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South Dakota Missouri River Lidar Project

Report Produced for U.S. Geological Survey

USGS Contract: G16PC00020

Task Order: G16PD00482

Report Date: 05\18\2018

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the South Dakota Missouri River Lidar project area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 2,000 m by 2,000 m. A total of 5,489 tiles were produced for the project encompassing an area of approximately 8,104 sq. miles.

THE PROJECT TEAM

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

Dewberry's Gary D. Simpson completed ground surveying for the project and delivered surveyed checkpoints and ground control points. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model.

He also acquired ground control points to use in the processing and calibration of the raw point cloud. Please see the separate Survey Reports included in the final deliverables.

Harris Corporation (Harris) completed lidar data acquisition and data calibration for the project area. Harris also surveyed ground control points for using in processing and calibration of the raw point cloud.

SURVEY AREA

The project area addressed by this report falls within the South Dakota counties of Campbell, Walworth, Potter, Sully, Stanley, Hughes, Hyde and Hand.

DATE OF SURVEY

The lidar aerial acquisition was conducted from May 28, 2016 and June 29, 2016.

COORDINATE REFERENCE SYSTEM

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

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 14
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the South Dakota Missouri River Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **8.0 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 **15.6 cm**, compared with the 19.6 cm specification.

For the South Dakota Missouri River Lidar Project, the tested VVA of the classified lidar data computed using the 95th percentile was equal to **44.7 cm,** compared with the 29.4 cm specification.

Additional accuracy information and statistics for the classified lidar data, raw point cloud data, and bare earth DEM data are found in the following sections of this report.

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Reflective Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (ESRI GDB)
5. Independent Survey Checkpoint Data (Report, Photos, & Points)
6. Calibration Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents, Including a shapefile derived from the lidar deliverable

PROJECT TILING FOOTPRINT

Five thousand four hundred eighty nine (5,489) tiles were delivered for the project. Each tile's extent is 2,000 meters by 2,000 meters.

Figure 1 - Project Map

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Harris Corporation of Melbourne, Florida. Harris Corporation was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

The lidar survey was conducted between May 28, 2016 and June 29, 2016.
Dewberry received final calibrated point cloud data from Harris between March 2017 and June 2017

LIDAR ACQUISITION DETAILS

Harris Corporation planned 183 passes within 6 planned bricks for the entire project area as a series of parallel East to West flight lines. The flight plan included zigzag flight line collection <70 nautical miles in length 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, Harris Corporation followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Harris' custom Mission Planner 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, Harris Corporation will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Harris Corporation 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. Harris Corporation accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

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

Harris GmAPD LiDAR sensors are calibrated after every system integration effort at one of our designated sites located throughout the United States. Sites include Bridgewater Air Park (Bridgewater, VA), Concord Regional Airport (Concord, NC), Gatlinburg-Pigeon Forge Regional Airport (Sevierville, TN), Harris Corporation ((2) Melbourne & Palm Bay, Florida), Kenosha Regional Airport (Kenosha, WI), Montgomery Field Airport (San Diego, CA), and Westside Elementary School (Thermal, CA) that have been professionally surveyed and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Harris Corporation operated a Beechcraft King Air 200 (Tail #(s) N40R and N49R) outfitted with the Harris GmAPD LiDAR system during the collection of the entire study area. Table 1 illustrates the Harris GmAPD system parameters for lidar acquisition on this project.

Item	Parameter
System	Harris GmAPD Mapping LiDAR Sensor
Altitude (AGL meters)	7620
Approx. Flight Speed (knots)	240
Scanner Pulse Rate (kHz)	50
Scan Frequency (hz)	17.7
Pulse Duration of the Scanner (nanoseconds)	0.46
Pulse Width of the Scanner (m)	0.138
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.05
Nominal Swath Width on the Ground (m)	3810
Swath Overlap (%)	55
Total Sensor Scan Angle (degree)	15
Computed Down Track spacing (m) per beam	N/A
Computed Cross Track Spacing (m) per beam	N/A
Nominal Pulse Spacing (single swath), (m)	0.5
Nominal Pulse Density (single swath) (ppsm), (m)	4
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.35
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	8
Maximum Number of Returns per Pulse	1 per detector (4096 detectors)

Table 1: Harris lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

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

Figure 2 shows the combined trajectory of the flightlines.

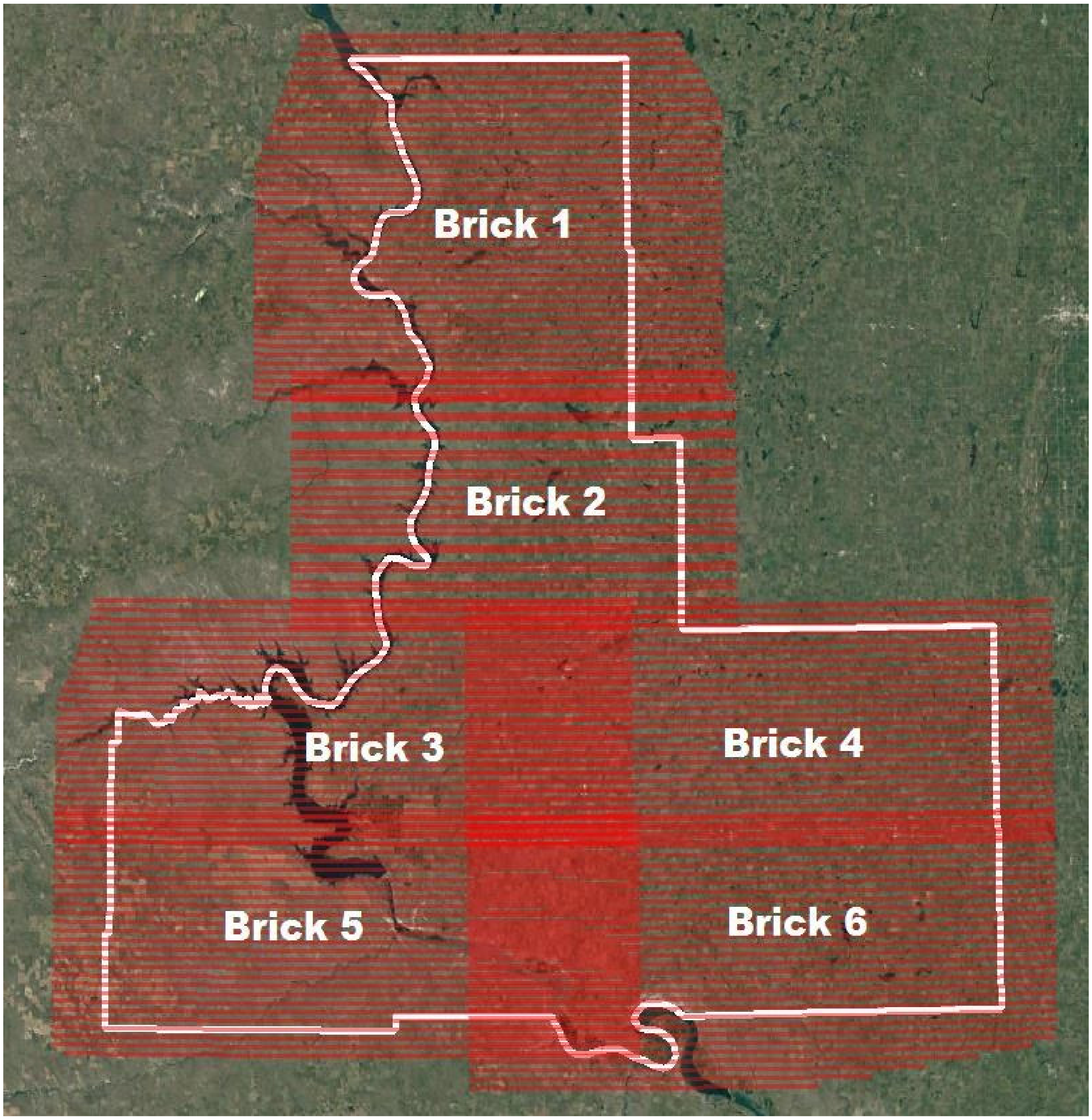
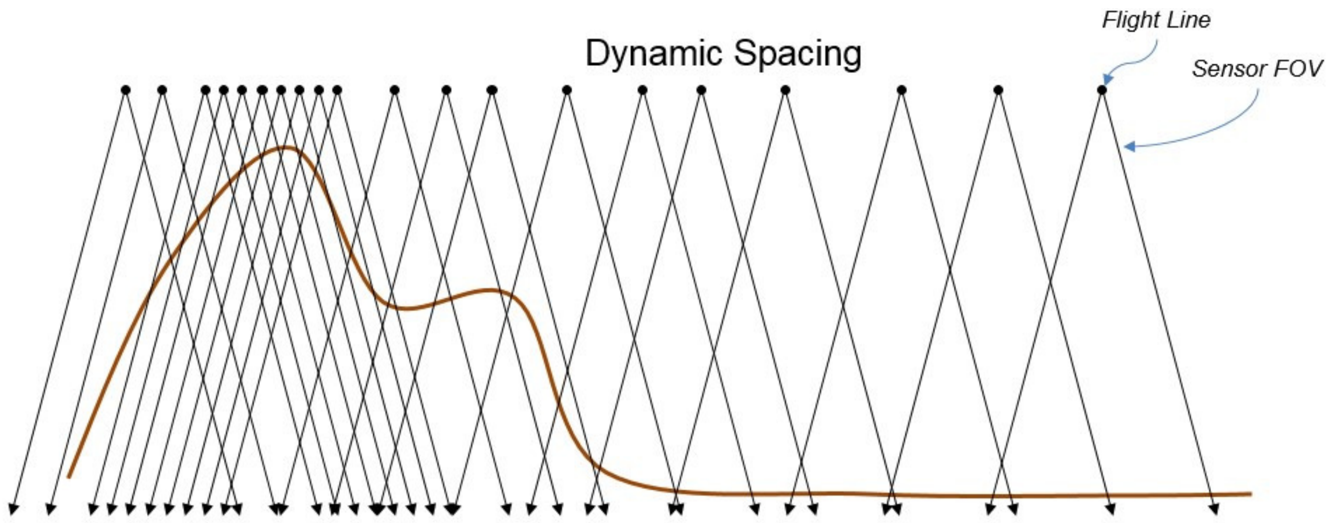


Figure 2: Trajectories as flown by Harris

Brick 2 in the above figure has a non-uniform flight line spacing pattern, but the spacing still ensures double coverage over the area. Flight line spacing is automatically determined by a dynamic flight line spacing algorithm. This algorithm uses low resolution reference elevation data to determine the minimal number of flight lines required to achieve double coverage at all elevations within a brick. Flight line to flight line spacing can change and be non-uniform due to terrain variation and the nature of the algorithm implementation, with the resulting plan ensuring that all areas of ground have at least double swath coverage.



LIDAR CONTROL

Nine existing NGS monuments and one hundred sixty-three newly established base stations were used to control the lidar acquisition for the South Dakota Missouri River Lidar project area.
All calibration points are also provided in shapefile format as part of the final deliverables.

Noted NGS monuments listed in the NSRS database. All positional values were within the 5 cm parameters.

	Observed Values			Data Sheet Values					
PT. #	NORTHING	EASTING	ELEVS.	NORTHING	EASTING	ELEVS.	Δ X	Δ Y	Δ Z
14 165.01	4881254.318	321650.493	585.643	4,881,254.368	321,650.511	585.6	0.050	0.018	-0.043
I90 228.4	4860915.485	419142.545	545.163	4,860,915.570	419,142.568	545.129	0.085	0.023	-0.034
L 463	4929245.929	419778.082	530.351	4,929,245.943	419,778.089	530.355	0.014	0.007	0.004
34 318.6	4879486.026	543858.237	425.944	4,879,486.019	543,858.243	426.0	-0.007	0.006	0.056
D 470	4983284.107	424333.706	628.889	4,983,284.109	424,333.714	628.871	0.002	0.008	-0.018
281 163.91	4985349.570	538346.019	394.481	4,985,349.582	538,346.032	394.483	0.012	0.013	0.002
12 243.45	5032877.015	466136.295	557.683	5,032,876.977	466,136.255	557.717	-0.038	-0.040	0.034
20 182.96	5036951.738	368669.234	660.554	5,036,951.763	368,669.251	660.558	0.025	0.017	0.004
FORT YATES DISCOVERY II	5105263.498	373675.687	495.974	5,105,263.551	373,675.682	496.0	0.053	-0.005	0.026

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data were processed using the PosPac kinematic Mobile Mapping Suite 8.0 software suite. A majority of flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP 3 or less. Distances from base station to aircraft were kept to a maximum of 40 km.

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

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

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.

Swath footprints are generated and displayed to confirm complete two swath minimum coverage (see Figure 3) and associated waterfall displays (captured for each sortie in Appendix B) are reviewed to confirm that there are no cloud obscurations.

Data collected is reviewed for completeness, acceptable coverage and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information logs, and ground control files are reviewed.

After product generation, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

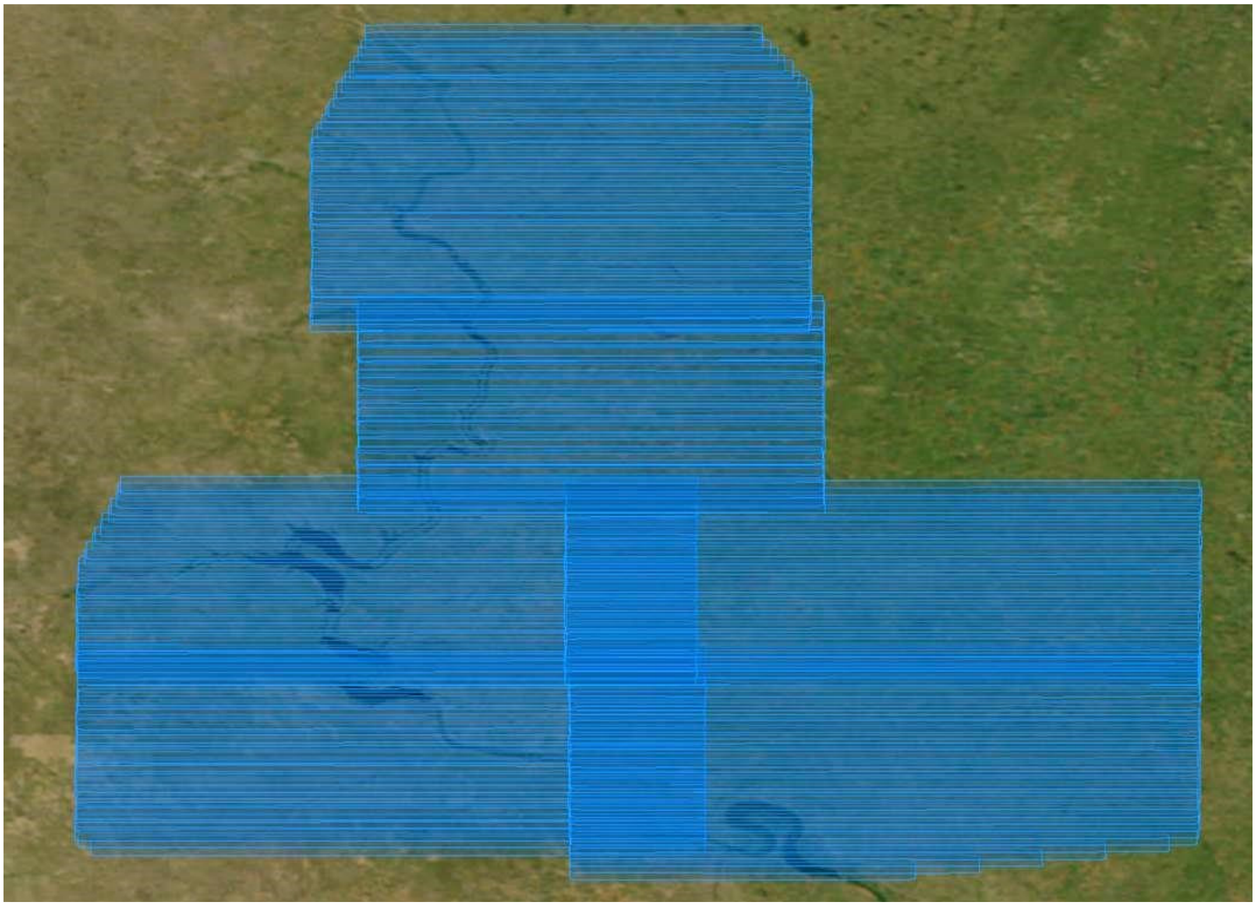


Figure 3 – Lidar swath output showing complete coverage.

CAMERA CALIBRATION, RELATIVE AND ABSOLUTE ACCURACY

Camera boresight angles are calibrated using surveyed calibration sites prior to collection. Orthogonal swaths at multiple altitudes are flown, sbets generated, and resulting point cloud data registered to find the swath to swath correspondences. The correspondences are used in a bundle adjustment minimization process to determine x, y and z boresight angles for the specific sensor. Swaths are then viewed and measured for relative offsets and compared to the calibration site ground control. The relative calibration is then adjusted to ground control to achieve a final camera calibration solution.

For the project flights, sbets are generated using Applanix recommended best practices, and in conjunction with the camera calibration, an initial transformation is performed for each swath, forward and aft looks, to generate initial point clouds.

The project is subdivided into blocks, with blocks grouped into ten separate registration sections. Figure 4 shows the logical blocks for the project with each registration section consisting of the following blocks:

Registration Section 1: Blocks 1, 2, 3 and 4
Registration Section 2: Blocks 5, 6 and 7
Registration Section 3: Blocks 8 and 9
Registration Section 4: Blocks 10 and 11
Registration Section 5: Blocks 12 and 13
Registration Section 6: Blocks 14 and 15
Registration Section 7: Blocks 16 and 17
Registration Section 8: Blocks 18 and 19
Registration Section 9: Blocks 20 and 21
Registration Section 10: Blocks 22 and 23

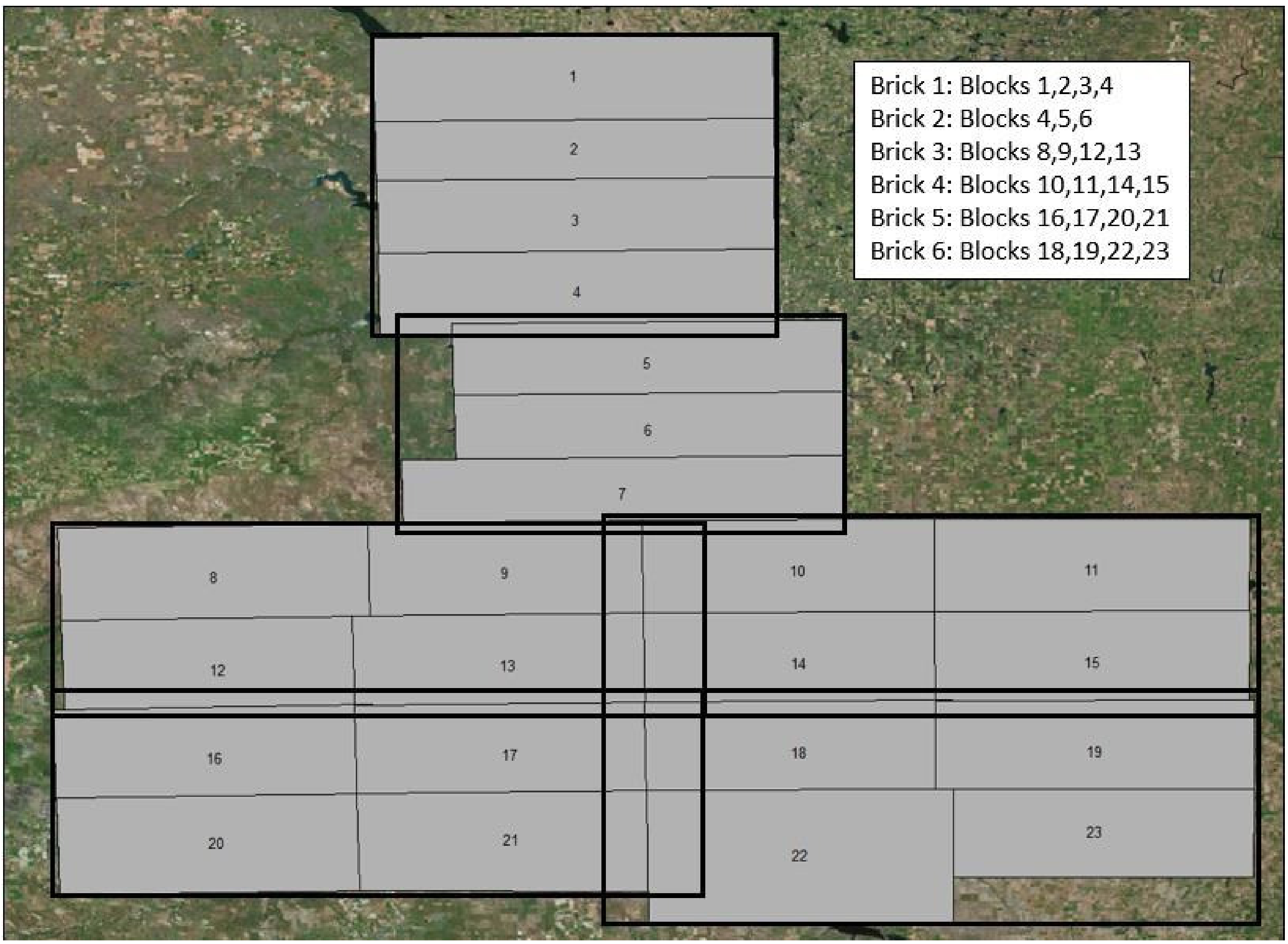


Figure 4-Registration sections for the project.

For each registration section, point clouds from each swath are matched to other swaths using every fourth processing tile (5x5 arc second tiles). Correspondences are used to perform a bundle adjustment on the trajectory positions and attitudes to generate adjusted trajectories that best align the datasets covering the area.

Using these adjusted trajectories, the final product is generated and evaluated against the ground control for the brick. The normal process of measuring offsets of point cloud features to lidar identifiable ground control with a subsequent translation of the project to the ground control is then performed. An analysis of the fit to ground control is then performed, along with an analysis of the fit of a registration section with the neighboring sections. A list of the ground control (GCPs) used for this project is shown in Table 3.

The final adjusted product is delivered to Dewberry. Dewberry uses independent ground check points to establish the final accuracy for the product.

2017 SOUTH DAKOTA GCP RECOLLECTION			
POINT #	NORTHING (m)	EASTING (m)	ELEV. (m)
GCP-001	5076989.666	417169.109	518.004
GCP-002	5090456.582	385300.295	502.467
GCP-003	5090456.576	385300.309	502.401
GCP-004	5070773.665	445860.414	572.716
GCP-005	5080277.120	445870.148	557.672
GCP-006	5091199.203	414028.776	555.717
GCP-007	5073898.217	413825.728	511.663
GCP-008	5072406.005	384995.968	614.001
GCP-009	5079059.933	386693.885	608.691
GCP-010	5064190.862	416853.427	525.334
GCP-011	5064513.817	384288.423	566.762
GCP-012	5054925.806	381108.377	497.970
GCP-013	5055710.887	416703.793	520.108
GCP-014	5058689.207	443685.077	542.821
GCP-015	5046363.342	382598.403	543.340
GCP-016	5049473.804	418205.766	521.830
GCP-017	5038980.490	418907.680	569.260
GCP-018	5037452.281	443152.875	616.055
GCP-019	5037635.266	382957.178	549.216
GCP-020	5026396.744	386812.328	494.878
GCP-021	5020876.252	380596.475	501.387
GCP-022	5029675.242	418762.376	600.856
GCP-023	5033092.448	446892.380	604.627
GCP-024	5020588.636	412176.571	544.801
GCP-025	5020365.152	444711.083	581.503
GCP-026	5019971.983	458959.285	559.137

GCP-027	5013604.865	457260.931	583.950
GCP-030	N/A	N/A	N/A
GCP-031	5005816.783	426263.386	595.715
GCP-032	5005529.059	458191.296	577.587
GCP-033	4993622.705	403577.702	554.357
GCP-034	4986600.625	397857.111	498.710
GCP-036	4974018.110	398395.715	546.969
GCP-037	4970165.346	325910.355	603.972
GCP-038	4974710.699	341546.159	538.441
GCP-039	4974163.772	425880.596	601.121
GCP-041	4988470.475	424316.007	668.731
GCP-042	4997764.035	426144.500	597.927
GCP-043	4995864.444	453062.607	589.070
GCP-044	4989439.795	453291.741	598.553
GCP-045	4982949.239	459591.889	582.556
GCP-046	4974829.037	456841.119	604.183
GCP-047	4971526.637	475369.735	598.463
GCP-048	4964916.008	497109.250	461.071
GCP-049	4971559.870	526663.848	399.712
GCP-050	4960500.760	525730.262	402.866
GCP-051	4953632.817	523299.164	417.523
GCP-052	4971529.425	500446.312	451.218
GCP-053	4957783.870	425676.120	564.915
GCP-054	4959759.097	395186.598	557.540
GCP-055	4951141.481	324554.532	505.763
GCP-056	N/A	N/A	N/A
GCP-057	4951262.865	395946.088	560.599
GCP-058	4952680.078	492908.128	478.572
GCP-059	4940731.101	524856.261	423.051
GCP-060	4940721.957	500867.361	455.237
GCP-061	4941651.035	401304.488	538.876
GCP-062	4942680.064	356887.438	621.229
GCP-063	4941910.752	330610.097	624.114
GCP-064	4928443.762	330239.698	688.066
GCP-065	4928874.311	392624.458	519.913
GCP-066	4930755.801	500608.030	476.594
GCP-067	4932719.427	523358.977	429.268
GCP-069	4911466.929	523792.657	447.431
GCP-070	4911211.148	458514.577	631.634
GCP-072	4908401.549	348665.424	601.552

GCP-073	4919235.980	329954.654	635.412
GCP-074	4901649.567	330124.887	631.319
GCP-075	4888181.239	329386.953	630.878
GCP-077	4899190.363	393328.841	556.223
GCP-077A	4899190.234	393329.022	556.201
GCP-077B	4899173.416	393329.106	555.501
GCP-078	4890801.886	355744.503	511.110
GCP-079	4901807.722	496454.851	552.203
GCP-080	4891915.318	496679.586	522.009
GCP-081	4891944.596	515711.815	575.445
GCP-082	4900216.749	524965.973	481.566
GCP-083	5062003.260	445755.120	570.269
GCP-084	5047493.529	446841.467	548.865
GCP-085	4977983.017	378018.614	530.464
GCP-087	4951501.550	375633.022	540.730
GCP-088	4966798.787	443820.535	575.198
GCP-089	N/A	N/A	N/A
GCP-090	4965534.744	473754.526	564.500
GCP-091	4950919.950	426685.540	550.665
GCP-092	4954585.003	452957.521	552.003
GCP-093	4958274.573	370054.393	498.229
GCP-094	4915292.144	353801.714	573.598
GCP-095	4931693.890	384593.575	493.335
GCP-096	4930793.795	427875.307	505.138
GCP-097	4941213.805	431609.645	527.926
GCP-098	4942437.064	451240.603	532.431
GCP-099	4930576.546	451616.002	543.217
GCP-100	4930635.041	475608.062	538.506
GCP-101	4921072.465	501342.138	523.337
GCP-102	4943351.519	470404.836	507.374
GCP-106	4911811.632	390597.778	440.189
GCP-108	4922816.304	422550.263	496.909
GCP-109	4919368.233	442616.852	591.622
GCP-110	4920891.306	472851.422	590.510
GCP-111	4909858.015	501288.949	578.204
GCP-112	4912028.779	471211.814	600.780
GCP-113	N/A	N/A	N/A
GCP-114	4903973.820	449398.570	604.668
GCP-115	4880672.070	451384.482	545.055
GCP-116	4880302.326	430648.040	529.398

GCP-117	4888354.196	425416.544	438.065
GCP-118	4897405.491	425714.273	448.087
GCP-119	4889624.598	392099.980	611.402
GCP-120	4890195.587	373371.771	596.669
GCP-121	4903175.602	377421.683	468.713
GCP-122	4911100.837	330382.540	621.261
GCP-123	4968717.287	358219.518	603.112
GCP-124	4904317.730	425733.791	447.394
GCP-126	4899999.596	476091.553	566.989
GCP-127	4989032.291	382880.916	496.867
GCP-128	5013812.030	394087.055	562.294
GCP-129	4951094.190	414391.695	568.873
GCP-130	4957265.879	349185.896	498.458
GCP-131	4908142.674	386796.339	452.450
GCP-132	4907400.522	414840.411	445.023
GCP-133	4894155.073	407558.672	544.097
GCP-134	4901881.600	367773.440	486.208
GCP-135	4898416.621	346548.200	620.278
GCP-136	4938018.761	352536.399	575.747
GCP-137	4918986.907	379315.604	553.325
GCP-138	4894229.856	464704.076	523.667
GCP-139	4891381.930	442820.625	437.438
GCP-140	4920912.110	404169.044	530.533
GCP-141	4931852.931	364349.482	539.476
GCP-142	4941856.555	377293.956	547.302
GCP-143	4964633.363	426422.468	557.526
2017 Brick 6 Alternate Points			
A-079	4901741.077	496526.797	547.517
A-080	4892759.273	496290.769	523.008
A-081	4891957.137	516925.810	584.919
A-110	4920920.260	473679.957	588.550
A-113	4882005.385	468960.668	453.134
A-114	4901971.349	457090.071	591.780
A-116	4880296.737	430678.507	531.591
A-118	4898051.011	425697.873	438.752
A-126	4891849.672	479740.439	510.157
2017 Brick 6 Additional Points			
N-065	4911571.318	445531.462	589.660
N-066	4904348.459	435671.296	512.765
N-601	4922785.616	523434.247	426.837

N-603	4897747.334	486803.121	563.302
N-604	4919234.187	458406.626	602.838
N-606	4922735.975	482812.027	617.853
N-607	4918591.072	509233.760	533.801
N-608	4912591.031	523742.109	448.889
N-609	4927619.979	526120.153	436.308
N-611	4922752.004	501312.162	509.576
N-613	4916274.827	490132.058	590.333
N-615	4930736.517	483480.051	519.679
N-617	4929927.613	464903.144	575.001
N-619	4926965.168	461677.982	557.502
N-621	4929925.345	441238.260	555.806
N-628	4916235.455	435401.471	538.031
N-629	4929124.392	510248.969	455.661
N-630	4900143.883	512974.375	561.065
N-632	4904962.918	485690.775	587.075
N-634	4903261.658	472908.046	569.209
N-637	4891885.972	454608.074	438.181
N-638	4900161.962	505760.614	560.485
N-663	4891827.401	526092.391	562.106

Table 3: Harris Ground Control Points

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

Once Dewberry receives the calibrated point cloud data from the acquisition provider, Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the unclassified data, intra-swath (within a single swath) relative accuracy validation, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Raw Vertical Accuracy Assessment

Once Dewberry received the calibrated point cloud data from Harris Corporation (Harris), Dewberry tested the vertical accuracy of the non-vegetated terrain point cloud data prior to additional processing. Dewberry tested the vertical accuracy of the unclassified data using the one hundred seventy (170) 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 unclassified points. Only checkpoints in non-vegetated terrain can be tested against unclassified 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 unclassified 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 South Dakota Missouri River Lidar Project satisfies this criteria. This unclassified lidar 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 $RMSE_z$ = 8.0 cm, equating to +/- 15.7 cm at 95% confidence level. The table below shows all calculated statistics for the unclassified data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	170	0.080	0.157	0.042	0.035	0.200	0.069	-0.105	0.238	-0.316

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

Point Removed from Swath Vertical Accuracy Assessment

One point was removed from the final unclassified vertical accuracy assessment. The point is shown below in table 5. NVA-85 was removed because a car was on top of the accuracy checkpoint, interfering with the calculation. A profile view of this point can be seen in figure 5.

Point ID	NAD83 (2011) UTM Zone 14N		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
NVA-085	398256.819	4984630.760	517.020	517.542	0.522	0.522

Table 5: NVA-085 coordinates and deltaZ.

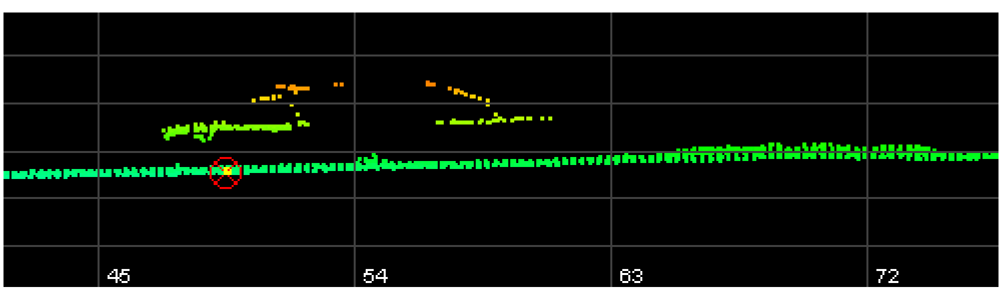


Figure 5: The figure shows NVA-085's location under a car.

Inter-Swath (Between Swath) Relative Accuracy

The South Dakota Missouri River Lidar project was collected using a Geiger-Mode lidar sensor. Geiger mode sensors do not collect data in "swaths" so inter-swath relative accuracy does not apply to this dataset.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The intra-swath relative accuracy of South Dakota Missouri River Lidar project met intra-swath relative accuracy specifications.

Horizontal Uncertainty on Vertical Features

There is a certain amount of horizontal uncertainty on vertical objects that can be observed in the lidar data. This uncertainty manifests itself in two ways. The first is that vertical walls will have a width of approximately 25 cm when measured. This width along the walls is a function of the collection system and is based on the relationship between the flying height and the IFOV of the sensor. The end result is that since this project was flown at 25,000 feet an observed uncertainty of 25 cm is expected. The second way that the horizontal uncertainty can be observed is along the very top and bottom of the feature. This point spread is a function of the noise filter applied to the data. For this project the point spread along the top and bottom of the feature is approximately 2 feet. Currently there is no way to automatically detect and classify these points as noise. As a result they remain as class 1 (unclassified).

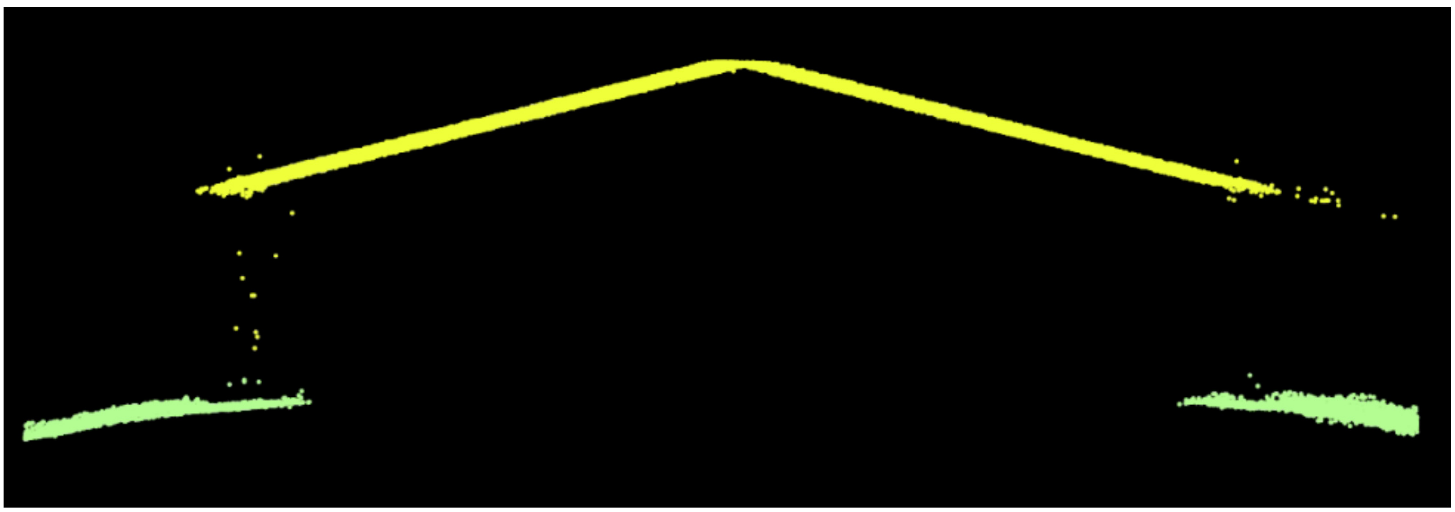


Figure 6– Point spread visible along the edge of the wall and along the overhang. Note points extending beyond the roofline to the east and west. This is also present on the ground points under the roofline.

Point Density and Spatial Distribution

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 and generating density grids, the project area was determined to meet all density requirements.

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

DATA CLASSIFICATION AND EDITING

Once the calibration, unclassified vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. The ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

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

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

The lidar tiles were classified to the following classification schema:

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

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

Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the reflectance values, 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 South Dakota Missouri River Lidar.

Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. No unacceptable voids are present in the South Dakota Missouri River Lidar project.

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

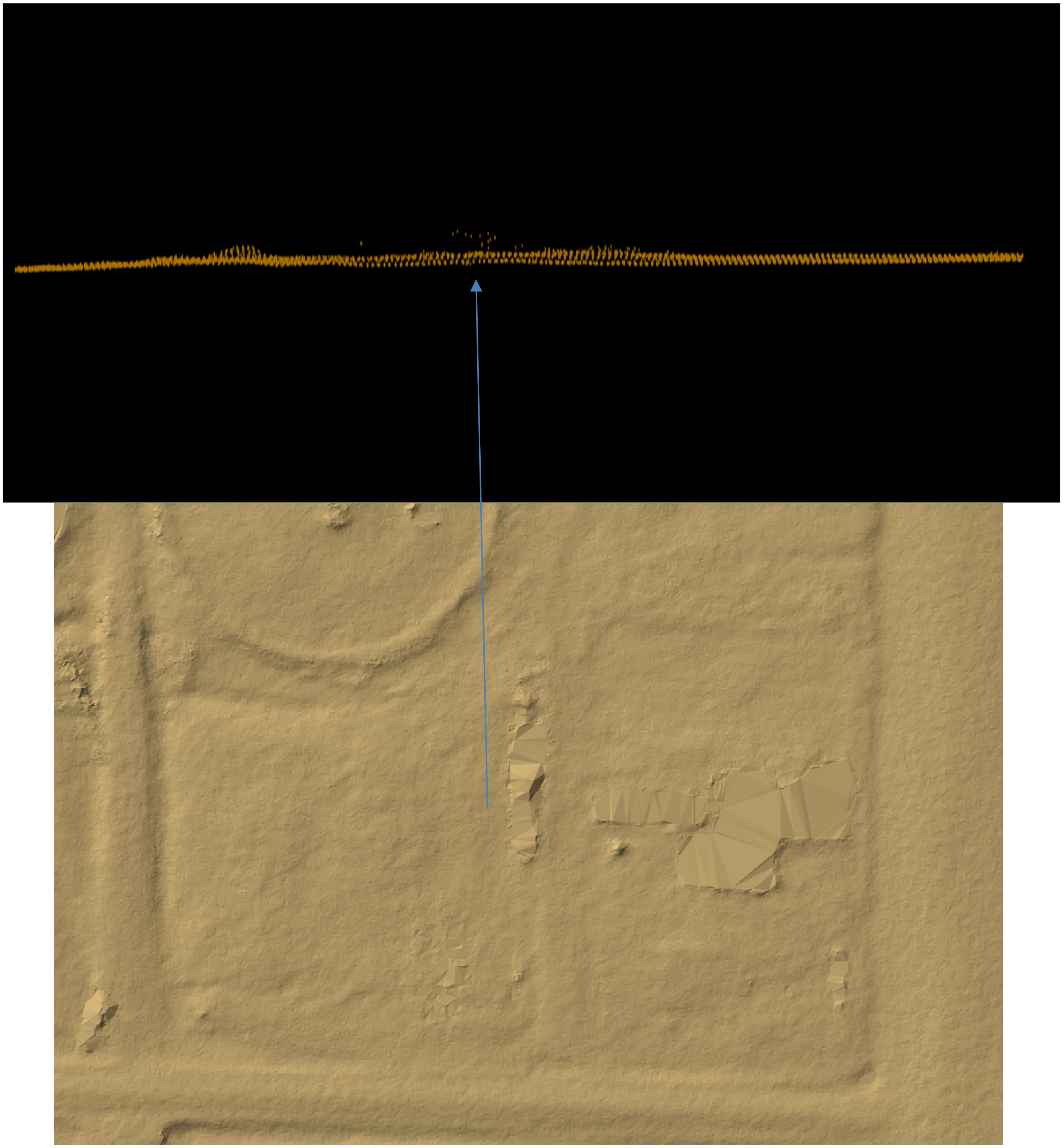


Figure 7 – Tile number 14TMQ43904930. Profile with points colored by class (class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

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

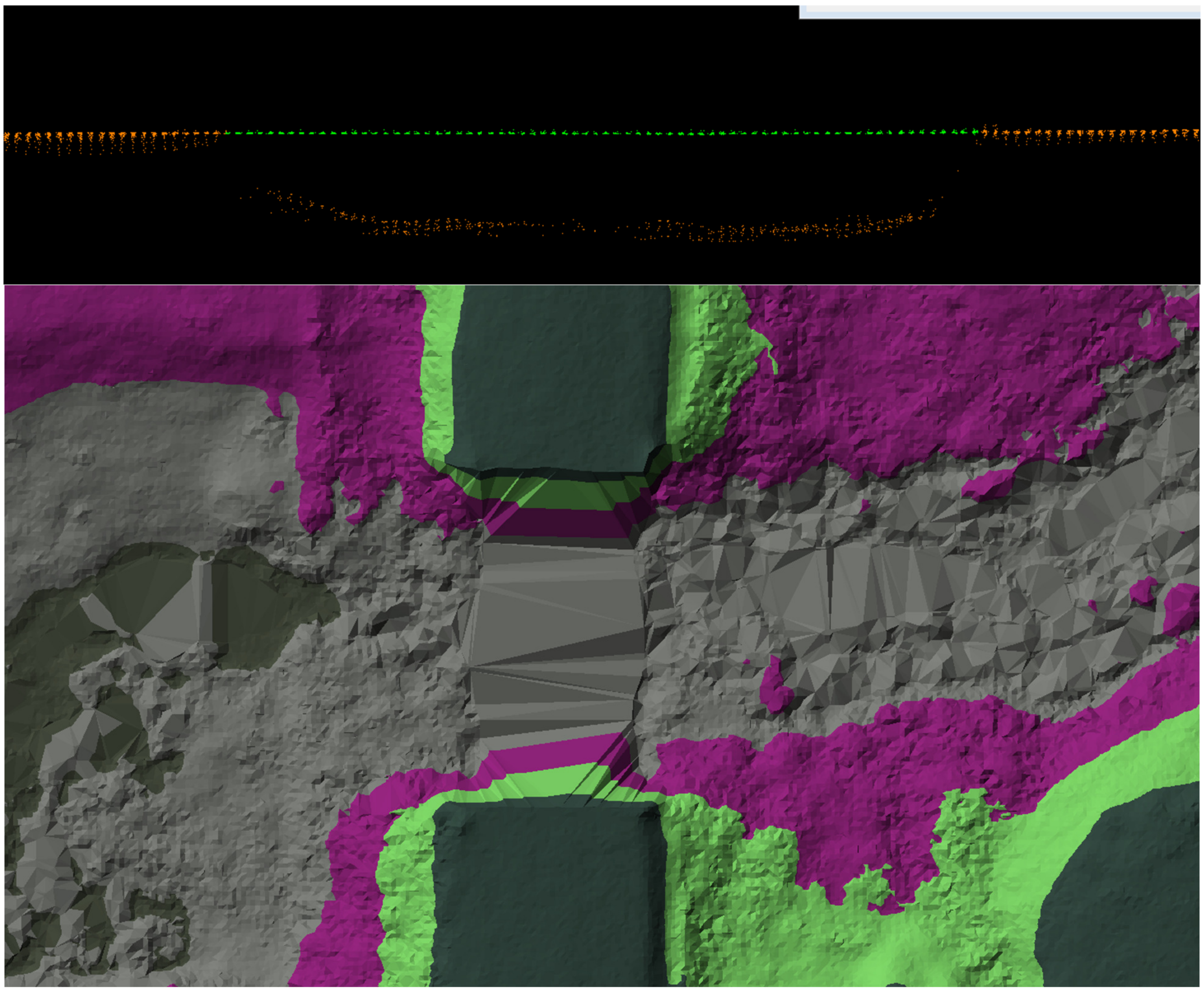


Figure 8 – Tile number 14TMQ43904928. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are classified as bridge deck (green).

Culverts and Bridges

Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

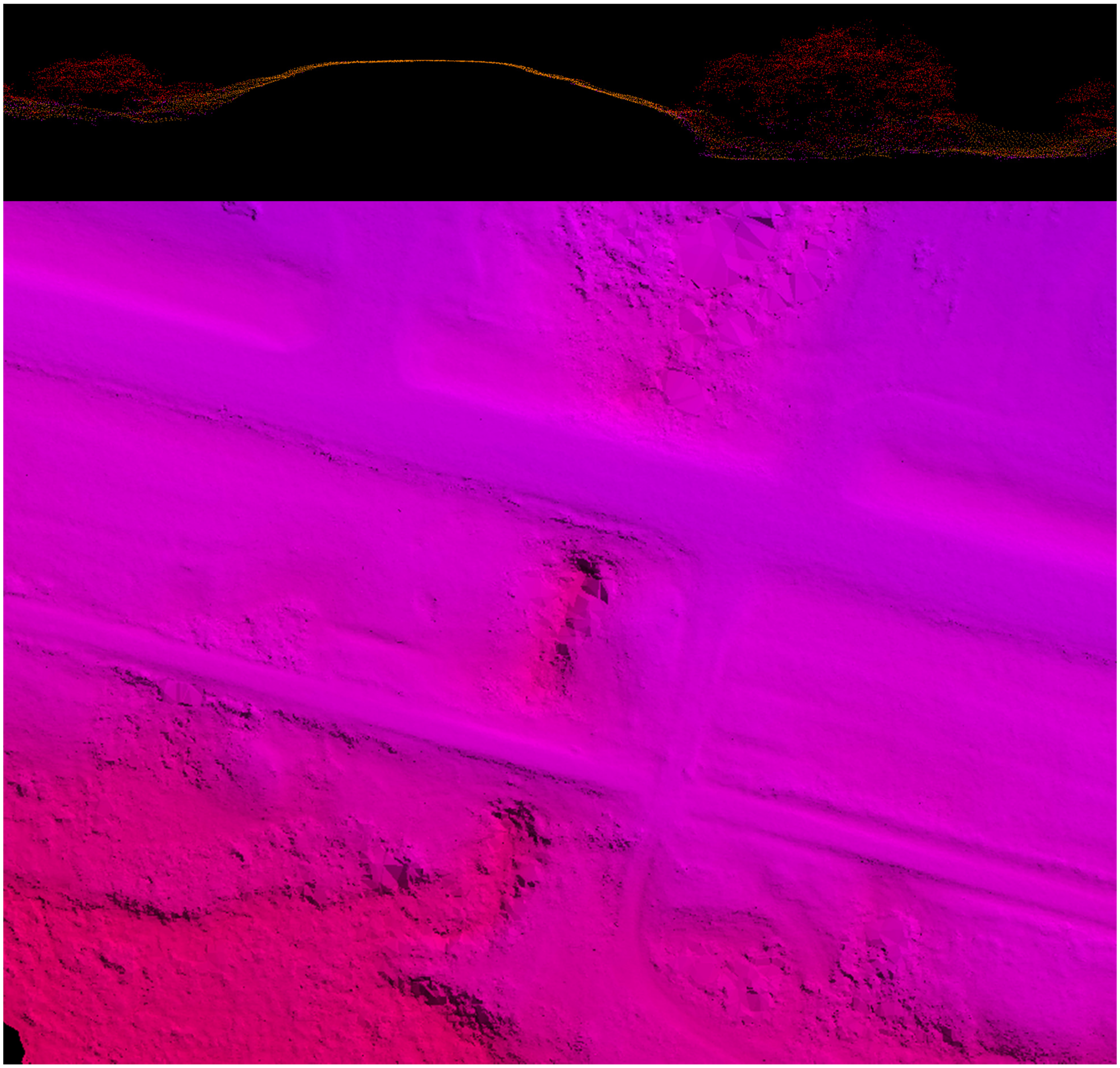


Figure 9– Tile number 14TMQ40104910. Profile with points colored by class (class 1=red, class 2=orange, class 7=purple) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Dirt Mounds

Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

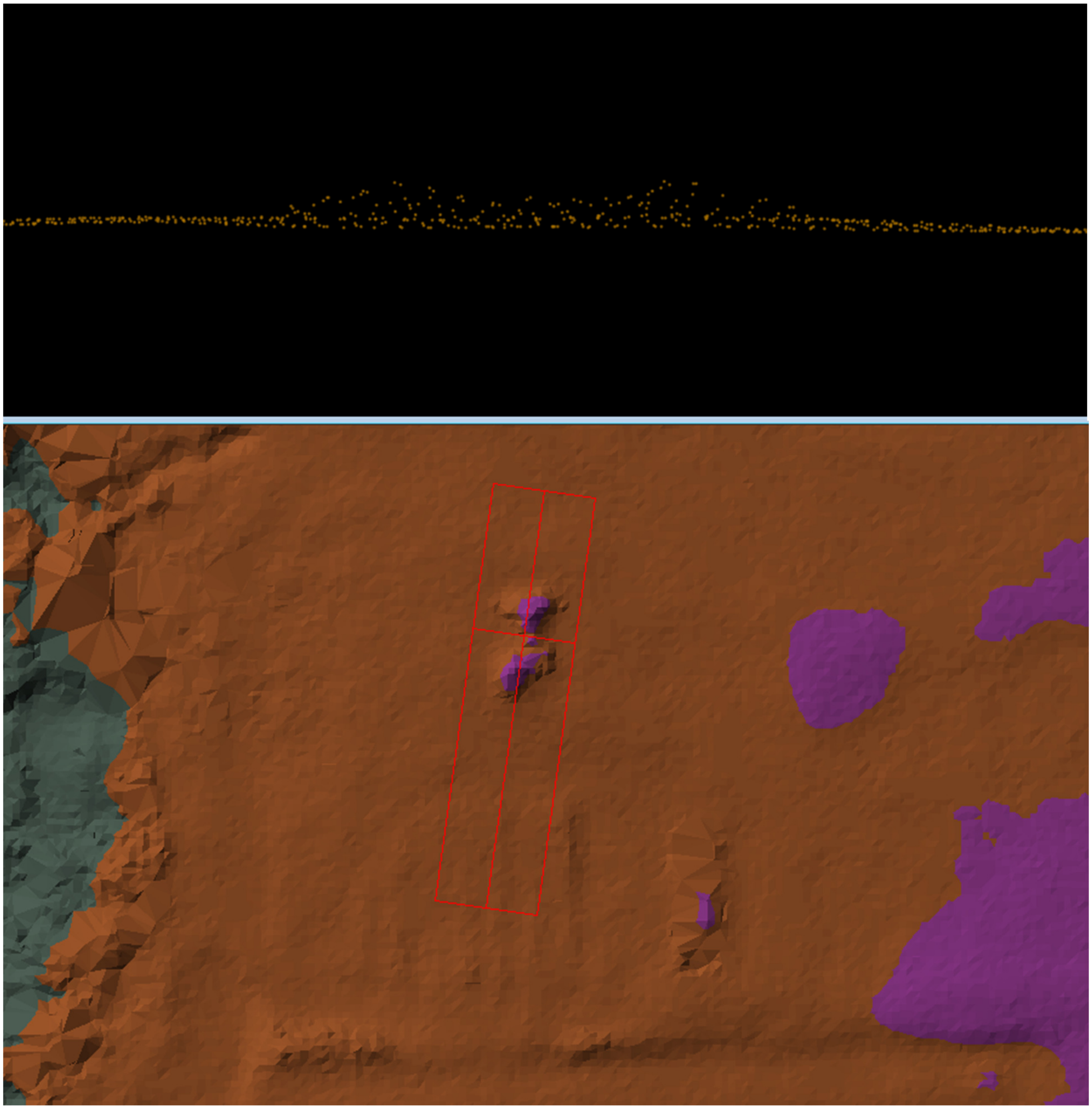


Figure 10 - Tile 14TMQ44504928. Profile with the points colored by class (class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Tile Edge Step

Calibration of the lidar for this project was performed on a block by block basis due to limitations with the process at the time of collection. This approach ensured that data between blocks matched within 8 cm based on the swath relative accuracy requirement. Every attempt was made to match calibration blocks within a zero tolerance between blocks but in some cases small offsets appear in the data. These issues were unavoidable given the current processing approach.

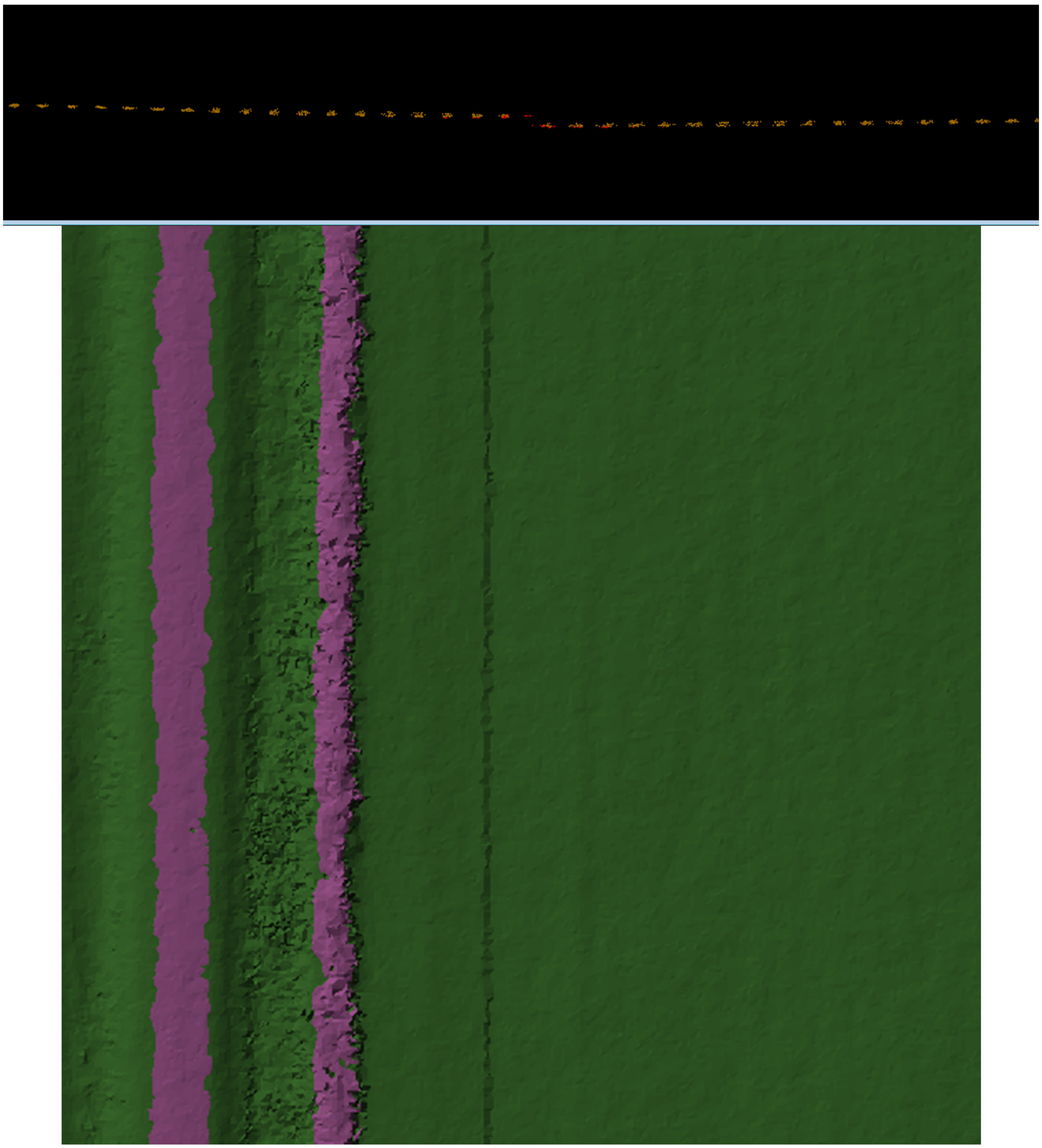


Figure 11 – 14TMQ42504930. Due to calibration limitations at the time of processing, there are some visible line artifacts in the final DEMs. Every attempt was made to limit these, but some artifacts between processing blocks do exist within the dataset. All artifacts are within the inter-swath 8 cm vertical offset limit. A visible line artifact between processing blocks is shown in the DEM in the bottom image. A profile, shown in the top image, shows the

vertical offset between adjacent point cloud data in neighboring processing blocks (ground=orange, unclassified=red).

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 14, 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	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 5: South Dakota Missouri River Lidar Formatting

There are several items within LAS headers and Point Data Records which are different for Geiger-mode lidar data compared to traditional lidar systems, including:

- The sensor is set to a forward looking 15 degree angle. The minimum and maximum scan angles in every lidar tile will be set at 15
- The Geiger-mode sensor does not collect data in contiguous swath format. Data is collected in footprints. As there are no true continuous swaths:
    i. Minimum and maximum point source IDs will be set to 0.
    ii. Minimum and maximum edge of flight line values will be set to 0.
    iii. The withheld bit is not applicable.
    iv. The overlap bit is not applicable.
- The Geiger-mode sensor does not oscillate or move and consists of a CCD array. As such:
    i. Minimum and maximum scan direction values will be set to 0.

- All returns are "first" returns. There are not multiple returns per pulse.
- The GPS timestamps may not be unique for every single lidar point.
- The intensity minimum and maximum values may also look different as these values are pseudo-intensity in that the Geiger-mode is not recording the signal strength of the lidar pulse but is recording how many measurements were observed for a location.

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. Dewberry typically uses LP360 software to test the unclassified 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 reflectance imagery. Photo-identifiable checkpoints in reflectance 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 reflectance 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, three hundred and one (301) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see the final survey deliverables 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 14		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
NVA-001	394713.226	5085428.300	518.942
NVA-002	399633.940	5083836.277	502.821
NVA-003	416562.031	5084881.901	525.823
NVA-004	437393.510	5081693.268	553.569
NVA-005	437869.660	5084644.255	600.674
NVA-006	437794.805	5074949.822	565.520
NVA-007	424765.420	5078308.383	531.233
NVA-008	416979.072	5076369.037	513.361
NVA-009	401592.484	5076136.203	594.071

NVA-010	395651.328	5072519.071	496.316
NVA-011	408841.889	5069840.456	598.764
NVA-012	416921.997	5070723.819	518.290
NVA-013	426583.289	5071871.794	551.054
NVA-014	437750.390	5068519.961	552.548
NVA-015	436092.853	5063666.818	563.121
NVA-016	416818.125	5064169.031	526.648
NVA-017	412296.863	5065673.014	554.949
NVA-018	402759.940	5062586.008	524.786
NVA-019	402243.855	5057829.410	599.428
NVA-020	391833.992	5053446.560	515.264
NVA-021	408642.303	5054452.742	564.735
NVA-022	419346.680	5057506.948	530.131
NVA-023	428041.532	5058971.000	544.910
NVA-024	439260.528	5055609.579	536.893
NVA-025	431391.122	5052476.719	535.321
NVA-026	424698.258	5051221.561	546.288
NVA-027	438333.144	5047644.683	612.774
NVA-028	431820.537	5046140.426	604.213
NVA-029	420602.741	5046282.020	529.548
NVA-030	412583.823	5046368.380	523.185
NVA-031	400553.308	5046610.704	525.286
NVA-032	386793.653	5045383.682	510.328
NVA-033	397158.659	5040201.611	504.854
NVA-034	405953.701	5037067.693	604.949
NVA-035	418850.996	5036622.810	589.118
NVA-036	430740.097	5039262.980	639.075
NVA-037	438250.290	5038560.654	652.112
NVA-038	441354.178	5031459.868	601.447
NVA-039	433300.903	5033213.391	601.749
NVA-040	423653.677	5031718.353	618.512
NVA-041	413018.531	5031868.350	593.672
NVA-042	398082.700	5033649.500	508.896
NVA-043	407718.371	5025512.226	576.693
NVA-044	418712.134	5025336.816	625.214
NVA-045	430048.625	5026811.743	628.473
NVA-046	438096.373	5025086.804	587.956
NVA-047	442844.481	5016885.600	585.527
NVA-048	434824.115	5020207.831	596.471
NVA-049	423502.140	5020867.765	586.940
NVA-050	417015.669	5020569.612	591.668
NVA-051	401999.359	5025565.687	536.463
NVA-052	400664.084	5019195.641	497.640
NVA-053	412143.610	5014151.386	580.971
NVA-054	416945.428	5010908.430	634.802

NVA-055	428279.459	5013949.252	610.351
NVA-056	438997.888	5010097.577	581.372
NVA-057	440578.499	5003264.124	588.580
NVA-058	451759.133	5005548.347	594.522
NVA-059	431403.762	5009046.813	587.763
NVA-060	421340.278	5005888.294	618.948
NVA-061	409600.606	5009277.006	593.182
NVA-062	404994.593	5006343.906	567.504
NVA-063	405261.632	4998025.975	565.923
NVA-064	416888.705	5004320.362	612.283
NVA-065	426157.976	4999383.694	593.977
NVA-066	438917.229	4999256.859	588.279
NVA-067	448513.538	4999774.521	583.134
NVA-068	453375.947	4989492.782	602.137
NVA-069	439901.761	4994390.659	590.346
NVA-070	430869.250	4993266.051	623.115
NVA-071	417986.845	4991440.153	618.532
NVA-072	409796.071	4993754.822	563.080
NVA-073	400335.776	4991668.047	530.081
NVA-074	403552.655	4991660.198	516.155
NVA-075	405041.298	4985154.549	575.710
NVA-076	414899.179	4984808.141	593.405
NVA-077	433978.228	4984818.196	628.120
NVA-078	440380.387	4984737.302	624.952
NVA-079	451578.871	4974977.286	591.904
NVA-080	441923.197	4976657.924	580.734
NVA-081	432236.606	4975205.163	580.220
NVA-082	423967.823	4976948.149	600.407
NVA-083	414591.729	4977792.528	594.227
NVA-084	402261.000	4977282.970	565.339
NVA-085	398256.819	4984630.760	517.053
NVA-086	398409.484	4972493.605	552.779
NVA-087	395244.736	4965819.861	558.019
NVA-088	401655.143	4965739.409	572.241
NVA-089	414981.145	4965559.729	562.586
NVA-090	428992.818	4966112.643	552.951
NVA-091	440263.847	4965254.907	584.502
NVA-092	451741.102	4968510.865	582.994
NVA-093	464408.212	4965011.972	563.997
NVA-094	481718.598	4968169.036	583.362
NVA-095	500966.966	4968153.516	446.726
NVA-096	517153.167	4963328.098	414.866
NVA-097	510575.353	4956901.224	421.328
NVA-098	492966.144	4958466.540	479.099
NVA-099	481678.300	4956181.027	508.449

NVA-100	464370.670	4958587.619	550.135
NVA-101	446598.308	4957108.816	548.354
NVA-102	429338.170	4957440.955	590.176
NVA-103	412844.346	4955900.095	573.909
NVA-104	395166.869	4956136.272	574.258
NVA-105	382194.376	4951365.154	597.607
NVA-106	357986.367	4950002.834	605.750
NVA-107	332335.441	4953872.691	562.794
NVA-108	329942.821	4946840.547	629.766
NVA-109	354697.990	4946153.216	619.554
NVA-110	373959.671	4943525.772	544.404
NVA-111	389341.786	4944902.768	520.999
NVA-112	397320.369	4936764.067	535.405
NVA-113	415914.255	4950606.260	571.033
NVA-114	415171.199	4928336.358	546.165
NVA-115	431952.326	4946053.566	527.400
NVA-116	438354.723	4941096.586	513.322
NVA-117	451308.378	4947415.935	540.549
NVA-118	458348.349	4937724.399	545.802
NVA-119	464127.345	4944097.258	520.780
NVA-120	464613.460	4929504.472	580.427
NVA-121	481624.563	4947261.543	497.099
NVA-122	483171.908	4937549.990	498.000
NVA-123	496053.194	4943954.518	468.887
NVA-124	499290.658	4937830.986	456.840
NVA-125	507618.745	4945612.710	428.846
NVA-126	515286.760	4939983.532	425.973
NVA-127	515644.336	4930744.549	445.472
NVA-128	506002.299	4922684.751	507.415
NVA-129	493276.447	4925937.596	539.096
NVA-130	472893.068	4928970.883	561.825
NVA-131	456880.467	4929368.607	550.970
NVA-132	447247.988	4930590.436	548.021
NVA-133	427968.188	4933198.826	511.991
NVA-134	408646.895	4930194.126	558.246
NVA-135	383131.147	4933752.675	506.127
NVA-136	4932058.803	372404.483	558.869
NVA-137	361015.651	4935771.806	653.683
NVA-138	4932746.924	344427.855	586.096
NVA-139	330137.753	4923454.818	648.638
NVA-140	352435.051	4918905.333	612.350
NVA-141	372177.041	4924142.840	593.785
NVA-142	392456.300	4920292.824	542.491
NVA-143	416618.431	4921284.511	551.476
NVA-144	435944.390	4921043.772	567.965

NVA-145	451997.983	4920881.495	608.033
NVA-146	464835.524	4923301.884	595.070
NVA-147	483643.082	4920306.567	620.363
NVA-148	501315.540	4917872.340	538.733
NVA-149	523772.035	4917922.657	436.096
NVA-150	512650.562	4909811.838	559.524
NVA-151	493264.588	4913040.242	600.947
NVA-152	464808.271	4911231.036	657.244
NVA-153	458385.717	4914427.595	622.199
NVA-154	442271.670	4912915.421	561.357
NVA-155	427767.566	4913083.586	510.952
NVA-156	406804.306	4909459.294	441.680
NVA-157	383239.833	4915823.579	535.623
NVA-158	365198.334	4915156.101	585.195
NVA-159	338671.537	4913148.045	610.519
NVA-160	334945.568	4900687.756	620.926
NVA-161	344485.460	4897164.376	627.048
NVA-162	363444.069	4897896.286	492.758
NVA-163	384514.290	4897854.342	575.173
NVA-164	410219.730	4898151.758	547.756
NVA-165	430643.192	4907074.007	495.634
NVA-166	432131.799	4895358.016	515.651
NVA-167	453456.476	4902508.131	626.930
NVA-168	463291.691	4899565.110	561.129
NVA-169	488413.255	4901765.662	582.395
NVA-170	501308.356	4900140.786	546.660
NVA-171	515855.077	4896942.277	579.611
NVA-101	446598.308	4957108.816	548.354
NVA-102	429338.170	4957440.955	590.176
VVA-001	515767.442	4904278.985	535.808
VVA-002	498858.426	4897269.150	564.918
VVA-003	480772.584	4901594.490	571.887
VVA-004	463009.024	4893494.977	527.816
VVA-005	443009.957	4890387.342	441.840
VVA-006	483397.166	4926521.161	568.235
VVA-007	400273.842	4895884.649	541.606
VVA-008	371149.949	4902206.389	476.701
VVA-009	362182.622	4899275.869	549.303
VVA-010	331303.013	4895961.422	636.315
VVA-011	334755.978	4916877.858	621.171
VVA-012	356304.297	4915149.445	581.677
VVA-013	382542.599	4908238.728	538.080
VVA-014	414969.354	4908370.176	438.491
VVA-015	431284.041	4917863.440	533.155
VVA-016	447844.459	4906445.360	618.446

VVA-017	464796.819	4916833.100	631.499
VVA-018	483585.953	4915094.672	604.354
VVA-019	501269.223	4912514.691	564.261
VVA-020	520209.400	4916261.685	458.120
VVA-021	515676.537	4925917.153	457.169
VVA-022	498400.711	4925942.409	496.243
VVA-023	435924.746	4902296.314	519.175
VVA-024	466524.721	4925764.692	565.529
VVA-025	451990.932	4925935.167	571.023
VVA-026	446468.203	4925736.743	581.371
VVA-027	429561.089	4925699.688	532.353
VVA-028	406819.901	4918185.262	525.722
VVA-029	385248.505	4928861.728	531.475
VVA-030	383779.417	4922637.742	511.024
VVA-031	363619.710	4924982.922	590.673
VVA-032	356920.492	4929275.814	640.292
VVA-033	338236.654	4926476.220	643.087
VVA-034	330492.566	4936292.186	629.661
VVA-035	337047.786	4943068.230	608.026
VVA-036	353656.366	4938305.866	601.362
VVA-037	362489.823	4936299.009	634.758
VVA-038	385320.873	4942134.384	498.942
VVA-039	398091.882	4933563.349	539.160
VVA-040	435911.417	4936347.334	509.376
VVA-041	444961.286	4936193.961	531.537
VVA-042	465575.024	4934359.008	545.637
VVA-043	478849.070	4929870.008	536.275
VVA-044	494450.971	4935818.258	474.810
VVA-045	508931.870	4937547.946	441.340
VVA-046	520159.761	4938770.535	424.057
VVA-047	515178.661	4950388.458	413.316
VVA-048	500116.464	4948793.465	462.619
VVA-049	480602.069	4942399.974	498.859
VVA-050	470434.587	4944255.784	510.312
VVA-051	457737.137	4947375.400	530.603
VVA-052	439709.289	4951031.133	513.058
VVA-053	420760.779	4946072.986	546.943
VVA-054	396636.785	4946416.086	535.637
VVA-055	377238.767	4946649.597	548.288
VVA-056	358516.524	4946872.171	624.605
VVA-057	334941.344	4954537.399	551.356
VVA-058	330597.465	4942728.636	644.309
VVA-059	355603.569	4954140.362	606.049
VVA-060	391950.498	4959421.974	556.468
VVA-061	405617.368	4955989.370	558.708

VVA-062	409690.311	4964005.030	574.431
VVA-063	423203.724	4959040.957	563.436
VVA-064	434503.165	4955604.462	568.698
VVA-065	451478.643	4957087.545	564.651
VVA-066	464215.005	4952544.041	525.433
VVA-067	474489.422	4960215.125	540.730
VVA-068	486502.940	4958413.466	503.673
VVA-069	521676.666	4957056.695	415.163
VVA-070	501420.046	4960105.182	455.297
VVA-071	510544.969	4969827.804	420.646
VVA-072	488436.383	4964976.998	513.336
VVA-073	461263.513	4964952.194	568.112
VVA-074	435409.180	4971908.929	564.480
VVA-075	414598.552	4971006.321	575.796
VVA-076	398455.483	4968293.834	561.952
VVA-077	398616.362	4982115.311	581.015
VVA-078	408230.747	4985083.567	581.838
VVA-079	424245.975	4980631.523	617.719
VVA-080	437164.701	4978333.947	597.679
VVA-081	444065.393	4975066.573	575.206
VVA-082	450097.348	4988232.350	607.147
VVA-083	438815.507	4986364.520	612.896
VVA-084	425603.347	4992924.426	626.273
VVA-085	411509.365	4990011.470	608.486
VVA-086	403576.790	4993392.784	564.036
VVA-087	404503.056	5001286.125	560.846
VVA-088	410486.197	5004444.428	600.929
VVA-089	418127.501	5001049.095	607.544
VVA-090	433008.967	5005846.151	577.314
VVA-091	443034.387	4999227.508	592.076
VVA-092	446937.925	5005632.975	588.027
VVA-093	425026.879	5010801.706	634.176
VVA-094	408033.493	5011013.969	562.092
VVA-095	406436.264	5019715.298	516.743
VVA-096	418728.007	5023833.954	612.010
VVA-097	437656.140	5018669.004	589.514
VVA-098	437973.674	5031552.152	611.256
VVA-099	426822.705	5032328.156	621.417
VVA-100	415573.031	5030223.868	598.806
VVA-101	404323.826	5031958.313	611.660
VVA-102	401273.470	5040597.789	538.609
VVA-103	412081.869	5036781.906	568.625
VVA-104	422108.188	5041433.806	586.151
VVA-105	436068.083	5034759.805	633.591
VVA-106	439548.126	5044342.632	629.310

VVA-107	431046.516	5049217.822	571.262
VVA-108	422153.917	5043857.968	553.462
VVA-109	405365.642	5049720.603	535.319
VVA-110	393542.202	5048339.738	578.761
VVA-111	398953.252	5054626.291	588.460
VVA-112	408722.539	5062554.930	577.530
VVA-113	421390.567	5054275.230	546.990
VVA-114	429509.591	5057301.730	530.279
VVA-115	442469.893	5053413.792	535.897
VVA-116	442567.953	5065239.907	569.027
VVA-117	426569.506	5067037.319	538.276
VVA-118	417163.249	5068776.150	516.552
VVA-119	407133.719	5064118.807	617.272
VVA-120	400796.194	5069544.445	608.466
VVA-121	408117.198	5077020.919	503.218
VVA-122	421794.911	5075125.548	540.250
VVA-123	434825.233	5075024.489	565.286
VVA-124	440521.762	5081371.465	554.861
VVA-125	430008.956	5086341.784	615.116
VVA-126	417109.437	5084199.890	534.676
VVA-127	408227.684	5084944.010	520.215
VVA-128	395824.123	5078891.353	514.506
VVA-129	402662.536	5085171.756	501.461
VVA-130	388974.545	5087595.417	495.383

Table 6: South Dakota Missouri River Lidar surveyed accuracy checkpoints

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

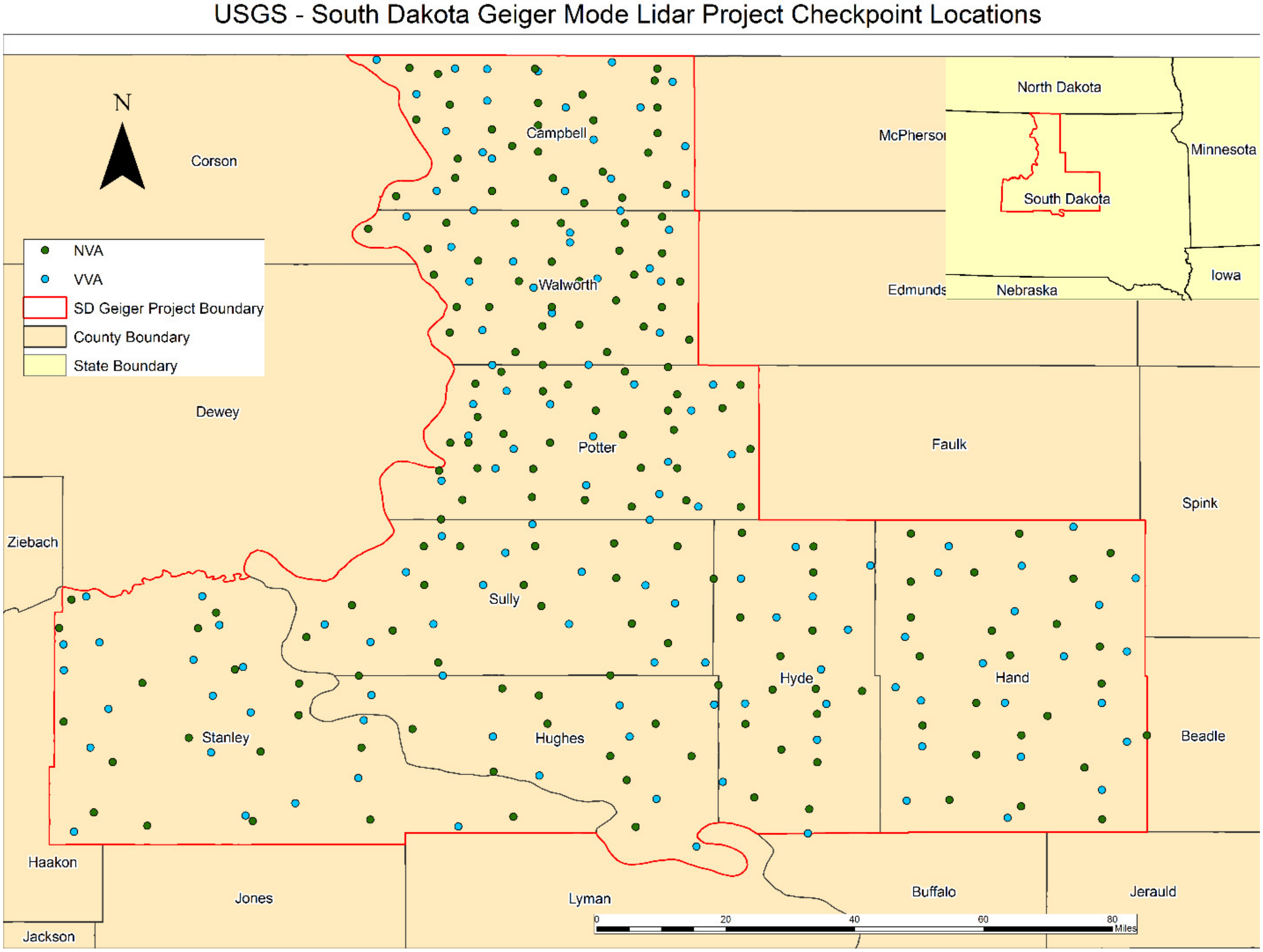


Figure 12 – Location of QA/QC Checkpoints

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 South Dakota Missouri River 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 95th percentile error for all checkpoints in all vegetated land cover categories combined. The South Dakota Missouri River 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 7.

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

Table 7 — Acceptance Criteria

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

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

VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	171	15.6	
VVA	130		44.7

Table 8 — Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 8 cm, equating to +/- 15.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 44.7 cm at the 95th percentile.

This dataset does not meet VVA requirements due to the sensor's inability (using the sensor parameters and configuration set-up for this specific project) to penetrate through tall/short grasslands and crops to reliably measure bare earth elevations. Please see the separate report titled "SD_VVA_Evaluation_final.pdf", delivered as part of the final project deliverables, for more details on the VVA testing and results.

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 +81 cm.

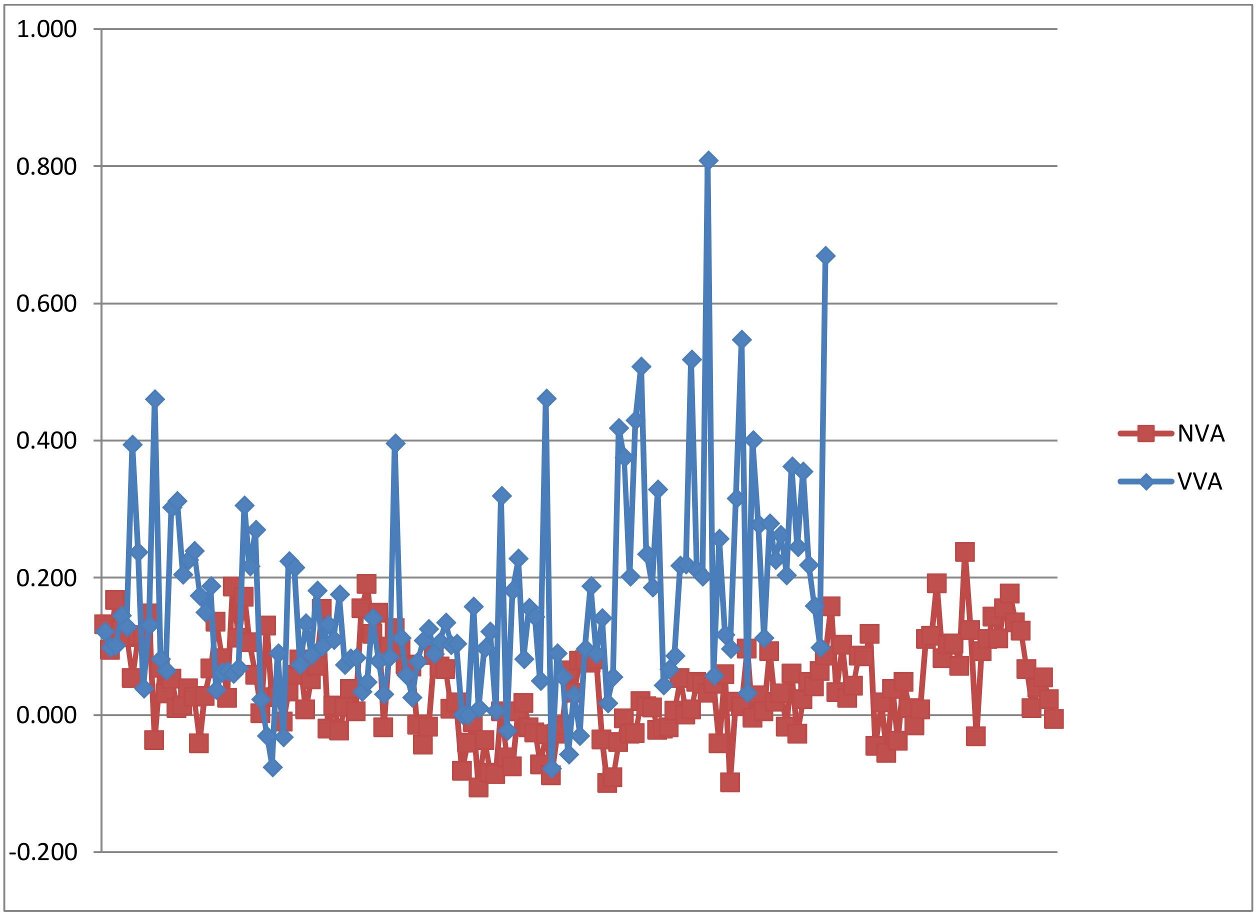


Figure 13 – Magnitude of elevation discrepancies per land cover category

Table 9 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) UTM Zone 14		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-009	362182.622	4899275.869	549.303	549.435	0.461	0.461
VVA-079	424245.975	4980631.523	617.669	617.719	0.462	0.462
VVA-096	418728.007	5023833.954	611.587	612.017	0.509	0.509
VVA-105	436068.083	5034759.805	633.370	633.590	0.519	0.519
VVA-114	429509.591	5057301.730	529.925	530.241	0.548	0.548
VVA-129	402662.536	5085171.756	501.365	501.464	0.670	0.670
VVA-108	422153.917	5043857.968	553.258	553.461	0.809	0.809

Table 9 – 5% Outliers

Table 10 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)

NVA	171	0.080	0.042	0.034	0.196	0.068	-0.304	-0.105	0.238
VVA	130	N/A	0.165	0.124	1.436	0.147	3.022	-0.077	0.809

Table 10 — 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 -0.11 meters and a high of +0.81 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.075 meters to +0.225 meters.

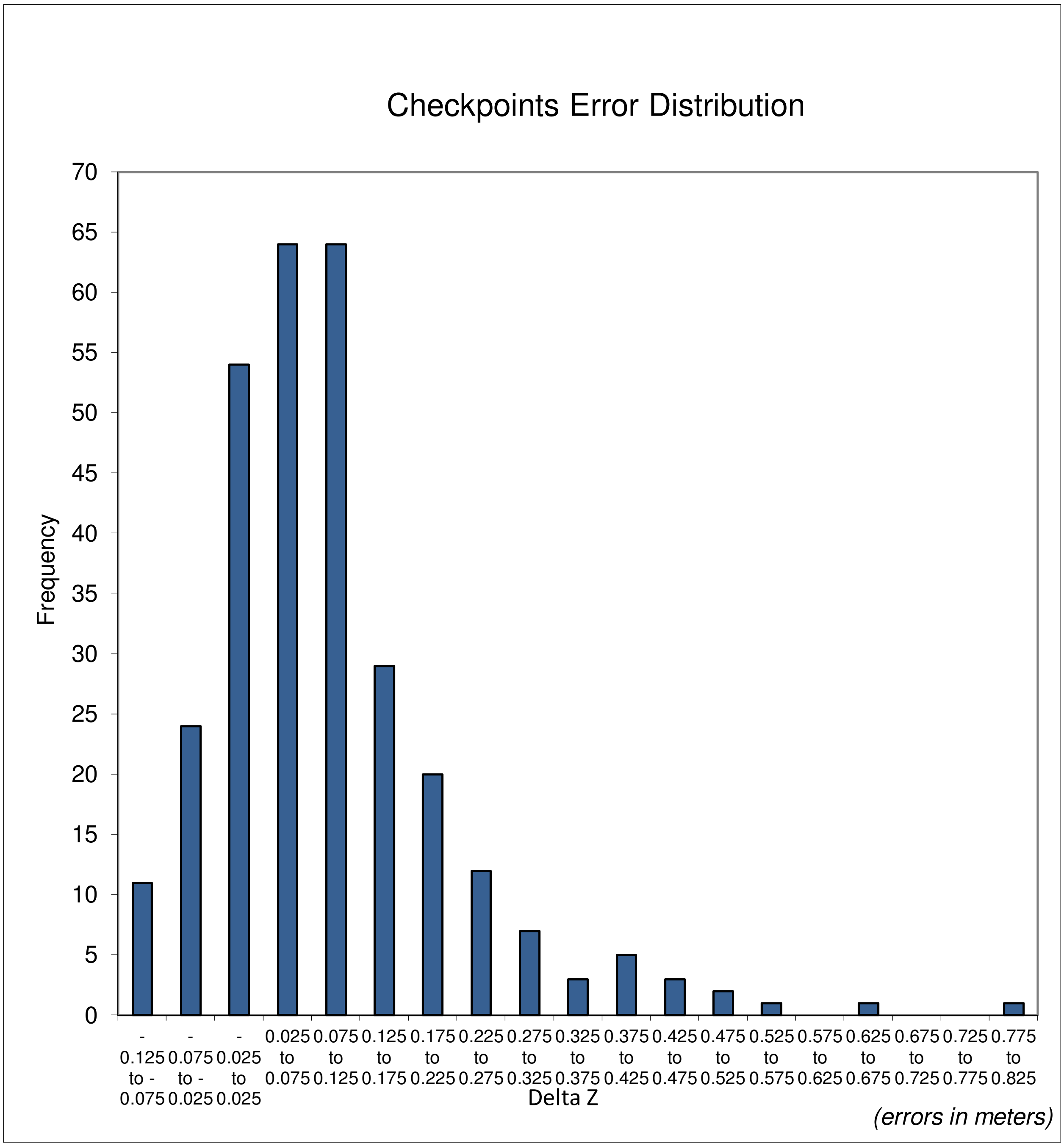


Figure 14 – Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the South Dakota Missouri River Lidar Project satisfies the project's pre-defined vertical accuracy criteria for NVA. This project does not meet the project's pre-defined vertical accuracy criteria for VVA. Please refer to the separate report "SD_VVA_Evaluation_final.pdf" for more details.

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 (or reflectance 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 reflectance 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 reflectance imagery.
2. Next, Dewberry identified the well-defined features in the reflectance imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar reflectance 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 reflectance imagery; horizontal accuracy could not be tested on this dataset.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry used a combination of lidargrammetry and automated techniques to collect breaklines for this project. The delineation of lakes and ponds, or other water bodies at a constant elevation, was achieved using eCognition software. Dewberry produced full point cloud reflectance imagery, bare earth ground models, density models, and slope models. These files were ingested into eCognition, segmented into polygons, and training samples were created to identify water. eCognition used the training samples and defined parameters to identify water segments throughout the project area. Water segments were then reviewed for completeness. Segments identified as lakes and ponds or tidal waters were merged and smoothed. 3D elevations were then applied to the breakline features. Lidargrammetry was used to monotonically collect streams and rivers, or features that have gradient 3D elevations. Dewberry used GeoCue software to develop lidar stereo models of the project area so the lidar derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using lidargrammetry procedures with lidar reflectance imagery, Dewberry used the stereo models to stereo-compile the streams and rivers in accordance with the project's Data Dictionary.

The grayscale imagery created from the Geiger-mode lidar data is pseudo-intensity imagery, termed reflectance imagery. This imagery is not showing the signal strength of the lidar pulse as traditional intensity imagery shows. Instead, the reflectance imagery is mapping the number of measurements observed for an xy location where "bright" or "white" areas were measured more times than "dark" or "black" areas. This difference between true intensity imagery and the reflectance imagery translates into differences in how the imagery is interpreted. One main difference is that open water typically appears very dark in traditional intensity imagery because the NIR wavelength of the lidar pulses are absorbed or scattered by water, resulting in very low or absent signal strength returning to the lidar sensor. In reflectance imagery, however, water and nearshore topographic features both appear very dark because both areas may have fewer measurements. This phenomenon impacted breakline collection and QAQC methods. As shown in the image below (left image), the horizontal placement of breaklines may appear to be incorrect if only compared to the reflectance imagery. But as the image below (right image) shows, the density of ground points is drastically different within actual open water features compared to nearshore topographic features (ground points are orange, water points are blue but the water points were the ground points prior to hydro-classification, and red points are noise). The density of the lidar data must be reviewed to determine true or more accurate breakline placement. Using this knowledge, Dewberry's breakline collection methods and review methods utilized density rasters to determine final breakline placement.

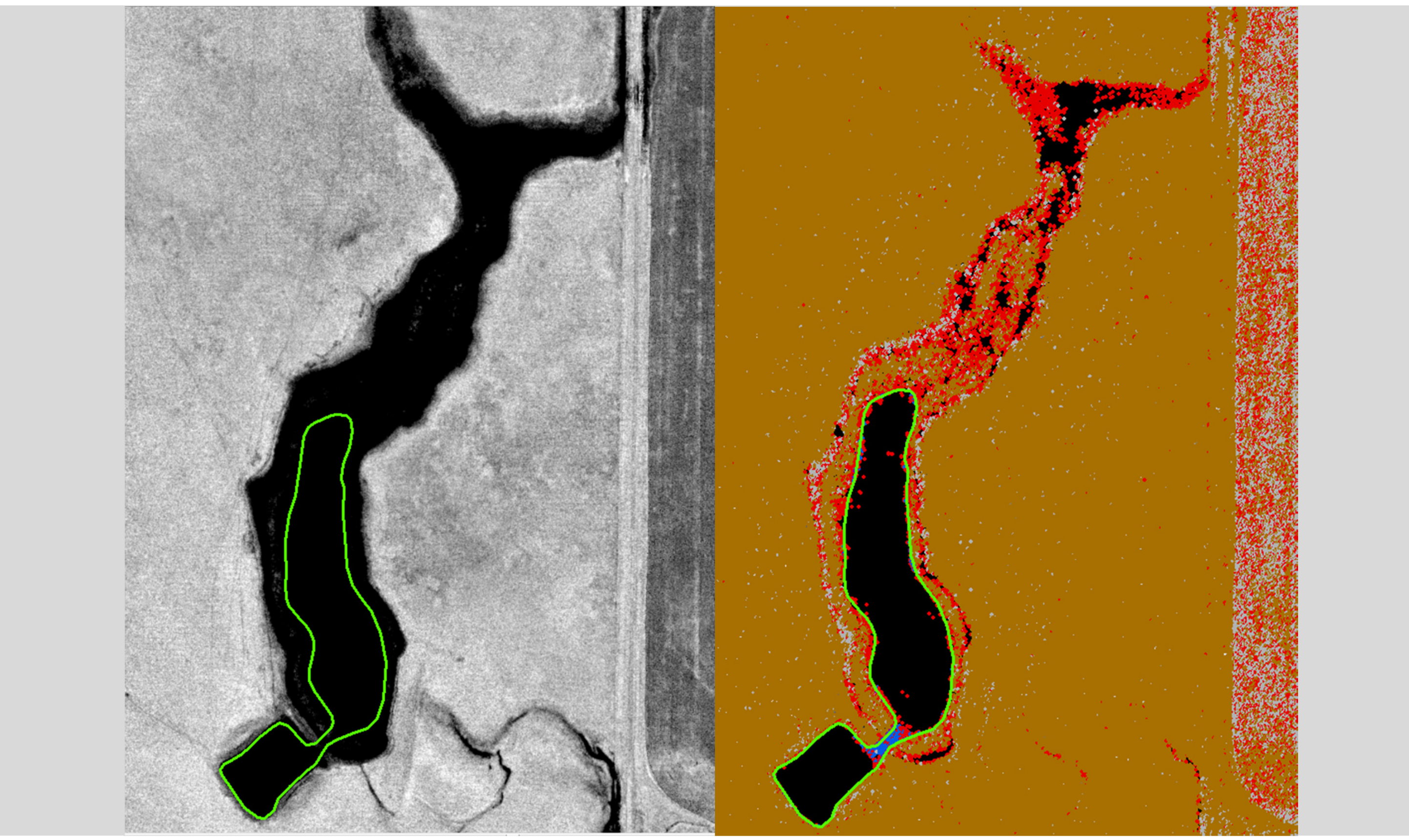


Figure 15-Both nearshore topographic ground and open water may appear very dark in the reflectance imagery (left image). Density models (right image) were used in production and QA/QC to determine more accurate horizontal breakline placement as open water will have a much lower density of points compared to the nearshore ground, even though both areas will appear very dark in the reflectance imagery.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against lidar reflectance imagery and density models. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the lidar.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

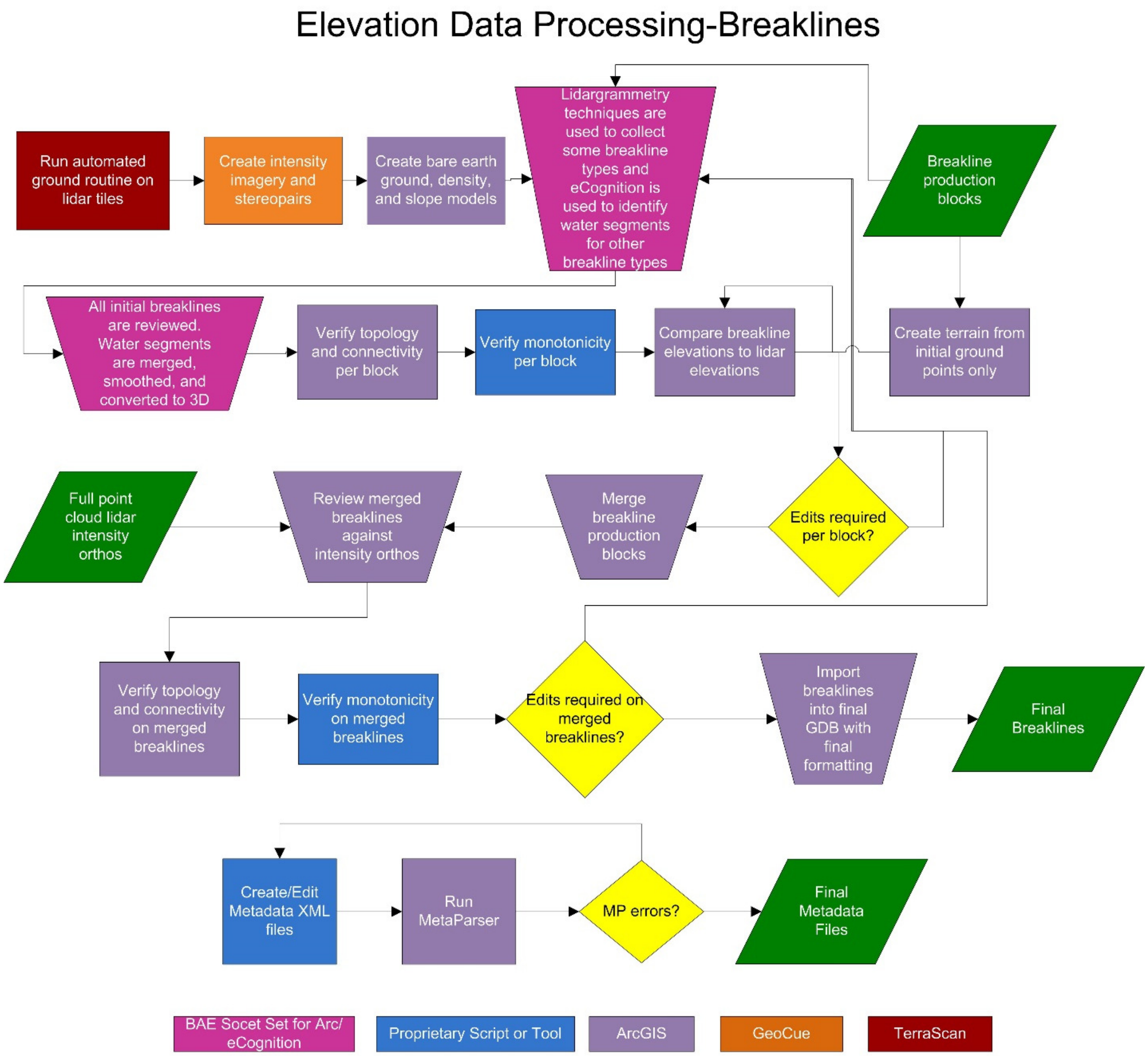


Figure 16-Breakline QA/QC workflow

BREAKLINE CHECKLIST

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

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).
Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 11-A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to UTM Zone 14, Horizontal Units in Meters and Vertical Units in Meters.

Inland Streams and Rivers

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

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

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Type: Polygon

Feature Class: PONDS_AND_LAKES
Contains M Values: No

Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

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

Table Definition

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

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Beneath Bridge Breaklines

Feature Dataset: BREAKLINES
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Feature Class: Bridge_Breaklines
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

Table Definition

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

Feature Definition

Description	Definition	Capture Rules
Bridge Breaklines	Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs.	Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs. Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck. The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production, starting from the lidar swath processing.

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

Figure 17-DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The image below shows an example of a bare earth DEM.

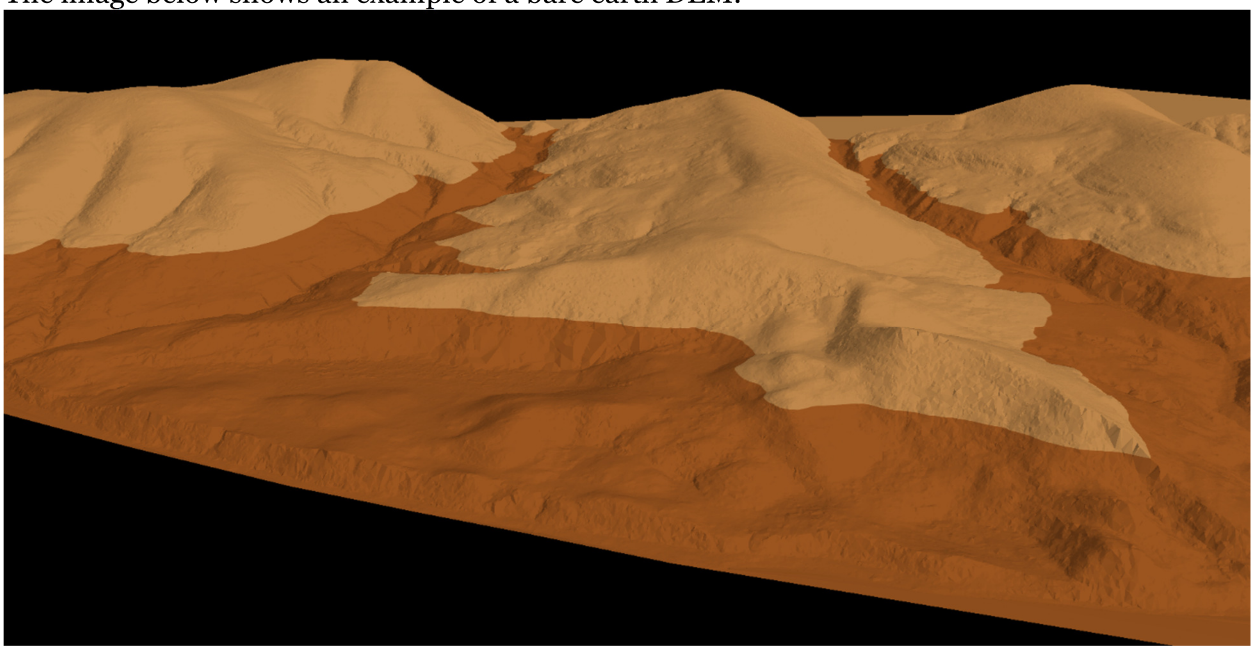


Figure 18-Tiles 14TLQ39304908, 14TLQ39304910, and 14TLQ39504908. 3D Profile view of the bare earth DEM

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

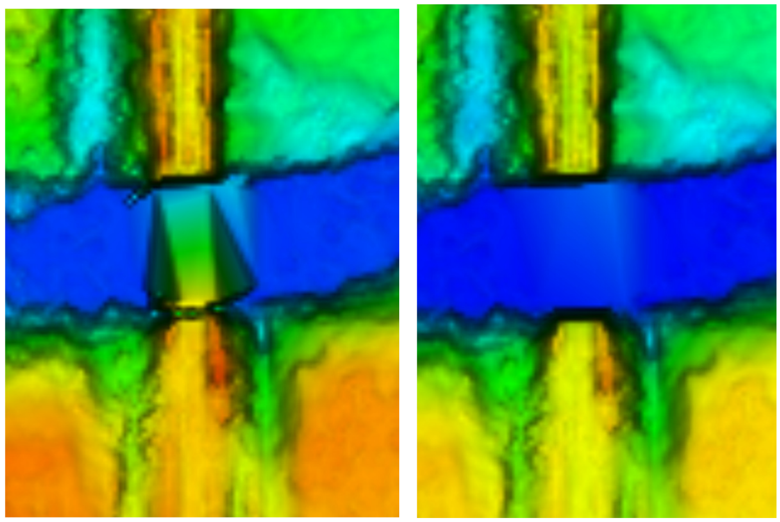


Figure 19-Tile 14TNQ51104946. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same three hundred and one 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 unclassified 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.

Table 12 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	171	15.6	
VVA	130		42.9

Table 12– DEM tested NVA and VVA

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$_z$ =8 cm, equating to +/- 15.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 42.9 cm at the 95th percentile.

This dataset does not meet VVA requirements due to the sensor's inability (using the sensor parameters and configuration set-up for this specific project) to penetrate through tall/short grasslands and crops to reliably measure bare earth elevations. Please see the separate report titled "SD_VVA_Evaluation_final.pdf", delivered as part of the final project deliverables, for more details on the VVA testing and results.

Table 13 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) UTM Zone 14		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-126	417109.437	5084199.890	534.243	534.676	0.433	0.433
VVA-010	331303.013	4895961.422	636.315	636.778	0.463	0.463
VVA-097	437656.140	5018669.004	589.006	589.514	0.508	0.508
VVA-106	439548.126	5044342.632	628.798	629.310	0.512	0.512
VVA-115	442469.893	5053413.792	535.340	535.897	0.557	0.557
VVA-130	388974.545	5087595.417	494.647	495.383	0.736	0.736
VVA-109	405365.642	5049720.603	534.494	535.319	0.825	0.825

Table 13 – 5% Outliers

Table 14 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	171	0.080	0.041	0.033	0.191	0.069	-0.287	-0.115	0.233
VVA	130	N/A	0.167	0.128	1.508	0.150	3.407	-0.074	0.825

Table 14 – Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the South Dakota Missouri River Lidar Project satisfies the project's pre-defined vertical accuracy criteria for NVA. This project does not meet the project's pre-defined vertical accuracy criteria for VVA. Please refer to the separate report "SD_VVA_Evaluation_final.pdf" for more details.

DEM CHECKLIST

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

Pass/Fail	Validation Step
Pass	Masspoints (LAS to multipoint) are created from ground points only (class 2 and class 8 if model key points created, but no class 10 ignored ground points or class 9 water points
Pass	Create a terrain for each production block using the final bare earth lidar points and final breaklines.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size
Pass	Create hillshades for all DEMs
Pass	Manually review bare-earth DEMs in ArcMap with hillshades to check for issues
Pass	DEMs should be hydro-flattened or hydro-enforced as required by project specifications
Pass	DEMs should be seamless across tile boundaries
Pass	Water should be flowing downhill without excessive water artifacts present
Pass	Water features should NOT be floating above surrounding
Pass	Bridges should NOT be present in bare-earth DEMs.

Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.
Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics
Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 15-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Survey Reports

Please see the separate survey report documents included in the survey deliverables to USGS for the following:

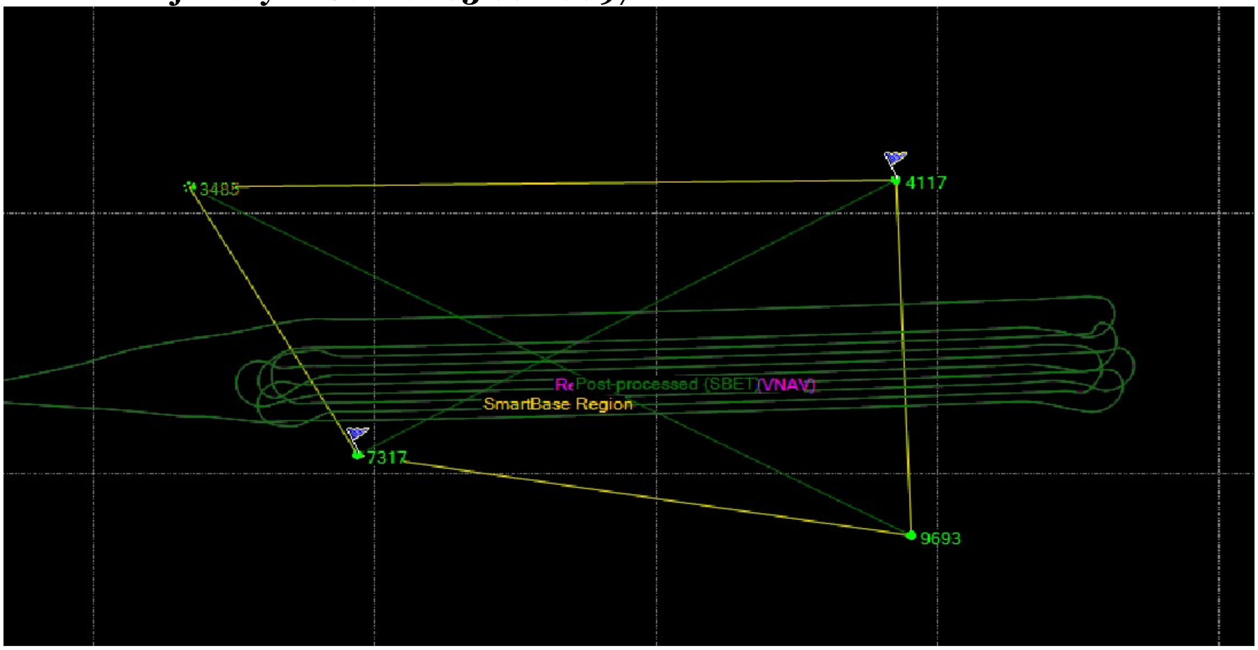
- South_Dakota_Checkpoint_Survey_Report.pdf
- South_Dakota_Control_Point_Survey_Report_Dewberry.pdf
- South_Dakota_Ground_Control_Survey_Report_Harris.pdf

Appendix B: GPS Processing

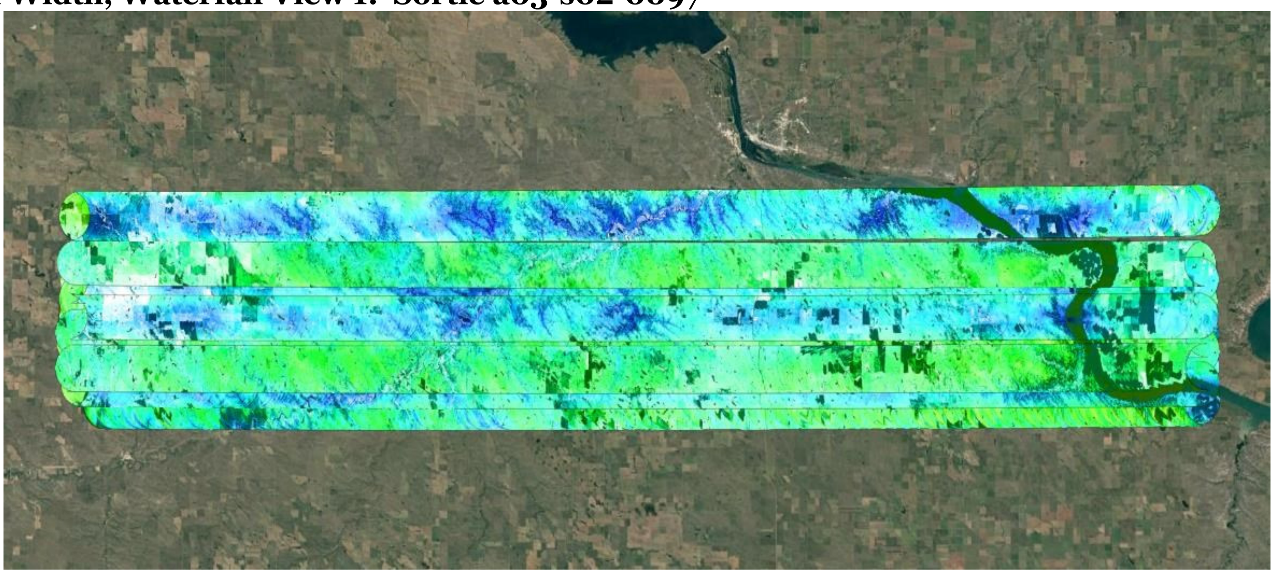
COLLECTION 1

Brick 5
Sortie a03-s02-0097
05/26/2016

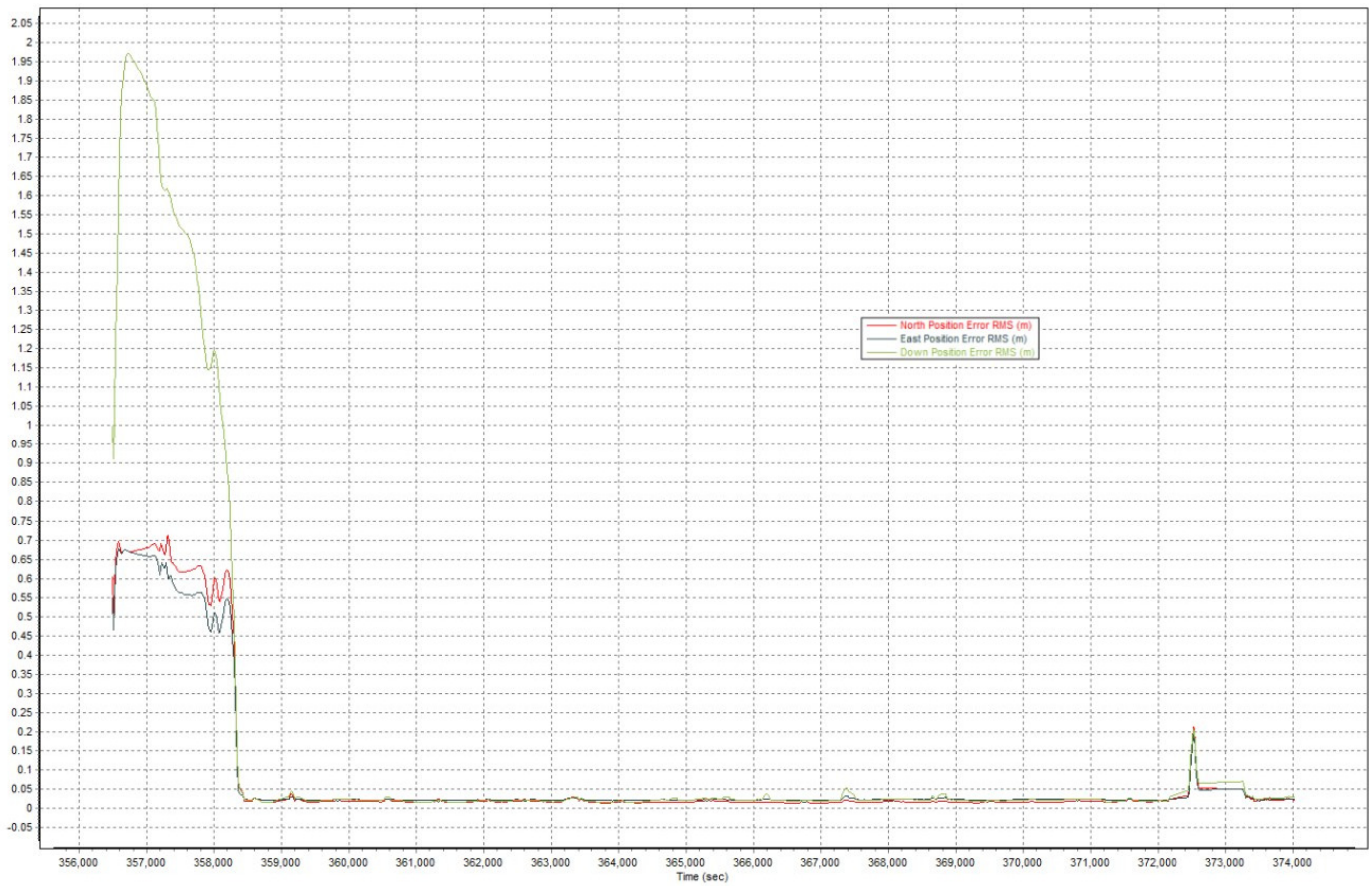
Map Run with Trajectory 1: Sortie a03-s02-0097



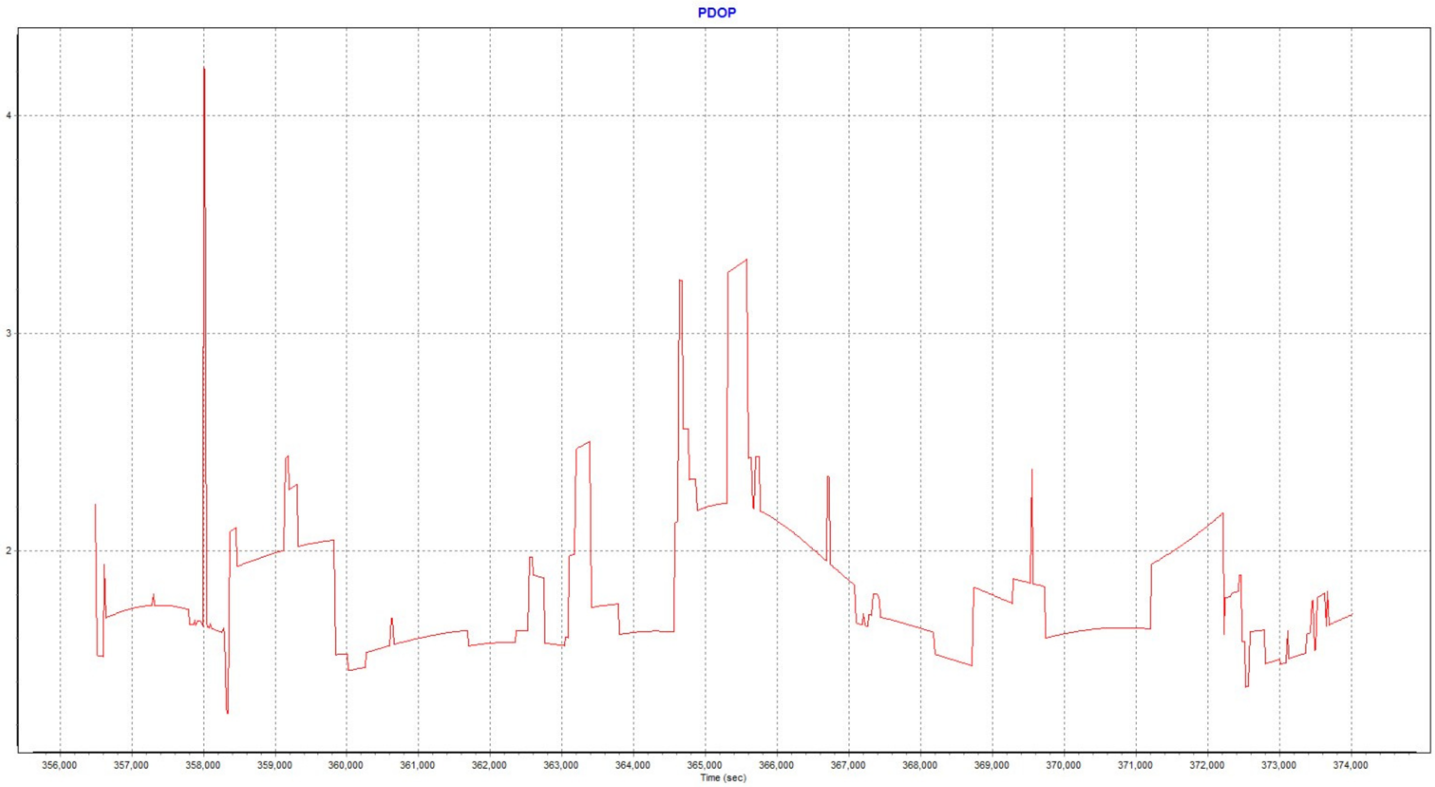
Swath Width, Waterfall View 1: Sortie a03-s02-0097



Combined SBET IAKAR Separation 1: Sortie a03-s02-0097

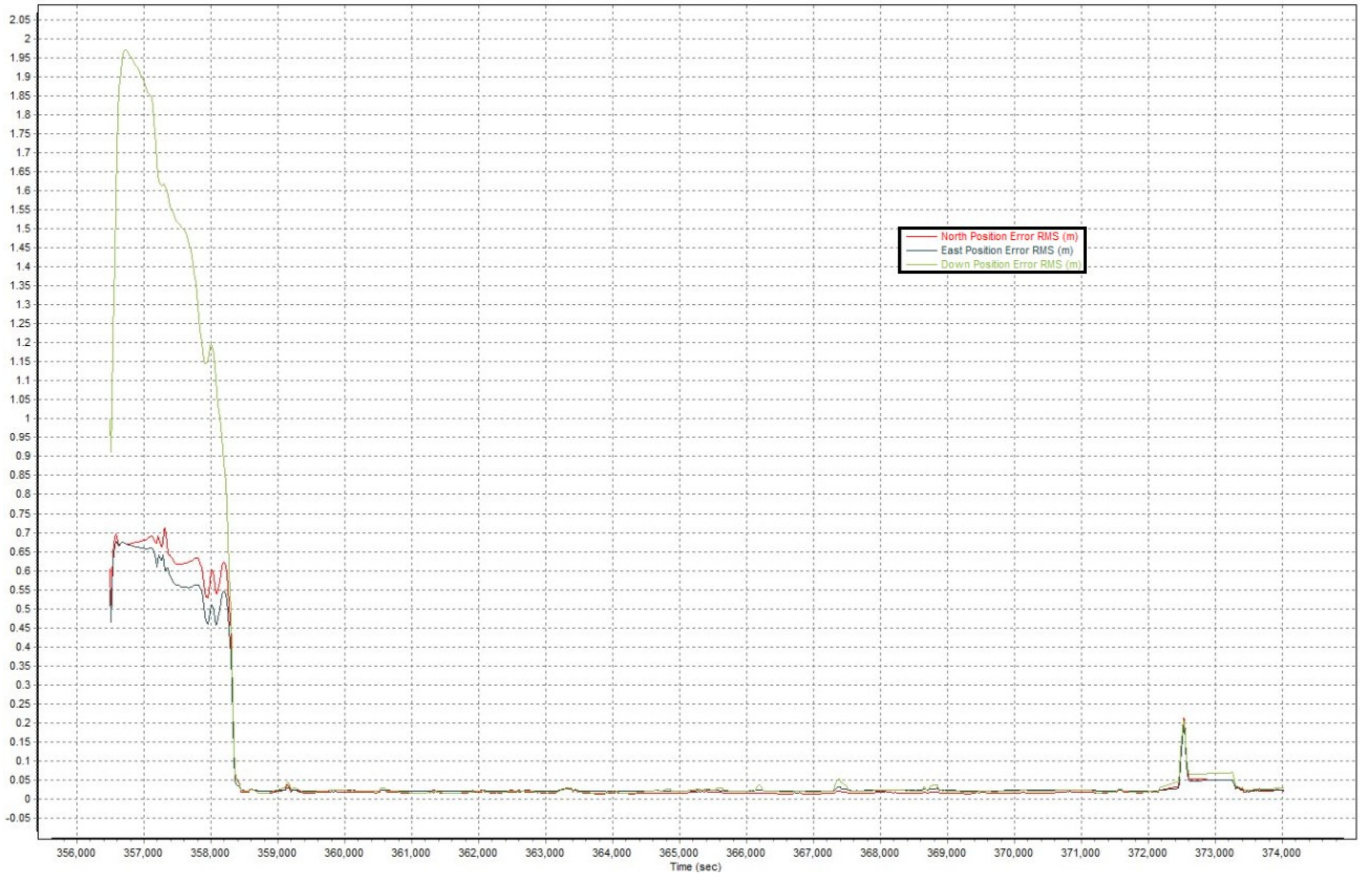


PDOP Plots 1: Sortie a03-s02-0097

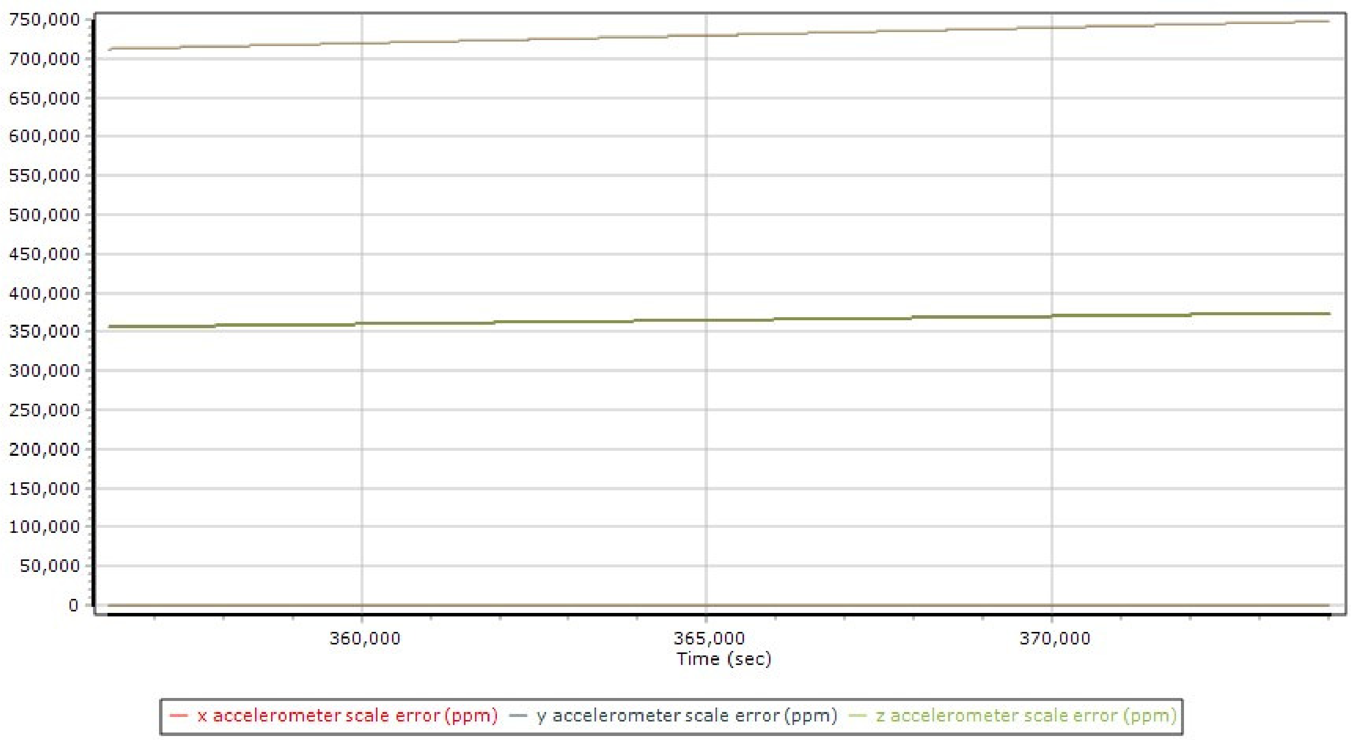


Number of Satellites (>6) Plots 1: Sortie a03-s02-0097

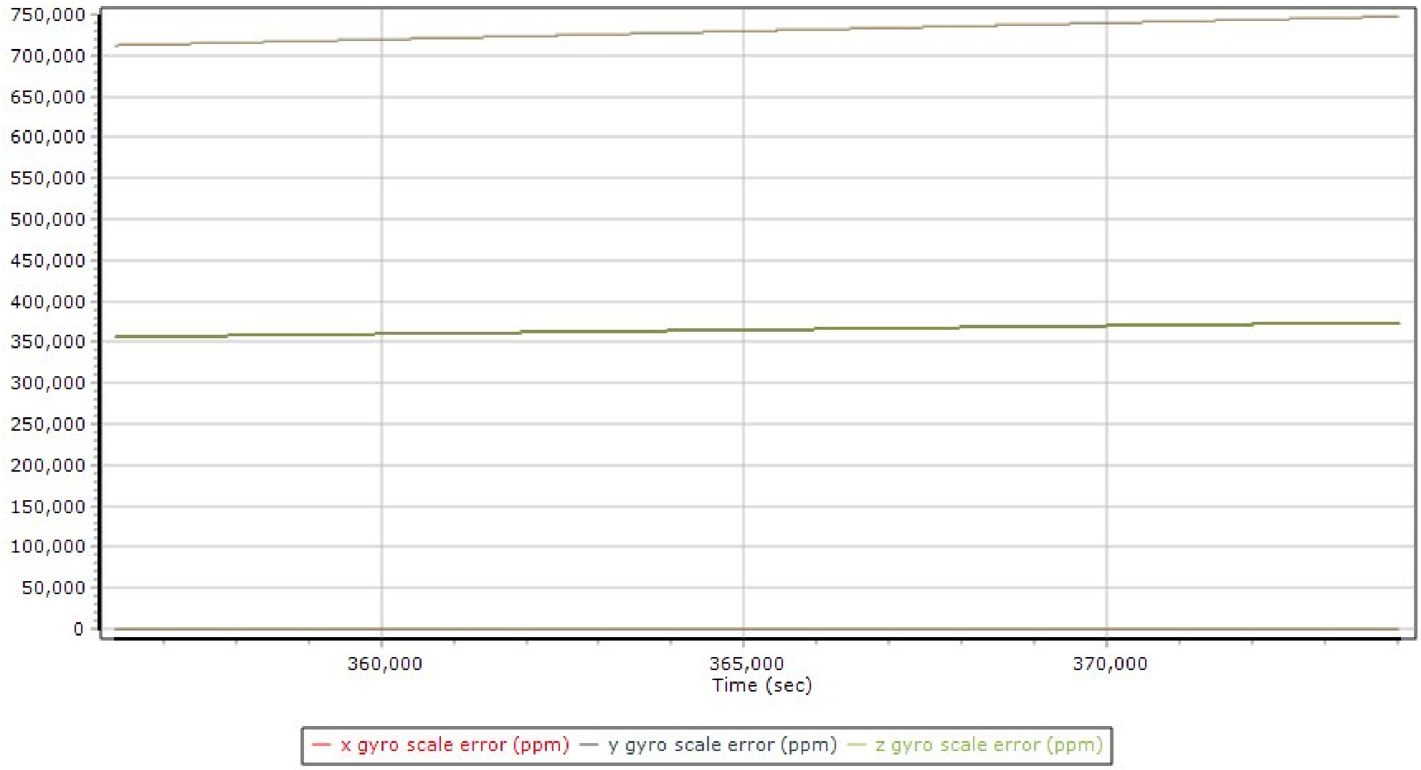
Sensor Position Error RMS (m) Plots 1: Sortie a03-s02-0097



Accelerometer Scale Error (ppm) Plots 1: Sortie a03-s02-0097



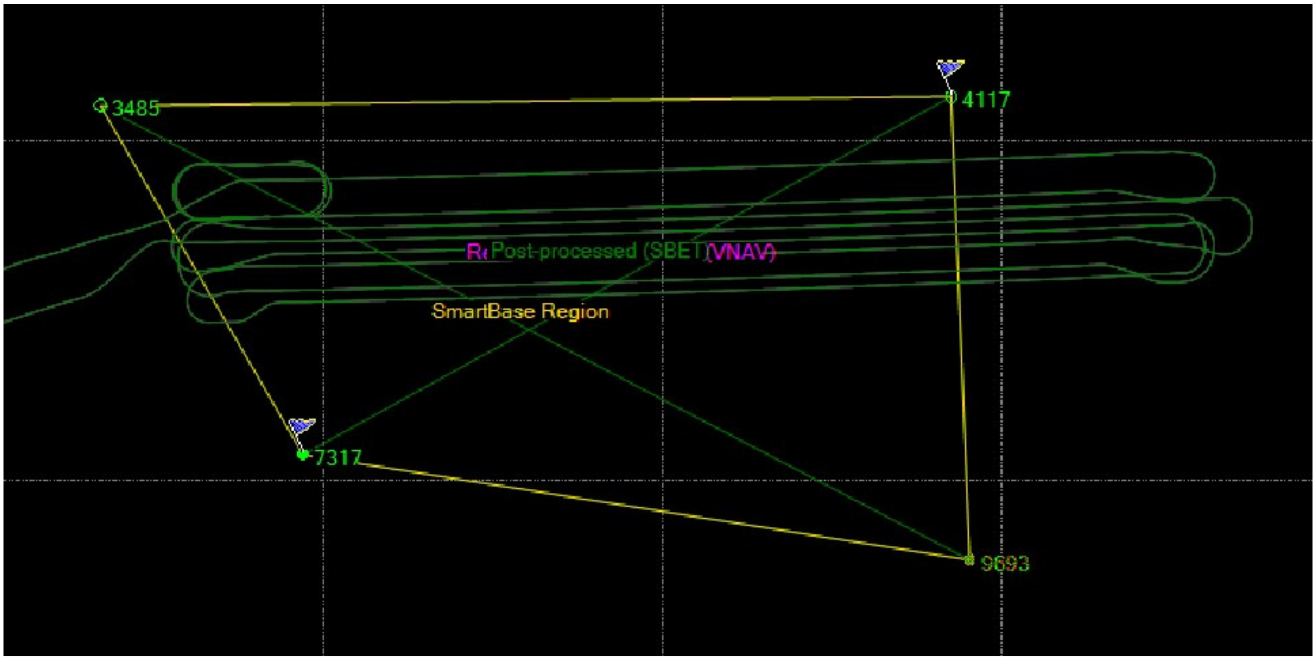
Gyro Scale Error (ppm) Plots 1: Sortie a03-s02-0097



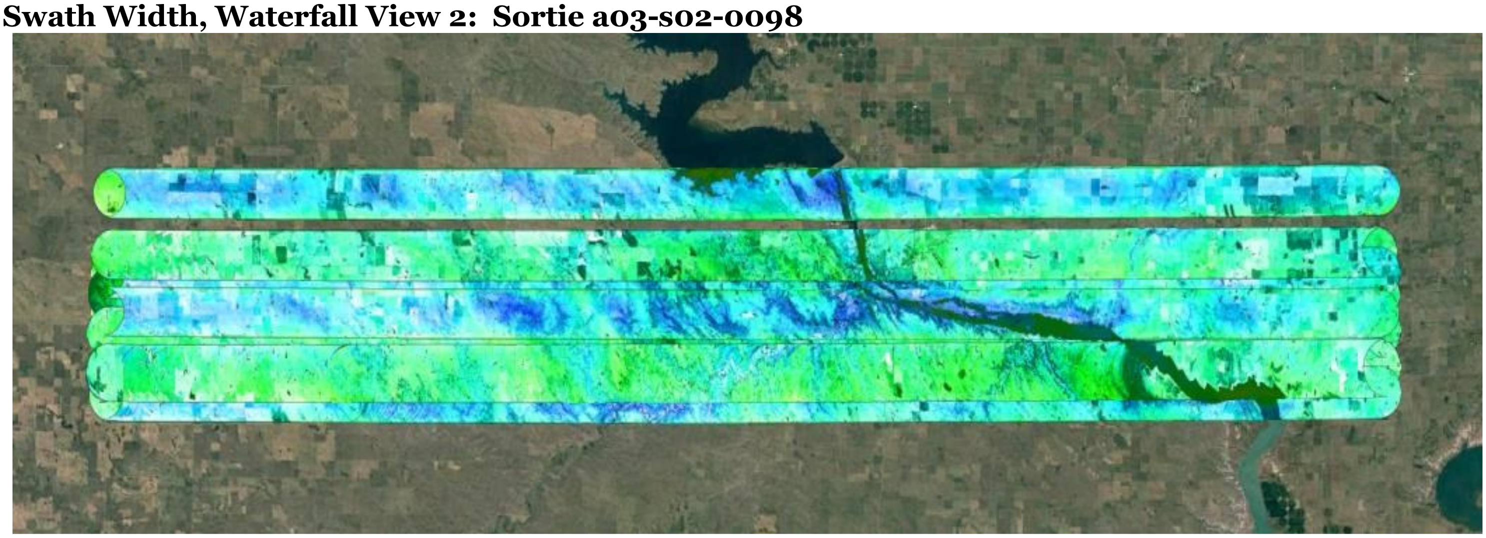
COLLECTION 2

Brick 5
Sortie a03-s02-0098
05/29/2016

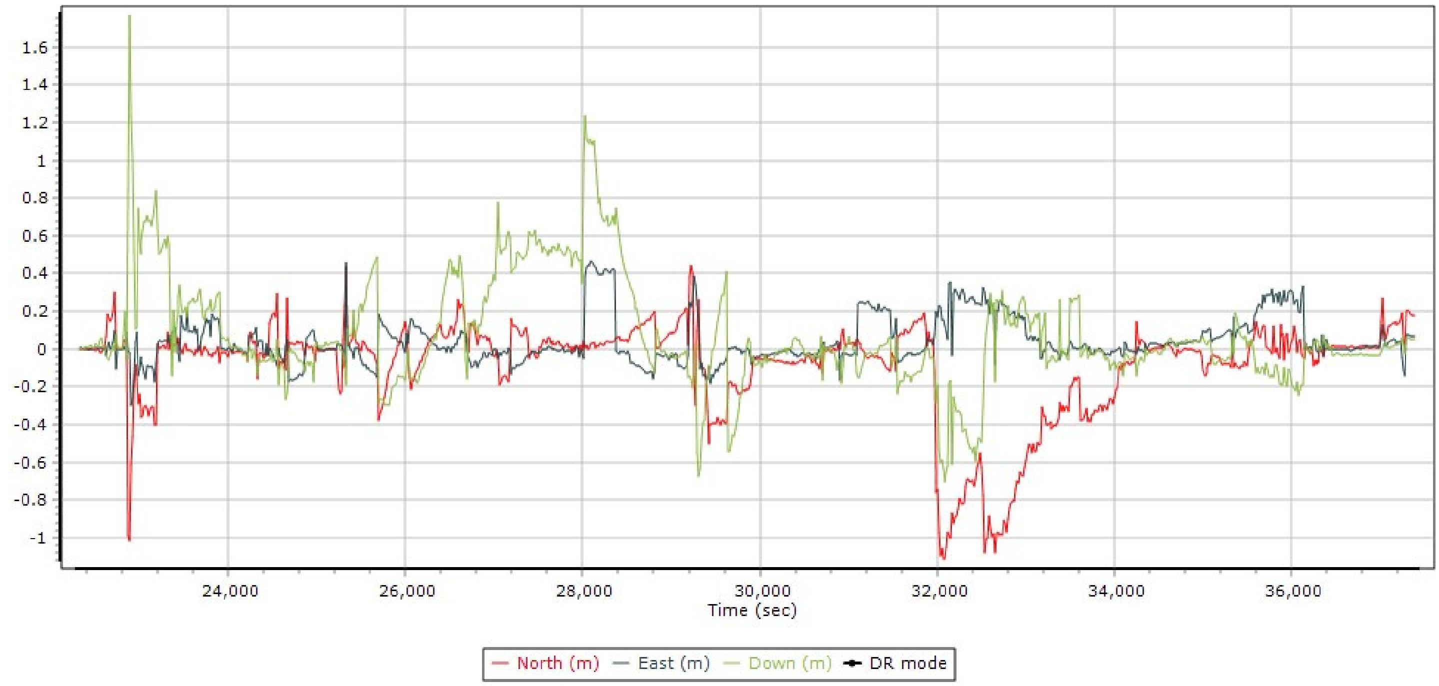
Map Run with Trajectory 2: Sortie a03-s02-0098



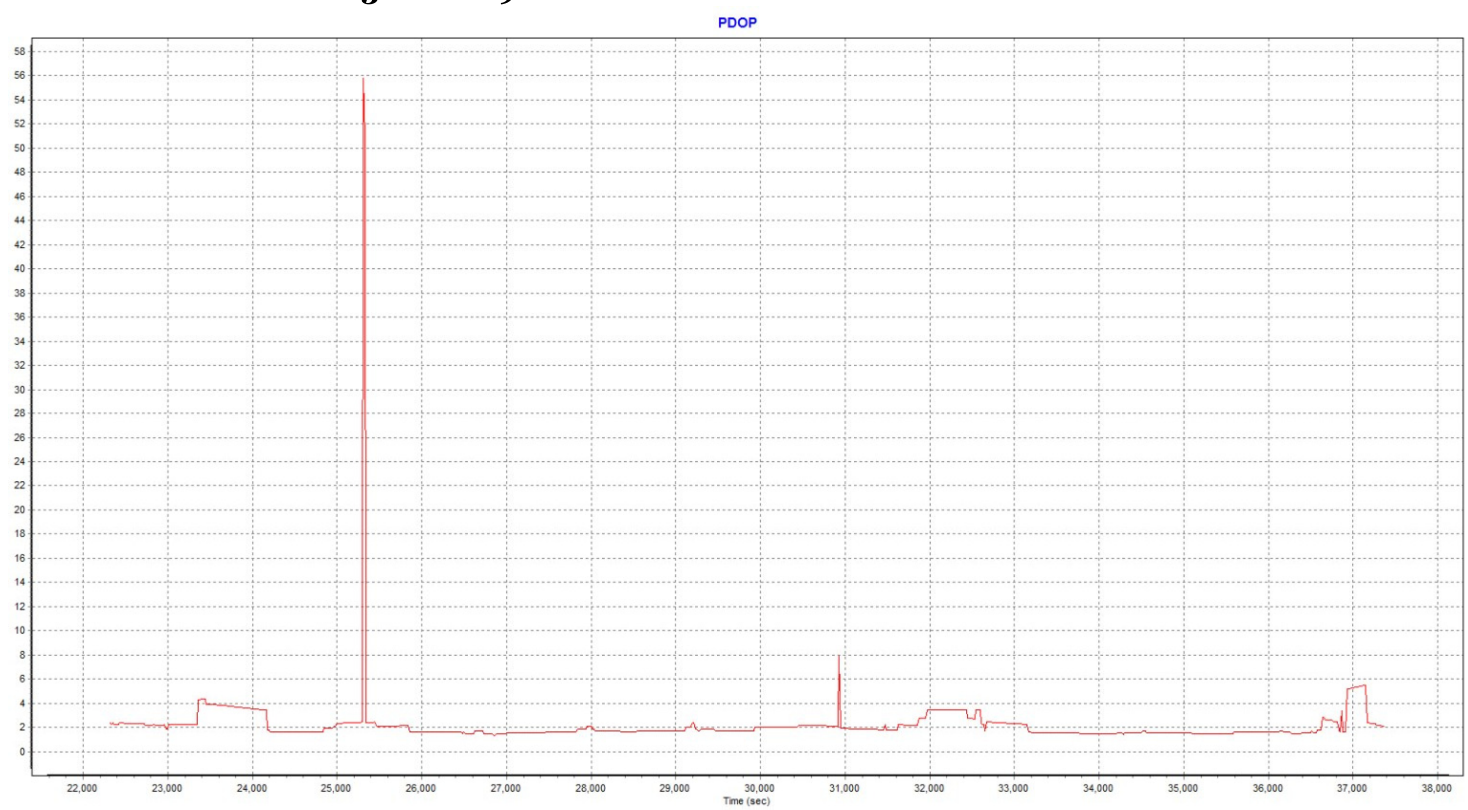
Swath Width, Waterfall View 2: Sortie a03-s02-0098



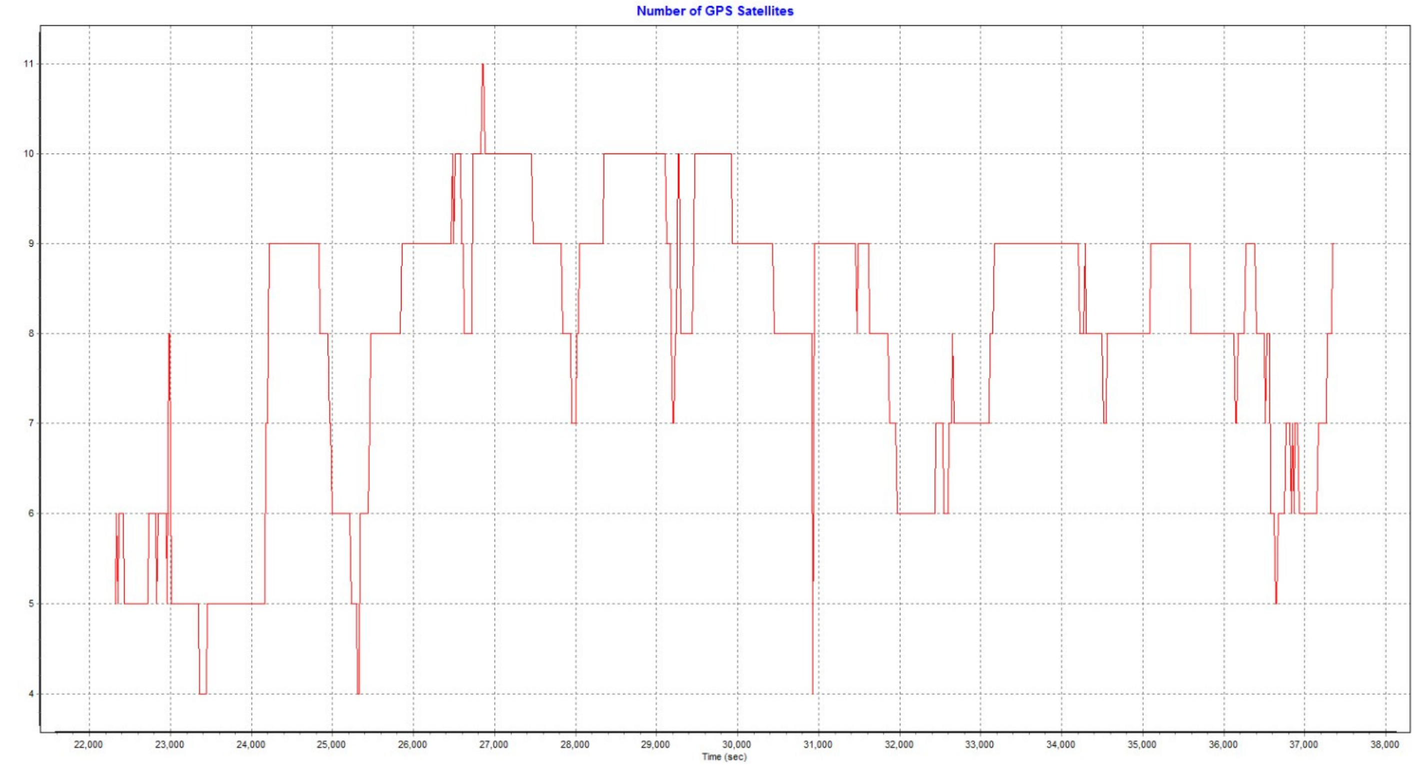
Combined SBET IAKAR Separation 2: Sortie a03-s02-0098



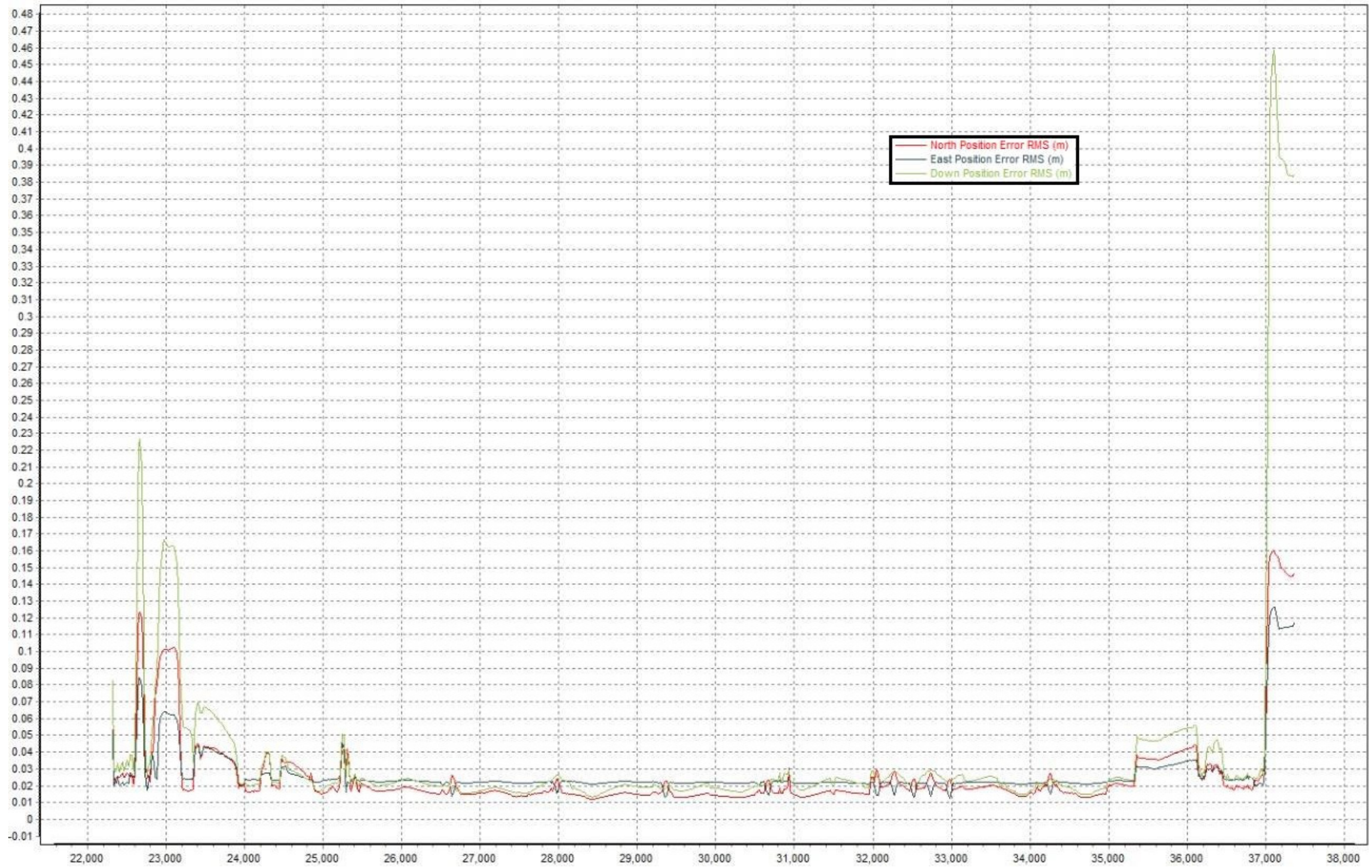
PDOP Plots 2: Sortie a03-s02-0098



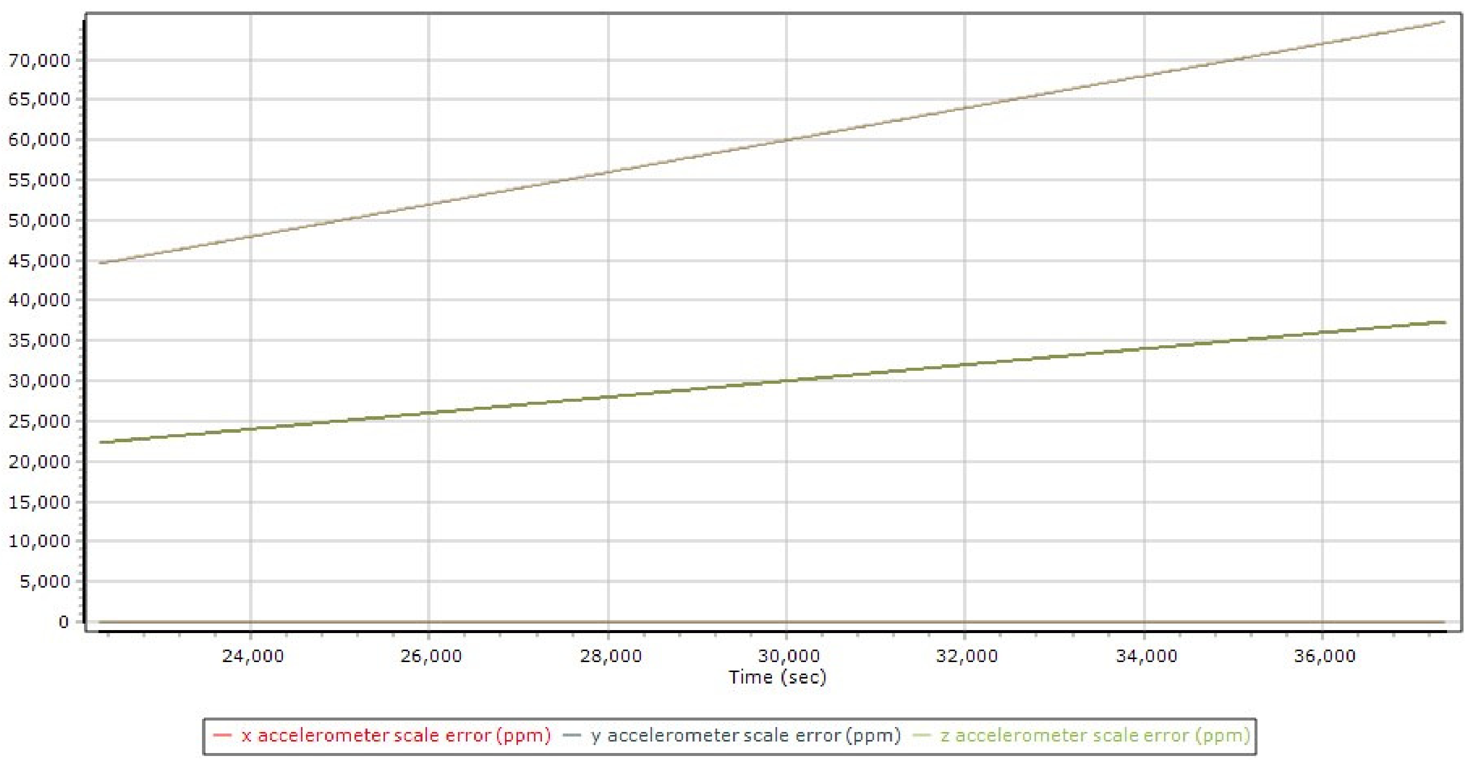
Number of Satellites (>6) Plots 2: Sortie a03-s02-0098



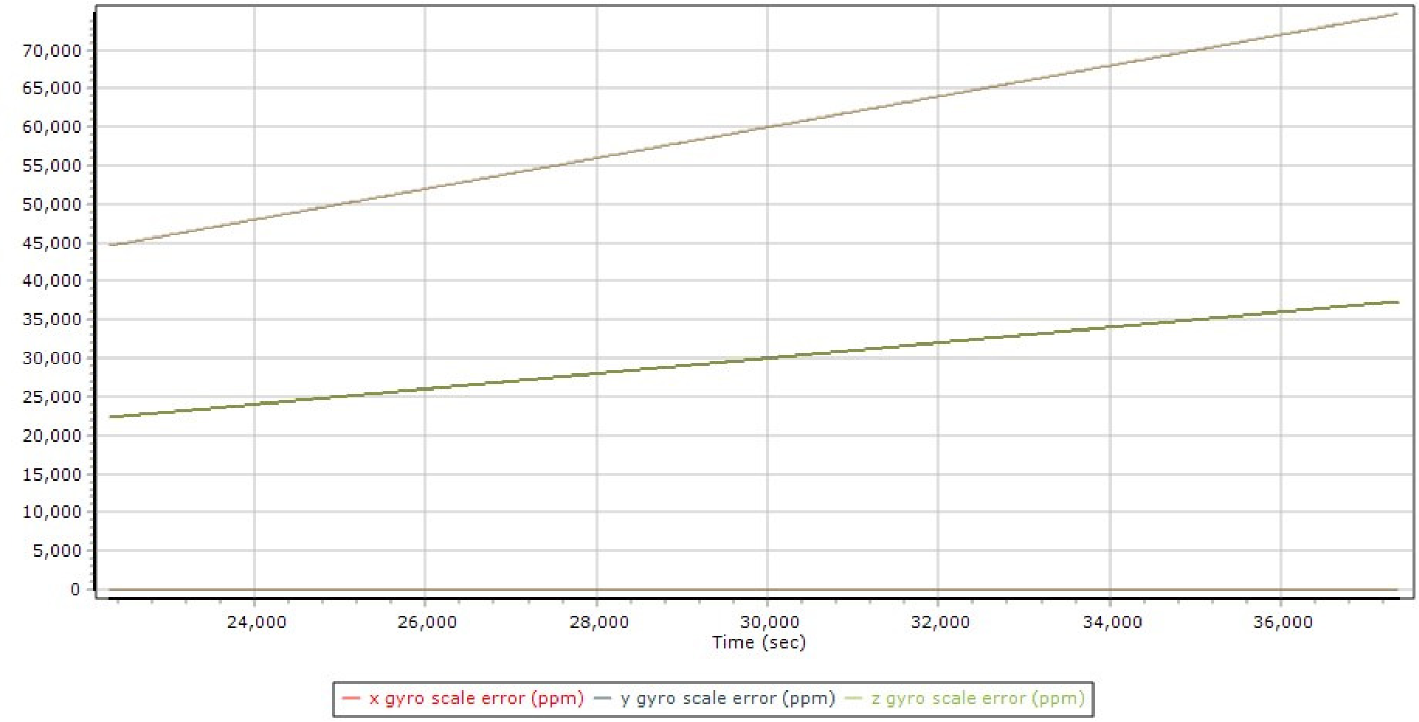
Sensor Position Error RMS (m) Plots 2: Sortie a03-s02-0098



Accelerometer Scale Error (ppm) Plots 2: Sortie a03-s02-0098



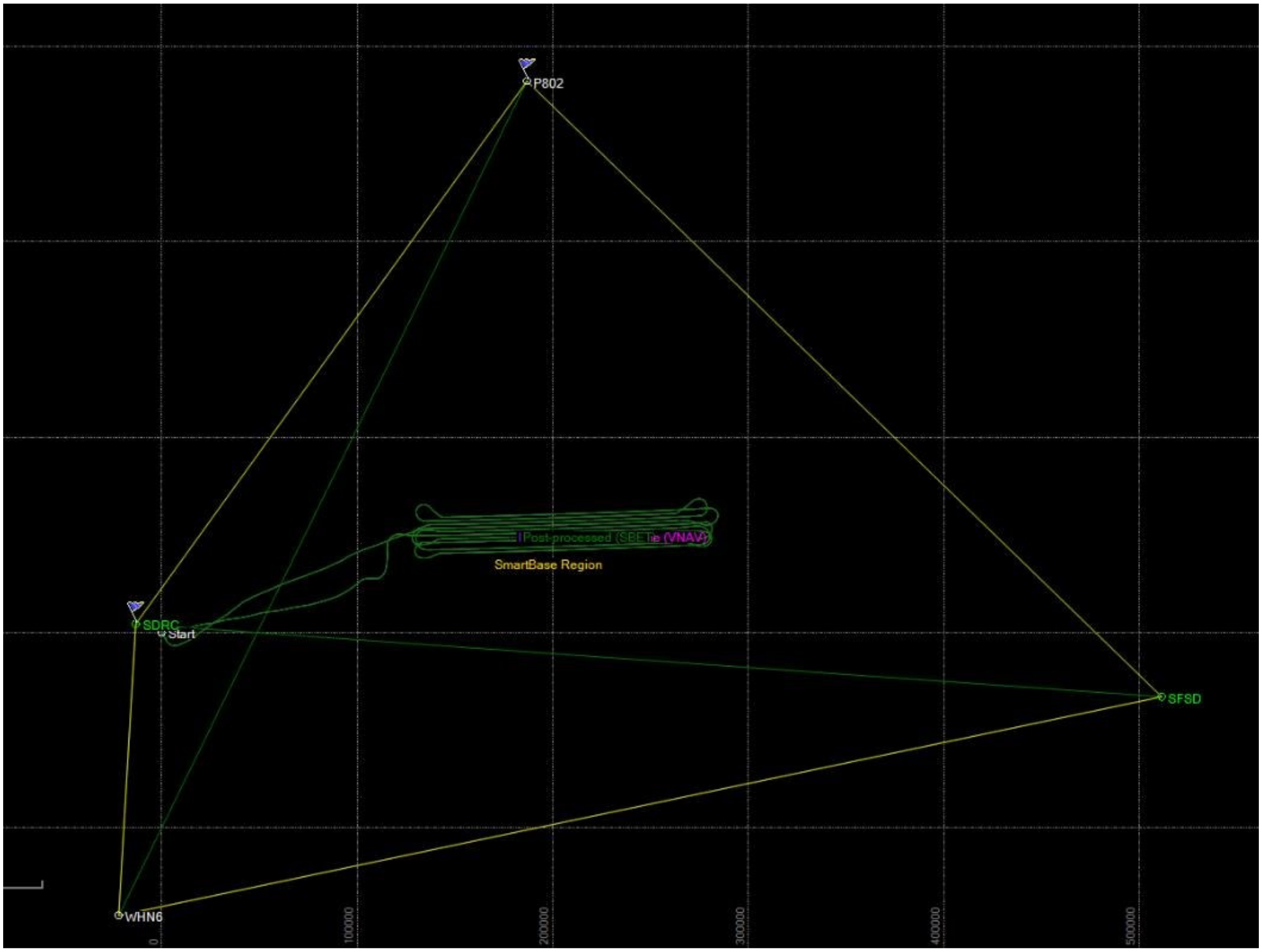
Gyro Scale Error (ppm) Plots 2: Sortie a03-s02-0098



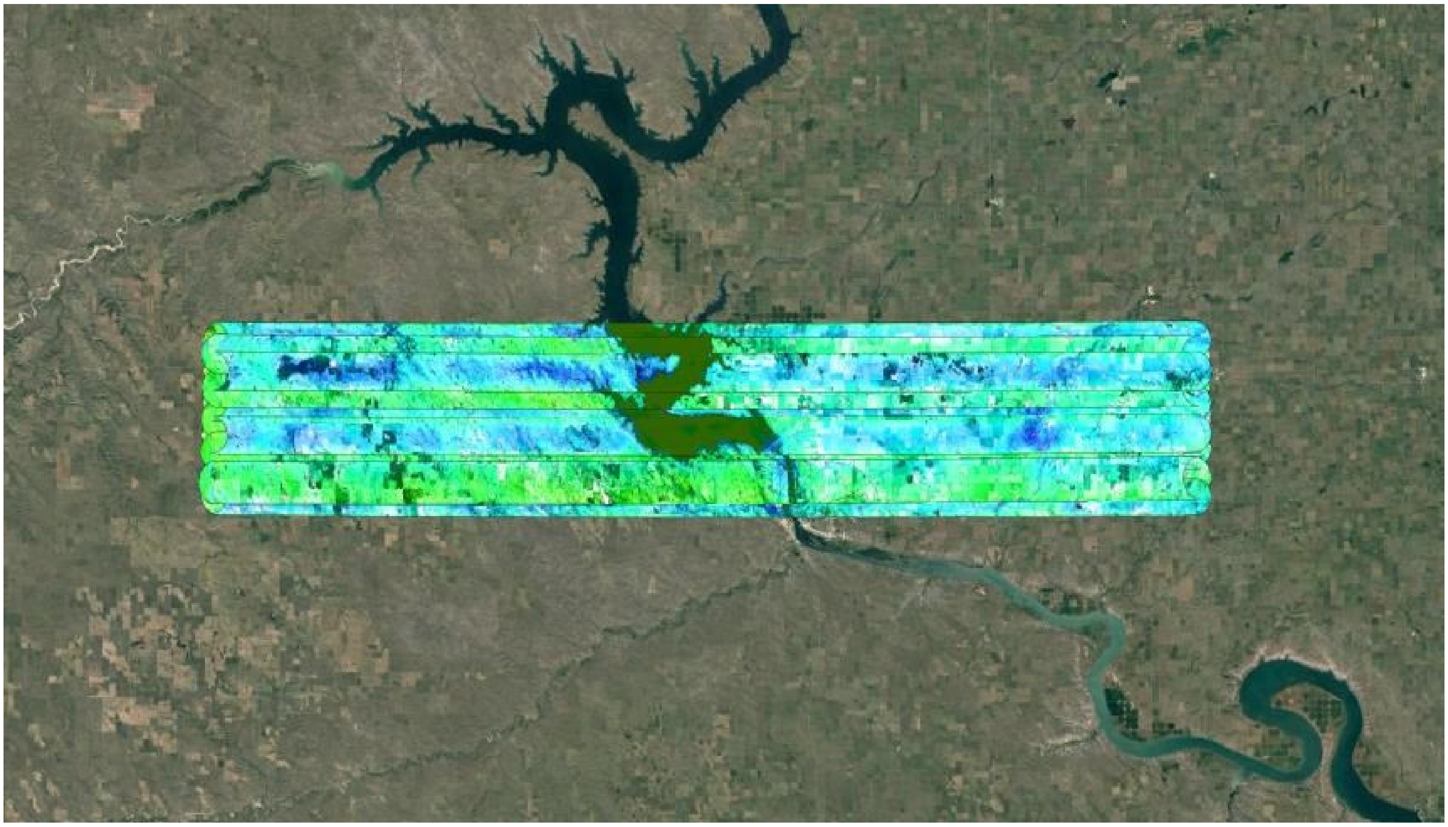
COLLECTION 3

Brick 5
Sortie a03-s02-0099
05/30/2016

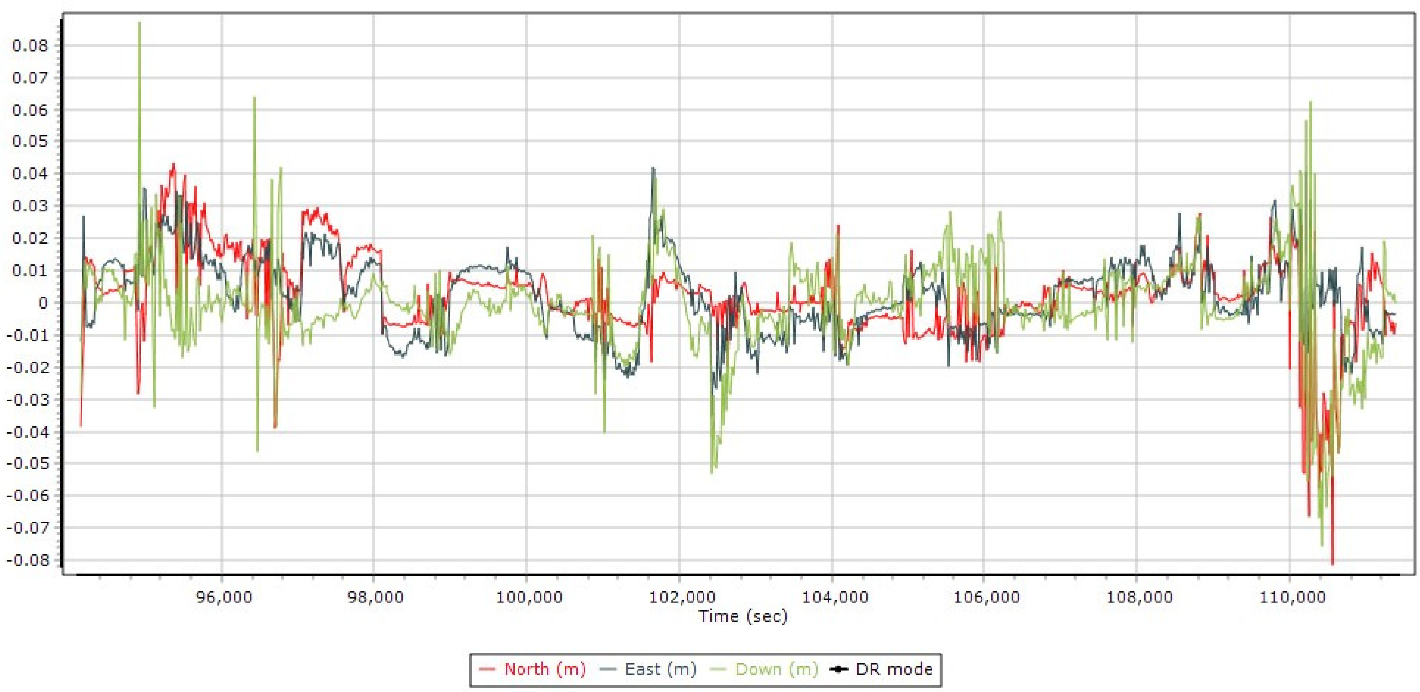
Map Run with Trajectory 3: Sortie a03-s02-0099



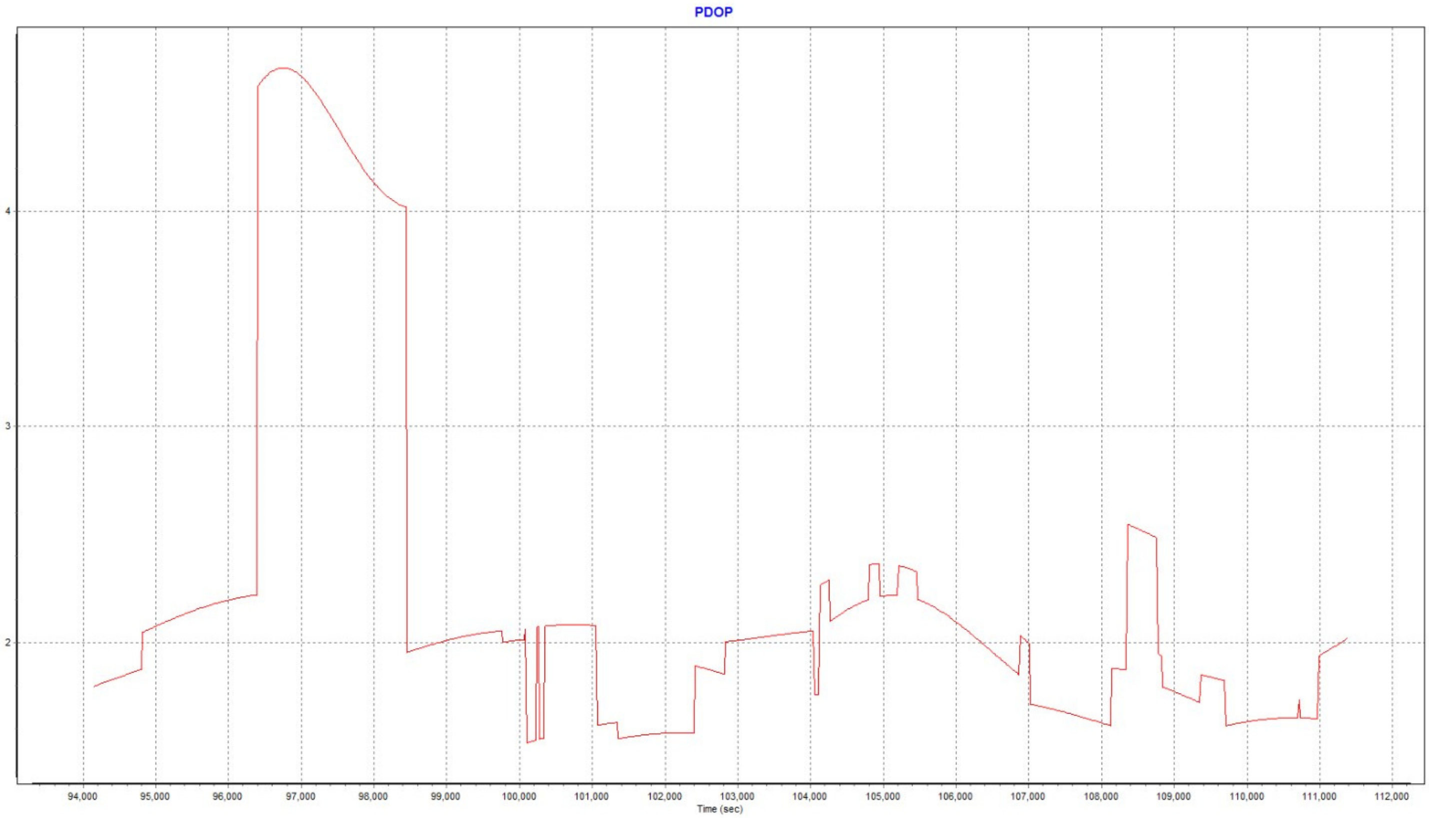
Swath Width, Waterfall View 3: Sortie a03-s02-0099



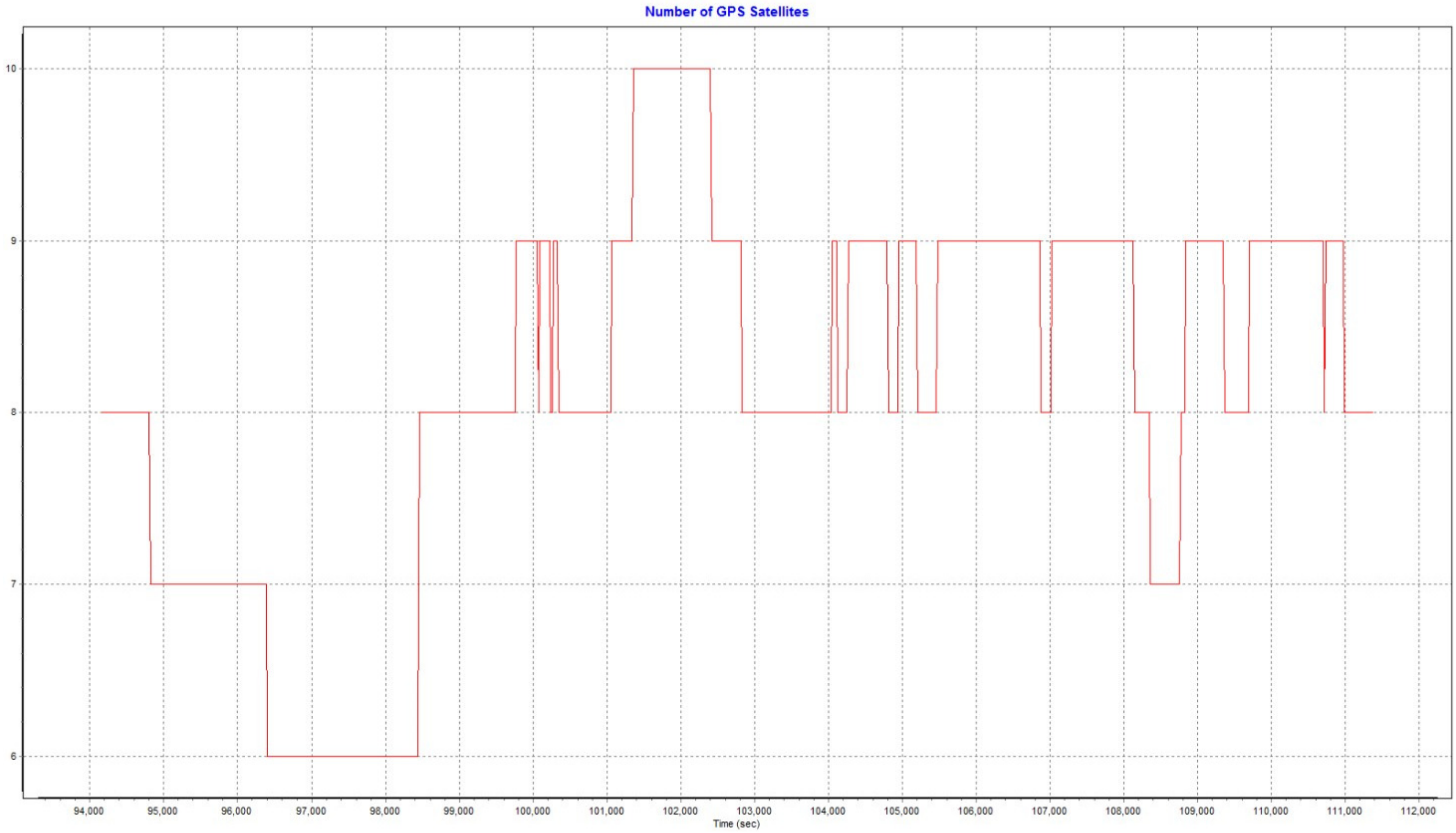
Combined SBET IAKAR Separation 3: Sortie a03-s02-0099



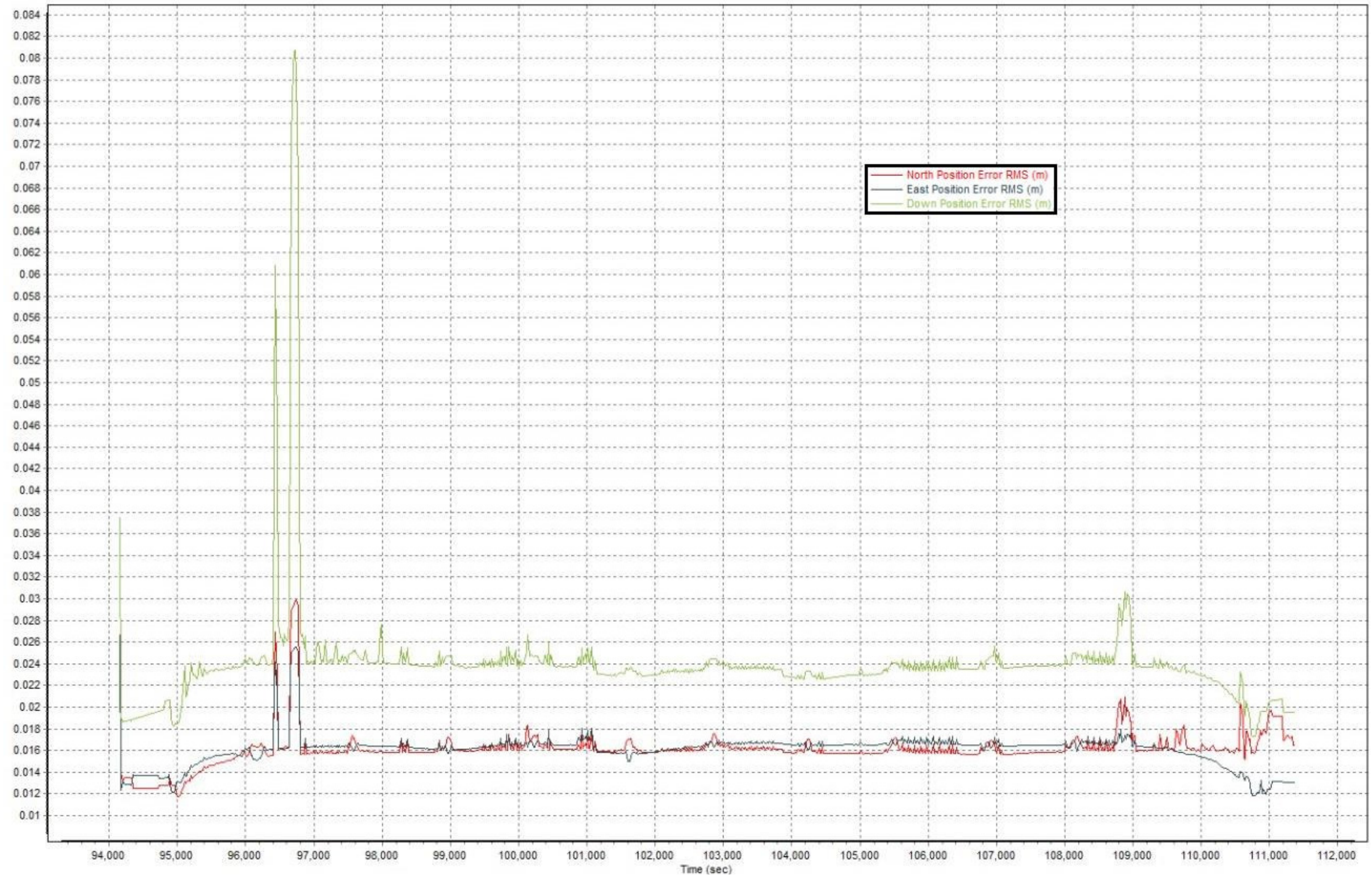
PDOP Plots 3: Sortie a03-s02-0099



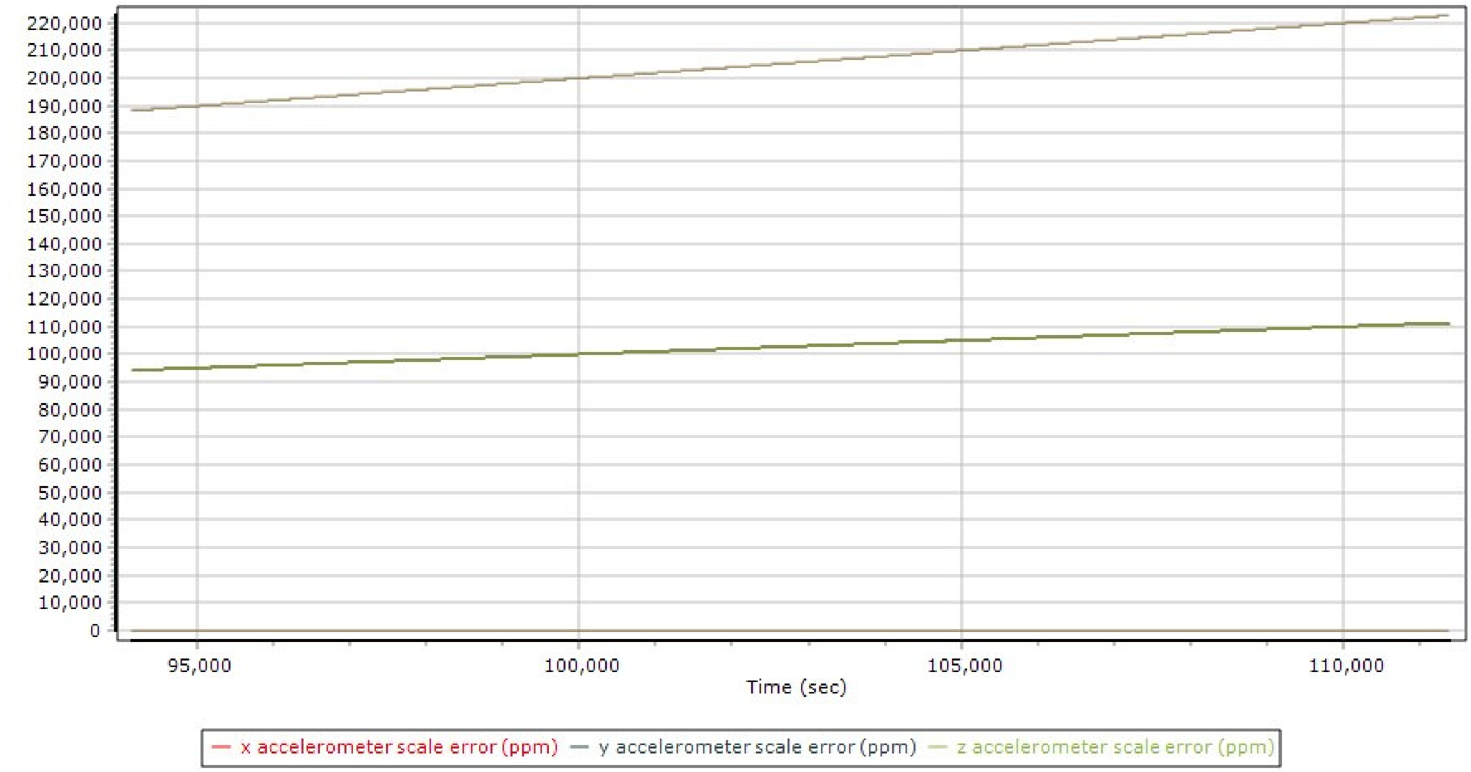
Number of Satellites (>6) Plots 3: Sortie a03-s02-0099



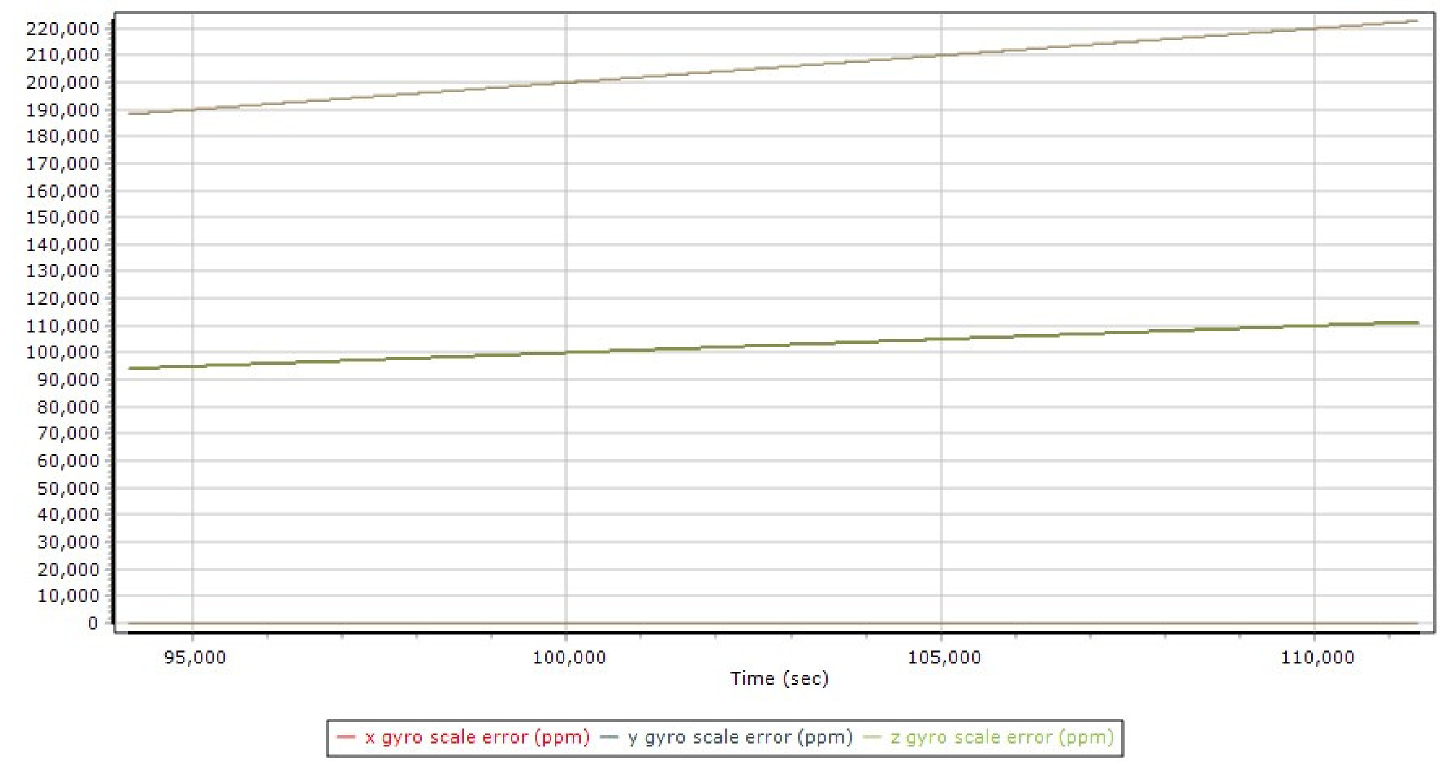
Sensor Position Error RMS (m) Plots 3: Sortie a03-s02-0099



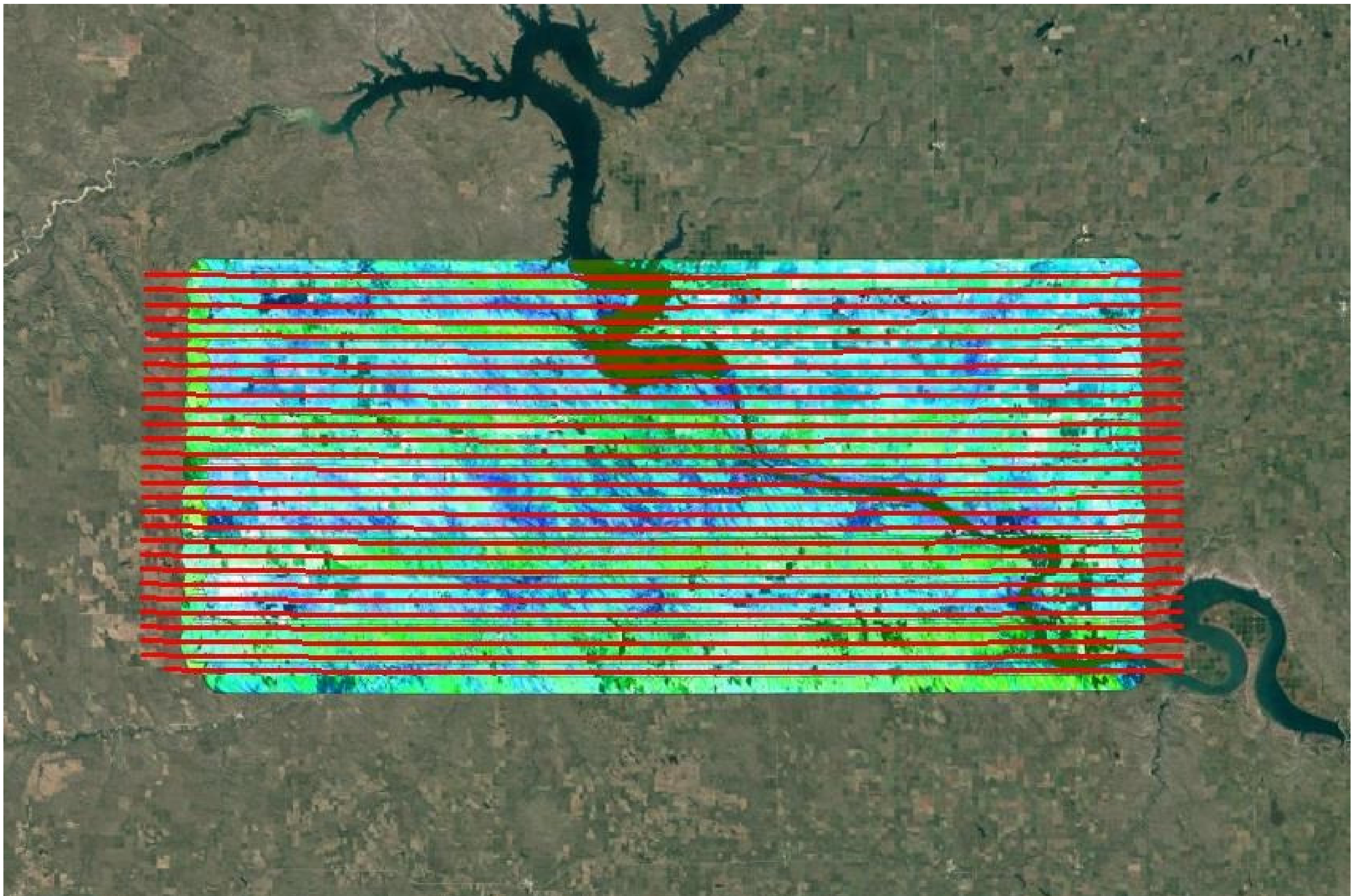
Accelerometer Scale Error (ppm) Plots 3: Sortie a03-s02-0099

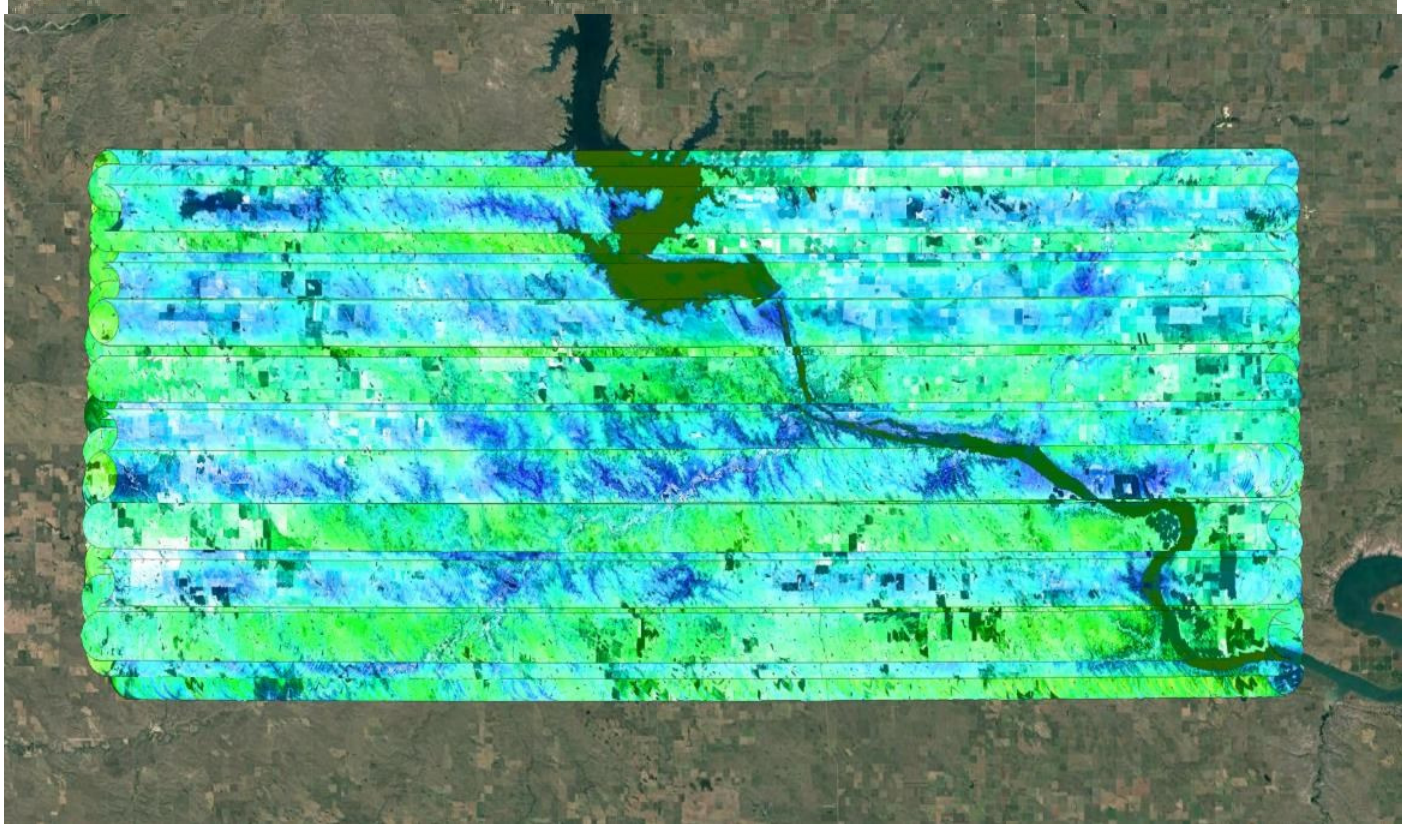


Gyro Scale Error (ppm) Plots 3: Sortie a03-s02-0099



Brick 5 Completion: Flight lines with complete waterfall coverage

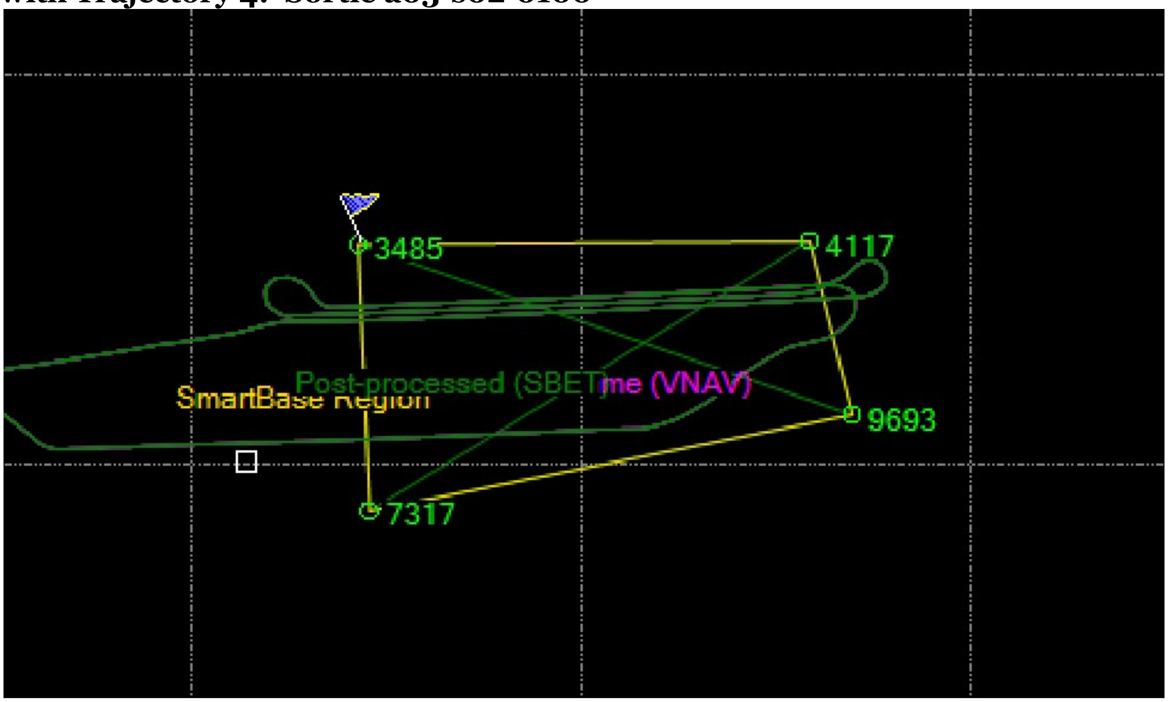




COLLECTION 4

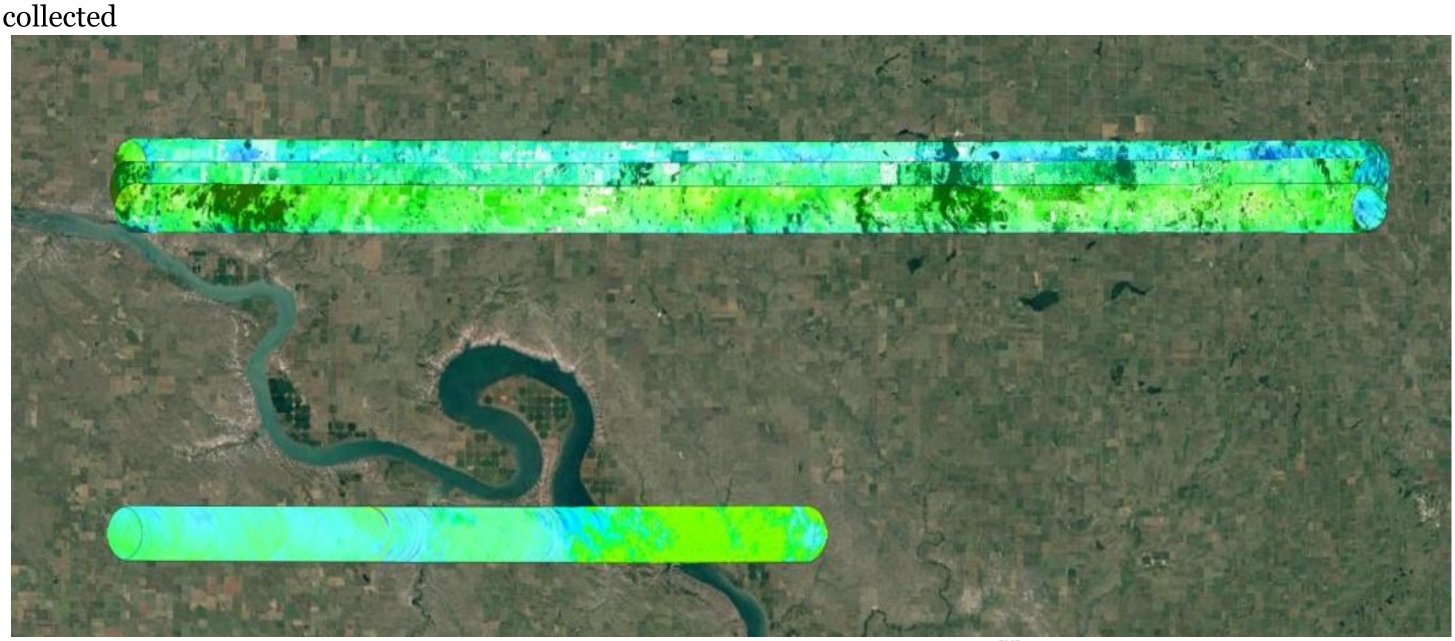
Brick 6
Sortie a03-s02-0100
06/01/2016

Map Run with Trajectory 4: Sortie a03-s02-0100

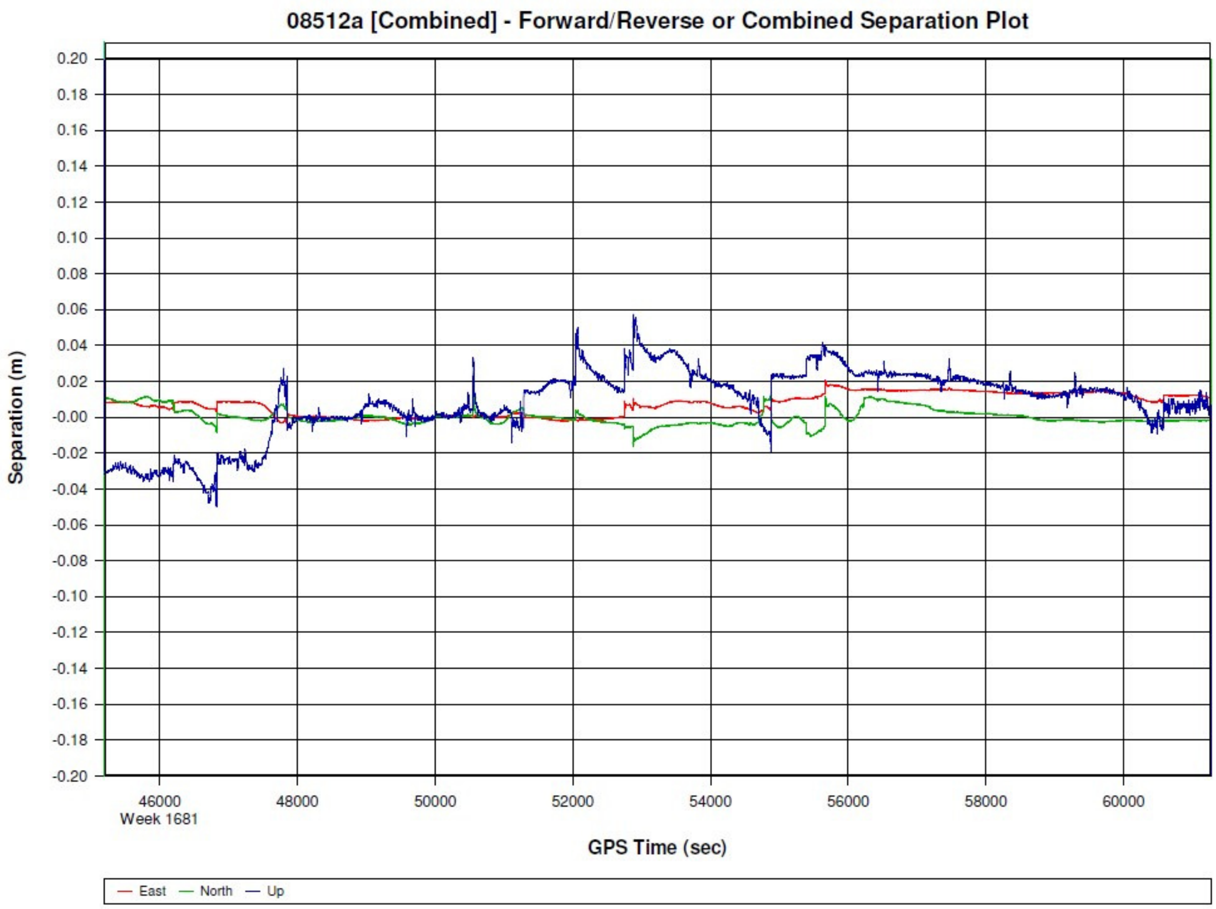


Swath Width, Waterfall View 4: Sortie a03-s02-0100

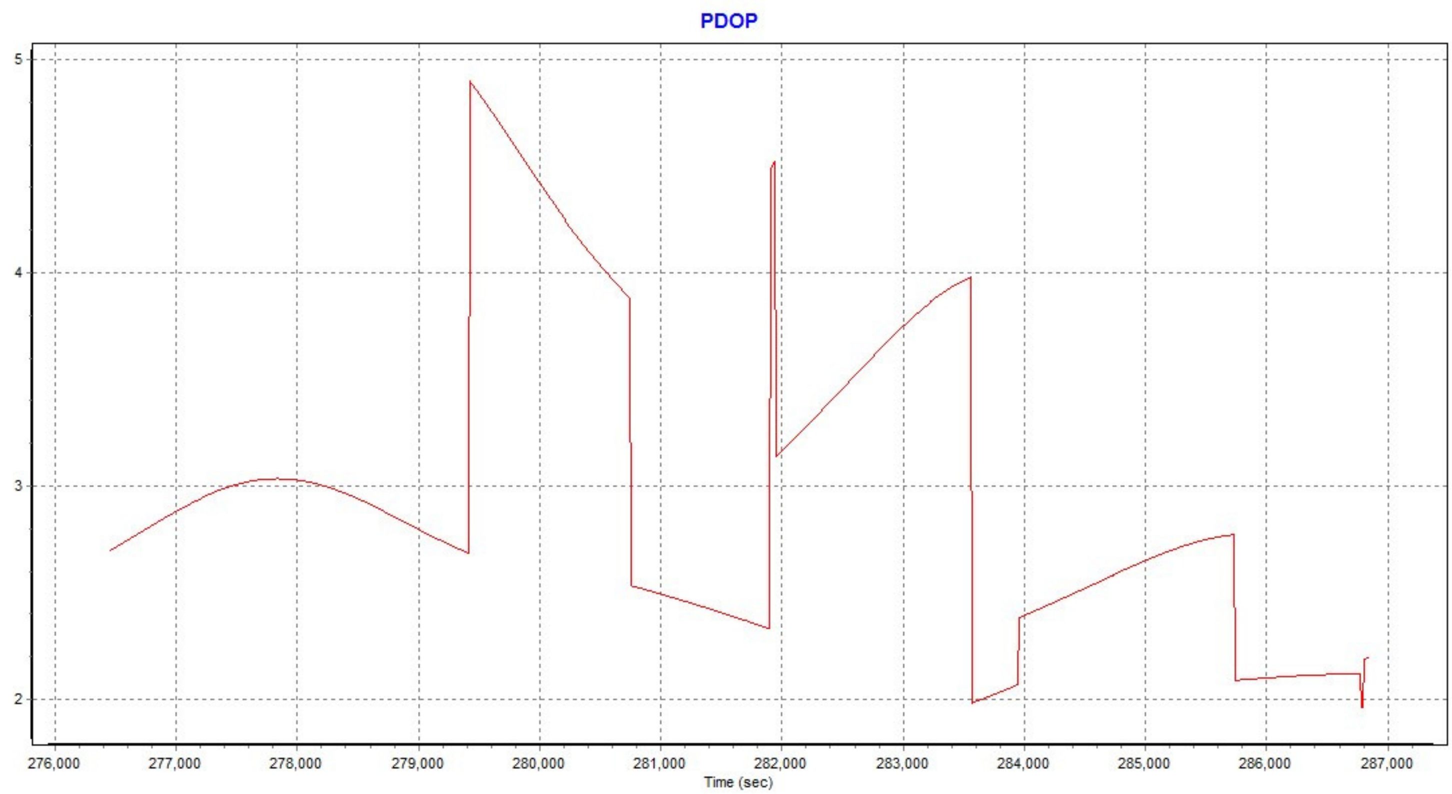
Mission aborted due to cloud cover, see Southern waterfall. North region clear early on. Three lines successfully collected



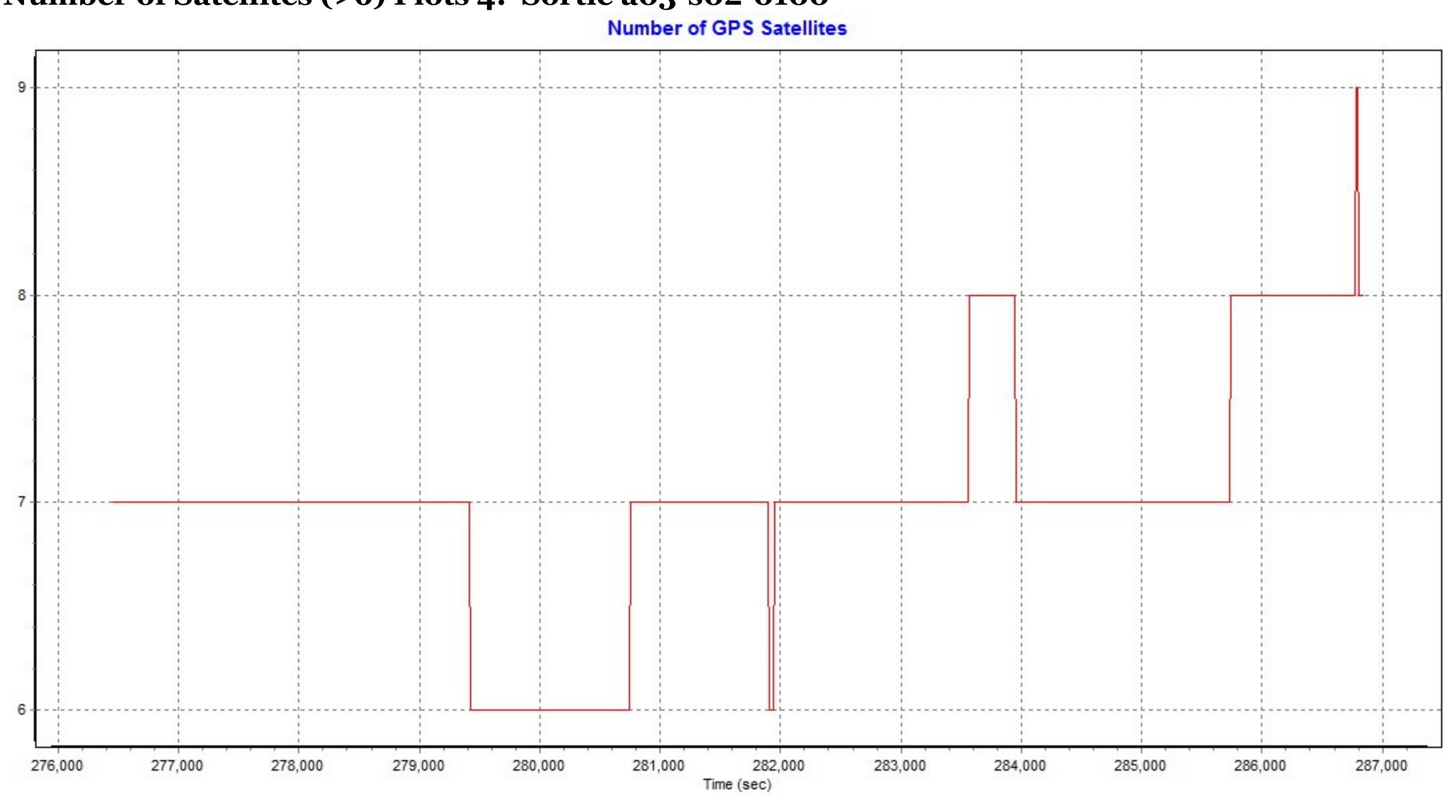
Combined SBET IAKAR Separation 4: Sortie a03-s02-0100



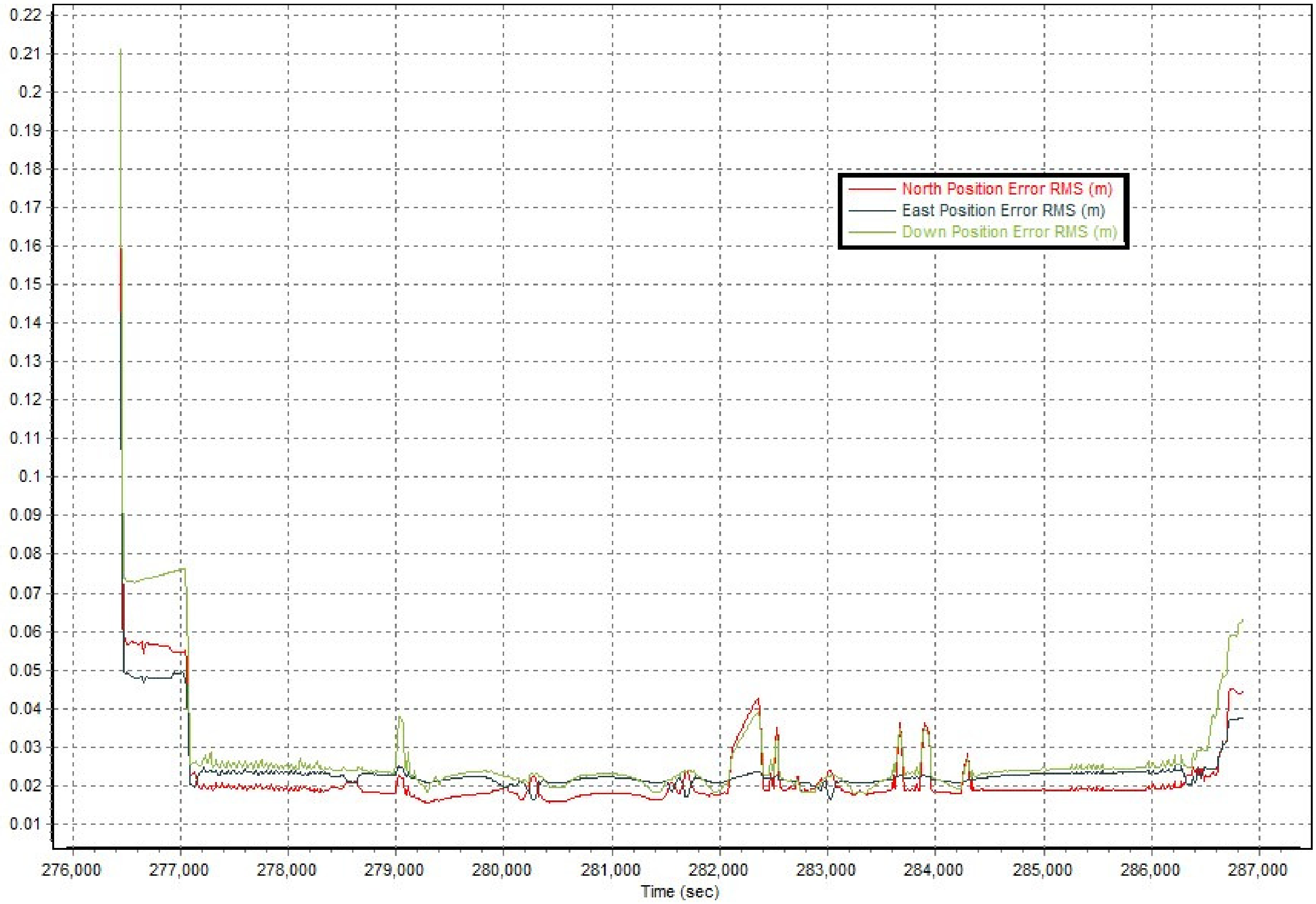
PDOP Plots 4: Sortie a03-s02-0100



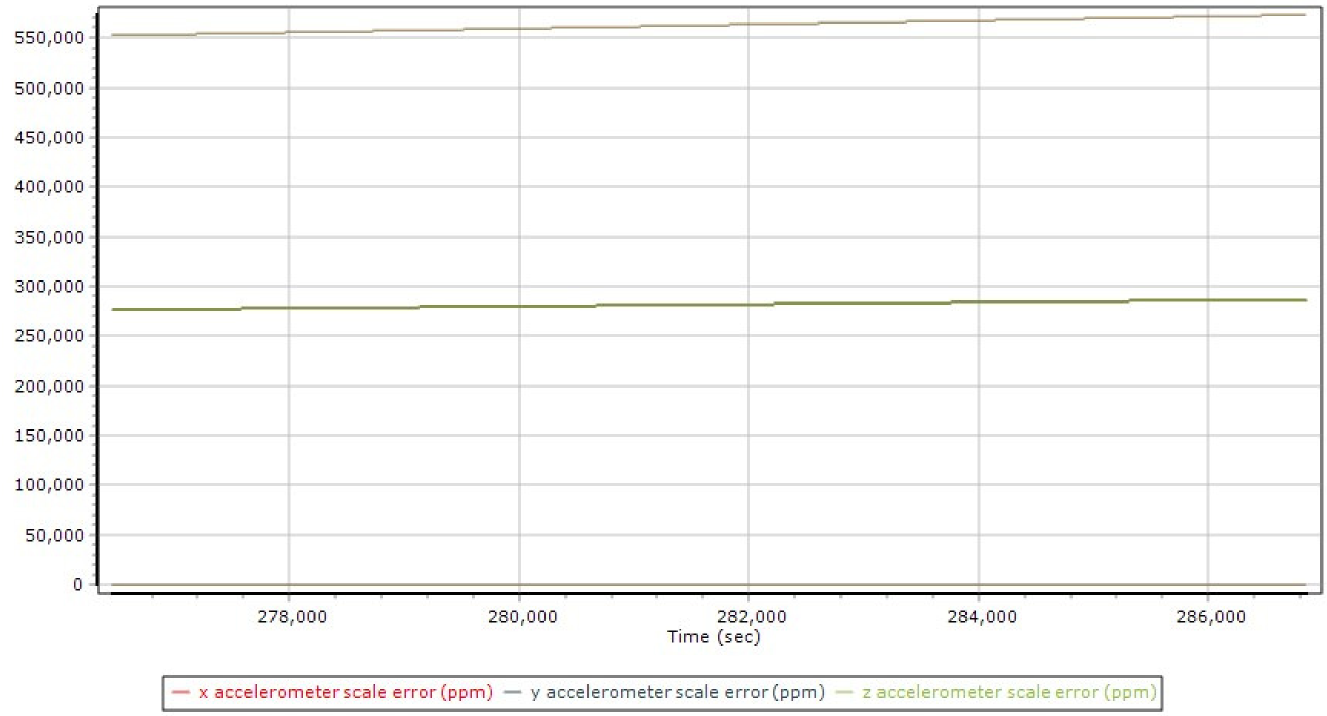
Number of Satellites (>6) Plots 4: Sortie a03-s02-0100



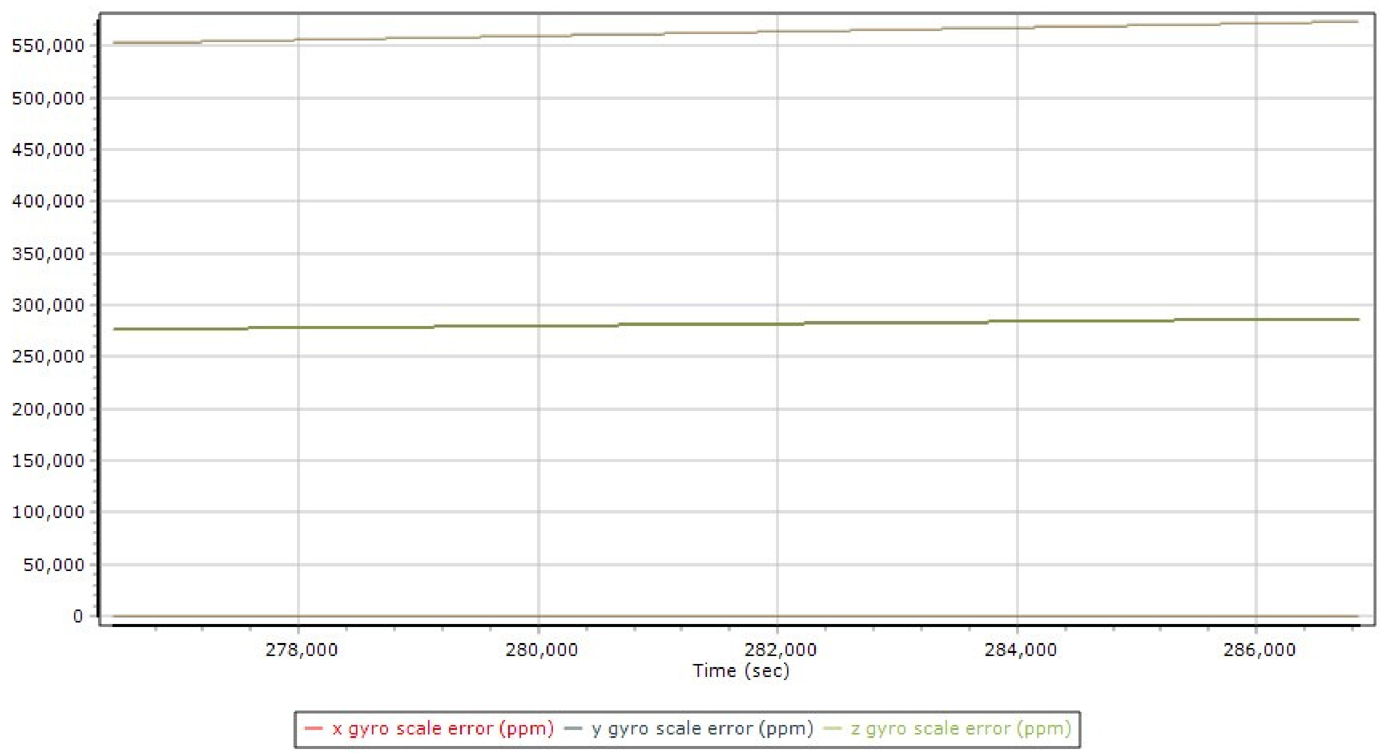
Sensor Position Error RMS (m) Plots 4: Sortie a03-s02-0100



Accelerometer Scale Error (ppm) Plots 4: Sortie a03-s02-0100



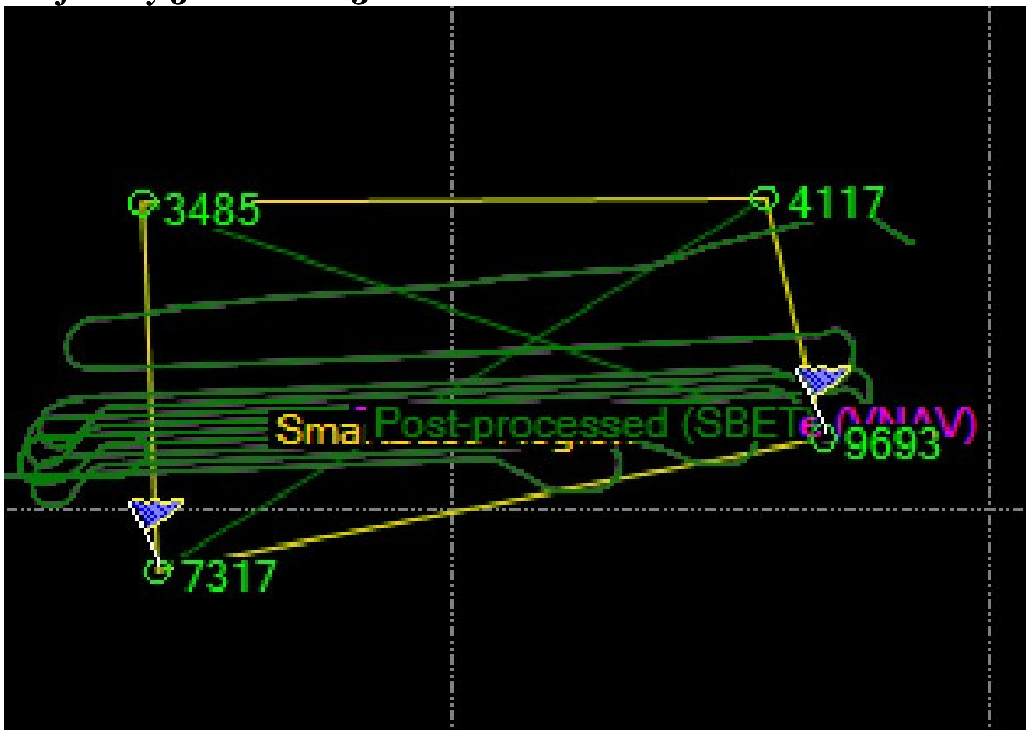
Gyro Scale Error (ppm) Plots 4: Sortie a03-s02-0100



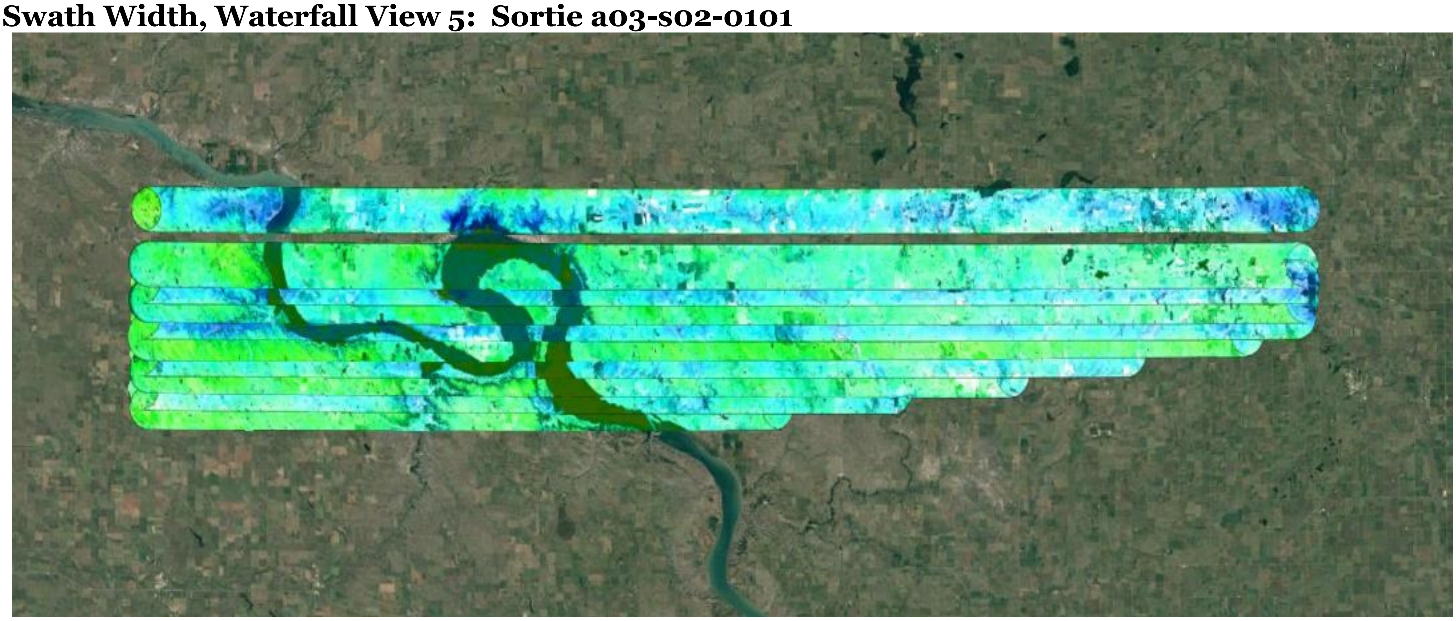
COLLECTION 5

Brick 6
Sortie a03-s02-0101
06/02/2016

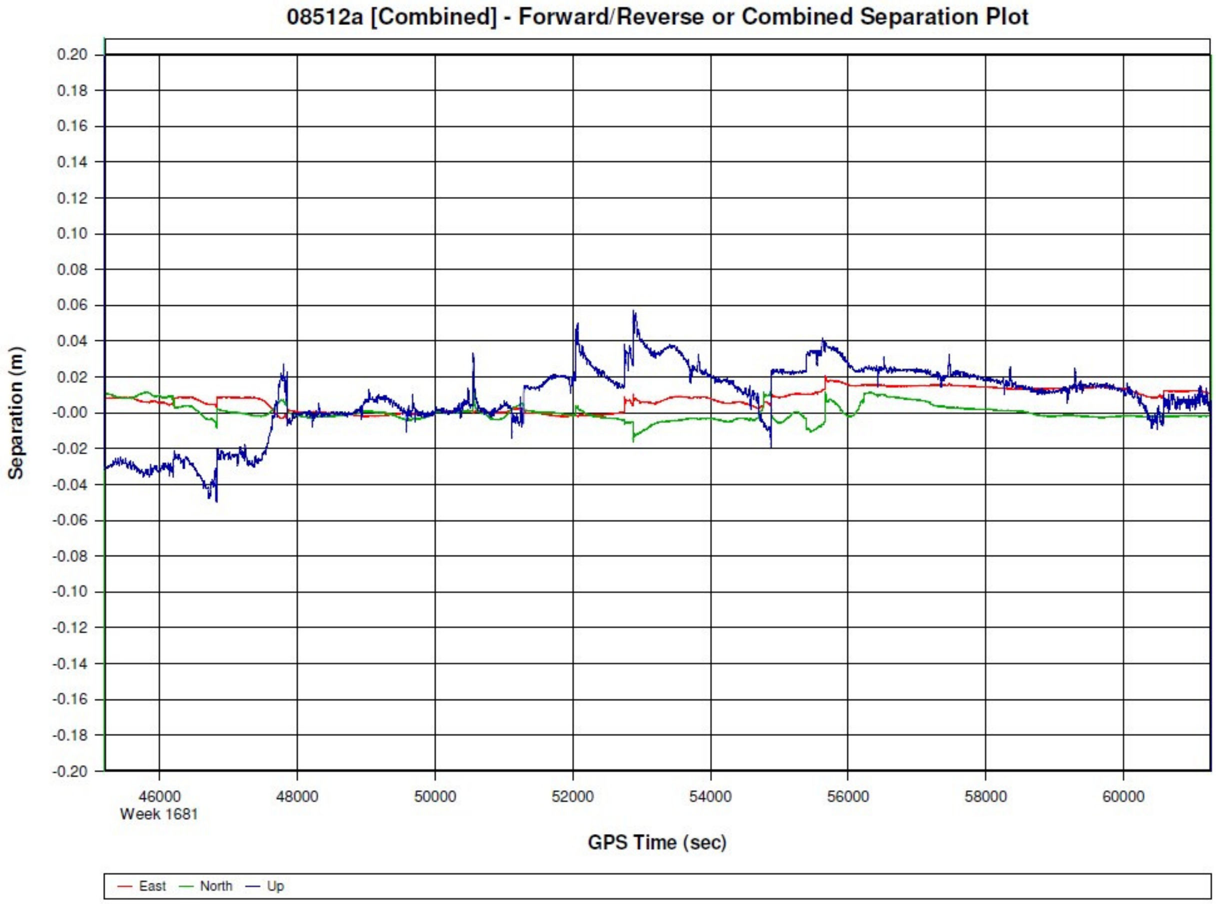
Map Run with Trajectory 5: Sortie a03-s02-0101



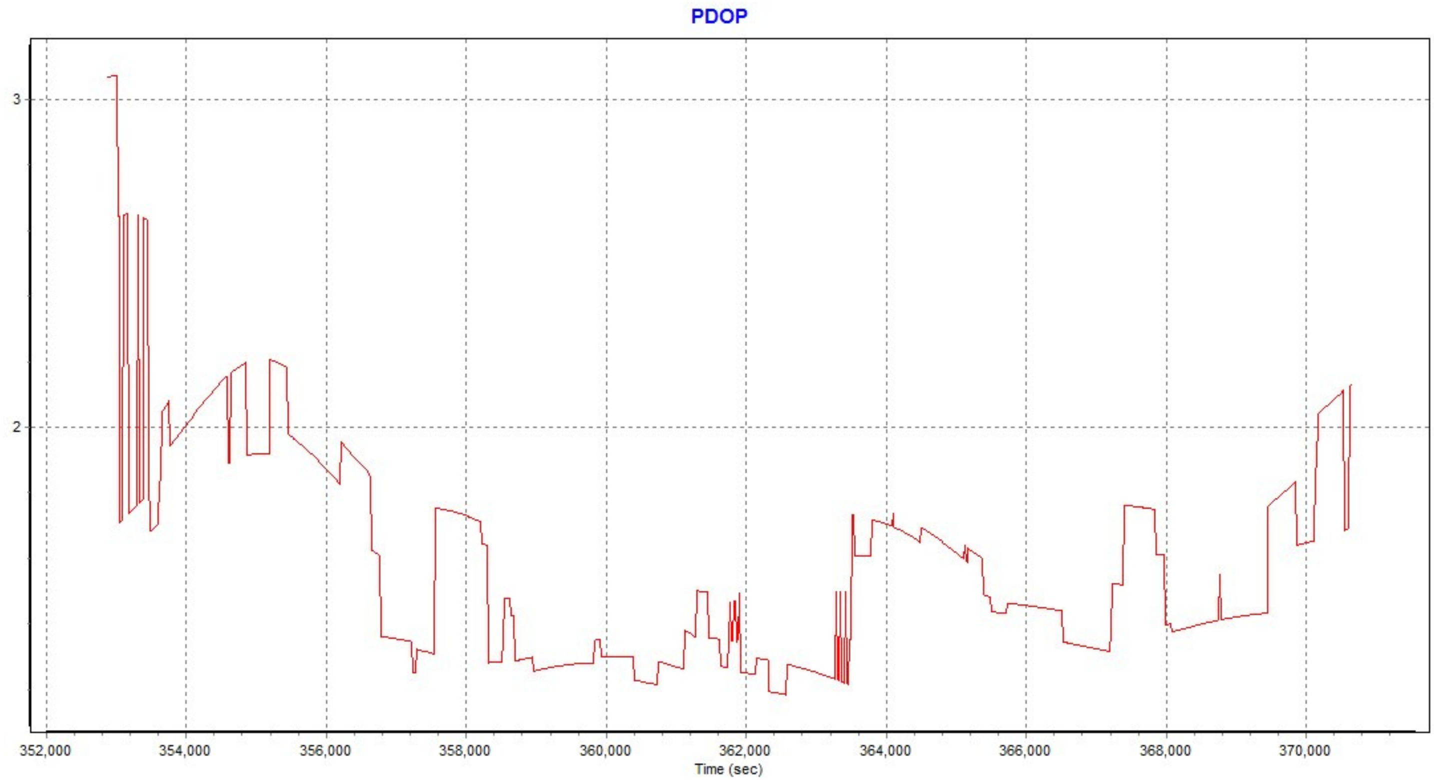
Swath Width, Waterfall View 5: Sortie a03-s02-0101



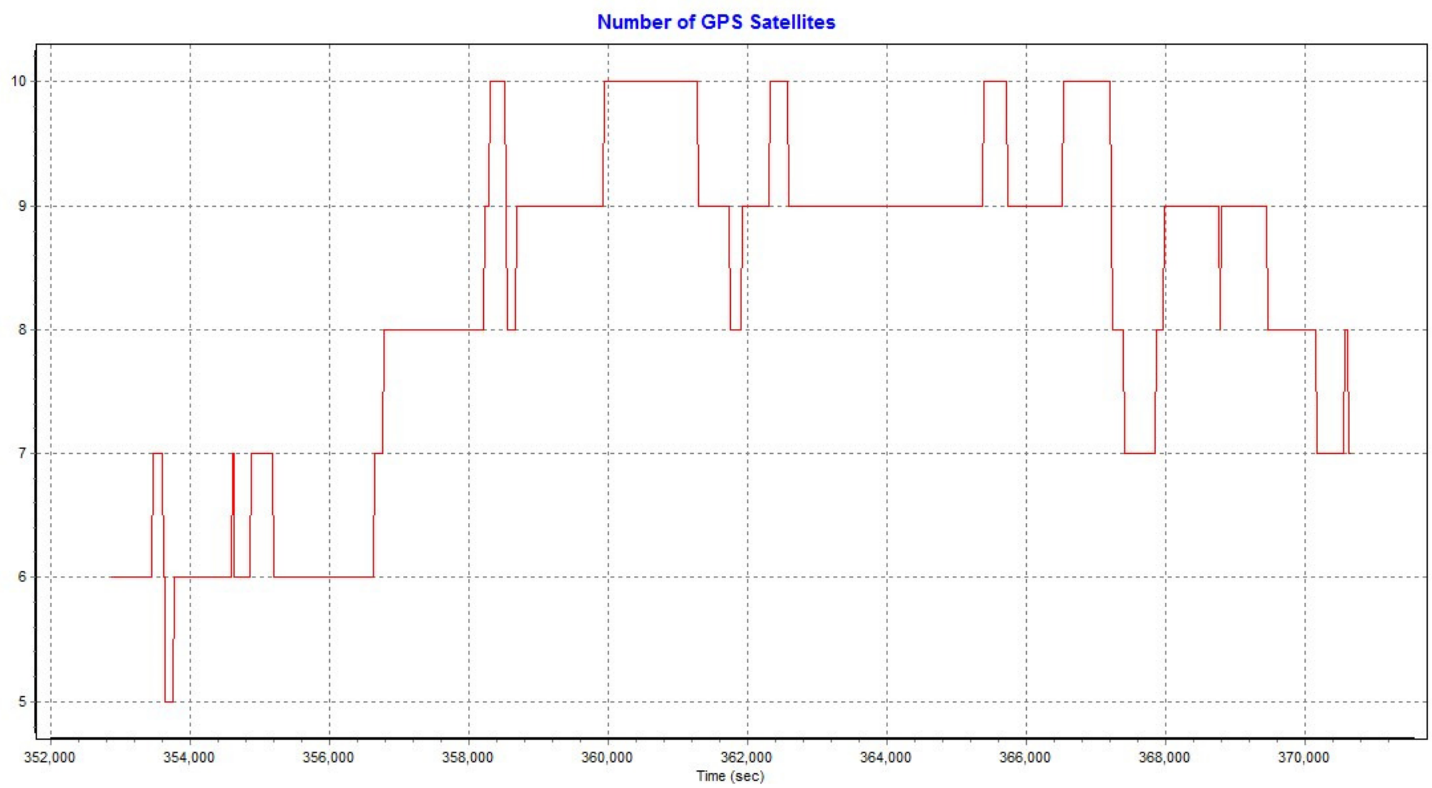
Combined Separation 5: Sortie a03-s02-0101



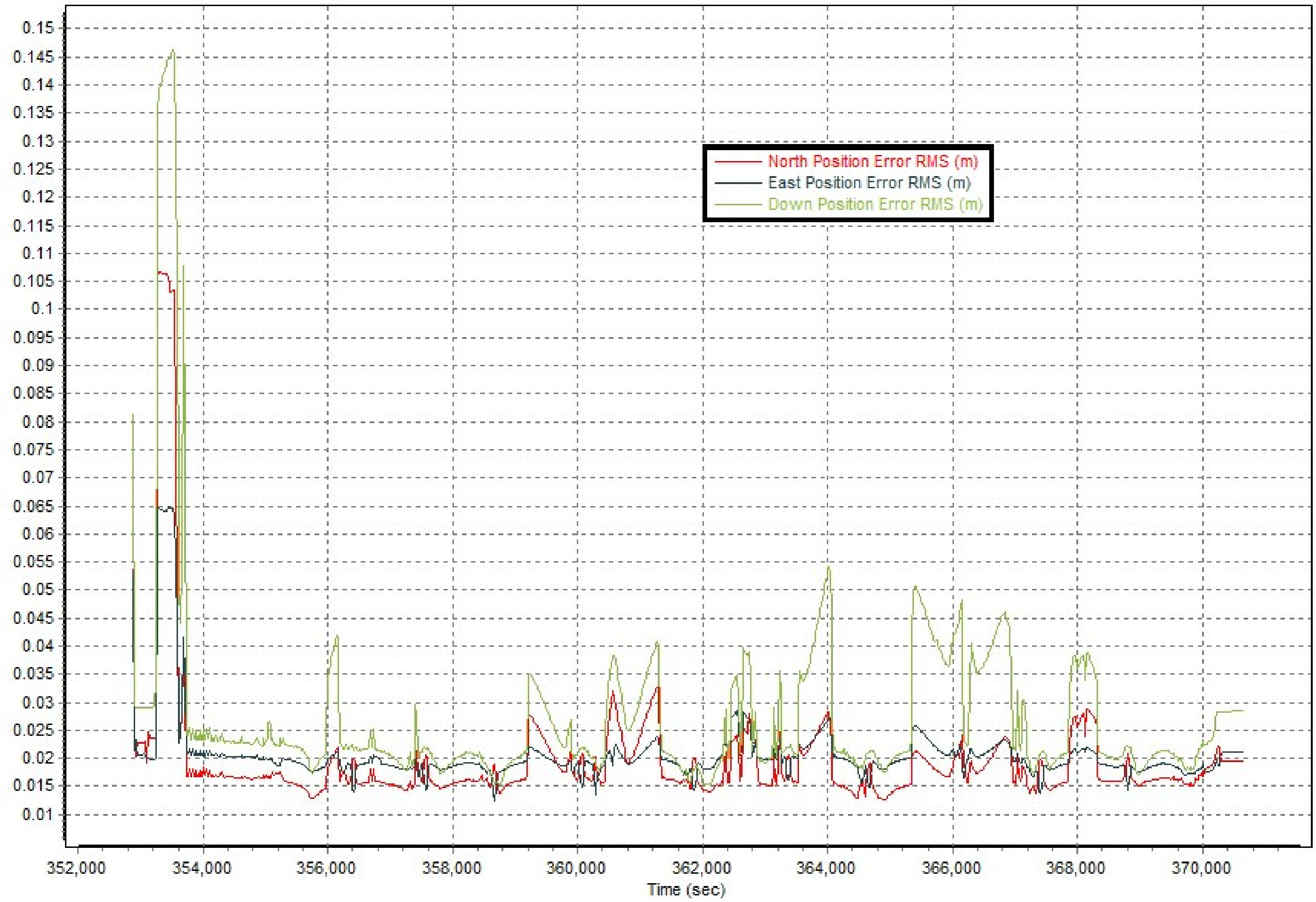
PDOP Plots 5: Sortie a03-s02-0101



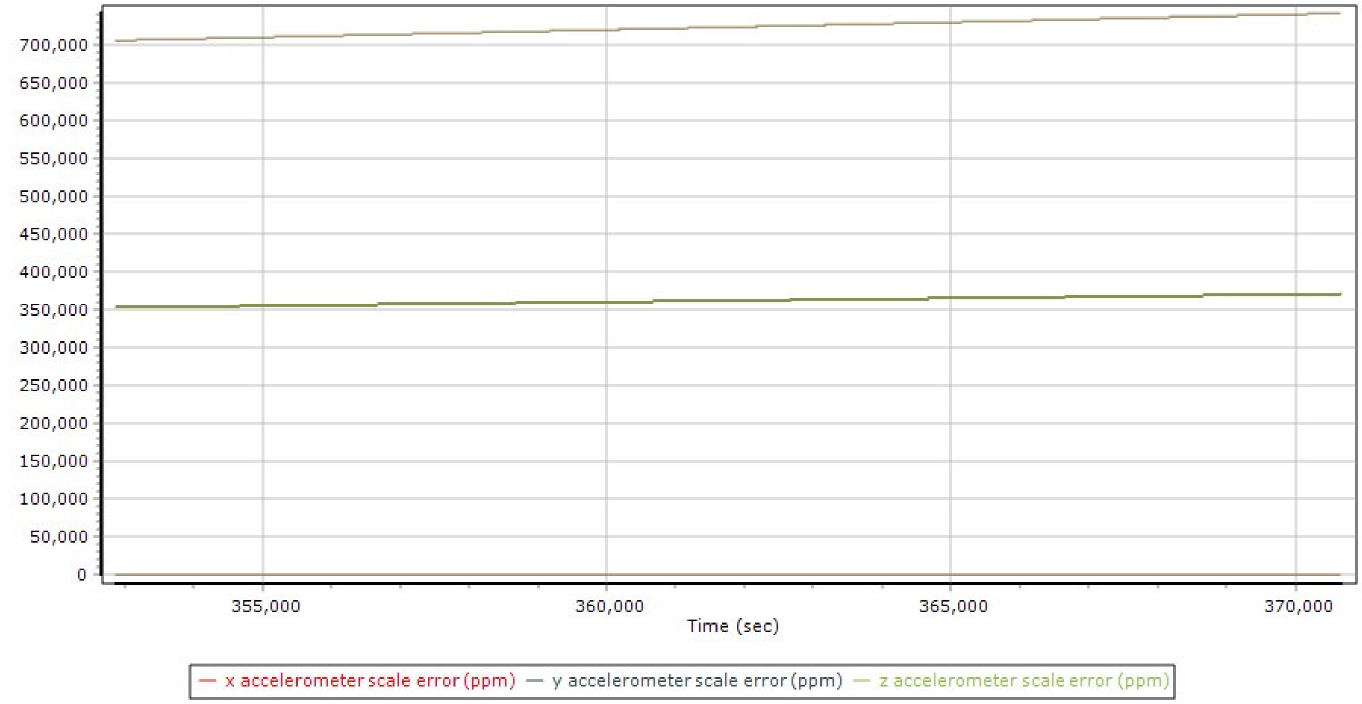
Number of Satellites (>6) Plots 5: Sortie a03-s02-0101



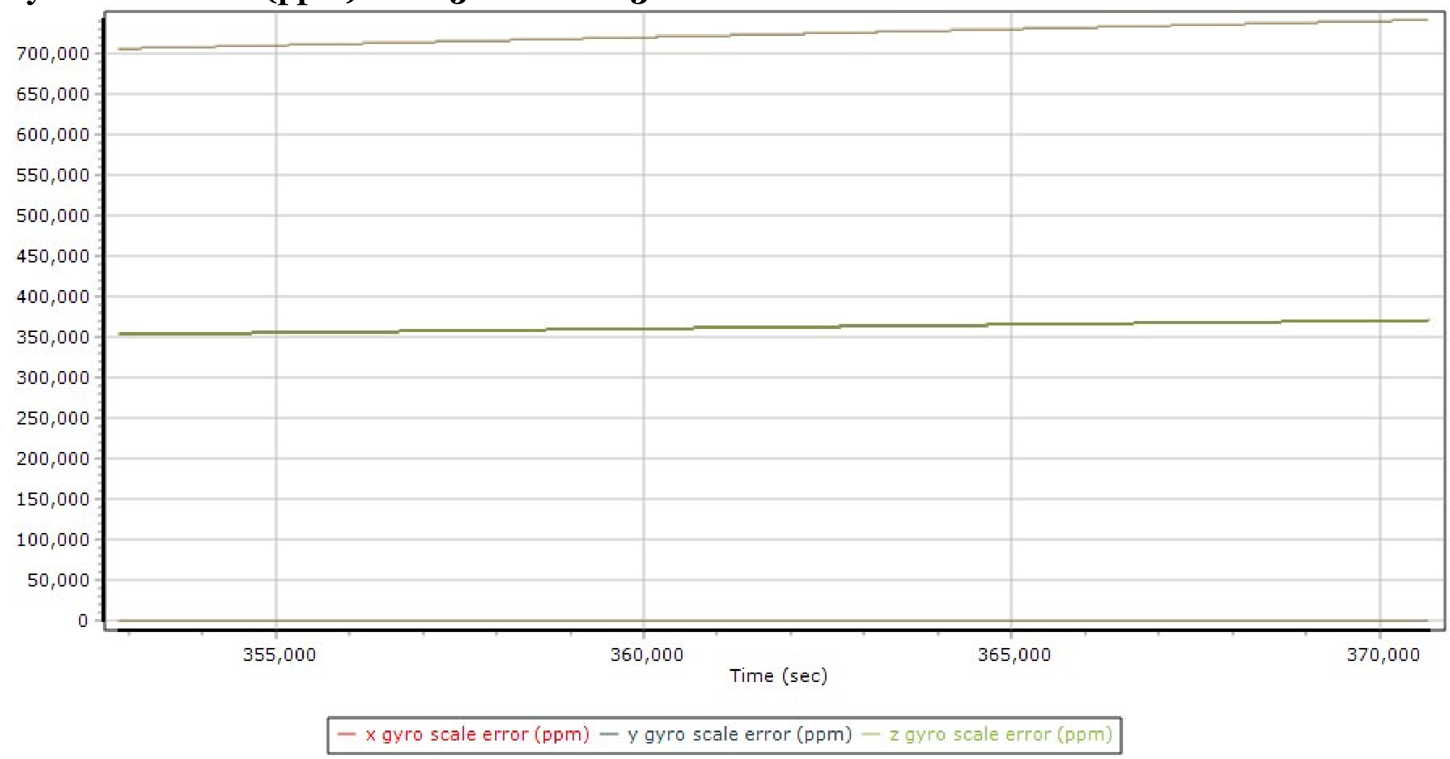
Sensor Position Error RMS (m) Plots 5: Sortie a03-s02-0101



Accelerometer Scale Error (ppm) Plots 5: Sortie a03-s02-0101



Gyro Scale Error (ppm) Plots 5: Sortie a03-s02-0101



COLLECTION 6

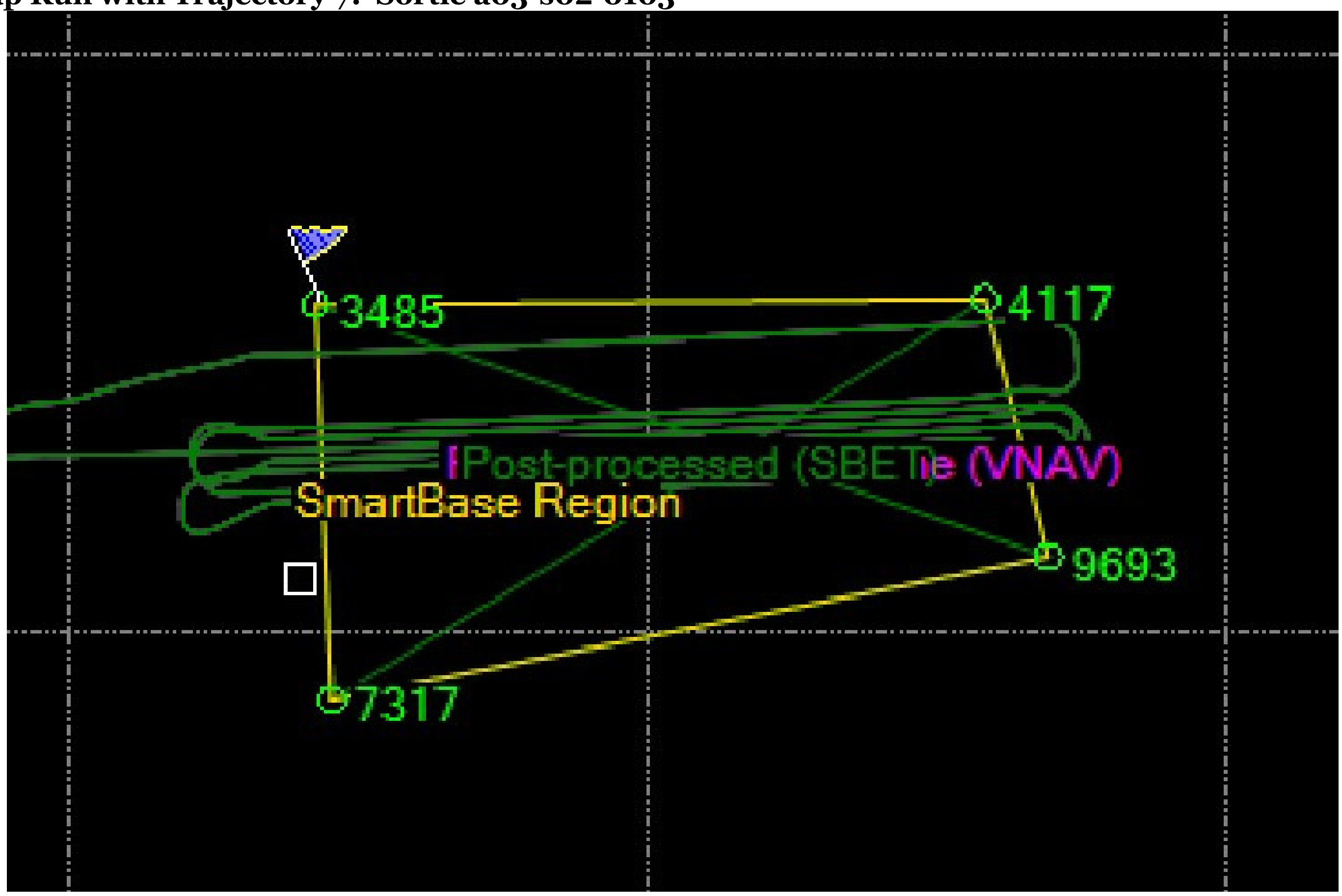
Brick 6
Sortie a03-s02-0102
06/02/2016

Attempted collection however once onsite, cloud cover had moved into region thus suspending all collections.

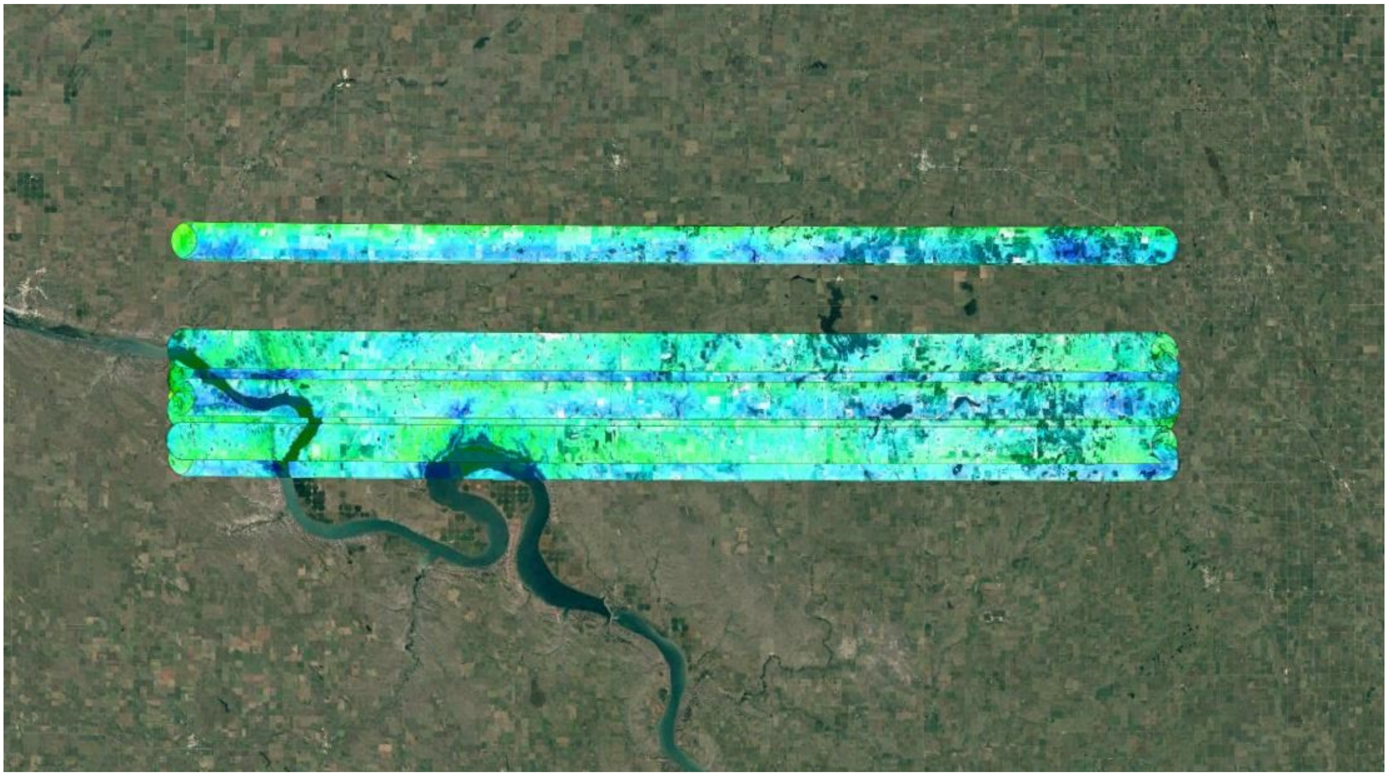
COLLECTION 7

Brick 6
Sortie a03-s02-0103
06/05/2016

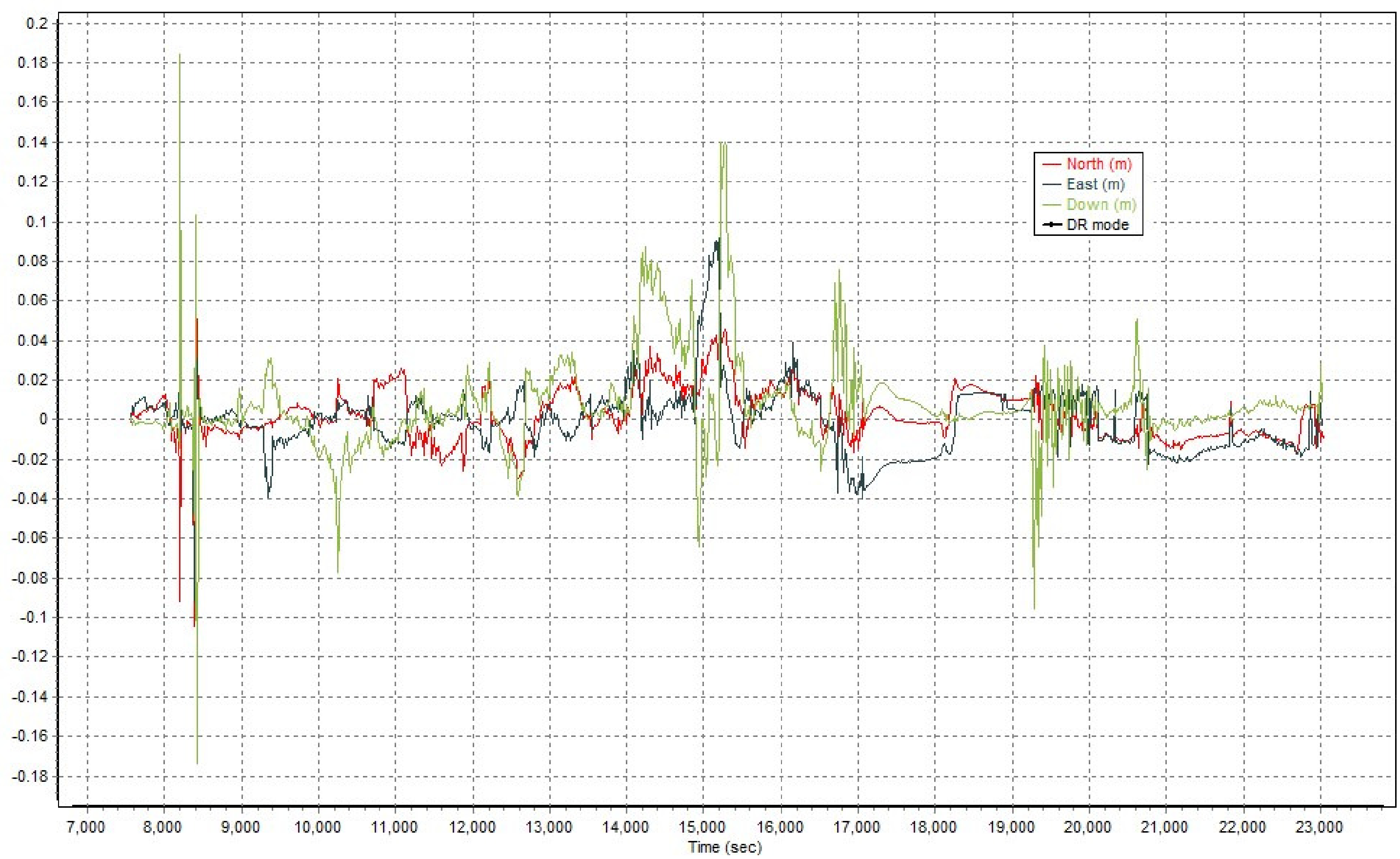
Map Run with Trajectory 7: Sortie a03-s02-0103



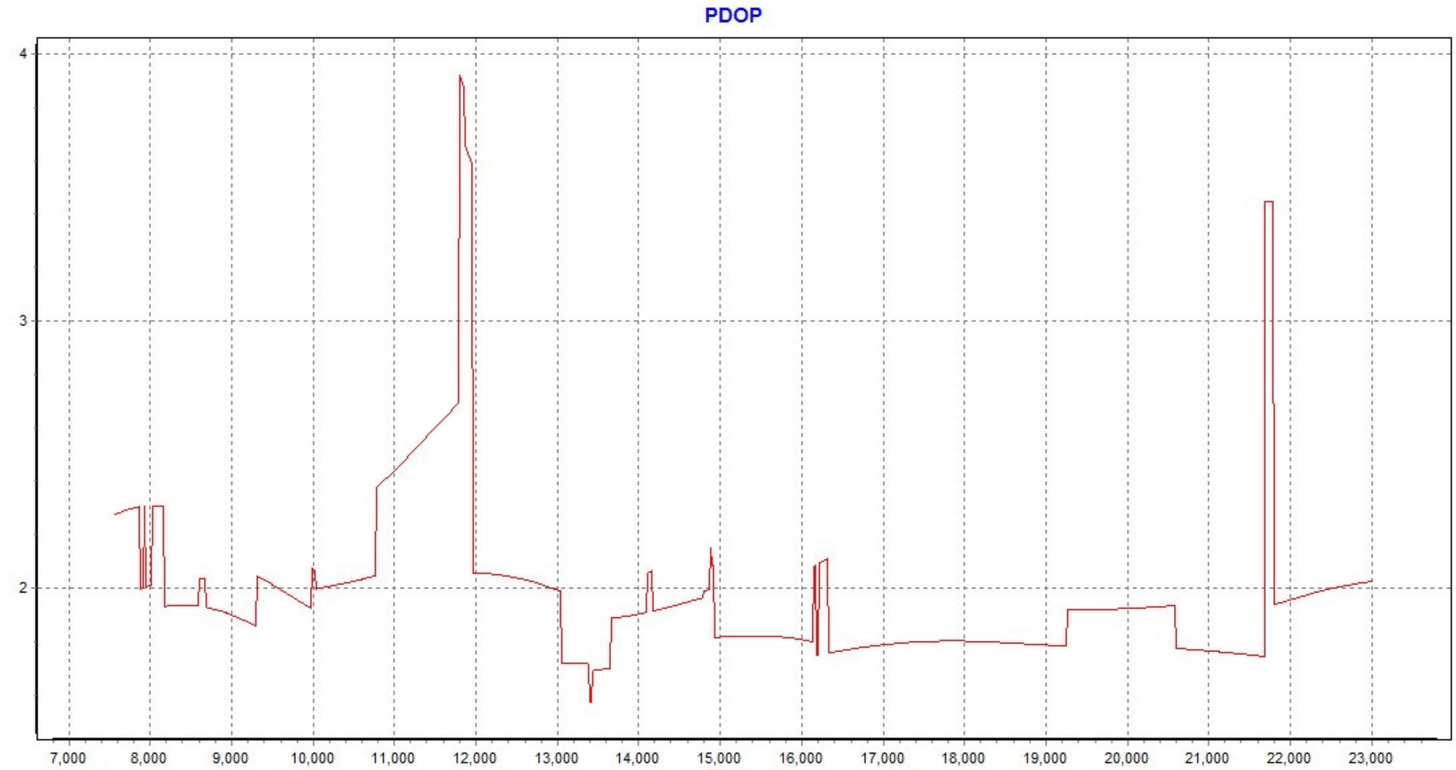
Swath Width, Waterfall View 7: Sortie a03-s02-0103



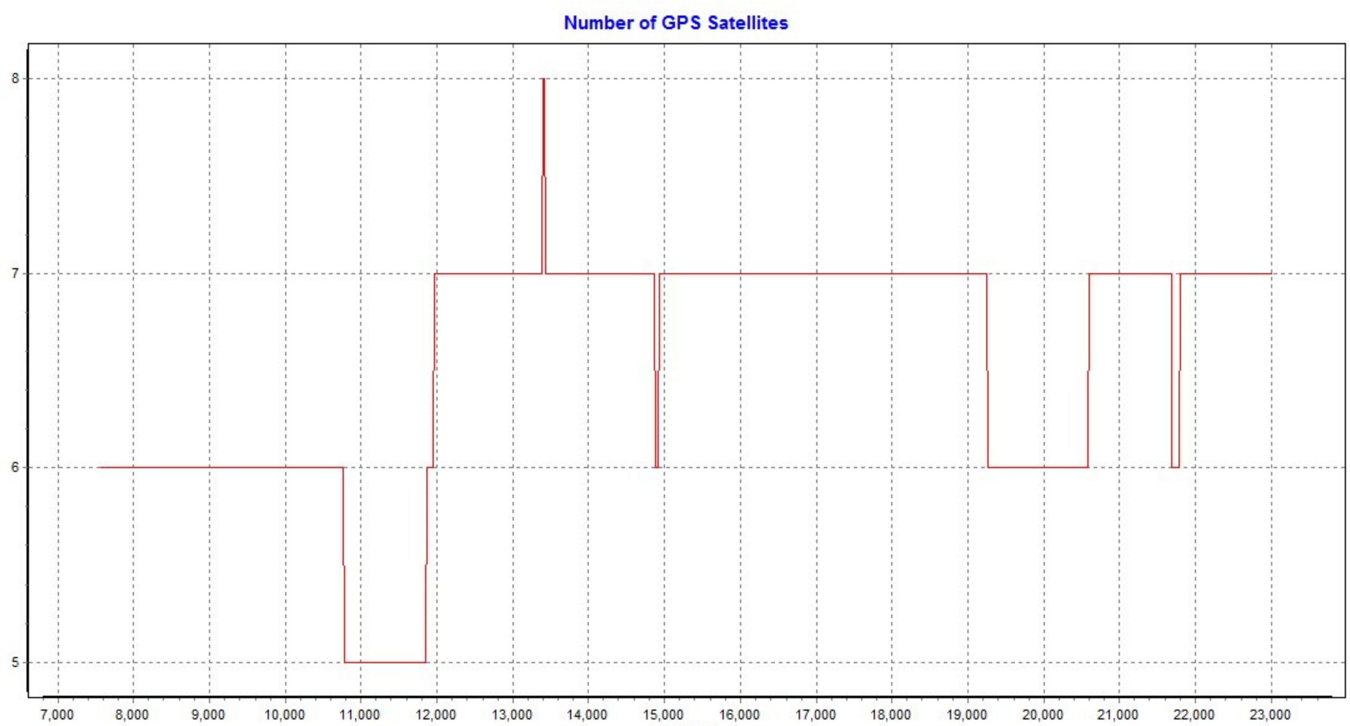
Combined SBET IAKAR Separation 7: Sortie a03-s02-0103



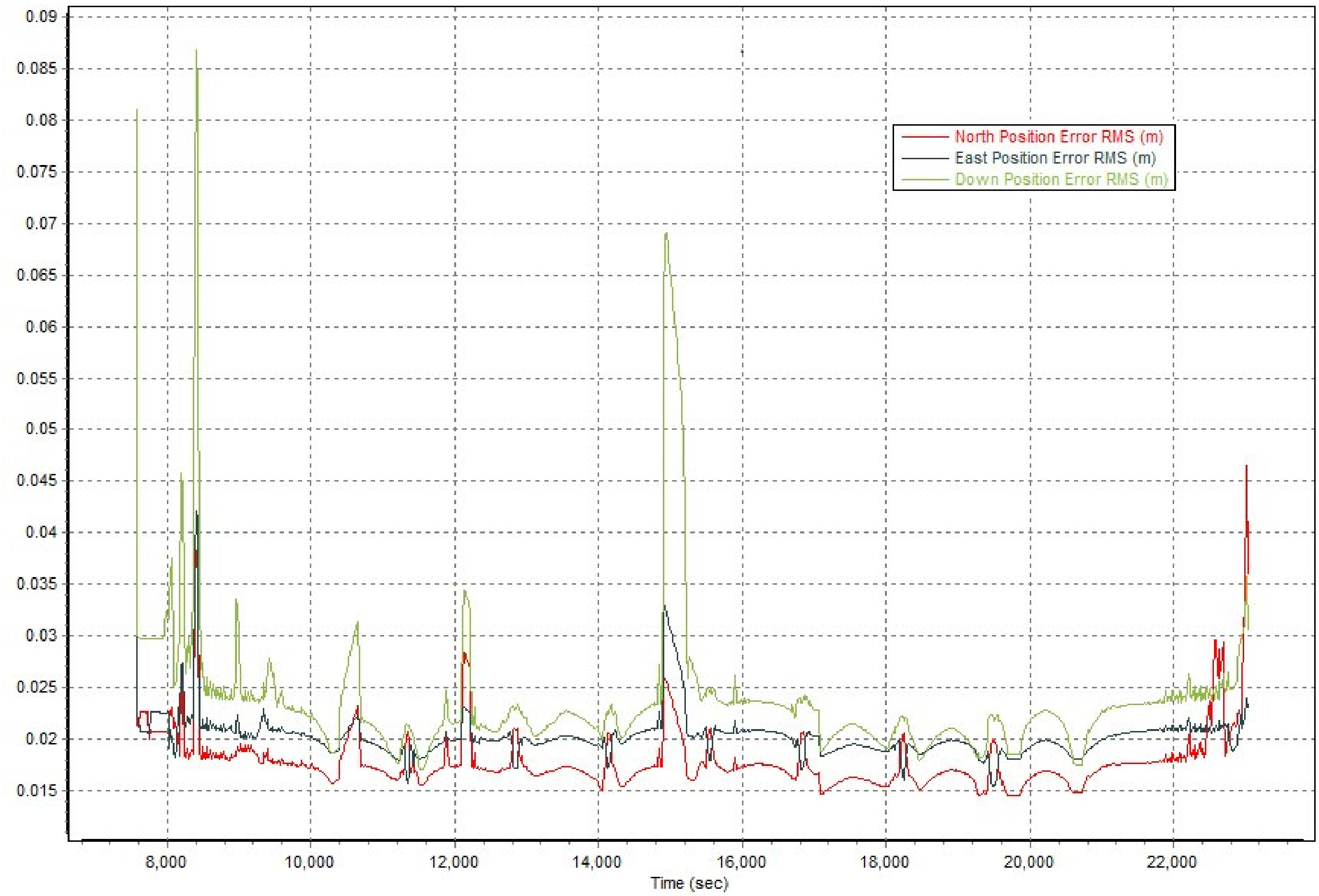
PDOP Plots 7: Sortie a03-s02-0103



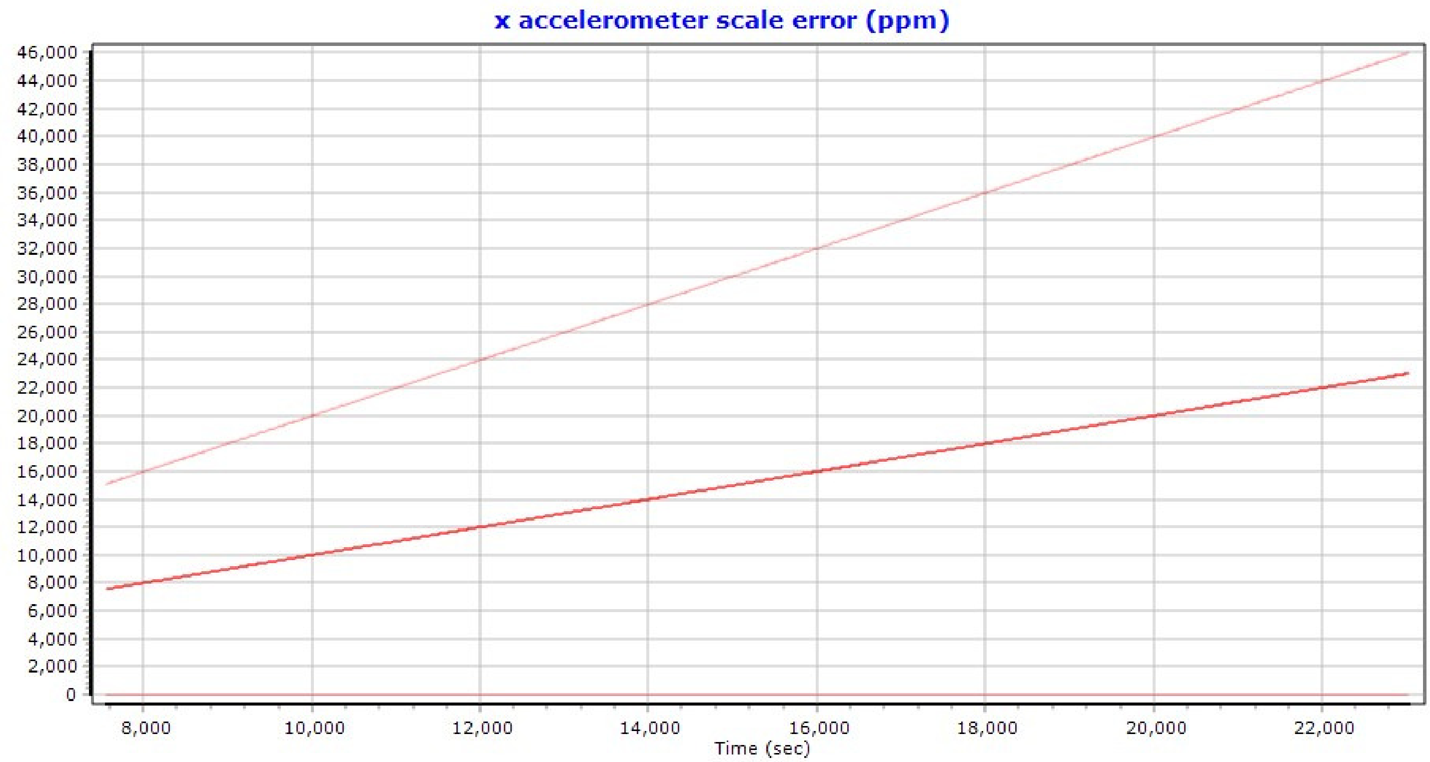
Number of Satellites (>6) Plots 7: Sortie a03-s02-0103



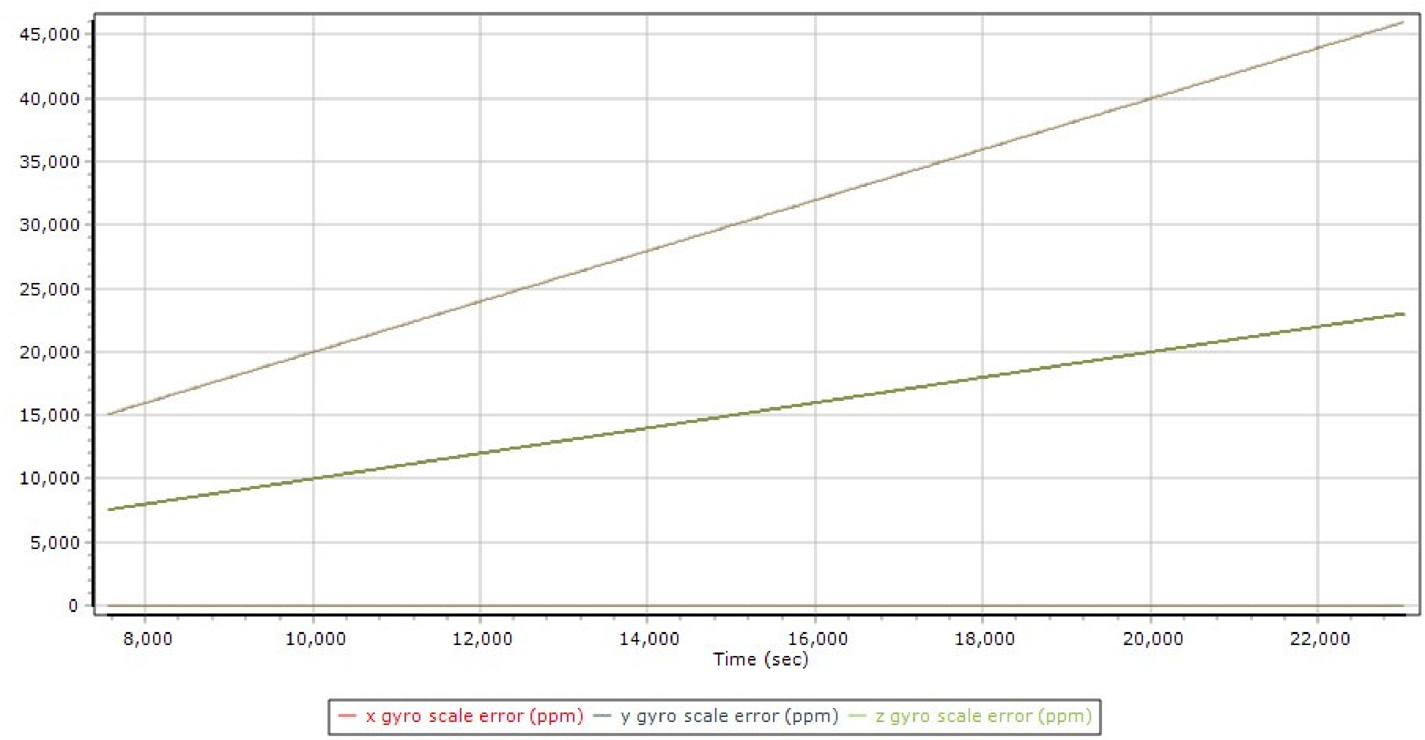
Sensor Position Error RMS (m) Plots 7: Sortie a03-s02-0103



Accelerometer Scale Error (ppm) Plots 7: Sortie a03-s02-0103



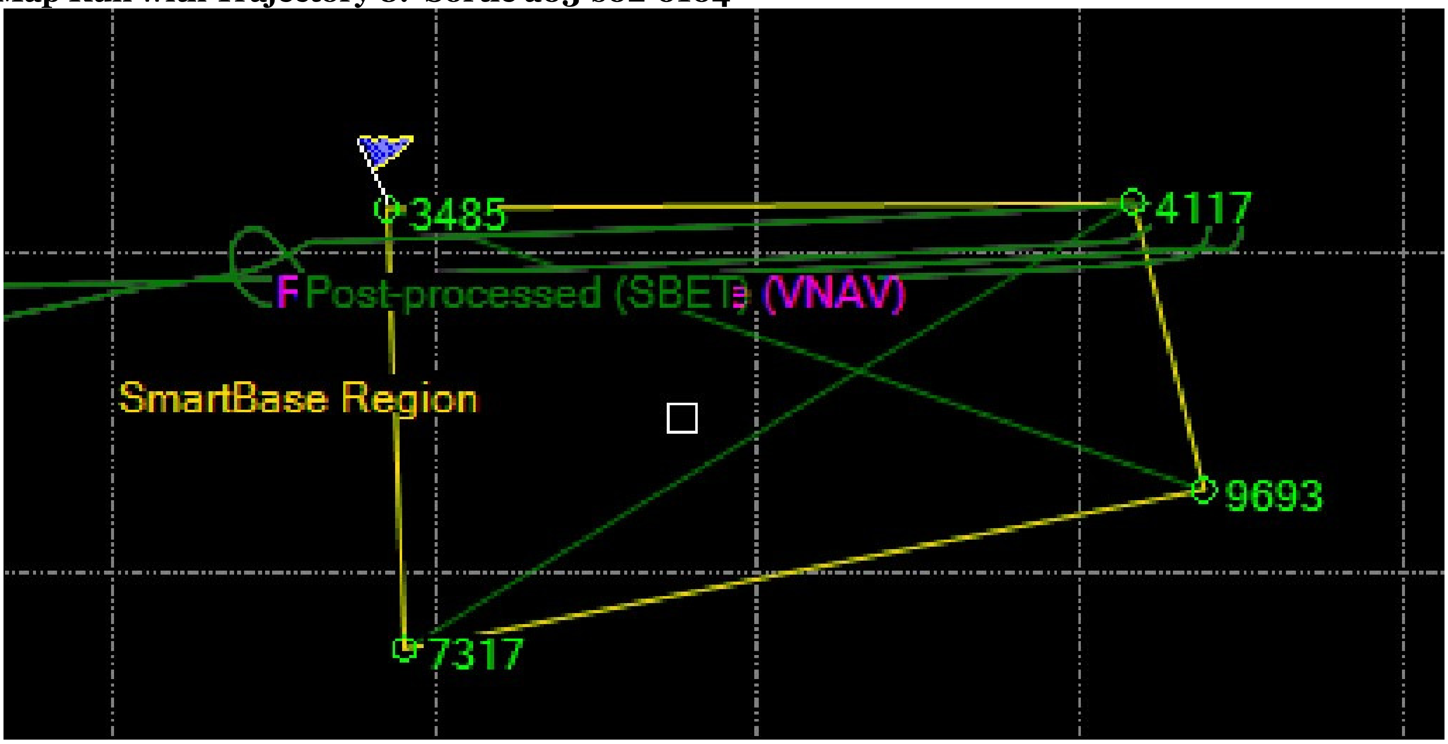
Gyro Scale Error (ppm) Plots 7: Sortie a03-s02-0103



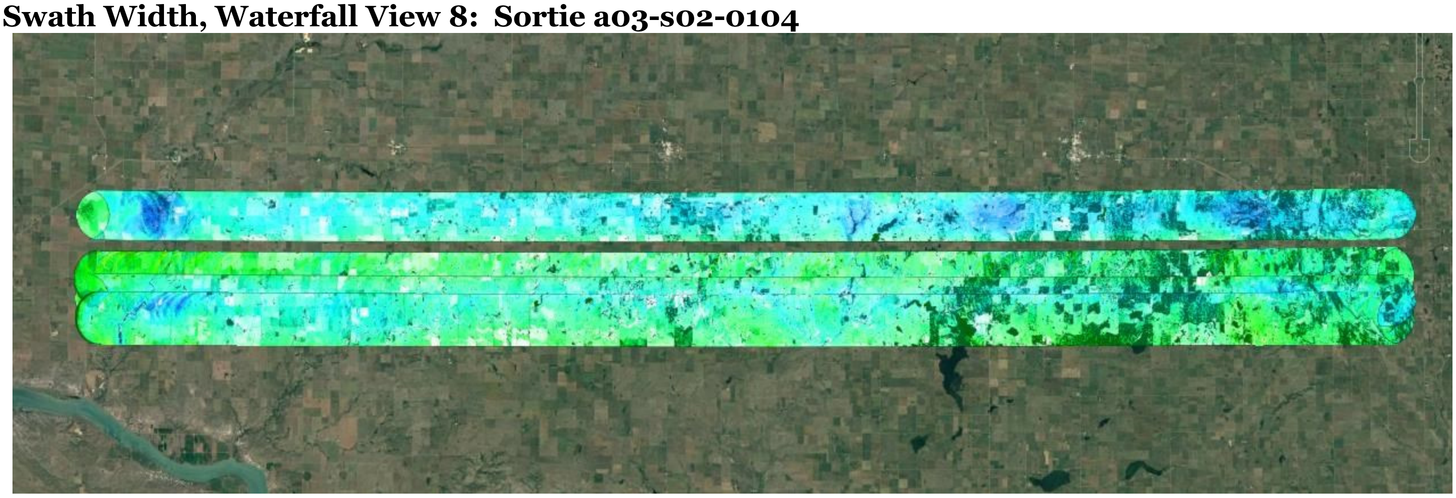
COLLECTION 8

Brick 6
Sortie a03-s02-0104
06/05/2016

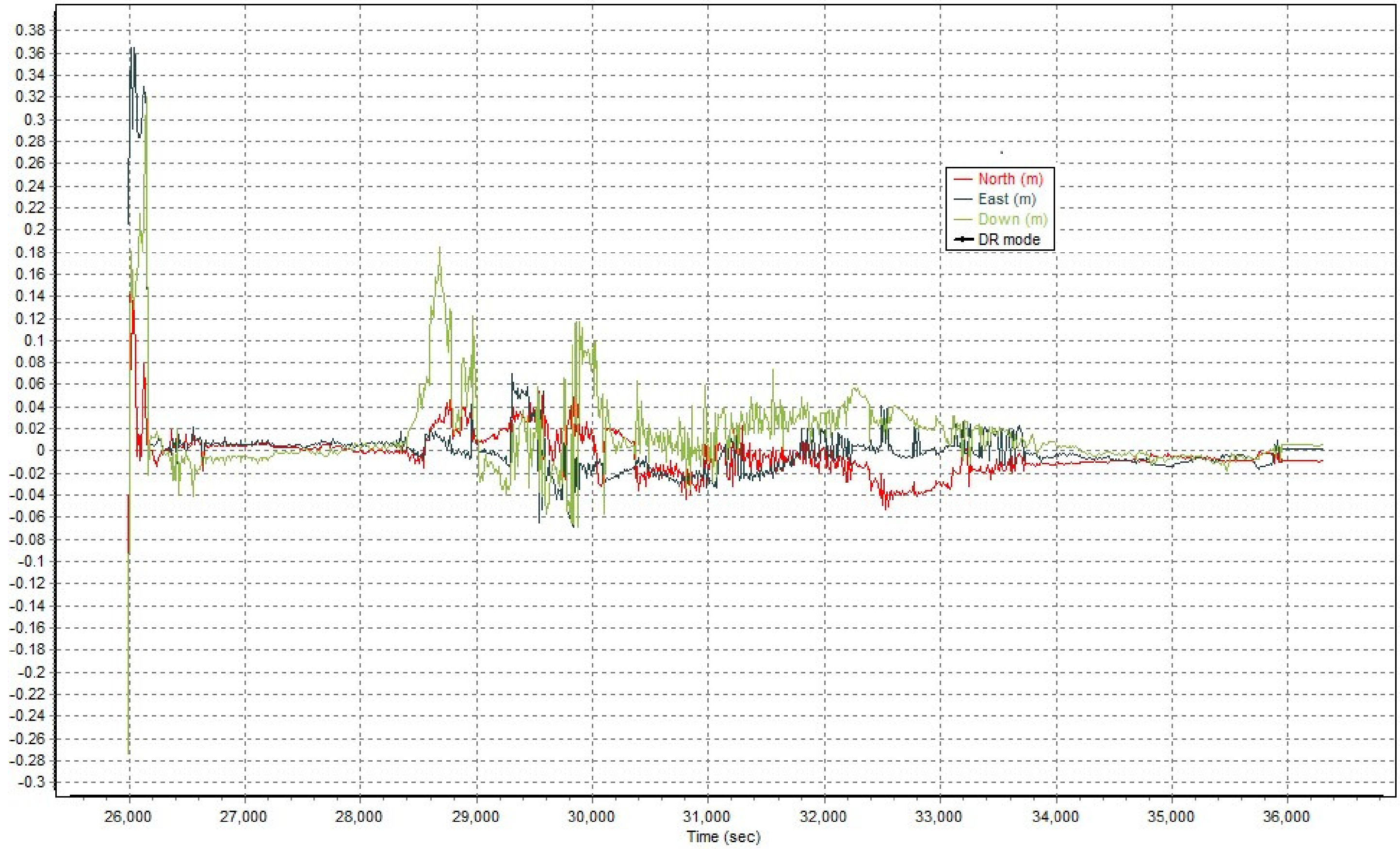
Map Run with Trajectory 8: Sortie a03-s02-0104



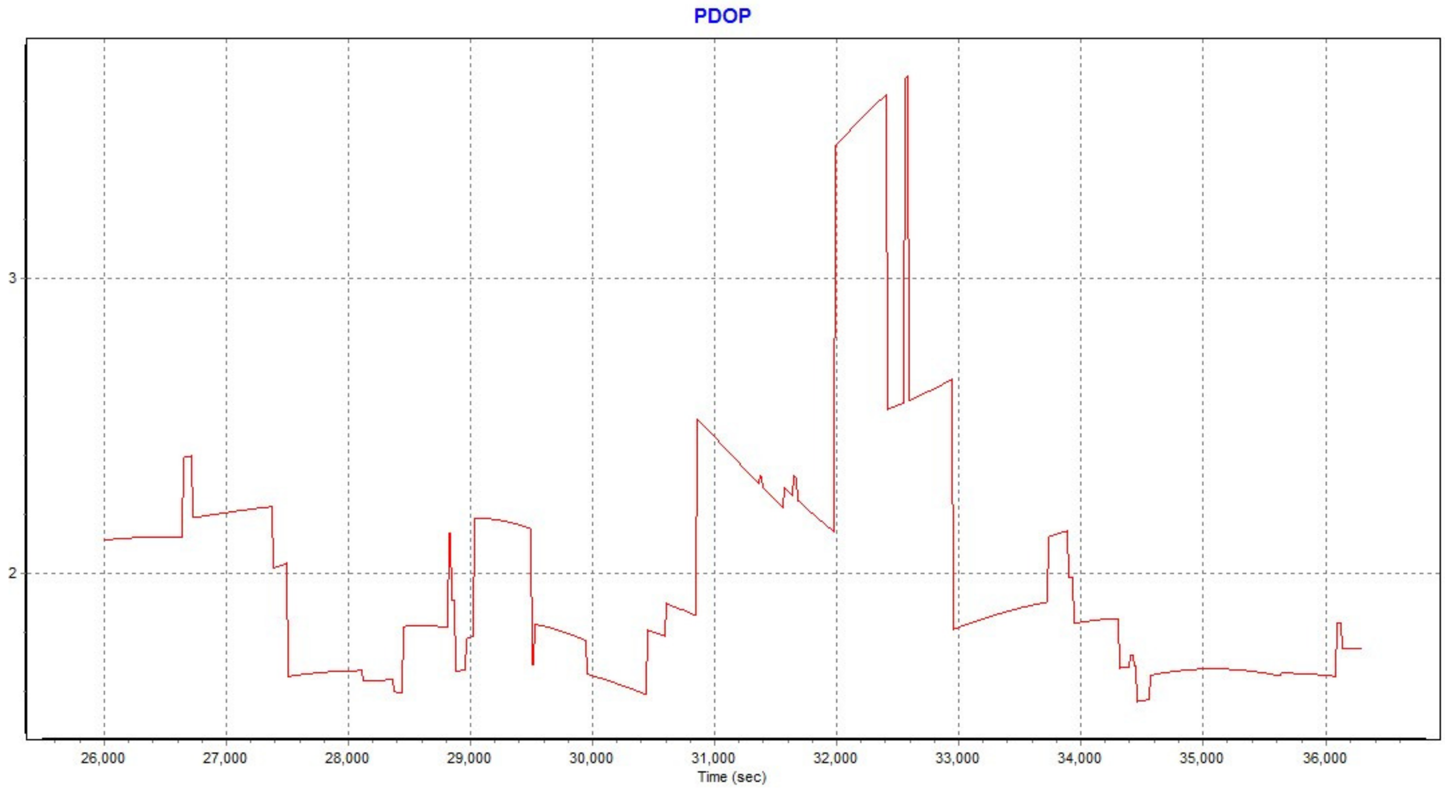
Swath Width, Waterfall View 8: Sortie a03-s02-0104



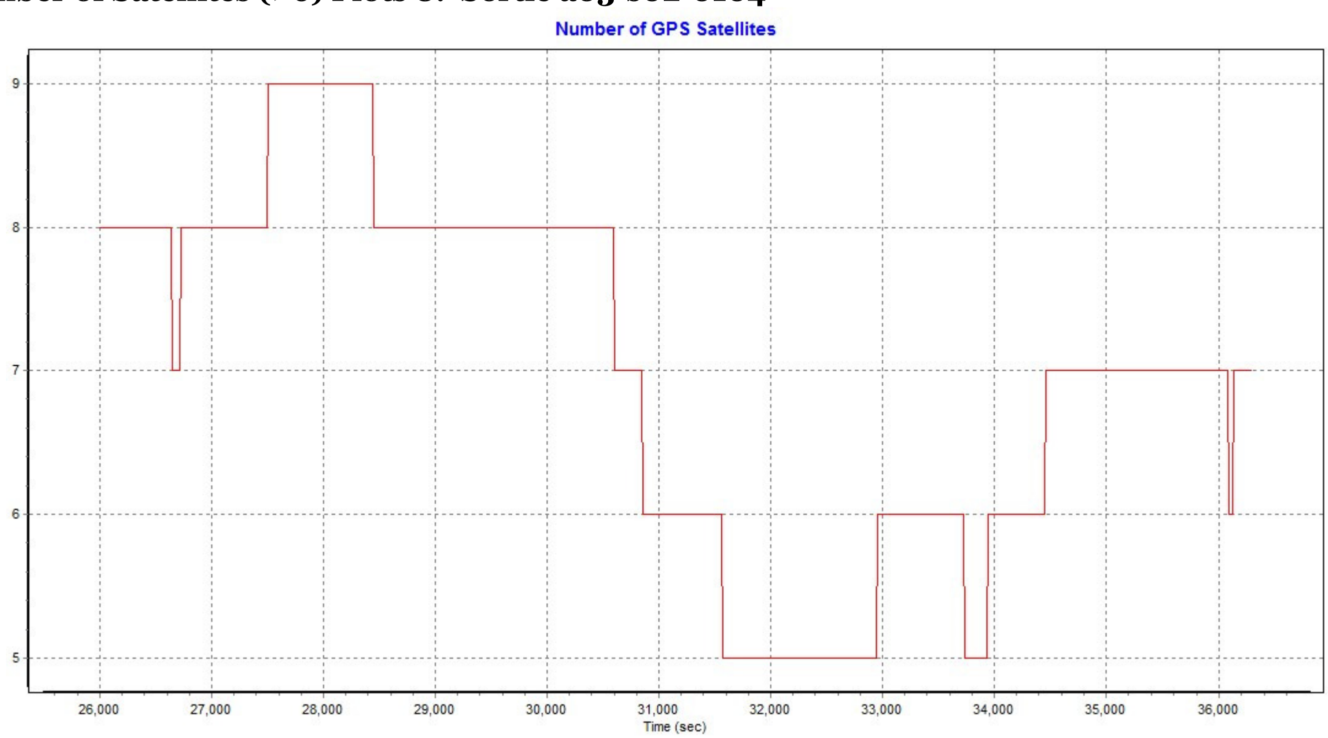
Combined SBET IAKAR Separation 8: Sortie a03-s02-0104



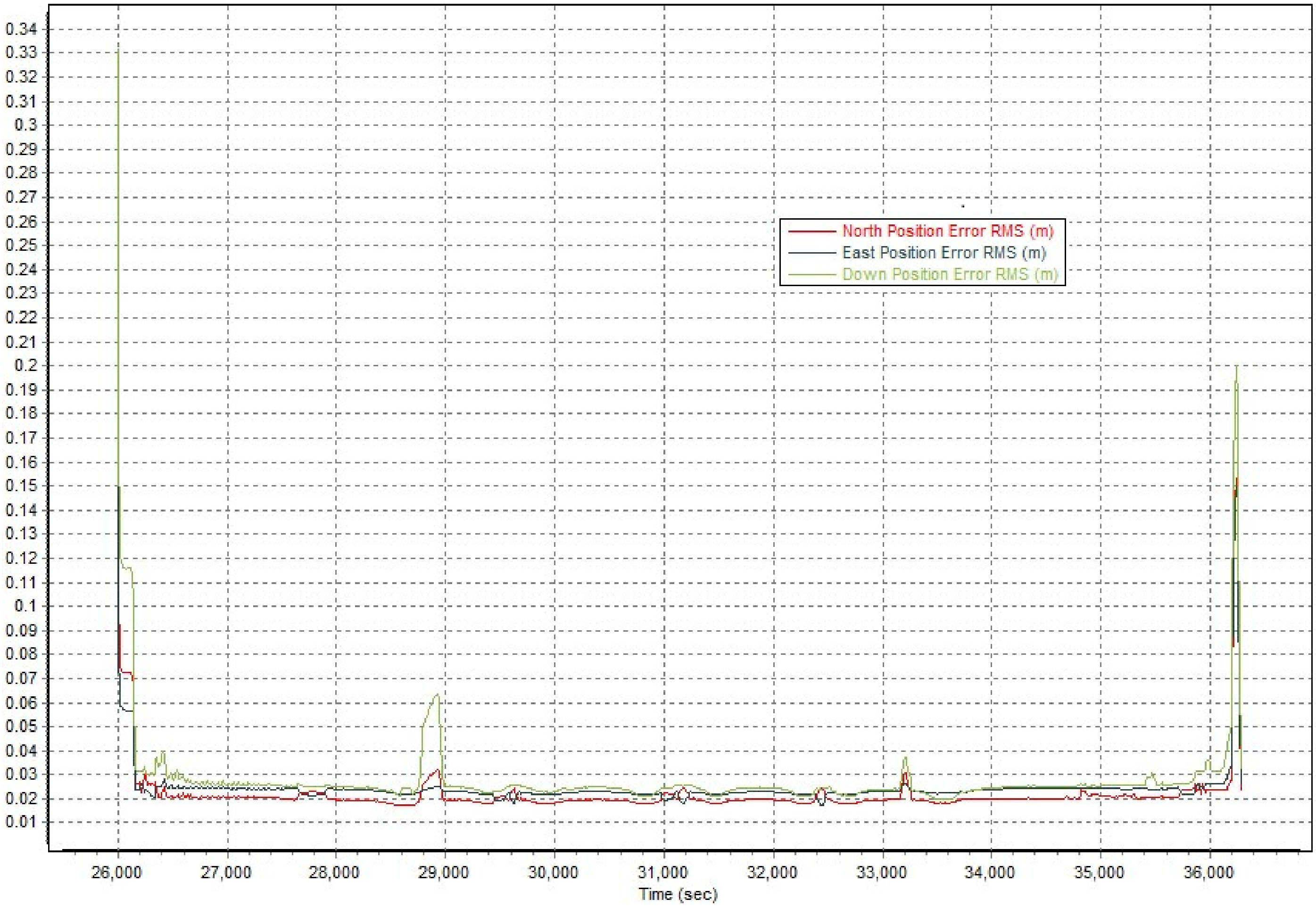
PDOP Plots 8: Sortie a03-s02-0104



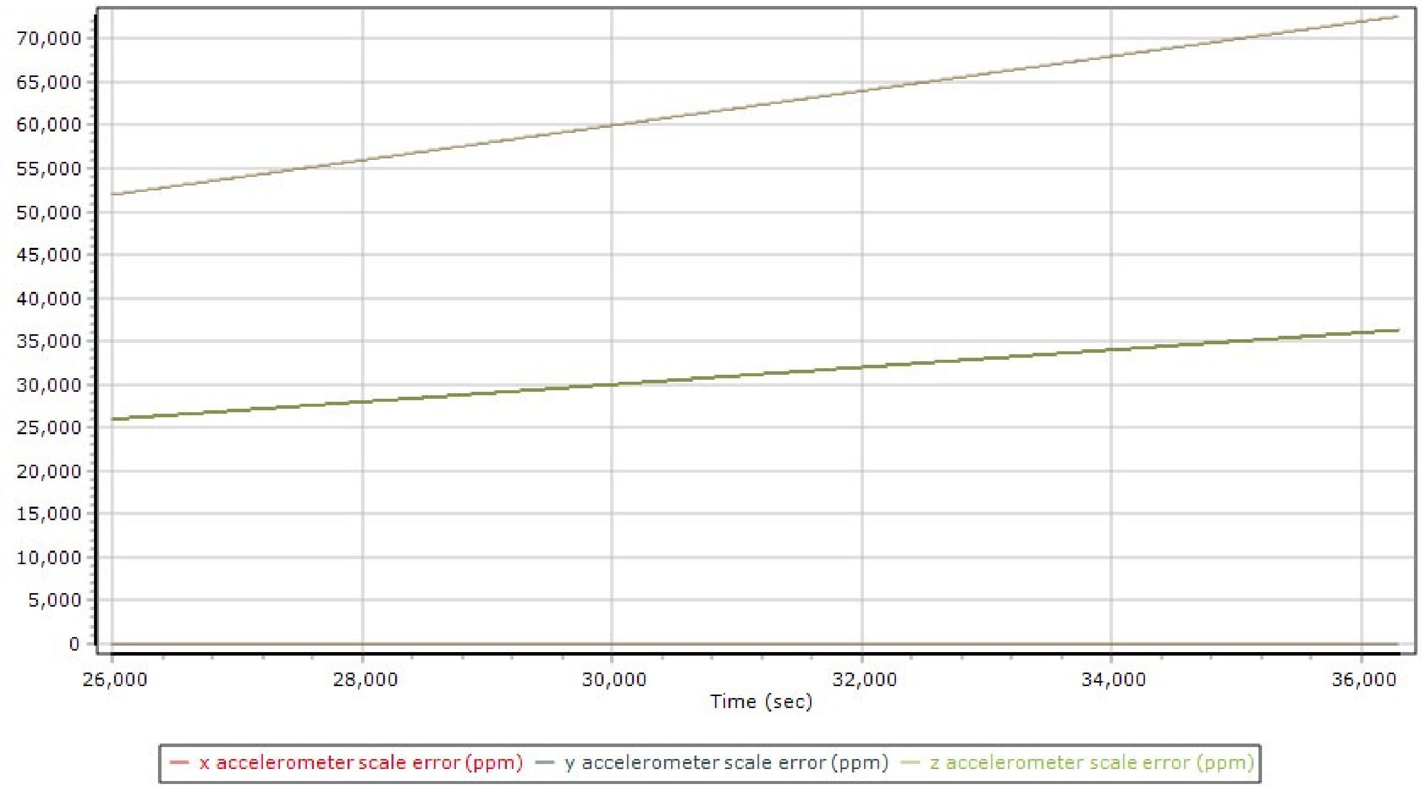
Number of Satellites (>6) Plots 8: Sortie a03-s02-0104



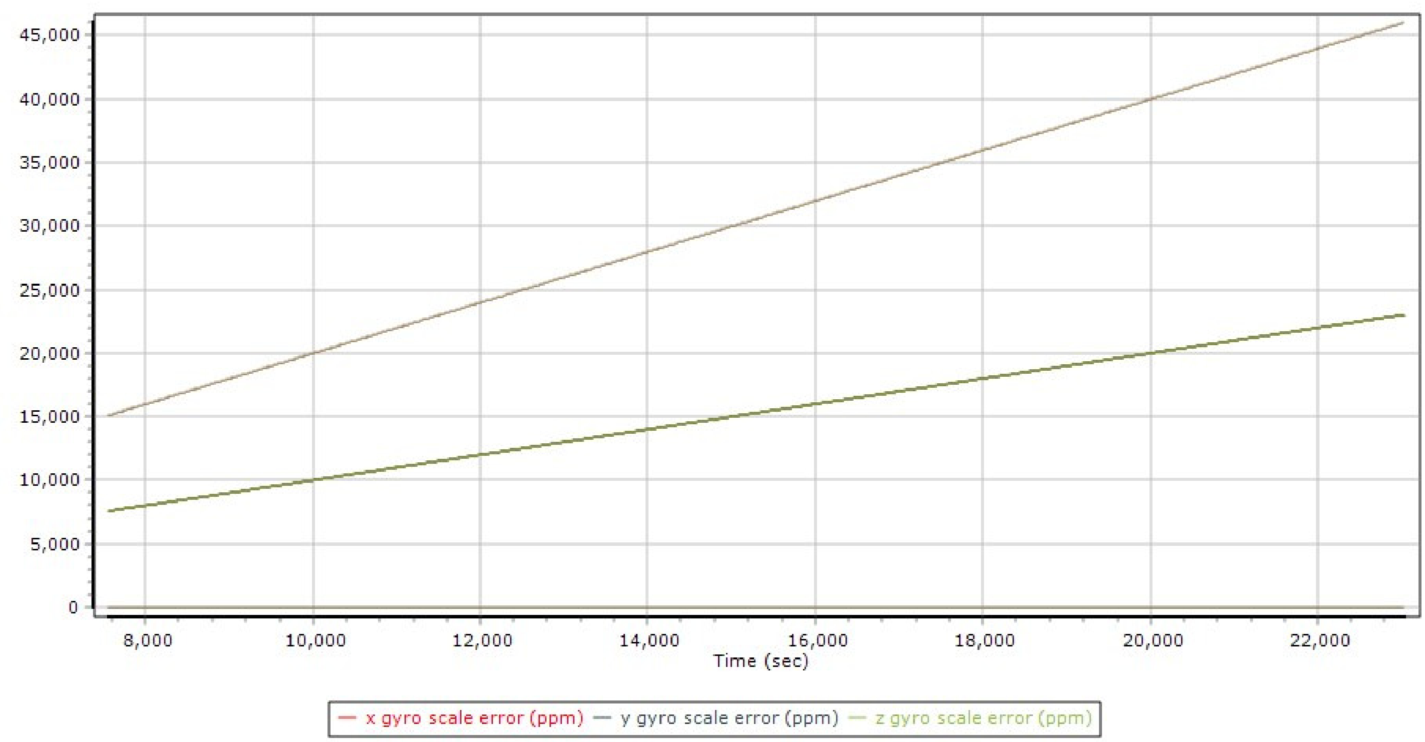
Sensor Position Error RMS (m) Plots 8: Sortie a03-s02-0104



Accelerometer Scale Error (ppm) Plots 8: Sortie a03-s02-0104



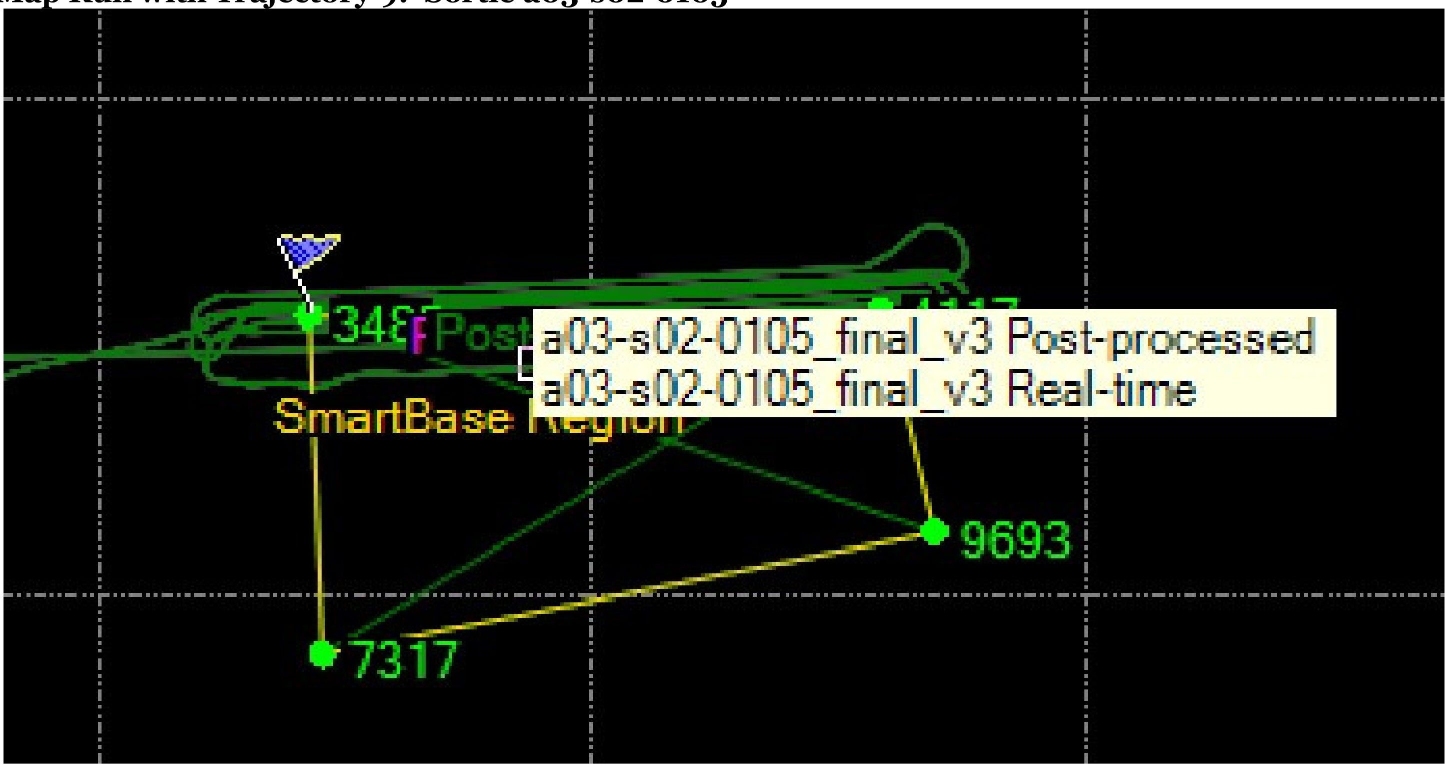
Gyro Scale Error (ppm) Plots 8: Sortie a03-s02-0104



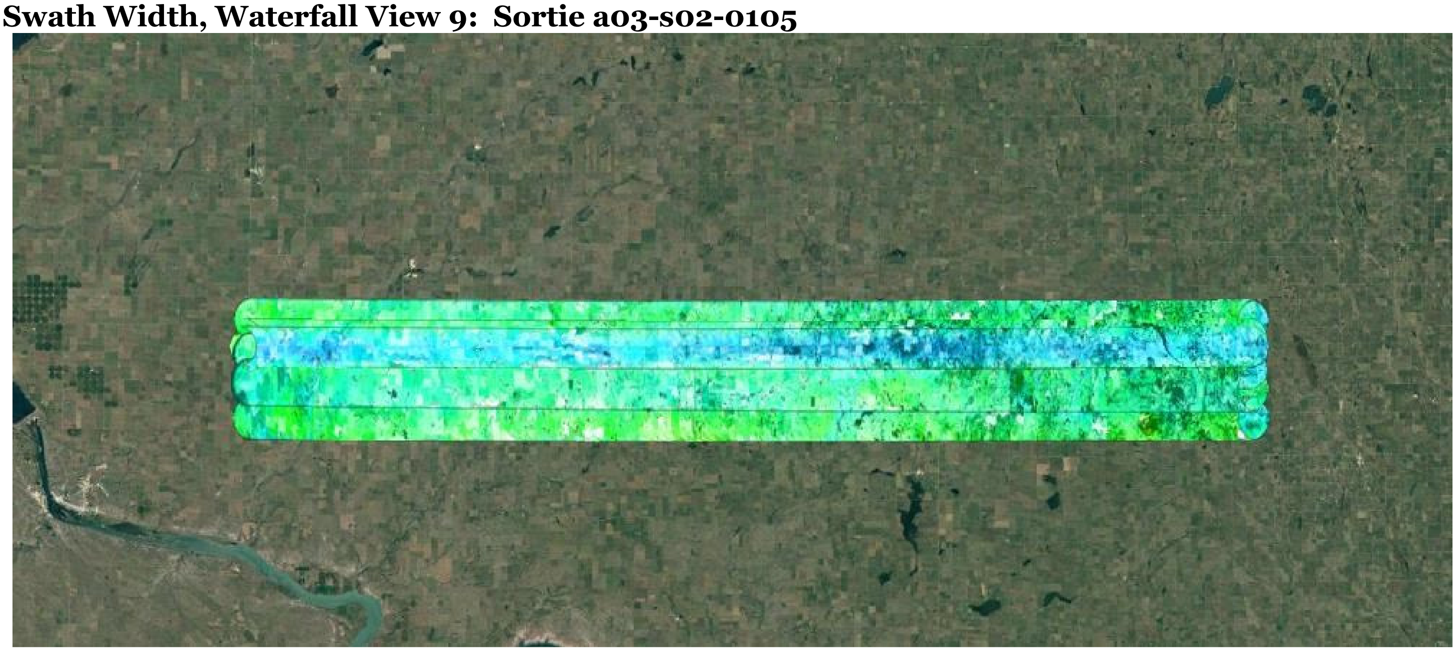
COLLECTION 9

Brick 6
Sortie a03-s02-0105
06/06/2016

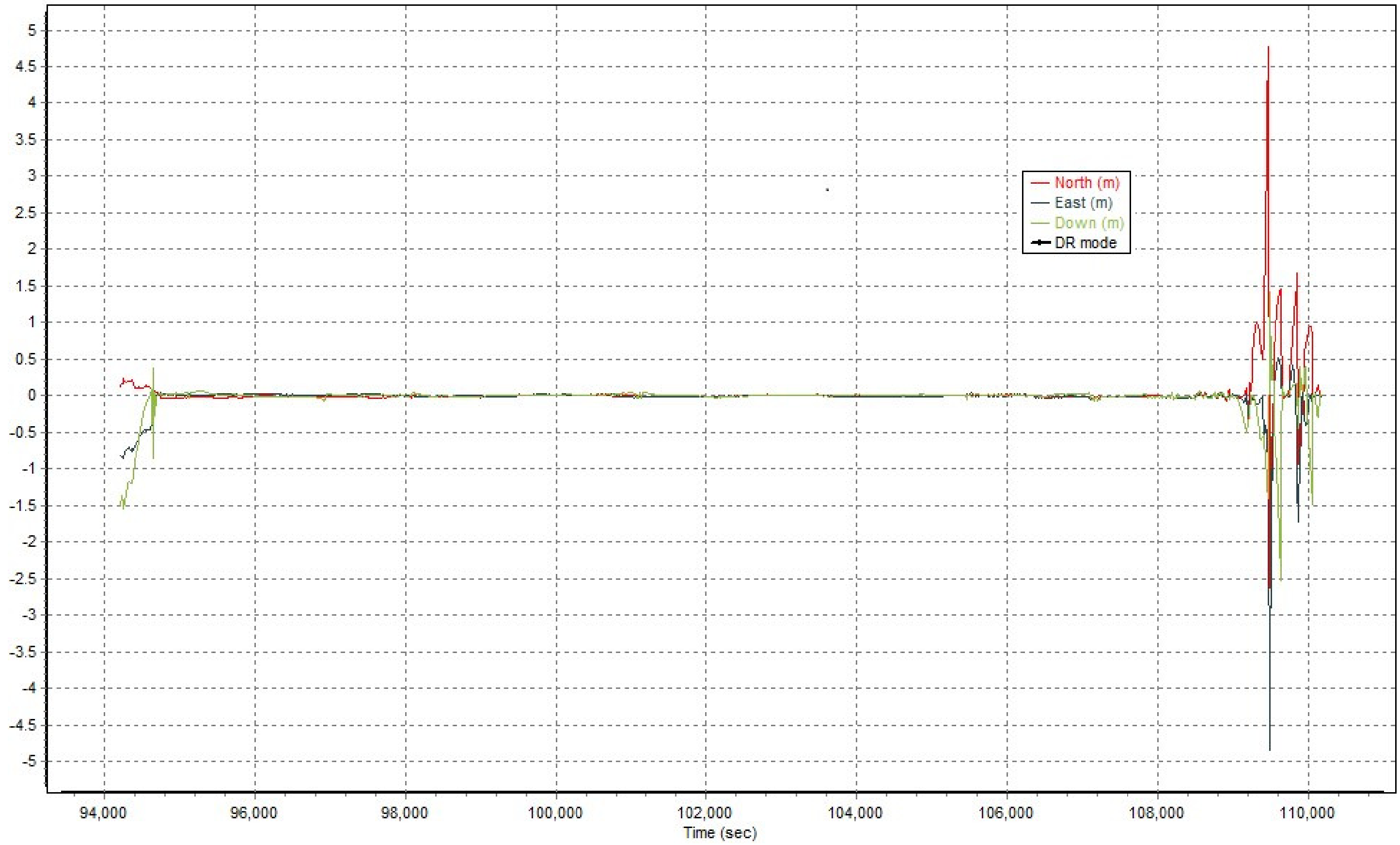
Map Run with Trajectory 9: Sortie a03-s02-0105



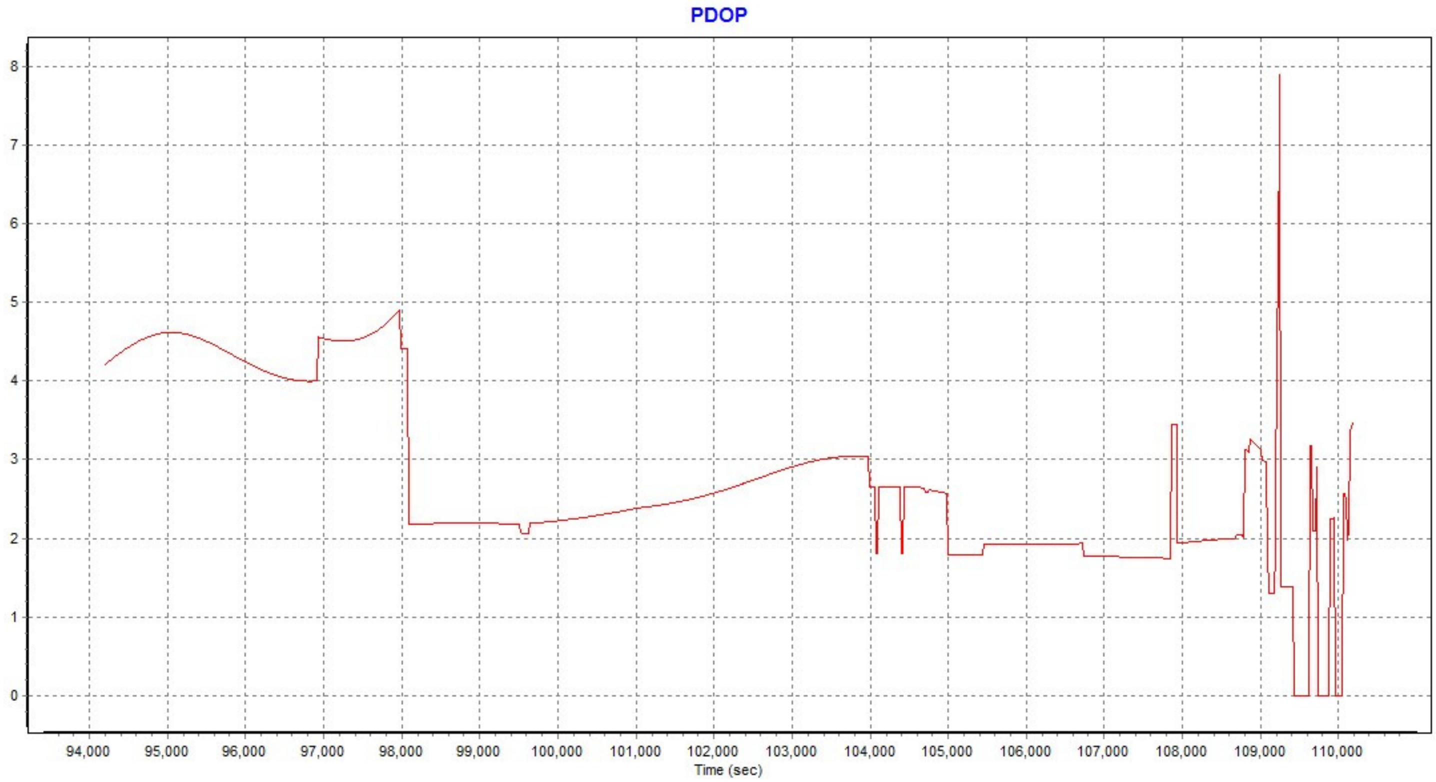
Swath Width, Waterfall View 9: Sortie a03-s02-0105



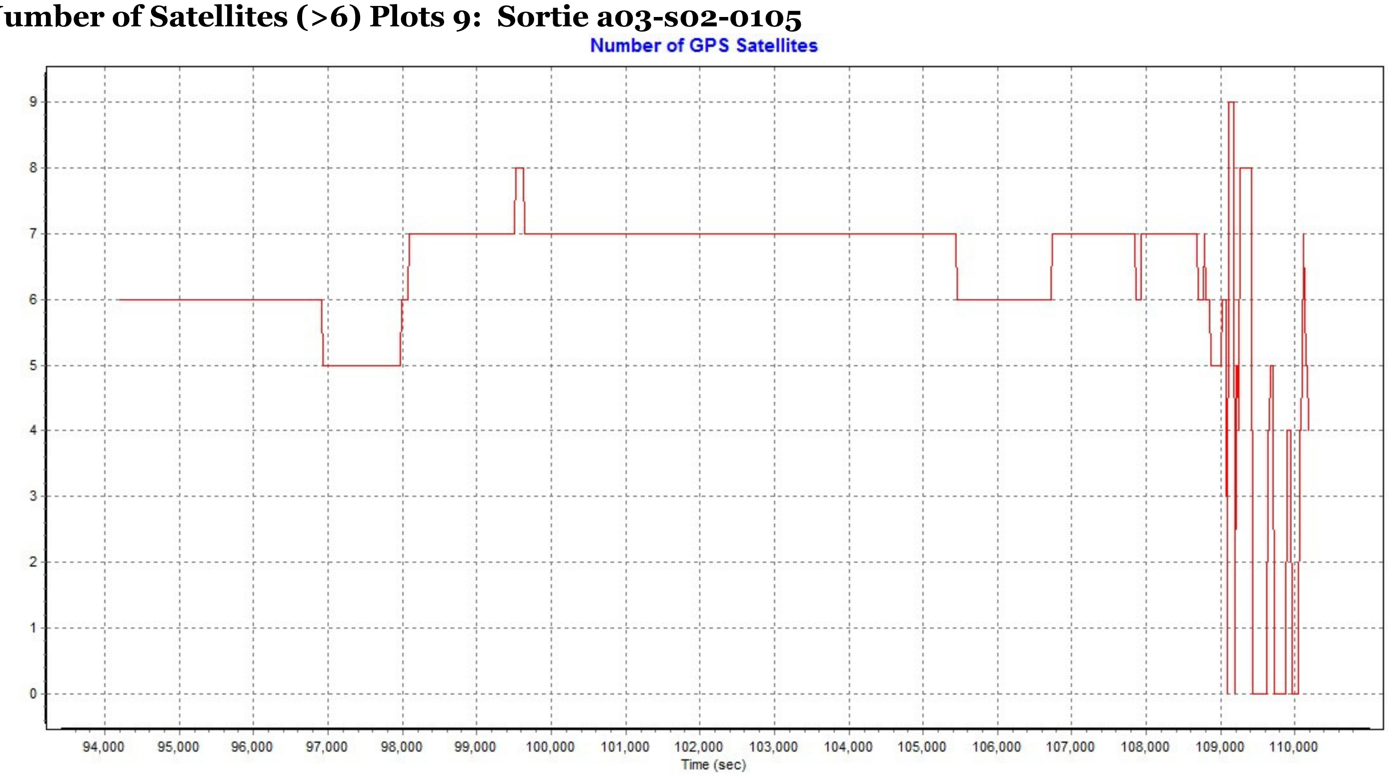
Combined SBET IAKAR Separation 9: Sortie a03-s02-0105



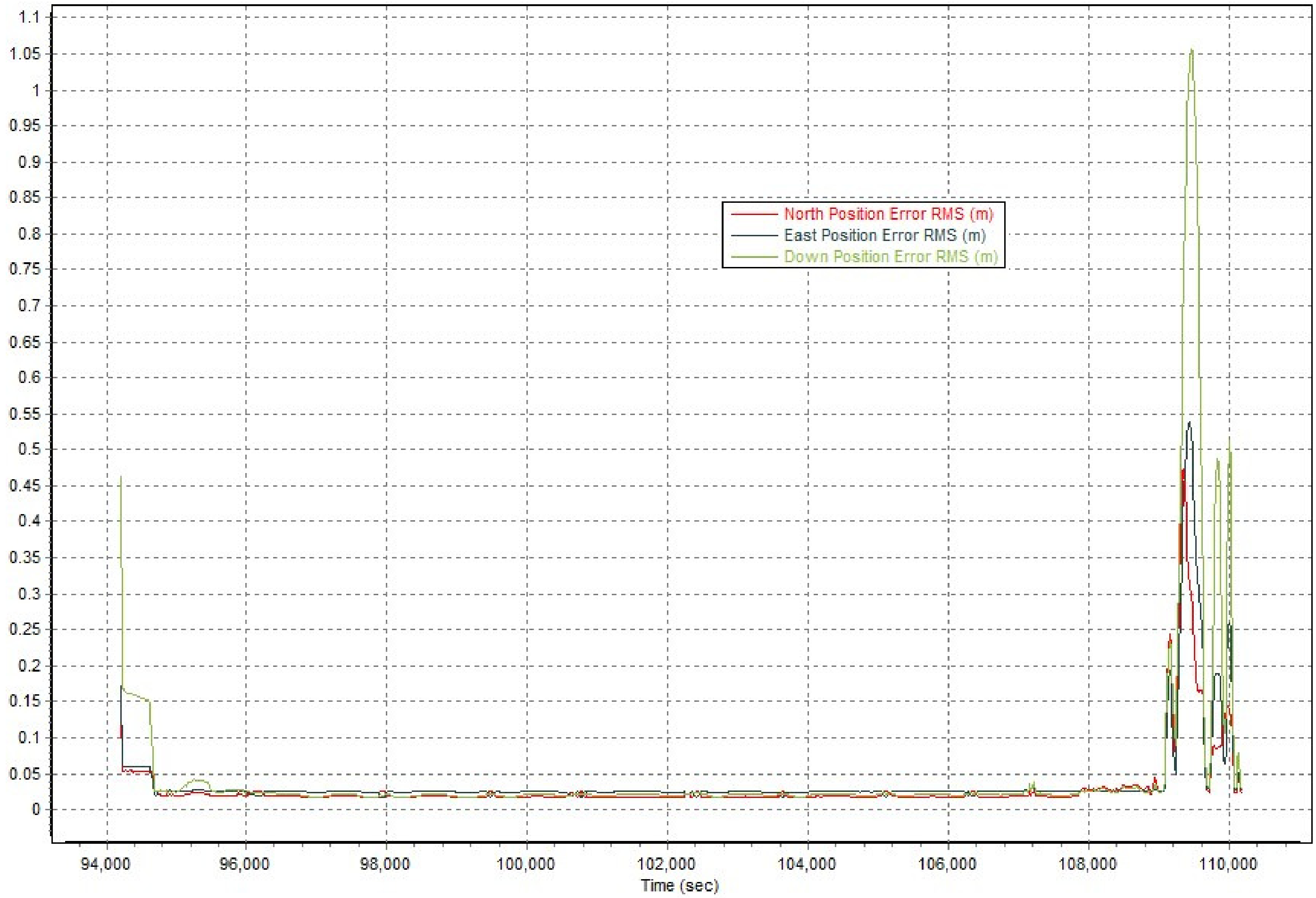
PDOP Plots 9: Sortie a03-s02-0105



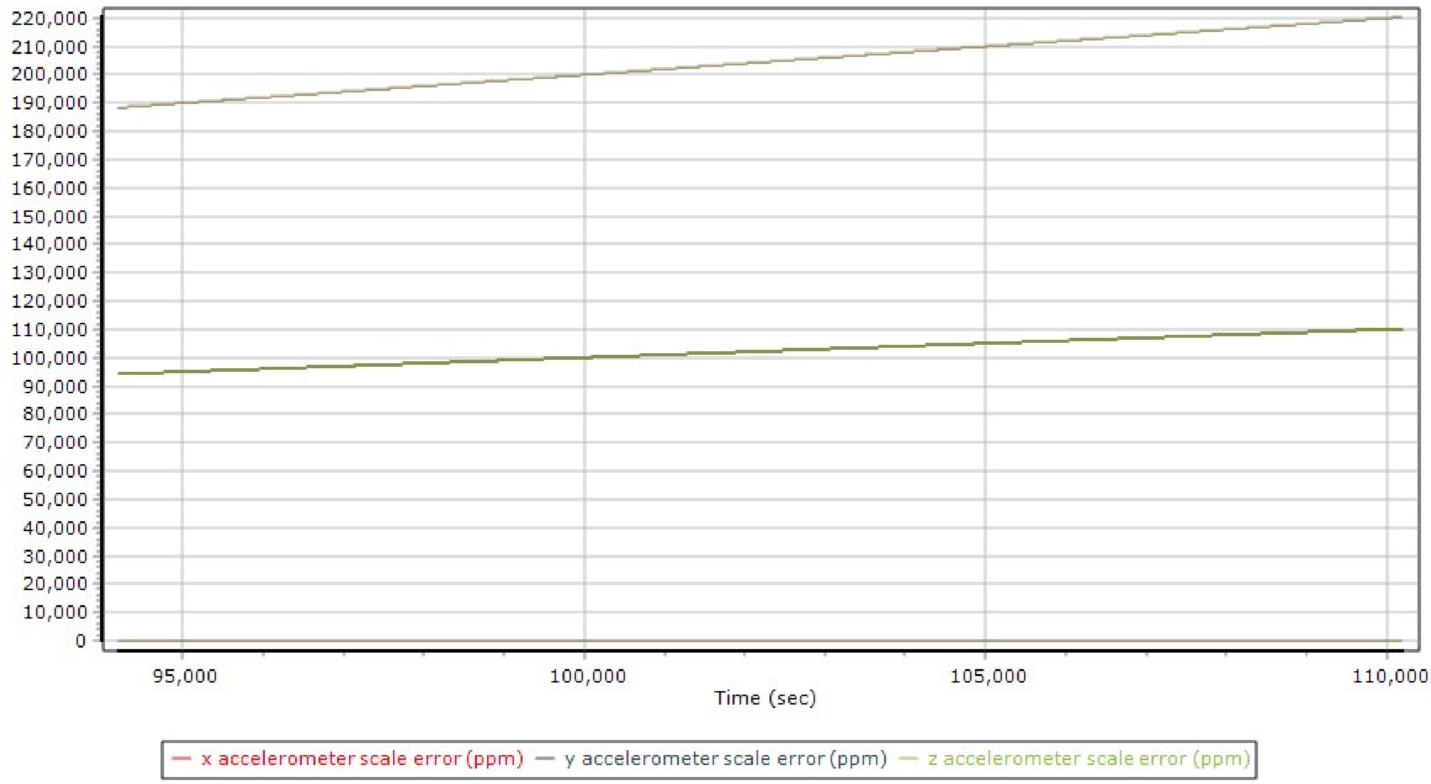
Number of Satellites (>6) Plots 9: Sortie a03-s02-0105



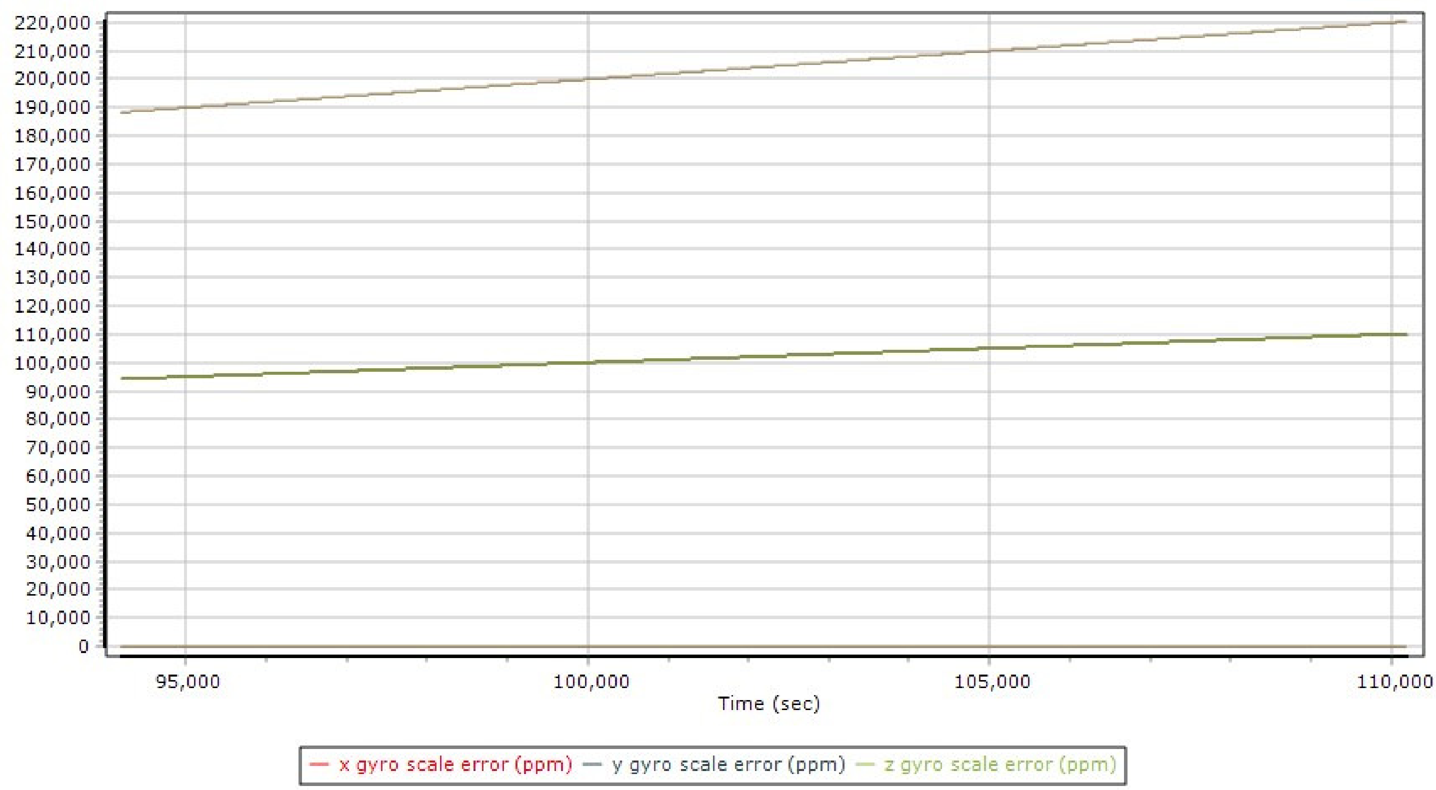
Sensor Position Error RMS (m) Plots 9: Sortie a03-s02-0105



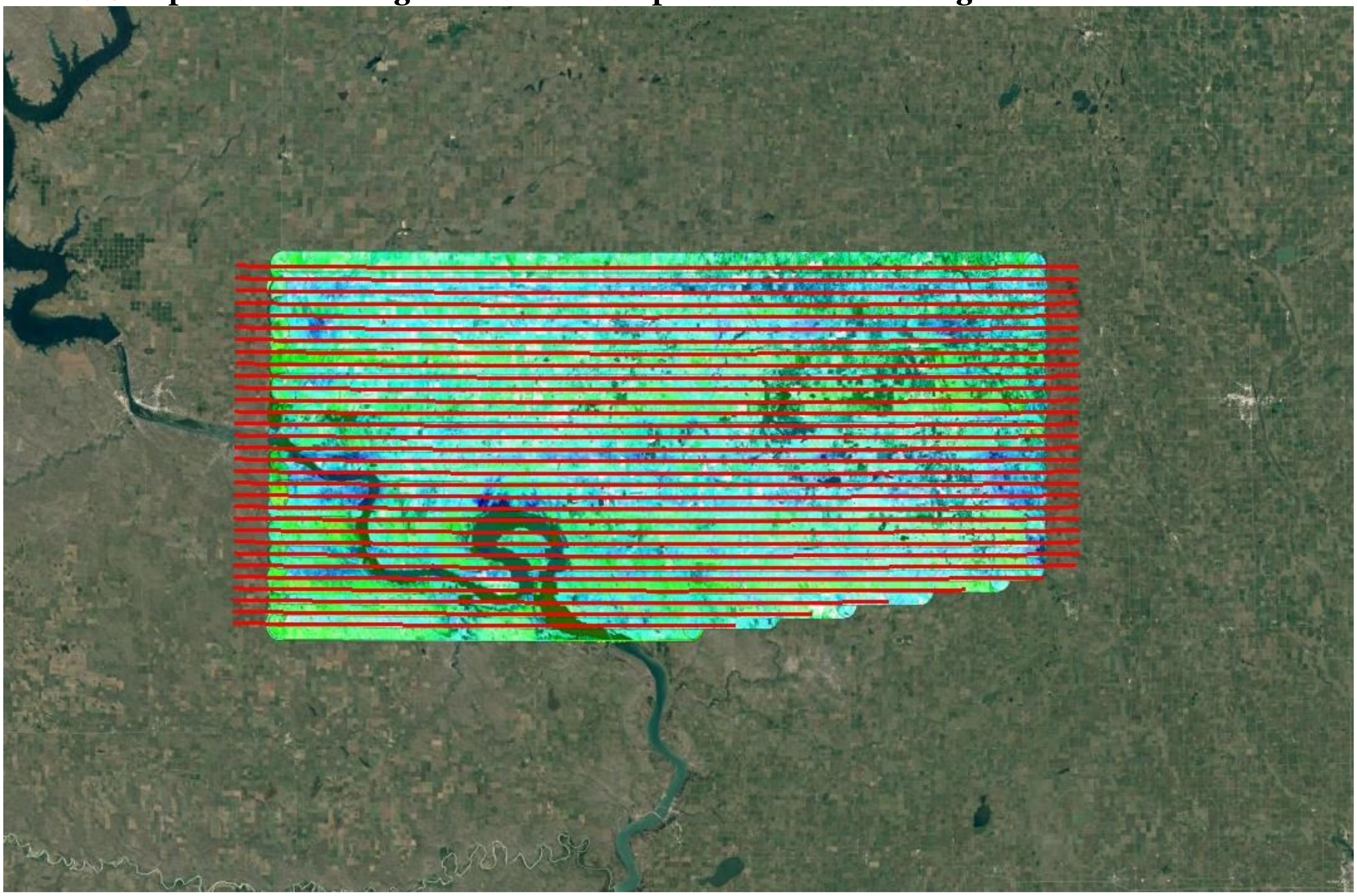
Accelerometer Scale Error (ppm) Plots 9: Sortie a03-s02-0105

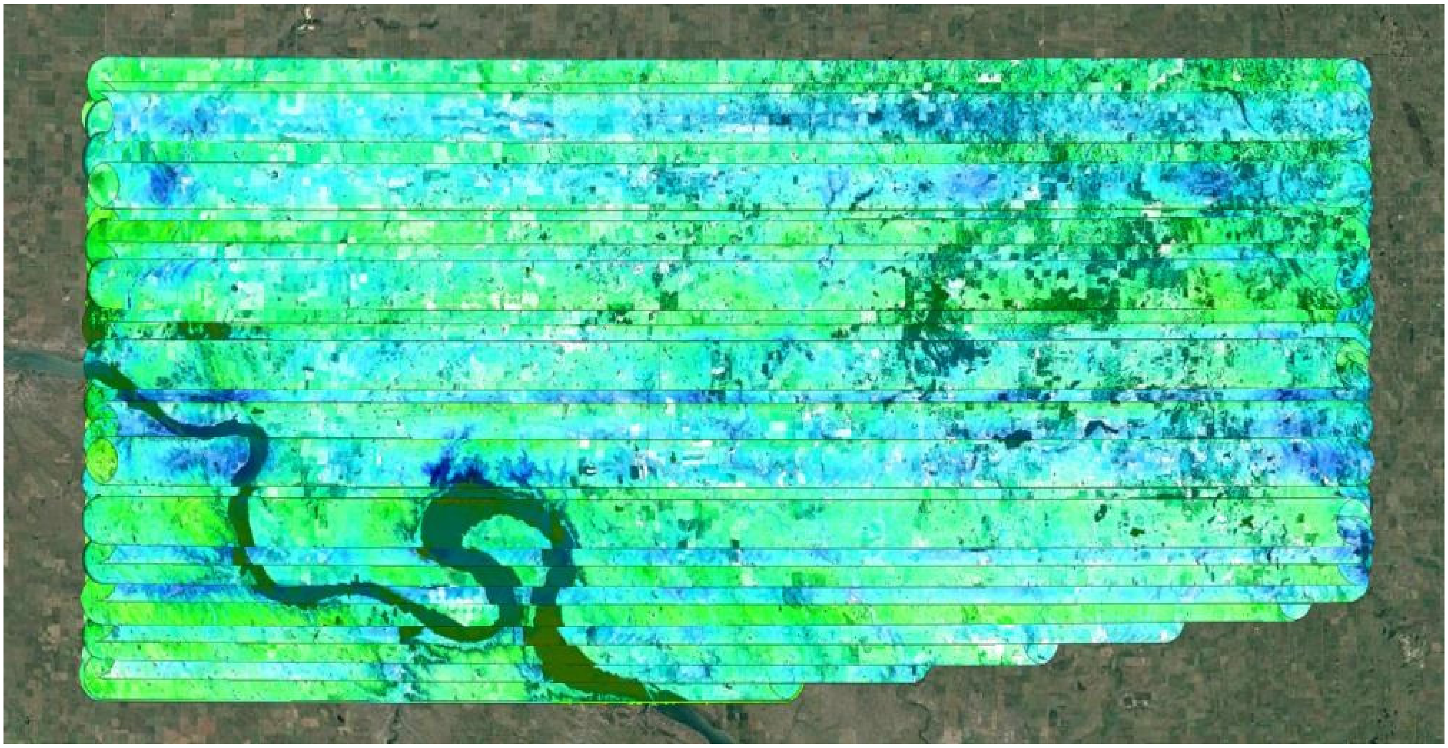


Gyro Scale Error (ppm) Plots 9: Sortie a03-s02-0105



Brick 6 Completion: Flight lines with complete waterfall coverage

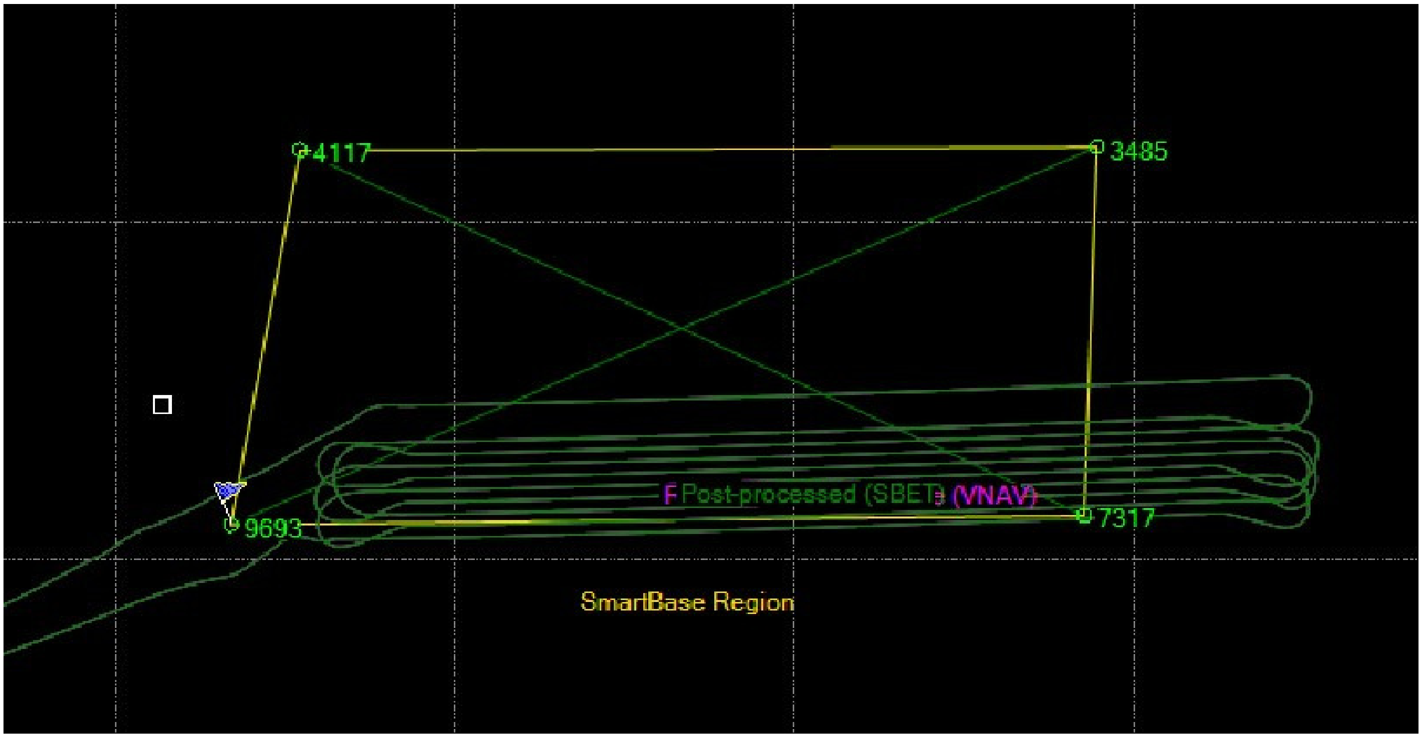




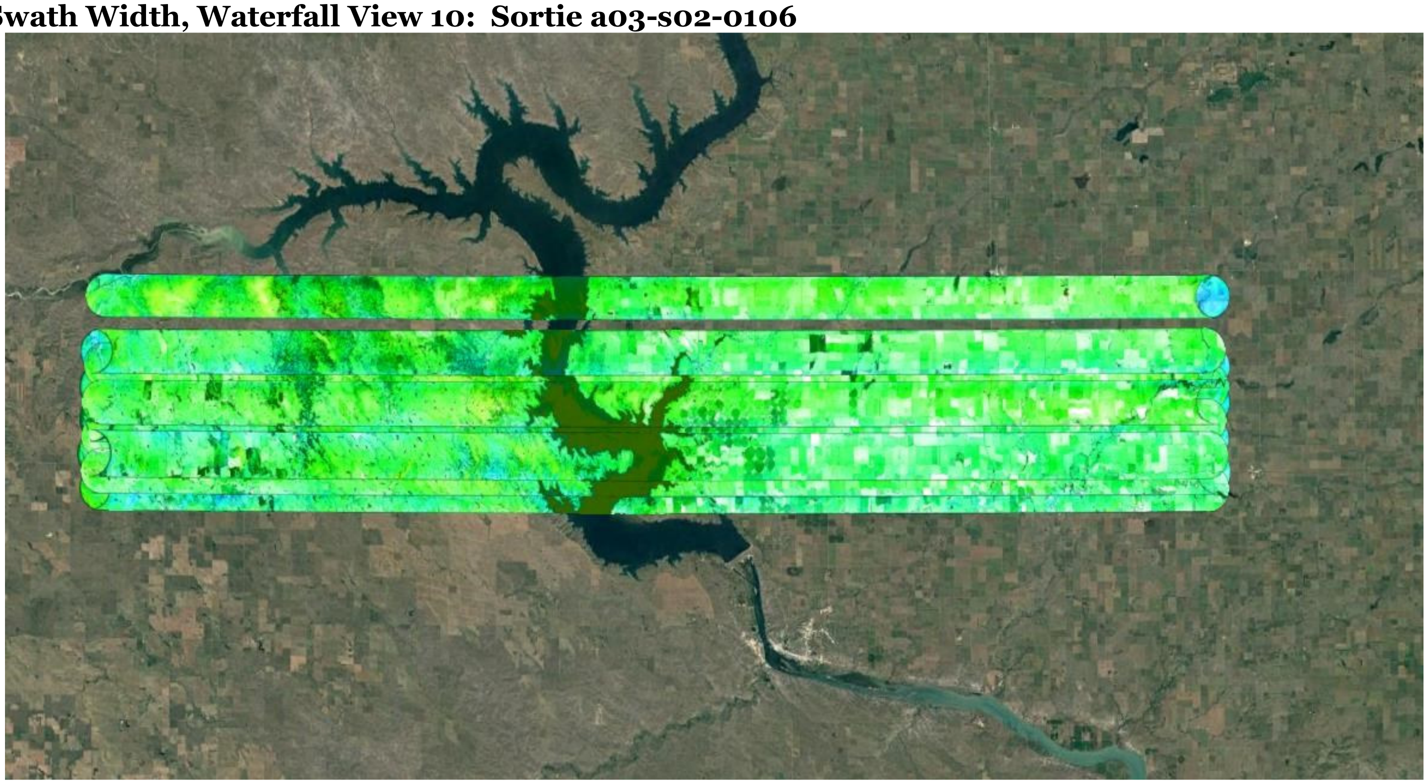
COLLECTION 10

Brick 3
Sortie a03-s02-0106
06/07/2016

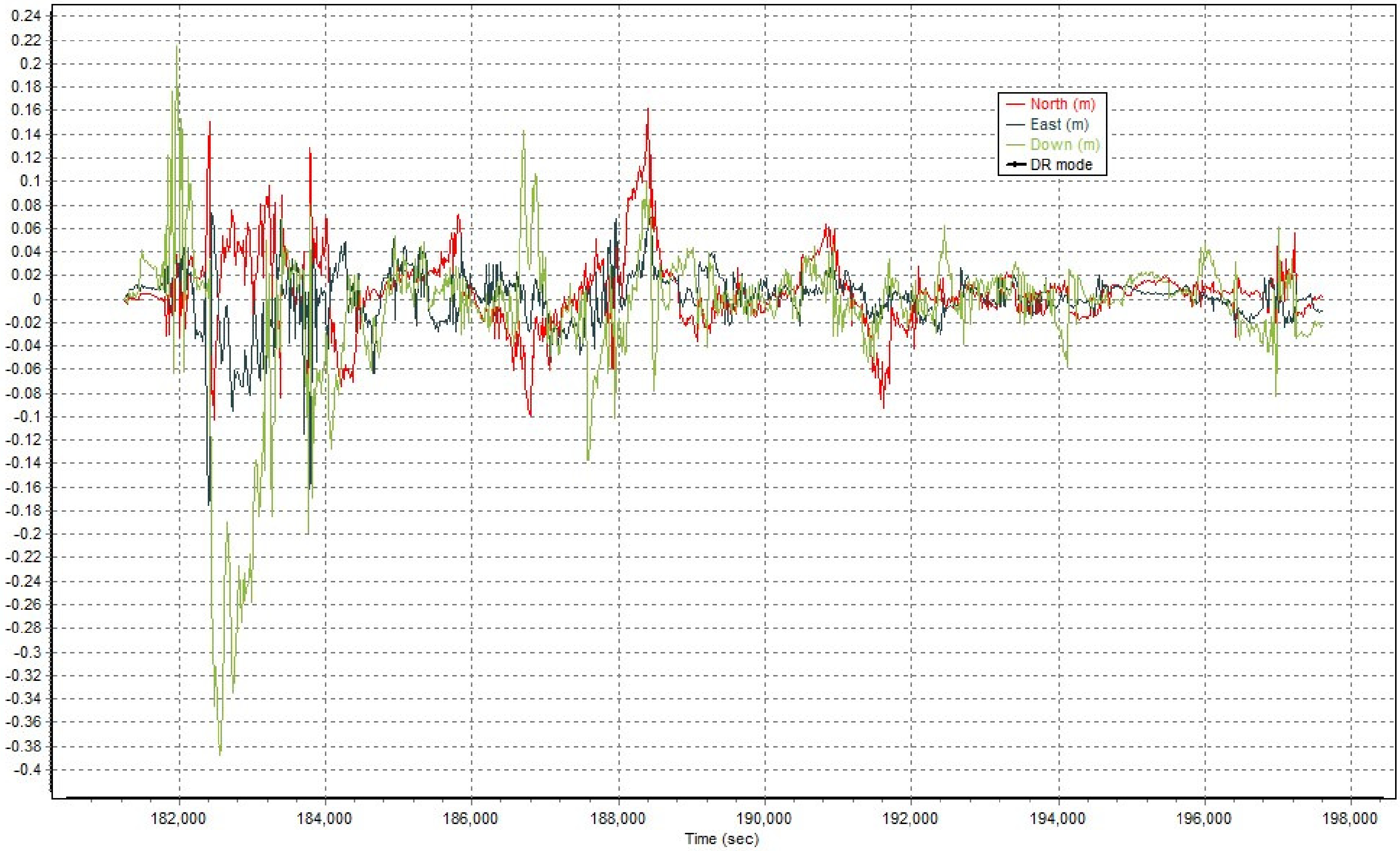
Map Run with Trajectory 10: Sortie a03-s02-0106



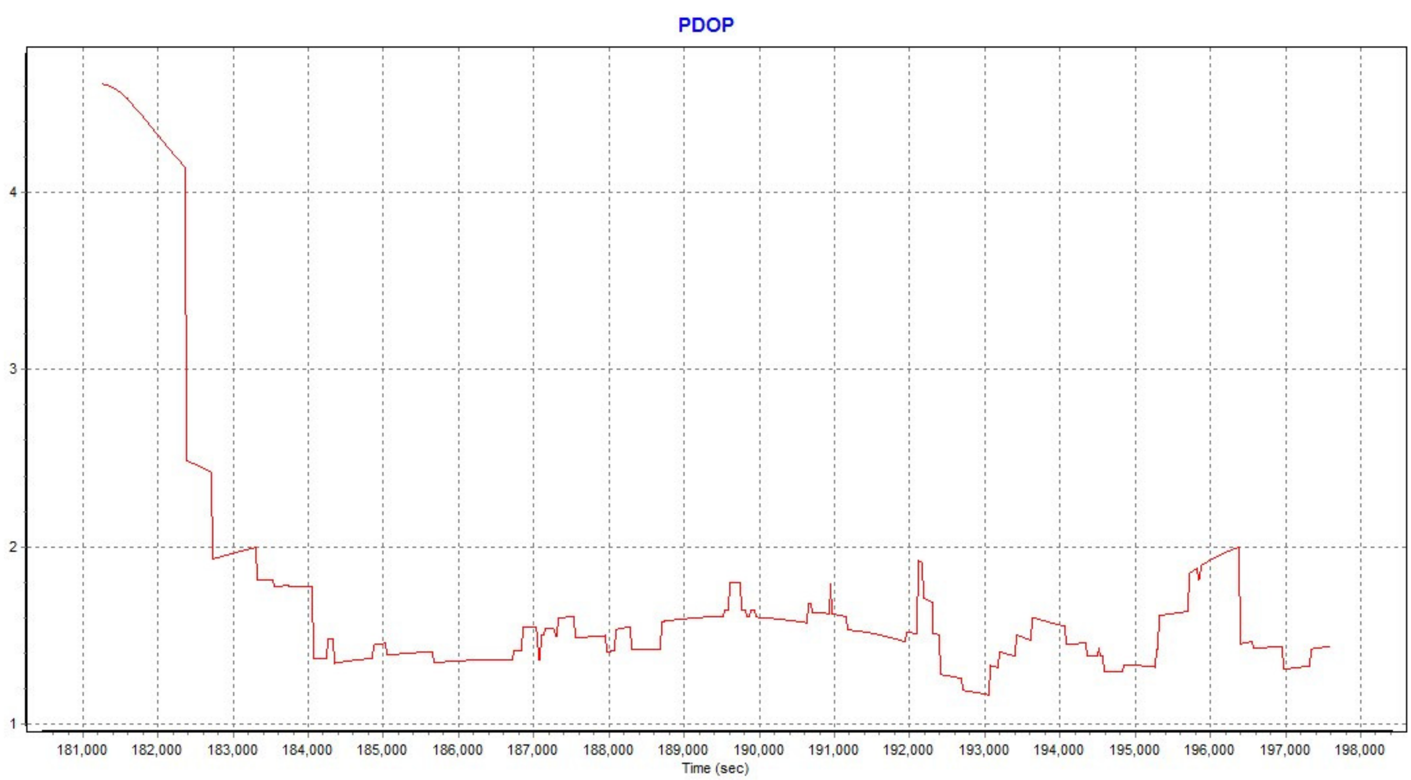
Swath Width, Waterfall View 10: Sortie a03-s02-0106



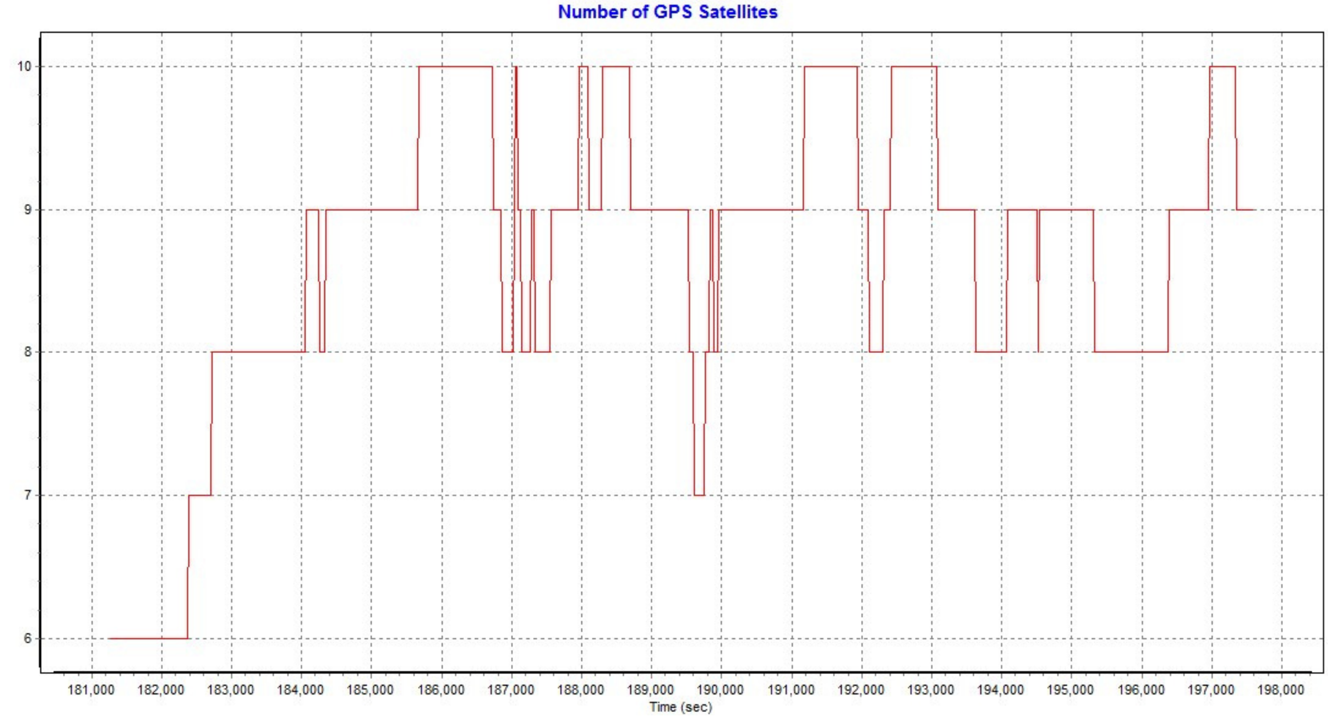
Combined SBET IAKAR Separation 10: Sortie a03-s02-0106



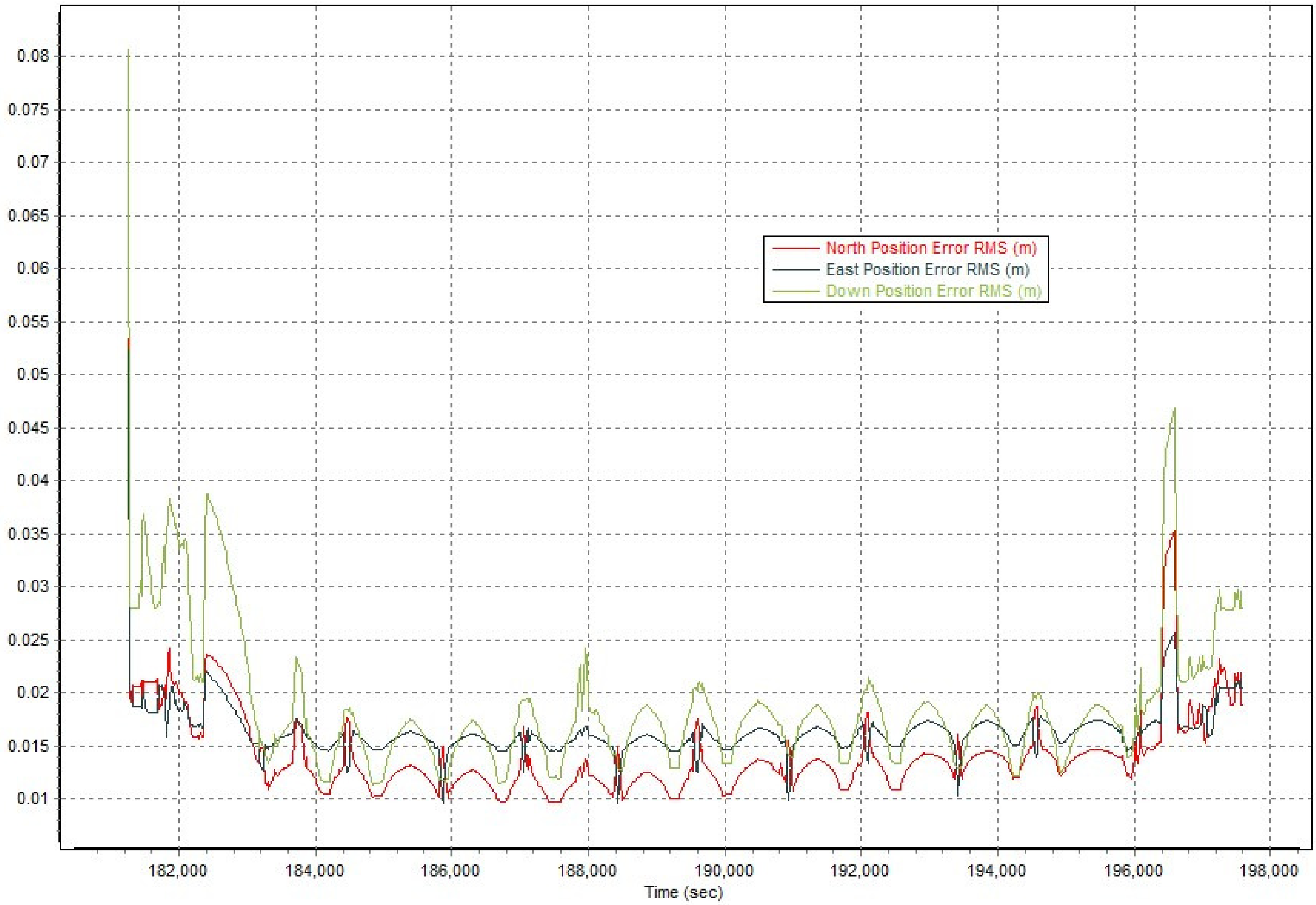
PDOP Plots 10: Sortie a03-s02-0106



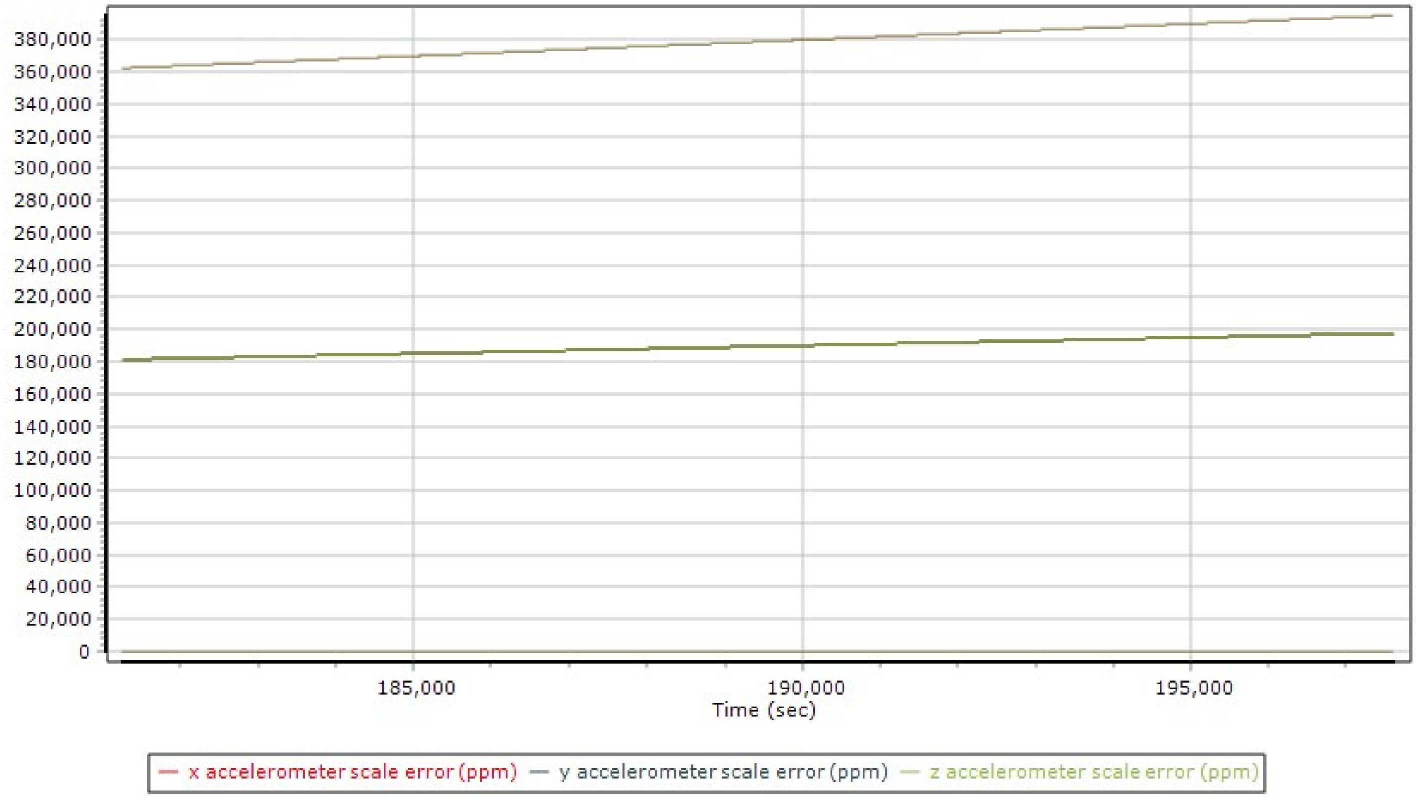
Number of Satellites (>6) Plots 10: Sortie a03-s02-0106



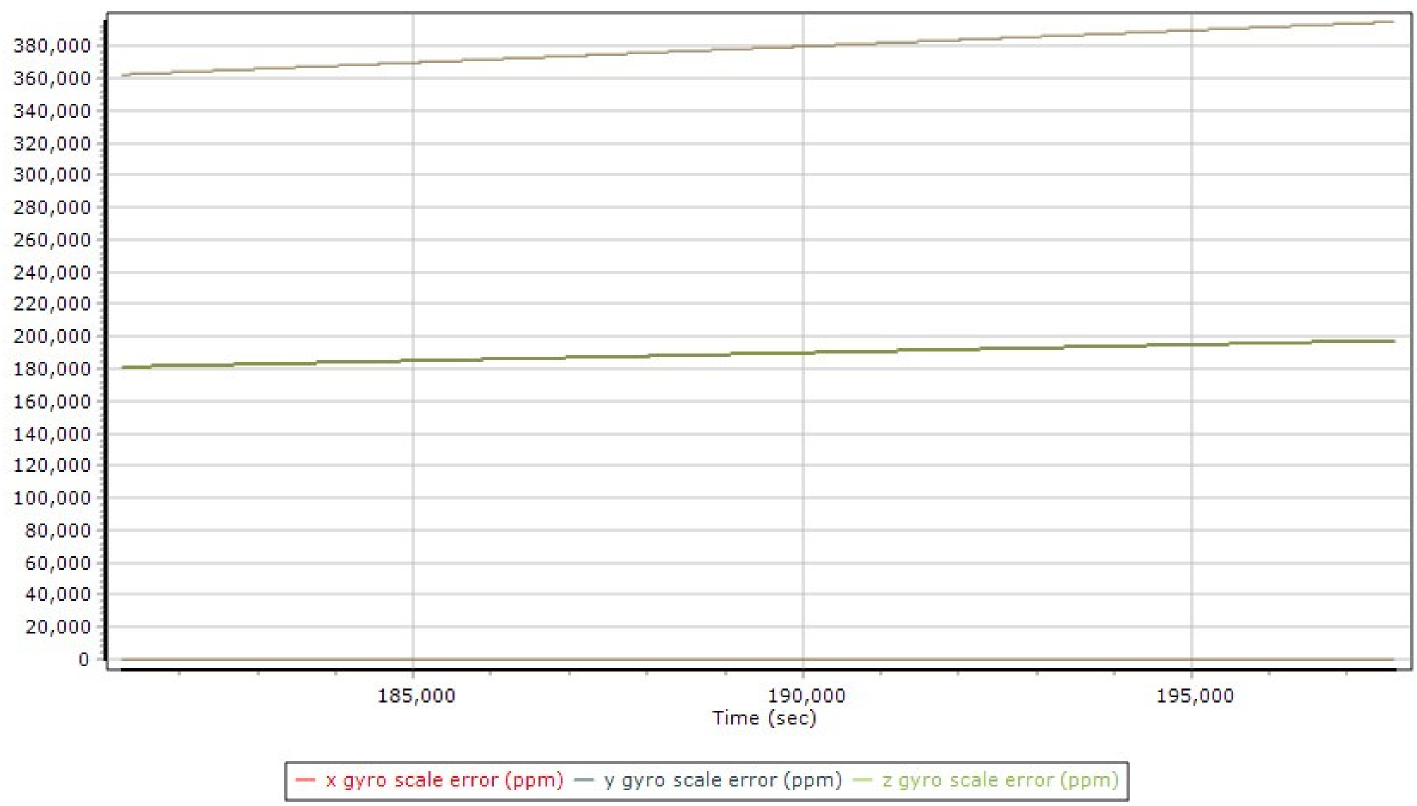
Sensor Position Error RMS (m) Plots 10: Sortie a03-s02-0106



Accelerometer Scale Error (ppm) Plots 10: Sortie a03-s02-0106



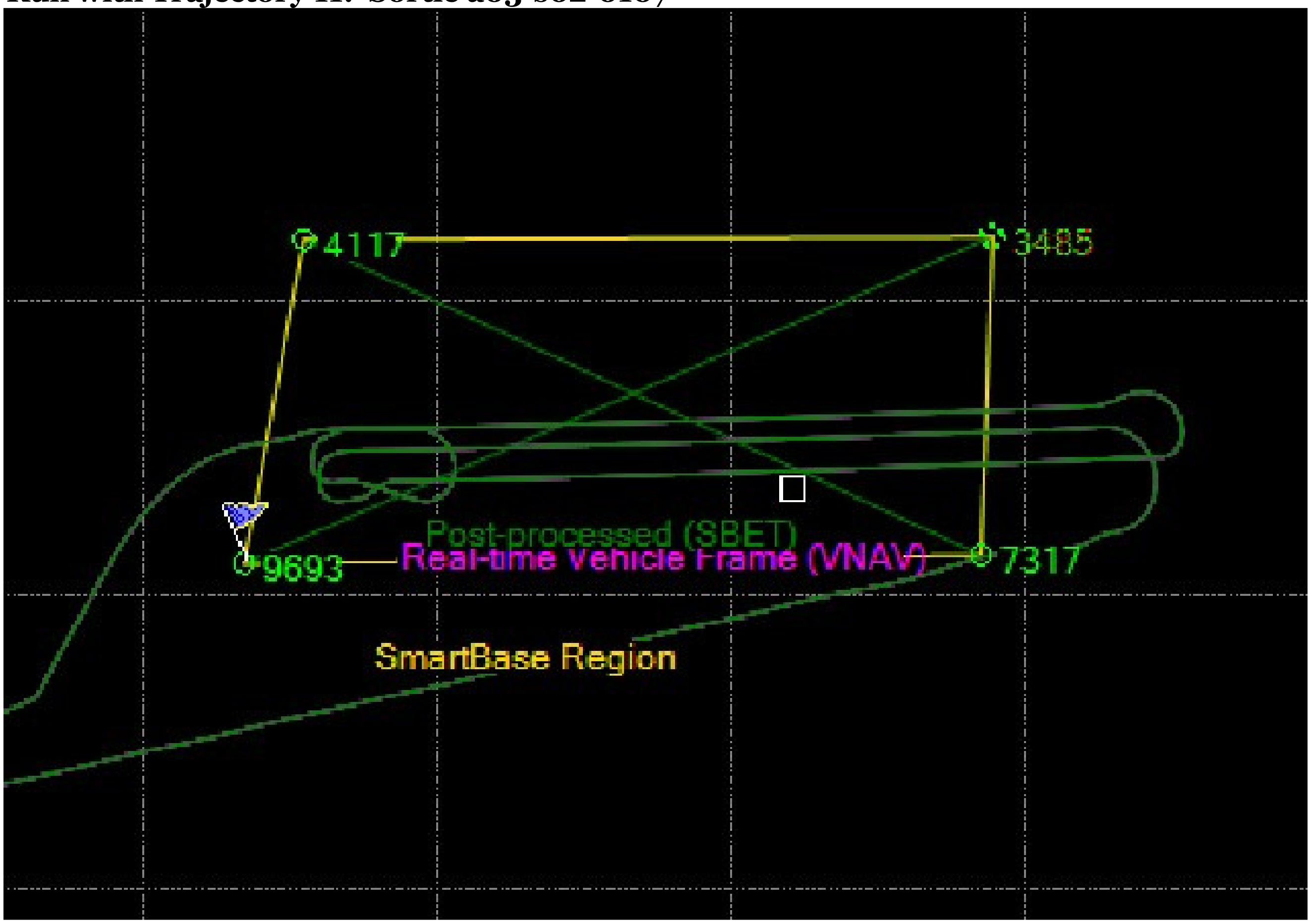
Gyro Scale Error (ppm) Plots 10: Sortie a03-s02-0106



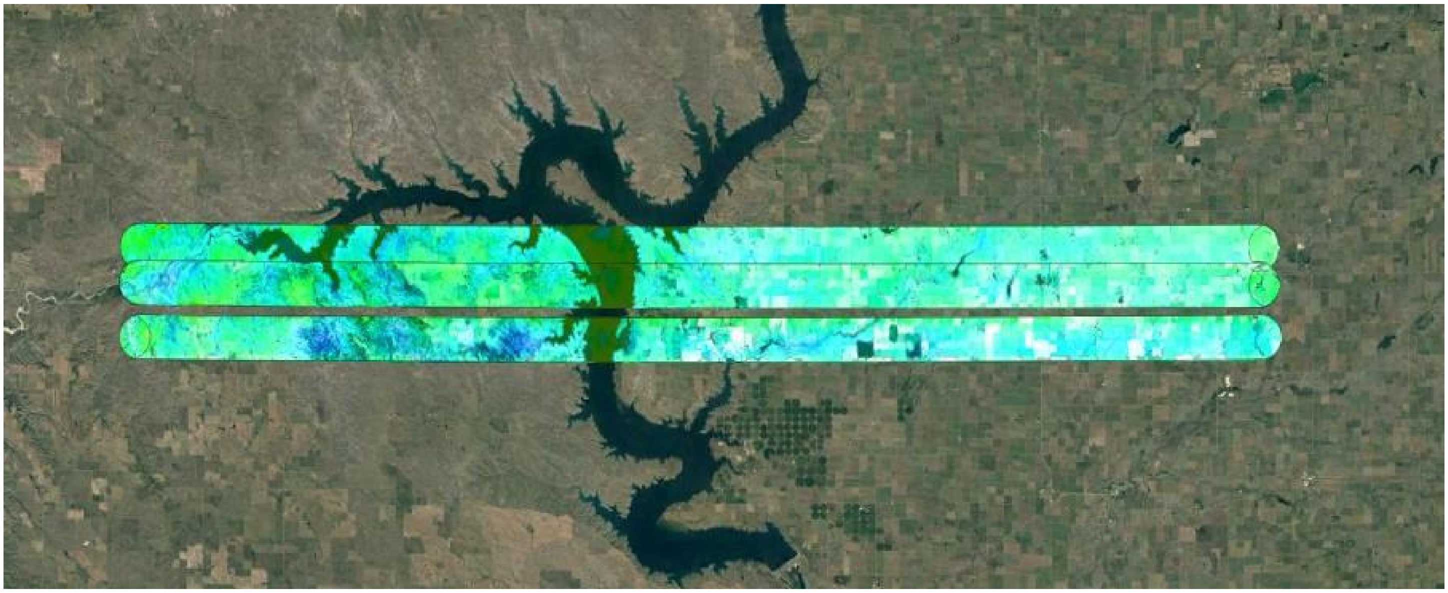
COLLECTION 11

Brick 3
Sortie a03-s02-0107
06/07/2016

Map Run with Trajectory 11: Sortie a03-s02-0107

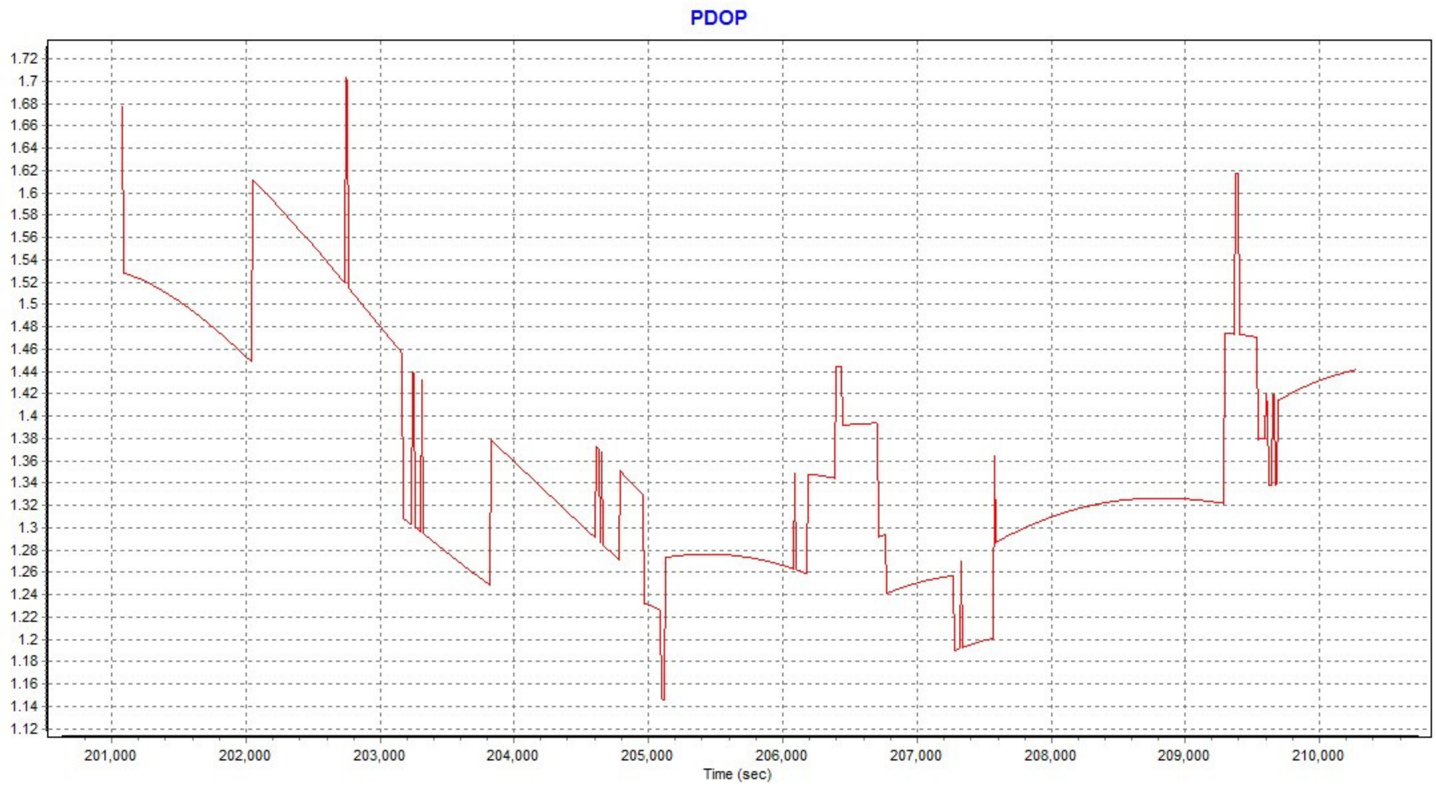


Swath Width, Waterfall View 11: Sortie a03-s02-0107

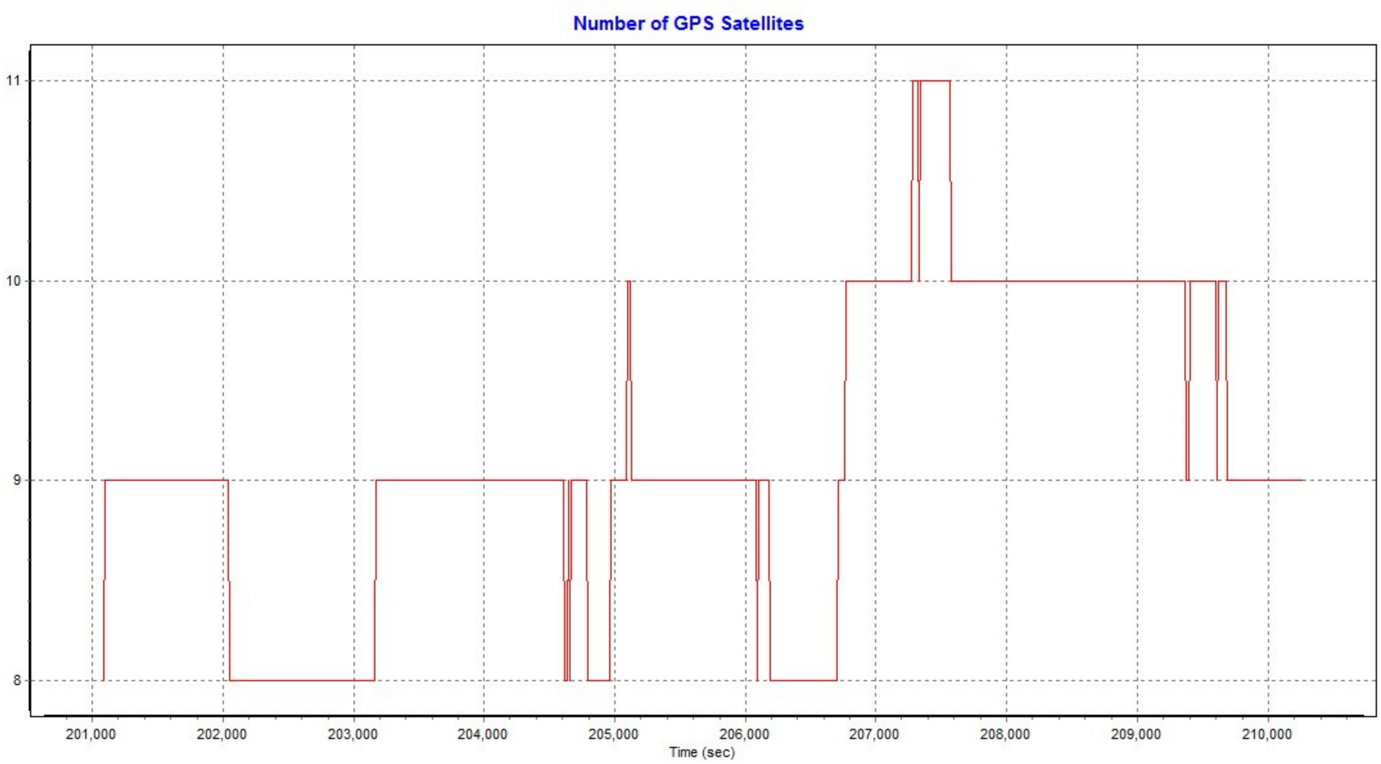


Combined SBET IAKAR Separation 11: Sortie a03-s02-0107

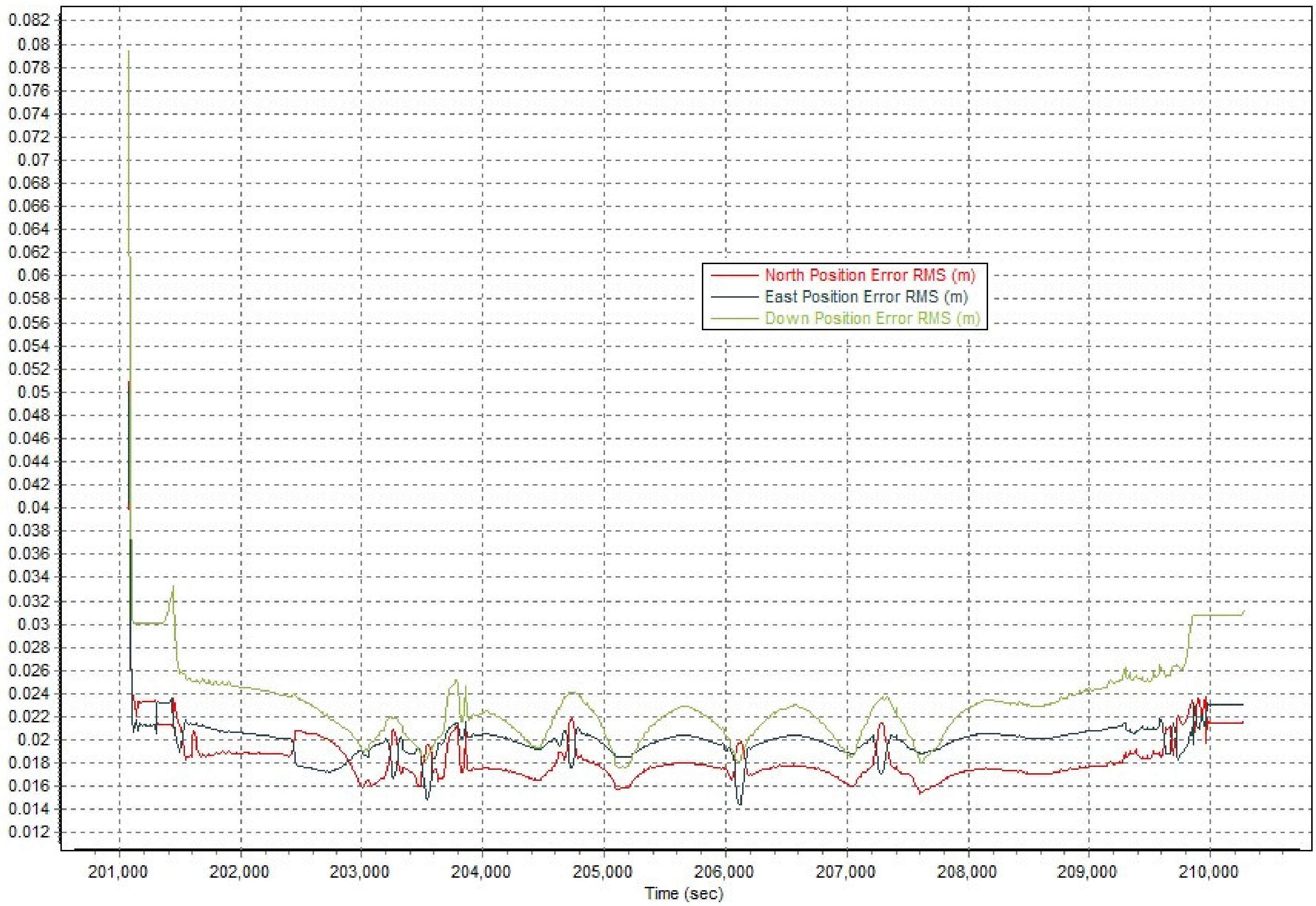
PDOP Plots 11: Sortie a03-s02-0107



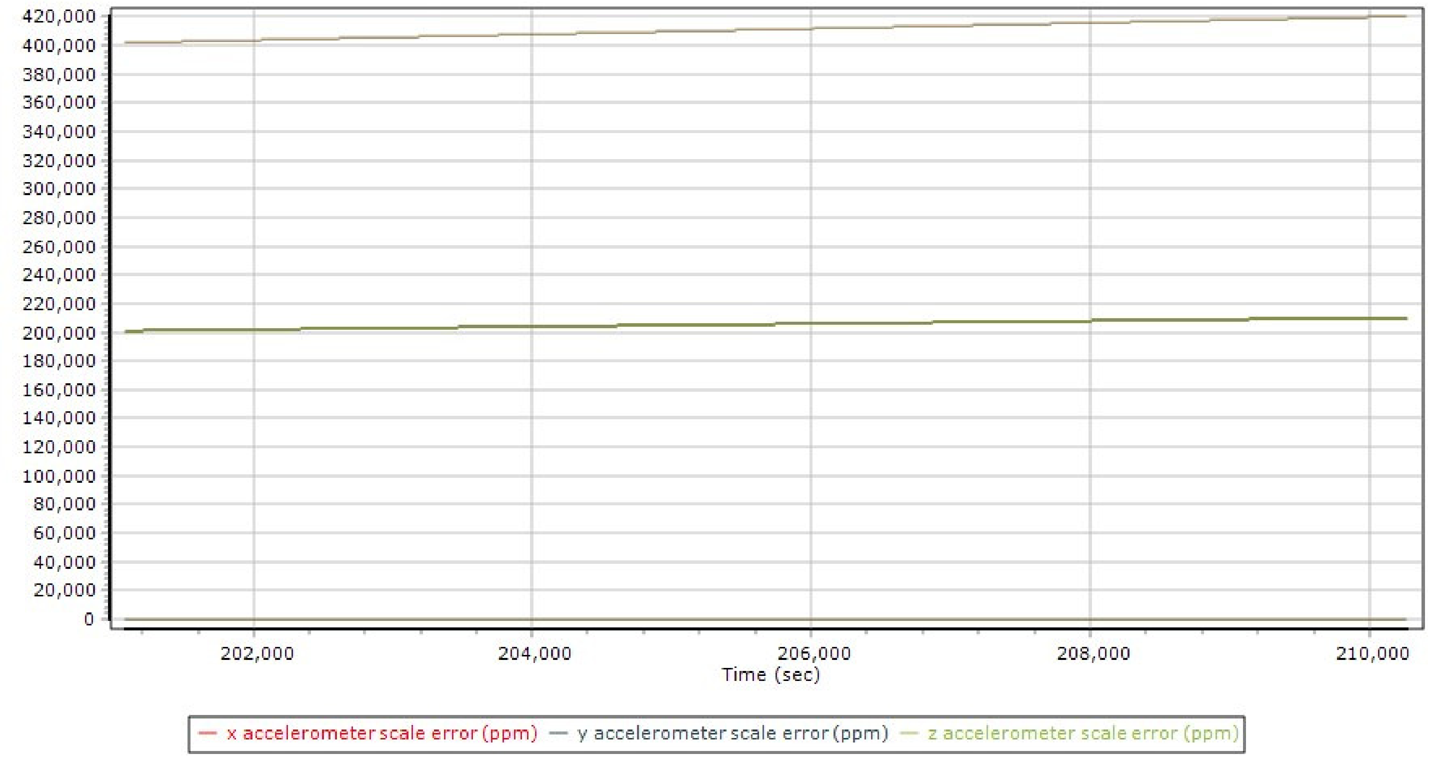
Number of Satellites (>6) Plots 11: Sortie a03-s02-0107



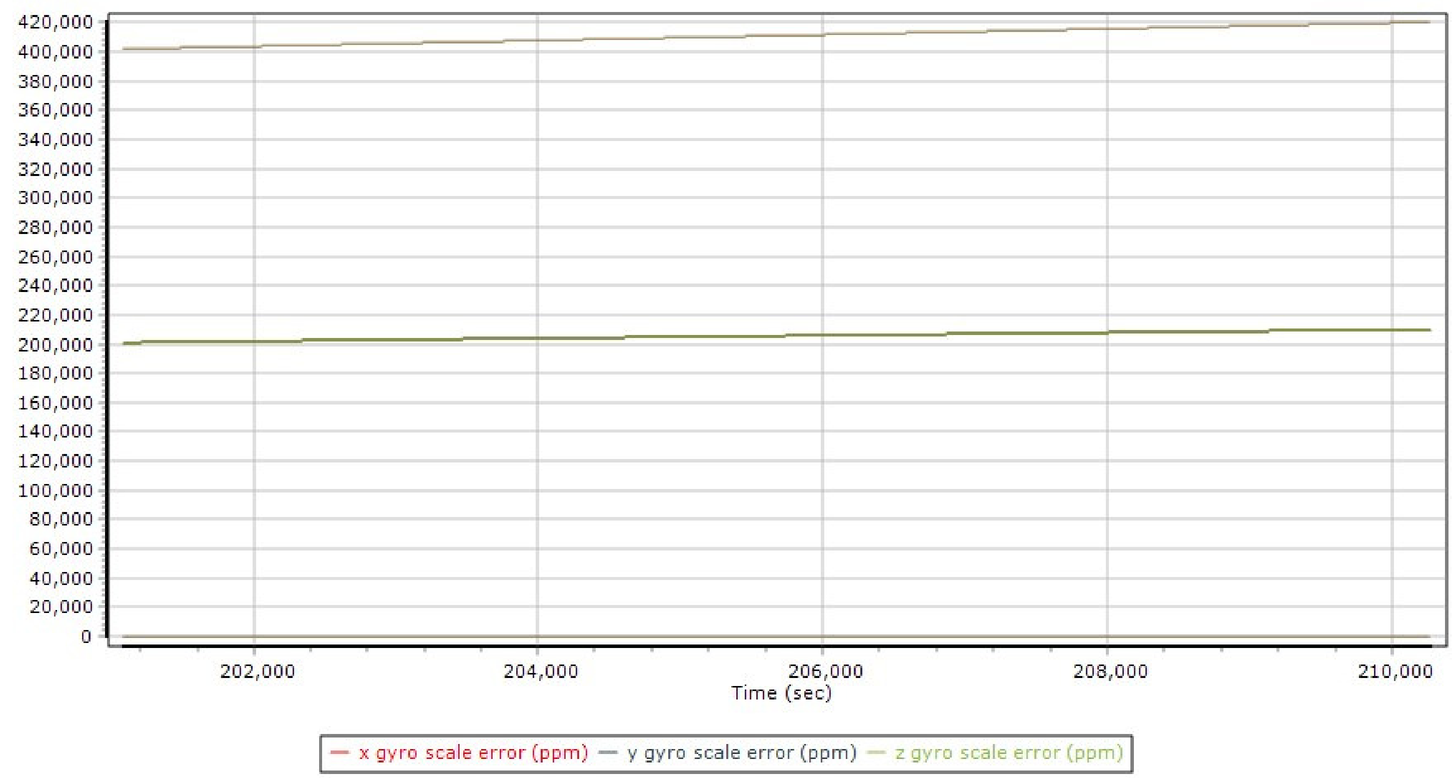
Sensor Position Error RMS (m) Plots 11: Sortie a03-s02-0107



Accelerometer Scale Error (ppm) Plots 11: Sortie a03-s02-0107



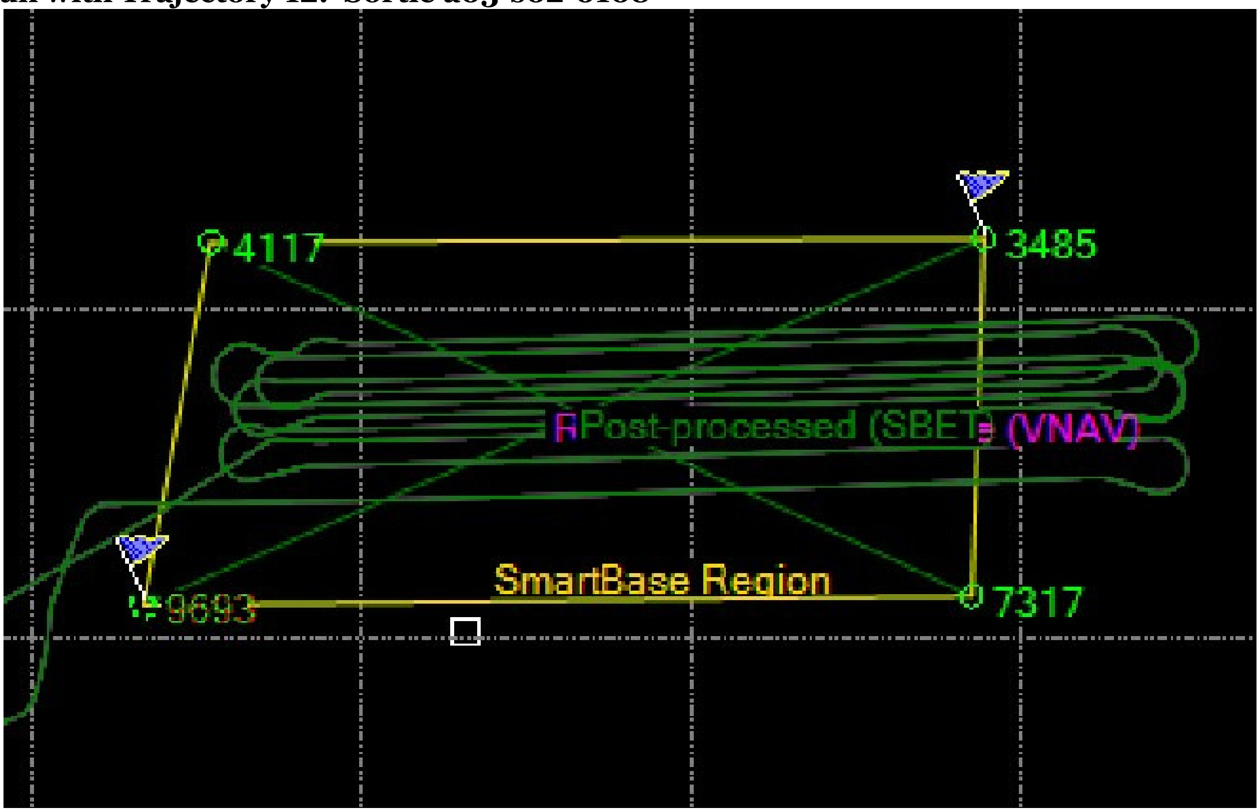
Gyro Scale Error (ppm) Plots 11: Sortie a03-s02-0107



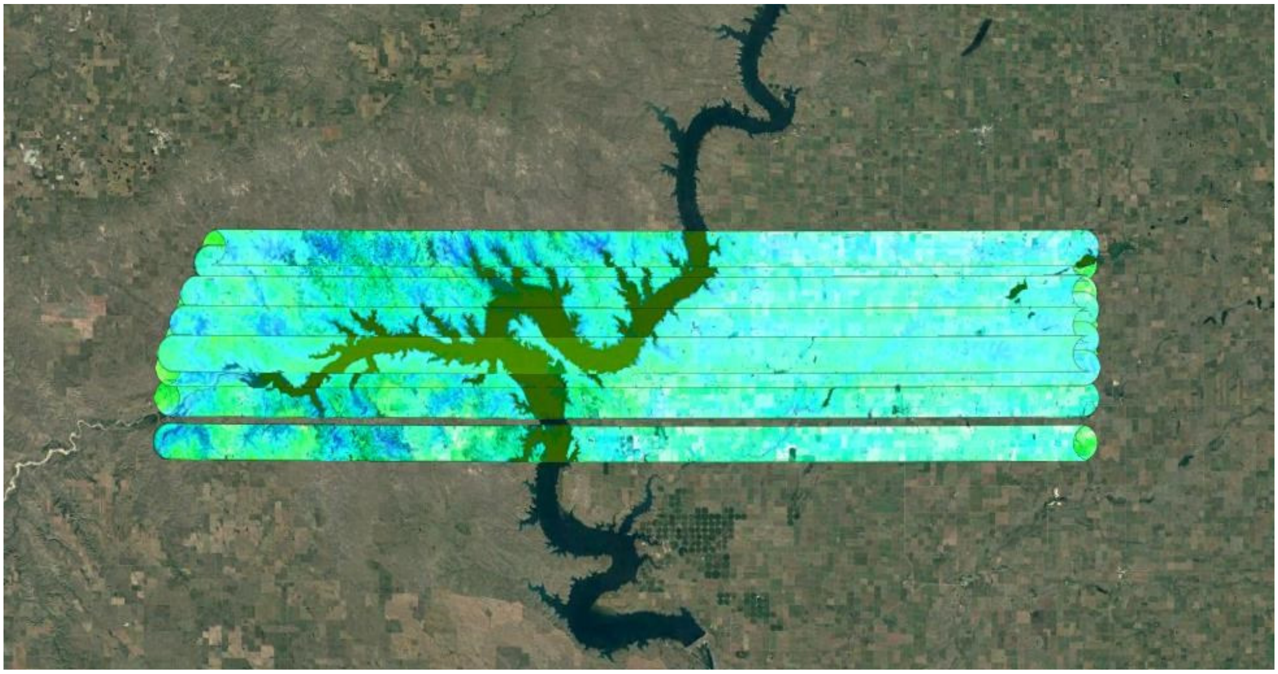
COLLECTION 12

Brick 3
Sortie a03-s02-0108
06/09/2016

Map Run with Trajectory 12: Sortie a03-s02-0108

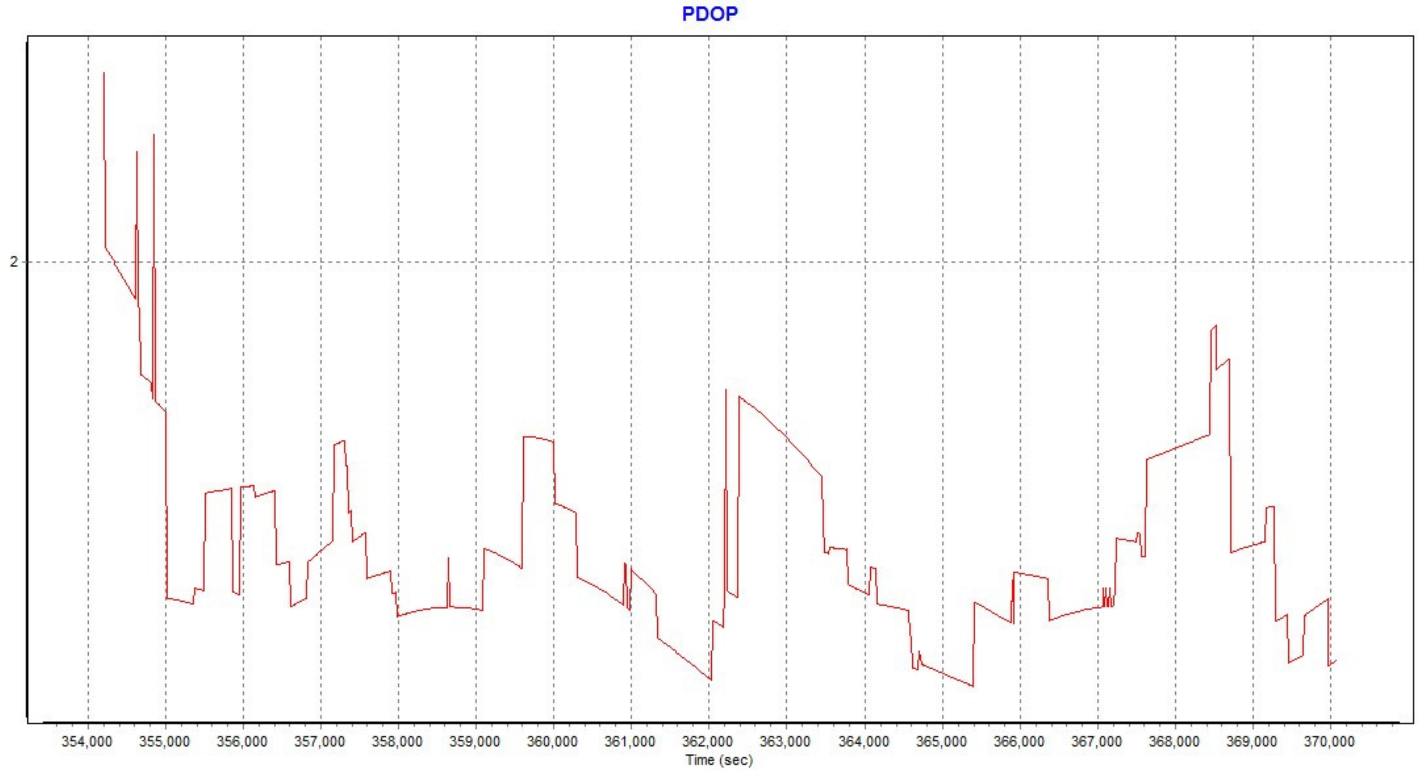


Swath Width, Waterfall View 12: Sortie a03-s02-0108

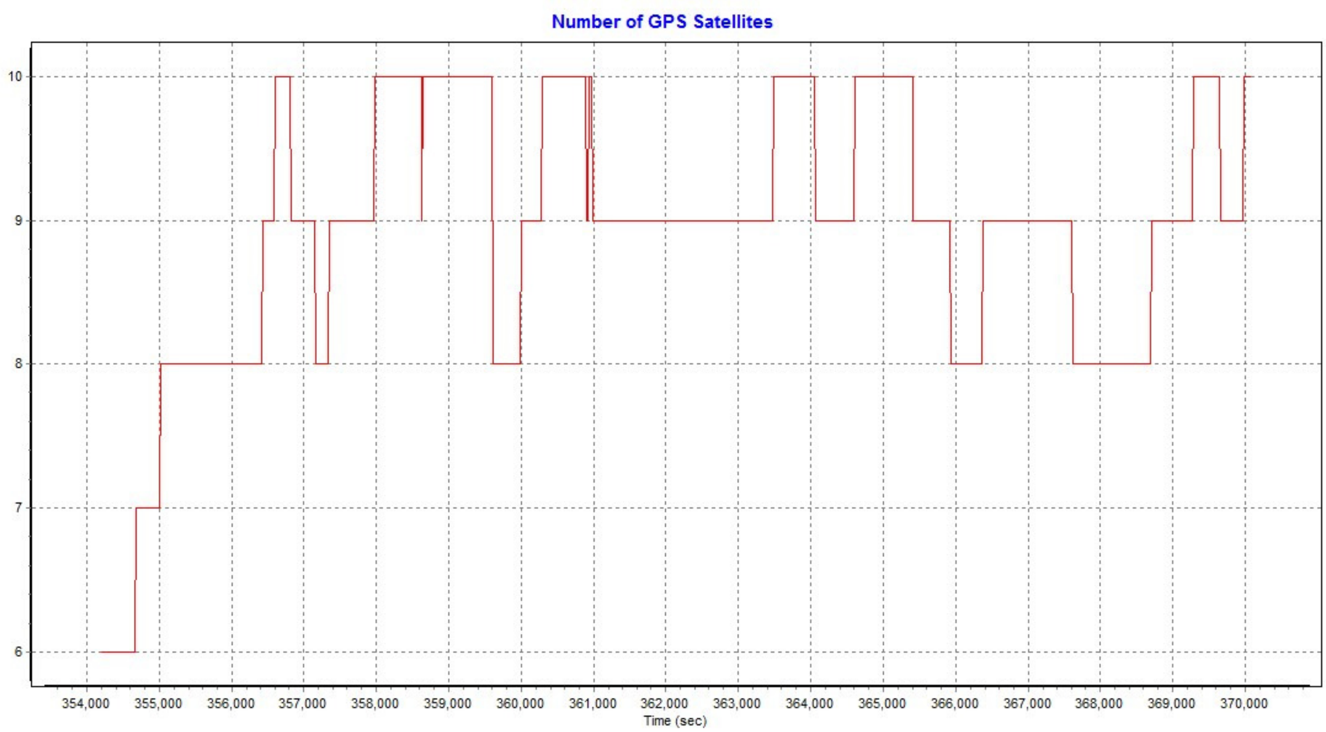


Combined SBET IAKAR Separation 12: Sortie a03-s02-0108

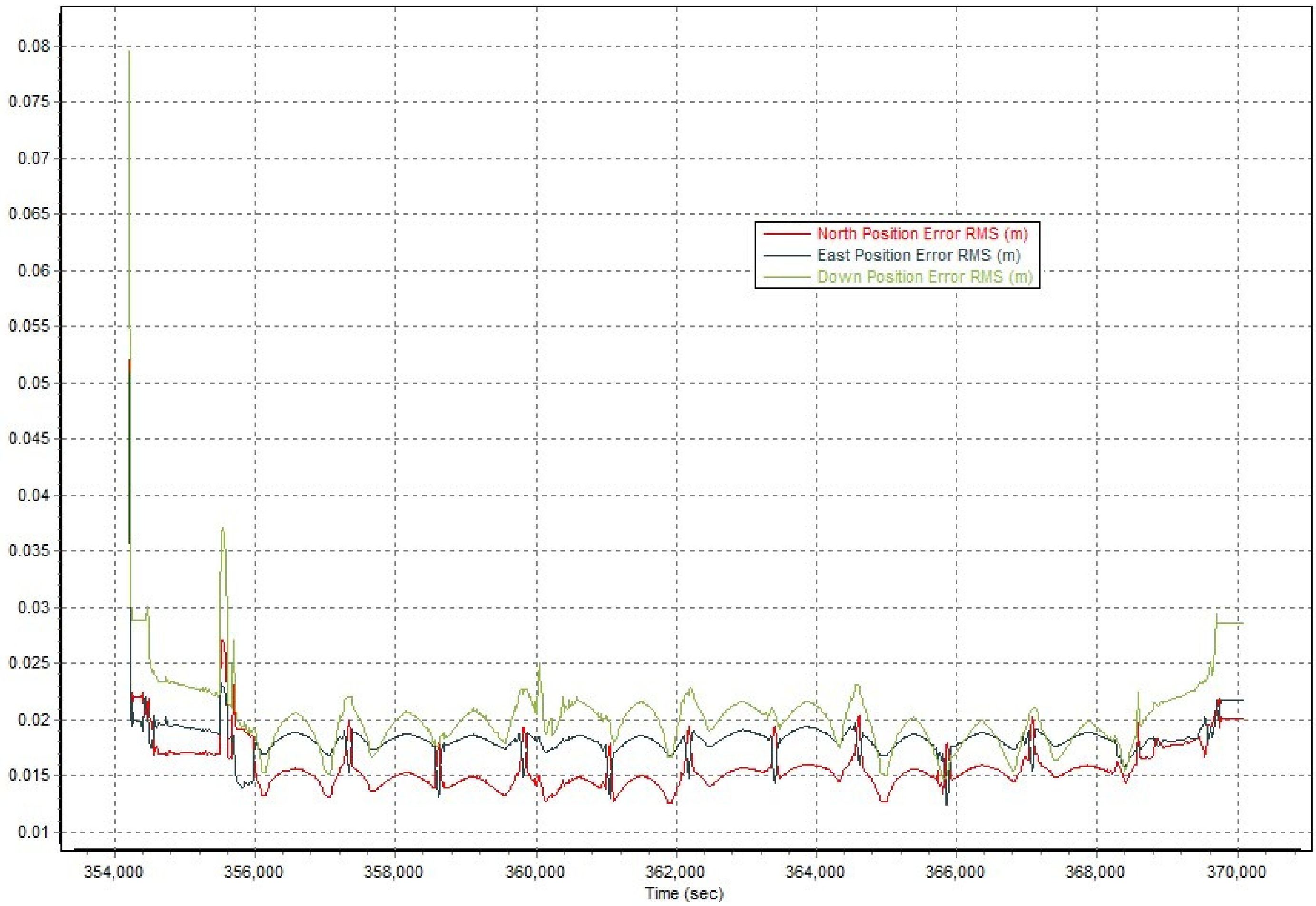
PDOP Plots 12: Sortie a03-s02-0108



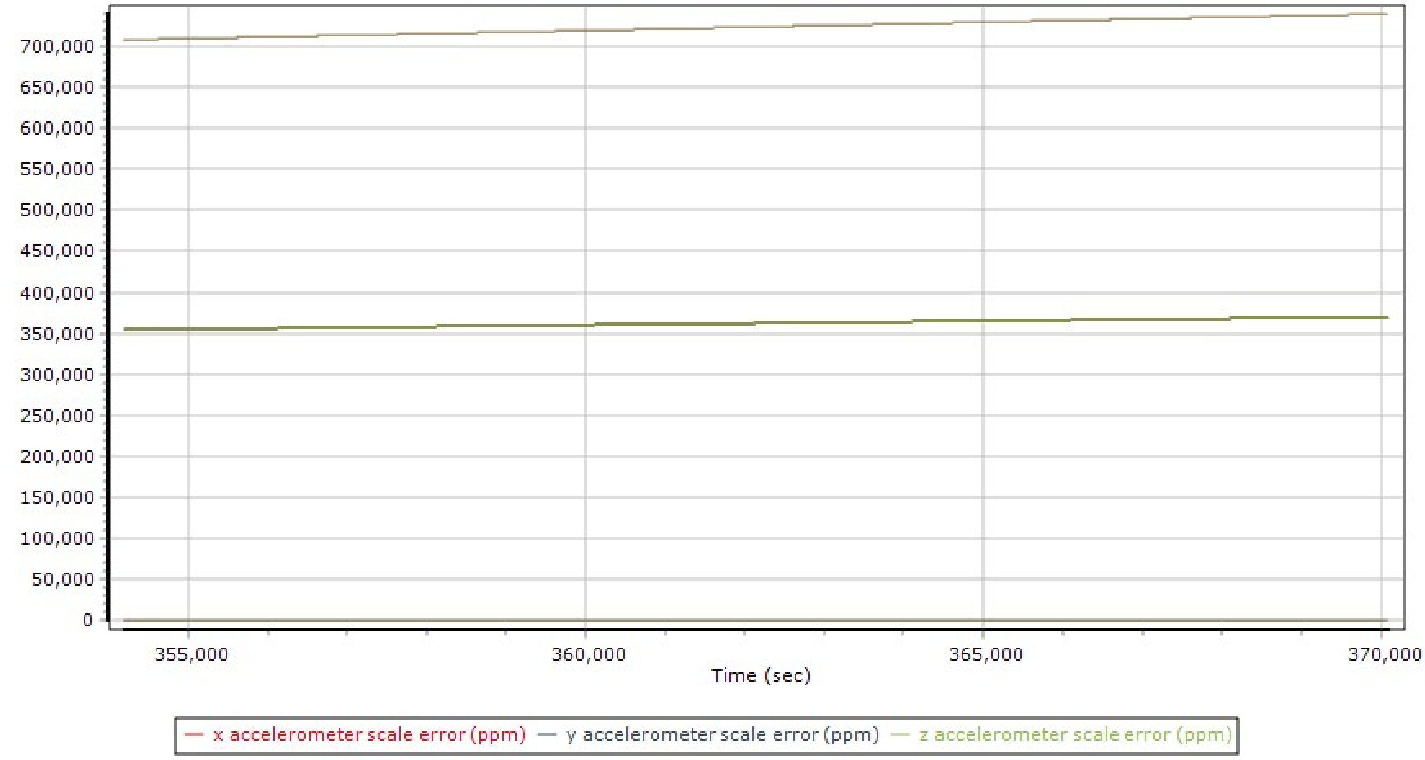
Number of Satellites (>6) Plots 12: Sortie a03-s02-0108



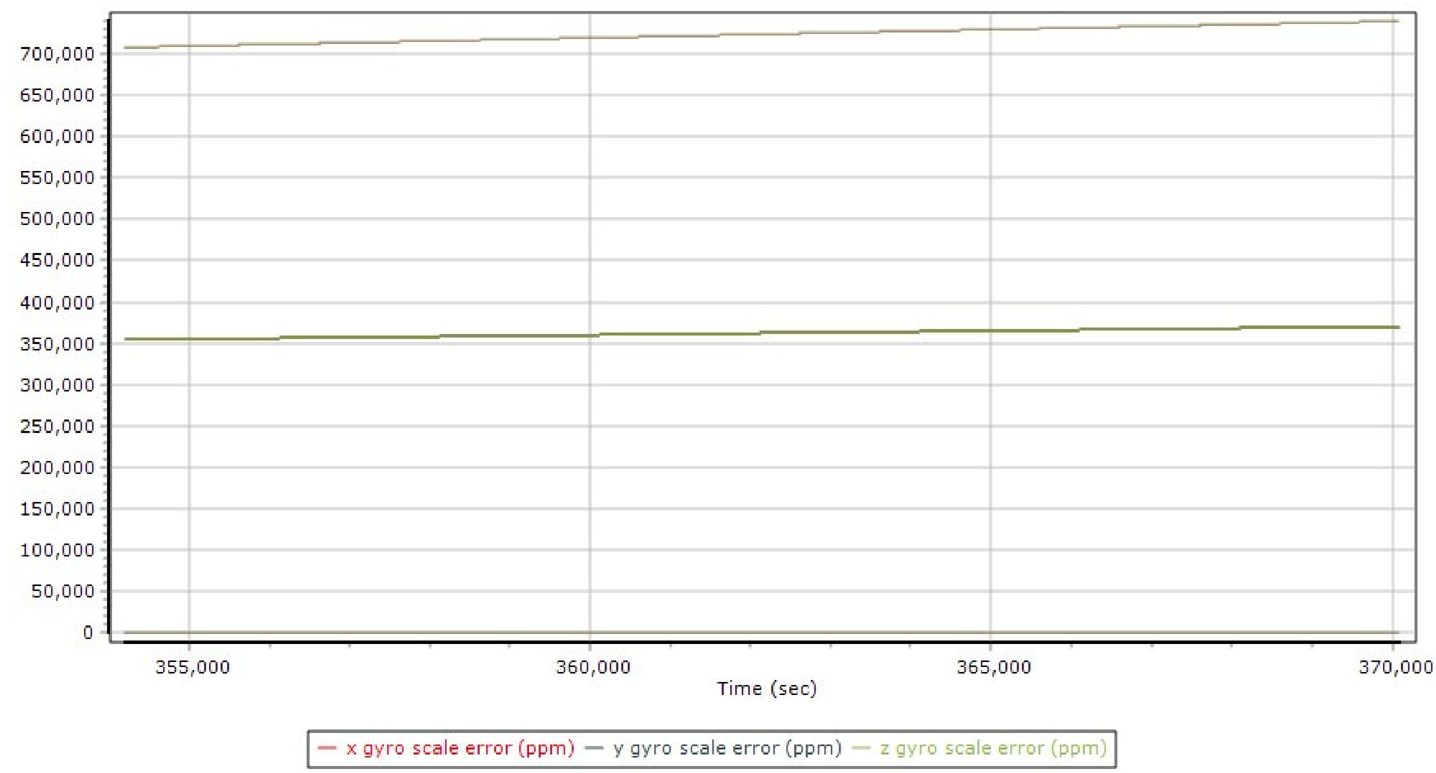
Sensor Position Error RMS (m) Plots 12: Sortie a03-s02-0108



Accelerometer Scale Error (ppm) Plots 12: Sortie a03-s02-0108



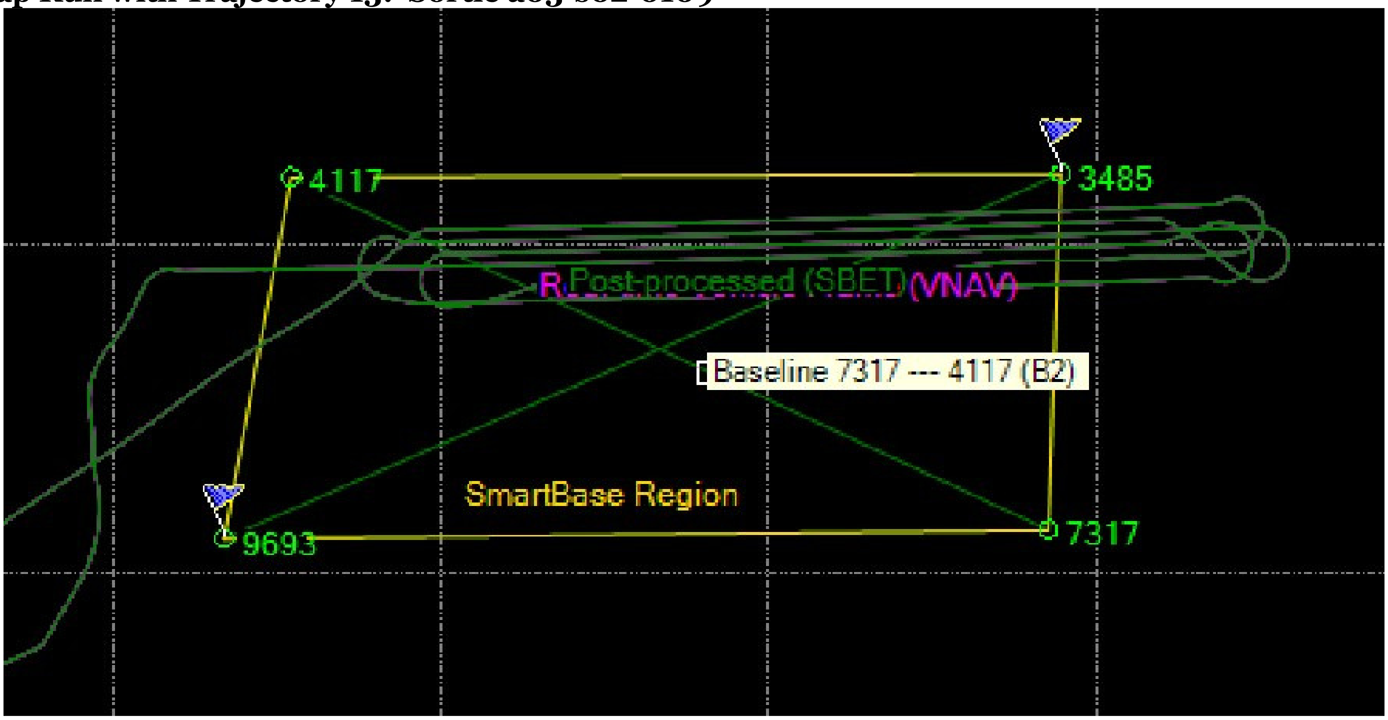
Gyro Scale Error (ppm) Plots 12: Sortie a03-s02-0108



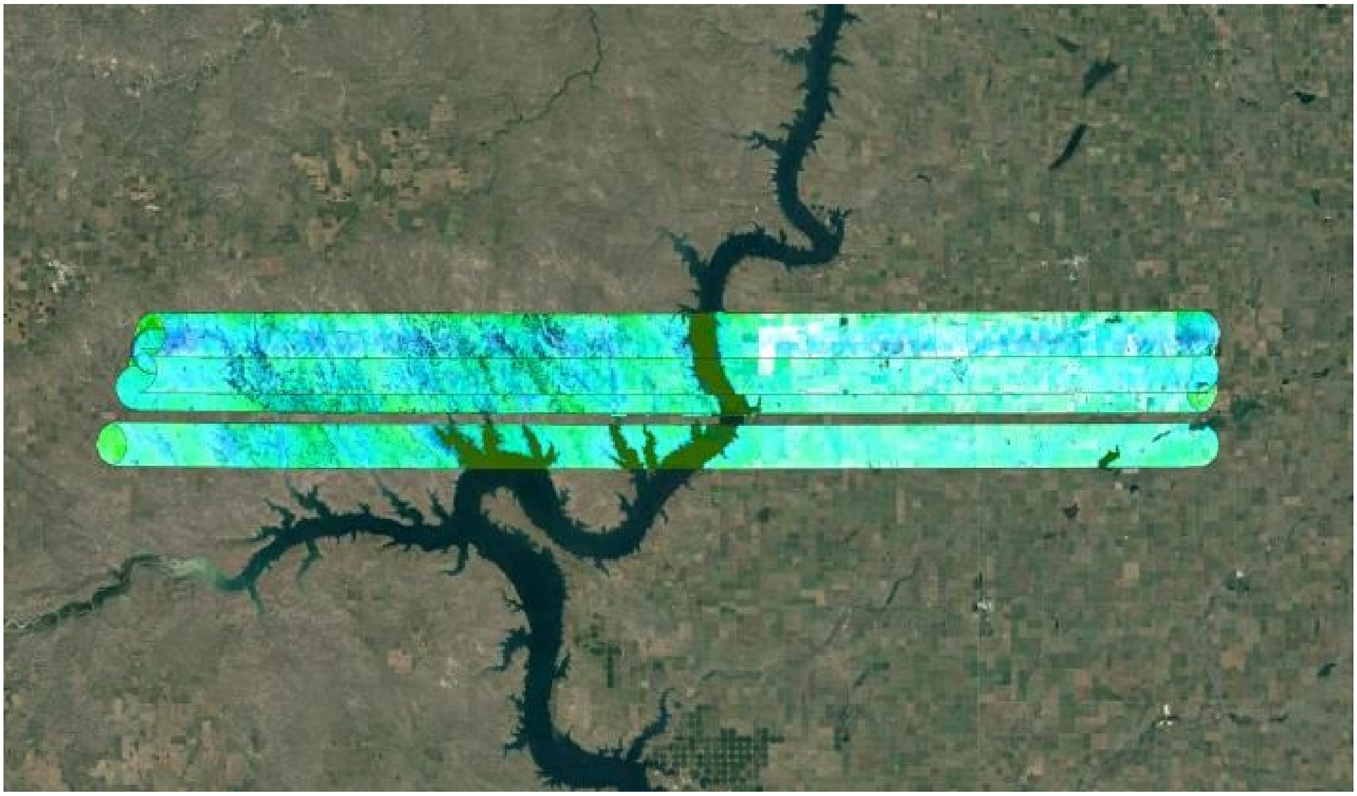
COLLECTION 13

Brick 3
Sortie a03-s02-0109
06/09/2016

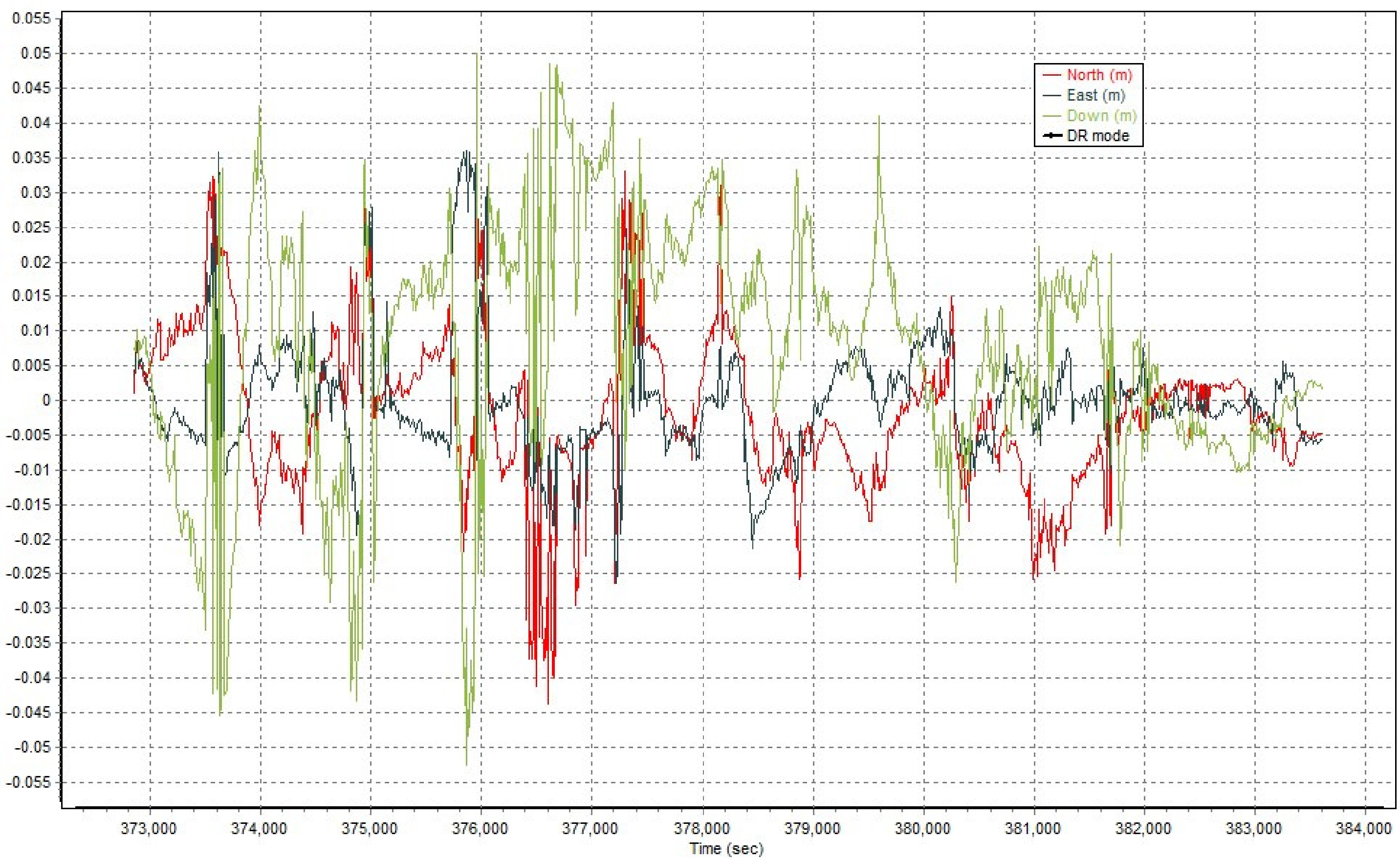
Map Run with Trajectory 13: Sortie a03-s02-0109



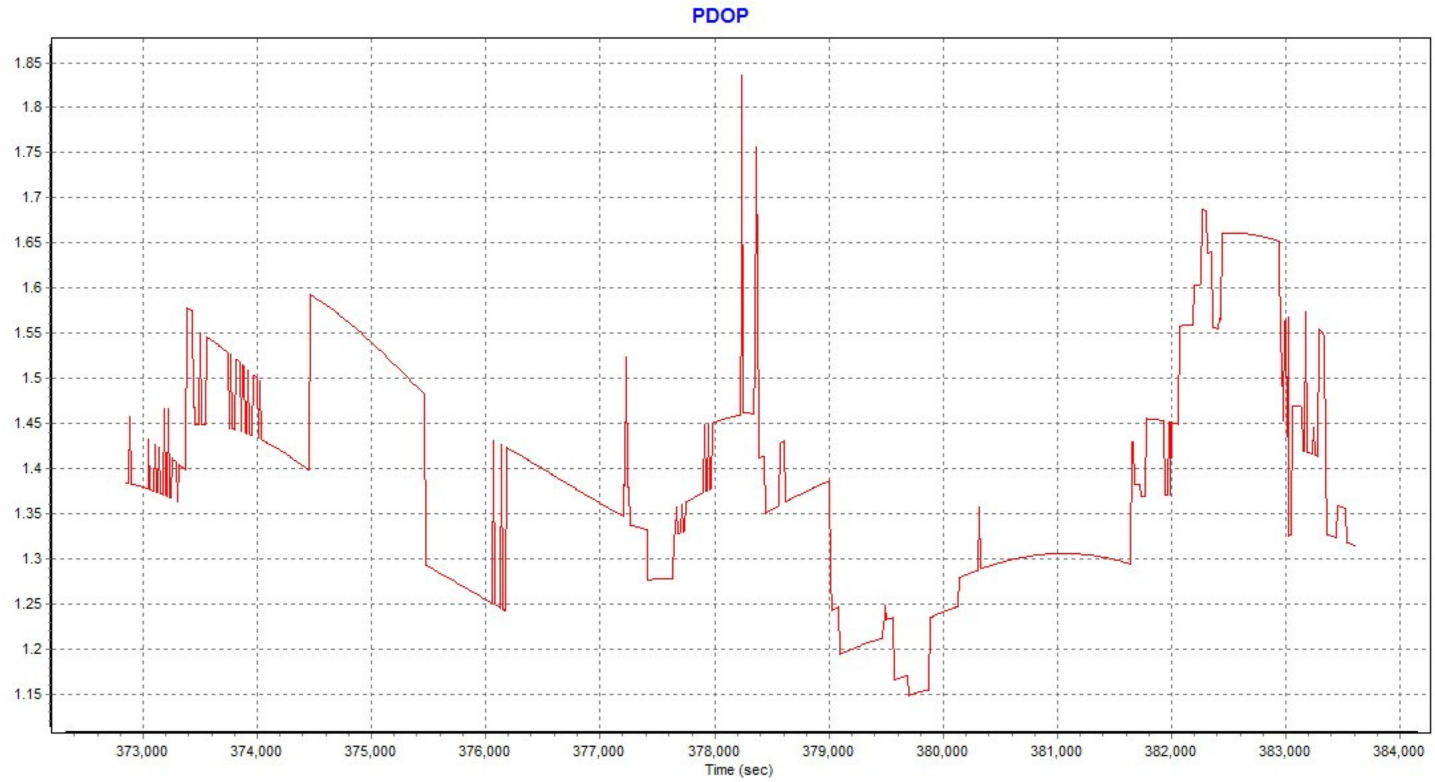
Swath Width, Waterfall View 13: Sortie a03-s02-0109



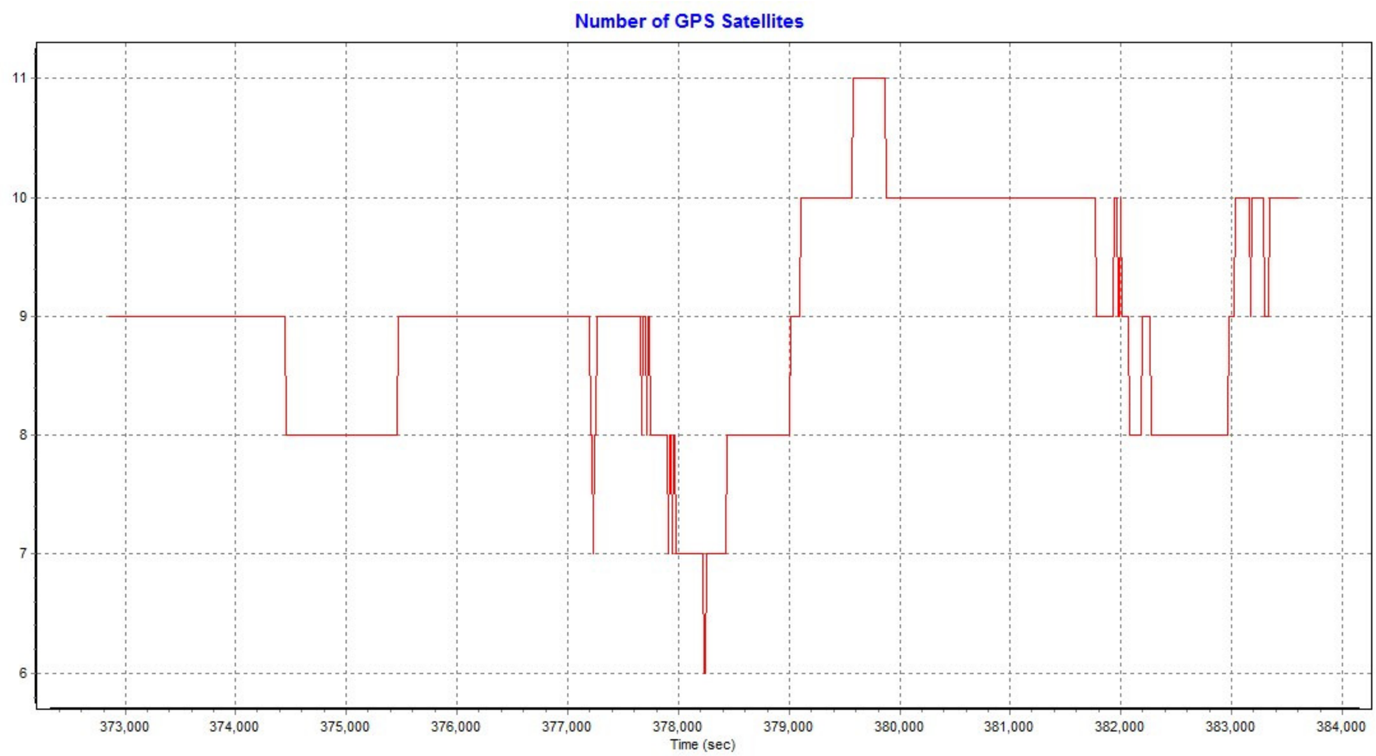
Combined SBET IAKAR Separation 13: Sortie a03-s02-0109



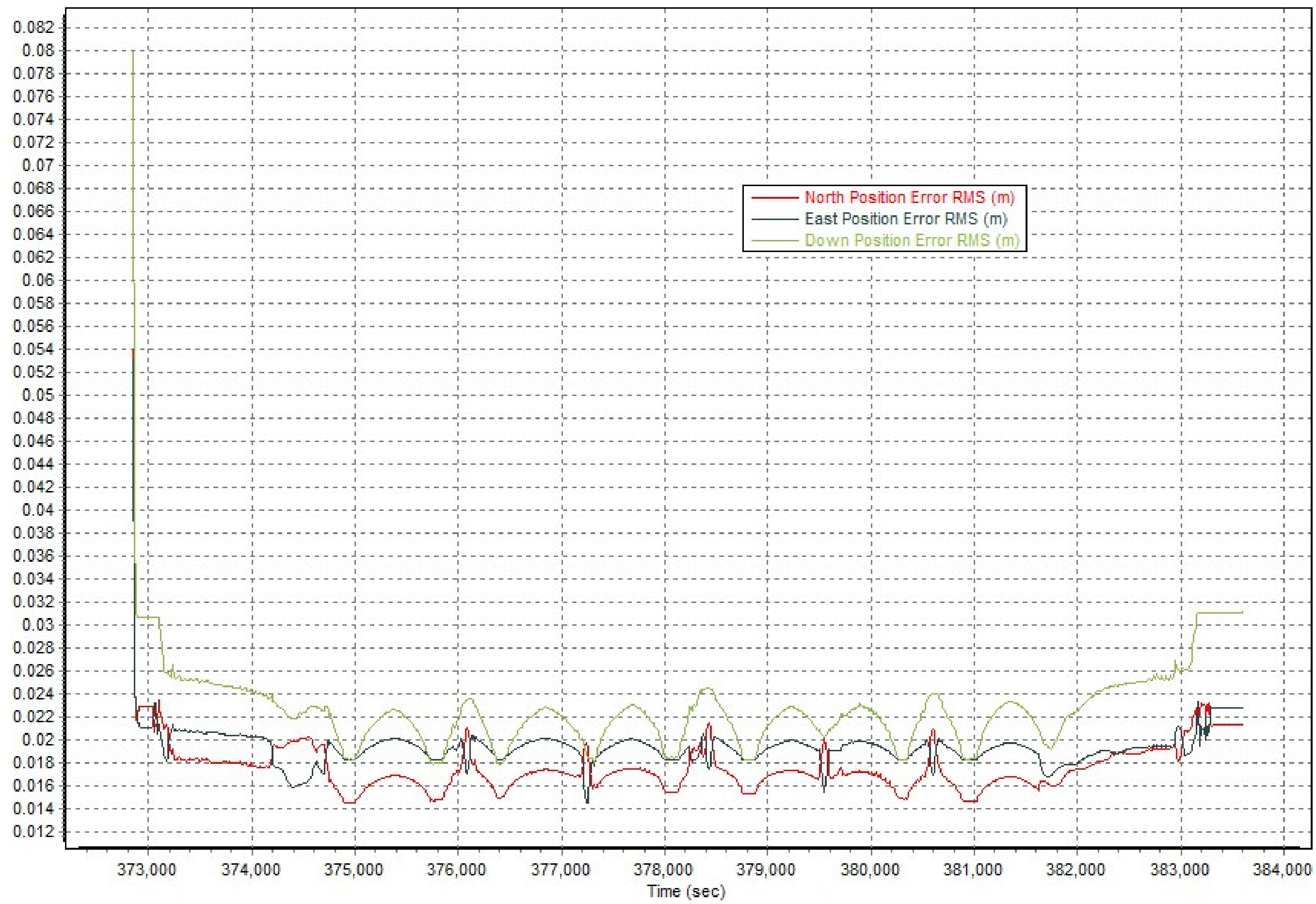
PDOP Plots 13: Sortie a03-s02-0109



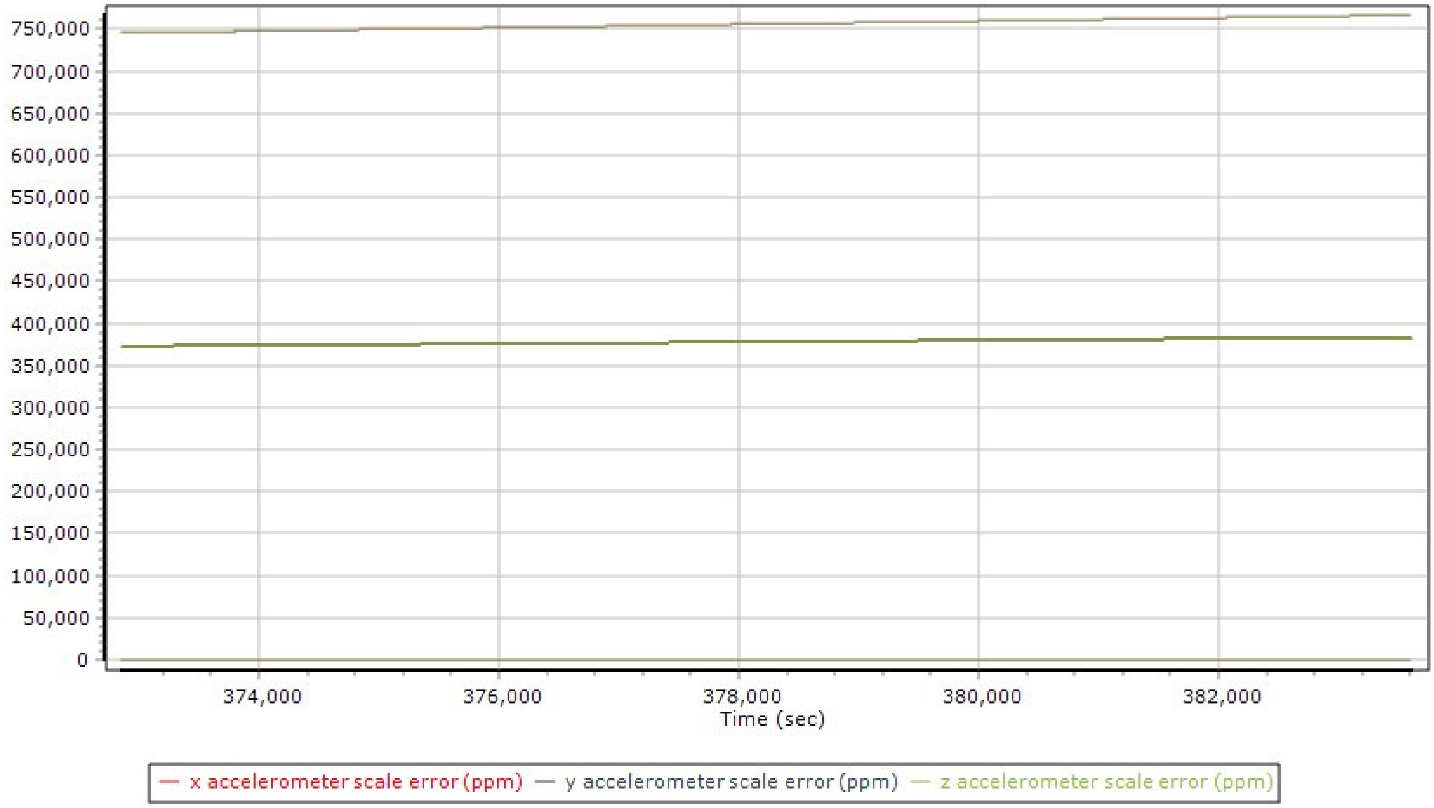
Number of Satellites (>6) Plots 13: Sortie a03-s02-0109



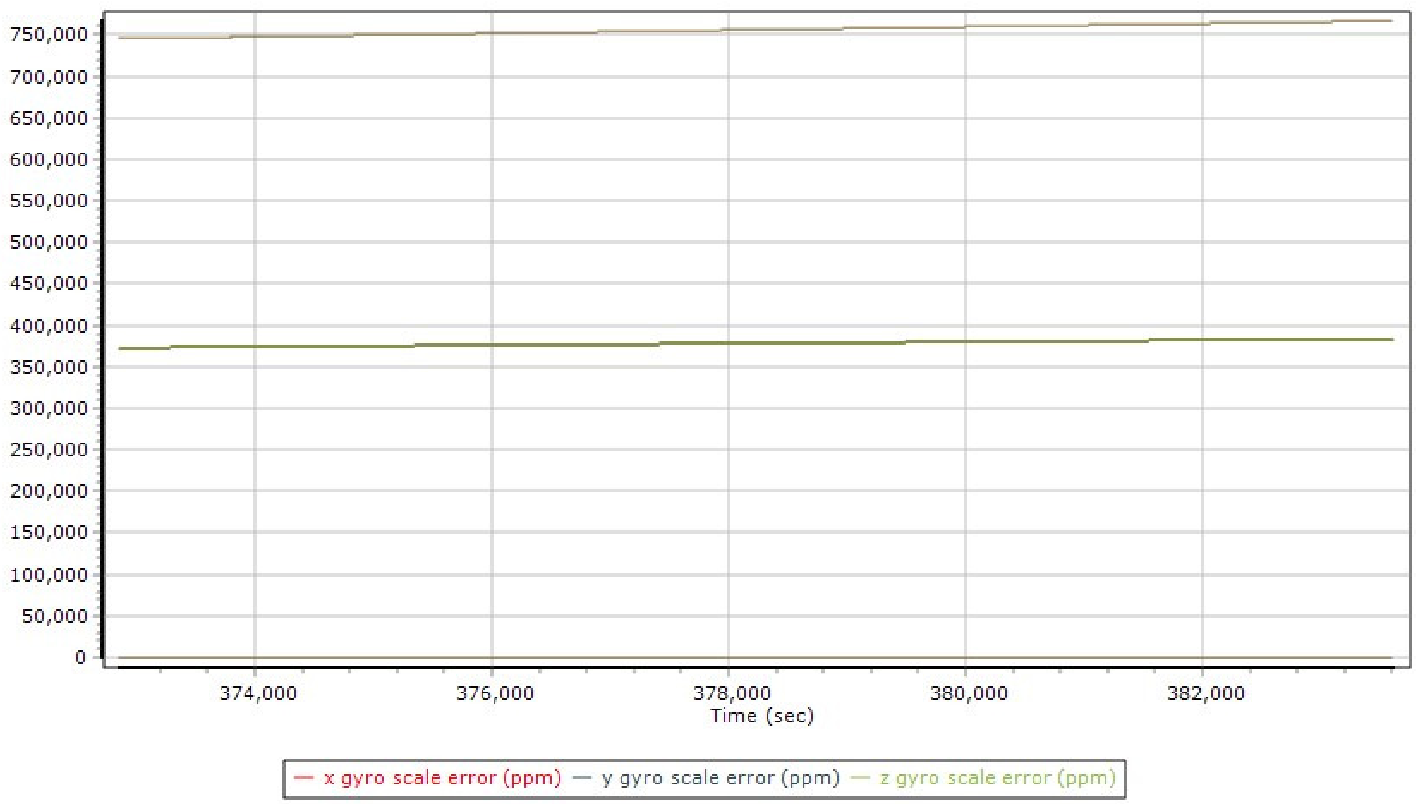
Sensor Position Error RMS (m) Plots 13: Sortie a03-s02-0109



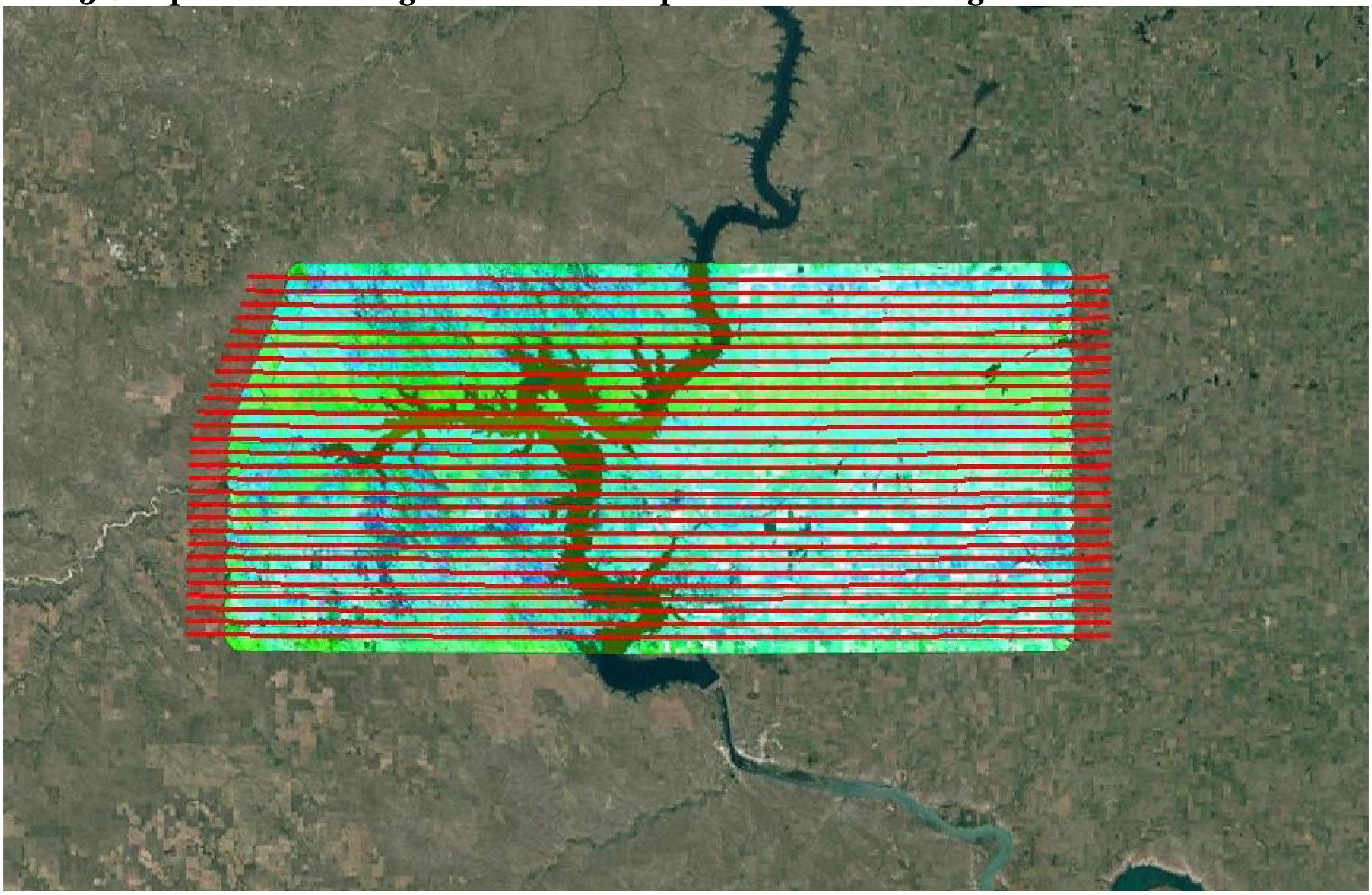
Accelerometer Scale Error (ppm) Plots 13: Sortie a03-s02-0109

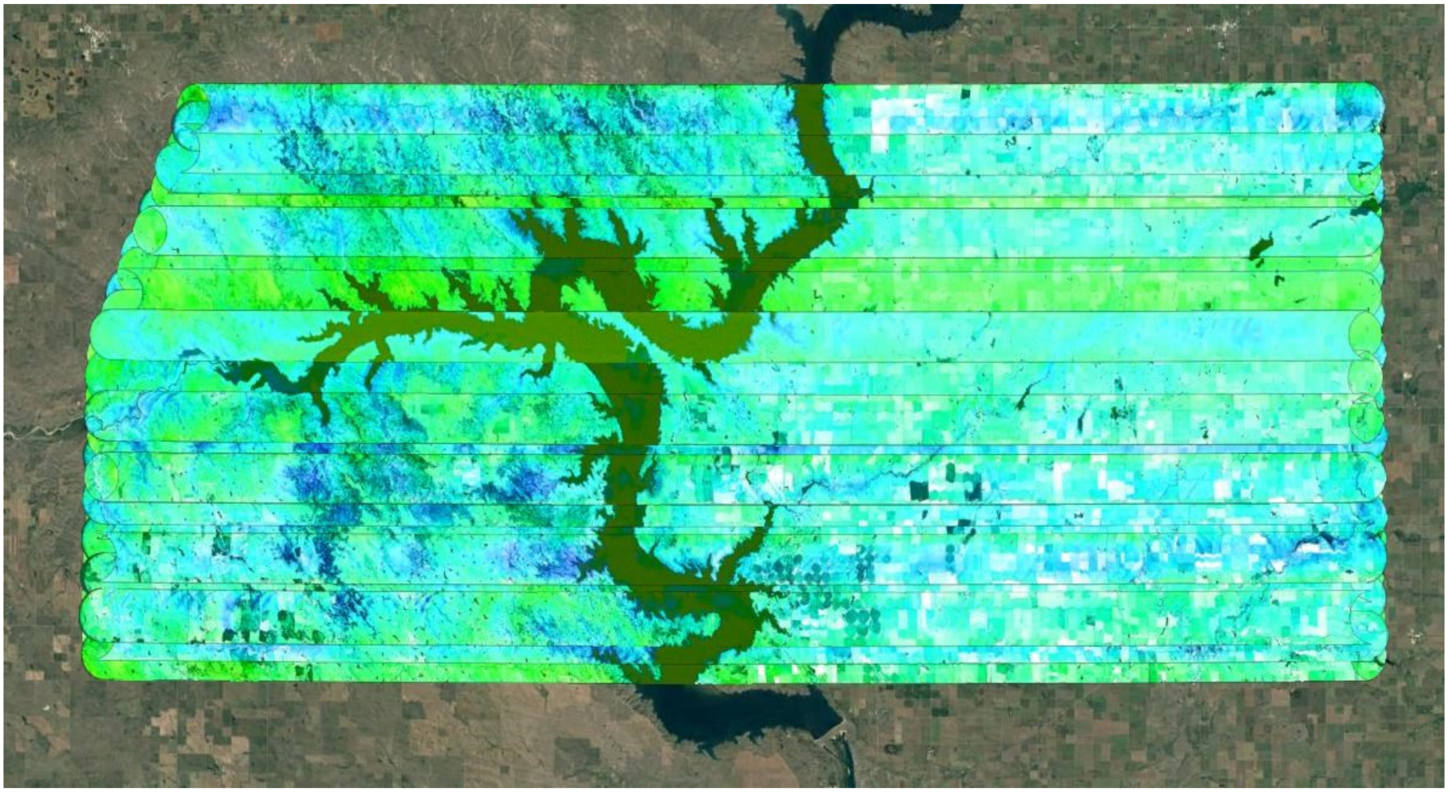


Gyro Scale Error (ppm) Plots 13: Sortie a03-s02-0109



Brick 3 Completion: Flight lines with complete waterfall coverage

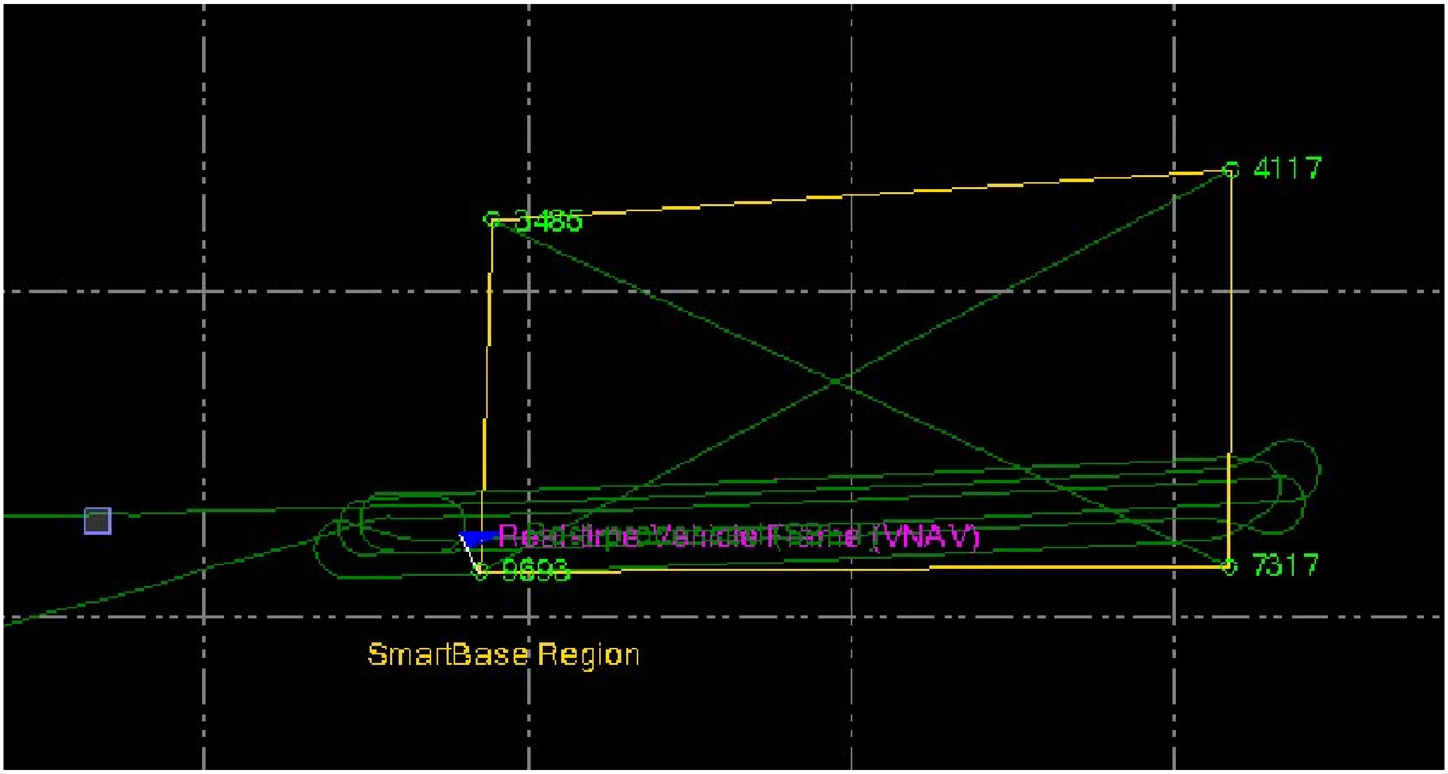




COLLECTION 14

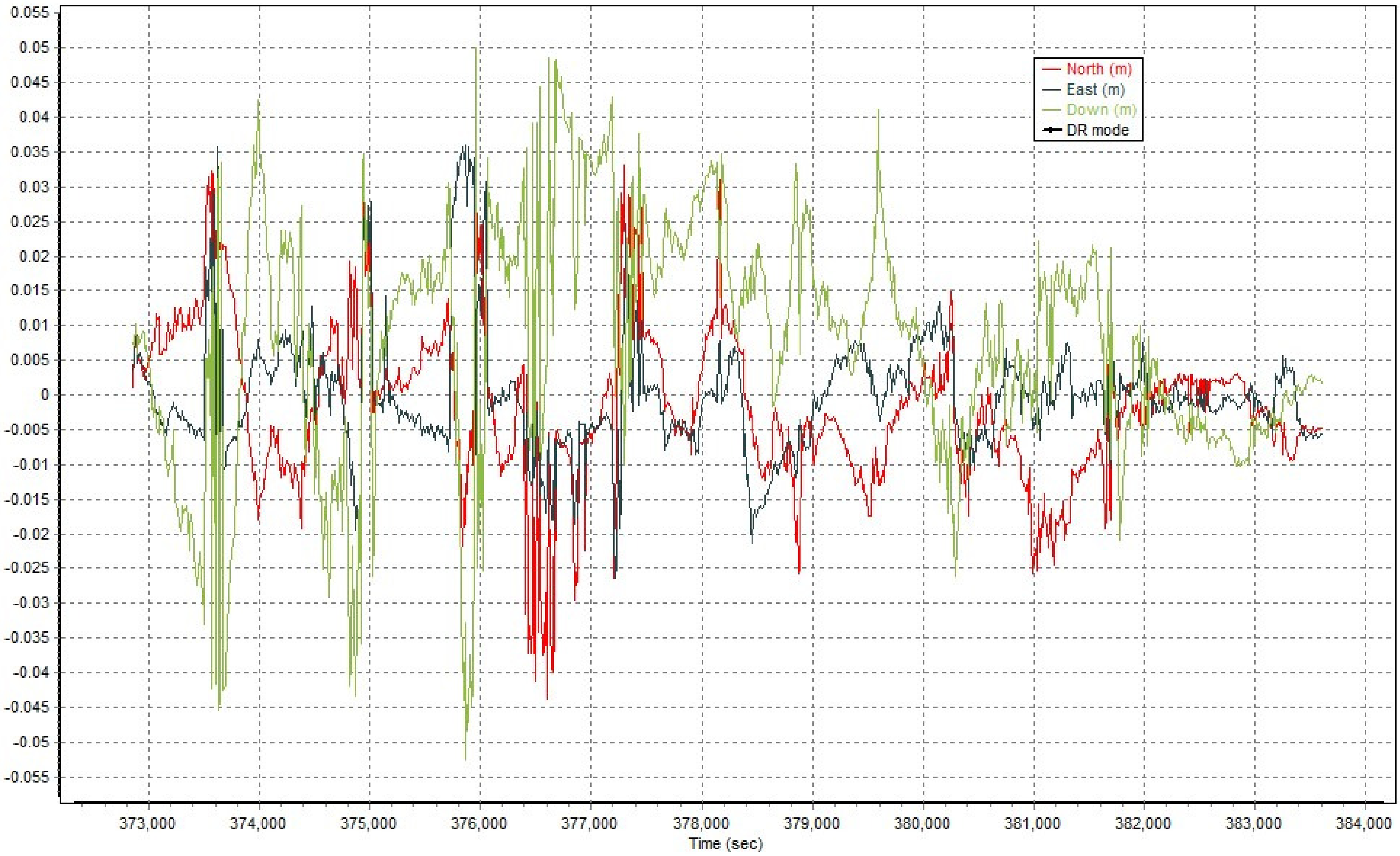
Brick 4
Sortie a03-s02-0110
06/10/2016

Map Run with Trajectory 14: Sortie a03-s02-0110

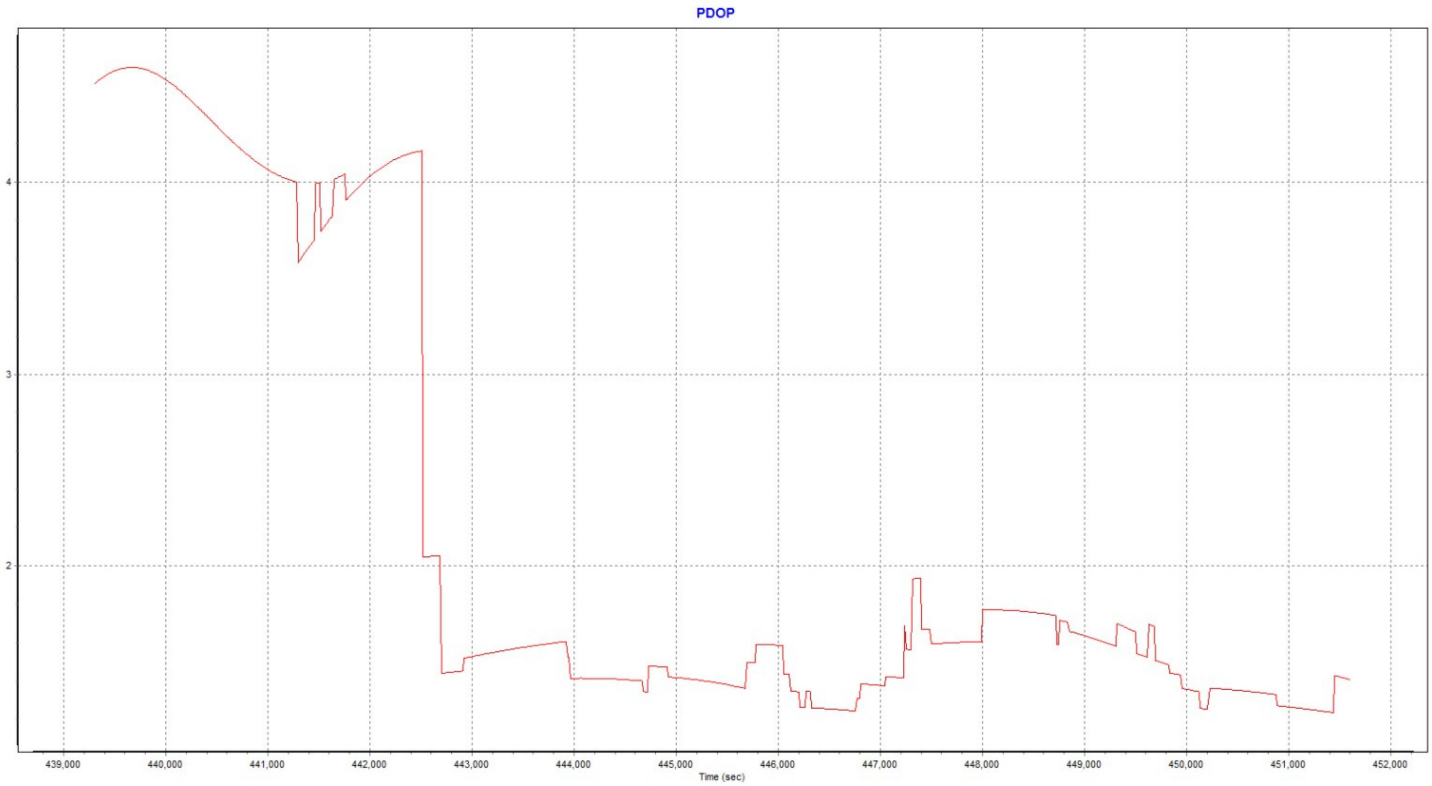


Swath Width, Waterfall View 14: Sortie a03-s02-0110

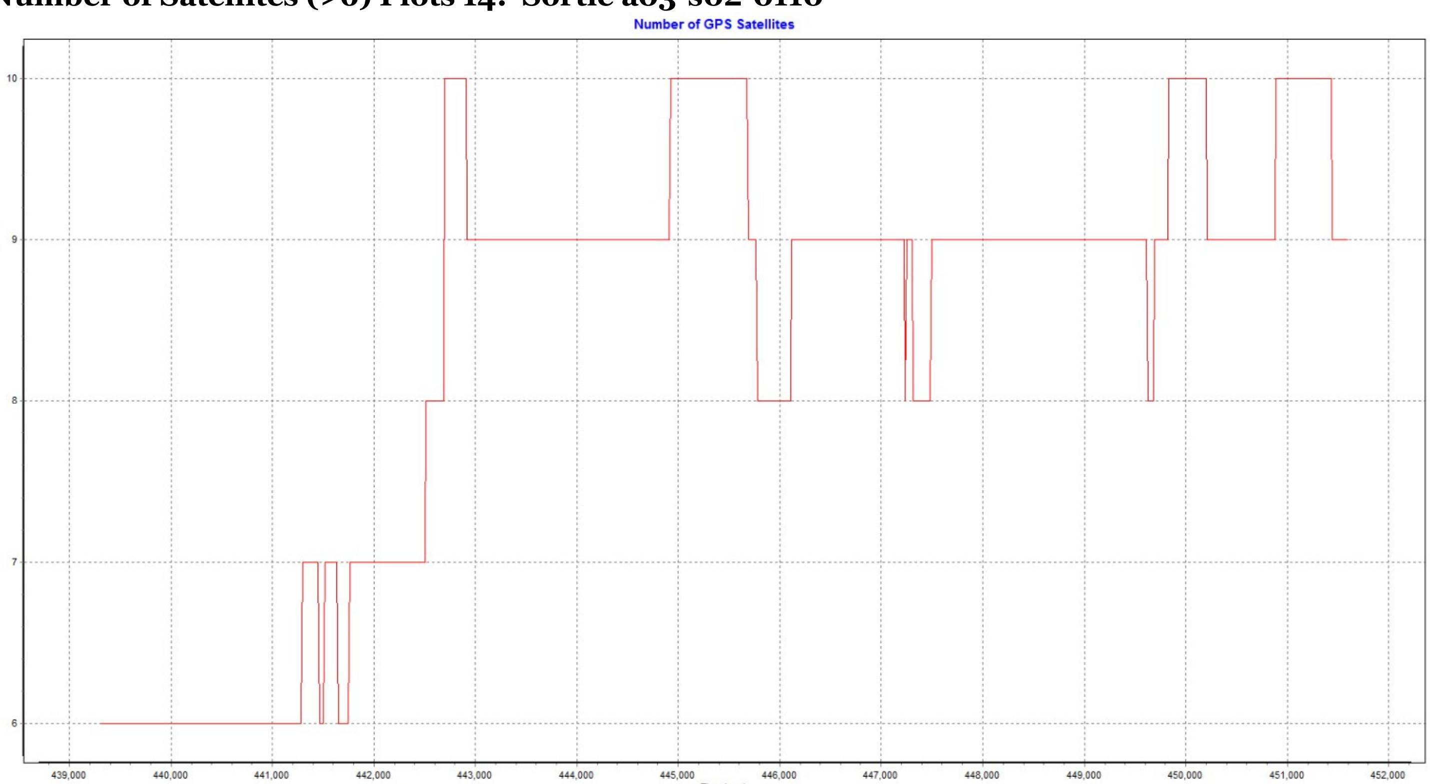
Combined SBET IAKAR Separation 14: Sortie a03-s02-0110



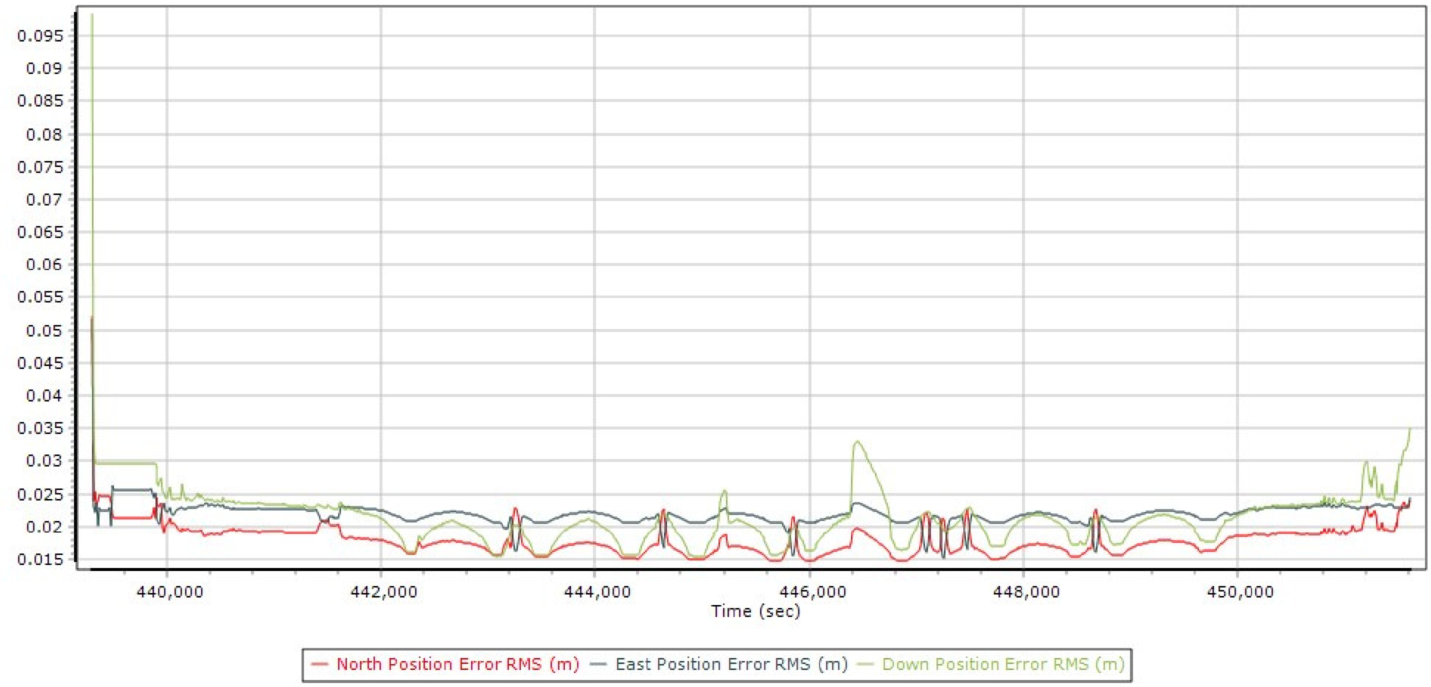
PDOP Plots 14: Sortie a03-s02-0110



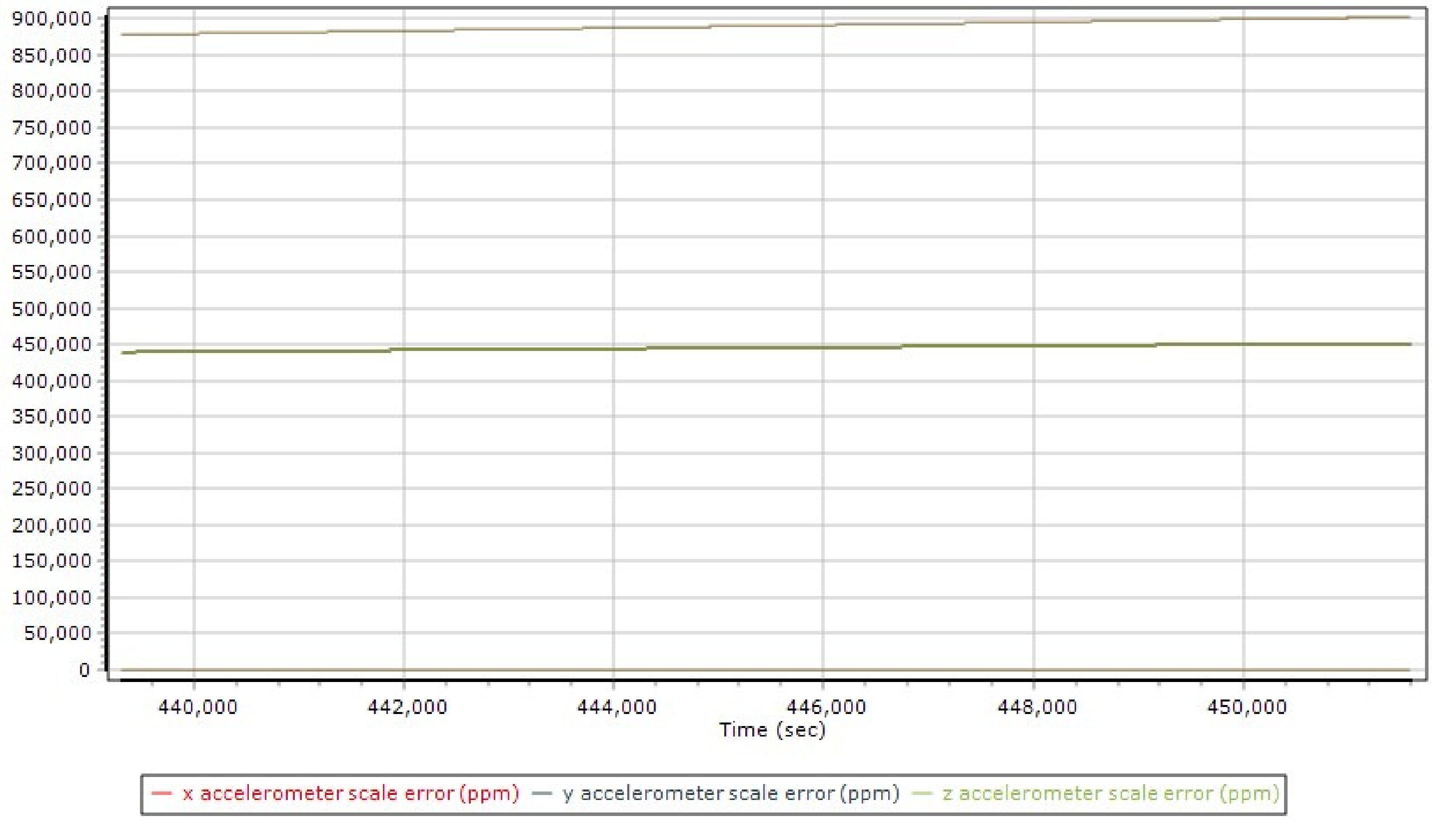
Number of Satellites (>6) Plots 14: Sortie a03-s02-0110



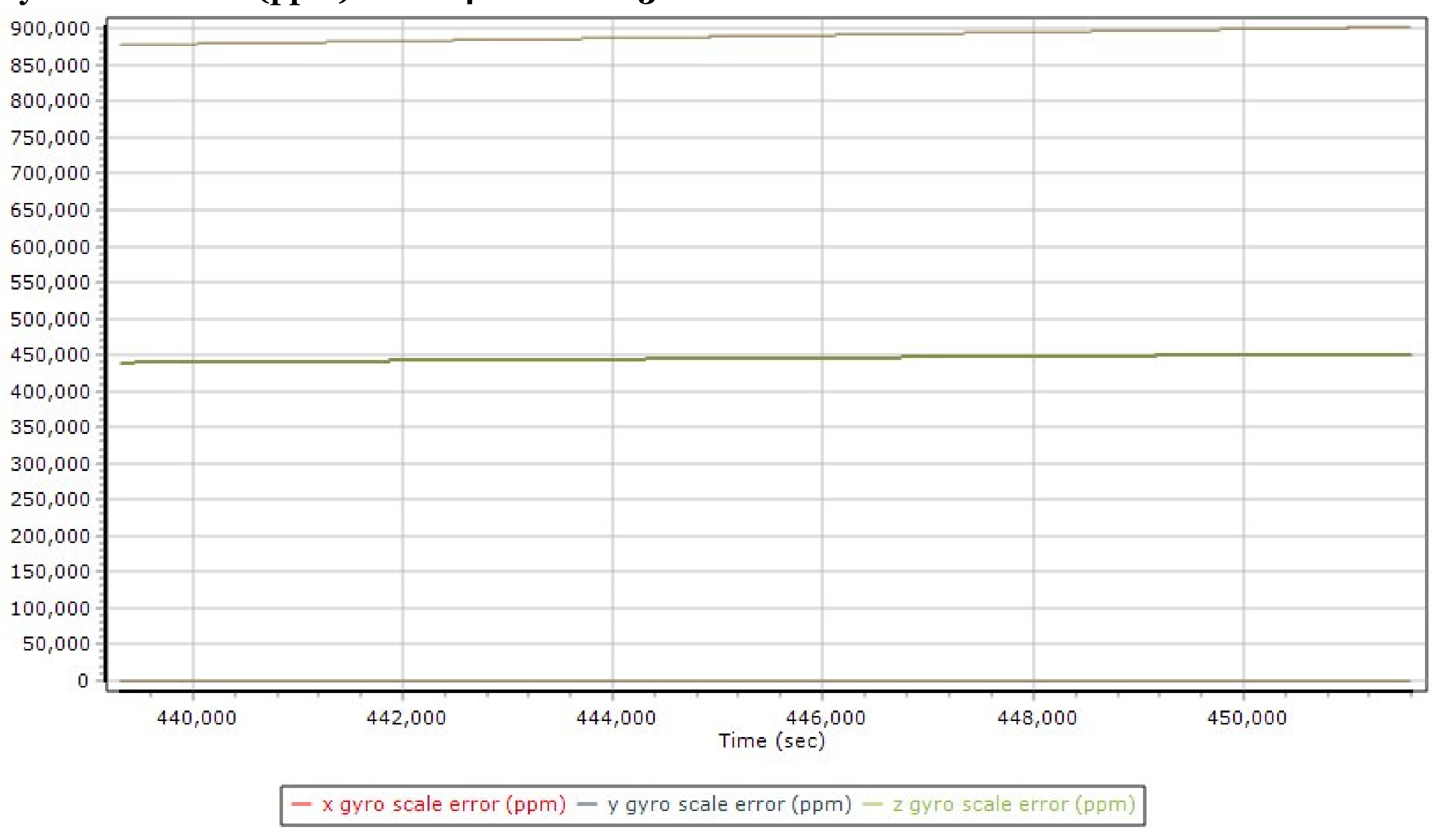
Sensor Position Error RMS (m) Plots 14: Sortie a03-s02-0110



Accelerometer Scale Error (ppm) Plots 14: Sortie a03-s02-0110



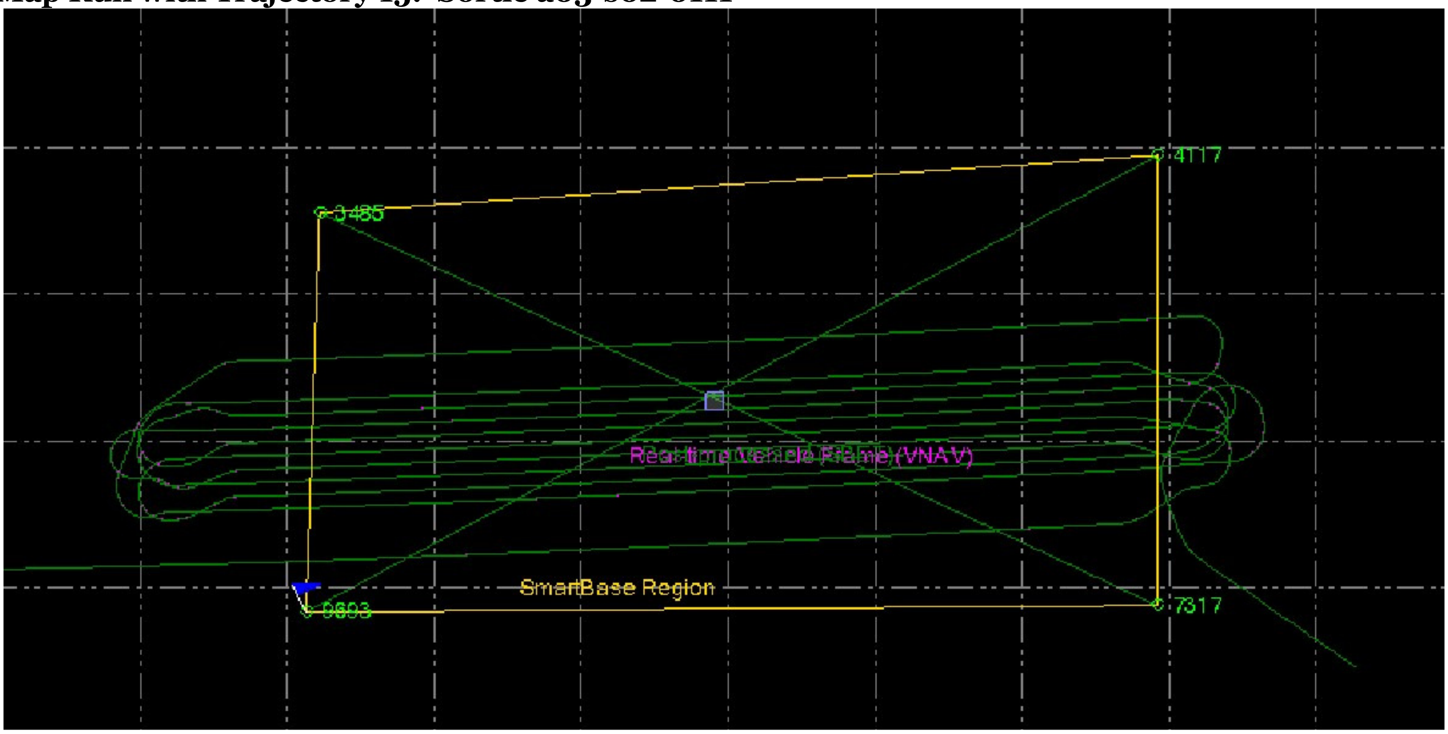
Gyro Scale Error (ppm) Plots 14: Sortie a03-s02-0110



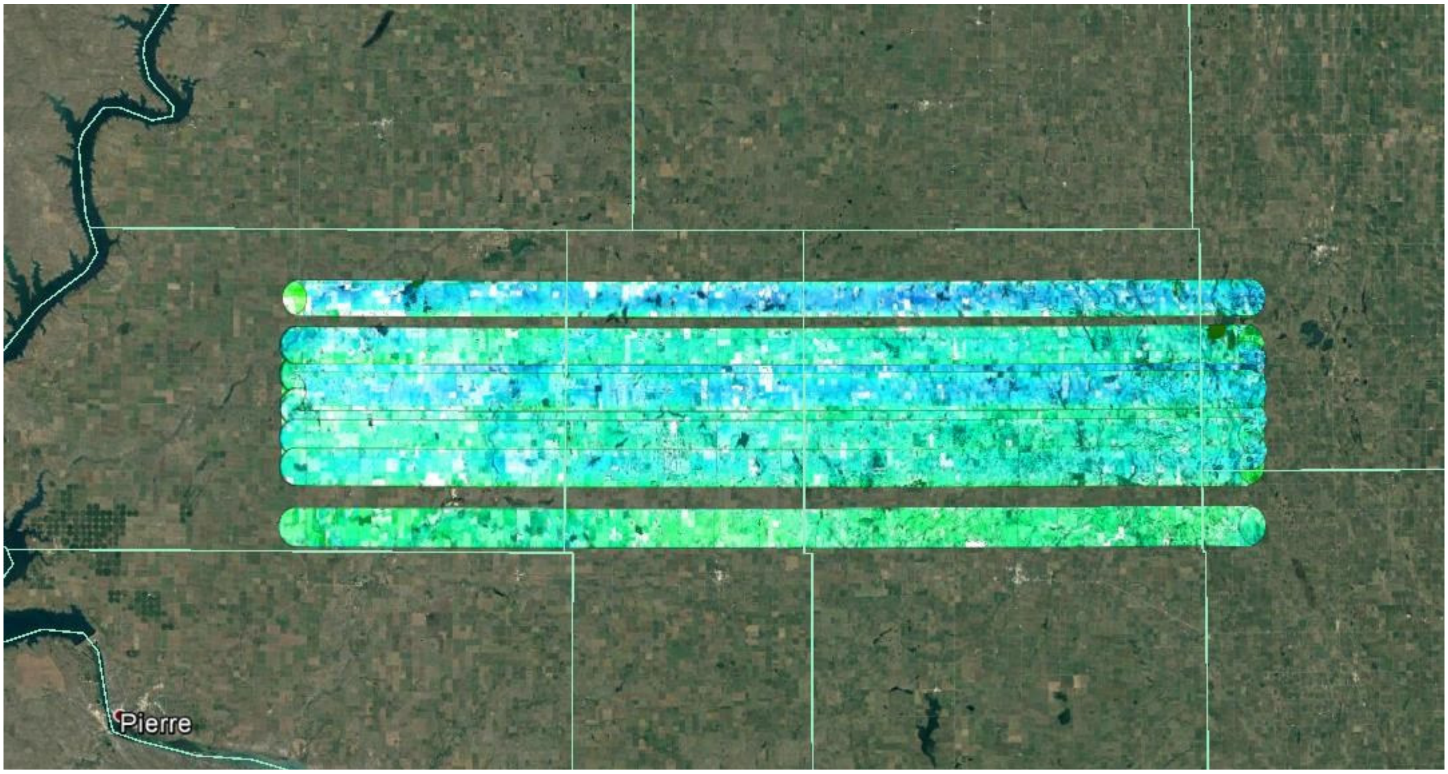
COLLECTION 15

Brick 4
Sortie a03-s02-0111
06/11/2016

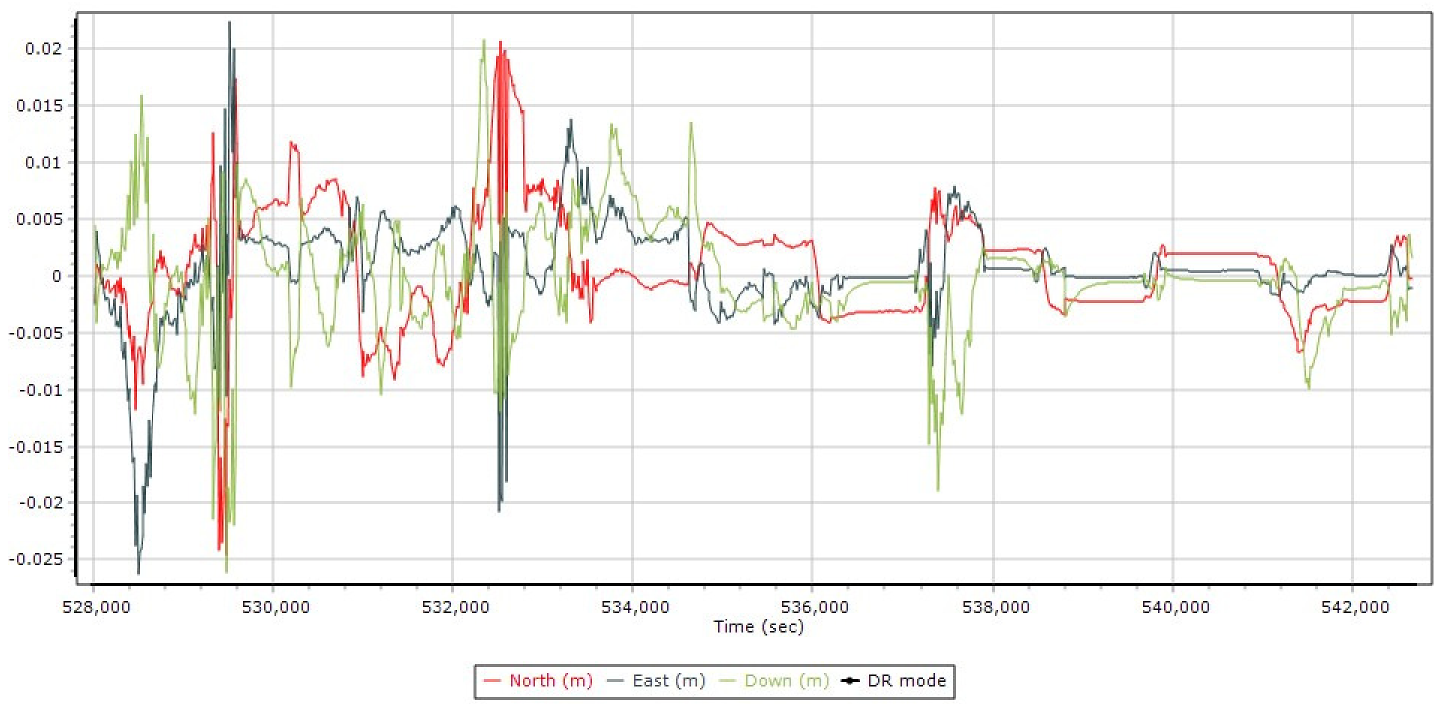
Map Run with Trajectory 15: Sortie a03-s02-0111



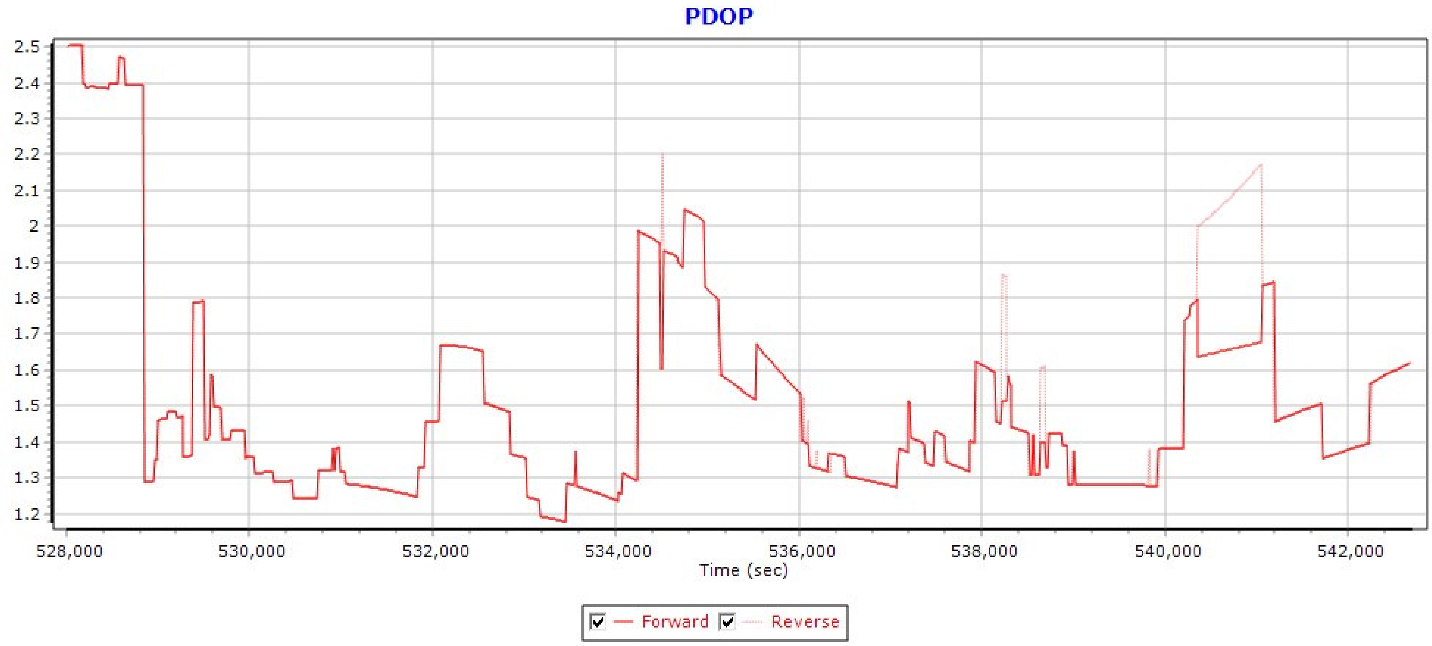
Swath Width, Waterfall View 15: Sortie a03-s02-0111



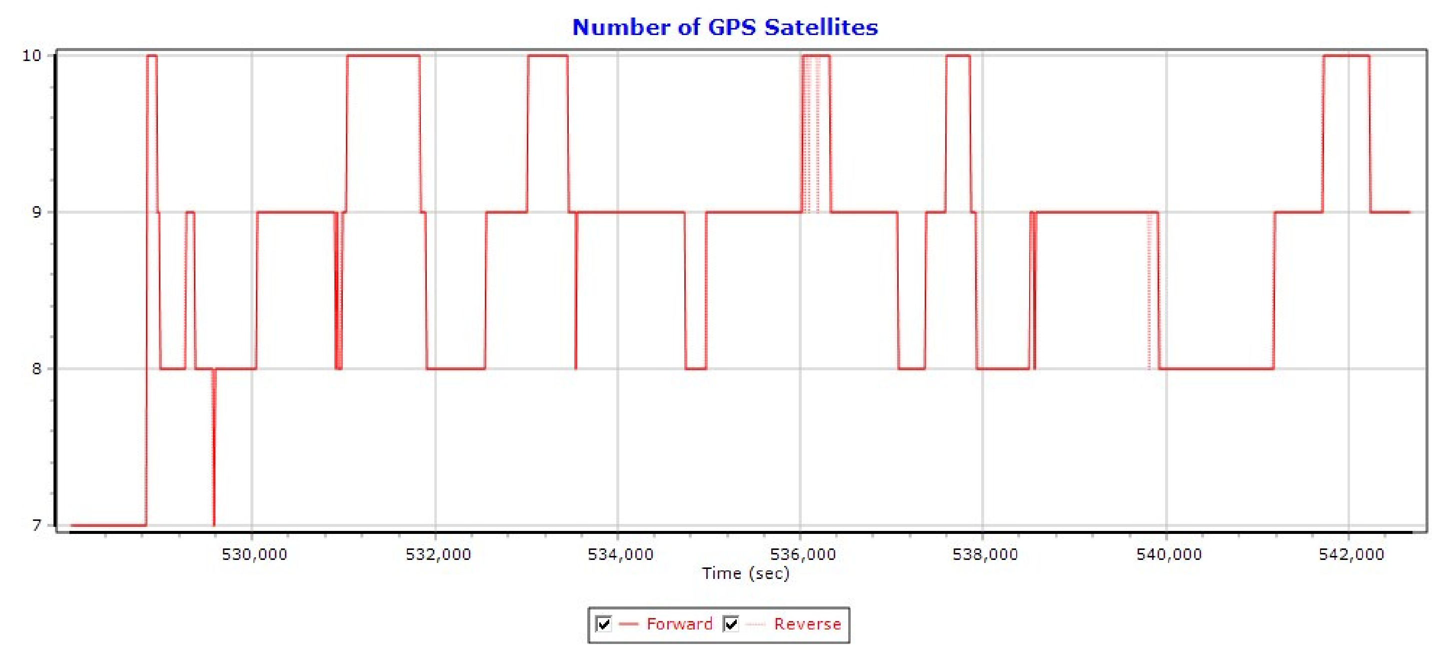
Combined SBET IAKAR Separation 15: Sortie a03-s02-0111



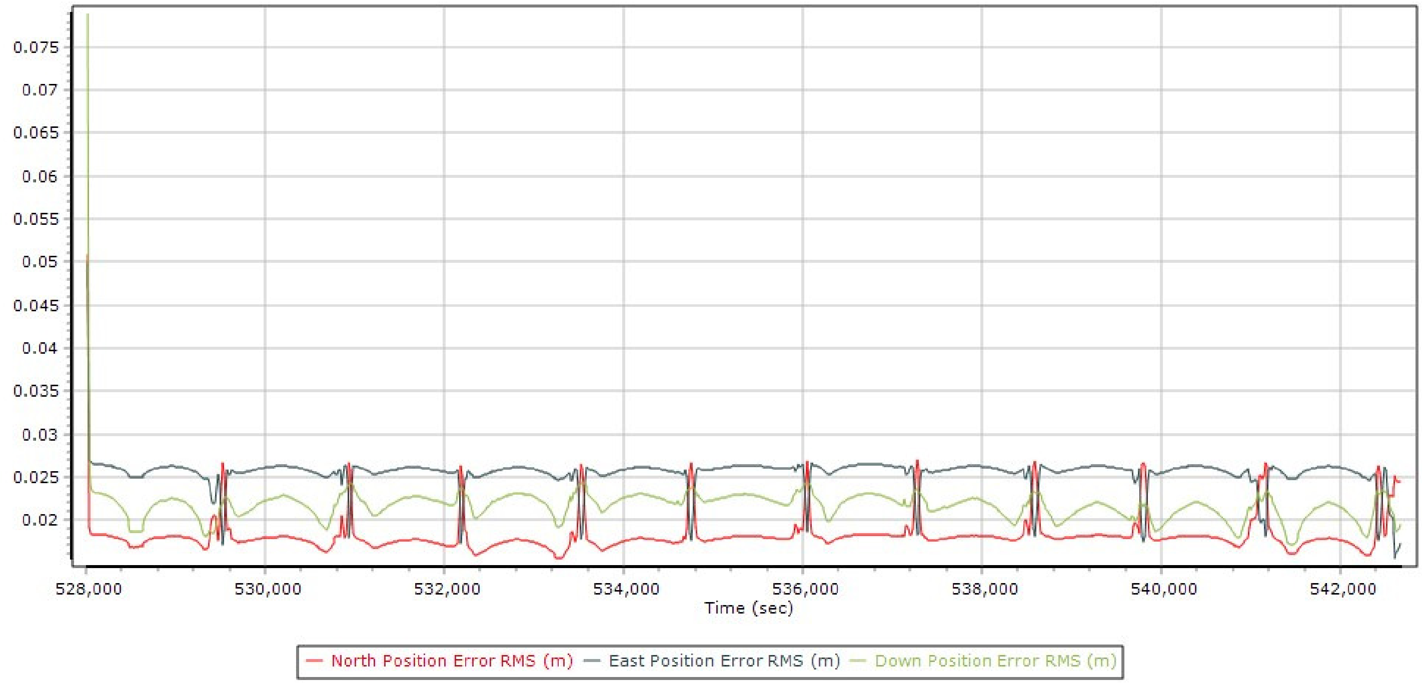
PDOP Plots 15: Sortie a03-s02-0111



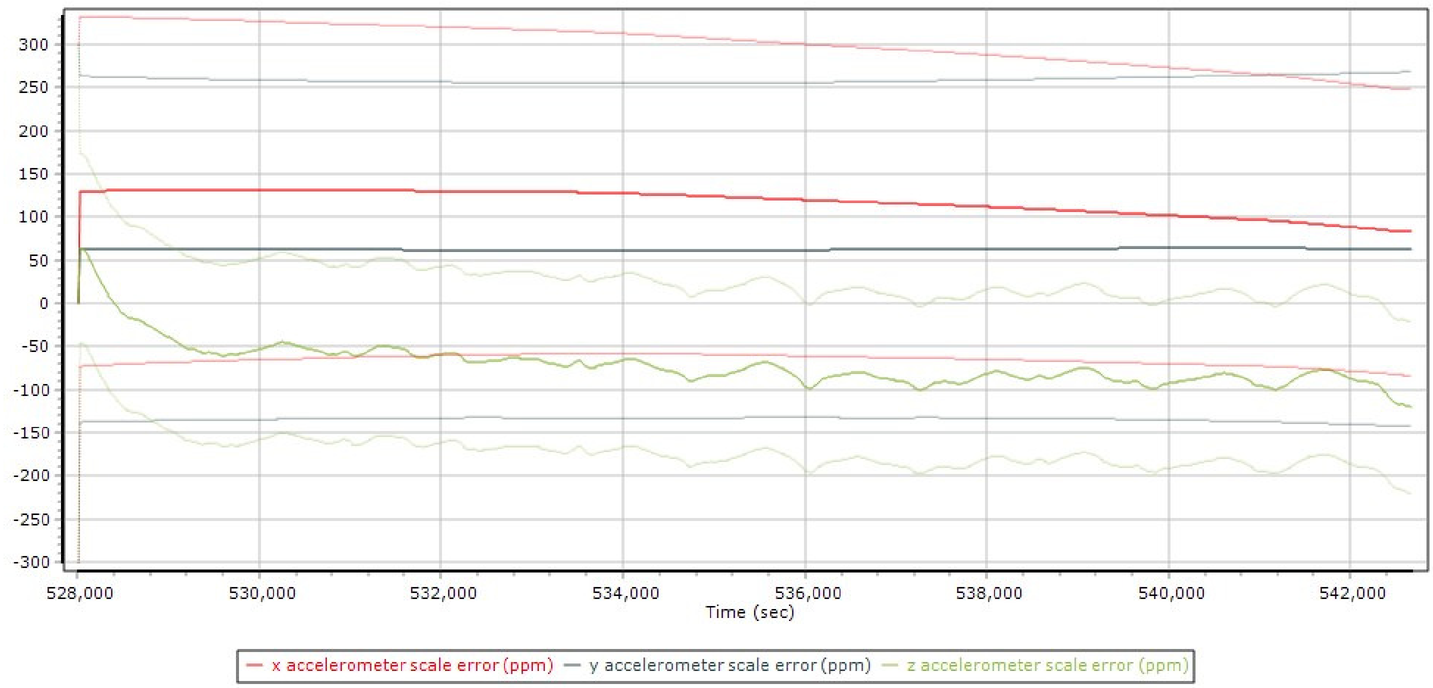
Number of Satellites (>6) Plots 15: Sortie a03-s02-0111



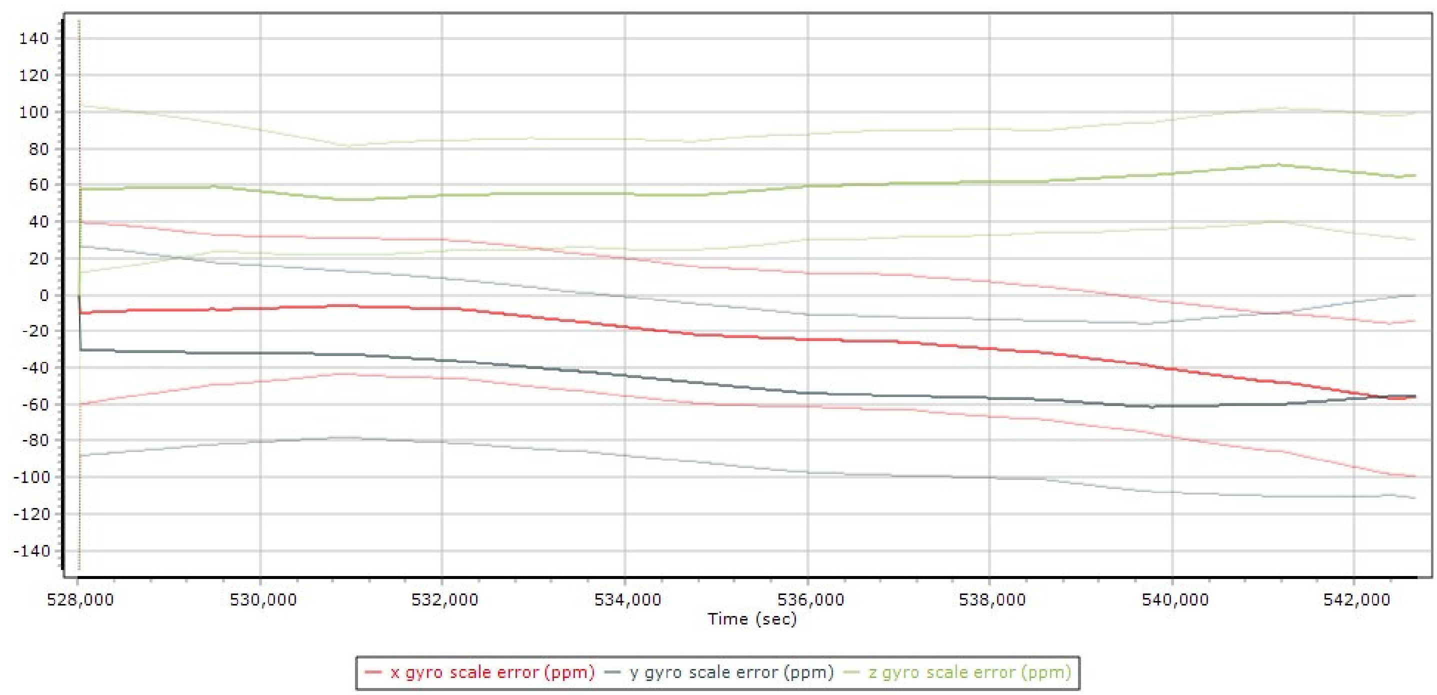
Sensor Position Error RMS (m) Plots 15: Sortie a03-s02-0111



Accelerometer Scale Error (ppm) Plots 15: Sortie a03-s02-0111



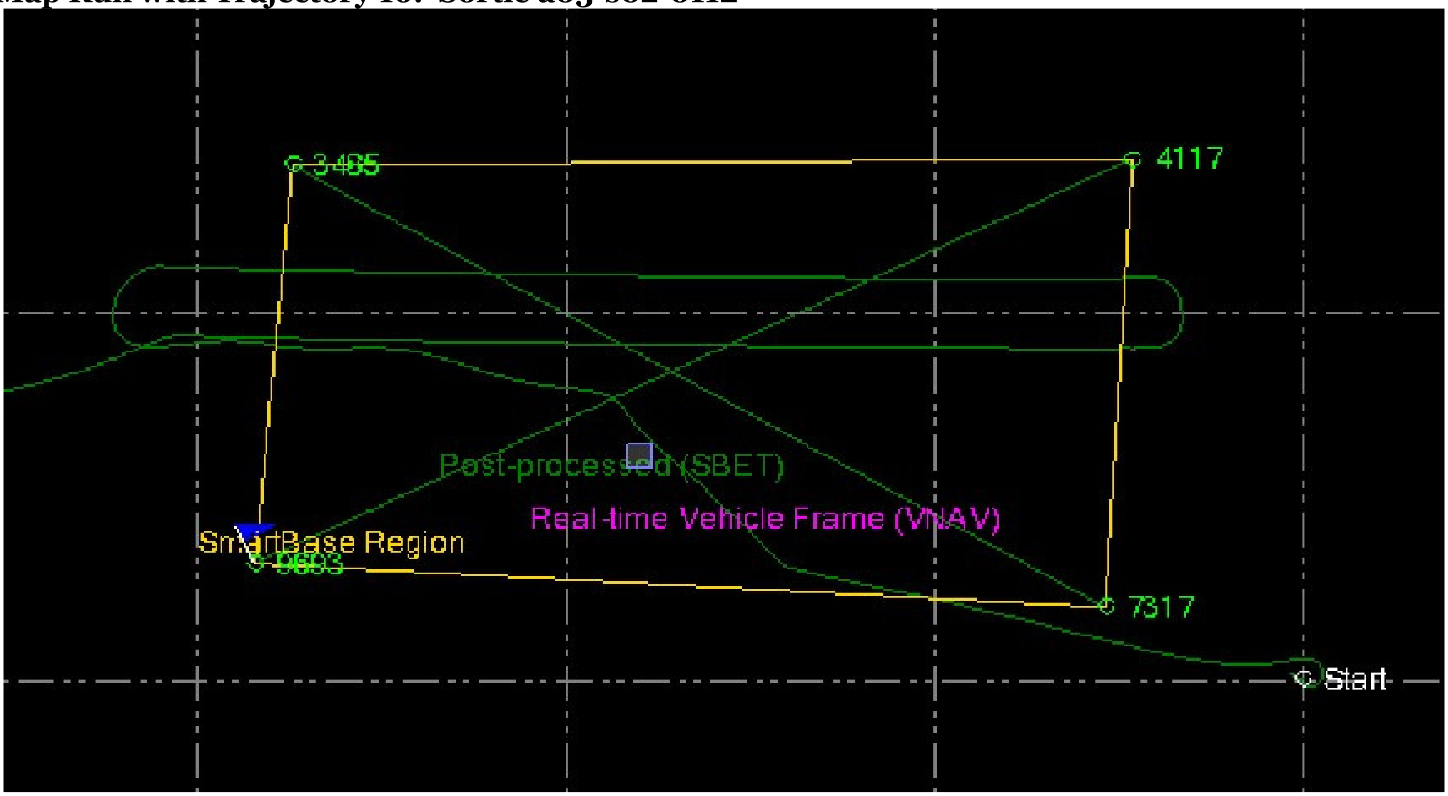
Gyro Scale Error (ppm) Plots 15: Sortie a03-s02-0111



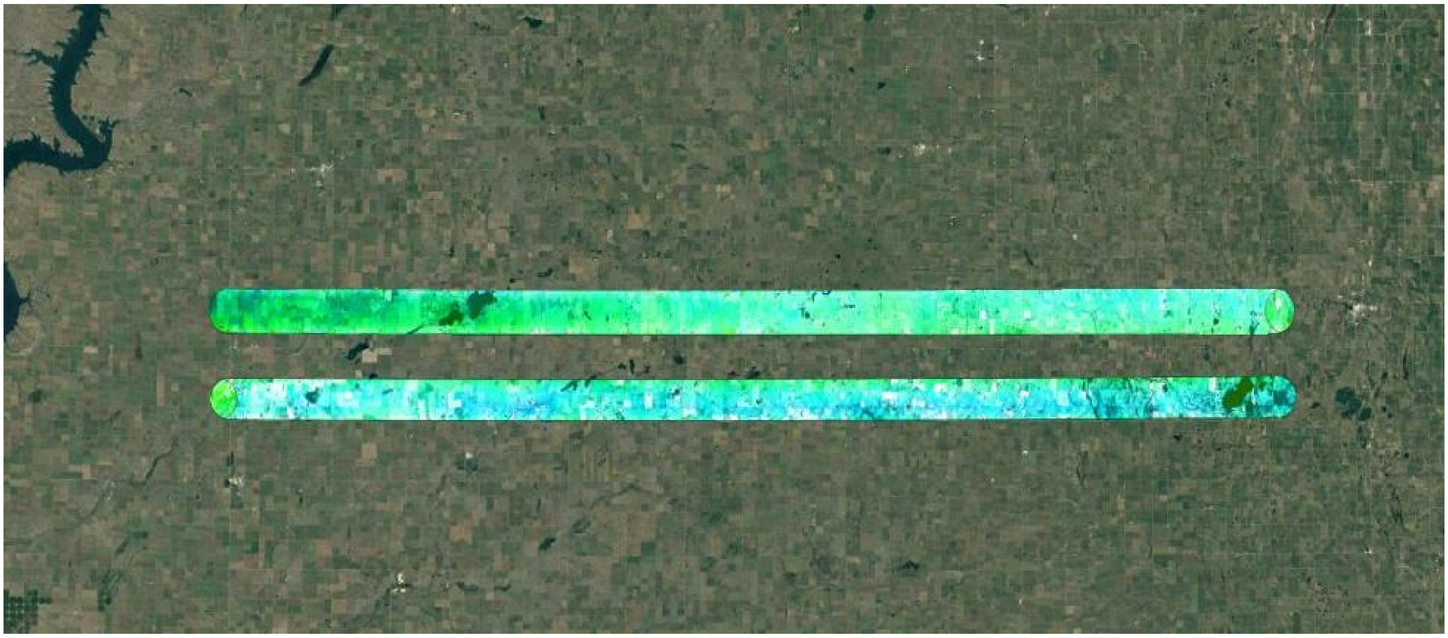
COLLECTION 16

Brick 4
Sortie a03-s02-0112
06/11/2016

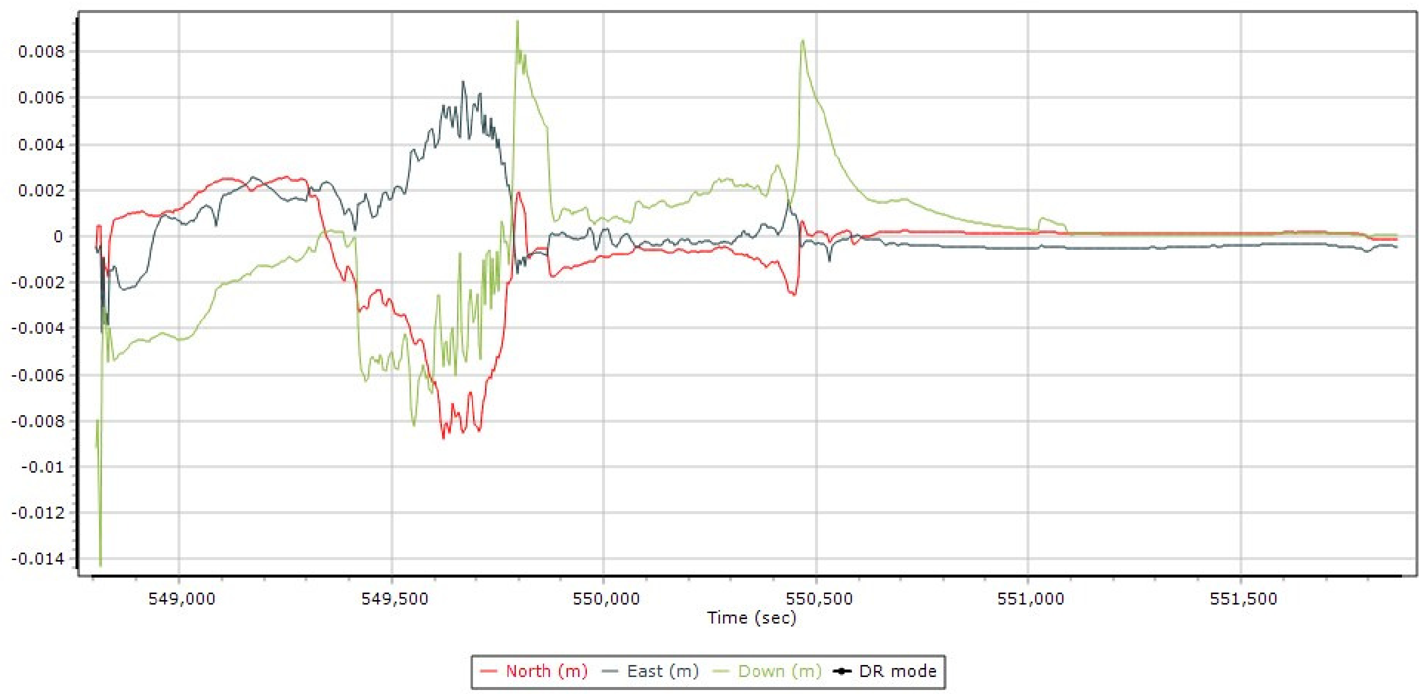
Map Run with Trajectory 16: Sortie a03-s02-0112



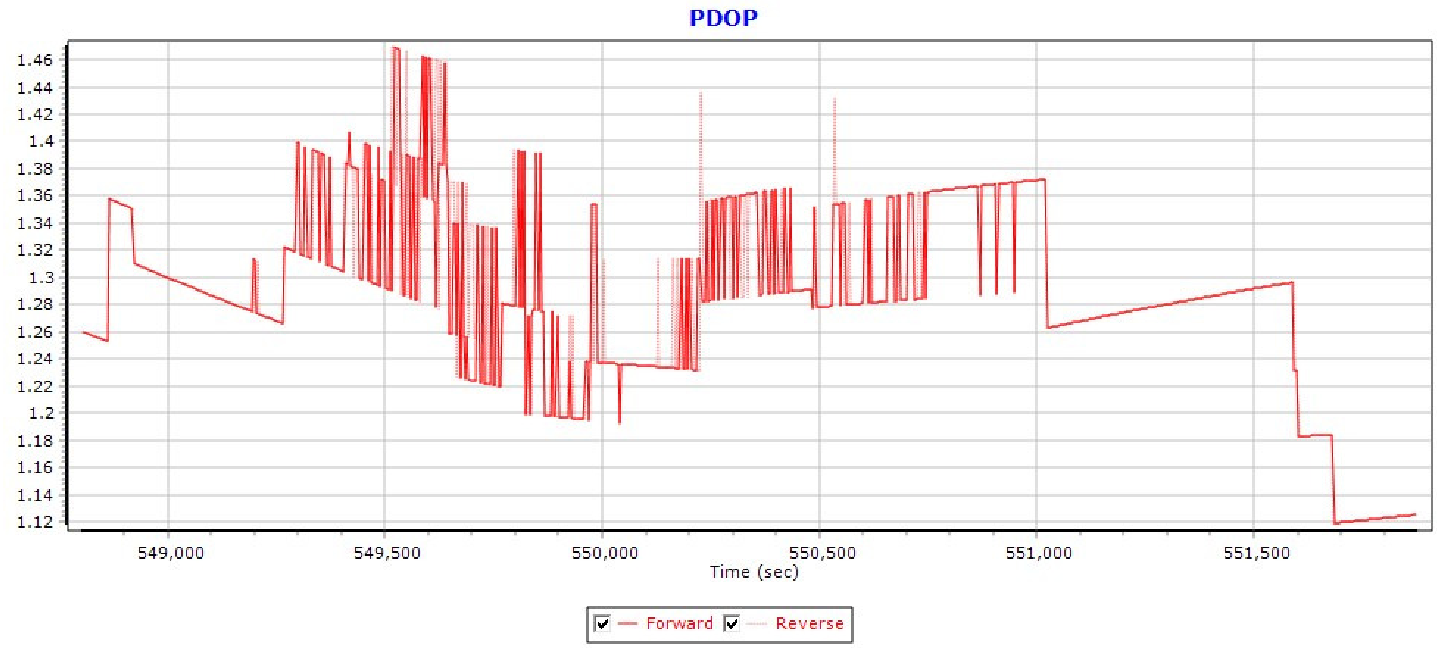
Swath Width, Waterfall View 16: Sortie a03-s02-0112



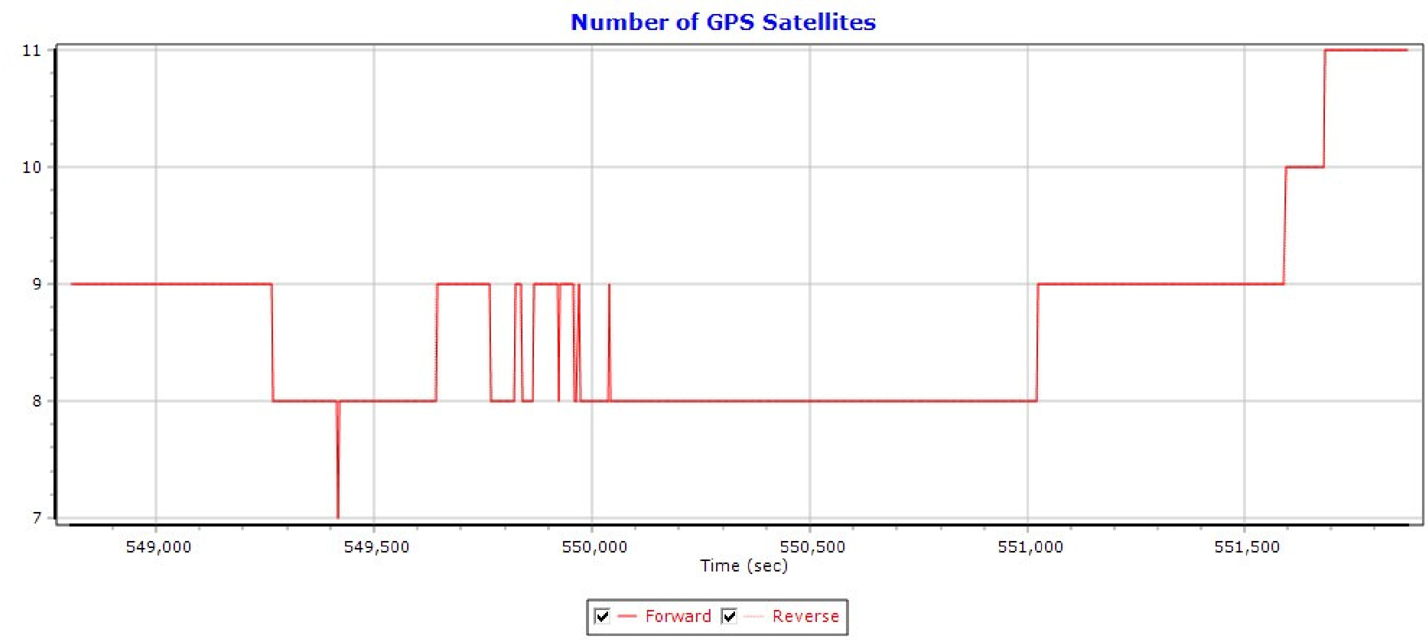
Combined SBET IAKAR Separation 16: Sortie a03-s02-0112



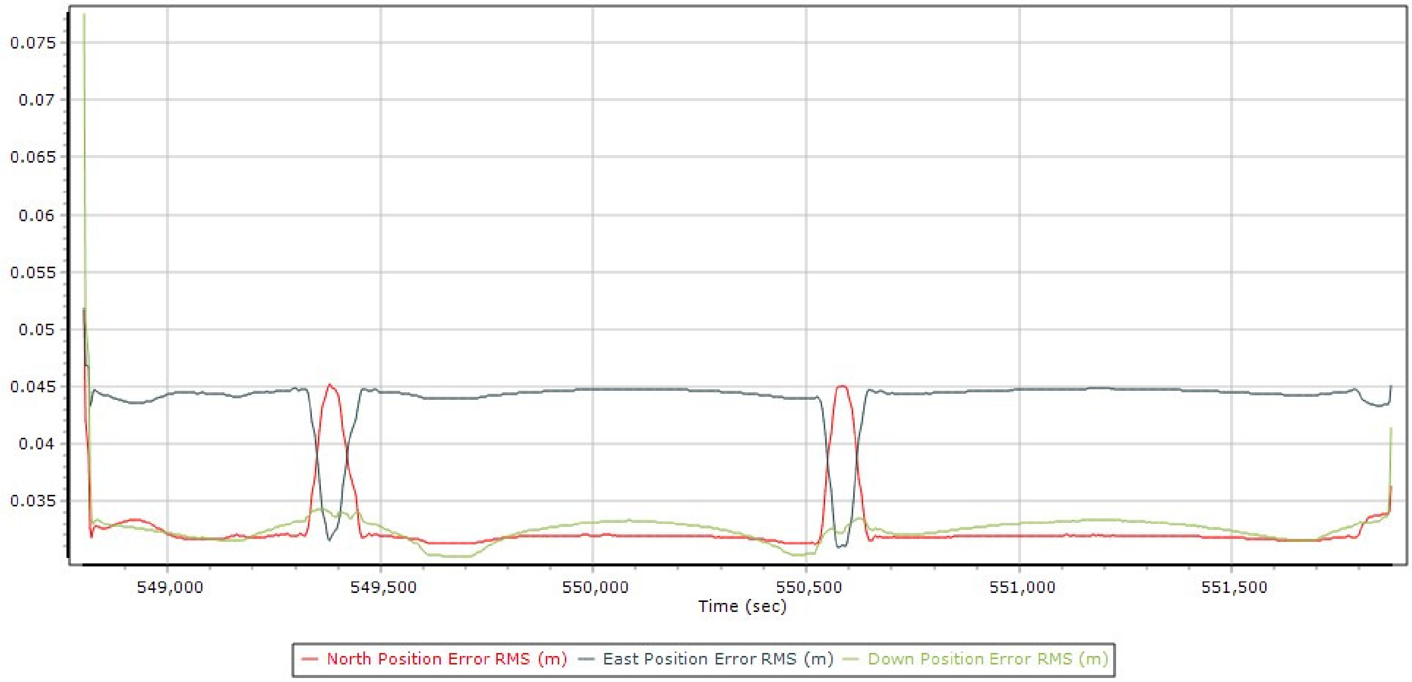
PDOP Plots 16: Sortie a03-s02-0112



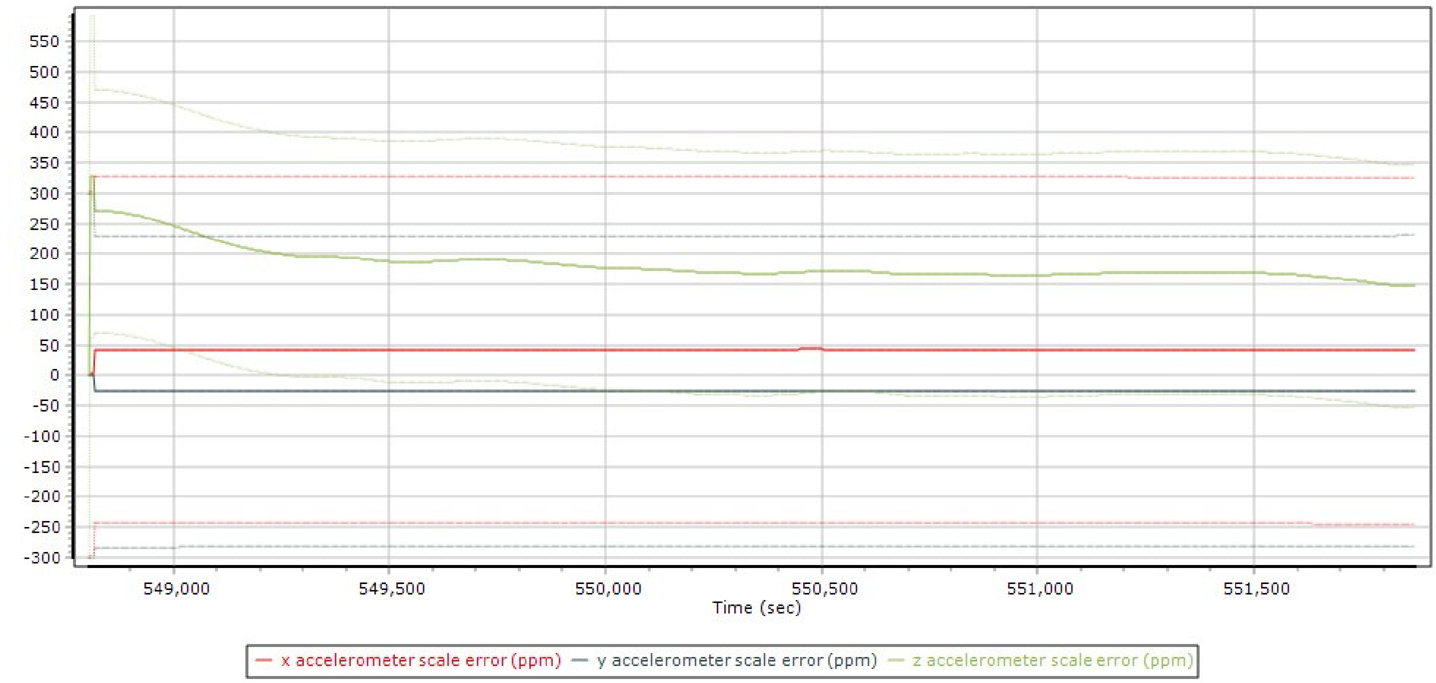
Number of Satellites (>6) Plots 16: Sortie a03-s02-0112



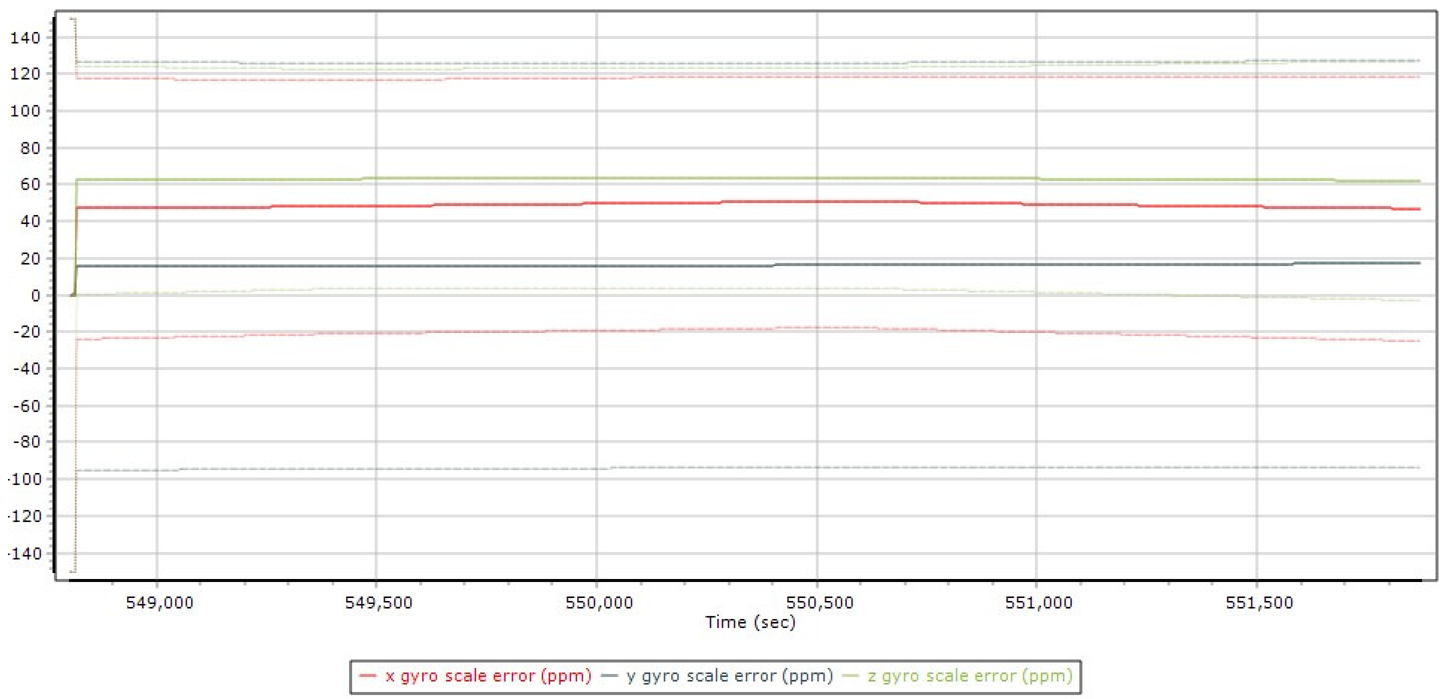
Sensor Position Error RMS (m) Plots 16: Sortie a03-s02-0112



Accelerometer Scale Error (ppm) Plots 16: Sortie a03-s02-0112



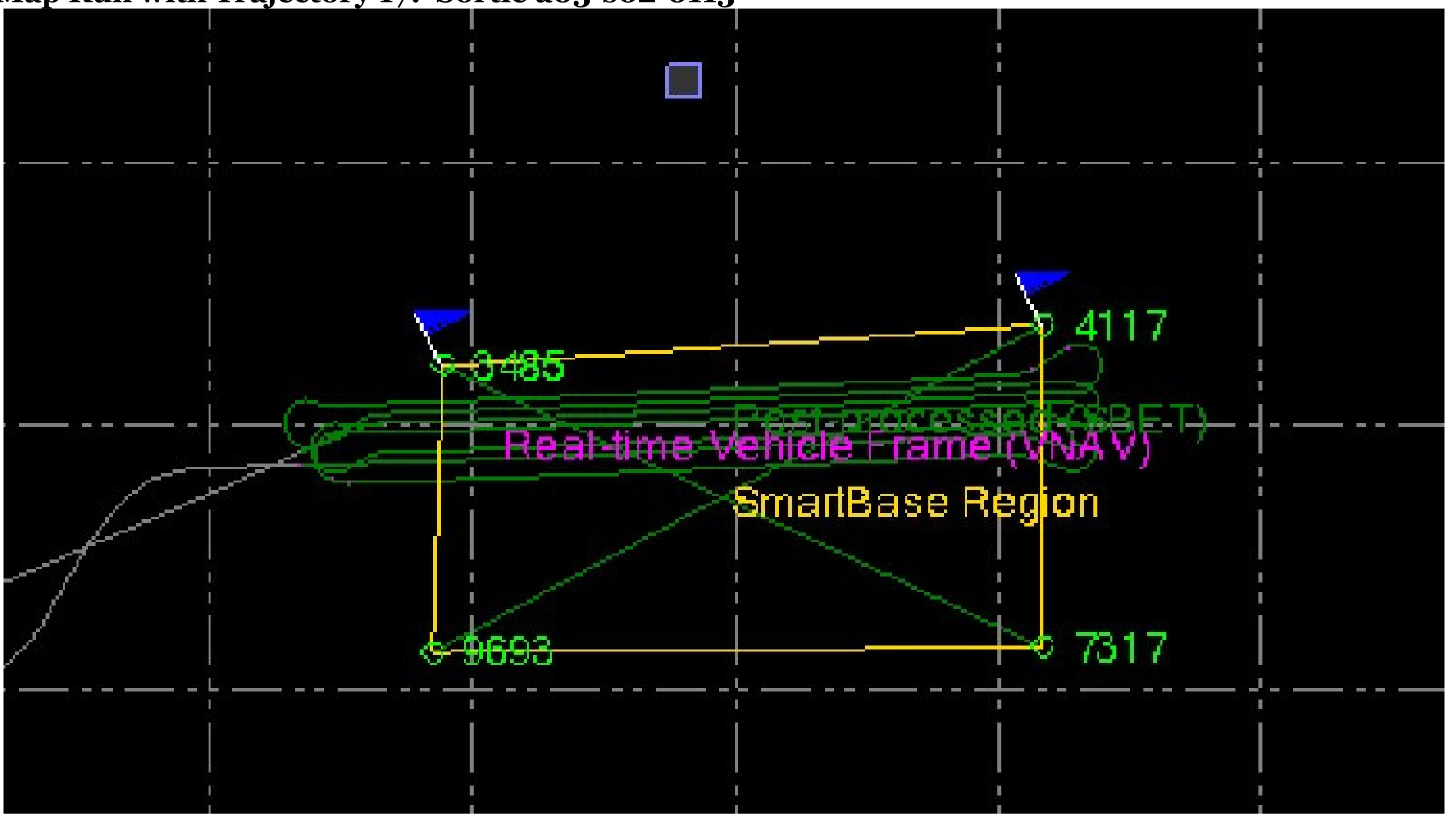
Gyro Scale Error (ppm) Plots 16: Sortie a03-s02-0112



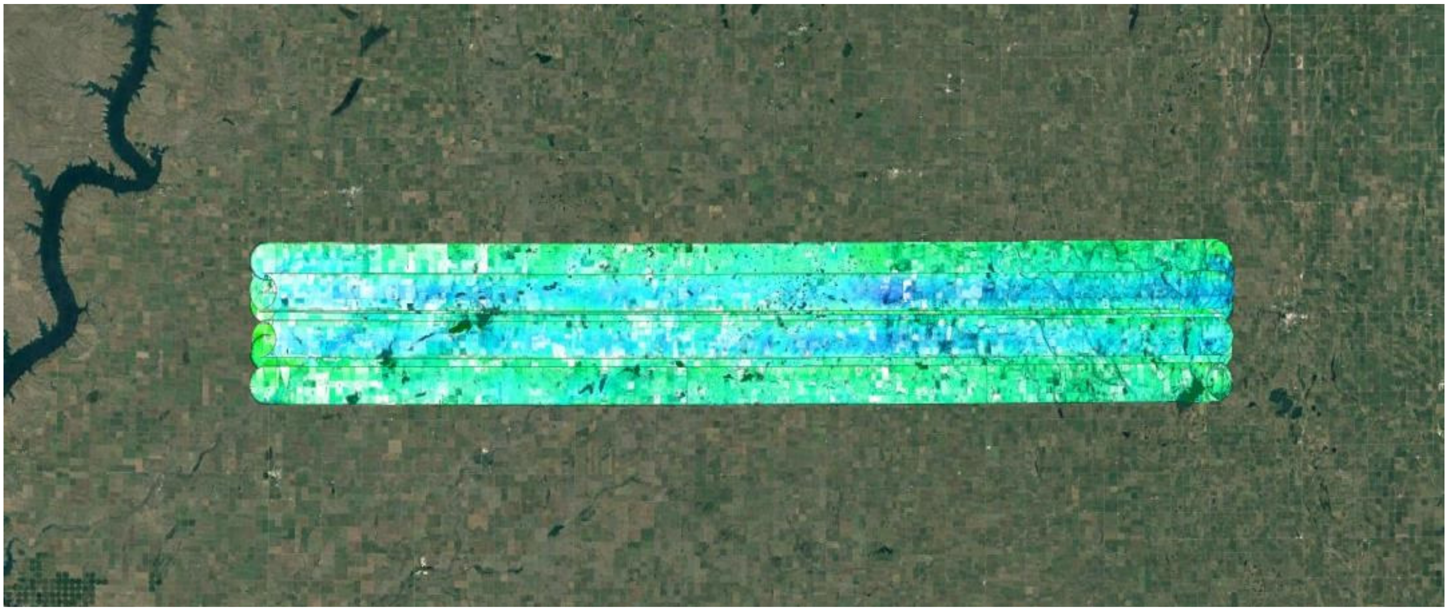
COLLECTION 17

Brick 4
Sortie a03-s02-0113
06/12/2016

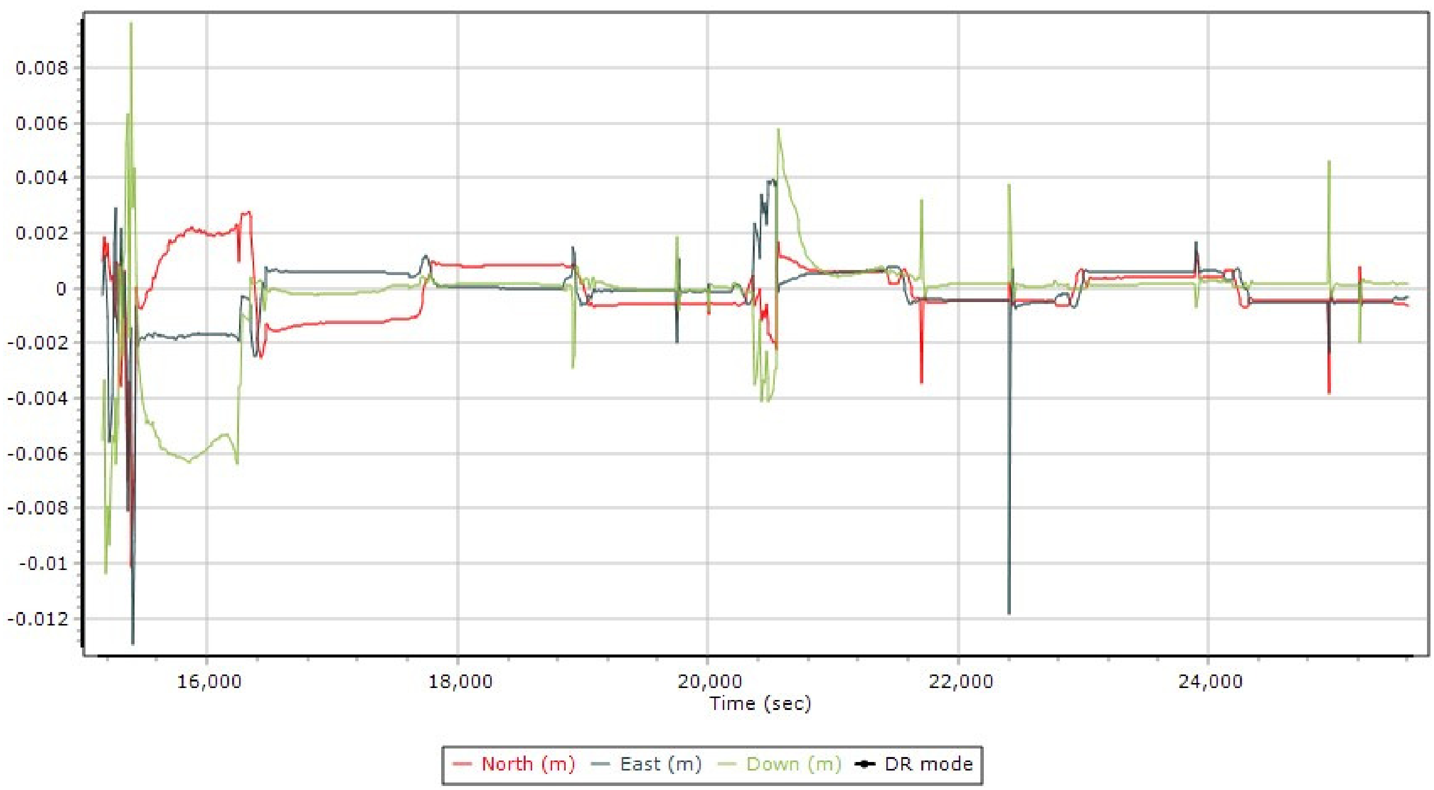
Map Run with Trajectory 17: Sortie a03-s02-0113



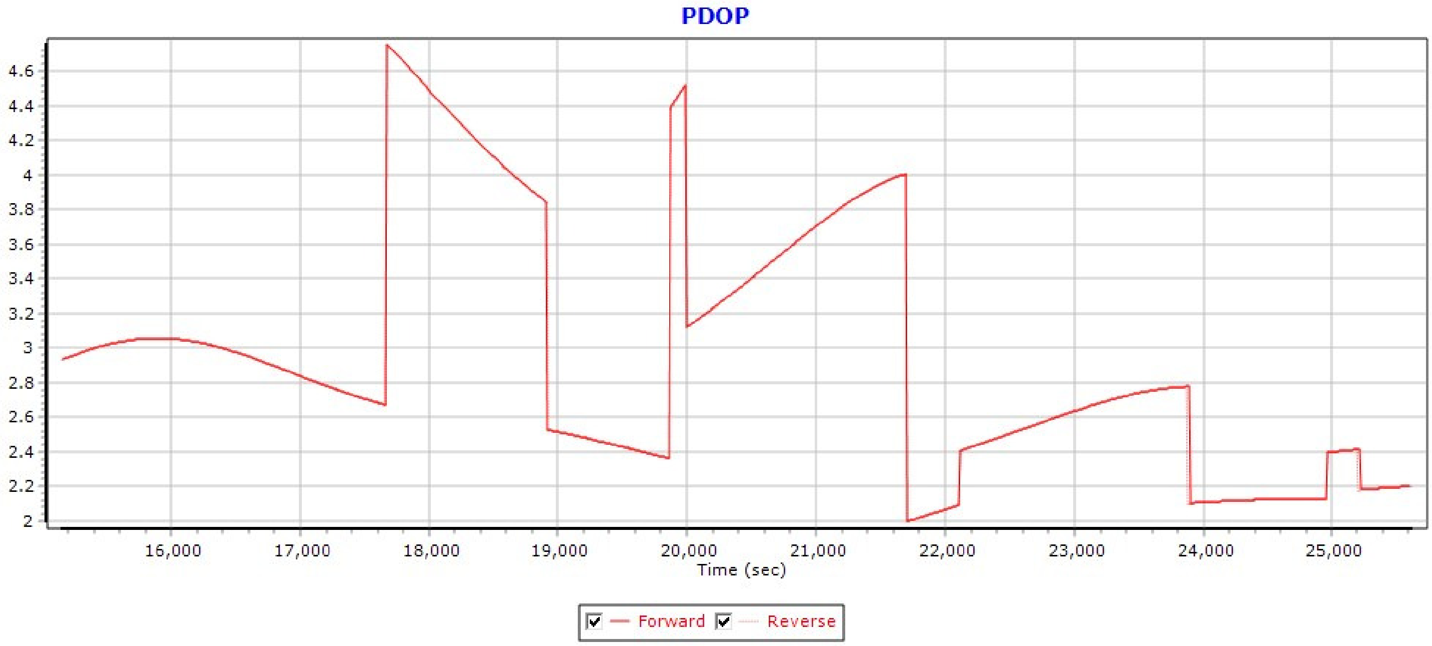
Swath Width, Waterfall View 17: Sortie a03-s02-0113



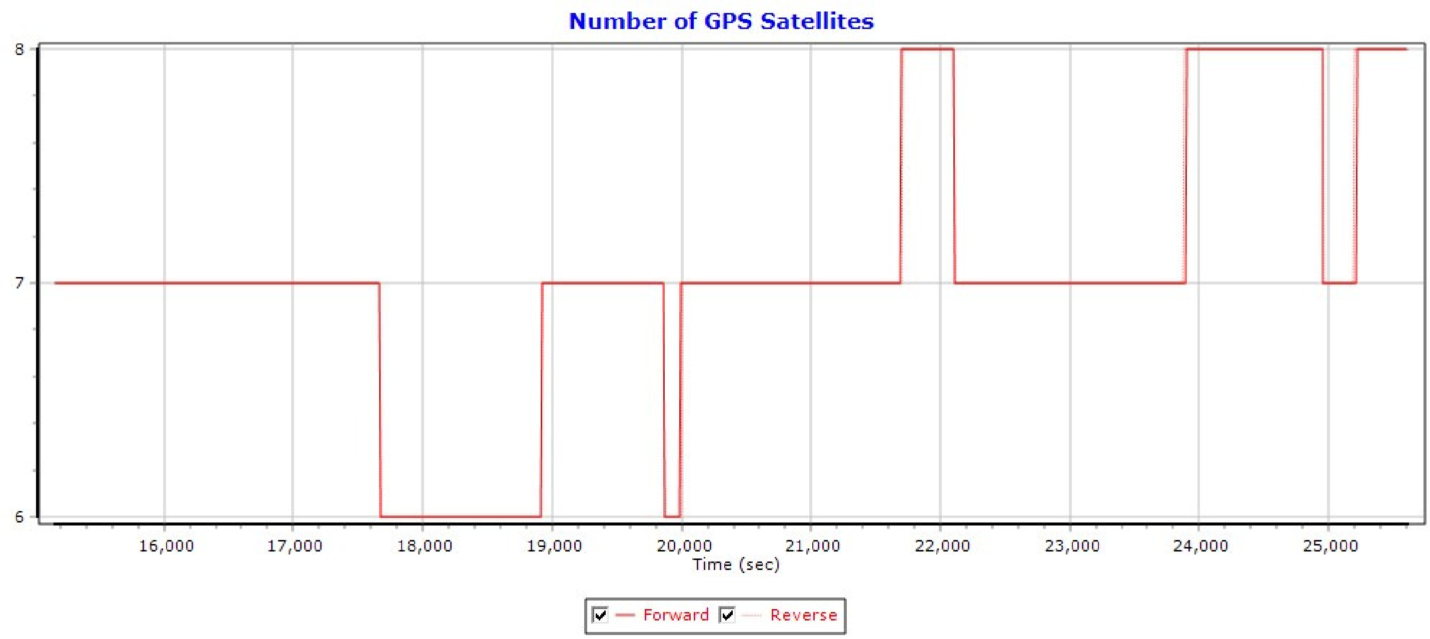
Combined SBET IAKAR Separation 17: Sortie a03-s02-0113



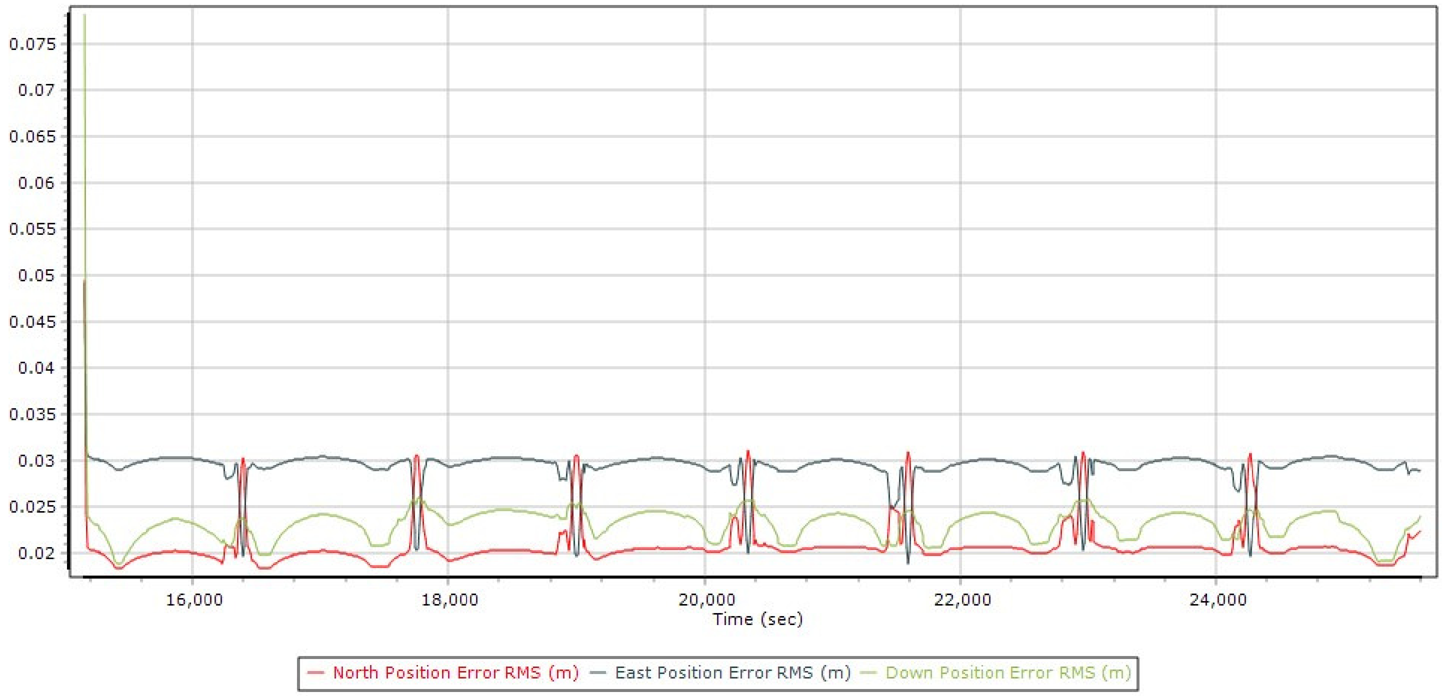
PDOP Plots 17: Sortie a03-s02-0113



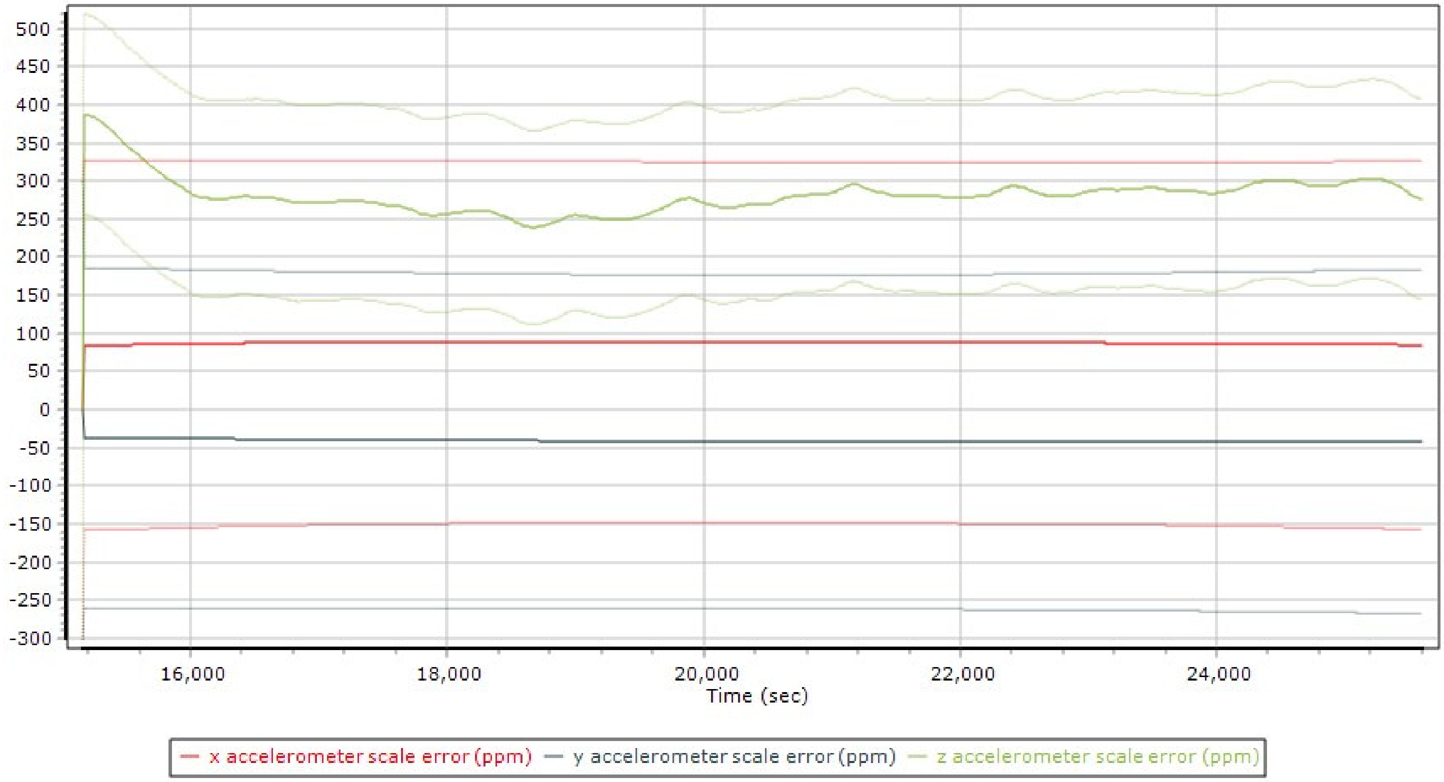
Number of Satellites (>6) Plots 17: Sortie a03-s02-0113



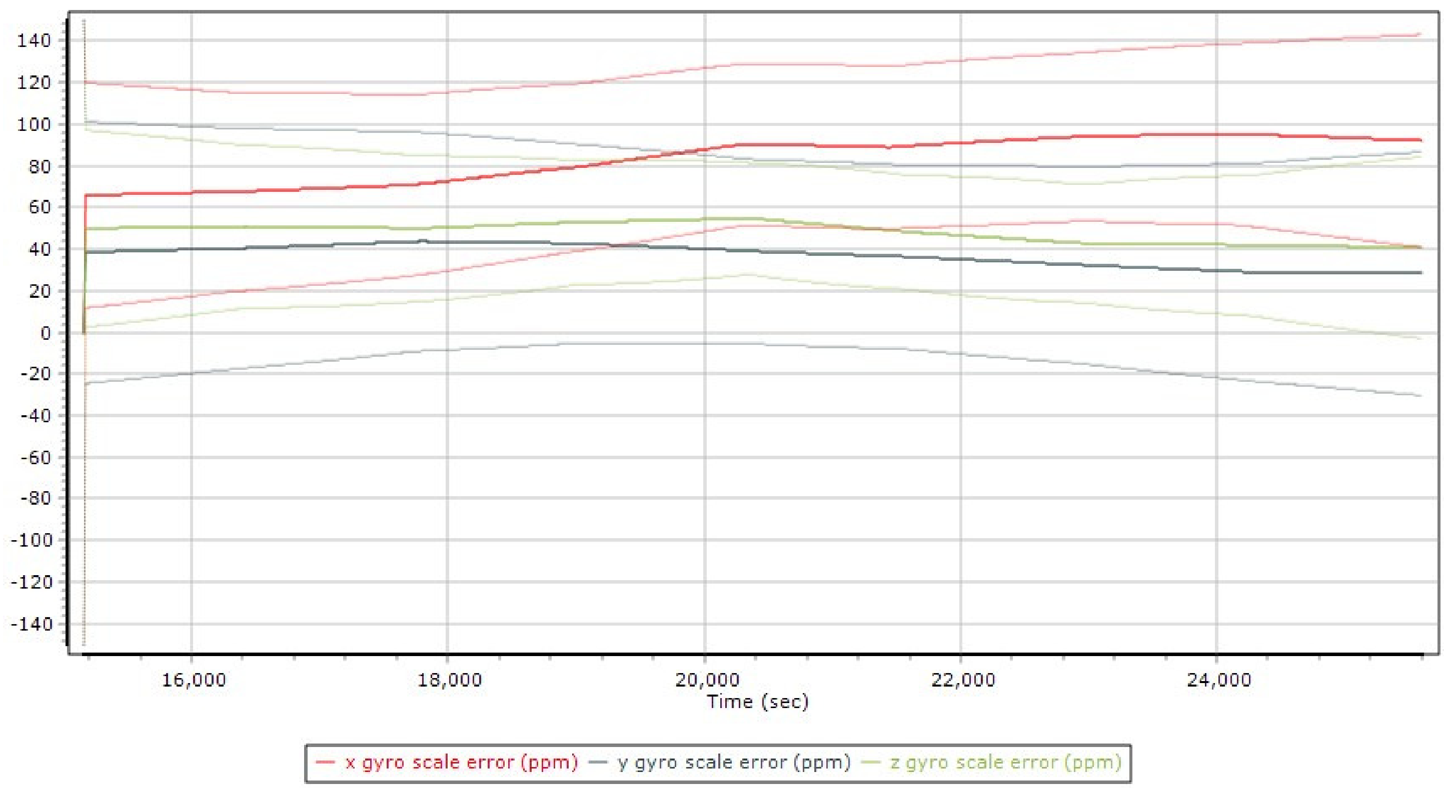
Sensor Position Error RMS (m) Plots 17: Sortie a03-s02-0113



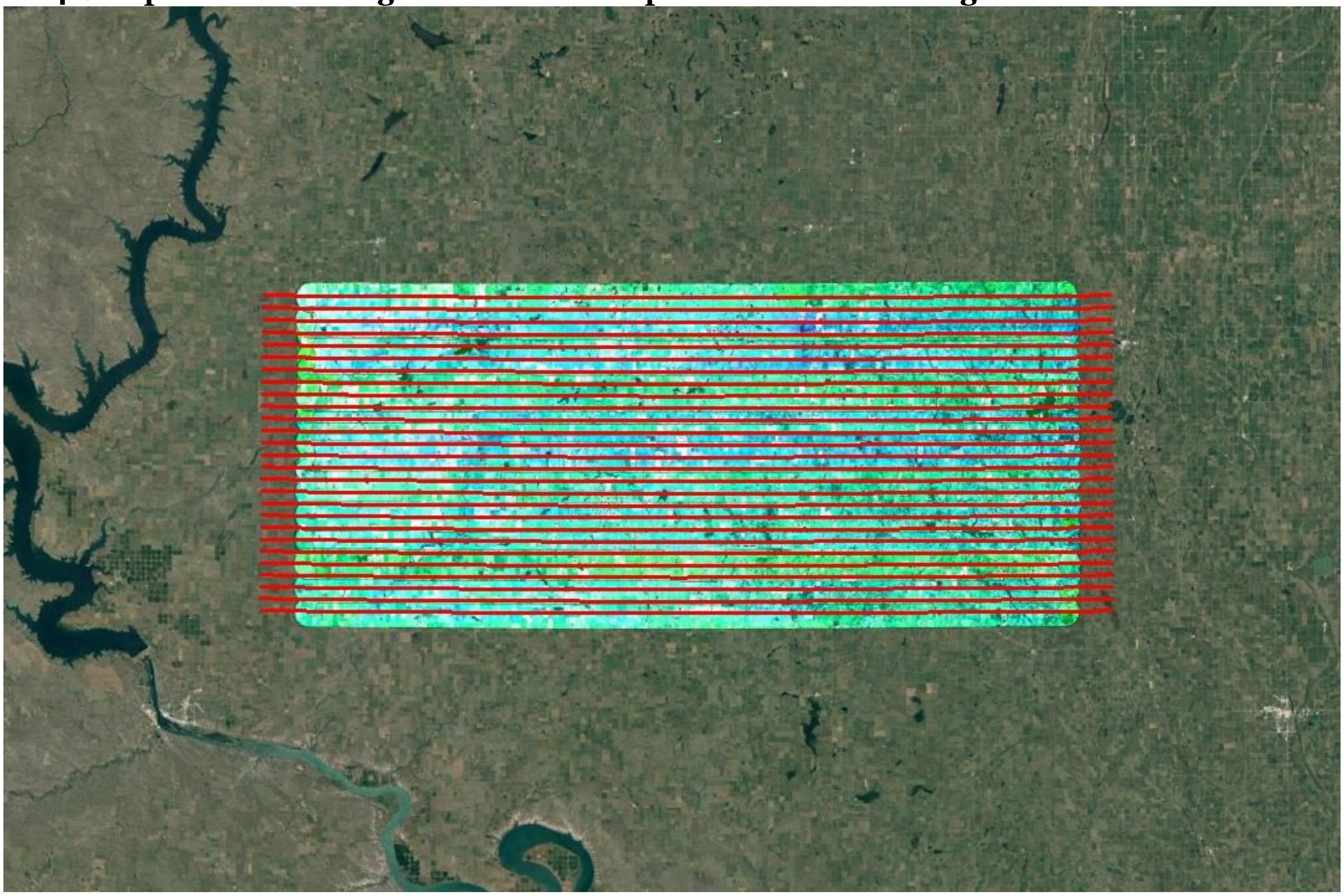
Accelerometer Scale Error (ppm) Plots 17: Sortie a03-s02-0113

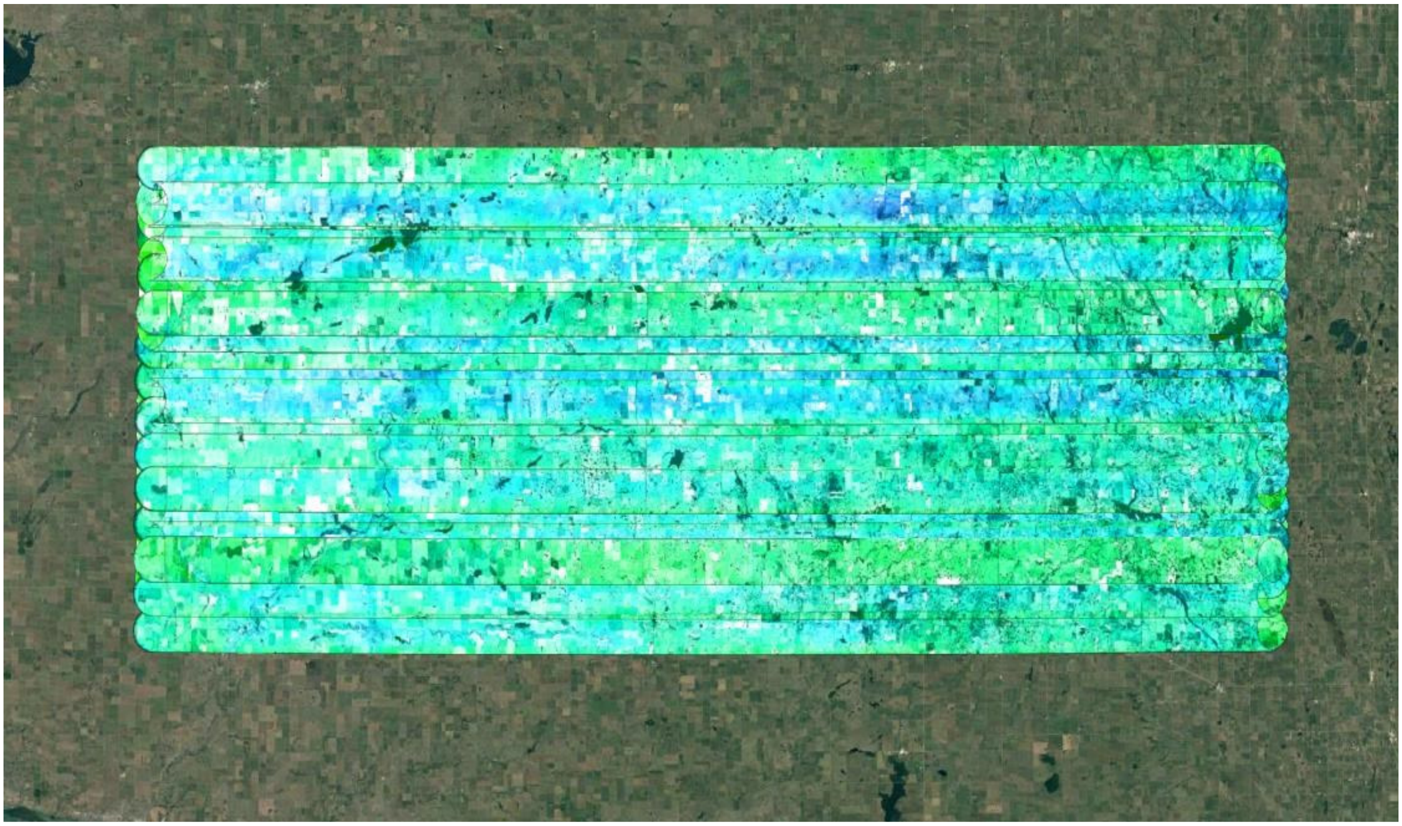


Gyro Scale Error (ppm) Plots 17: Sortie a03-s02-0113



Brick 4 Completion: Flight lines with complete waterfall coverage

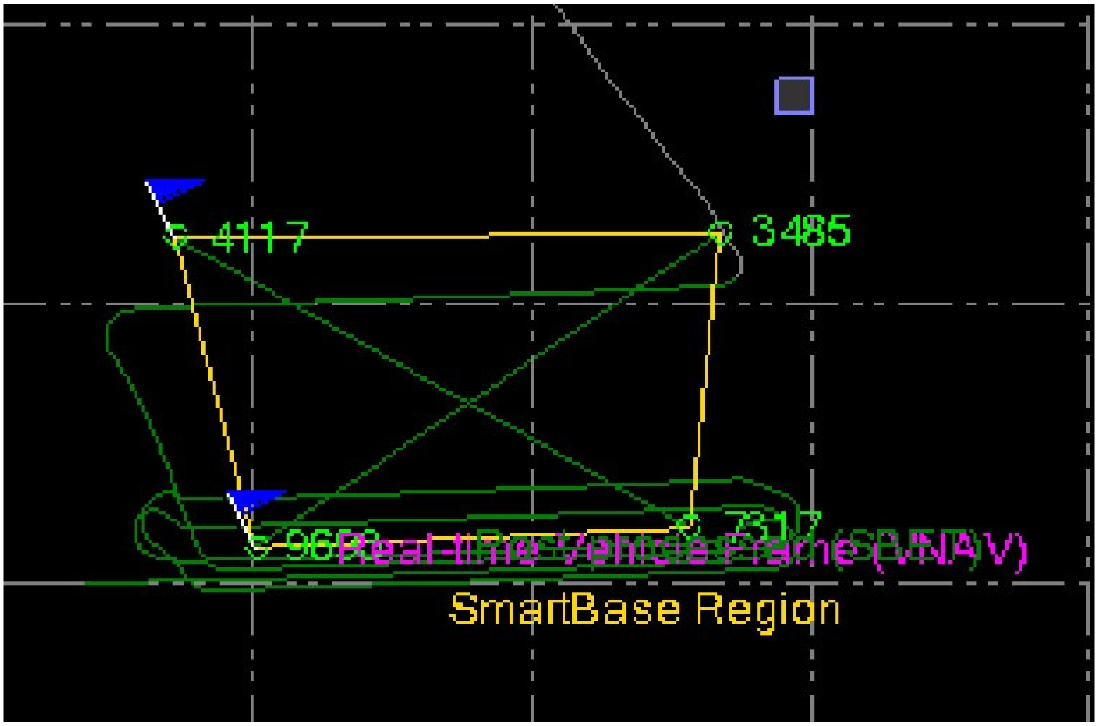




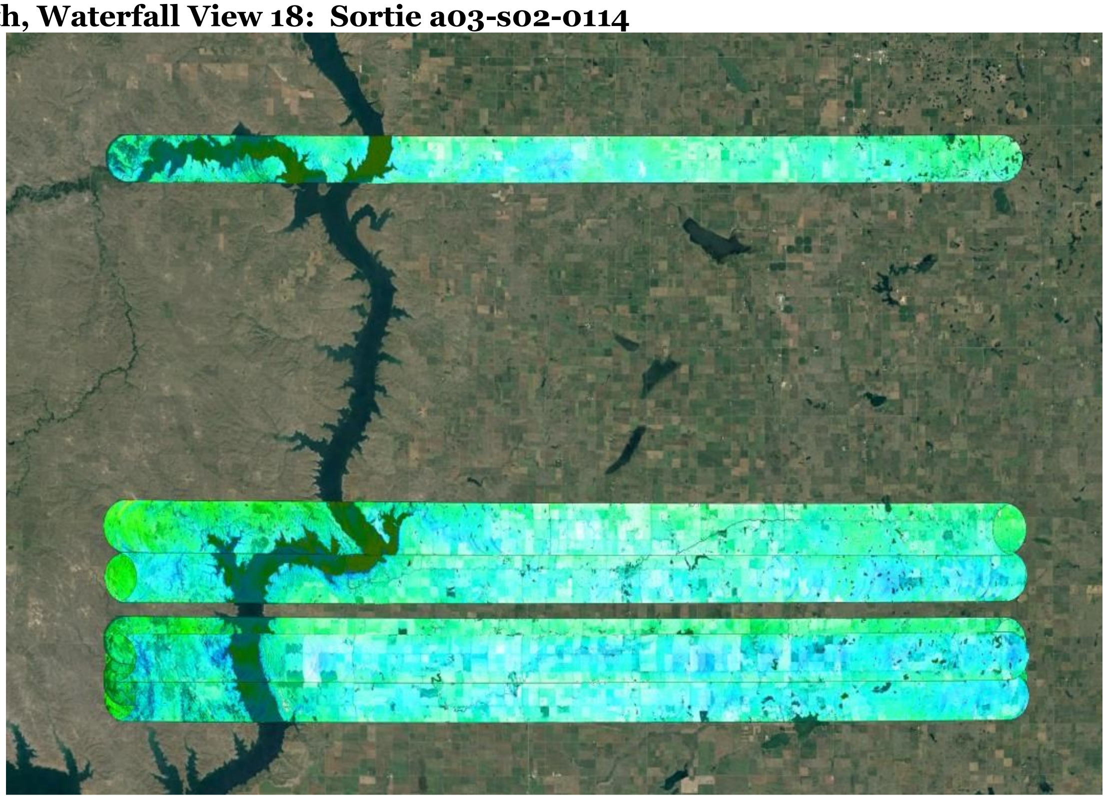
COLLECTION 18

Brick 2
Sortie a03-s02-0114
06/13/2016

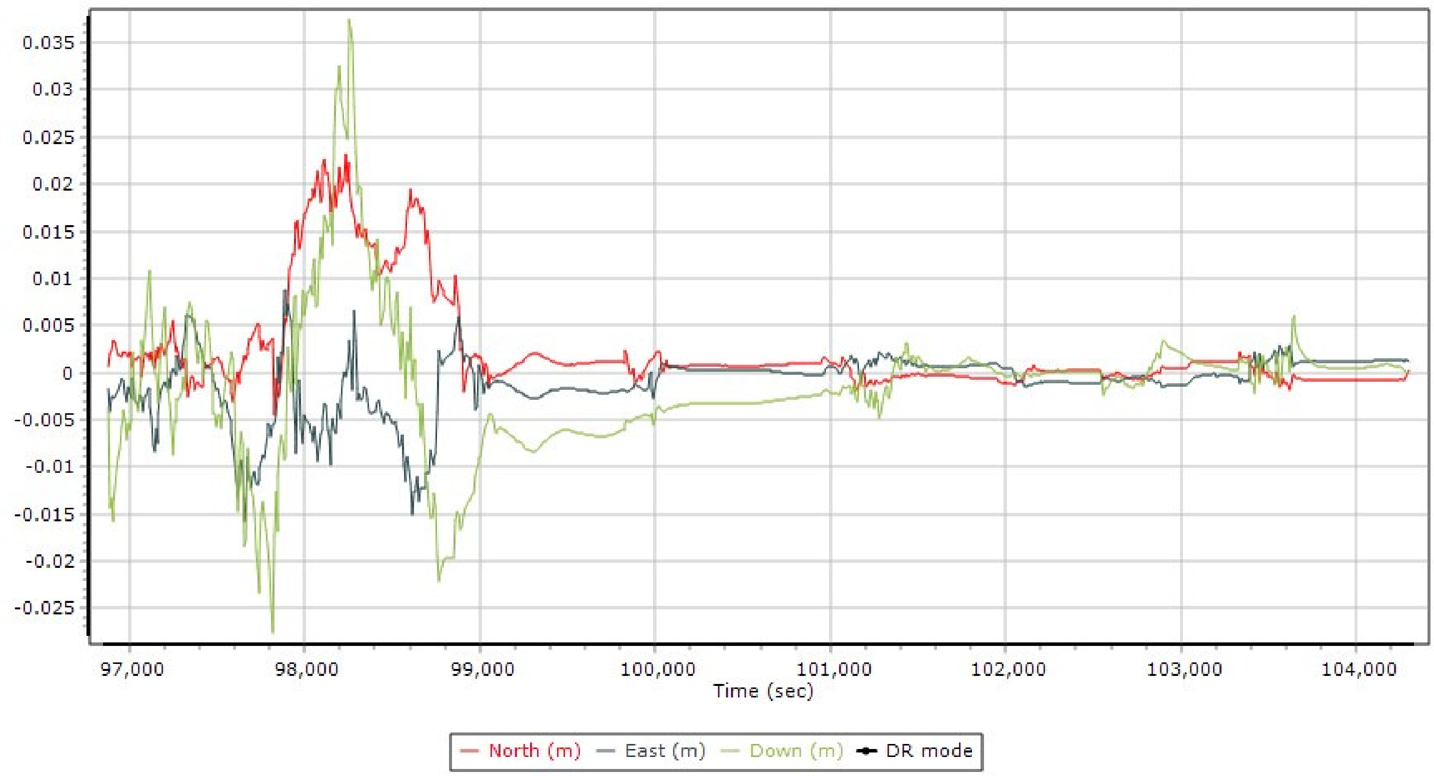
Map Run with Trajectory 18: Sortie a03-s02-0114



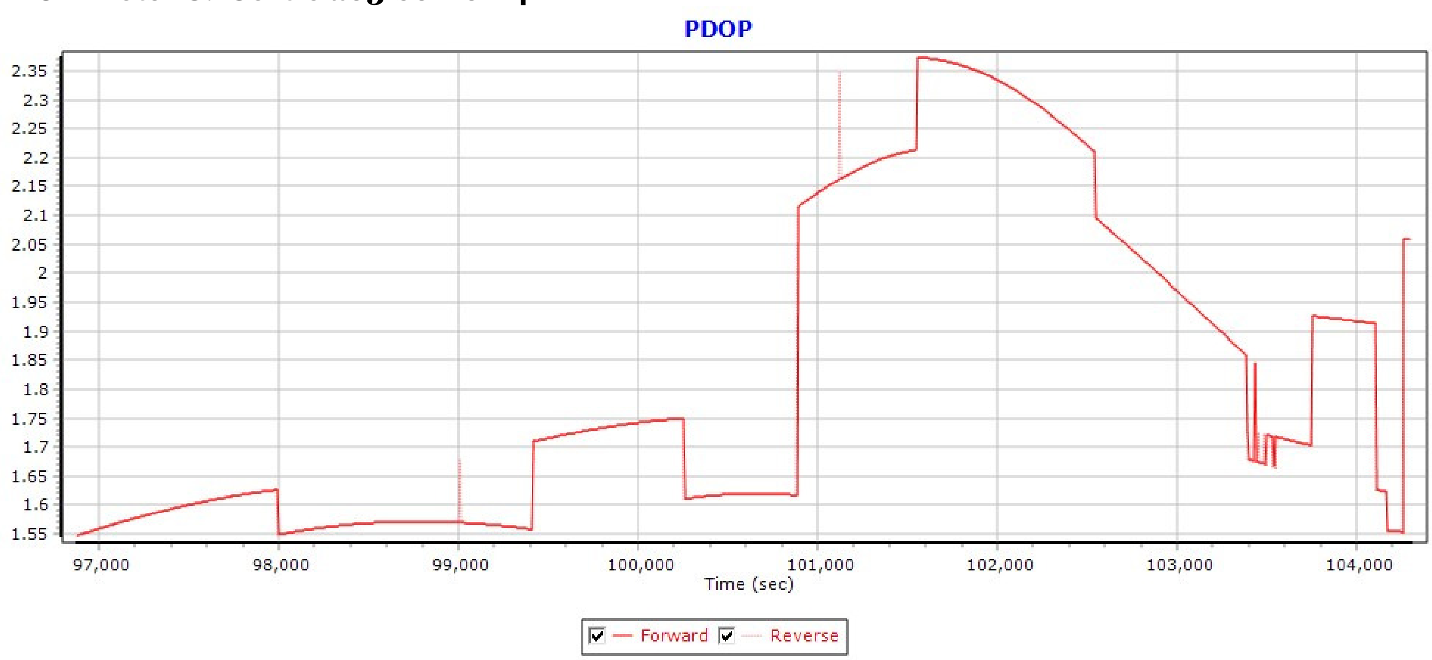
Swath Width, Waterfall View 18: Sortie a03-s02-0114



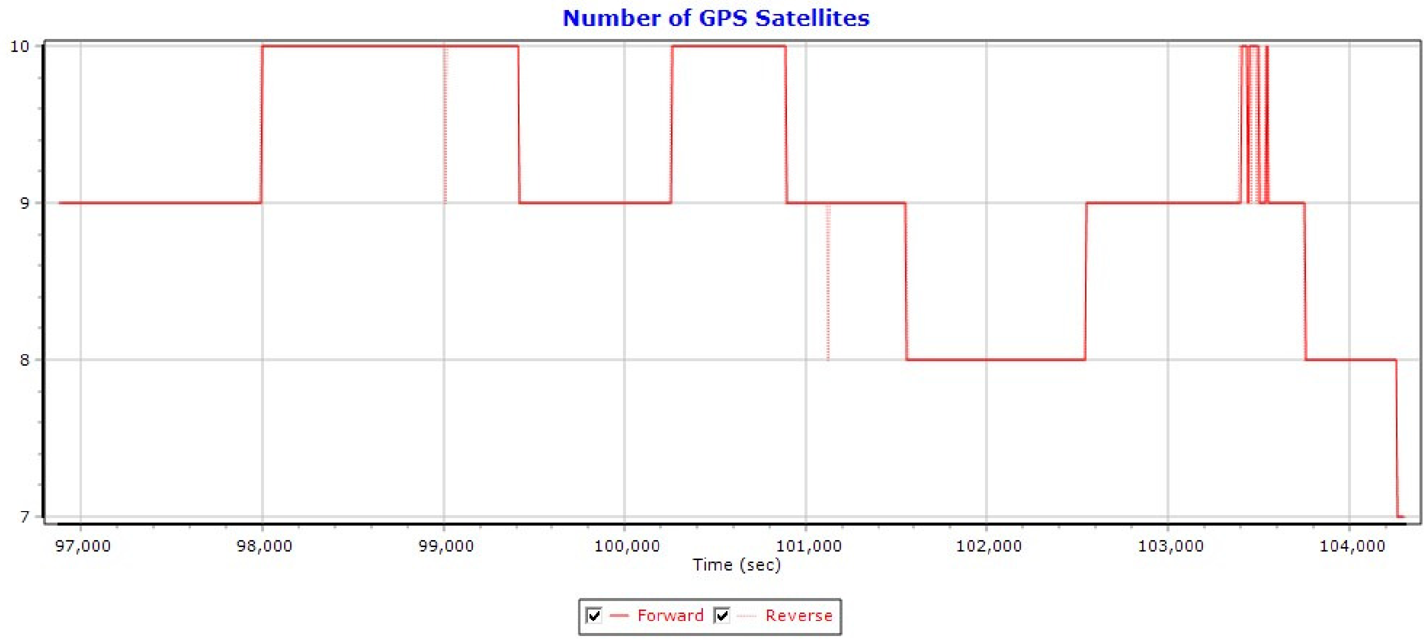
Combined SBET IAKAR Separation 18: Sortie a03-s02-0114



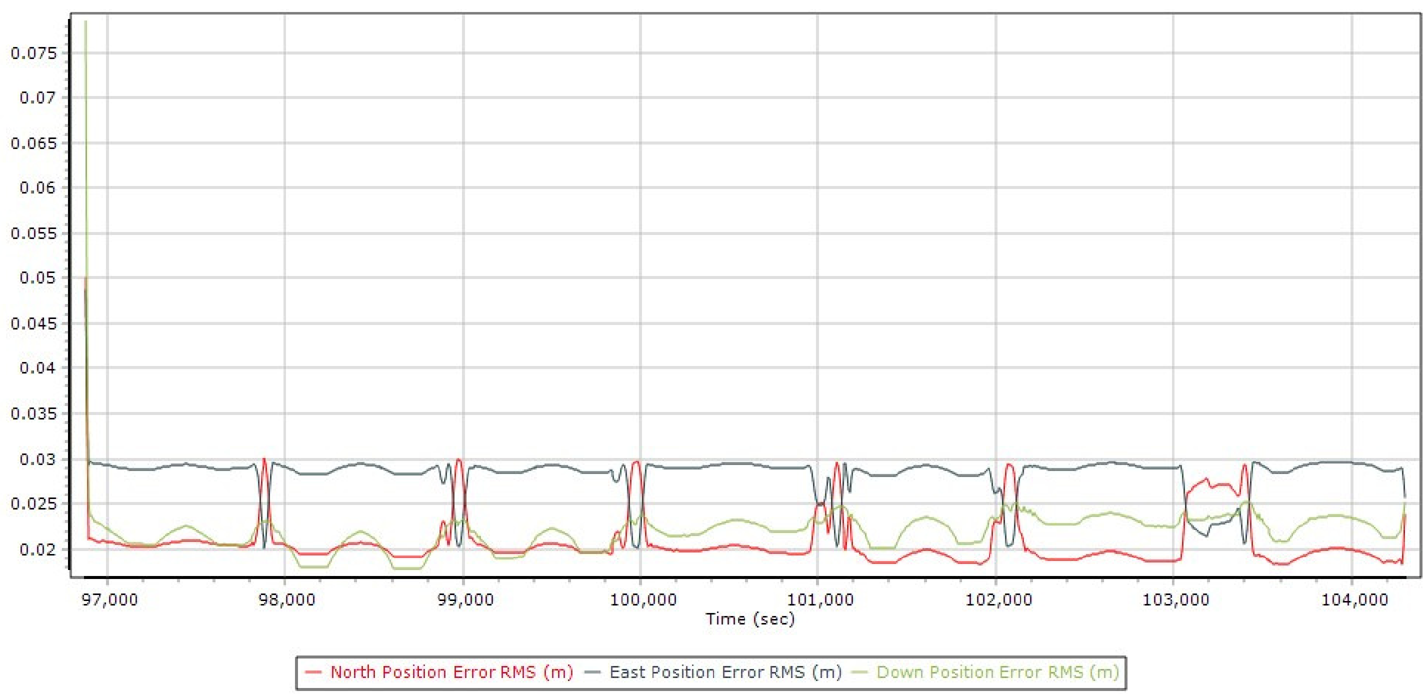
PDOP Plots 18: Sortie a03-s02-0114



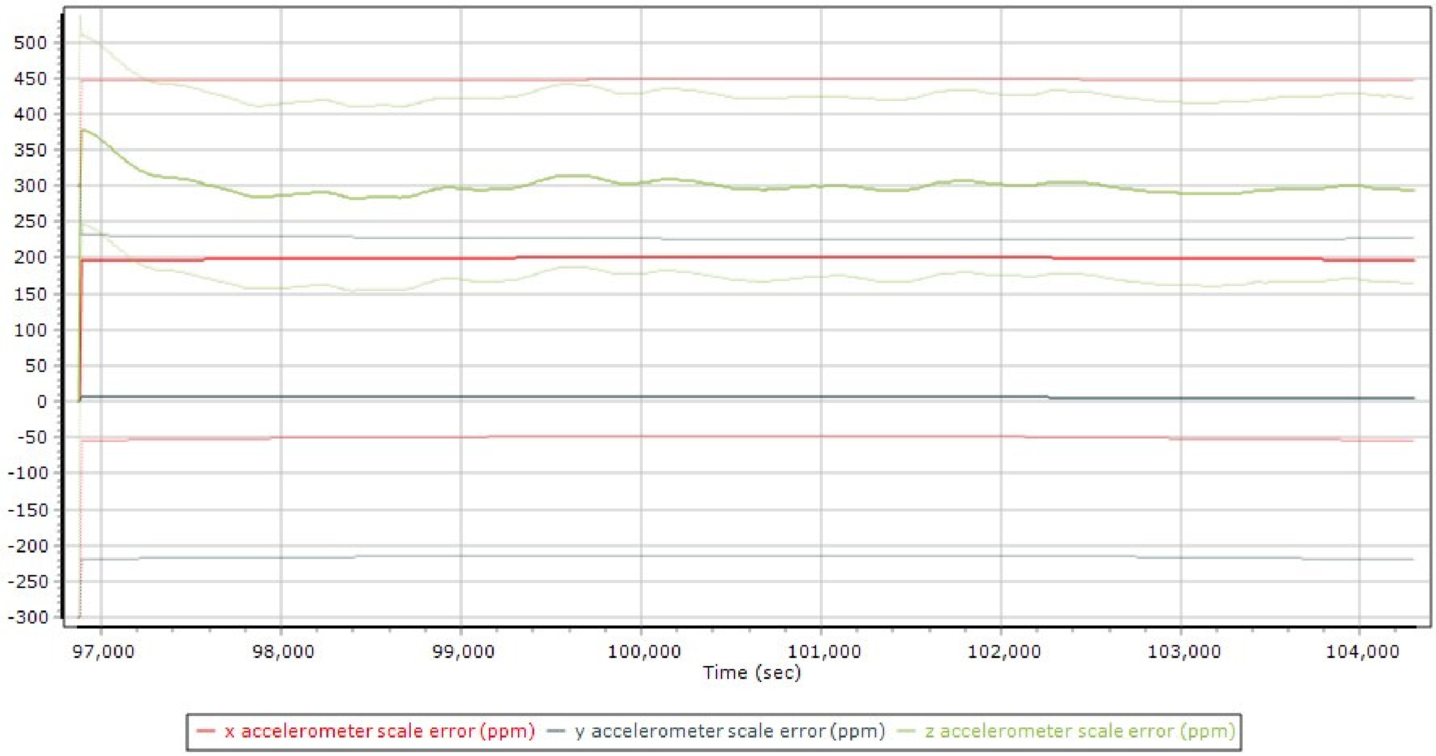
Number of Satellites (>6) Plots 18: Sortie a03-s02-0114



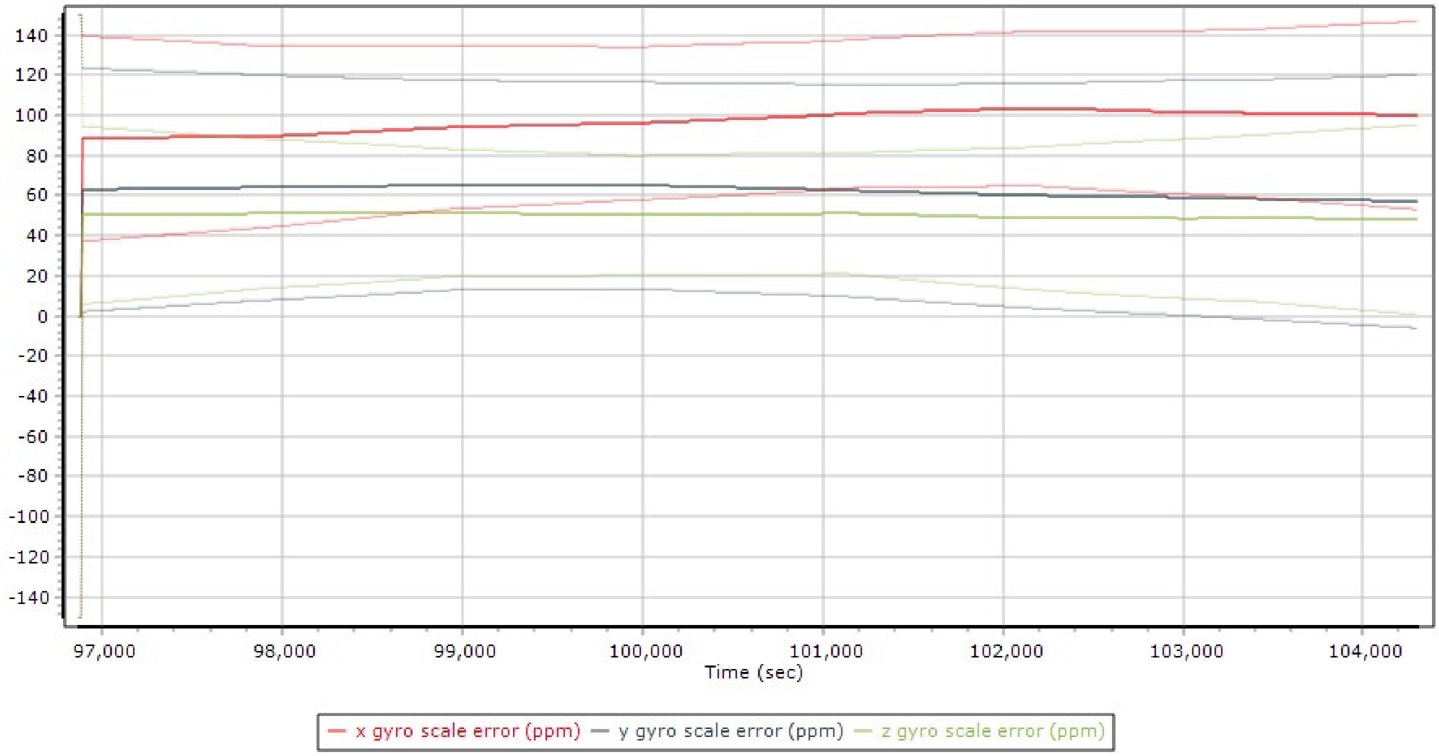
Sensor Position Error RMS (m) Plots 18: Sortie a03-s02-0114



Accelerometer Scale Error (ppm) Plots 18: Sortie a03-s02-0114



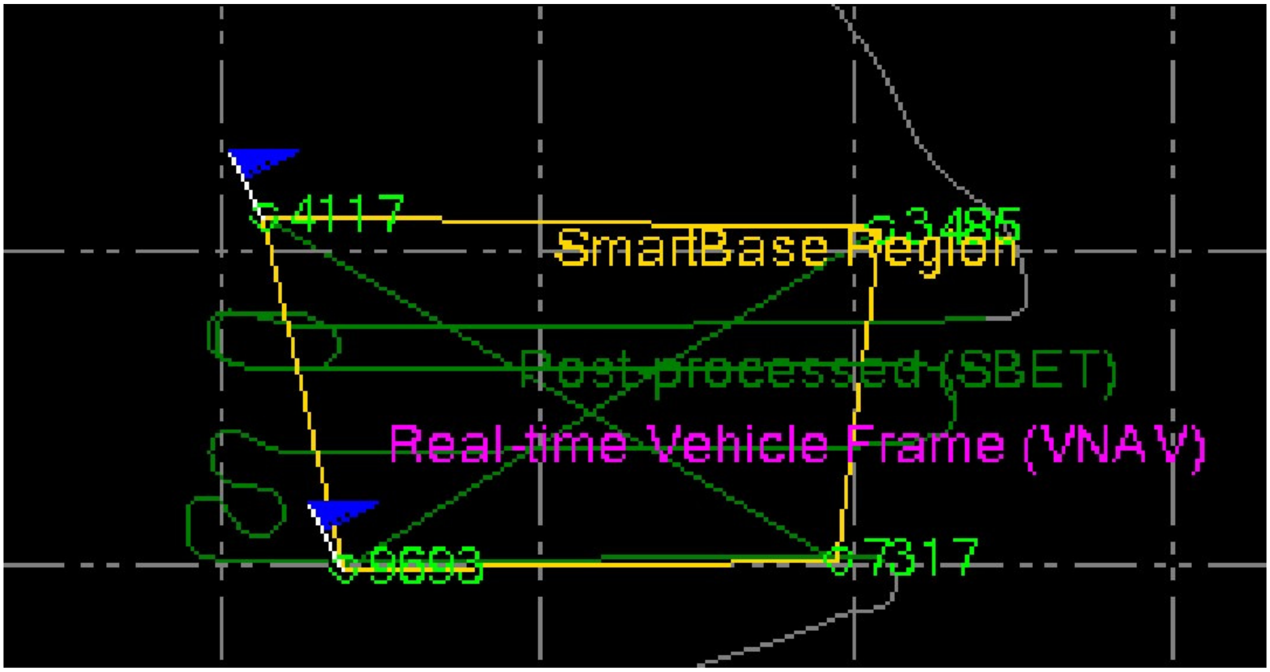
Gyro Scale Error (ppm) Plots 18: Sortie a03-s02-0114



COLLECTION 19

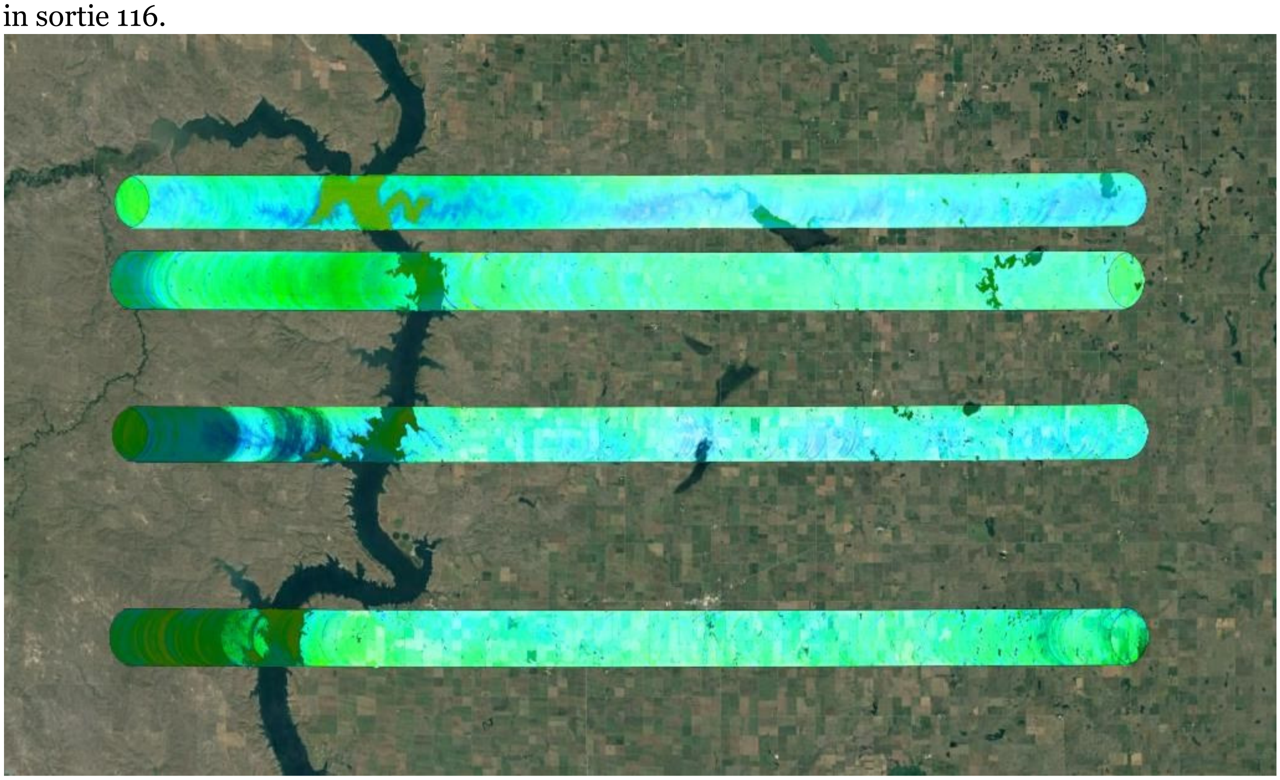
Brick 2
Sortie a03-s02-0115
06/13/2016

Map Run with Trajectory 19: Sortie a03-s02-0115

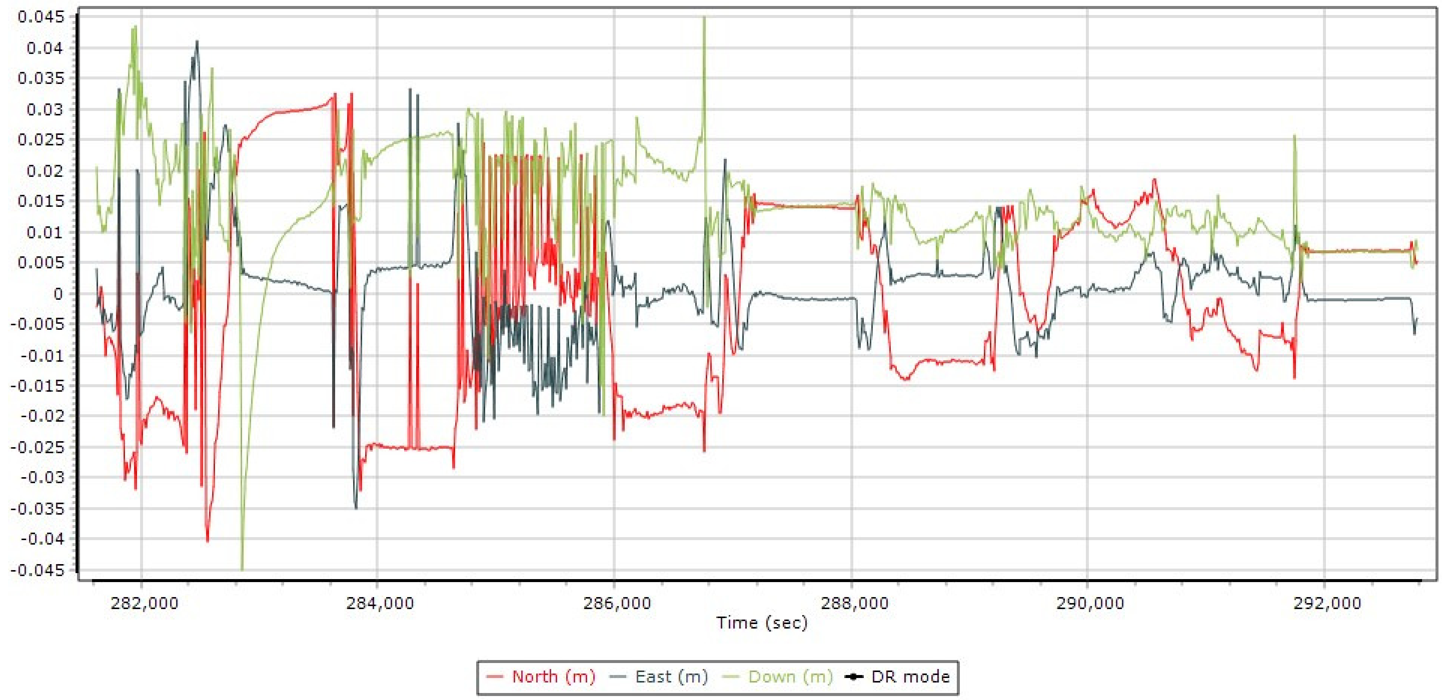


Swath Width, Waterfall View 19: Sortie a03-s02-0115

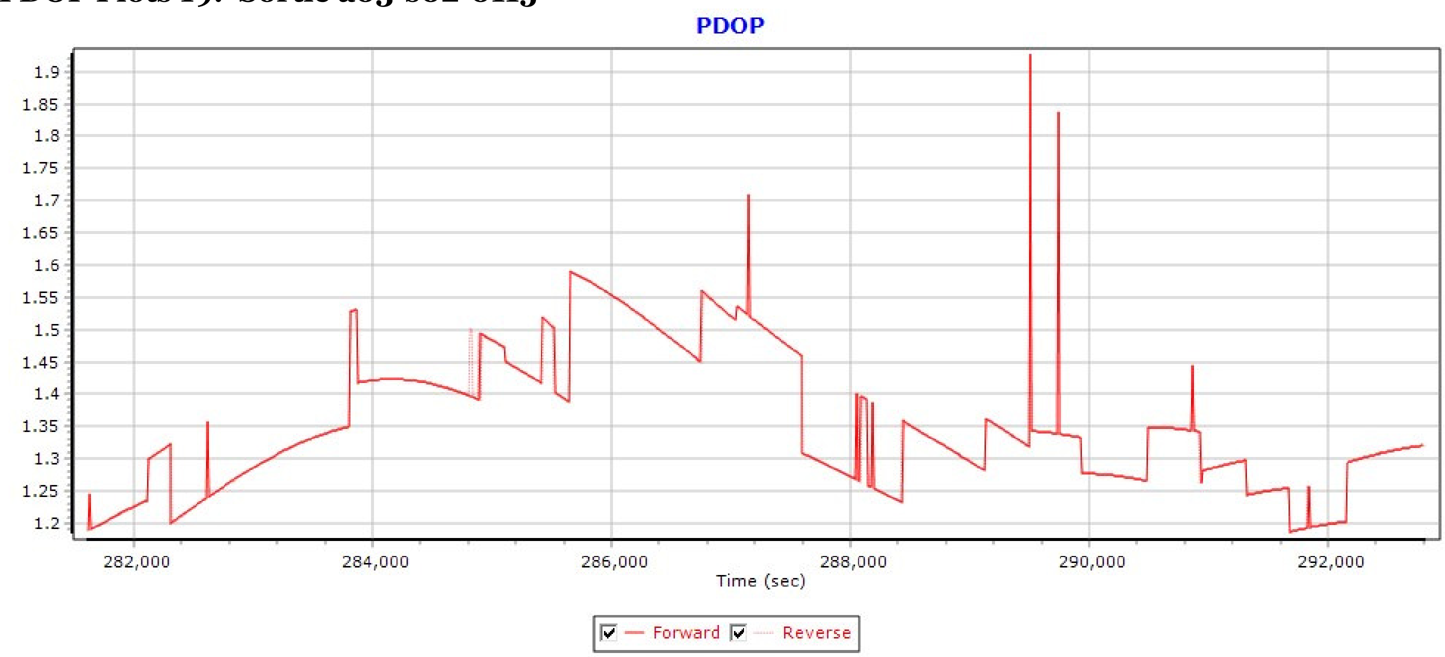
Due to Clouds on the western portion of the collect, the mission was shortened and the lower three lines were re-tasked in sortie 116.



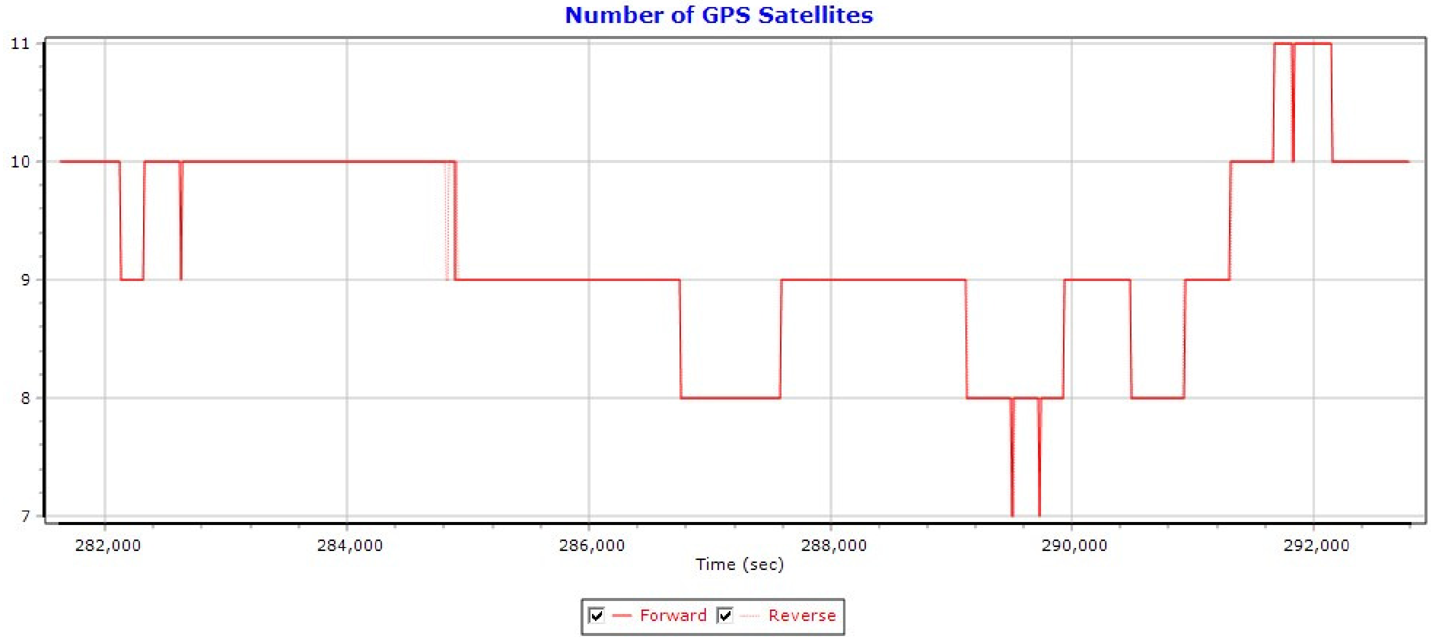
Combined SBET IAKAR Separation 19: Sortie a03-s02-0115



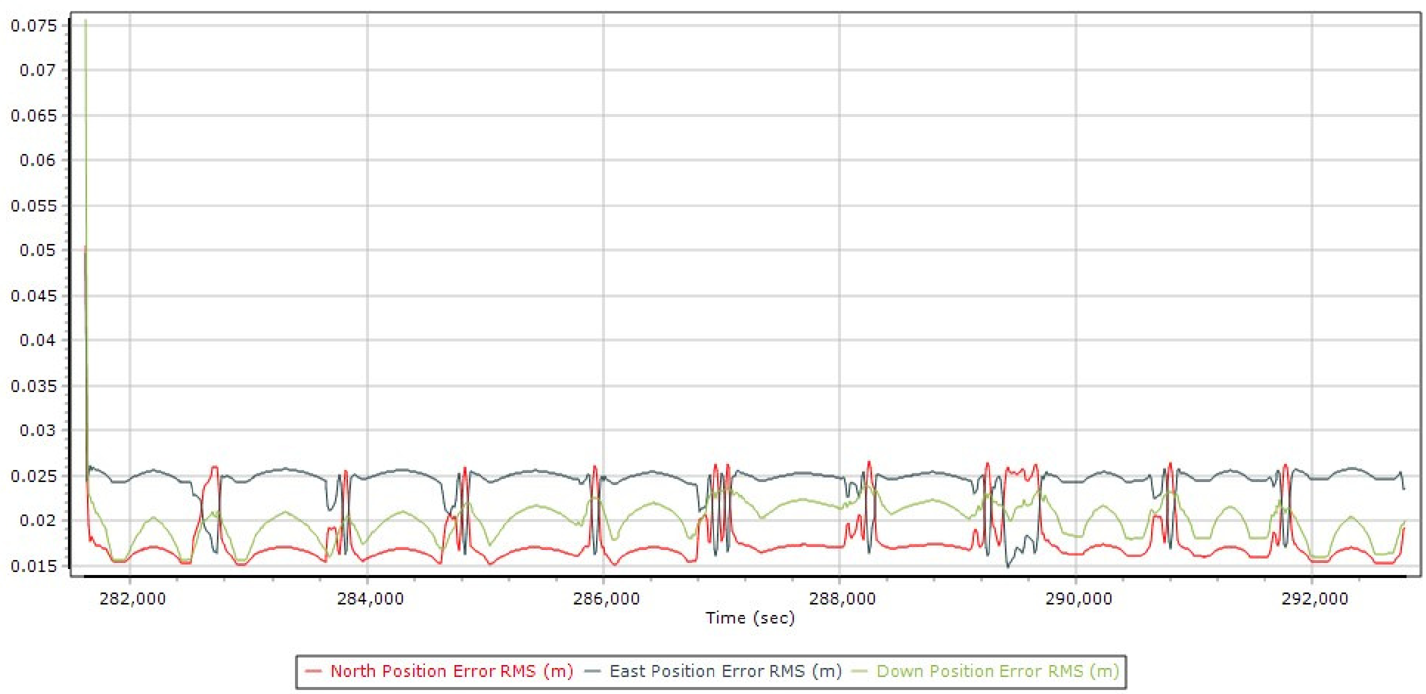
PDOP Plots 19: Sortie a03-s02-0115



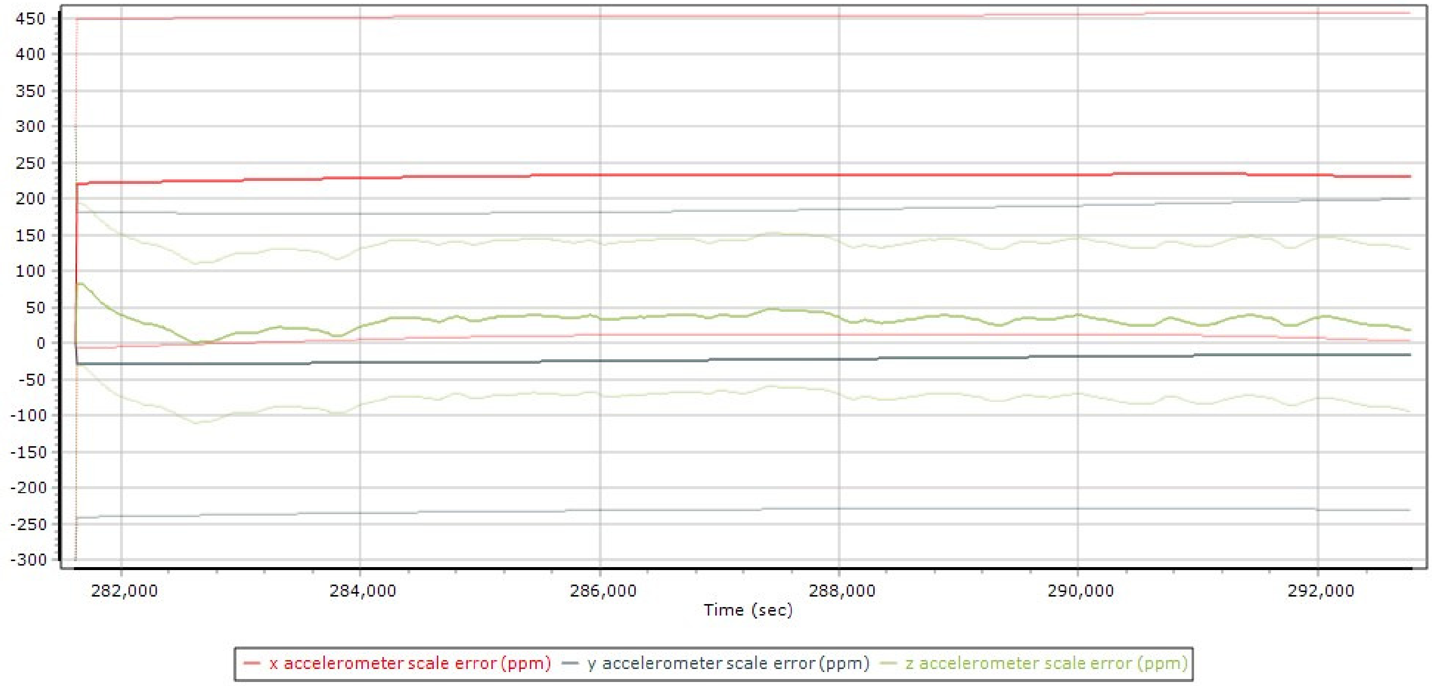
Number of Satellites (>6) Plots 19: Sortie a03-s02-0115



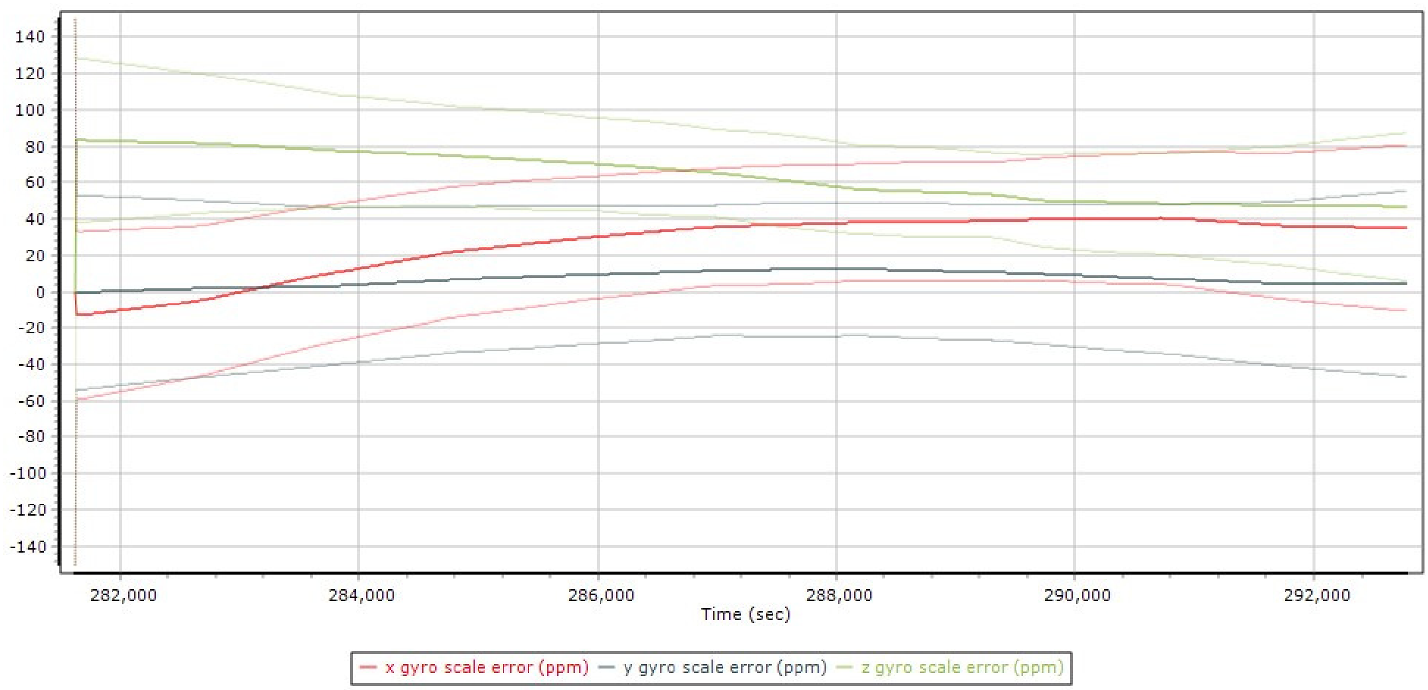
Sensor Position Error RMS (m) Plots 19: Sortie a03-s02-0115



Accelerometer Scale Error (ppm) Plots 19: Sortie a03-s02-0115



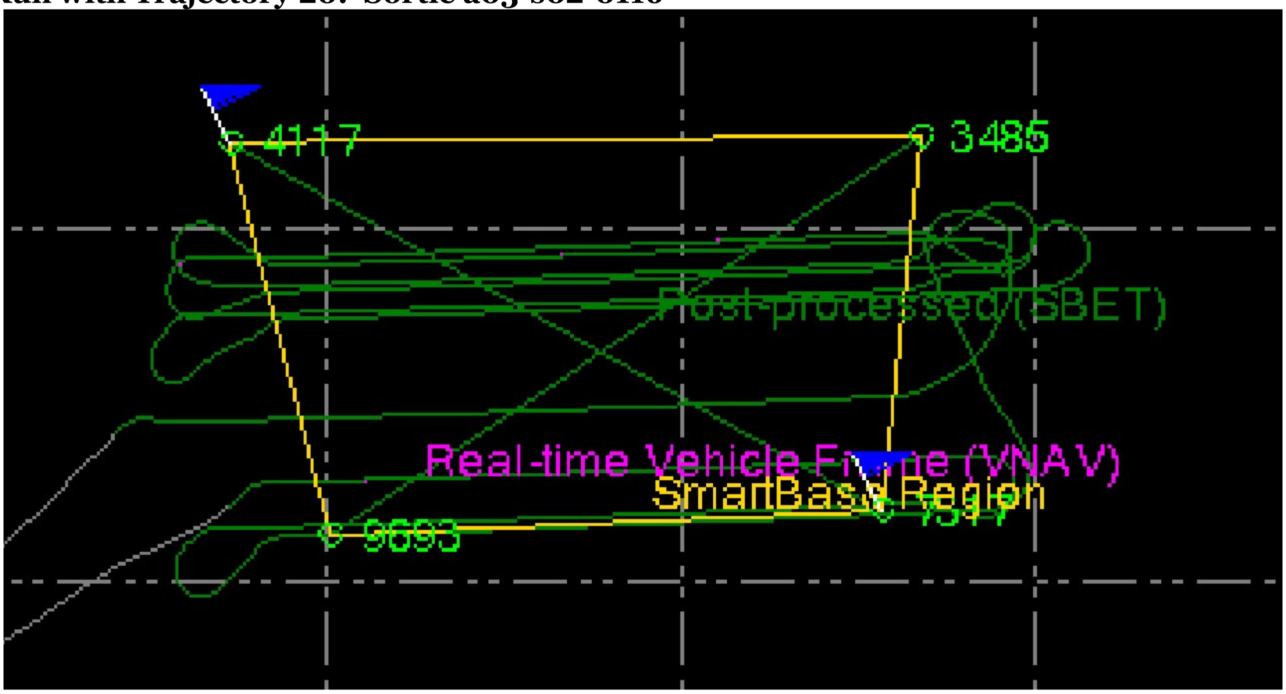
Gyro Scale Error (ppm) Plots 1: Sortie a03-s02-0115



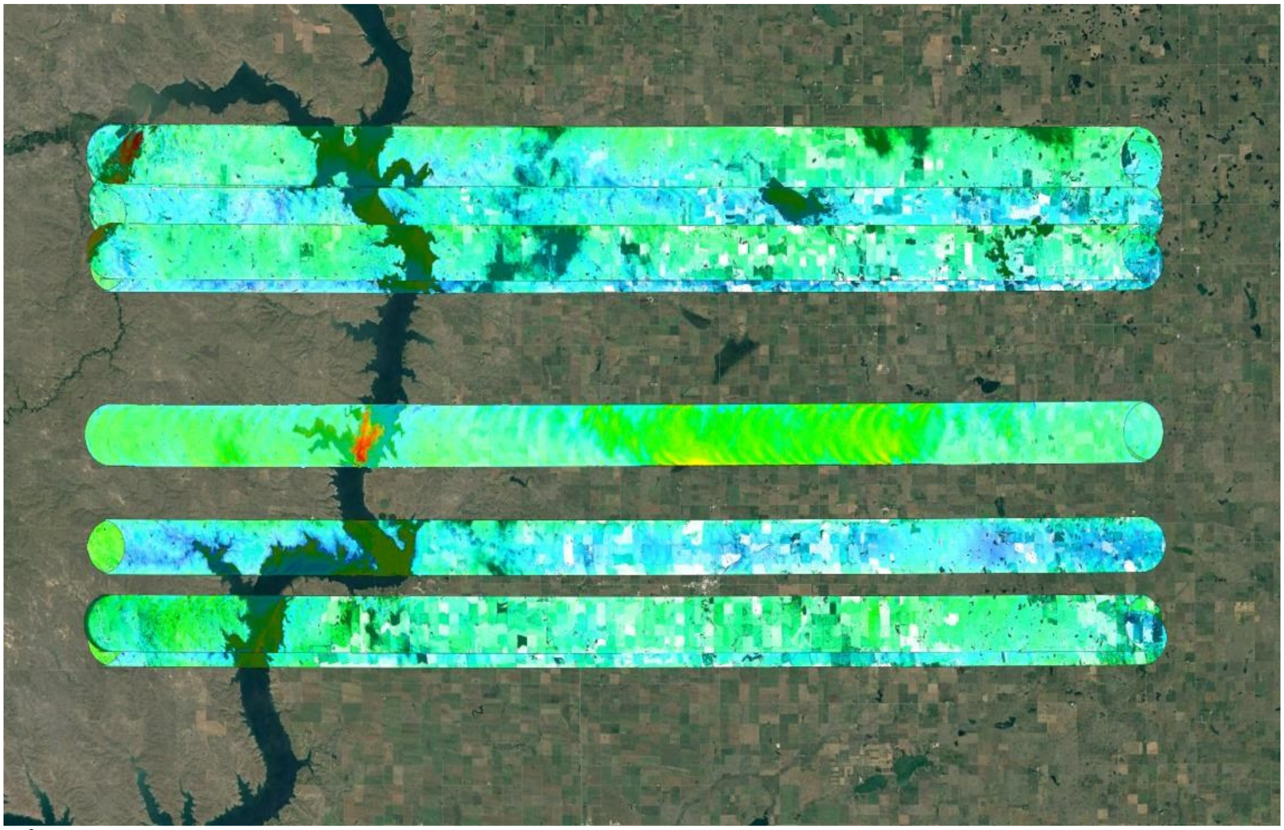
COLLECTION 20

Brick 2
Sortie a03-s02-0116
06/15/2016

Map Run with Trajectory 20: Sortie a03-s02-0116

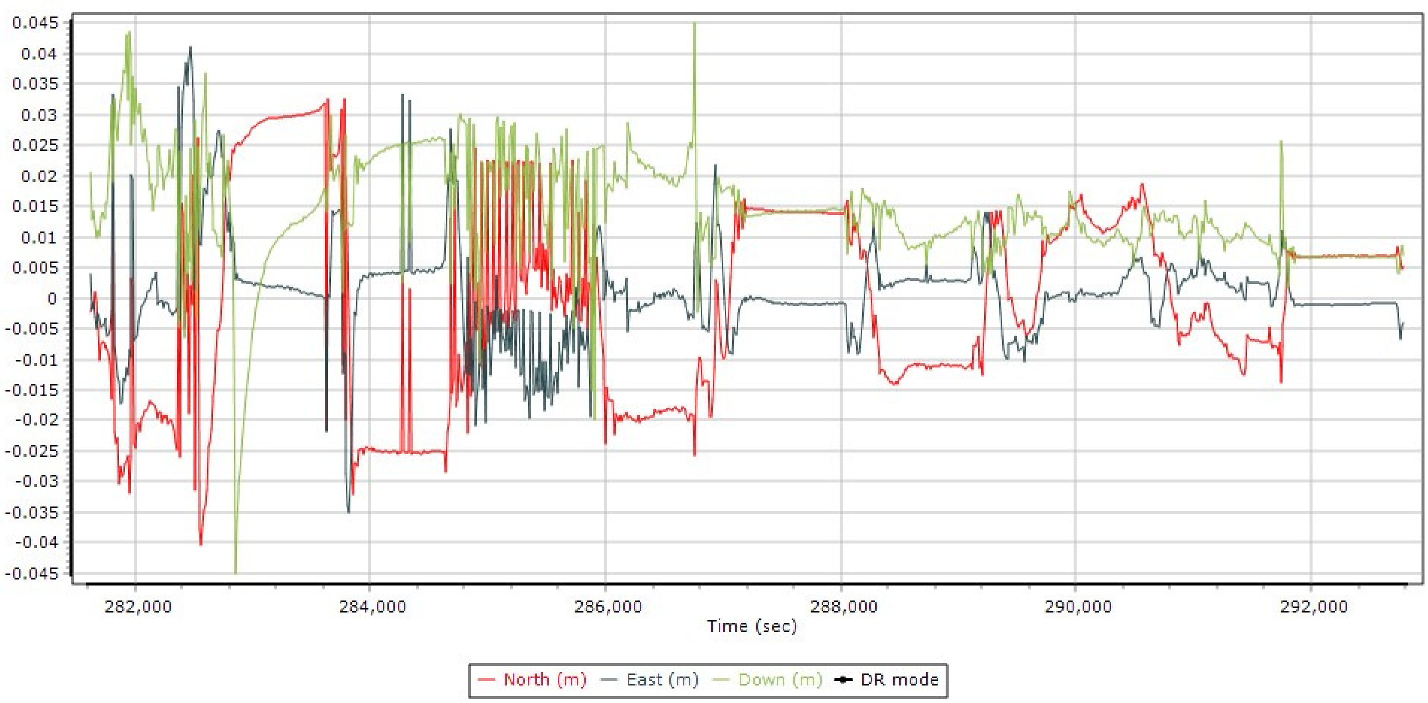


Swath Width, Waterfall View 20: Sortie a03-s02-0116

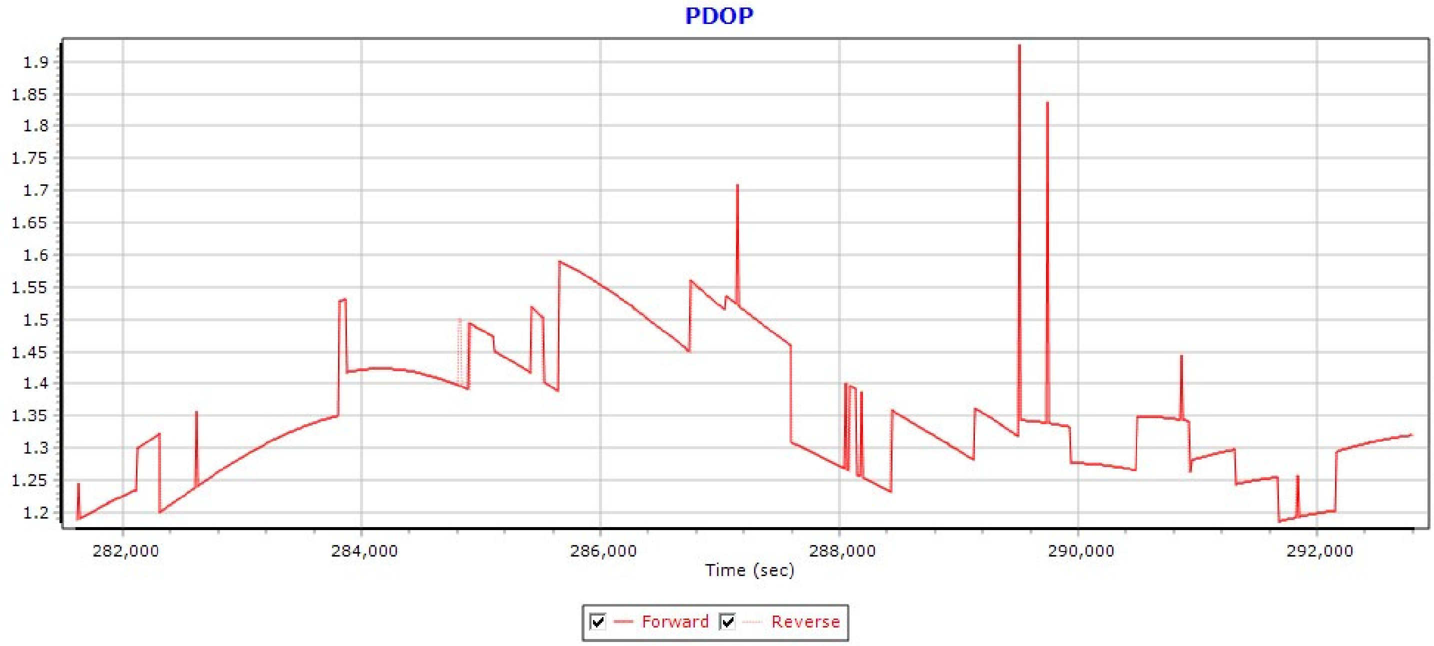


of

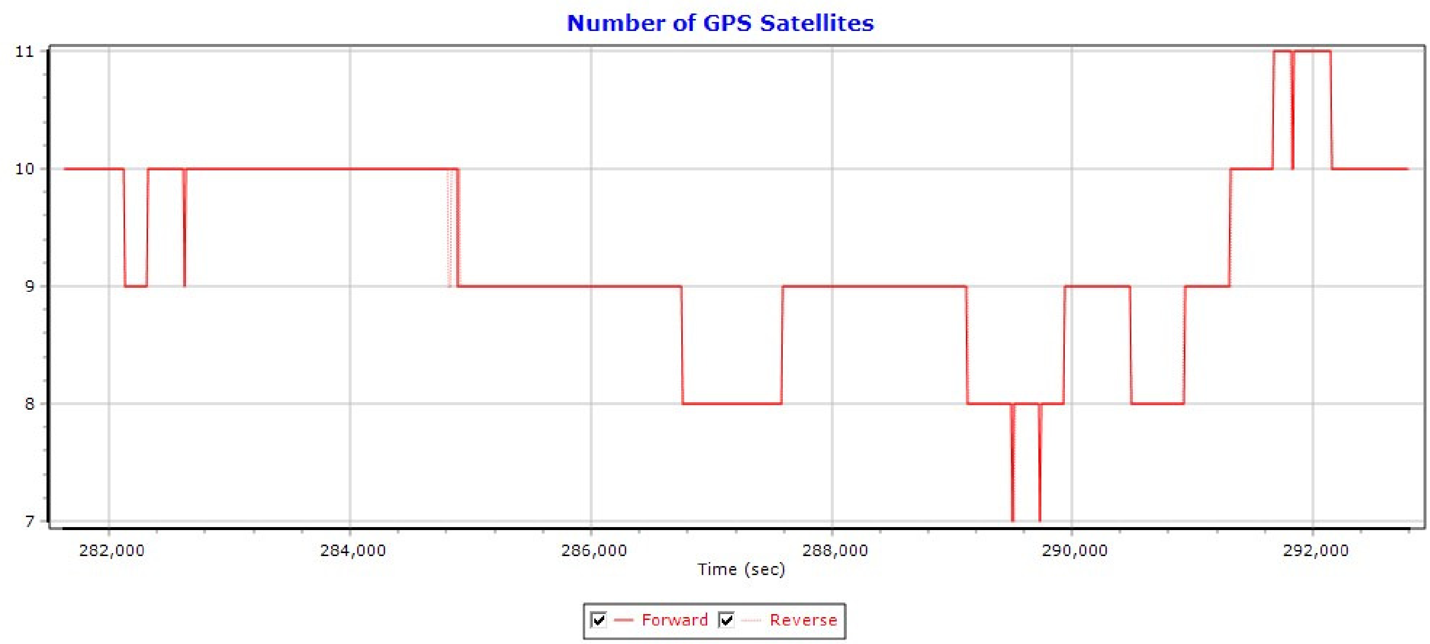
Combined SBET IAKAR Separation 20: Sortie a03-s02-0116



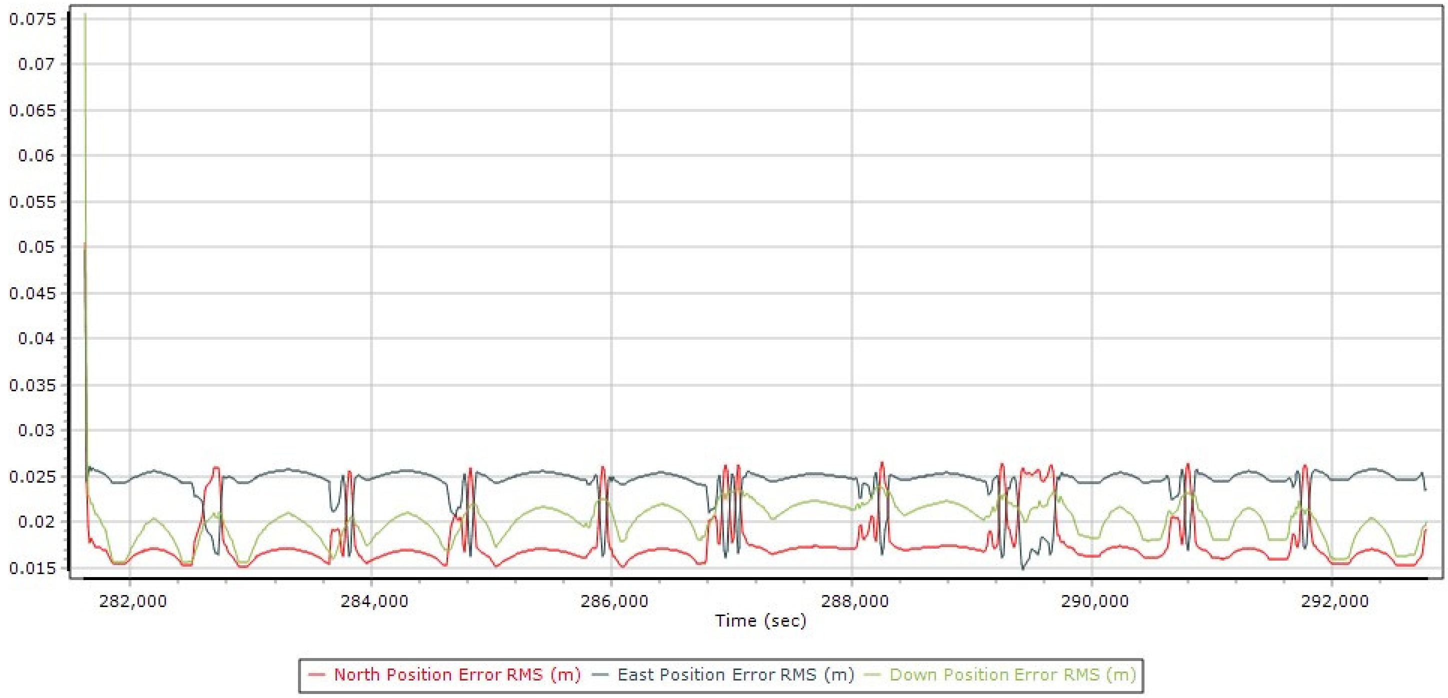
PDOP Plots 20: Sortie a03-s02-0116



Number of Satellites (>6) Plots 20: Sortie a03-s02-0116

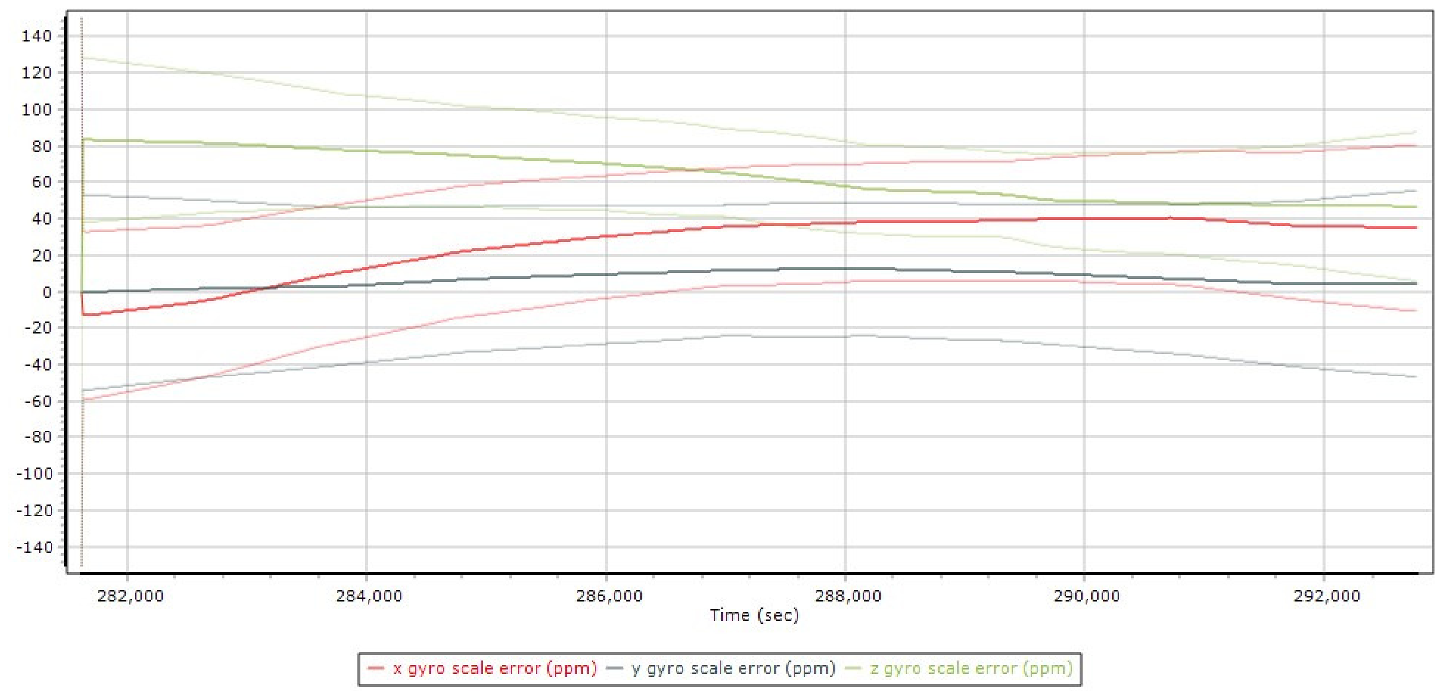


Sensor Position Error RMS (m) Plots 20: Sortie a03-s02-0116



Accelerometer Scale Error (ppm) Plots 20: Sortie a03-s02-0116

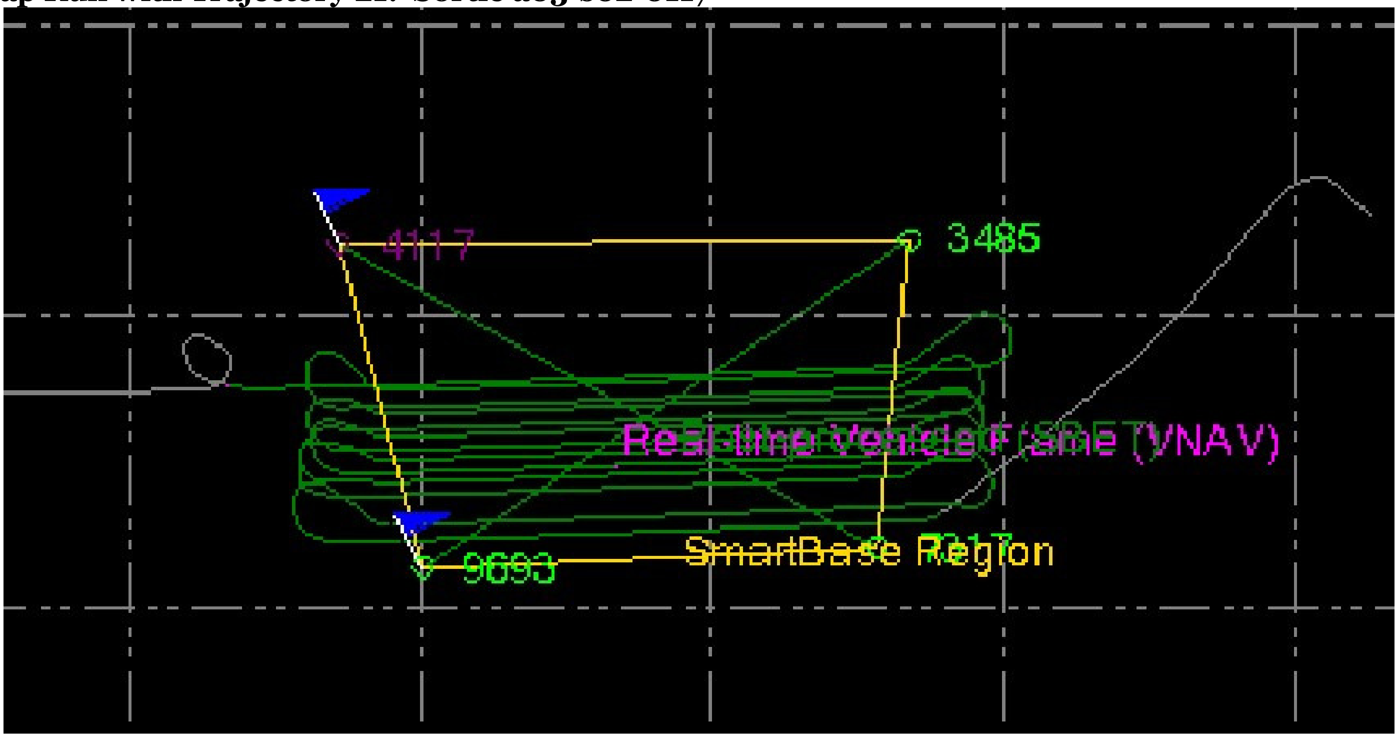
Gyro Scale Error (ppm) Plots 20: Sortie a03-s02-0116



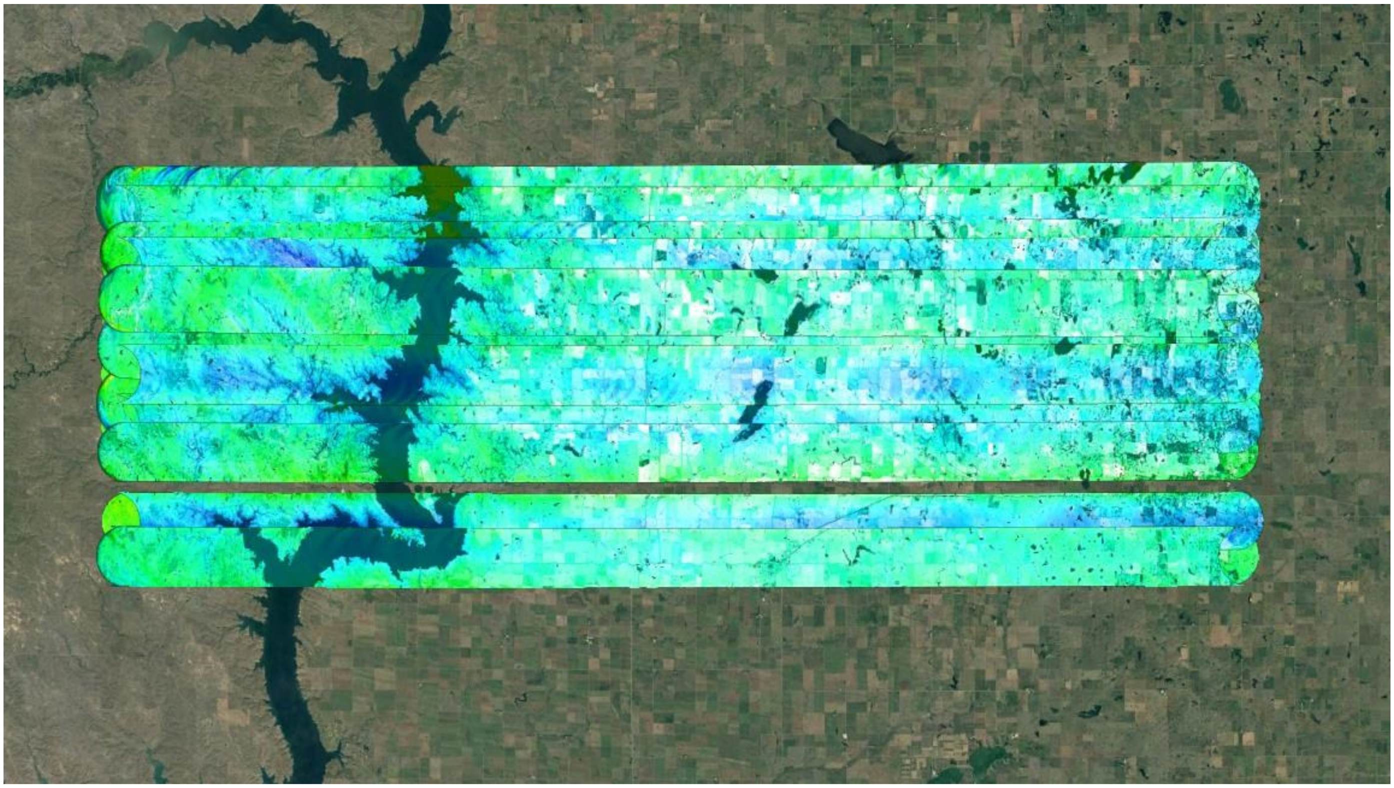
COLLECTION 21

Brick 2
Sortie a03-s02-0117
06/15/2016

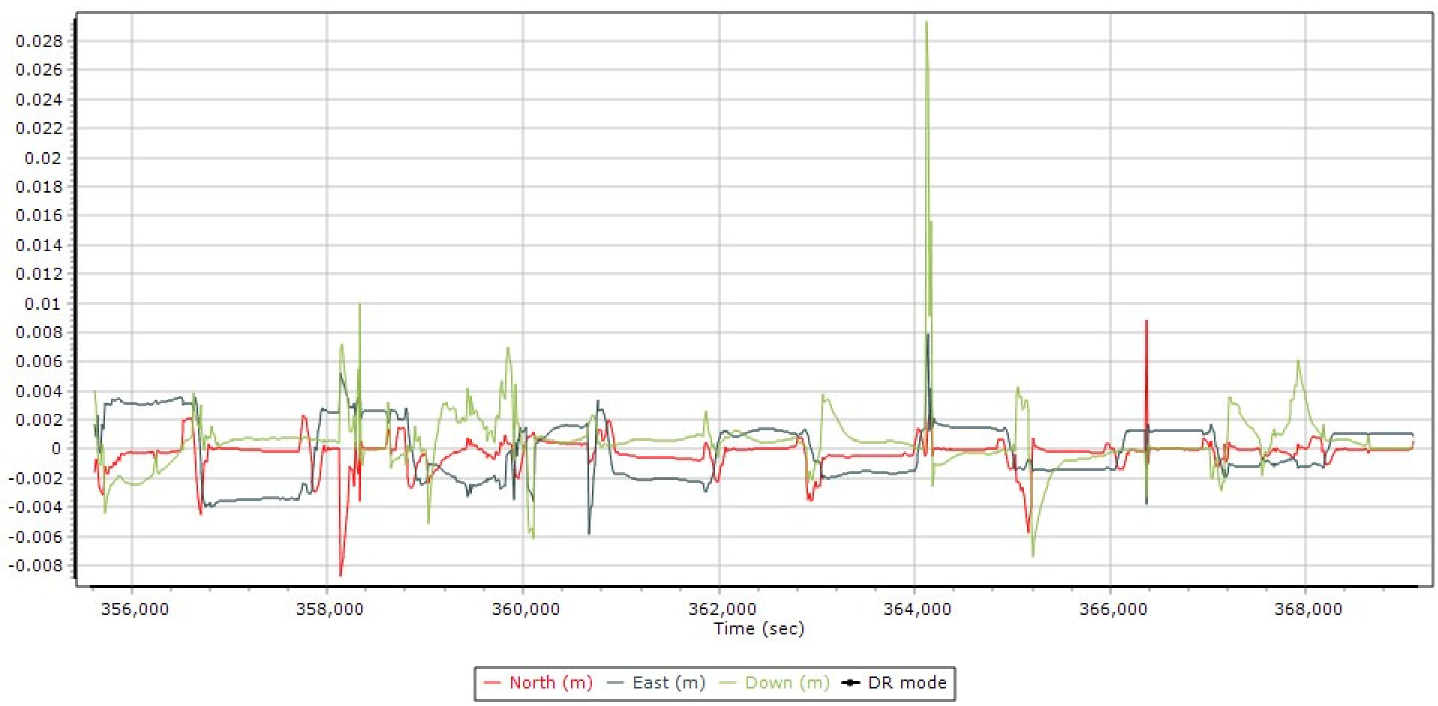
Map Run with Trajectory 21: Sortie a03-s02-0117



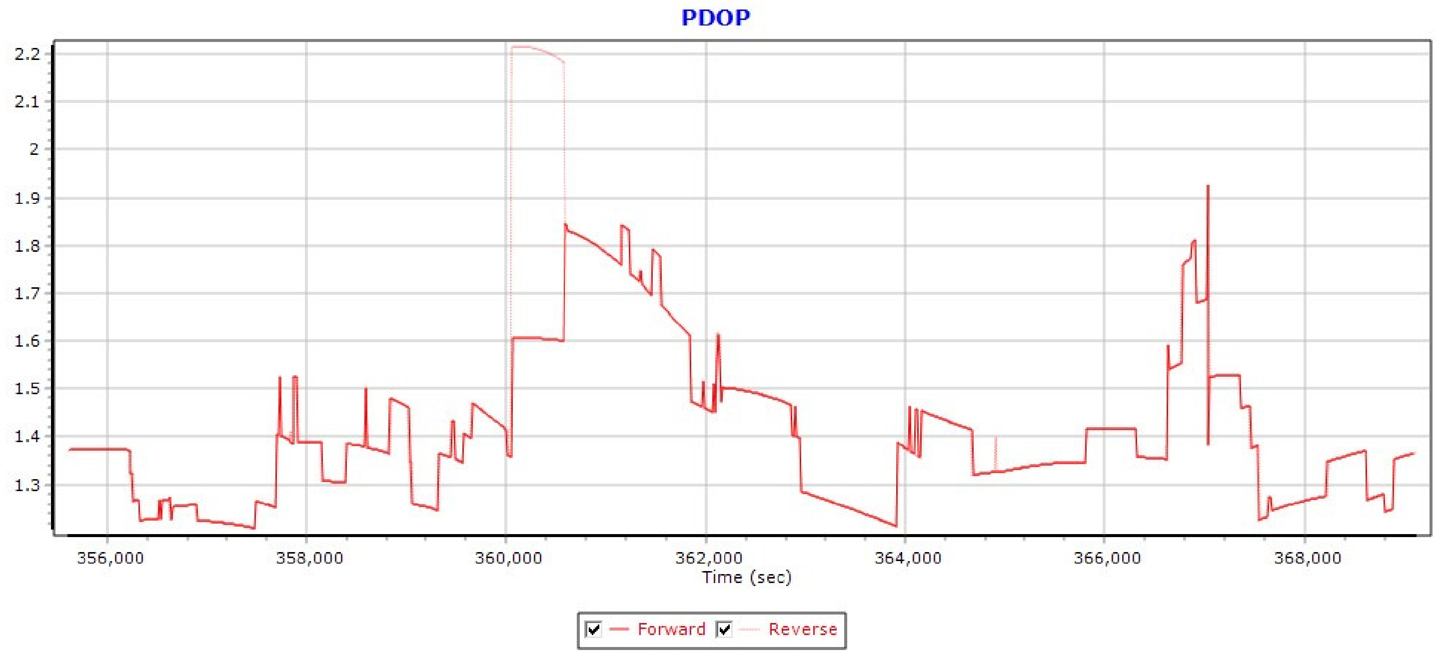
Swath Width, Waterfall View 21: Sortie a03-s02-0117



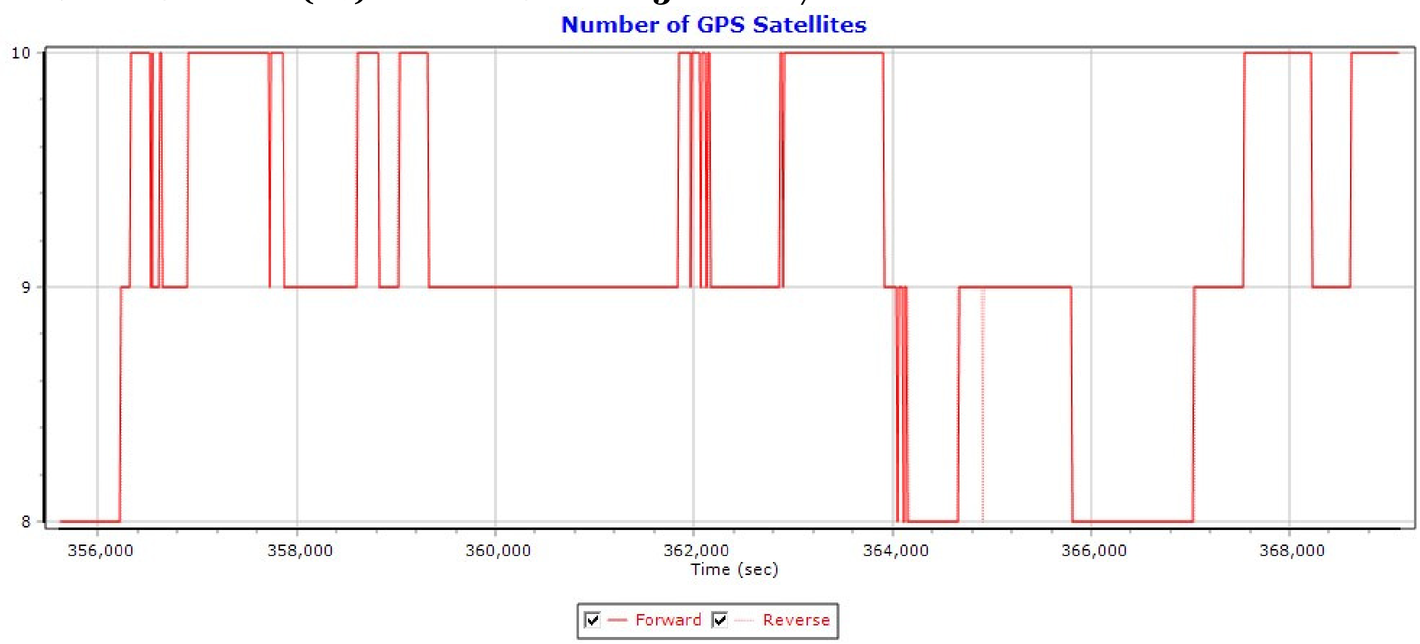
Combined SBET IAKAR Separation 21: Sortie a03-s02-0117



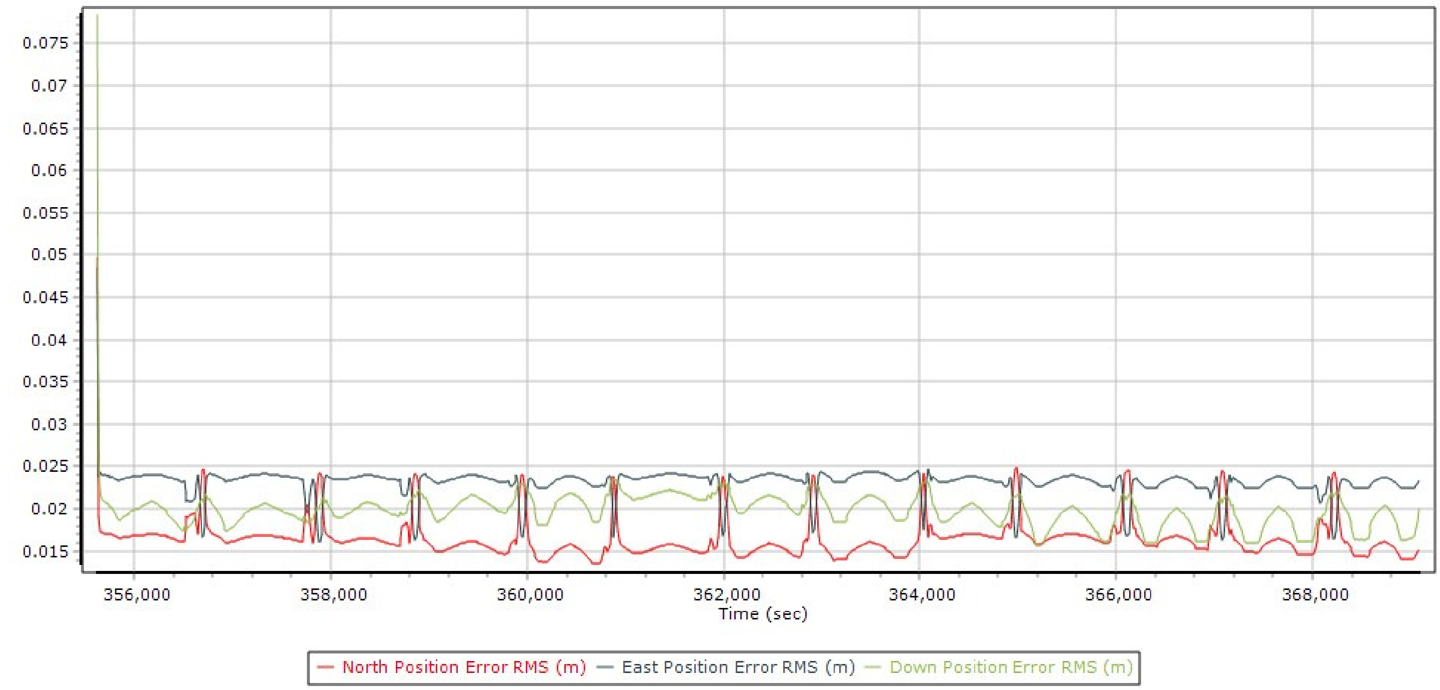
PDOP Plots 21: Sortie a03-s02-0117



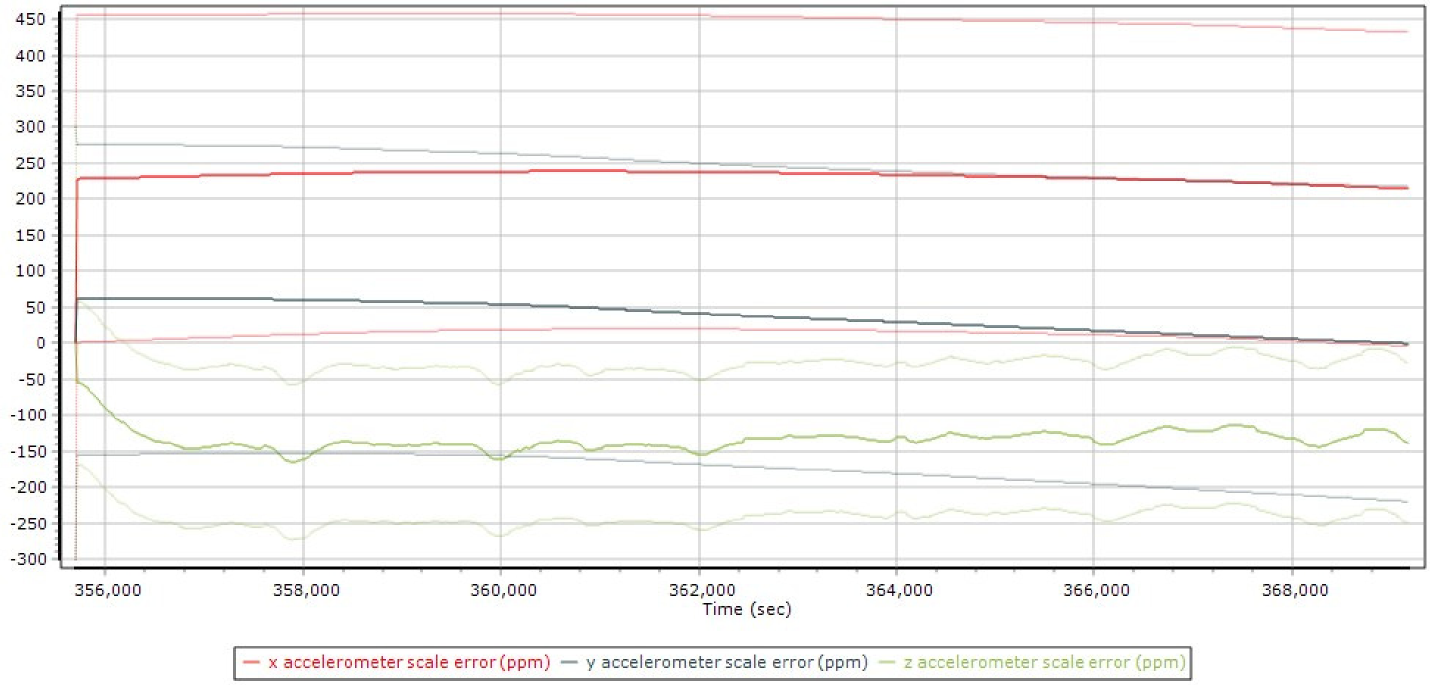
Number of Satellites (>6) Plots 21: Sortie a03-s02-0117



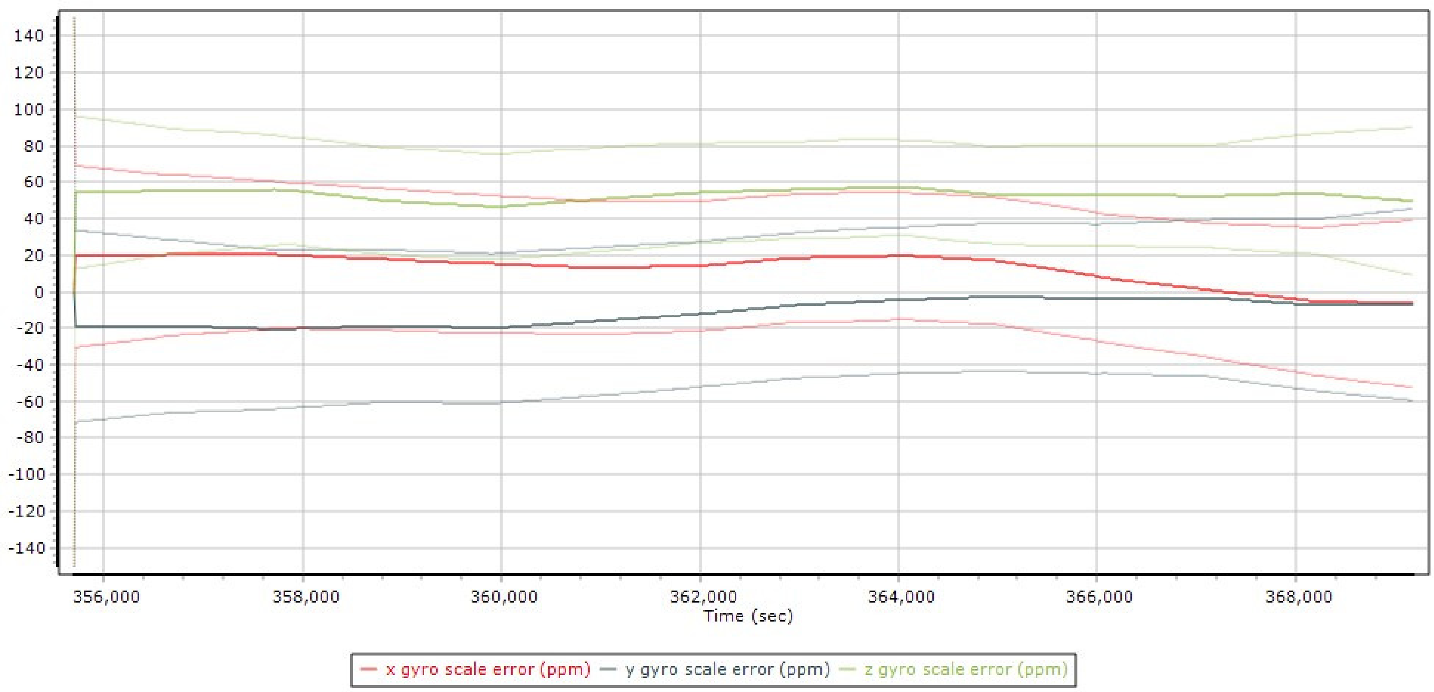
Sensor Position Error RMS (m) Plots 21: Sortie a03-s02-0117



Accelerometer Scale Error (ppm) Plots 21: Sortie a03-s02-0117



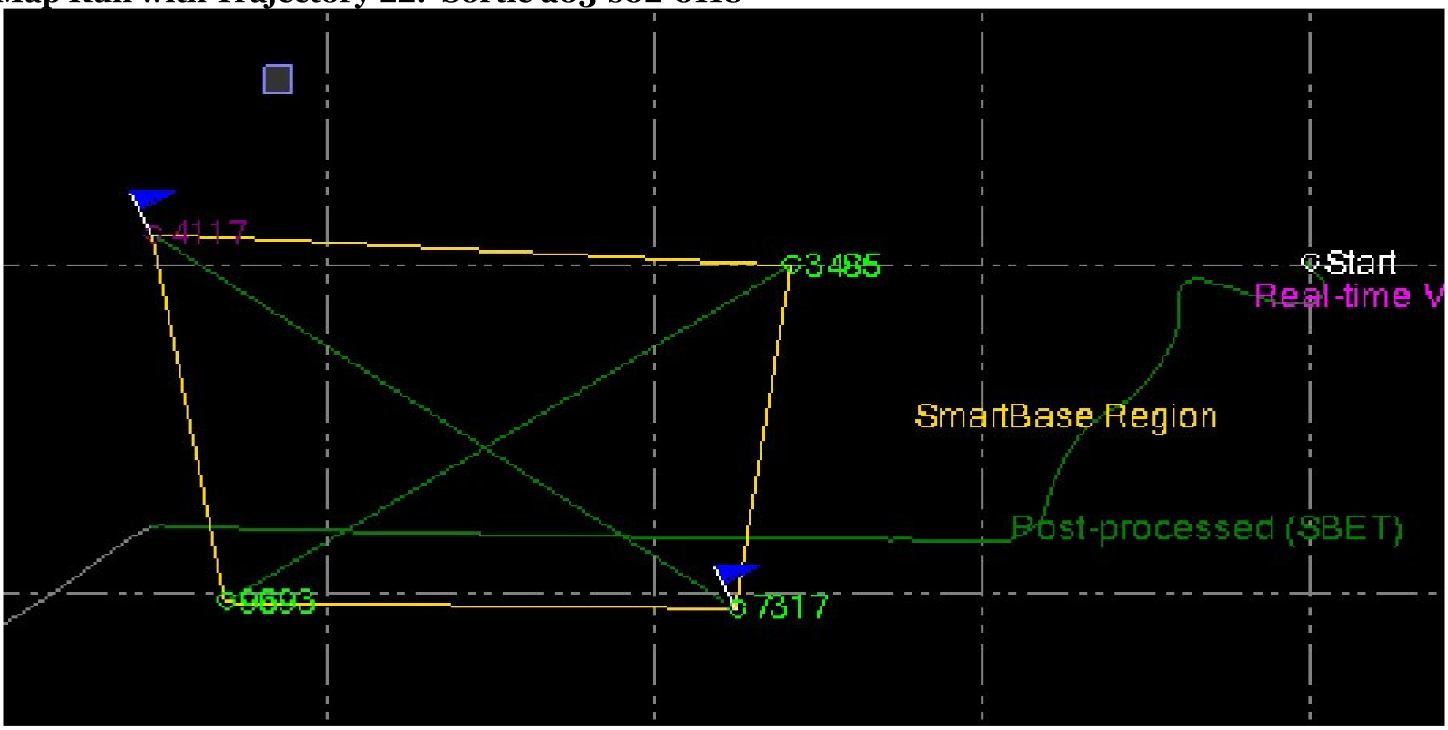
Gyro Scale Error (ppm) Plots 21: Sortie a03-s02-0117



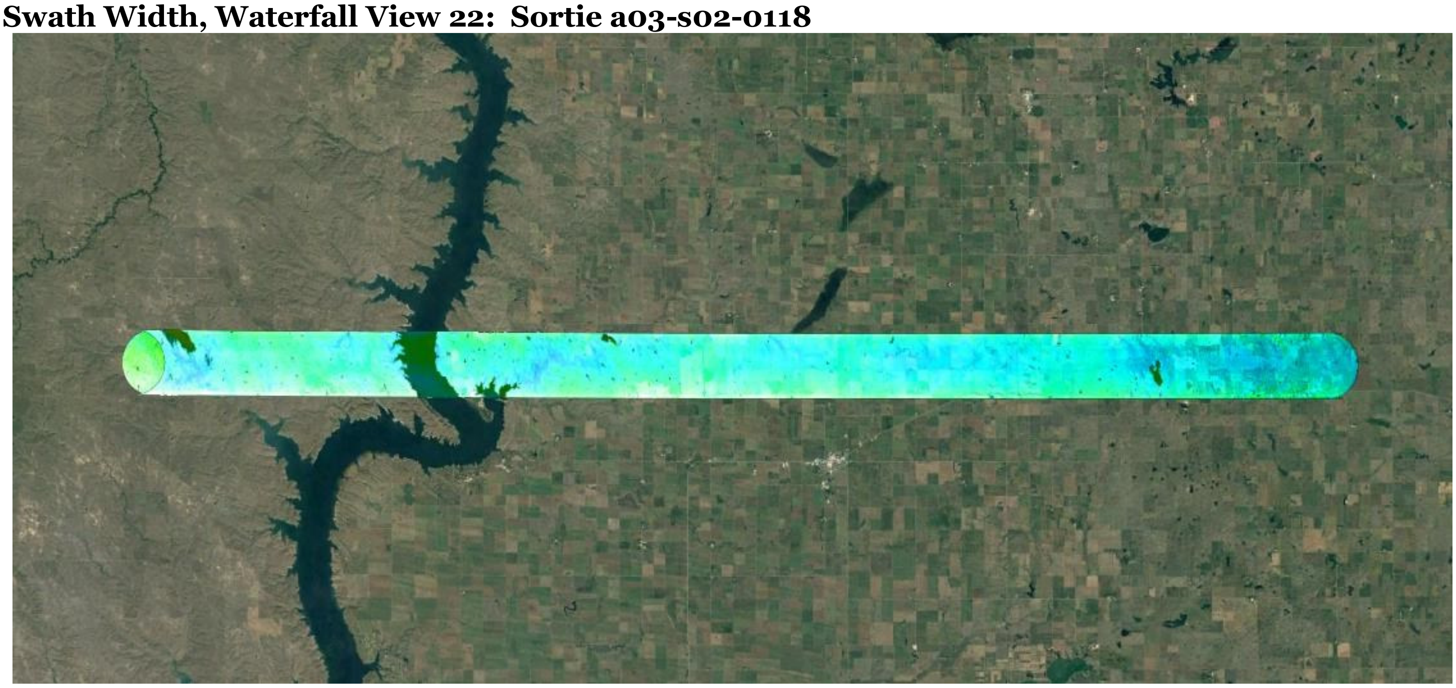
COLLECTION 22

Brick 2
Sortie a03-s02-0118
06/16/2016

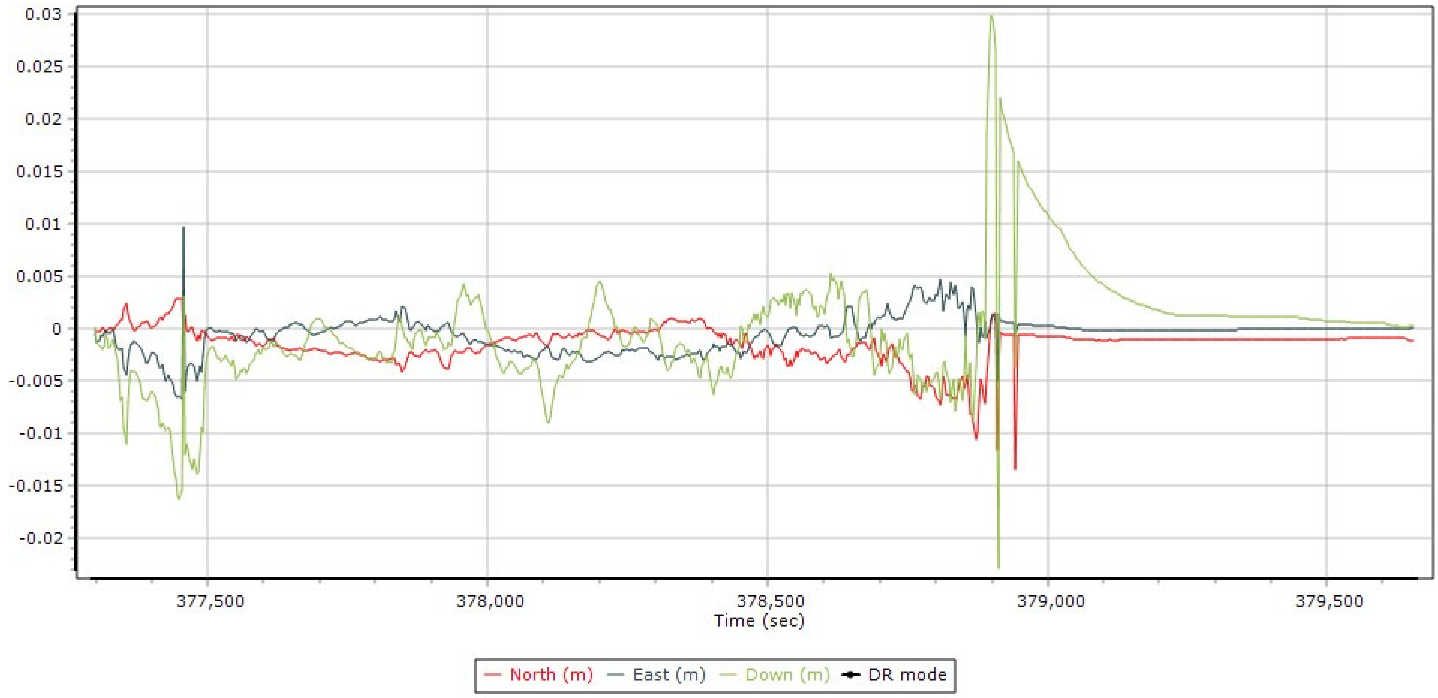
Map Run with Trajectory 22: Sortie a03-s02-0118



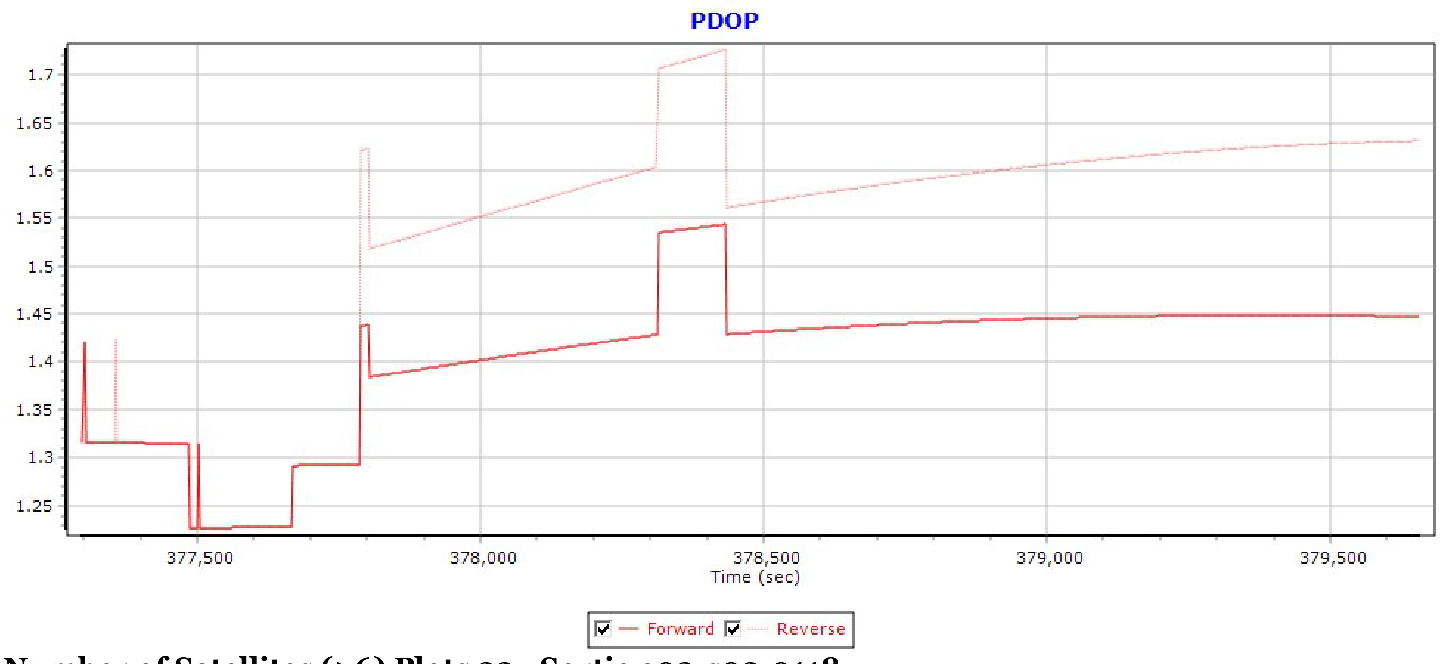
Swath Width, Waterfall View 22: Sortie a03-s02-0118



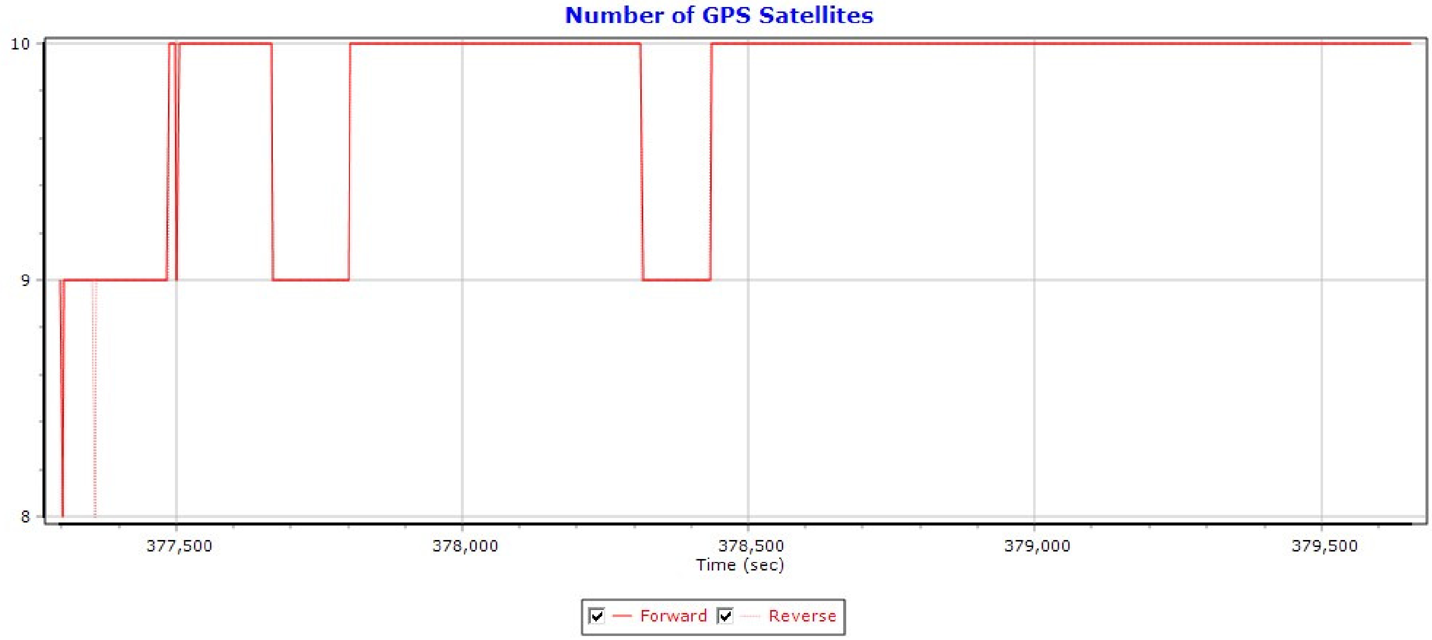
Combined SBET IAKAR Separation 22: Sortie a03-s02-0118



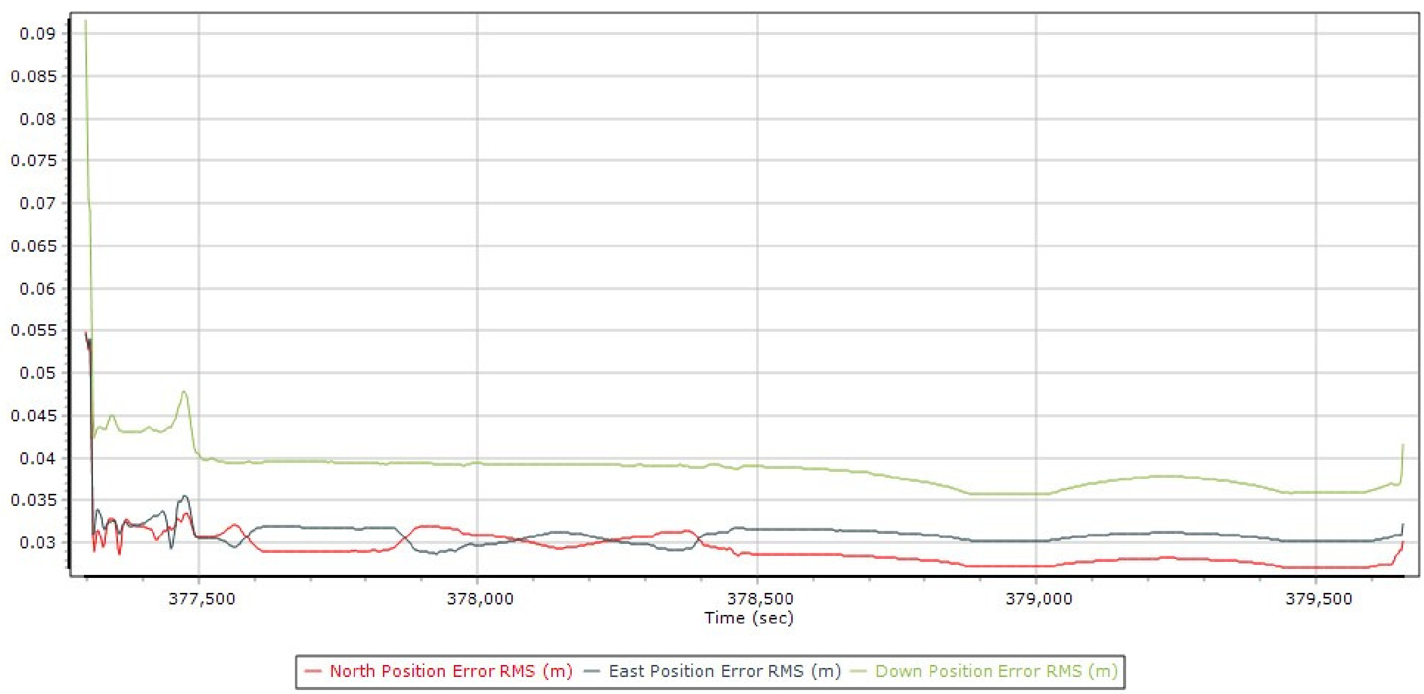
PDOP Plots 22: Sortie a03-s02-0118



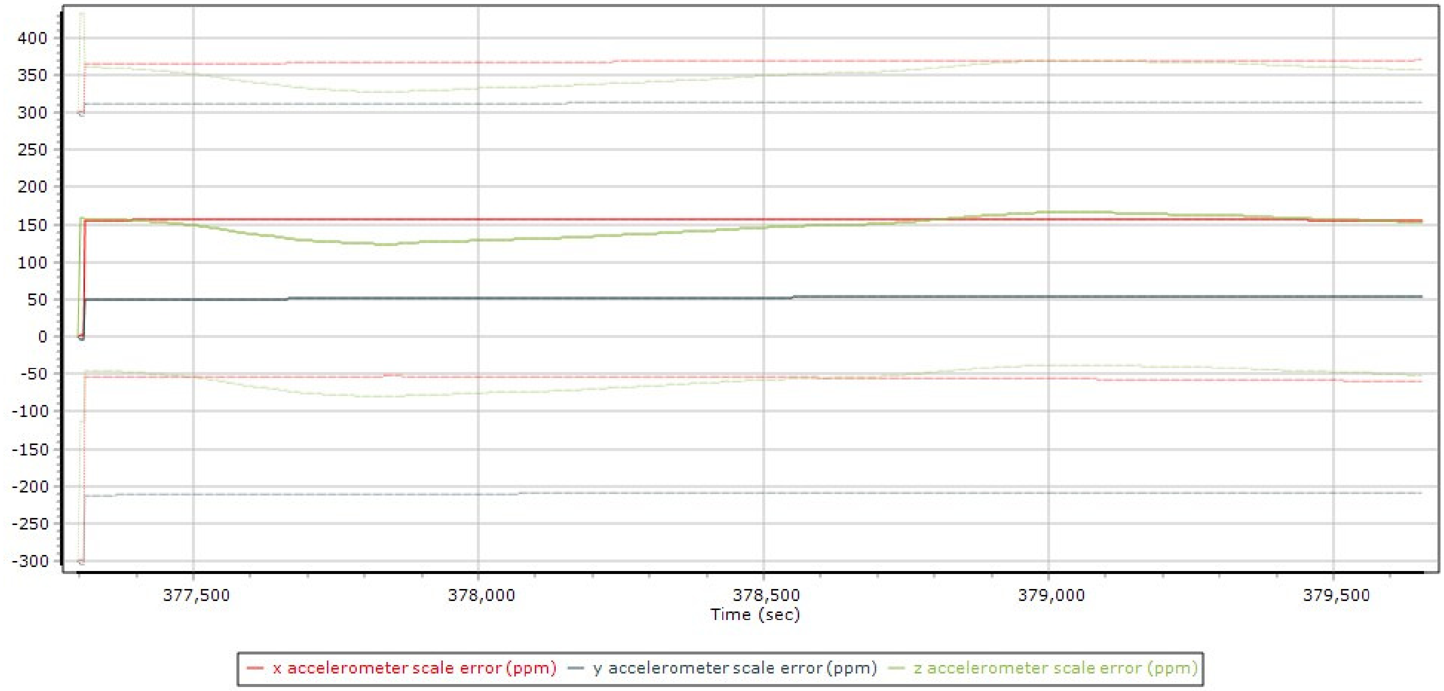
Number of Satellites (>6) Plots 22: Sortie a03-s02-0118



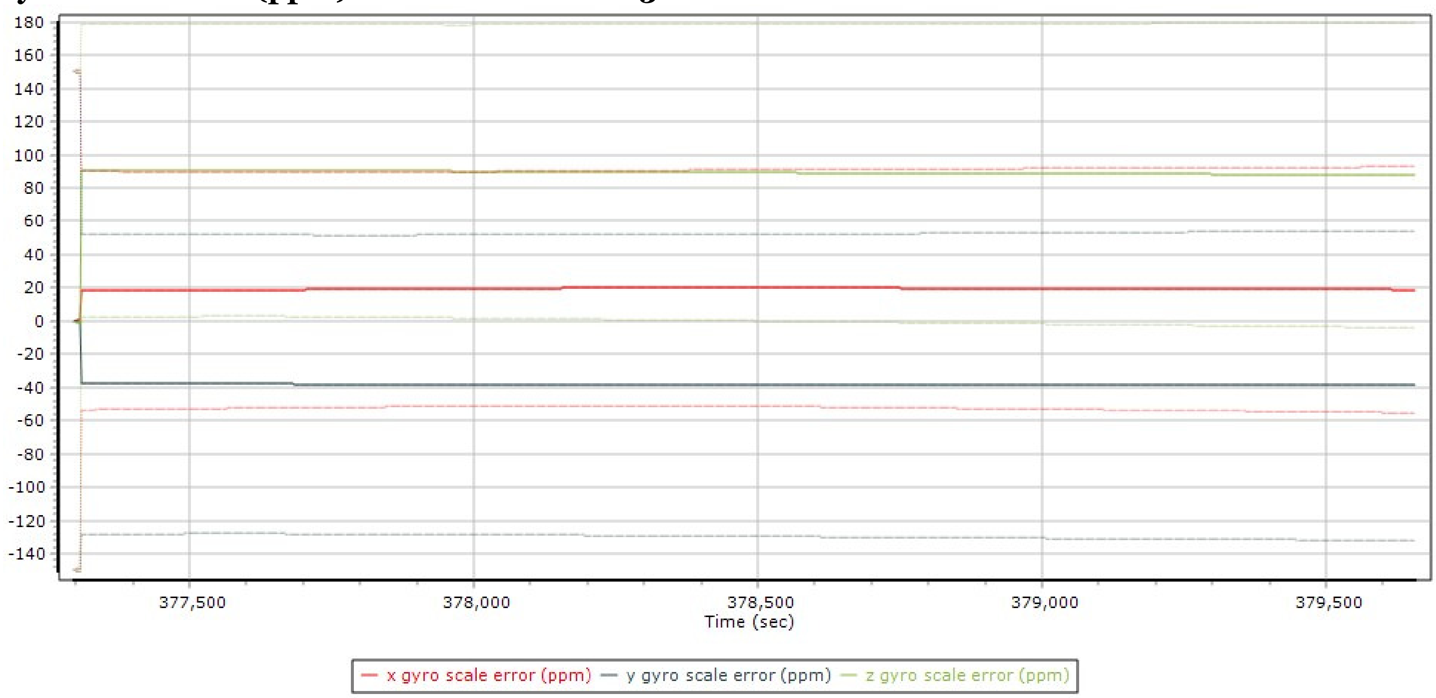
Sensor Position Error RMS (m) Plots 22: Sortie a03-s02-0118



Accelerometer Scale Error (ppm) Plots 22: Sortie a03-s02-0118



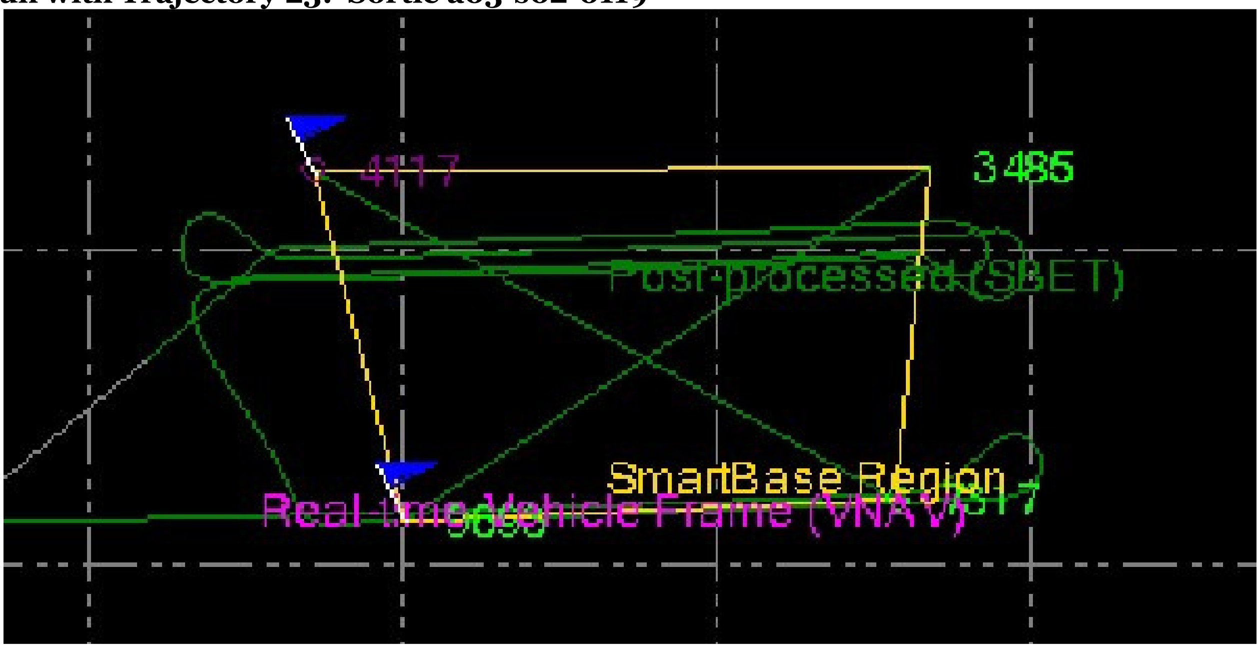
Gyro Scale Error (ppm) Plots 22: Sortie a03-s02-0118



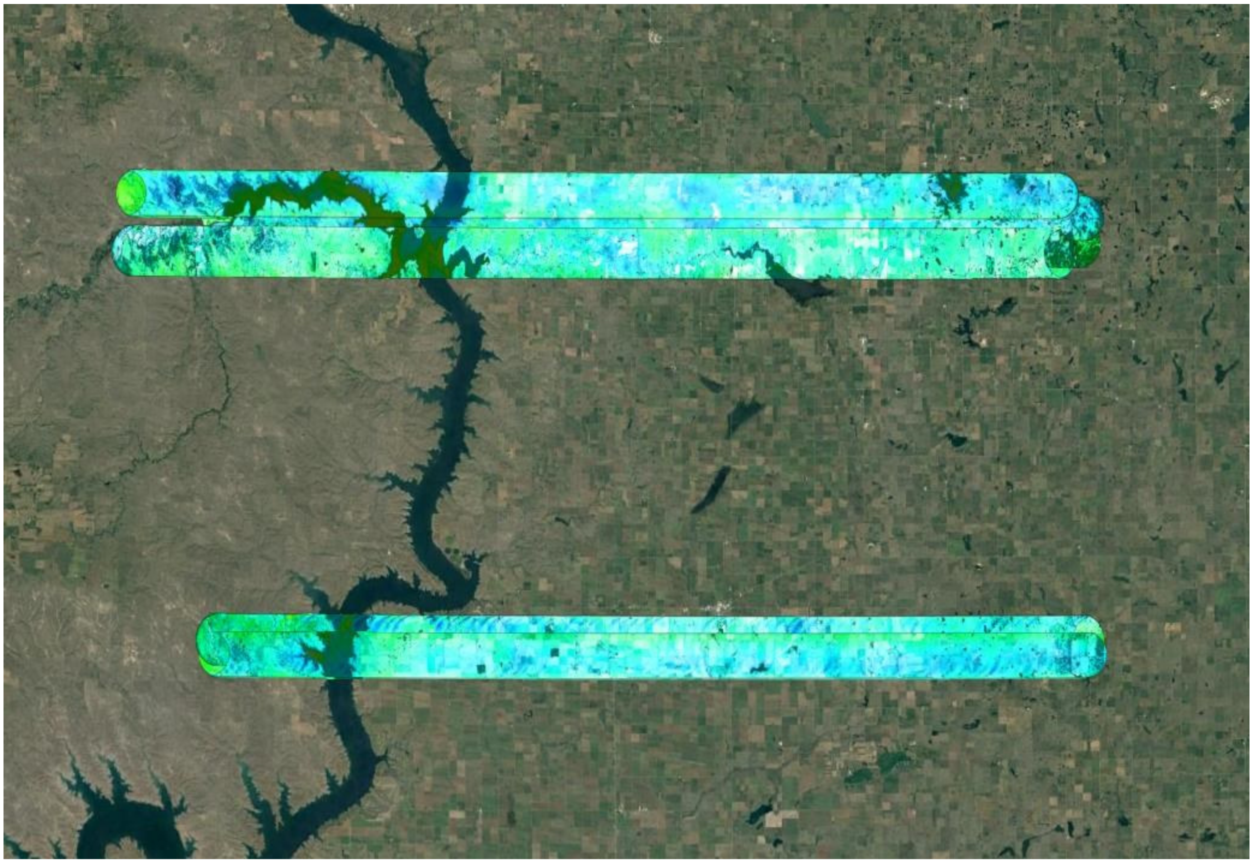
COLLECTION 23

Brick 2
Sortie a03-s02-0119
06/17/2016

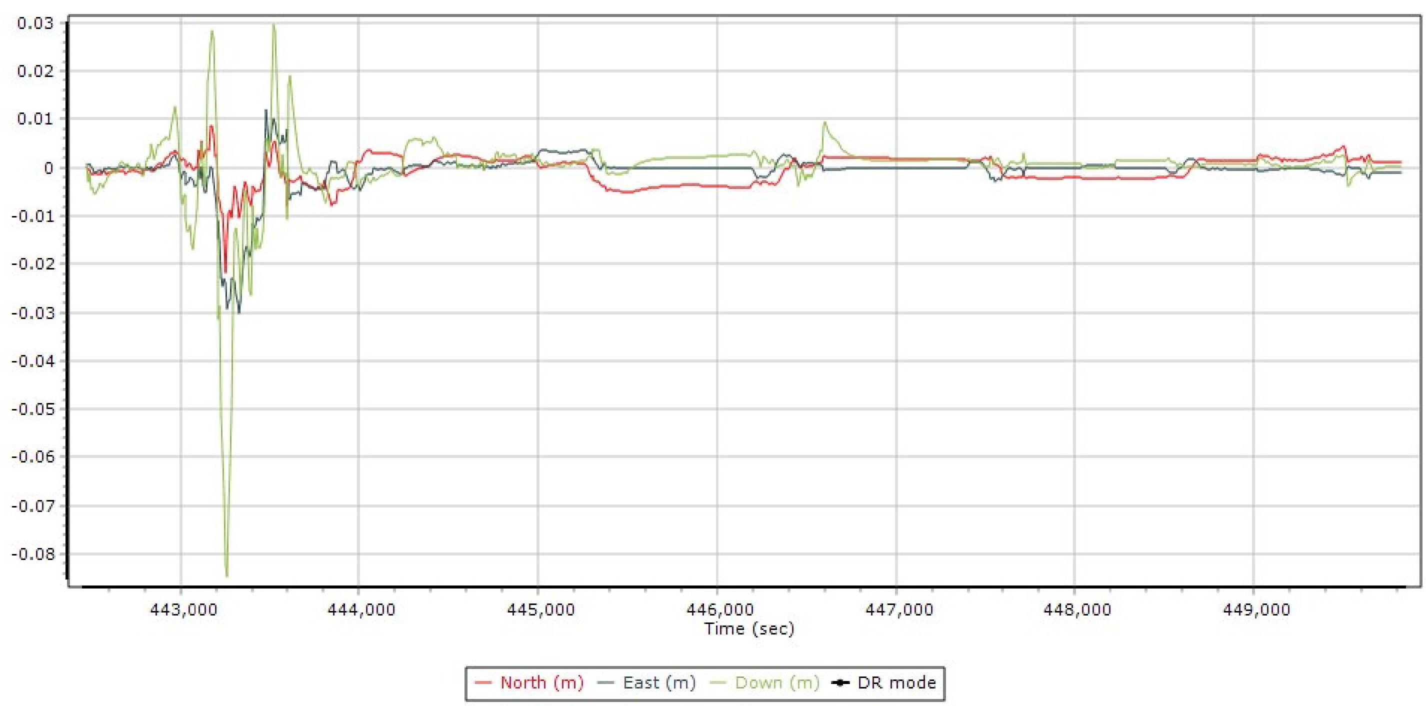
Map Run with Trajectory 23: Sortie a03-s02-0119



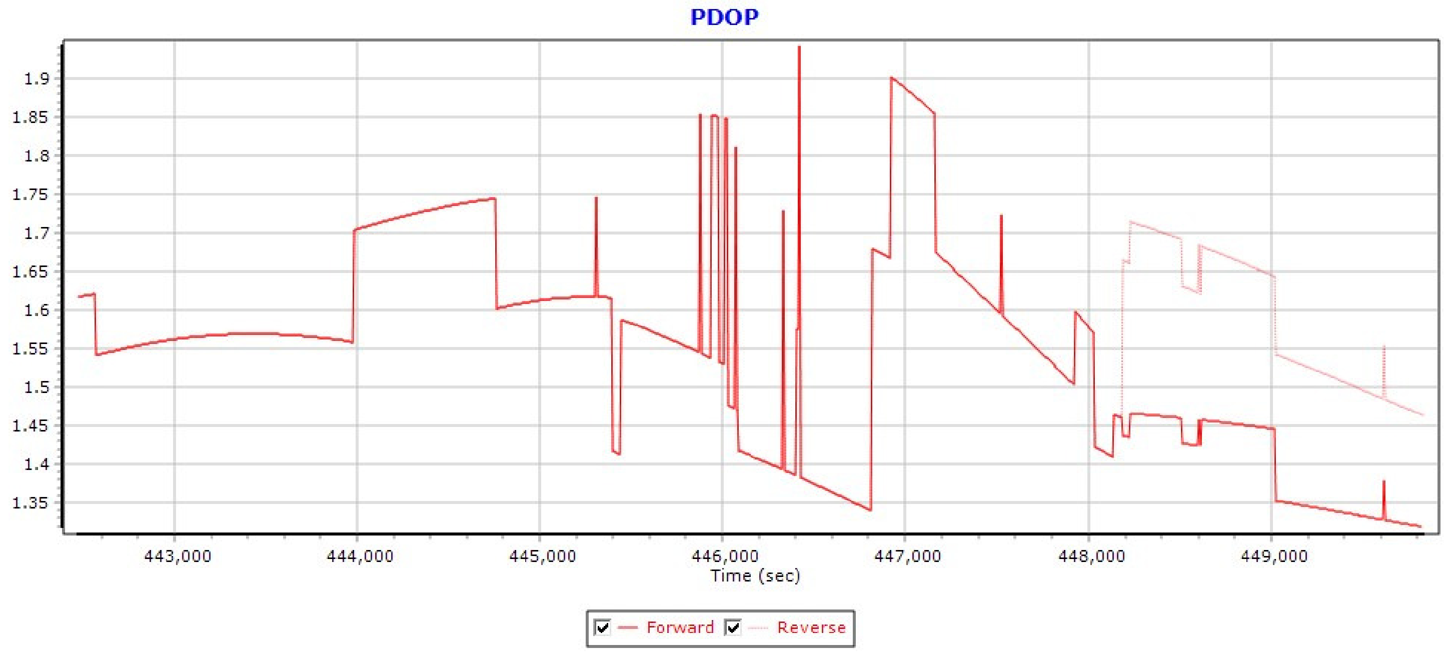
Swath Width, Waterfall View 23: Sortie a03-s02-0119



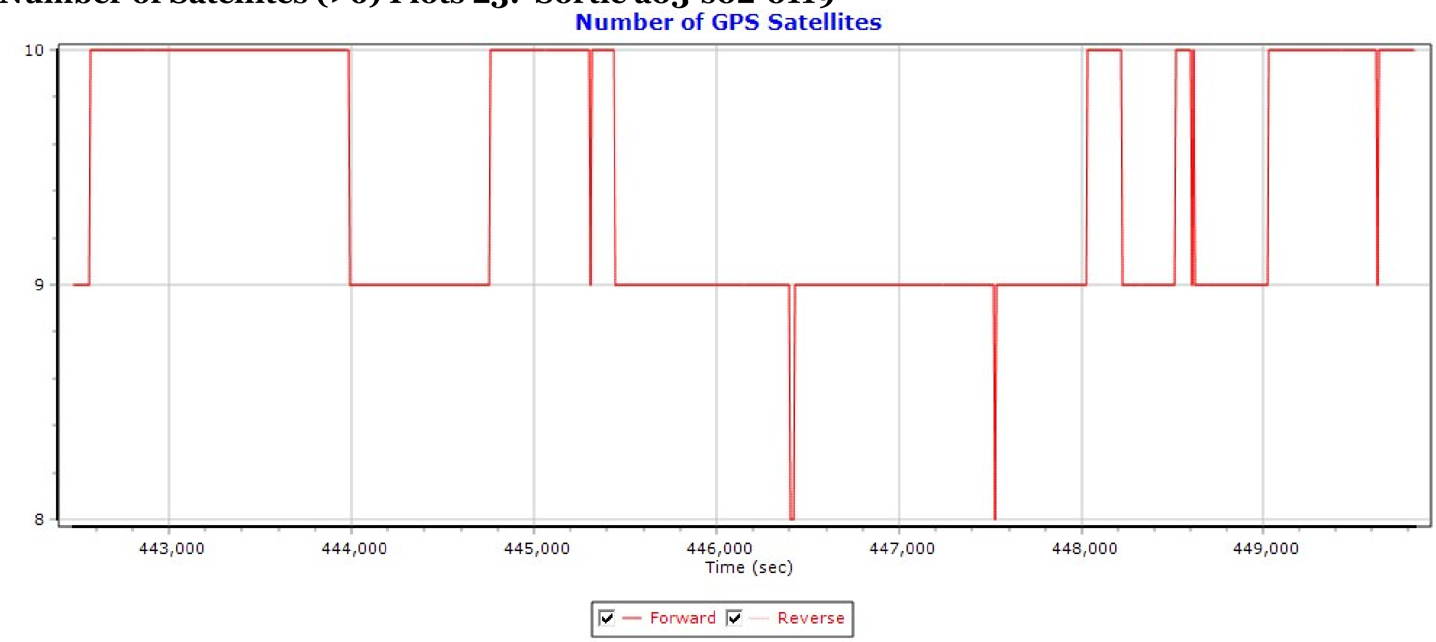
Combined SBET IAKAR Separation 23: Sortie a03-s02-0119



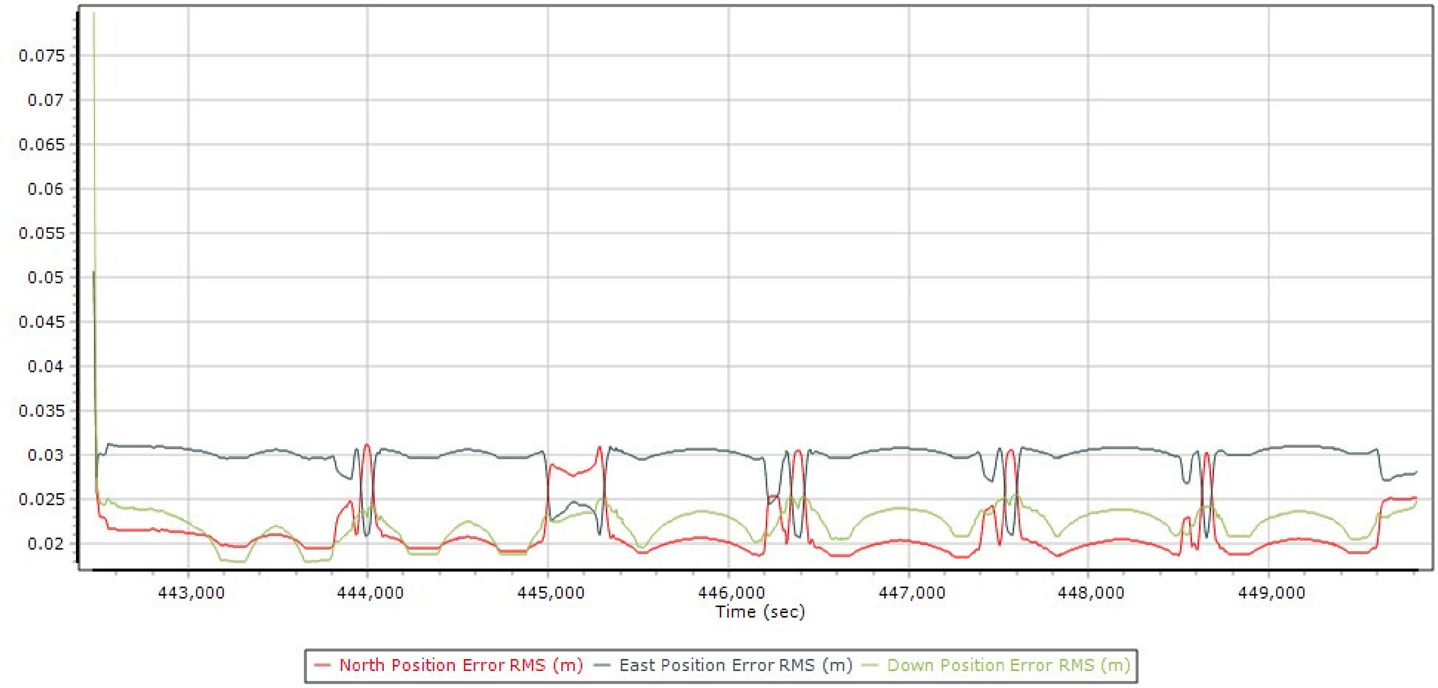
PDOP Plots 23: Sortie a03-s02-0119



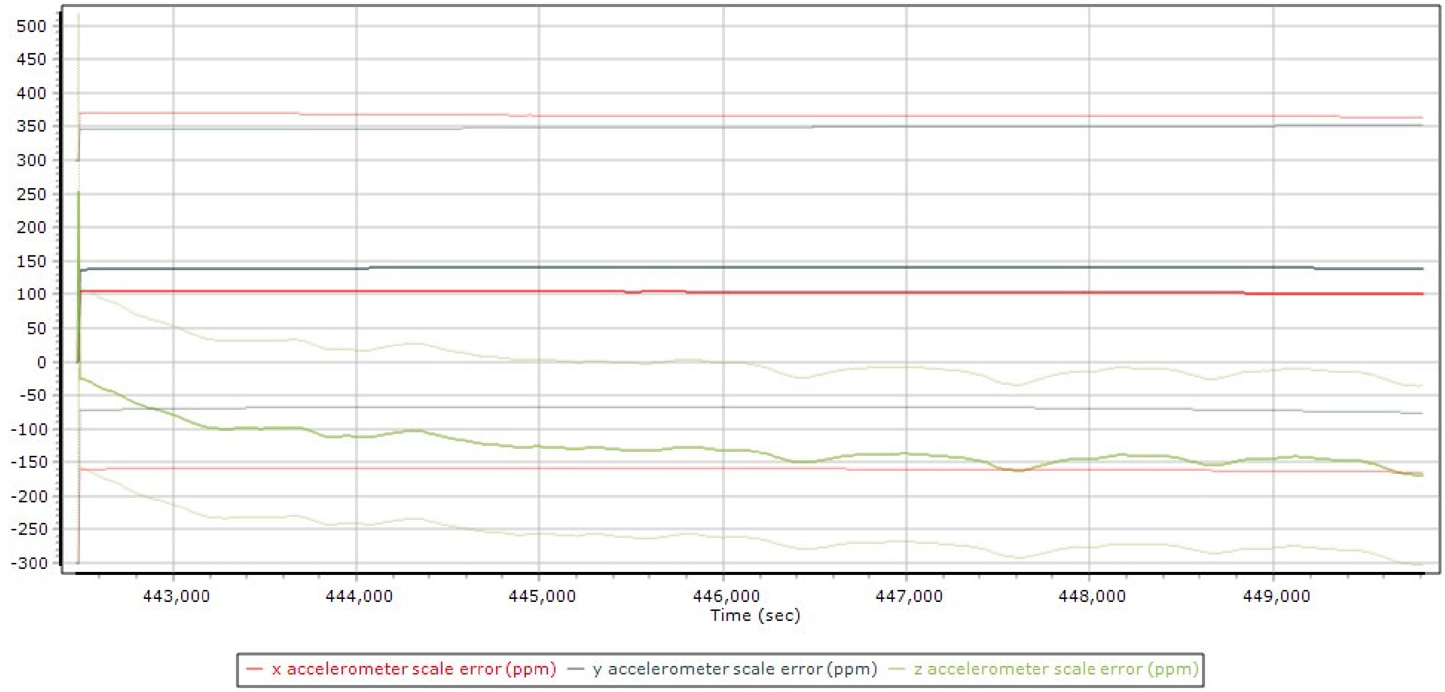
Number of Satellites (>6) Plots 23: Sortie a03-s02-0119



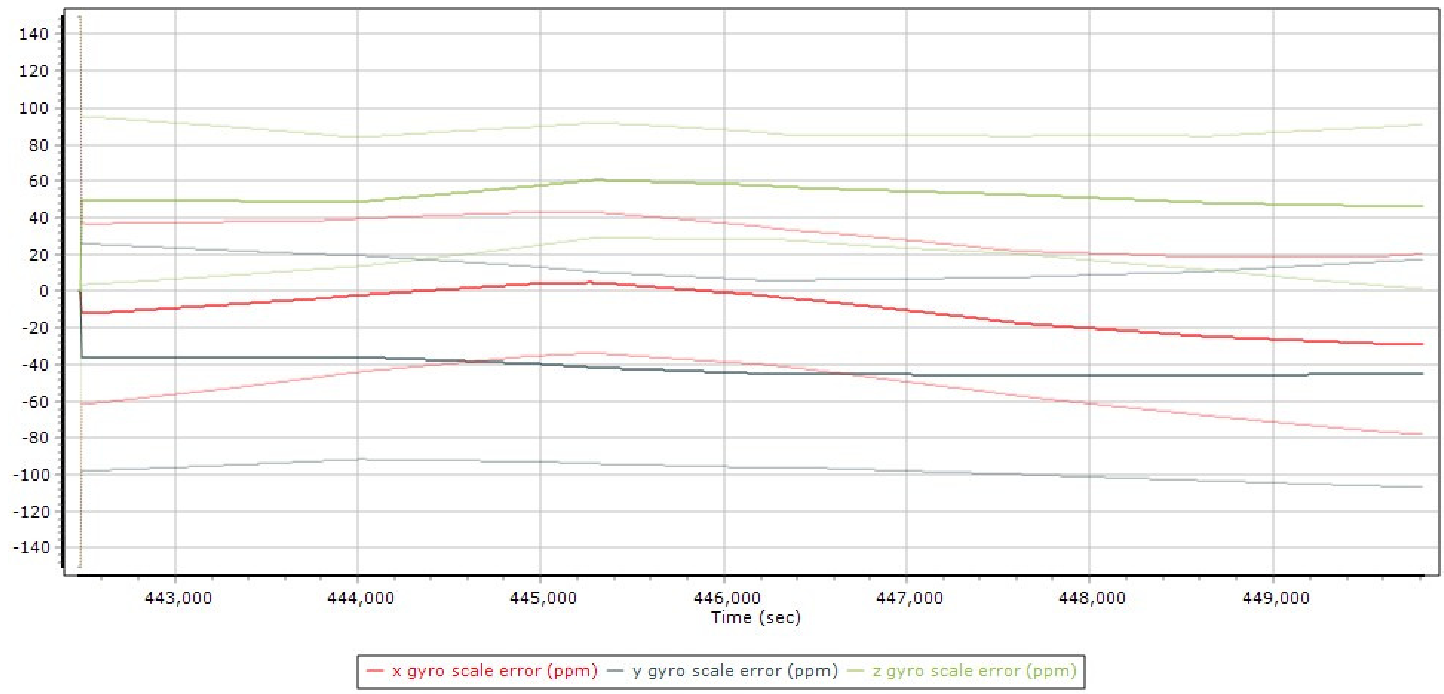
Sensor Position Error RMS (m) Plots 23: Sortie a03-s02-0119



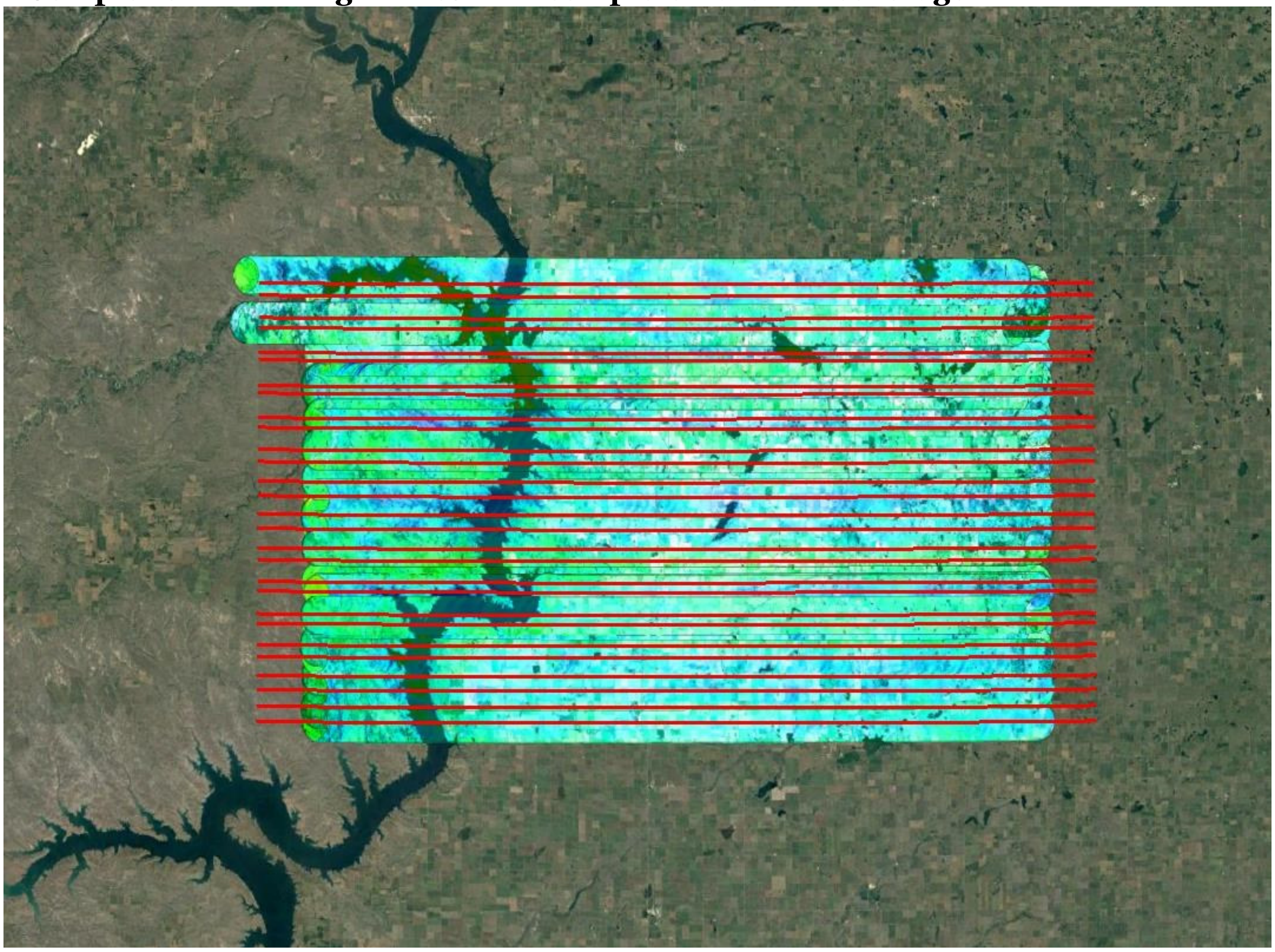
Accelerometer Scale Error (ppm) Plots 23: Sortie a03-s02-0119

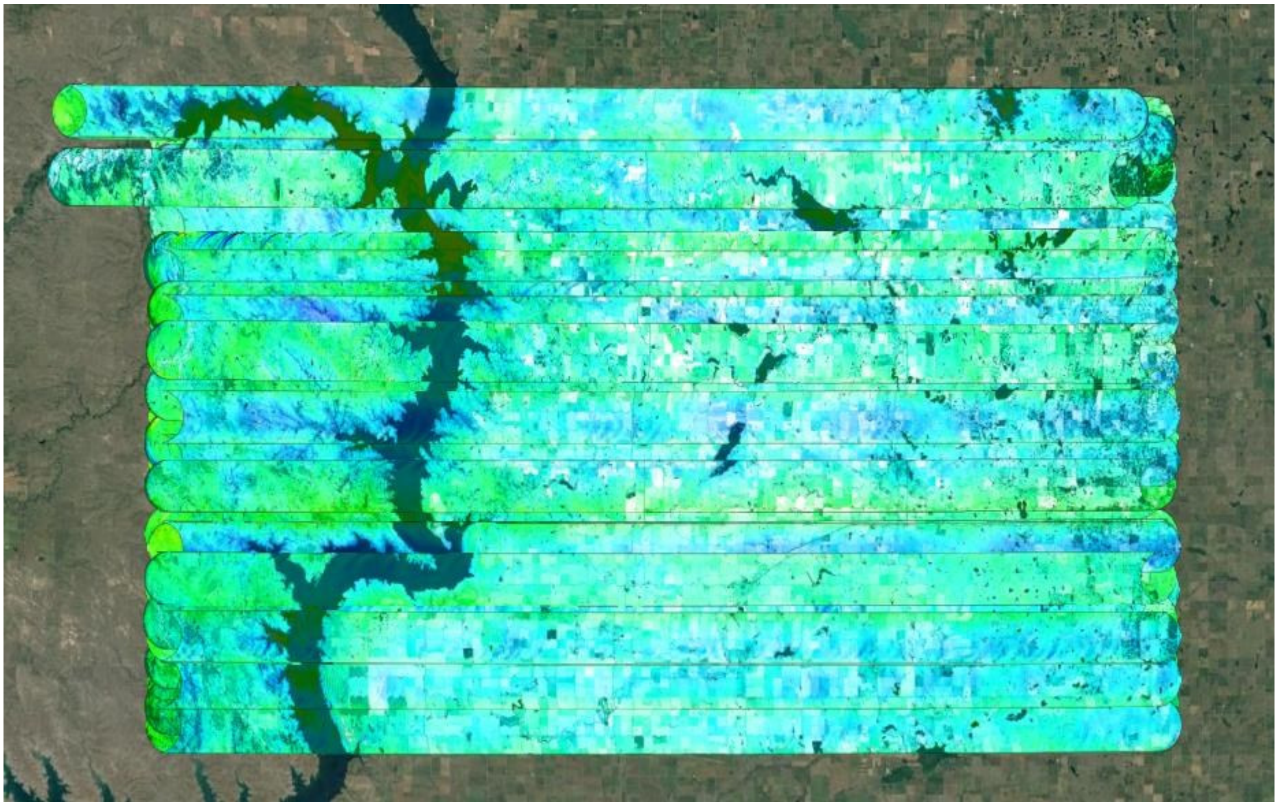


Gyro Scale Error (ppm) Plots 23: Sortie a03-s02-0119



Brick 2 Completion: **Flight lines with complete waterfall coverage**

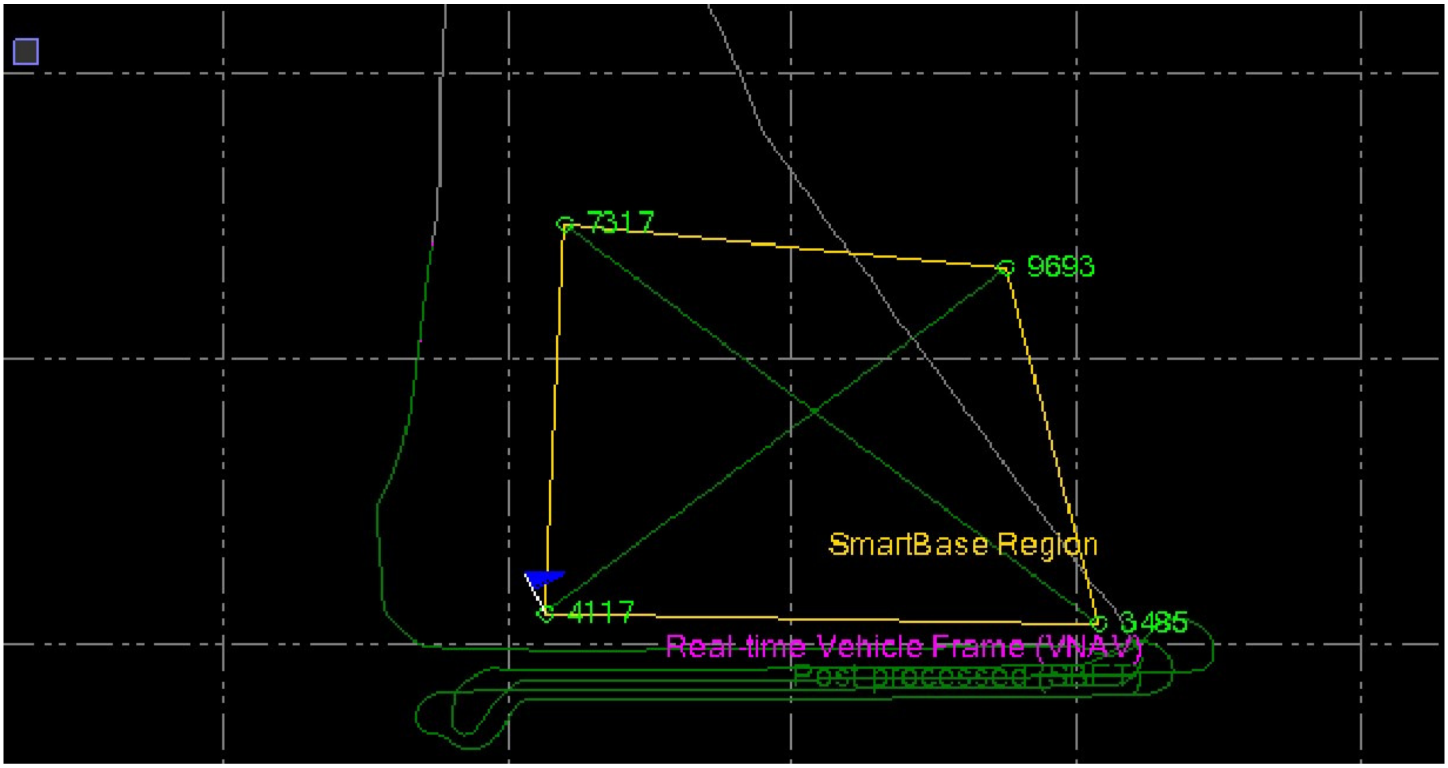




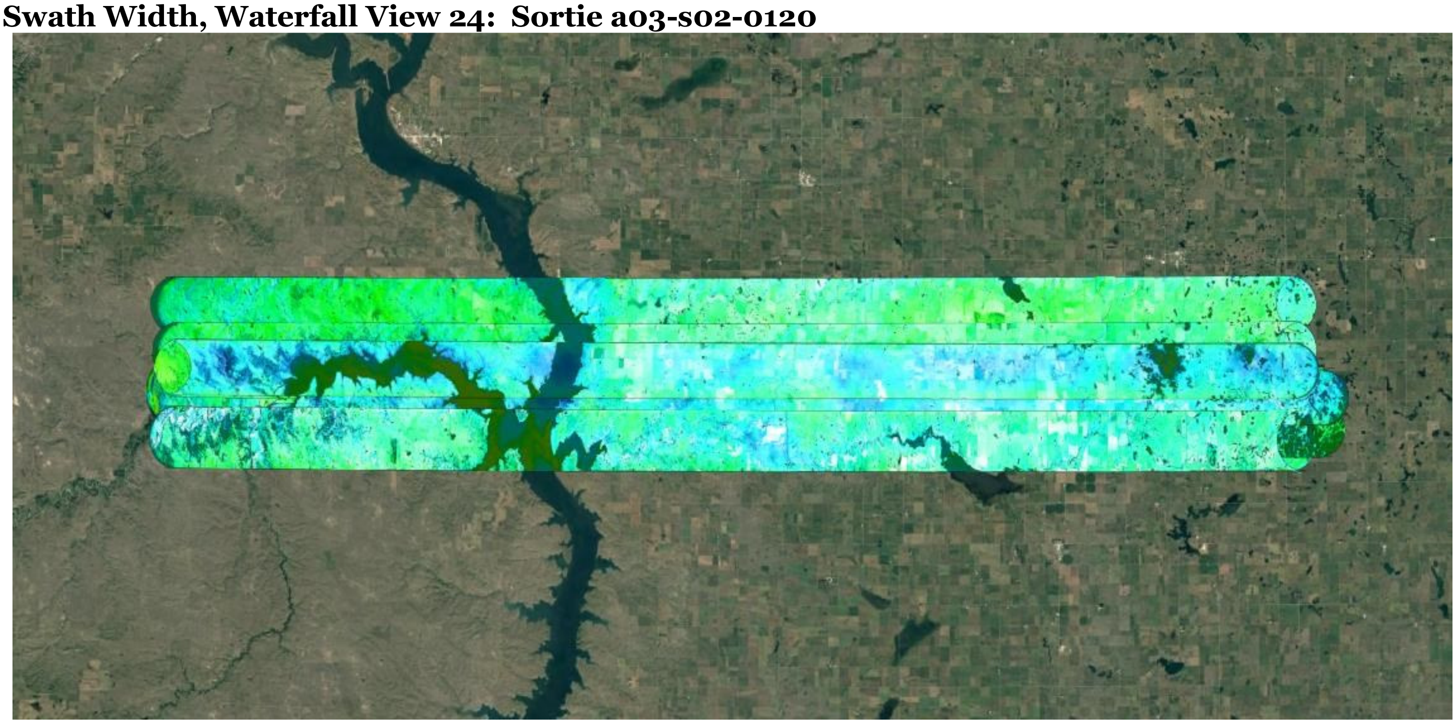
COLLECTION 24

Brick 1
Sortie a03-s02-0120
06/23/2016

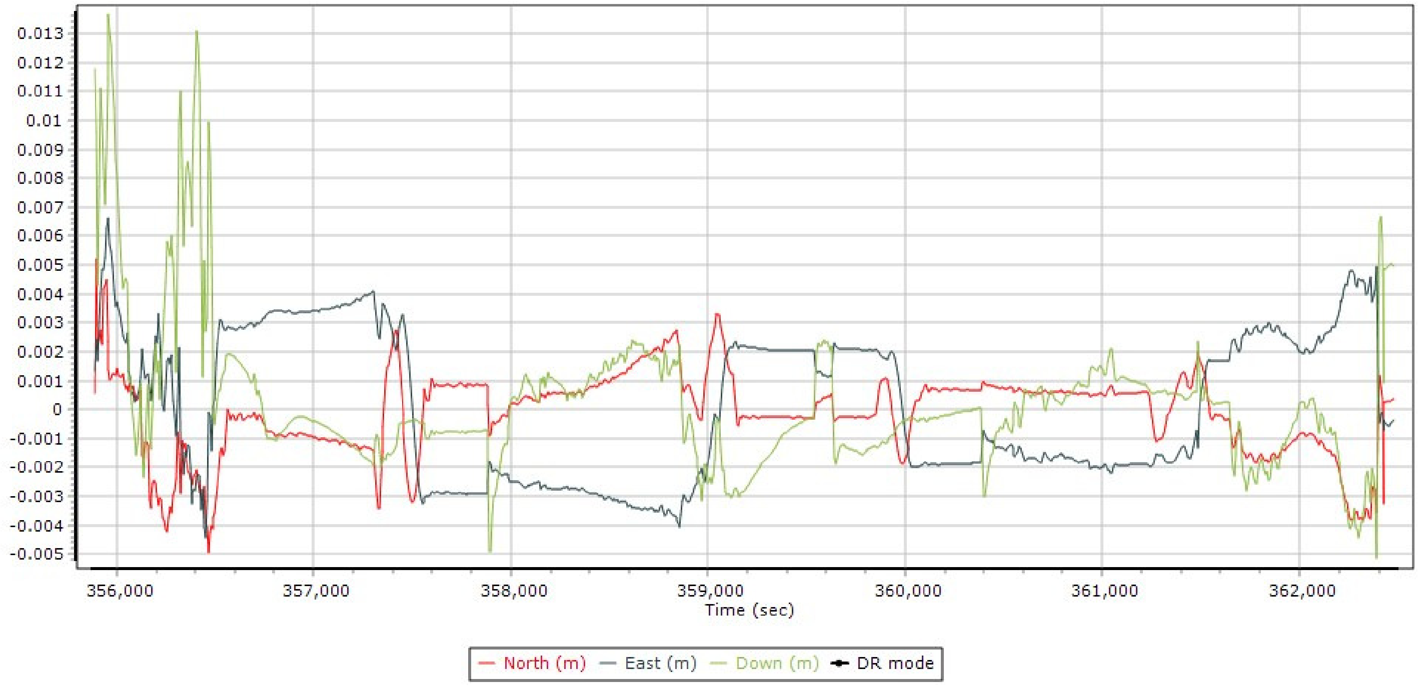
Map Run with Trajectory 24: Sortie a03-s02-0120



Swath Width, Waterfall View 24: Sortie a03-s02-0120

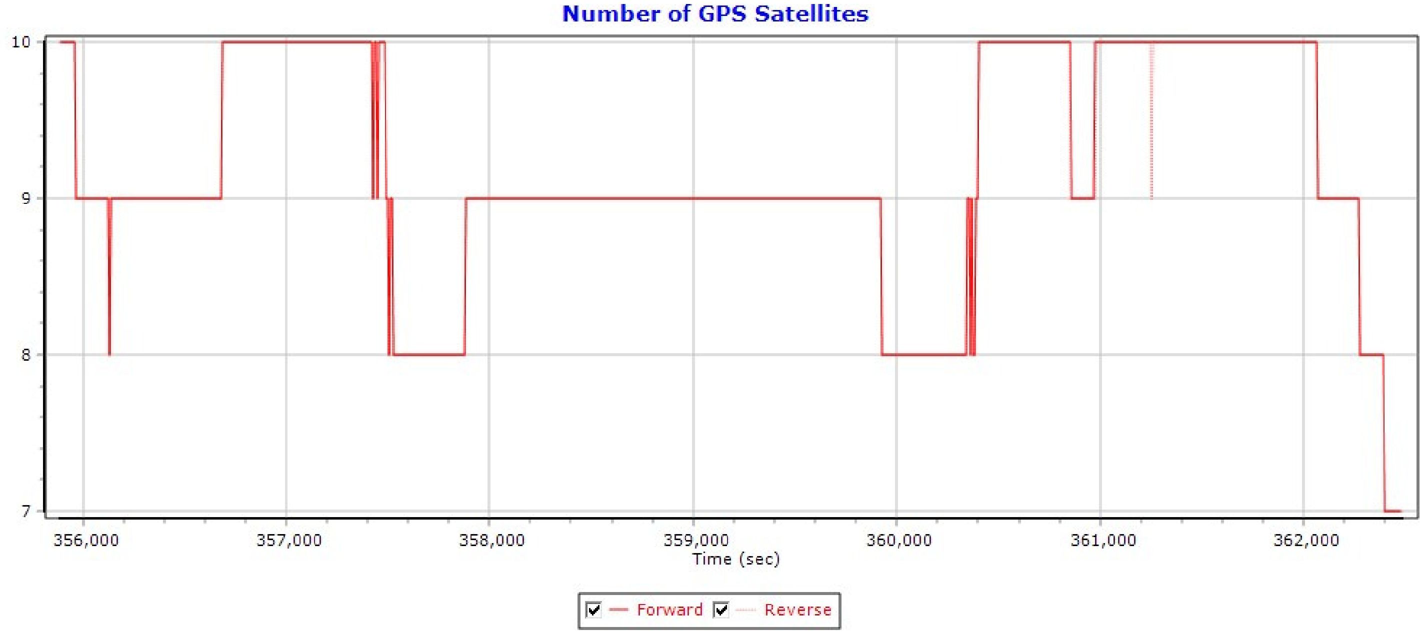


Combined SBET IAKAR Separation 24: Sortie a03-s02-0120

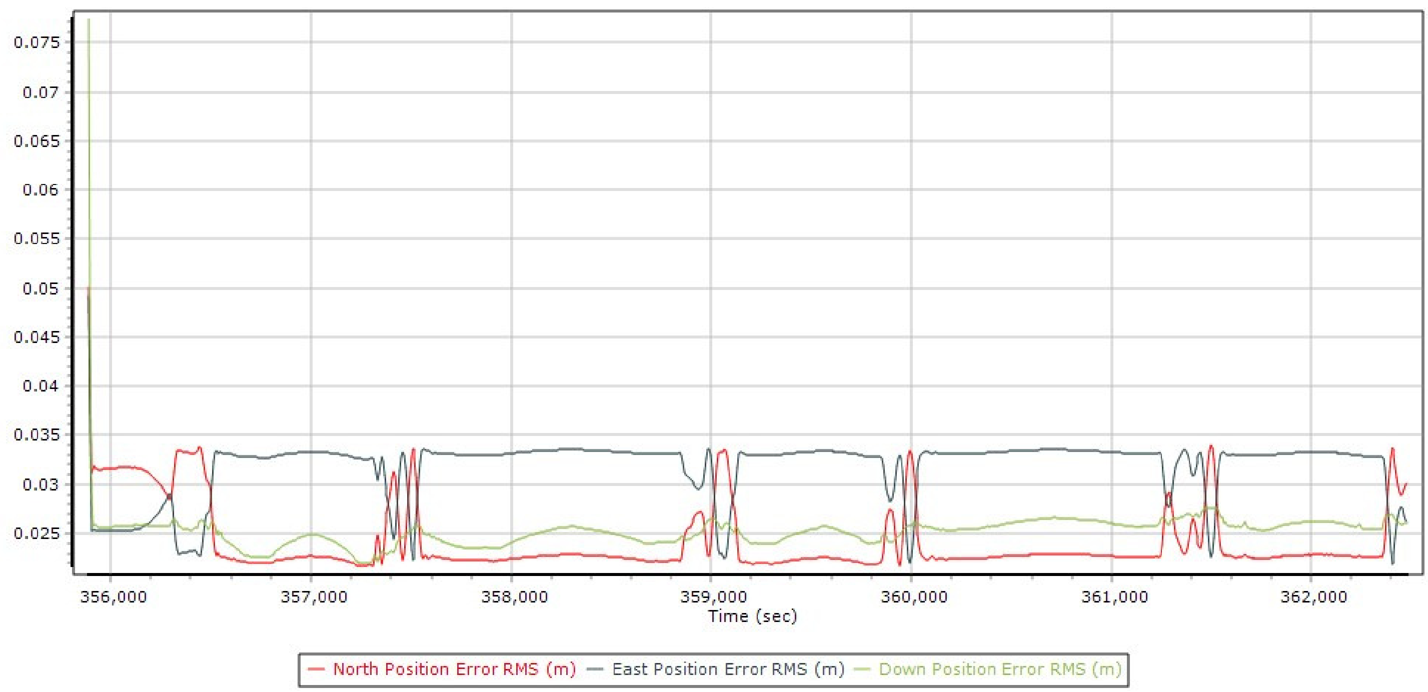


PDOP Plots 24: Sortie a03-s02-0120

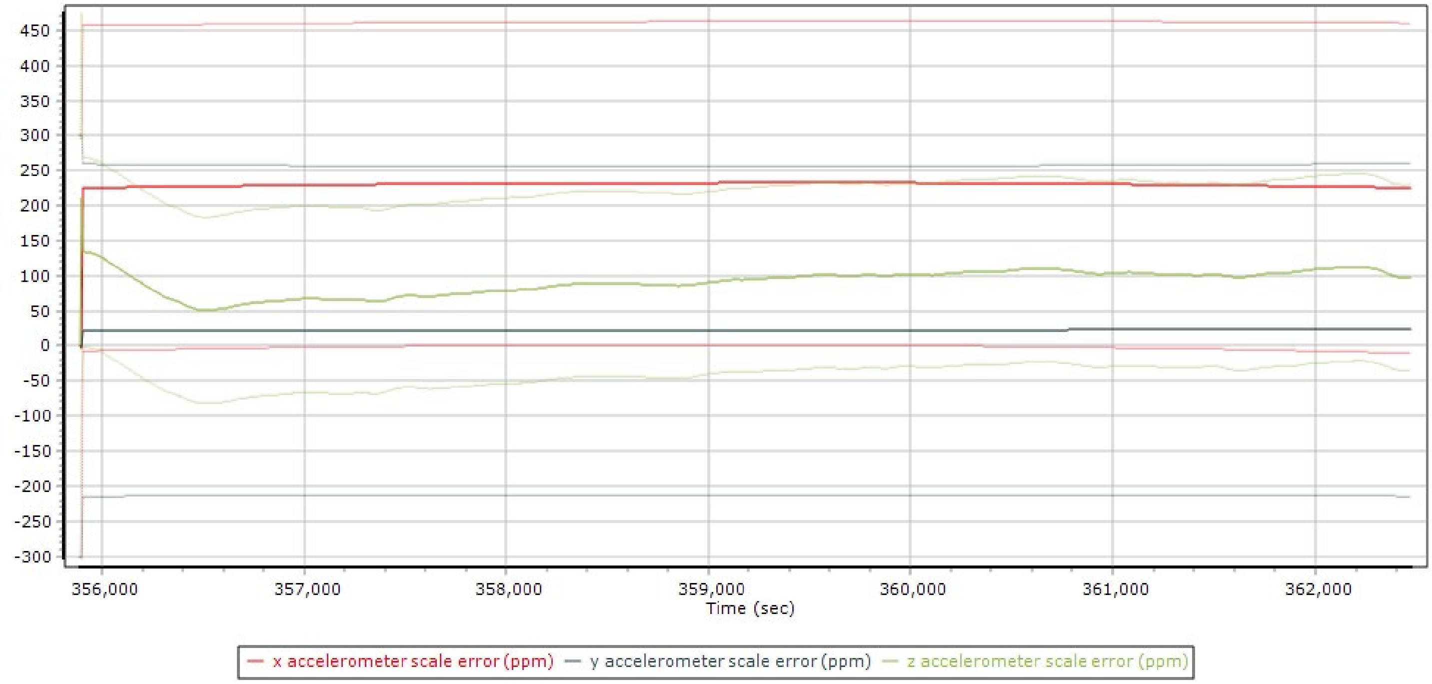
Number of Satellites (>6) Plots 24: Sortie a03-s02-0120



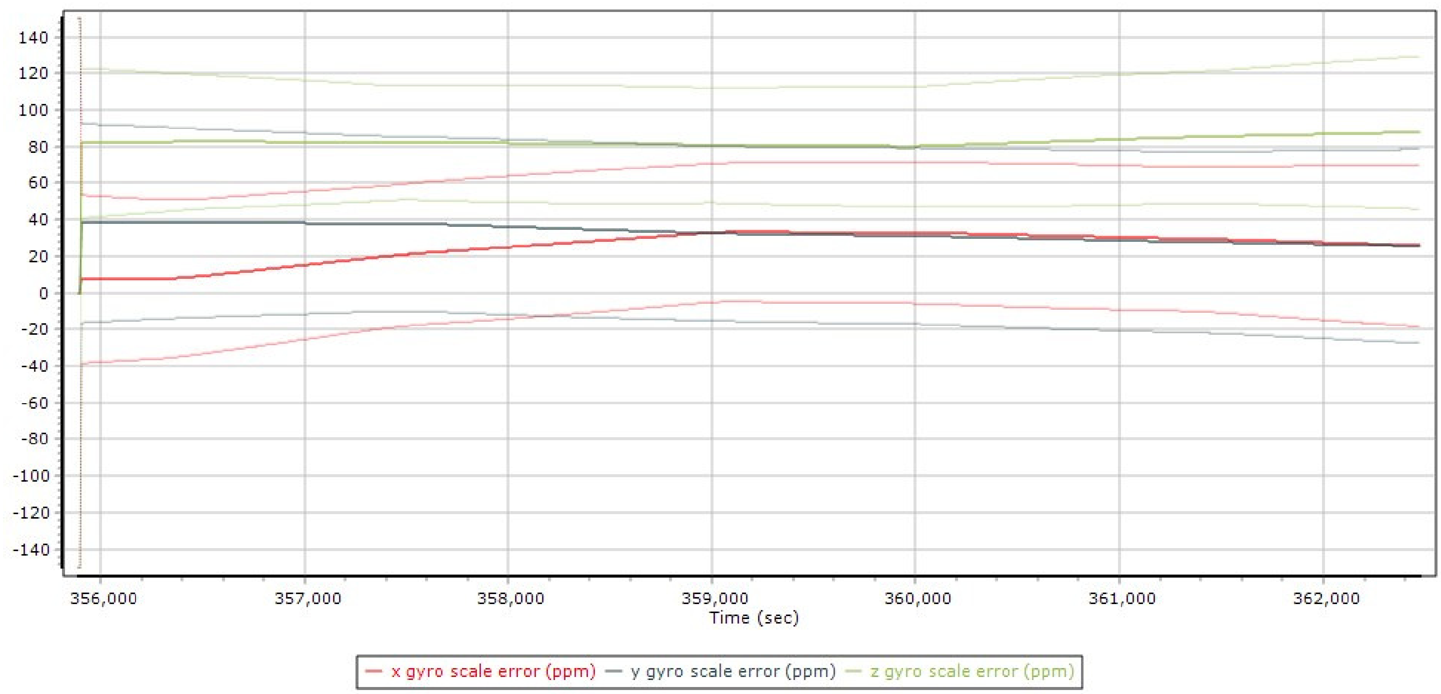
Sensor Position Error RMS (m) Plots 24: Sortie a03-s02-0120



Accelerometer Scale Error (ppm) Plots 24: Sortie a03-s02-0120



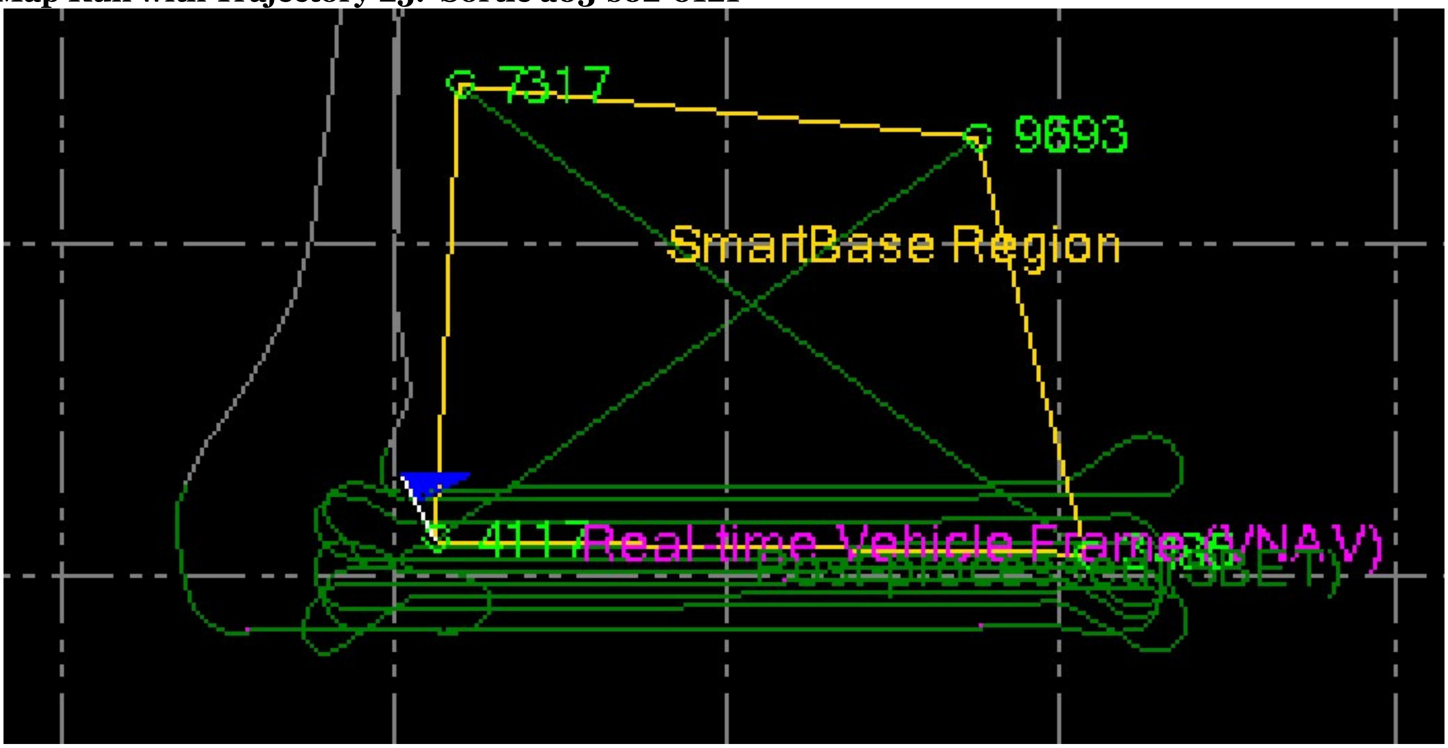
Gyro Scale Error (ppm) Plots 24: Sortie a03-s02-0120



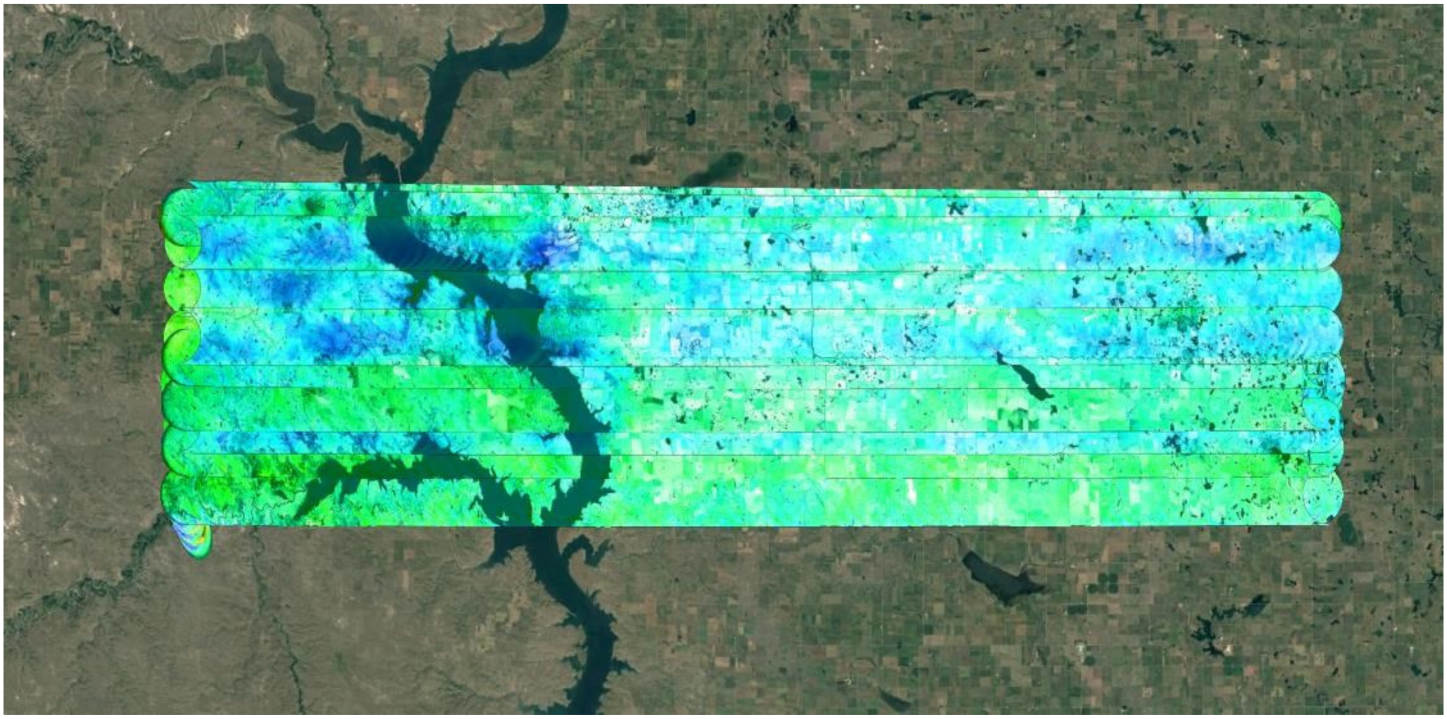
COLLECTION 25

Brick 1
Sortie a03-s02-0121
06/24/2016

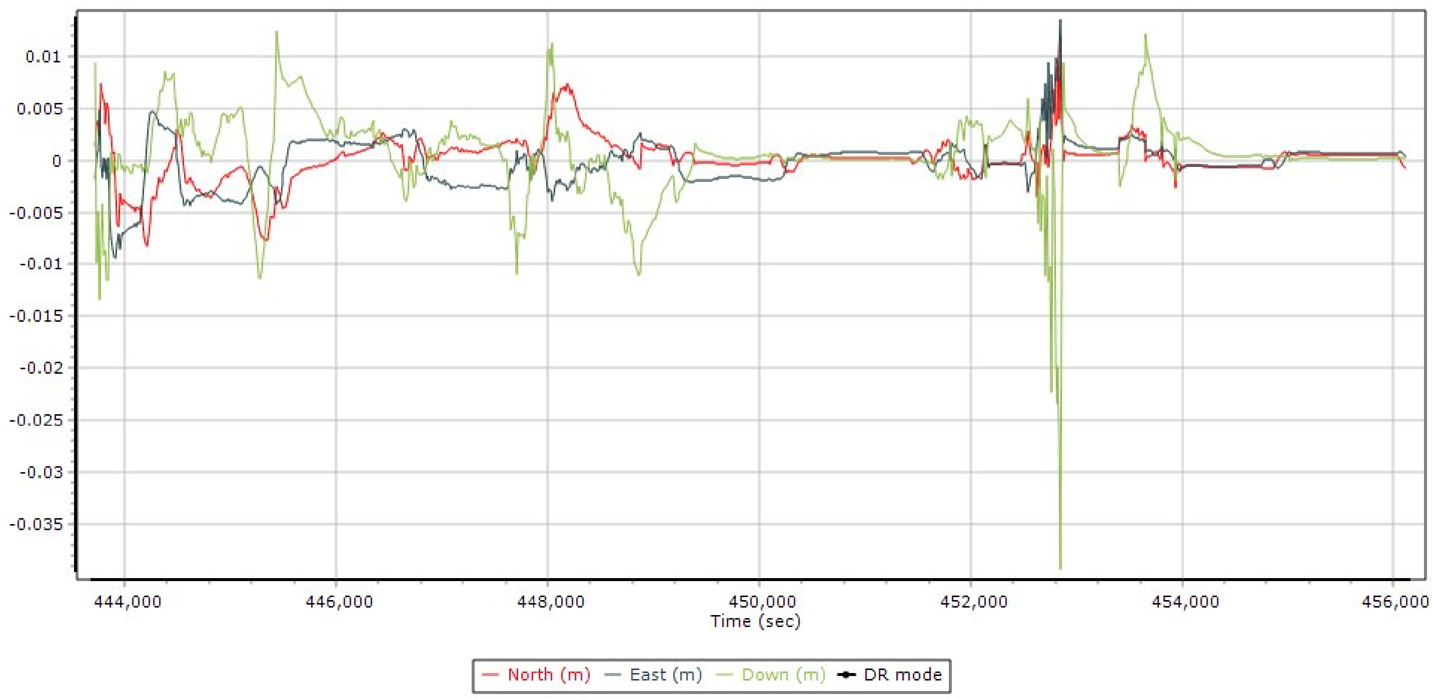
Map Run with Trajectory 25: Sortie a03-s02-0121



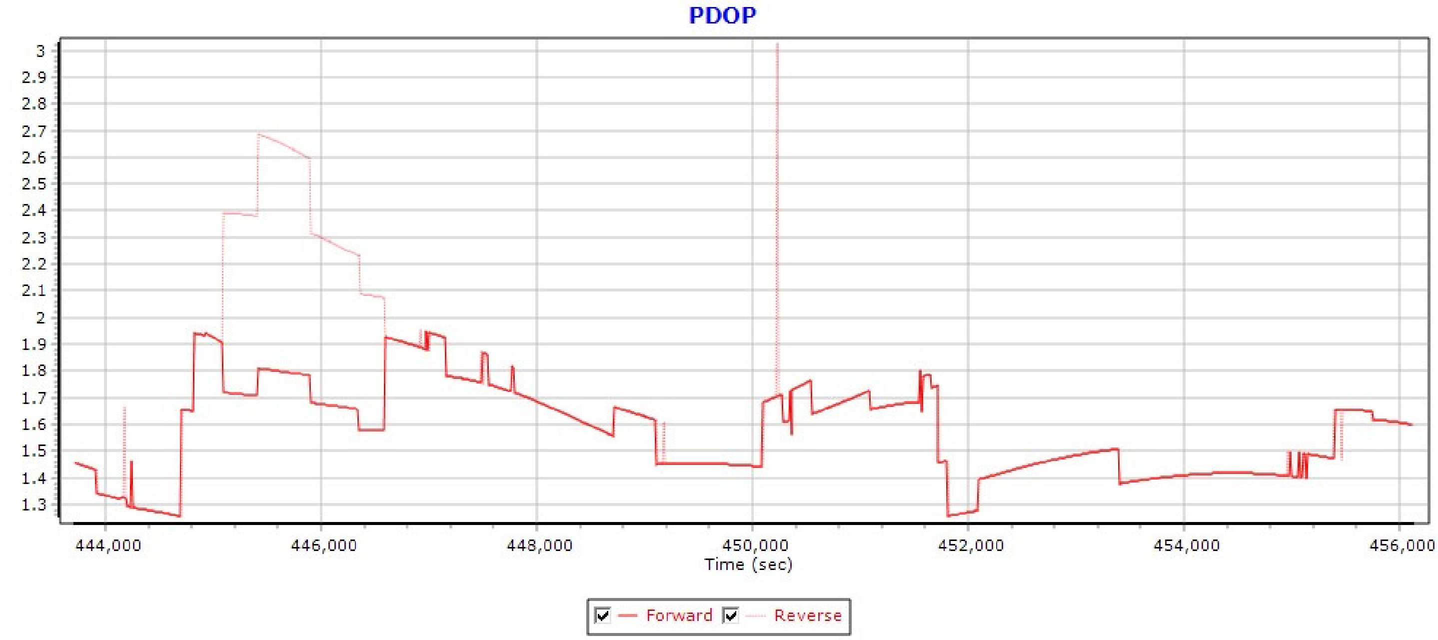
Swath Width, Waterfall View 25: Sortie a03-s02-0121



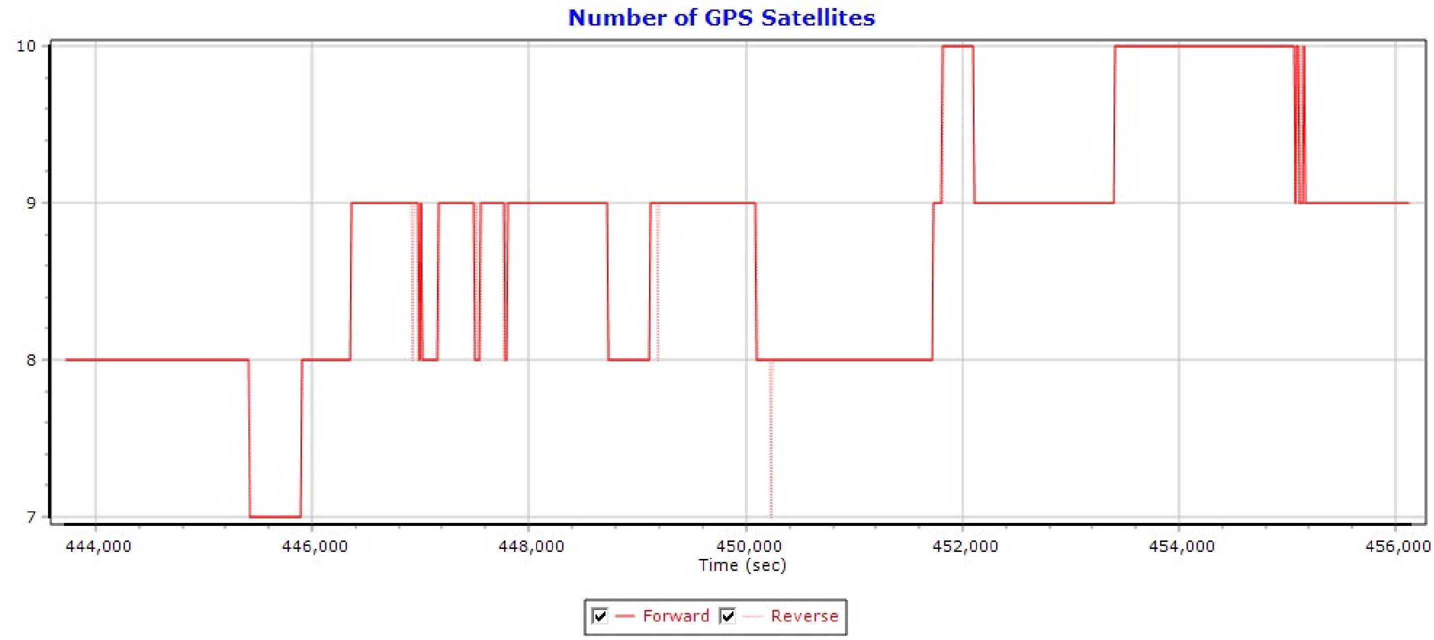
Combined SBET IAKAR Separation 25: Sortie a03-s02-0121



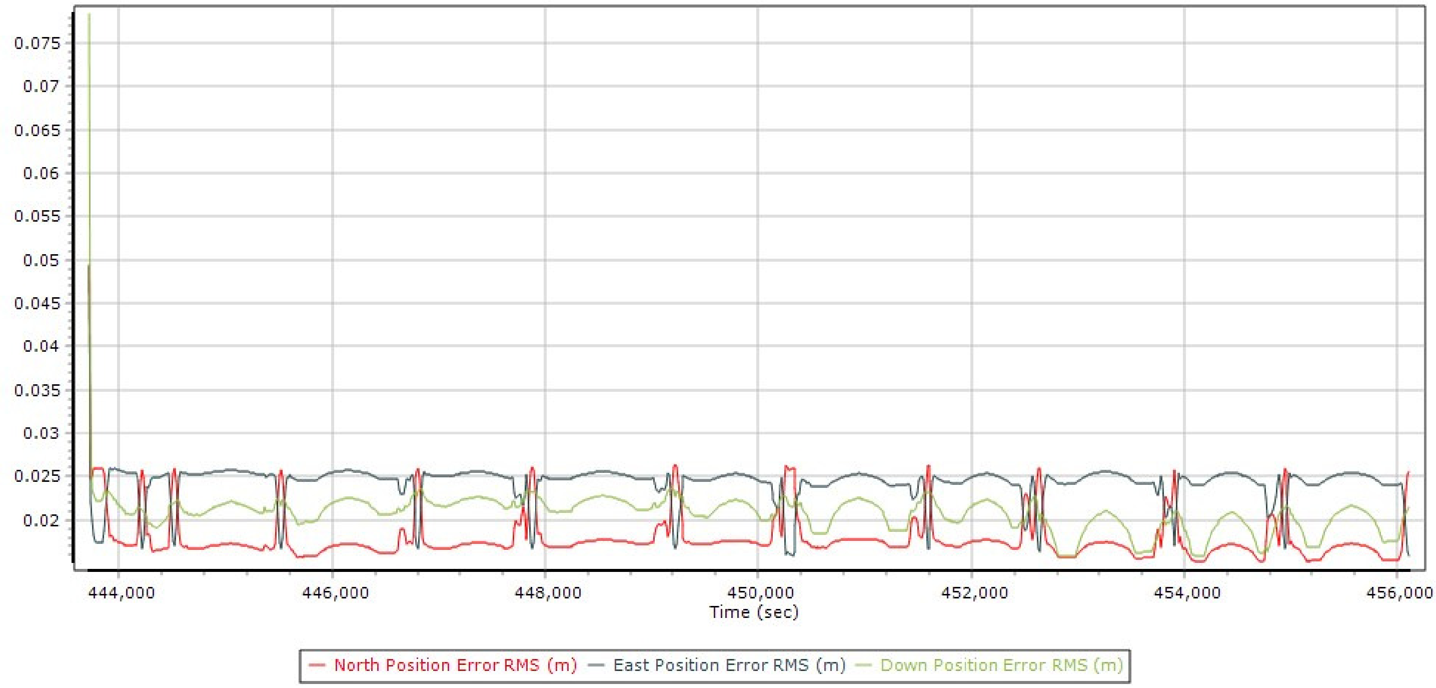
PDOP Plots 25: Sortie a03-s02-0121



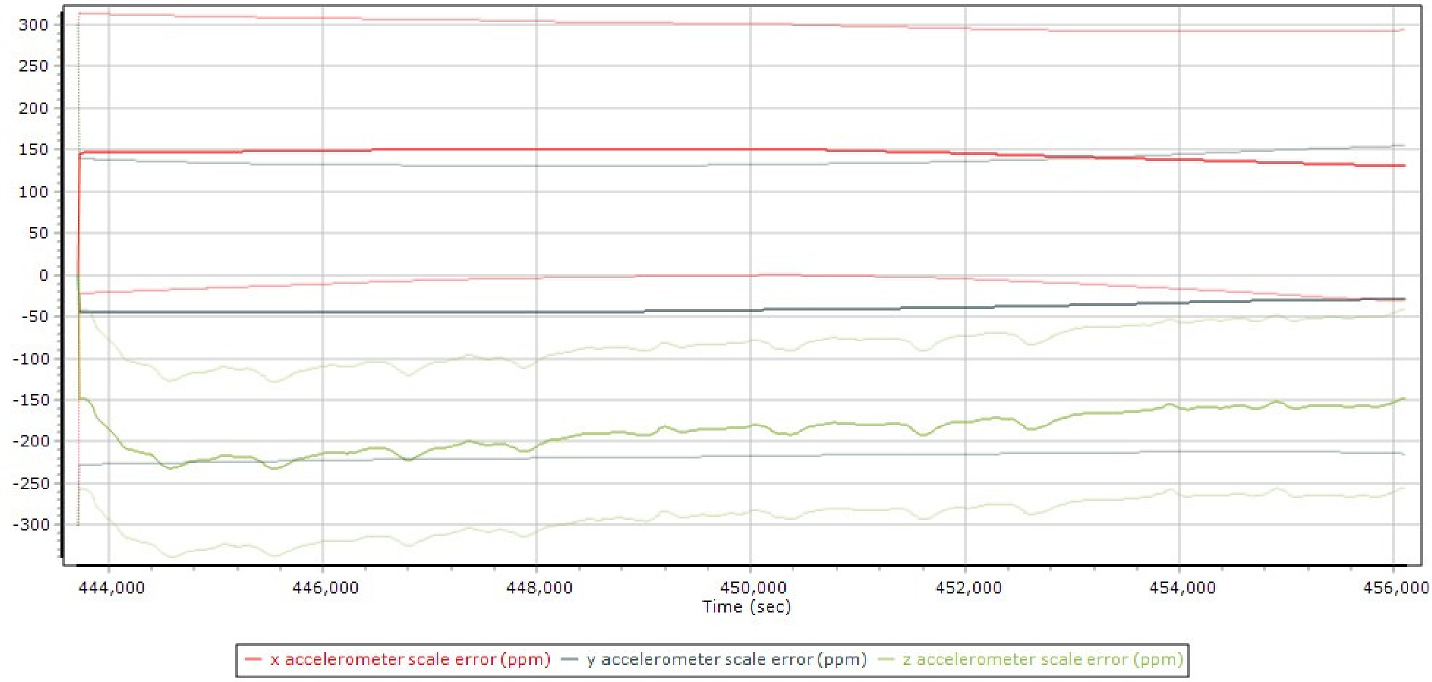
Number of Satellites (>6) Plots 25: Sortie a03-s02-0121



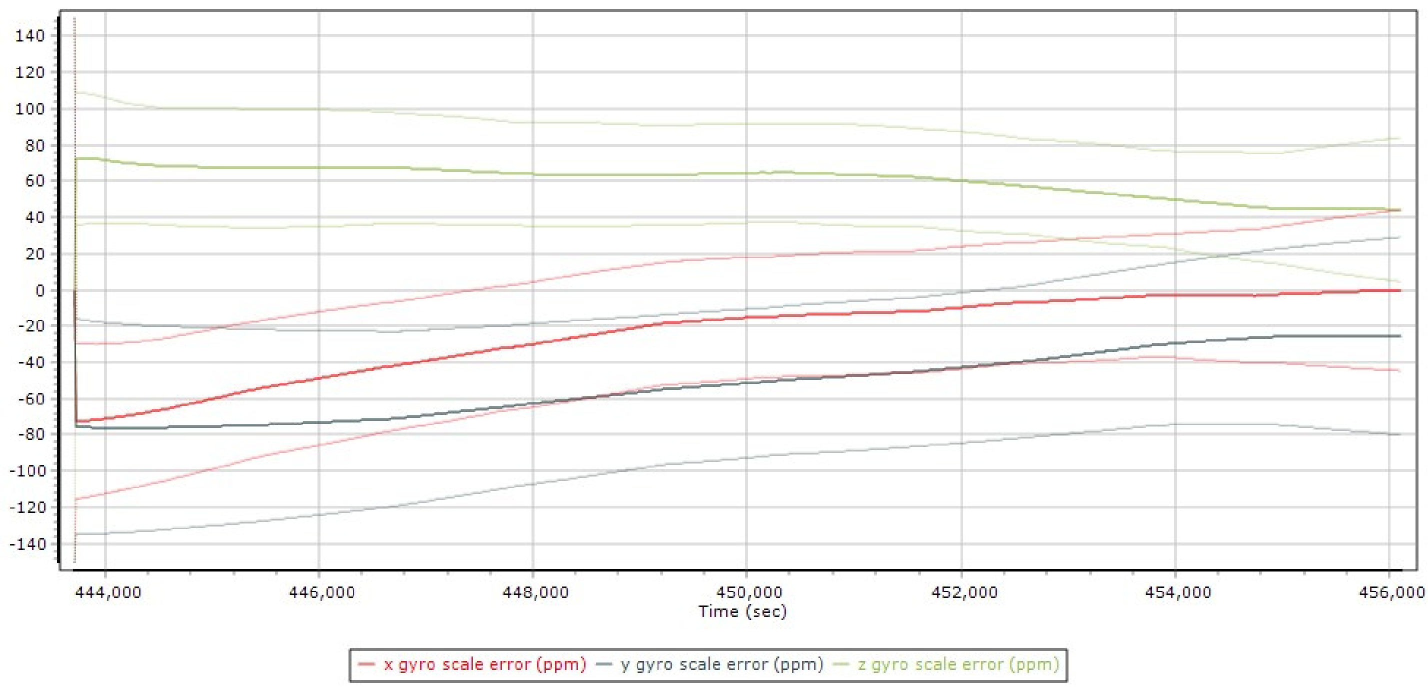
Sensor Position Error RMS (m) Plots 25: Sortie a03-s02-0121



Accelerometer Scale Error (ppm) Plots 25: Sortie a03-s02-0121



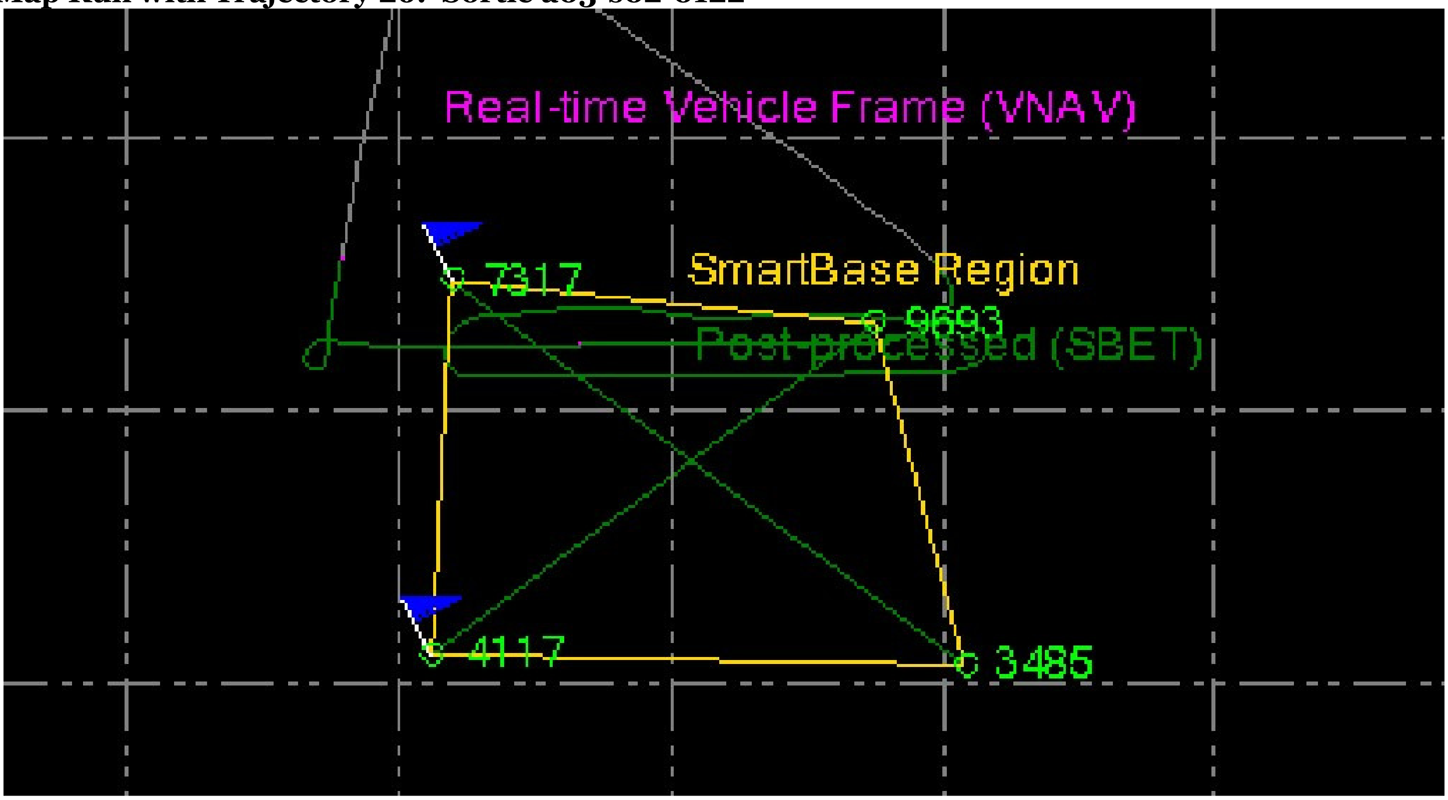
Gyro Scale Error (ppm) Plots 25: Sortie a03-s02-0121



COLLECTION 26

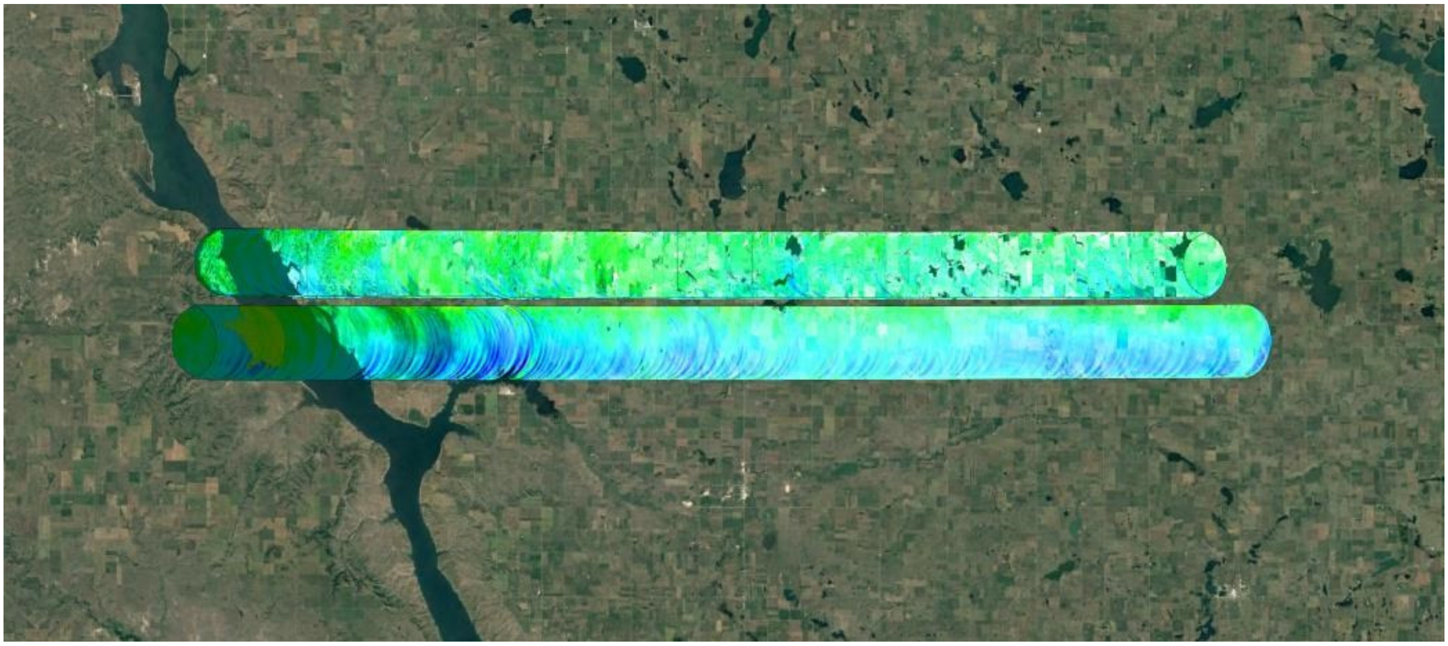
Brick 1
Sortie a03-s02-0122
06/25/2016

Map Run with Trajectory 26: Sortie a03-s02-0122

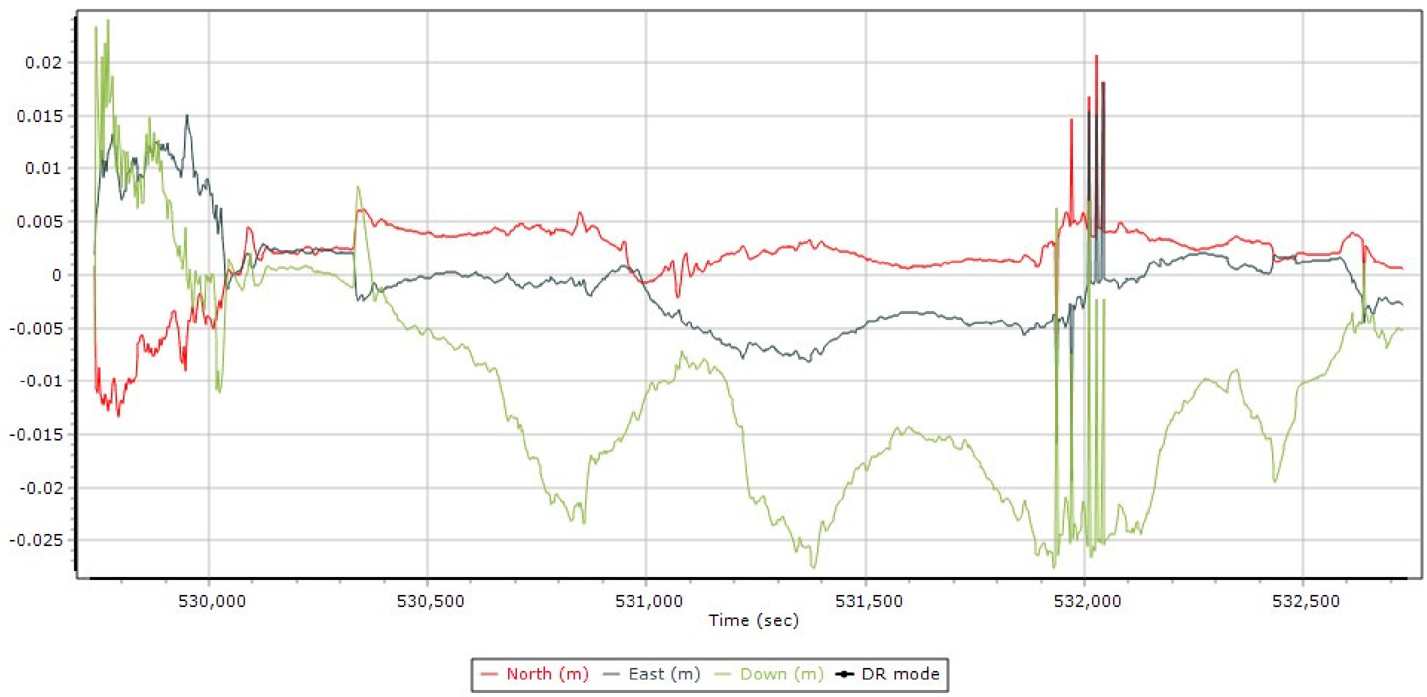


Swath Width, Waterfall View 26: Sortie a03-s02-0122

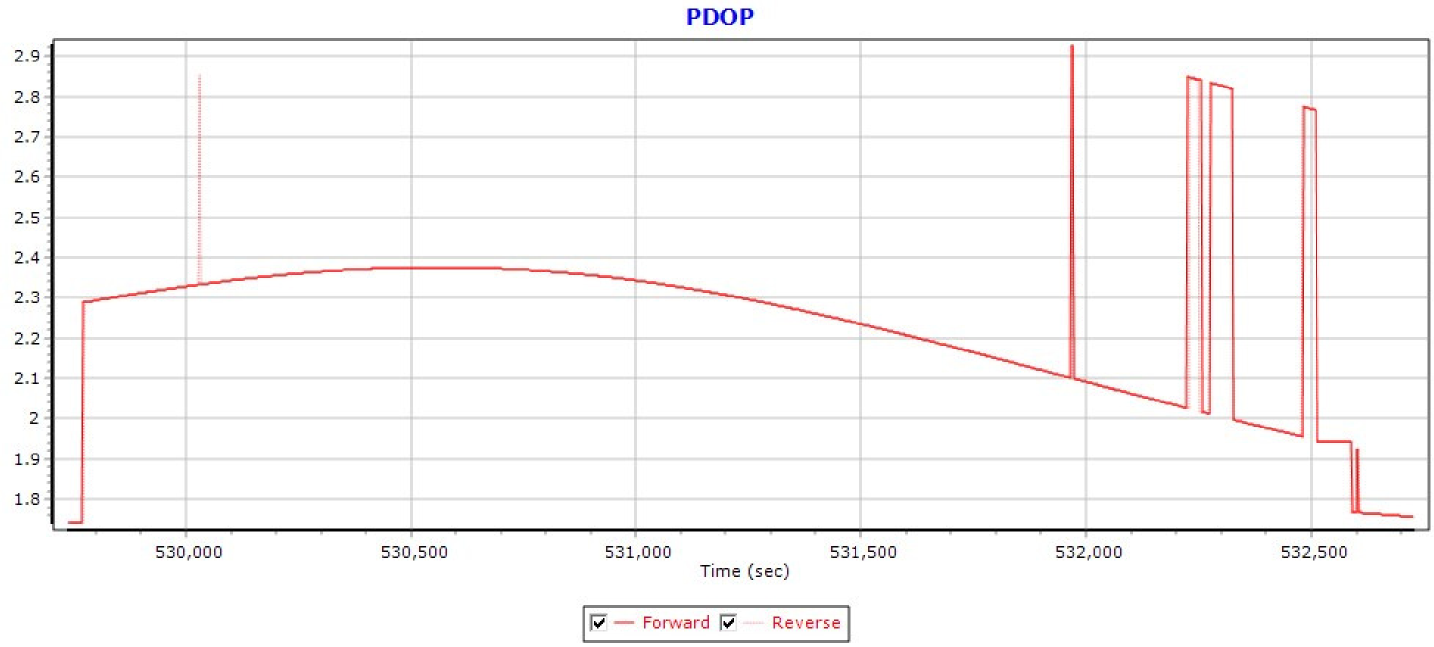
Mission discontinued after 2nd collection line was disrupted by cloud cover.



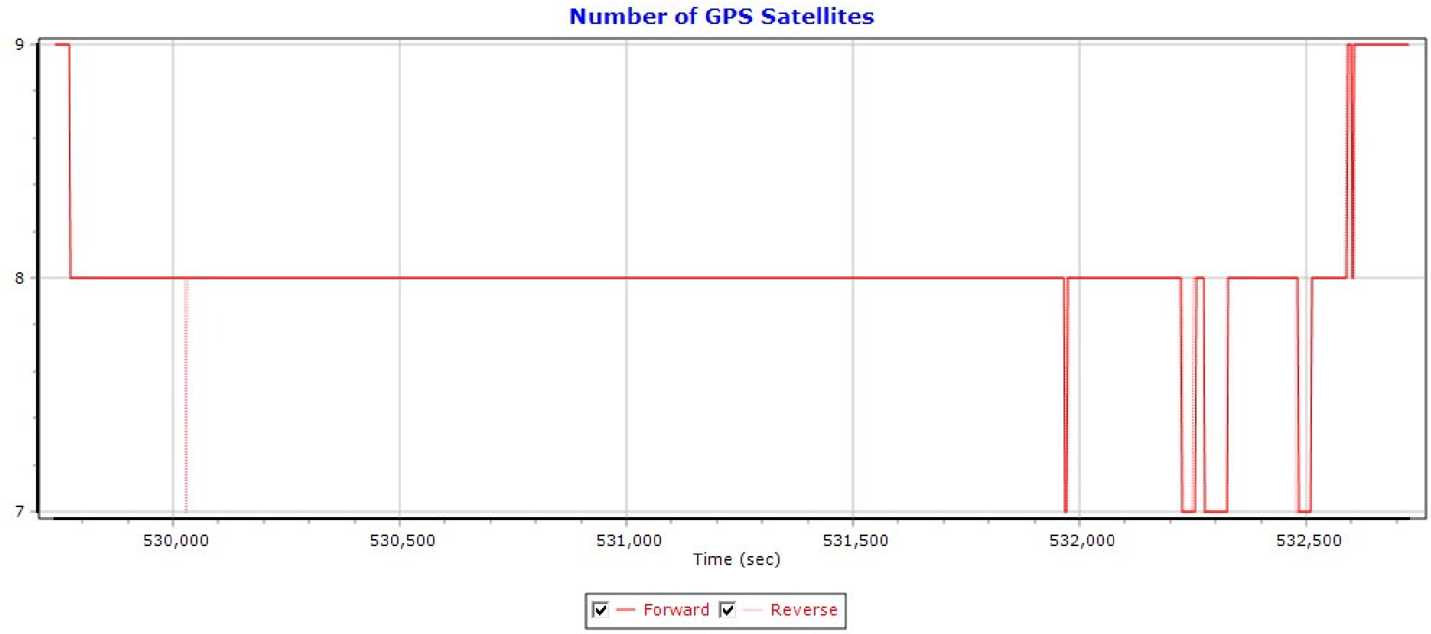
Combined SBET IAKAR Separation 26: Sortie a03-s02-0122



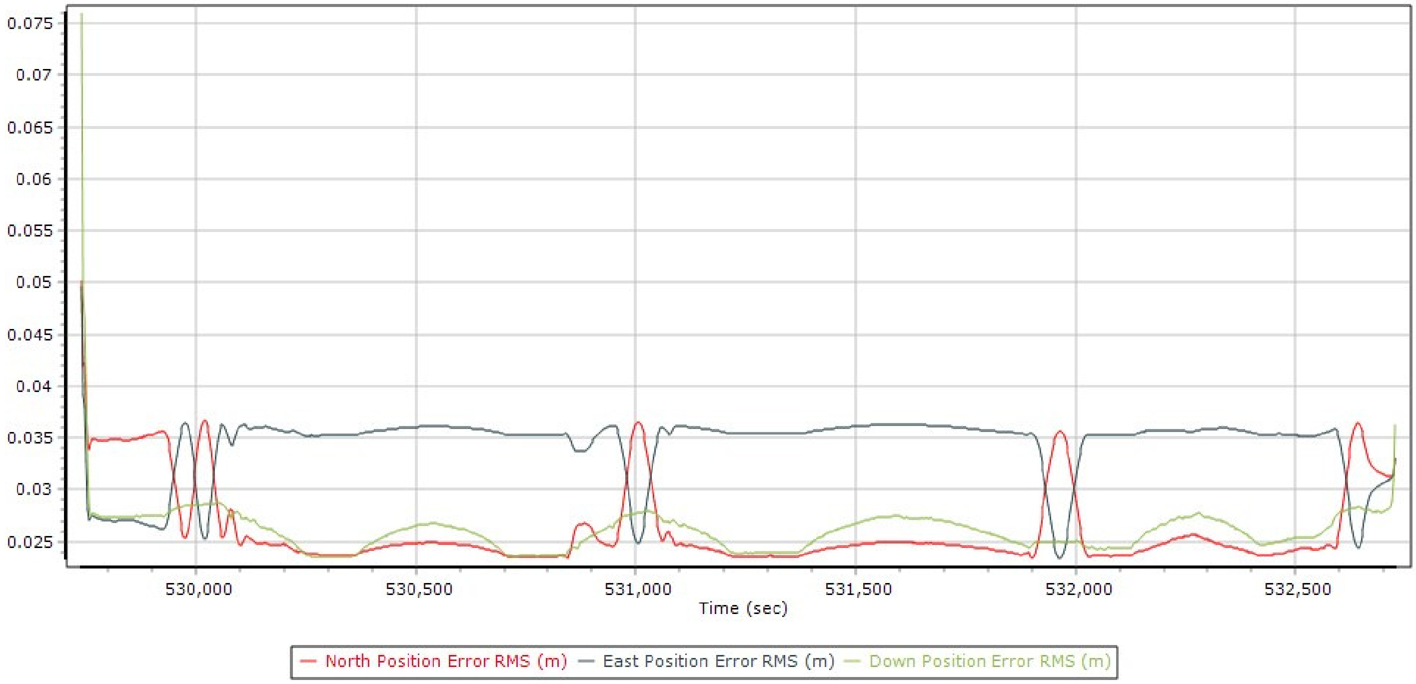
PDOP Plots 26: Sortie a03-s02-0122



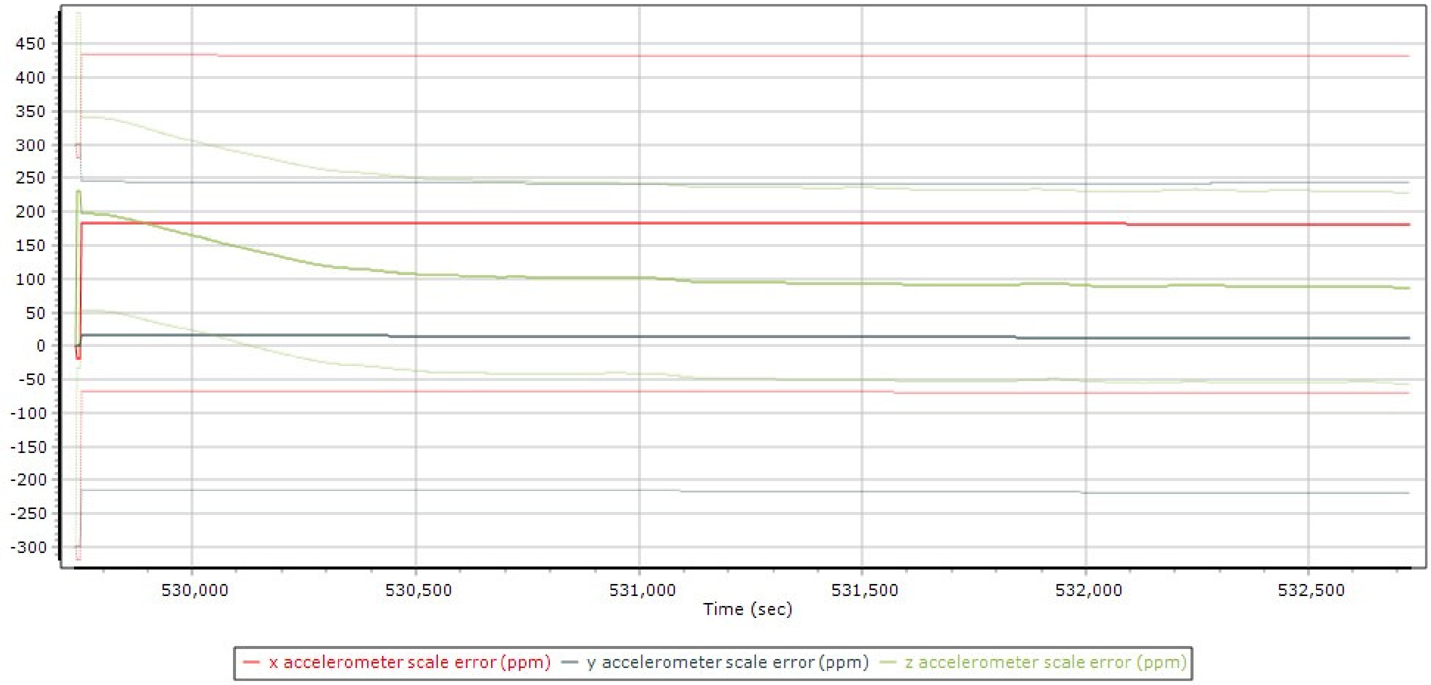
Number of Satellites (>6) Plots 26: Sortie a03-s02-0122



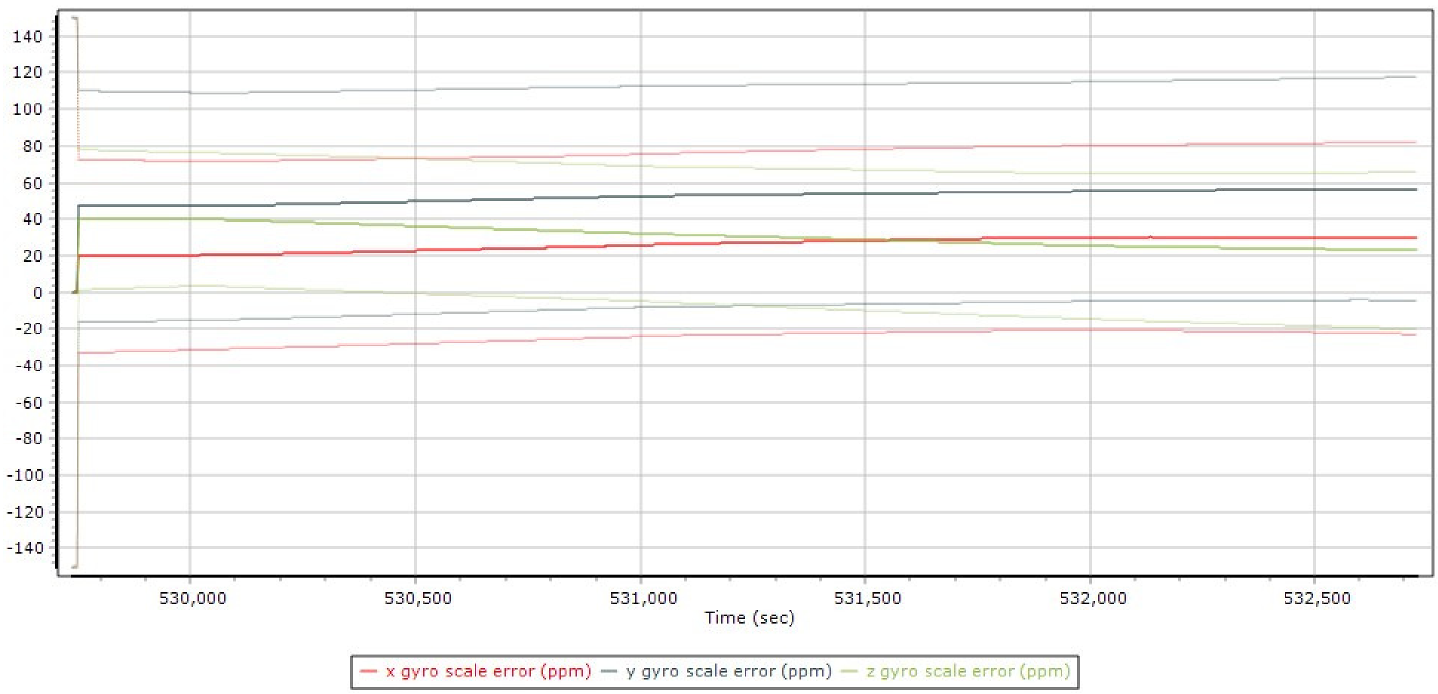
Sensor Position Error RMS (m) Plots 26: Sortie a03-s02-0122



Accelerometer Scale Error (ppm) Plots 26: Sortie a03-s02-0122



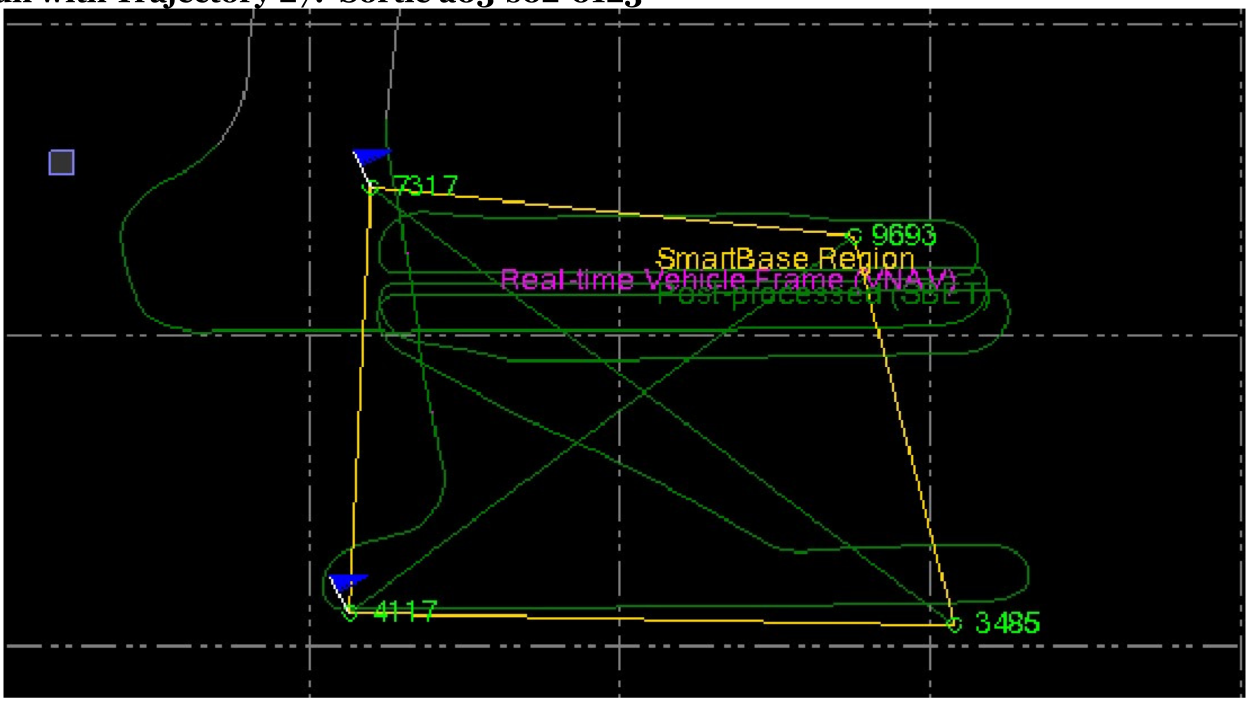
Gyro Scale Error (ppm) Plots 26: Sortie a03-s02-0122



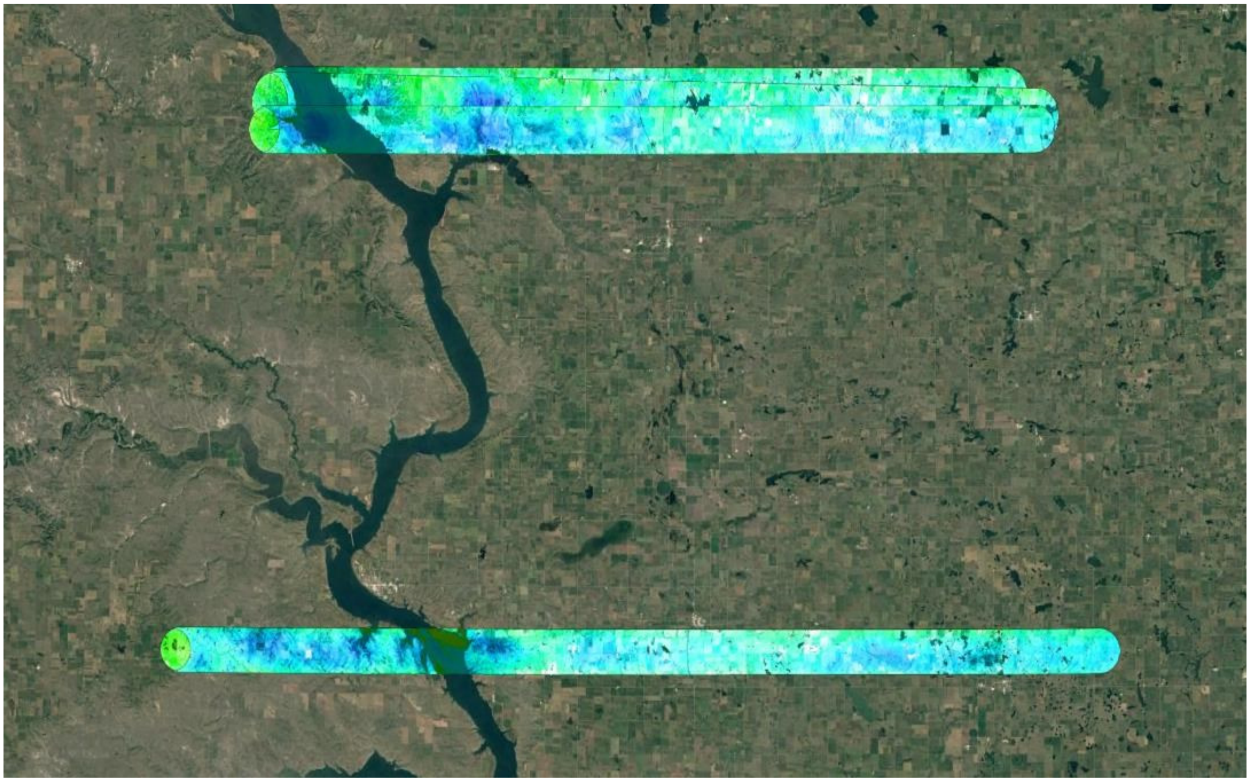
COLLECTION 27

Brick 1
Sortie a03-s02-0123
06/26/2016

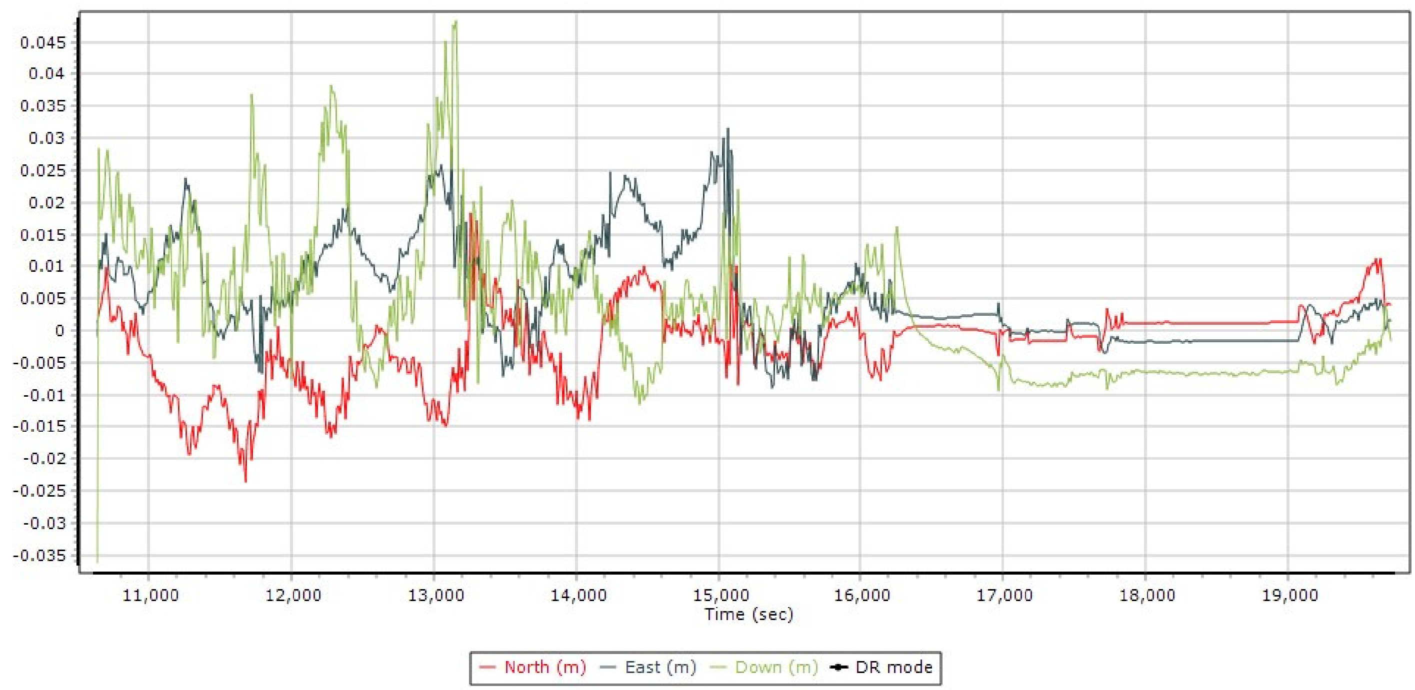
Map Run with Trajectory 27: Sortie a03-s02-0123



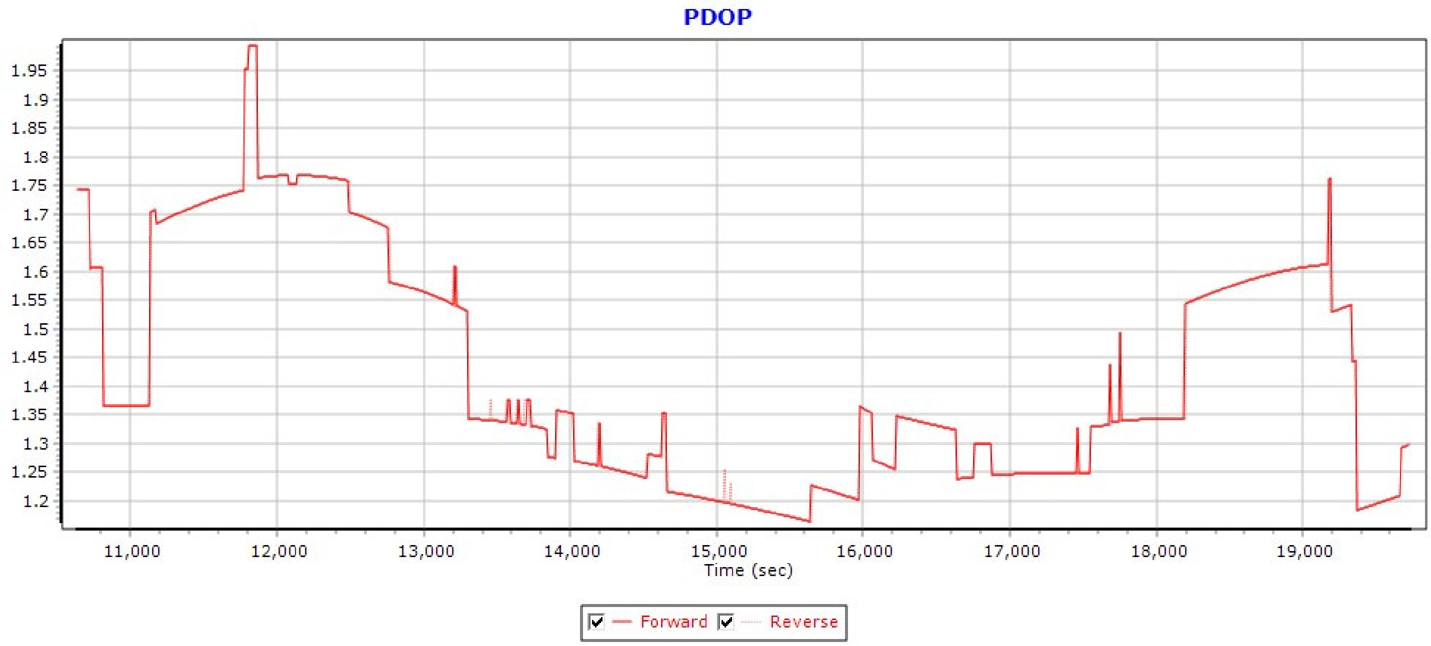
Swath Width, Waterfall View 27: Sortie a03-s02-0123



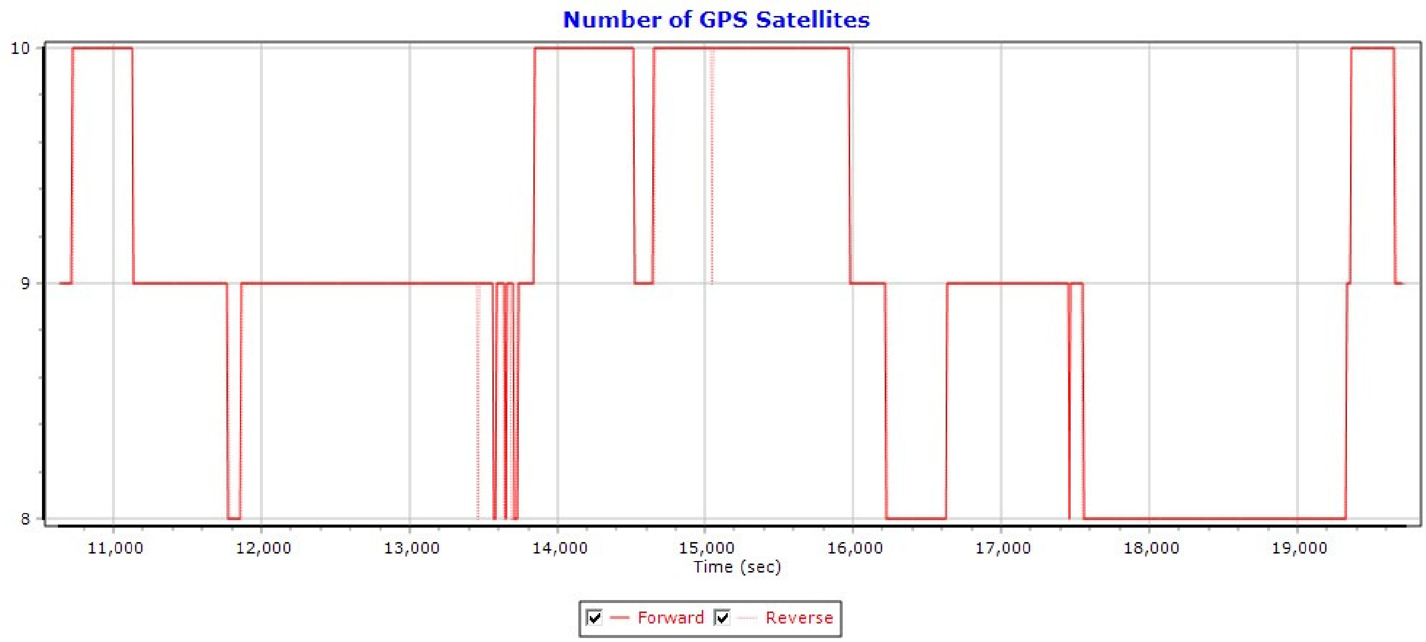
Combined SBET IAKAR Separation 27: Sortie a03-s02-0123



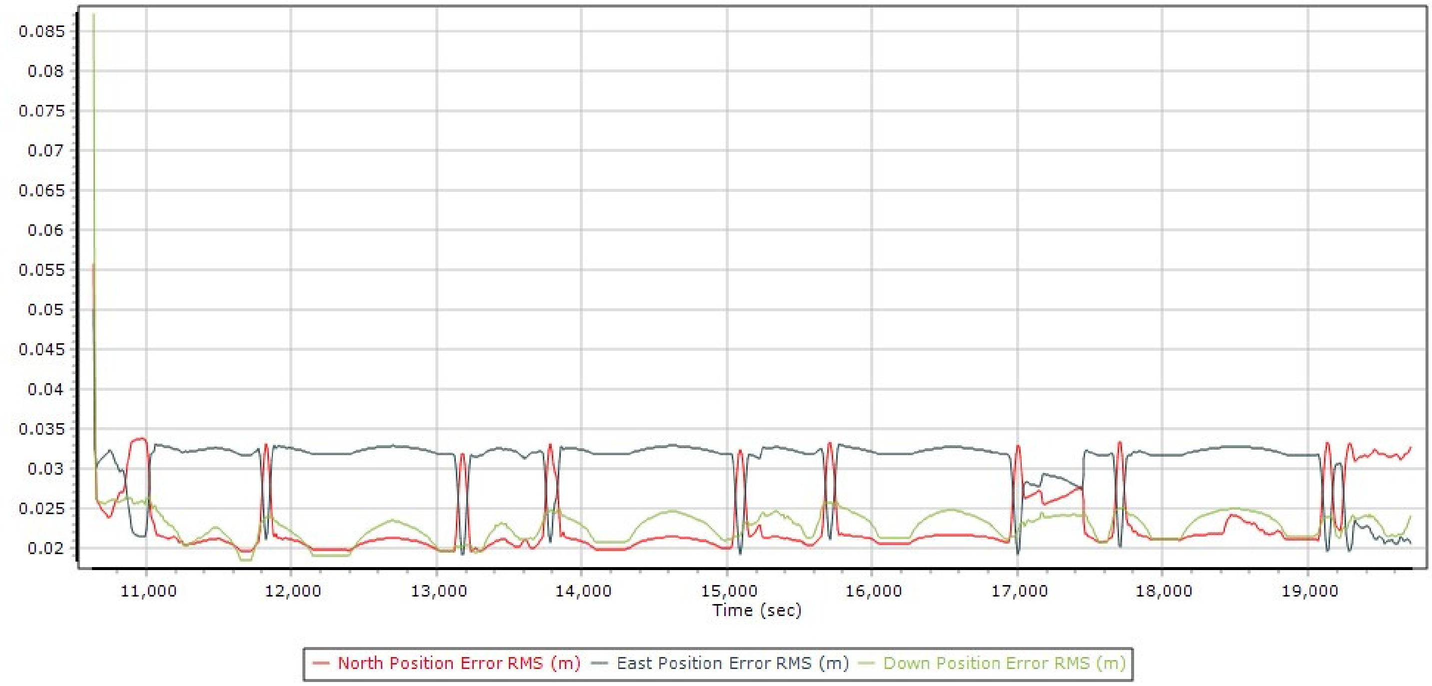
PDOP Plots 27: Sortie a03-s02-0123



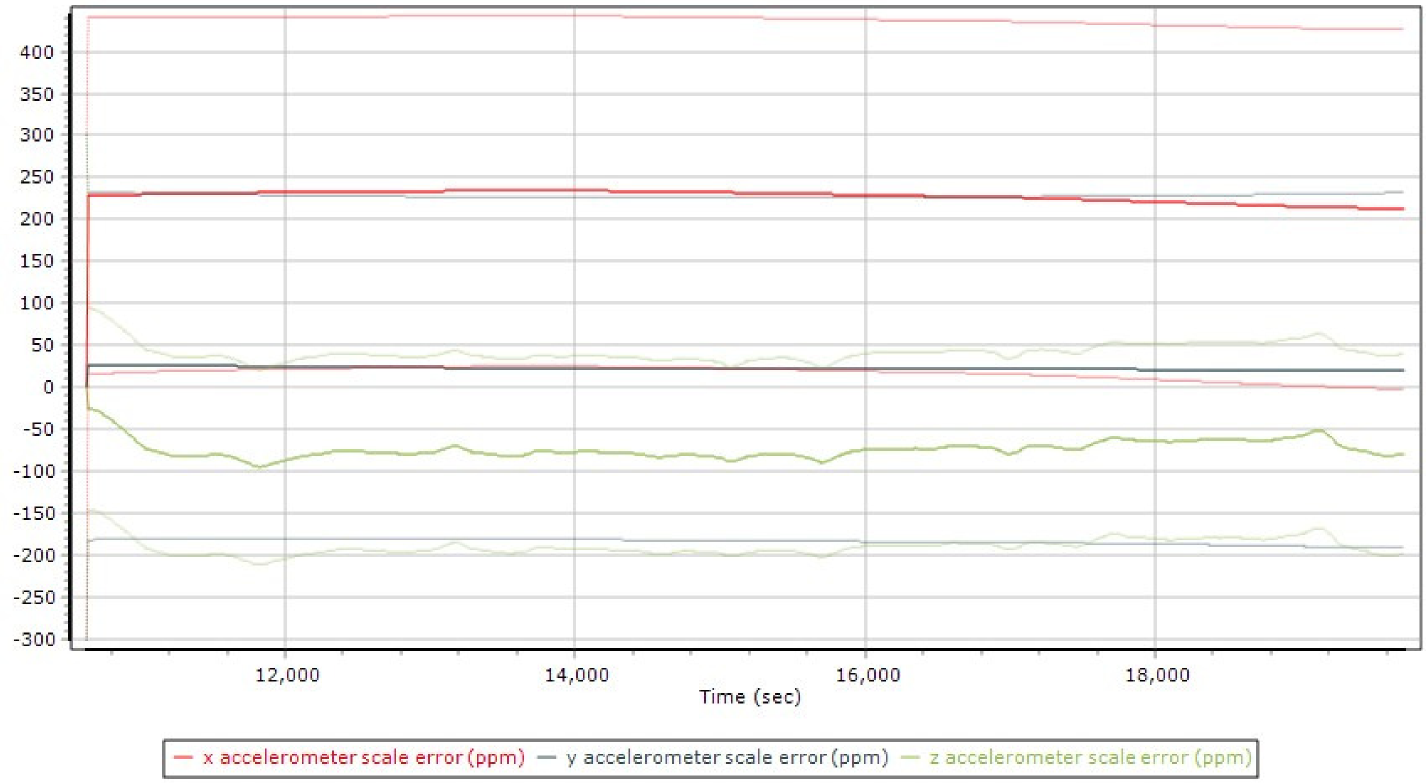
Number of Satellites (>6) Plots 27: Sortie a03-s02-0123



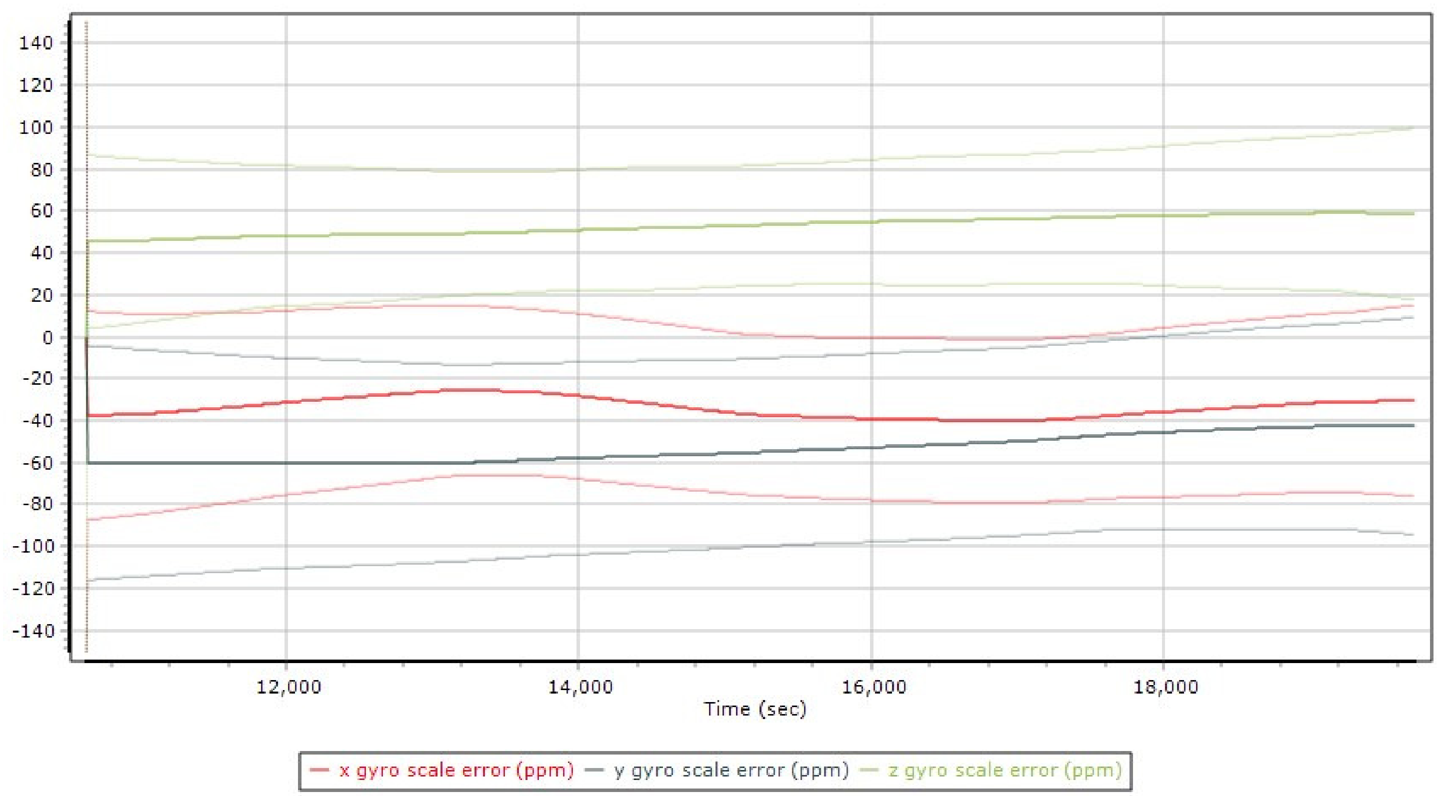
Sensor Position Error RMS (m) Plots 27: Sortie a03-s02-0123



Accelerometer Scale Error (ppm) Plots 27: Sortie a03-s02-0123



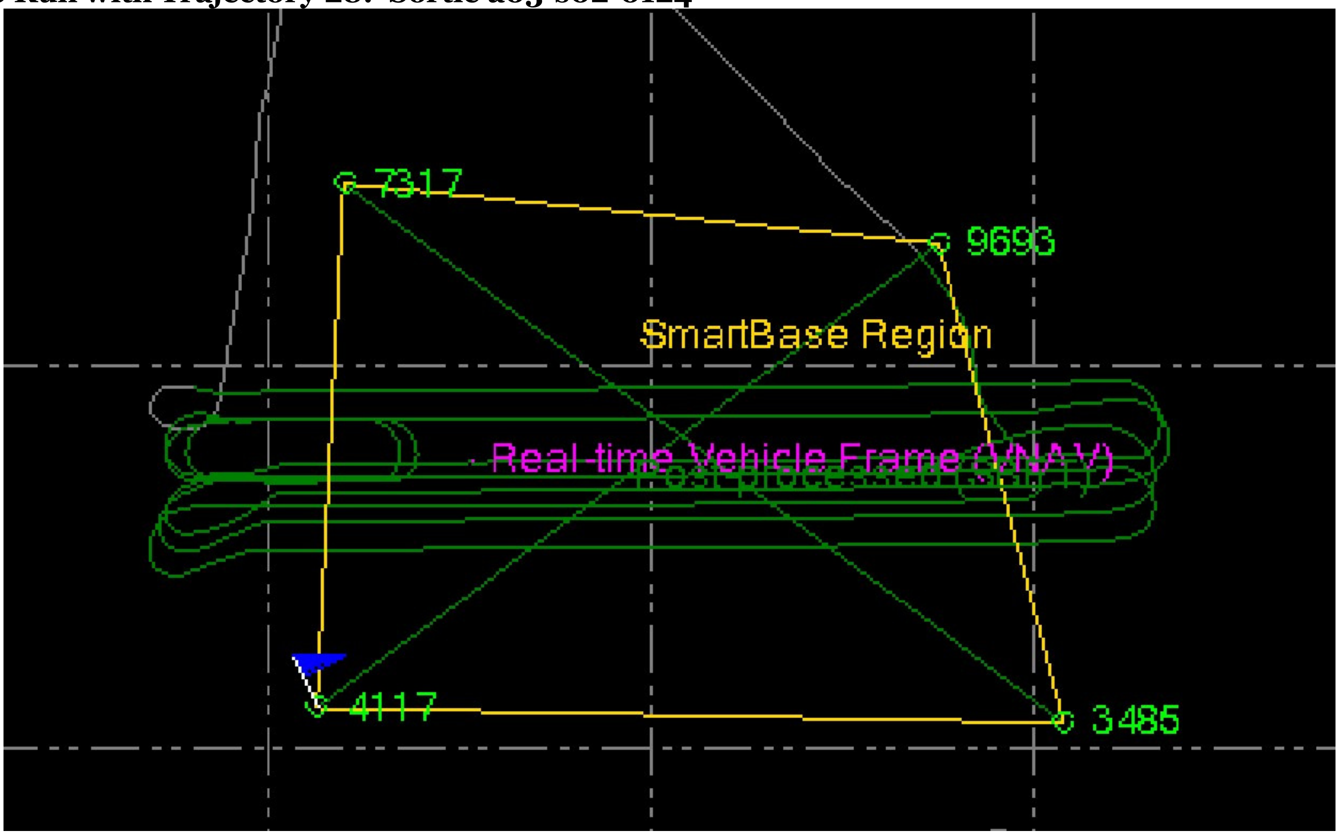
Gyro Scale Error (ppm) Plots 27: Sortie a03-s02-0123



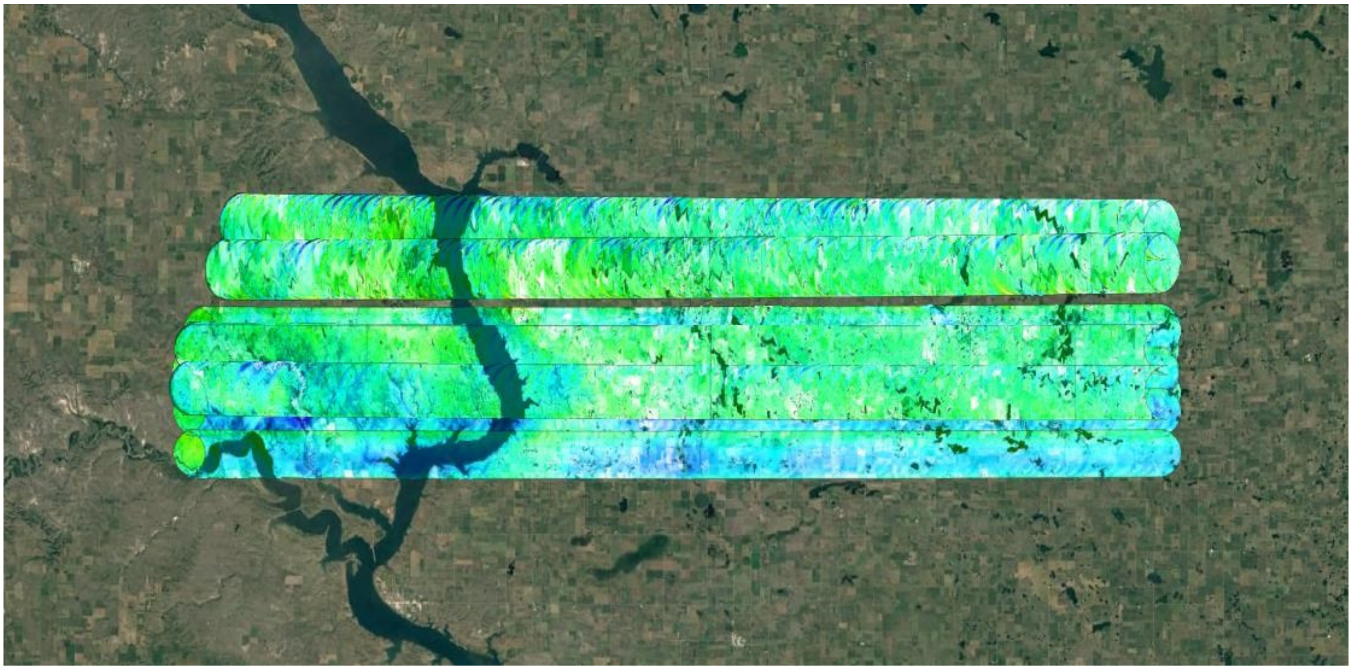
COLLECTION 28

Brick 1
Sortie a03-s02-0124
06/29/2016

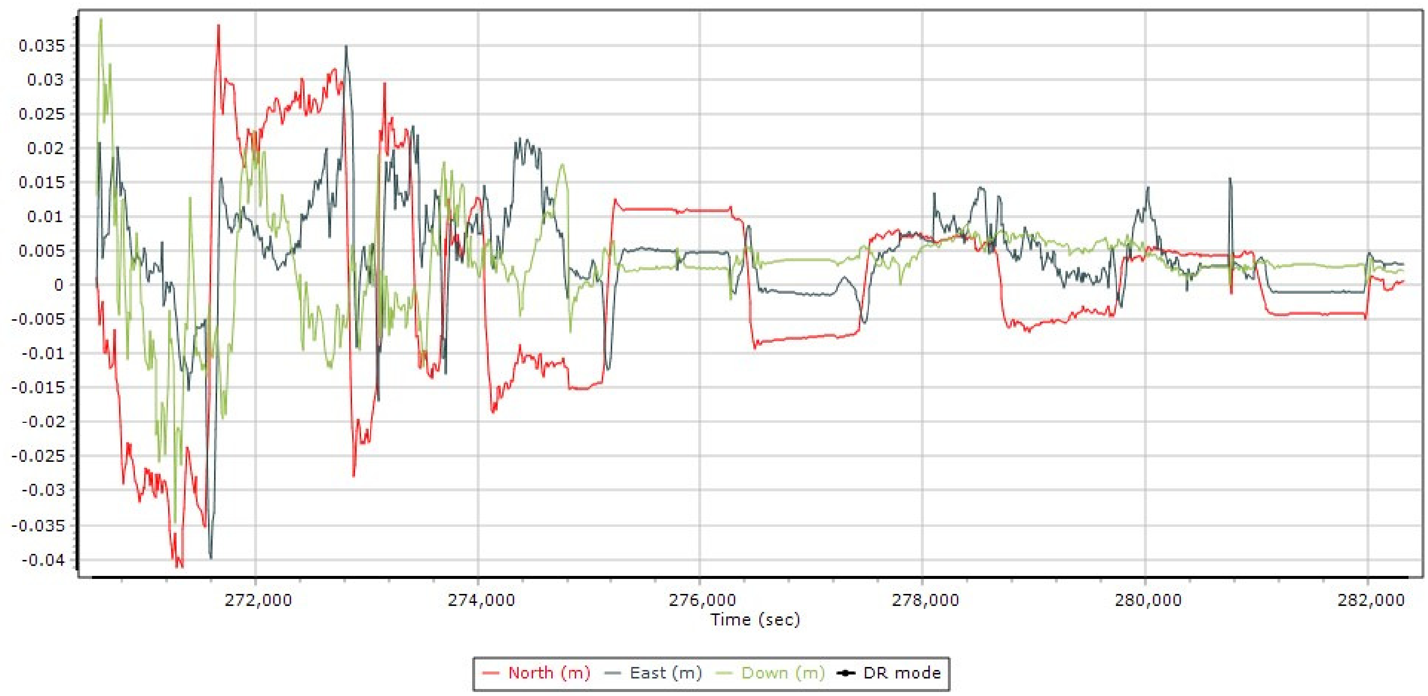
Map Run with Trajectory 28: Sortie a03-s02-0124



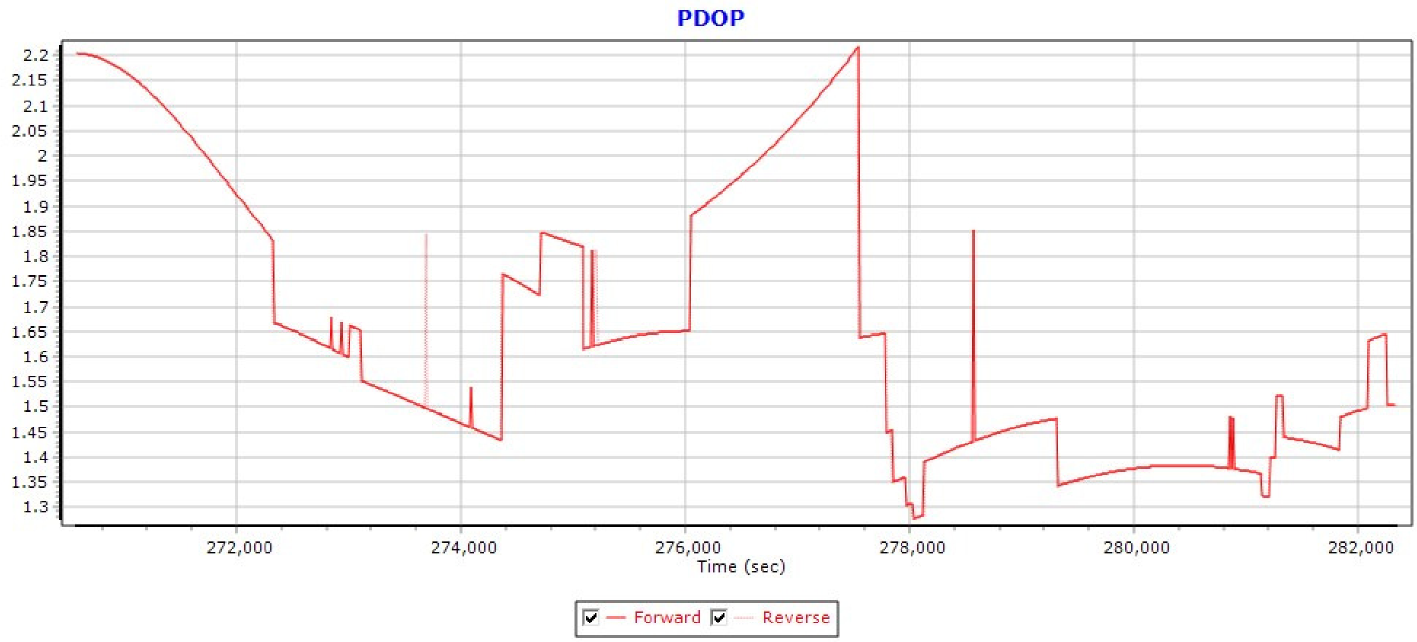
Swath Width, Waterfall View 28: Sortie a03-s02-0124



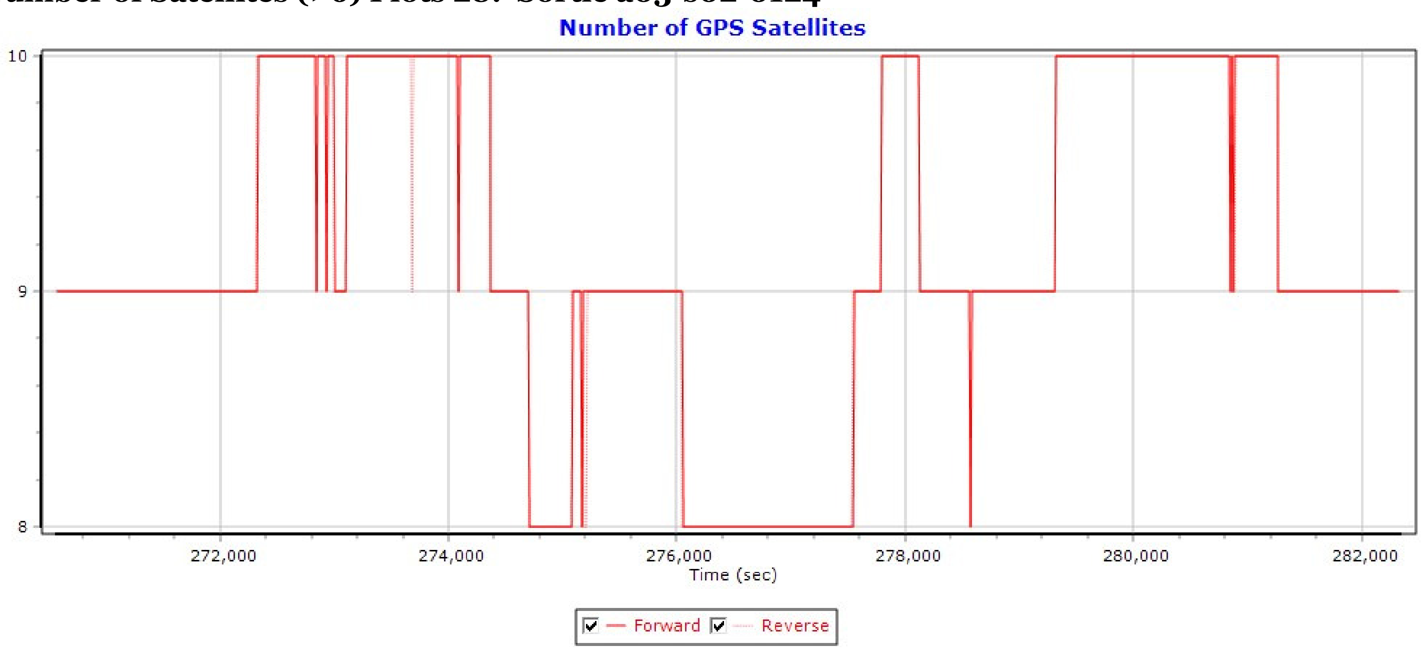
Combined SBET IAKAR Separation 28: Sortie a03-s02-0124



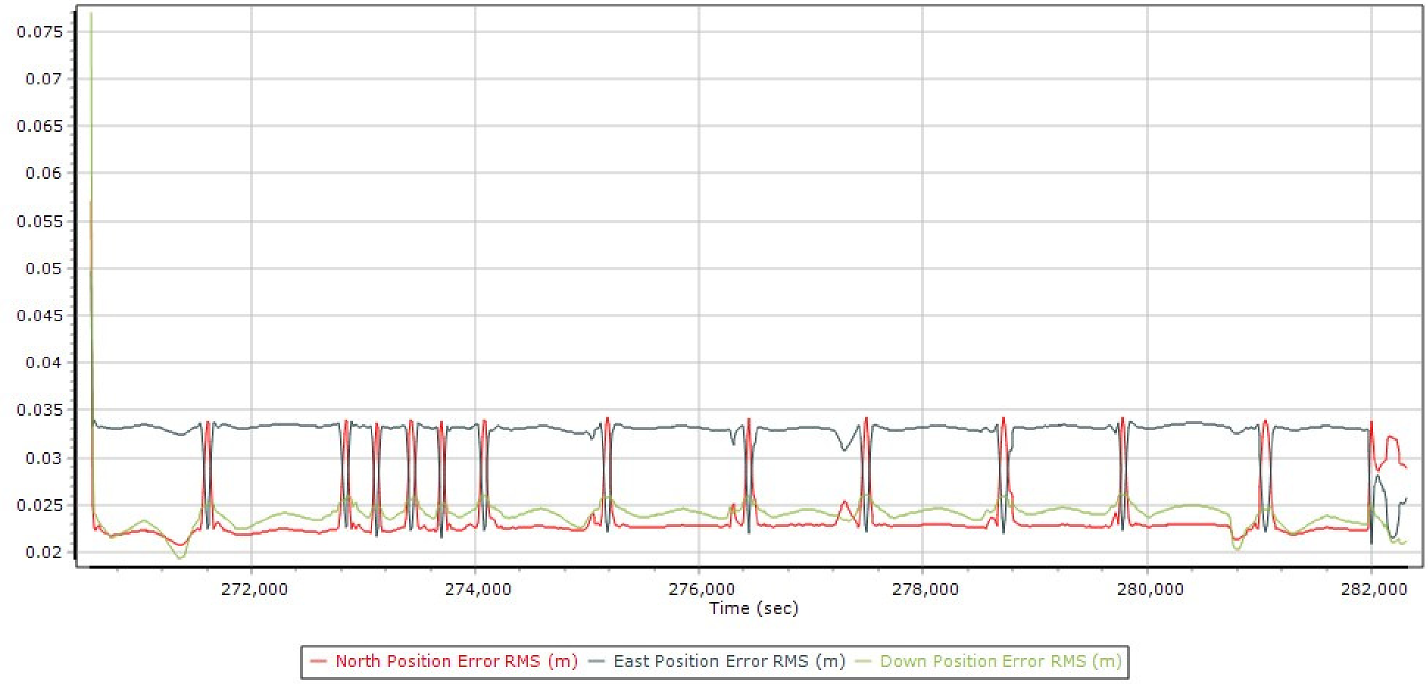
PDOP Plots 28: Sortie a03-s02-0124



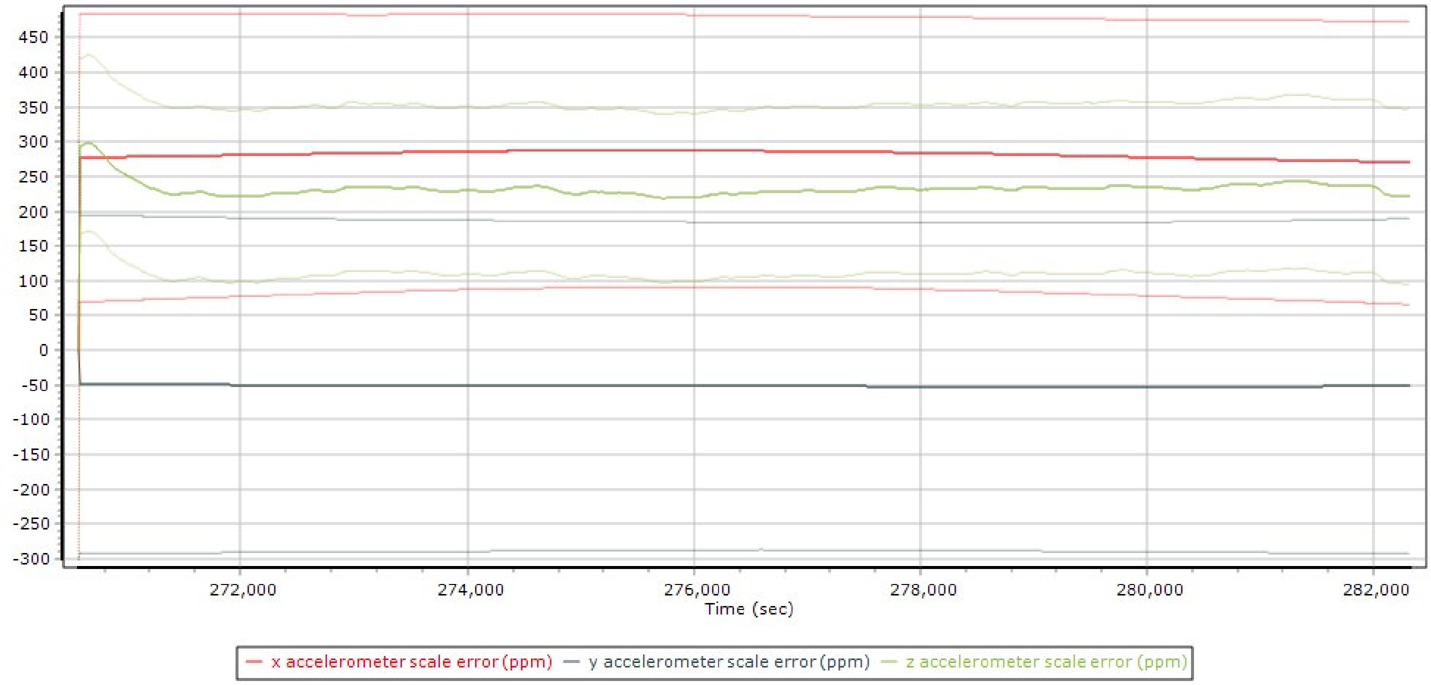
Number of Satellites (>6) Plots 28: Sortie a03-s02-0124



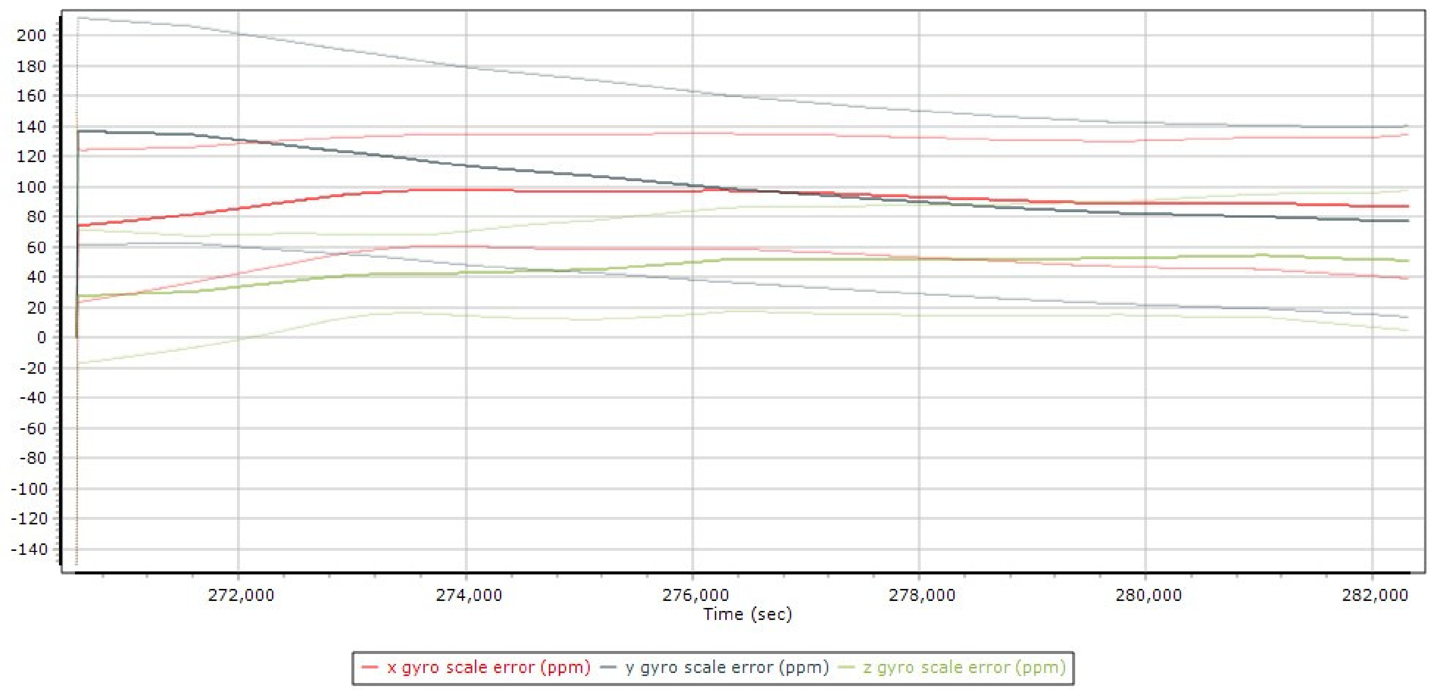
Sensor Position Error RMS (m) Plots 28: Sortie a03-s02-0124



Accelerometer Scale Error (ppm) Plots 28: Sortie a03-s02-0124



Gyro Scale Error (ppm) Plots 28: Sortie a03-s02-0124

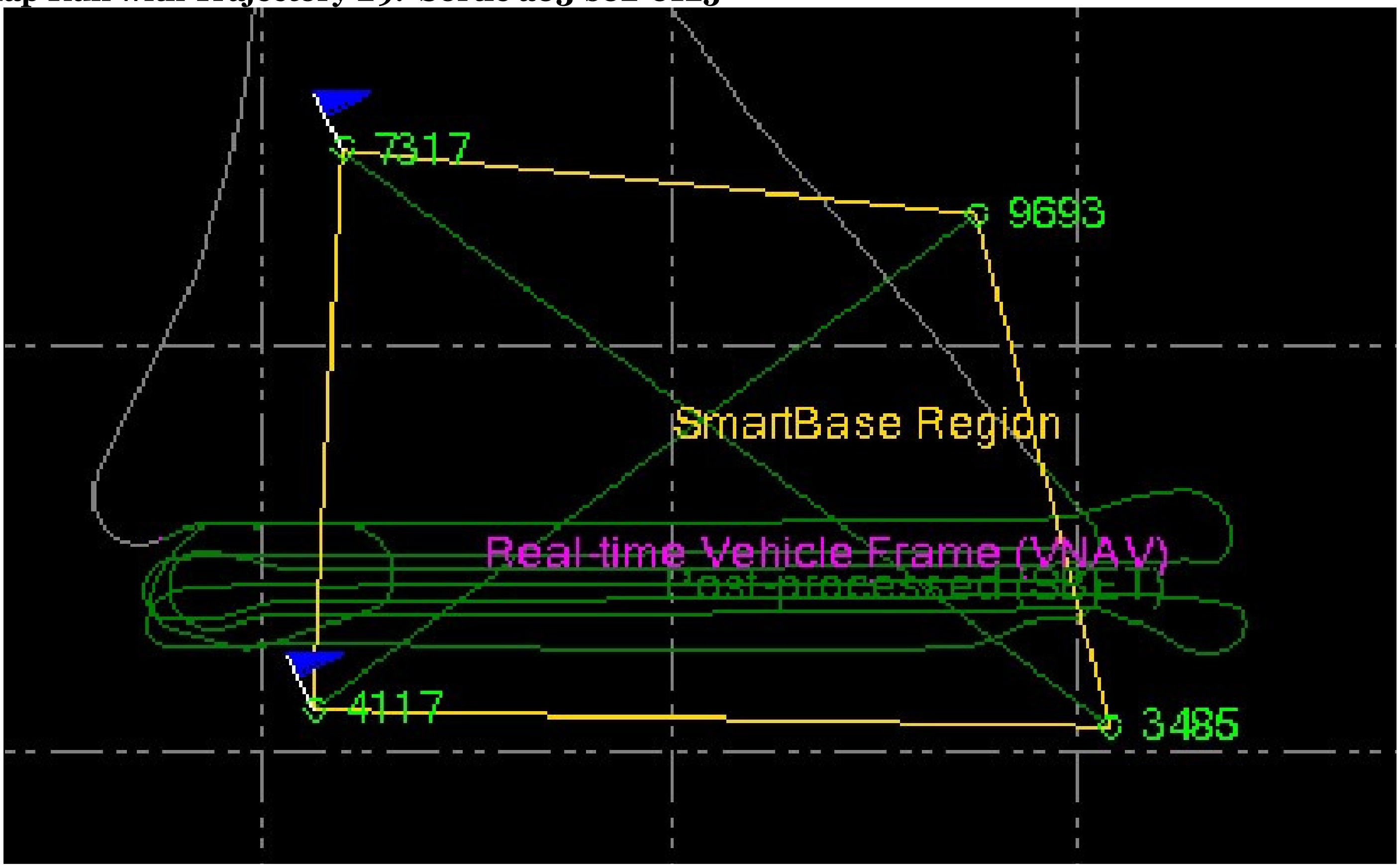


COLLECTION 29

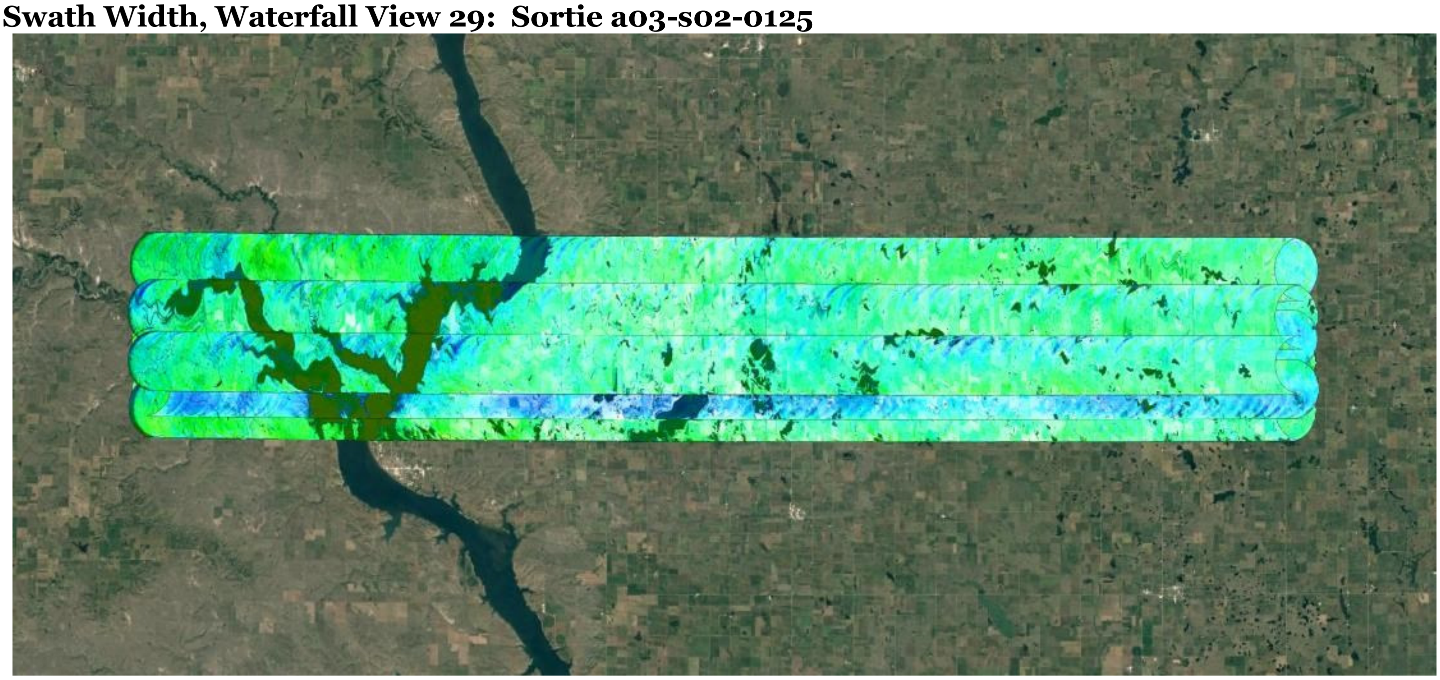
Brick 1

Sortie a03-s02-0125
06/29/2016

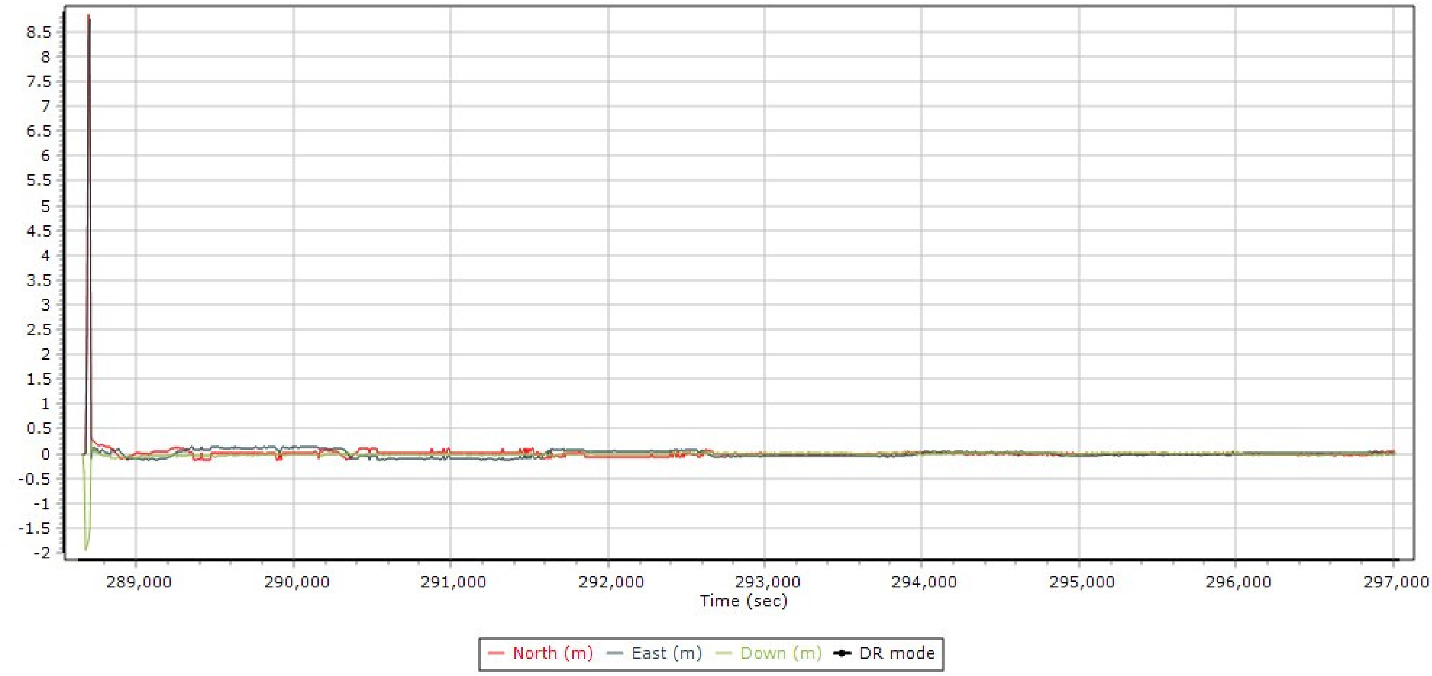
Map Run with Trajectory 29: Sortie a03-s02-0125



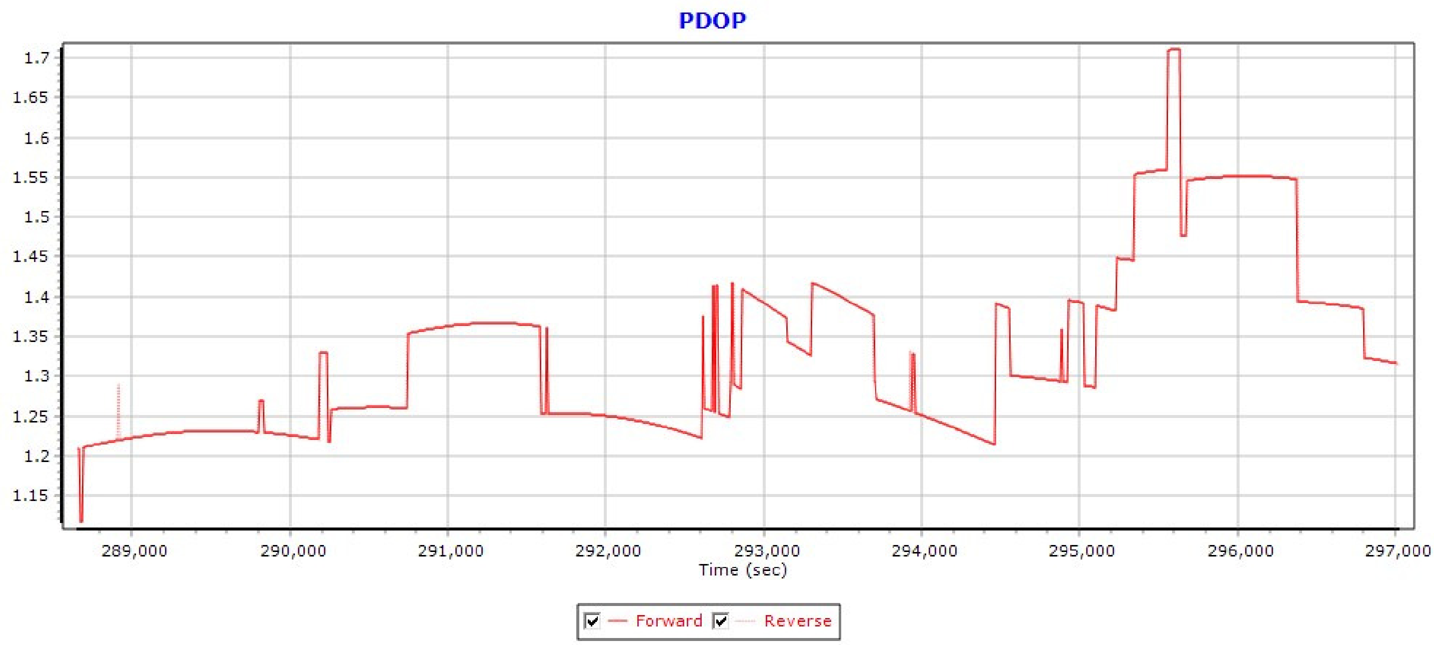
Swath Width, Waterfall View 29: Sortie a03-s02-0125



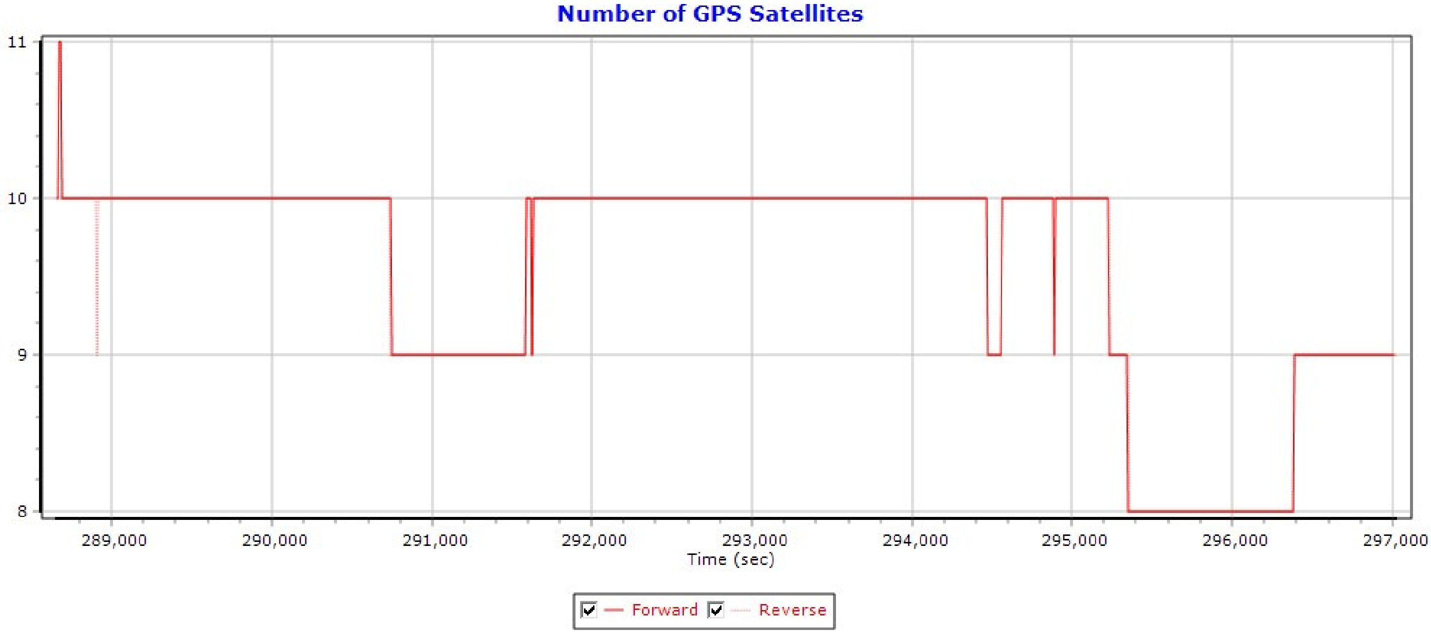
Combined SBET IAKAR Separation 29: Sortie a03-s02-0125



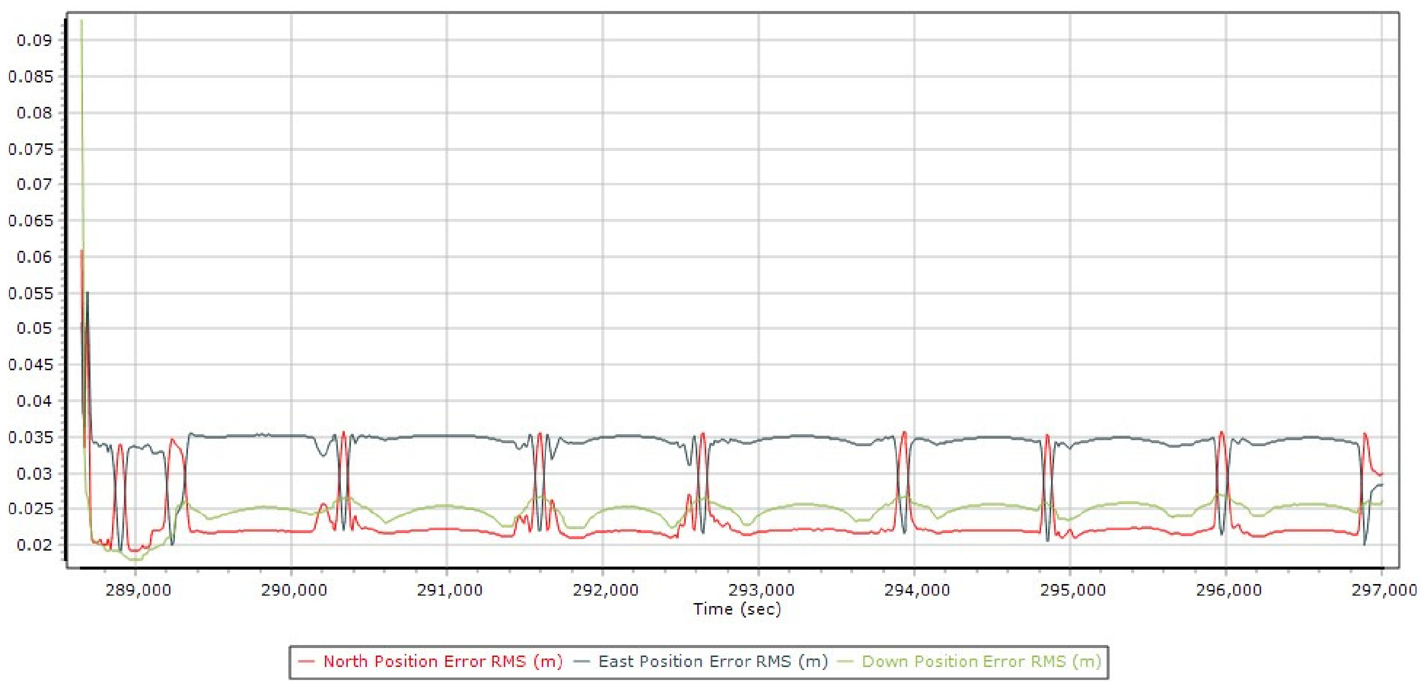
PDOP Plots 29: Sortie a03-s02-0125



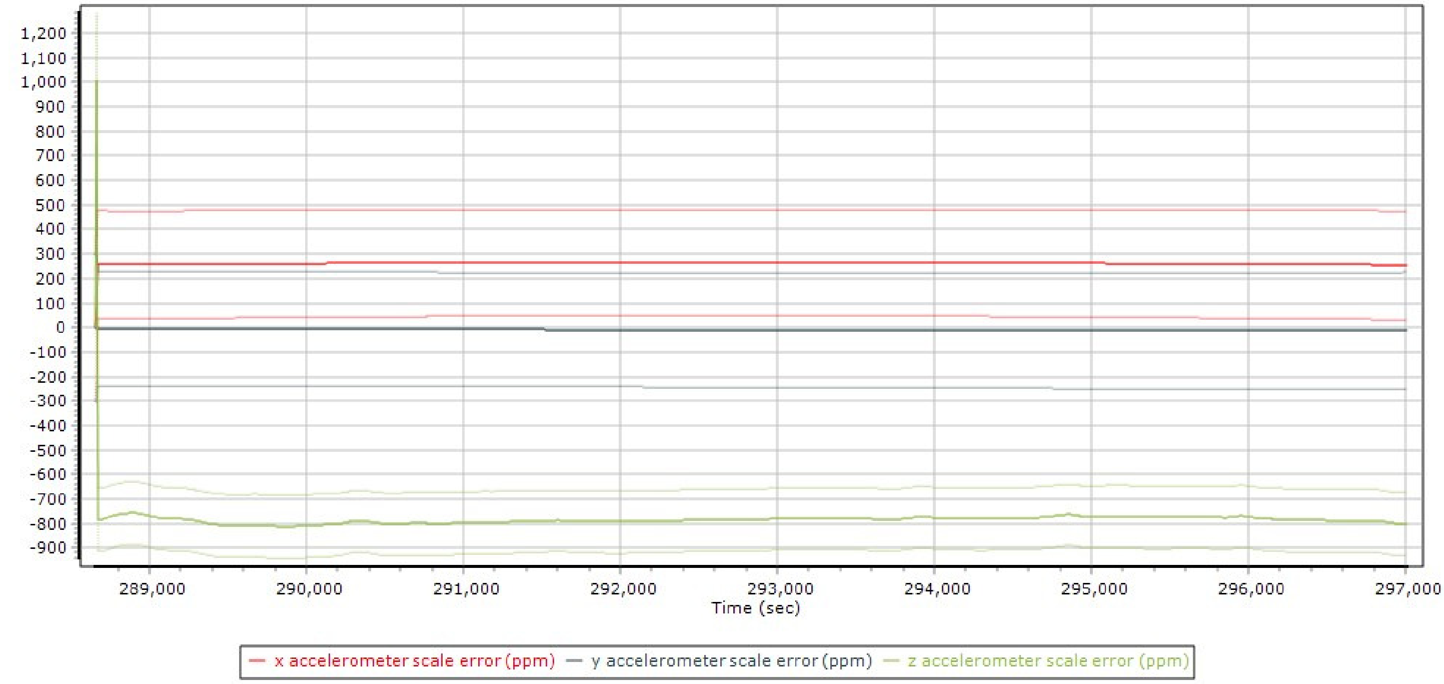
Number of Satellites (>6) Plots 29: Sortie a03-s02-0125



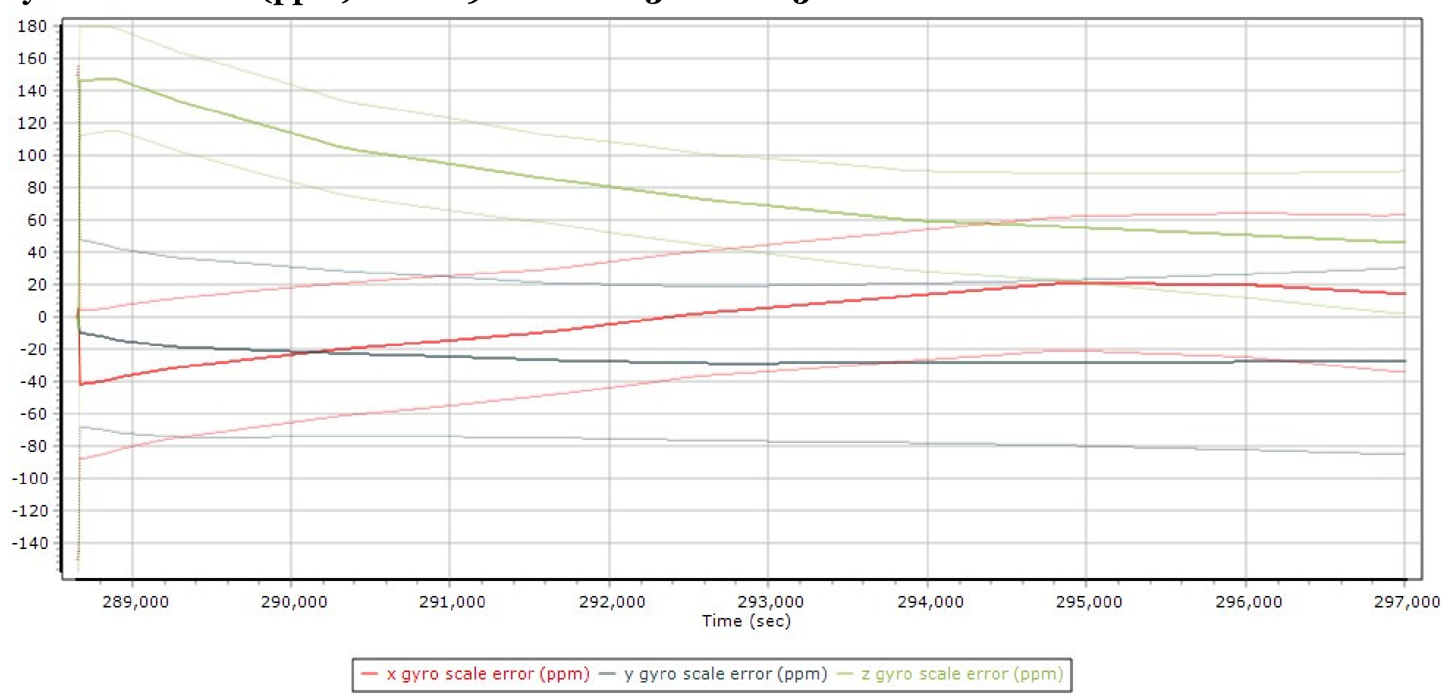
Sensor Position Error RMS (m) Plots 29: Sortie a03-s02-0125



Accelerometer Scale Error (ppm) Plots 29: Sortie a03-s02-0125



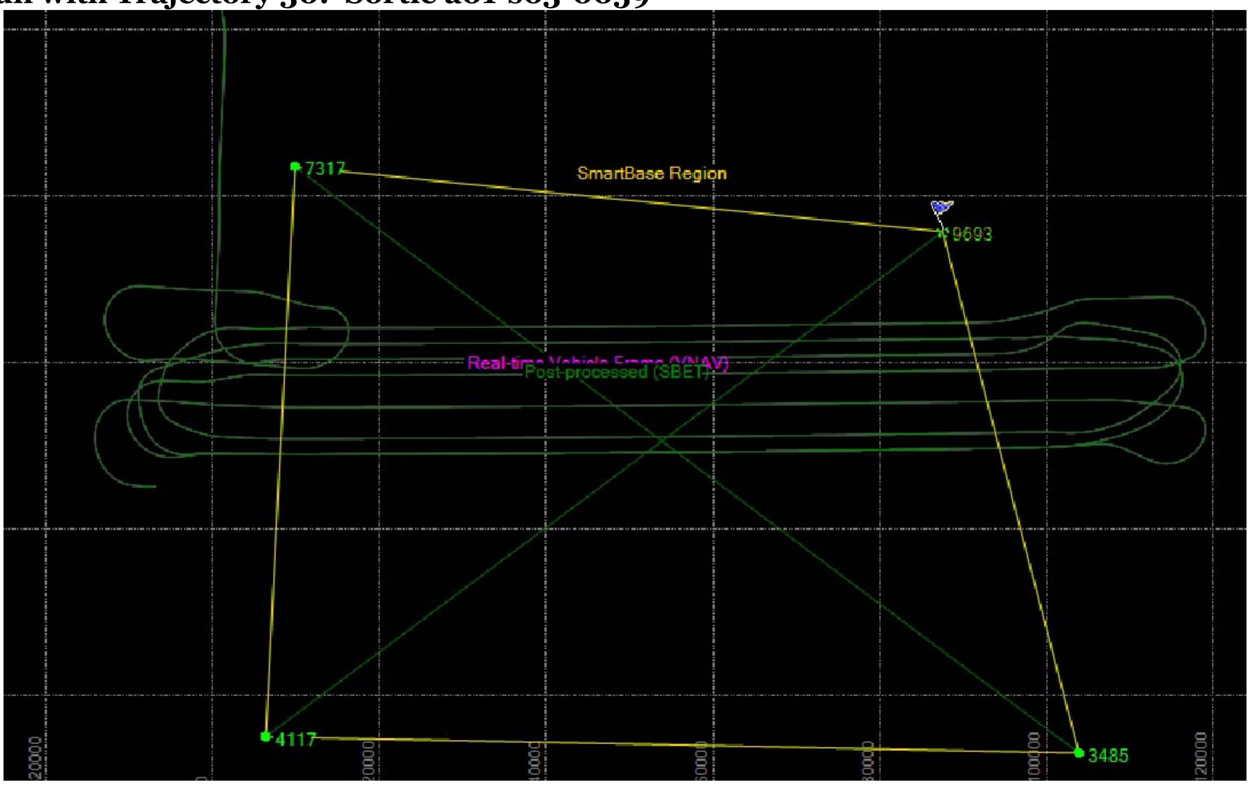
Gyro Scale Error (ppm) Plots 29: Sortie a03-s02-0125



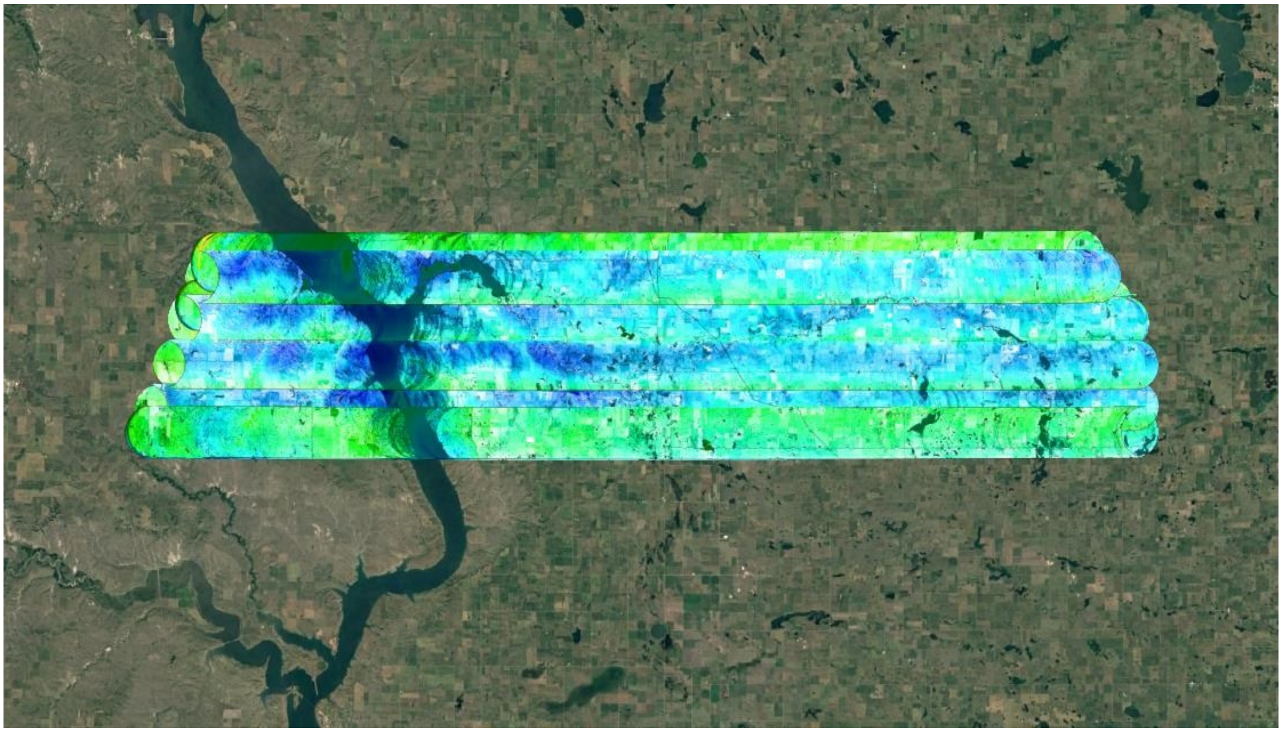
COLLECTION 30

Brick 1
Sortie a01-s03-0059
06/28/2016

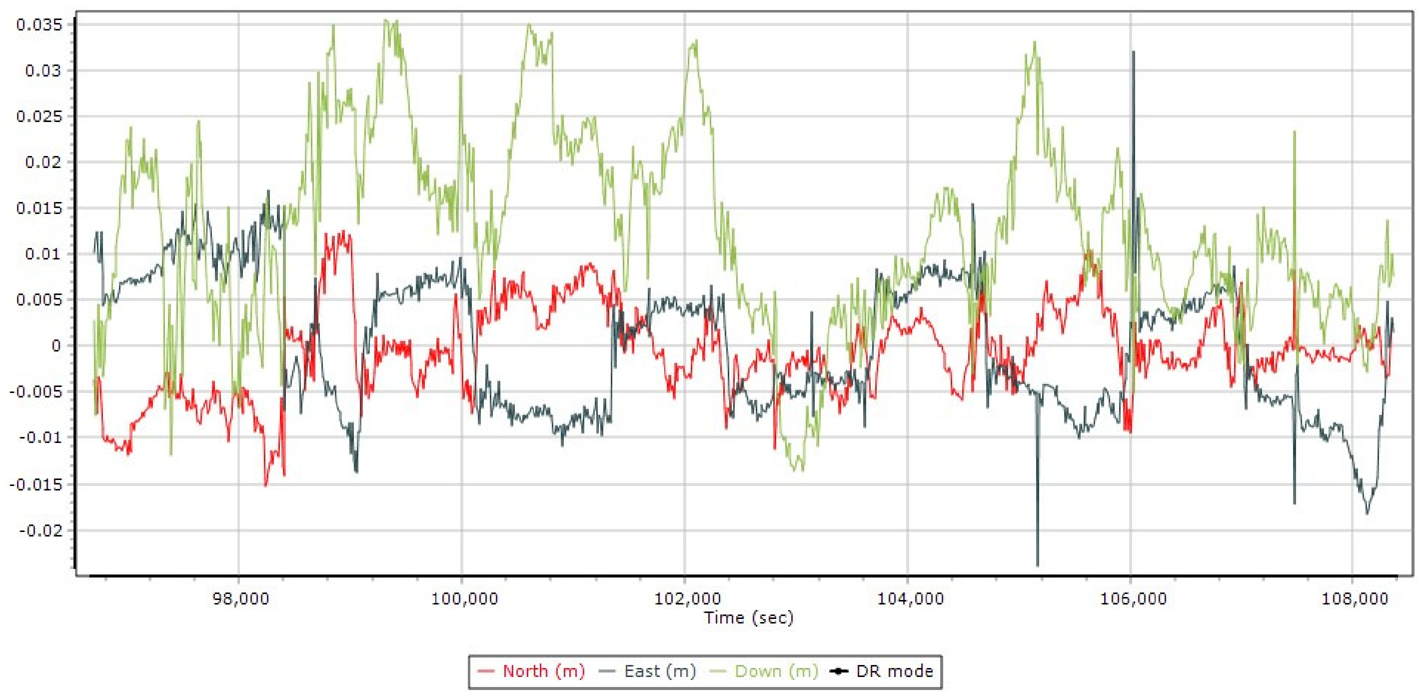
Map Run with Trajectory 30: Sortie a01-s03-0059



Swath Width, Waterfall View 30: Sortie a01-s03-0059

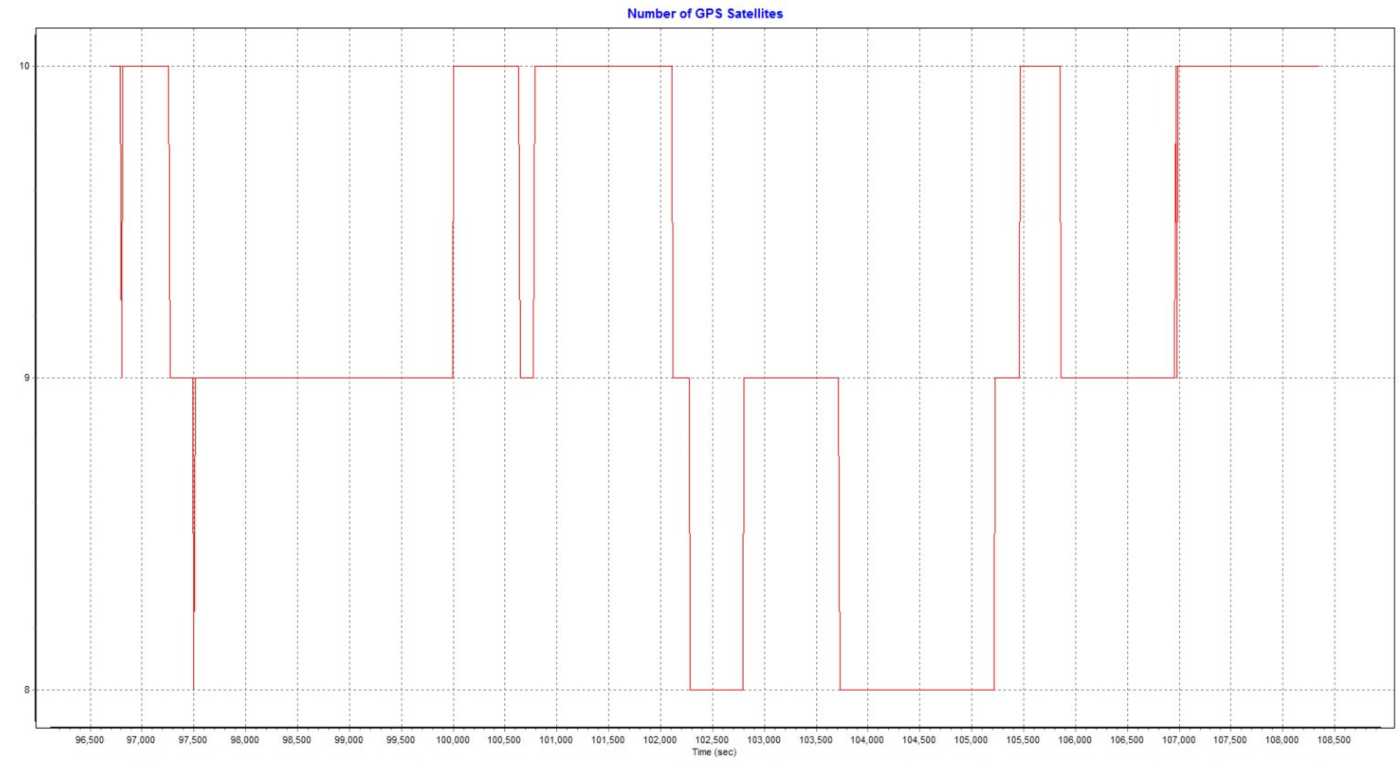


Combined SBET IAKAR Separation 30: Sortie a01-s03-0059

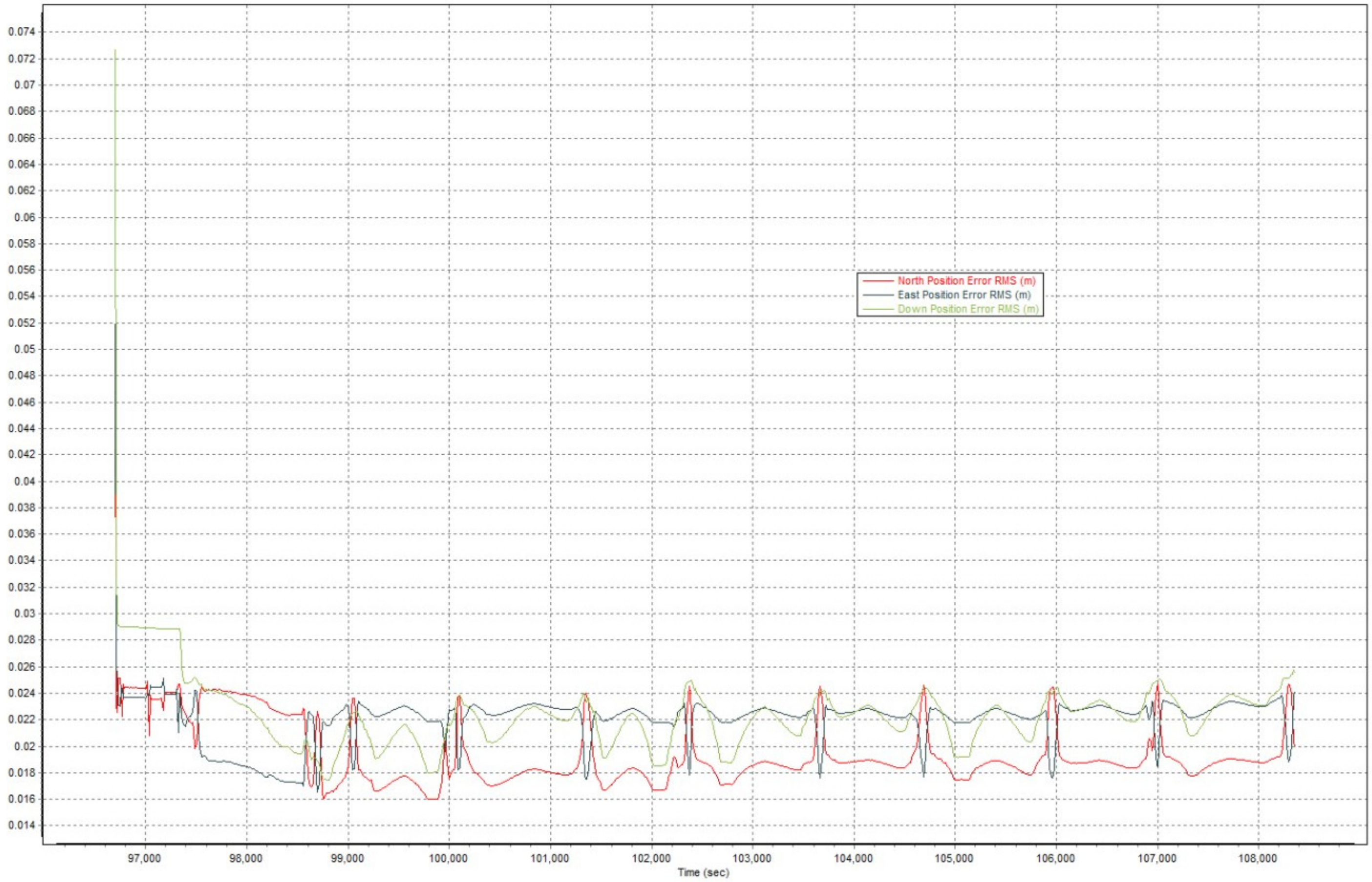


PDOP Plots 30: Sortie a01-s03-0059

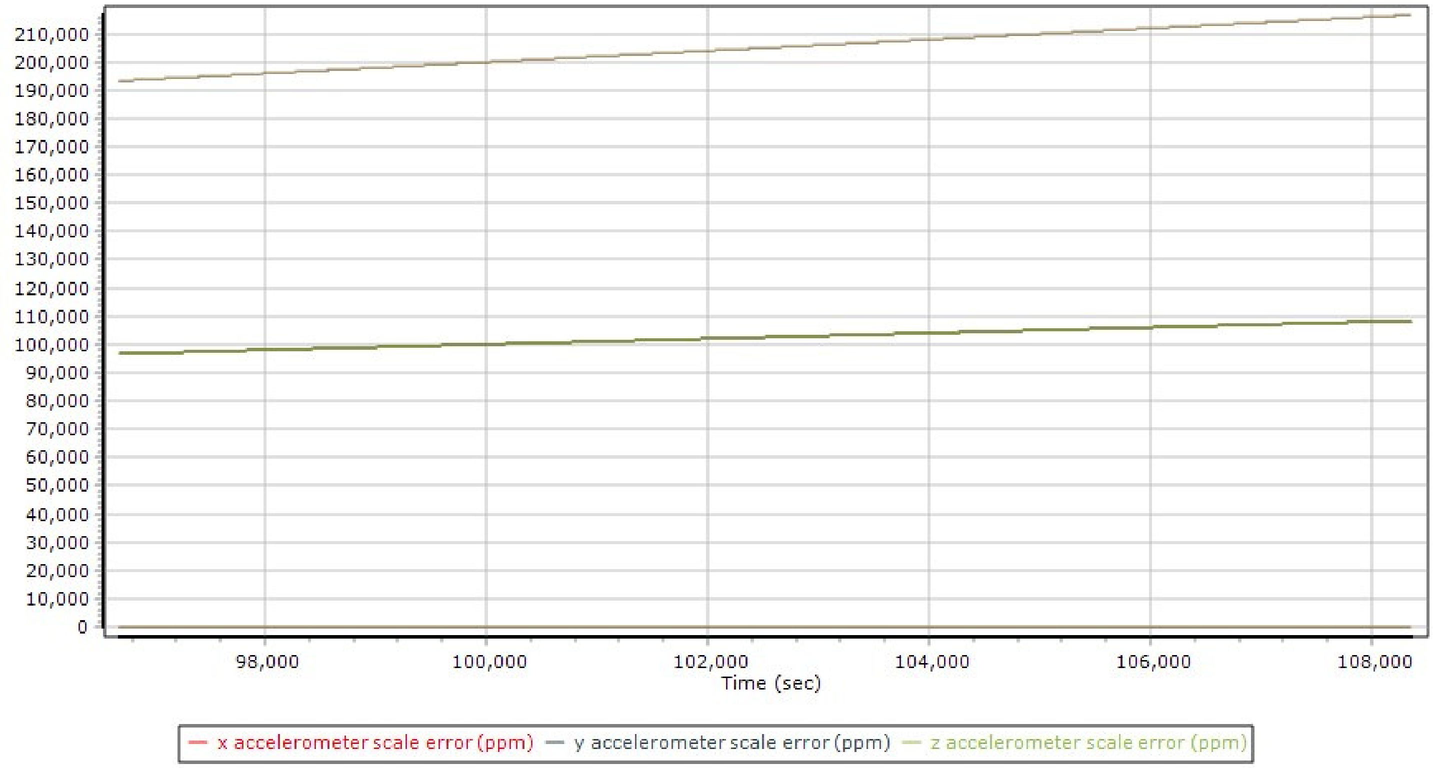
Number of Satellites (>6) Plots 30: Sortie a01-s03-0059



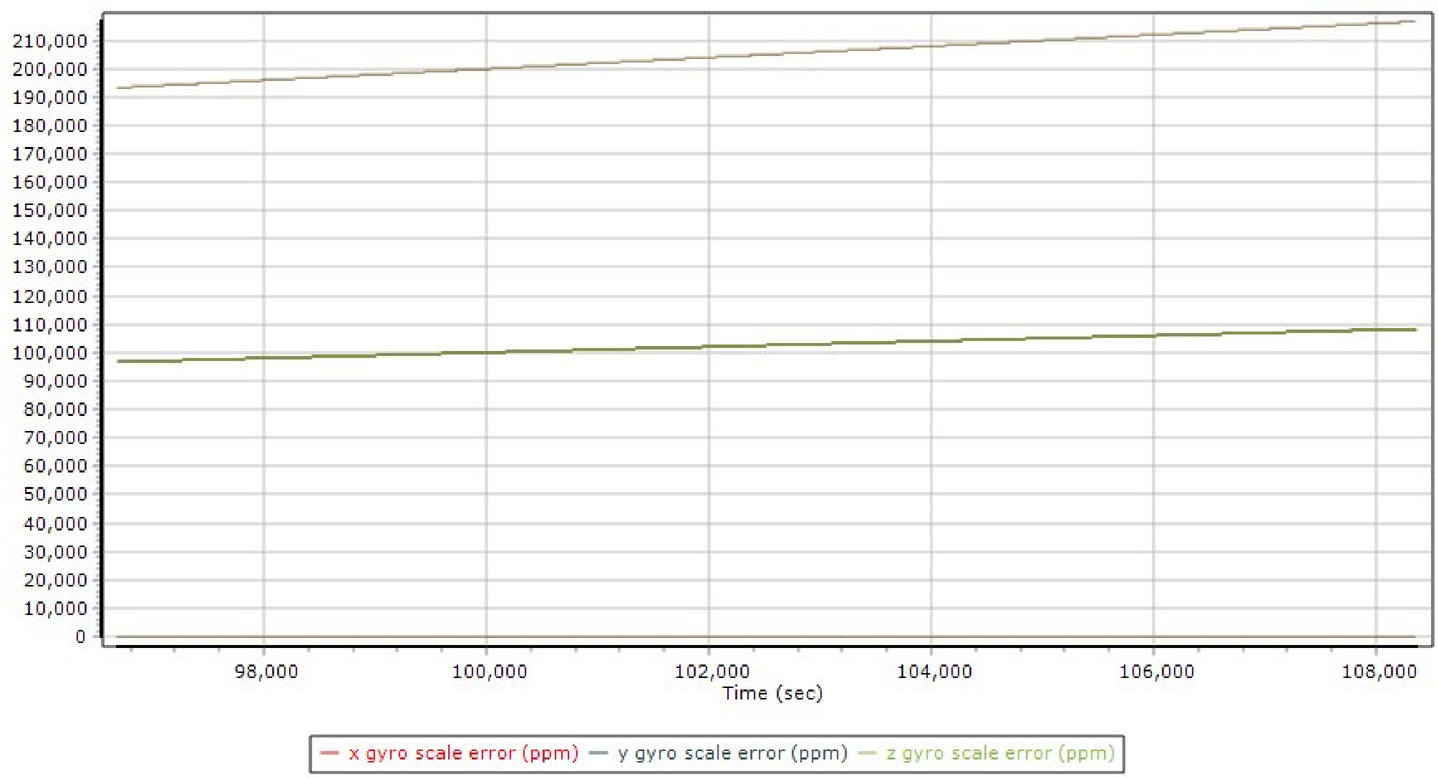
Sensor Position Error RMS (m) Plots 30: Sortie a01-s03-0059



Accelerometer Scale Error (ppm) Plots 30: Sortie a01-s03-0059



Gyro Scale Error (ppm) Plots 30: Sortie a01-s03-0059



Brick 1 Completion: Flight lines with complete waterfall coverage