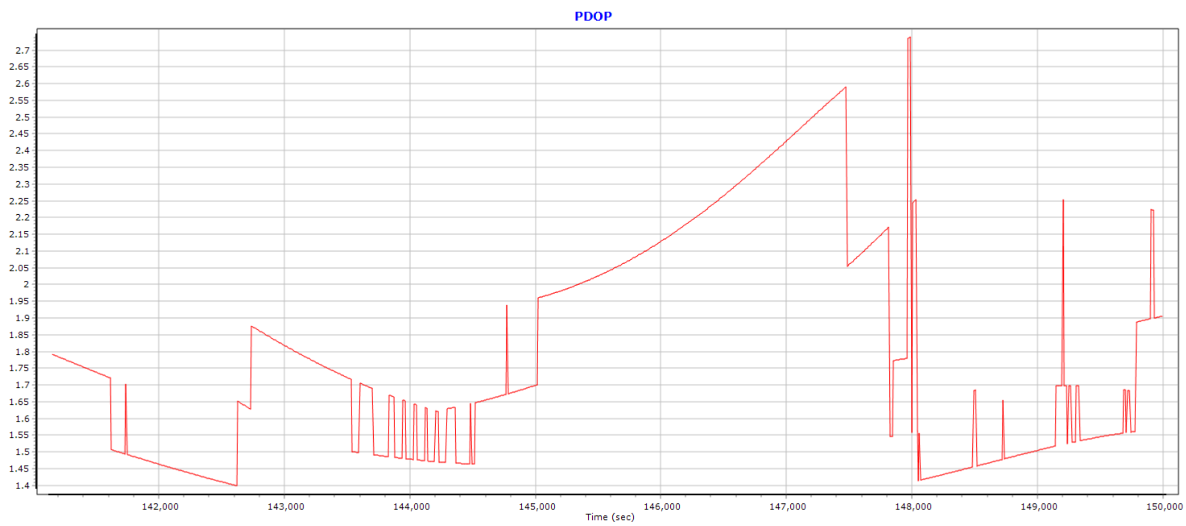
SBET IAKAR Separation

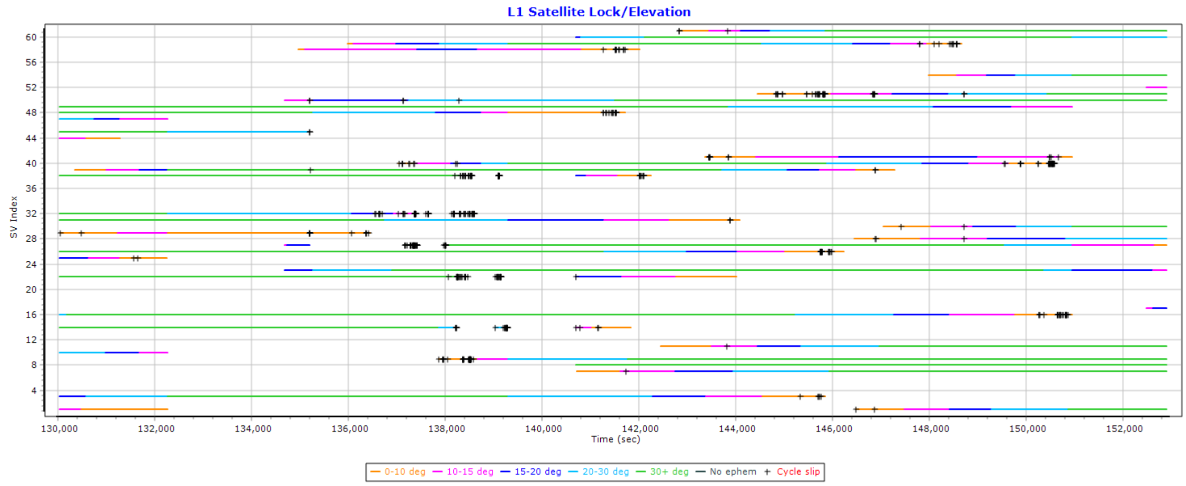
Mission: 20170522_A
Trajectory

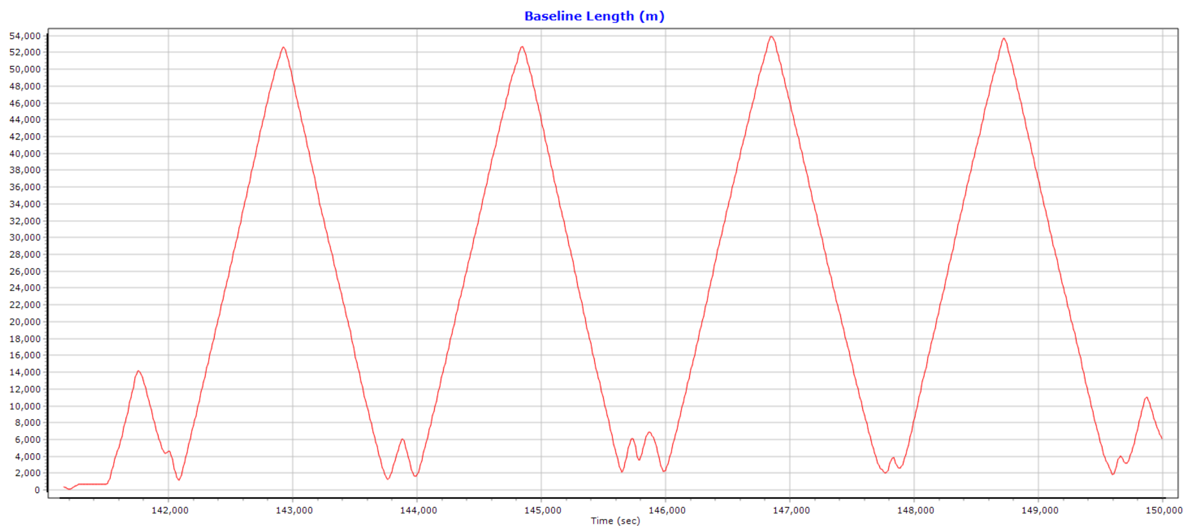


Smoothed Performance Metrics





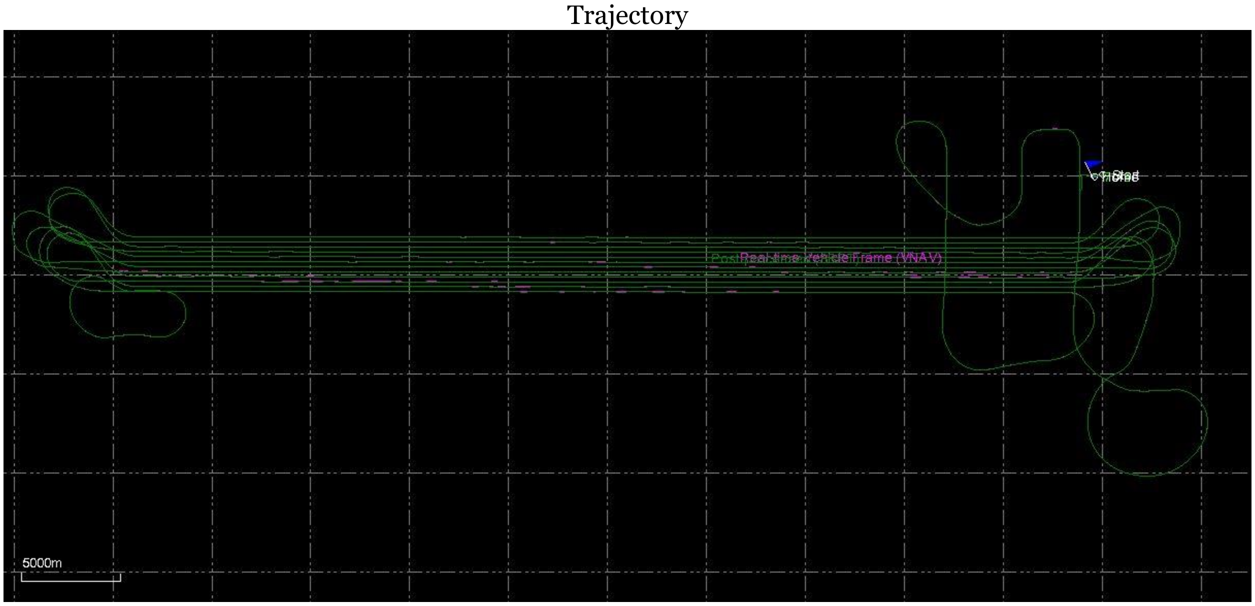

L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip


Baseline Length (m)
Time (sec)

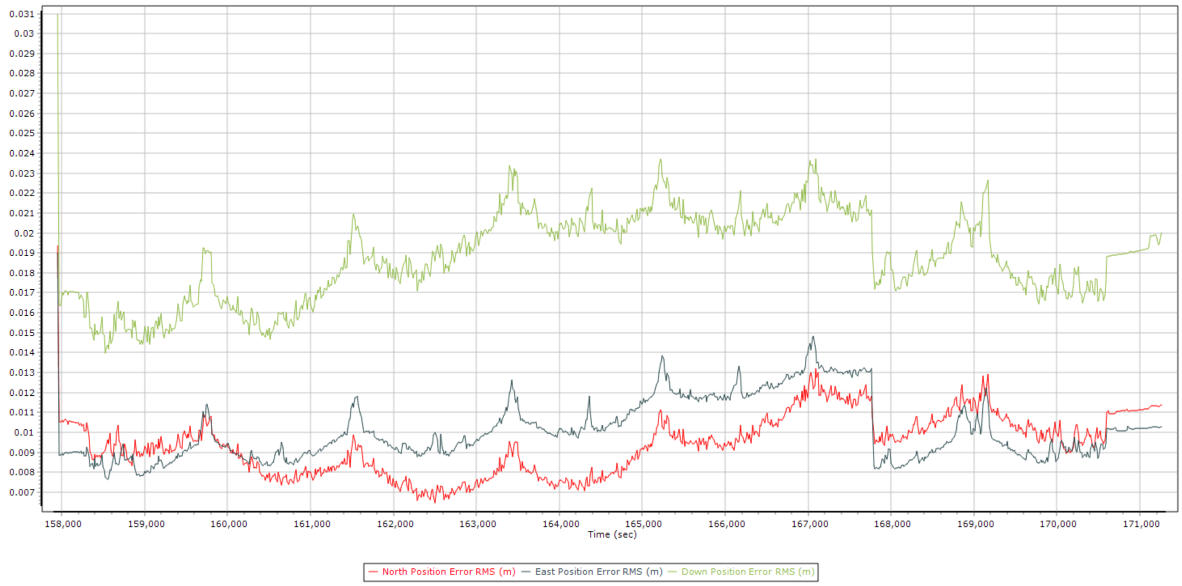
SBET IAKAR Separation

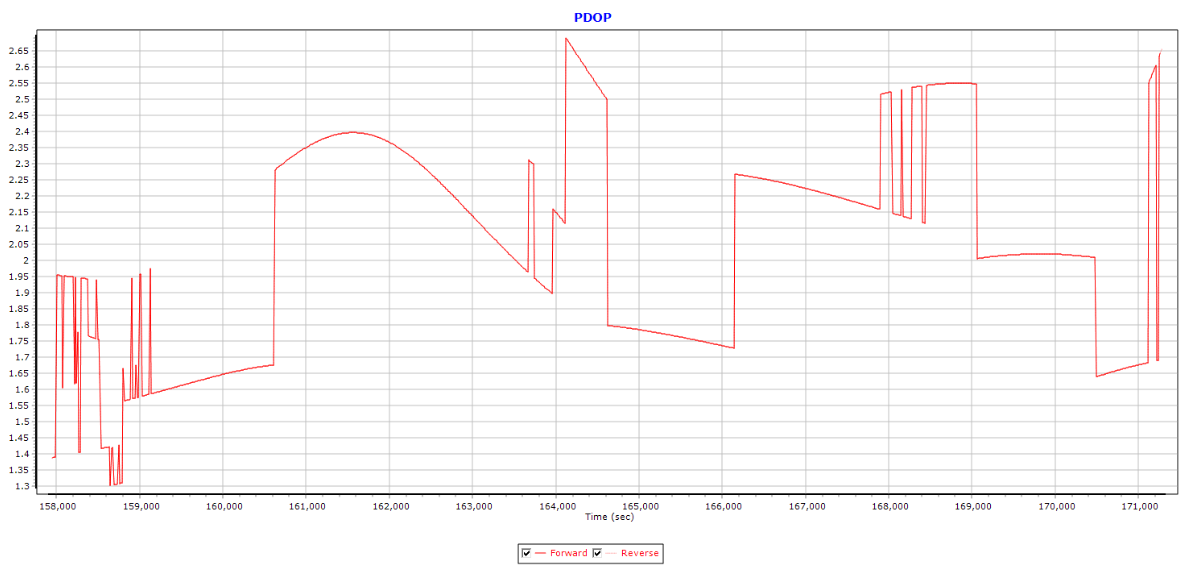
Mission: 20170522_B

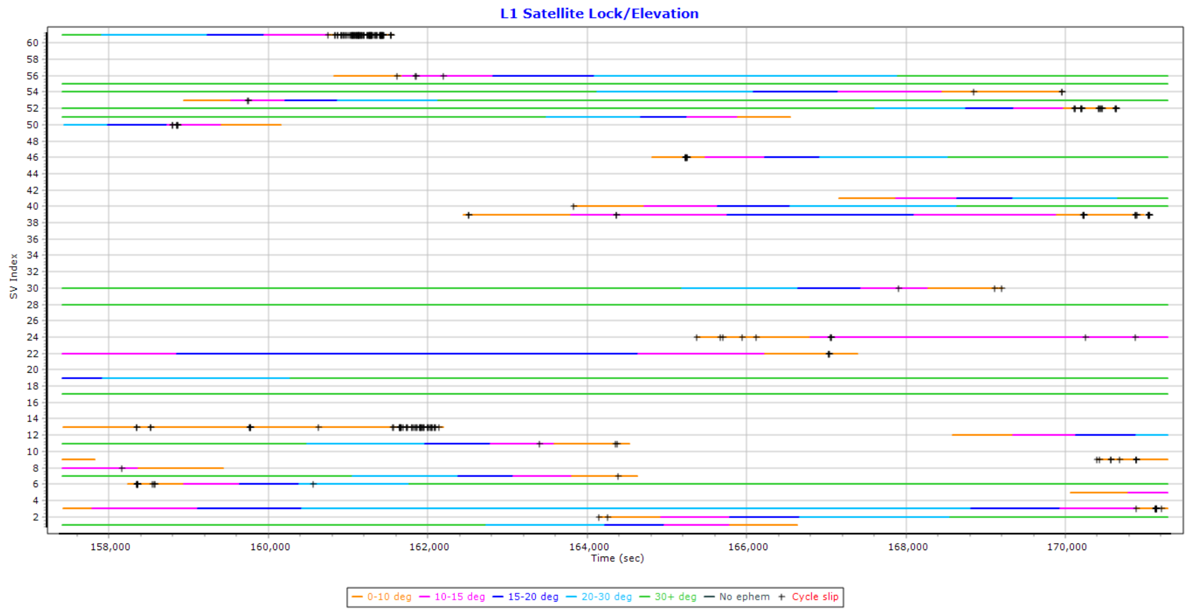
Trajectory



Smoothed Performance Metrics

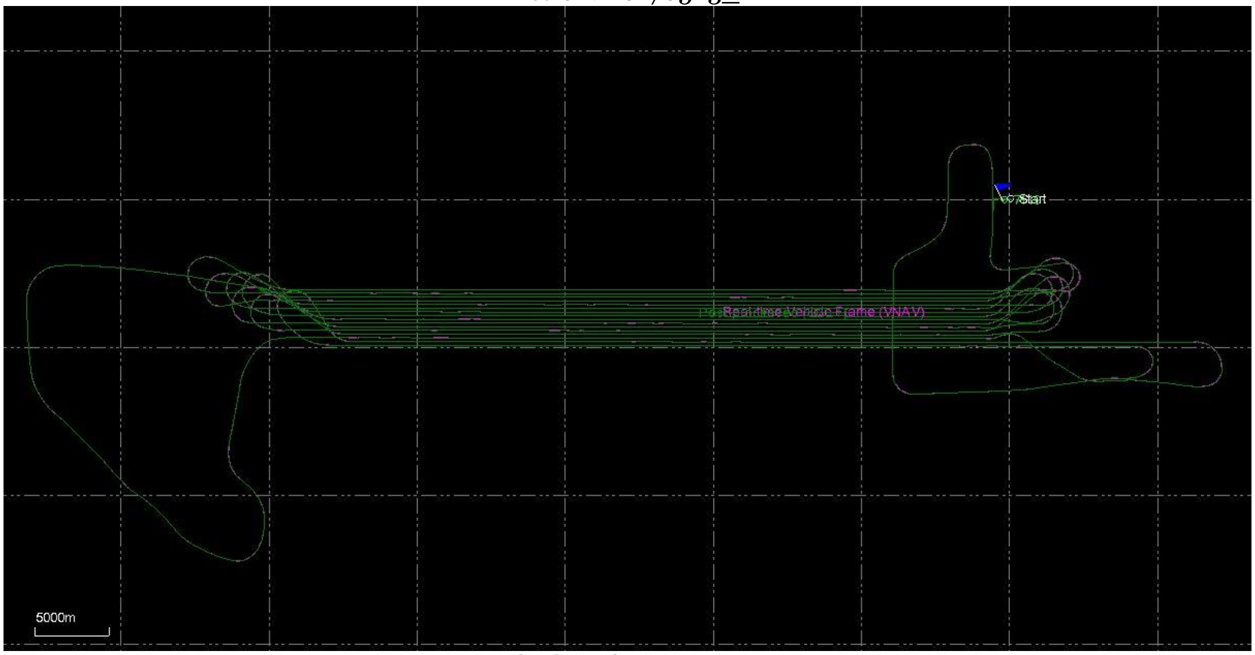




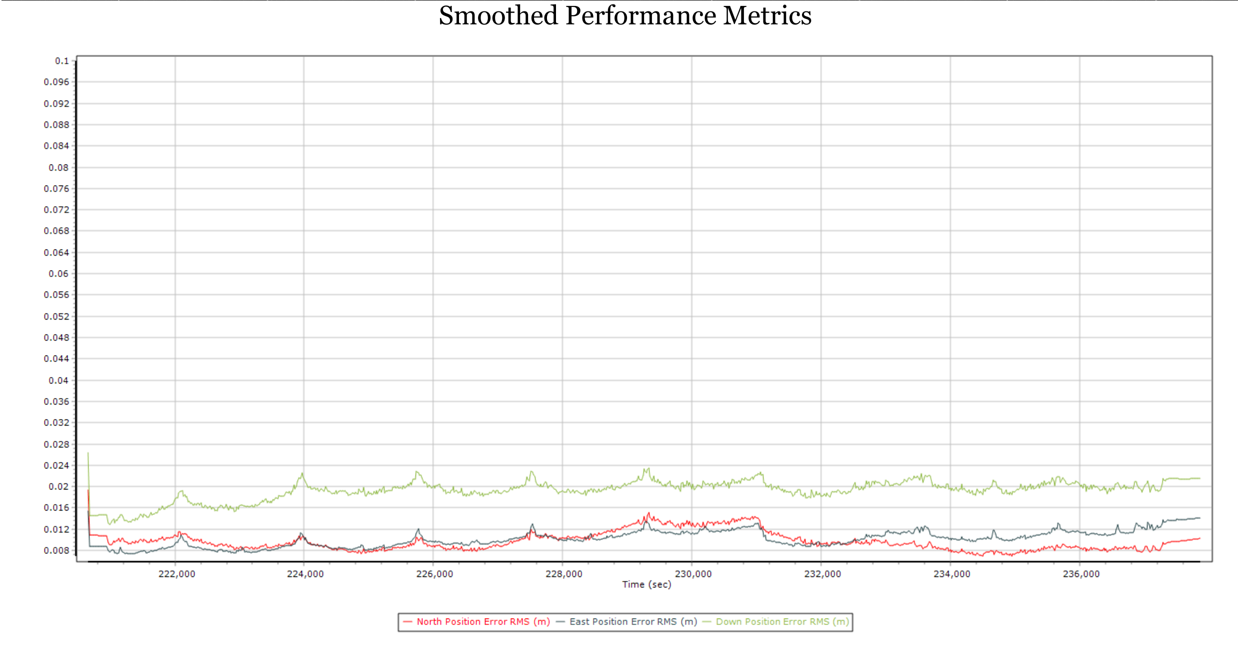

L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

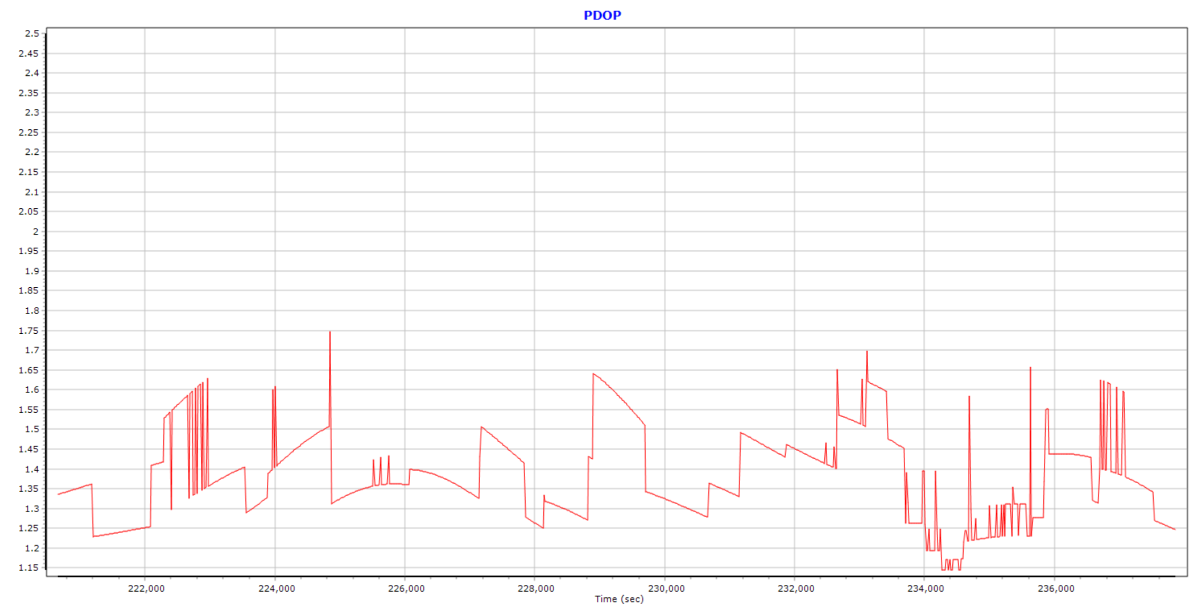

Time (sec)
North (m)
East (m)
Down (m)
DR mode

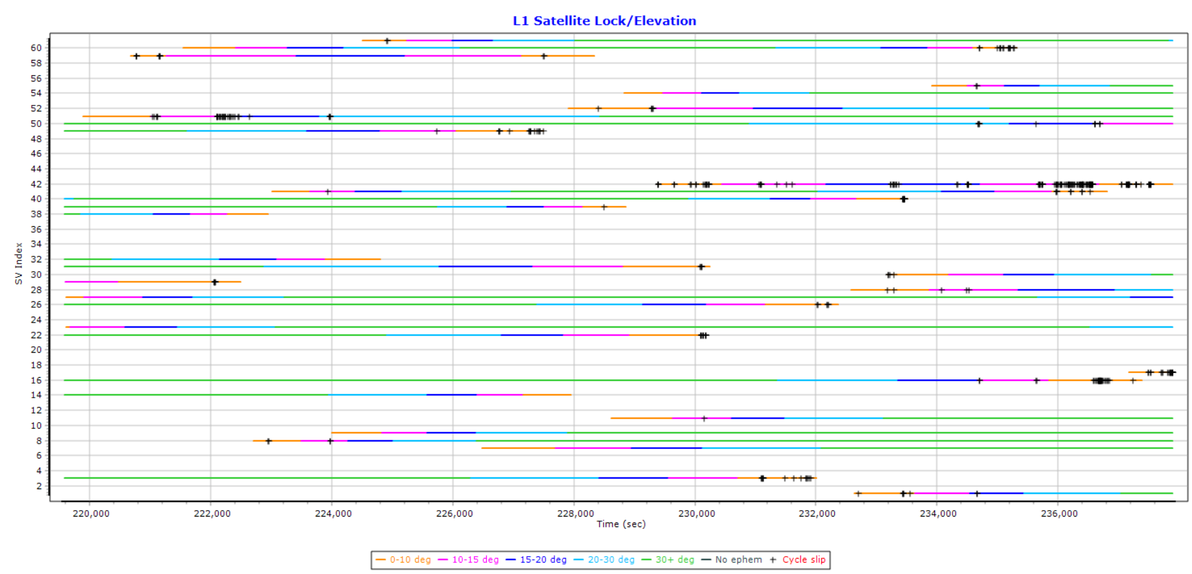
Mission: 20170523_A

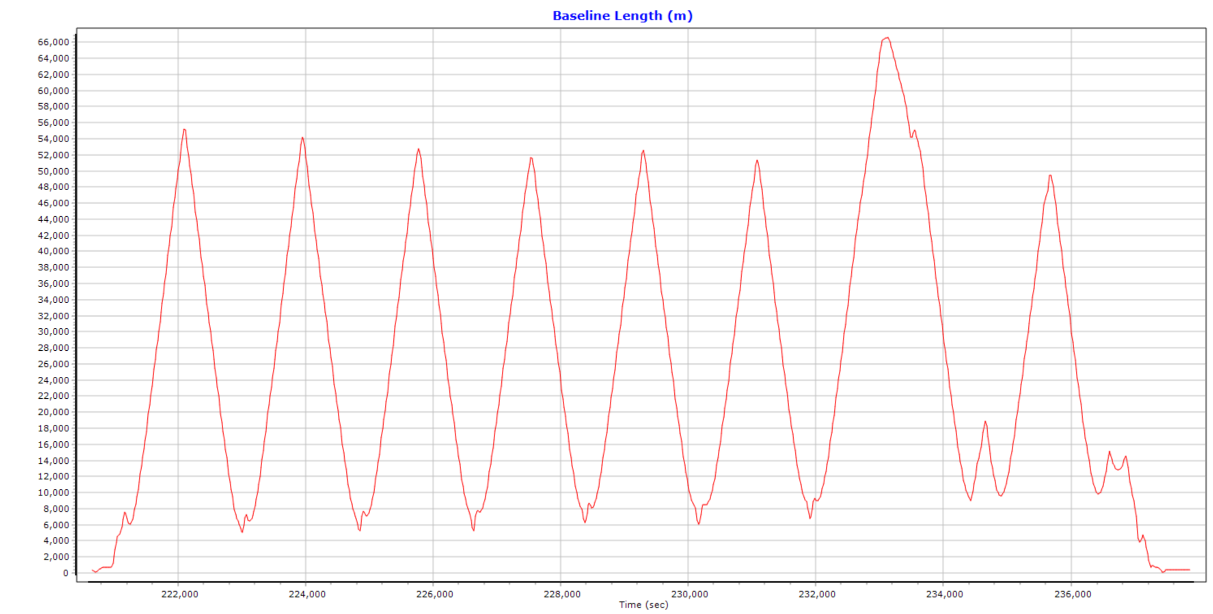


Smoothed Performance Metrics




PDOP
Time (sec)

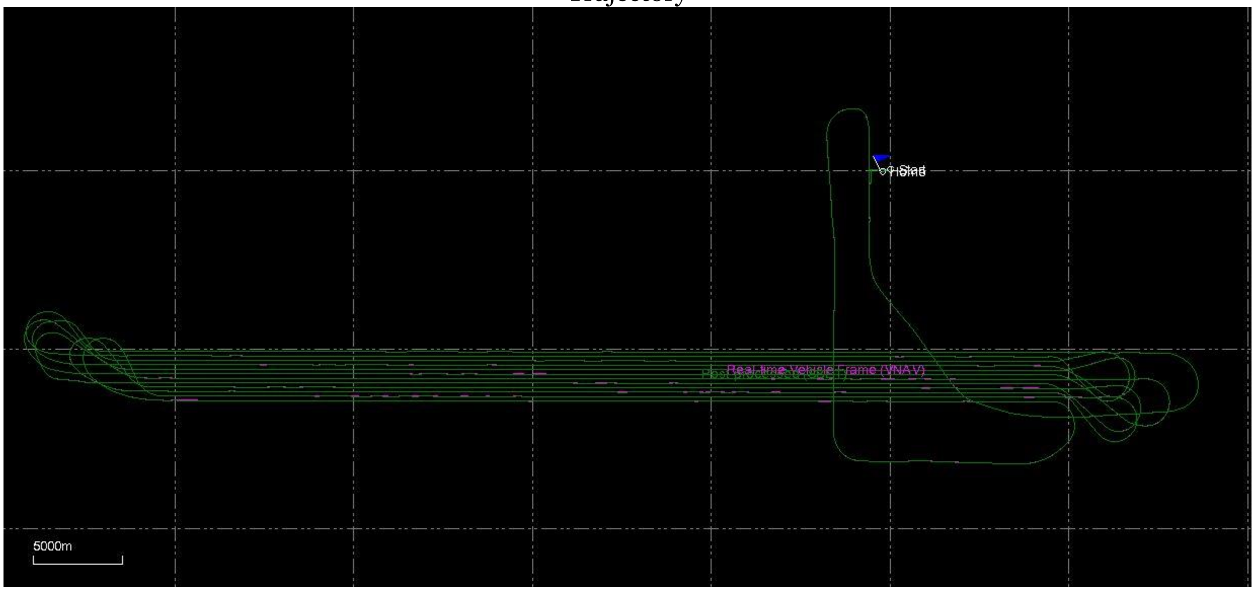

L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip



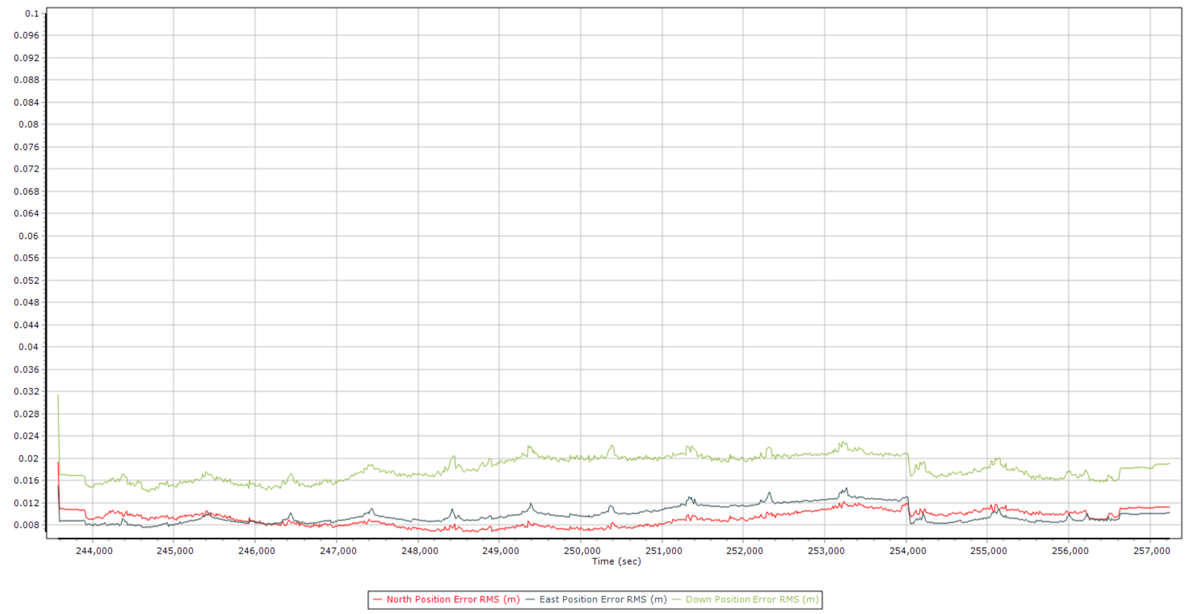
SBET IAKAR Separation

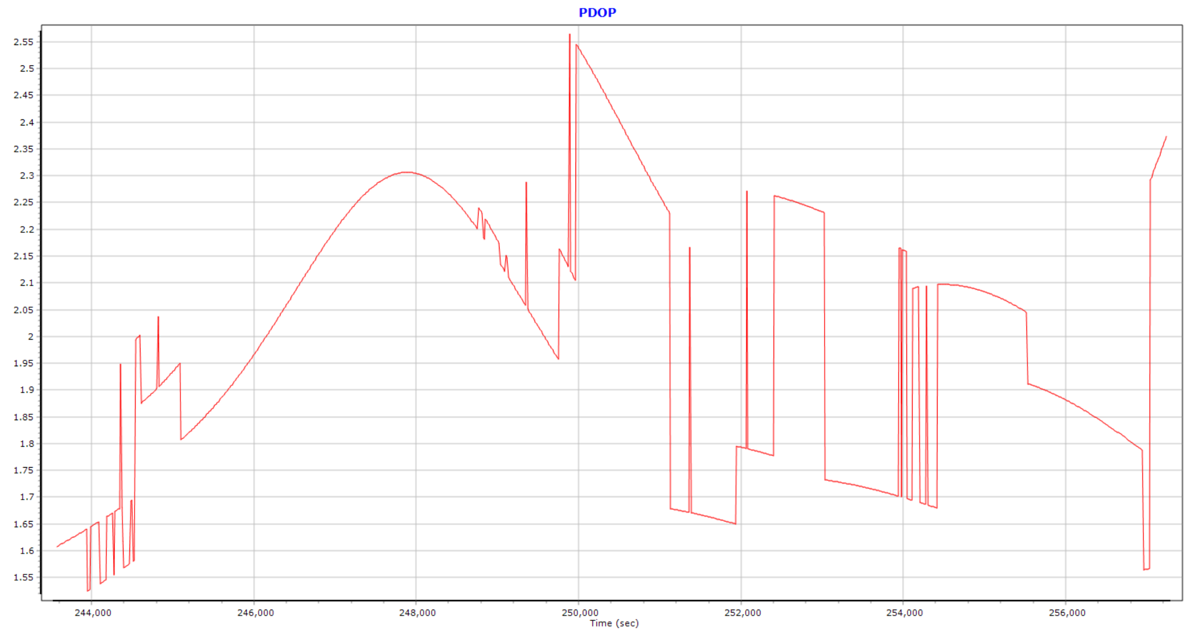
Mission: 20170523_B

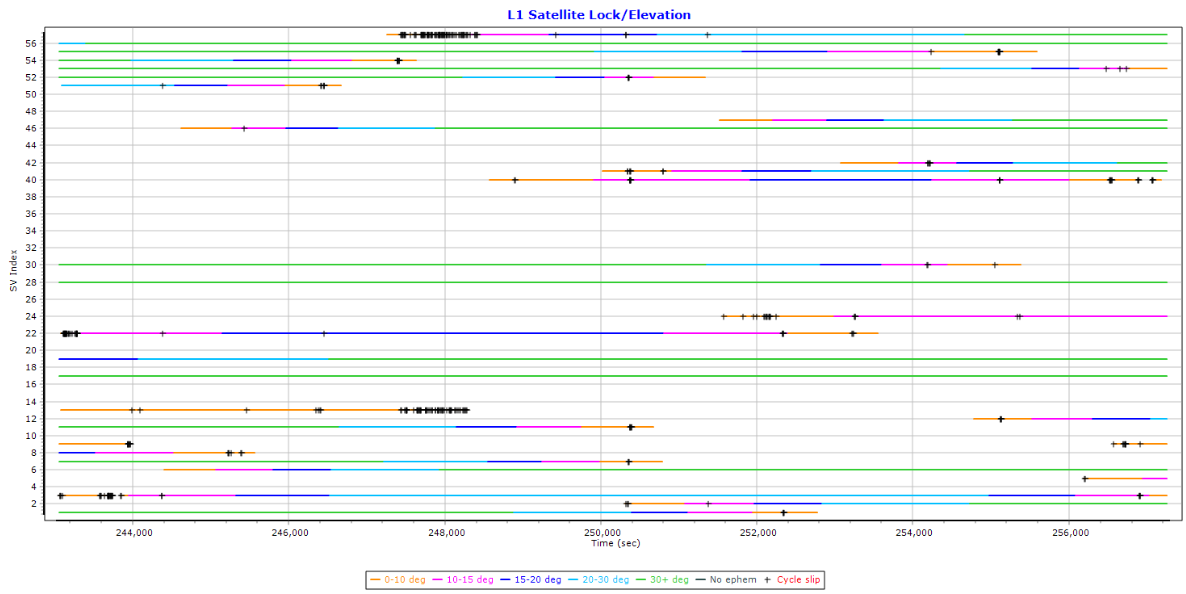
Trajectory

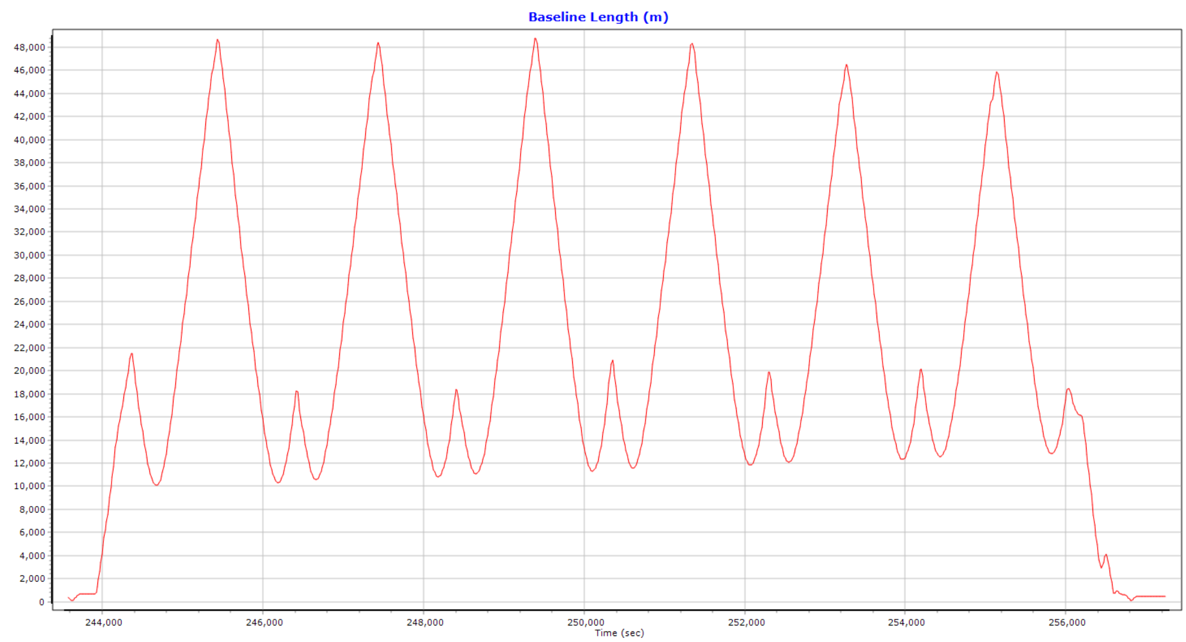


Smoothed Performance Metrics


Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

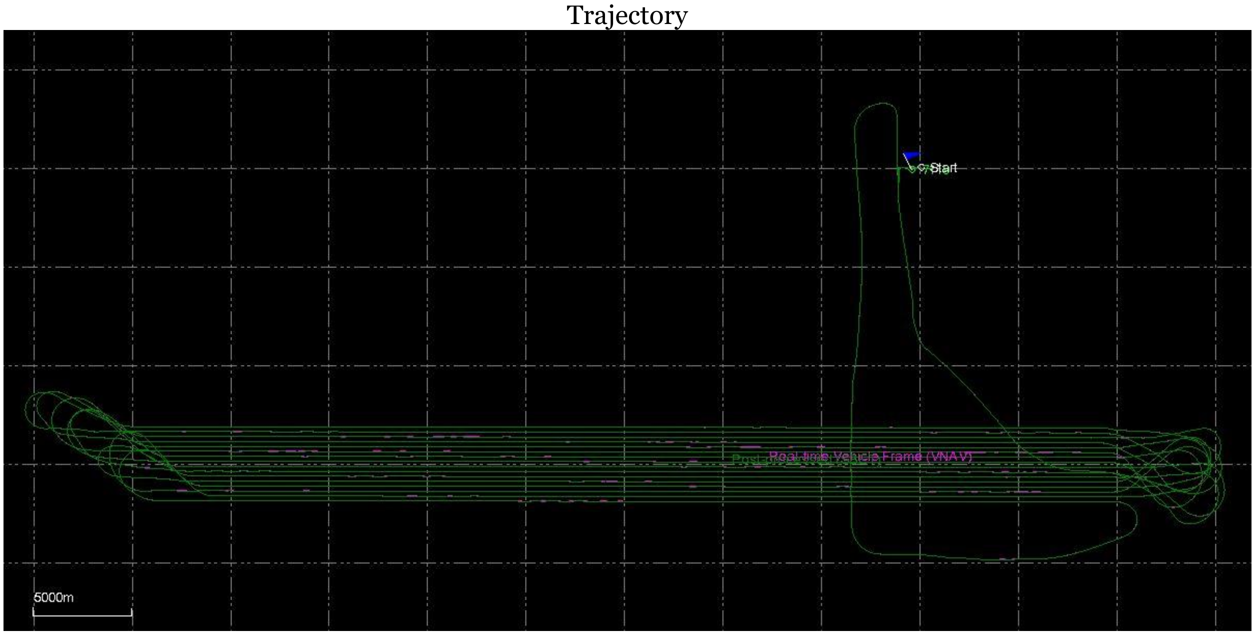

PDOP
Time (sec)


L1 Satellite Lock/Elevation
SV Index
Time (sec)
244,000
246,000
248,000
250,000
252,000
254,000
256,000
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

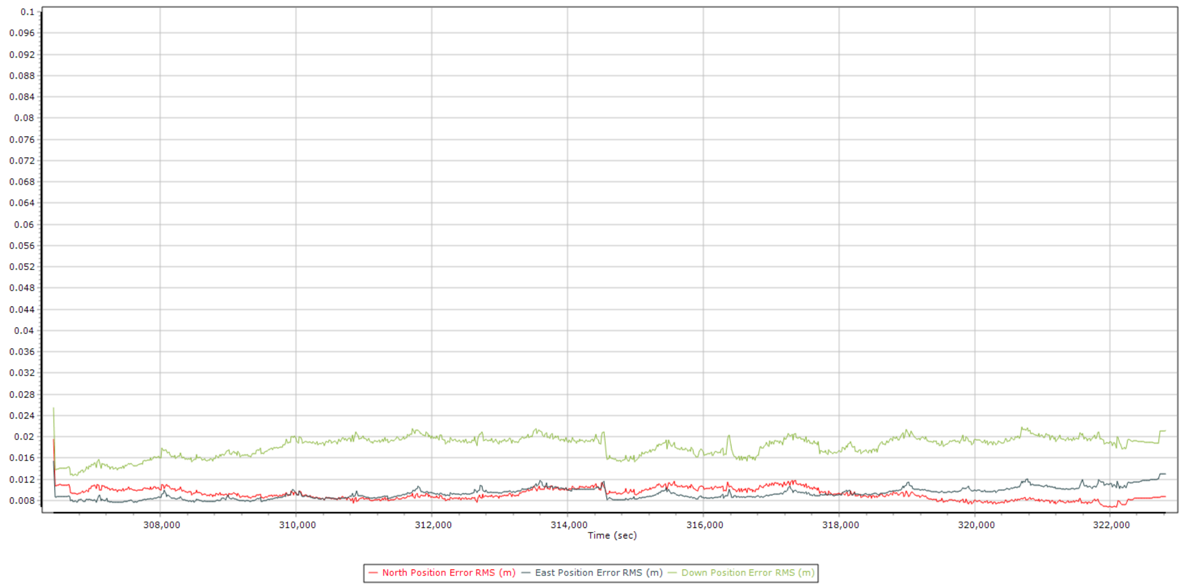

Baseline Length (m)
Time (sec)
244,000
246,000
248,000
250,000
252,000
254,000
256,000

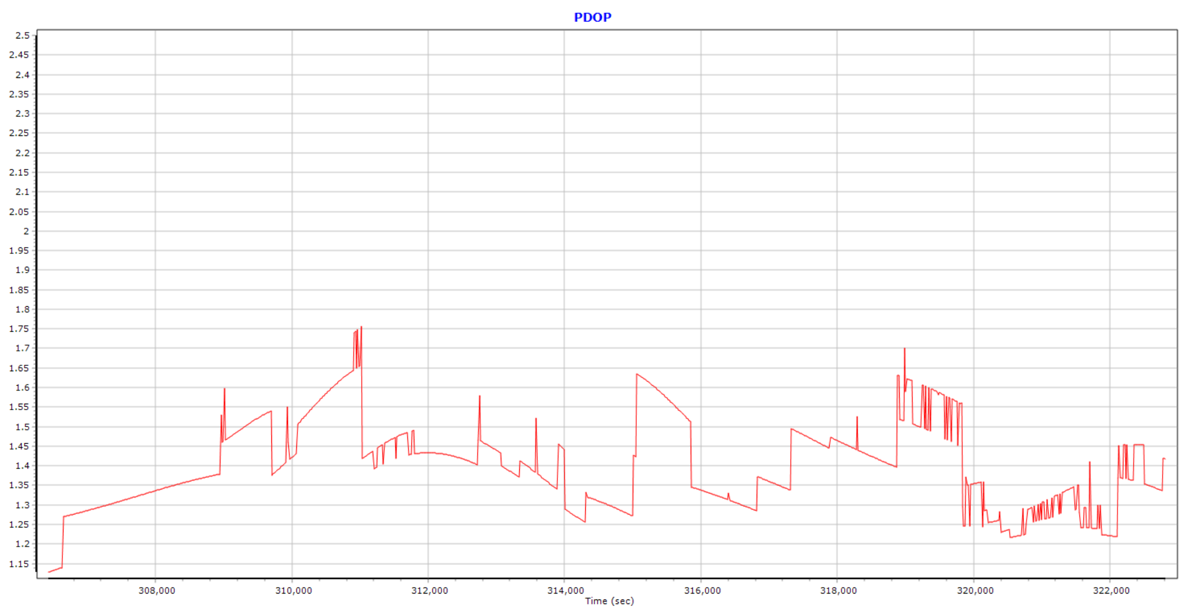
SBET IAKAR Separation

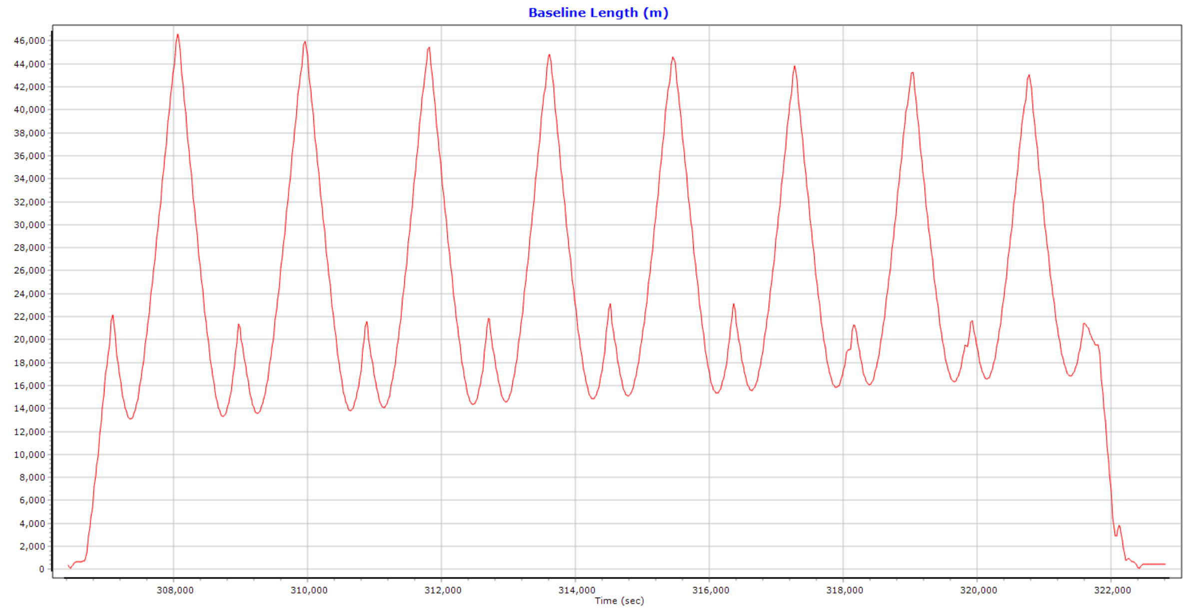
Mission: 20170524_A
Trajectory

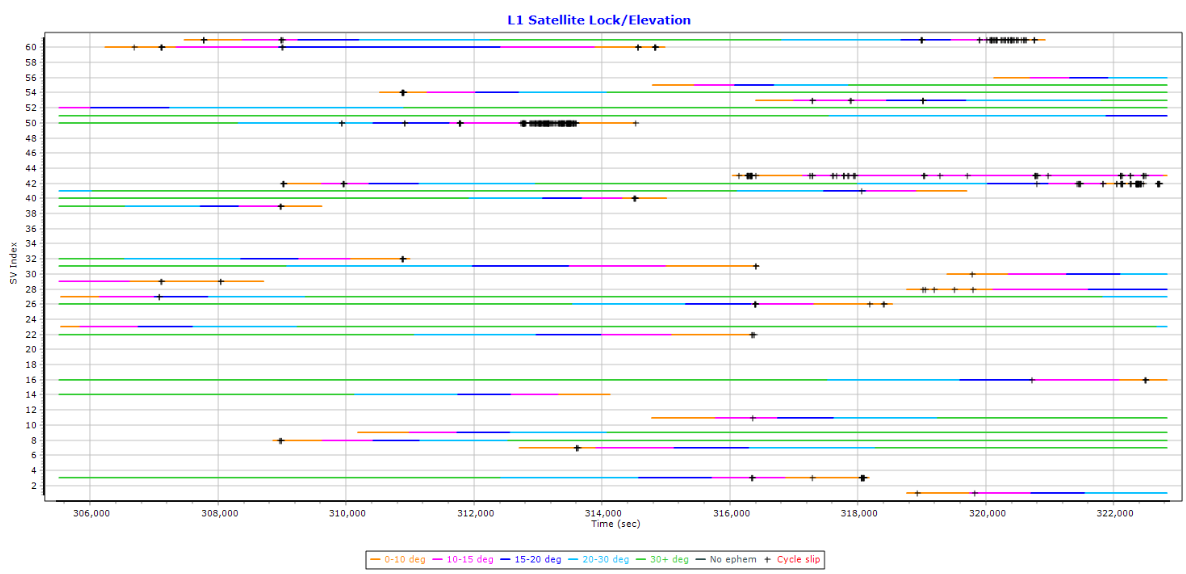


Smoothed Performance Metrics

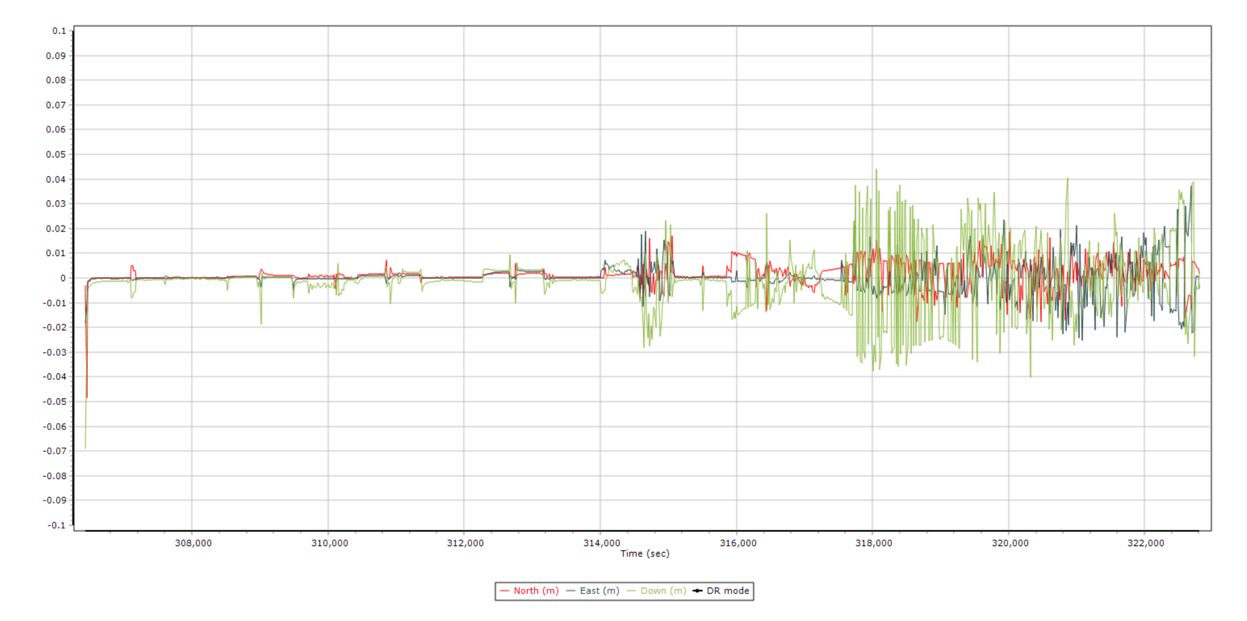

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


PDOP
Time (sec)



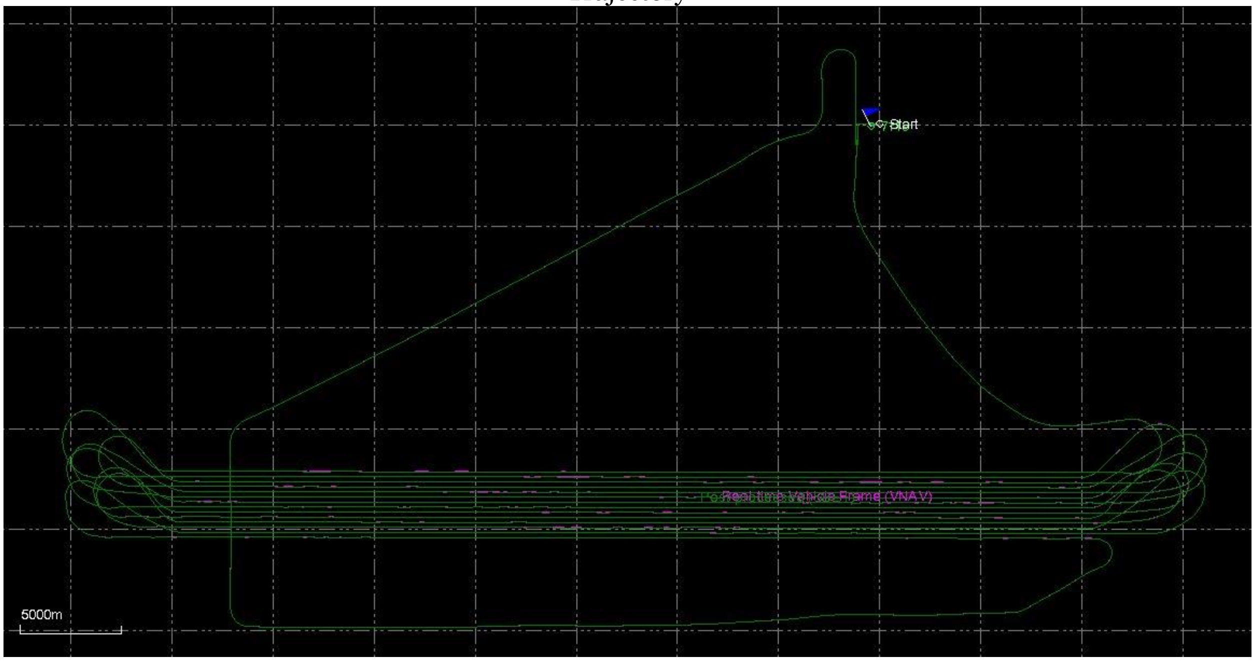


SBET IAKAR Separation

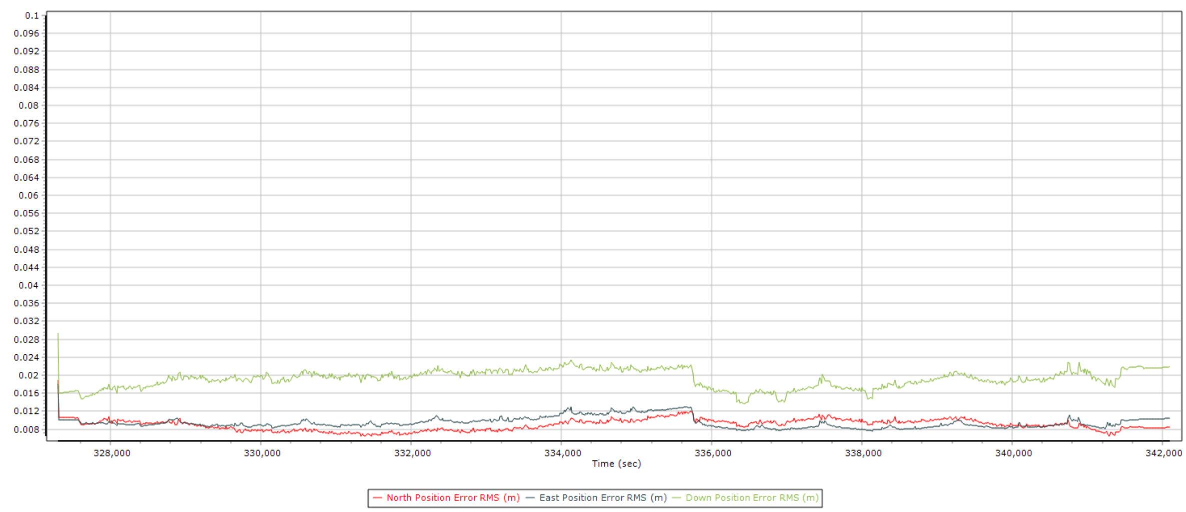


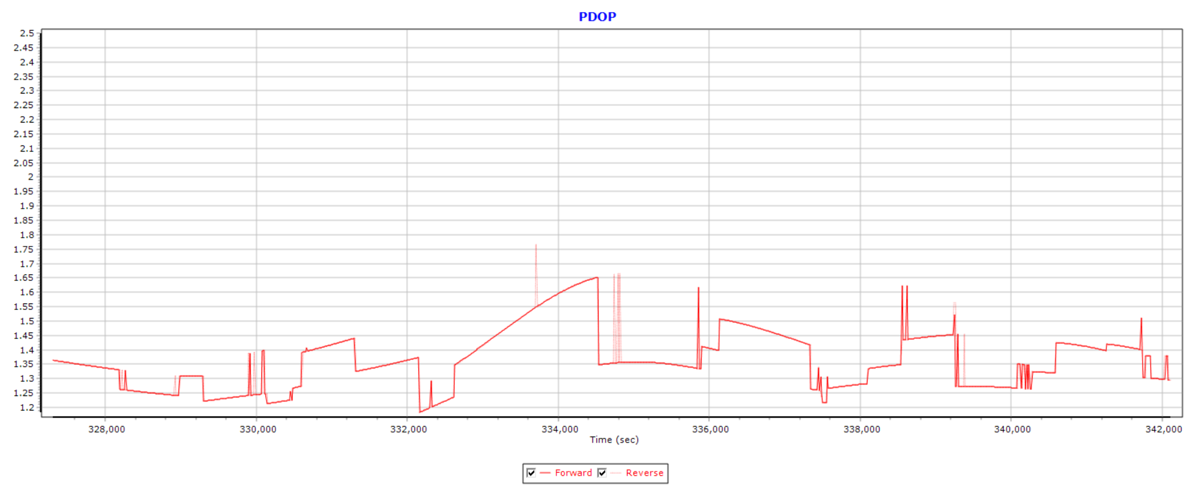
Mission: 20170524_B

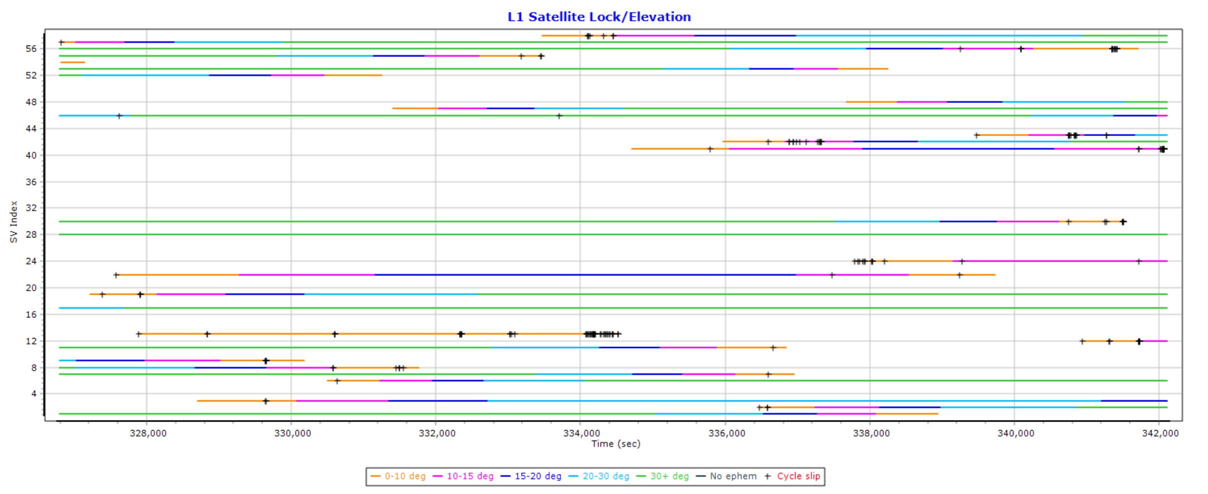
Trajectory

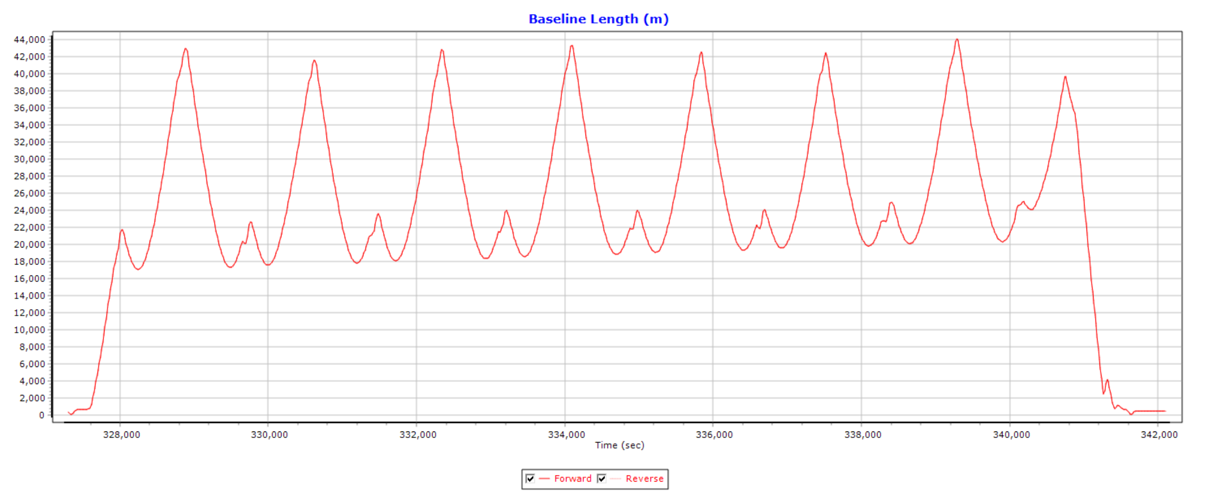


Smoothed Performance Metrics



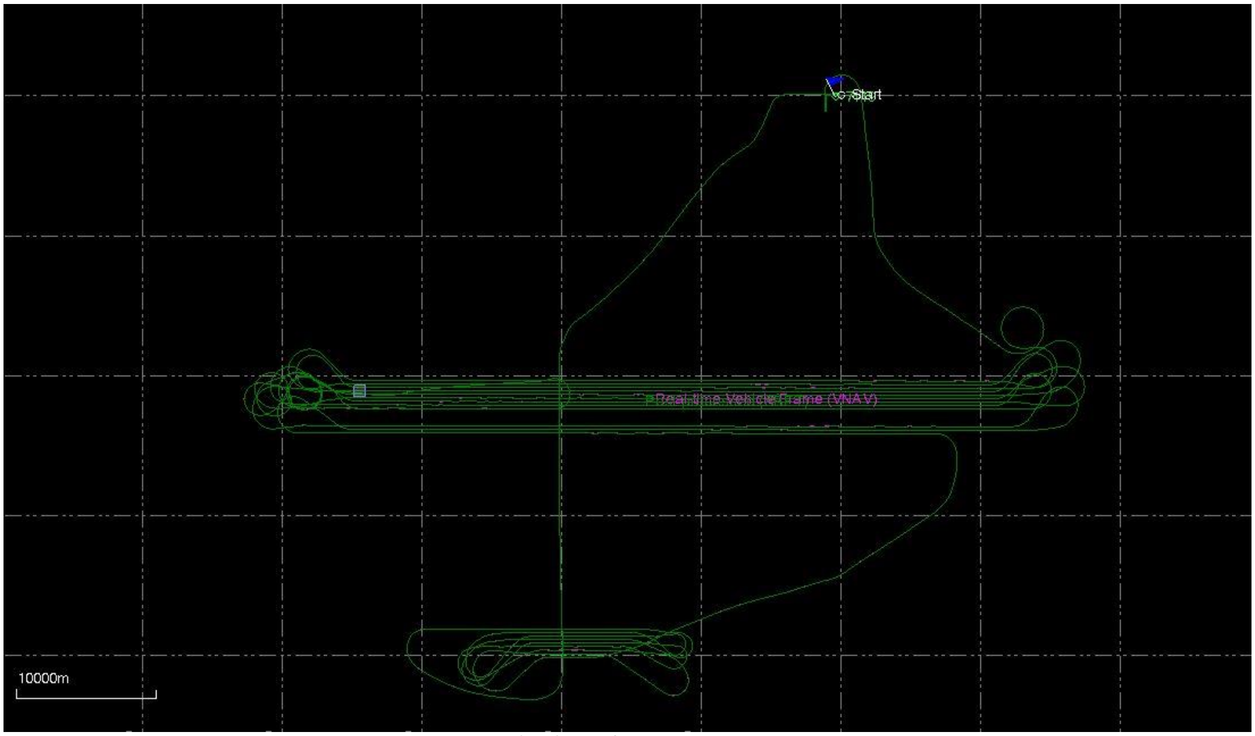




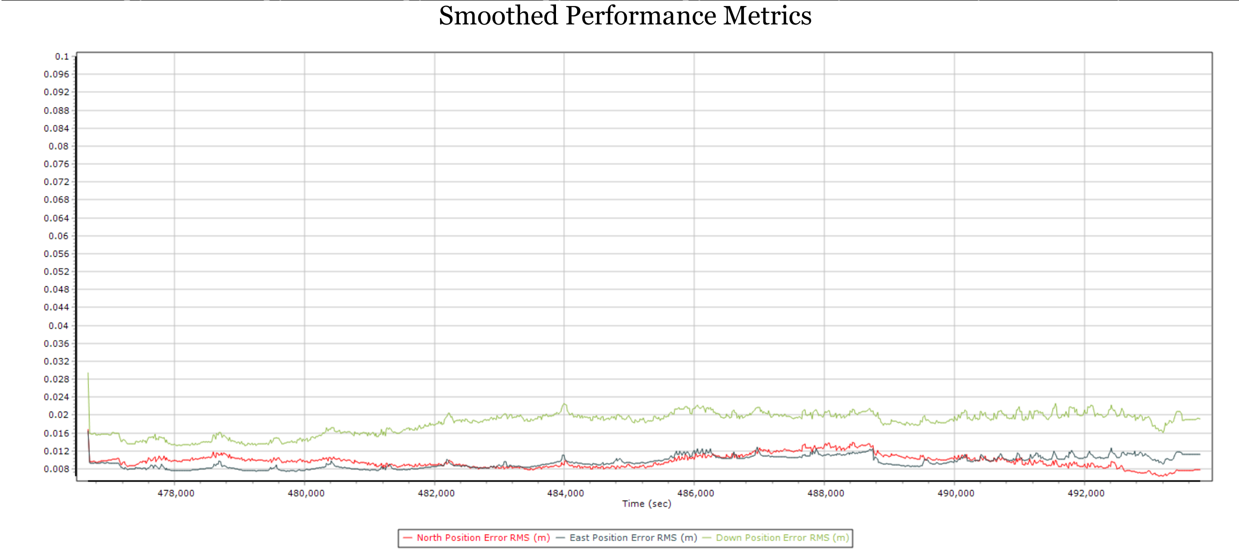


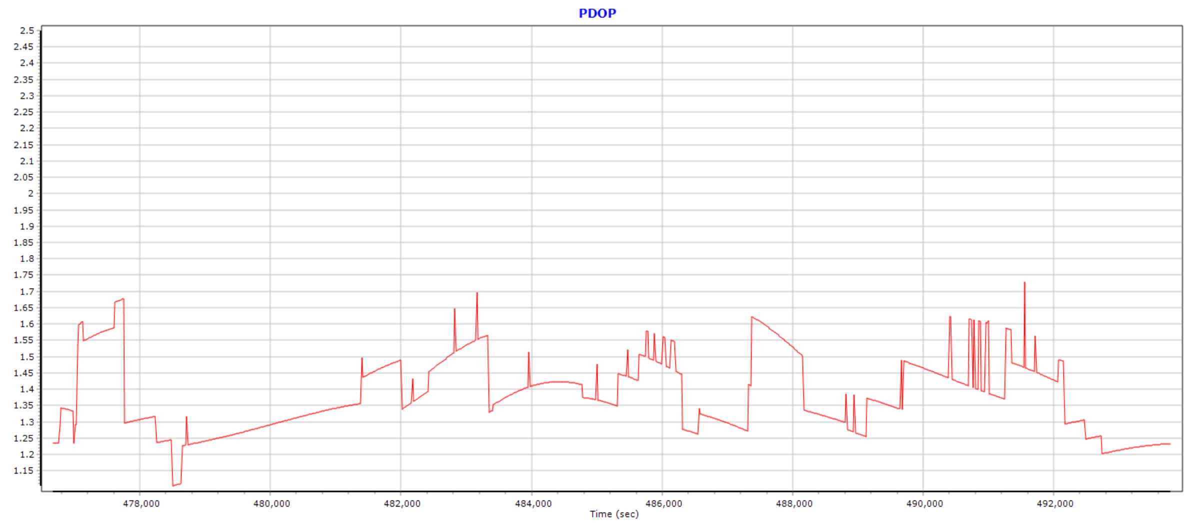
SBET IAKAR Separation

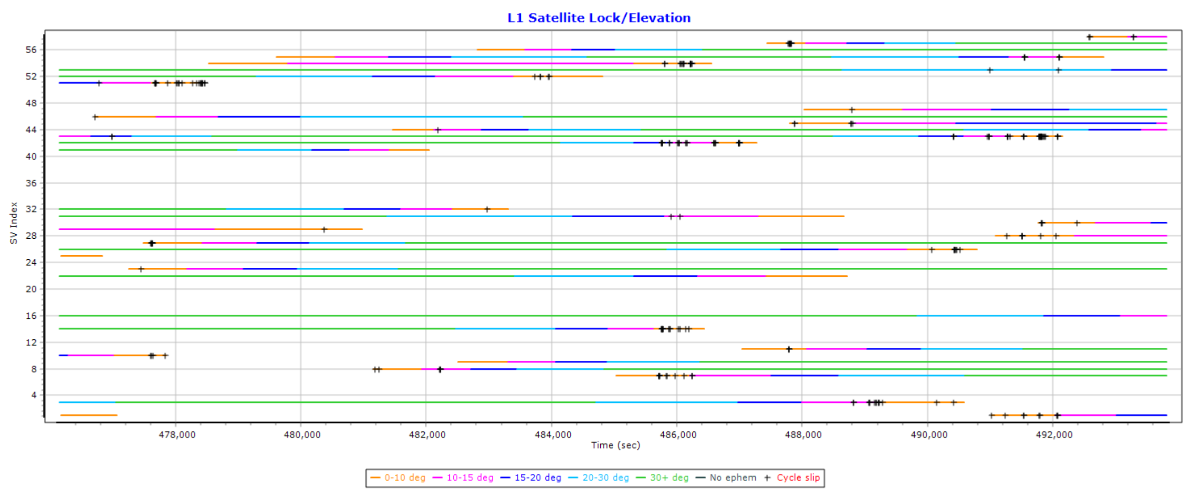
Mission: 20170526
Trajectory

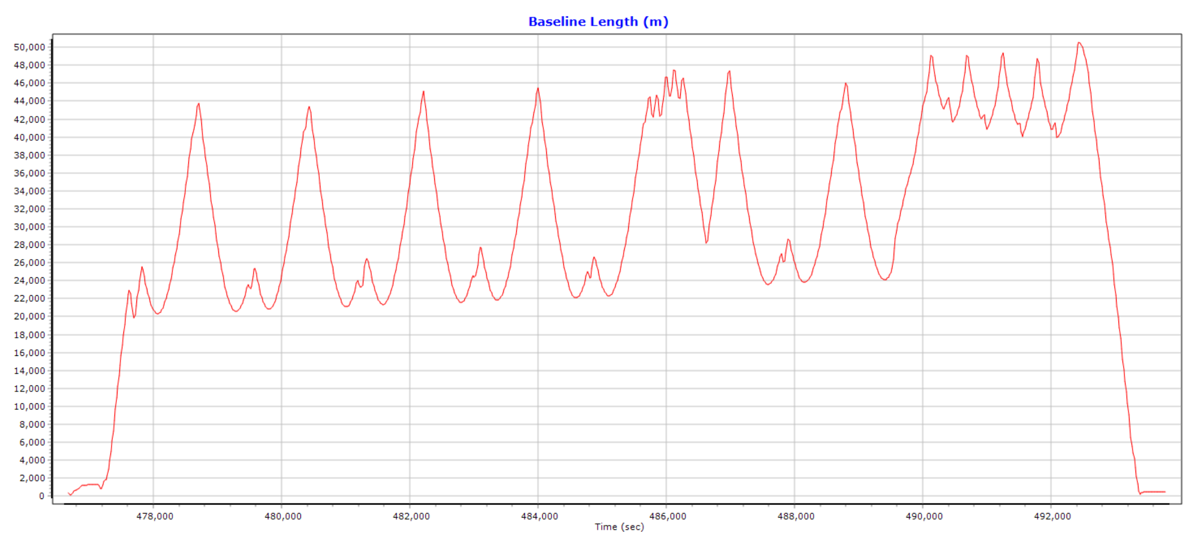


Smoothed Performance Metrics



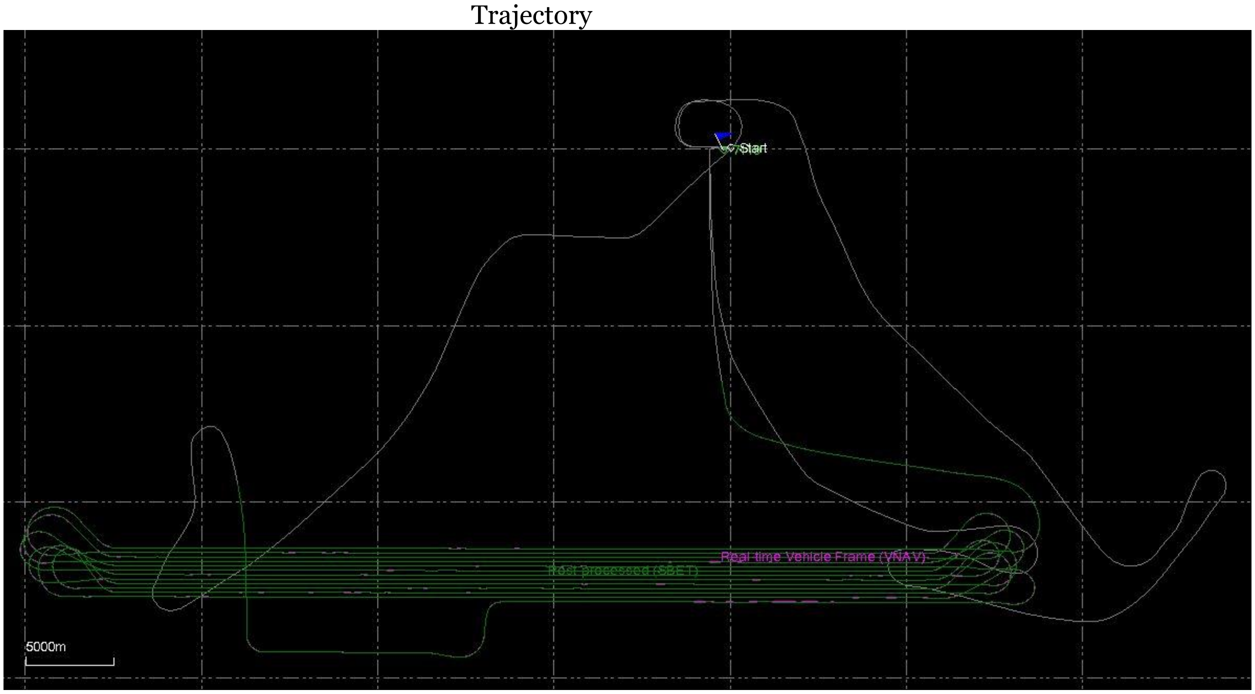

PDOP
Time (sec)


L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

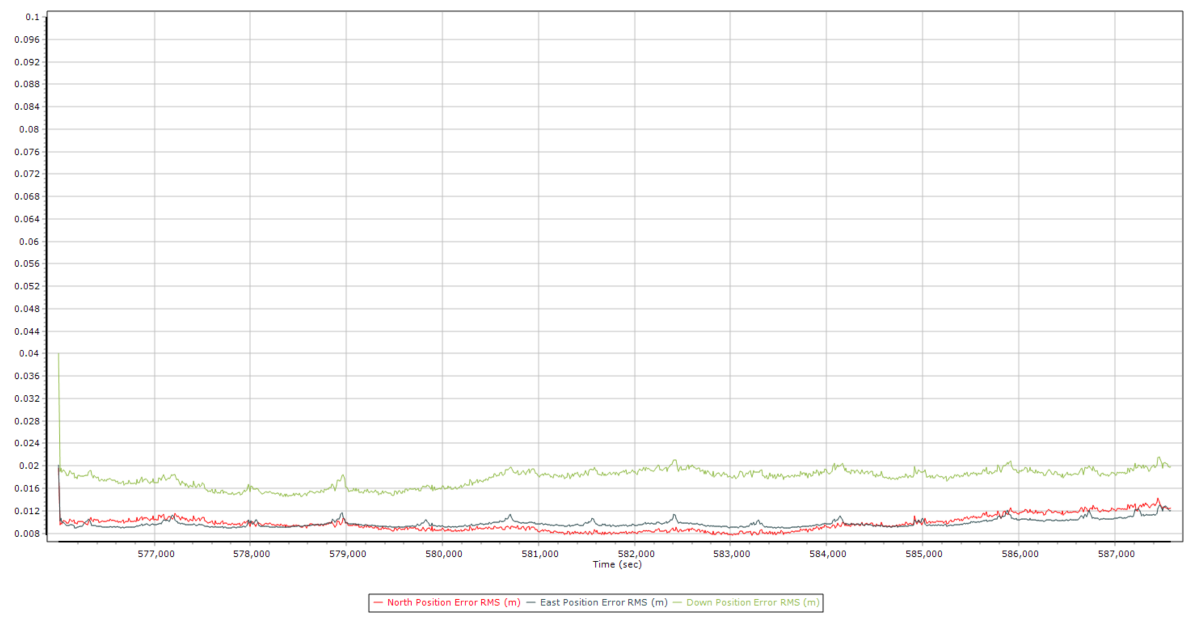

Baseline Length (m)
Time (sec)

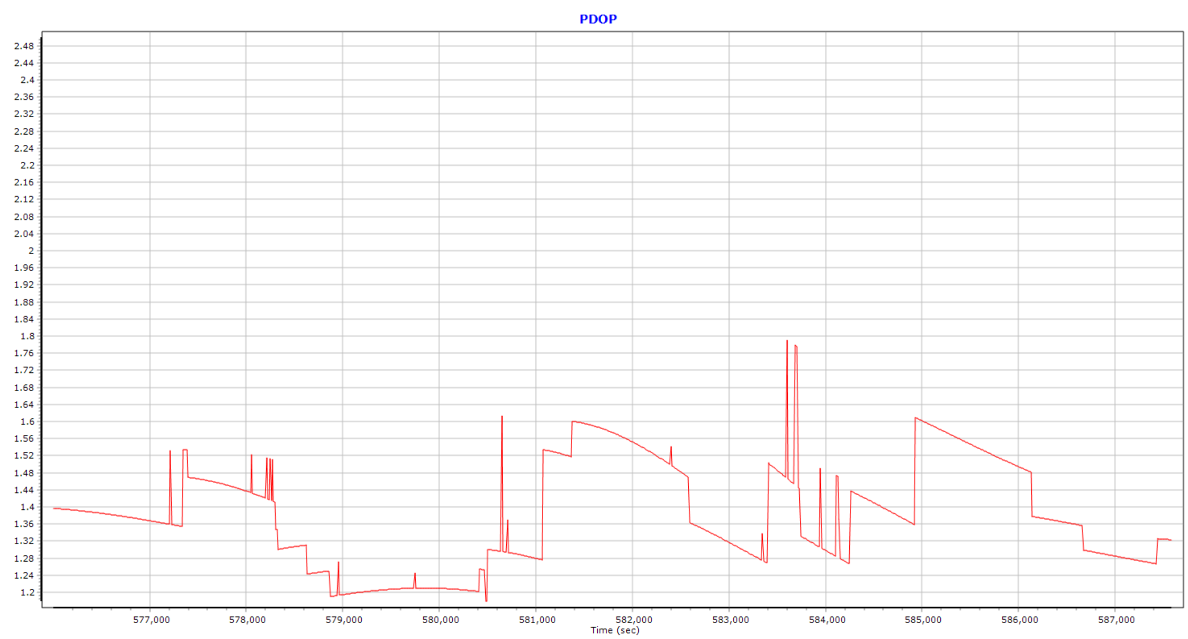
SBET IAKAR Separation

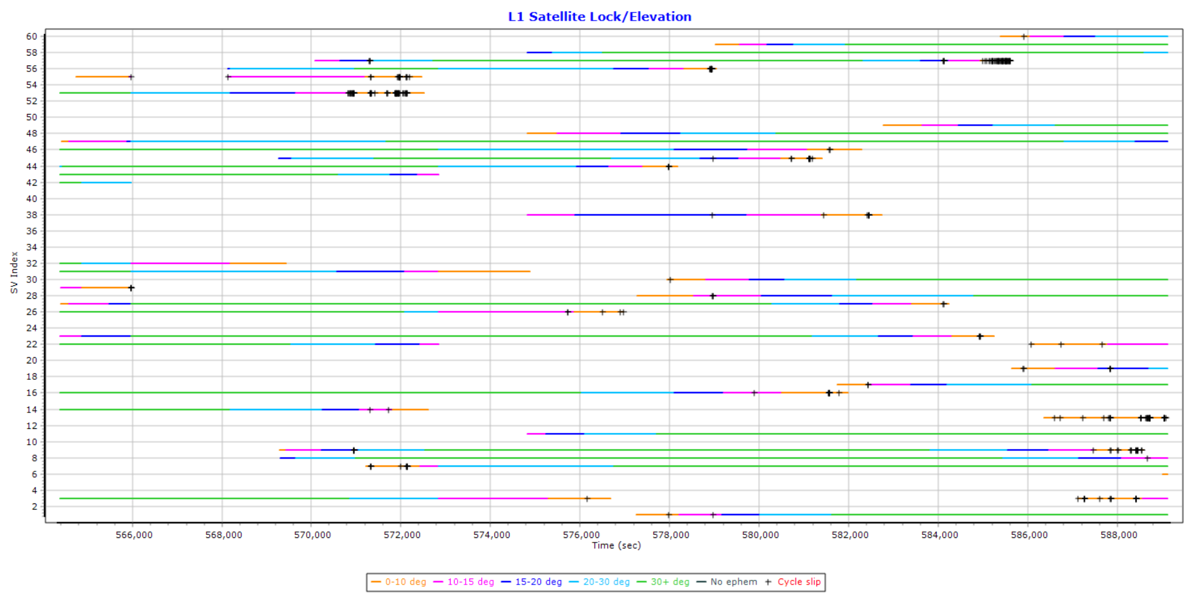
Mission: 20170527
Trajectory

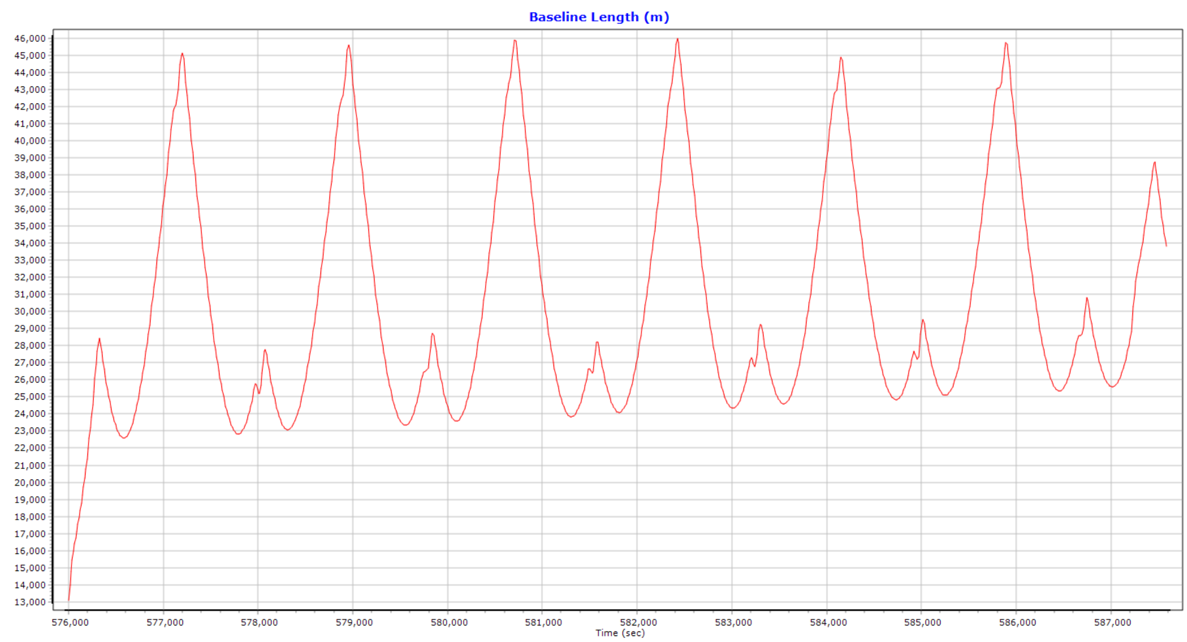


Smoothed Performance Metrics

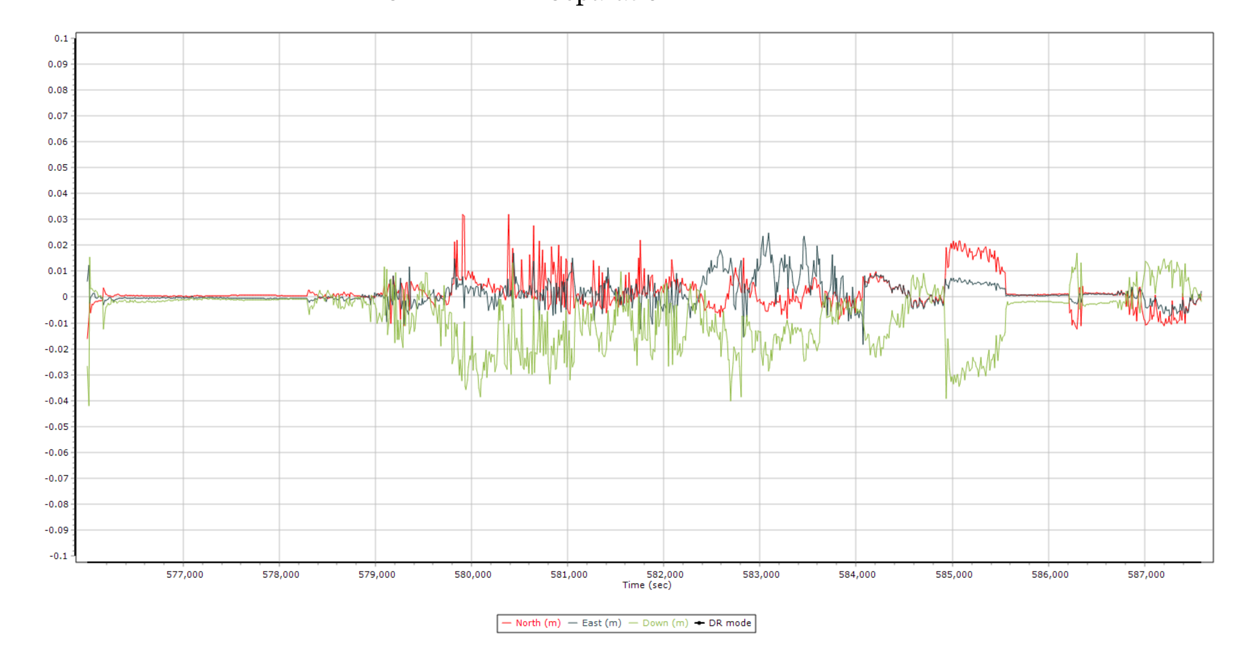





L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

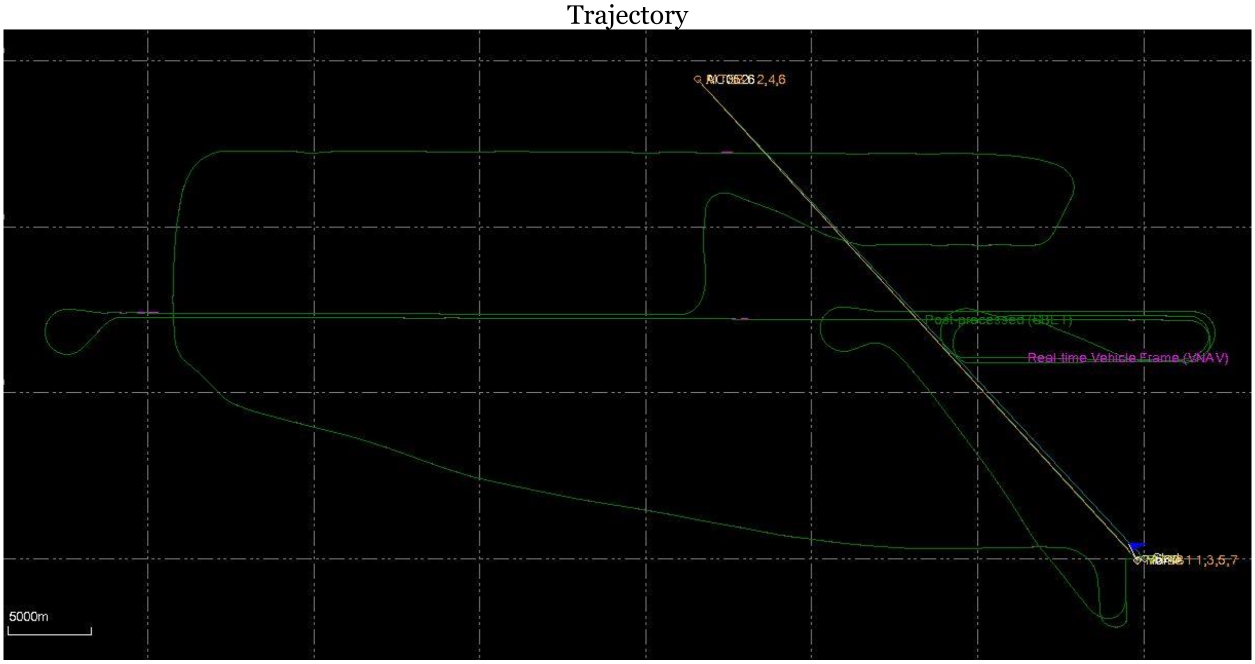

Baseline Length (m)
Time (sec)

SBET IAKAR Separation

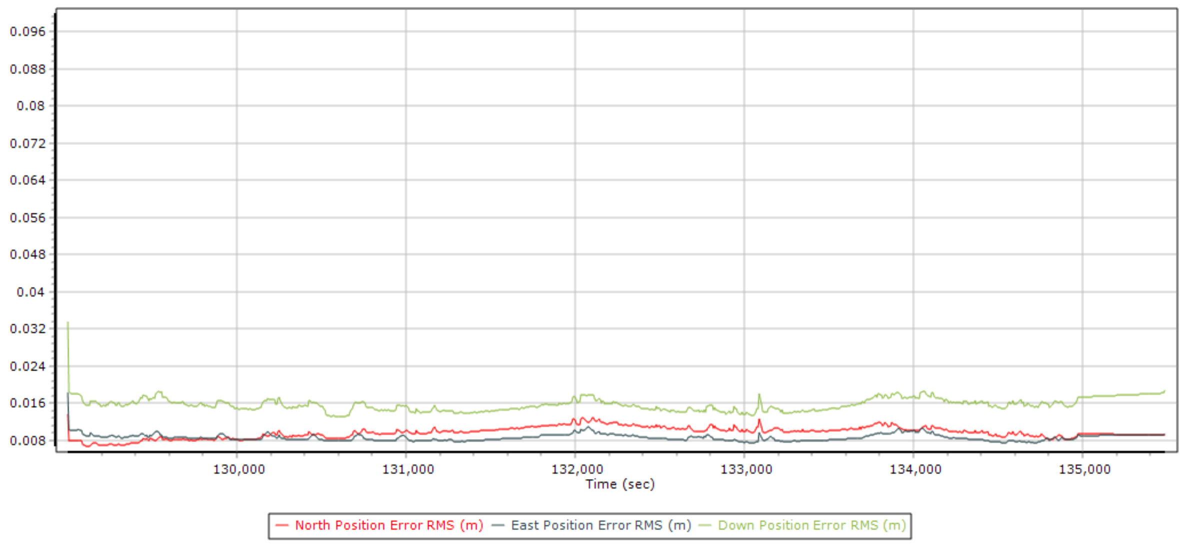


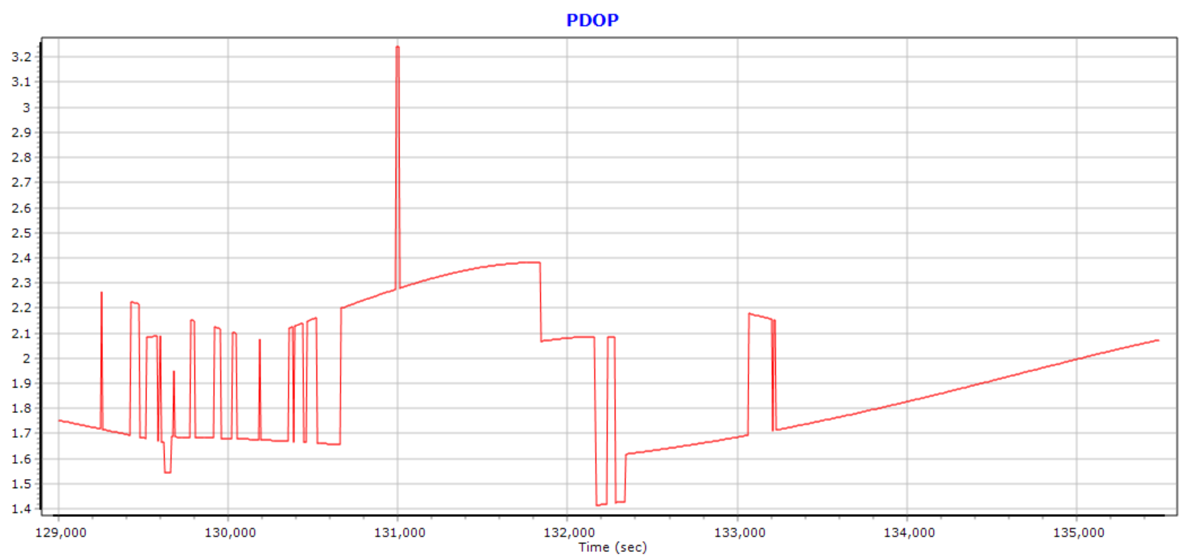
Mission: 20170529_A

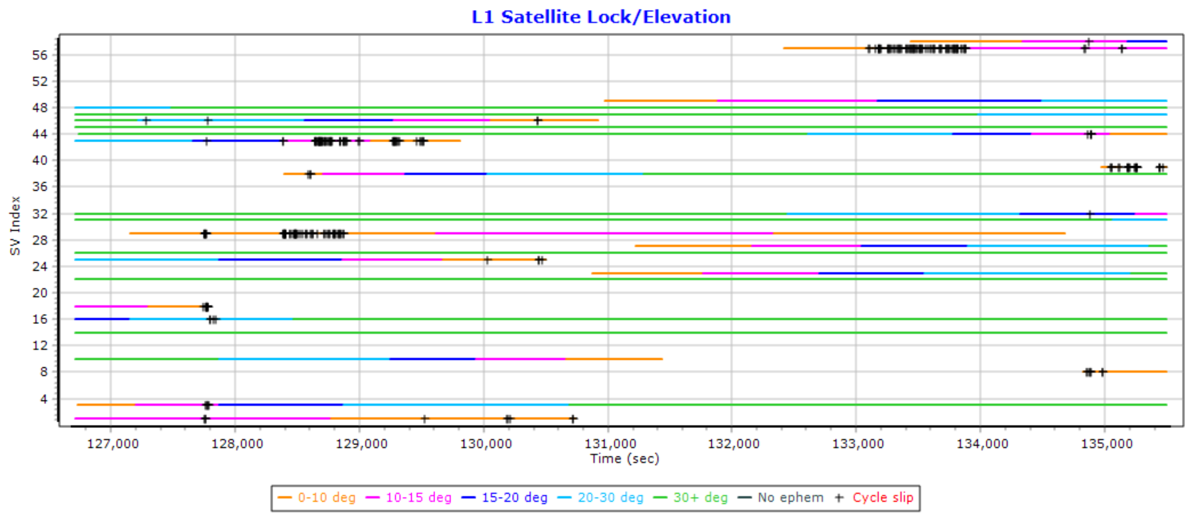
Trajectory

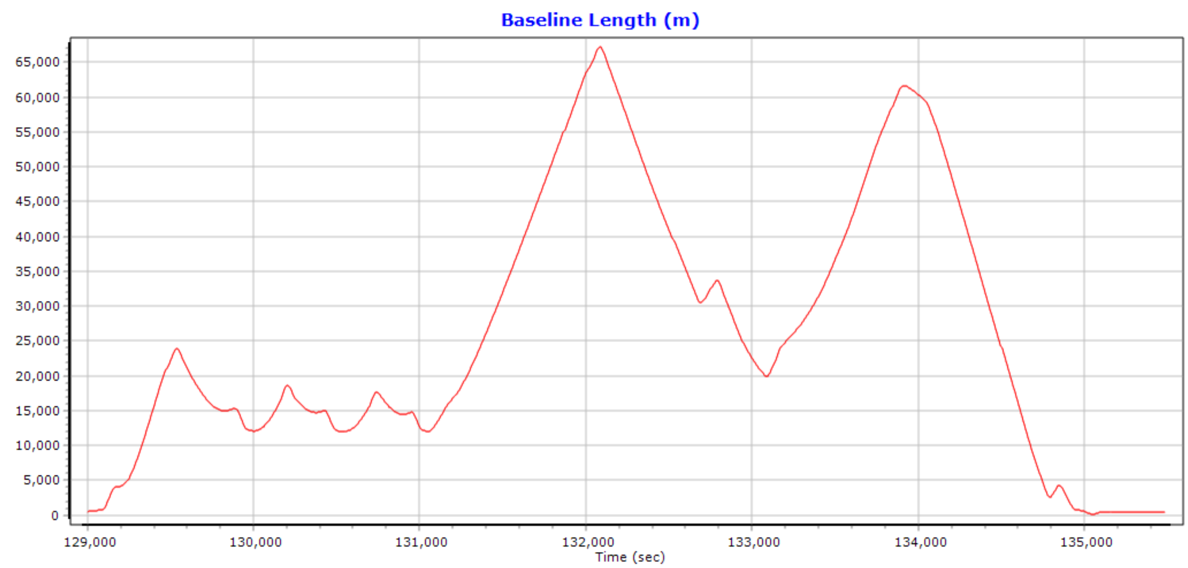


Smoothed Performance Metrics

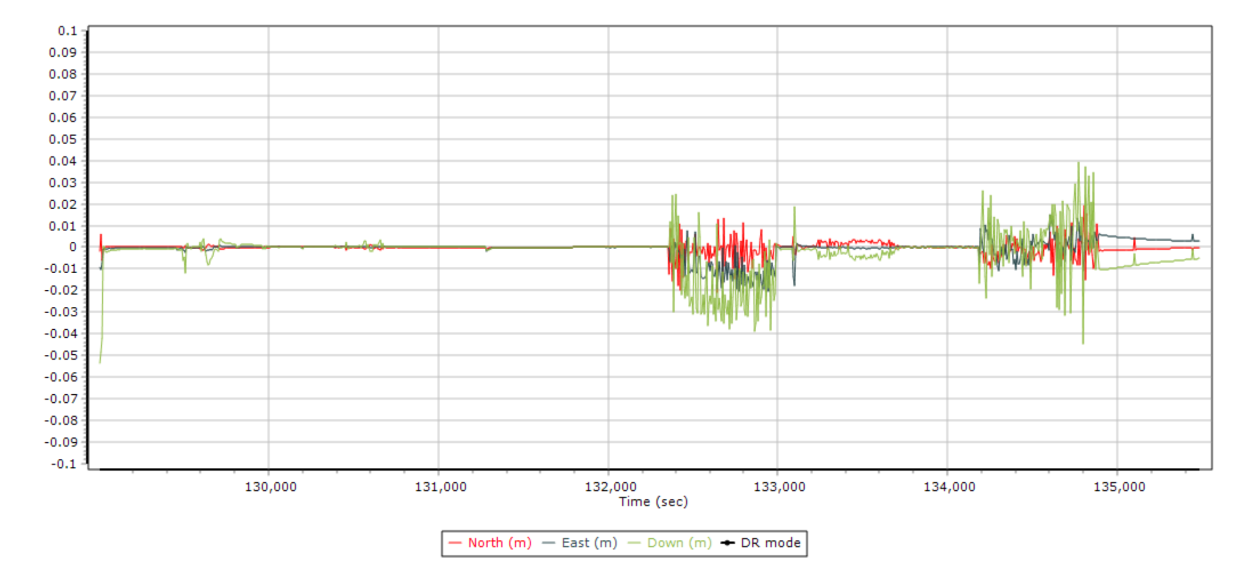




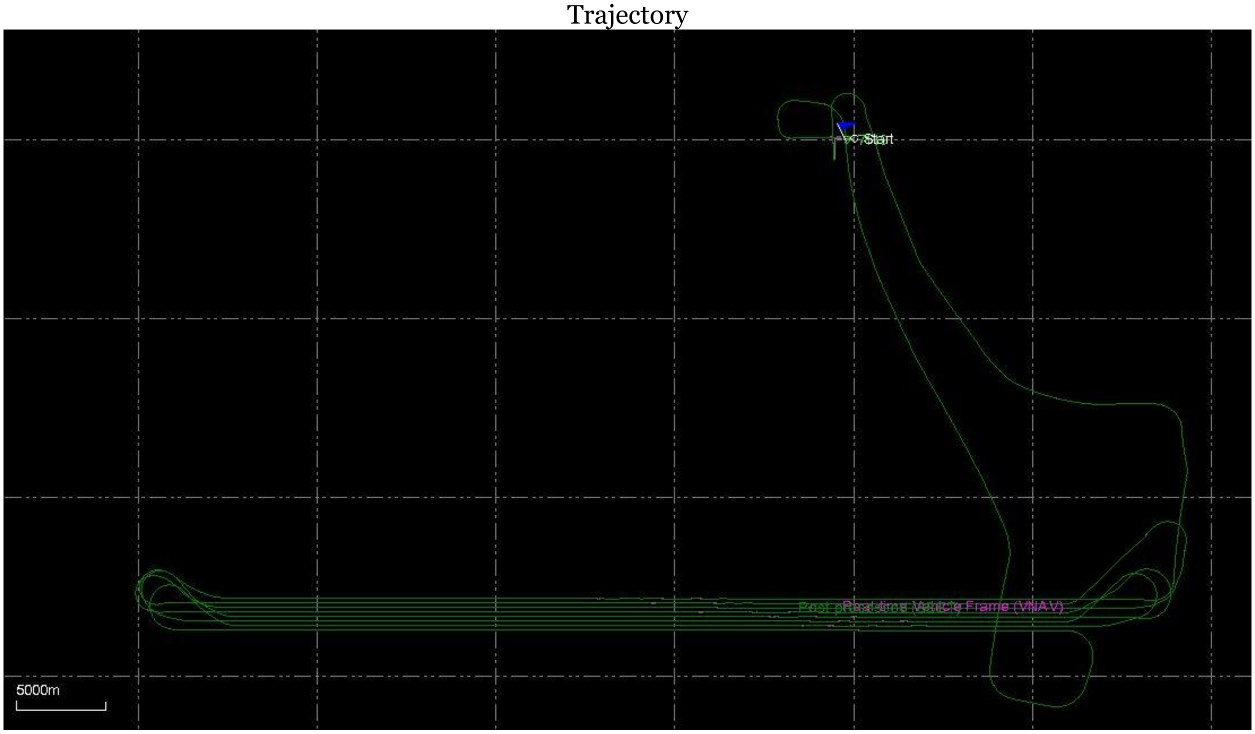

L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip


Baseline Length (m)
Time (sec)

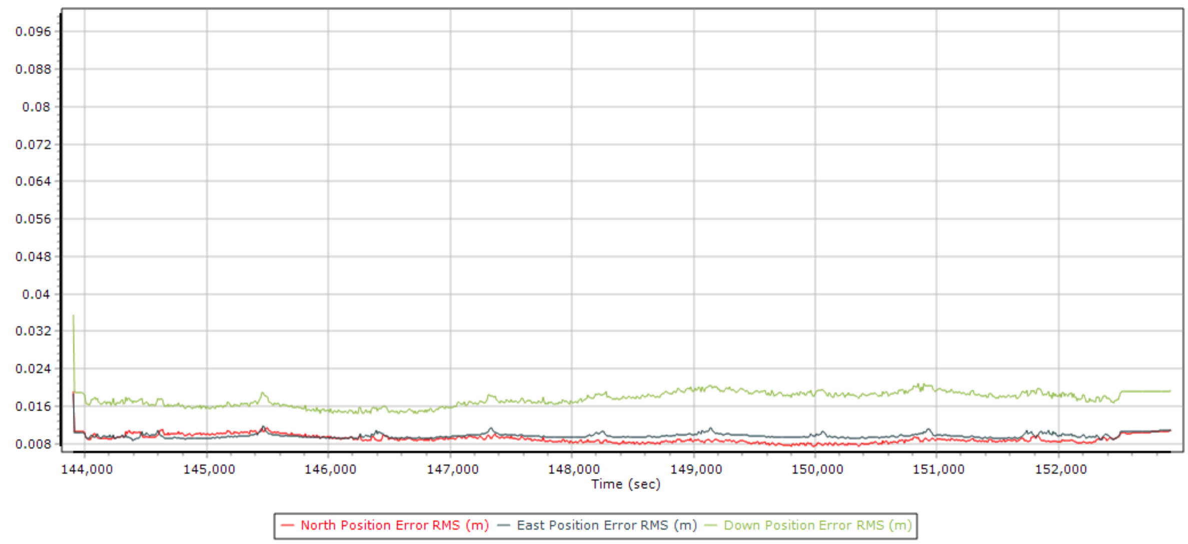
SBET IAKAR

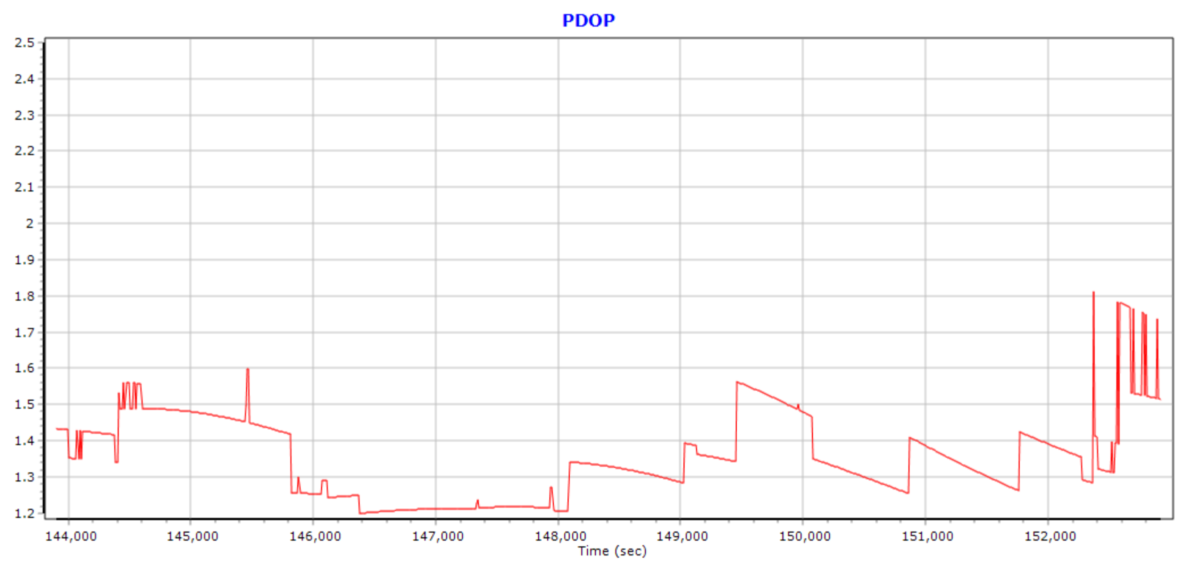


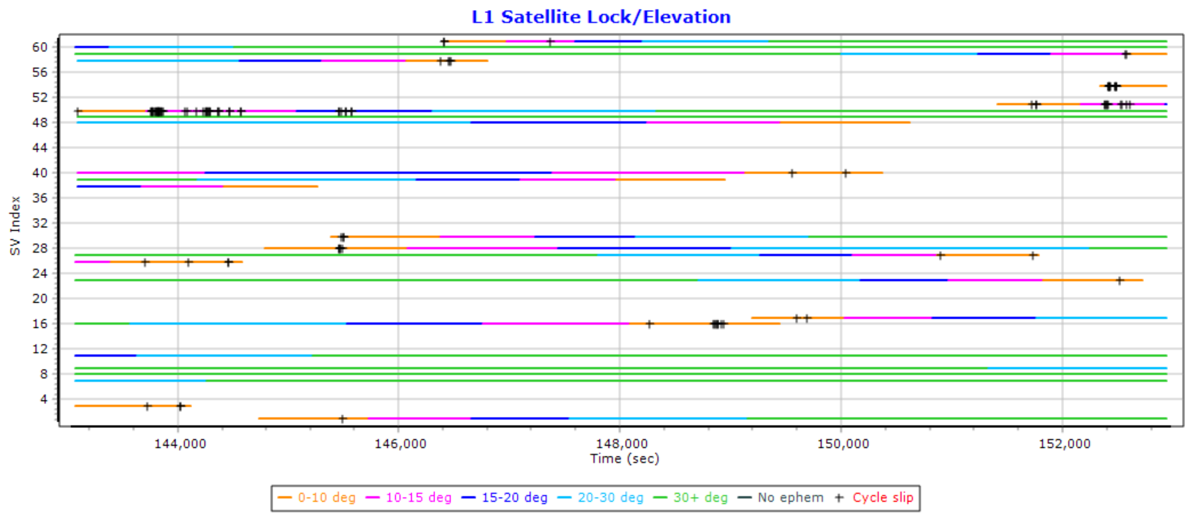
Mission: 20170529_B
Trajectory

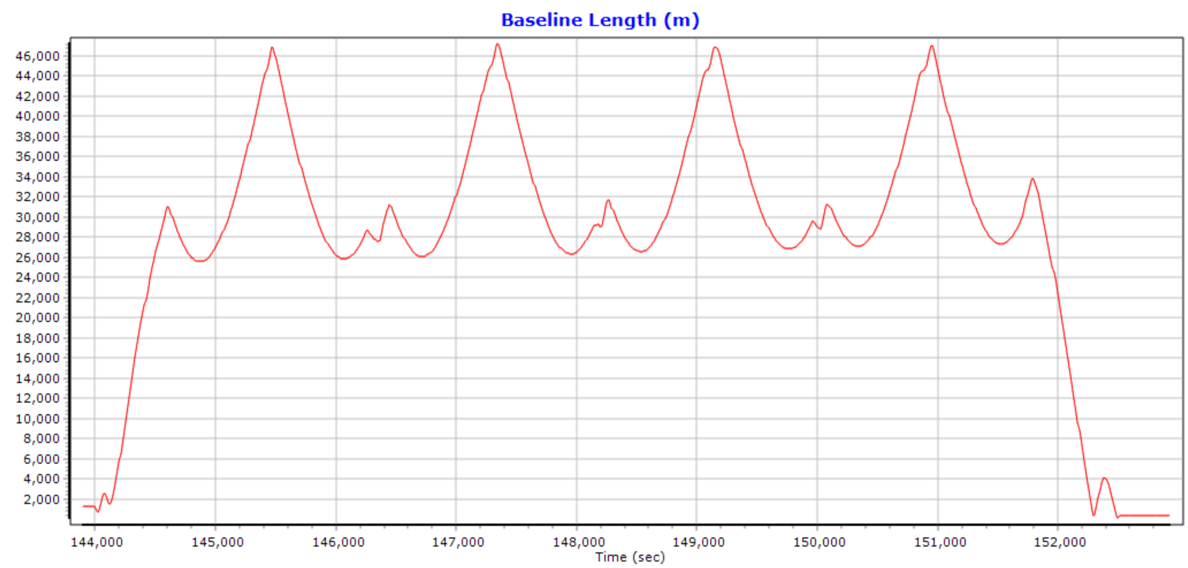


Smoothed Performance Metrics

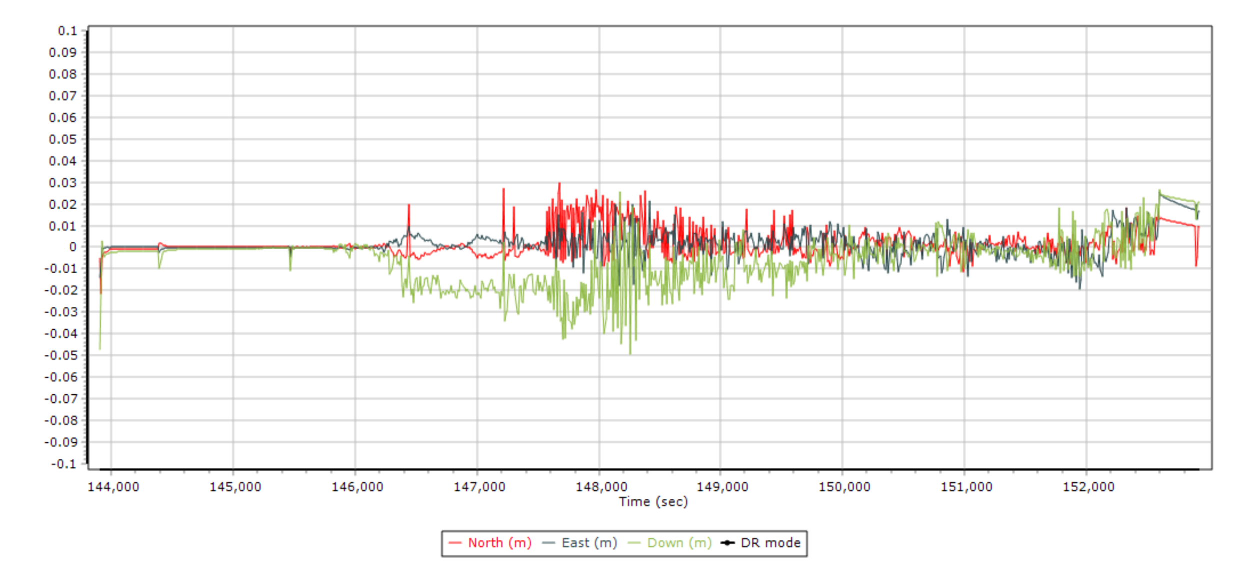






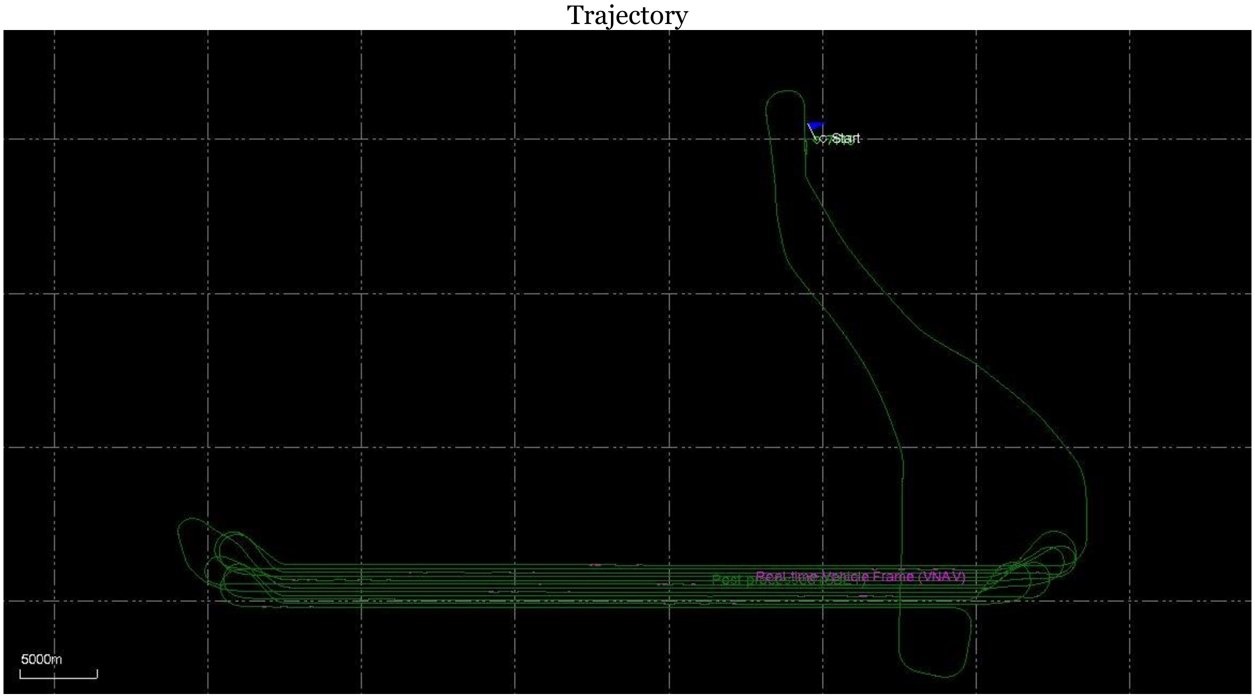


SBET IAKAR Separation

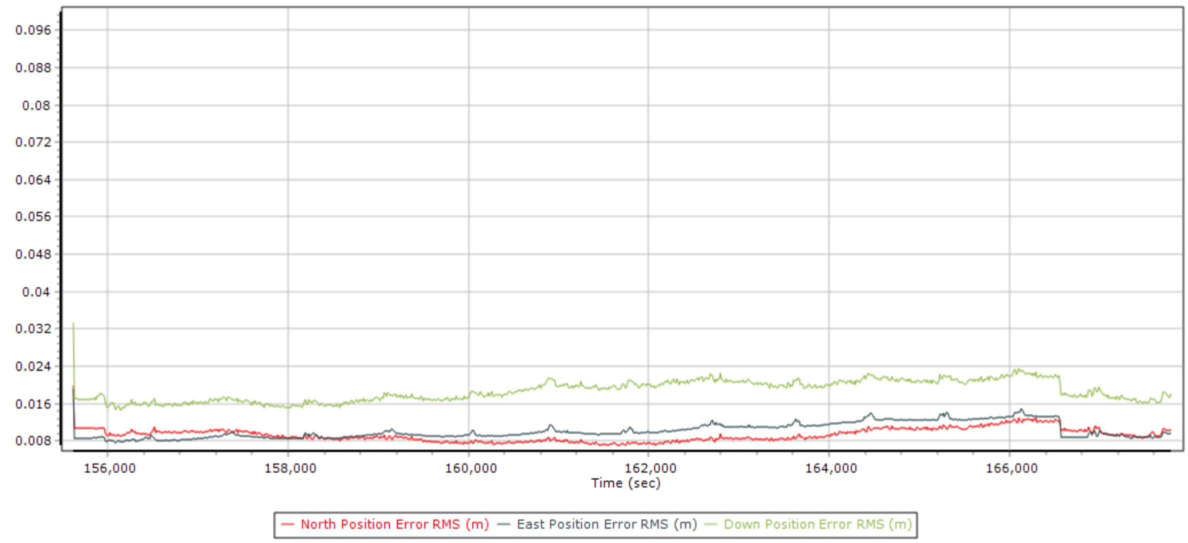


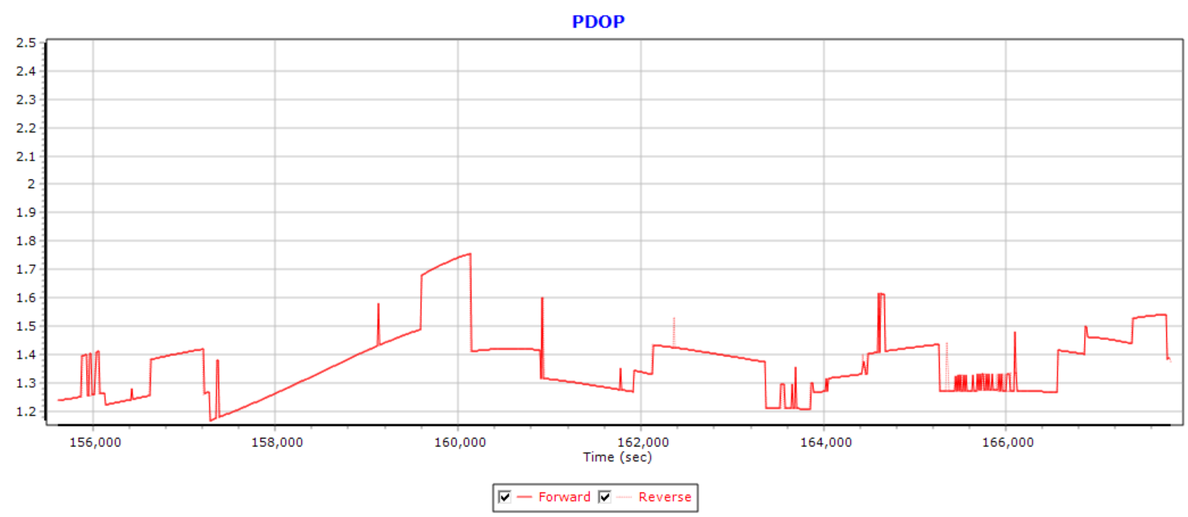
Mission: 20170529_C

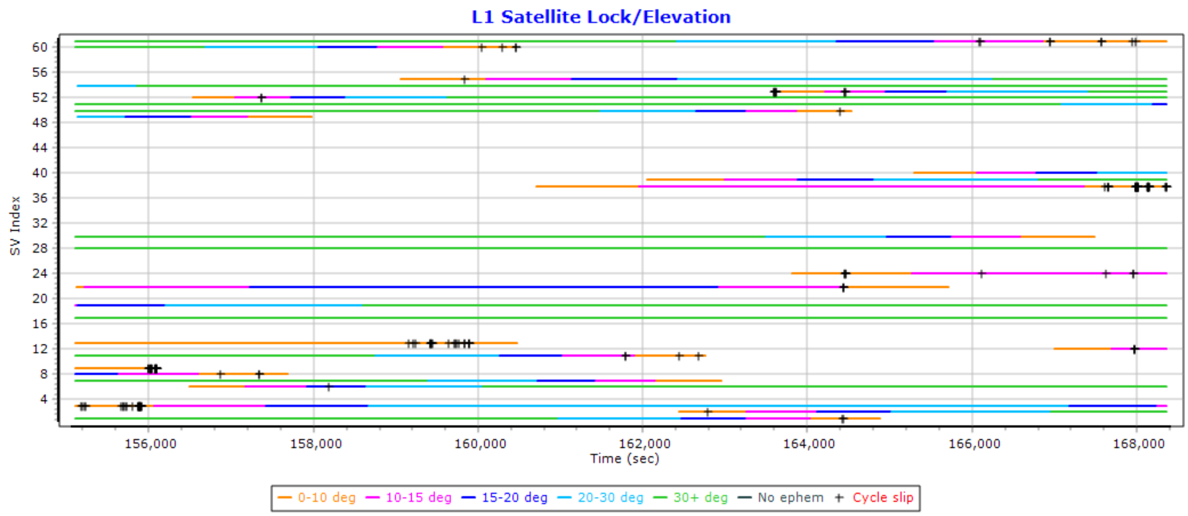
Trajectory

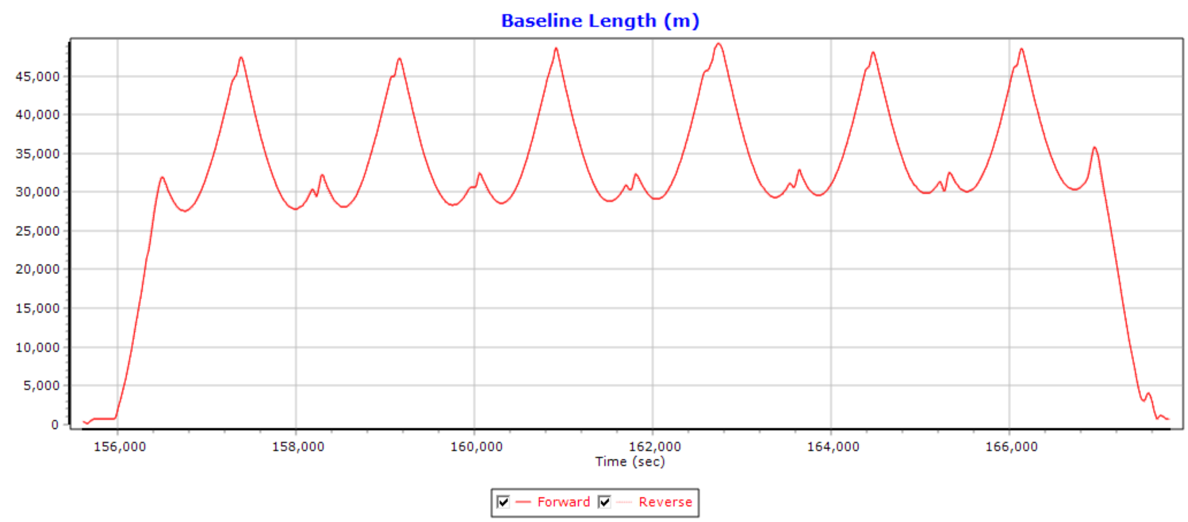


Smoothed Performance Metrics

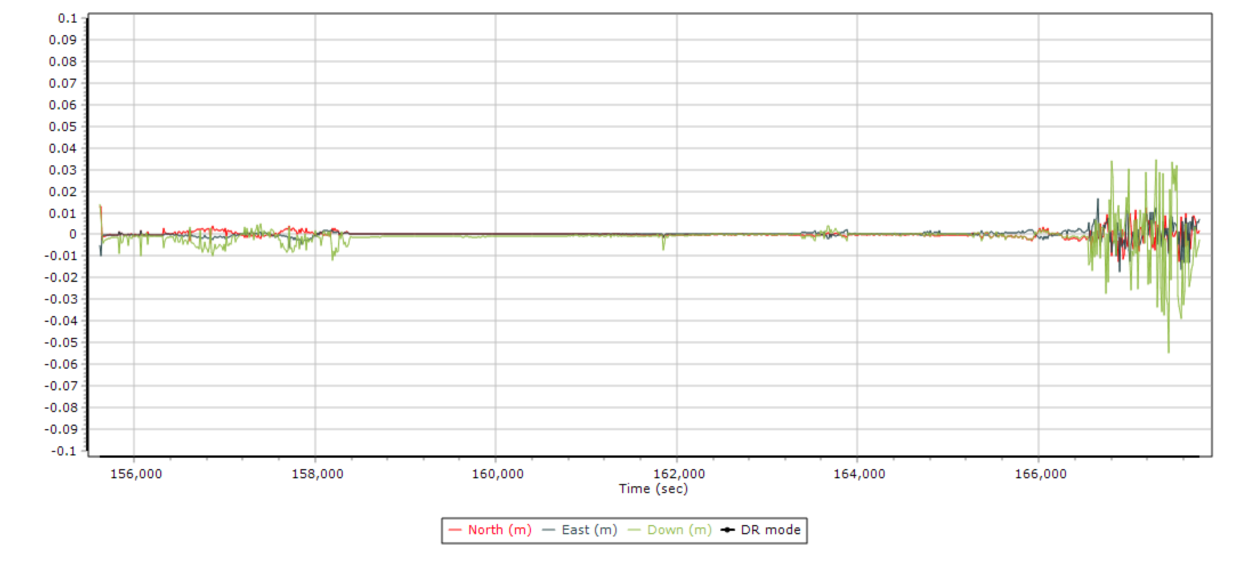

0.096
0.088
0.08
0.072
0.064
0.056
0.048
0.04
0.032
0.024
0.016
0.008
156,000
158,000
160,000
162,000
164,000
166,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


PDOP
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
156,000
158,000
160,000
162,000
164,000
166,000
Time (sec)
Forward
Reverse

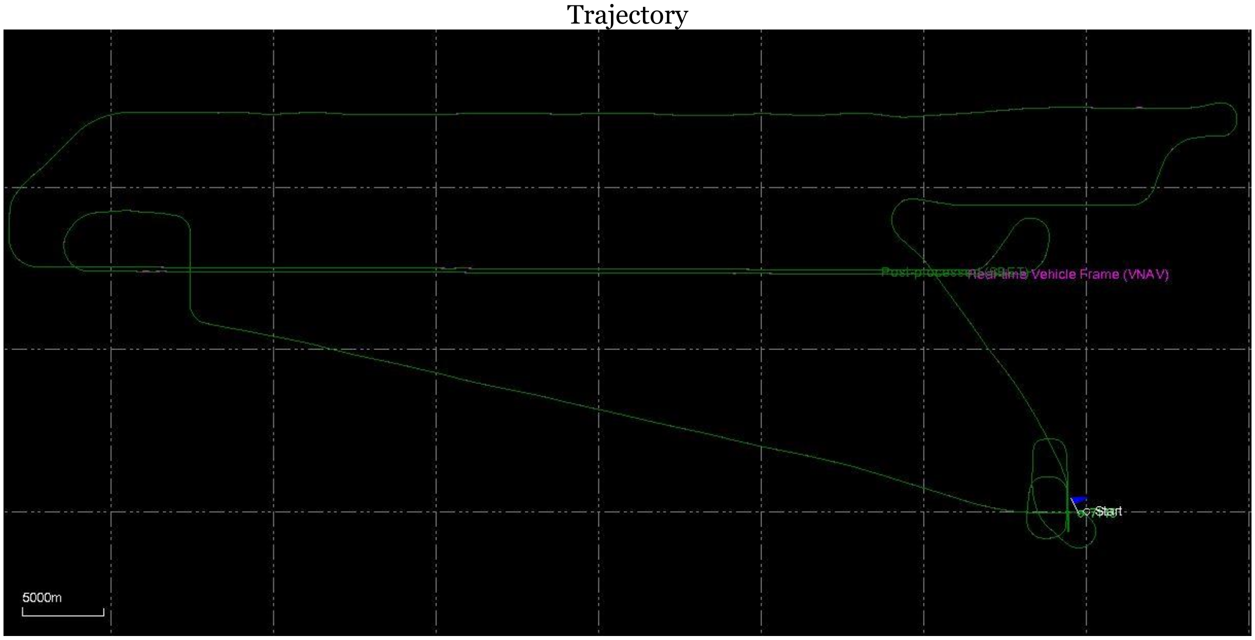

L1 Satellite Lock/Elevation
SV Index
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
156,000
158,000
160,000
162,000
164,000
166,000
168,000
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip


Baseline Length (m)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
156,000
158,000
160,000
162,000
164,000
166,000
Time (sec)
Forward
Reverse

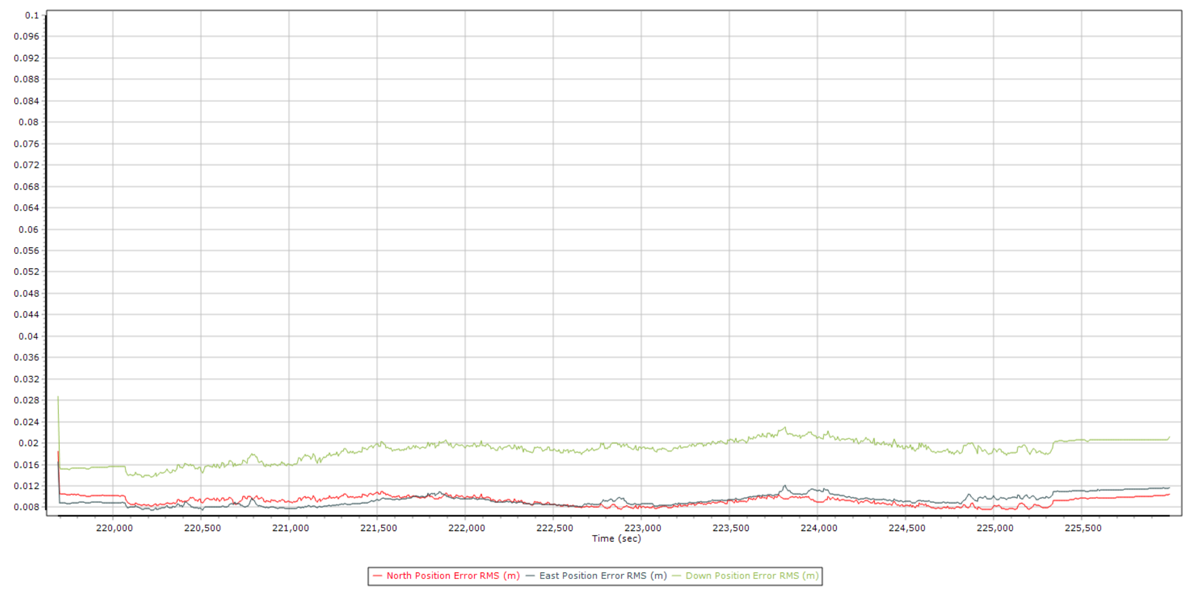
SBET IAKAR Separation

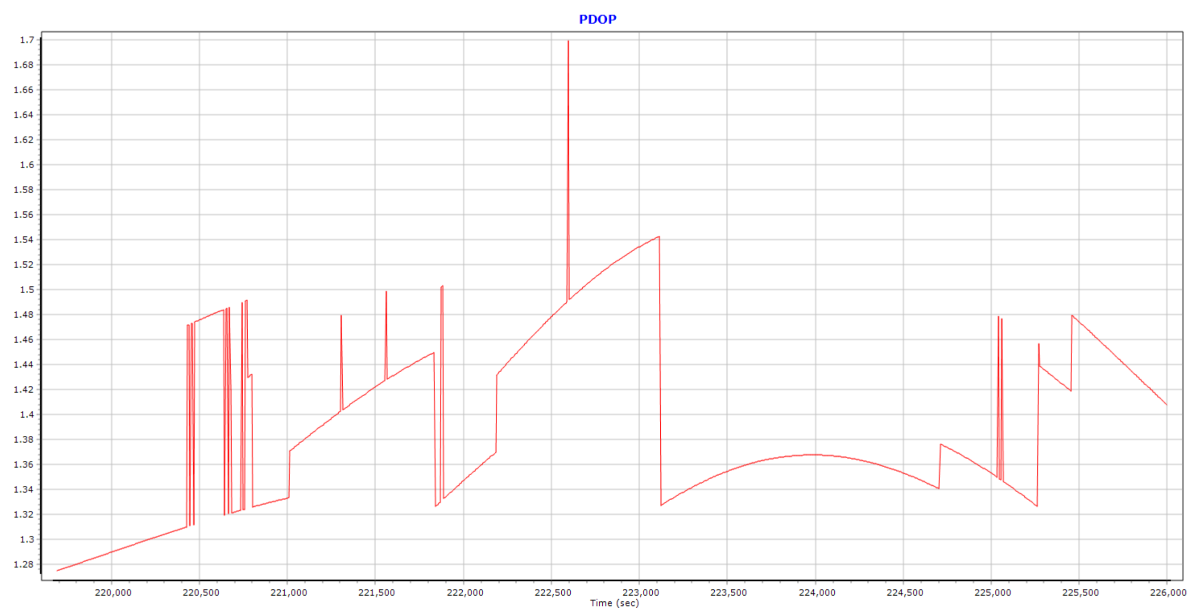


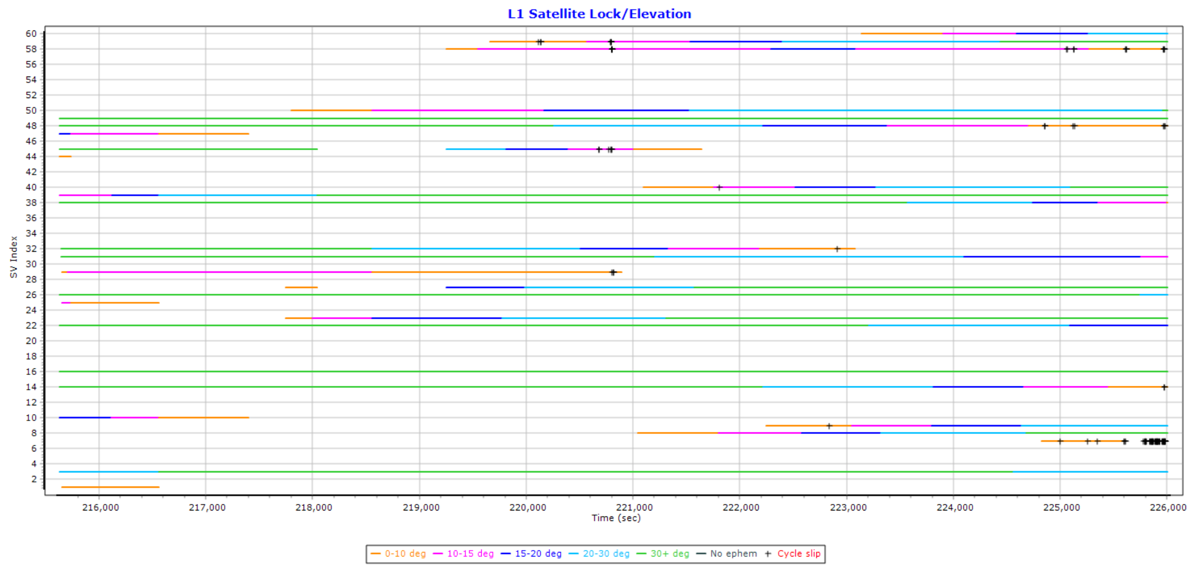
Mission: 20170530_A
Trajectory

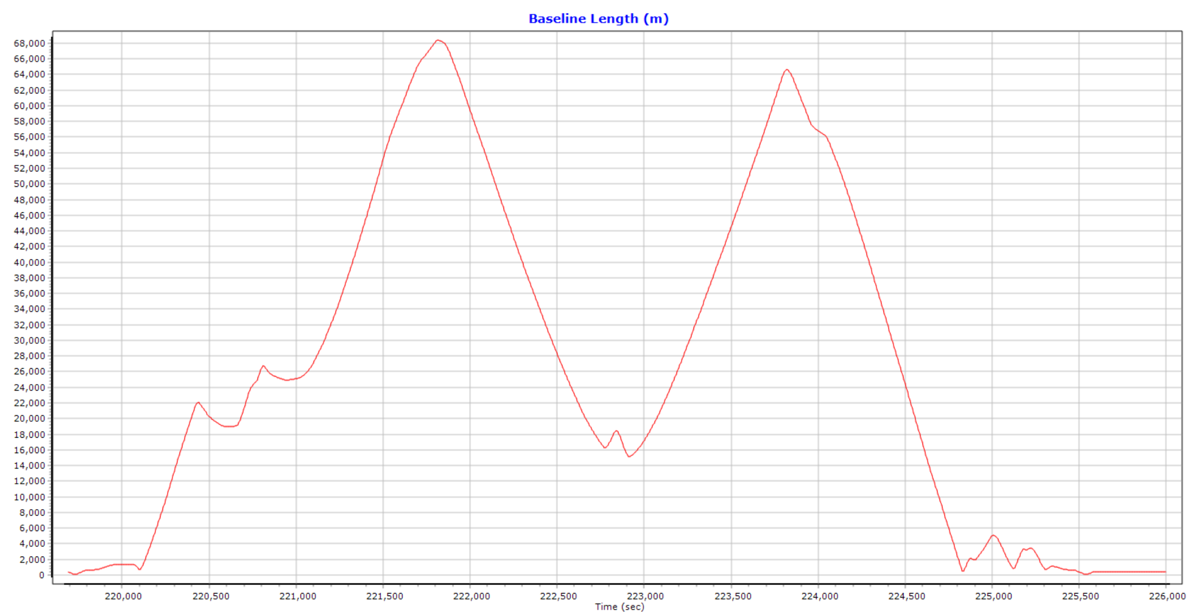


Smoothed Performance Metrics



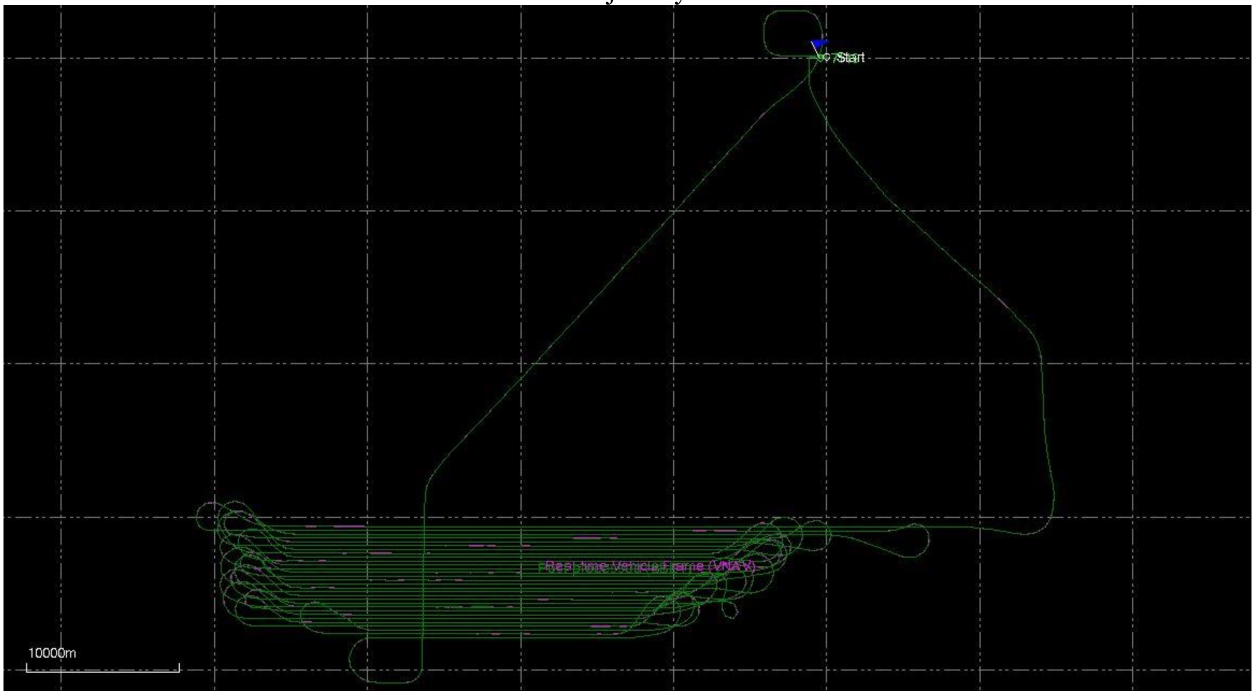



L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

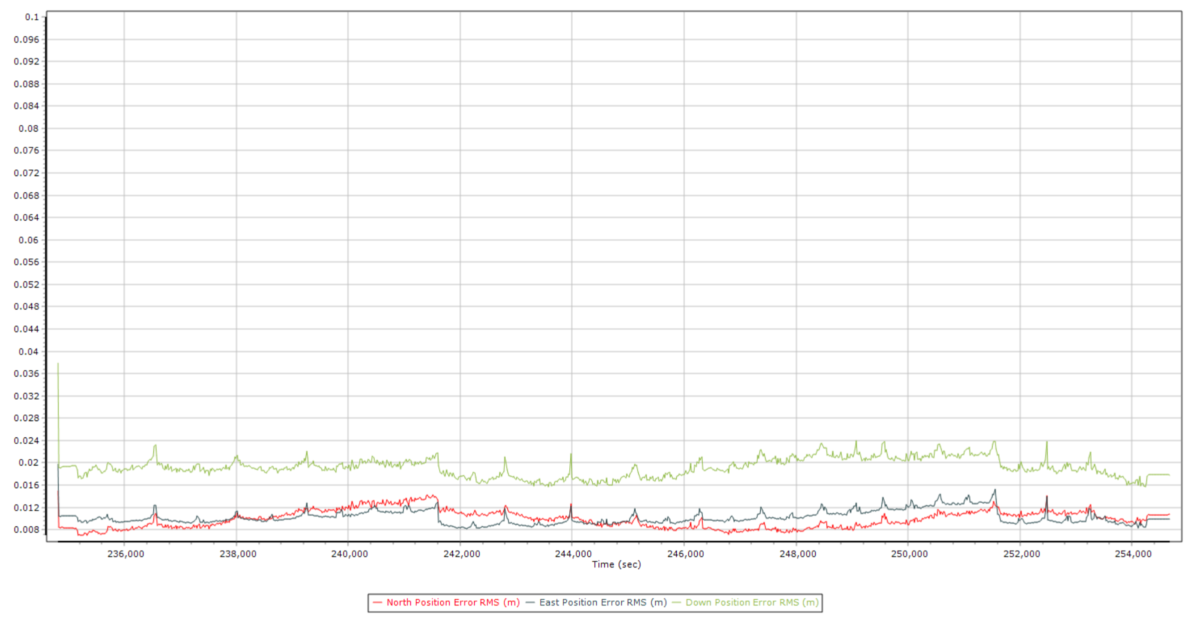

Baseline Length (m)
Time (sec)

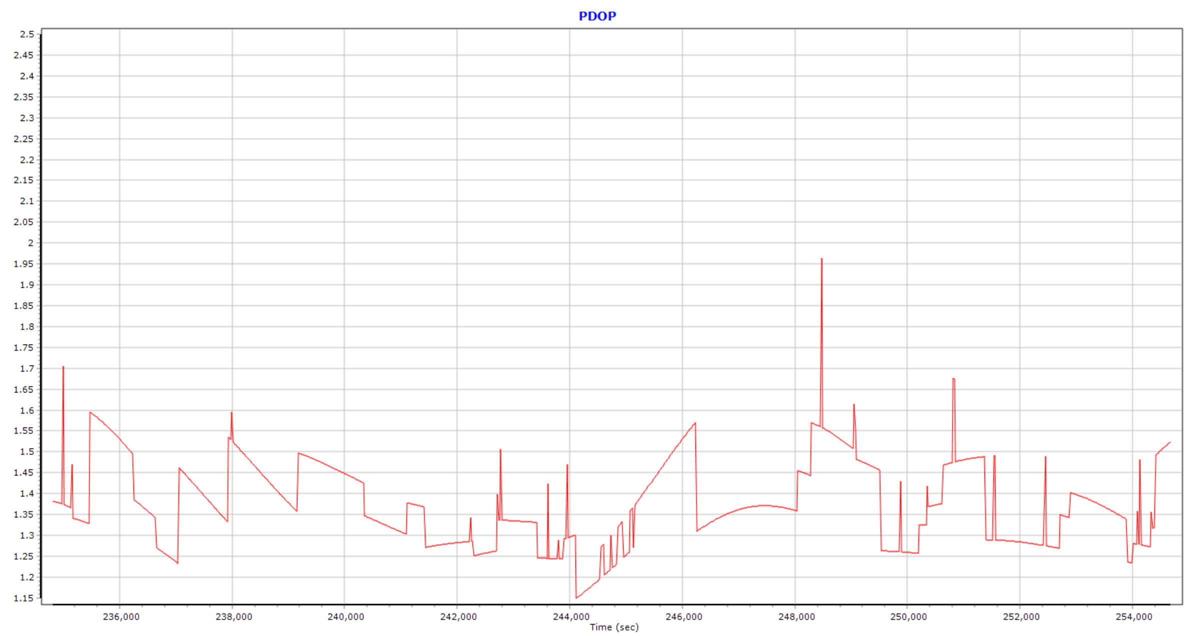
SBET IAKAR Separation

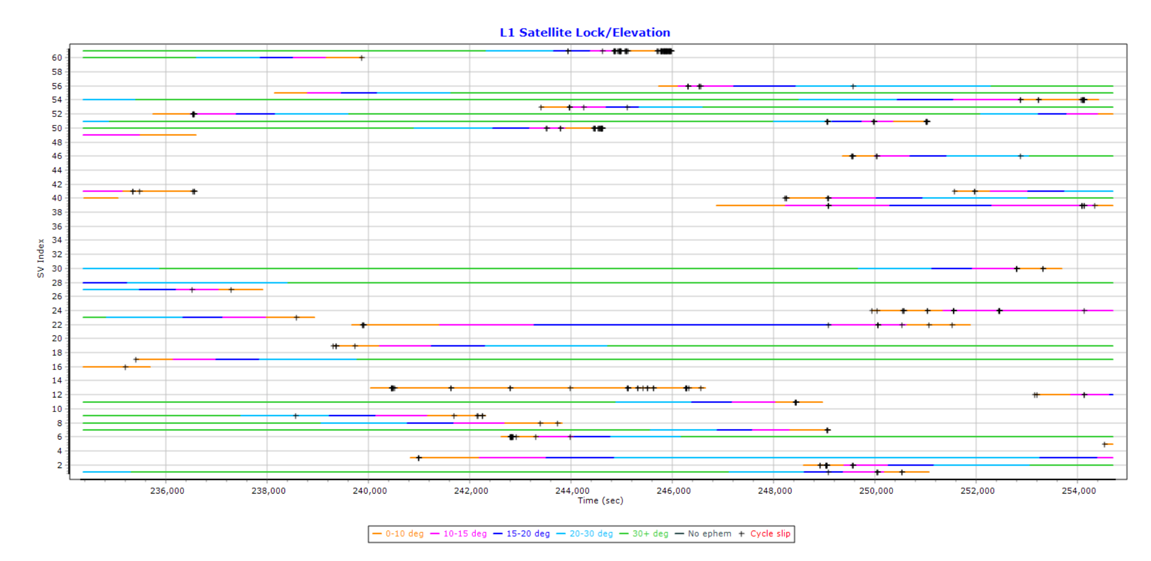
Mission: 20170530_B
Trajectory

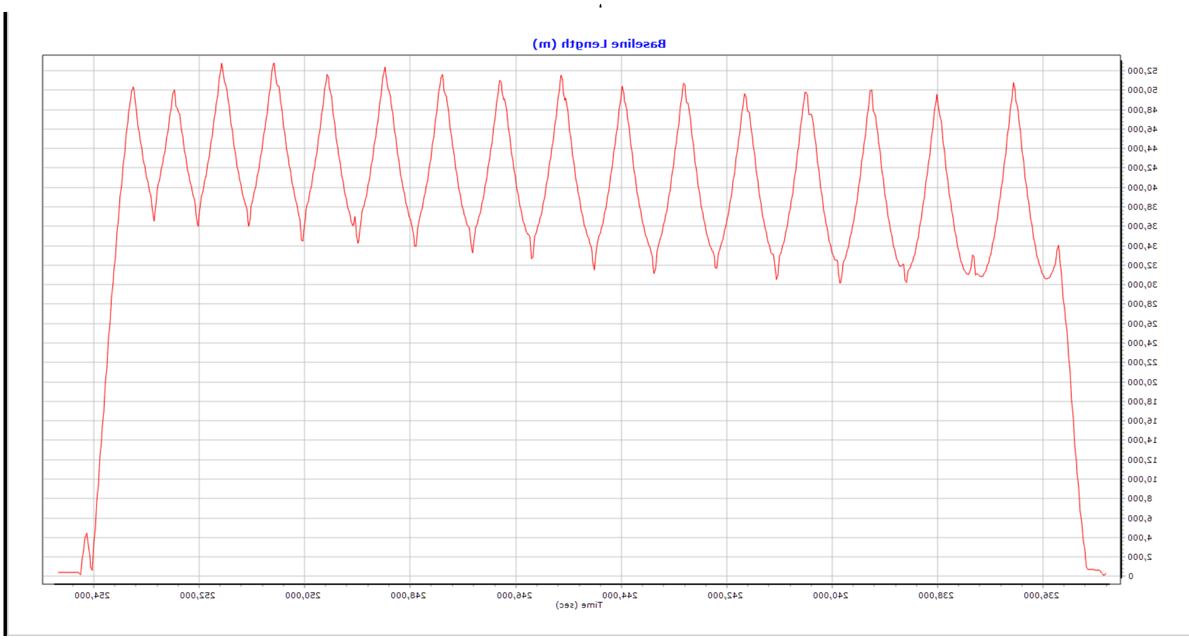


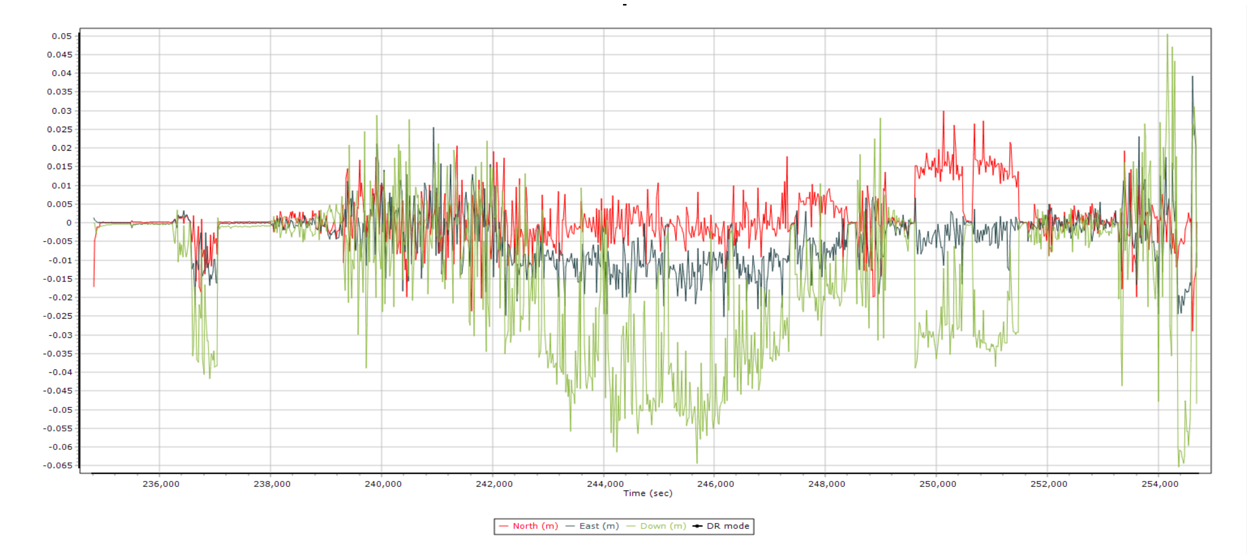
Smoothed Performance Metrics



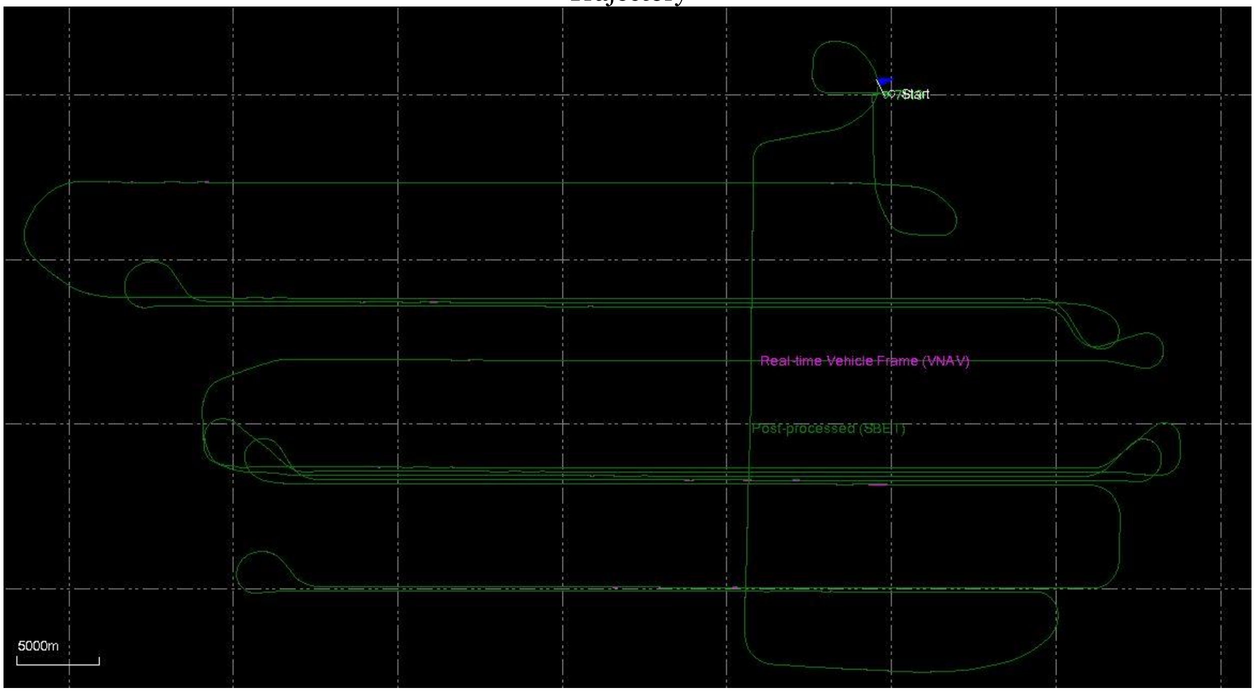


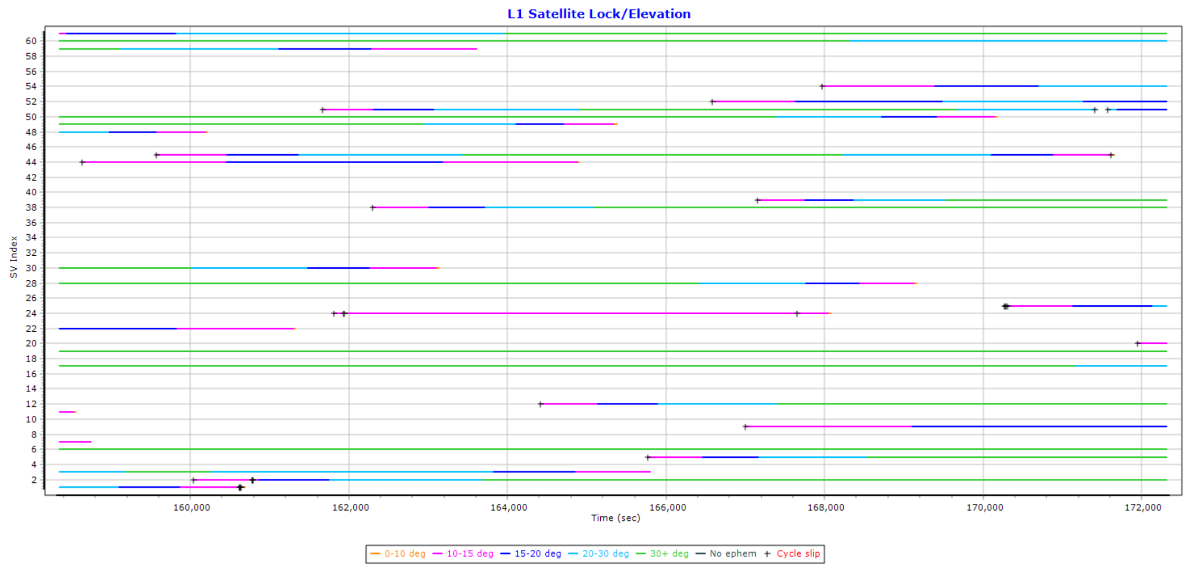

L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip

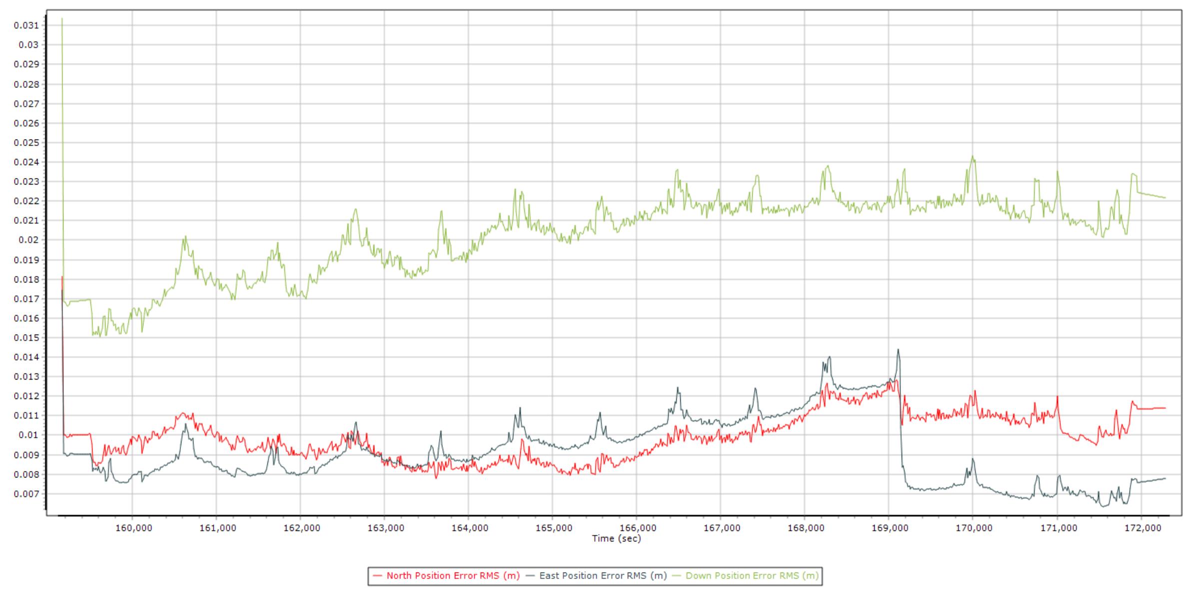

Baseline Length (m)
Time (sec)

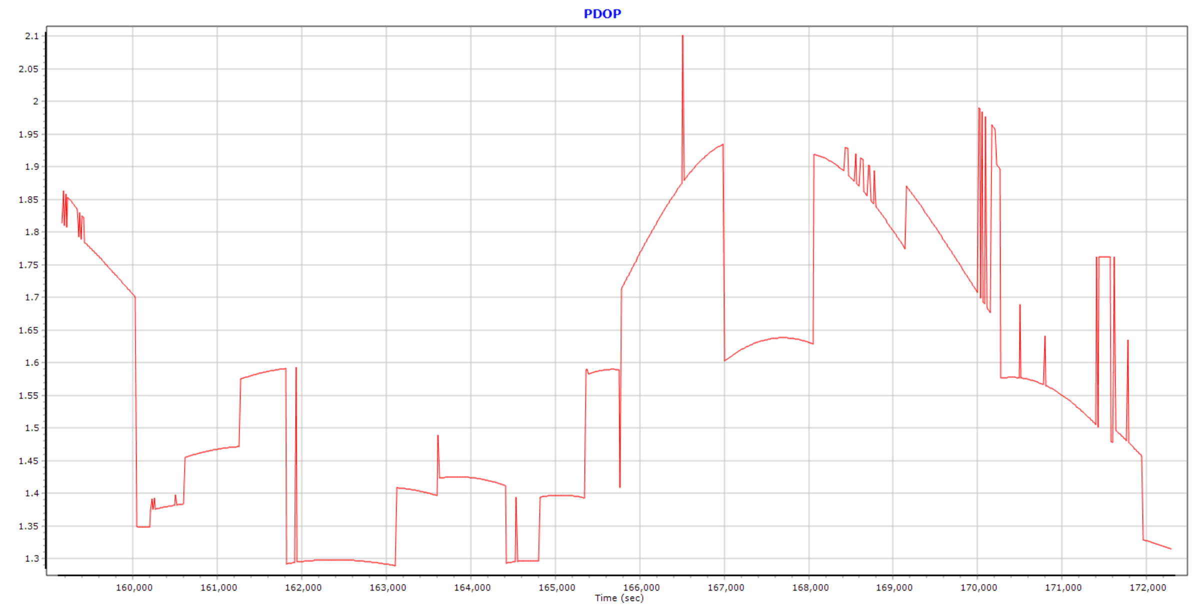


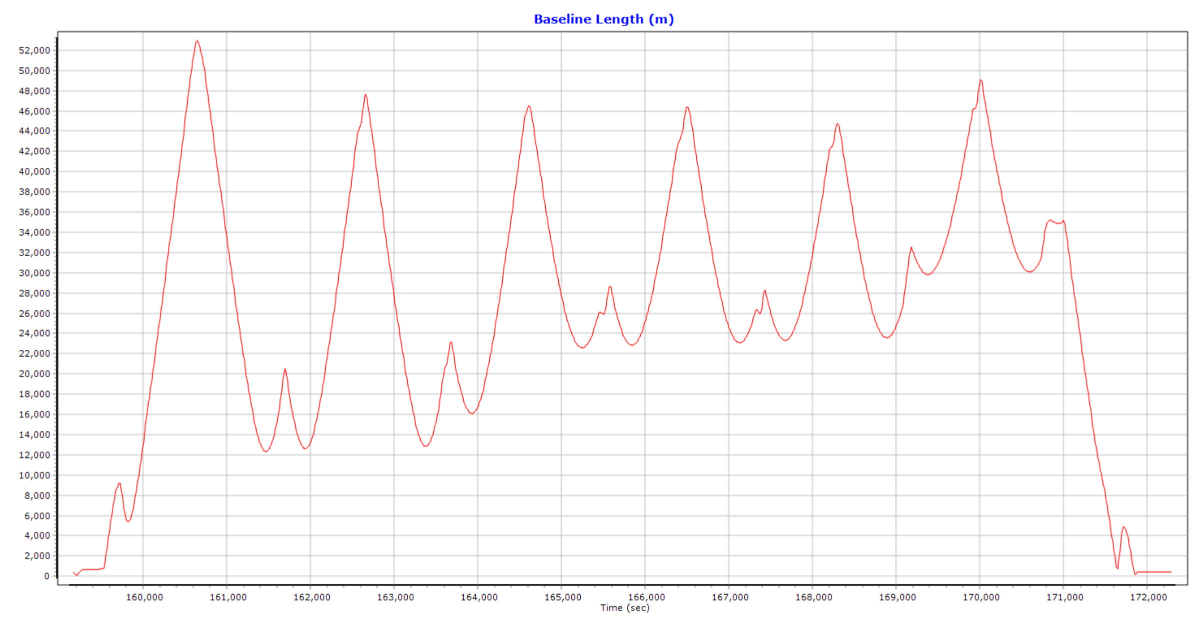
Mission: 20170612_A
Trajectory

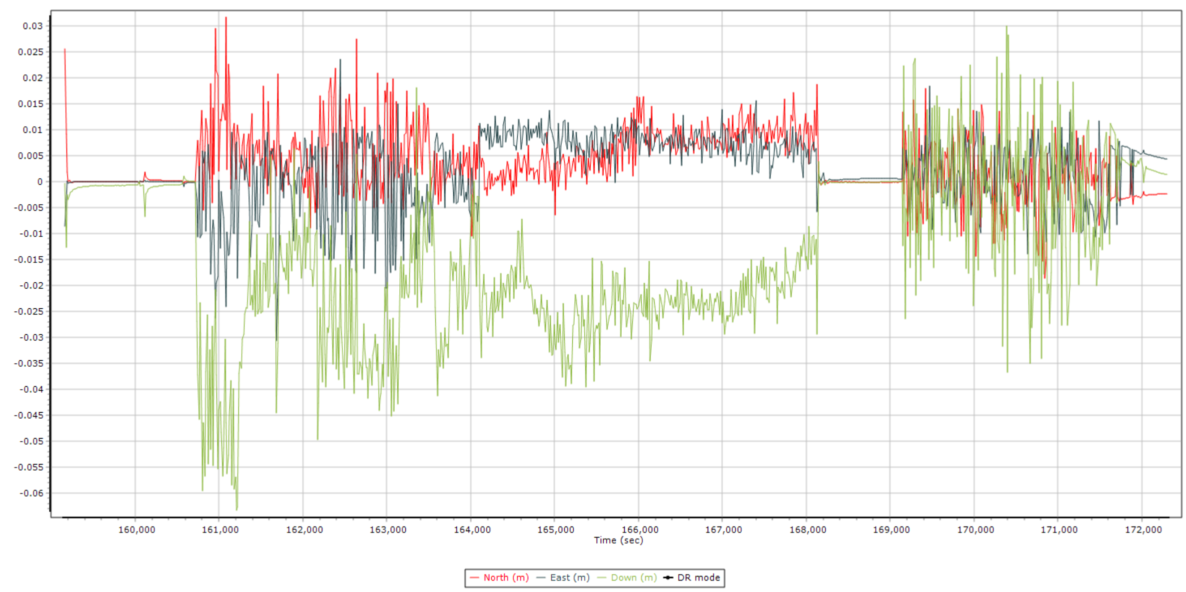



L1 Satellite Lock/Elevation
SV Index
Time (sec)
0-10 deg
10-15 deg
15-20 deg
20-30 deg
30+ deg
No ephem
Cycle slip


Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


PDOP
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
169,000
170,000
171,000
172,000
Time (sec)


Baseline Length (m)
52,000
50,000
48,000
46,000
44,000
42,000
40,000
38,000
36,000
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
169,000
170,000
171,000
172,000
Time (sec)



Program: POSGPS
Version: 4.30.3108
Project: G:\Projects\Dewberry\AR\12085a\pos\GPS\08512a.gnv

Solution Type: Combined Fwd/Rev

Number of Epochs:

Total in GPB file: 176637
No processed position: 160557
Missing Fwd or Rev: 4
With bad C/A code: 0
With bad L1 Phase: 0

Measurement RMS Values:

L1 Phase: 0.0163 (m)
C/A Code: 0.93 (m)
L1 Doppler: 0.016 (m/s)

Fwd/Rev Separation RMS Values:

East: 0.010 (m)
North: 0.008 (m)
Height: 0.022 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (16074 occurrences):

East: 0.009 (m)
North: 0.004 (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 %

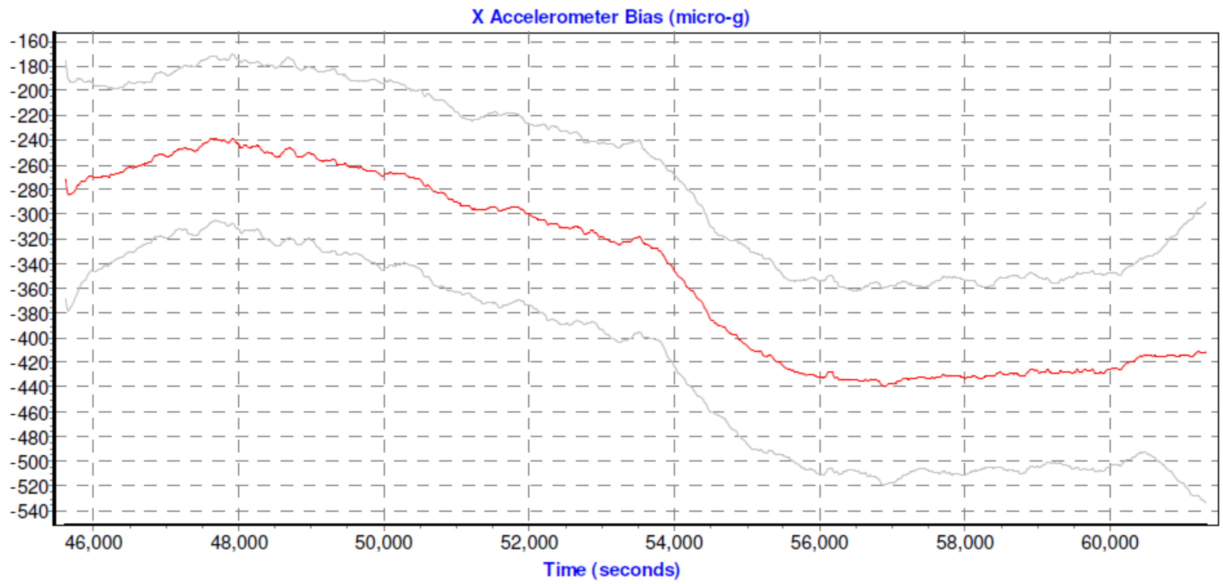
Percentages of epochs with DD_DOP over 10.00:

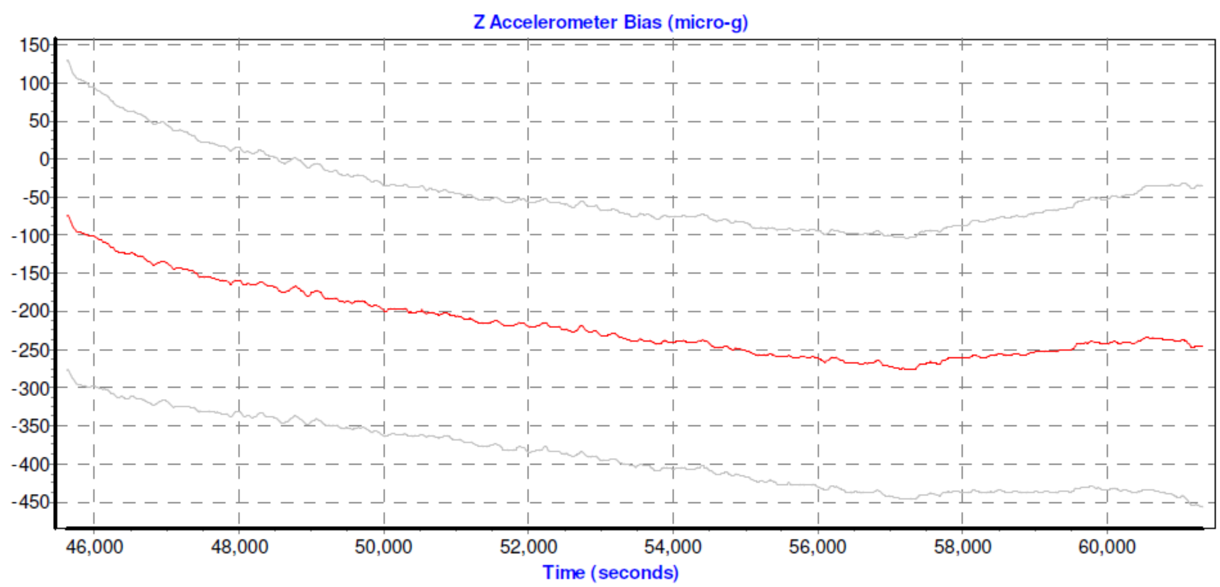
DOP over Tol: 0.0 %

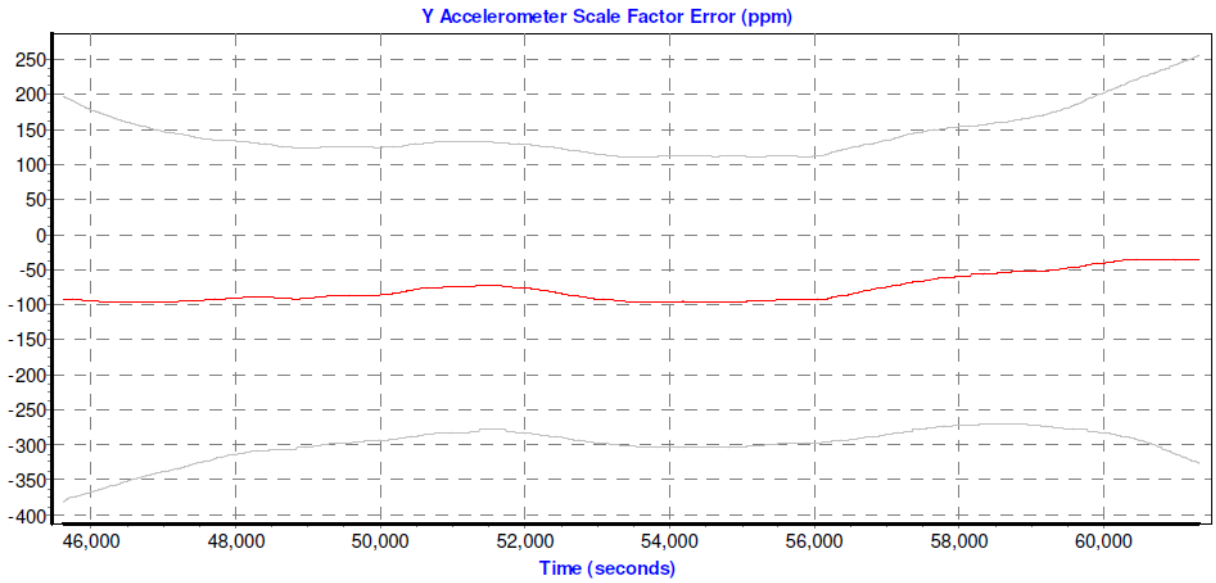
Baseline Distances:

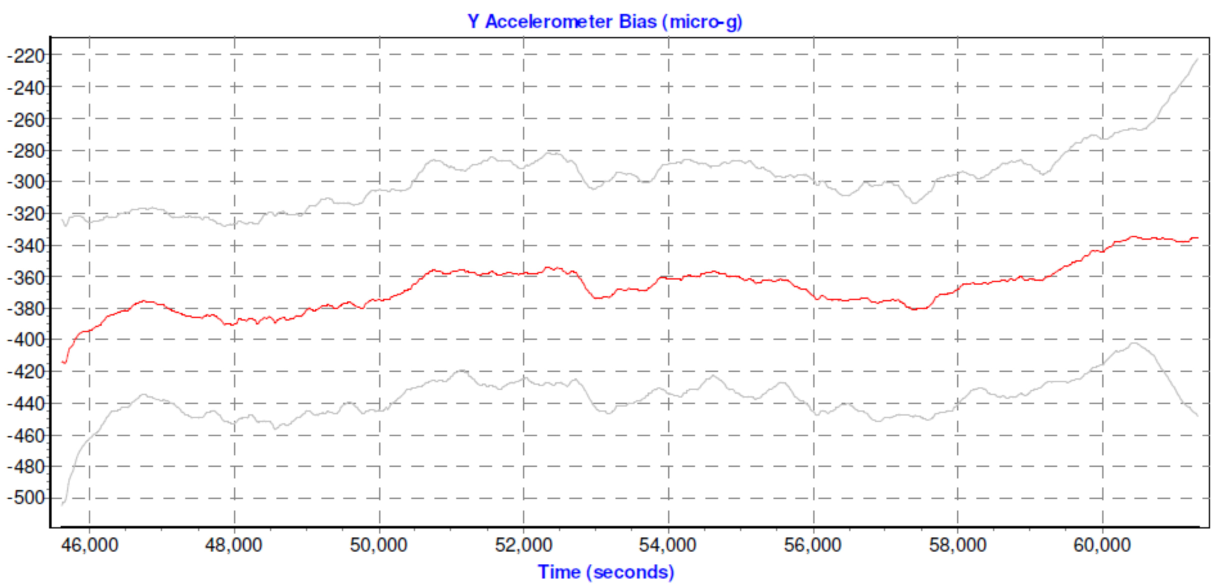
Maximum: 45.062 (km)
Minimum: 1.438 (km)
Average: 23.646 (km)
First Epoch: 41.528 (km)
Last Epoch: 45.062 (km)

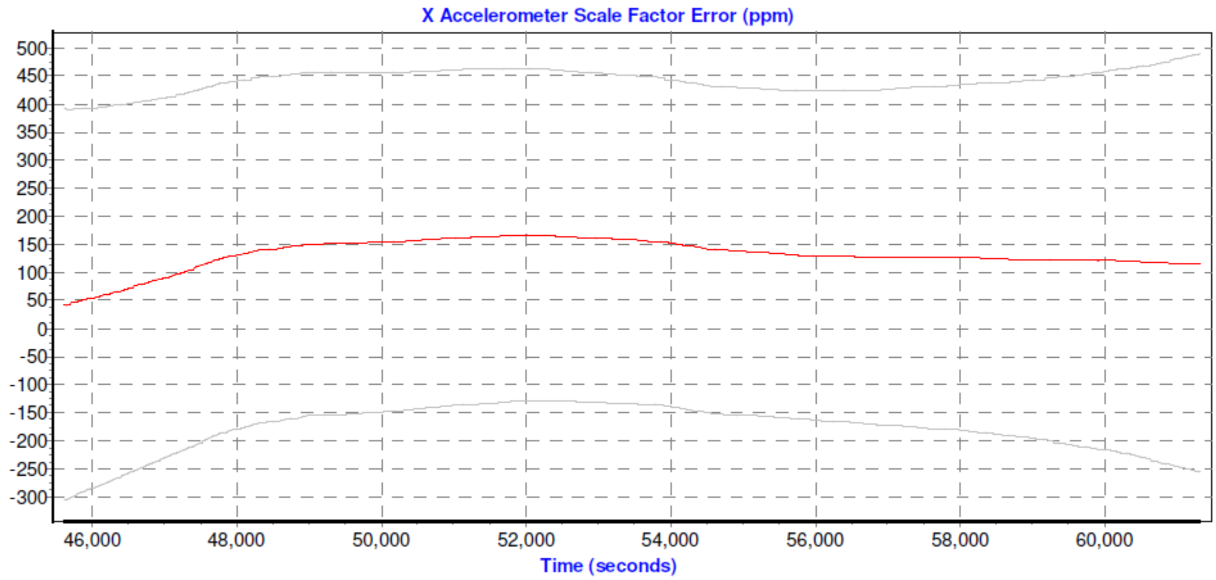
Sensor Errors

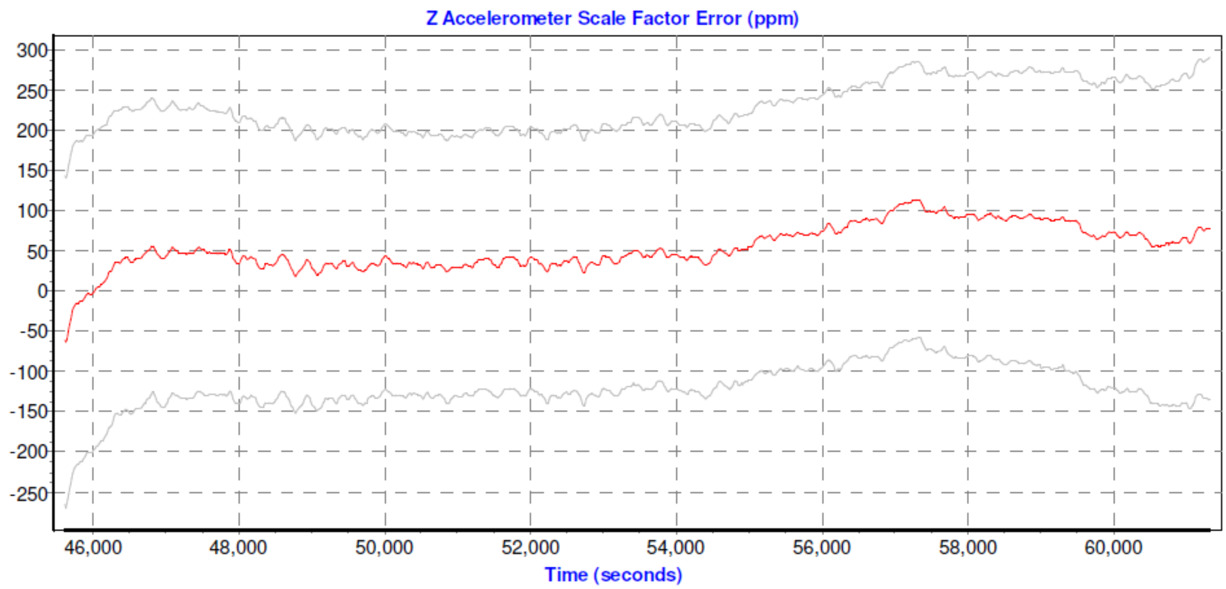


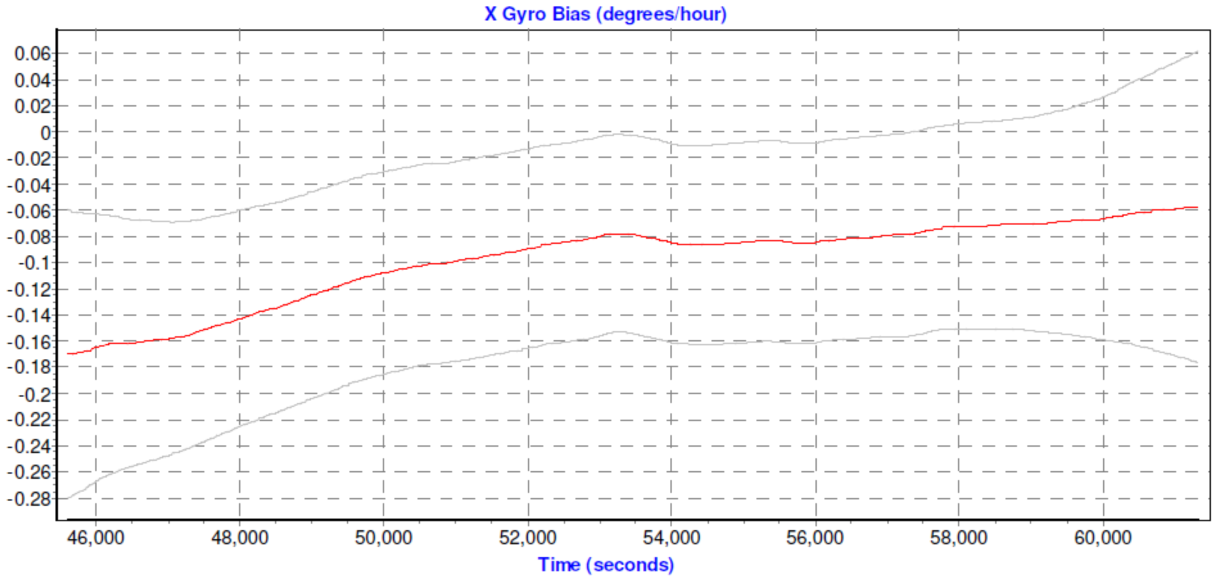


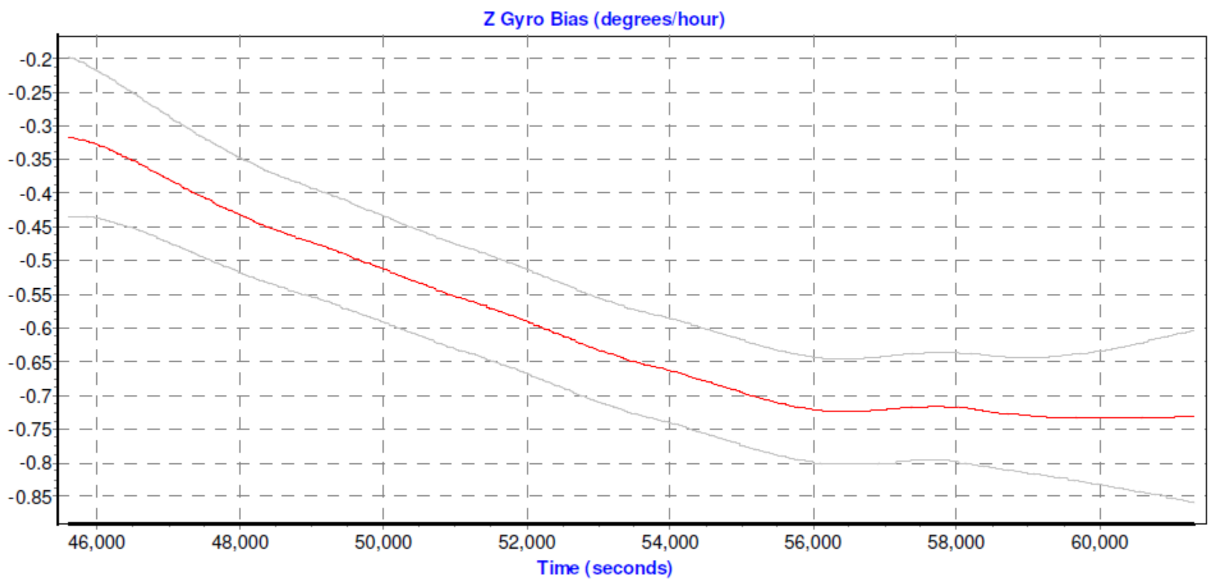

Y Accelerometer Scale Factor Error (ppm)
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)

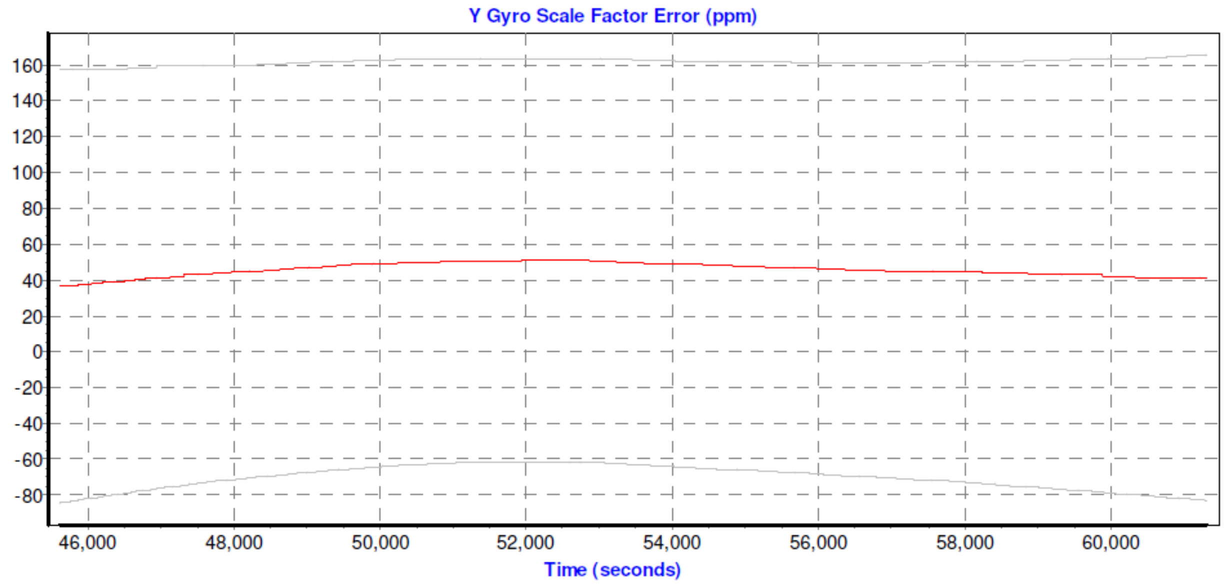

Y Accelerometer Bias (micro-g)
-220
-240
-260
-280
-300
-320
-340
-360
-380
-400
-420
-440
-460
-480
-500
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)

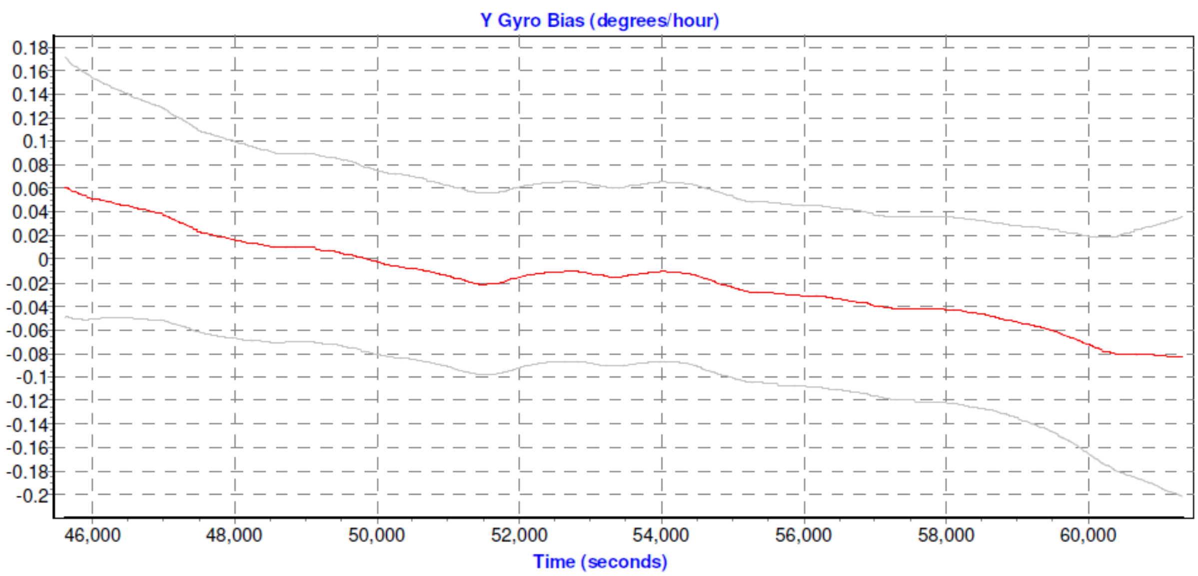

X Accelerometer Scale Factor Error (ppm)
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)

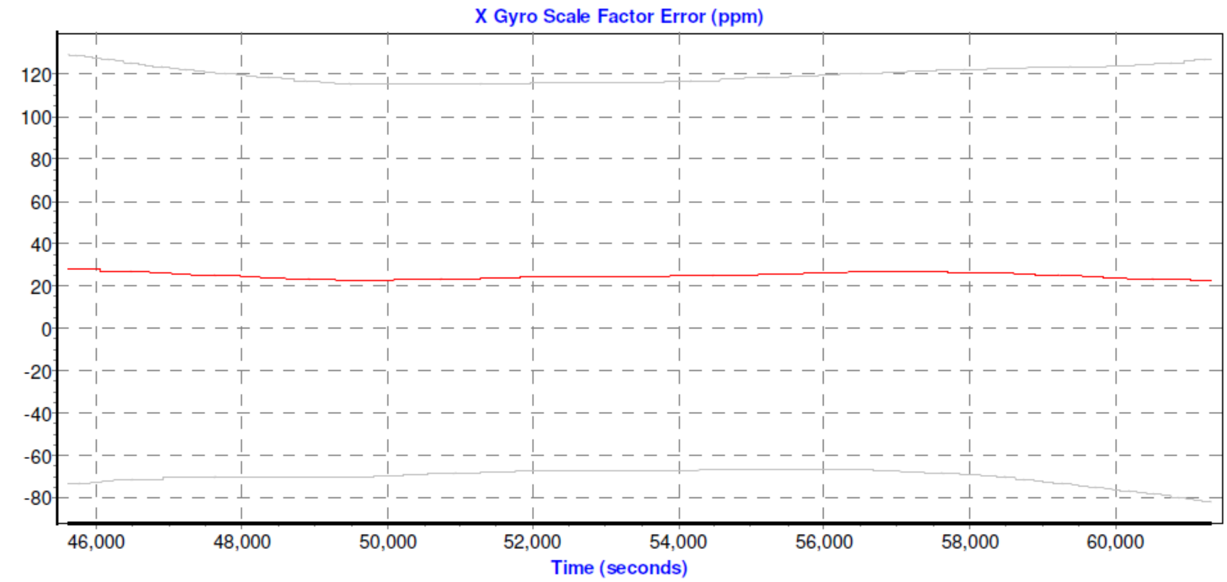

Z Accelerometer Scale Factor Error (ppm)
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)

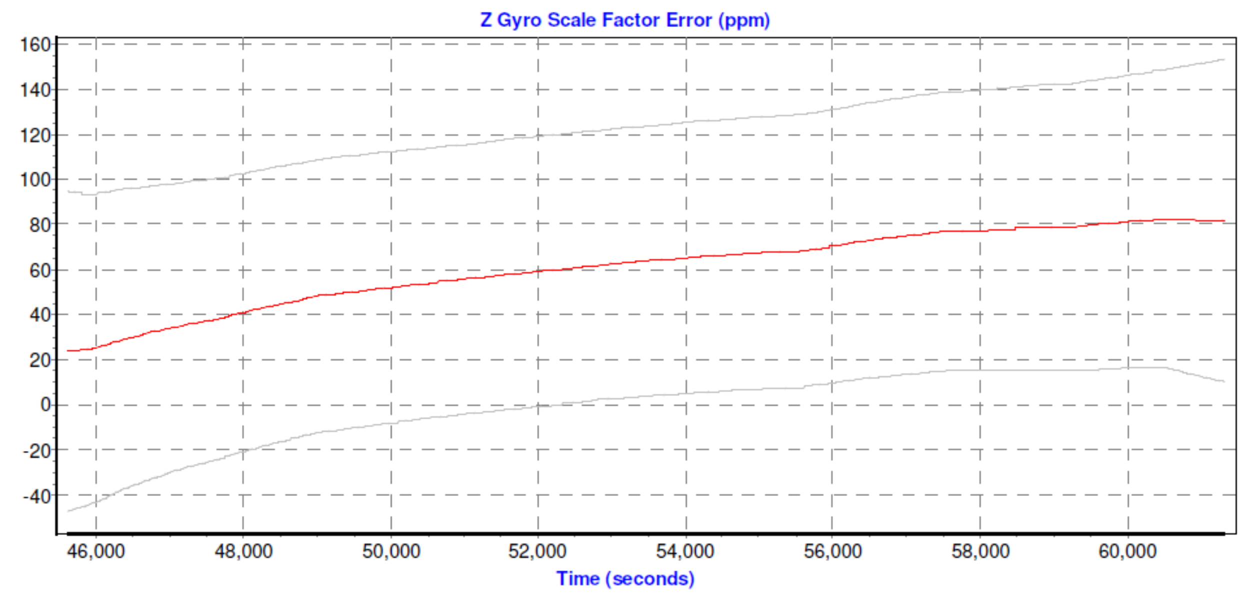

X Gyro Bias (degrees/hour)
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
-0.22
-0.24
-0.26
-0.28
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)


Z Gyro Bias (degrees/hour)
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
-0.55
-0.6
-0.65
-0.7
-0.75
-0.8
-0.85
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)


Y Gyro Scale Factor Error (ppm)
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)


Y Gyro Bias (degrees/hour)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)


X Gyro Scale Factor Error (ppm)
120
100
80
60
40
20
0
-20
-40
-60
-80
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)


Z Gyro Scale Factor Error (ppm)
160
140
120
100
80
60
40
20
0
-20
-40
46,000
48,000
50,000
52,000
54,000
56,000
58,000
60,000
Time (seconds)