# NE Northeast Phase 2 Lidar Acquisition and Calibration Report

Report Date: 1/12/2021


SUBMITTED BY:

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## Table of Contents

# Overview

Dewberry elected to subcontract the lidar acquisition and calibration activities for this USGS project to Ahtna Solutions, LLC (ASL). ASL was responsible for providing lidar acquisition, calibration, and delivery of lidar data files to Dewberry. Through ASL's Mentor-Protege relationship with Merrick & Company (Merrick), Merrick provided technical support under subcontract to ASL. The project was delivered in 3 separate block sections (North, Central, and South).

## PROJECT AREA

The project area addressed by this report falls within several whole and partial counties in the state of Nebraska. The counties include Antelope, Boone, Boyd, Butler, Colfax, Dodge, Hamilton, Holt, Merrick, Platte, Polk, and Saunders. The total size of the project is approximately 7,415 square miles.

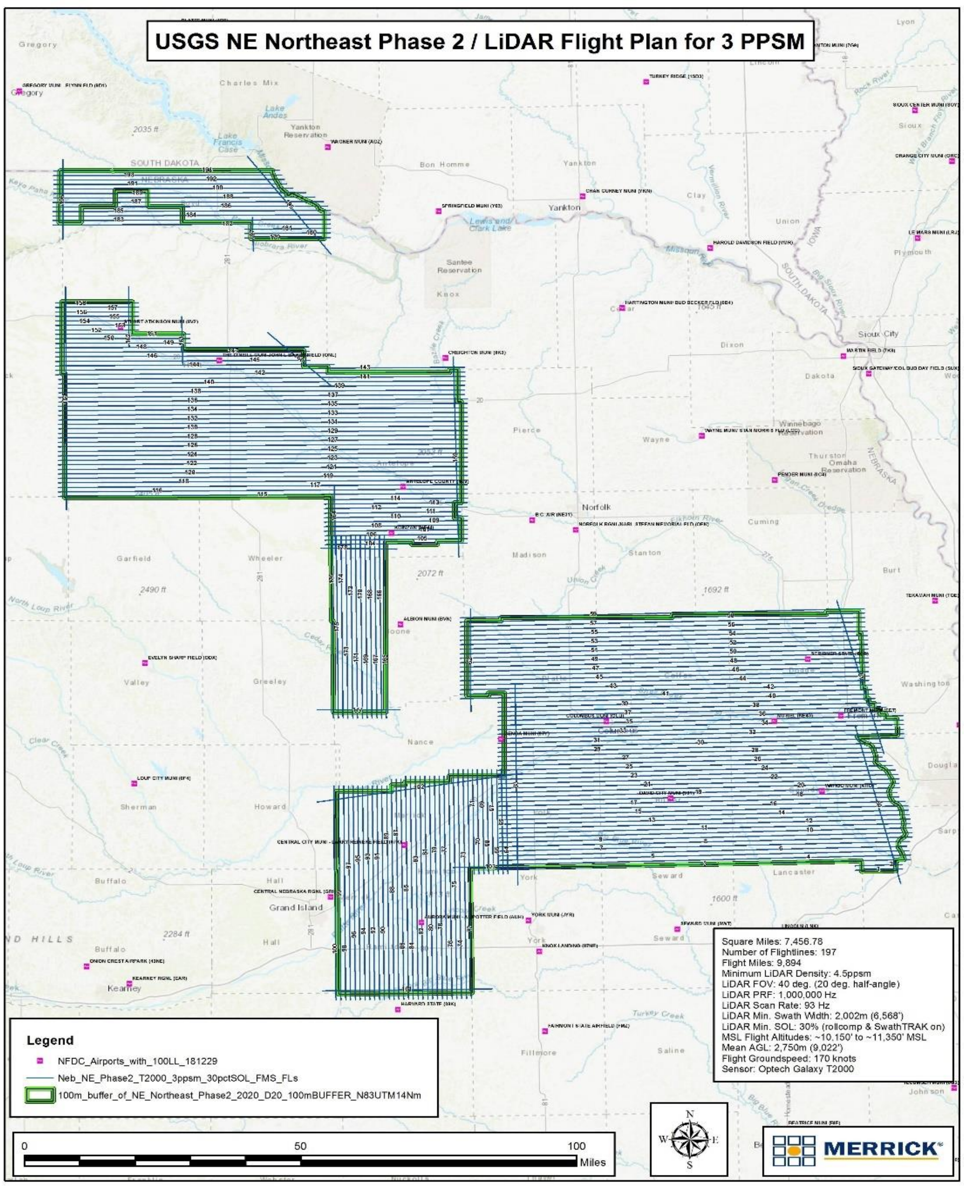



**Figure 1 – Area of Interest**

## ACQUISITION DATES

The lidar survey was conducted between November 6, 2020 and December 9, 2020. Each mission represents a lift of the aircraft and system from the ground, data collection, and landing. Multiple lifts within a day are represented by Mission A, B, C, and D. The table below relates each mission to the date collected, the sensor and serial number used, and the actual average MSL in meters.

| Mission(s) | Date | Sensor S/N | Actual Avg. MSL (m) |
|---|---|---|---|
| 201106_A | November 6, 2020 | 5060449 | 3210 |
| 201116_A | November 16, 2020 | 5060449 | 3260 |
| 201117_A | November 17, 2020 | 5060449 | 3280 |
| 201117_B | November 17, 2020 | 5060449 | 3310 |
| 201118_A | November 18, 2020 | 5060449 | 3310 |
| 201119_A | November 19, 2020 | 5060449 | 3340 |
| 201122_A | November 22, 2020 | 5060449 | 3380 |
| 201126_A | November 26, 2020 | 5060449 | 3180 |
| 201127_A | November 27, 2020 | 5060449 | 3350 |
| 201128_A | November 28, 2020 | 5060449 | 3360 |
| 201128_B | November 28, 2020 | 5060449 | 3370 |
| 201130_A | November 30, 2020 | 5060449 | 3370 |
| 201130_B | November 30, 2020 | 5060449 | 3380 |
| 201201_A | December 1, 2020 | 5060449 | 3315 |
| 201202_A | December 2, 2020 | 5060449 | 3225 |
| 201204_A | December 4, 2020 | 5060449 | 3210 |
| 201205_A | December 5, 2020 | 5060449 | 3200 |
| 201207_A | December 7, 2020 | 5060449 | 3180 |
| 201208_A | December 8, 2020 | 5060449 | 3190 |
| 201209_A | December 9, 2020 | 5060449 | 3205 |
| 201209_B | December 9, 2020 | 5060449 | 3190 |

## DATUM REFERENCE

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

**Horizontal Datum:** North American Datum of 1983 (NAD 83), National Adjustment of 2011 (NA2011) (epoch 2010.00)
**Vertical Datum:** North American Vertical Datum of 1988 (NAVD 88); using the latest NGS-approved geoid (i.e., GEOID18)
**Coordinate System:** UTM Zone 14
**Units:** Horizontal units are in meters; Vertical units are in meters.
**Geoid Model:** Geoid18 (Geoid18 was used to convert ellipsoid heights to orthometric heights).

# Lidar Acquisition Details

ASL planned 200 passes for the the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. In order to reduce any margin for error in the flight plan, ASL followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, including the following criteria:

- A digital flight line layout using Optech's FMS 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, ASL will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

ASL monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that would affect the collection of data, such as leaves on hardwoods, snow, rain, fog, smoke, mist and low clouds. ASL 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, ASL 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.

ASL lidar sensors are calibrated at designated sites and are periodically checked and adjusted to minimize corrections at project sites.

## LIDAR SYSTEM PARAMETERS

ASL operated a fixed wing aircraft outfitted with a Galaxy Prime T2000 lidar system during the collection of the study area. Table 1 illustrates ASL system parameters for lidar acquisition on this project.

| Item | Parameter |
|---|---|
| System | Galaxy Prime T2000 - SN5060449 |
| Maximum Number of Returns per Pulse | 8 |
| Nominal Pulse Spacing (single swath), (m) | 0.58 |
| Nominal Pulse Density (single swath) (ppsm), (m) | 3 |
| Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal) | 0.58 |
| Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal) | 3 |

| Item | Parameter |
|---|---|
| Altitude (AGL meters) | 2750 |
| Approx. Flight Speed (knots) | 170 |
| Total Sensor Scan Angle (degree) | 40 |
| Scan Frequency (hz) | 93 |
| Scanner Pulse Rate (kHz) | 1000 |
| Pulse Duration of the Scanner (nanoseconds) | 3.5 |
| Pulse Width of the Scanner (m) | 1.375 |
| Central Wavelength of the Sensor Laser (nanometers) | 1064 |
| Did the Sensor Operate with Multiple Pulses in The Air? (yes/no) | Yes |
| Beam Divergence (milliradians) | 0.25 |
| Nominal Swath Width on the Ground (m) | 2002 |
| Swath Overlap (%) | 30 |
| Computed Down Track spacing (m) per beam | 0.47 |
| Computed Cross Track Spacing (m) per beam | 0.47 |

**Table 1: ASL 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. 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 ASL**

## ACQUISITION STATIC CONTROL

ASL used Virtual Ground GNSS Base Station(s) to control the lidar airborne flight lines. Trimble CenterPoint™ RTX™ correction service is a high-accuracy, satellite-delivered global positioning service. This technology provides high-accuracy GNSS positioning without the use of traditional reference station-based differential RTK infrastructure and delivers very high cm level accuracy. In addition, CORS (Continually Operating Reference Stations) are at times used to further enhance the airborne solution.

## AIRBORNE GNSS KINEMATIC

The airborne GNSS data was post-processed using Applanix POSPac Mobile Mapping Suite version 8.x. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, lidar acquisition was limited to periods when the PDOP was less than 4.0. PDOP indicates satellite geometry relating to position. Generally, PDOP's of 4.0 or less result in a good quality solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. Usually as the number of satellites increase, the PDOP decreases. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. An analysis of the number of satellites, present during the flight and data collection times, is also performed.

The GNSS trajectory was combined with the raw IMU data and post-processed using POSPac Mobile Mapping Suite version 8.x. The SBET and refined attitude data are then utilized in the LMS Post Processor to compute the laser point-positions – the trajectory is combined with the altitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the Optech LMS processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

GNSS processing reports for each mission are included in Appendix A.

## GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

ASL takes great care to ensure all lidar acquisition missions are carried out in a manner conducive to post-processing an accurate data set. This begins in the flight-planning stage with attention to GPS baseline distances and GPS satellite constellation geometry and outages. Proper AGPS surveying techniques are always followed including pre- and post-mission static initializations. In-air IMU alignments are performed both before and after on-site collection to ensure proper calibration of the IMU accelerometers and gyros.

A minimum of one cross-flight is planned throughout the project area across all flightlines and over roadways where possible. The cross-flight provides a common control surface used to remove any vertical discrepancies in the lidar data between flightlines. The cross-flight is critical to ensure flightline ties across the project area. The areas of overlap between flightlines are used to boresight (calibrate) the lidar point cloud to achieve proper flightline-to-lightline alignment in all three axes. This includes adjustment of both IMU and scanner-related variables such as roll, pitch, heading, timing interval (range), and torsion. Each lidar mission flown is accompanied by a hands-on boresight in the office.

A more detailed calibration workflow can be found in Appendix B.

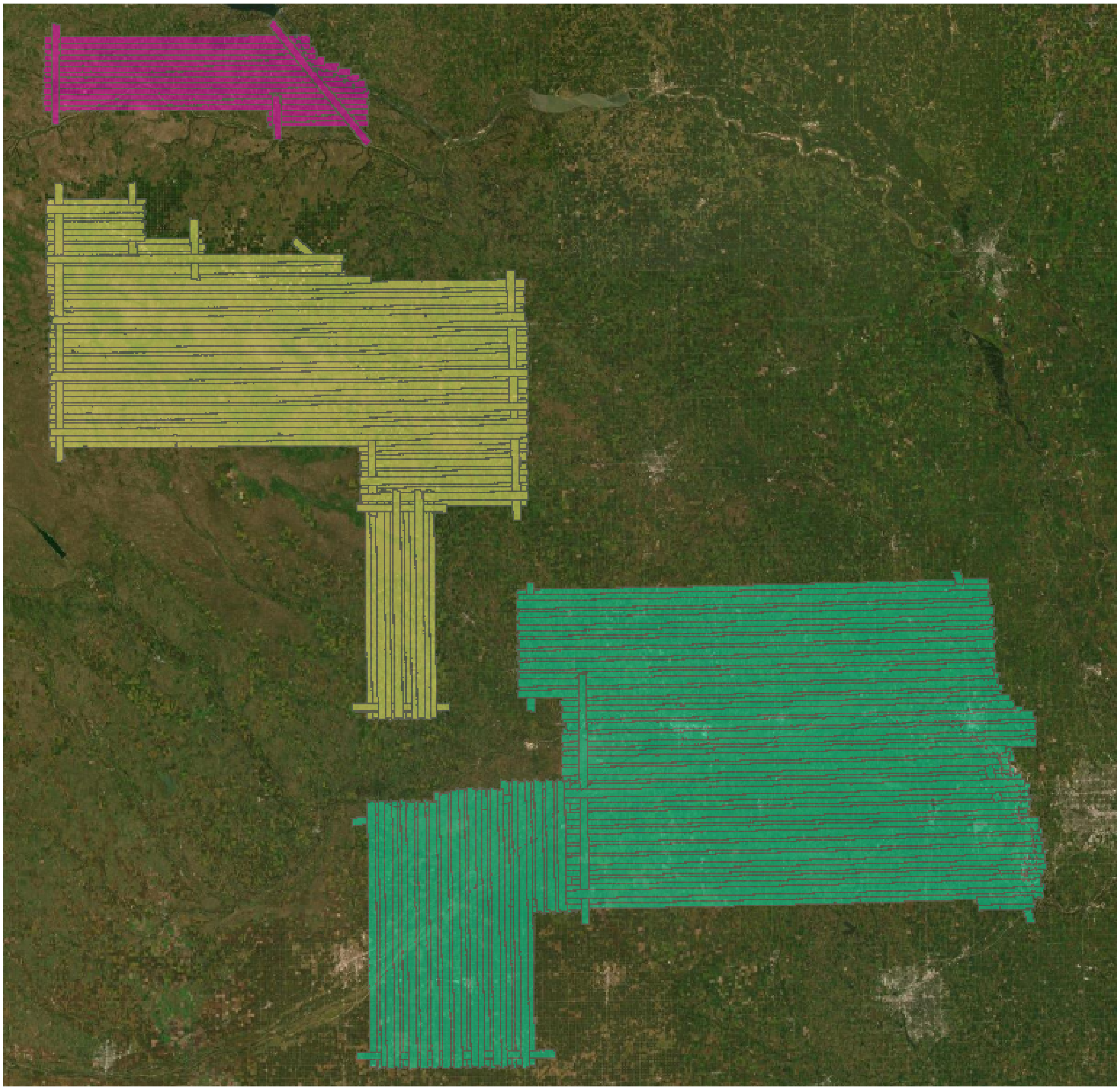


Figure 3 – Lidar swath output showing complete coverage.

## Boresight and Relative accuracy

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

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

For this project the specifications used are as follow:

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

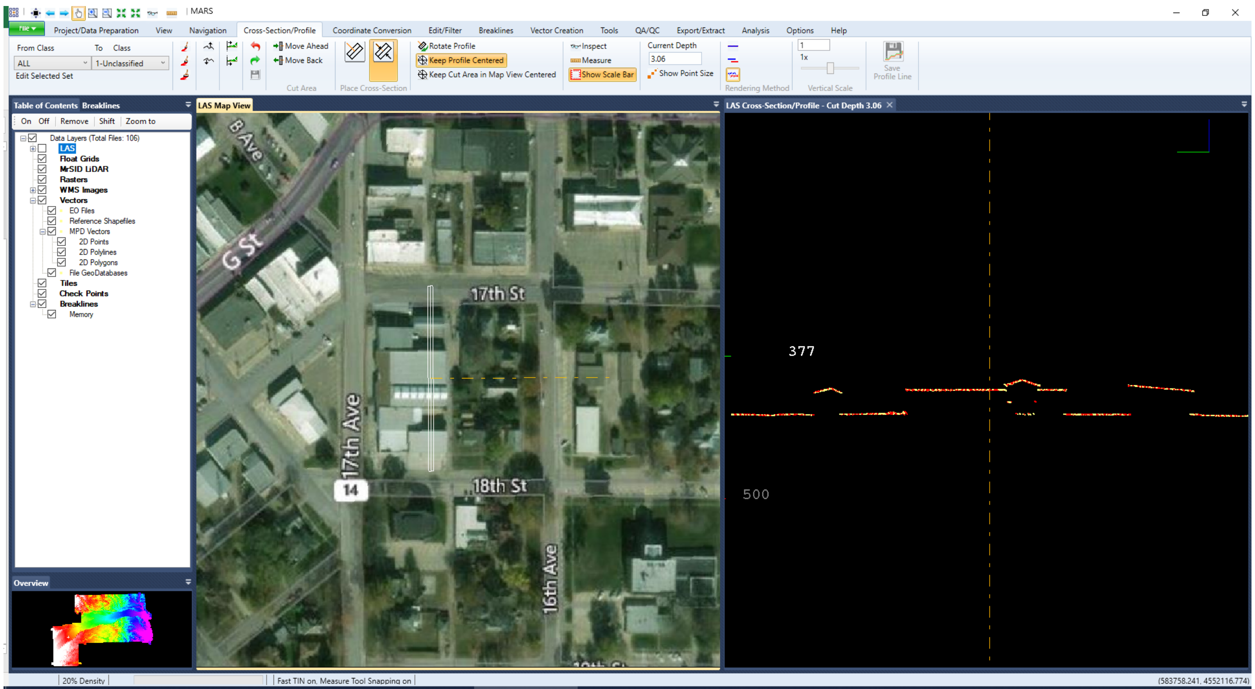



**Figure 4 – Profile views showing correct roll and pitch adjustments.**

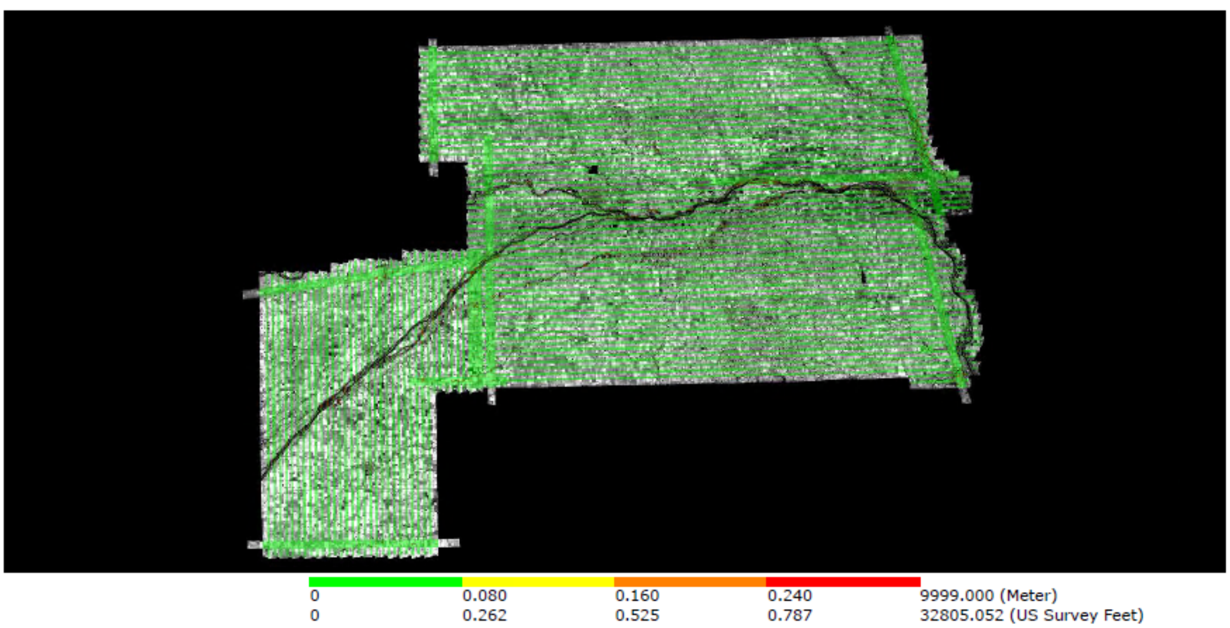



**Figure 5 – QC block colored by distance to ensure accuracy at swath edges.**

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

## Final Calibration Verification

ASL conducted the survey for 96 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 96 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided in table 3 and the accuracy results from testing the calibrated swath data against the GCPs by delivery block is provided in table 4.

| ID | X | Y | Coverage | Z | Z From LiDAR NVA or VVA | Z Error | Minimum Z | Median Z | Maximum Z | Intensity | Scan Angle Rank | Returns | Description | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3075 | 543398.455 | 4741499.885 | Yes | 427.09 | 427.089 | -0.001 | 427.087 | 427.09 | 427.108 | 1486 | 18 | 1,1,1 | LIPT | |
| 3076 | 482458.301 | 4756155.024 | Yes | 626.958 | 626.929 | -0.029 | 626.92 | 626.924 | 626.931 | 1453 | -1429 | 1,1,1 | LIPT | |
| 3077 | 522418.417 | 4759896.928 | Yes | 556.992 | 557.032 | 0.04 | 557.002 | 557.012 | 557.057 | 789 | 2018 | 1,1,1 | LIPT | |
| 3078 | 481393.142 | 4746327.514 | Yes | 584.619 | 584.626 | 0.007 | 584.584 | 584.63 | 584.644 | 1148 | 1527 | 1,1,1 | LIPT | |
| 3079 | 521035.985 | 4748234.438 | Yes | 519.168 | 519.139 | -0.029 | 519.114 | 519.115 | 519.151 | 1088 | -161 | 1,1,1 | LIPT | |
| 3080 | 543168.773 | 4753163.474 | Yes | 468.389 | 468.354 | -0.035 | 468.312 | 468.357 | 468.357 | 977 | -1336 | 1,1,1 | LIPT | |
| 3076B | 496928.735 | 4755059.248 | Yes | 588.323 | 588.368 | 0.045 | 588.339 | 588.356 | 588.37 | 1003 | 146 | 1,1,1 | LIPT | |

| ID | X | Y | Coverage | Z | Z From LiDAR NVA or VVA | Z Error | Minimum Z | Median Z | Maximum Z | Intensity | Scan Angle Rank | Returns | Description | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3052 | 504001.692 | 4707218.42 | Yes | 639.924 | 640 | 0.076 | 639.952 | 639.975 | 640.011 | 1015 | -226 | 1,1,1 | LIPT | |
| 3061 | 488281.879 | 4715788.407 | Yes | 655.432 | 655.491 | 0.059 | 655.446 | 655.465 | 655.516 | 1140 | 176 | 1,1,1 | LIPT | |
| 3059 | 569535.179 | 4638336.848 | Yes | 593.941 | 593.999 | 0.058 | 593.989 | 594.006 | 594.018 | 1156 | 270 | 1,1,1 | LIPT | |
| 3049 | 547455.445 | 4701624.413 | Yes | 592.777 | 592.83 | 0.053 | 592.807 | 592.842 | 592.861 | 660 | 956 | 1,1,1 | LIPT | |
| 3071 | 544887.075 | 4687171.849 | Yes | 579.936 | 579.984 | 0.048 | 579.948 | 579.978 | 579.992 | 783 | 1648 | 1,1,1 | LIPT | |
| 3054B | 575888.599 | 4648819.072 | Yes | 585.17 | 585.217 | 0.047 | 585.206 | 585.231 | 585.241 | 907 | 1096 | 1,1,1 | LIPT | |
| 3065 | 483100.32 | 4706080.08 | Yes | 679.987 | 680.021 | 0.034 | 680.017 | 680.021 | 680.06 | 1560 | -743 | 1,1,1 | LIPT | |
| 3073 | 514331.289 | 4664453.497 | Yes | 668.876 | 668.906 | 0.03 | 668.875 | 668.88 | 668.916 | 1512 | 2543 | 1,1,1 | LIPT | |
| 3066 | 486980.223 | 4682819.234 | Yes | 708.269 | 708.296 | 0.027 | 708.29 | 708.291 | 708.299 | 1251 | -2386 | 1,1,1 | LIPT | |
| 3055 | 562115.988 | 4614885.468 | Yes | 610.784 | 610.811 | 0.027 | 610.792 | 610.799 | 610.84 | 935 | -2310 | 1,1,1 | LIPT | |
| 3048B | 554363.284 | 4679172.213 | Yes | 564.339 | 564.361 | 0.022 | 564.337 | 564.356 | 564.374 | 828 | 2375 | 1,1,1 | LIPT | |
| 3074 | 572211.995 | 4600461.023 | Yes | 535.739 | 535.754 | 0.015 | 535.734 | 535.748 | 535.758 | 1101 | 2201 | 1,1,1 | LIPT | |
| 3053A | 592976.623 | 4673174.612 | Yes | 535.896 | 535.904 | 0.008 | 535.888 | 535.904 | 535.906 | 1221 | -69 | 1,1,1 | LIPT | |
| 3060 | 527944.193 | 4672572.346 | Yes | 626.083 | 626.086 | 0.003 | 626.065 | 626.082 | 626.106 | 978 | 33 | 1,1,1 | LIPT | |
| 3057 | 513660.431 | 4702980.069 | Yes | 619.556 | 619.559 | 0.003 | 619.533 | 619.544 | 619.603 | 699 | -614 | 1,1,1 | LIPT | |
| 3067C | 559848.924 | 4648623.664 | Yes | 629.799 | 629.799 | 0 | 629.795 | 629.807 | 629.81 | 827 | 1319 | 1,1,1 | LIPT | |
| 3054 | 578076.098 | 4655256.955 | Yes | 584.061 | 584.061 | 0 | 584.035 | 584.067 | 584.081 | 1112 | -2789 | 1,1,1 | LIPT | |
| 3072 | 556173.626 | 4667916.706 | Yes | 604.592 | 604.59 | -0.002 | 604.588 | 604.59 | 604.596 | 1150 | 2136 | 1,1,1 | LIPT | |
| 3070B | 584700.508 | 4687829.109 | Yes | 566.997 | 566.991 | -0.006 | 566.986 | 567.015 | 567.021 | 1058 | 1961 | 1,1,1 | LIPT | |
| 3063 | 528689.468 | 4690295.441 | Yes | 614.324 | 614.317 | -0.007 | 614.275 | 614.321 | 614.328 | 729 | 997 | 1,1,1 | LIPT | |
| 3069B | 501711.836 | 4672444.708 | Yes | 684.711 | 684.69 | -0.021 | 684.678 | 684.694 | 684.694 | 773 | 41 | 1,1,1 | LIPT | |
| 3070 | 580138.195 | 4682641.387 | Yes | 590.613 | 590.59 | -0.023 | 590.575 | 590.592 | 590.595 | 1279 | 291 | 1,1,1 | LIPT | |
| 3063B | 528698.356 | 4686908.497 | Yes | 620.245 | 620.214 | -0.031 | 620.184 | 620.212 | 620.222 | 828 | 2295 | 1,1,1 | LIPT | |
| 3056 | 494274.819 | 4661190.773 | Yes | 710.26 | 710.229 | -0.031 | 710.196 | 710.226 | 710.269 | 926 | 79 | 1,1,1 | LIPT | |
| 3061B | 495947.923 | 4717350.003 | Yes | 647.891 | 647.854 | -0.037 | 647.837 | 647.849 | 647.895 | 1213 | -973 | 1,1,1 | LIPT | |
| 3064 | 567687.866 | 4668833.984 | Yes | 546.147 | 546.105 | -0.042 | 546.089 | 546.091 | 546.127 | 1007 | -673 | 1,1,1 | LIPT | |
| 3062 | 591073.777 | 4695684.667 | Yes | 510.434 | 510.391 | -0.043 | 510.389 | 510.395 | 510.396 | 861 | -548 | 1,1,1 | LIPT | |
| 3058 | 528828.33 | 4661284.34 | Yes | 629.938 | 629.888 | -0.05 | 629.879 | 629.893 | 629.902 | 1094 | -144 | 1,1,1 | LIPT | |
| 3069A | 503011.523 | 4689323.033 | Yes | 673.376 | 673.324 | -0.052 | 673.311 | 673.366 | 673.411 | 546 | 402 | 1,1,1 | LIPT | |
| 3068 | 594395.02 | 4689435.96 | Yes | 536.714 | 536.64 | -0.074 | 536.6 | 536.613 | 536.648 | 1180 | -1539 | 1,1,1 | LIPT | |
| 3048 | 553790.853 | 4678752.249 | Yes | 566.361 | 566.278 | -0.083 | 566.272 | 566.293 | 566.298 | 569 | 1688 | 1,1,1 | LIPT | |

| ID | X | Y | Coverage | Z | Z From LiDAR NVA or VVA | Z Error | Minimum Z | Median Z | Maximum Z | Intensity | Scan Angle Rank | Returns | Description | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3001 | 596998.512 | 4526851.048 | Yes | 533.926 | 534.012 | 0.086 | 533.953 | 534.029 | 534.033 | 393 | 1335 | 1,1,1 | LIPT | |
| 3002A | 680616.188 | 4588684.443 | Yes | 394.451 | 394.449 | -0.002 | 394.439 | 394.45 | 394.46 | 1038 | 779 | 1,1,1 | LIPT | |
| 3003 | 698986.596 | 4580440.313 | Yes | 389.551 | 389.53 | -0.021 | 389.525 | 389.542 | 389.545 | 948 | 2119 | 1,1,1 | LIPT | |
| 3004 | 675787.485 | 4620154.119 | Yes | 444.213 | 444.179 | -0.034 | 444.168 | 444.175 | 444.229 | 847 | -2974 | 1,1,1 | LIPT | |
| 3005 | 611227.87 | 4574227.836 | Yes | 473.626 | 473.644 | 0.018 | 473.605 | 473.645 | 473.673 | 640 | -2471 | 1,1,1 | LIPT | |
| 3005B | 614074.717 | 4575990.338 | Yes | 469.406 | 469.461 | 0.055 | 469.435 | 469.461 | 469.468 | 915 | 898 | 1,1,1 | LIPT | |
| 3006 | 684227.954 | 4563945.588 | Yes | 414.814 | 414.834 | 0.02 | 414.82 | 414.848 | 414.855 | 597 | -53 | 1,1,1 | LIPT | |
| 3006B | 679546.105 | 4555751.553 | Yes | 422.481 | 422.523 | 0.042 | 422.51 | 422.534 | 422.582 | 1133 | -1264 | 1,1,1 | LIPT | |
| 3007 | 584293.926 | 4534026.493 | Yes | 552.192 | 552.214 | 0.022 | 552.205 | 552.228 | 552.229 | 832 | -1290 | 1,1,1 | LIPT | |
| 3008 | 666830.157 | 4592547.386 | Yes | 408.996 | 408.967 | -0.029 | 408.959 | 408.965 | 408.976 | 1092 | -896 | 1,1,1 | LIPT | |
| 3009 | 569926.008 | 4540971.478 | Yes | 540.597 | 540.649 | 0.052 | 540.643 | 540.645 | 540.689 | 1007 | -2219 | 1,1,1 | LIPT | |
| 3010 | 601674.12 | 4547871.434 | Yes | 532.164 | 532.202 | 0.038 | 532.183 | 532.215 | 532.219 | 674 | 1070 | 1,1,1 | LIPT | |
| 3011 | 597598.6 | 4505944.223 | Yes | 526.043 | 526.042 | -0.001 | 526.037 | 526.038 | 526.058 | 1034 | -1189 | 1,1,1 | LIPT | |
| 3012 | 670142.272 | 4571665.157 | Yes | 459.454 | 459.477 | 0.023 | 459.473 | 459.488 | 459.491 | 930 | 722 | 1,1,1 | LIPT | |
| 3012B | 672187.031 | 4576499.374 | Yes | 448.352 | 448.321 | -0.031 | 448.314 | 448.321 | 448.343 | 887 | 756 | 1,1,1 | LIPT | |
| 3013 | 708007.064 | 4558086.996 | Yes | 343.644 | 343.677 | 0.033 | 343.665 | 343.681 | 343.704 | 1244 | 1310 | 1,1,1 | LIPT | |
| 3014 | 720976.004 | 4545220.994 | Yes | 333.537 | 333.568 | 0.031 | 333.529 | 333.57 | 333.581 | 711 | -747 | 1,1,1 | LIPT | |
| 3015 | 621535.573 | 4560281.888 | Yes | 506.418 | 506.418 | 0 | 506.415 | 506.435 | 506.443 | 692 | -2171 | 1,1,1 | LIPT | |
| 3015B | 627125.268 | 4564411.485 | Yes | 502.889 | 502.898 | 0.009 | 502.888 | 502.9 | 502.955 | 1093 | 2887 | 1,1,1 | LIPT | |
| 3016 | 610661.116 | 4583454.111 | Yes | 477.667 | 477.684 | 0.017 | 477.682 | 477.686 | 477.71 | 1108 | 500 | 1,1,1 | LIPT | |
| 3017A | 627554.013 | 4583754.503 | Yes | 451.618 | 451.639 | 0.021 | 451.622 | 451.637 | 451.648 | 833 | 443 | 1,1,1 | LIPT | |
| 3018 | 695850.036 | 4591806.596 | Yes | 376.889 | 376.87 | -0.019 | 376.834 | 376.869 | 376.895 | 1270 | 1533 | 1,1,1 | LIPT | |
| 3019 | 591648.802 | 4567846.294 | Yes | 499.663 | 499.625 | -0.038 | 499.607 | 499.626 | 499.631 | 749 | -1765 | 1,1,1 | LIPT | |
| 3020 | 562164.194 | 4507144.074 | Yes | 571.399 | 571.363 | -0.036 | 571.348 | 571.37 | 571.374 | 946 | 371 | 1,1,1 | LIPT | |
| 3021 | 577166.37 | 4568498.78 | Yes | 528.618 | 528.59 | -0.028 | 528.586 | 528.597 | 528.607 | 1281 | -536 | 1,1,1 | LIPT | |
| 3022 | 698308.42 | 4547333.548 | Yes | 365.282 | 365.316 | 0.034 | 365.276 | 365.299 | 365.348 | 1149 | 340 | 1,1,1 | LIPT | |
| 3023 | 571714.4 | 4518516.299 | Yes | 559.708 | 559.606 | -0.102 | 559.602 | 559.607 | 559.658 | 698 | 2687 | 1,1,1 | LIPT | |
| 3024 | 627952.741 | 4601504.238 | Yes | 508.539 | 508.534 | -0.005 | 508.524 | 508.535 | 508.538 | 833 | 552 | 1,1,1 | LIPT | |
| 3025 | 700851.258 | 4569205.951 | Yes | 373.291 | 373.325 | 0.034 | 373.307 | 373.314 | 373.336 | 575 | 1965 | 1,1,1 | LIPT | |
| 3025B | 709324.792 | 4566834.417 | Yes | 369.599 | 369.574 | -0.025 | 369.556 | 369.566 | 369.582 | 1217 | 2111 | 1,1,1 | LIPT | |
| 3026 | 659829.694 | 4619760.401 | Yes | 474.472 | 474.448 | -0.024 | 474.425 | 474.459 | 474.492 | 810 | -2410 | 1,1,1 | LIPT | |
| 3027 | 670864.18 | 4549108.477 | Yes | 449.476 | 449.459 | -0.017 | 449.45 | 449.461 | 449.486 | 1129 | 2586 | 1,1,1 | LIPT | |
| 3028 | 608463.745 | 4612452.888 | Yes | 536.576 | 536.568 | -0.008 | 536.554 | 536.58 | 536.582 | 1151 | 37 | 1,1,1 | LIPT | |
| 3028B | 616662.452 | 4617425.396 | Yes | 514.059 | 514.064 | 0.005 | 514.058 | 514.063 | 514.067 | 1009 | 2365 | 1,1,1 | LIPT | |
| 3029 | 684063.767 | 4612269.984 | Yes | 418.364 | 418.307 | -0.057 | 418.294 | 418.299 | 418.324 | 1072 | -2792 | 1,1,1 | LIPT | |
| 3030 | 649047.219 | 4596627.997 | Yes | 450.855 | 450.815 | -0.04 | 450.796 | 450.823 | 450.838 | 1426 | -232 | 1,1,1 | LIPT | |
| 3031 | 652033.89 | 4548717.378 | Yes | 462.713 | 462.782 | 0.069 | 462.759 | 462.781 | 462.788 | 1319 | 1092 | 1,1,1 | LIPT | |
| 3032 | 634933.085 | 4577431.864 | Yes | 449.995 | 449.957 | -0.038 | 449.928 | 449.953 | 449.967 | 921 | -2392 | 1,1,1 | LIPT | |
| 3032B | 638553.299 | 4587693.551 | Yes | 439.386 | 439.419 | 0.033 | 439.416 | 439.422 | 439.427 | 1220 | 668 | 1,1,1 | LIPT | |
| 3033 | 661763.665 | 4606119.861 | Yes | 472.312 | 472.299 | -0.013 | 472.297 | 472.304 | 472.31 | 811 | -2719 | 1,1,1 | LIPT | |
| 3033B | 671294.867 | 4607131.972 | Yes | 423.291 | 423.231 | -0.06 | 423.229 | 423.233 | 423.235 | 1012 | 455 | 1,1,1 | LIPT | |
| 3034 | 570808.265 | 4560332.114 | Yes | 532.999 | 533.033 | 0.034 | 533.02 | 533.033 | 533.044 | 624 | 1327 | 1,1,1 | LIPT | |
| 3034B | 561221.938 | 4560217.759 | Yes | 552.122 | 552.14 | 0.018 | 552.097 | 552.11 | 552.177 | 608 | -2304 | 1,1,1 | LIPT | |
| 3035 | 561950.92 | 4536106.694 | Yes | 552.095 | 552.124 | 0.029 | 552.122 | 552.123 | 552.127 | 568 | -818 | 1,1,1 | LIPT | |
| 3036 | 646470.848 | 4561593.983 | Yes | 476.635 | 476.675 | 0.04 | 476.659 | 476.68 | 476.715 | 884 | 82 | 1,1,1 | LIPT | |
| 3037 | 694621.67 | 4614981.528 | Yes | 381.348 | 381.3 | -0.048 | 381.273 | 381.299 | 381.3 | 768 | -1444 | 1,1,1 | LIPT | |
| 3037B | 696876.835 | 4612350 | Yes | 379.156 | 379.145 | -0.011 | 379.145 | 379.145 | 379.153 | 1378 | -1765 | 1,1,1 | LIPT | |
| 3038 | 710771.462 | 4601618.185 | Yes | 367.596 | 367.599 | 0.003 | 367.597 | 367.599 | 367.617 | 1123 | -1855 | 1,1,1 | LIPT | |
| 3039 | 721601.825 | 4589019.385 | Yes | 351.638 | 351.618 | -0.02 | 351.605 | 351.619 | 351.633 | 829 | 339 | 1,1,1 | LIPT | |
| 3040 | 707830.809 | 4623125.806 | Yes | 399.766 | 399.782 | 0.016 | 399.731 | 399.768 | 399.803 | 776 | 2128 | 1,1,1 | LIPT | |
| 3041 | 715431.851 | 4576124.739 | Yes | 390.812 | 390.779 | -0.033 | 390.773 | 390.783 | 390.801 | 743 | 1512 | 1,1,1 | LIPT | |
| 3042 | 602021.719 | 4620354.54 | Yes | 559.93 | 559.86 | -0.07 | 559.84 | 559.855 | 559.9 | 872 | 1618 | 1,1,1 | LIPT | |
| 3043 | 632307.164 | 4548507.588 | Yes | 502.286 | 502.298 | 0.012 | 502.29 | 502.305 | 502.339 | 902 | 375 | 1,1,1 | LIPT | |
| 3044 | 618530.745 | 4592478.662 | Yes | 462.675 | 462.668 | -0.007 | 462.636 | 462.637 | 462.677 | 1134 | 2372 | 1,1,1 | LIPT | |
| 3044B | 614768.07 | 4596476.725 | Yes | 527.55 | 527.572 | 0.022 | 527.548 | 527.562 | 527.592 | 1330 | -2217 | 1,1,1 | LIPT | |
| 3045 | 562714.329 | 4565084.106 | Yes | 533.199 | 533.221 | 0.022 | 533.199 | 533.232 | 533.236 | 785 | 2077 | 1,1,1 | LIPT | |
| 3046 | 637297.364 | 4619388.382 | Yes | 499.851 | 499.787 | -0.064 | 499.782 | 499.8 | 499.824 | 1038 | -2292 | 1,1,1 | LIPT | |
| 3047 | 600240.383 | 4597893.519 | Yes | 510.829 | 510.851 | 0.022 | 510.821 | 510.857 | 510.864 | 805 | 1622 | 1,1,1 | LIPT | |

**Table 3 –surveyed ground control points (GCPs).**

This project must meet Non-vegetated Vertical Accuracy (NVA) ≤ 0.64 ft (19.6 cm) at the 95% confidence level based on $RMSE_z$ ≤ 0.33 ft (10 cm) x 1.9600.

Project Data Unit: Meter
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0-118, 120-255

Check Points in Report: 7
Check Points with LiDAR Coverage: 7
Check Points (NVA): 7
Check Points (VVA): 0
Average Vertical Error Reported: 0.000 Meter
Maximum (highest) Vertical Error Reported: 0.045 Meter
Median Vertical Error Reported: -0.001 Meter
Minimum (lowest) Vertical Error Reported: -0.035 Meter
Standard deviation of Vertical Error: 0.033 Meter
Skewness of Vertical Error: 0.372
Kurtosis of Vertical Error: -1.440
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 3.066cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 6.010cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 6.010cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 2.848cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 5.582cm PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 3.066cm, equating to +/- 6.010cm at the 95% confidence level.

Project Data Unit: Meter
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0-118, 120-255

Check Points in Report: 31
Check Points with LiDAR Coverage: 31
Check Points (NVA): 31
Check Points (VVA): 0
Average Vertical Error Reported: 0.000 Meter
Maximum (highest) Vertical Error Reported: 0.076 Meter
Median Vertical Error Reported: 0.000 Meter
Minimum (lowest) Vertical Error Reported: -0.083 Meter
Standard deviation of Vertical Error: 0.041 Meter
Skewness of Vertical Error: -0.124
Kurtosis of Vertical Error: -0.744
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 4.007cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 7.854cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 7.854cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 4.417cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 8.658cm PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 4.007cm, equating to +/- 7.854cm at the 95% confidence level.

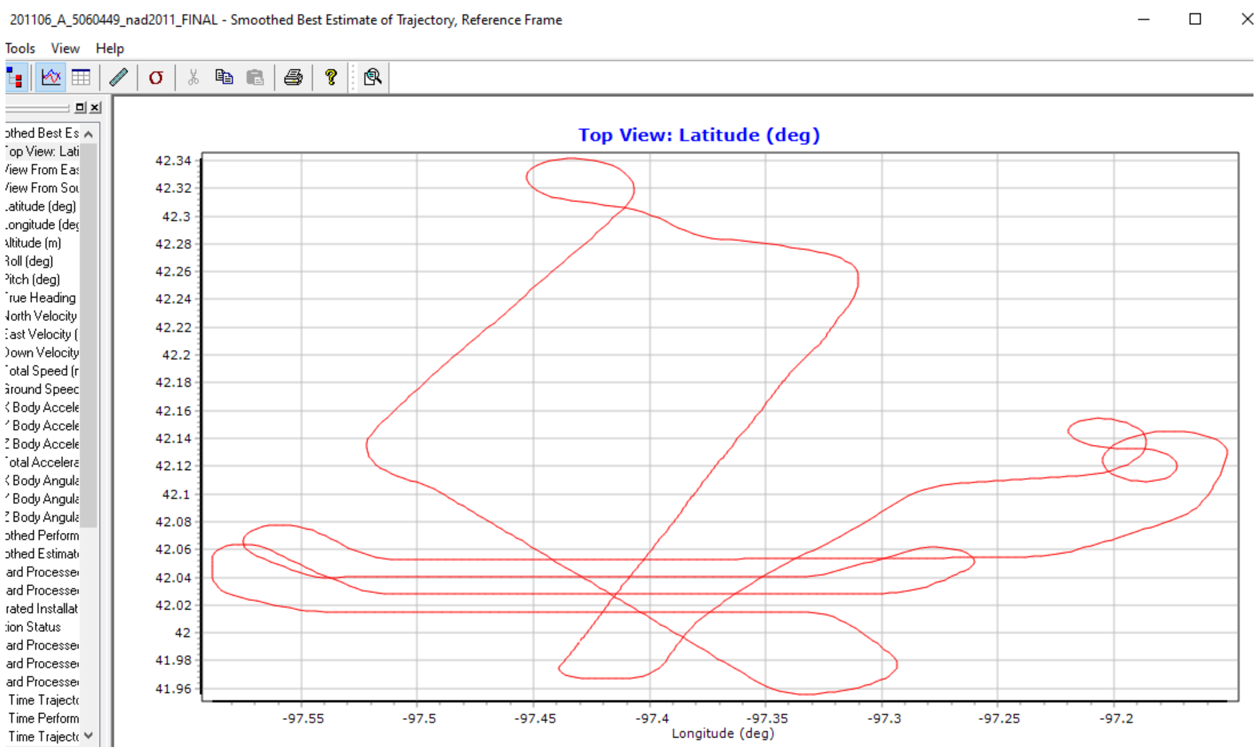
Project Data Unit: Meter
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0-118, 120-255

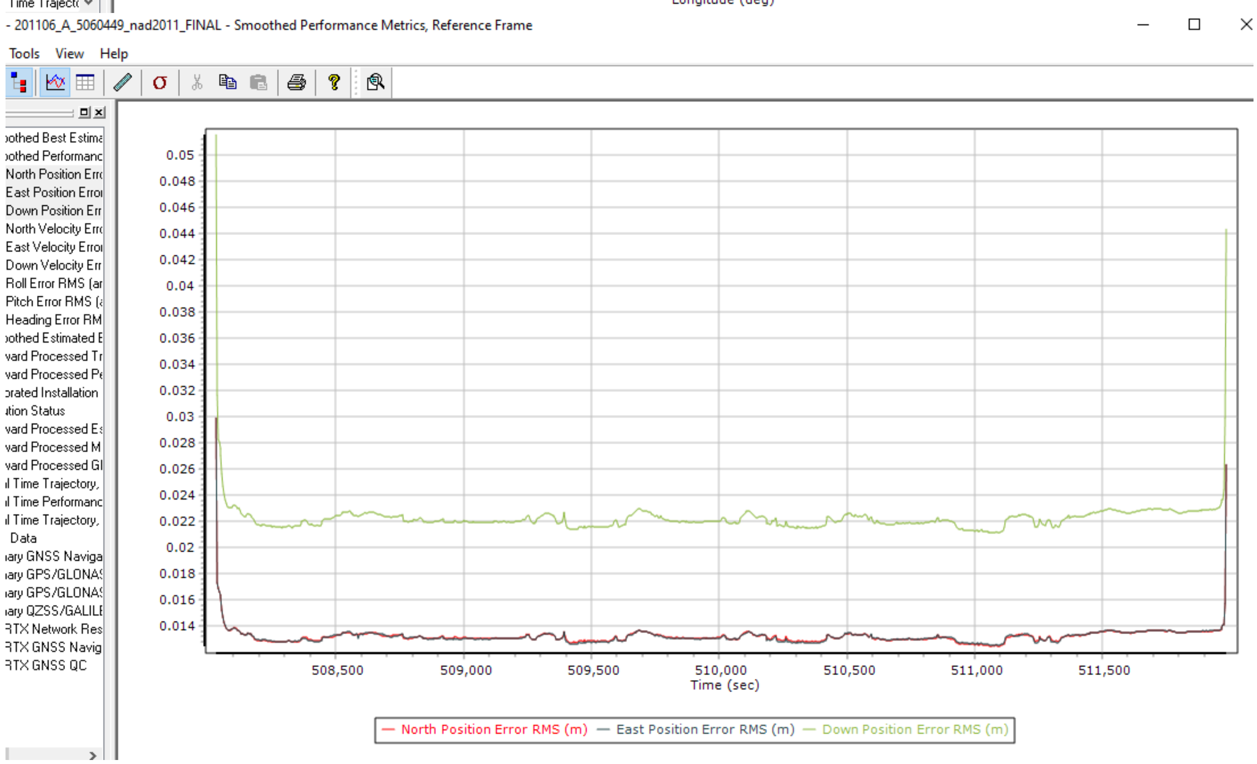
Check Points in Report: 58
Check Points with LiDAR Coverage: 58
Check Points (NVA): 58
Check Points (VVA): 0
Average Vertical Error Reported: 0.000 Meter
Maximum (highest) Vertical Error Reported: 0.086 Meter
Median Vertical Error Reported: 0.002 Meter
Minimum (lowest) Vertical Error Reported: -0.102 Meter
Standard deviation of Vertical Error: 0.037 Meter
Skewness of Vertical Error: -0.260
Kurtosis of Vertical Error: -0.052
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 3.648cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 7.150cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 7.150cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 3.929cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 7.701cm PASS

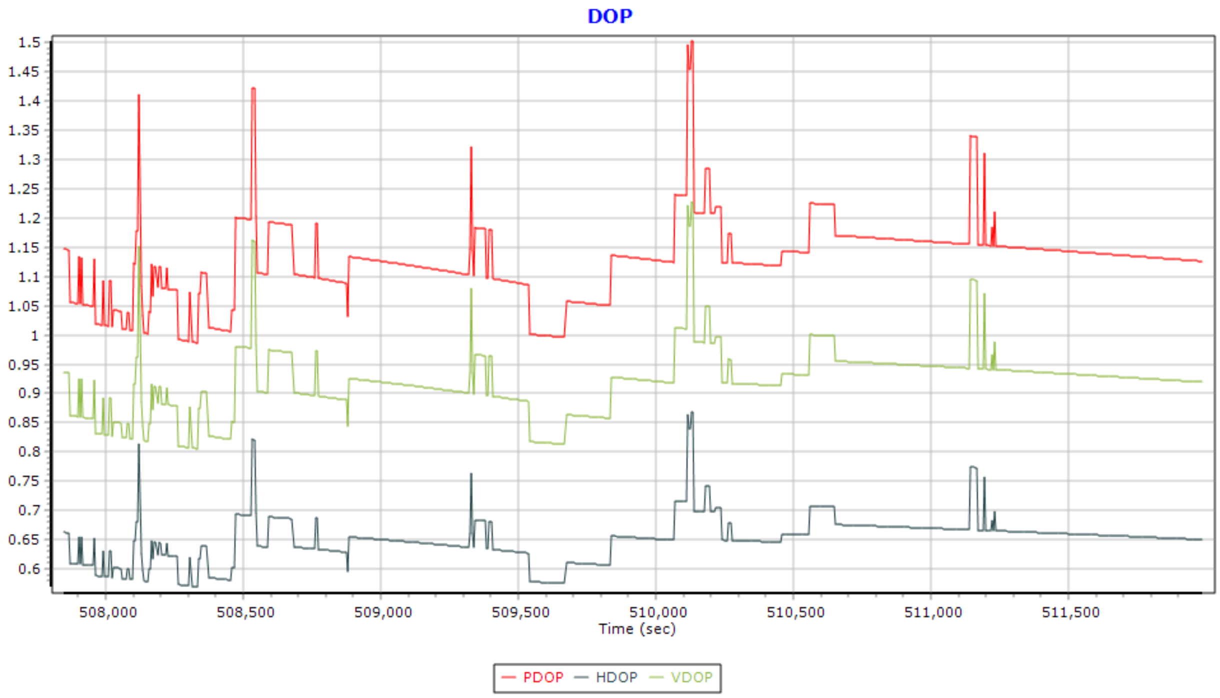
This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 3.648cm, equating to +/- 7.150cm at the 95% confidence level.

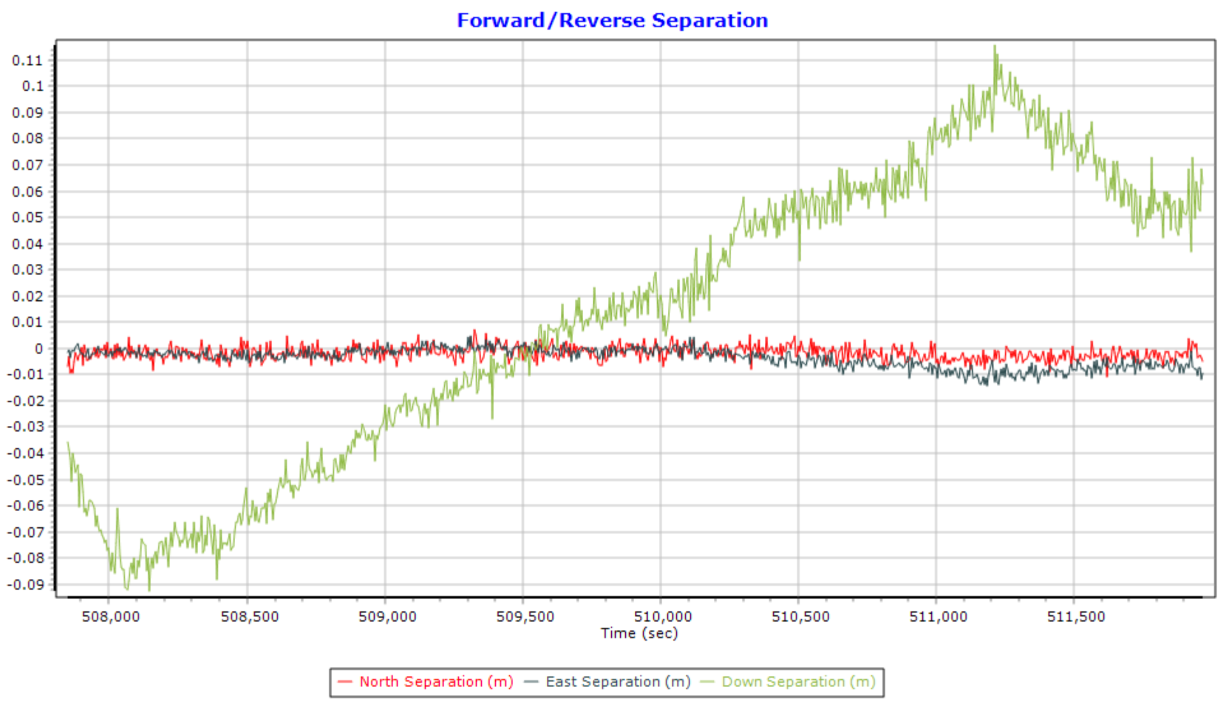
**Table 4 - Ground control points (GCPs) vertical accuracy results.**

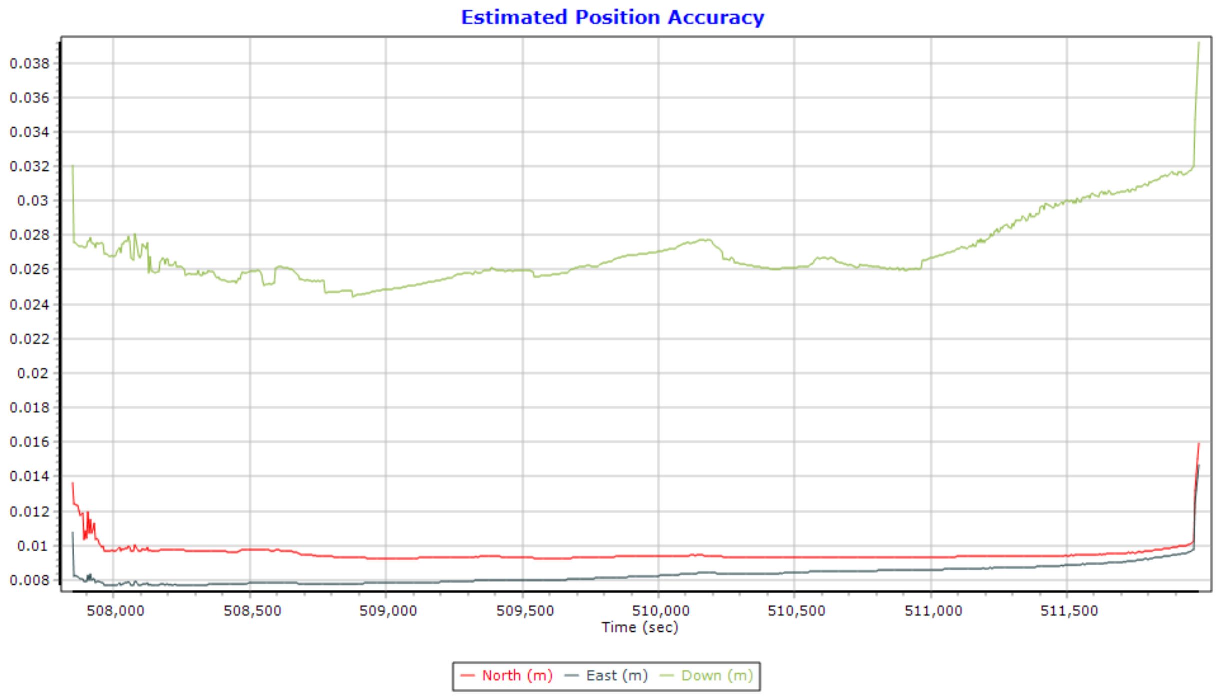
# Appendix A: GNSS and IMU Processing Reports for Each Mission

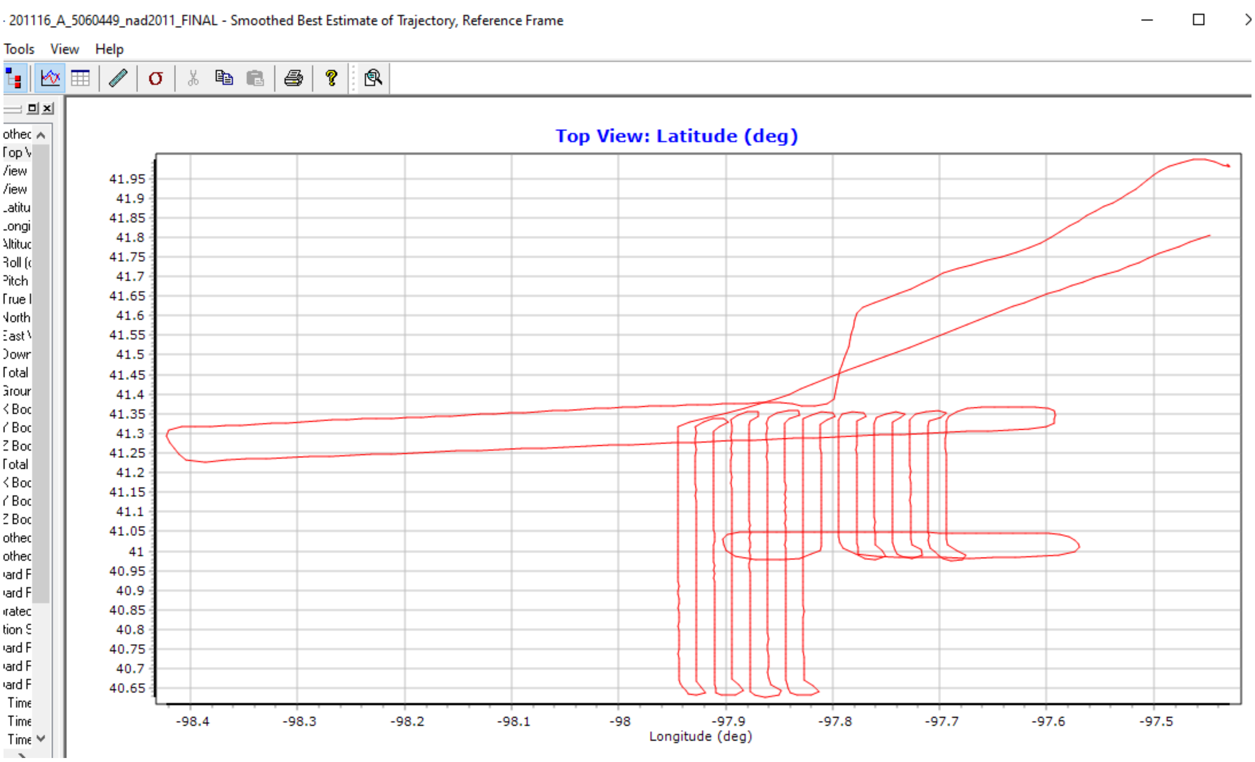


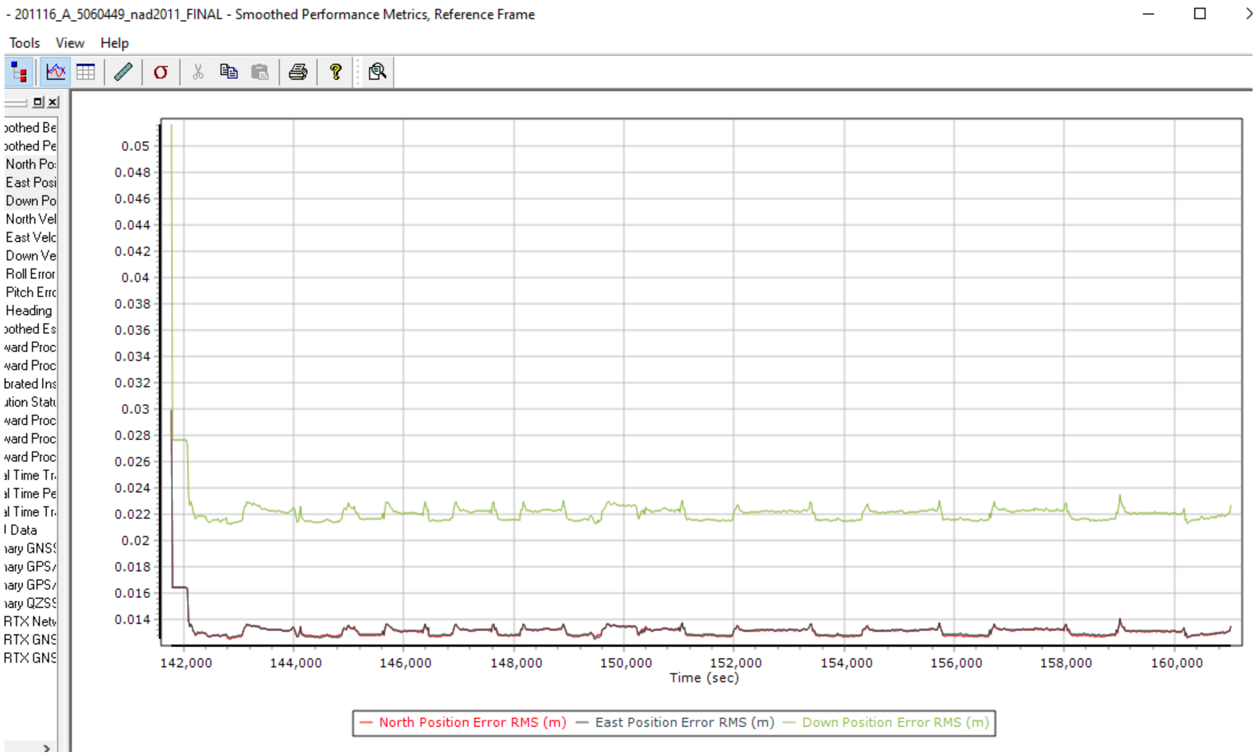



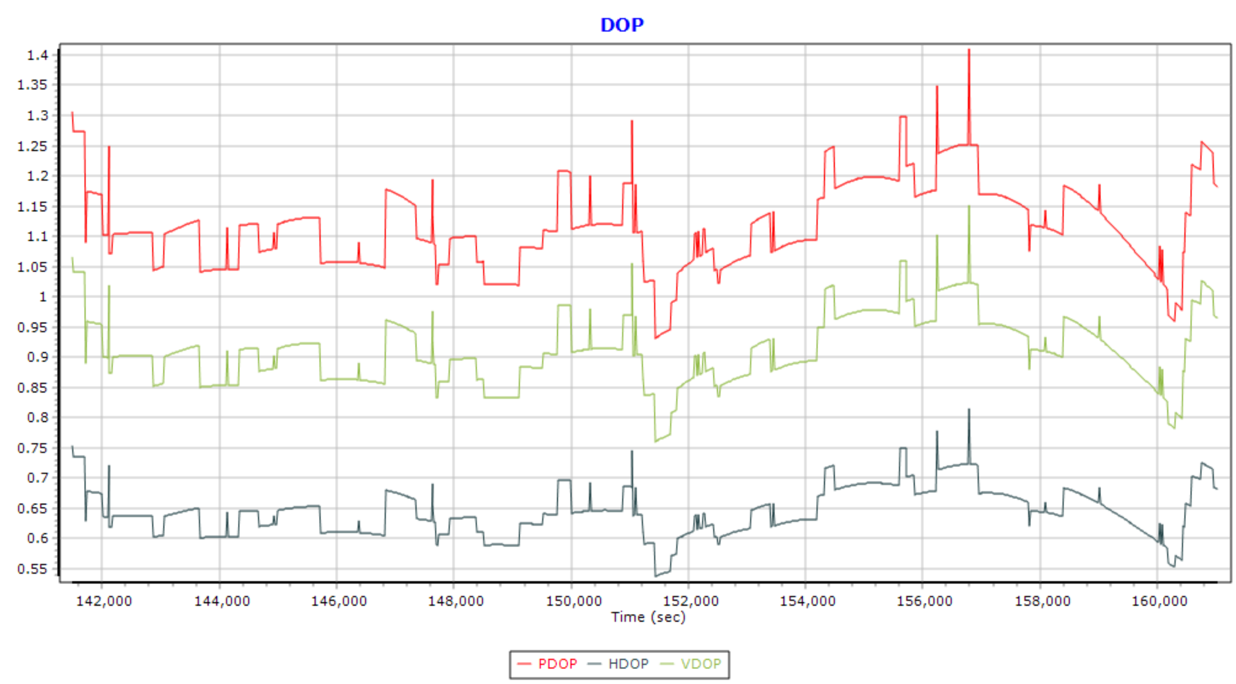

DOP
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
508,000
508,500
509,000
509,500
510,000
510,500
511,000
511,500
Time (sec)
PDOP
HDOP
VDOP

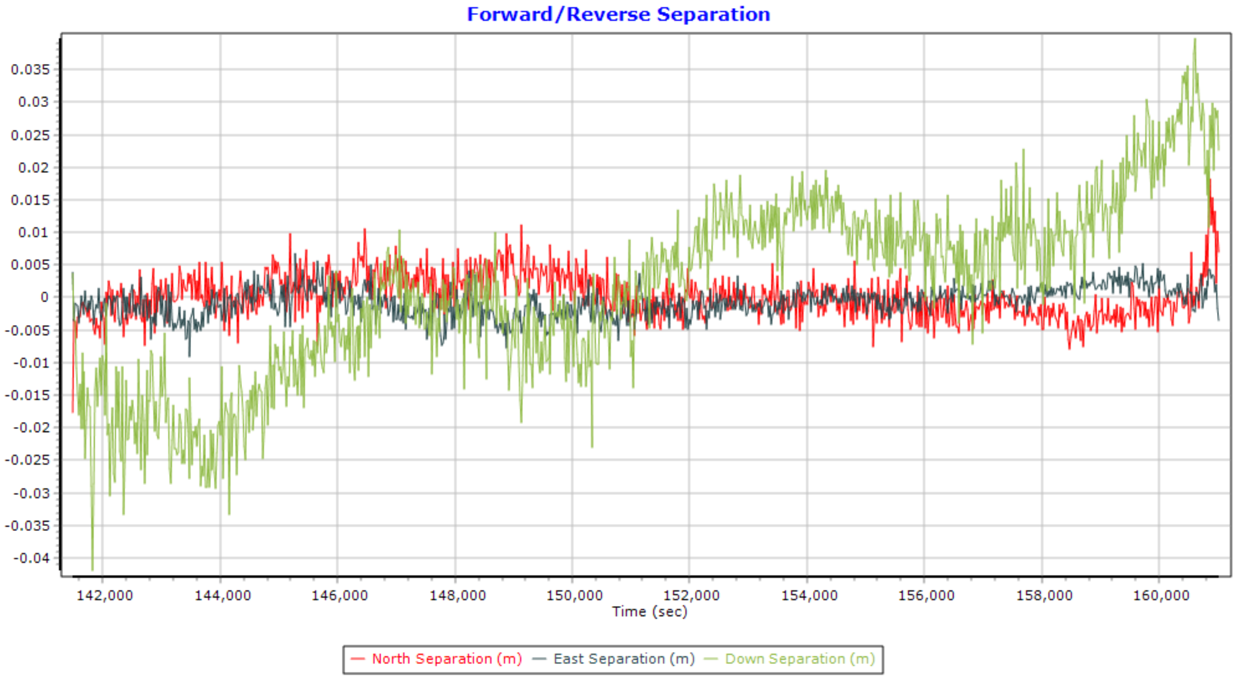

Forward/Reverse Separation
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
508,000
508,500
509,000
509,500
510,000
510,500
511,000
511,500
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

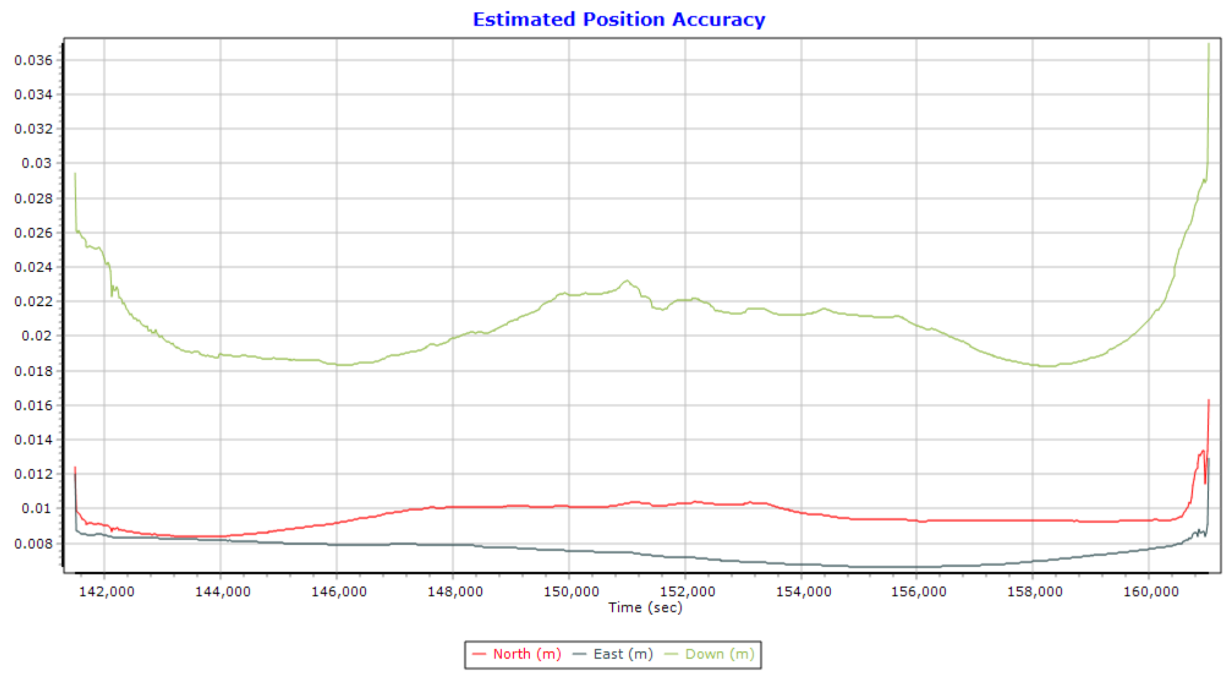

Estimated Position Accuracy
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
508,000
508,500
509,000
509,500
510,000
510,500
511,000
511,500
Time (sec)
North (m)
East (m)
Down (m)

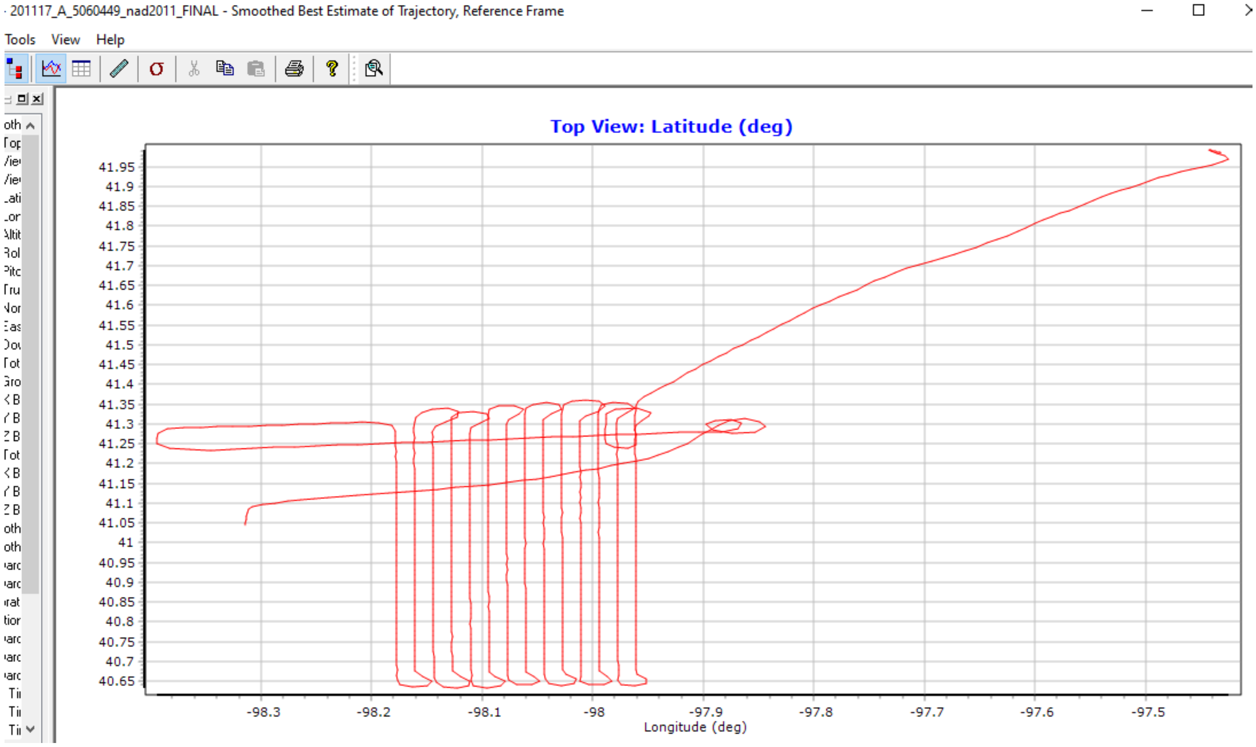

201116_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
41.95
41.9
41.85
41.8
41.75
41.7
41.65
41.6
41.55
41.5
41.45
41.4
41.35
41.3
41.25
41.2
41.15
41.1
41.05
41
40.95
40.9
40.85
40.8
40.75
40.7
40.65
-98.4
-98.3
-98.2
-98.1
-98
-97.9
-97.8
-97.7
-97.6
-97.5
Longitude (deg)

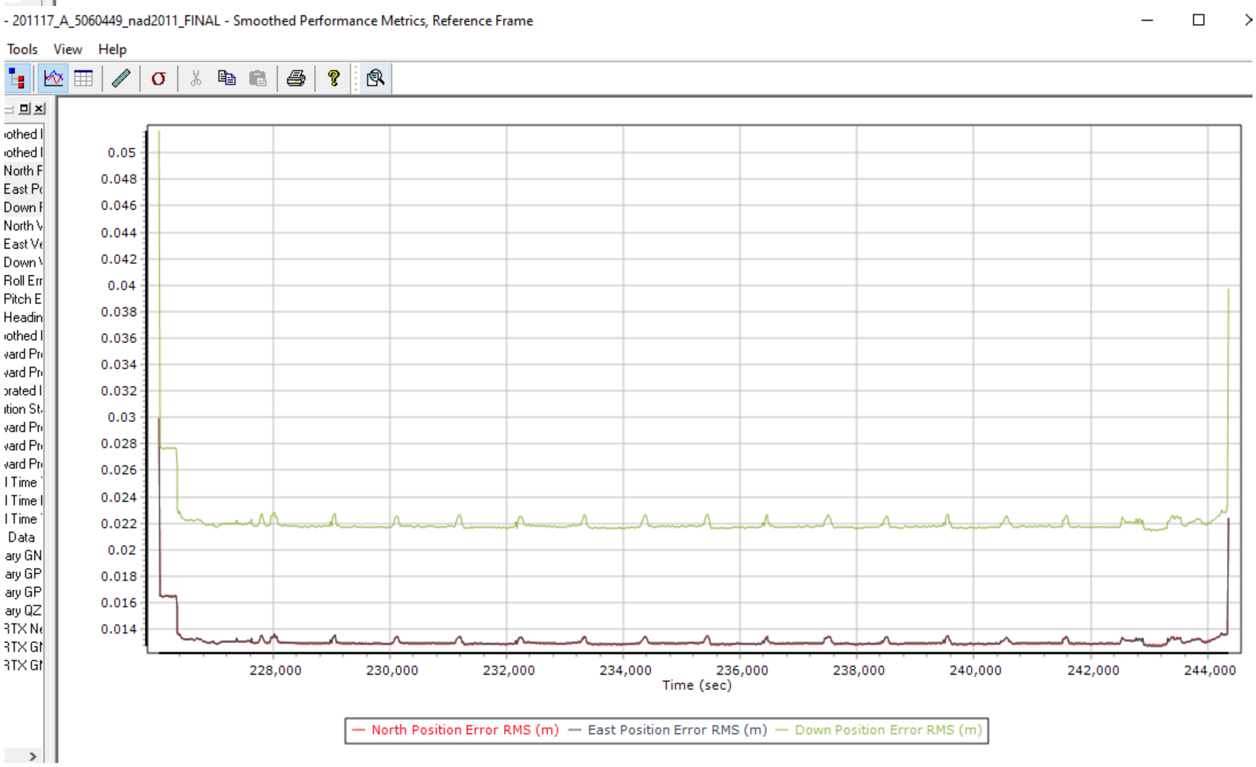

- 201116_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

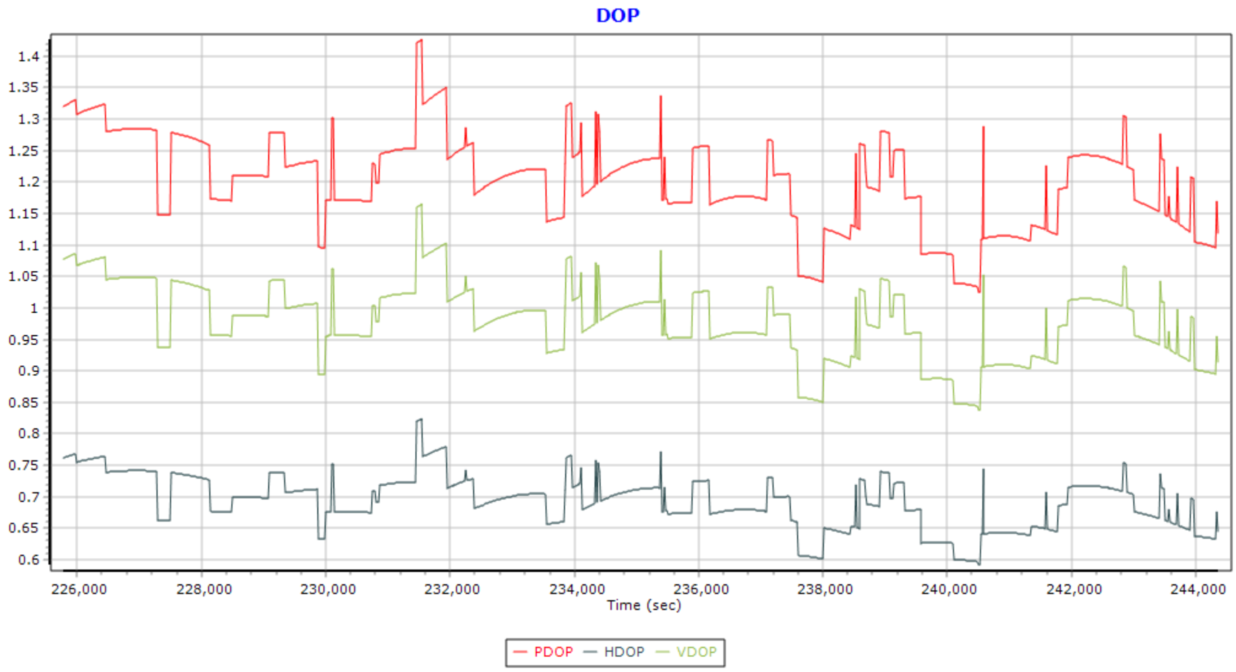

DOP
Time (sec)
PDOP
HDOP
VDOP


Forward/Reverse Separation
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
158,000
160,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)


Estimated Position Accuracy
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
158,000
160,000
Time (sec)
North (m)
East (m)
Down (m)


201117_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
41.95
41.9
41.85
41.8
41.75
41.7
41.65
41.6
41.55
41.5
41.45
41.4
41.35
41.3
41.25
41.2
41.15
41.1
41.05
41
40.95
40.9
40.85
40.8
40.75
40.7
40.65
-98.3
-98.2
-98.1
-98
-97.9
-97.8
-97.7
-97.6
-97.5
Longitude (deg)


201117_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
228,000
230,000
232,000
234,000
236,000
238,000
240,000
242,000
244,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)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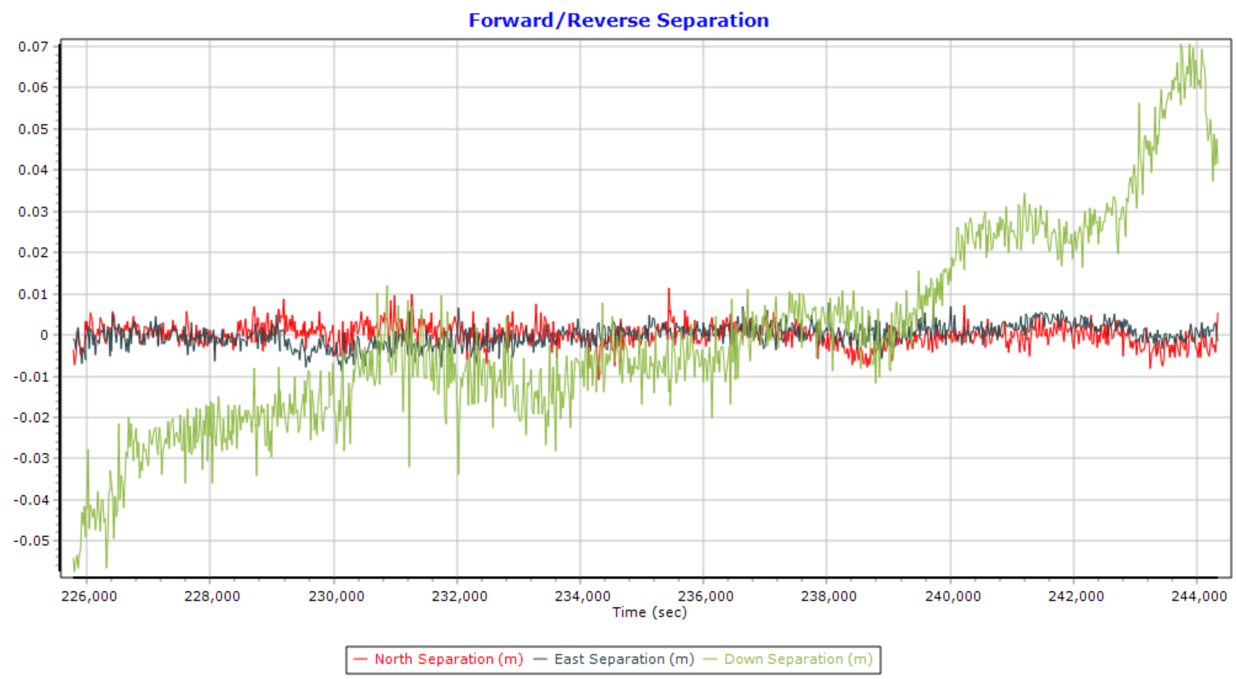
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
242,000
244,000
Time (sec)
PDOP
HDOP
VDOP


Forward/Reverse Separation
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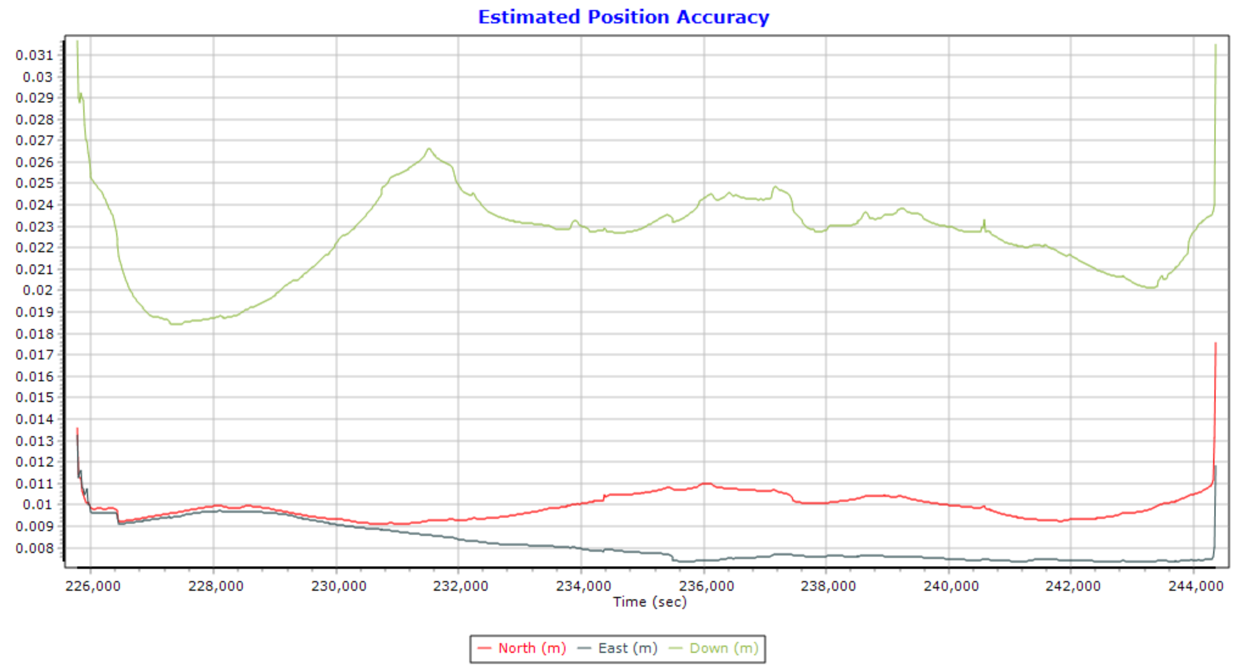
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
242,000
244,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)


Estimated Position Accuracy
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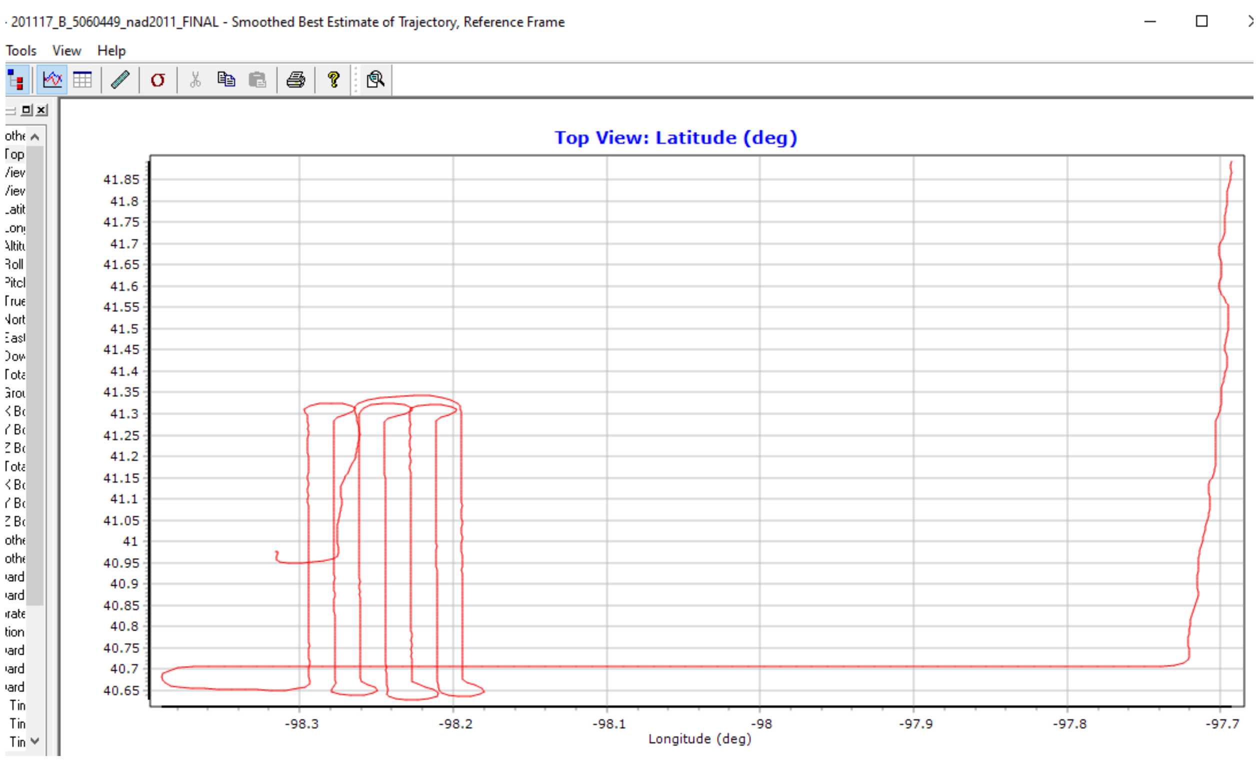
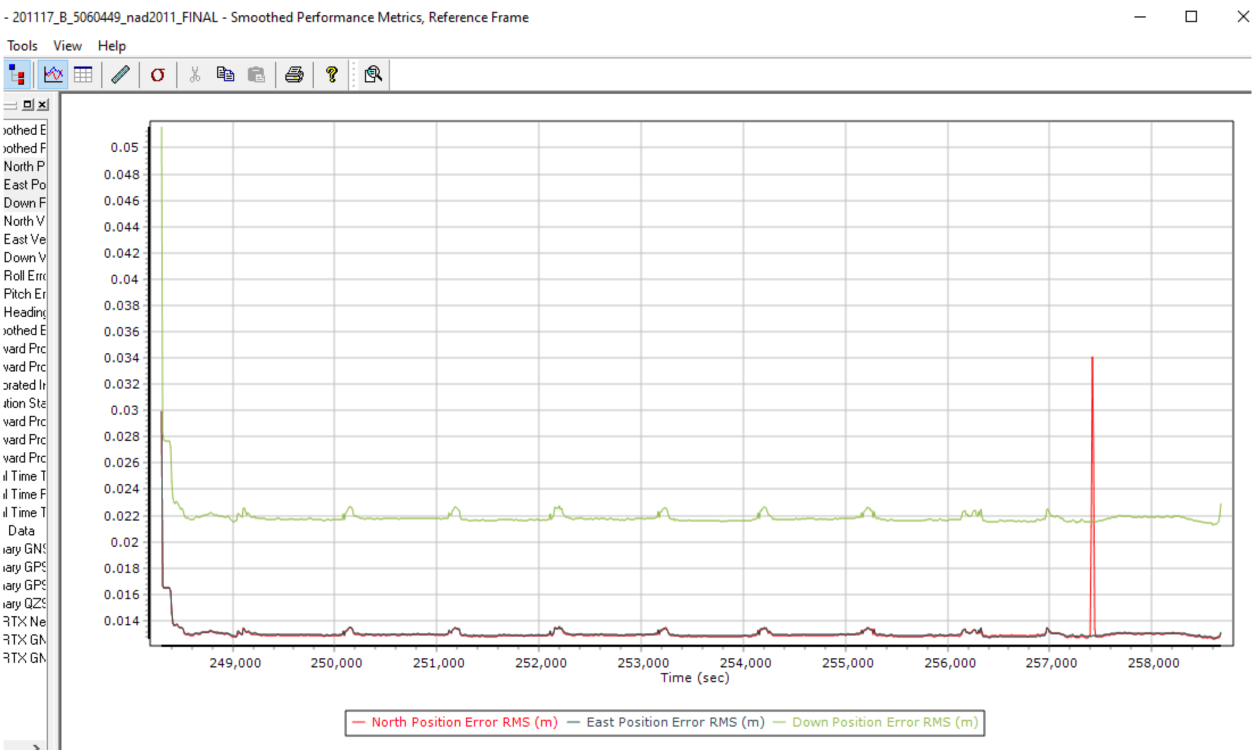
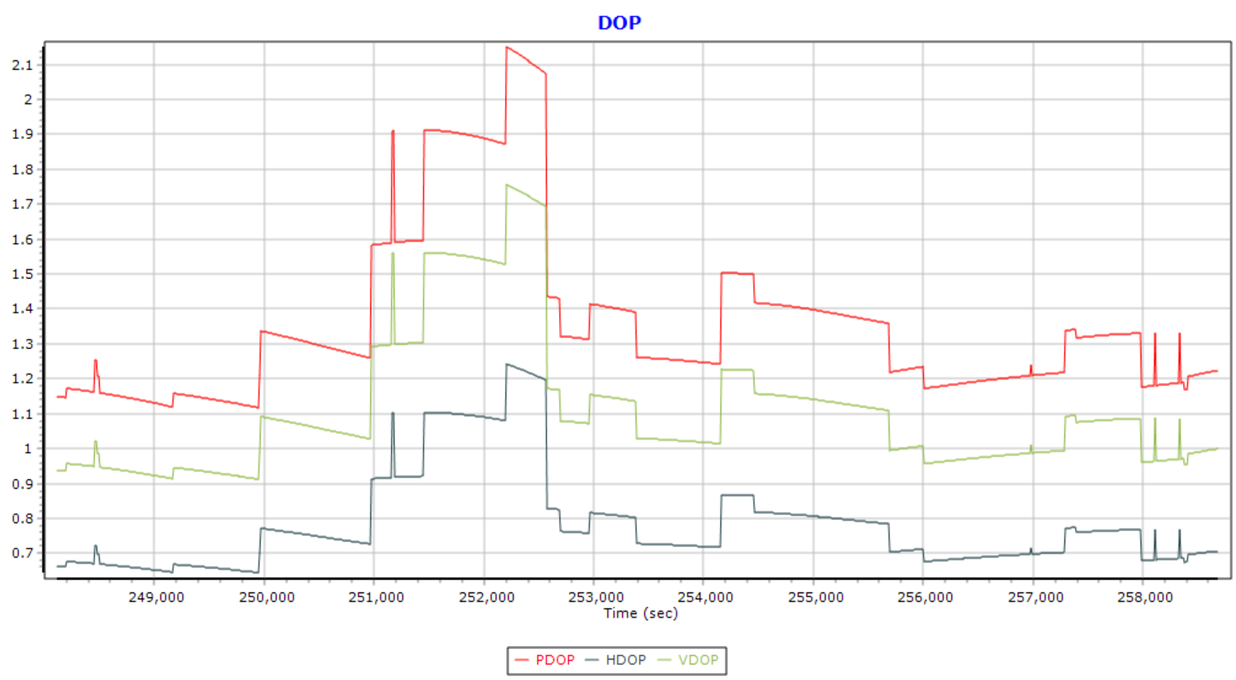
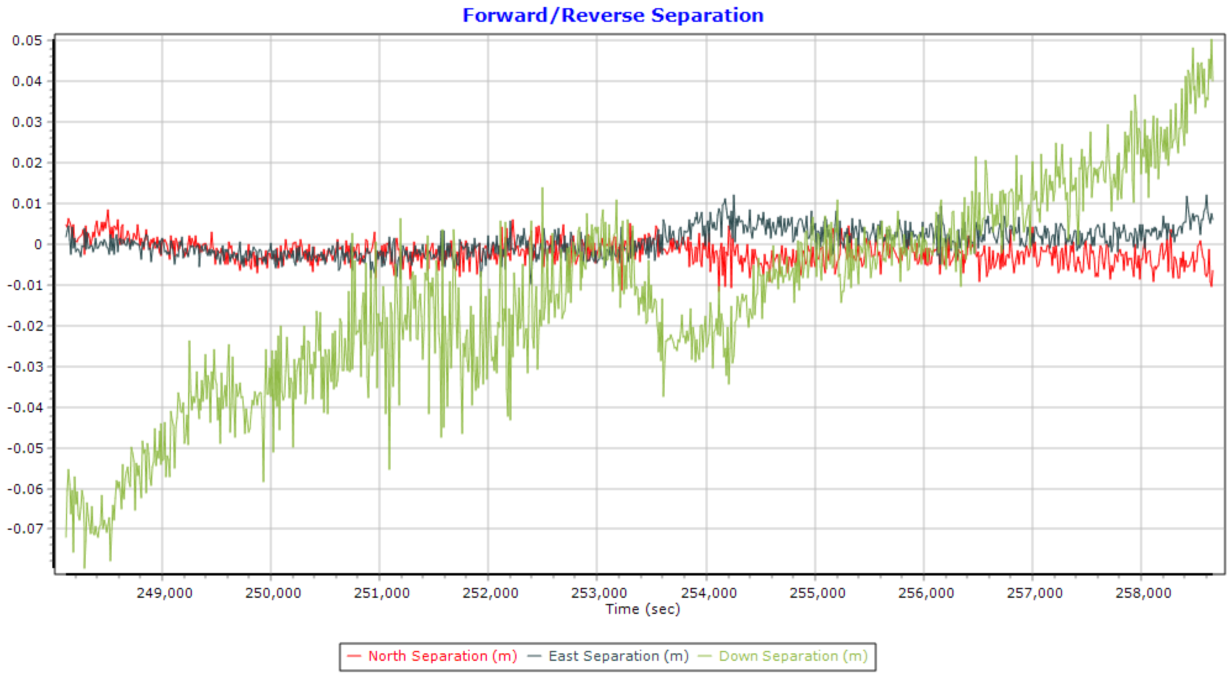
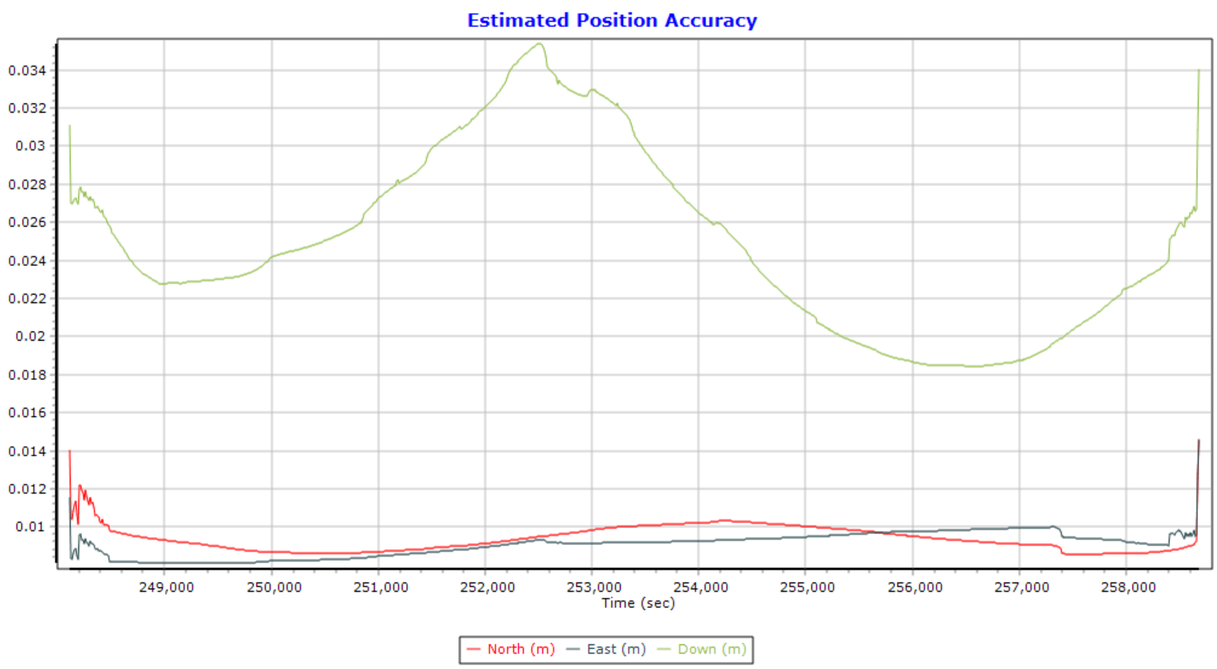
0.03
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
242,000
244,000
Time (sec)
North (m)
East (m)
Down (m)

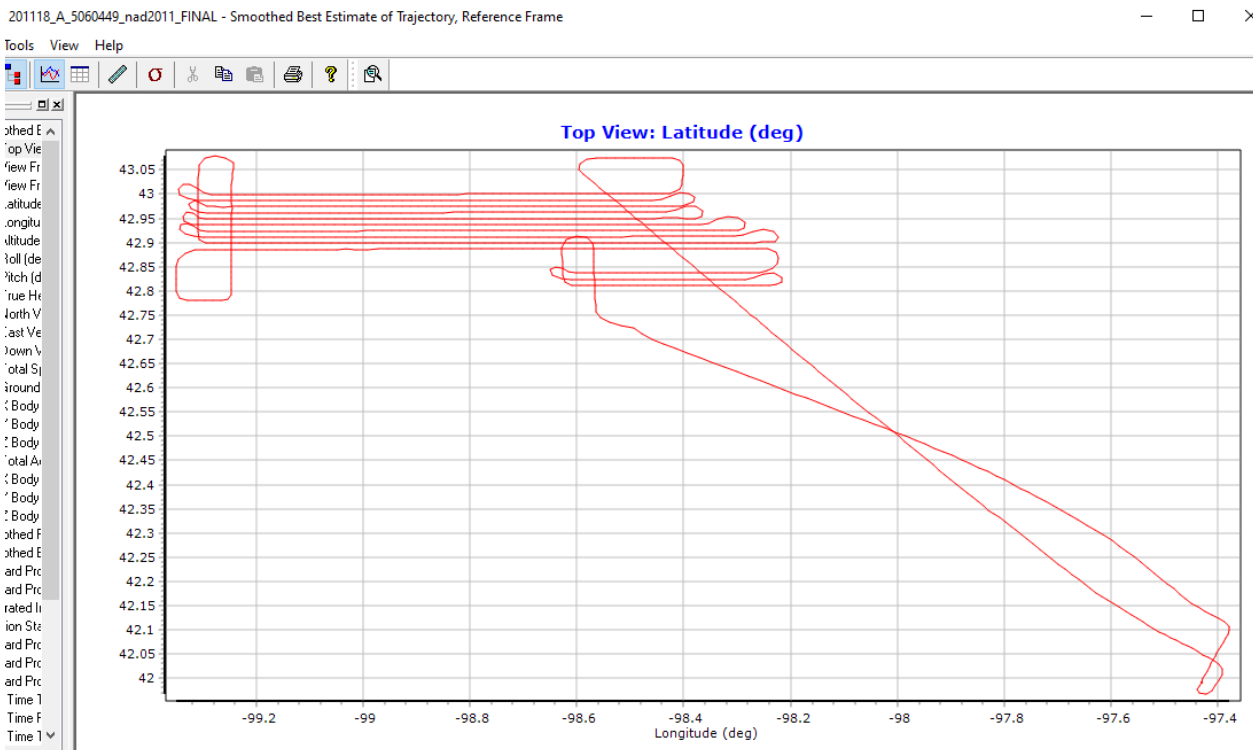

201117_B_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
41.85
41.8
41.75
41.7
41.65
41.6
41.55
41.5
41.45
41.4
41.35
41.3
41.25
41.2
41.15
41.1
41.05
41
40.95
40.9
40.85
40.8
40.75
40.7
40.65
-98.3
-98.2
-98.1
-98
-97.9
-97.8
-97.7
Longitude (deg)

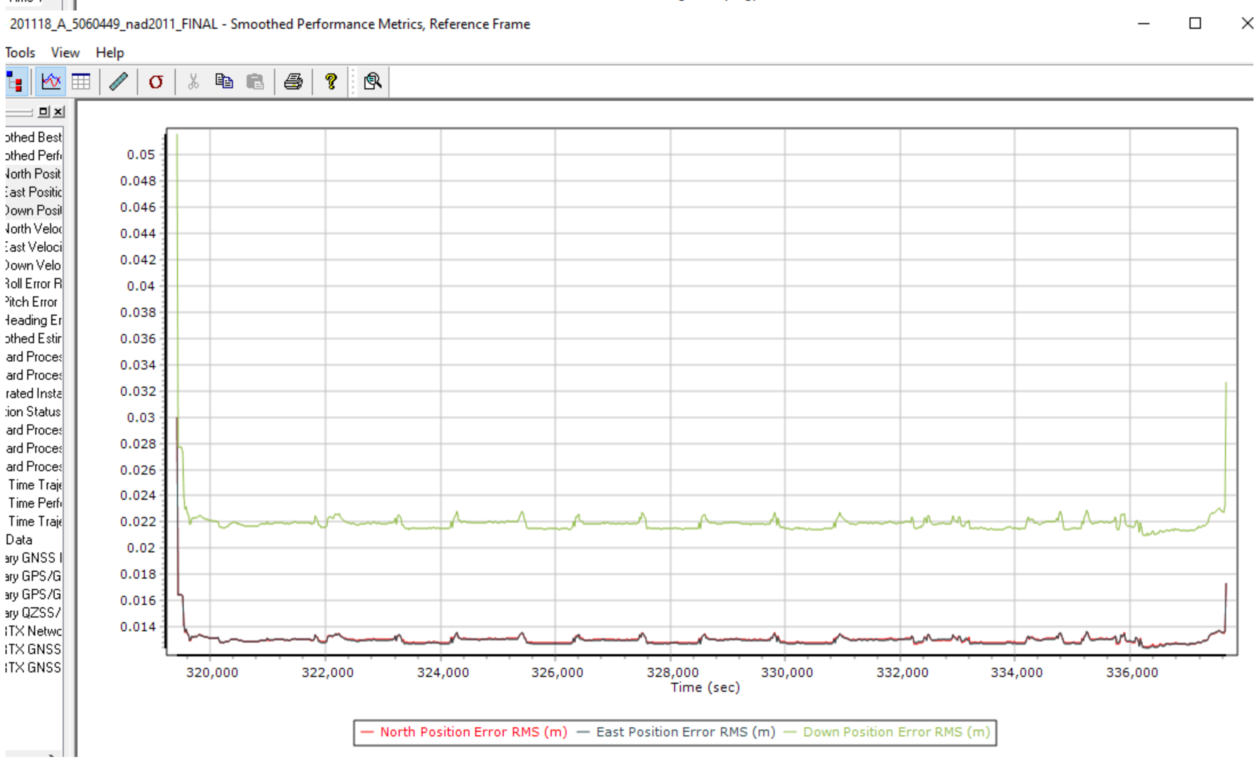

- 201117_B_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
249,000
250,000
251,000
252,000
253,000
254,000
255,000
256,000
257,000
258,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

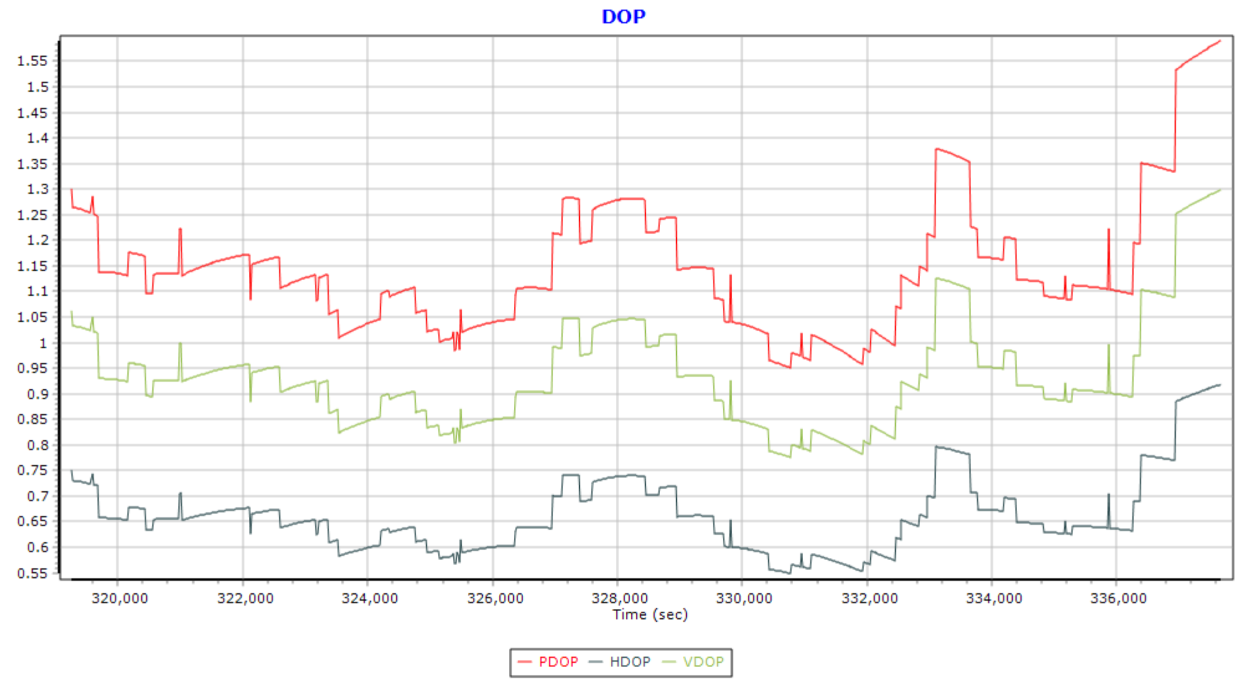

DOP
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
249,000
250,000
251,000
252,000
253,000
254,000
255,000
256,000
257,000
258,000
Time (sec)
PDOP
HDOP
VDOP

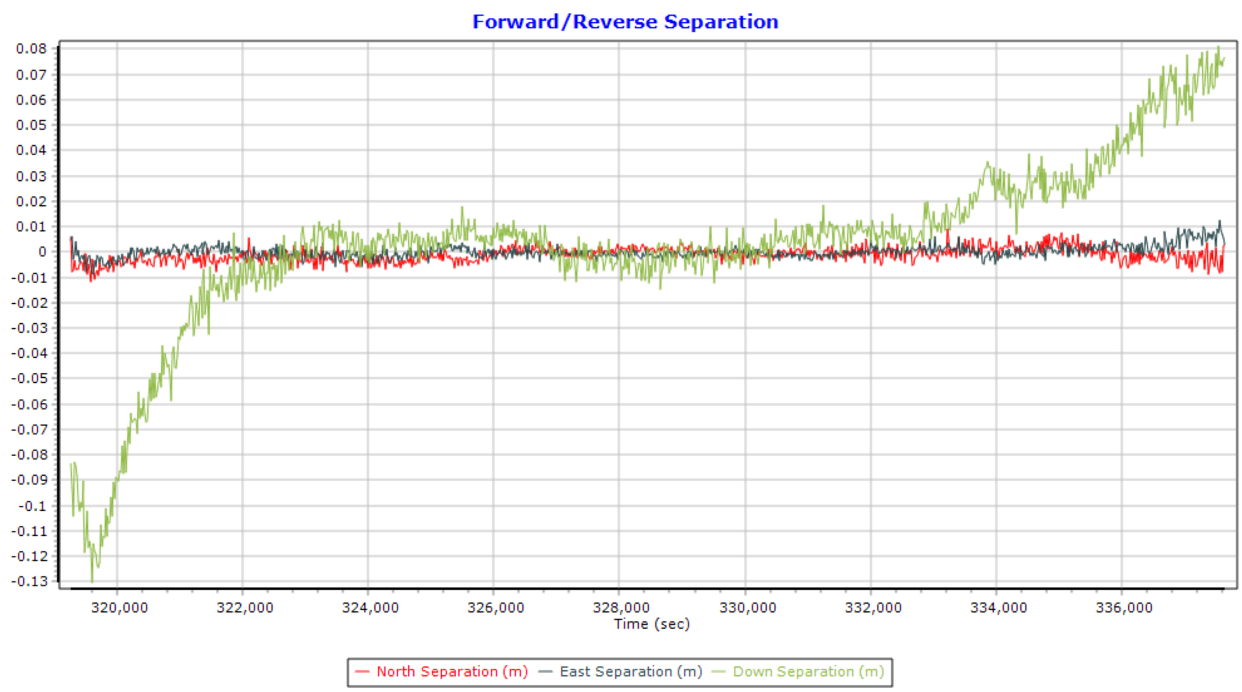

Forward/Reverse Separation
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
249,000
250,000
251,000
252,000
253,000
254,000
255,000
256,000
257,000
258,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

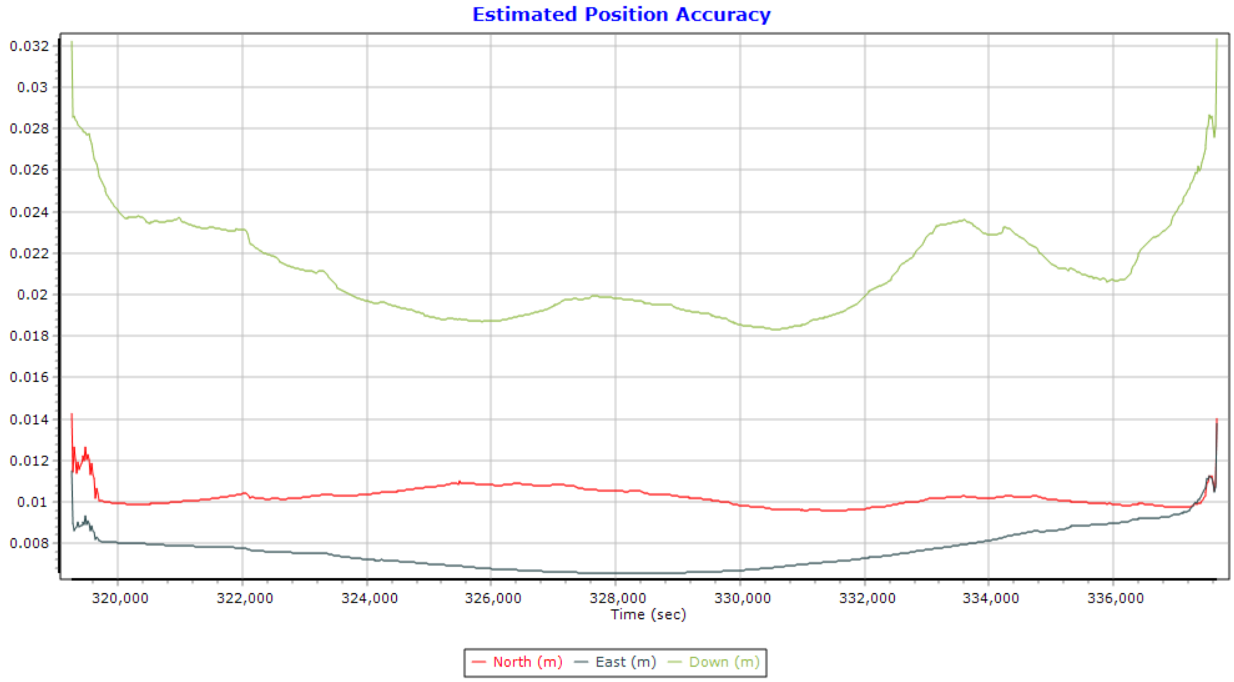

Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
249,000
250,000
251,000
252,000
253,000
254,000
255,000
256,000
257,000
258,000
Time (sec)
North (m)
East (m)
Down (m)

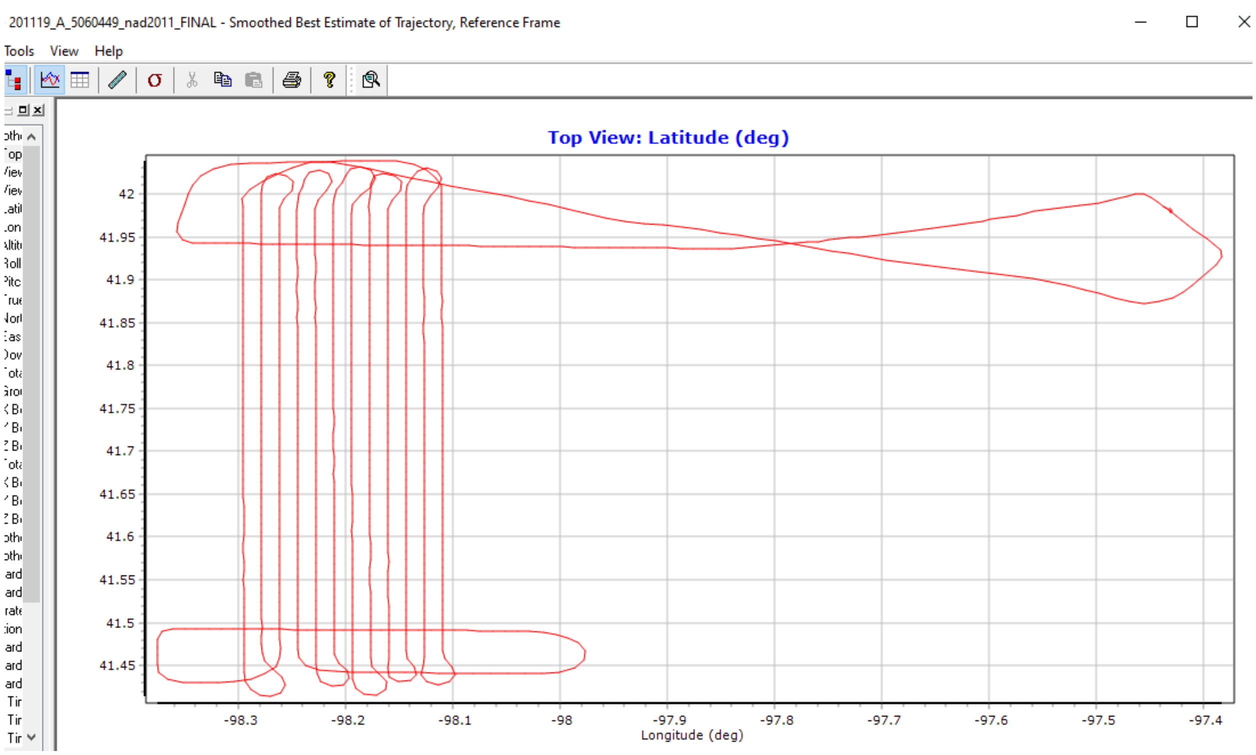

201118_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
43.05
43
42.95
42.9
42.85
42.8
42.75
42.7
42.65
42.6
42.55
42.5
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
-97.4
Longitude (deg)

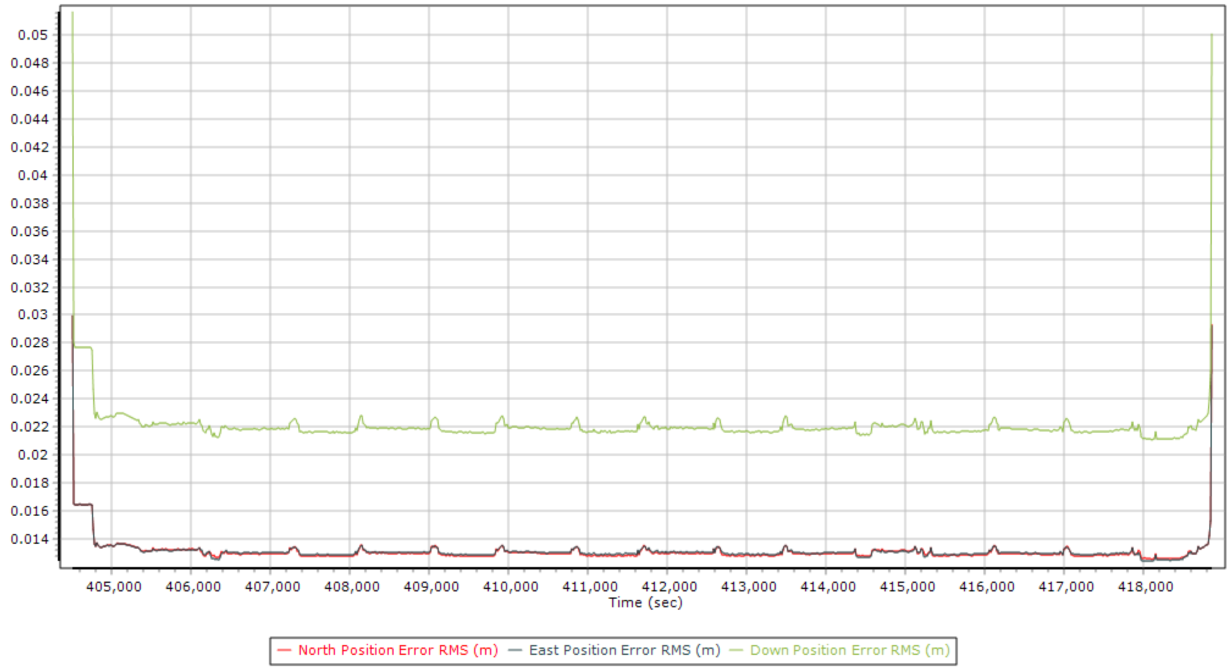

201118_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
320,000
322,000
324,000
326,000
328,000
330,000
332,000
334,000
336,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

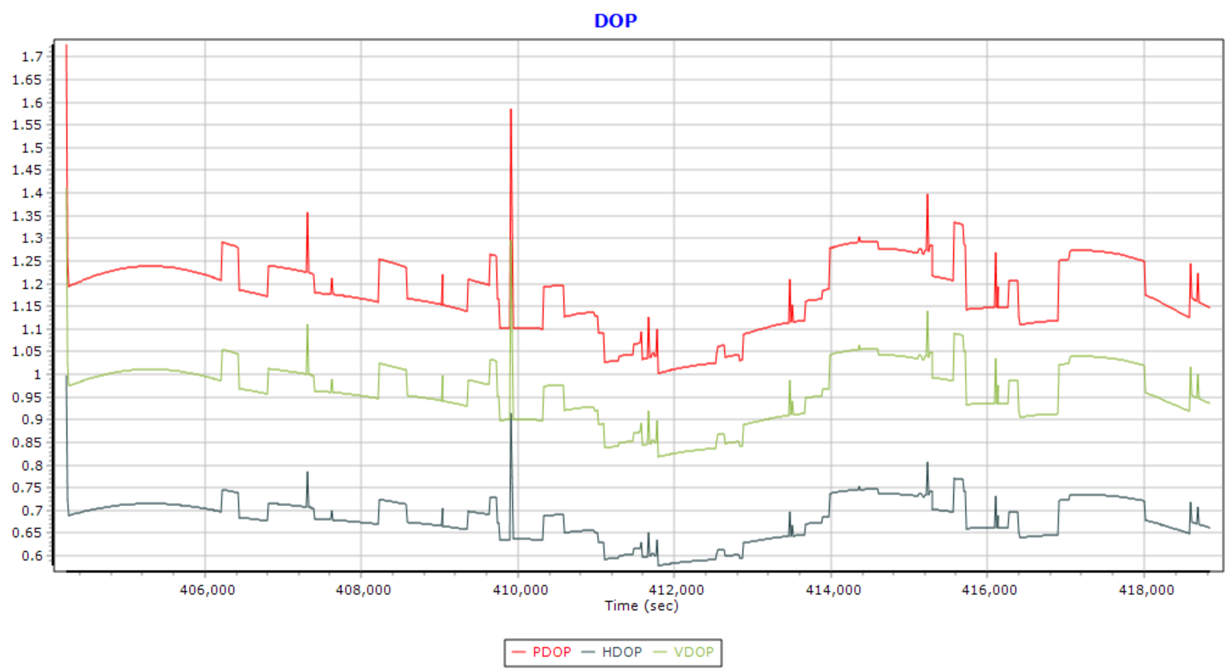

DOP
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
320,000
322,000
324,000
326,000
328,000
330,000
332,000
334,000
336,000
Time (sec)
PDOP
HDOP
VDOP

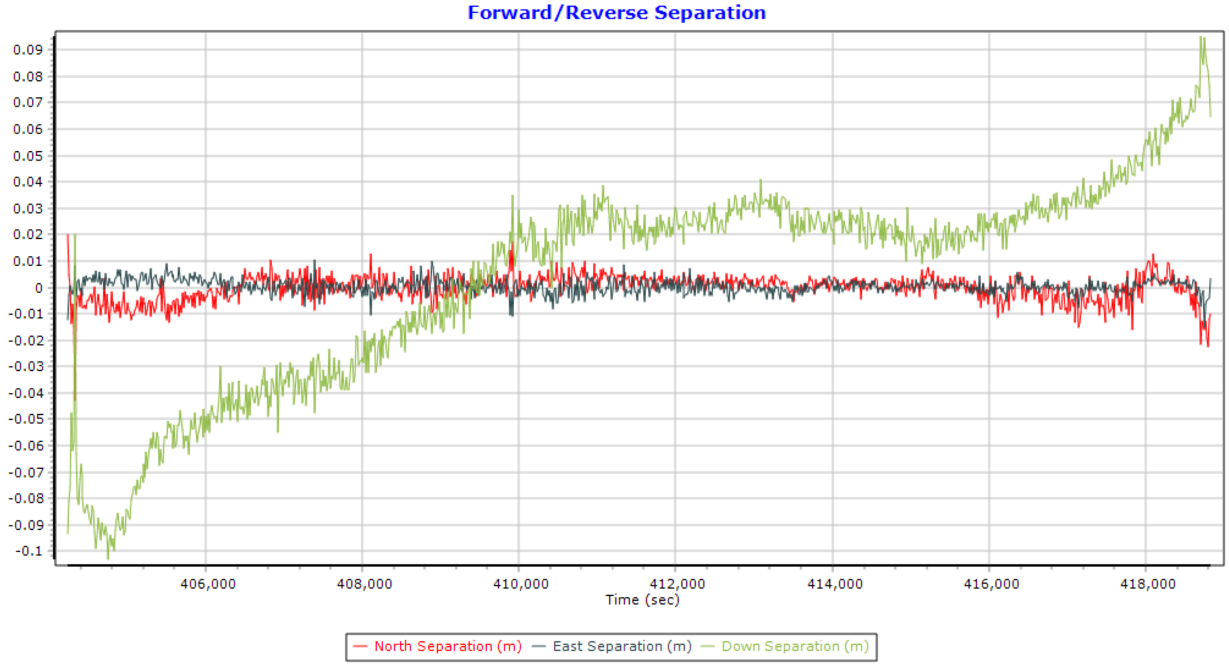

Forward/Reverse Separation
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
320,000
322,000
324,000
326,000
328,000
330,000
332,000
334,000
336,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

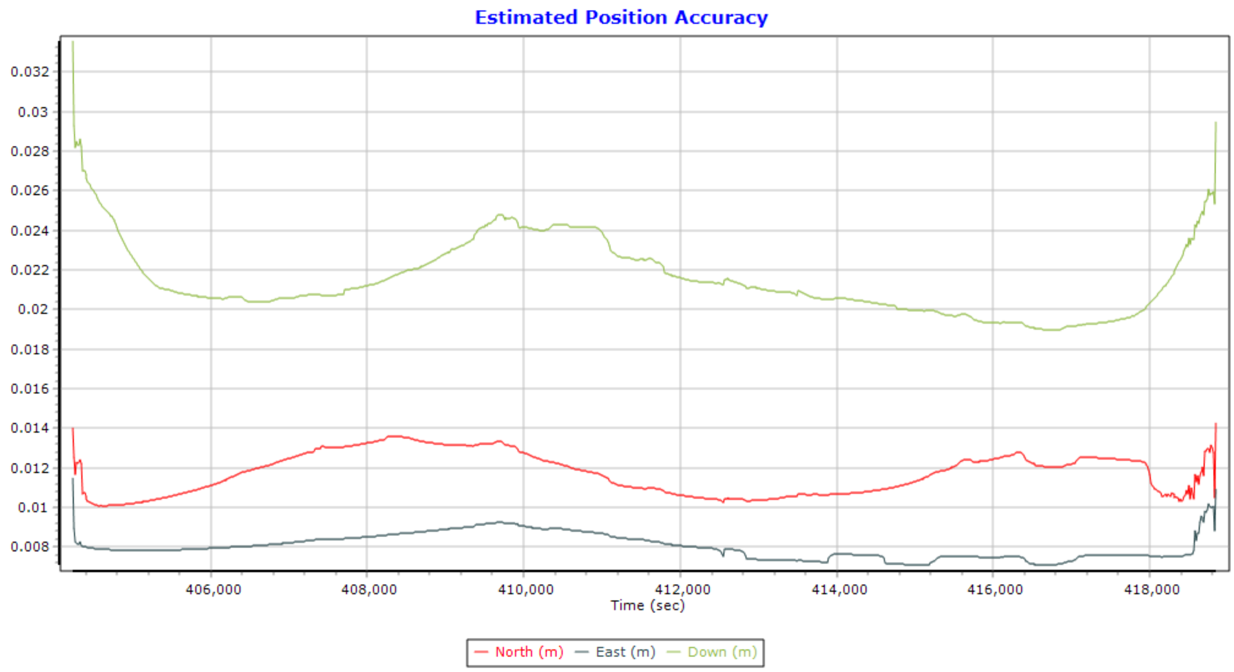

Estimated Position Accuracy
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
320,000
322,000
324,000
326,000
328,000
330,000
332,000
334,000
336,000
Time (sec)
North (m)
East (m)
Down (m)

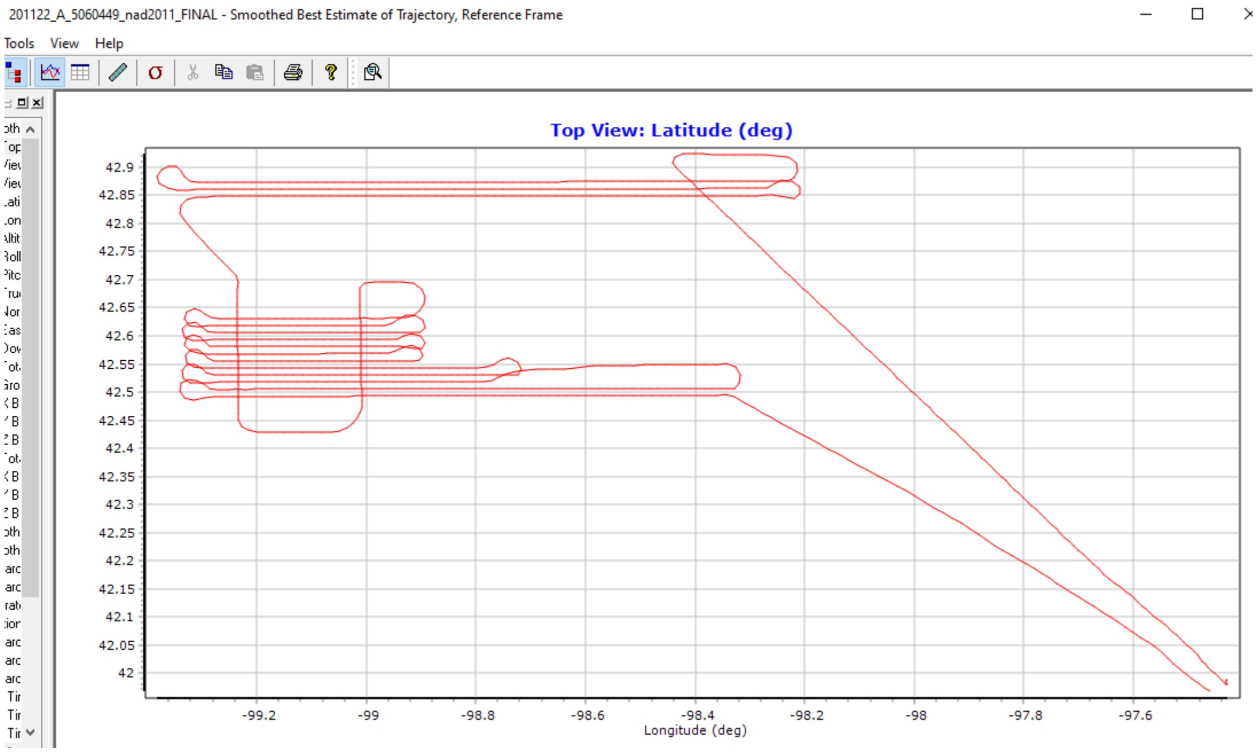

201119_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
42
41.95
41.9
41.85
41.8
41.75
41.7
41.65
41.6
41.55
41.5
41.45
-98.3
-98.2
-98.1
-98
-97.9
-97.8
-97.7
-97.6
-97.5
-97.4
Longitude (deg)


0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
405,000
406,000
407,000
408,000
409,000
410,000
411,000
412,000
413,000
414,000
415,000
416,000
417,000
418,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

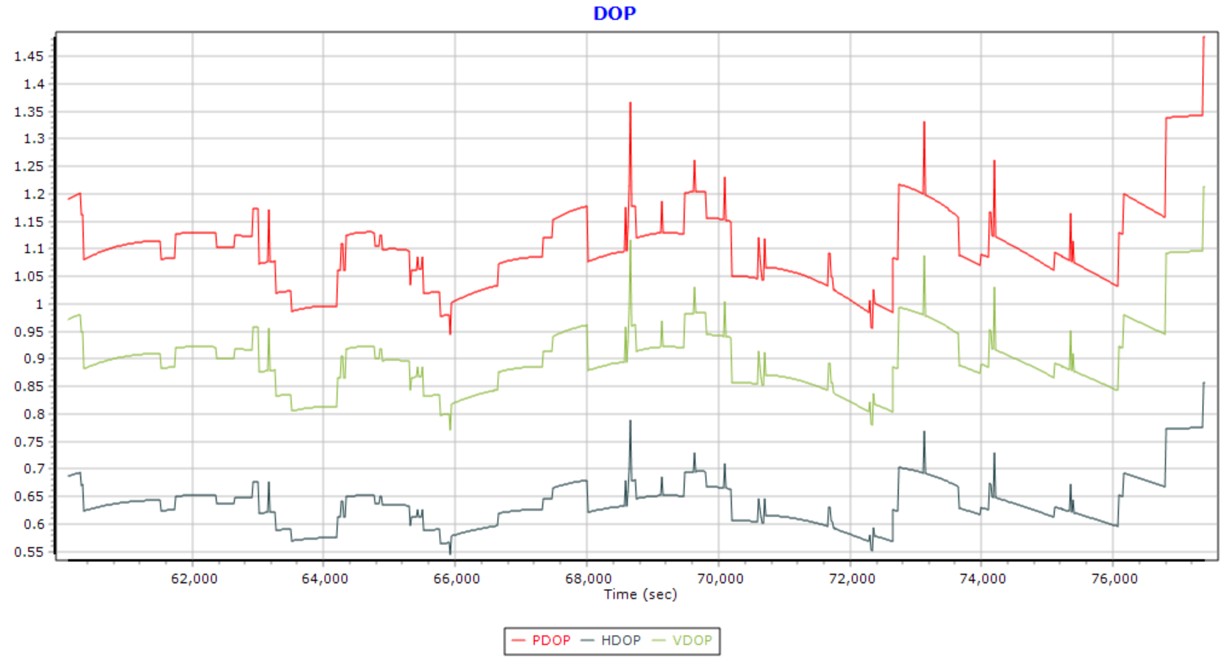

DOP
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
406,000
408,000
410,000
412,000
414,000
416,000
418,000
Time (sec)
PDOP
HDOP
VDOP

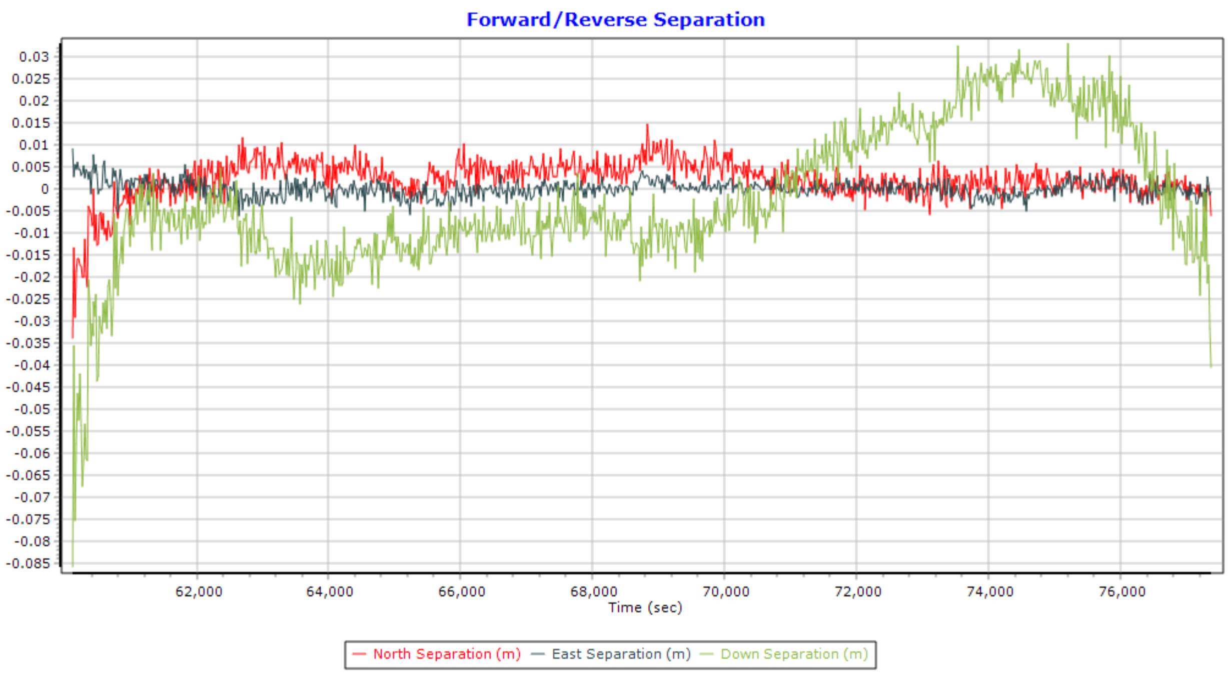

Forward/Reverse Separation
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
406,000
408,000
410,000
412,000
414,000
416,000
418,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

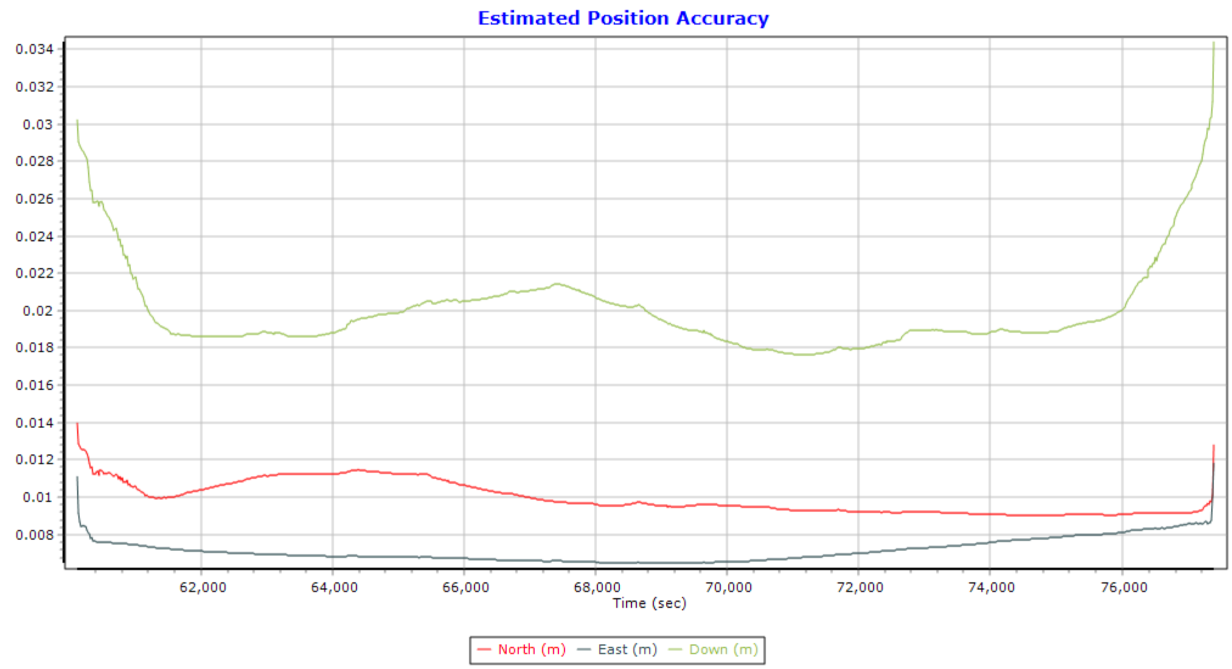

Estimated Position Accuracy
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
406,000
408,000
410,000
412,000
414,000
416,000
418,000
Time (sec)
North (m)
East (m)
Down (m)

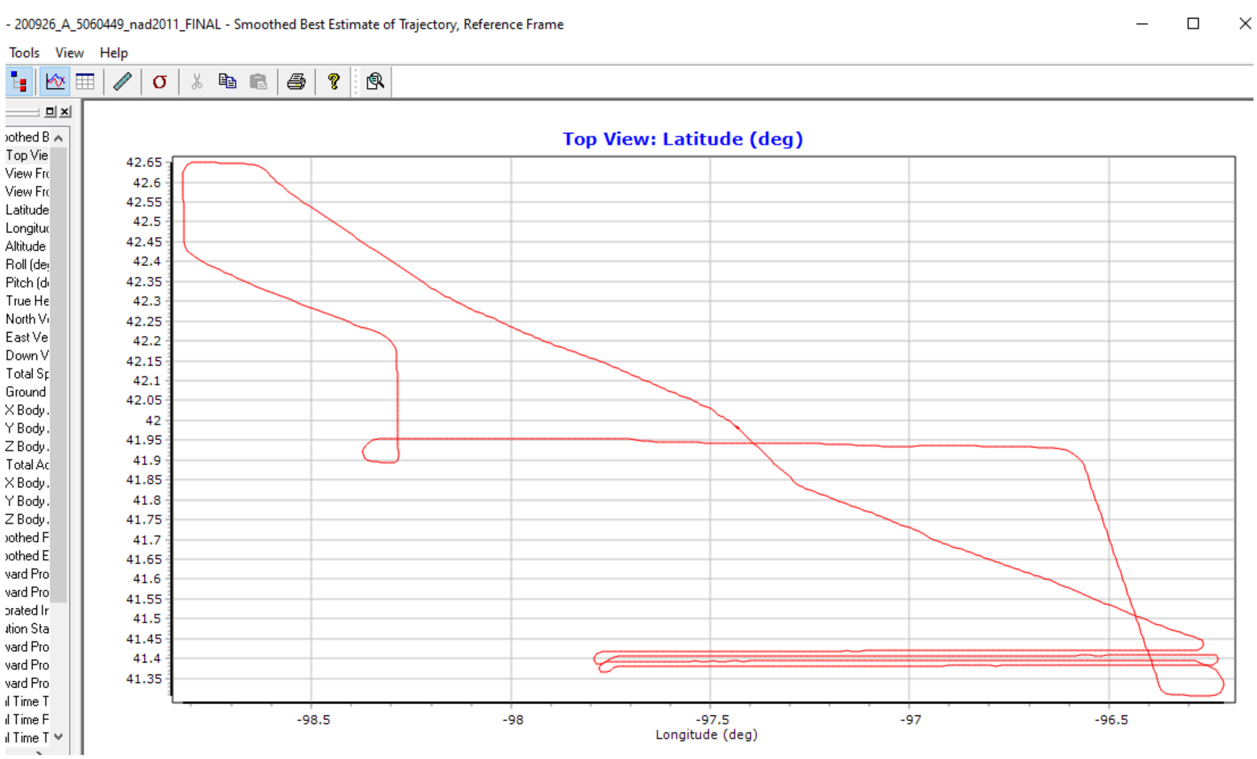

201122_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
42.9
42.85
42.8
42.75
42.7
42.65
42.6
42.55
42.5
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
Longitude (deg)

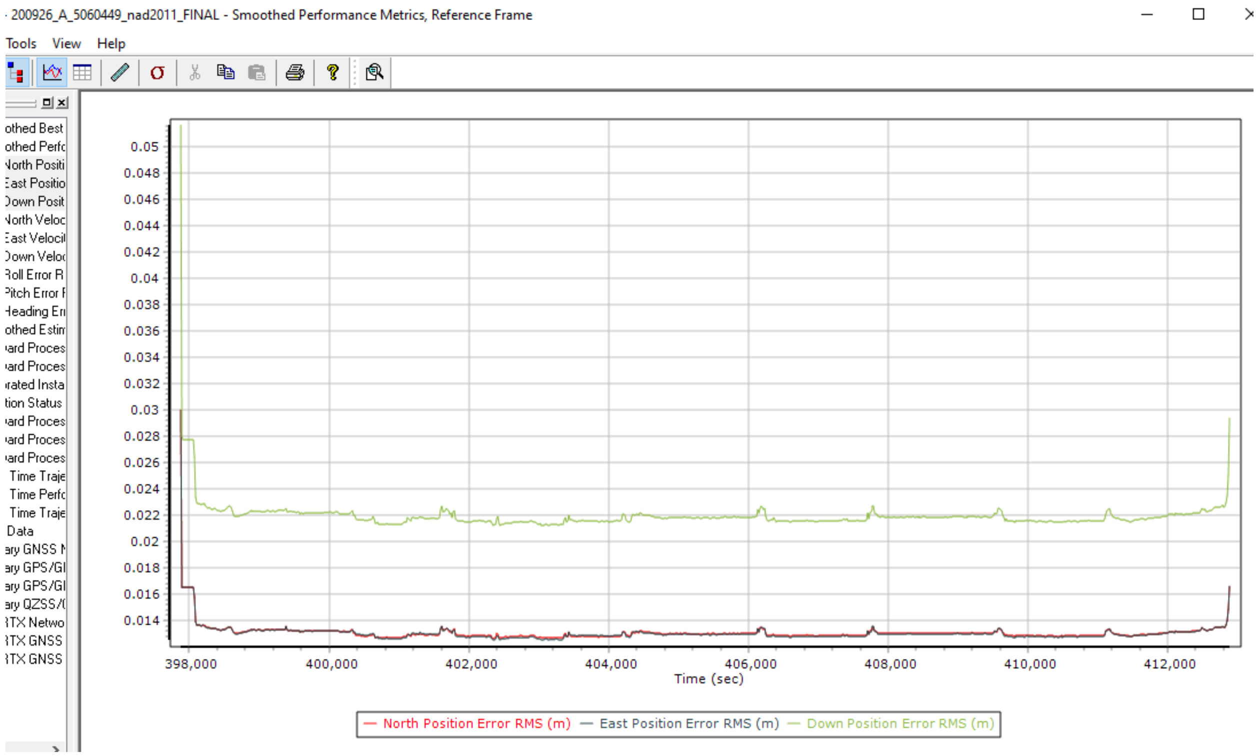

201122_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
62,000
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

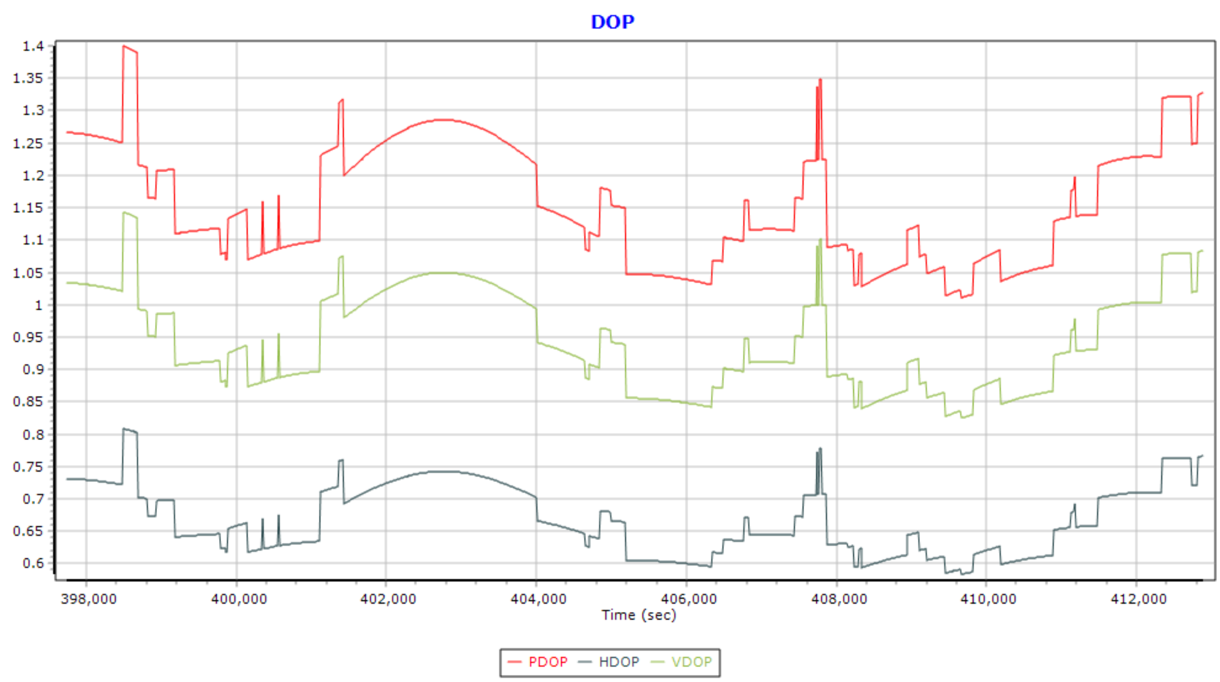

DOP
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
62,000
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)
PDOP
HDOP
VDOP

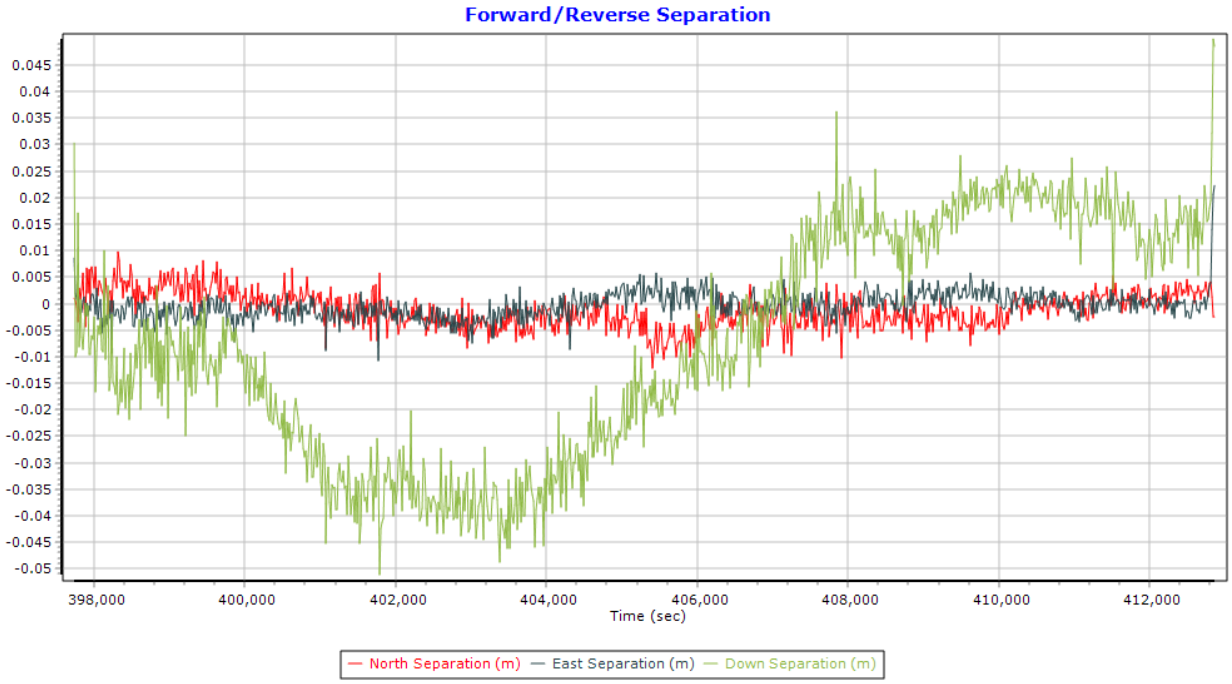

Forward/Reverse Separation
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
-0.055
-0.06
-0.065
-0.07
-0.075
-0.08
-0.085
62,000
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

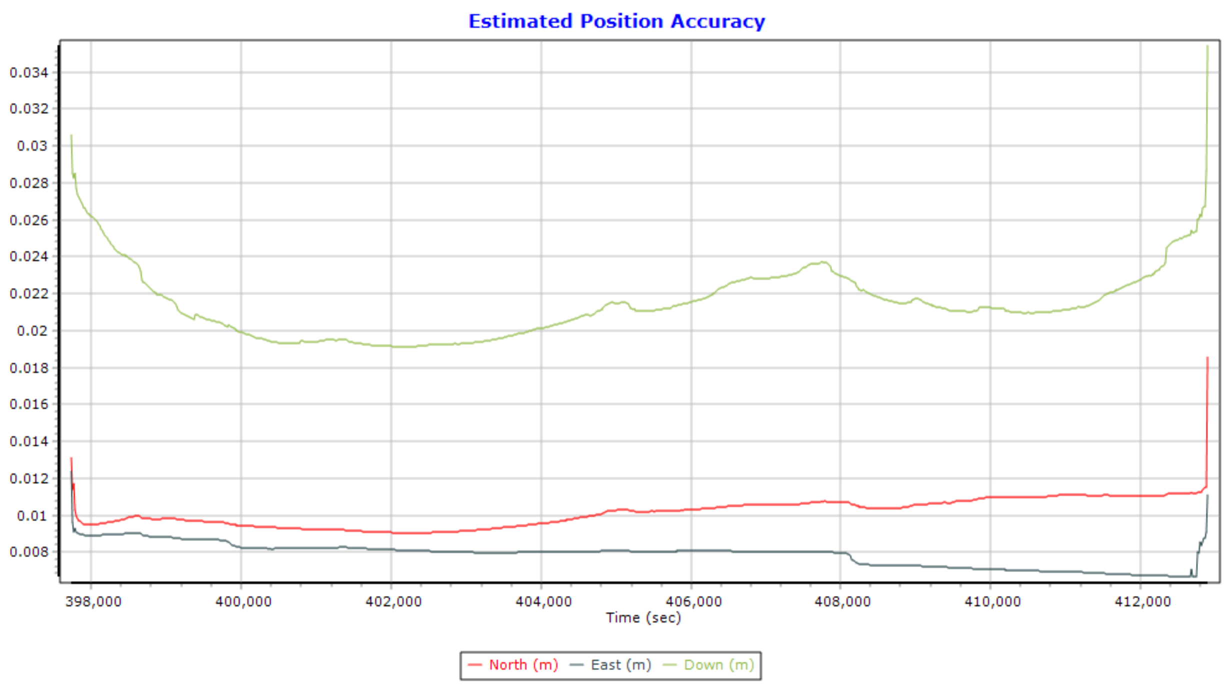

Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
62,000
64,000
66,000
68,000
70,000
72,000
74,000
76,000
Time (sec)
North (m)
East (m)
Down (m)

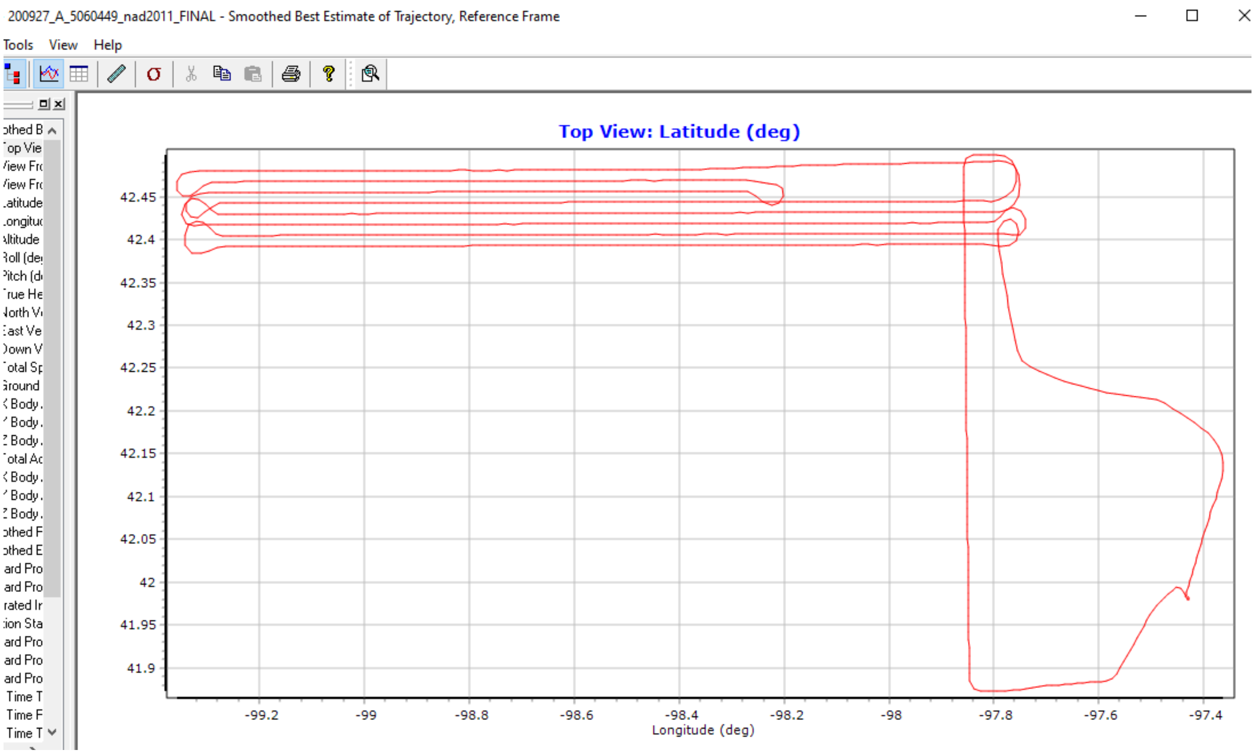

- 200926_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
42.65
42.6
42.55
42.5
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
41.95
41.9
41.85
41.8
41.75
41.7
41.65
41.6
41.55
41.5
41.45
41.4
41.35
-98.5
-98
-97.5
-97
-96.5
Longitude (deg)


200926_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
398,000
400,000
402,000
404,000
406,000
408,000
410,000
412,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

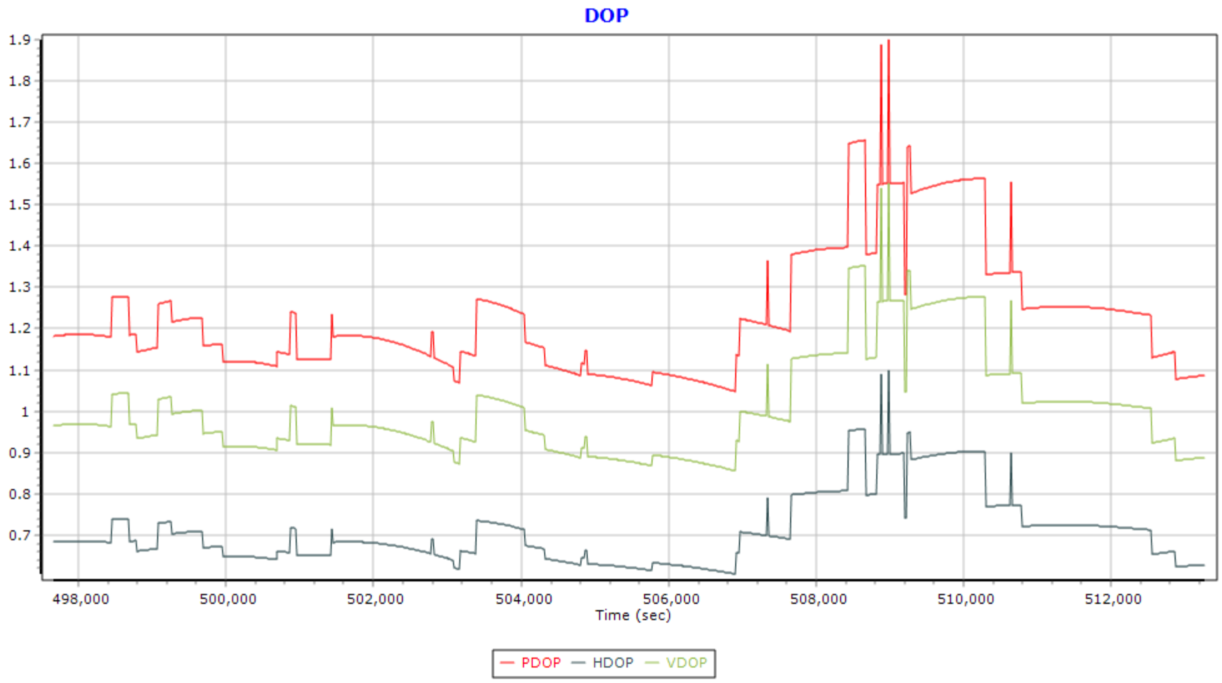

DOP
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
398,000
400,000
402,000
404,000
406,000
408,000
410,000
412,000
Time (sec)
PDOP
HDOP
VDOP

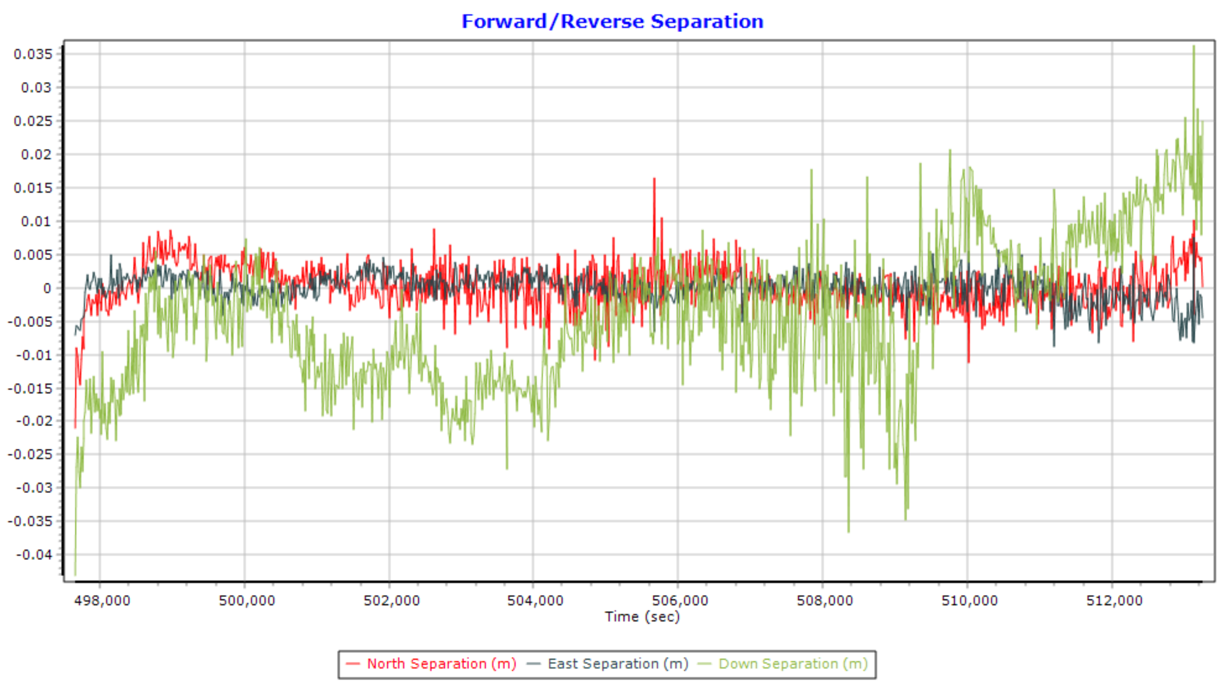

Forward/Reverse Separation
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
398,000
400,000
402,000
404,000
406,000
408,000
410,000
412,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

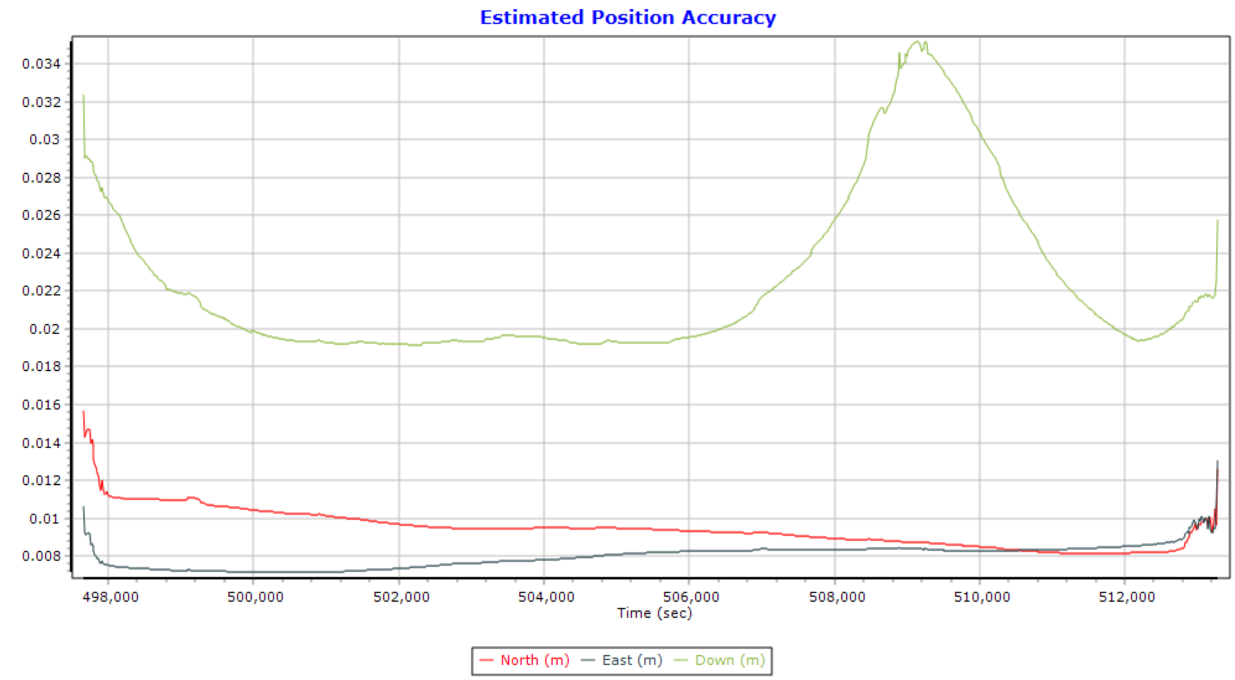

Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
398,000
400,000
402,000
404,000
406,000
408,000
410,000
412,000
Time (sec)
North (m)
East (m)
Down (m)

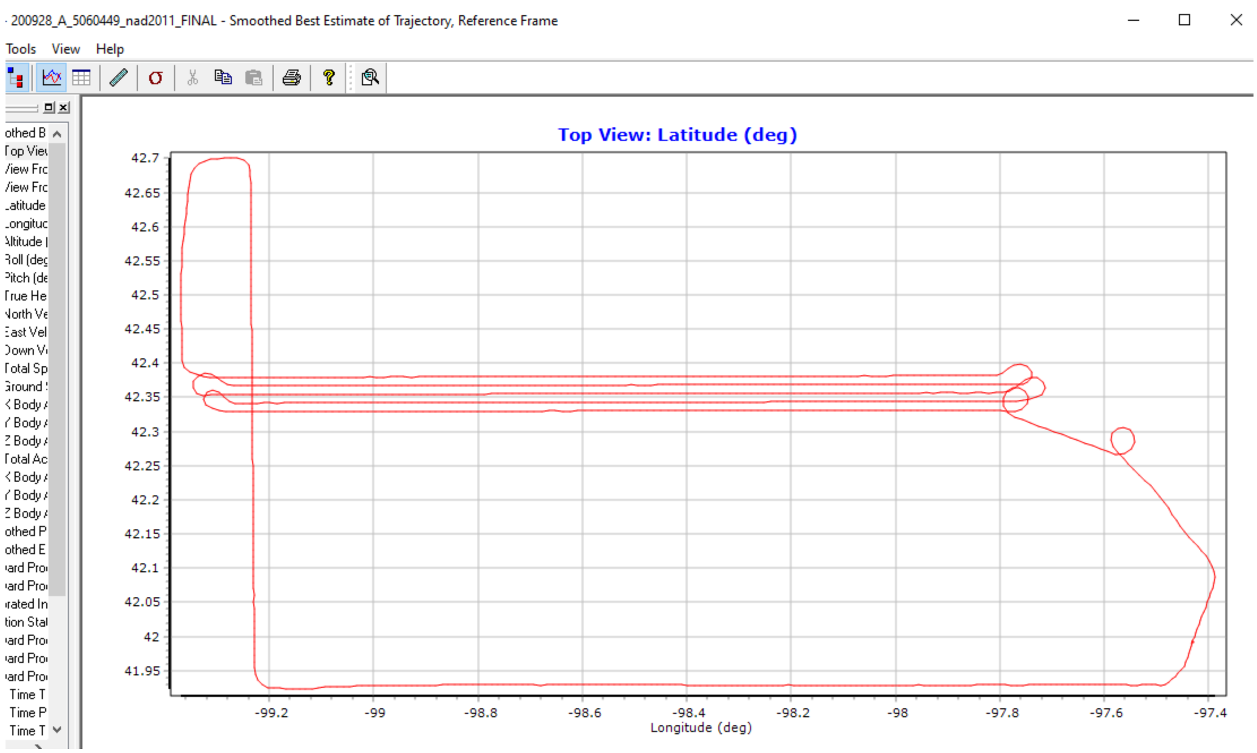

200927_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
41.95
41.9
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
-97.4
Longitude (deg)

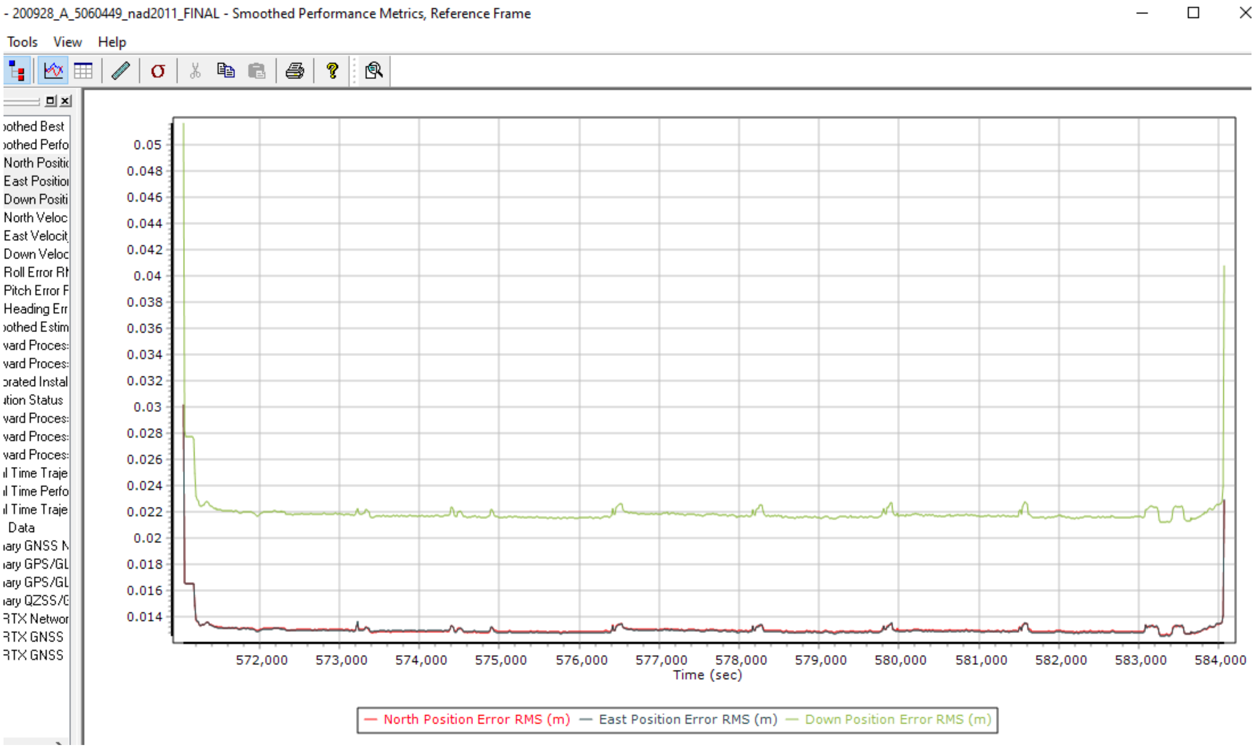

200927_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
498,000
500,000
502,000
504,000
506,000
508,000
510,000
512,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

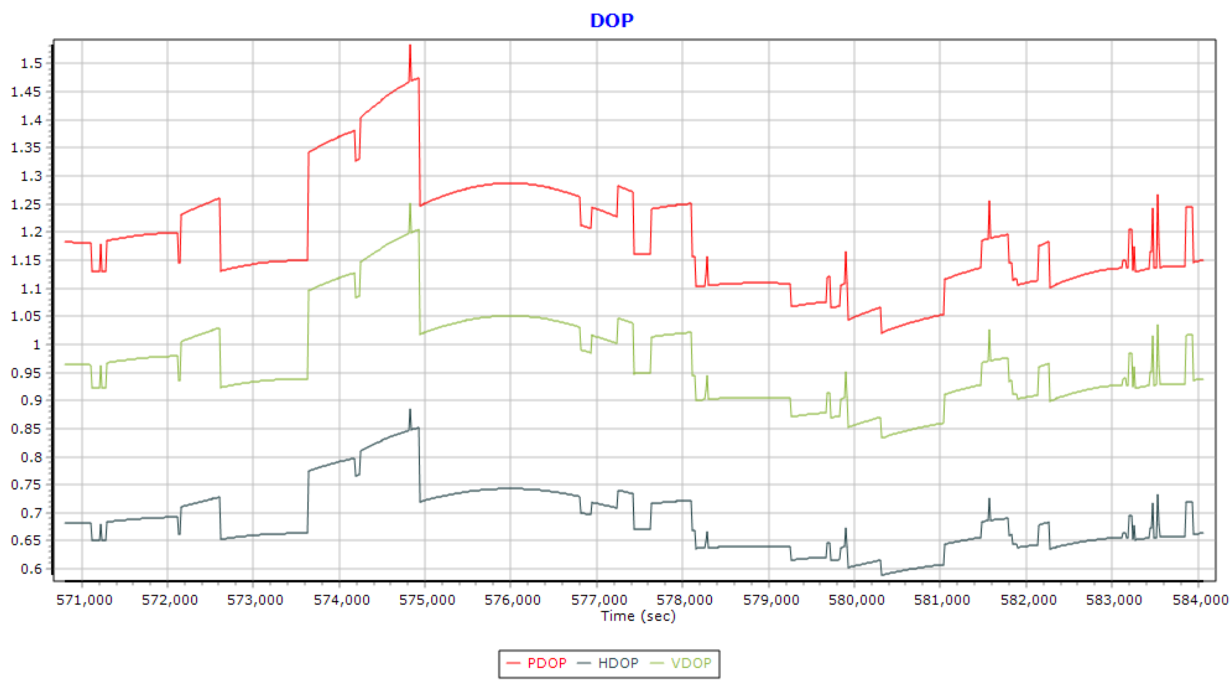

DOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
498,000
500,000
502,000
504,000
506,000
508,000
510,000
512,000
Time (sec)
PDOP
HDOP
VDOP

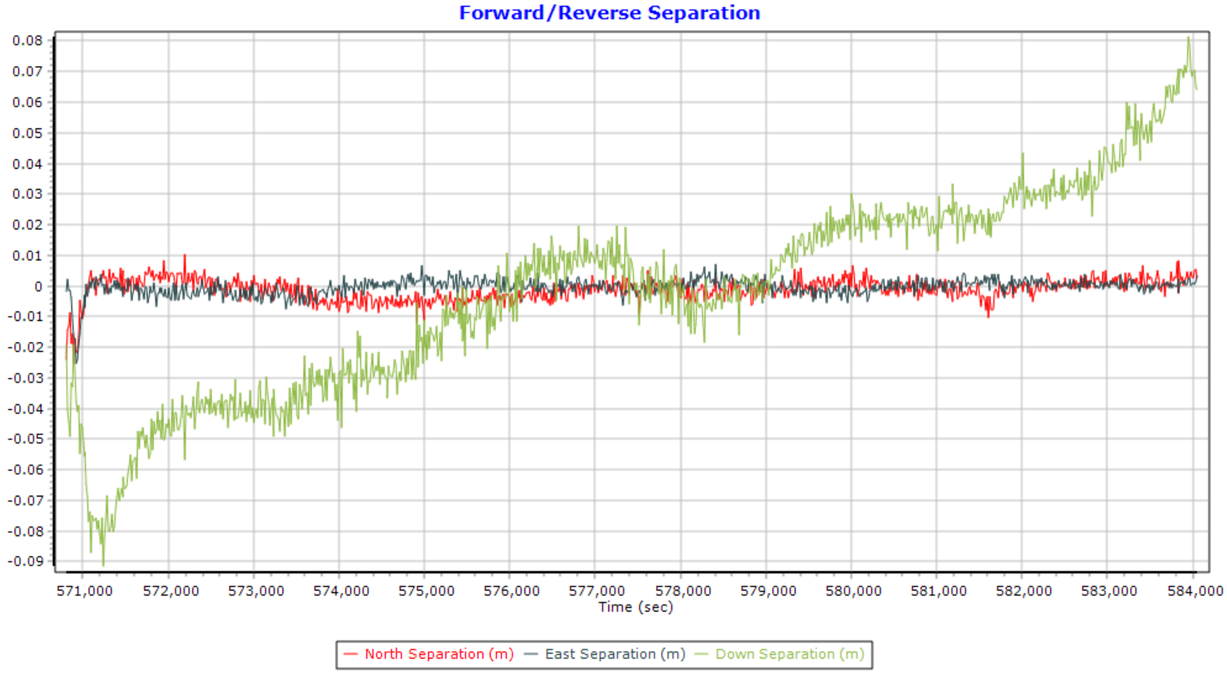

Forward/Reverse Separation
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
498,000
500,000
502,000
504,000
506,000
508,000
510,000
512,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

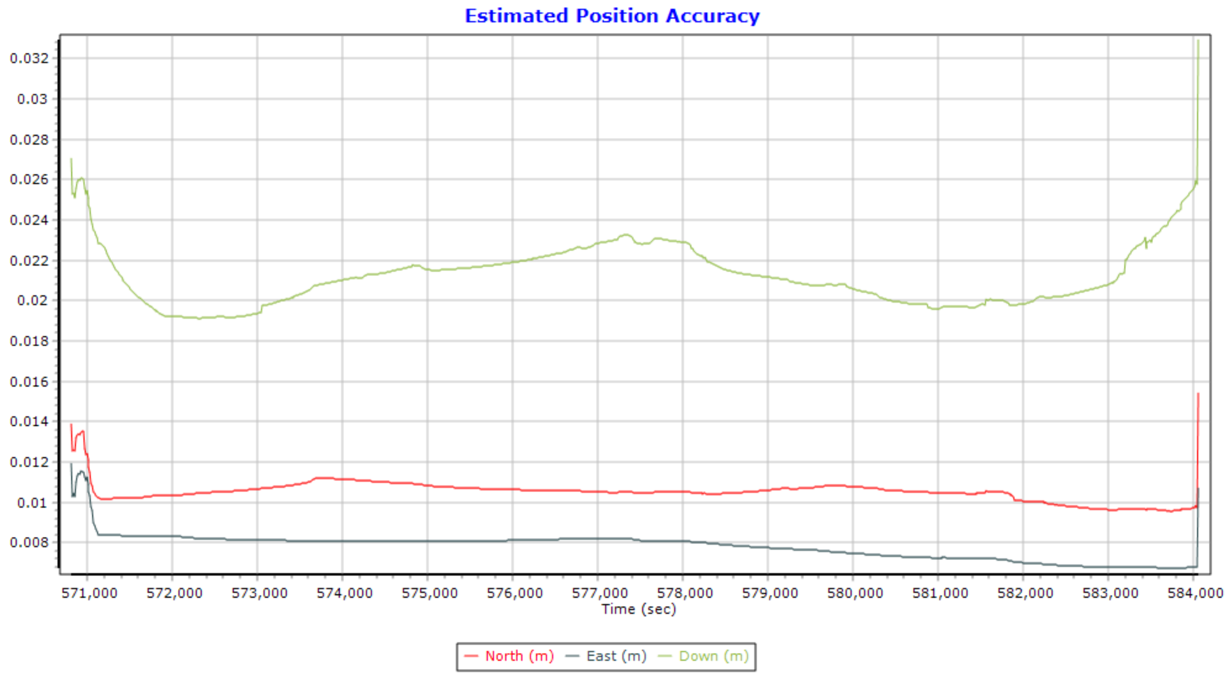

Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
498,000
500,000
502,000
504,000
506,000
508,000
510,000
512,000
Time (sec)
North (m)
East (m)
Down (m)

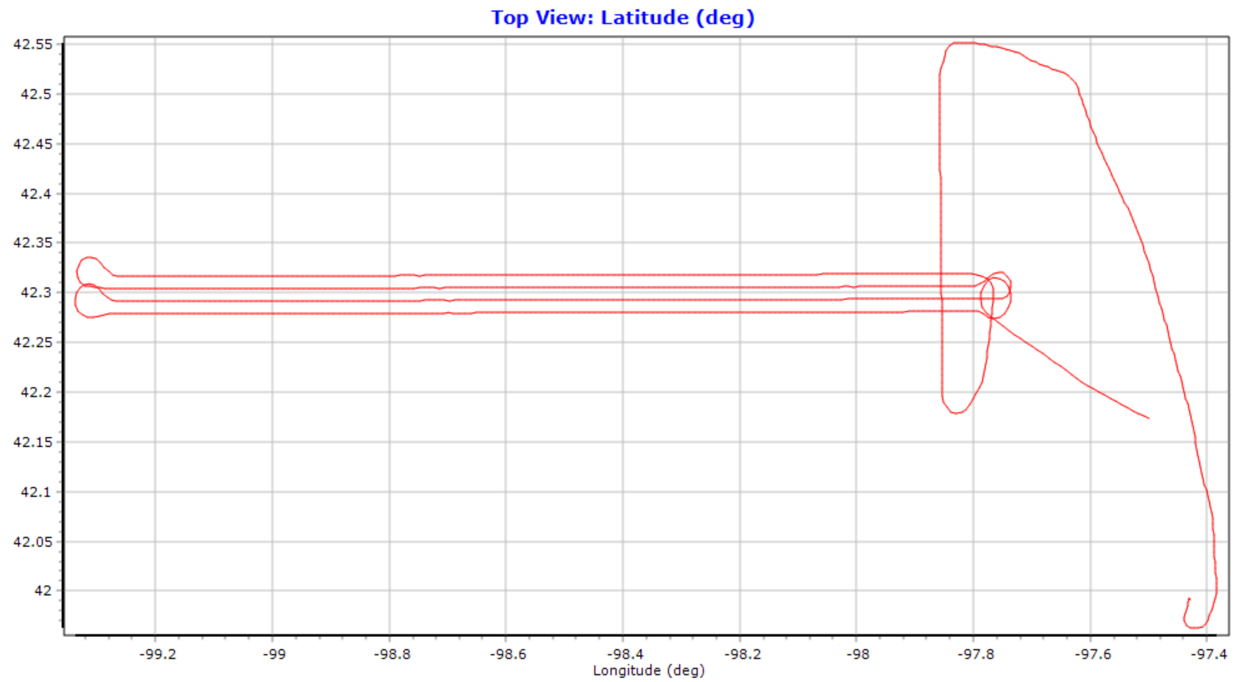

200928_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
42.7
42.65
42.6
42.55
42.5
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
41.95
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
-97.4
Longitude (deg)

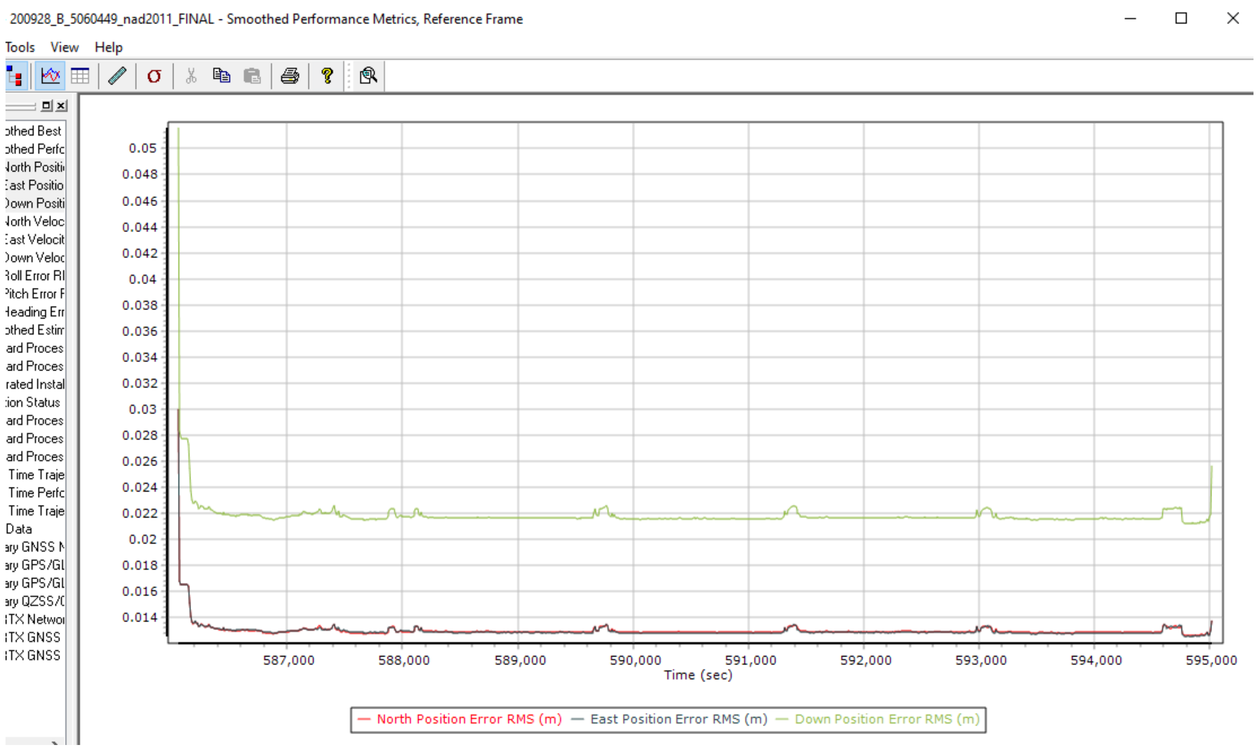

- 200928_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

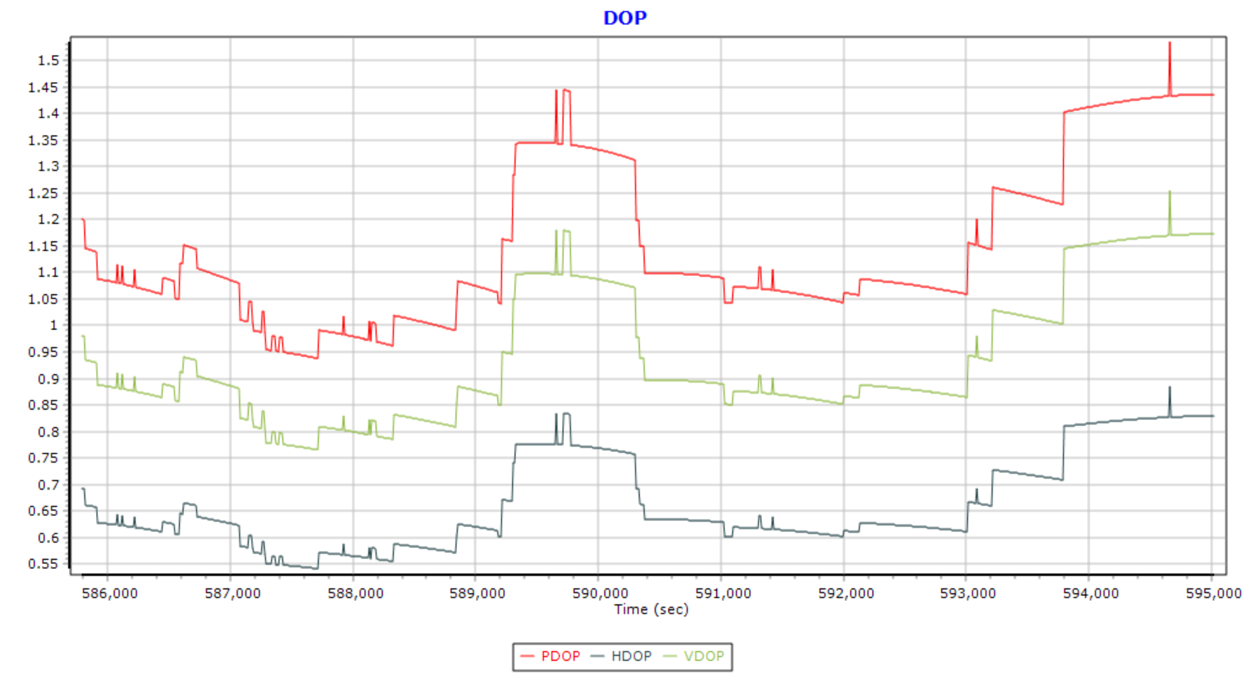

DOP
Time (sec)
PDOP
HDOP
VDOP

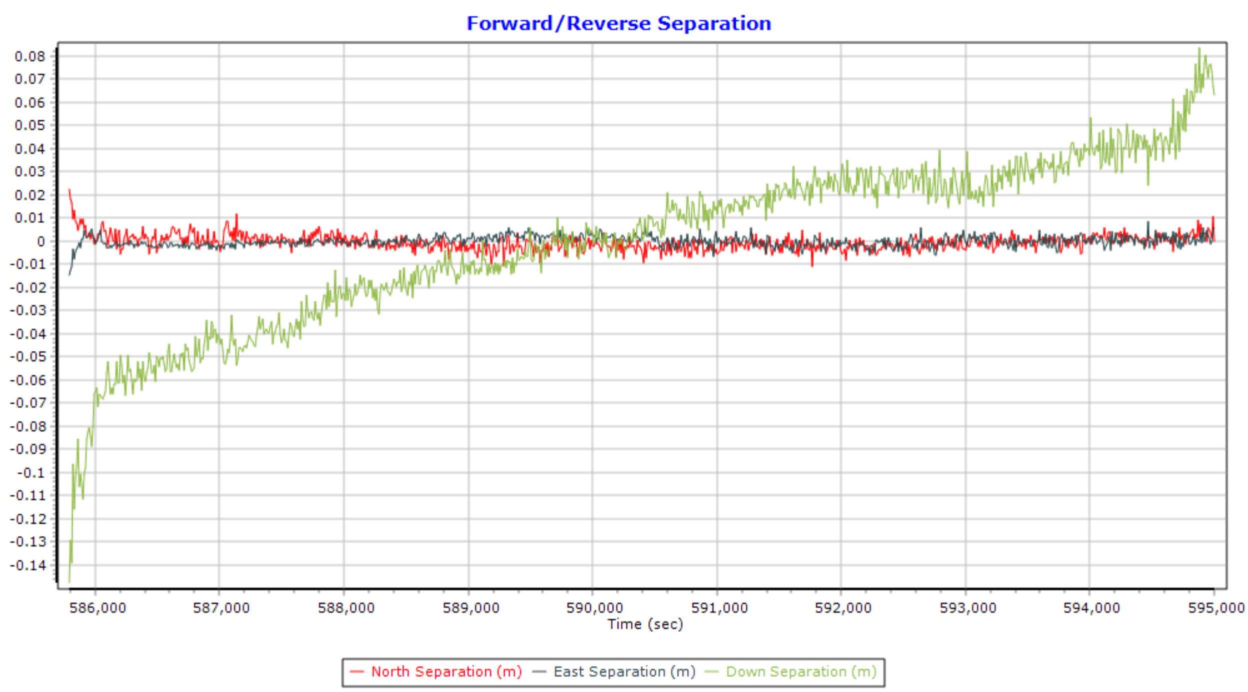

Forward/Reverse Separation
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
571,000
572,000
573,000
574,000
575,000
576,000
577,000
578,000
579,000
580,000
581,000
582,000
583,000
584,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

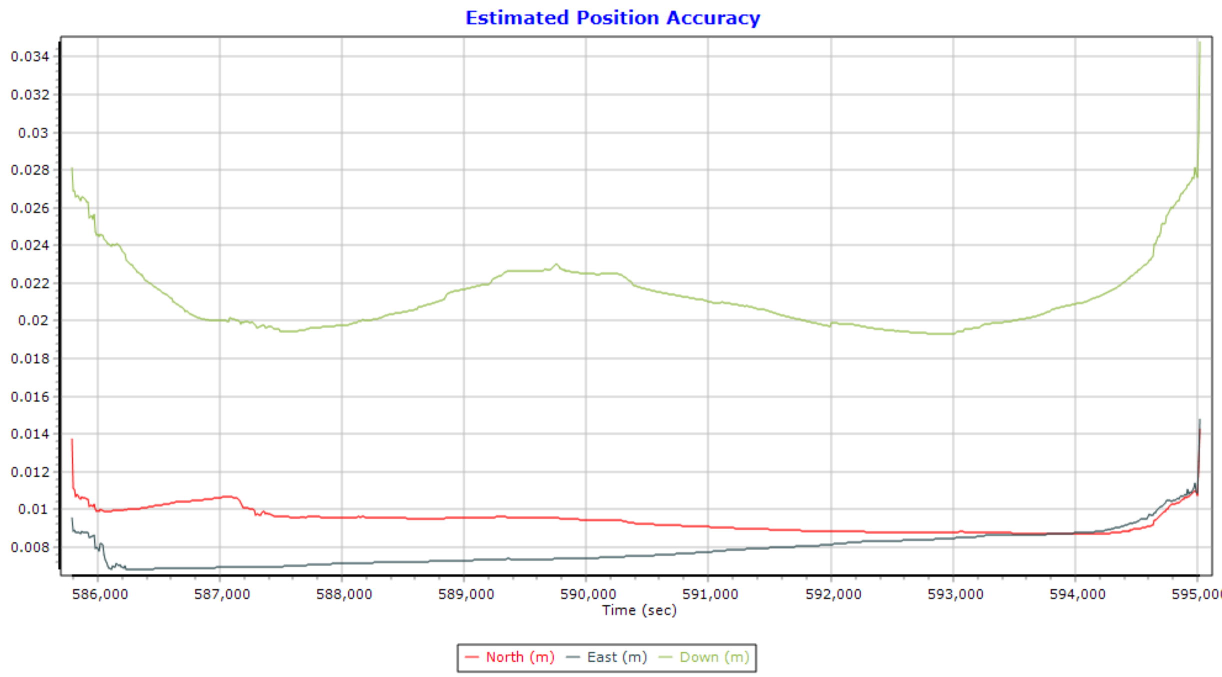

Estimated Position Accuracy
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
571,000
572,000
573,000
574,000
575,000
576,000
577,000
578,000
579,000
580,000
581,000
582,000
583,000
584,000
Time (sec)
North (m)
East (m)
Down (m)

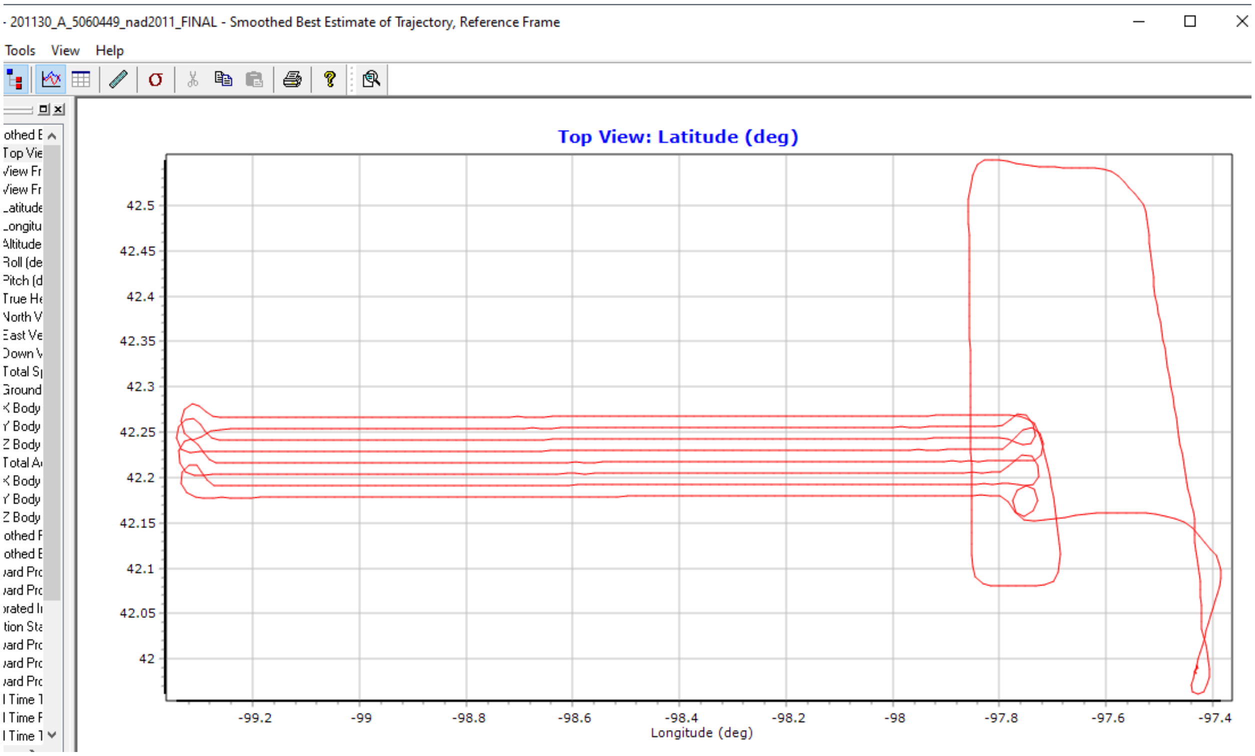

Top View: Latitude (deg)
42.55
42.5
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
-97.4
Longitude (deg)

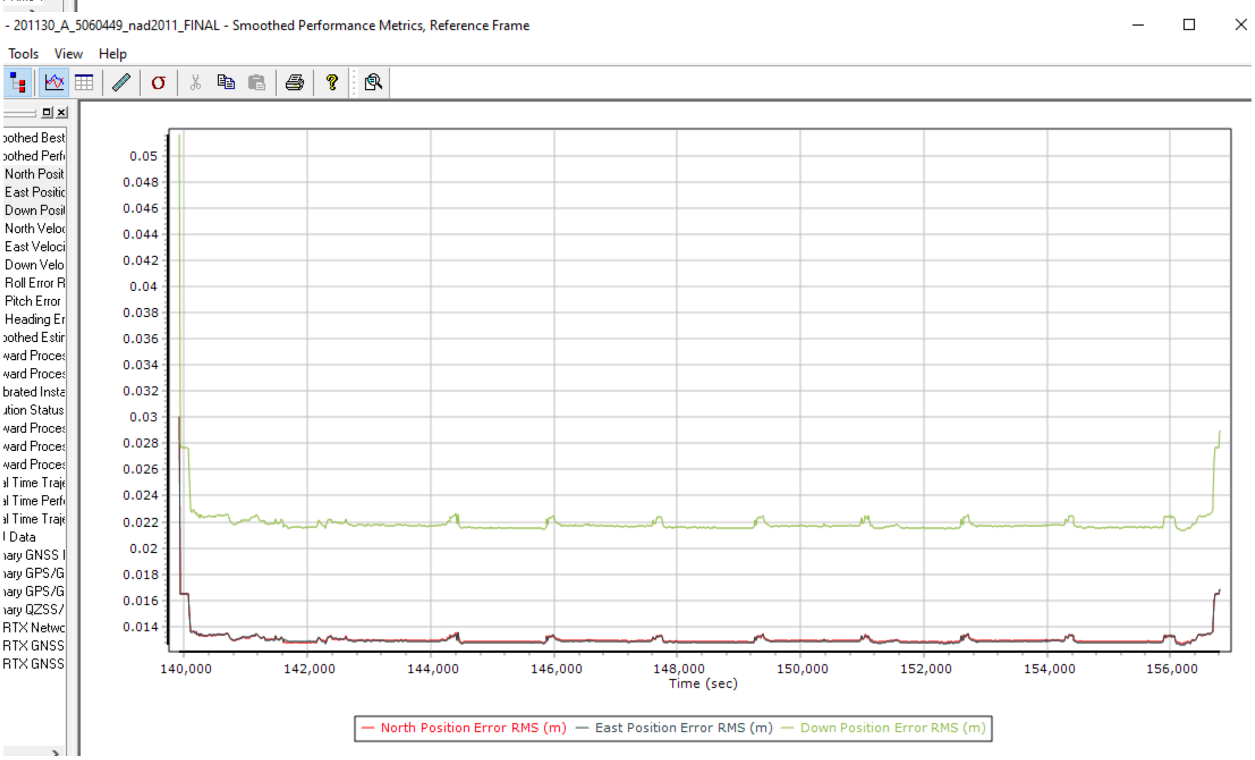

200928_B_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
587,000
588,000
589,000
590,000
591,000
592,000
593,000
594,000
595,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

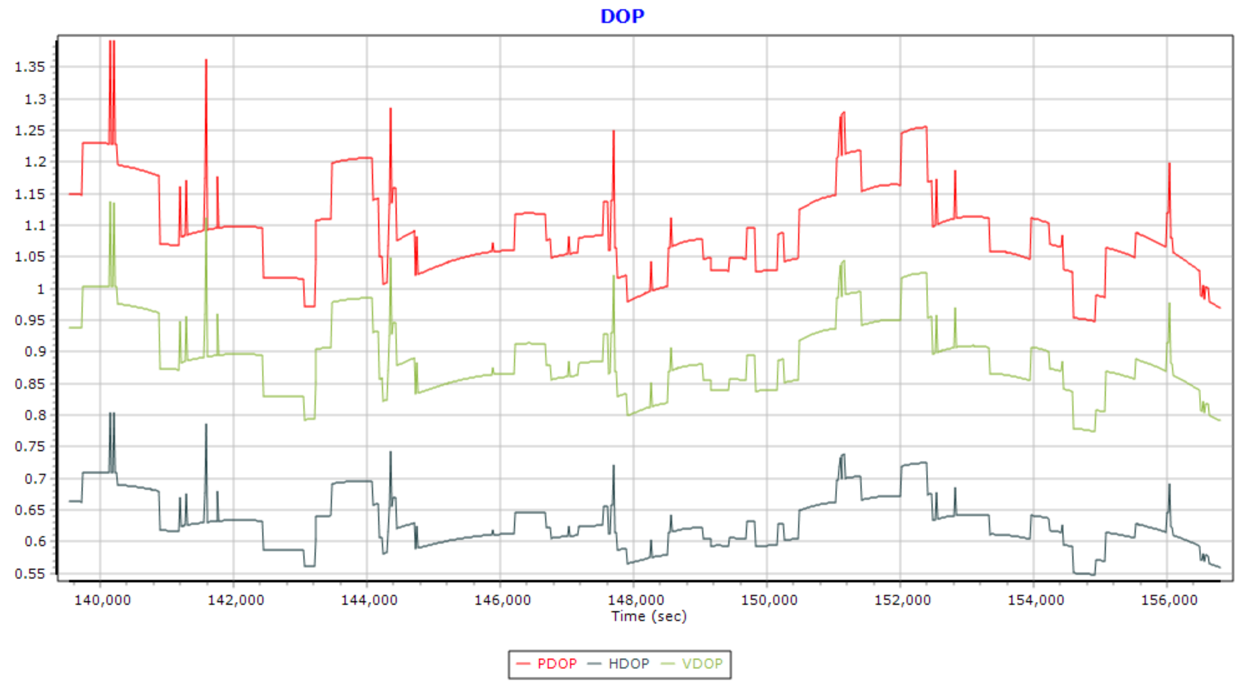

DOP
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
586,000
587,000
588,000
589,000
590,000
591,000
592,000
593,000
594,000
595,000
Time (sec)
PDOP
HDOP
VDOP

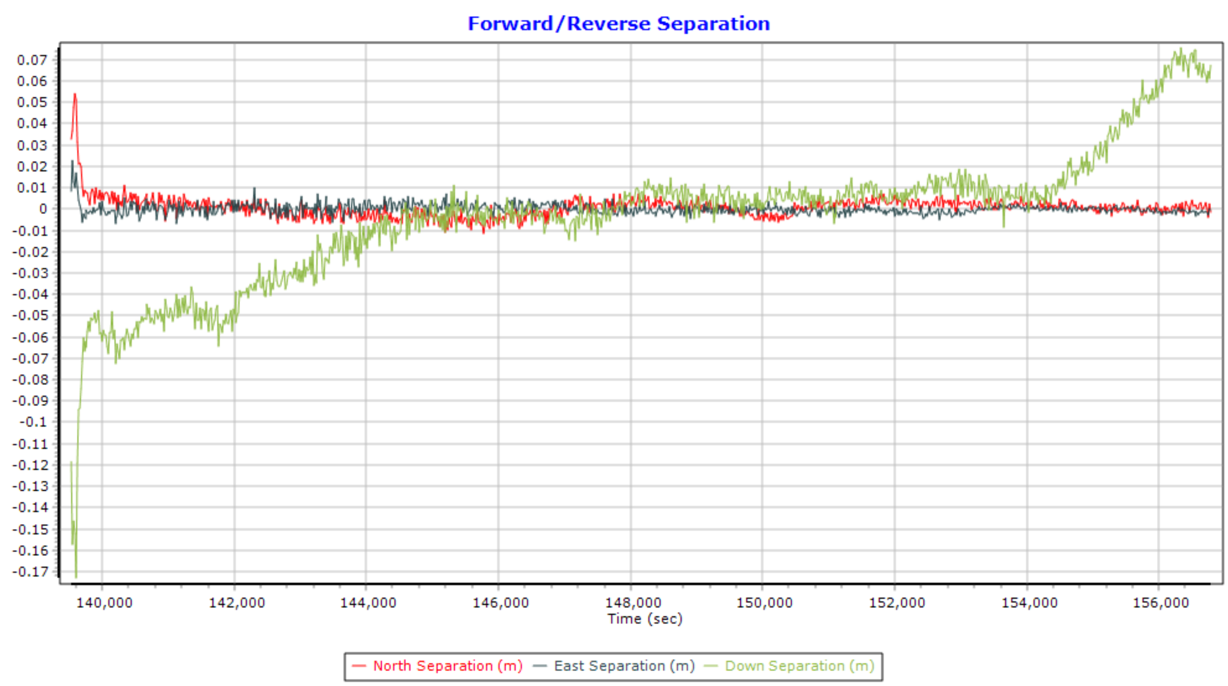

Forward/Reverse Separation
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
586,000
587,000
588,000
589,000
590,000
591,000
592,000
593,000
594,000
595,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

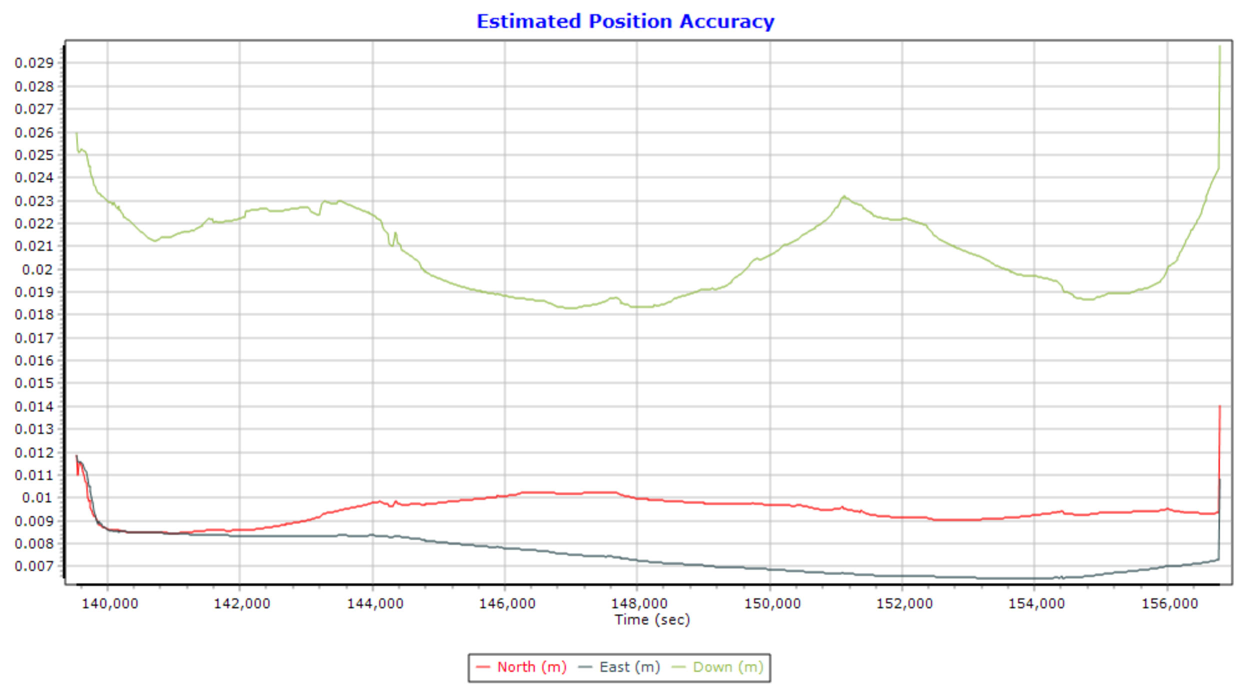

Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
586,000
587,000
588,000
589,000
590,000
591,000
592,000
593,000
594,000
595,000
Time (sec)
North (m)
East (m)
Down (m)

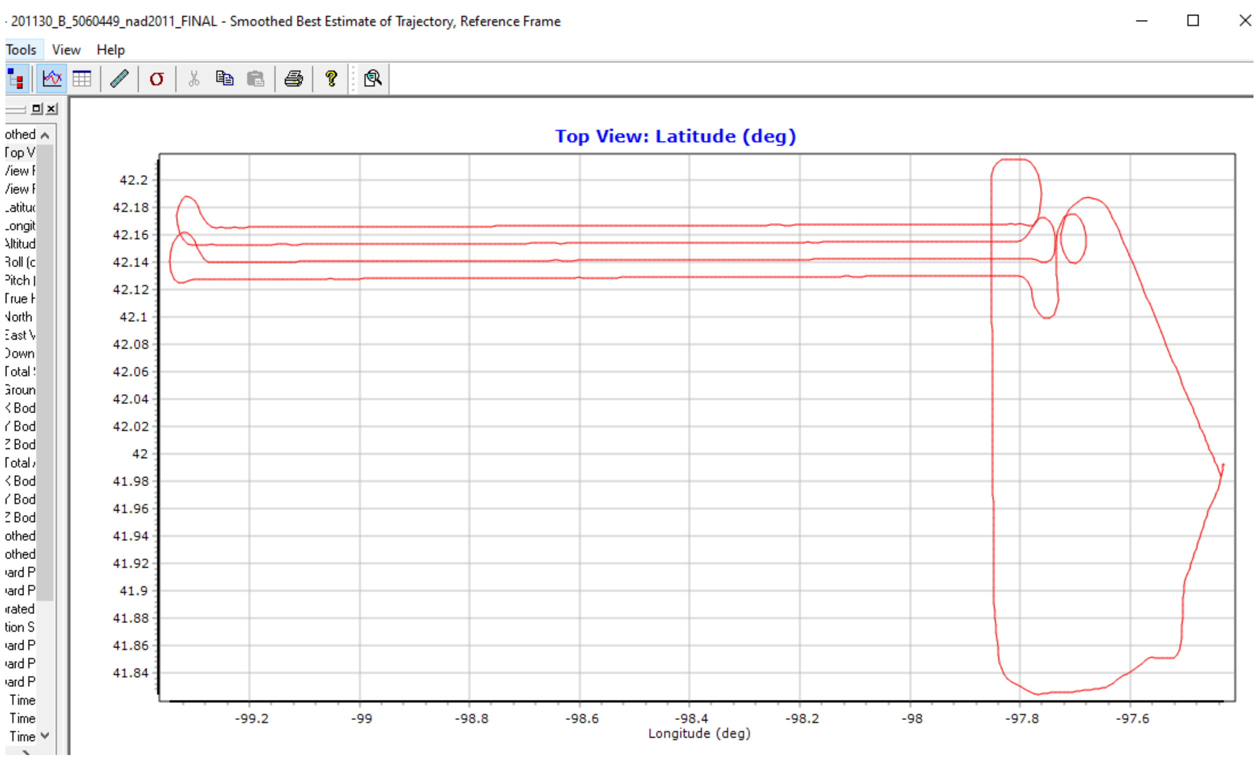

- 201130_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
42.5
42.45
42.4
42.35
42.3
42.25
42.2
42.15
42.1
42.05
42
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
-97.4
Longitude (deg)

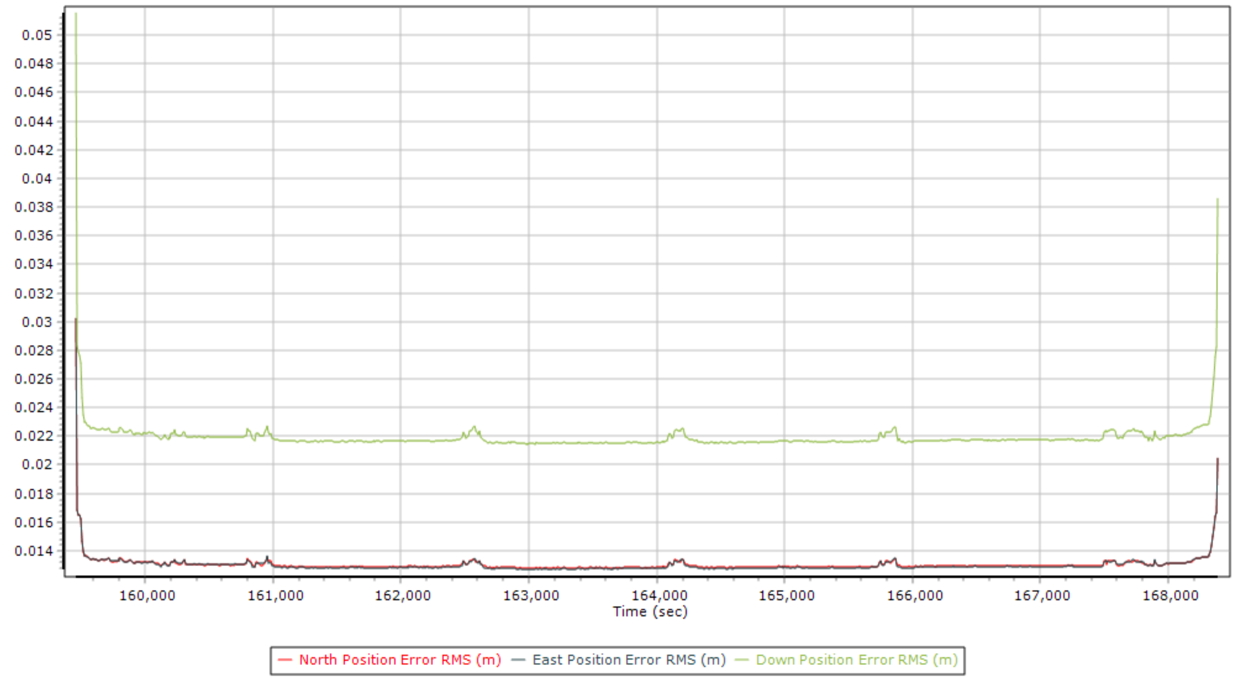

- 201130_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
140,000
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

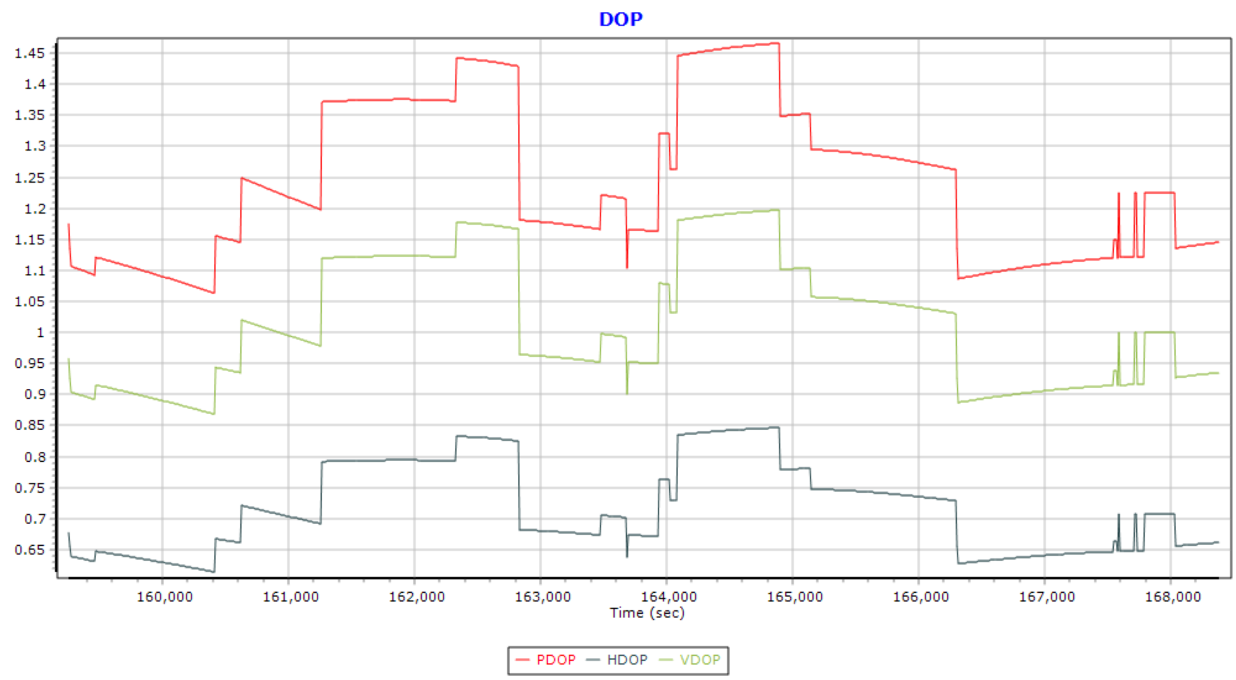

DOP
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
140,000
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
Time (sec)
PDOP
HDOP
VDOP

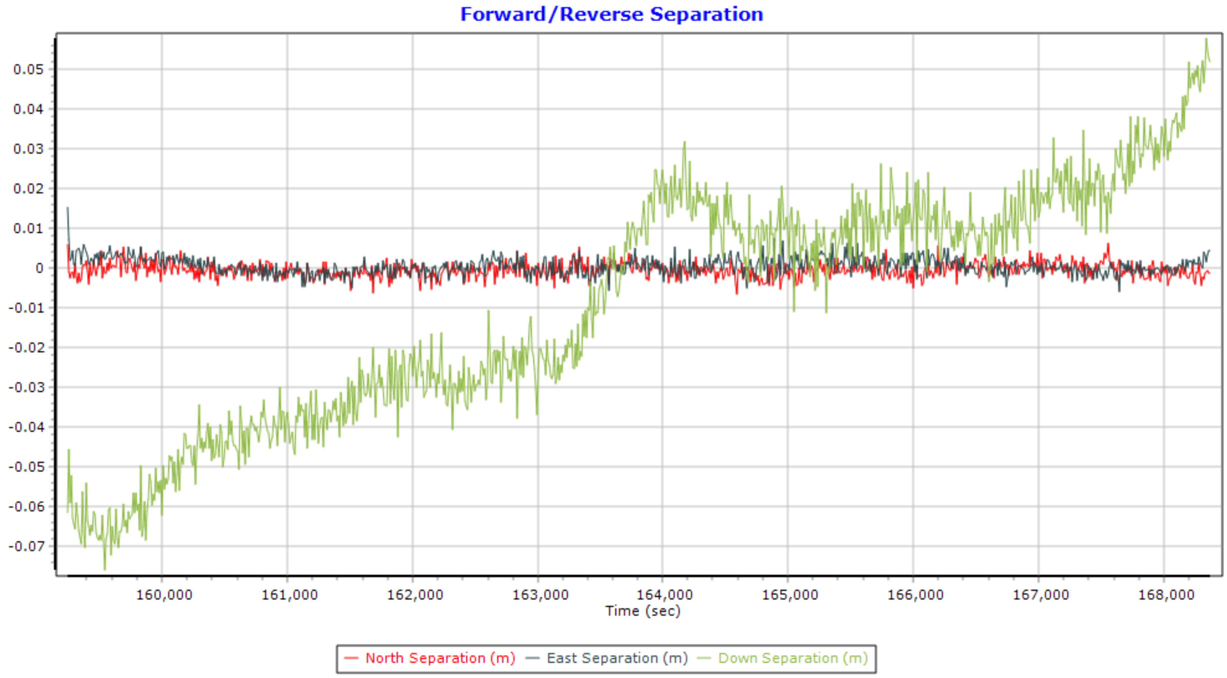

Forward/Reverse Separation
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
140,000
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

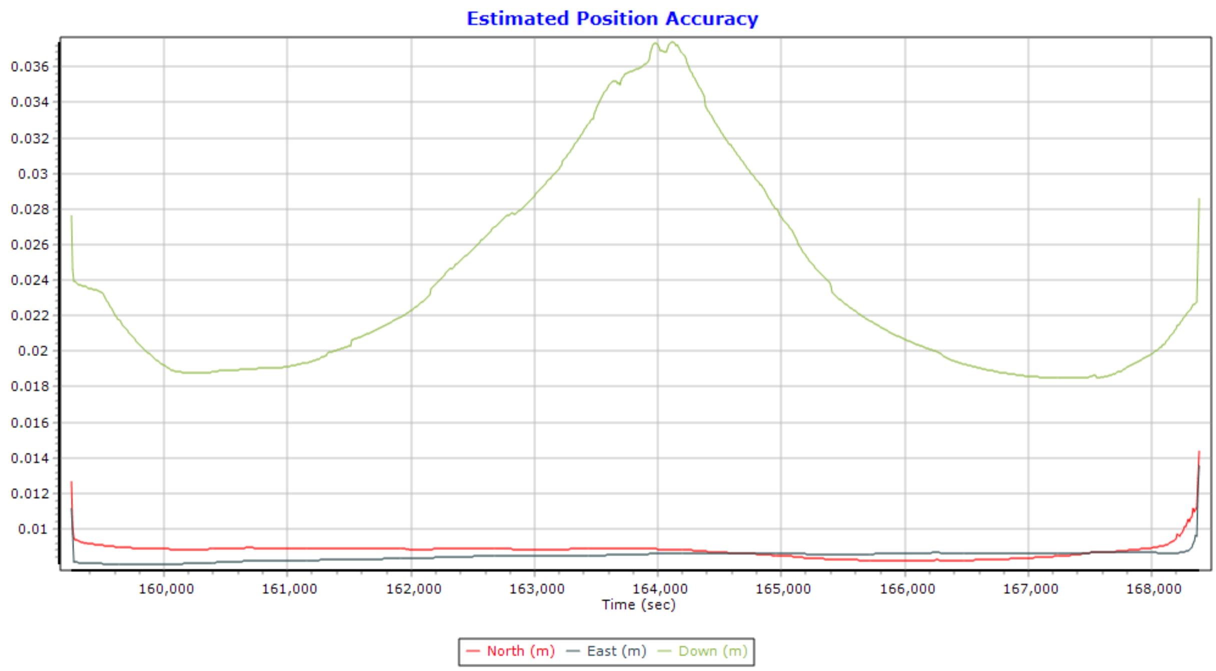

Estimated Position Accuracy
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
140,000
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
Time (sec)
North (m)
East (m)
Down (m)

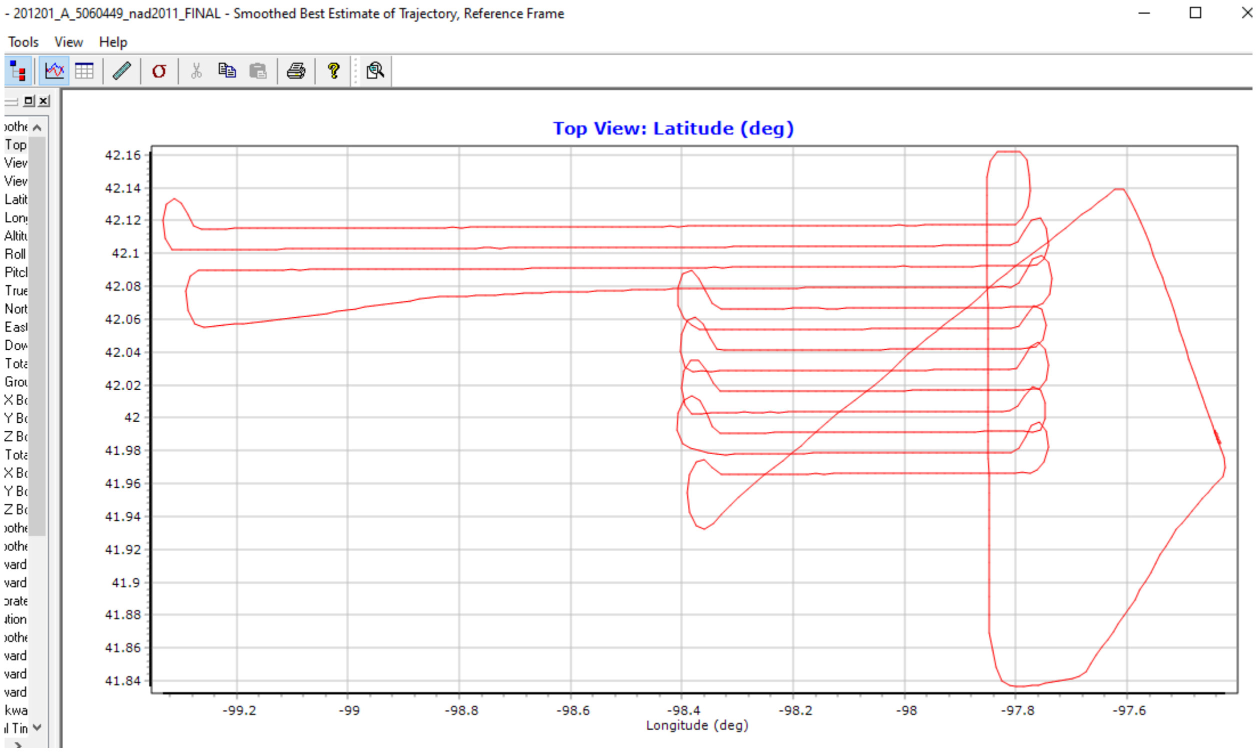

201130_B_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
42.2
42.18
42.16
42.14
42.12
42.1
42.08
42.06
42.04
42.02
42
41.98
41.96
41.94
41.92
41.9
41.88
41.86
41.84
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
Longitude (deg)

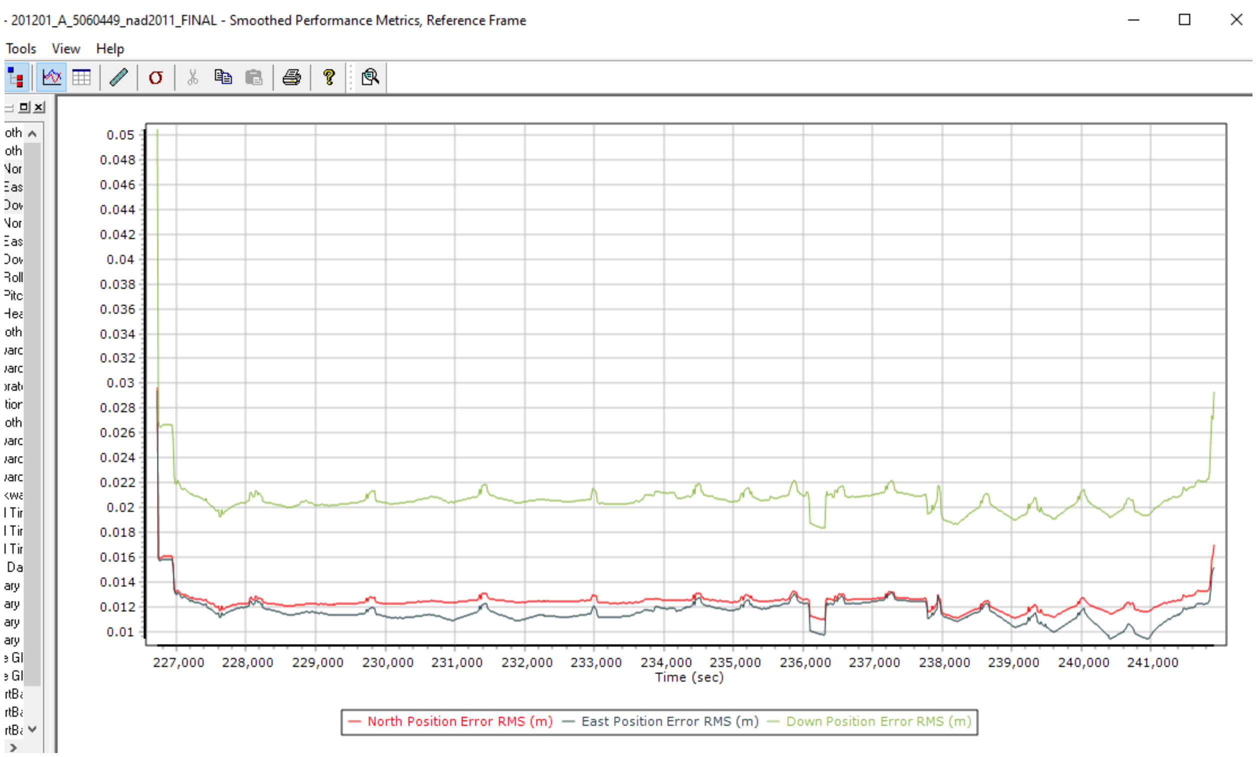

0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

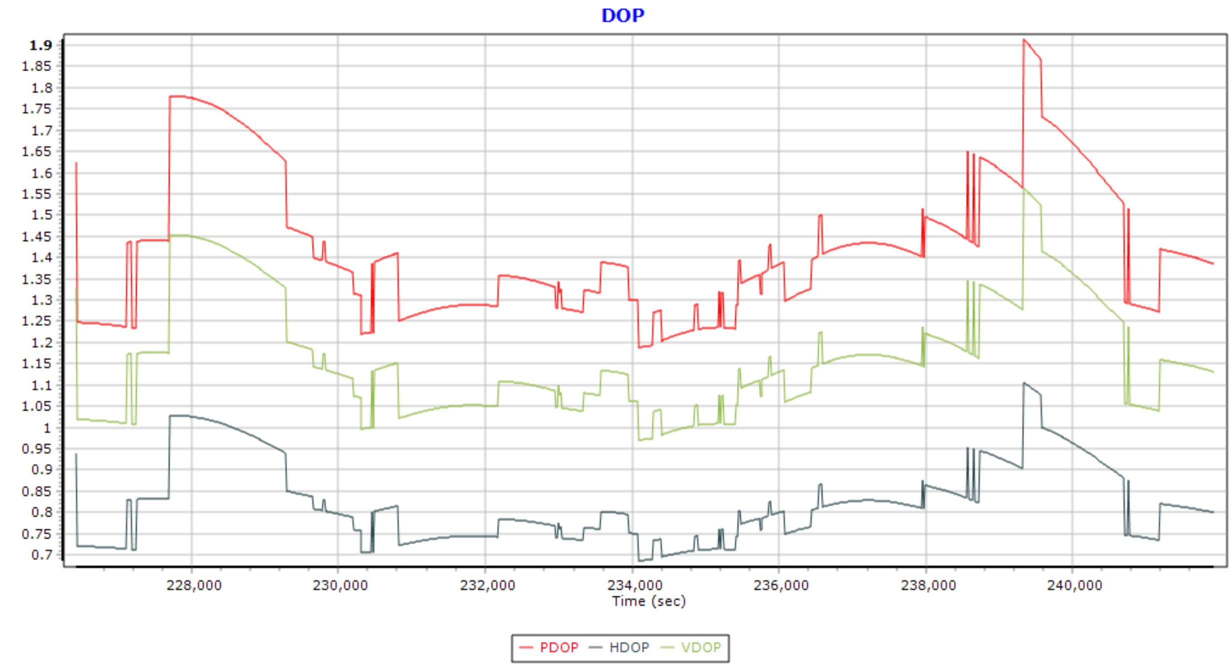

DOP
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
Time (sec)
PDOP
HDOP
VDOP

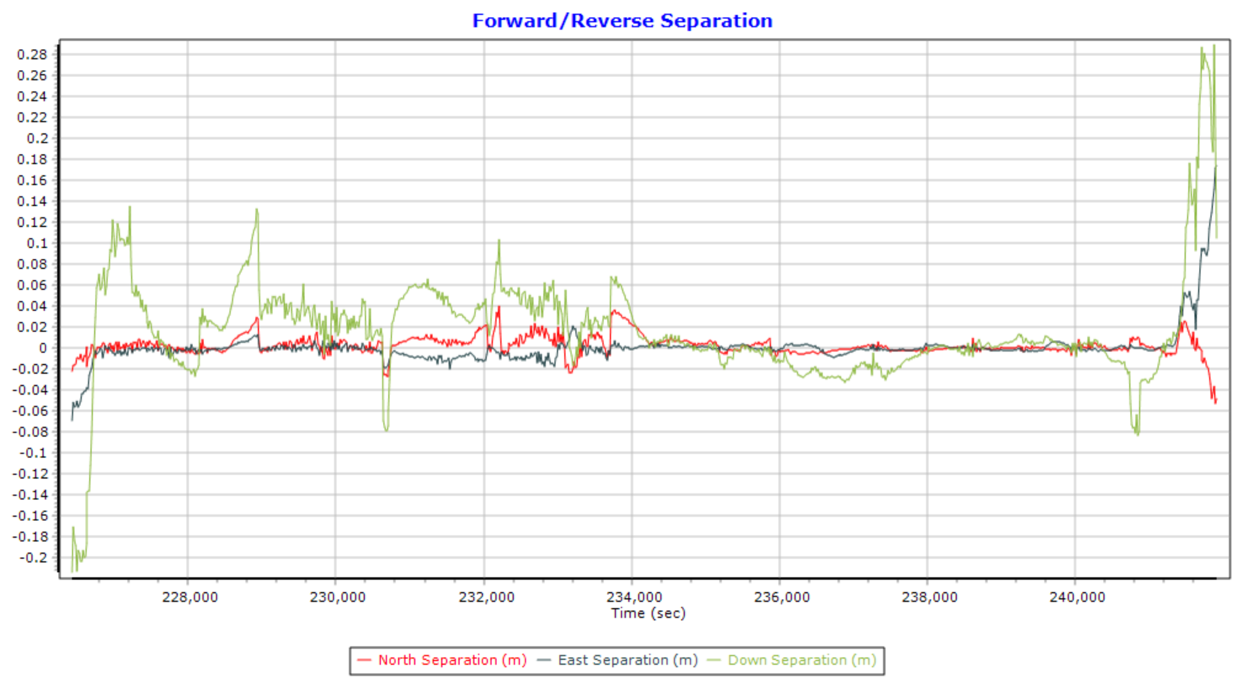

Forward/Reverse Separation
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

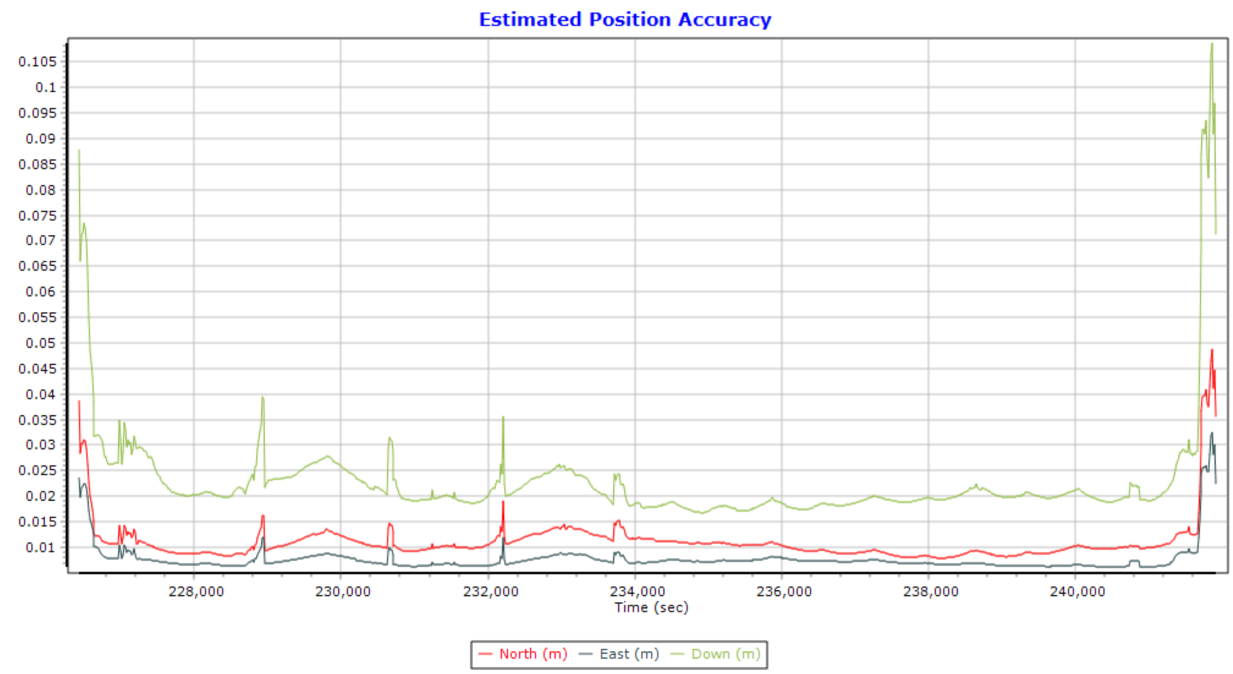

Estimated Position Accuracy
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
Time (sec)
North (m)
East (m)
Down (m)

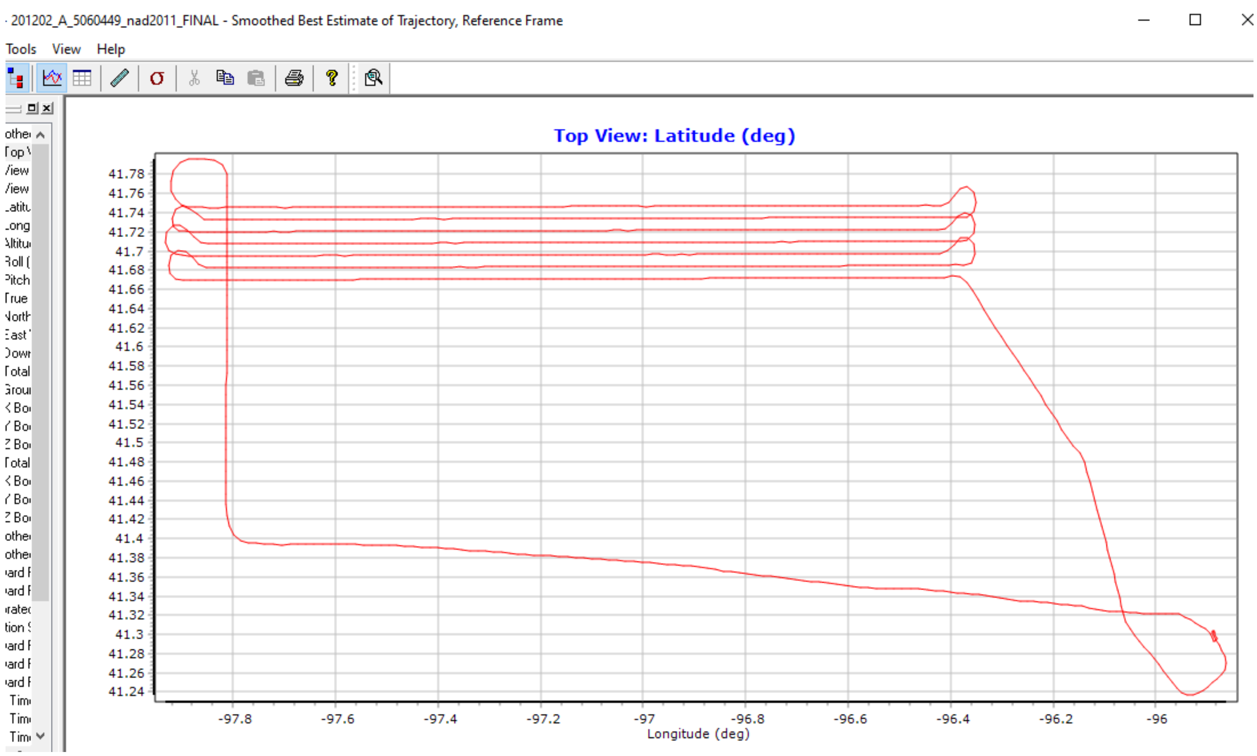

- 201201_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
42.16
42.14
42.12
42.1
42.08
42.06
42.04
42.02
42
41.98
41.96
41.94
41.92
41.9
41.88
41.86
41.84
-99.2
-99
-98.8
-98.6
-98.4
-98.2
-98
-97.8
-97.6
Longitude (deg)


- 201201_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
227,000
228,000
229,000
230,000
231,000
232,000
233,000
234,000
235,000
236,000
237,000
238,000
239,000
240,000
241,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

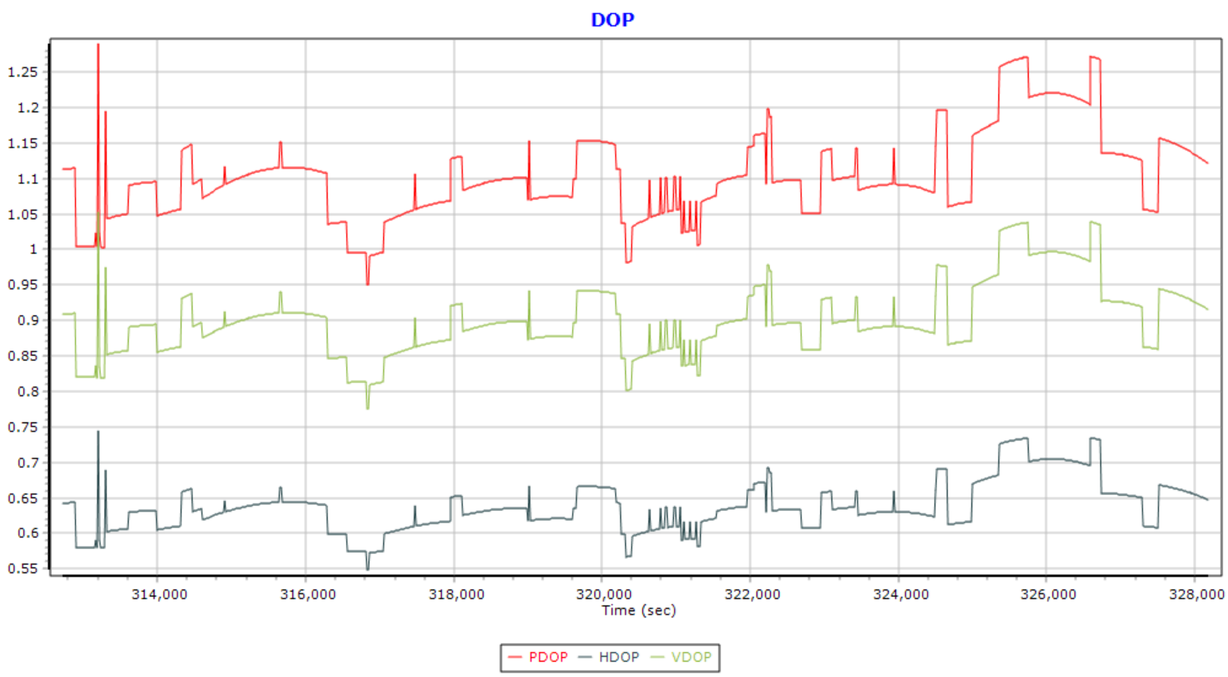

DOP
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
PDOP
HDOP
VDOP

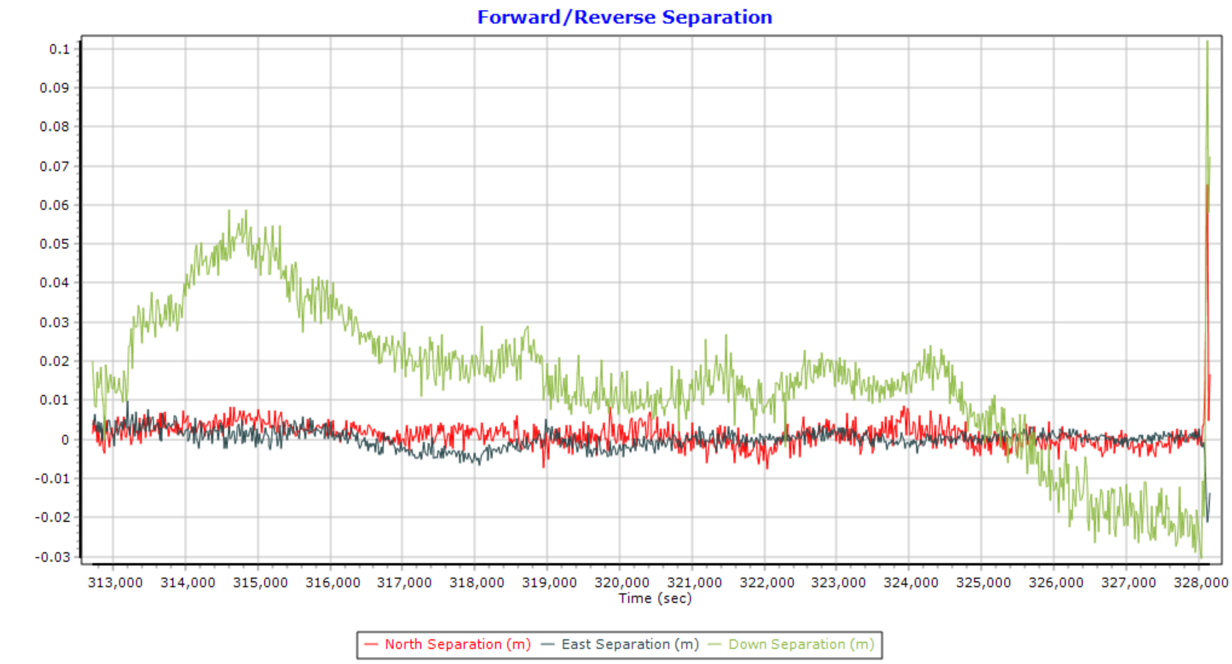

Forward/Reverse Separation
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

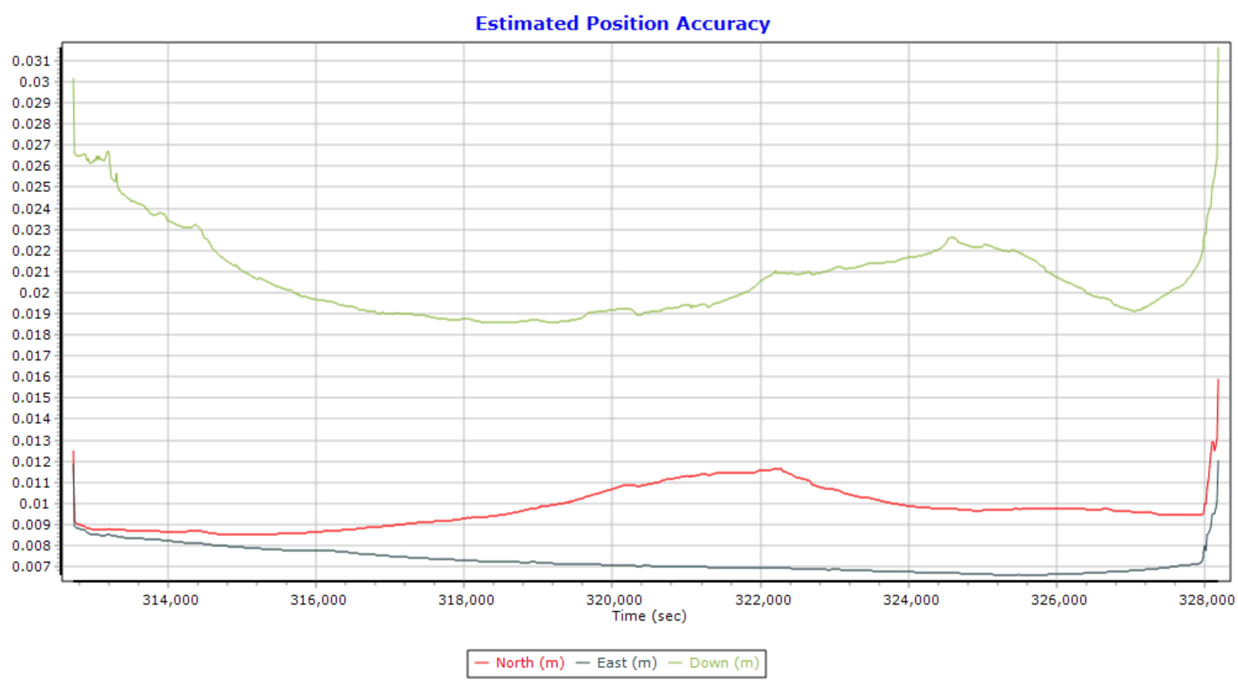

Estimated Position Accuracy
0.105
0.1
0.095
0.09
0.085
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
North (m)
East (m)
Down (m)

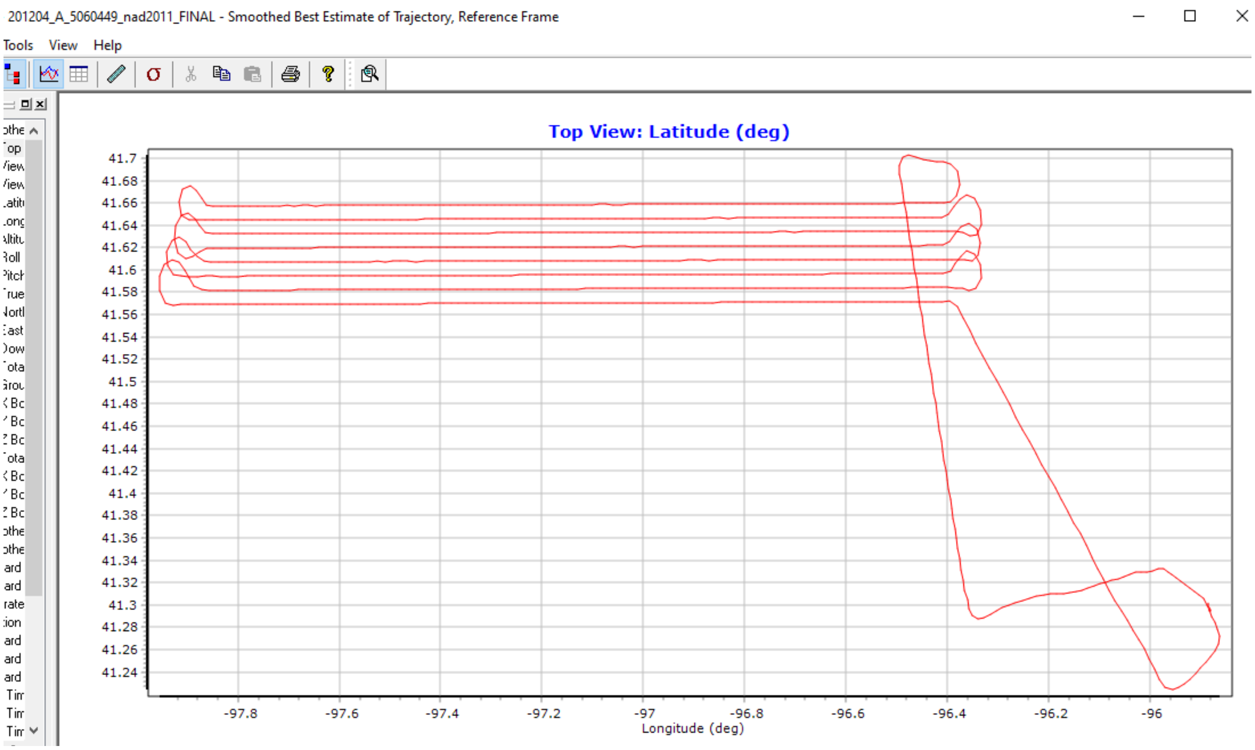

201202_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
41.78
41.76
41.74
41.72
41.7
41.68
41.66
41.64
41.62
41.6
41.58
41.56
41.54
41.52
41.5
41.48
41.46
41.44
41.42
41.4
41.38
41.36
41.34
41.32
41.3
41.28
41.26
41.24
-97.8
-97.6
-97.4
-97.2
-97
-96.8
-96.6
-96.4
-96.2
-96
Longitude (deg)

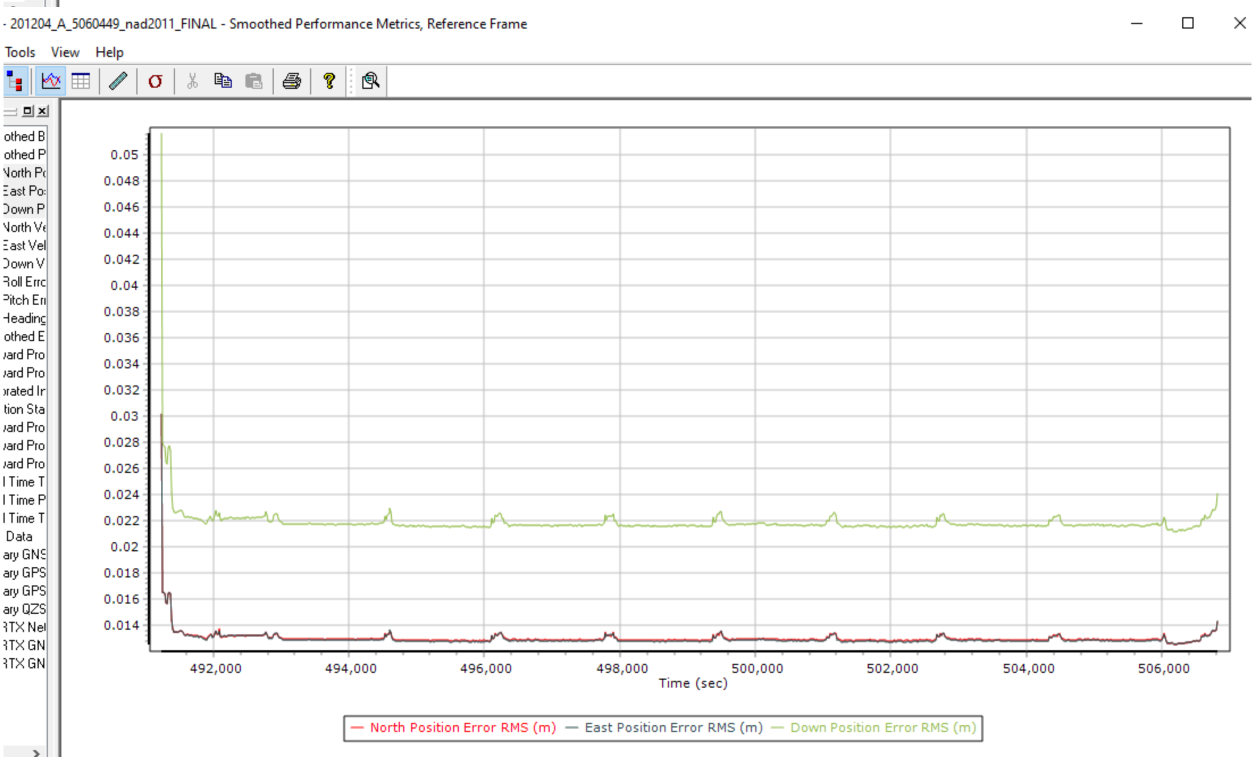

- 201202_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
313,000 314,000 315,000 316,000 317,000 318,000 319,000 320,000 321,000 322,000 323,000 324,000 325,000 326,000 327,000 328,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

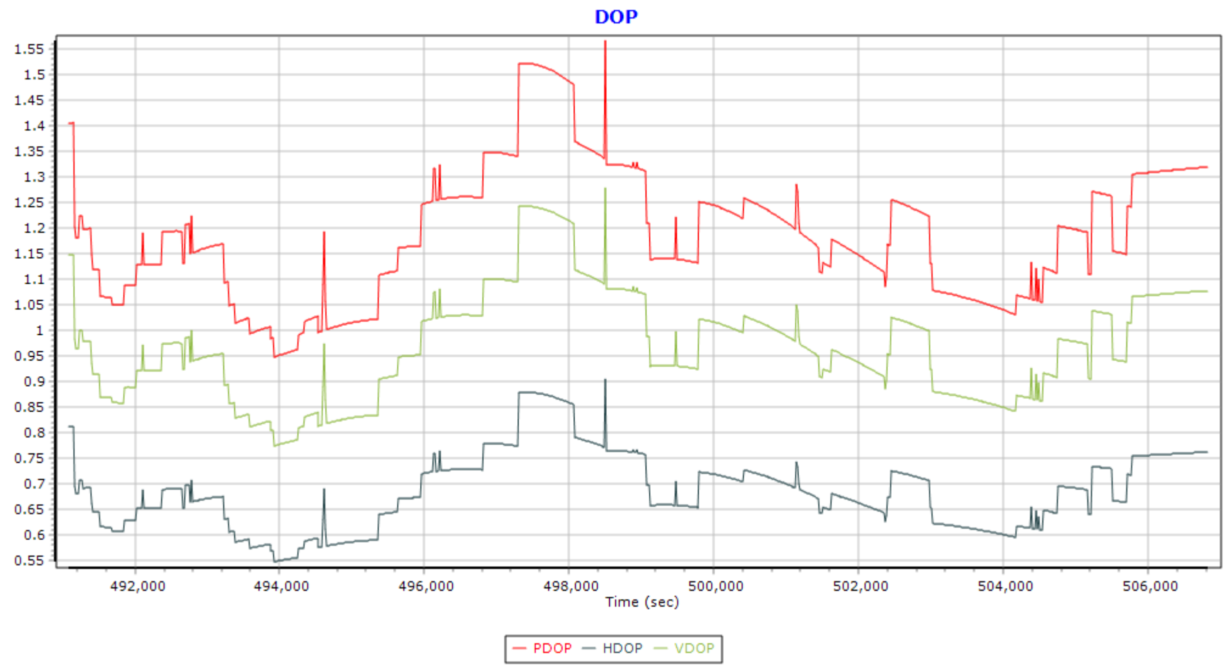

DOP
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
314,000 316,000 318,000 320,000 322,000 324,000 326,000 328,000
Time (sec)
PDOP
HDOP
VDOP

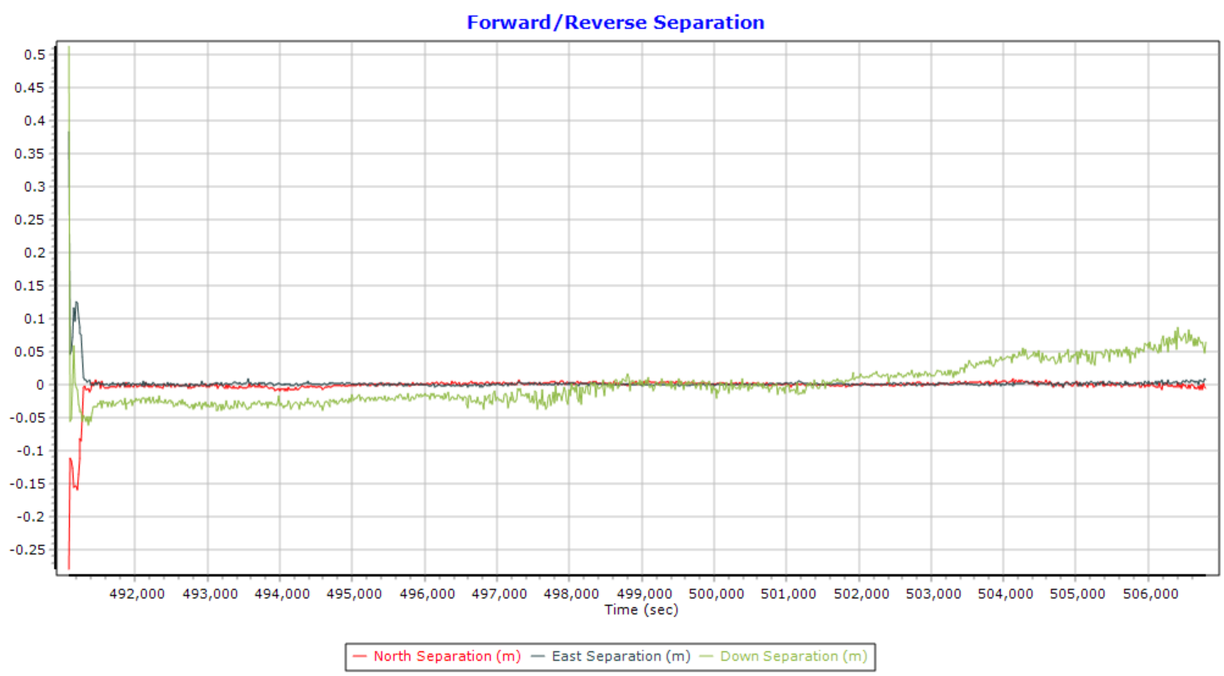

Forward/Reverse Separation
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
313,000 314,000 315,000 316,000 317,000 318,000 319,000 320,000 321,000 322,000 323,000 324,000 325,000 326,000 327,000 328,000
Time (sec)
North Separation (m) East Separation (m) Down Separation (m)

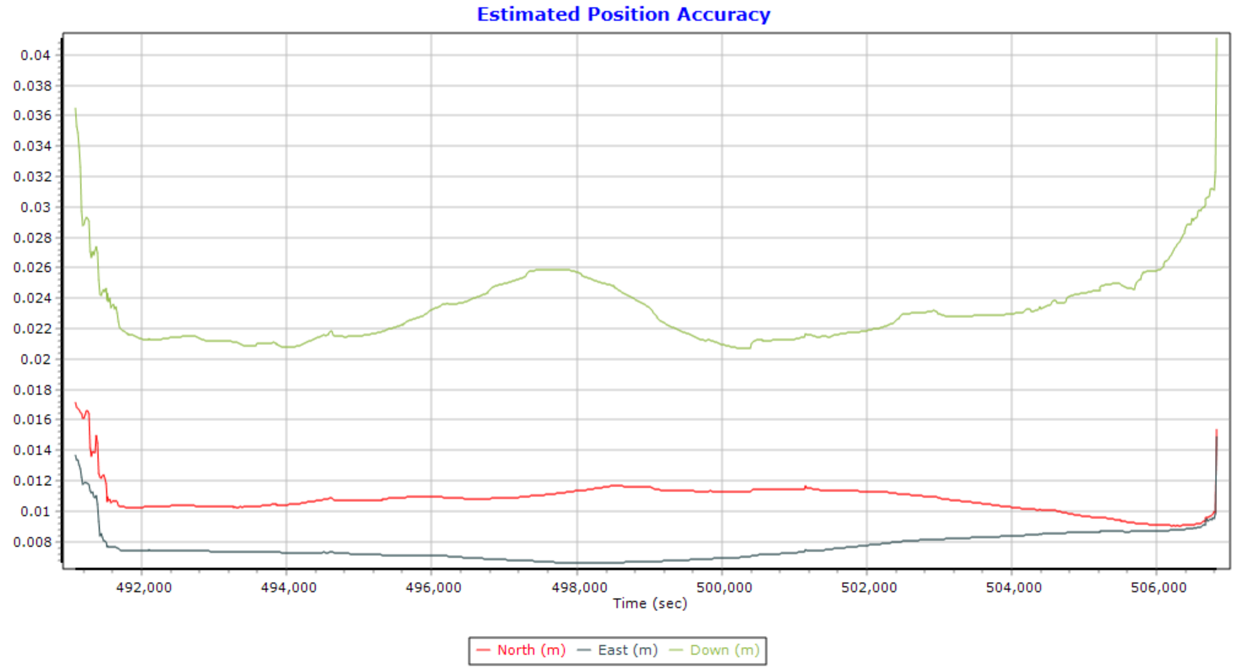

Estimated Position Accuracy
0.031
0.03
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
314,000 316,000 318,000 320,000 322,000 324,000 326,000 328,000
Time (sec)
North (m) East (m) Down (m)

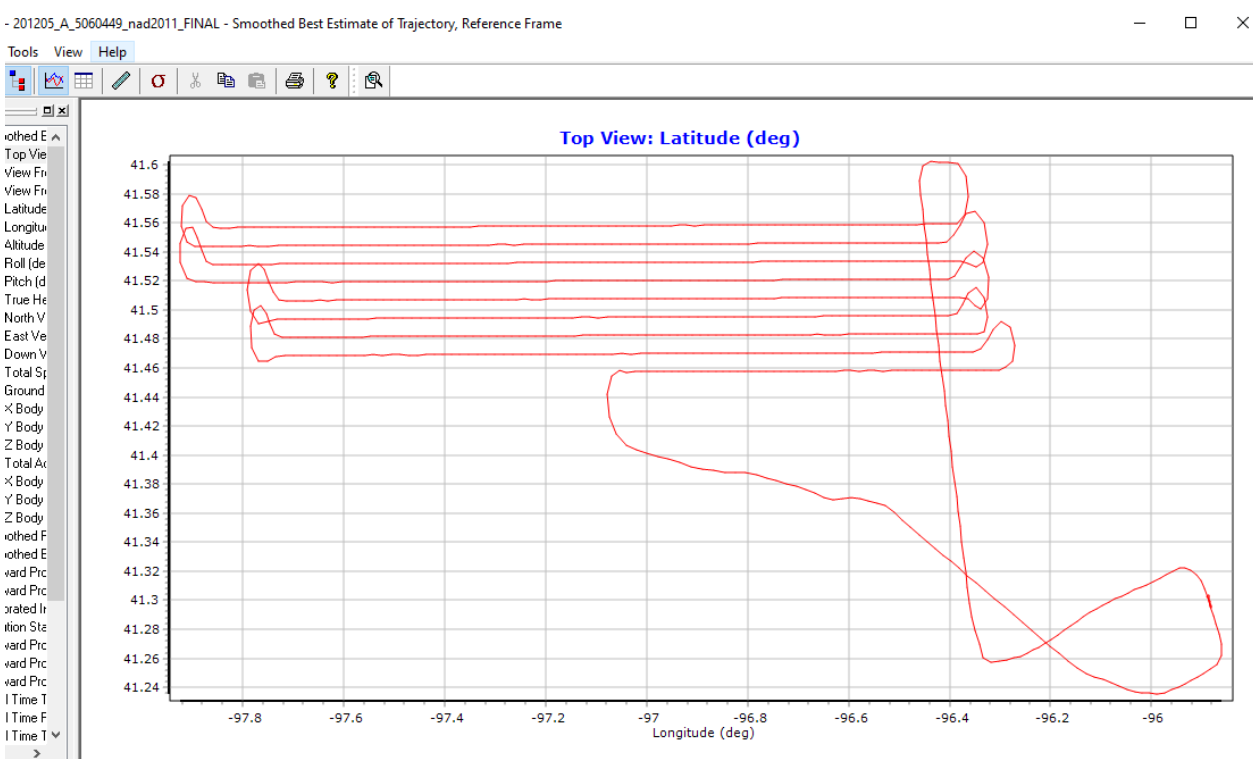

201204_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
41.7
41.68
41.66
41.64
41.62
41.6
41.58
41.56
41.54
41.52
41.5
41.48
41.46
41.44
41.42
41.4
41.38
41.36
41.34
41.32
41.3
41.28
41.26
41.24
-97.8
-97.6
-97.4
-97.2
-97
-96.8
-96.6
-96.4
-96.2
-96
Longitude (deg)

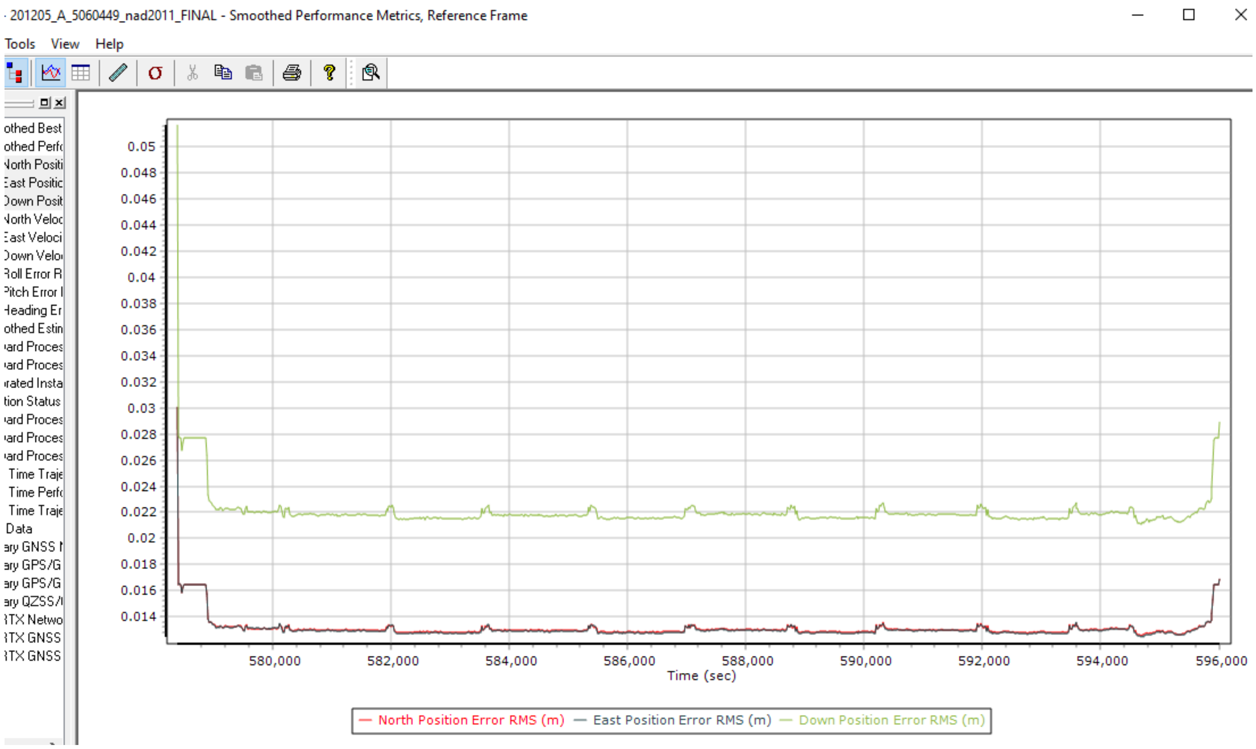

201204_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
492,000
494,000
496,000
498,000
500,000
502,000
504,000
506,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

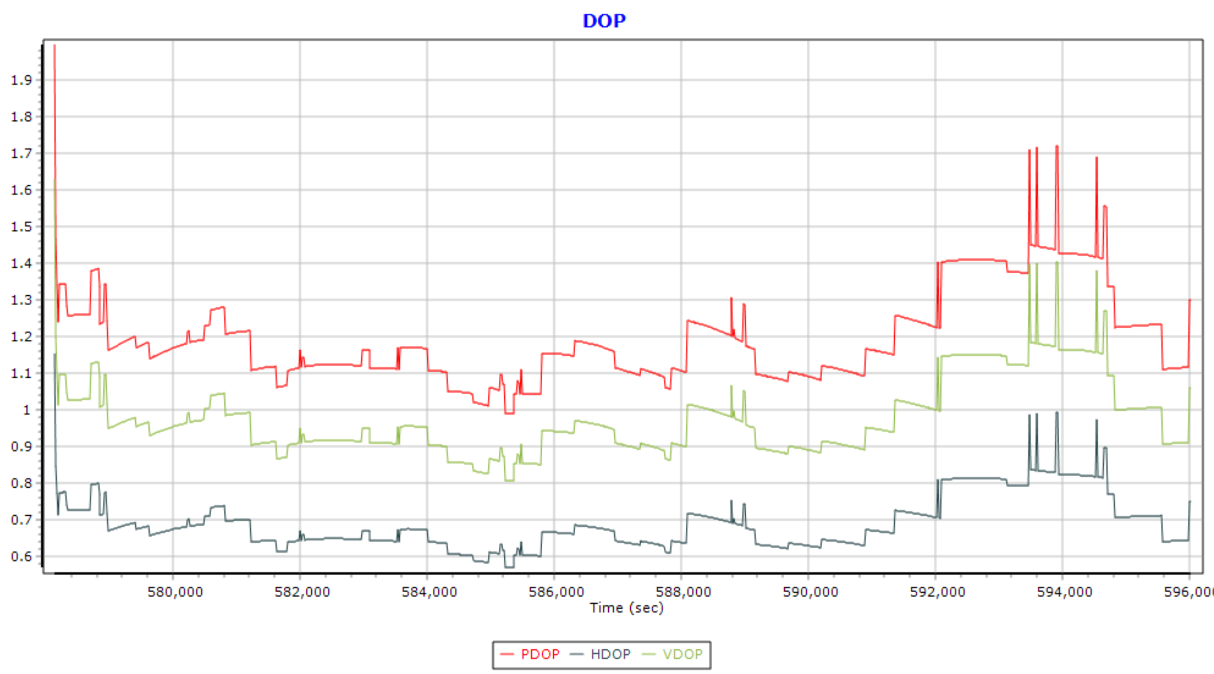

DOP
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
492,000
494,000
496,000
498,000
500,000
502,000
504,000
506,000
Time (sec)
PDOP
HDOP
VDOP

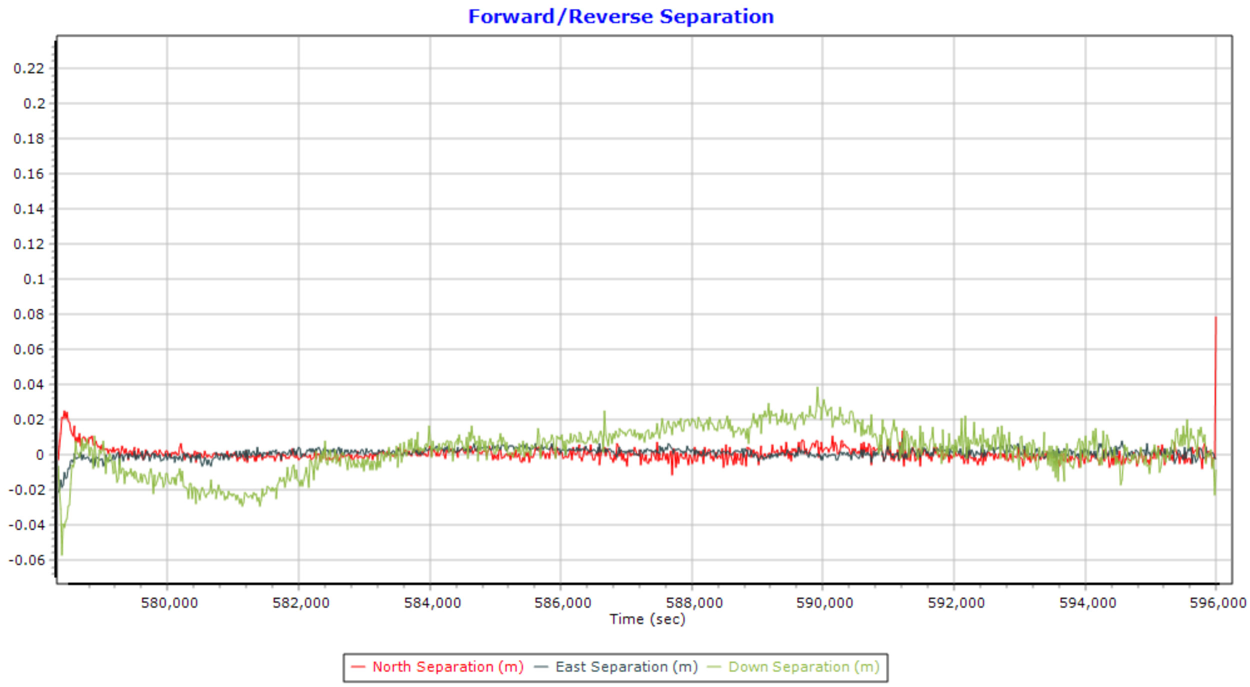

Forward/Reverse Separation
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
492,000
493,000
494,000
495,000
496,000
497,000
498,000
499,000
500,000
501,000
502,000
503,000
504,000
505,000
506,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

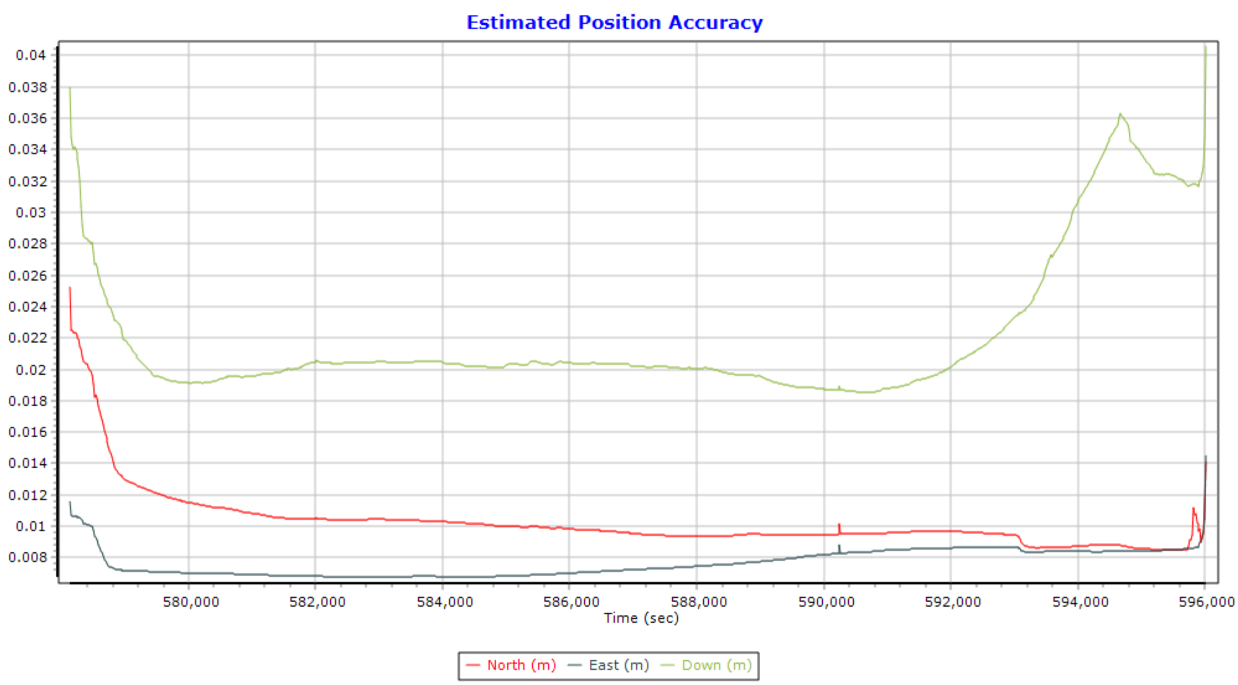

Estimated Position Accuracy
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
492,000
494,000
496,000
498,000
500,000
502,000
504,000
506,000
Time (sec)
North (m)
East (m)
Down (m)

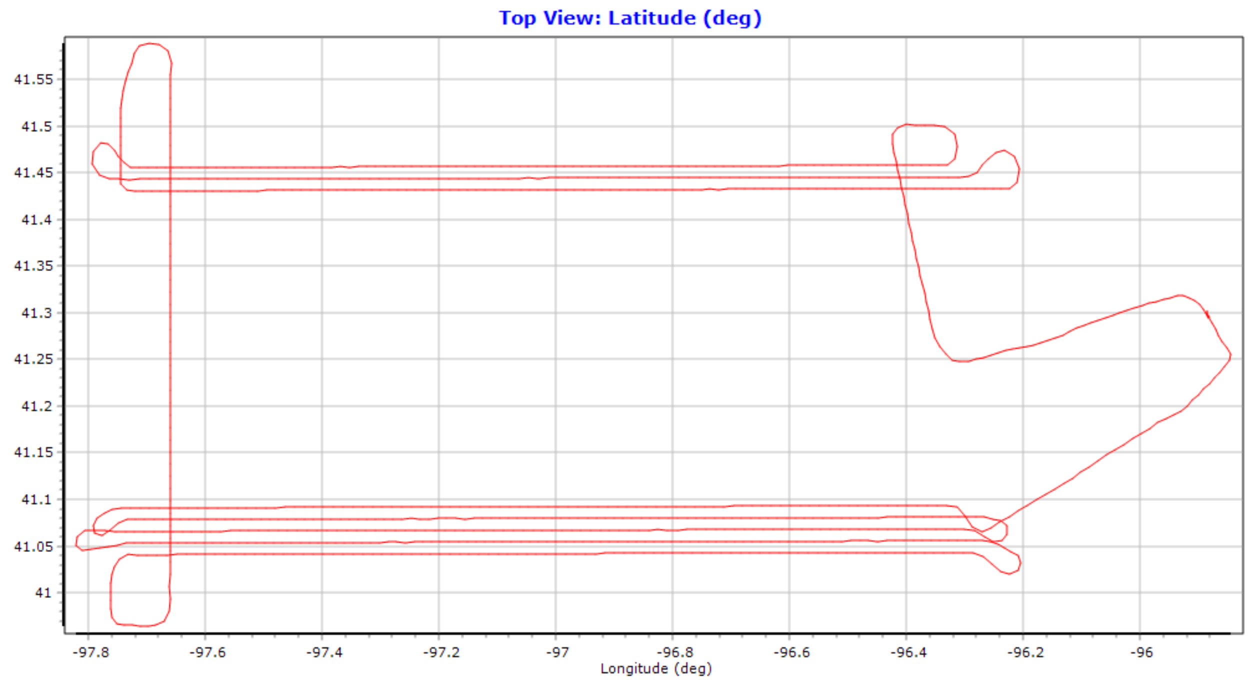

- 201205_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
41.6
41.58
41.56
41.54
41.52
41.5
41.48
41.46
41.44
41.42
41.4
41.38
41.36
41.34
41.32
41.3
41.28
41.26
41.24
-97.8
-97.6
-97.4
-97.2
-97
-96.8
-96.6
-96.4
-96.2
-96
Longitude (deg)


201205_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
Time (sec)
North Position Error RMS (m) — East Position Error RMS (m) — Down Position Error RMS (m)

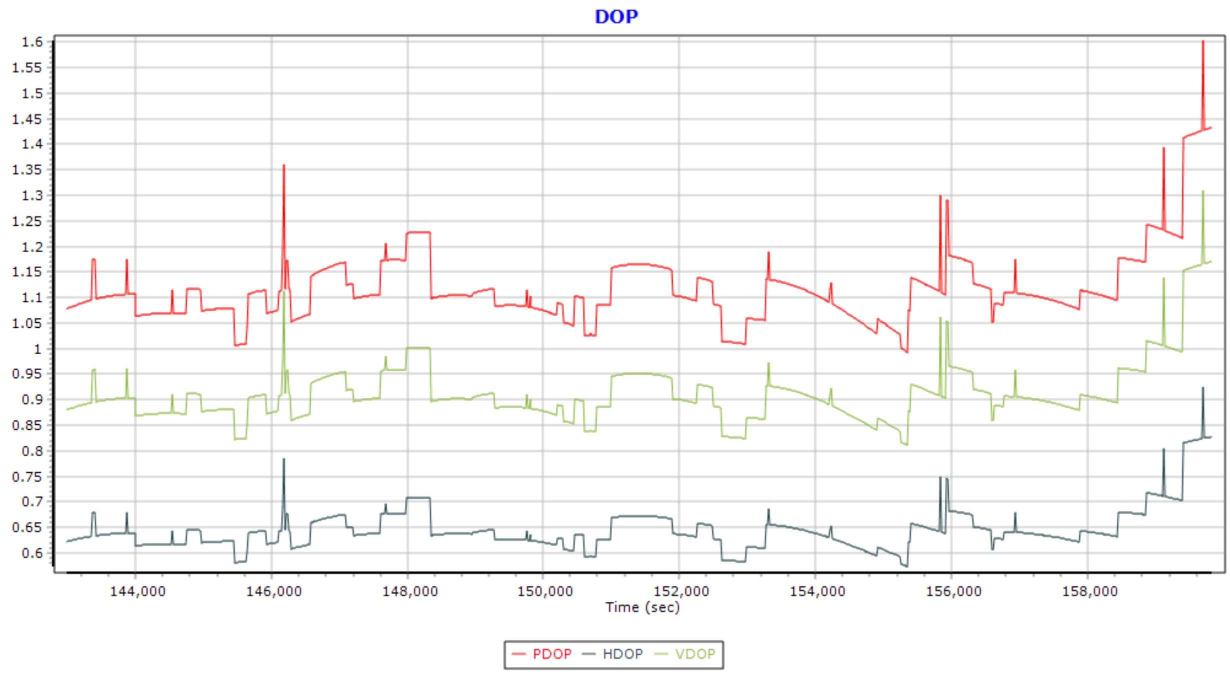

DOP
Time (sec)
PDOP — HDOP — VDOP

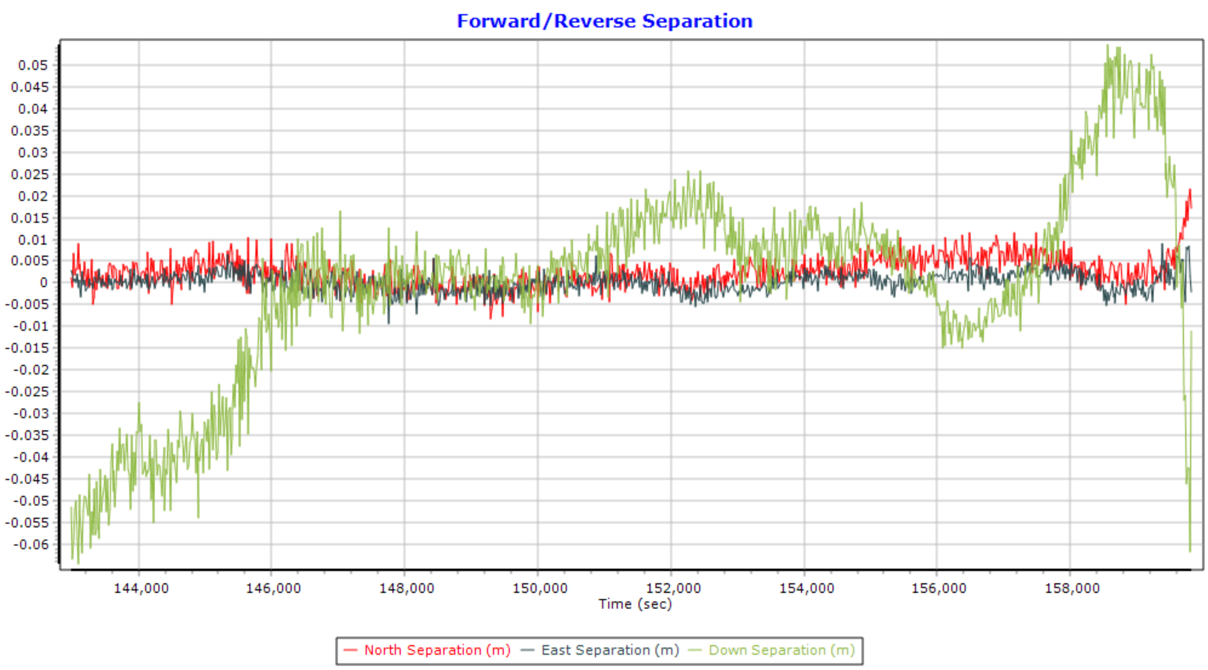

Forward/Reverse Separation
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
580,000
582,000
584,000
586,000
588,000
590,000
592,000
594,000
596,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

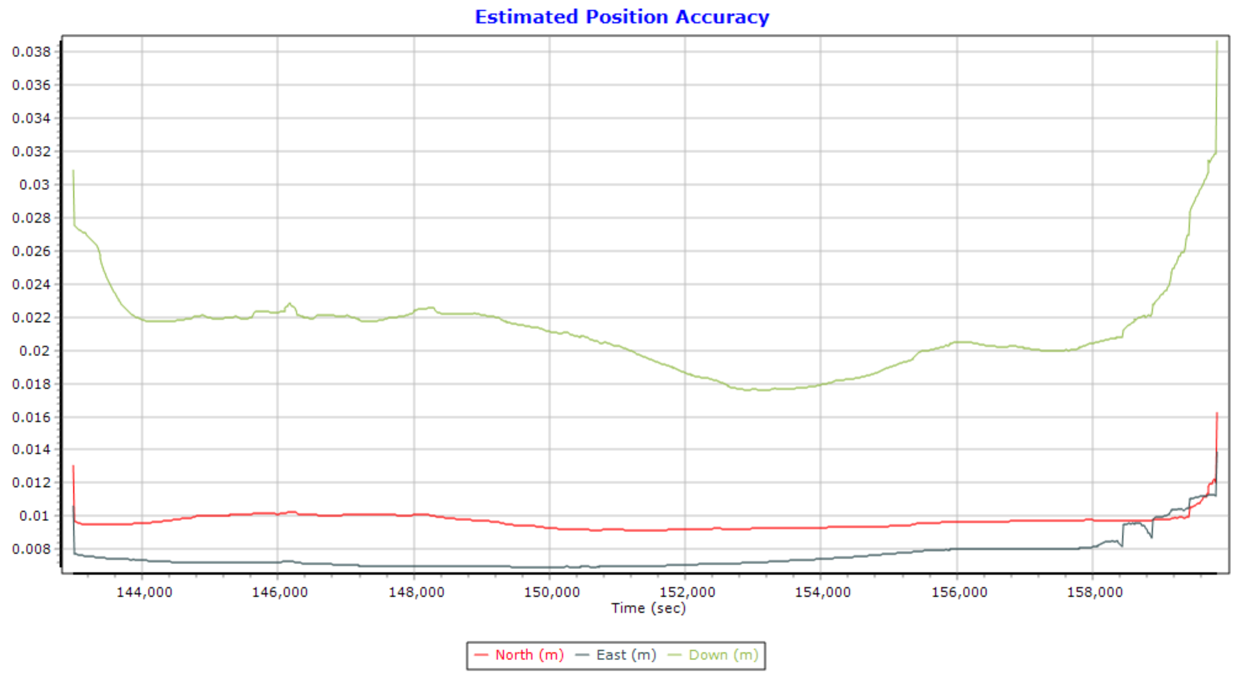

Estimated Position Accuracy
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
580,000
582,000
584,000
586,000
588,000
590,000
592,000
594,000
596,000
Time (sec)
North (m)
East (m)
Down (m)

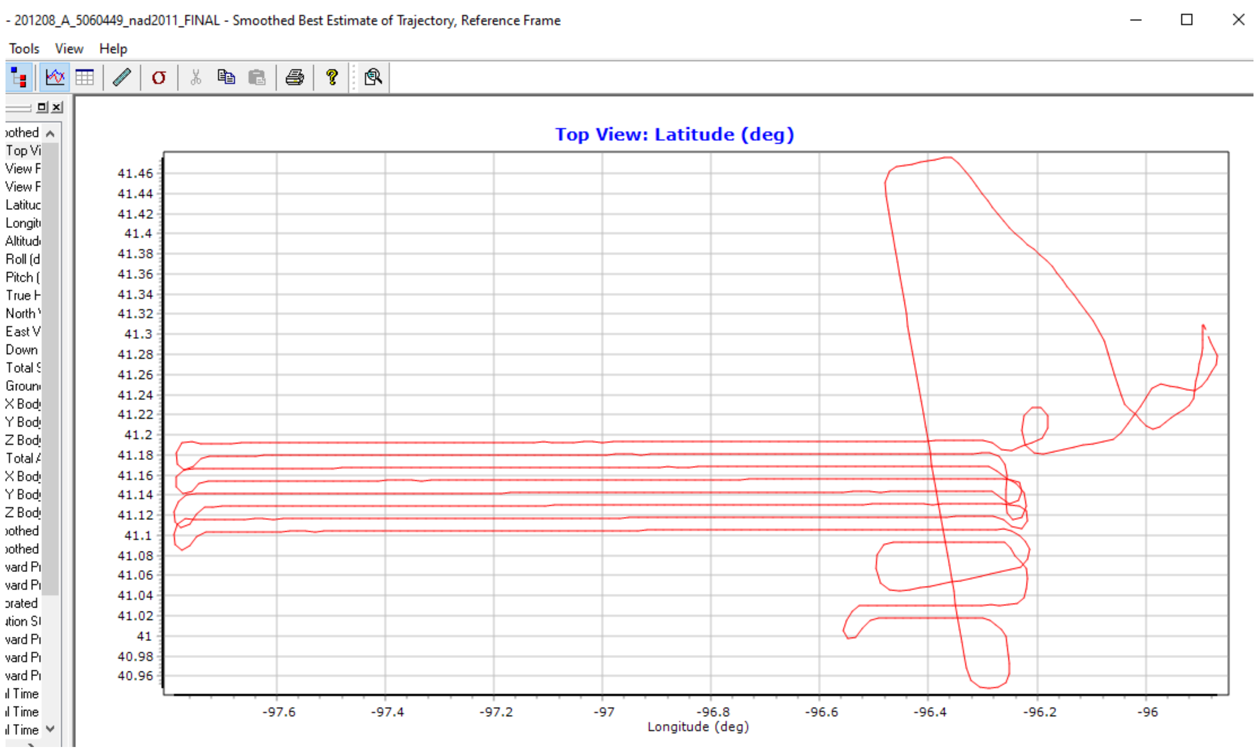

Top View: Latitude (deg)
41.55
41.5
41.45
41.4
41.35
41.3
41.25
41.2
41.15
41.1
41.05
41
-97.8
-97.6
-97.4
-97.2
-97
-96.8
-96.6
-96.4
-96.2
-96
Longitude (deg)

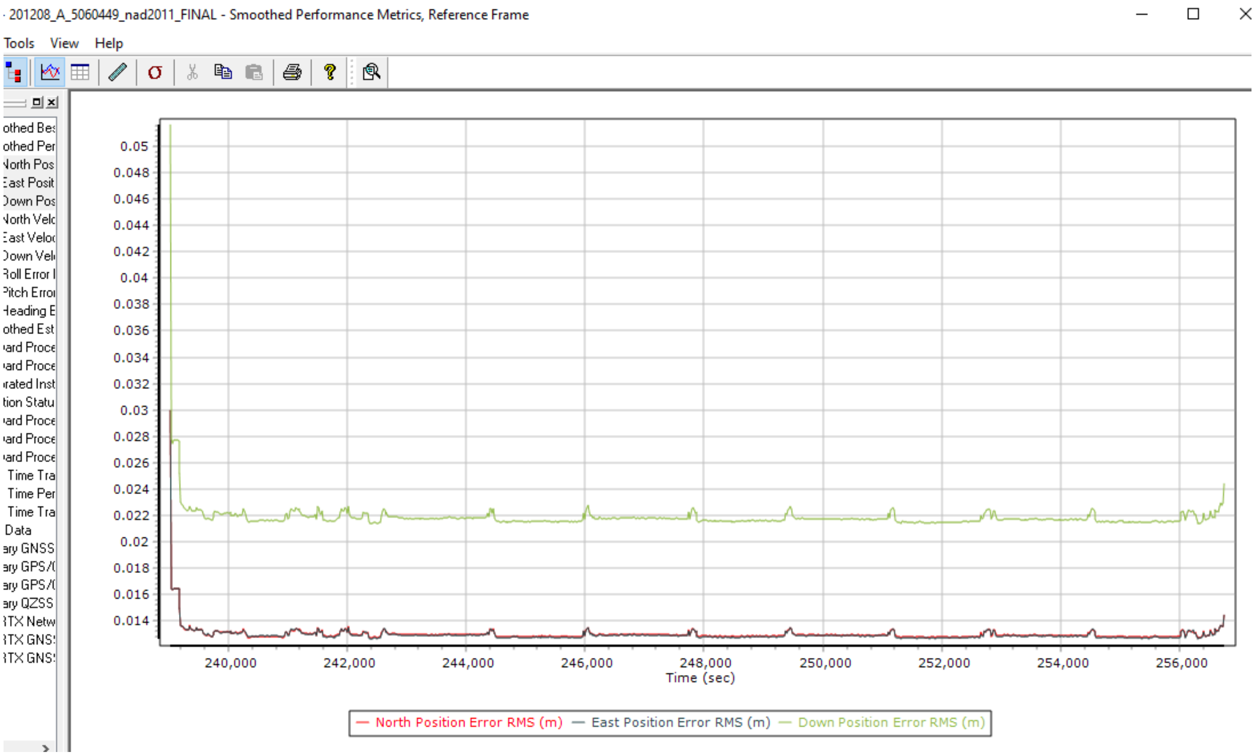

- 201207_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
144,000
146,000
148,000
150,000
152,000
154,000
156,000
158,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

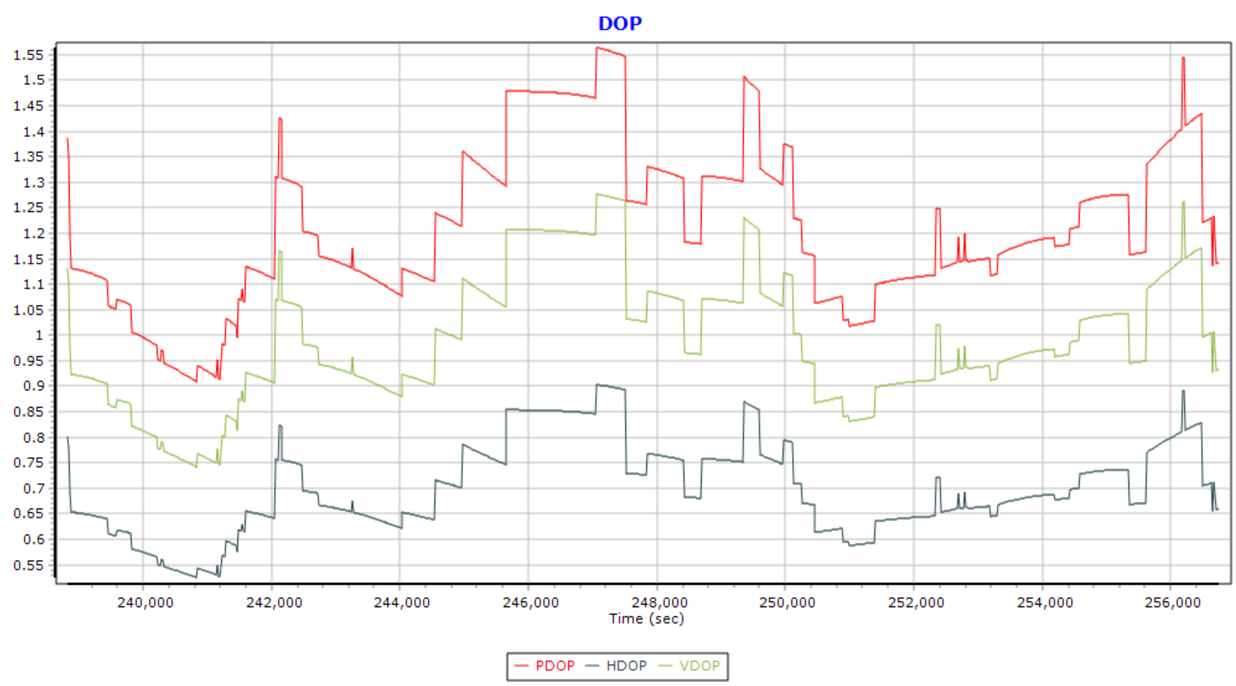

DOP
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
144,000
146,000
148,000
150,000
152,000
154,000
156,000
158,000
Time (sec)
PDOP
HDOP
VDOP

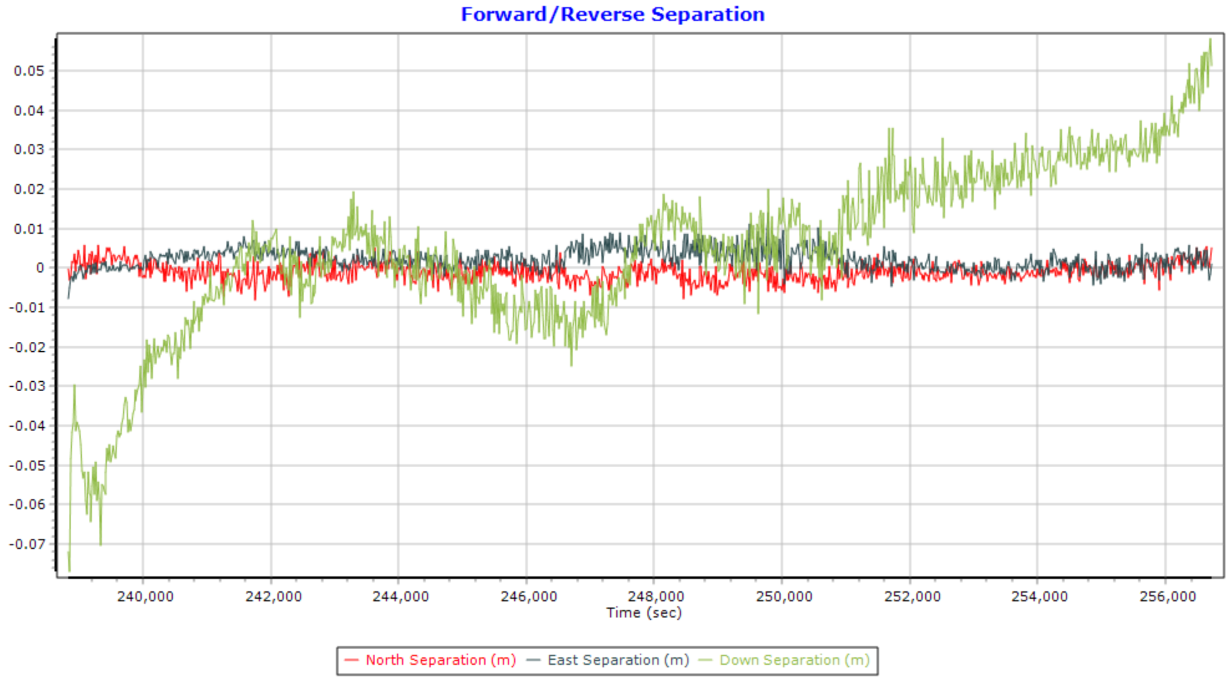

Forward/Reverse Separation
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
-0.055
-0.06
144,000
146,000
148,000
150,000
152,000
154,000
156,000
158,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

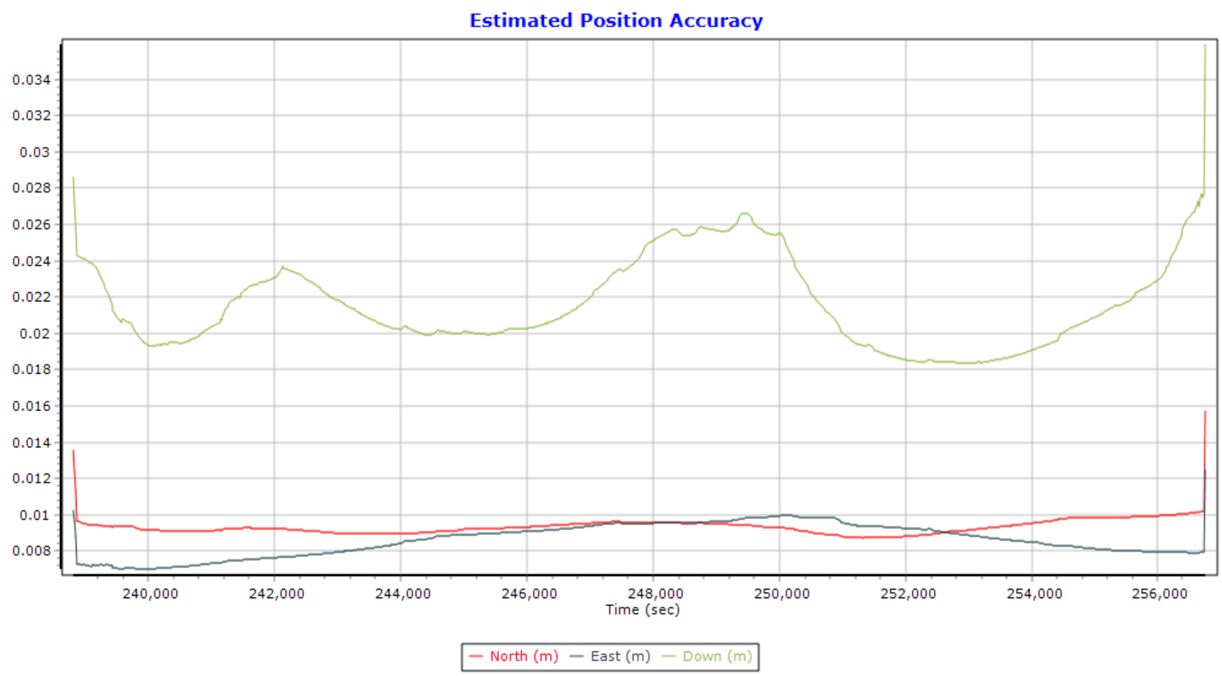

Estimated Position Accuracy
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
144,000
146,000
148,000
150,000
152,000
154,000
156,000
158,000
Time (sec)
North (m)
East (m)
Down (m)

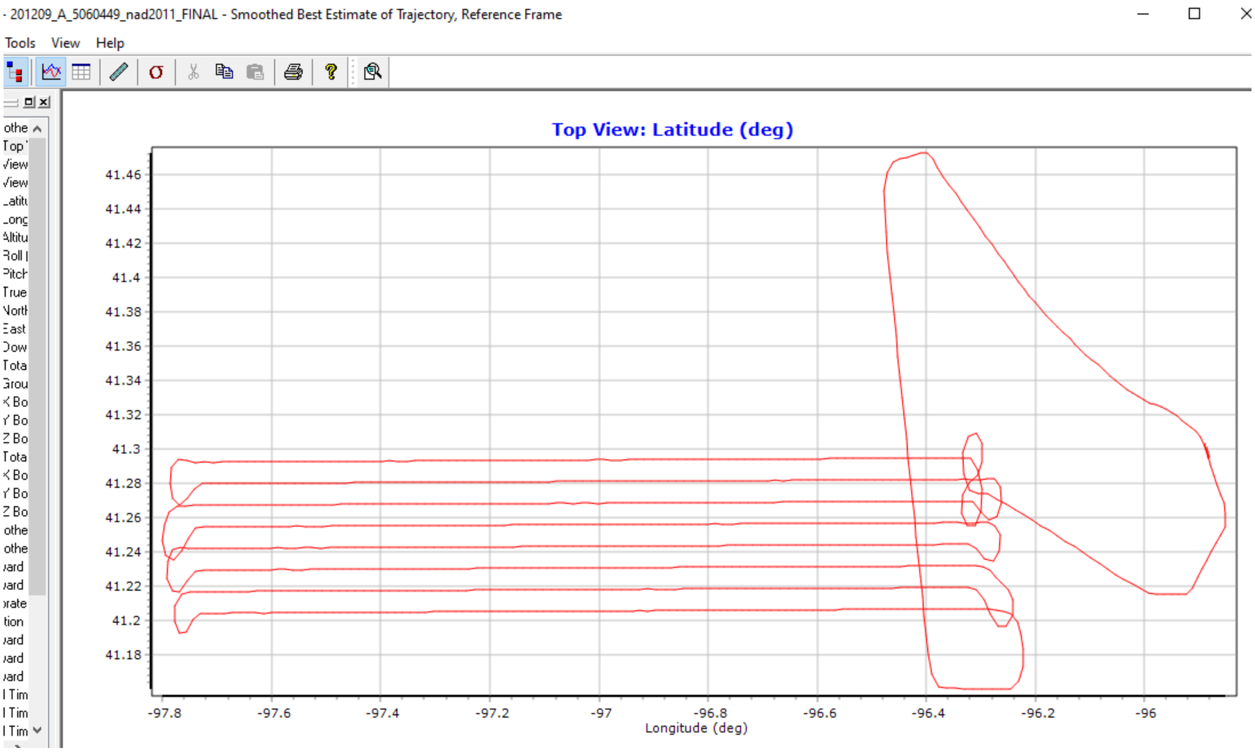

- 201208_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
41.46
41.44
41.42
41.4
41.38
41.36
41.34
41.32
41.3
41.28
41.26
41.24
41.22
41.2
41.18
41.16
41.14
41.12
41.1
41.08
41.06
41.04
41.02
41
40.98
40.96
-97.6
-97.4
-97.2
-97
-96.8
-96.6
-96.4
-96.2
-96
Longitude (deg)

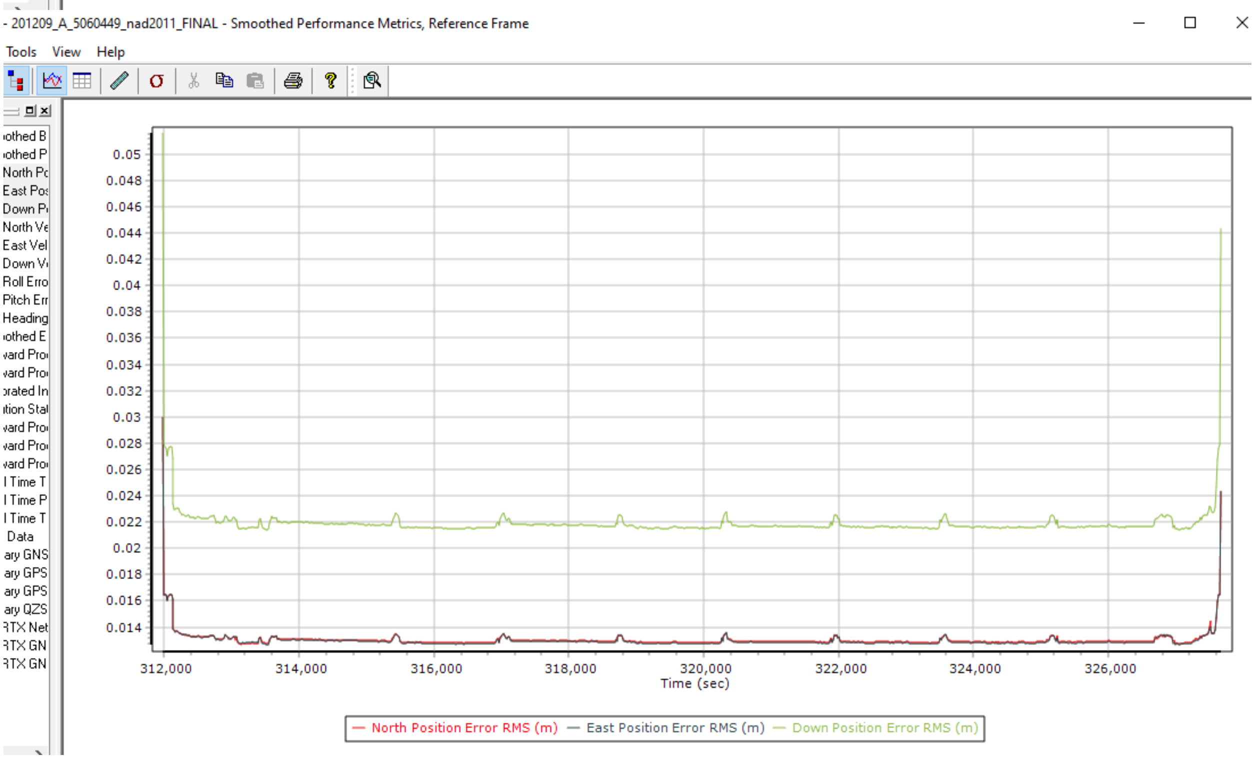

201208_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools
View
Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
240,000
242,000
244,000
246,000
248,000
250,000
252,000
254,000
256,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

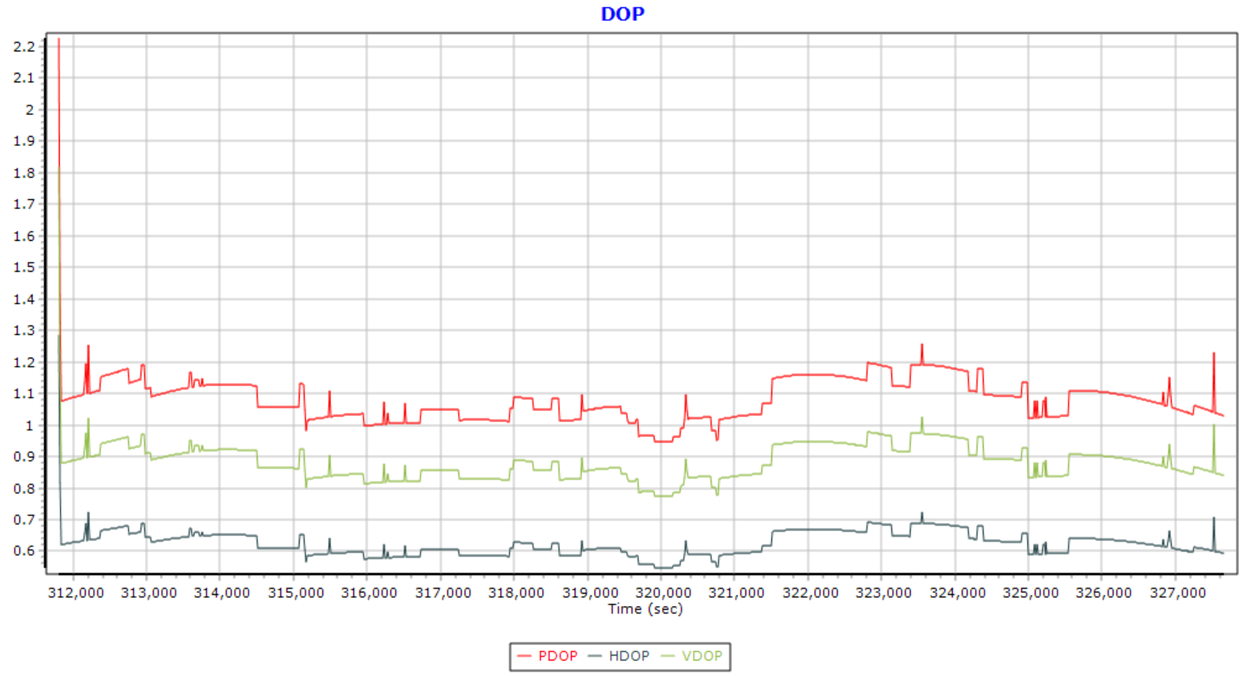

DOP
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
240,000
242,000
244,000
246,000
248,000
250,000
252,000
254,000
256,000
Time (sec)
PDOP
HDOP
VDOP

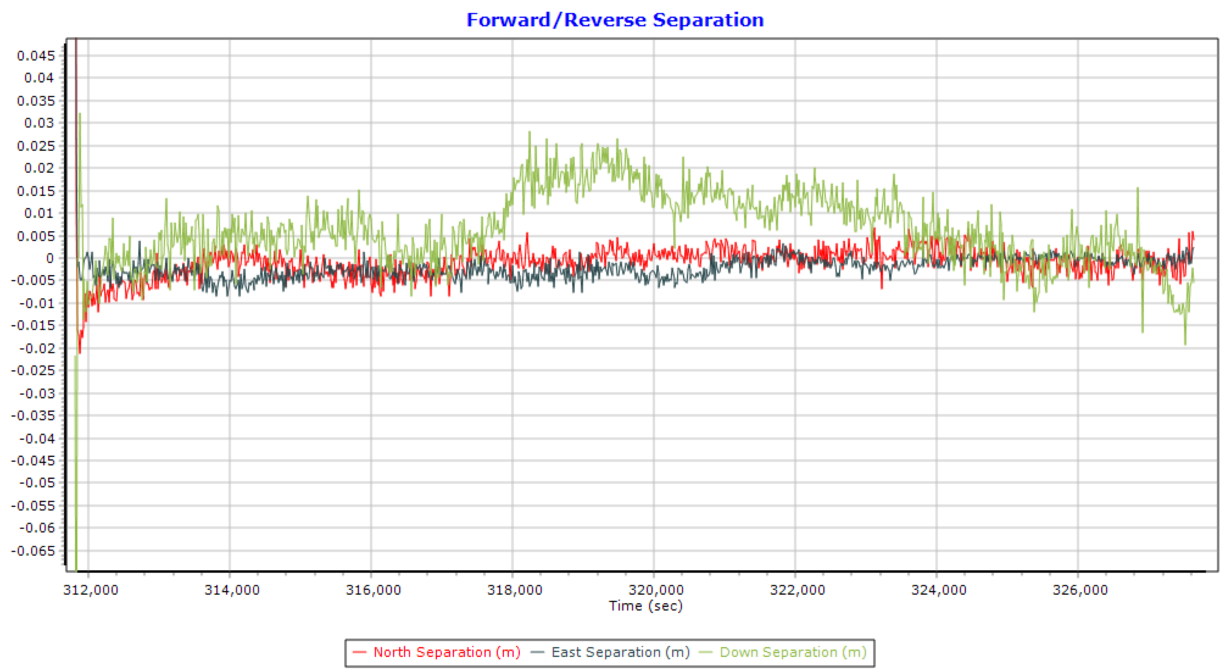

Forward/Reverse Separation
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
240,000
242,000
244,000
246,000
248,000
250,000
252,000
254,000
256,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

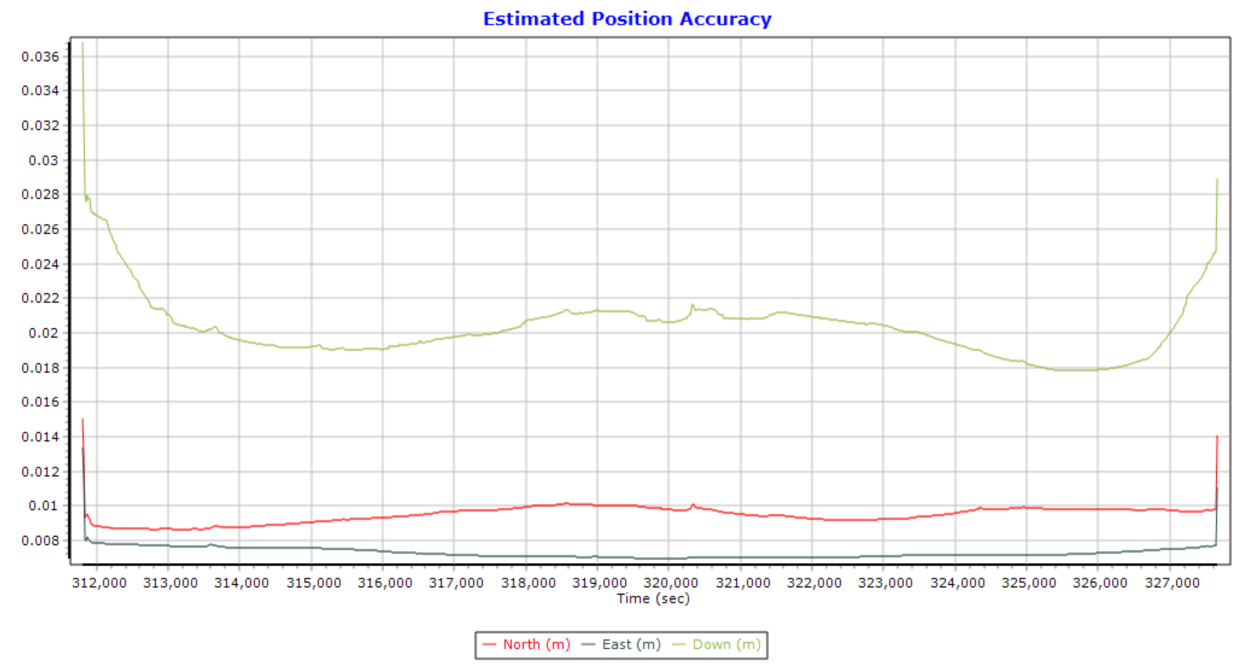

Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
240,000
242,000
244,000
246,000
248,000
250,000
252,000
254,000
256,000
Time (sec)
North (m)
East (m)
Down (m)

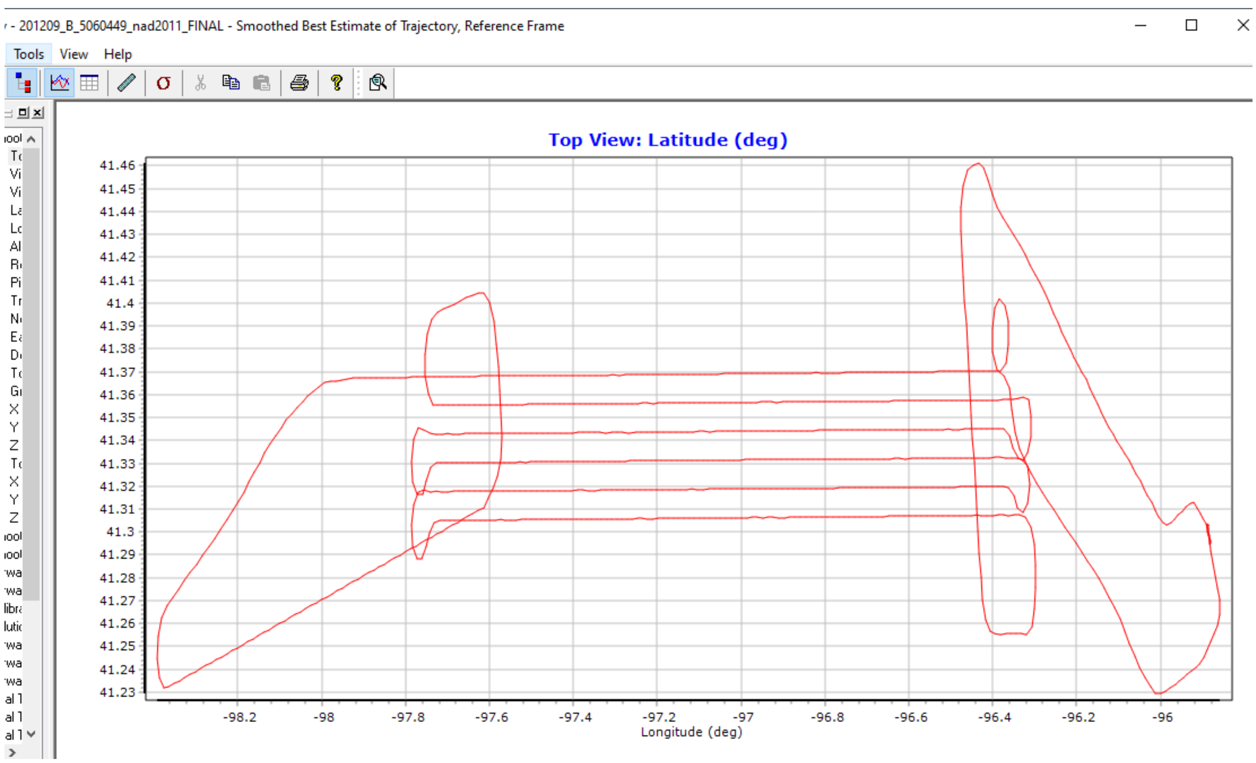

- 201209_A_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools View Help
Top View: Latitude (deg)
41.46
41.44
41.42
41.4
41.38
41.36
41.34
41.32
41.3
41.28
41.26
41.24
41.22
41.2
41.18
-97.8
-97.6
-97.4
-97.2
-97
-96.8
-96.6
-96.4
-96.2
-96
Longitude (deg)

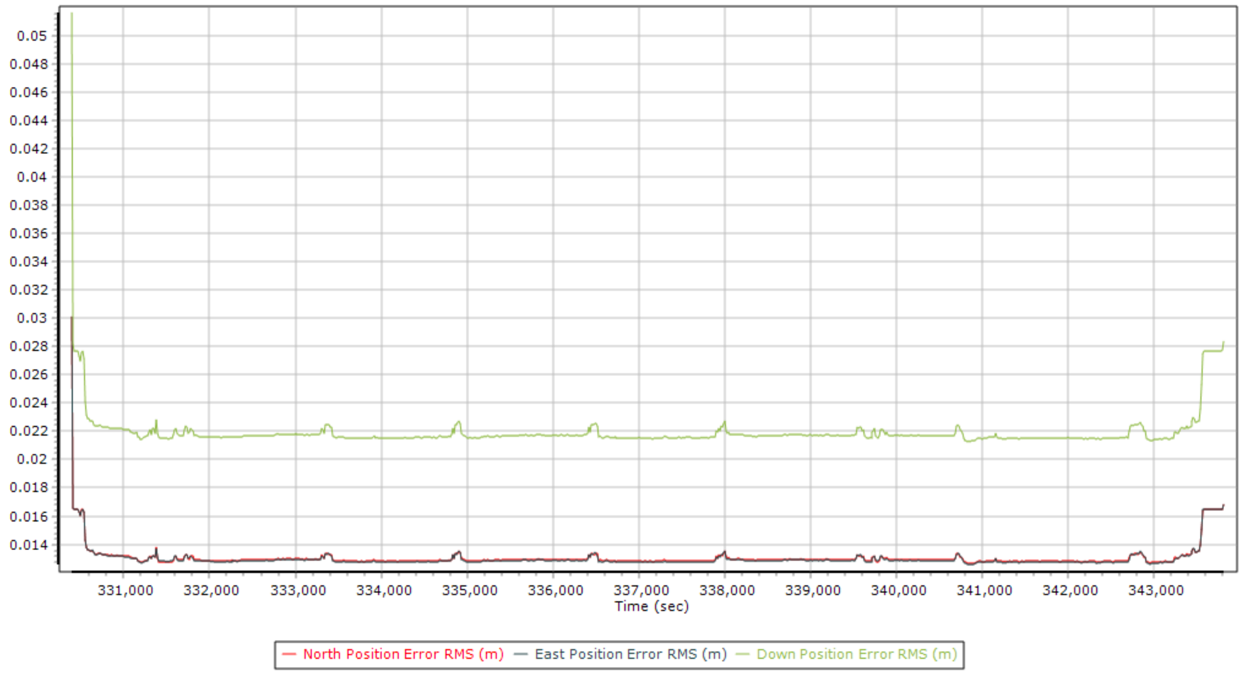

- 201209_A_5060449_nad2011_FINAL - Smoothed Performance Metrics, Reference Frame
Tools View Help
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
312,000
314,000
316,000
318,000
320,000
322,000
324,000
326,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

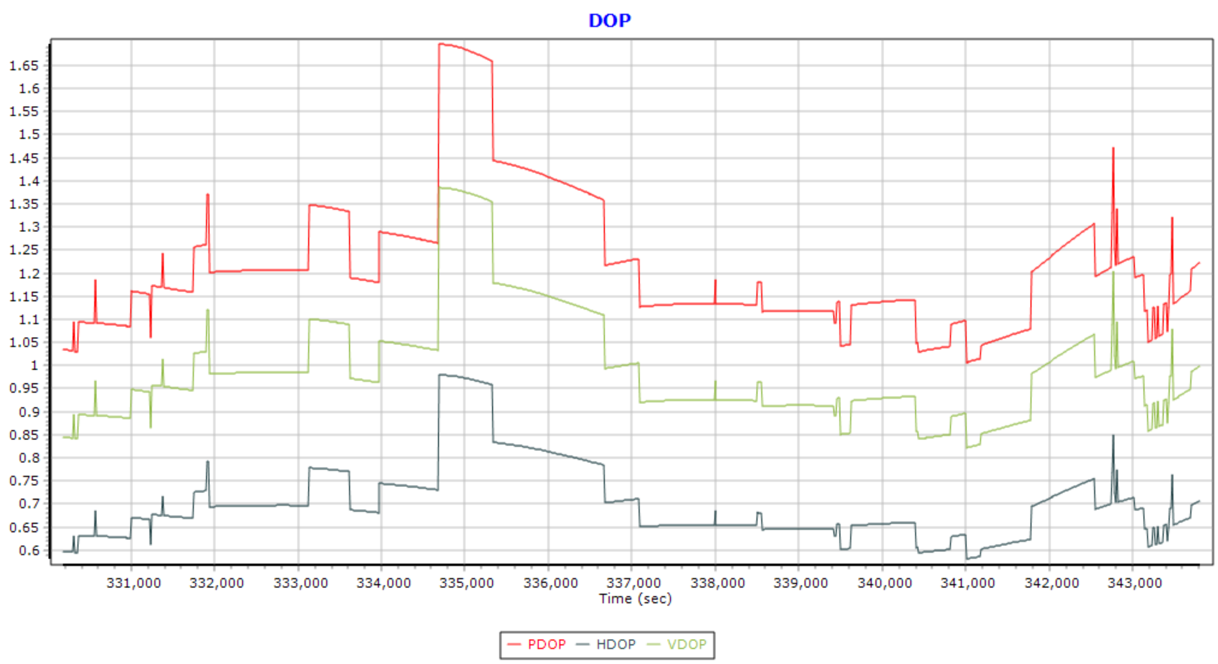

DOP
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
312,000 313,000 314,000 315,000 316,000 317,000 318,000 319,000 320,000 321,000 322,000 323,000 324,000 325,000 326,000 327,000
Time (sec)
PDOP
HDOP
VDOP

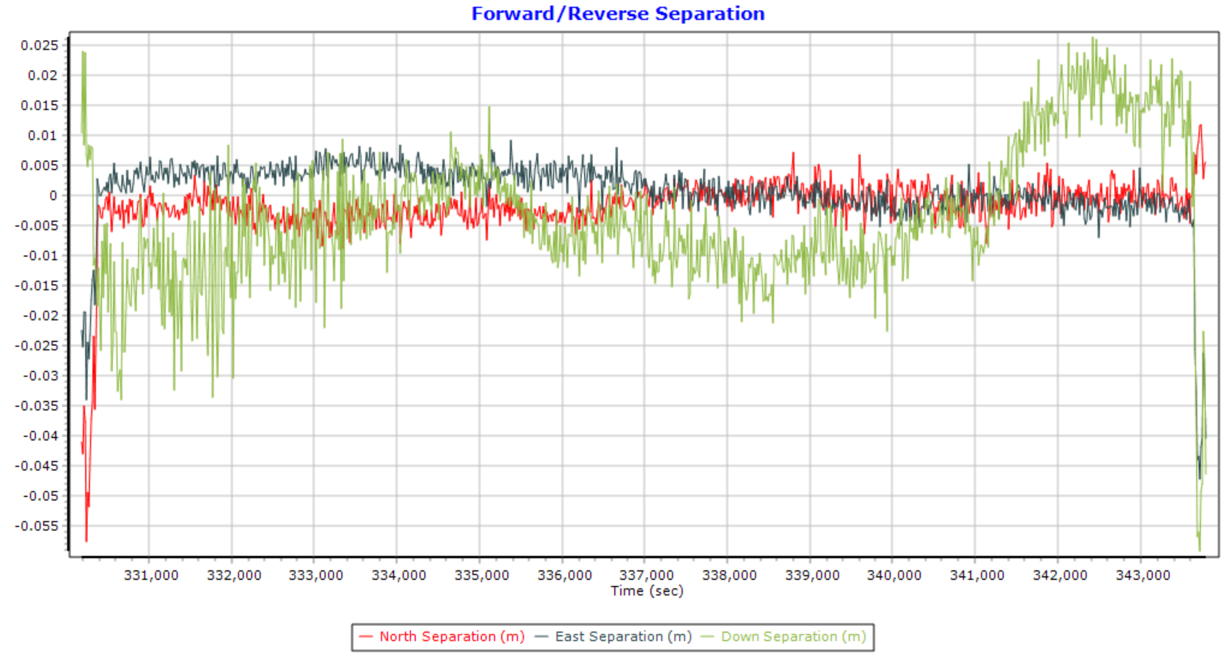

Forward/Reverse Separation
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
-0.055
-0.06
-0.065
312,000 314,000 316,000 318,000 320,000 322,000 324,000 326,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

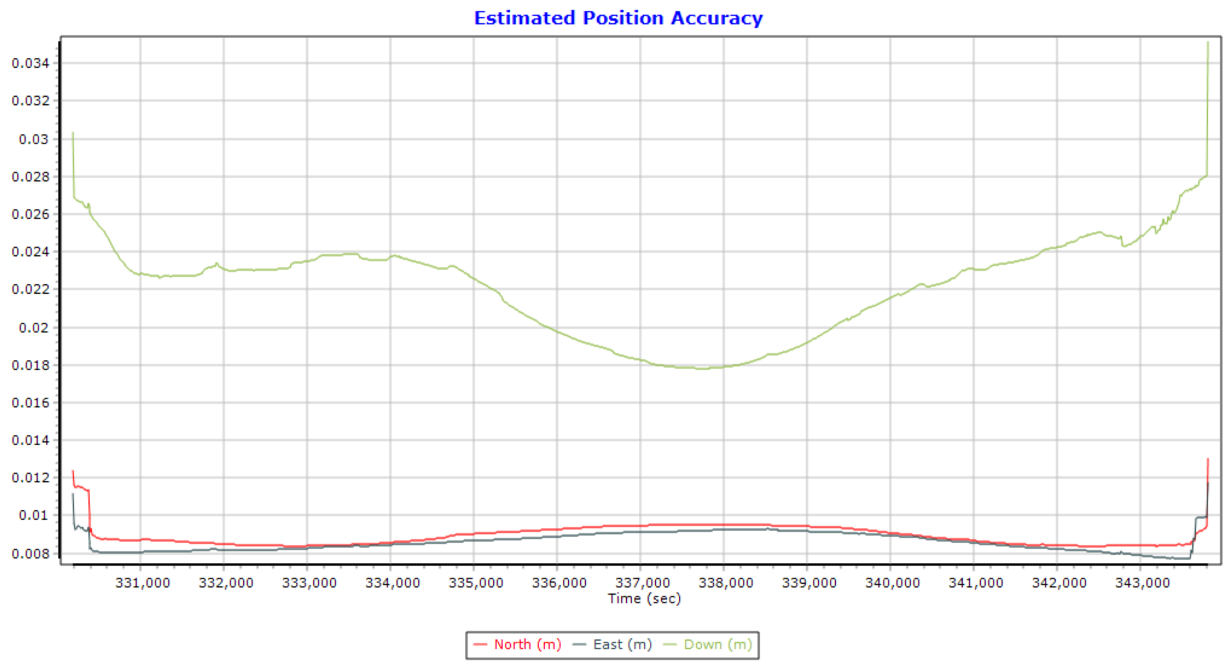

Estimated Position Accuracy
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
312,000 313,000 314,000 315,000 316,000 317,000 318,000 319,000 320,000 321,000 322,000 323,000 324,000 325,000 326,000 327,000
Time (sec)
North (m)
East (m)
Down (m)


201209_B_5060449_nad2011_FINAL - Smoothed Best Estimate of Trajectory, Reference Frame
Tools
View
Help
Top View: Latitude (deg)
41.46
41.45
41.44
41.43
41.42
41.41
41.4
41.39
41.38
41.37
41.36
41.35
41.34
41.33
41.32
41.31
41.3
41.29
41.28
41.27
41.26
41.25
41.24
41.23
-98.2 -98 -97.8 -97.6 -97.4 -97.2 -97 -96.8 -96.6 -96.4 -96.2 -96
Longitude (deg)


0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
331,000
332,000
333,000
334,000
335,000
336,000
337,000
338,000
339,000
340,000
341,000
342,000
343,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)


DOP
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
331,000
332,000
333,000
334,000
335,000
336,000
337,000
338,000
339,000
340,000
341,000
342,000
343,000
Time (sec)
PDOP
HDOP
VDOP


Forward/Reverse Separation
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
-0.055
331,000
332,000
333,000
334,000
335,000
336,000
337,000
338,000
339,000
340,000
341,000
342,000
343,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)


Estimated Position Accuracy
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
331,000
332,000
333,000
334,000
335,000
336,000
337,000
338,000
339,000
340,000
341,000
342,000
343,000
Time (sec)
North (m)
East (m)
Down (m)

## Appendix B: Following is a more detailed calibration workflow

**LIDAR CALIBRATION AND BLOCK LAS OUTPUT**

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from the project.

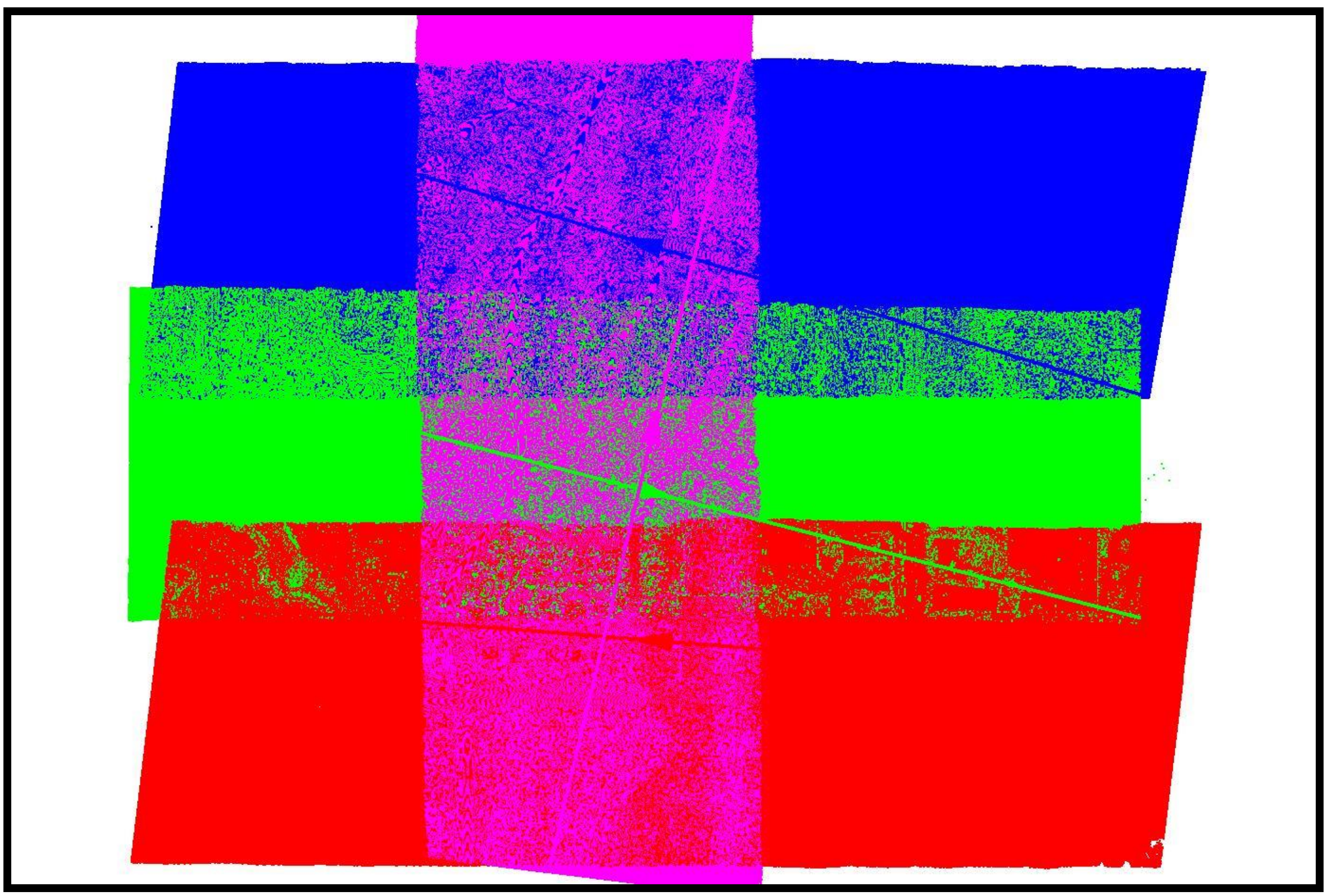
**Initial Processing**

Lidar data is output as LAS point data using Optech's Lidar Mapping Suite (LMS). LMS matches ground and roof planes plus roof lines to self-calibrate and correct system biases. These biases occur within the hardware of the laser scanning systems, within the Inertial Measurement Unit (IMU) and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include scale, roll, pitch, and heading.

In addition to the self-calibration mode LMS runs a "production" mode which applies the self-calibration parameters and then analyzes each individual flight line and applies small adjustments to each line to tie overlapping lidar points even more tightly together.

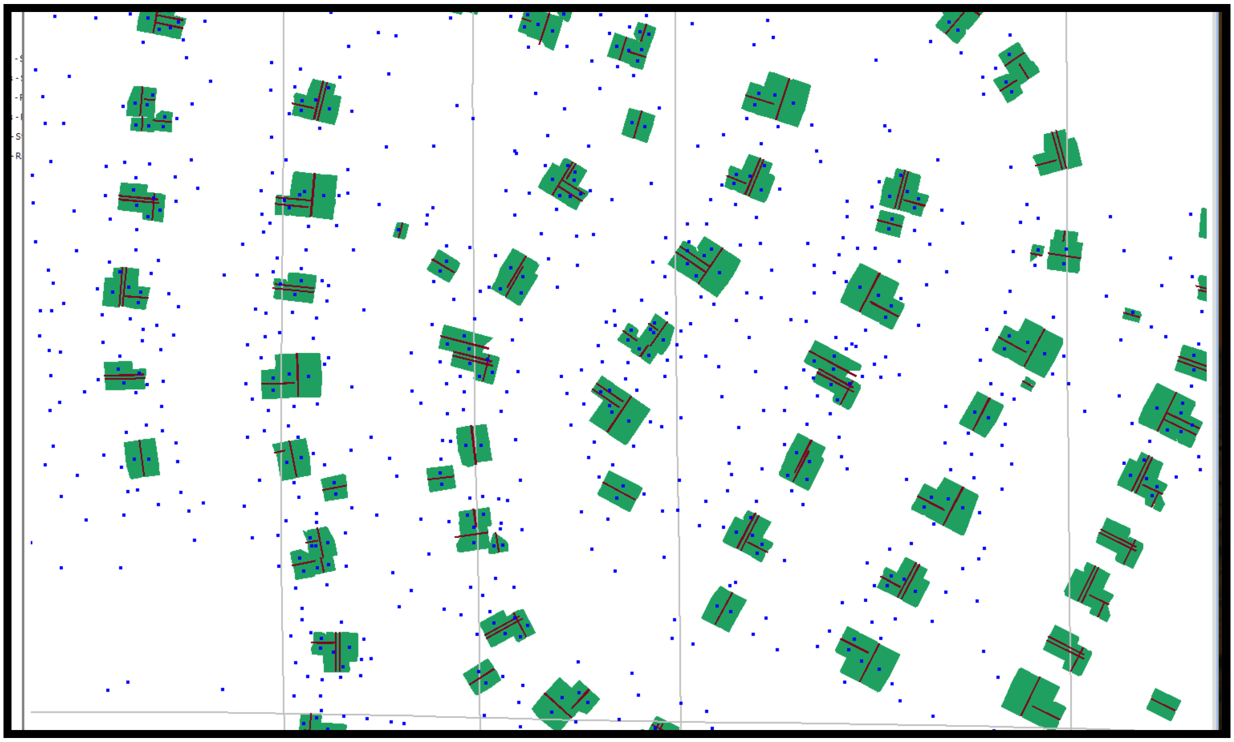
**Boresight Self-Calibration Processing Procedures**

An LMS boresight calibration is performed on an as-needed basis to correct scale, roll, pitch and heading biases. A minimum of three overlapping flights are flown in opposing directions with one cross flight.



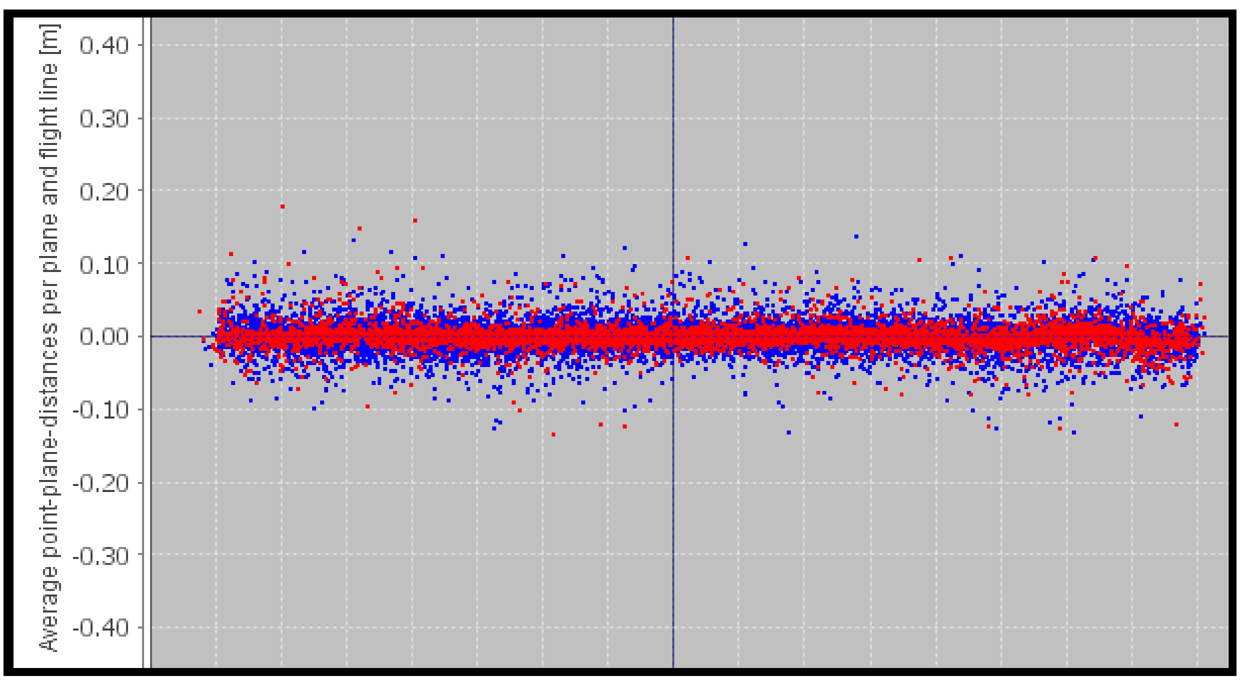
The Boresighting module frees scan angle scale, scan angle lag, XYZ boresight corrections and elevation position corrections while locking scan angle offset and XY position corrections.

The picked calibration site will have a good distribution of buildings for the self-calibration software to match ground planes, roof planes and roof lines.

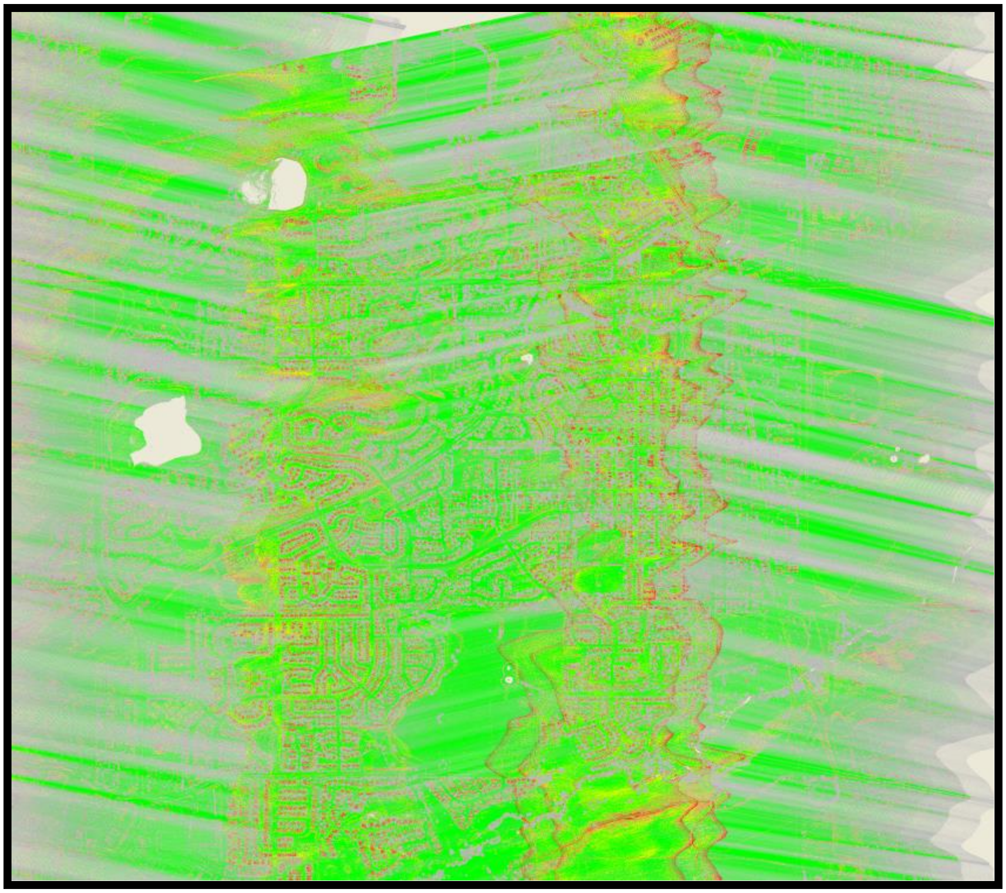


At the conclusion of the self-calibration run the data is quality checked with LMS plots

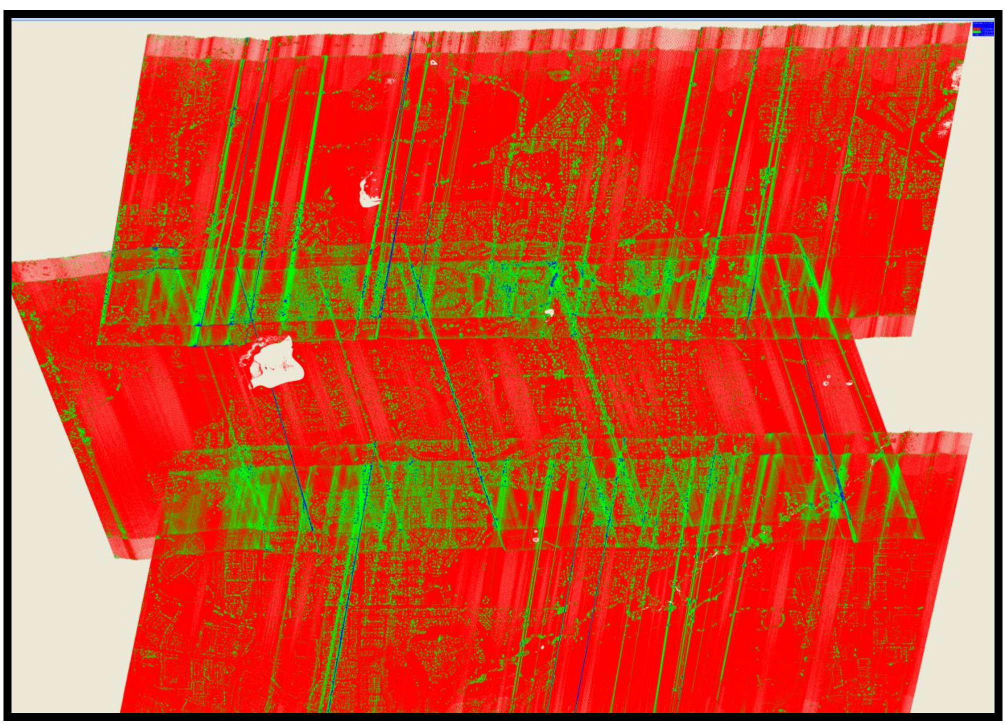
Plot of plane vertical distances from datum plane.



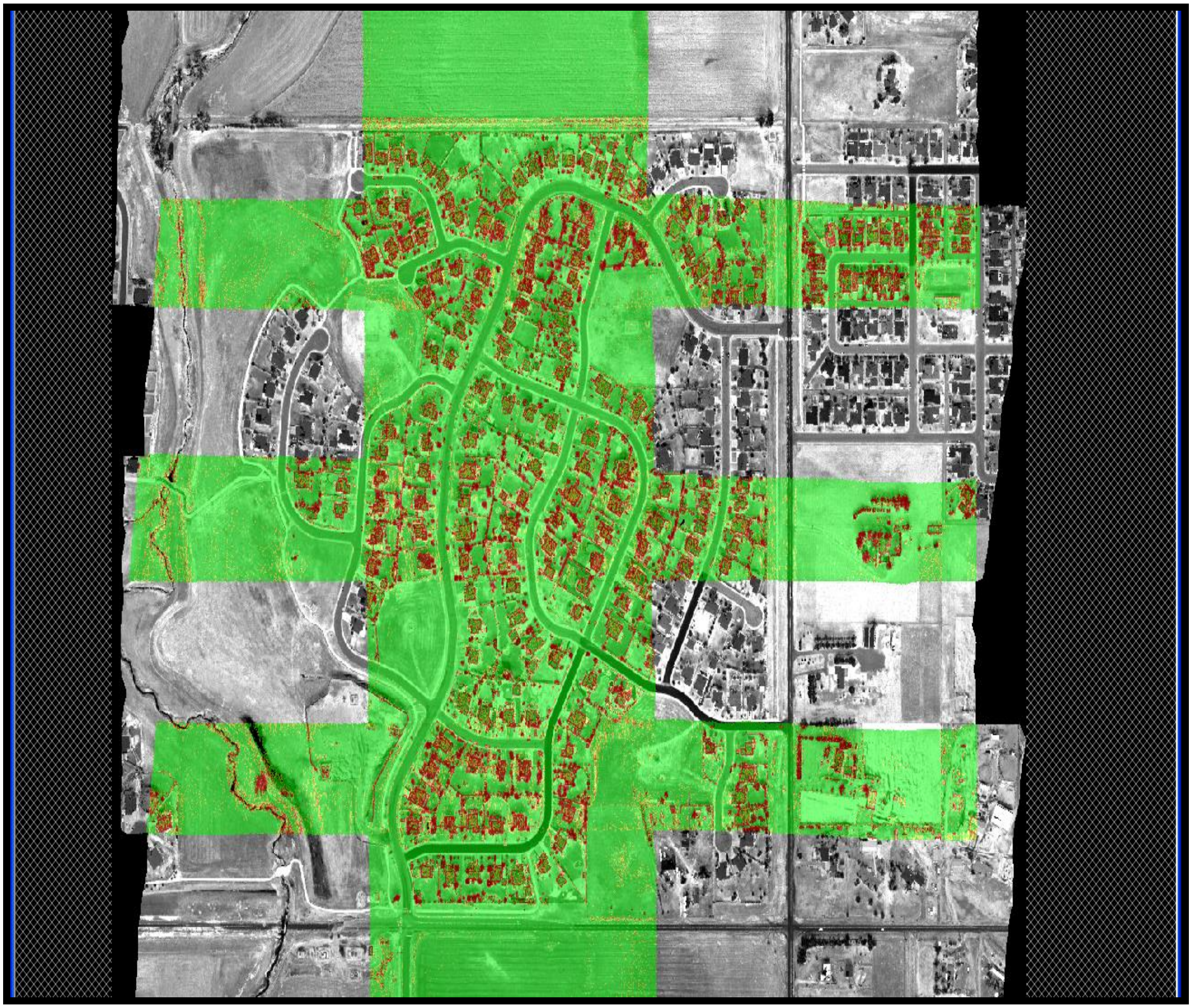
Plot of height differenced between flight lines. (Green=less than 5cm).



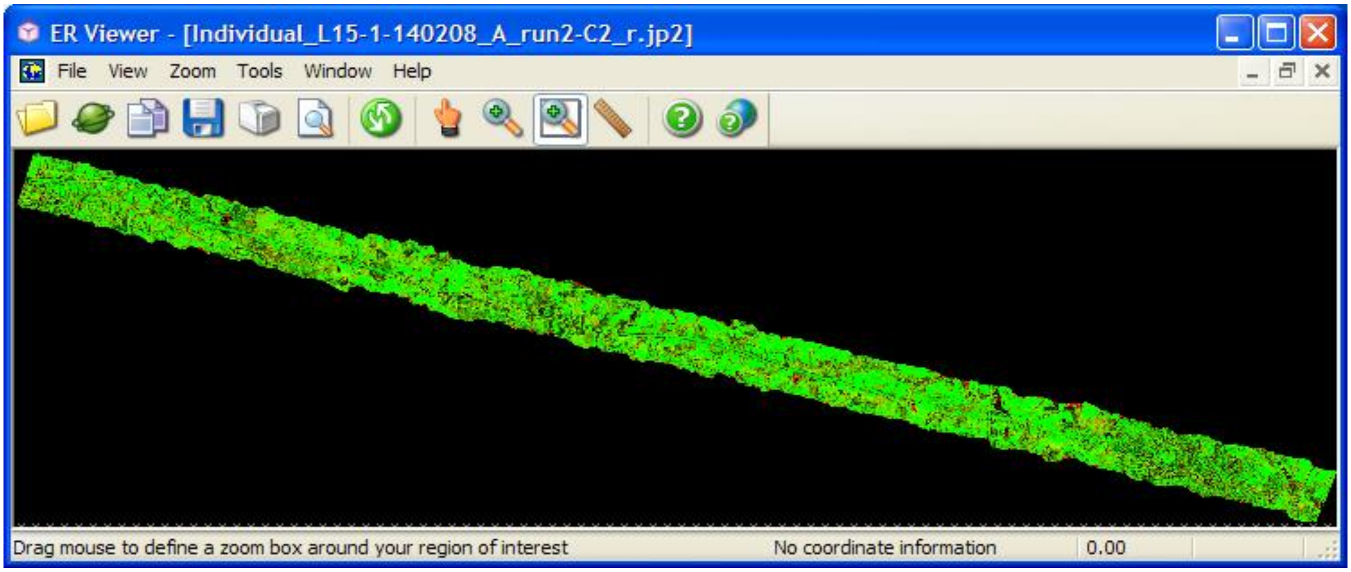
Plot of point densities. (Red=5-9 points per cell, green 10+ points per cell).



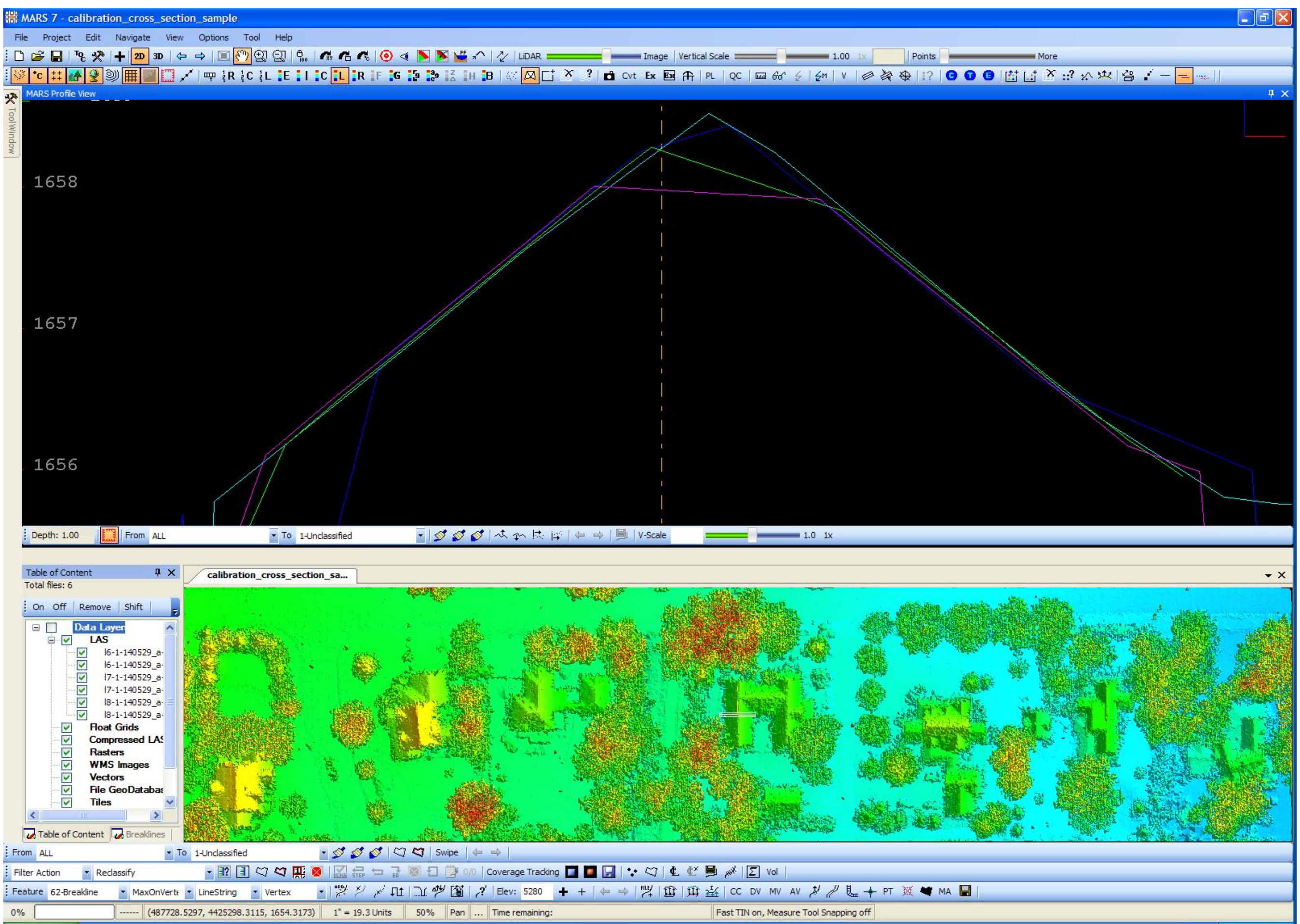
A Flight Line Separation Raster image is generated in Merrick Advanced Remote Sensing Software (MARS®), in this example ground returns from multiple flight lines that are fitting within 3 centimeters are colored green.



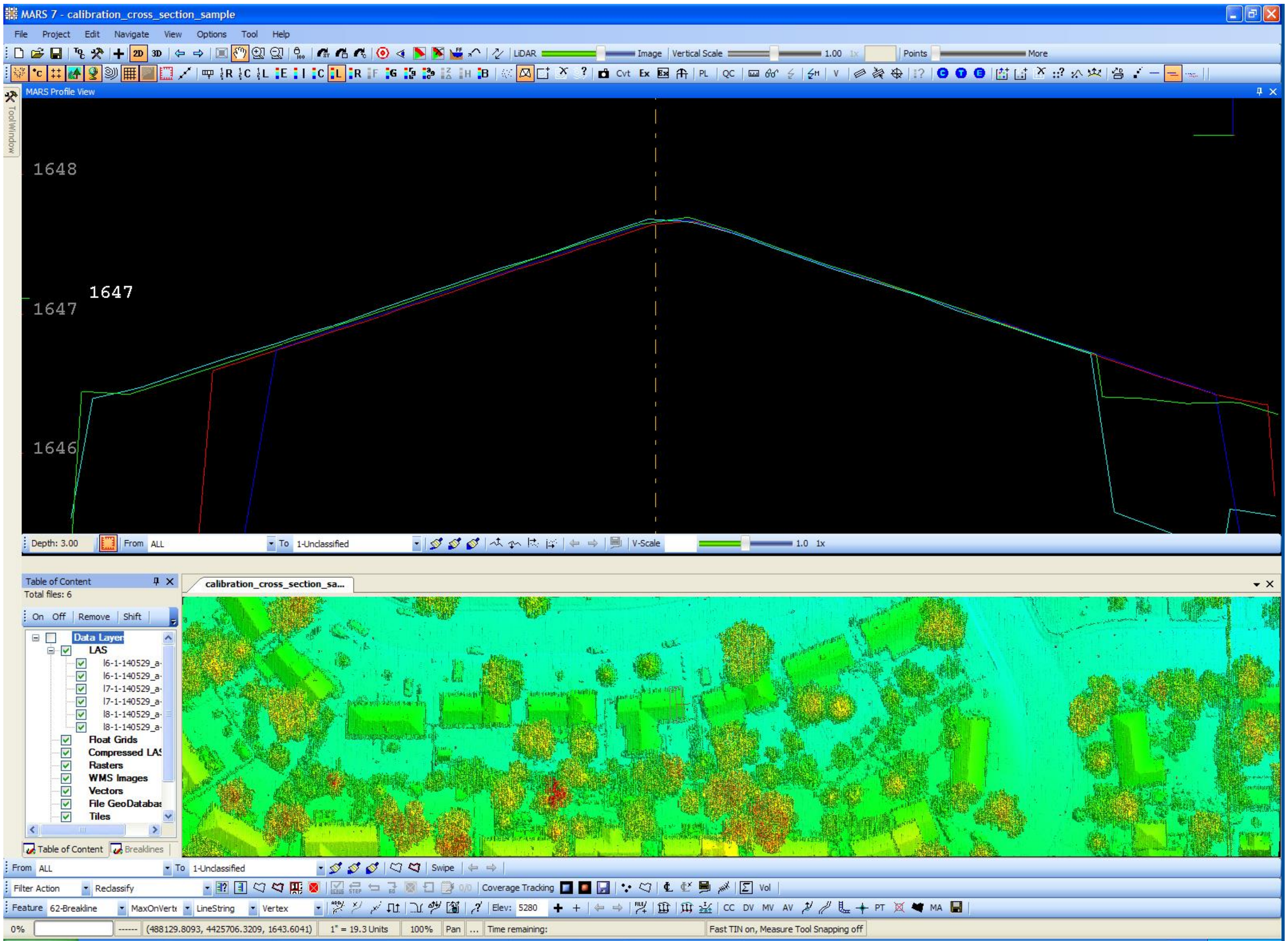
MARS® tests for internal relative vertical accuracy using inbound and outbound scan values. Again, Green is showing inbound and outbound scan data fitting to 3 centimeters.




Building cross sections are checked for good alignment. Pitch and heading are checked on roof planes parallel to the flight direction.



Roll and scale are checked on roof planes perpendicular to the flight direction.

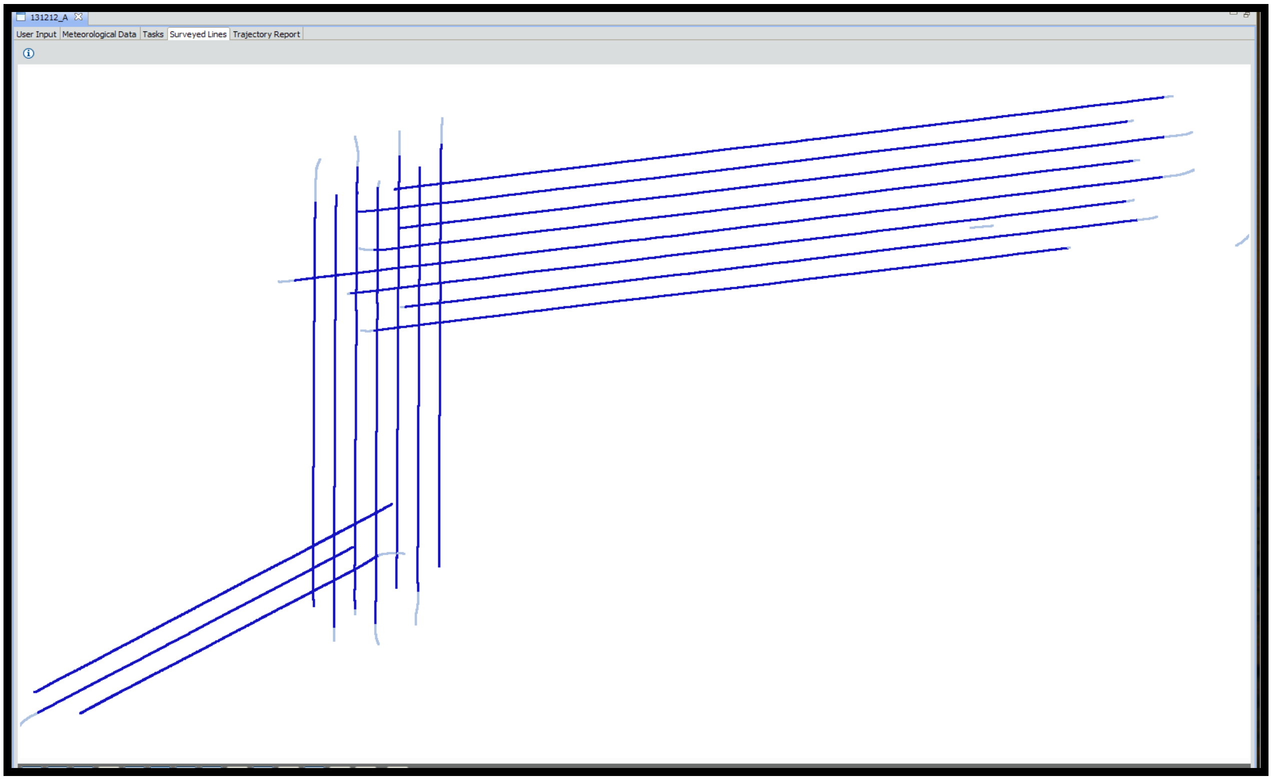



The LMS program outputs a "LCP" file with all the correction parameters. The calibration process may be run several times until the boresight adjustments are acceptable. When the boresight solution is acceptable the LCP file adjustments are saved and also applied to subsequent projects. Each new project is again analyzed and when the adjustment biases show too much drift a new boresight calibration is run. The LCP file may hold calibration tolerances for several projects.

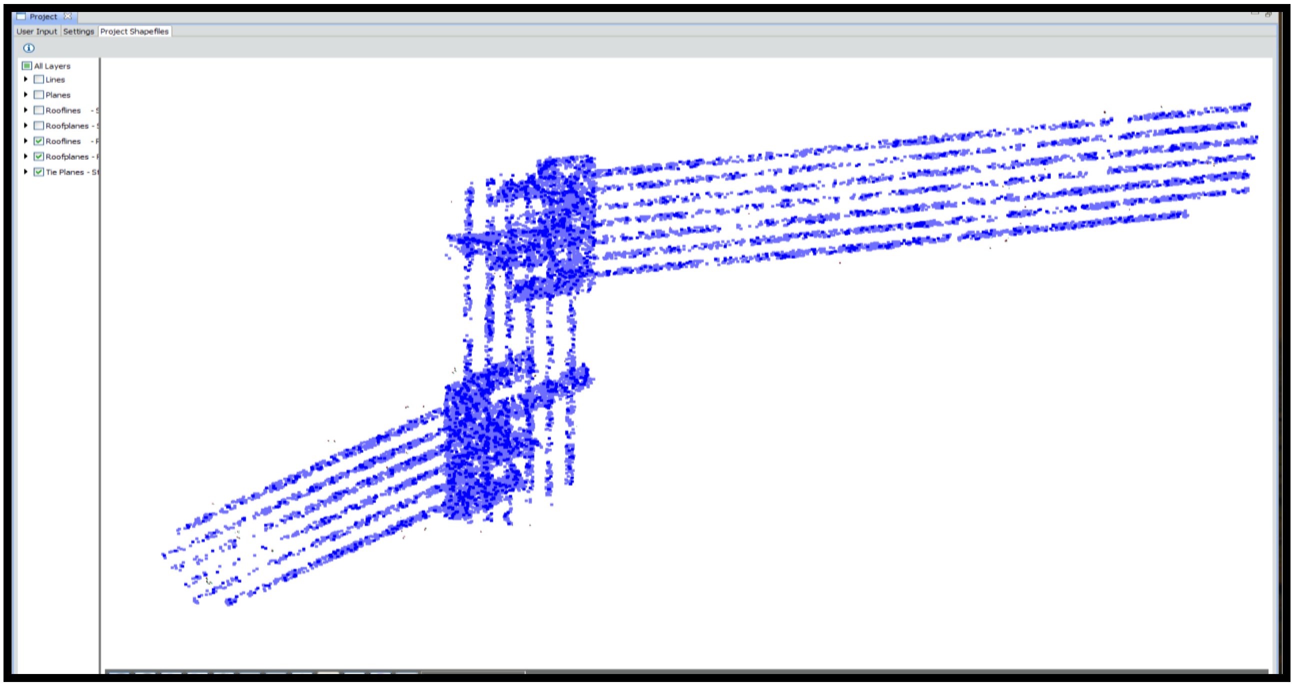
**Block LAS Production Processing Procedures**

The LMS production mode is run on each flight line to further tie the final lidar LAS flight line files tightly together.  Production settings allow scan angle scale, scan angle lag to float and allows elevation to move slightly during flight line to flight line comparison thus further tying flight lines together. A cross flight with locked elevation data is used for controlling flight line elevations.

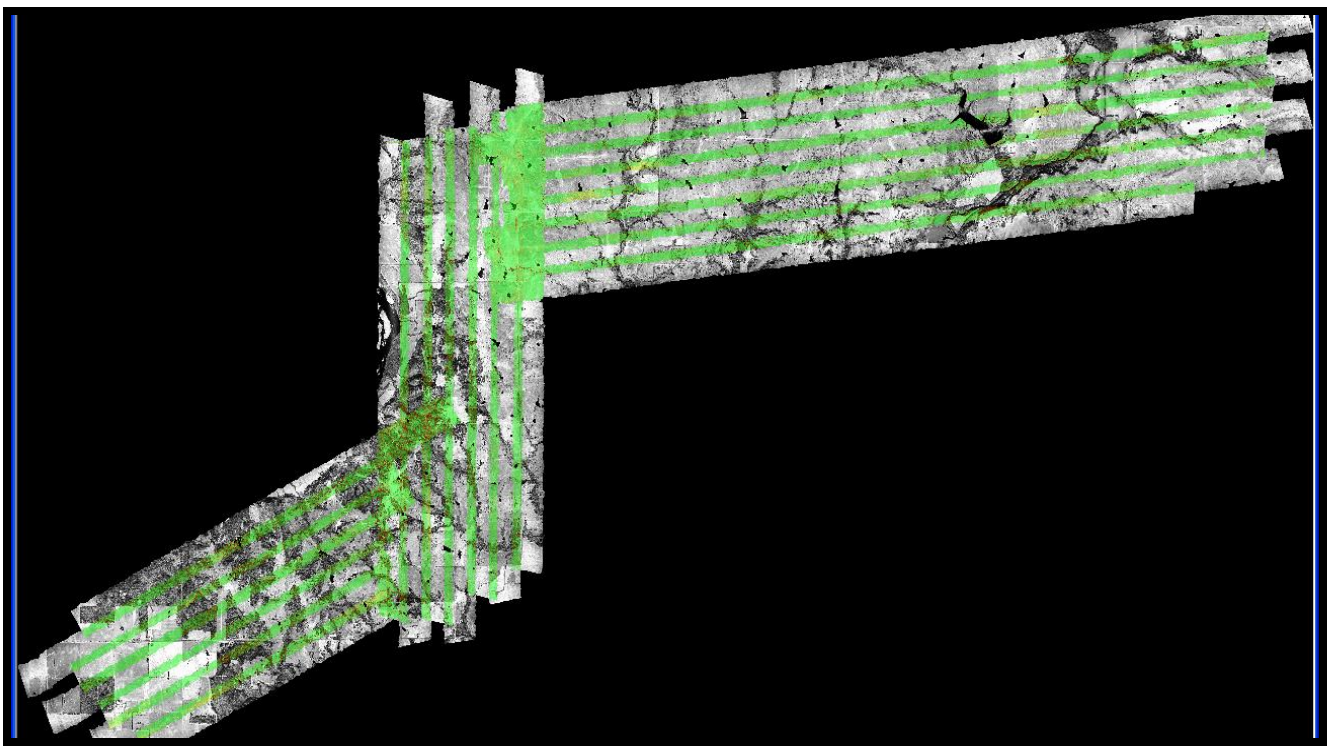
A block of data is selected to process with LMS production settings. Data collected during turns at the ends of flight lines is deselected (light blue lines).



As in self-calibration the LMS production program analyses ground, roof planes and rooflines. One cross flight is locked in elevation and all other lines are adjusted to it. Unlike the calibration site the distribution of roof planes is usually much less dense. Here matched ground tie planes are blue.

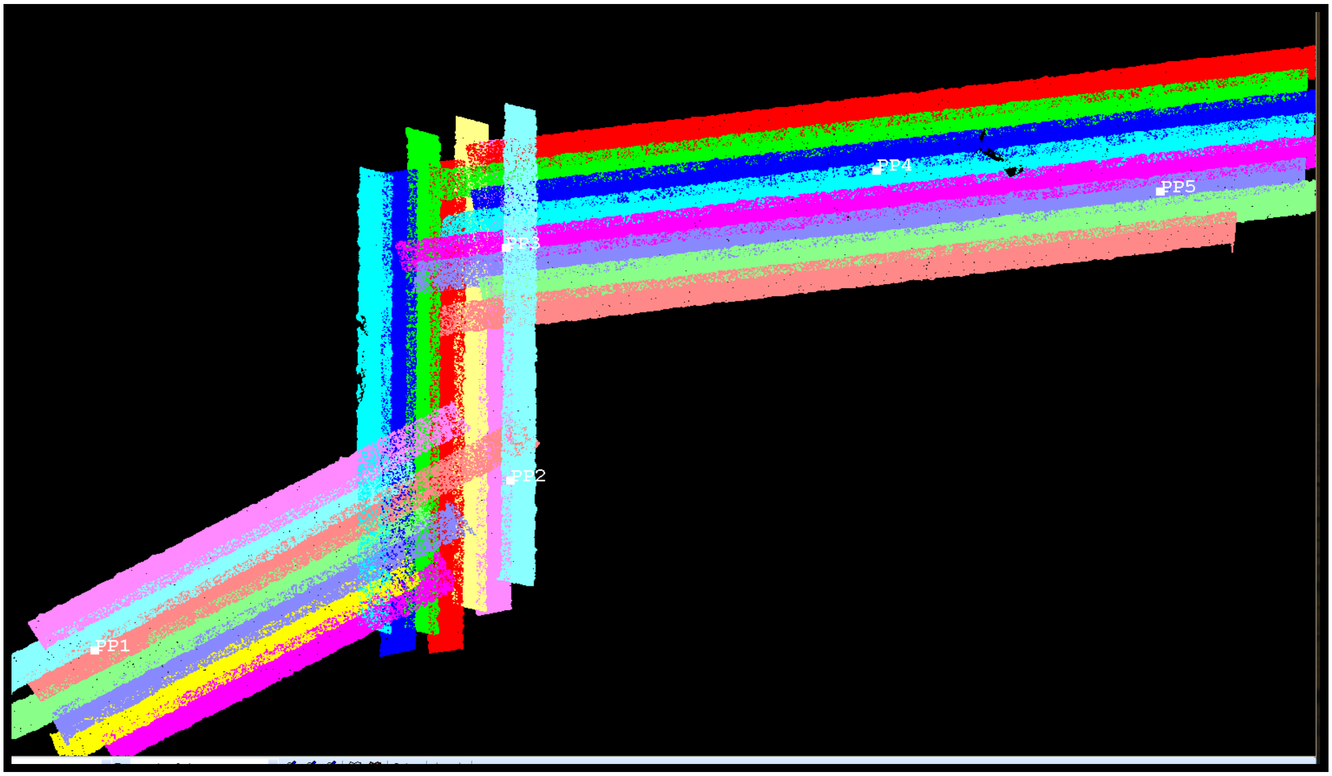



The same quality control outputs used to check self-calibrations are available to analyze the production run. Output plots are again available in LMS and cross sections plus a Flight Line Separation Raster are generated in MARS® to check coverage and quality.



**Correcting the Final Elevation**

After all the lines are tied together a ground control network is imported into MARS®. The ground control network may be pre-existing or collected by a licensed surveyor.




The next step is to match the ground control elevations to the lidar data set. A control report is run and the data set is shifted slightly to zero out the average elevation error and points checked for quality.

The final step before boresighted, leveled LAS files are ready for filtering is to run the MARS® QC Module on the block data. The Boresighted lidar QC Report outputs individual reports on Point Density, Nominal Pulse Spacing, Data Voids, Spatial Distribution, Scan Angles, Control Report, Flight Line Separation, Flight Line Overlap, Buffered Boundary, LAS Formats, Datums and Coordinates.
These reports are checked with the required specifications in the Project Management Plan.