

# **USGS\_IA\_Western\_3\_2020\_D21**

## **Lidar 2020 Final Report**

Report Produced for U.S. Geological Survey

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Submitted From:

**Aerial Services, Inc.**

6315 Chancellor Dr.

Cedar Falls, IA 50613

319.277.0436

Submitted to:

**U.S. Geological Survey**

1400 Independence Road

Rolla, MO 65401

573.308.3810

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## Overview

This task order is for a fall 2020/spring 2021 leaf-off lidar survey to be collected over a primary Defined Project Area (DPA) in the state of Iowa of approximately 12,233 square miles, including the counties of; Lyon, Sioux, O'Brien, Plymouth, Cherokee, Woodbury, Ida, Monona, Crawford, Harrison, Shelby, Audubon, Pottawattamie, Cass, Mills, Montgomery, Adams, Fremont, Page and Taylor. This project will support FEMA, NRCS, and the 3DEP mission. USGS\_IA\_WesternIA\_2020\_D21 was planned for the acquisition, processing, and derivative products of lidar data to be collected at an aggregate nominal pulse spacing (ANPS) of =0.71 meters (QL2). Approximately 4698 square miles of USGS\_IA\_WesternIA\_2020\_D21 referred to as USGS\_IA\_Western\_3\_2020\_D21 was acquired in the late fall of 2020 and early spring 2021. USGS\_IA\_Western\_3\_2020\_D21 project area consists of all or part 11 Iowa counties; Harrison, Shelby, Audubon, Pottawattamie, Cass, Mills, Montgomery, Adams, Fremont, Page and Taylor. The condition of the ground was good during the collection of the survey.

Acquisition of the USGS\_IA\_WesternIA\_2020\_D21 project DPA was broken out to three subcontractors in the following manner.

Contractor	Number of Flight Days	Square Miles Flown
Aerial Services, Inc.	11	~3,371.70
Aerial Surveys International	5	~3,217.34
TAC	11	~5,616.31

Table 1: Prime Contractor and Subcontractor Days of Flight and Square Miles Flown

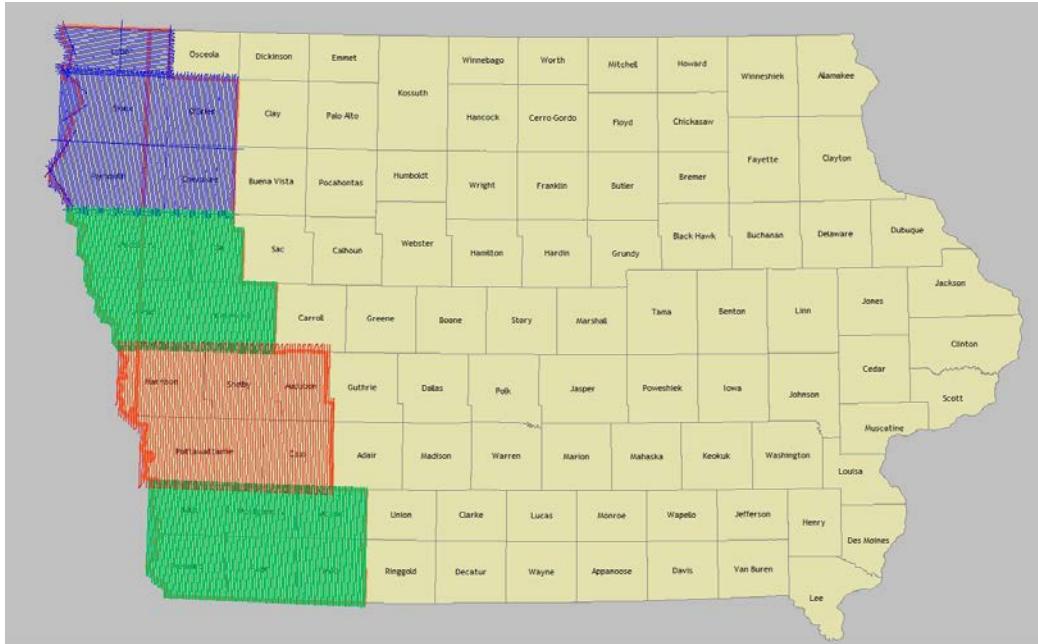


Figure 1: Western Iowa DPA Contractor and Subcontractor Breakout

The LiDAR data for USGS\_IA\_WesternIA\_2020\_D21 project, hereafter known as USGS\_IA\_Western\_3\_2020\_D21 project area, was processed and classified according to project specifications. Detailed breaklines, bare earth Digital Elevation Models (DEMs), and Intensity Images

were produced for the USGS\_IA\_Western\_3\_2020\_D21 project area. Data was formatted into tiles with each tile covering an area of 1000 meters by 1000 meters. A total of 12,387 LAS files, 12,388 DEMs, and 12,387 Intensity Images were produced for the project, encompassing the USGS\_IA\_Western\_3\_2020\_D21 project area of approximately 4698 square miles and formatted into 12,389 total tiles.

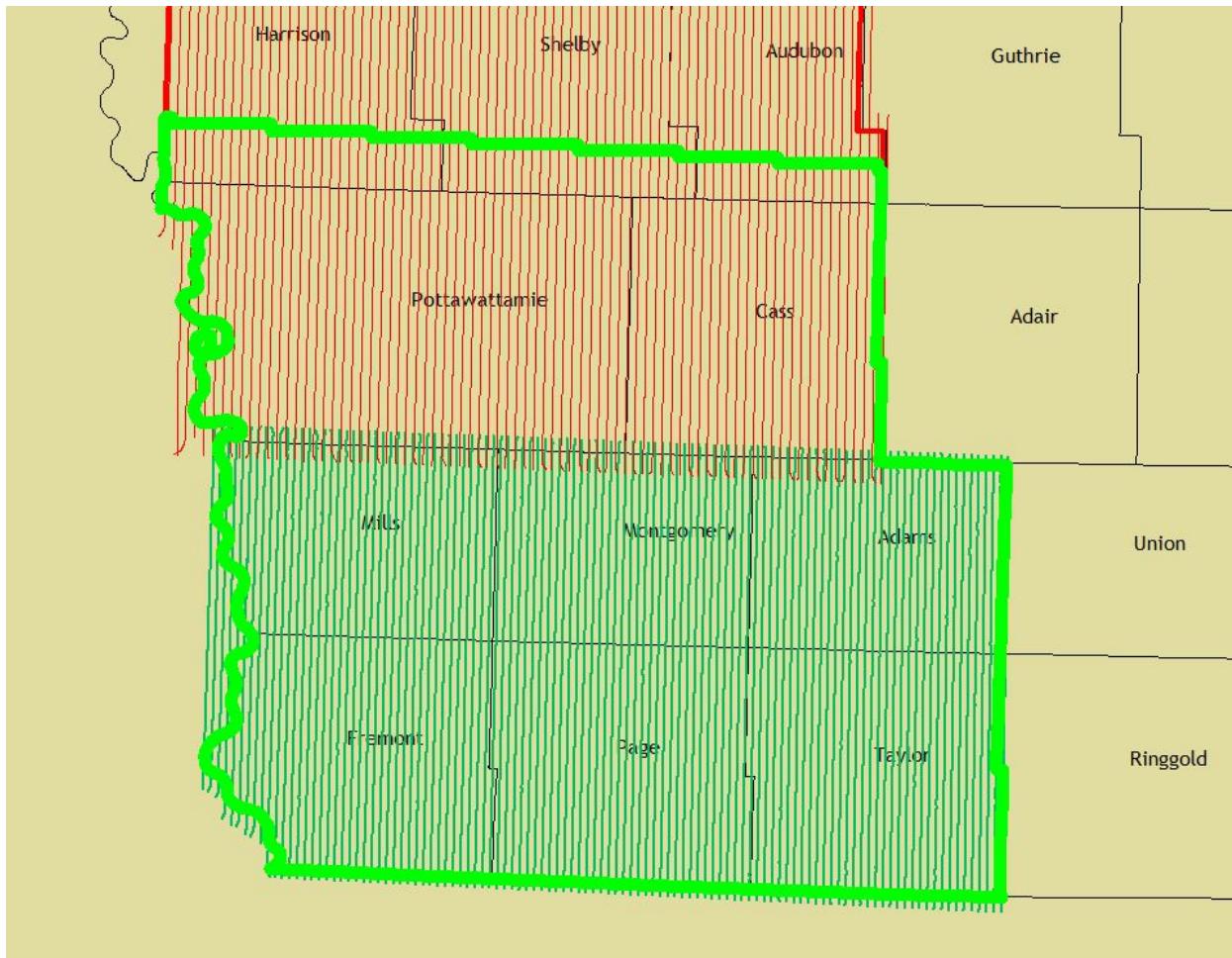


Figure 2: USGS\_IA\_Western\_3\_2020\_D21 project area Breakout

## Project team

Aerial Services, Inc. (ASI) served as the prime contractor for the project. In addition to project management, ASI was responsible for bare earth cleanup of the entire USGS\_IA\_WesternIA\_2020\_D21 project. ASI produced the LiDAR products; Digital Elevation Model (DEM) production, Intensity Image production, and quality assurance for the entire project. Subcontractor: Aerial Surveys Incorporated, LLC was responsible for LiDAR acquisition and calibration of 1820.75 square miles of the southern section of this USGS\_IA\_Western\_3\_2020\_D21 project area. Subcontractor: Technical Applications and Consulting, LLC (TAC) was responsible for LiDAR acquisition and calibration of 2877.25 square miles of the southern and part of the central section of this USGS\_IA\_Western\_3\_2020\_D21 project area. Subcontractor: Michael Backer International collected hydro for the entire USGS\_IA\_Western\_3\_2020\_D21 project area. All follow-on processing was completed by the prime contractor.

Foth Infrastructure & Environment, LLC completed ground surveying for the project and delivered surveyed checkpoints. Foth Infrastructure & Environment, LLC was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. Please see SURVEY REPORT to view the separate Survey Report that was provided for this portion of the project.

## Survey area

The project area addressed by this report falls in the Western Iowa UTM Zone 15N Block 3 project area consisting of all or part of 11 Iowa counties; Harrison, Shelby, Audubon, Pottawattamie, Cass, Mills, Montgomery, Adams, Fremont, Page and Taylor.

## Date of survey

LiDAR acquisition for USGS\_IA\_Western\_3\_2020\_D21 project area was conducted between the dates of December 5, 2020 to March 19, 2021.

## Coordinate reference system

Data produced for the project was 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:** Universal Transverse Mercator (UTM) Zone 15 North.

**Units:** Horizontal units are in meters, Vertical units are in meters.

**Geoid Model:** Geoid18

## Lidar vertical accuracy

For the USGS\_IA\_Western\_3\_2020\_D21 project area, the tested RMSEz of the classified LiDAR data for checkpoints in non-vegetated terrain equaled 0.035 meters compared with the 10 cm specification: The 95% confidence value of NVA of the classified LiDAR data computed using RMSEz x 1.96 and was found to equal 0.069 meters compared with the 0.196 meter specification.

For the USGS\_IA\_Western\_3\_2020\_D21 project area, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to 0.105 meters, compared with the 0.294 meter specification.

This project must meet Non-vegetated Vertical Accuracy (NVA)  $\leq 0.0196$  meters (19.6 cm) at the 95% confidence level based on  $\text{RMSEz} \leq 0.100$  meters (10 cm)  $\times 1.9600$ .

100 % of Totals	# of Points	RMSEz NVA (m)	NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	86	0.035	0.069	0.001	0.003	0.143	0.036	-0.091	0.108	0.711

Table 2: Non-vegetated Vertical Accuracy (NVA) results

Additional accuracy information and statistics for the classified LiDAR data, raw swath data, and bare earth DEM data can be found in following sections of this report.

## Project deliverables

The deliverables for the project are listed below.

- Classified Point Cloud Data (Tiled)
- Bare Earth Surface (Raster DEM – IMG format)
- Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
- Breakline Data (File GDB)
- Independent Survey Checkpoint Data (File GDB)
- Calibration Points (File GDB)
- Metadata
- Maximum surface height raster
- Swath separation Images
- Project Report (Acquisition, Processing, QC)
- Swaths Extents (File GDB)
- Tile Index (File GDB)
- DPA (File GDB)

## Project tiling footprint

A total of 12,387 LAS files, 12,388 DEMs, and 12,387 Intensity Images were produced for the project, encompassing the USGS\_IA\_Western\_3\_2020\_D21 project area of approximately 4698 square miles and formatted into 12,389 total tiles were delivered for the project. Each tile's extent is 1000 meter by 1000 meter. (See Appendix A for a complete listing of delivered tiles.) Two of the tiles contained no LAS data and one DEM tile was excluded due to it containing a small sliver tile < 1 meter at its widest.

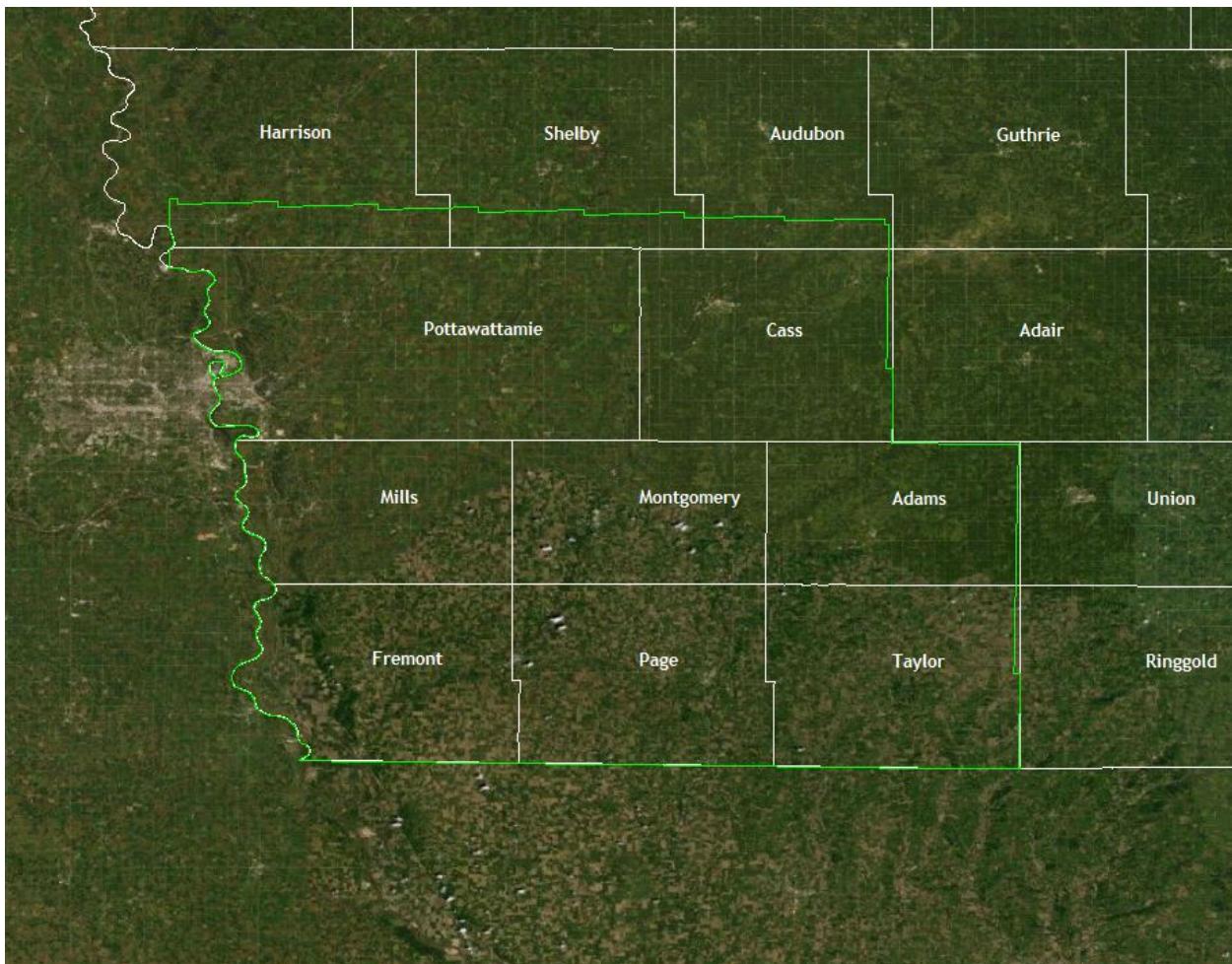


Figure 3: USGS\_IA\_Western\_3\_2020\_D21 Project Area of Interest

## Project Area Elevation Model

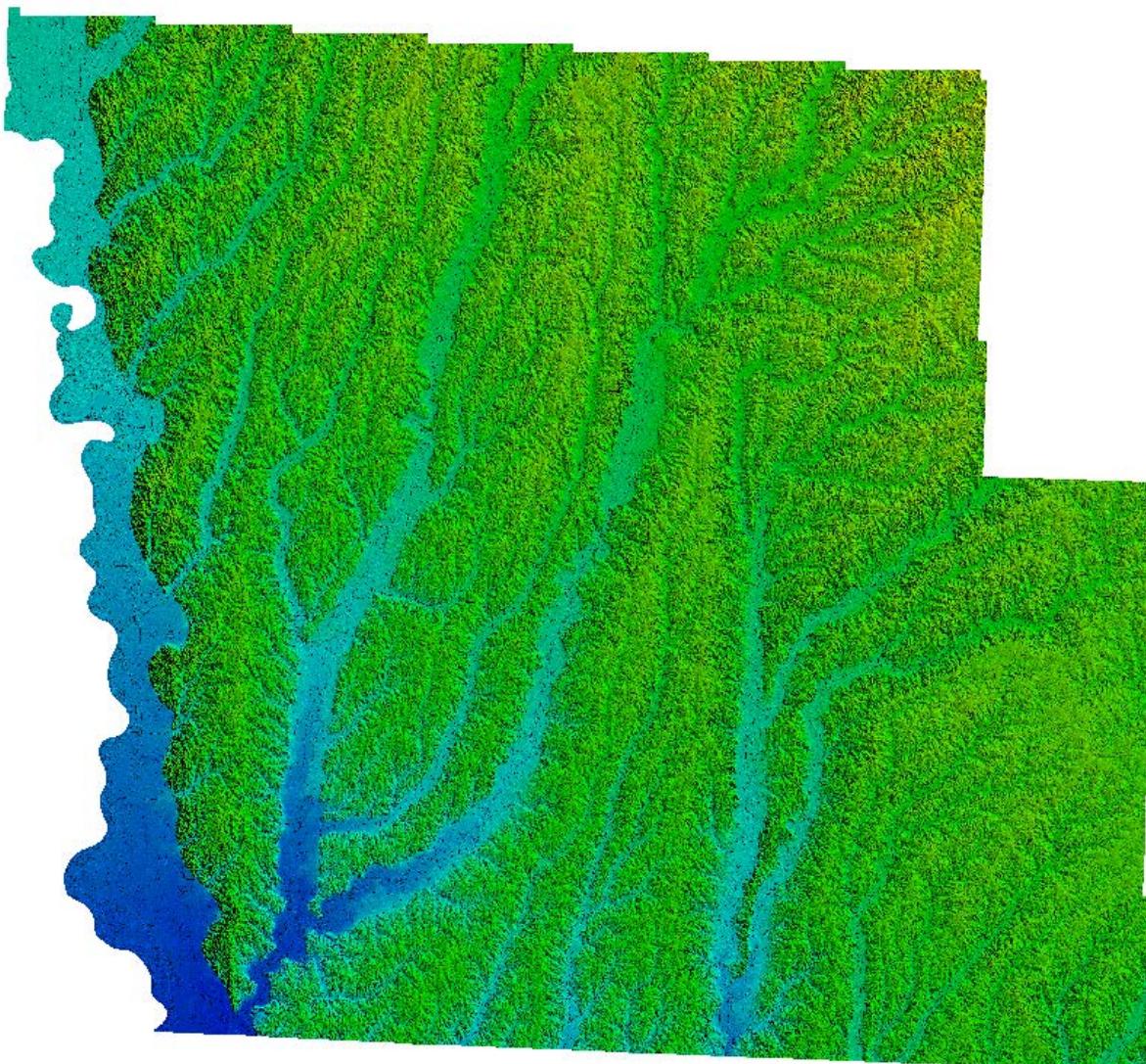


Figure 4: USGS\_IA\_Western\_3\_2020\_D21 Project Area Elevation DEM

## Aerial Surveys International, LLC LiDAR Acquisition Details and System Parameters for the Western IA 2020 D21 project

Aerial Surveys International, LLC planned 171 passes for the USGS\_IA\_WesternIA\_2020\_D21 project and a series of cross flightlines for quality control. Of the 171 passes, 81 full or partial passes covered the USGS\_IA\_Western\_3\_2020\_D21 project area.

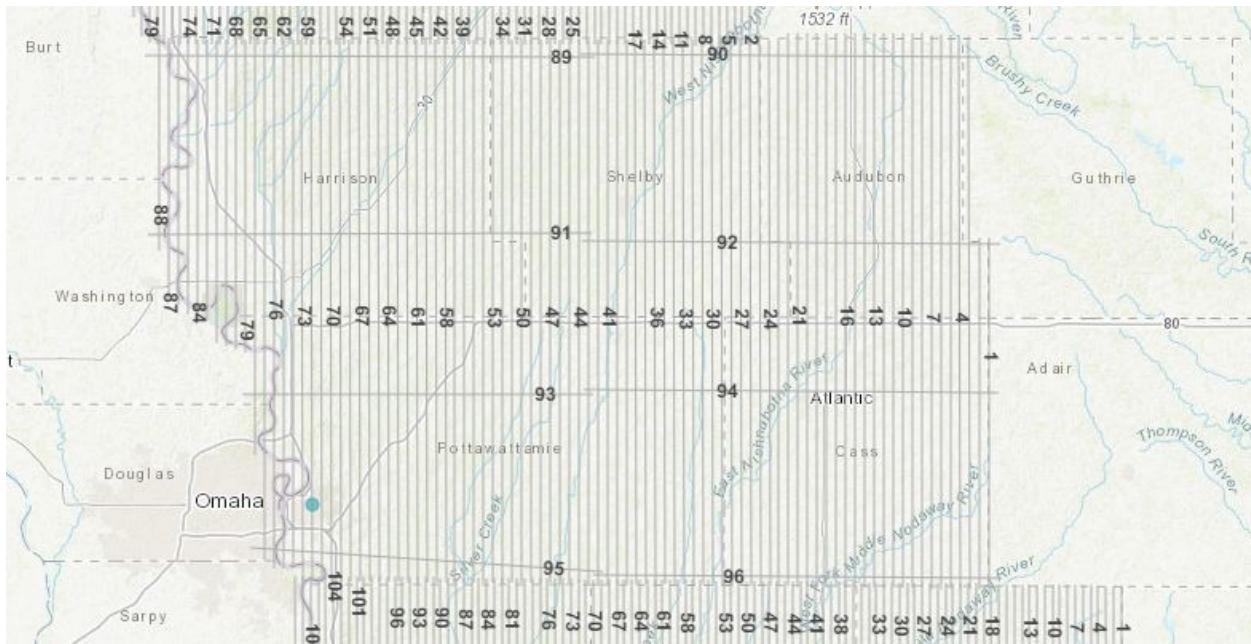


Figure11: Aerial Surveys International, LLC planned flight line overview

In order to reduce any margin for error in the flight plan, AERIAL SURVEYS INTERNATIONAL, LLC followed FEMA's Appendix A guidelines for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Topoflight flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables. A buffered AOI was provided by ASI.
- All airspace was coordinated and any controlled or restricted areas were pre coordinated and approval granted from the airspace owner.

AERIAL SURVEYS INTERNATIONAL, LLC operated a Cessna 310 (Registration N7516Q) and a Cessna 402 (registration N2JJ) each equipped with an Optech T2000 Lidar system during the collection of this task order. Data was acquired between December 10, 2020 to March 19, 2021.

Item	Parameter
System	Optech T2000
Maximum Number of Returns per Pulse	8
Nominal Pulse Spacing (single swath), (m)	0.67
Nominal Pulse Density (single swath) (ppsm), (m)	2.49
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.67
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.21
Altitude (AGL meters)	2300
Approx. Flight Speed (knots)	160
Total Sensor Scan Angle (degrees)	46
Scan Rate (hz)	61
Scanner Pulse Rate (kHz)	400
Did the Sensor Operate with Multiple Pulses in The Air? (MPiA) (yes/no)	Yes
Beam Divergence (mRADs)	0.16
Nominal Swath Width on the Ground (m)	1953
Swath Overlap (%)	30
Computed Down Track spacing (m) per beam	0.67
Computed Cross Track Spacing (m) per beam	0.67

Table 3: AERIAL SURVEYS INTERNATIONAL, LLC LiDAR system parameters

## Calibration Report

### Acquisition Control

AERIAL SURVEYS INTERNATIONAL, LLC, utilized POSPac PP-RTX to control the lidar acquisition for the USGS\_IA\_WesternIA\_2020\_D21 project. POSPac PP-RTX is a cloud based global GNSS correction service which utilizes Trimble's RTX technology to provide cm level post-processed positioning accuracy without base stations.

### Airborne GPS Kinematic

Airborne GPS data was processed using PosPac MMS software suite. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded. GPS processing reports for each mission are included in Appendix A.

### Generation and Calibration of Laser Points (raw data)

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

Subsequently the mission points are output using Optech's LiDAR Mapping Suite (LMS), initially with default values from Optech's LiDAR Mapping Suite or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within our MARS 8 software for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch, and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

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

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

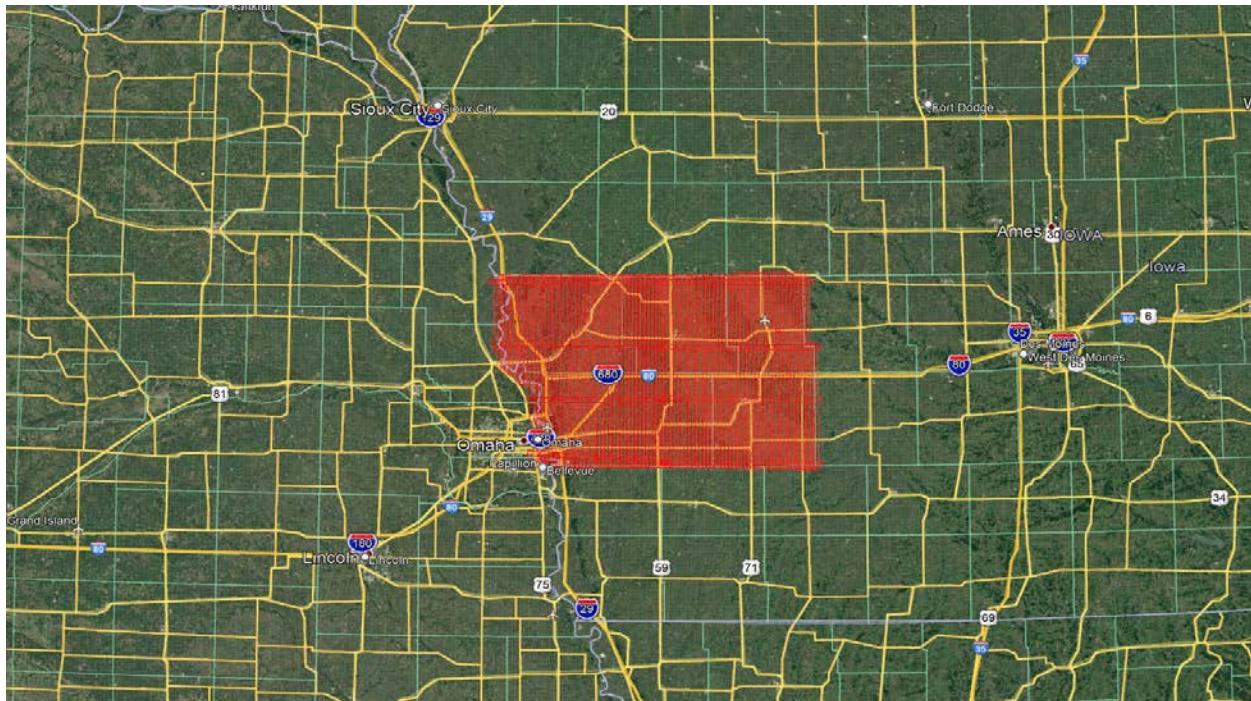


Figure 5: LiDAR swath output showing complete coverage

#### *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 follows (derived from LiDAR base specifications for QL2):  
Relative accuracy (smooth surface repeatability)  $\leq 6$  cm maximum differences within individual swaths and  $\leq 8$  cm RMSD<sub>z</sub> between adjacent and overlapping swaths.

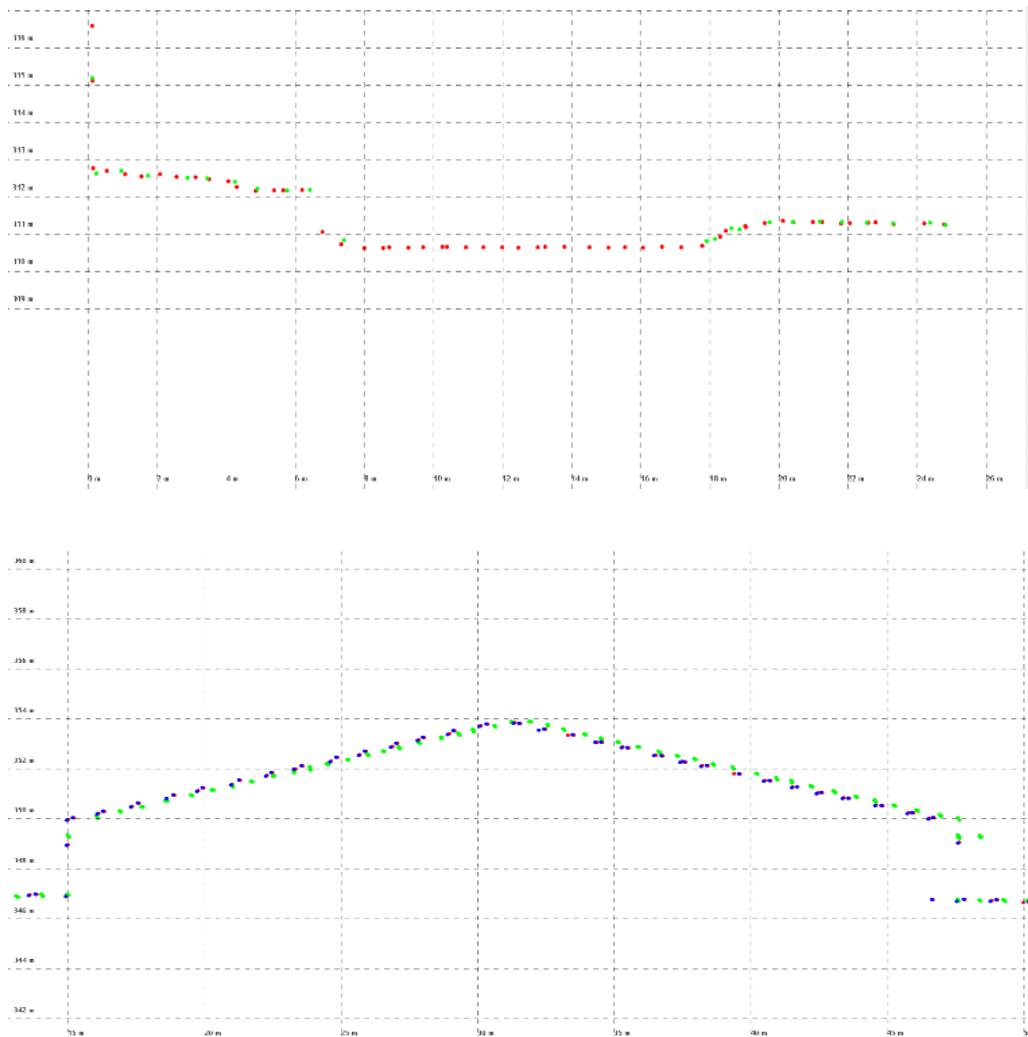


Figure 6: Profile views showing correct roll and pitch adjustments

## Technical Applications & Consulting, LLC (TAC) LiDAR Acquisition Details and System Parameters - IA\_WesternIA\_2020\_D21

Technical Applications & Consulting, LLC (TAC) planned 221 passes for the USGS\_IA\_WesternIA\_2020\_D21 project as well as a series of cross flight lines for quality control. Of the 221 passes, 110 full or partial passes covered the USGS\_IA\_Western\_2\_2020\_D21 project area.

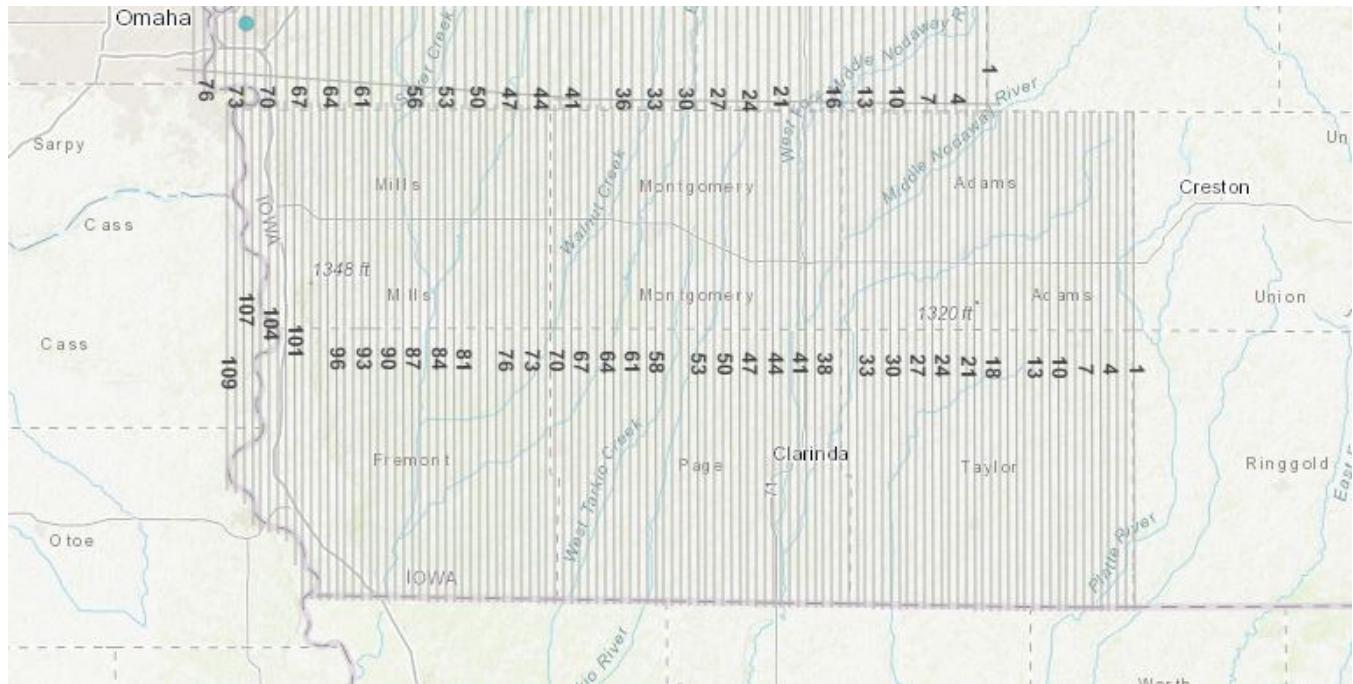


Figure 7: Technical Applications & Consulting, LLC planned flight line overview

To reduce any margin for error in the flight plan, TAC followed FEMA's Appendix A guidelines for flight planning that included the following criteria:

- A digital flight line layout using Optech AMM Software flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables. A buffered AOI was provided by ASI.
- All airspace was coordinated and any controlled or restricted areas were pre coordinated and approval granted from the airspace owner.

TAC operated a Cessna Turbo Utility 206 (Registration N8647Q) equipped with an Optech Galaxy LiDAR system during the collection of this project. Data was acquired between 12/05/2020 to 3/19/21. TAC experienced acquisition delays due to inclement weather in the specified area of interest. Once the snow melted TAC collected any necessary refights.

Item	Parameter
System	Optech Galaxy T500
Maximum Number of Returns per Pulse	6
Nominal Pulse Spacing (single swath), (m)	0.43
Nominal Pulse Density (single swath) (ppsm), (m)	5
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.43
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	5
Altitude (AGL meters)	1485
Approx. Flight Speed (knots)	120
Total Sensor Scan Angle (degrees)	50
Scan Rate (hz)	70
Scanner Pulse Rate (kHz)	500
Did the Sensor Operate with Multiple Pulses in The Air? (MPiA) (yes/no)	Yes
Beam Divergence (mRADs)	0.25
Nominal Swath Width on the Ground (m)	1385
Swath Overlap (%)	20
Computed Down Track spacing (m) per beam	0.44
Computed Cross Track Spacing (m) per beam	0.44

Table 4: TAC LiDAR system parameters

## Calibration Report

### Airborne GPS Kinematic

Airborne GPS data was processed using POSPac MMS 8.6 GNSS-aided inertial post-processing software suite. Flights were flown with a minimum of 6 satellites in view ( $13^{\circ}$  above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded. GPS processing reports for each mission are included in Appendix A.

### Generation and Calibration of Laser Points (raw data)

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

The mission point .LAS is output using LMS Pro with default values or the last boresight for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch, and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally to ensure quality.

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

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

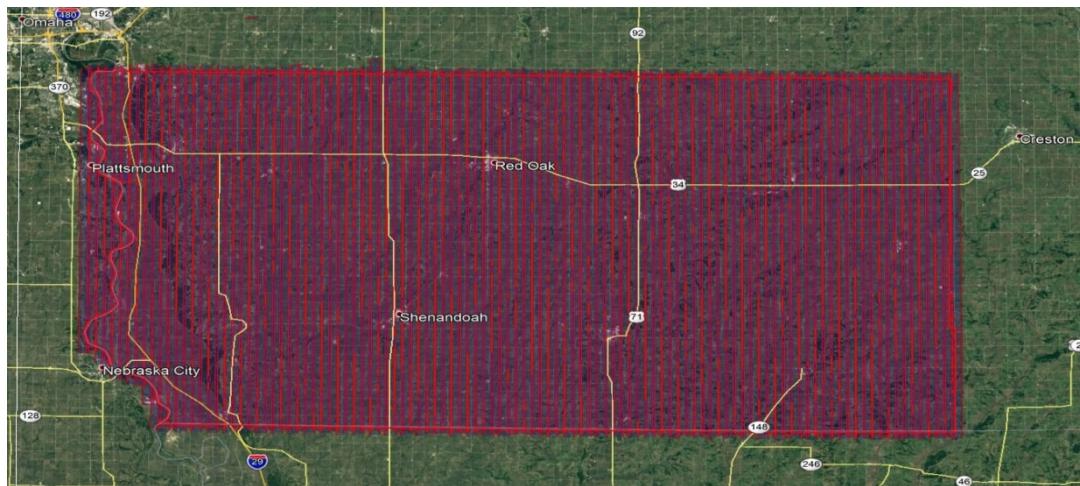


Figure 8: LiDAR swath output showing complete coverage

### *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 follows (derived from LiDAR base specifications for QL2):  
Relative accuracy (smooth surface repeatability)  $\leq 6$  cm maximum differences within individual swaths and  $\leq 8$  cm RMSDz between adjacent and overlapping swaths.

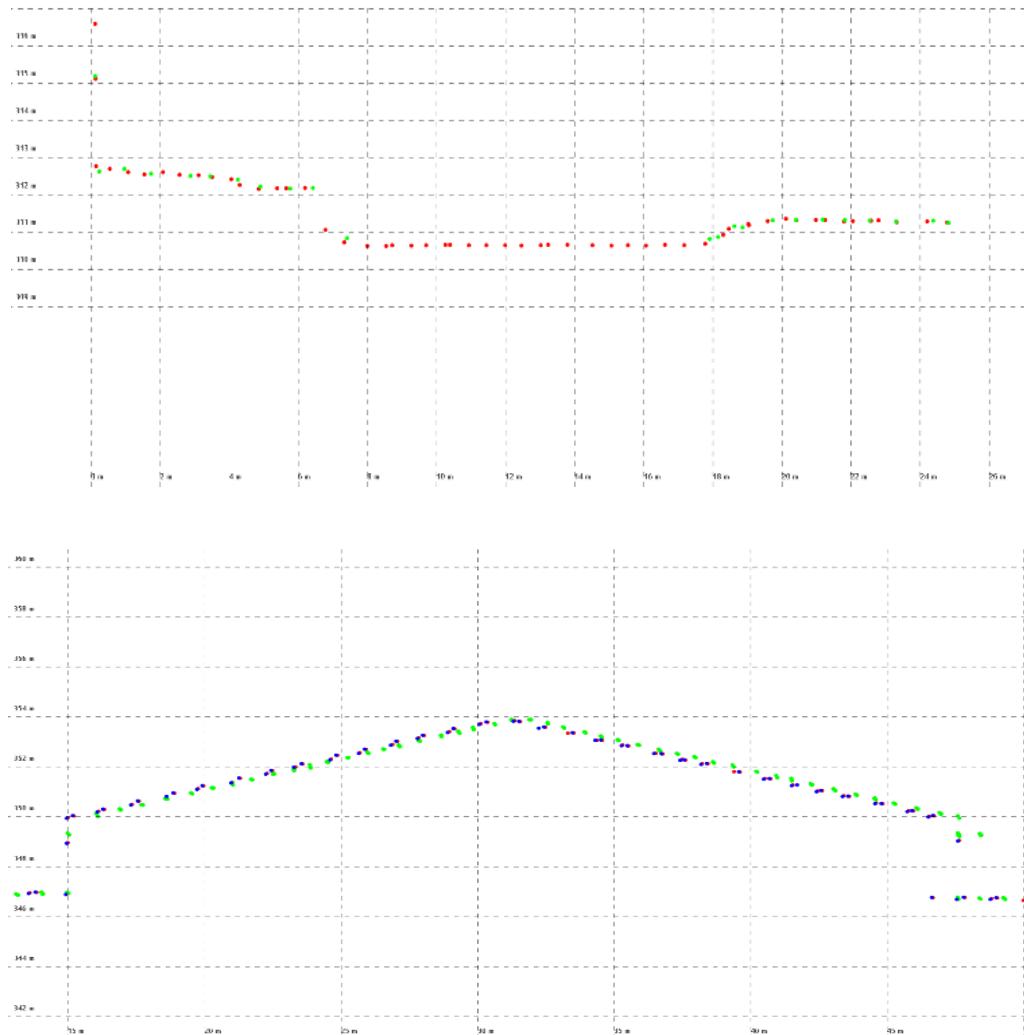


Figure 9: Profile views showing correct roll and pitch adjustments

The table below lists the Flight lines and corresponding, Lift\_ID, Date, Point Source ID, Scanner, and adjusted GPS Start and End times.

Name	Lift_ID	Date	PT Source ID	Scanner	Start Time	End Time
20201210_231744	1210_2	12/10/2020	6093	Optech	291677464	291678571
20210311_194415	311_1	03/11/2021	6094	Optech	299527055	299528209
20210311_200524	311_1	03/11/2021	6095	Optech	299528324	299529438
20210311_202641	311_1	03/11/2021	6096	Optech	299529601	299530796
20210311_205552	311_1	03/11/2021	6097	Optech	299531353	299532482
20210311_211819	311_1	03/11/2021	6098	Optech	299532699	299533871
20210311_214027	311_1	03/11/2021	6099	Optech	299534028	299535146
20210311_220108	311_1	03/11/2021	6100	Optech	299535268	299536414
20210311_222310	311_1	03/11/2021	6101	Optech	299536590	299537680
20210311_224320	311_1	03/11/2021	6102	Optech	299537801	299538974
20210311_230513	311_1	03/11/2021	6103	Optech	299539113	299540213
20210311_232547	311_1	03/11/2021	6104	Optech	299540347	299541488
20210311_234736	311_1	03/11/2021	6105	Optech	299541656	299542765
20210312_000803	311_1	03/11/2021	6106	Optech	299542883	299544004
20210312_014522	311_2	03/11/2021	6107	Optech	299548722	299549847
20210312_020747	311_2	03/11/2021	6108	Optech	299550068	299551189
20210312_023101	311_2	03/11/2021	6109	Optech	299551462	299552580
20210312_025357	311_2	03/11/2021	6110	Optech	299552837	299553959
20210319_165157	210319_386A	03/19/2021	3002	Optech	300207917	300209060
20210319_171356	210319_386A	03/19/2021	3003	Optech	300209236	300210315
20210319_173447	210319_386A	03/19/2021	3004	Optech	300210487	300211664
20210319_175654	210319_386A	03/19/2021	3005	Optech	300211814	300212891
20210319_181801	210319_386A	03/19/2021	3006	Optech	300213081	300214264
20210319_213247	210319_386B	03/19/2021	3008	Optech	300224767	300225943
20210319_215449	210319_386B	03/19/2021	3009	Optech	300226089	300227174
20210319_221642	210319_386B	03/19/2021	3010	Optech	300227402	300228566

20210319_223837	210319_386B	03/19/2021	3011	Optech	300228717	300229777
20210319_225846	210319_386B	03/19/2021	3012	Optech	300229926	300231088
20210319_232054	210319_386B	03/19/2021	3013	Optech	300231254	300232365
20210319_234306	210319_386B	03/19/2021	3014	Optech	300232586	300233731
20210320_145442	210320_386A	03/20/2021	3016	Optech	300287282	300288520
20210320_151759	210320_386A	03/20/2021	3017	Optech	300288679	300289742
20210320_153950	210320_386A	03/20/2021	3018	Optech	300289990	300291240
20210320_160324	210320_386A	03/20/2021	3019	Optech	300291404	300292470
20210320_162357	210320_386A	03/20/2021	3020	Optech	300292637	300293888
20210320_164744	210320_386A	03/20/2021	3021	Optech	300294064	300295174
20210320_170909	210320_386A	03/20/2021	3022	Optech	300295349	300296603
20210320_173325	210320_386A	03/20/2021	3023	Optech	300296805	300297903
20210320_175457	210320_386A	03/20/2021	3024	Optech	300298097	300299352
20210320_205615	210320_386B	03/20/2021	3026	Optech	300308975	300310060
20210320_211715	210320_386B	03/20/2021	3027	Optech	300310235	300311477
20210320_214124	210320_386B	03/20/2021	3028	Optech	300311684	300312769
20210320_220200	210320_386B	03/20/2021	3029	Optech	300312920	300314118
20210321_145730	210321_386	03/21/2021	3033	Optech	300373850	300374914
20210321_151913	210321_386	03/21/2021	3034	Optech	300375153	300376457
20210321_154514	210321_386	03/21/2021	3035	Optech	300376714	300377785
20210321_160704	210321_386	03/21/2021	3036	Optech	300378024	300379301
20210321_163112	210321_386	03/21/2021	3037	Optech	300379472	300380541
20210321_165146	210321_386	03/21/2021	3038	Optech	300380706	300382019
20210321_171638	210321_386	03/21/2021	3039	Optech	300382198	300383255
20210321_173830	210321_386	03/21/2021	3040	Optech	300383510	300384835
20210328_152113	210328_386	03/28/2021	3042	Optech	300980073	300981239
20210328_154336	210328_386	03/28/2021	3043	Optech	300981416	300982488
20210328_160520	210328_386	03/28/2021	3044	Optech	300982720	300983857
20210328_162717	210328_386	03/28/2021	3045	Optech	300984037	300985111
20201210_201929	201210_448	12/10/2020	4002	Optech	291666769	291667483

20201210_203422	201210_448	12/10/2020	4003	Optech	291667662	291668376
20201210_204843	201210_448	12/10/2020	4004	Optech	291668523	291669635
20201210_211058	201210_448	12/10/2020	4005	Optech	291669858	291670949
20201210_213157	201210_448	12/10/2020	4006	Optech	291671117	291672231
20210319_155827	210319_448A	03/19/2021	4008	Optech	300204707	300205778
20210319_161840	210319_448A	03/19/2021	4009	Optech	300205920	300206968
20210319_205442	210319_448B	03/19/2021	4018	Optech	300222482	300223131
20210319_210826	210319_448B	03/19/2021	4019	Optech	300223306	300223978
20210319_212130	210319_448B	03/19/2021	4020	Optech	300224090	300224763
20210319_213550	210319_448B	03/19/2021	4021	Optech	300224950	300226038
20210319_215527	210319_448B	03/19/2021	4022	Optech	300226127	300227187
20210320_145540	210320_448A	03/20/2021	4024	Optech	300287340	300288509
20210320_151814	210320_448A	03/20/2021	4025	Optech	300288694	300289761
20210320_153844	210320_448A	03/20/2021	4026	Optech	300289924	300291084
20210320_160044	210320_448A	03/20/2021	4027	Optech	300291244	300292303
20210320_162053	210320_448A	03/20/2021	4028	Optech	300292453	300293607
20210320_164317	210320_448A	03/20/2021	4029	Optech	300293797	300294858
20210320_170357	210320_448A	03/20/2021	4030	Optech	300295037	300296196
20210320_172539	210320_448A	03/20/2021	4031	Optech	300296339	300297404
20210320_204627	210320_448B	03/20/2021	4033	Optech	300308387	300309476
20210320_210707	210320_448B	03/20/2021	4034	Optech	300309627	300310757
20210320_212823	210320_448B	03/20/2021	4035	Optech	300310903	300311985
20210320_214902	210320_448B	03/20/2021	4036	Optech	300312142	300313273
20210320_221054	210320_448B	03/20/2021	4037	Optech	300313454	300314545
20210320_223118	210320_448B	03/20/2021	4038	Optech	300314678	300315785
20210320_225232	210320_448B	03/20/2021	4039	Optech	300315952	300317038
20210321_145244	210321_448	03/21/2021	4041	Optech	300373564	300374648
20210321_151421	210321_448	03/21/2021	4042	Optech	300374861	300376138
20210321_153852	210321_448	03/21/2021	4043	Optech	300376332	300377408
20210321_160008	210321_448	03/21/2021	4044	Optech	300377608	300378828

20210321_162257	210321_448	03/21/2021	4045	Optech	300378977	300380035
20210321_164347	210321_448	03/21/2021	4046	Optech	300380227	300381534
20210321_170815	210321_448	03/21/2021	4047	Optech	300381695	300382739
20210328_150947	210328_448A	03/28/2021	4050	Optech	300979387	300980552
20210328_153118	210328_448A	03/28/2021	4051	Optech	300980678	300981772
20210328_155242	210328_448A	03/28/2021	4052	Optech	300981962	300983100
20210328_161342	210328_448A	03/28/2021	4053	Optech	300983222	300984299
20210328_163448	210328_448A	03/28/2021	4054	Optech	300984488	300985630
20210328_165548	210328_448A	03/28/2021	4055	Optech	300985748	300986817
20210328_221832	210328_448B	03/28/2021	4056	Optech	301005112	301006204
20210328_223931	210328_448B	03/28/2021	4057	Optech	301006371	301007470
20210328_225959	210328_448B	03/28/2021	4058	Optech	301007599	301008697
20210328_232049	210328_448B	03/28/2021	4059	Optech	301008849	301009939
20201205_152848	1205_1	12/05/2020	6001	Optech	291217329	291218279
20201205_154647	1205_1	12/05/2020	6002	Optech	291218407	291219281
20201205_160331	1205_1	12/05/2020	6003	Optech	291219411	291220411
20201205_162158	1205_1	12/05/2020	6004	Optech	291220518	291221464
20201205_163911	1205_1	12/05/2020	6005	Optech	291221551	291222619
20201205_165855	1205_1	12/05/2020	6006	Optech	291222736	291223096
20201205_170804	1205_1	12/05/2020	6007	Optech	291223284	291223928
20201205_171943	1205_1	12/05/2020	6008	Optech	291223984	291225082
20201205_185157	1205_2	12/05/2020	6009	Optech	291229518	291230496
20201205_191015	1205_2	12/05/2020	6010	Optech	291230616	291231791
20201205_193119	1205_2	12/05/2020	6011	Optech	291231879	291232965
20201205_195117	1205_2	12/05/2020	6012	Optech	291233077	291234386
20201205_201500	1205_2	12/05/2020	6013	Optech	291234501	291235548
20201205_203456	1205_2	12/05/2020	6014	Optech	291235697	291237013
20201205_205858	1205_2	12/05/2020	6015	Optech	291237138	291238211
20201205_211911	1205_2	12/05/2020	6016	Optech	291238351	291239661
20201205_214247	1205_2	12/05/2020	6017	Optech	291239767	291240846

20201205_220331	1205_2	12/05/2020	6018	Optech	291241012	291242309
20201205_222651	1205_2	12/05/2020	6019	Optech	291242411	291243502
20201205_224710	1205_2	12/05/2020	6020	Optech	291243631	291244953
20201207_173154	1207	12/07/2020	6021	Optech	291397514	291398588
20201207_175219	1207	12/07/2020	6022	Optech	291398740	291400055
20201207_181703	1207	12/07/2020	6023	Optech	291400223	291401291
20201207_183812	1207	12/07/2020	6024	Optech	291401493	291402787
20201207_190240	1207	12/07/2020	6025	Optech	291402961	291404055
20201207_192334	1207	12/07/2020	6026	Optech	291404214	291405436
20201207_194631	1207	12/07/2020	6027	Optech	291405592	291406667
20201207_200716	1207	12/07/2020	6028	Optech	291406837	291408014
20201207_202950	1207	12/07/2020	6029	Optech	291408191	291409257
20201207_204950	1207	12/07/2020	6030	Optech	291409390	291410553
20201207_211059	1207	12/07/2020	6031	Optech	291410659	291411745
20201207_213125	1207	12/07/2020	6032	Optech	291411886	291413060
20201208_155028	1208	12/08/2020	6033	Optech	291477828	291478900
20201208_161100	1208	12/08/2020	6034	Optech	291479061	291480276
20201208_163345	1208	12/08/2020	6035	Optech	291480426	291481500
20201208_165440	1208	12/08/2020	6036	Optech	291481680	291482885
20201208_171721	1208	12/08/2020	6037	Optech	291483042	291484133
20201208_173848	1208	12/08/2020	6038	Optech	291484329	291485544
20201208_180202	1208	12/08/2020	6039	Optech	291485722	291486792
20201208_182300	1208	12/08/2020	6040	Optech	291486981	291488207
20201208_184514	1208	12/08/2020	6041	Optech	291488315	291489379
20201208_190540	1208	12/08/2020	6042	Optech	291489540	291490738
20201208_192747	1208	12/08/2020	6043	Optech	291490868	291491959
20201208_195014	1208	12/08/2020	6044	Optech	291492214	291493373
20201208_201143	1208	12/08/2020	6045	Optech	291493503	291494583
20201208_203226	1208	12/08/2020	6046	Optech	291494747	291495900
20201208_205349	1208	12/08/2020	6047	Optech	291496030	291497104

20201208_211438	1208	12/08/2020	6048	Optech	291497278	291498414
20201209_143407	1209_1	12/09/2020	6049	Optech	291559648	291560746
20201209_145550	1209_1	12/09/2020	6050	Optech	291560951	291562164
20201209_151814	1209_1	12/09/2020	6051	Optech	291562295	291563394
20201209_154020	1209_1	12/09/2020	6052	Optech	291563620	291564792
20201209_160222	1209_1	12/09/2020	6053	Optech	291564943	291566049
20201209_162348	1209_1	12/09/2020	6054	Optech	291566228	291567388
20201209_164543	1209_1	12/09/2020	6055	Optech	291567543	291568657
20201209_170725	1209_1	12/09/2020	6056	Optech	291568846	291569985
20201209_172854	1209_1	12/09/2020	6057	Optech	291570134	291571255
20201209_175011	1209_1	12/09/2020	6058	Optech	291571412	291572561
20201209_181059	1209_1	12/09/2020	6059	Optech	291572659	291573758
20201209_183156	1209_1	12/09/2020	6060	Optech	291573916	291575051
20201209_185312	1209_1	12/09/2020	6061	Optech	291575193	291576315
20201209_191343	1209_1	12/09/2020	6062	Optech	291576424	291577579
20201209_193453	1209_1	12/09/2020	6063	Optech	291577693	291578783
20201209_195526	1209_1	12/09/2020	6064	Optech	291578927	291580068
20201209_212930	1209_2	12/09/2020	6065	Optech	291584570	291585662
20201209_214939	1209_2	12/09/2020	6066	Optech	291585779	291586906
20201209_221015	1209_2	12/09/2020	6067	Optech	291587016	291588125
20201209_223015	1209_2	12/09/2020	6068	Optech	291588215	291589336
20201209_225025	1209_2	12/09/2020	6069	Optech	291589426	291590534
20201209_231021	1209_2	12/09/2020	6070	Optech	291590621	291591716
20201210_141245	1210_1	12/10/2020	6071	Optech	291644766	291645893
20201210_143321	1210_1	12/10/2020	6072	Optech	291646001	291647098
20201210_145324	1210_1	12/10/2020	6073	Optech	291647204	291648320
20201210_151337	1210_1	12/10/2020	6074	Optech	291648418	291649520
20201210_153349	1210_1	12/10/2020	6075	Optech	291649630	291650739
20201210_155422	1210_1	12/10/2020	6076	Optech	291650862	291651950
20201210_161405	1210_1	12/10/2020	6077	Optech	291652045	291653170

20201210_163452	1210_1	12/10/2020	6078	Optech	291653293	291654395
20201210_165432	1210_1	12/10/2020	6079	Optech	291654472	291655603
20201210_171504	1210_1	12/10/2020	6080	Optech	291655704	291656815
20201210_173514	1210_1	12/10/2020	6081	Optech	291656915	291658021
20201210_175551	1210_1	12/10/2020	6082	Optech	291658152	291659255
20201210_181544	1210_1	12/10/2020	6083	Optech	291659344	291660462
20201210_183627	1210_1	12/10/2020	6084	Optech	291660588	291661677
20201210_185648	1210_1	12/10/2020	6085	Optech	291661808	291662930
20201210_191713	1210_1	12/10/2020	6086	Optech	291663034	291664150
20201210_193740	1210_1	12/10/2020	6087	Optech	291664260	291665396
20201210_213723	1210_2	12/10/2020	6088	Optech	291671443	291672555
20201210_215734	1210_2	12/10/2020	6089	Optech	291672655	291673774
20201210_221814	1210_2	12/10/2020	6090	Optech	291673895	291675000
20201210_223806	1210_2	12/10/2020	6091	Optech	291675086	291676180
20201210_225757	1210_2	12/10/2020	6092	Optech	291676278	291677374

Table5: USGS\_IA\_Western\_3\_2020\_D21 Project Area Flight lines by Mission

## Final Calibration Verification

Foth Infrastructure & Environment, LLC conducted the survey throughout the area of interest. 167 ground control points (GCPs) were used to test the accuracy of the calibrated swath data. Of these 167 GCPs 57 were used 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 the figure below. Surveyed ground control points (GCPs) and the accuracy results from testing the calibrated swath data against the GCPs is provided in the following tables. Ground control points (GCPs) vertical accuracy results no further adjustments to the swath data were required based on the accuracy results of the GCPs.

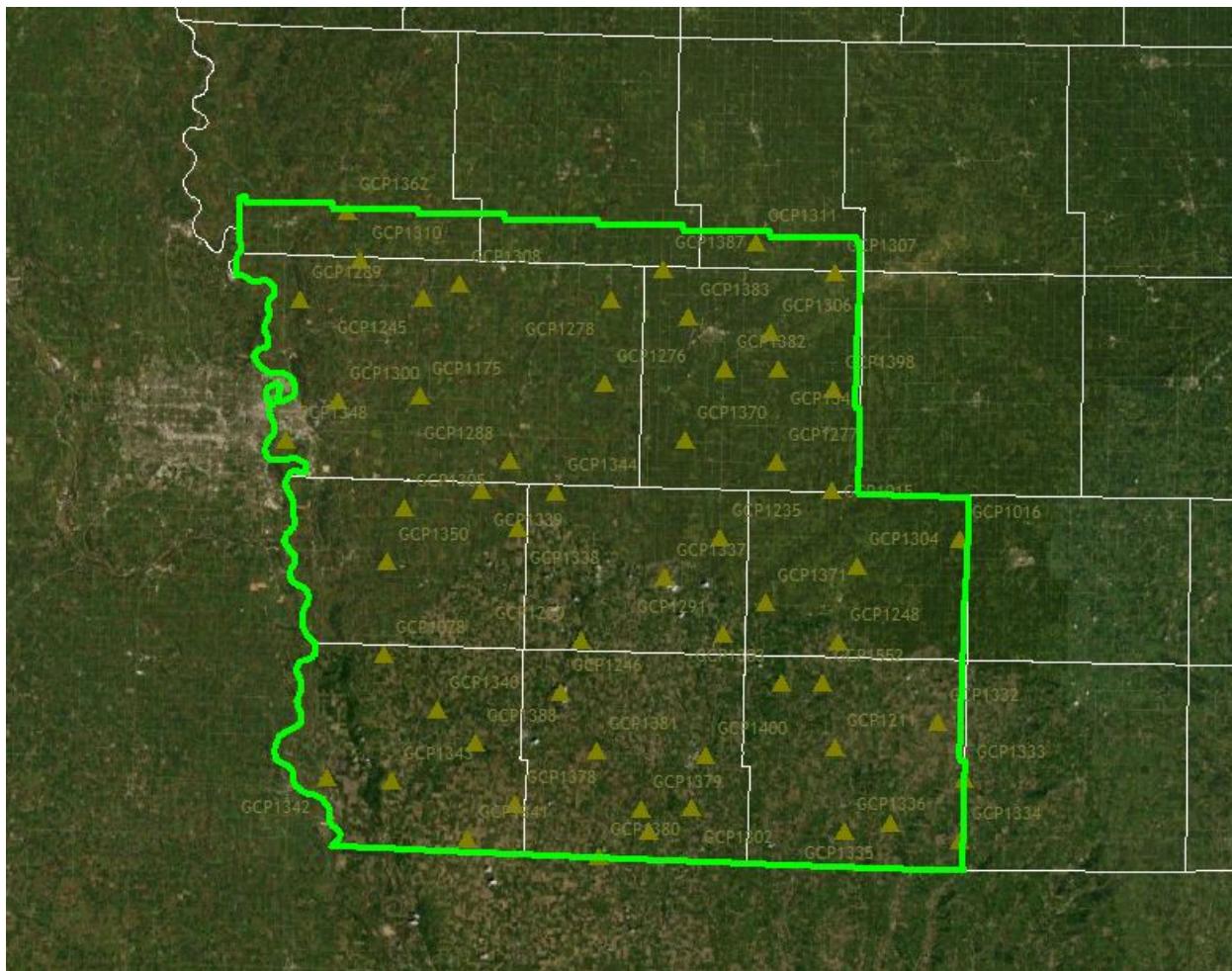


Figure 10: Surveyed Ground Control Point Locations in UTM 15N Block 3 project area.

Point ID	NAD83 (2011 adj) UTM Zone 15 N		NAVD88 (Geoid 18)		
	Easting X (M)	Northing Y (M)	Z-Survey (M)	Z-LiDAR (M)	Dz (M)
GCP1552	351079.334	4524310.115	371.453	371.430	-0.023
GCP1400	330647.951	4511774.763	302.272	302.290	0.018
GCP1398	352894.341	4575395.525	404.293	404.300	0.007
GCP1388	290646.546	4513959.290	289.836	289.860	0.024
GCP1387	323226.703	4596261.545	395.991	395.960	-0.031
GCP1383	327853.777	4588012.958	383.635	383.620	-0.015
GCP1382	333987.176	4579058.567	354.080	354.070	-0.010
GCP1381	311892.480	4512564.227	343.027	343.010	-0.017
GCP1380	311986.908	4494425.460	307.774	307.820	0.046
GCP1379	319447.416	4502469.796	335.235	335.240	0.005
GCP1378	297695.706	4503273.353	359.500	359.530	0.030
GCP1371	341249.993	4538287.376	352.476	352.390	-0.086
GCP1370	327308.123	4566477.563	393.318	393.290	-0.028
GCP1362	268647.457	4606334.792	363.657	363.640	-0.017
GCP1350	275506.596	4545593.739	370.904	370.970	0.066
GCP1348	257836.796	4566681.265	297.835	297.810	-0.025
GCP1345	343324.224	4578816.287	417.854	417.870	0.016
GCP1344	304673.951	4557536.727	371.368	371.370	0.002
GCP1343	276250.720	4507448.903	342.448	342.410	-0.038
GCP1342	265130.865	4507958.824	283.647	283.710	0.063
GCP1341	289465.481	4497202.182	337.198	337.150	-0.048
GCP1340	284277.878	4519862.222	288.665	288.660	-0.005

GCP1339	291854.405	4557918.908	358.892	358.940	0.048
GCP1338	298091.624	4551301.998	371.611	371.710	0.099
GCP1337	323497.763	4542672.416	366.593	366.580	-0.013
GCP1336	354837.051	4498661.534	362.557	362.550	-0.007
GCP1335	362713.687	4500088.169	366.734	366.720	-0.014
GCP1334	374858.754	4497024.828	331.521	331.570	0.049
GCP1333	375747.062	4507818.131	372.236	372.250	0.014
GCP1332	371110.829	4517466.538	367.564	367.570	0.006
GCP1311	339516.065	4600873.473	368.814	368.810	-0.004
GCP1310	270785.639	4597886.993	357.079	357.090	0.011
GCP1308	287907.566	4593798.159	363.502	363.510	0.008
GCP1307	353262.469	4595638.883	400.775	400.800	0.025
GCP1306	341926.065	4585278.643	386.735	386.710	-0.025
GCP1305	278563.335	4554691.516	318.902	318.850	-0.052
GCP1304	357053.437	4544629.164	385.770	385.840	0.070
GCP1303	343824.565	4524526.311	383.266	383.290	0.024
GCP1302	328237.775	4502887.955	298.639	298.720	0.081
GCP1301	320750.592	4498778.589	350.119	350.060	-0.059
GCP1300	266939.608	4573577.255	354.162	354.170	0.008
GCP1291	333666.725	4532815.738	326.780	326.700	-0.080
GCP1289	260383.119	4590894.497	310.214	310.250	0.036
GCP1288	296690.084	4562995.730	345.245	345.260	0.015
GCP1278	314364.132	4590965.423	411.480	411.470	-0.010
GCP1277	343000.337	4562837.544	355.598	355.590	-0.008

GCP1276	313168.838	4576433.261	401.058	401.050	-0.008
GCP1248	353640.736	4531634.088	380.331	380.240	-0.091
GCP1246	305441.925	4522918.697	303.086	303.010	-0.076
GCP1245	281792.070	4591135.202	336.572	336.580	0.008
GCP1235	333239.533	4549513.507	332.137	332.210	0.073
GCP1211	353295.618	4513077.593	358.041	358.080	0.039
GCP1200	309085.965	4531871.769	306.774	306.780	0.006
GCP1175	281239.140	4574172.153	356.290	356.320	0.030
GCP1078	275005.746	4529404.241	374.173	374.250	0.077
GCP1016	374867.739	4549349.788	379.011	379.050	0.039
GCP1015	352544.065	4557726.085	396.096	396	-0.096

Table 5: USGS\_IA\_Western\_3\_2020\_D21 surveyed ground control points (GCPs).

This project meets Ground Control Vertical Accuracy  $\leq 19.6$  cm at the 95% confidence level based on RMSEz  $\leq 10$  cm  $\times 1.9600$ .

<b>100 % of Totals</b>	<b># of Points</b>	<b>RMSEz NVA (m)</b>	<b>NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) m)</b>	<b>Mean (m)</b>	<b>Median (m)</b>	<b>Skew</b>	<b>Std Dev (m)</b>	<b>Min (m)</b>	<b>Max (m)</b>	<b>Kurtosis</b>
GCP	57	0.044	0.086	0.003	0.006	-0.198	0.044	-0.096	0.099	0.015

Table 6: USGS\_IA\_Western\_3\_2020\_D21 Ground Control Vertical Accuracy (GCP) results

NVA was run on the unclassified point cloud which met the Non-Vegetated Accuracy (NVA) of  $\leq 19.6$  cm at the 95% confidence level based on RMSEz  $\leq 10$  cm  $\times 1.9600$ .

<b>100 % of Totals</b>	<b># of Points</b>	<b>RMSEz NVA (m)</b>	<b>NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) m)</b>	<b>Mean (m)</b>	<b>Median (m)</b>	<b>Skew</b>	<b>Std Dev (m)</b>	<b>Min (m)</b>	<b>Max (m)</b>	<b>Kurtosis</b>
NVA	86	0.035	0.069	0.001	0.003	0.143	0.036	-0.091	0.108	0.711

Table 7: USGS\_IA\_Western\_3\_2020\_D21 Vertical Accuracy NVA results

### **Between Swath Relative Accuracy (DZ Orthos)**

Inter-swath relative accuracy passes specification. All pixels colored green are areas where overlapping flight lines are within 8 cm of each other. Areas colored red are where differences greater than 16 cm exist (this is expected in vegetated and sloped areas).

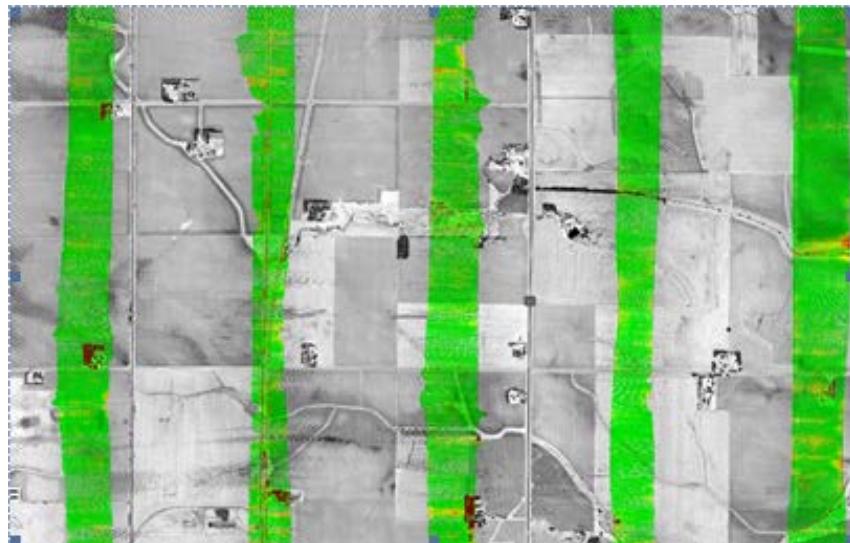


Figure 11: DZ Ortho of inter-swath

### Within Swath Relative Accuracy (Intraswath)

Intra-swath relative accuracy was reviewed and passes specification. All flight lines were reviewed to confirm intra-swath within 6 cm (green) of each on flat plainer surfaces. Areas colored red are where differences greater than 6 cm exist. Red areas are expected in vegetated and sloped areas as this is an assessment only of hard surface repeatability.

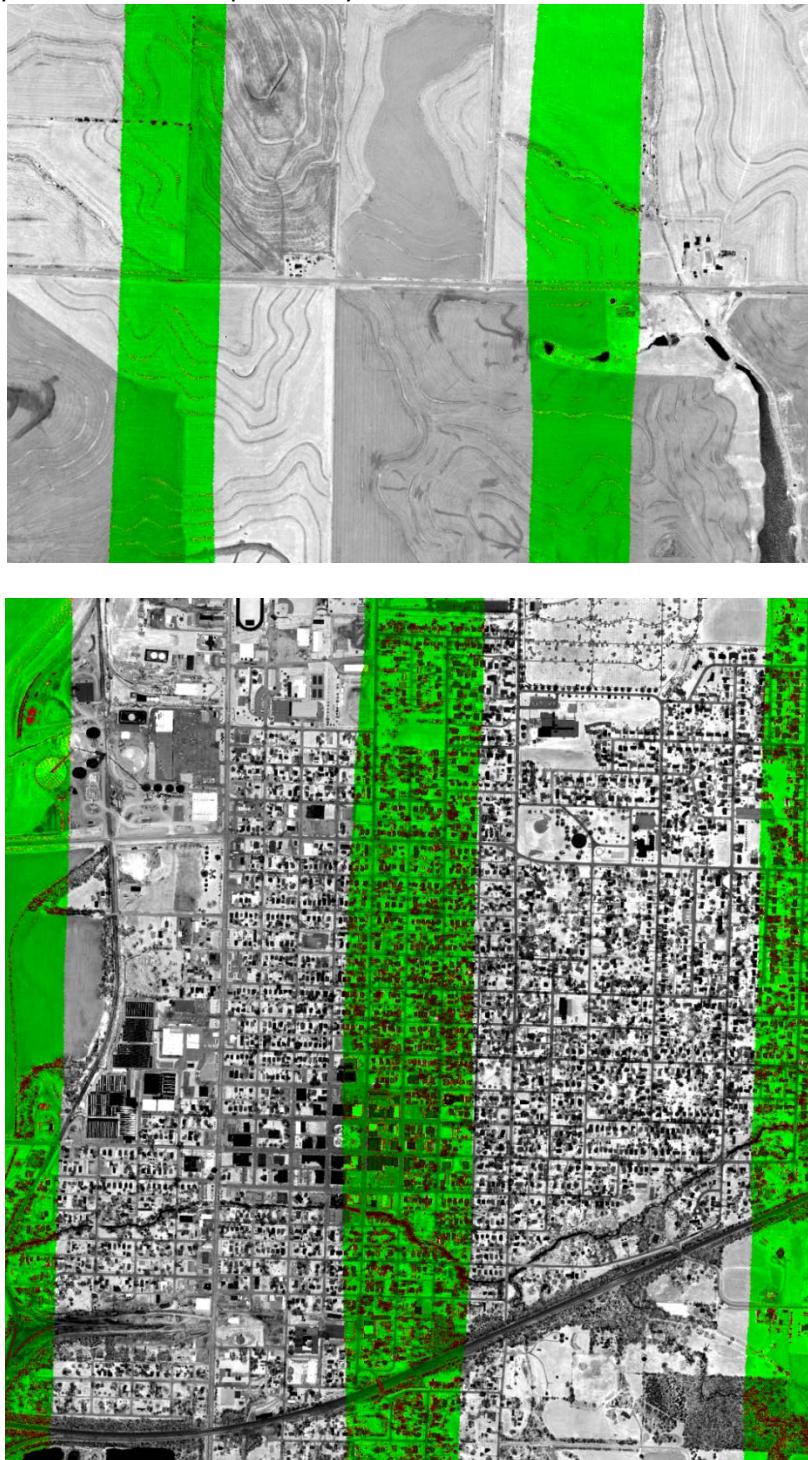


Figure 12: Intra-swath DZ ortho

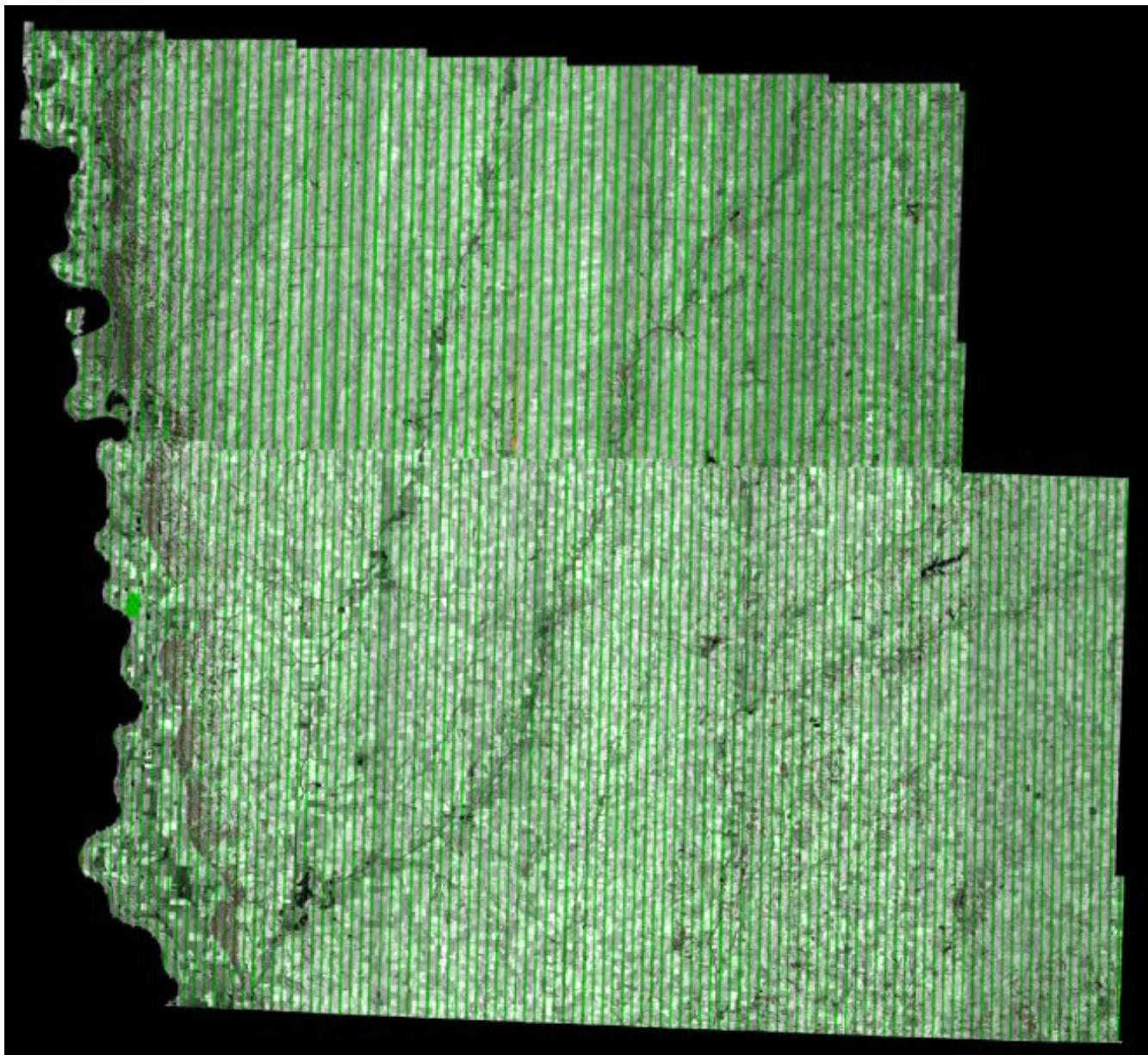


Figure 13: USGS\_IA\_Western\_3\_2020\_D21 Project Area Delta-z raster image.

## Horizontal Alignment/Calibration Check (Rooftops/Planar Surface Profiles)

The profiles show lidar points colored by flight line. The overlapping flight lines match and there is no horizontal (or vertical) offset between the flight lines.

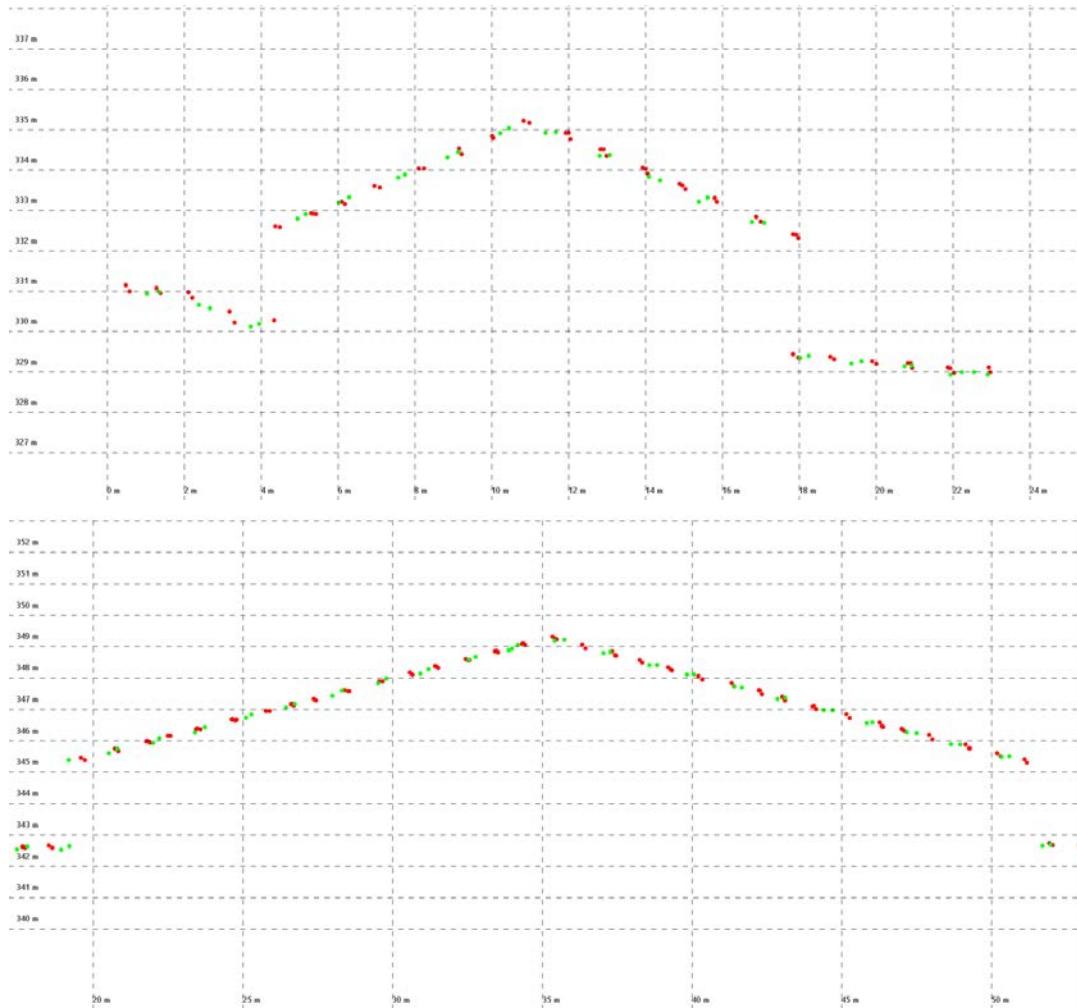


Figure 14: Profile views showing alignment checks

See Appendix B: For Aerial Services, Inc. GPS and IMU Processing Reports

## DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, ASI utilized TerraScan software for data processing. The acquired 3D laser point clouds, in LAS binary format, were imported into the 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. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

In TerraScan surface models for each tile was created to examine the ground classification. ASI analysts visually reviewed the ground surface model for artifacts left in the ground classification. These artifacts consist of vegetation, buildings, and bridges that were still present in the ground after initial processing. ASI analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that errant points are removed from the ground classification. Bridge decks are manually classified to class 17. After the ground classification had been completed, the dataset was processed through a water classification routine that utilized breaklines compiled by the Prime and Subcontractor 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, ground points that are within 2x NPS or less of the hydrographic features are moved to class 20 ignored ground, due to breakline proximity. Overage points are then identified in TerraScan and used to set the overlap bit for those points. The withheld points identified during the classification routine are used to set the withheld bit. The LiDAR tiles were classified to the following classification schema:

- o Class 1 – Default, Processed, but unclassified
- o Class 2 – Ground, Bare-earth
- o Class 7 – Low Noise (low and manually identified)
- o Class 9 – Water
- o Class 17 – Bridge Decks
- o Class 18 – High Noise (high, manually identified)
- o Class 20 – Ignored Ground (Breakline Proximity)

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, the LAS files were then bitset finalized to LAS v1.4 using TerraScan software to flag the overlap bit and withheld bit. An LP360 64 bit was used to deduce the Well Known Text (WKT) and ASI proprietary software was used to format the LAS to the final LAS v1.4 Format 6 version. LASTools by rapidlasso GmbH, open source, lasInfo (open source LGPL) and ASI proprietary software was used to perform final analysis to checks on LAS header information, LAS point classes, and LAS timestamps.

This project consists of 78,914,463,513 lidar points the table below shows the total number of points for every class.

Project Count by Class		
Class 1	Processed, unclassified	3499371321
Class 2	Bare-earth ground	52386403891
Class 7	Low Noise	1198483
Class 9	Water	99234669
Class 17	Bridge Decks	4192181
Class 18	High Noise	61
Class 20	Ignored-Ground	4623129
Class Overlap 1	Overlap Processed, unclassified	3856682942
Class Overlap 2	Overlap Bare-earth ground	19044641054
Class Overlap 7	Overlap Low Noise	405928
Class Overlap 9	Overlap Water	4318239
Class Overlap 17	Overlap Bridge Decks	1620058
Class Overlap 18	Overlap High Noise	1570334
Class Overlap 20	Overlap Ignored-Ground	1006941
Class Withheld 18	Withheld High Noise	8815975
Class Overlap Withheld 18	Overlap Withheld	378307
Project Total Count		78914463513

Table 8: By Class Point Count.

## **LiDAR Qualitative Assessment**

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

## **VISUAL REVIEW**

The following sections describe common types of issues identified in LiDAR data and the results of the visual review USGS\_IA\_Western\_3\_2020\_D21 project area.

### **Data Voids**

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 USGS\_IA\_Western\_3\_2020\_D21 project area.

### 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. 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 bridge deck (blue).

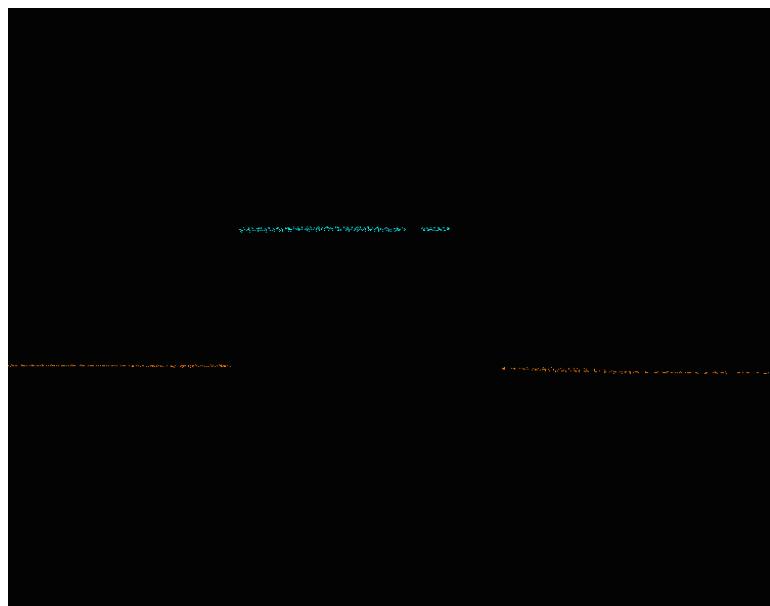


Figure 15: Profile view of a classified bridge deck (blue) and ground (orange).

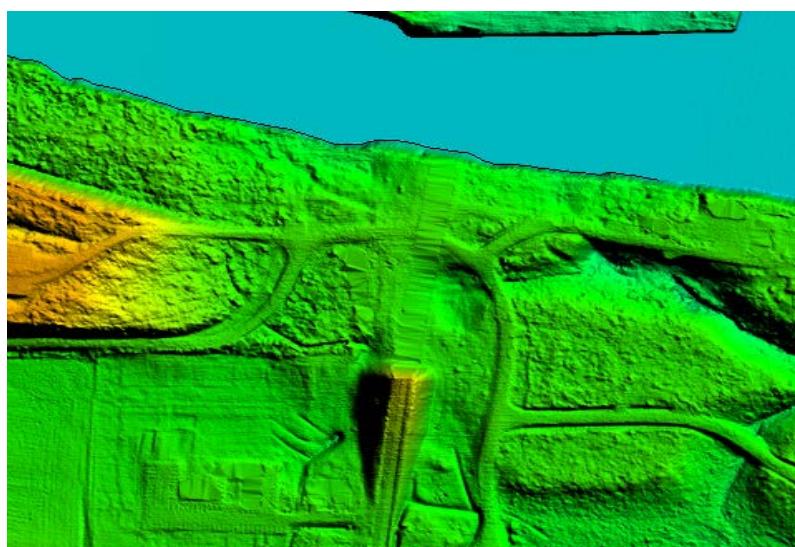


Figure 16: DEM with bridge removed from surface model.

## Culverts

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, ASI 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.

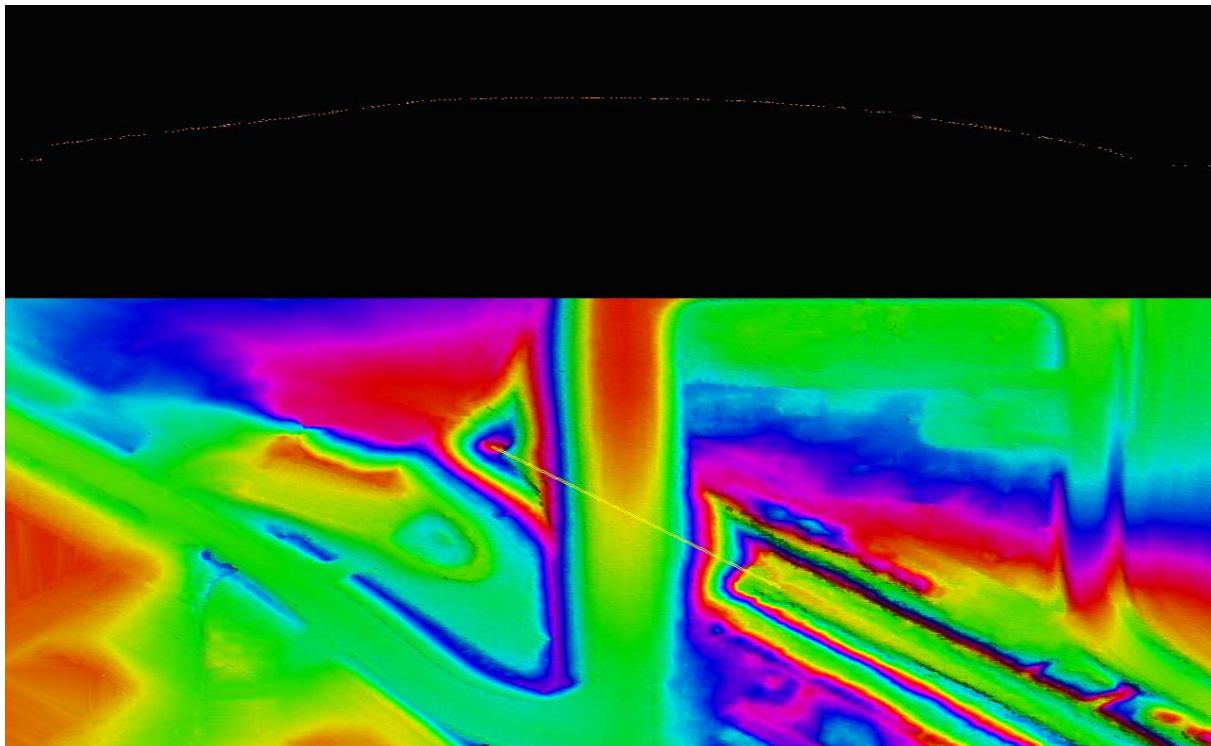


Figure 17: Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

## Dirt Mounds

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

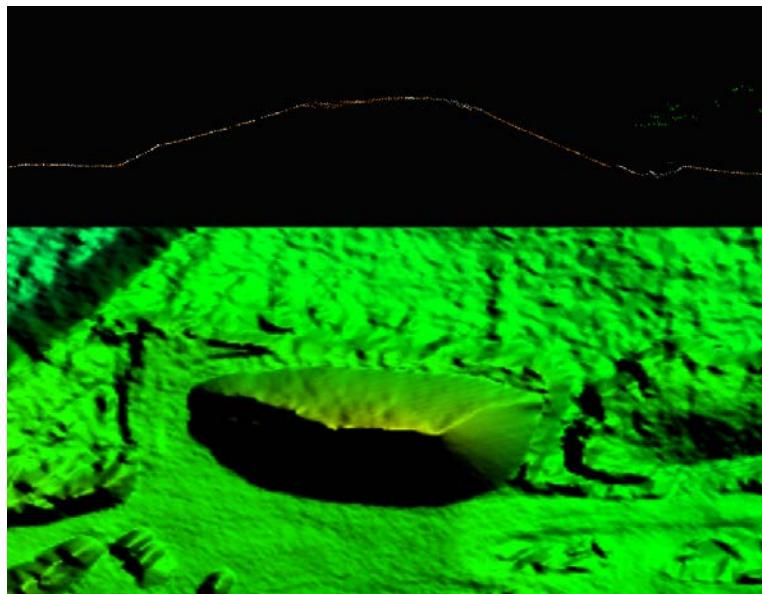


Figure 18: Profile with the points colored by class (unclassified points are white, ground points are orange) is shown on the right and a DEM of the surface is shown to the left. These features are correctly included in the ground classification.

## Flightline Ridges

Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flightline ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible flightline ridge that is within tolerance is shown below.

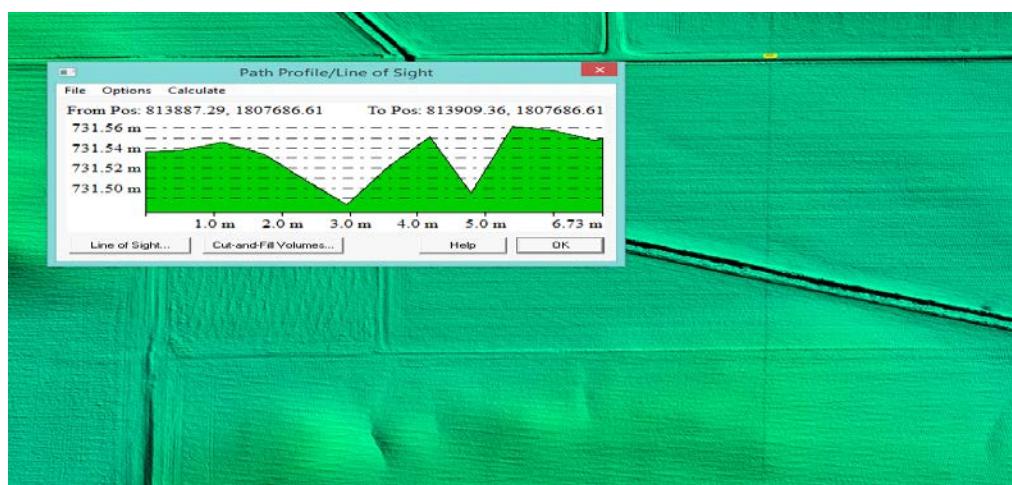


Figure 19: The flight line ridge is less than 8 cm. Overall; this project data meets the project specifications for 8 cm RMSDz relative accuracy requirement.

### Dam and Lock system

Irregularities in the natural water flow exist in sections of river affected by Lock and Dam systems. Series of locks enable vessels to “step” up or down a river or canal from one water level to another. There are no Lock systems in the USGS\_IA\_Western\_3\_2020\_D21 project area.

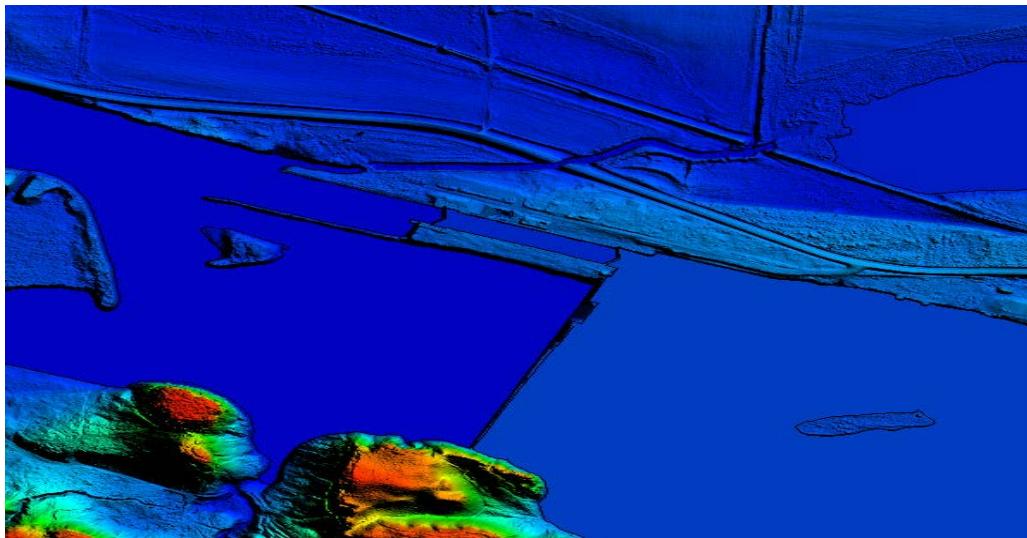


Figure 20: DEM shows Large Dam structure that disrupts natural monotonic river flow, coupled with a lock system.

## 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 ASI proprietary tools. ASI routinely reviews for: proper LAS versions, Coordinate Reference System, Global Encoder Bit, Time Stamp, System ID, Multiple Returns, Intensity, Classification, Overlap and Withheld Points, Scan angle, XYZ Coordinates.

### *LiDAR Positional Accuracy*

## BACKGROUND

ASI quantitatively tested the dataset by testing the vertical accuracy of the LiDAR. The vertical accuracy is tested by comparing the discrete measurement of the survey checkpoints to that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. The nature of lidar data makes it difficult to assess absolute horizontal accuracy as one would with imagery or compiled planimetric data. Guidance on how

absolute horizontal accuracy can be estimated and reported based on the error budget of the instrumentation and operational parameters can be found in ASPRS (2014). The horizontal accuracy of each lidar project shall be reported using the form specified by the ASPRS (2014).

## SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment of USGS\_IA\_Western\_3\_2020\_D21 project eighty six check points were surveyed. All of those check points are located within bare earth/open terrain (86 NVA points). Please see provided survey report which details and validates how the survey was completed for this project. Please see provided 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 15 North	NAD83 (2011) UTM Zone 15 North	NAVD88 (Geoid18)
	Easting (M)	Northing (M)	Elevation (M)
NVA1399	263409.681	4522785.284	285.402
NVA1368	333606.892	4563062.963	376.017
NVA1349	271415.934	4568148.457	359.764
NVA1309	270563.474	4590709.799	360.163
NVA1290	300350.973	4516622.935	296.642
NVA1282	323580.466	4590768.158	375.838
NVA1261	361784.624	4537751.193	388.608
NVA1249	364723.070	4542567.647	353.031
NVA1247	303458.482	4512806.325	338.853
NVA1238	337347.575	4585407.242	394.021
NVA1232	328028.334	4595698.583	397.916
NVA1227	258603.485	4604529.078	307.367
NVA1225	289886.213	4544583.482	306.235
NVA1224	319102.865	4557127.150	333.053
NVA1223	339603.263	4510214.181	374.237
NVA1222	333702.277	4569422.513	357.309

NVA1221	312925.271	4566926.178	386.303
NVA1210	332975.972	4538139.873	327.646
NVA1209	278943.177	4606369.066	348.470
NVA1208	349541.901	4544754.421	392.411
NVA1207	322996.338	4523434.394	370.449
NVA1206	283764.276	4527828.089	297.255
NVA1205	289862.214	4506879.325	323.908
NVA1204	369236.357	4503923.144	365.441
NVA1203	367711.361	4507957.332	383.313
NVA1202	340421.667	4498377.583	360.341
NVA1201	317924.503	4512422.740	347.404
NVA1199	298197.589	4544909.200	347.478
NVA1198	371493.826	4537546.517	386.904
NVA1197	365340.450	4554373.783	401.999
NVA1196	352543.390	4589652.494	387.352
NVA1174	311437.348	4502761.232	302.812
NVA1159	257540.156	4582201.925	303.799
NVA1158	260746.227	4597812.535	406.017
NVA1157	287901.845	4584422.847	396.818
NVA1156	295396.858	4596761.437	404.137
NVA1155	321133.145	4576272.897	351.031
NVA1154	343126.049	4570777.369	388.490
NVA1153	353493.513	4524277.990	354.538
NVA1152	354664.633	4503320.607	345.814

NVA1151	345534.110	4508298.723	372.038
NVA1150	332595.759	4523629.142	313.223
NVA1148	314507.664	4596170.167	392.365
NVA1147	304356.092	4584694.182	373.779
NVA1146	298292.196	4557763.066	327.018
NVA1145	312851.448	4557124.644	347.058
NVA1144	320542.199	4567029.503	335.948
NVA1142	337569.162	4595624.808	365.158
NVA1089	304994.947	4596790.292	382.213
NVA1088	276370.702	4583963.328	347.469
NVA1087	283097.907	4597485.472	344.226
NVA1086	300392.648	4576640.675	375.263
NVA1085	281026.729	4567893.568	369.928
NVA1084	278989.394	4559853.449	342.250
NVA1083	297207.691	4567442.707	330.910
NVA1082	263318.817	4559161.154	301.842
NVA1081	282584.861	4542196.524	305.815
NVA1080	298338.045	4530575.497	324.878
NVA1079	311762.396	4523759.270	363.875
NVA1077	276495.085	4514019.979	356.044
NVA1076	296830.098	4514035.828	296.246
NVA1075	328801.504	4509924.653	300.749
NVA1074	362807.423	4503889.001	370.290
NVA1073	361407.715	4517799.565	381.903

NVA1072	368874.507	4526043.144	395.269
NVA1071	311049.199	4542987.049	318.276
NVA1070	323334.235	4538794.119	358.716
NVA1069	340387.574	4533643.433	330.622
NVA1068	353984.732	4538876.061	344.330
NVA1067	333116.799	4556722.696	356.531
NVA1066	351795.026	4568317.884	385.063
NVA1065	328857.826	4585600.765	349.590
NVA1045	297475.398	4495221.616	311.859
NVA1044	328176.620	4495640.396	306.912
NVA1043	348954.501	4494401.999	324.409
NVA1042	362621.284	4492440.246	364.071
NVA1041	374251.082	4517427.397	383.319
NVA1040	352966.642	4581825.994	421.261
NVA1031	264460.983	4530014.538	288.536
NVA1020	250224.094	4604264.656	307.045
NVA1019	259993.596	4574049.264	298.710
NVA1018	262524.186	4547564.704	294.107
NVA1017	262499.385	4508026.701	281.733
NVA1014	353364.167	4601025.114	423.212
NVA1004	375522.209	4492177.964	306.091
NVA1003	268547.66	4498065.29	277.897
VVA1560	373883.452	4537525.701	370.172
VVA1556	342304.649	4529425.187	350.235

VVA1555	310982.383	4503149.503	323.983
VVA1554	268505.022	4497172.302	278.236
VVA1553	297459.181	4494963.419	319.85
VVA1551	343269.084	4574007.821	374.211
VVA1540	342693.642	4546423.969	363.519
VVA1454	258545.293	4598003.292	306.134
VVA1441	280969.415	4591647.315	331.219
VVA1440	305281.779	4604111.042	354.051
VVA1439	264002.282	4541136.549	291.122
VVA1438	274592.722	4531104.65	382.584
VVA1437	266208.742	4525918.882	286.671
VVA1436	262631.935	4517745.509	283.917
VVA1435	268232.928	4571556.076	365.472
VVA1434	281785.05	4567741.084	379.204
VVA1433	302221.522	4584880.688	336.61
VVA1432	357069.973	4548092.678	362.818
VVA1431	345215.644	4594402.135	388.898
VVA1430	325159.079	4574848.897	359.619
VVA1429	328415.142	4556881.468	366.846
VVA1428	305857.216	4565519.383	357.675
VVA1427	308984.154	4532152.737	305.983
VVA1426	299044.102	4575483.879	328.699
VVA1425	258996.747	4571635.704	299.883
VVA1424	260465.574	4565164.68	297.336

VVA1423	291731.822	4553330.62	315.361
VVA1422	330673.299	4585085.877	352.837
VVA1421	351982.417	4590545.89	419.383
VVA1420A	344677.9	4564397.857	368.629
VVA1420	344377.573	4562866.228	384.087
VVA1419	352482.594	4545979.533	363.332
VVA1418	358051.015	4509801.831	368.182
VVA1417	369549.685	4521799.198	374.983
VVA1416	375150.713	4497214.175	344.129
VVA1415	371668.914	4505363.405	365.617
VVA1414	355193.81	4504230.924	352.897
VVA1413	332044.608	4514370.489	300.619
VVA1412	333841.14	4496977.237	318.825
VVA1411	312355.421	4512554.802	338.995
VVA1410	297005.459	4511354.242	298.051
VVA1409	281147.889	4507310.608	283.158
VVA1408	273652.68	4506909.88	362.961
VVA1407	327898.487	4537802.599	380.42
VVA1406	375557.477	4556238.214	395.73
VVA1405	354158.931	4538302.498	338.128
VVA1404	316584.025	4542863.065	353.604
VVA1403	289862.821	4544409.949	305.385
VVA1402	270119.108	4548062.519	304.108

Table 9: USGS\_IA\_Western\_3\_2020\_D21 project area project LiDAR Validation Checkpoints

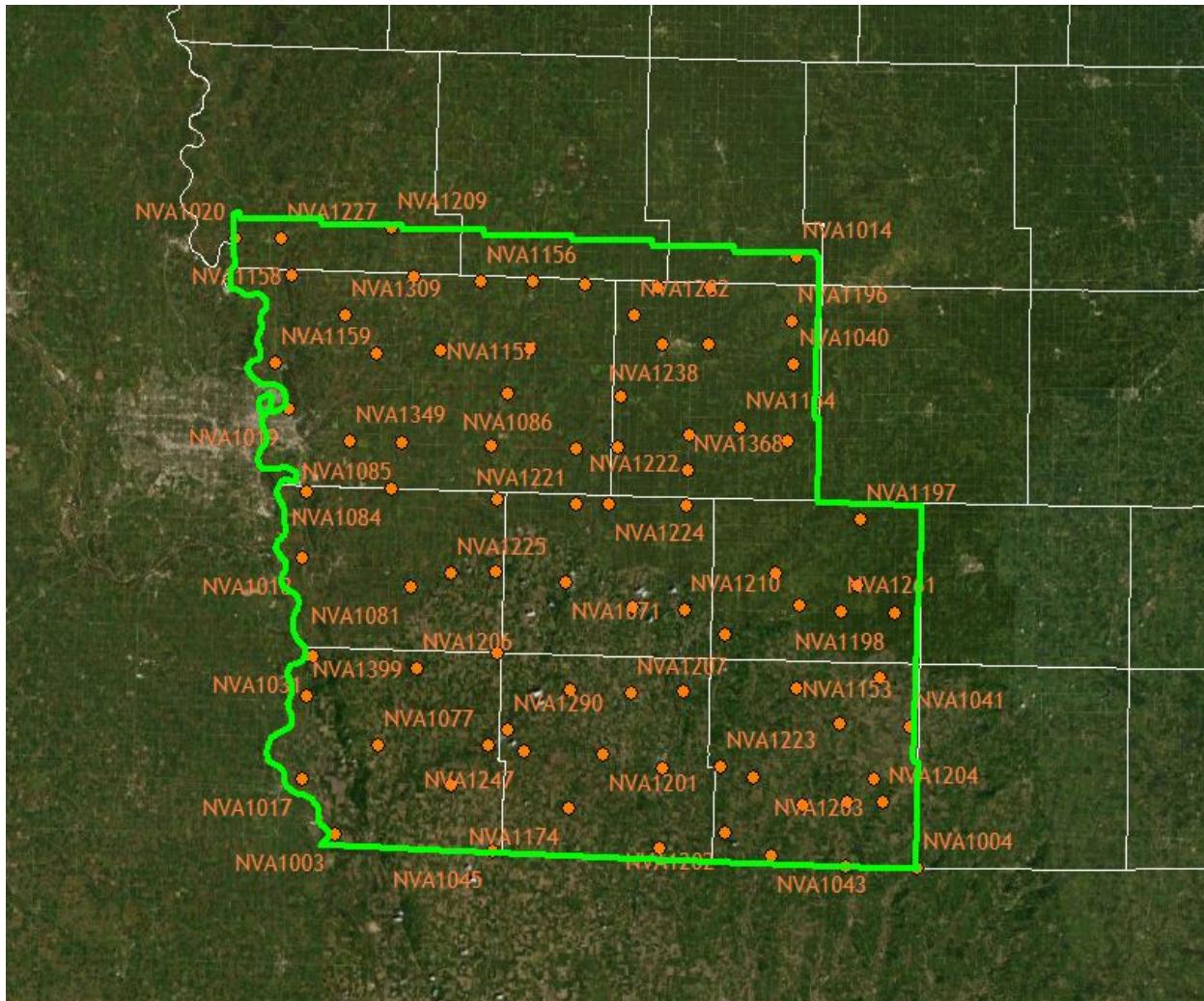


Figure 21: Location of USGS\_IA\_Western\_3\_2020\_D21 project area LiDAR NVA Checkpoints

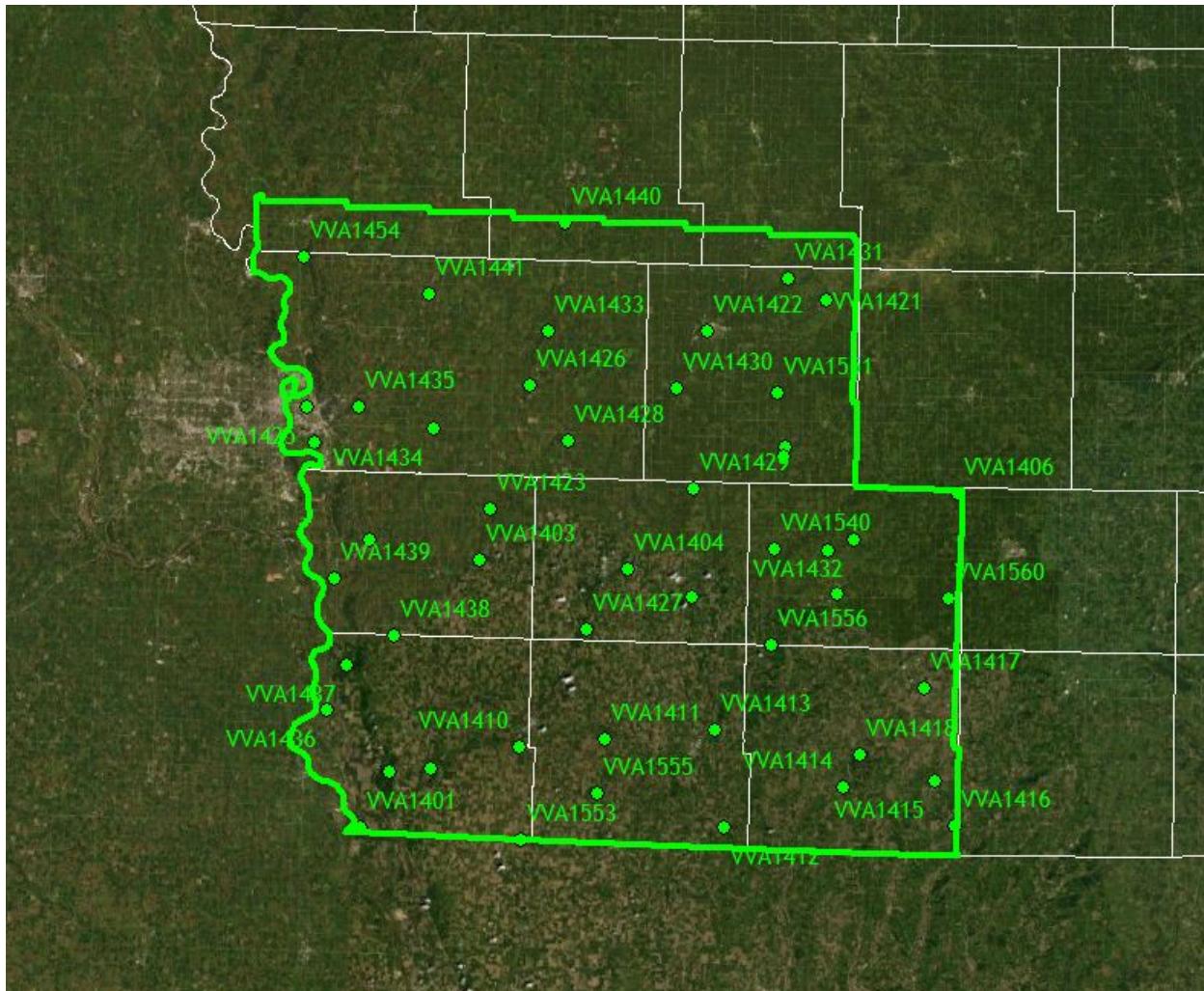


Figure 22: VVA Checkpoints were located in USGS\_IA\_Western\_3\_2020\_D21

## VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in nonvegetated 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 (RMSEz) of the checkpoints  $x 1.9600$ . For the USGS\_IA\_Western\_3\_2020\_D21 project area, vertical accuracy must be 19.6 cm (0.64 ft) or less based on an RMSEz of 10 cm (0.33 ft)  $\times 1.9600$ . 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 USGS\_IA\_Western\_3\_2020\_D21 project area VVA standard is 29.4 cm (0.96 ft) based on the 95th percentile.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using RMSEz *1.96	19.6 cm (based on RMSEz (10 cm)*1.96)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined and at the 95 <sup>th</sup> Percentile error	29.4 cm (based on combined 95th percentile)

Table 10: Acceptance Criteria.

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

1. Foth Infrastructure & Environment, LLC surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, ASI interpolated the bare-earth LiDAR DTM to provide the z-value for every checkpoint.
3. ASI 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 ASI 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 (95% confidence) Spec = 0.196 m	VVA – Vegetated Vertical Accuracy (95 <sup>th</sup> Percentile) spec = 0.294 m
NVA	86	0.069	
VVA	48		0.105

Table 11: Tested NVA and VVA.

## HORIZONTAL ACCURACY TEST PROCEDURES

The Optech Galaxy Prime data set was produced to meet ASPRS “Positional Accuracy Standards for Digital Geospatial Data” (2014) for a 32.72 (cm) RMSE<sub>x</sub> / RMSE<sub>y</sub> Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 64.13 cm at a 95% confidence level.

## ***Breakline Production methodology***

MicroStation, in conjunction with TerraSolid's TerraScan and TerraModeler was utilized for the collection of hydrologic breaklines, which occurred independently of manual edit. Collection was done using 2D information in the LAS format, intensity format, and ground surface. Breaklines are developed to the limit of the defined project boundary. Breaklines are in the same coordinate reference system and unit of measure as the LiDAR point delivery. Hydrologic water-surface edges are set at or just below the immediately surrounding terrain. Breaklines are developed to the limit of the project boundary.

## **Breakline Qualitative Assessment**

Completeness and horizontal placement is verified through visual review against LiDAR intensity imagery, and bare earth surface. Breakline features are checked for connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

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

## **Feature Definition**

### **Inland Streams and Rivers**

Streams and Rivers with a nominal width of 30 meters (100 feet), were collected to best fit the shoreline by using information in the LAS format; intensity format, ground surface TIN, and sometimes "quick guide" contours. Streams and rivers do not break at bridges, but they are closed ended breaks at culvert locations. Streams and Rivers breaklines have been delivered in PolylineZ format in the final GDB.

### **Inland Ponds and Lakes**

Inland ponds and lakes of 2 acres (86,111 square feet/ ~350'/~106 meter diameter for a round pond) or greater were collected. Inland pond and Lakes were collected to best fit the shoreline by using information in the LAS format; intensity format, ground surface TIN, and sometimes "quick guide" contours. Inland pond and Lakes Breaklines have been delivered in PolygonZ format in the final GDB.

### **Islands**

Permanent island 4000m<sup>2</sup> (1 acre) or larger were delineated within all water bodies. Breaklines have been delivered in PolygonZ format in the final GDB

### **Bridge Breaklines**

Breaklines were placed across the bottom of the bridge embankment when triangulation occurred due to bridge deck classification. Breaklines have been delivered in PolylineZ format in the final GDB.

## *Intensity Imagery Production & Qualitative Assessment*

### **INTENSITY PRODUCTION METHODOLOGY**

ASI utilized MicroStation in conjunction with TerraSolid's TerraScan for Intensity production. Global Mapper was used to QC the products. ArcGIS was used to finalize the Intensity's projection.

Intensity Images are created for each tile in the tiling schema. The Intensities are reviewed for any issues requiring corrections. Tiles are verified for final formatting and loaded into Global Mapper to ensure there are no missing, or corrupt tiles, and to check for seamlessness across tile boundaries.

### **INTENSITY QUALITATIVE ASSESSMENT**

ASI performed a qualitative assessment of the Intensity deliverables to ensure that all tiled Intensity products were delivered with the proper extents, and contained proper referencing information. Intensity bounding values were manually set in RiProcess to utilize the full range of values available. Subcontractor intensities were linearly scaled to match the intensity of ASI's collection. During some reprocessing to improve the calibration, some points received maximum value intensity; however these were corrected to the original output values prior to delivery.



Figure 23: Intensity Image example.

## ***DEM Production & Qualitative Assessment***

### **DEM PRODUCTION METHODOLOGY**

ASI utilized MicroStation Connect in conjunction with TerraSolid's TerraScan and TerraModeler for DEM production. Global Mapper version 21.0 was used to format and QC the products. GDAL version 2.4.0 was used to finalize the DEMs projection.

The final bare earth LiDAR points are used to create a terrain. The final 3D breaklines collected for the project are enforced in the terrain. The terrain is then converted to raster format using linear interpolation. DEMs are created for each tile in the tiling schema. The DEMs are reviewed for any issues requiring corrections, including remaining LiDAR ground misclassification, erroneous breakline elevations, poor hydro flattening, and processing artifacts. Tiles are verified for final formatting and loaded into Global Mapper to ensure there are no missing, or corrupt tiles, and to check for seamlessness across tile boundaries.

### **DEM QUALITATIVE ASSESSMENT**

ASI performed a 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 proper referencing information.

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

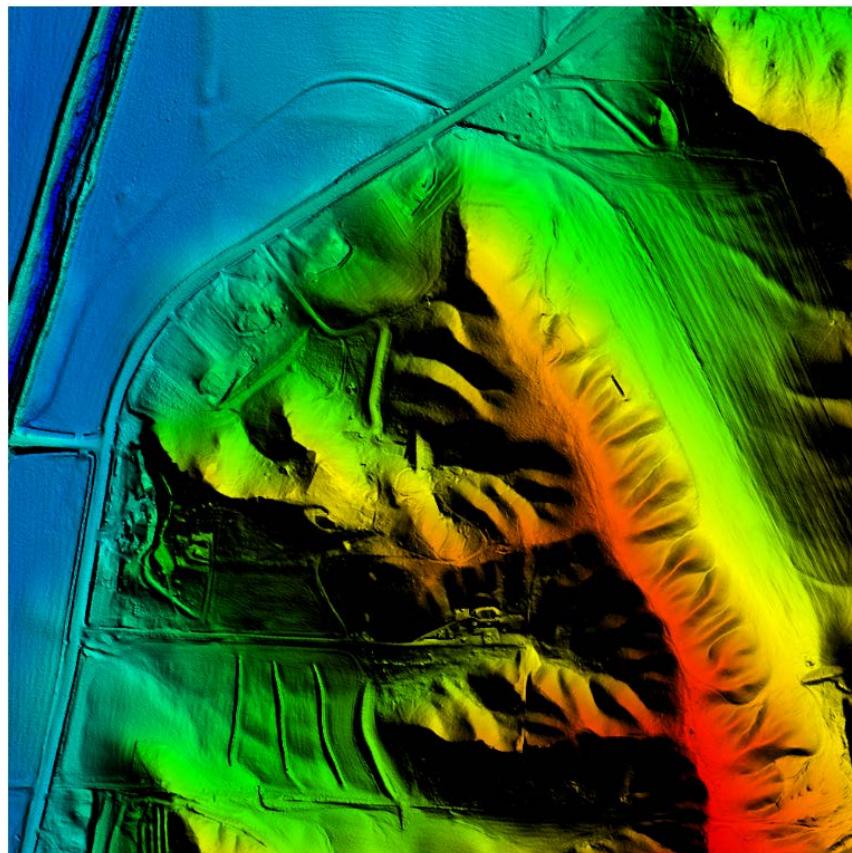


Figure 24: Bare Earth DEM example

## DEM VERTICAL ACCURACY RESULTS

The same 134 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. The DEM pixel does not average several LiDAR point's together, it interpolates (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 survey elevations.

The following table; summarizes the tested vertical accuracy result from a comparison of surveyed checkpoint to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSEz x 1.960)	VVA – Vegetated Vertical Accuracy (95 <sup>th</sup> percentile)
NVA	86	0.068	
VVA	48		0.102

Table 12: DEM vertical accuracy summary

DEM datasets were 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 RMSEz = 0.035 meters with a 0.068 meters accuracy at 95 % confidence level. Actual VVA accuracy tested 0.102 meters using checkpoints located in forested land cover categories at the 95th percentile, derived according to ASPRS guidelines, tested against the DEM. Based on the vertical accuracy testing conducted by ASI, the DEM dataset for the USGS\_IA\_Western\_3\_2020\_D21 project area satisfies the project's pre-defined vertical accuracy criteria.

### ***Appendix A: List of Delivered LAS File***

w2490n4595	w2520n4600	w2540n4595	w2550n4599
w2490n4596	w2520n4601	w2540n4596	w2550n4600
w2490n4597	w2520n4602	w2540n4597	w2550n4601
w2490n4598	w2520n4603	w2540n4598	w2550n4602
w2490n4599	w2520n4604	w2540n4599	w2550n4603
w2490n4601	w2520n4605	w2540n4600	w2550n4604
w2490n4602	w2520n4606	w2540n4601	w2550n4605
w2490n4603	w2520n4607	w2540n4602	w2550n4606
w2490n4604	w2530n4579	w2540n4603	w2550n4607
w2490n4605	w2530n4580	w2540n4604	w2560n4510
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w3710n4506	w3720n4492	w3720n4543	w3730n4529
w3710n4507	w3720n4493	w3720n4544	w3730n4530
w3710n4508	w3720n4494	w3720n4545	w3730n4531
w3710n4509	w3720n4495	w3720n4546	w3730n4532
w3710n4510	w3720n4496	w3720n4547	w3730n4533
w3710n4511	w3720n4497	w3720n4548	w3730n4534
w3710n4512	w3720n4498	w3720n4549	w3730n4535
w3710n4513	w3720n4499	w3720n4550	w3730n4536
w3710n4514	w3720n4500	w3720n4551	w3730n4537
w3710n4515	w3720n4501	w3720n4552	w3730n4538
w3710n4516	w3720n4502	w3720n4553	w3730n4539
w3710n4517	w3720n4503	w3720n4554	w3730n4540
w3710n4518	w3720n4504	w3720n4555	w3730n4541
w3710n4519	w3720n4505	w3720n4556	w3730n4542
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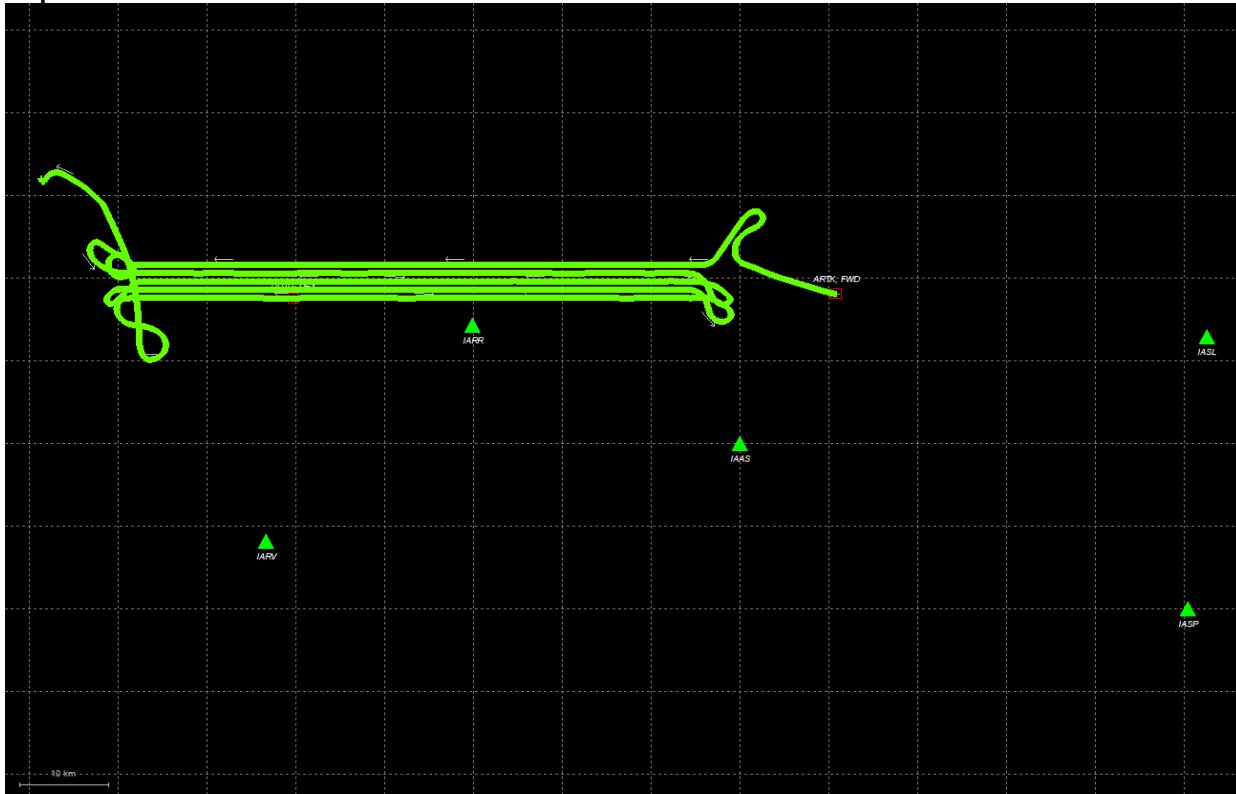
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w3730n4548	w3740n4521	w3750n4494	w3750n4535
w3730n4549	w3740n4522	w3750n4495	w3750n4536
w3730n4550	w3740n4523	w3750n4496	w3750n4537
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w3740n4515	w3740n4553	w3750n4529	w3760n4555
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w3740n4517	w3740n4555	w3750n4531	

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***Appendix B: GPS and IMU Processing Report***

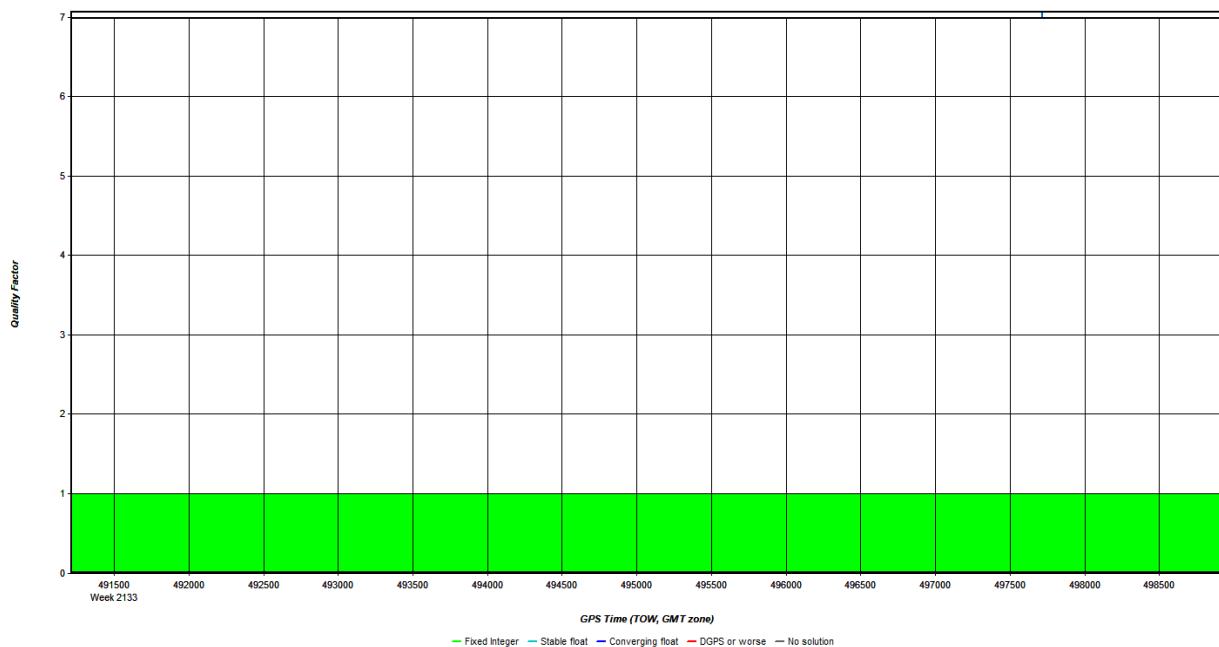
20201127-162331.docx QC Report - 06/22/2021 09:07:25  
Smoothed Trajectory Information

Top View

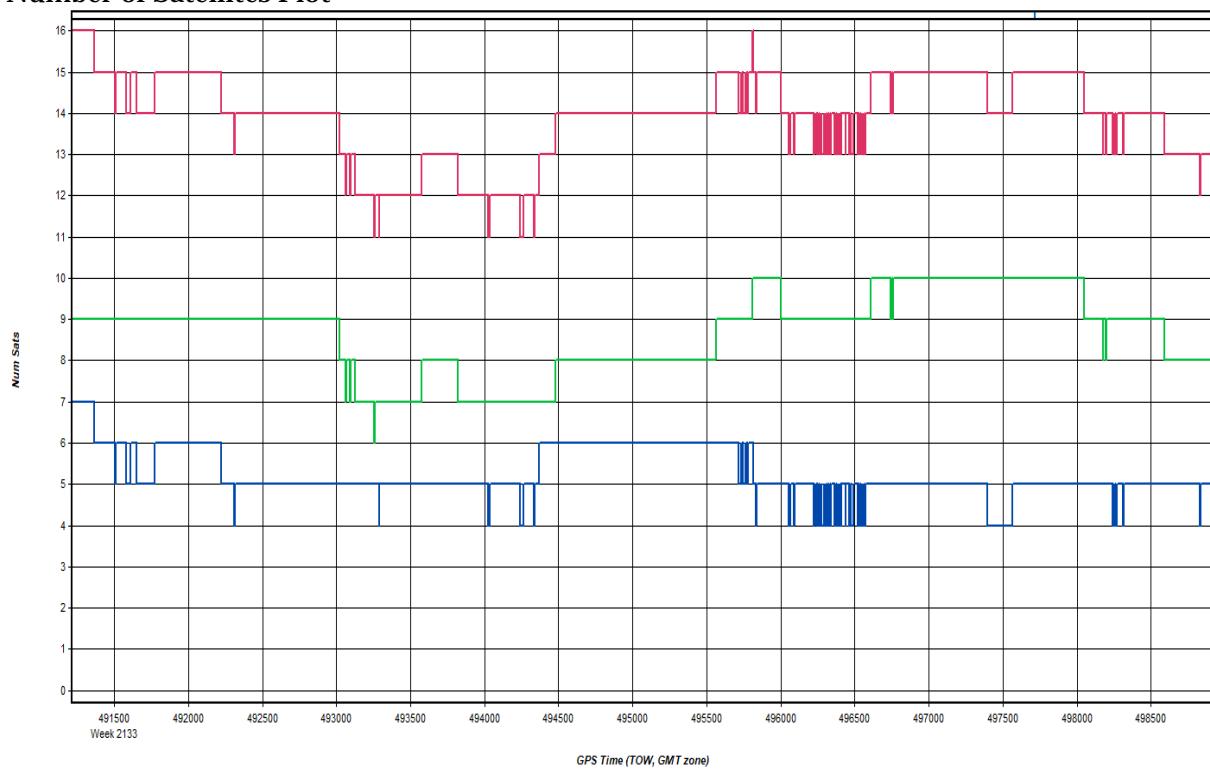


**GNSS QC**

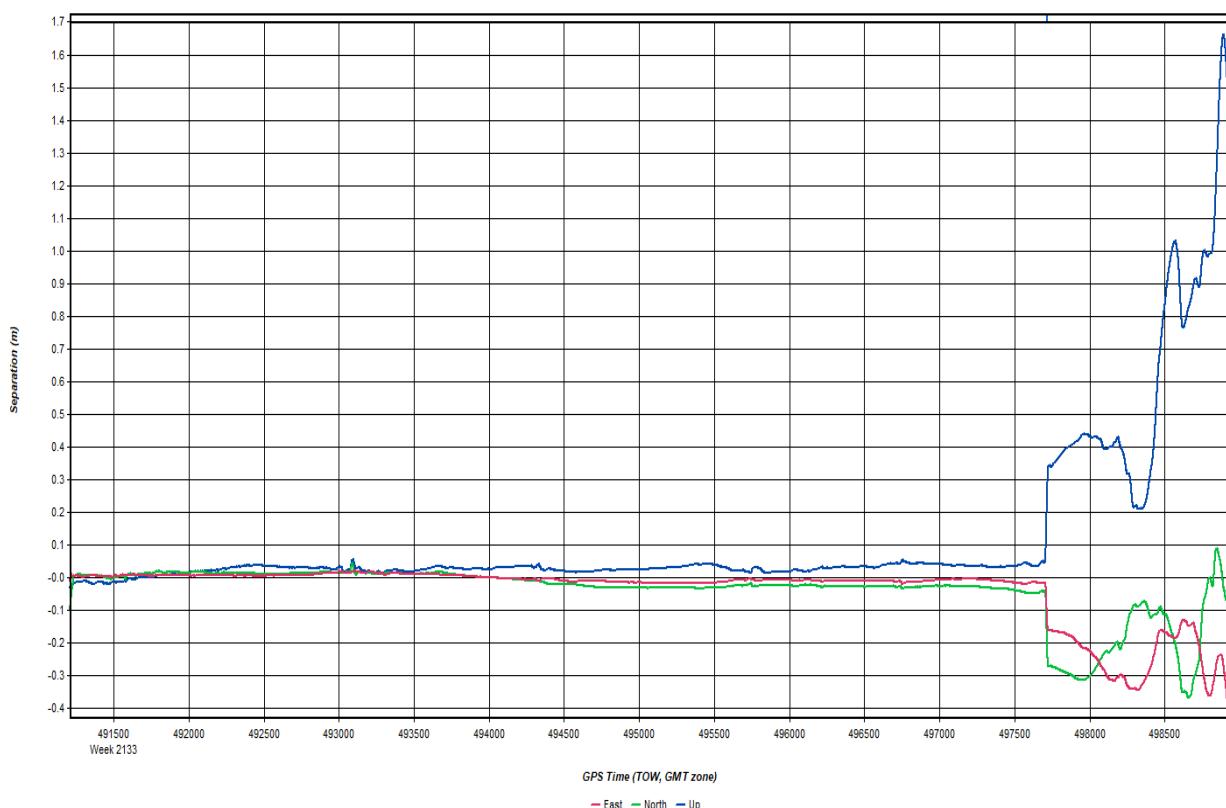
**Quality Factor Plot**



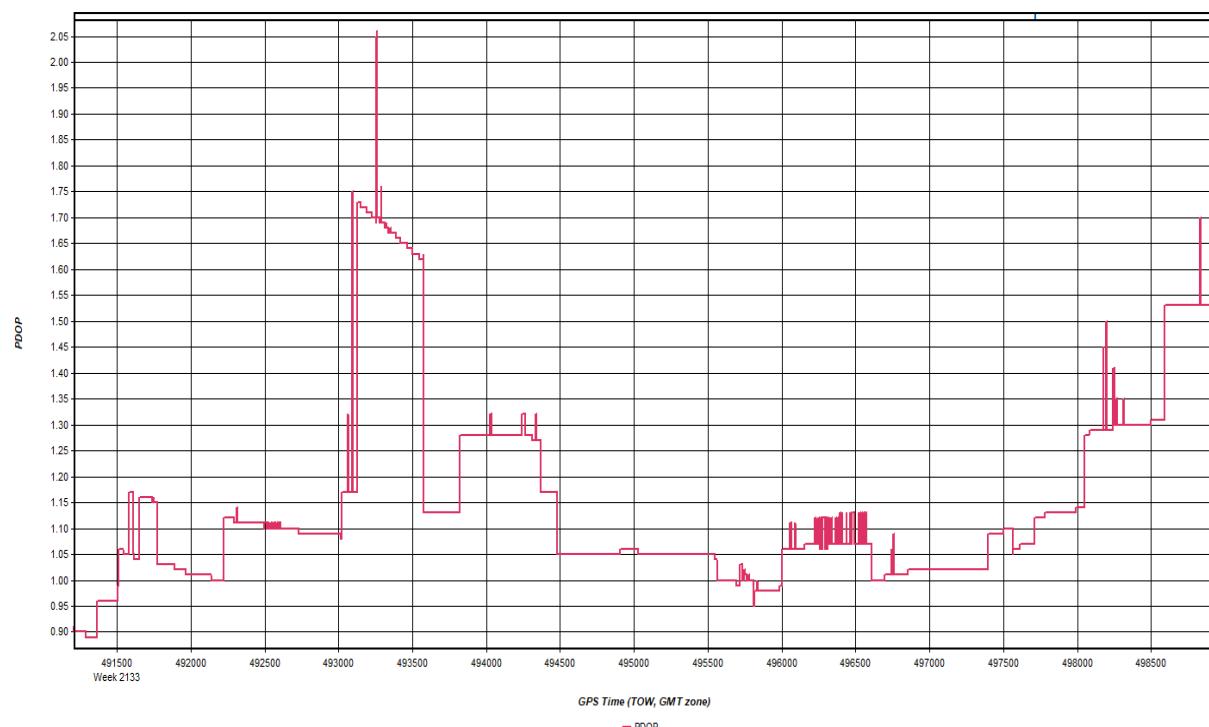
### Number of Satellites Plot



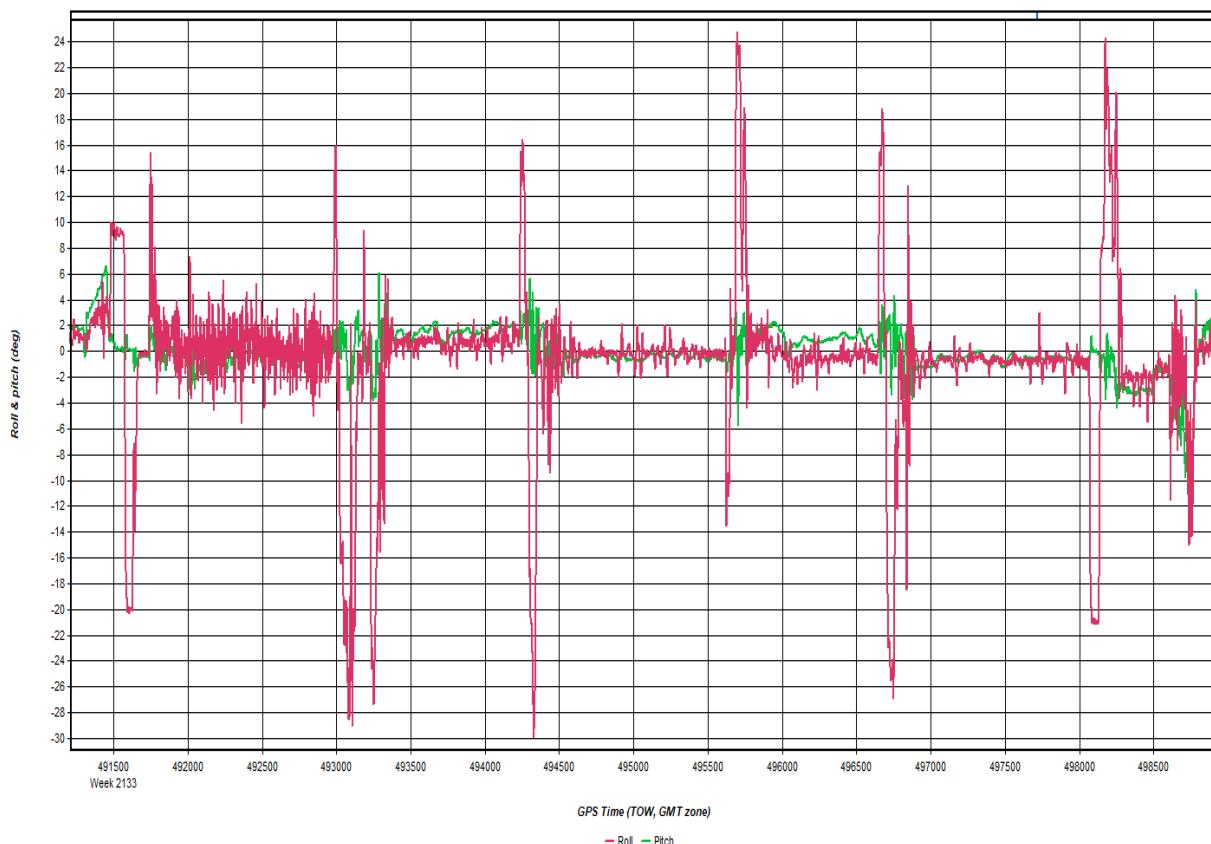
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

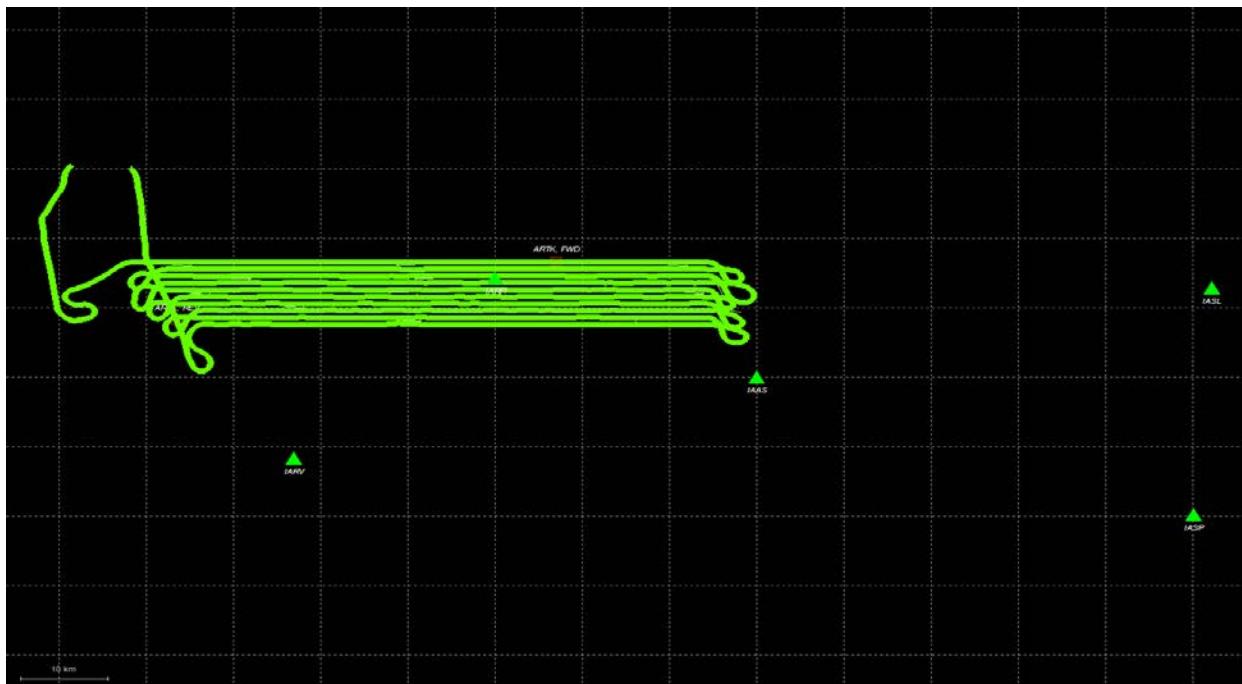


### Roll & Pitch Plot



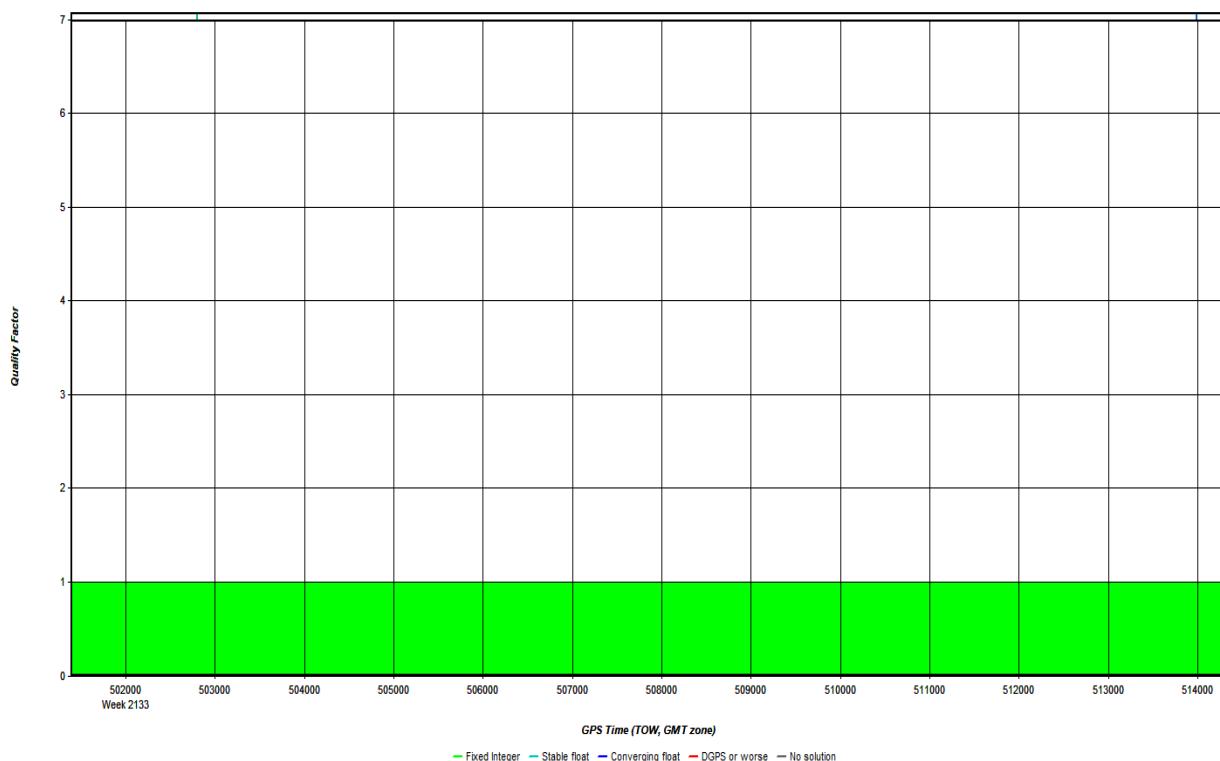
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Smoothed Trajectory Information

Top View

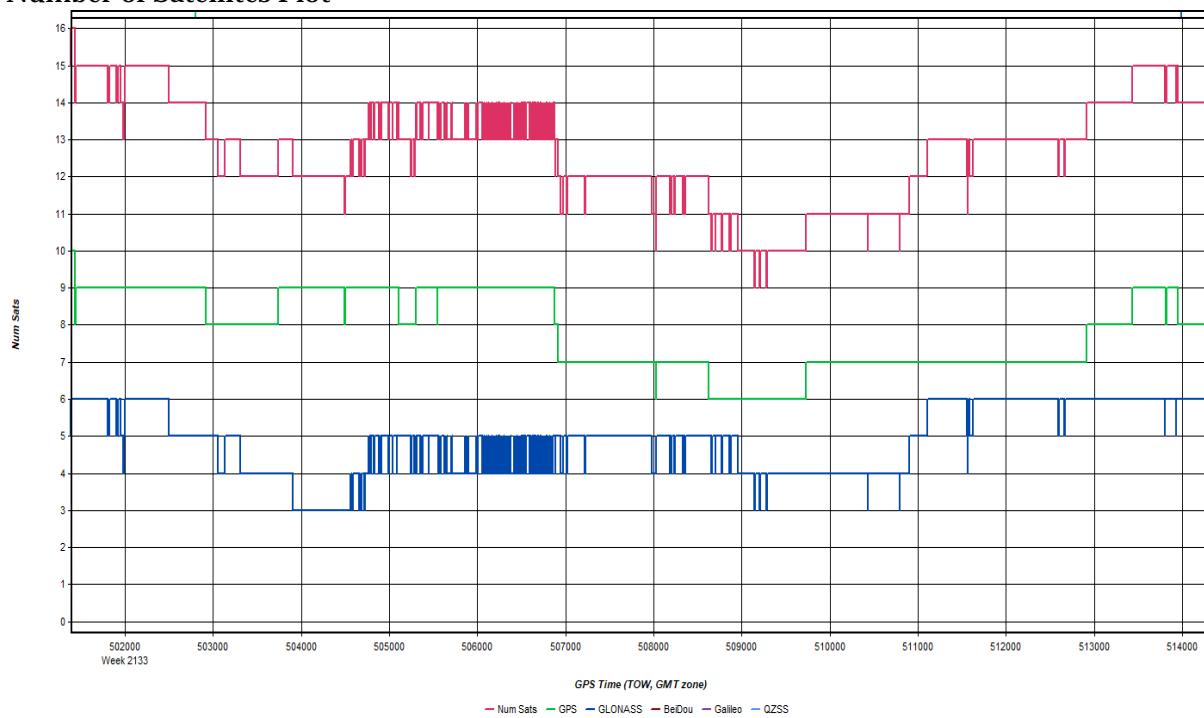


**GNSS QC**

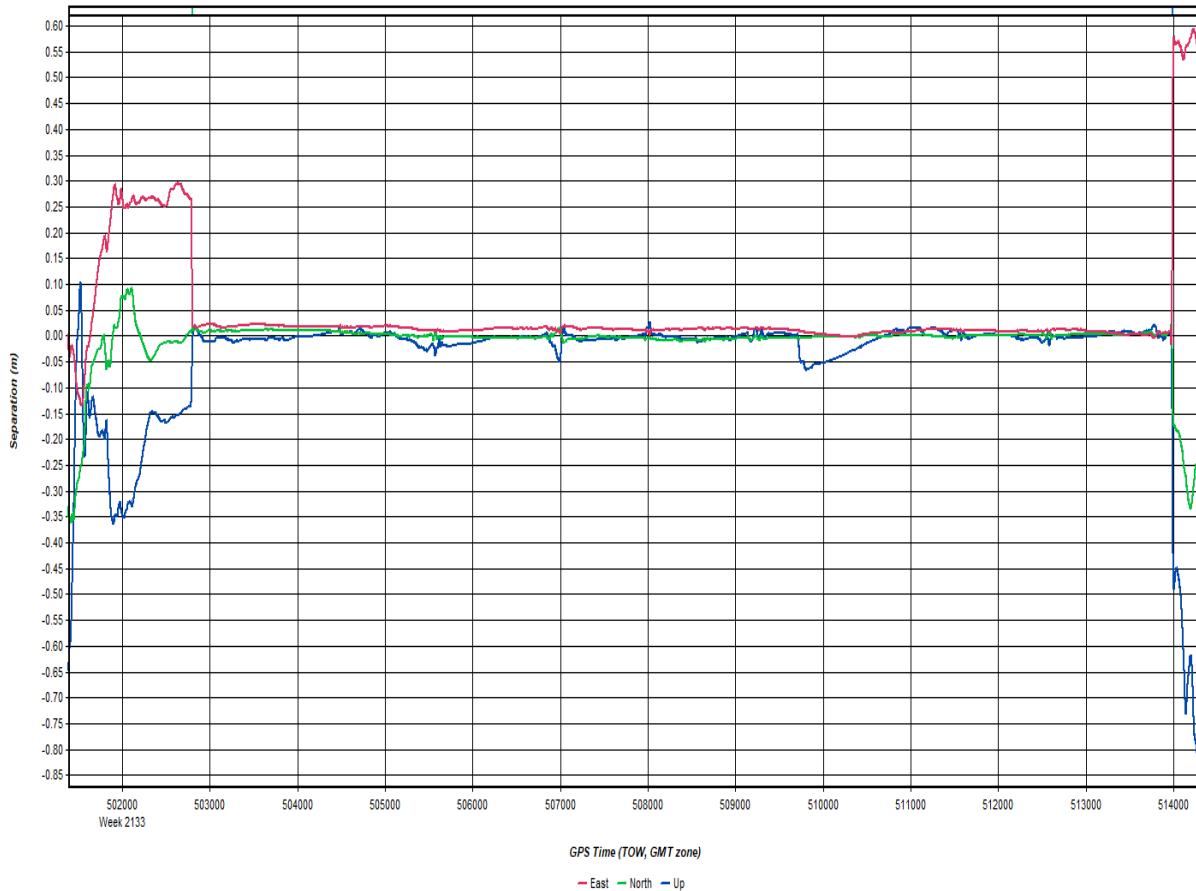
**Quality Factor Plot**



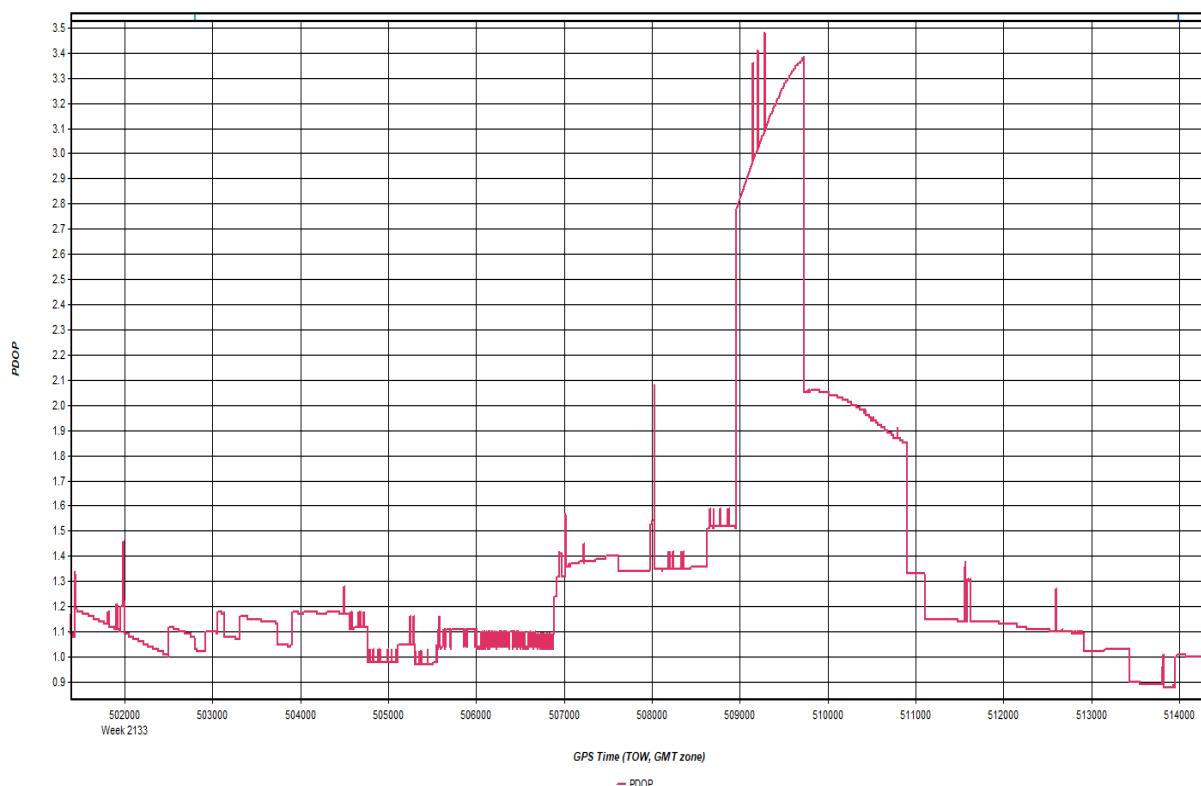
### Number of Satellites Plot



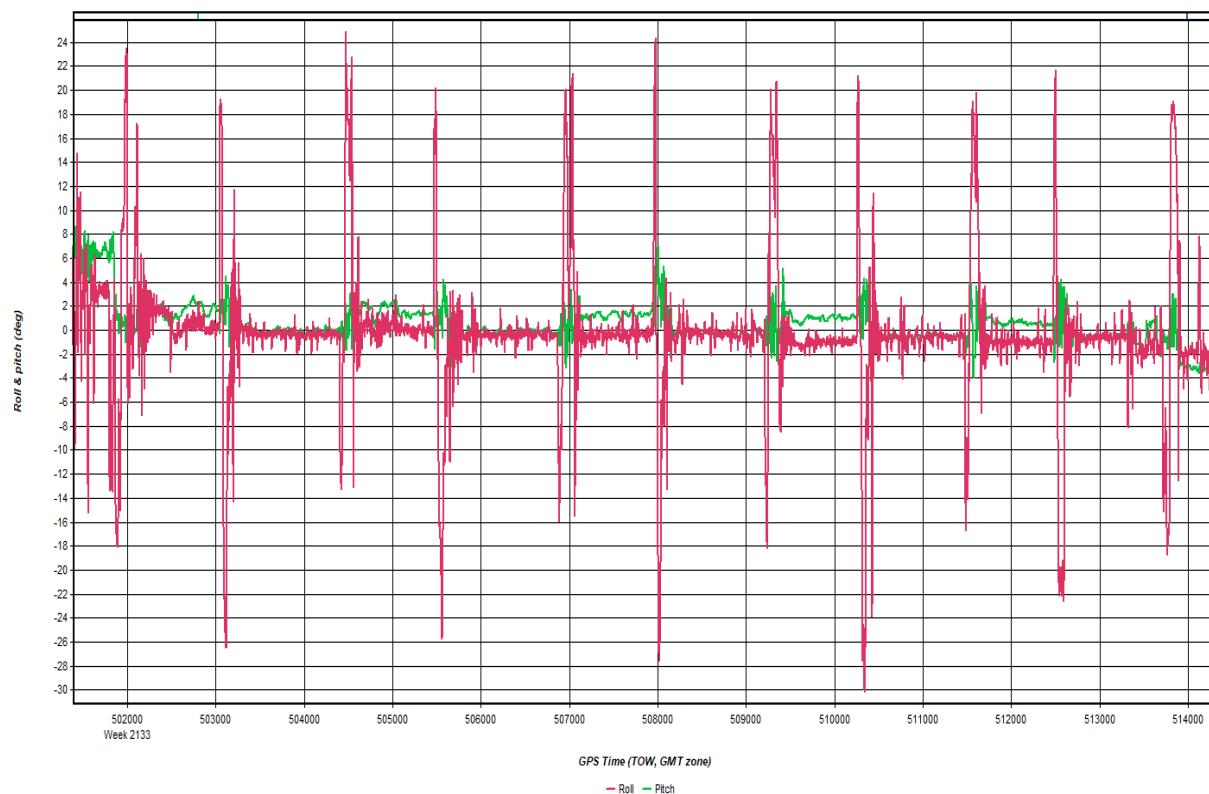
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

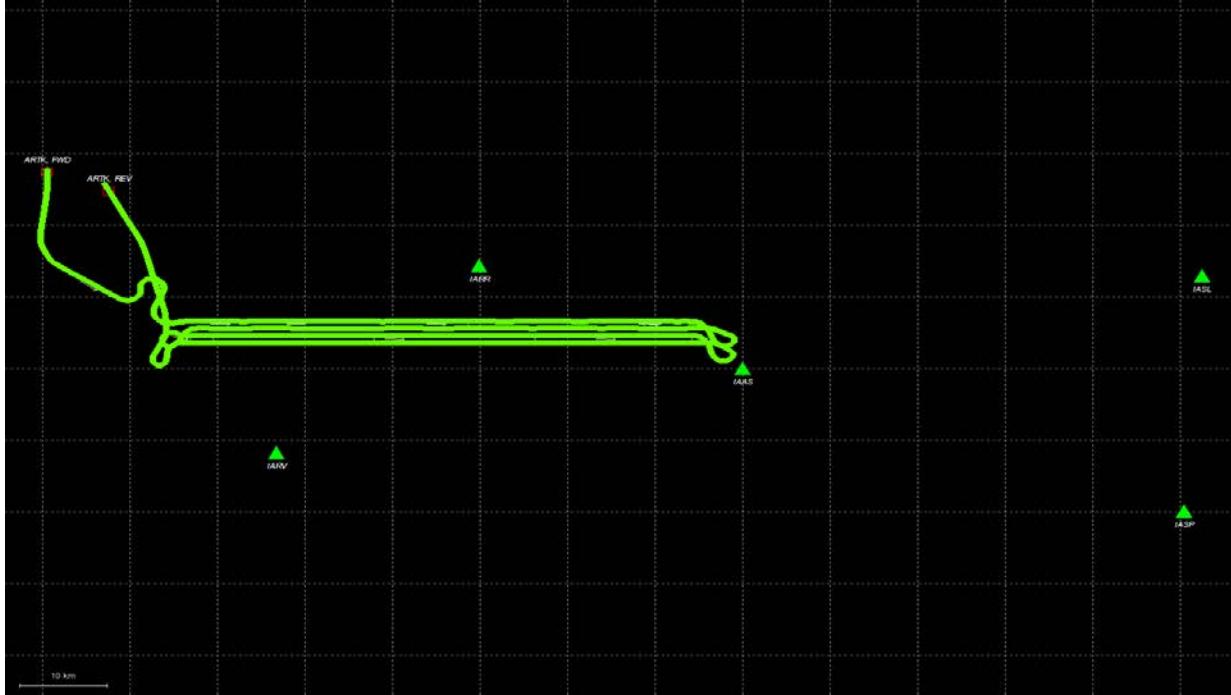


### Roll & Pitch Plot



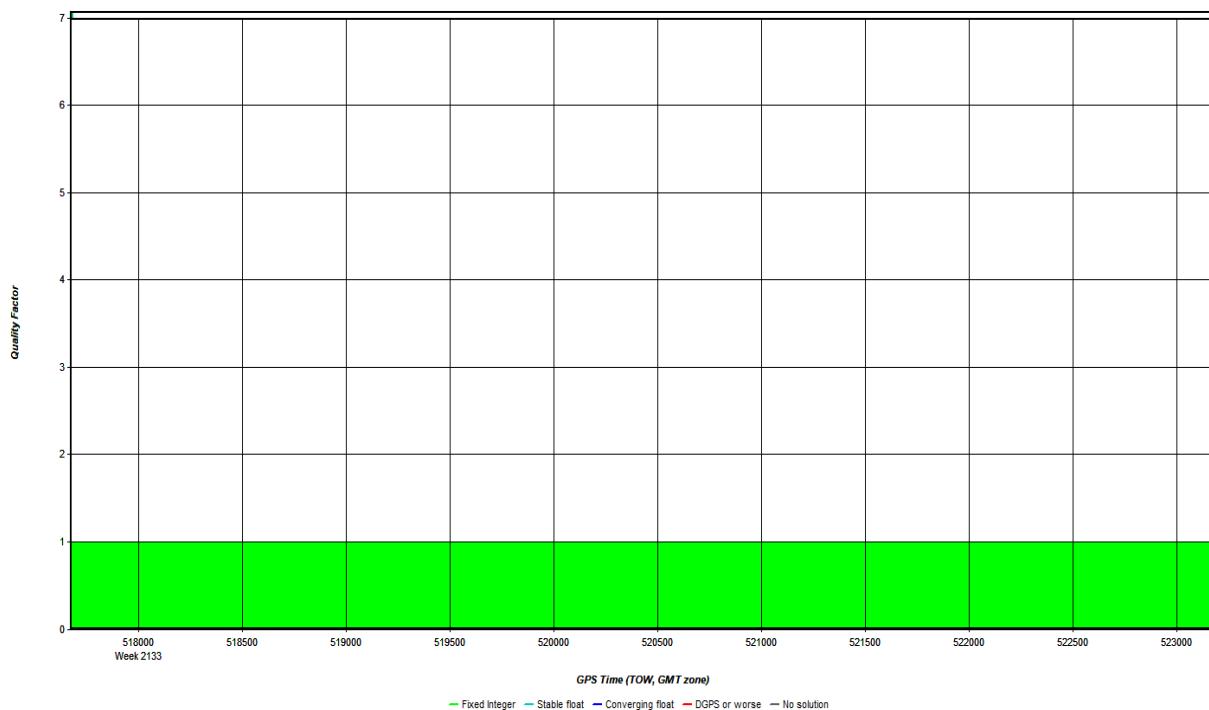
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Smoothed Trajectory Information

Top View

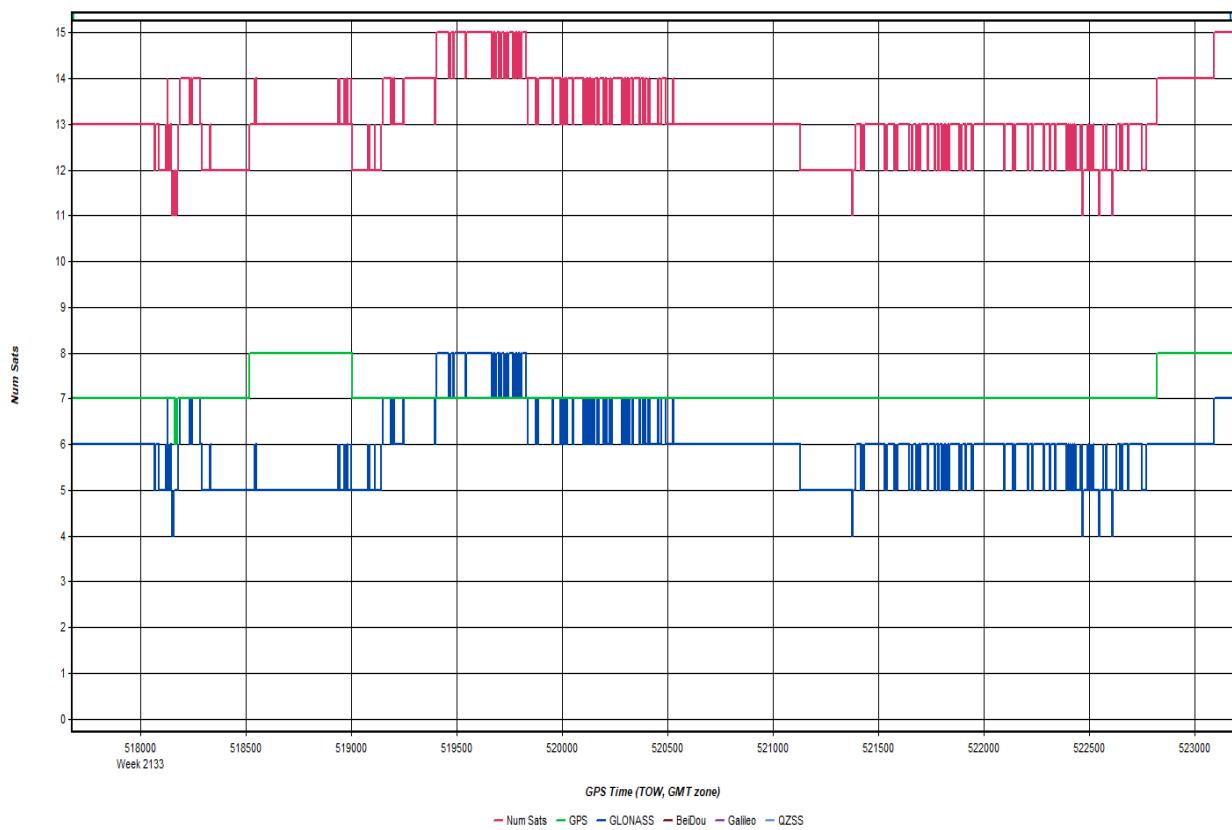


GNSS QC

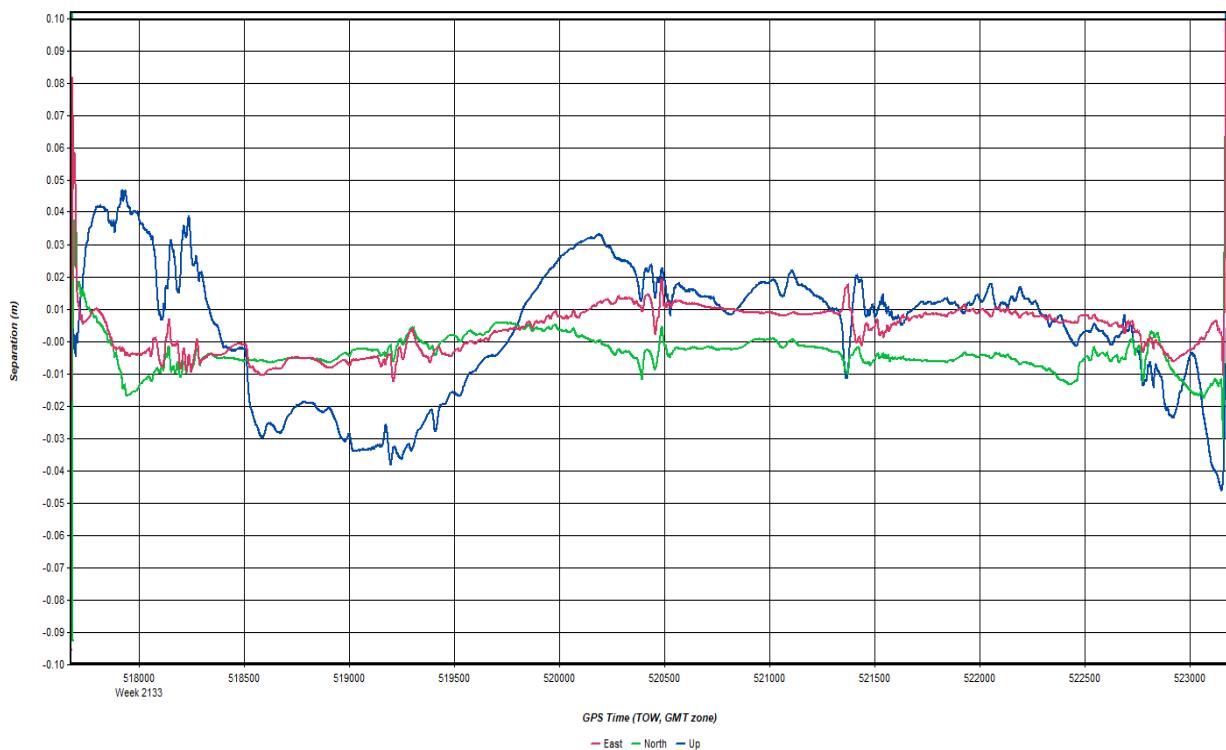
Quality Factor Plot



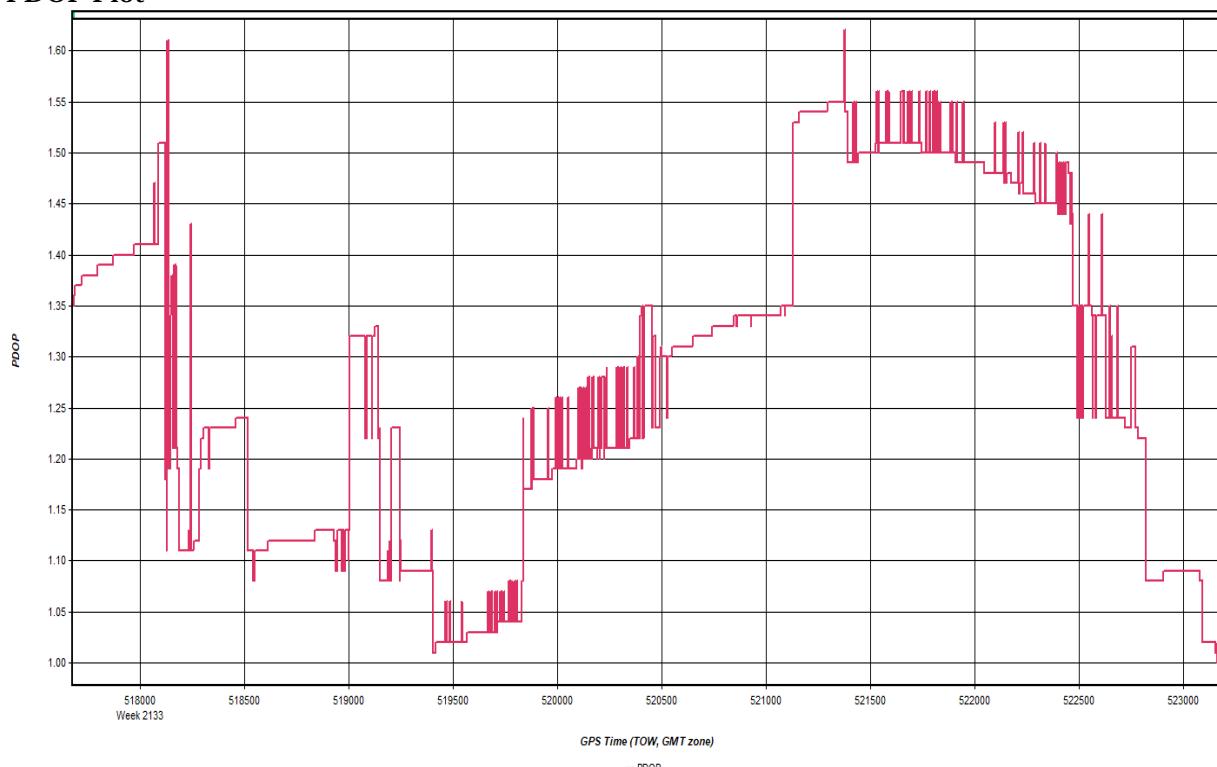
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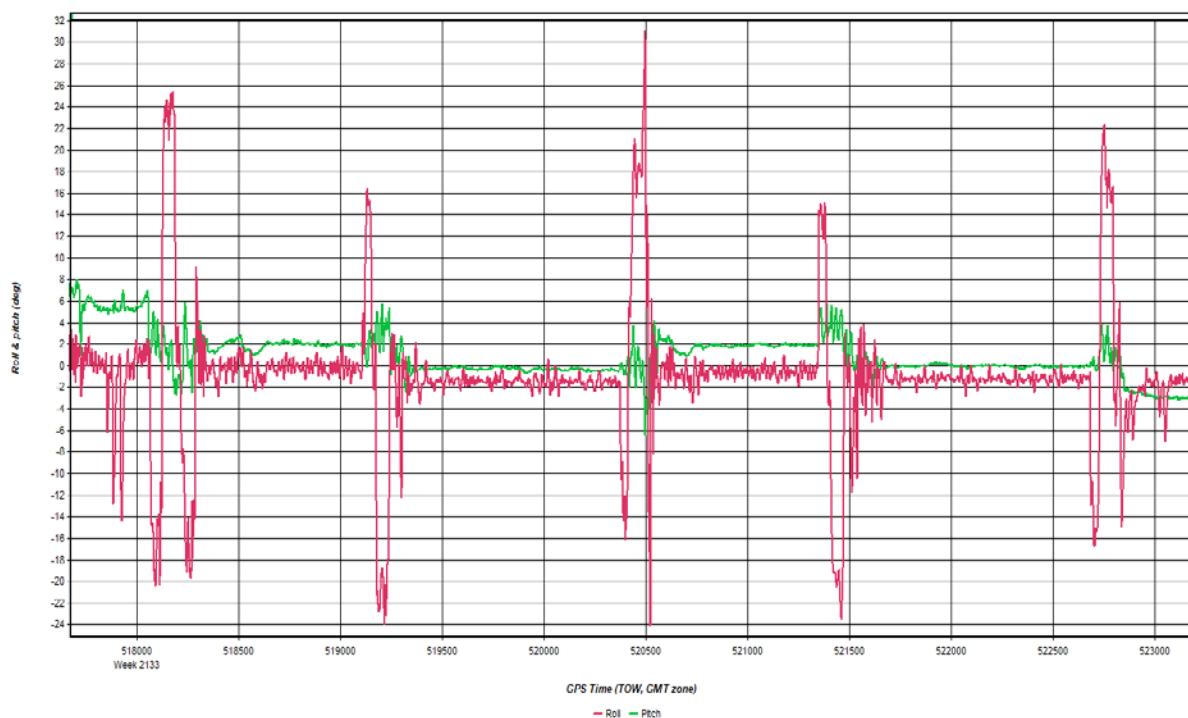
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

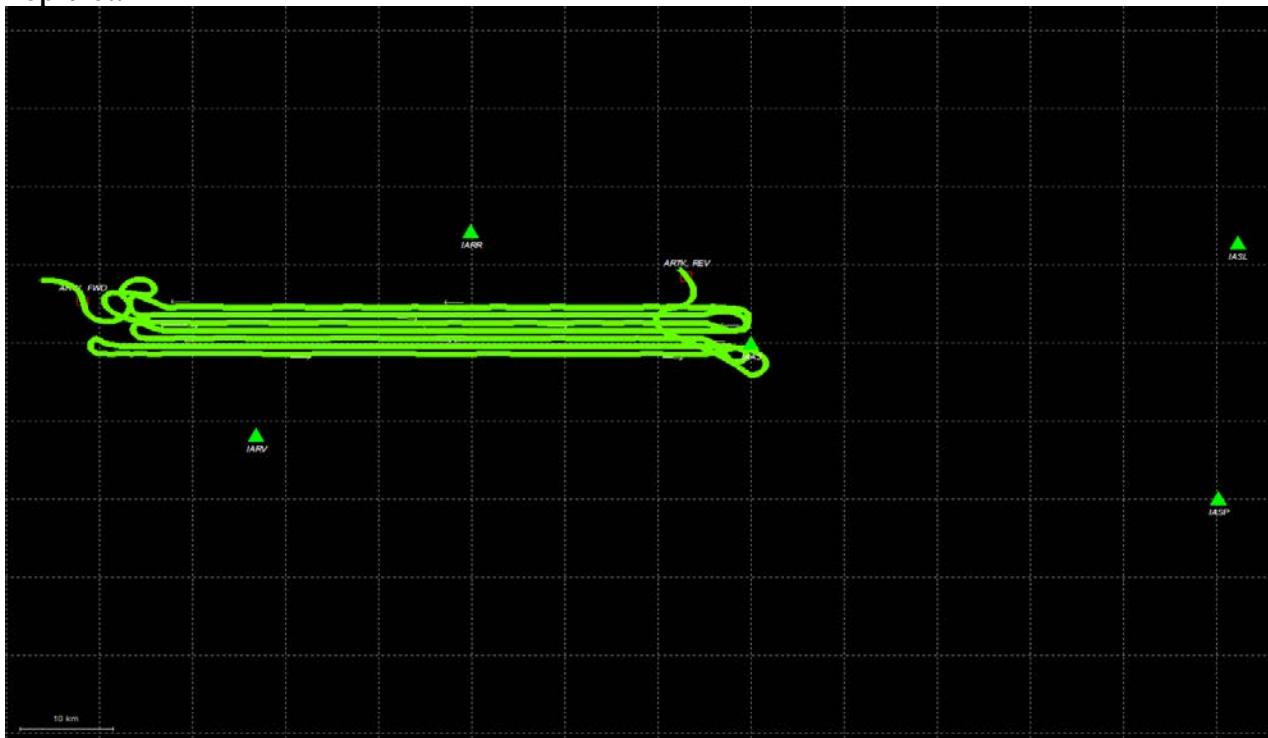


### Roll & Pitch Plot



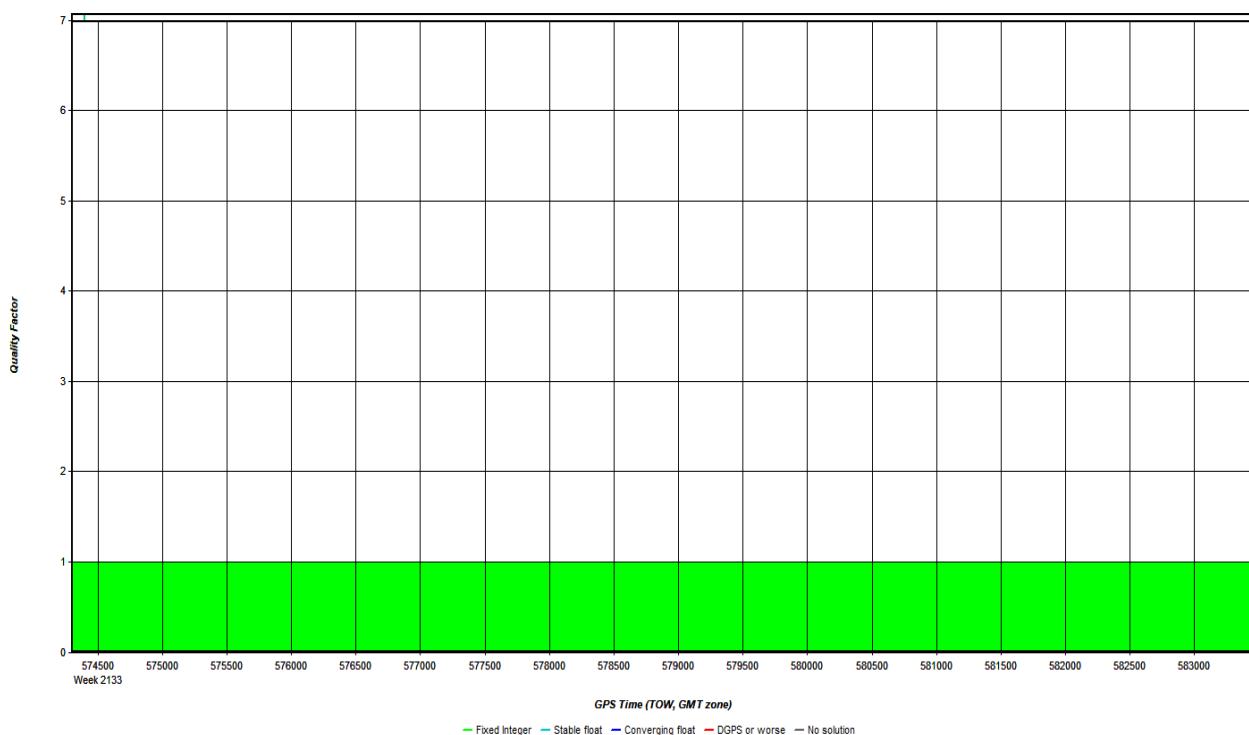
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Smoothed Trajectory Information

Top View

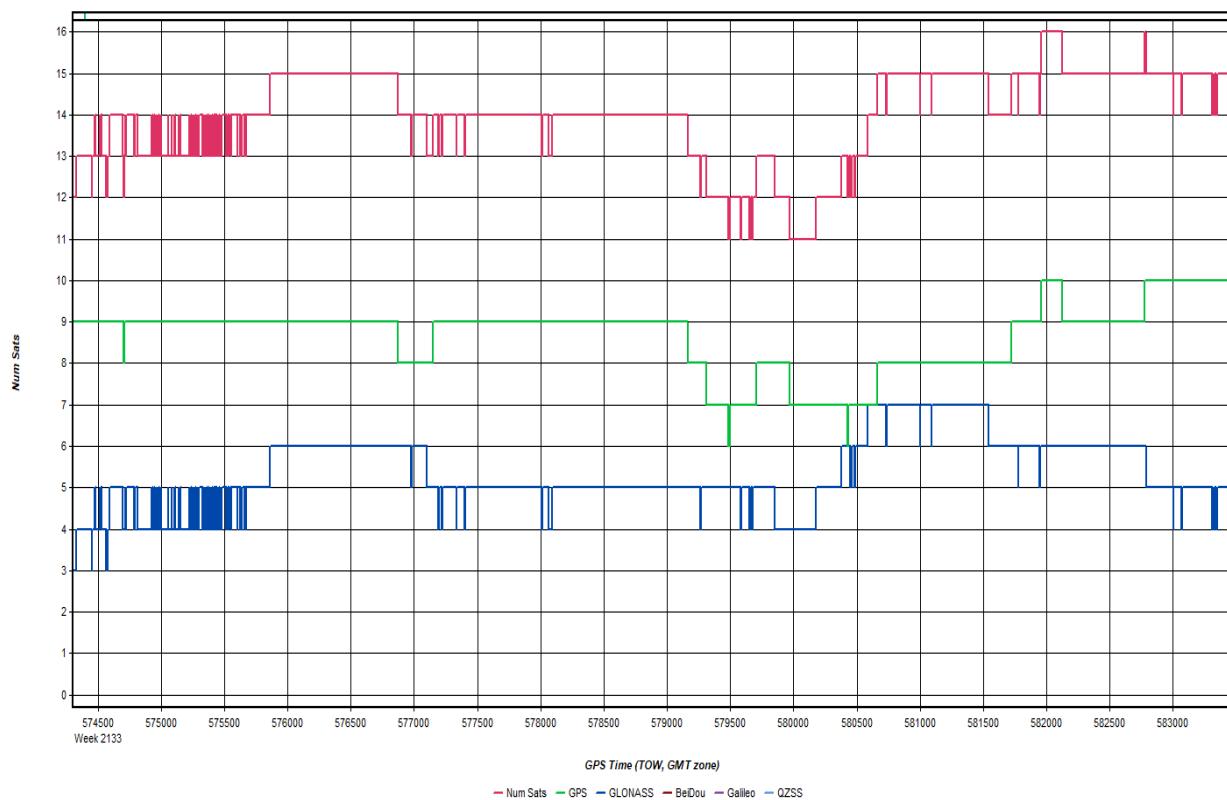


**GNSS QC**

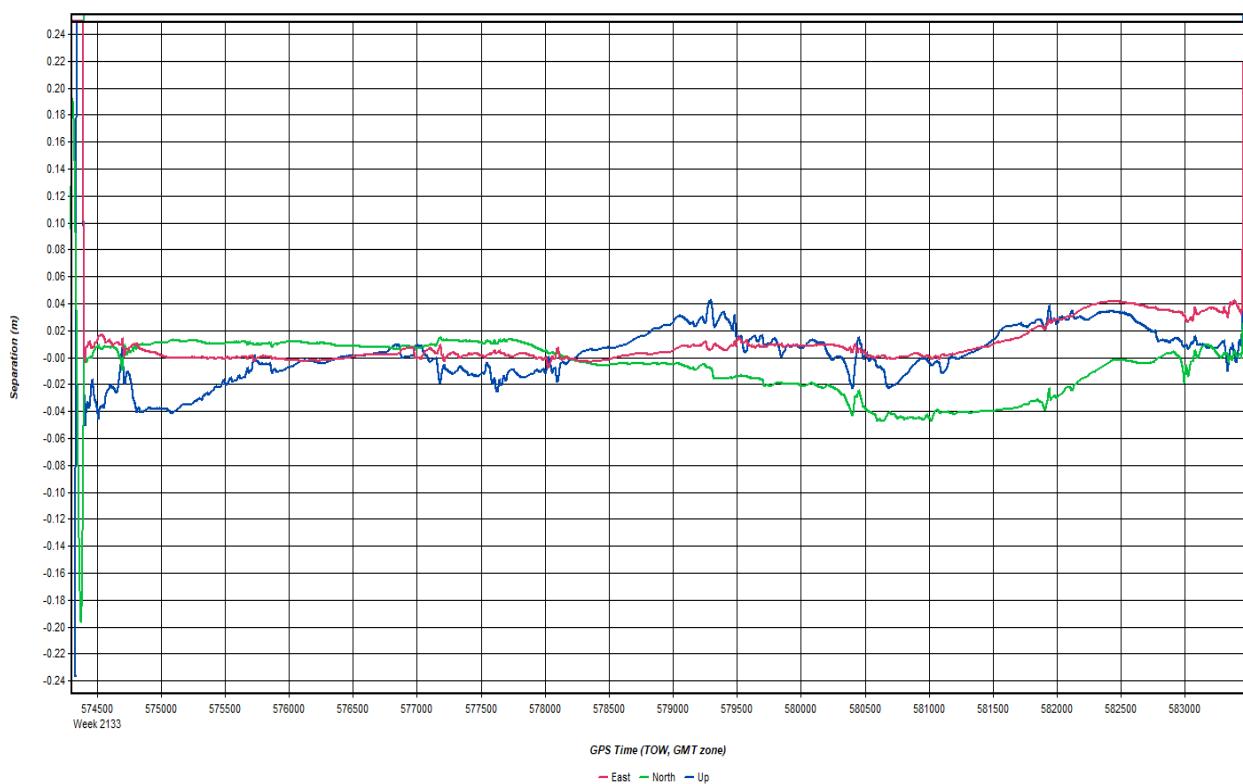
**Quality Factor Plot**



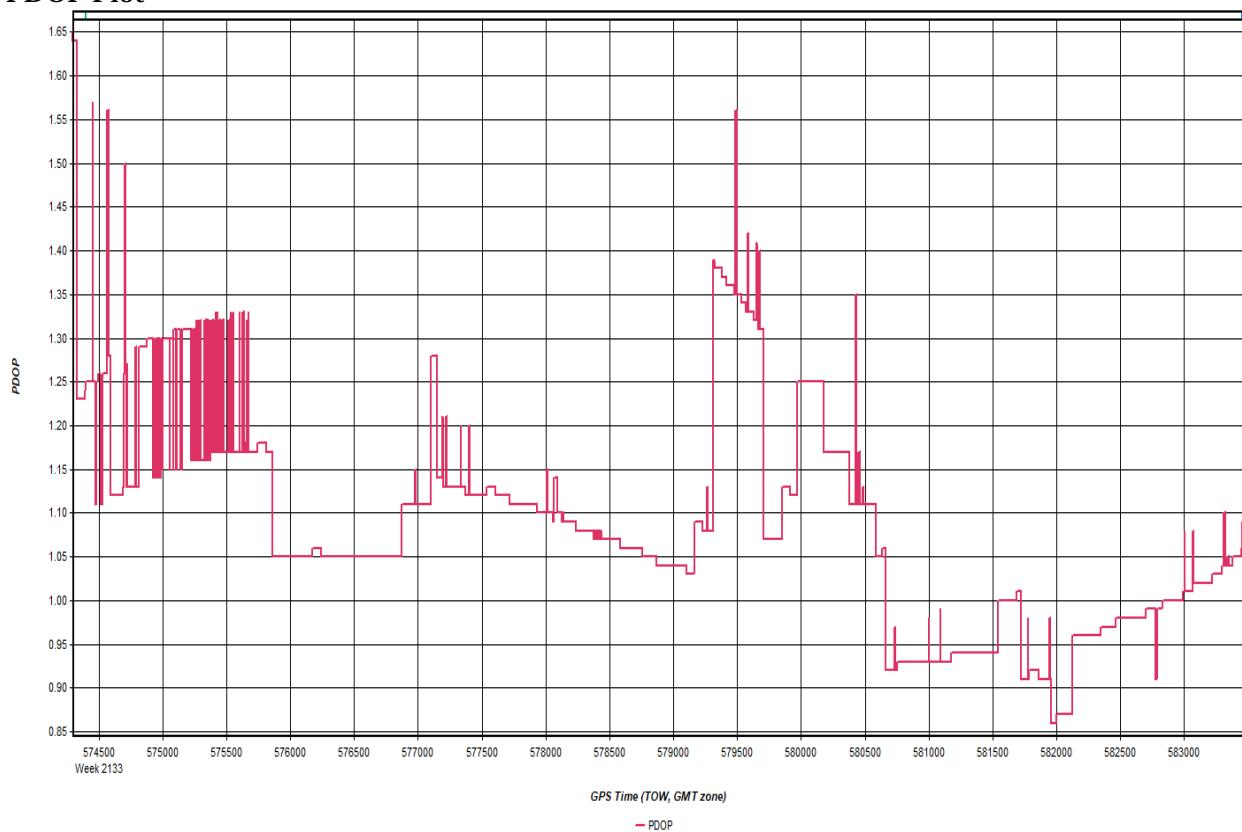
### Number of Satellites Plot



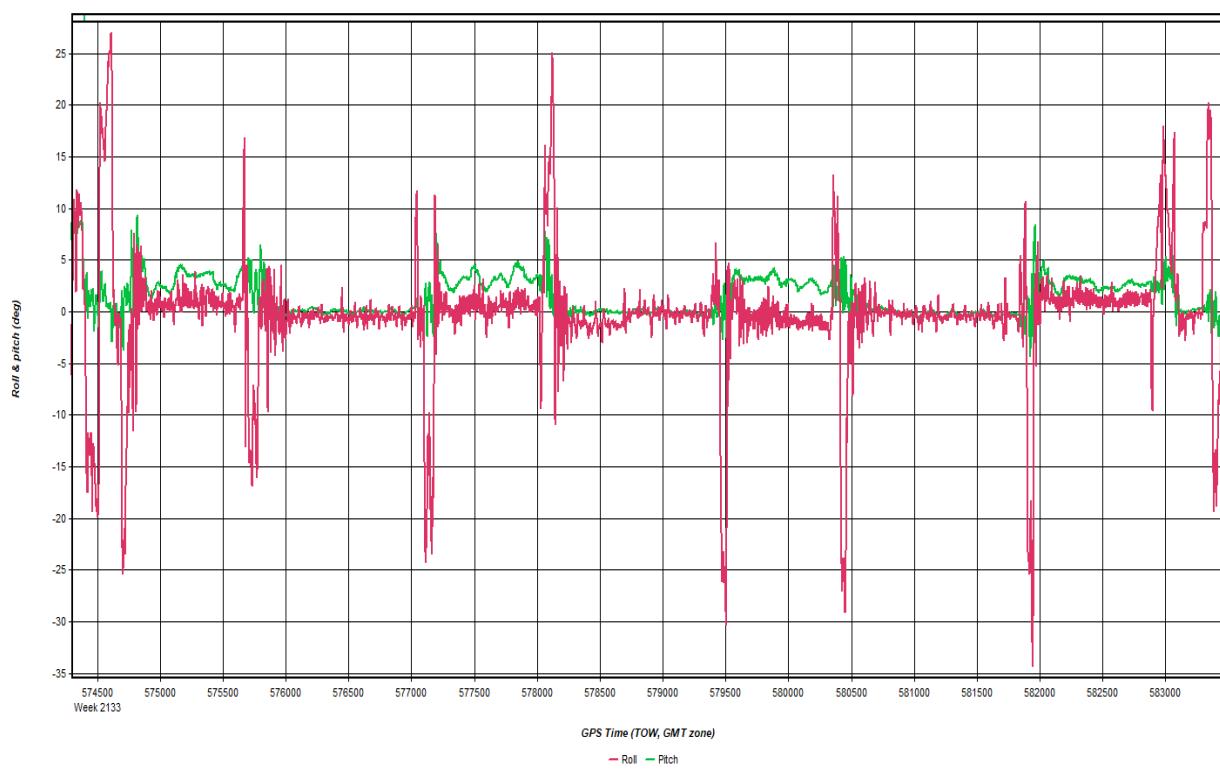
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

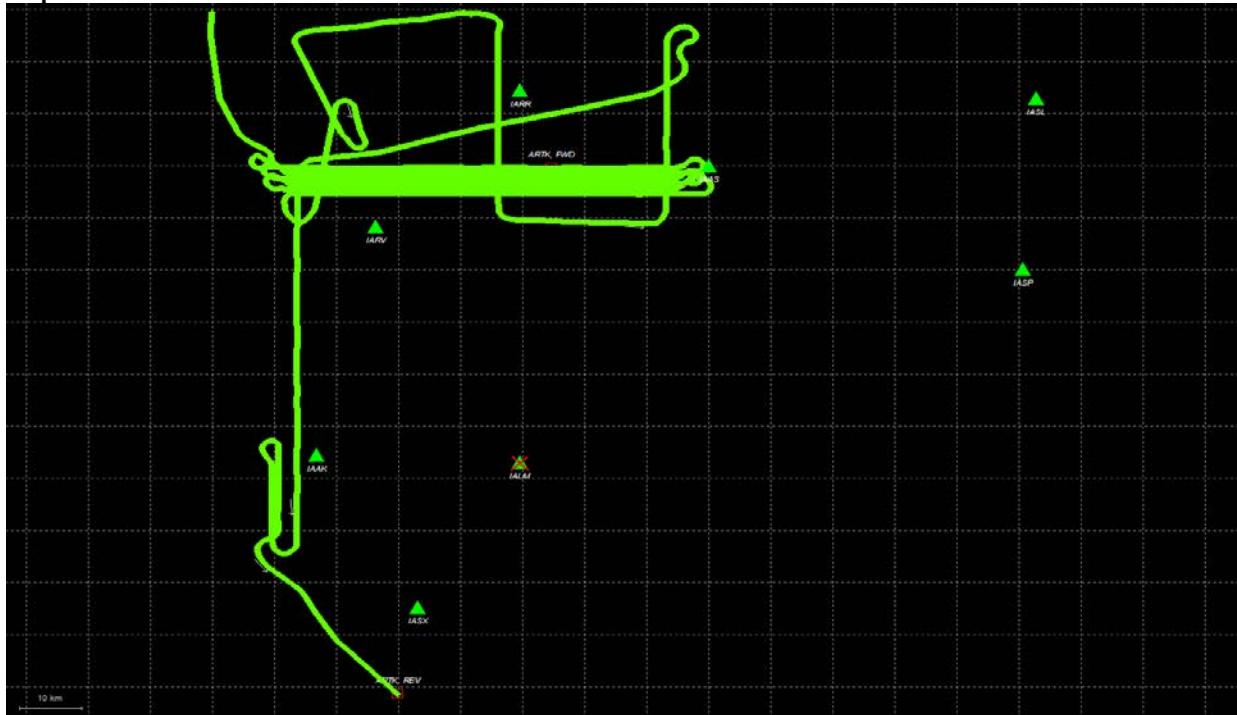


### Roll & Pitch Plot



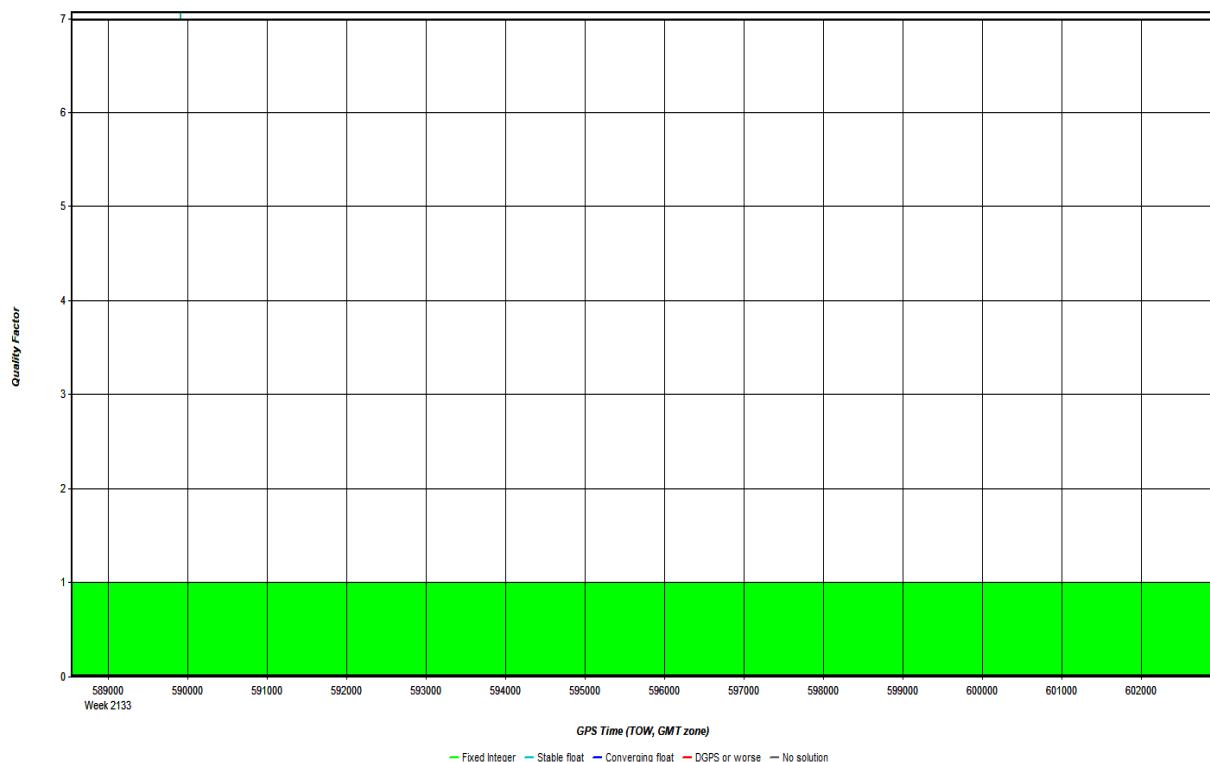
### Smoothed Trajectory Information

#### Top View

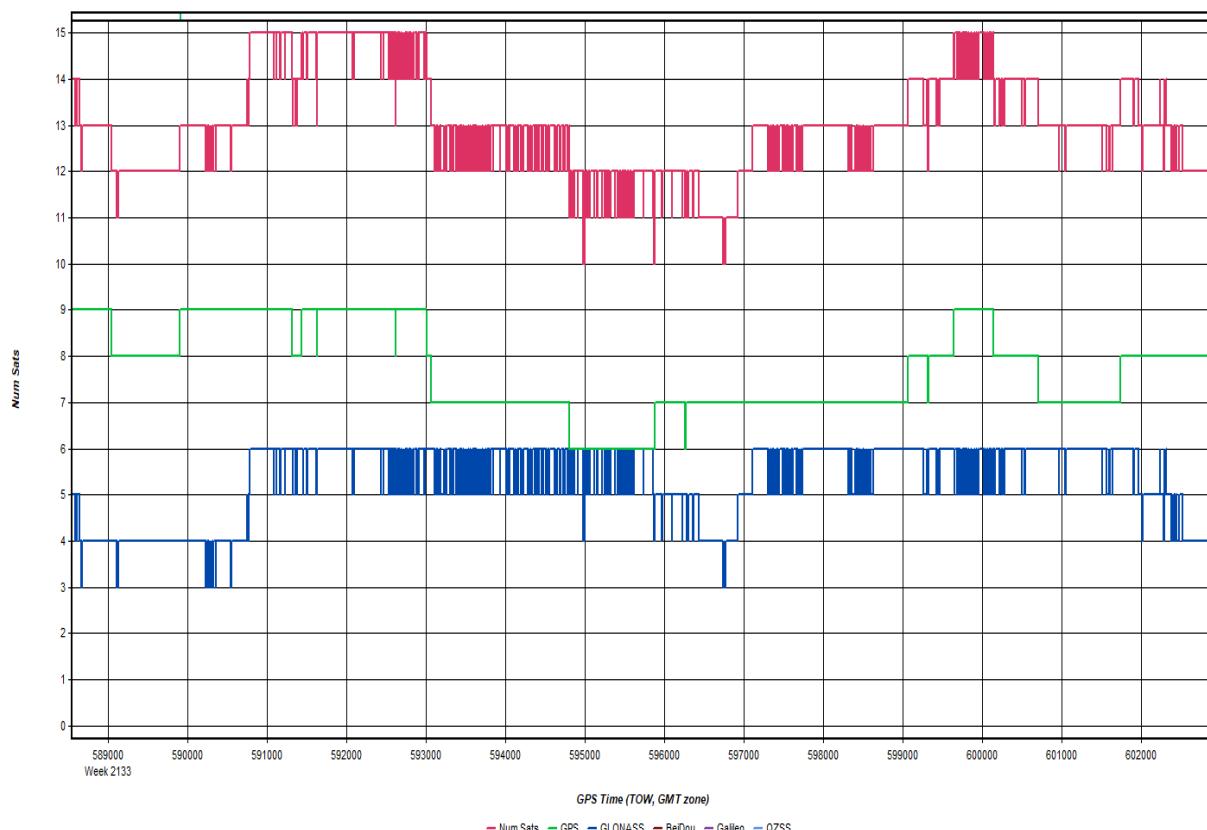


#### GNSS QC

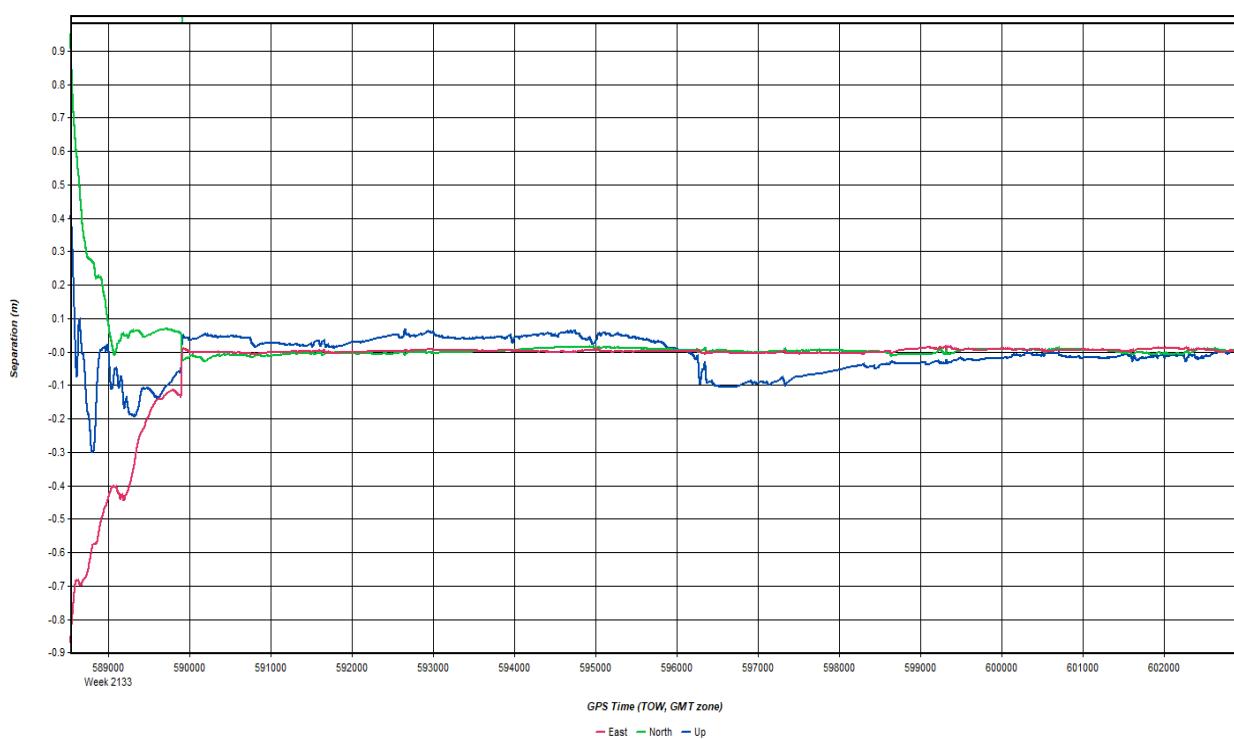
##### Quality Factor Plot



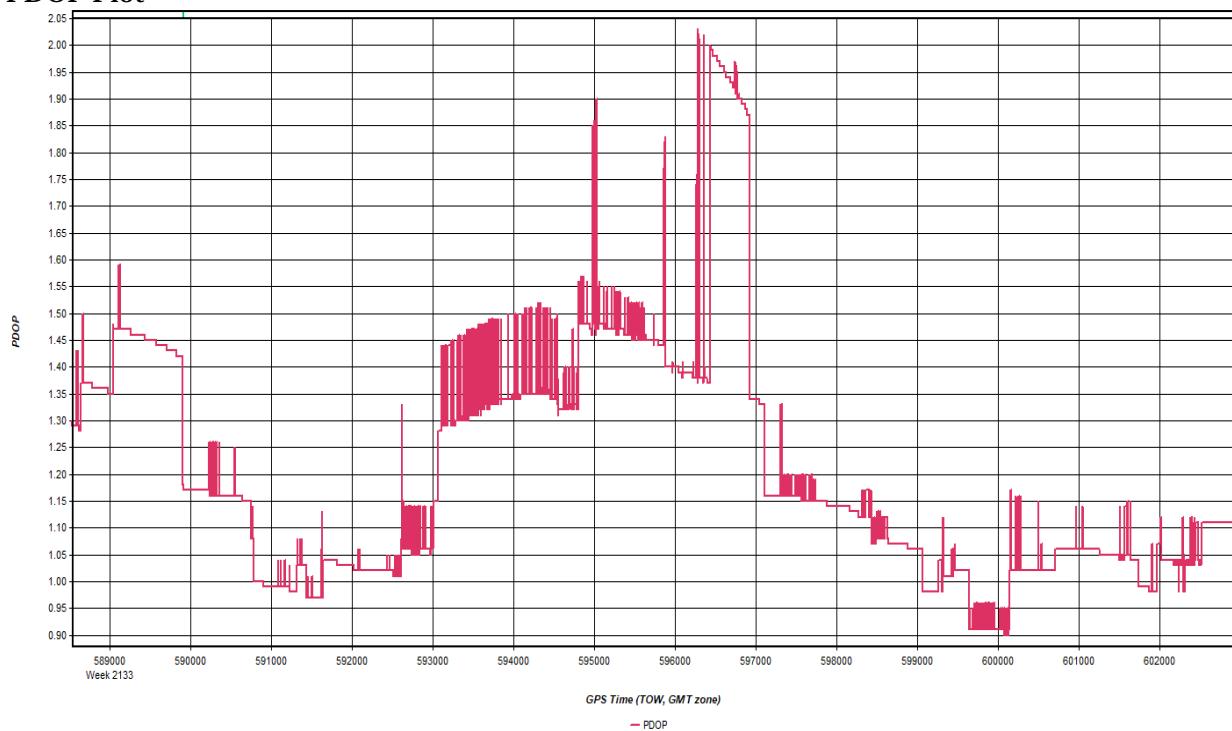
### Number of Satellites Plot



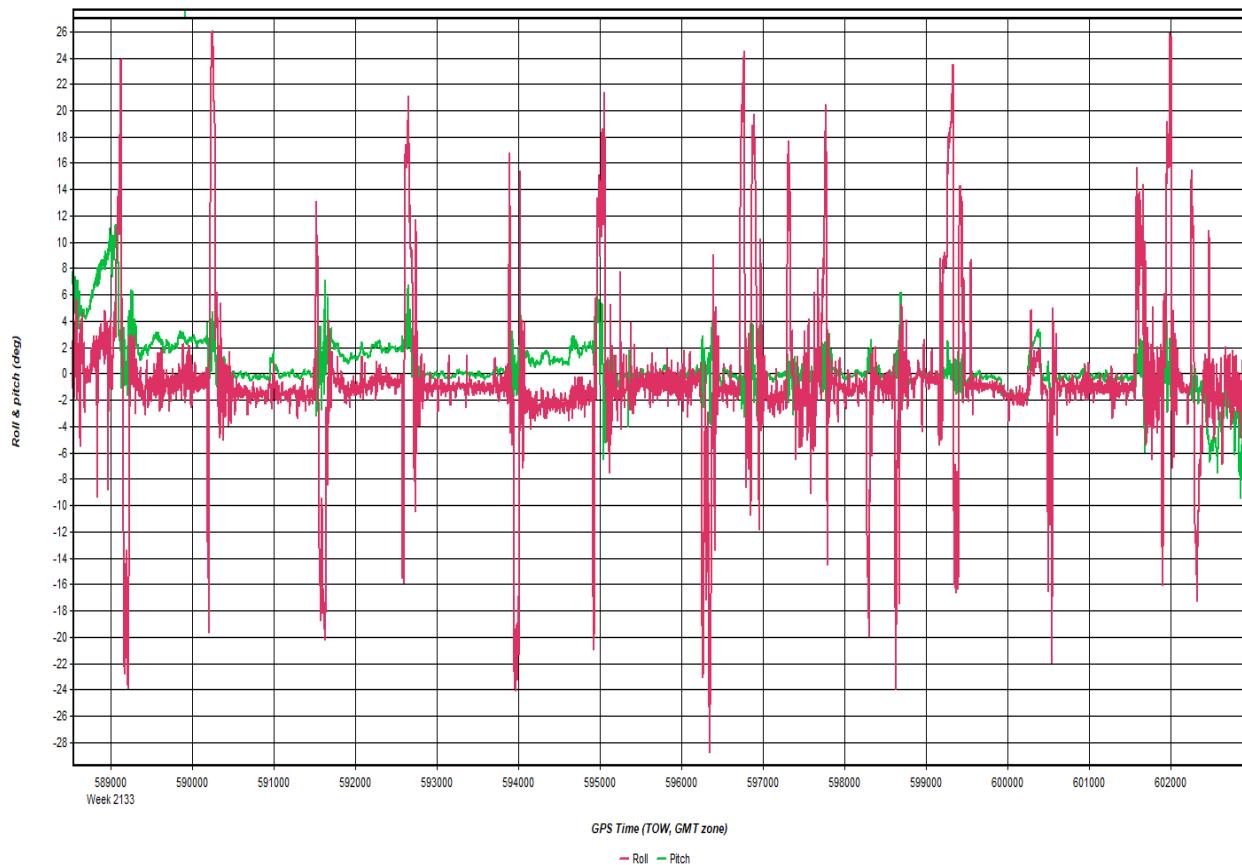
### Forward/Reverse or Combined Separation Plot



### PDOP Plot



### Roll & Pitch Plot



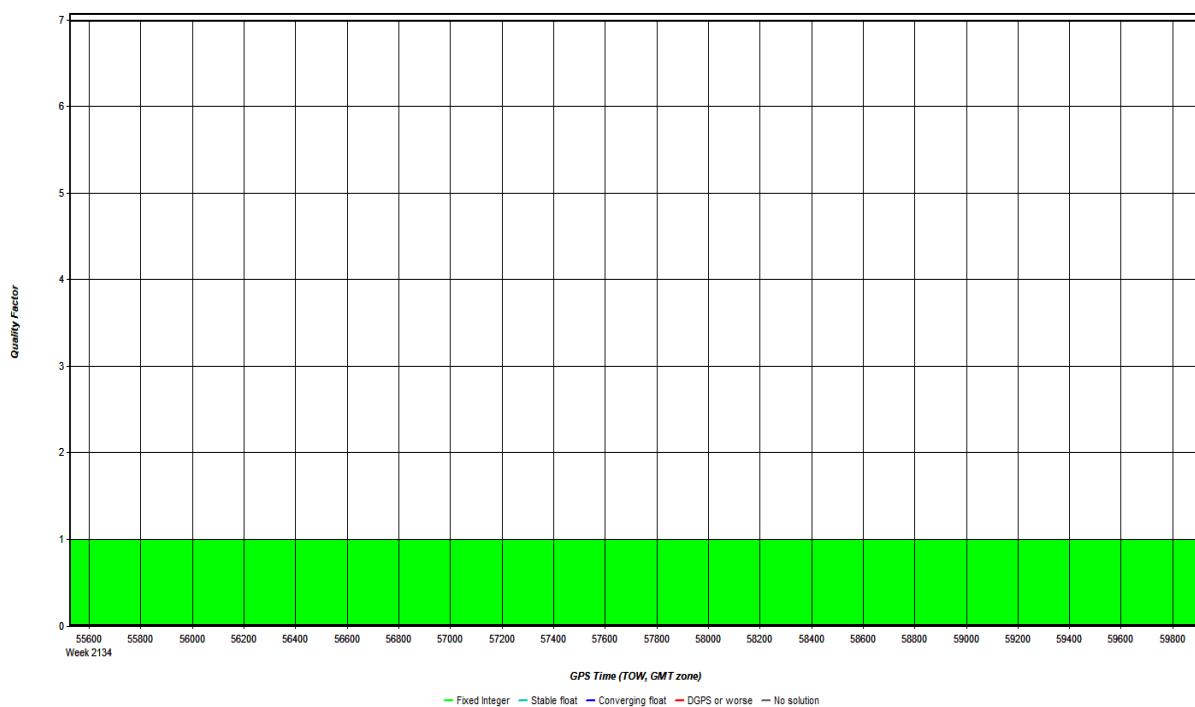
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Smoothed Trajectory Information

Top View

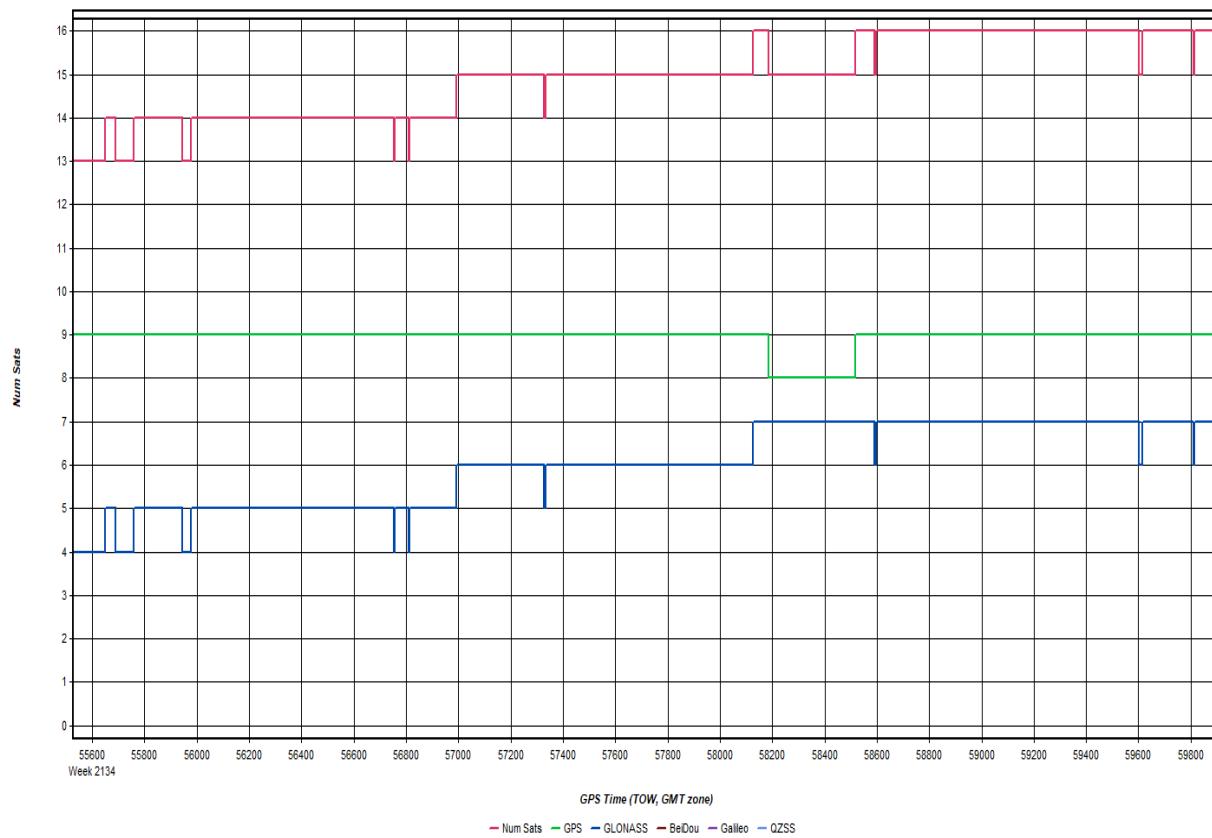


GNSS QC

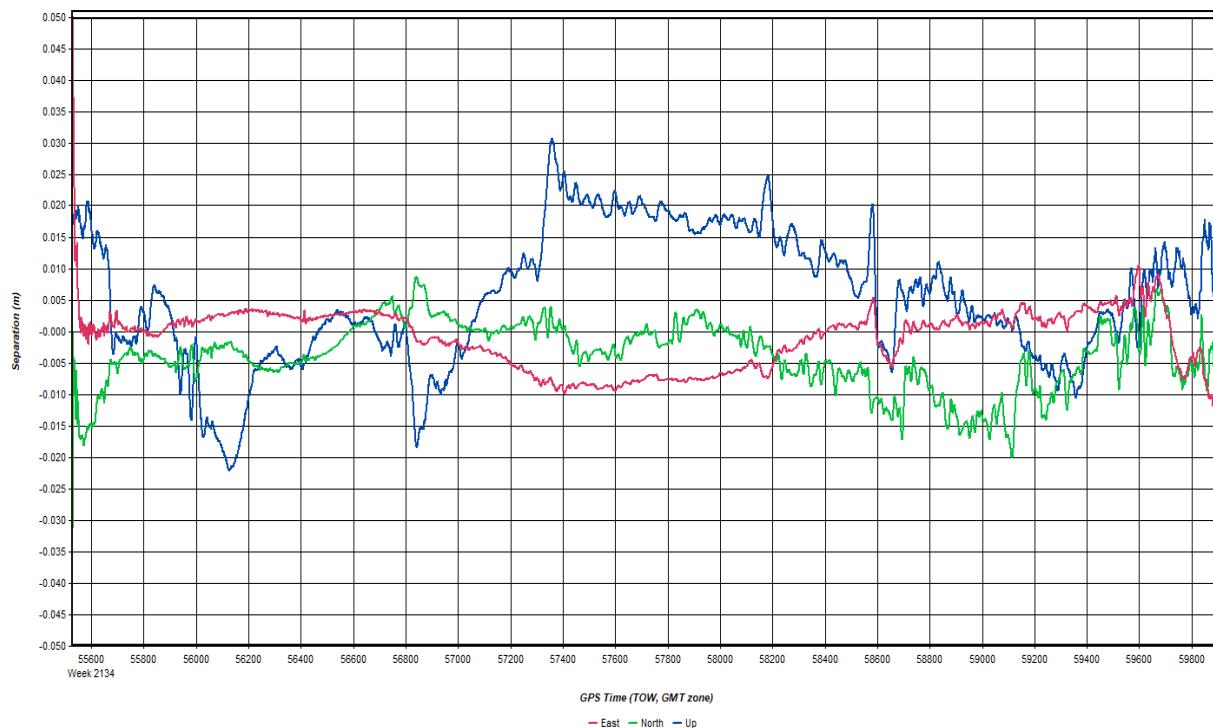
Quality Factor Plot



### Number of Satellites Plot

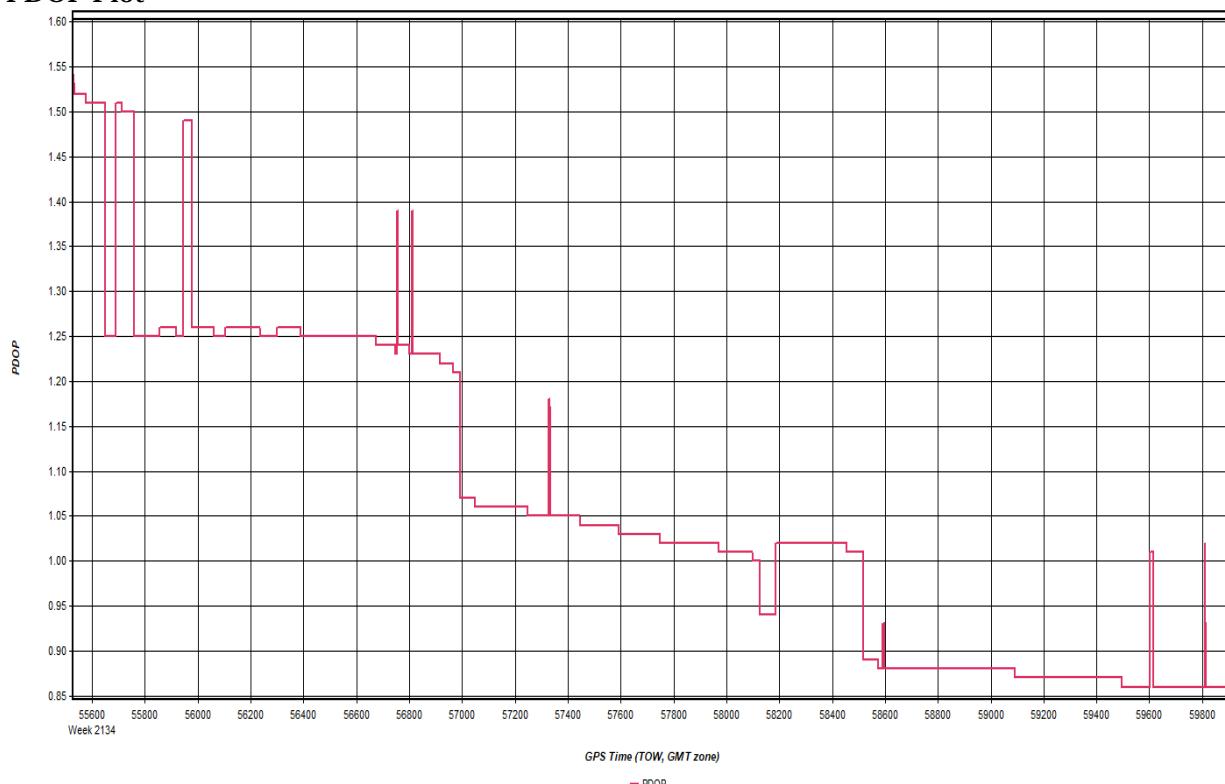


### Forward/Reverse or Combined Separation Plot

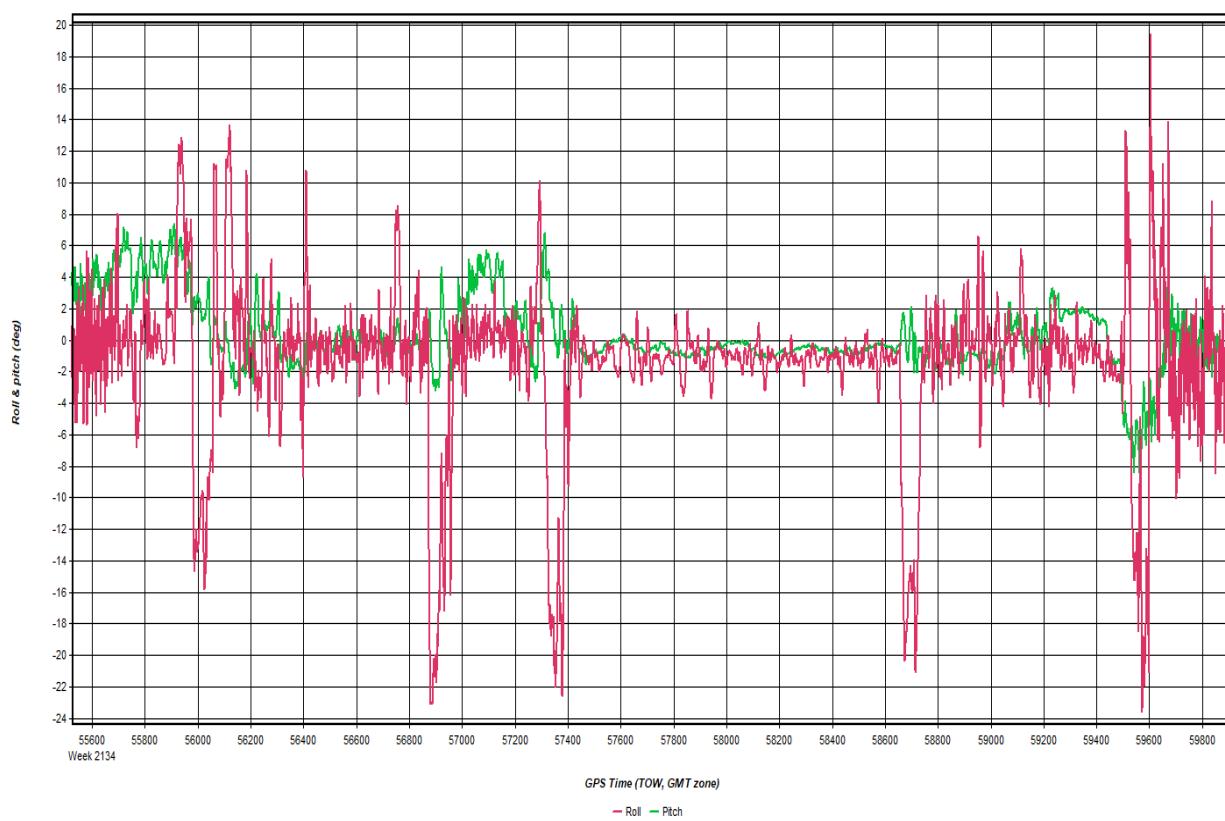


IA West 2020  
11/24/2021

### PDOP Plot

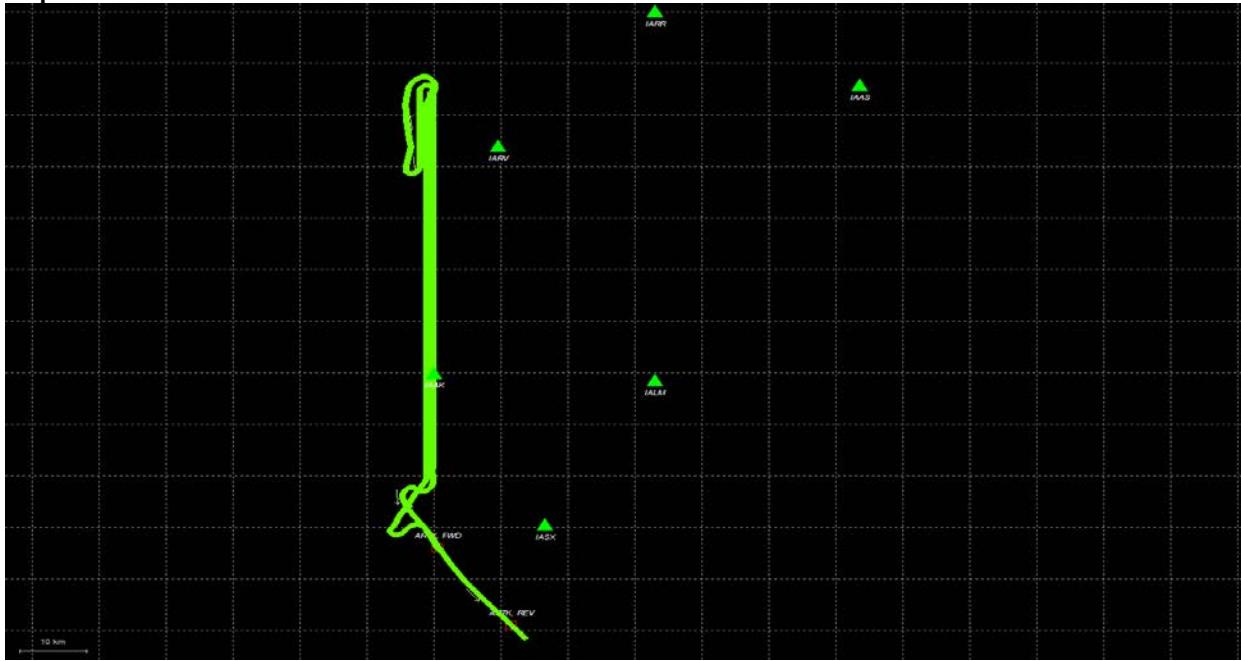


### Roll & Pitch Plot



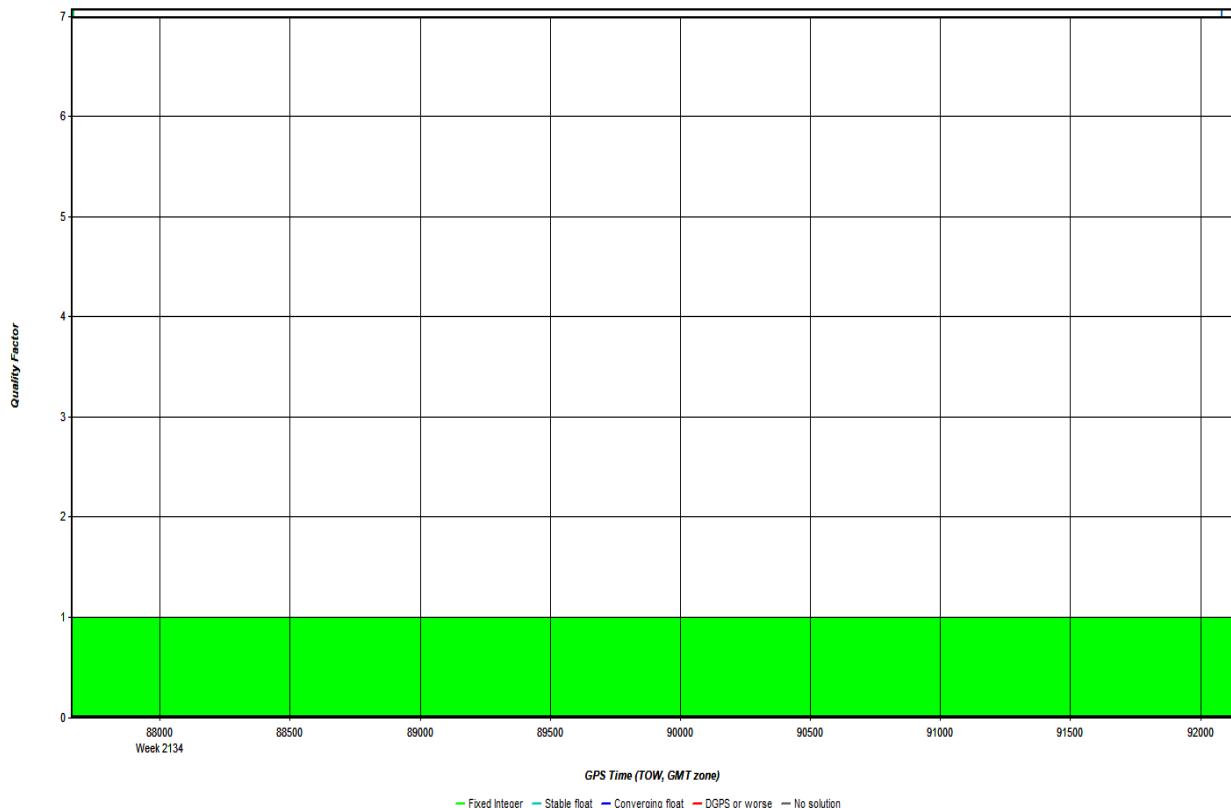
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Smoothed Trajectory Information

Top View

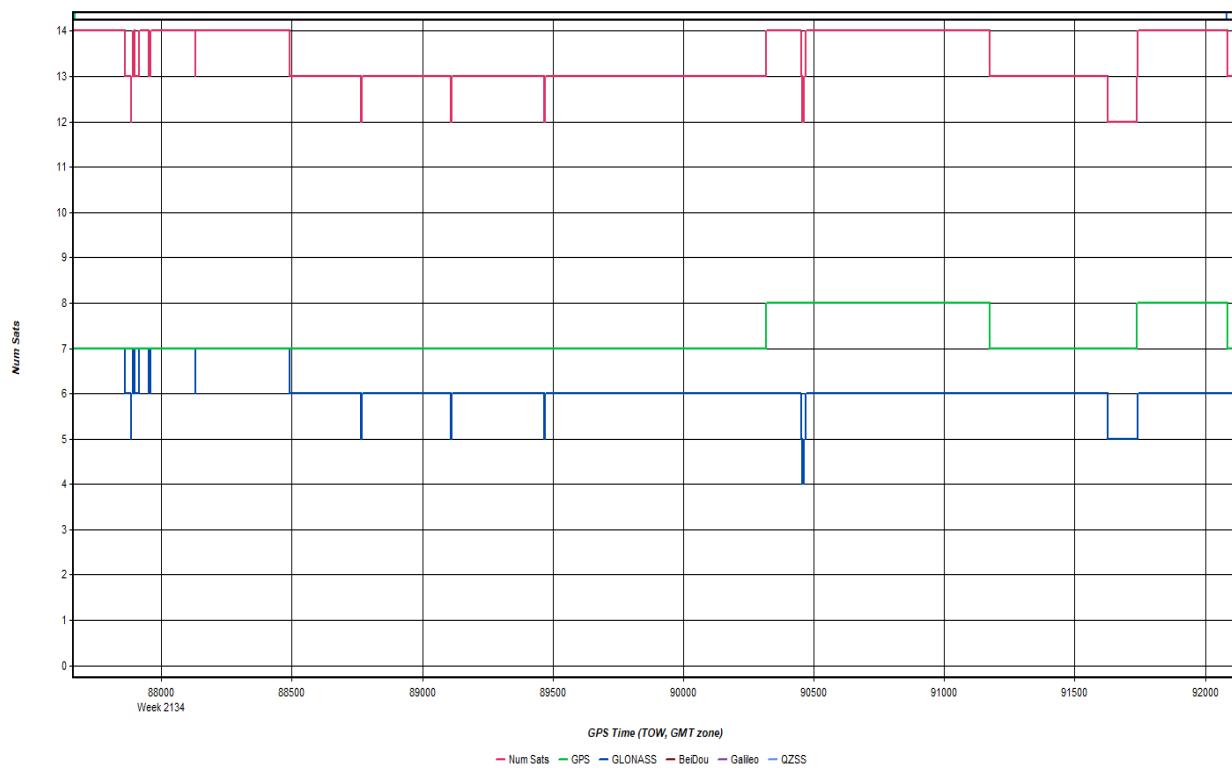


**GNSS QC**

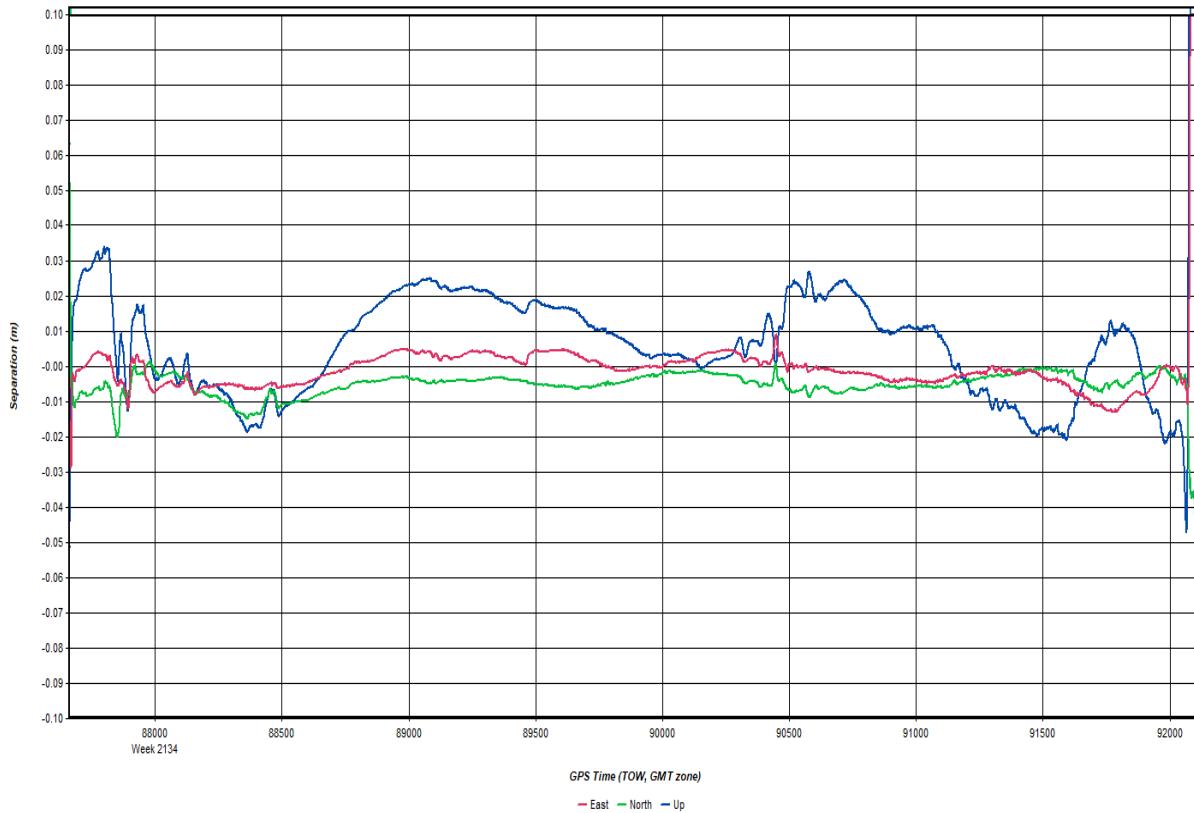
**Quality Factor Plot**



### Number of Satellites Plot

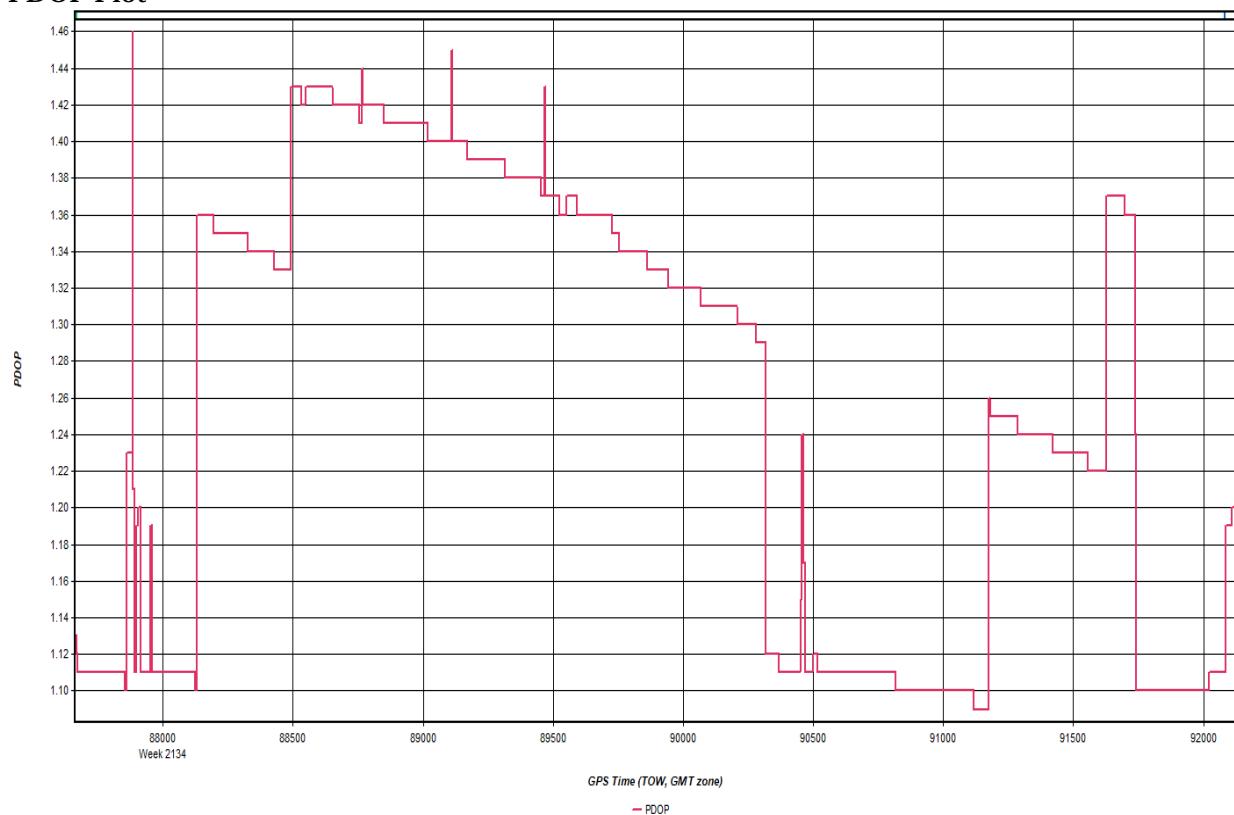


### Forward/Reverse or Combined Separation Plot

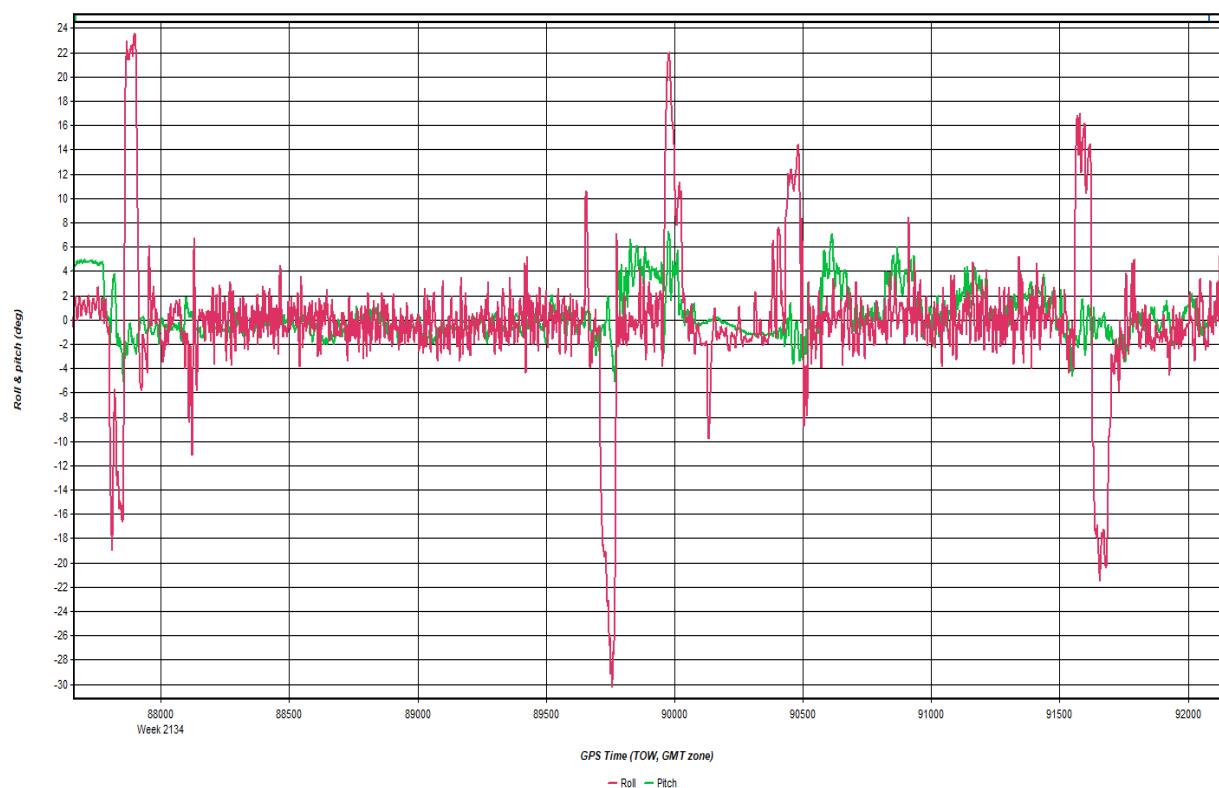


IA West 2020  
11/24/2021

### PDOP Plot

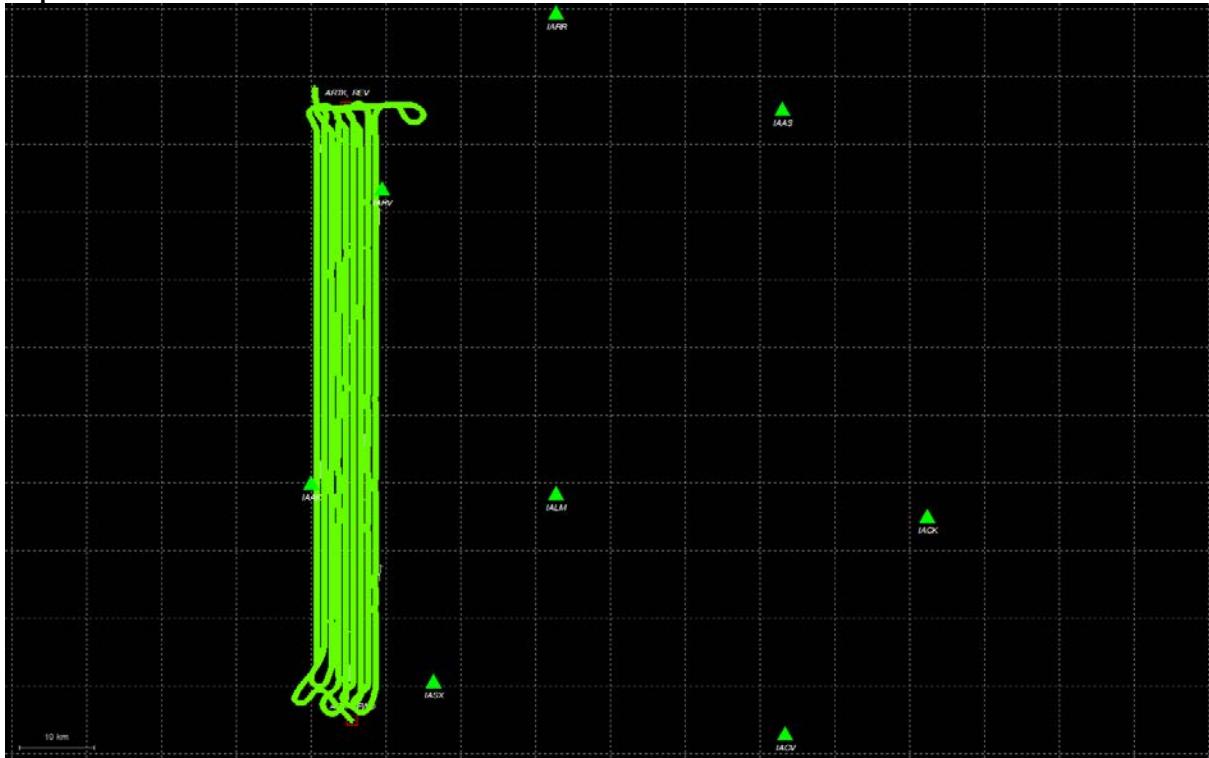


### Roll & Pitch Plot



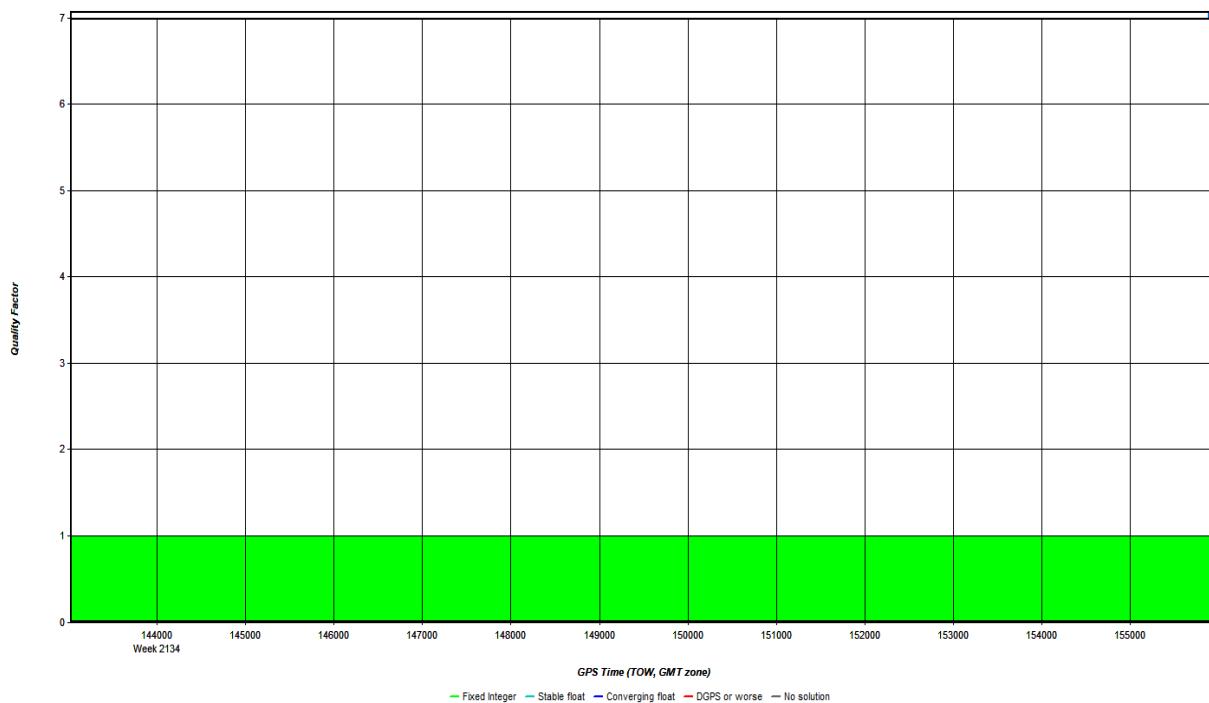
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Smoothed Trajectory Information

Top View

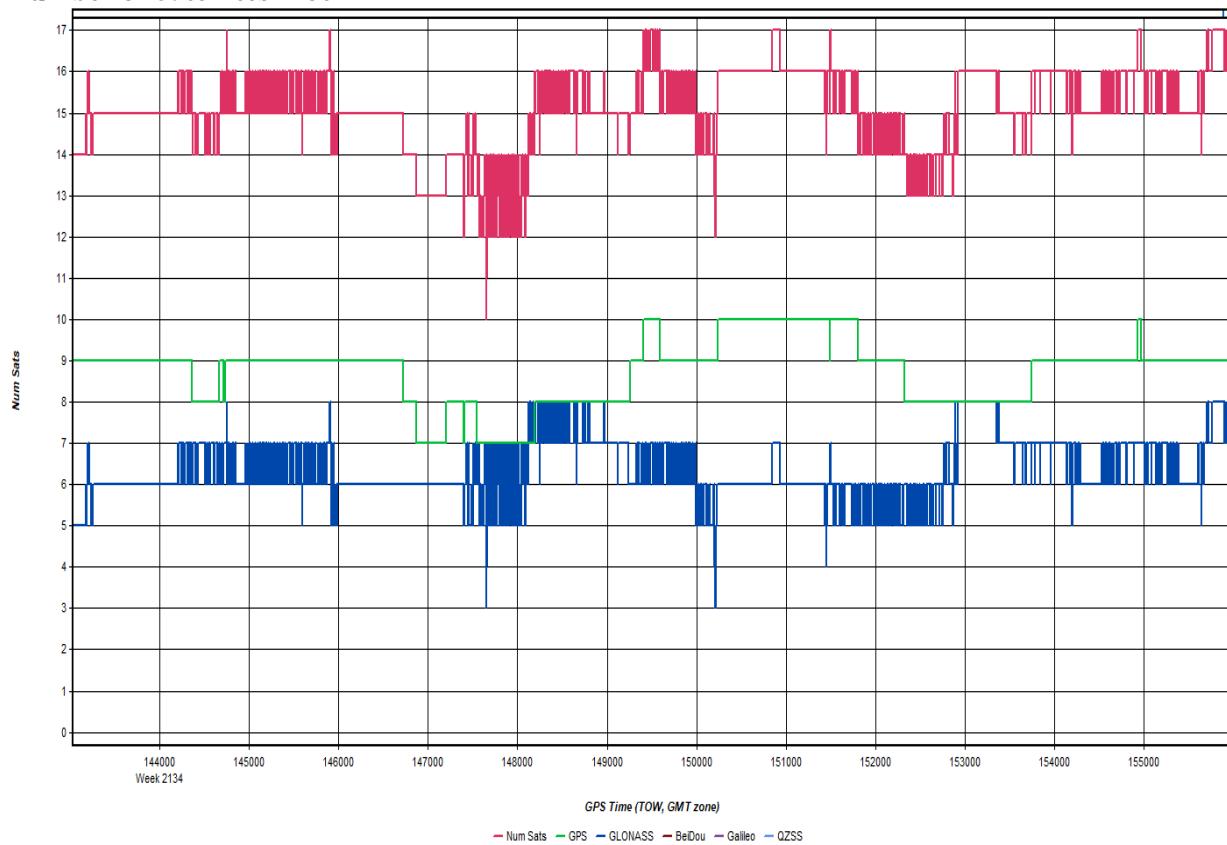


GNSS QC

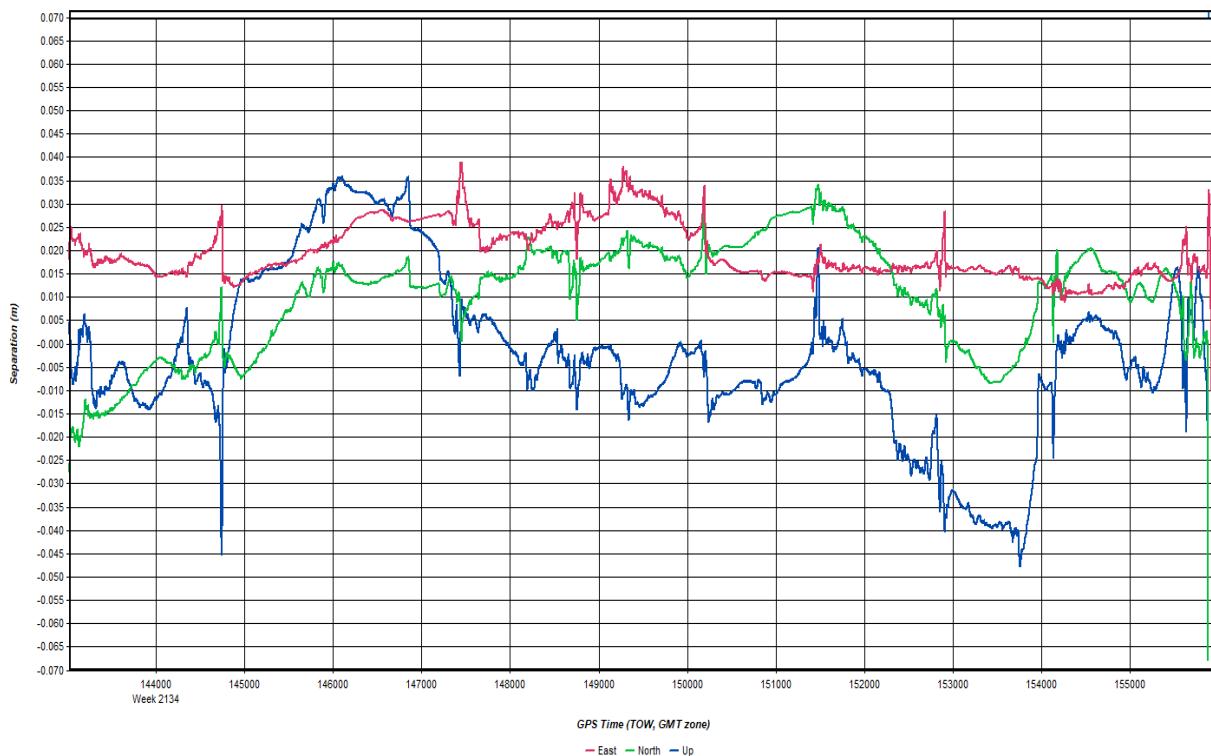
Quality Factor Plot



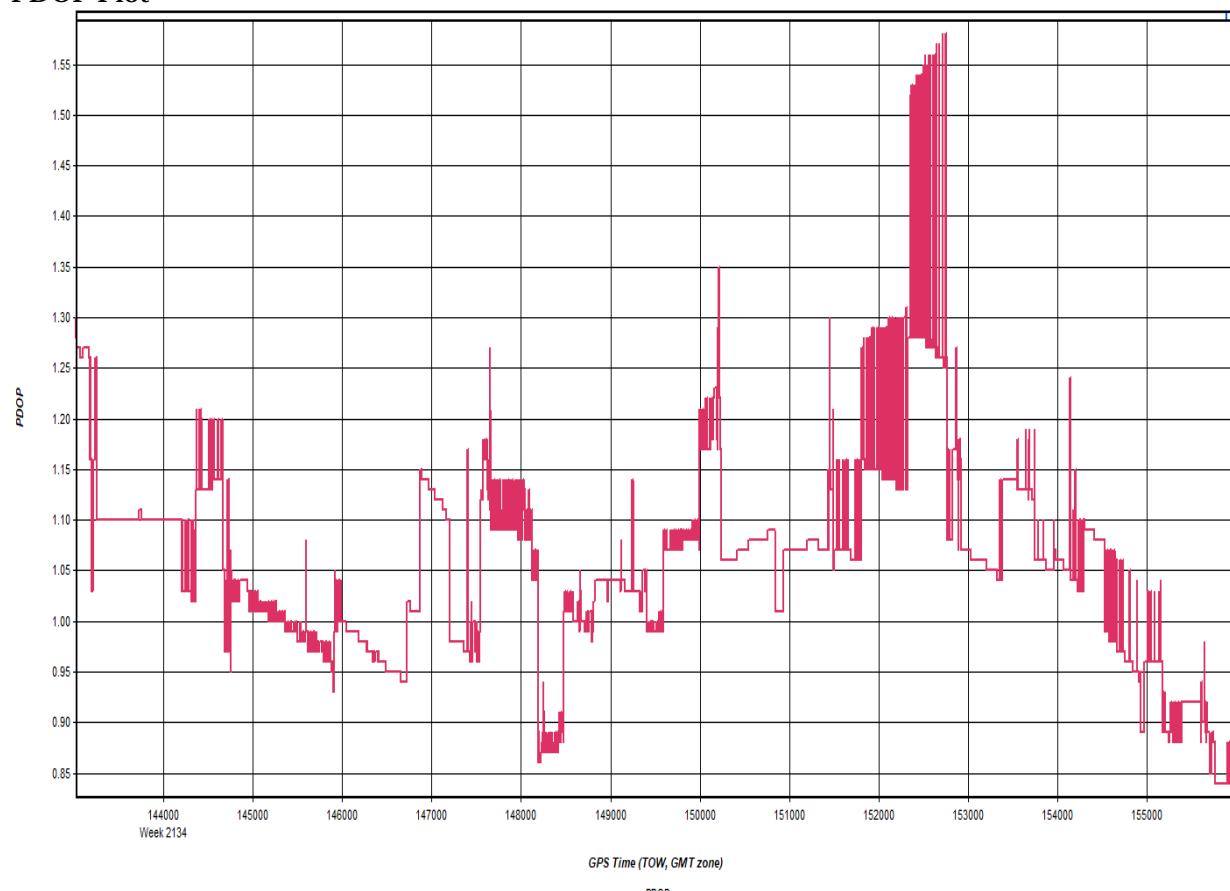
### Number of Satellites Plot



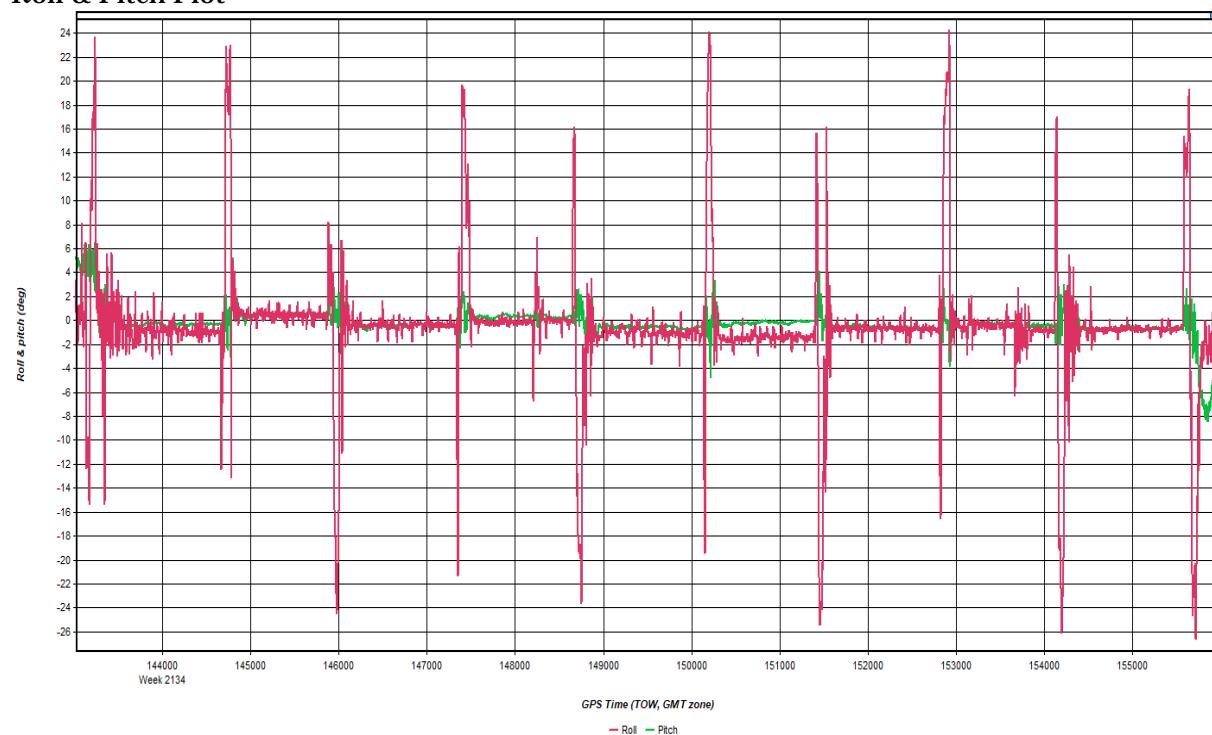
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

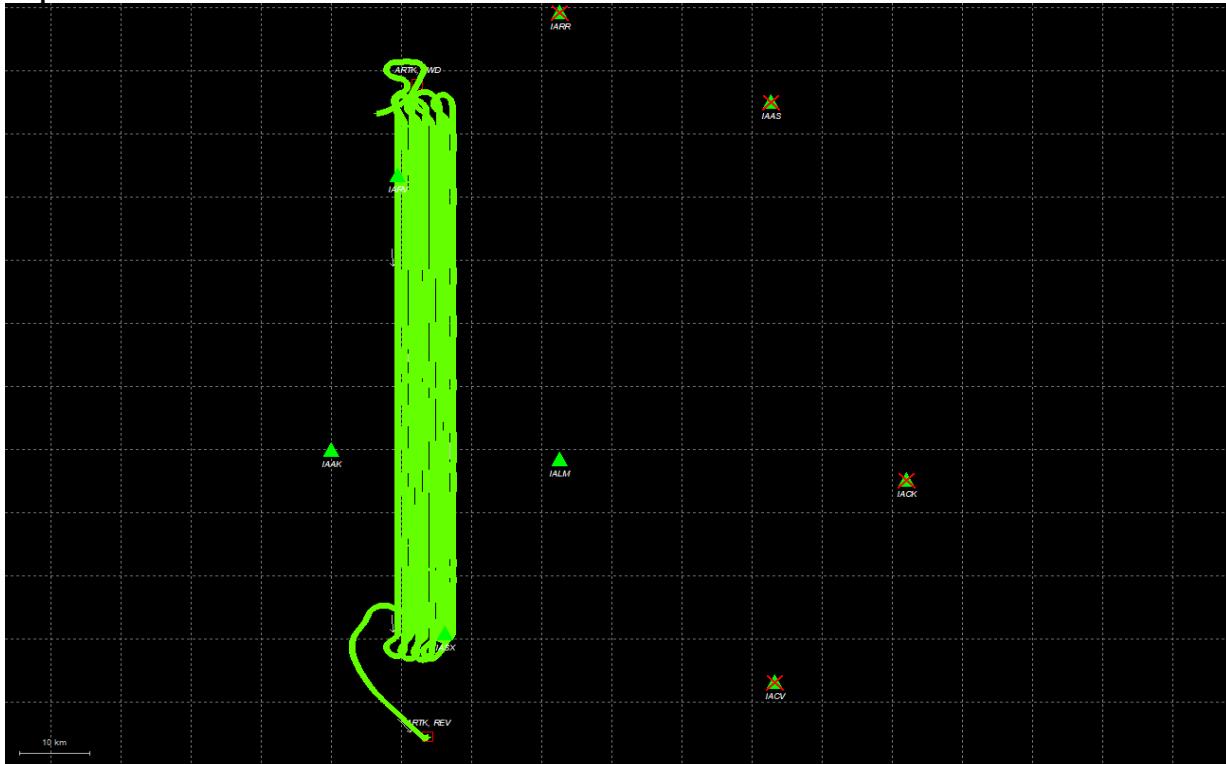


### Roll & Pitch Plot



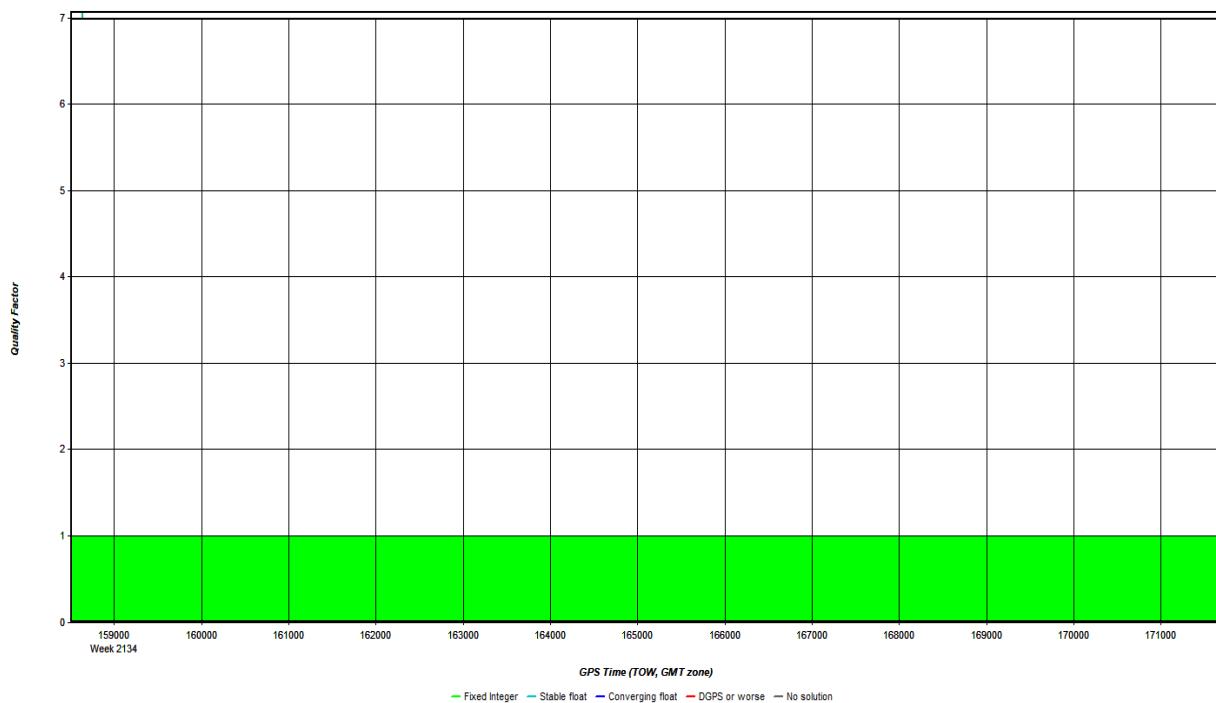
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Smoothed Trajectory Information

Top View

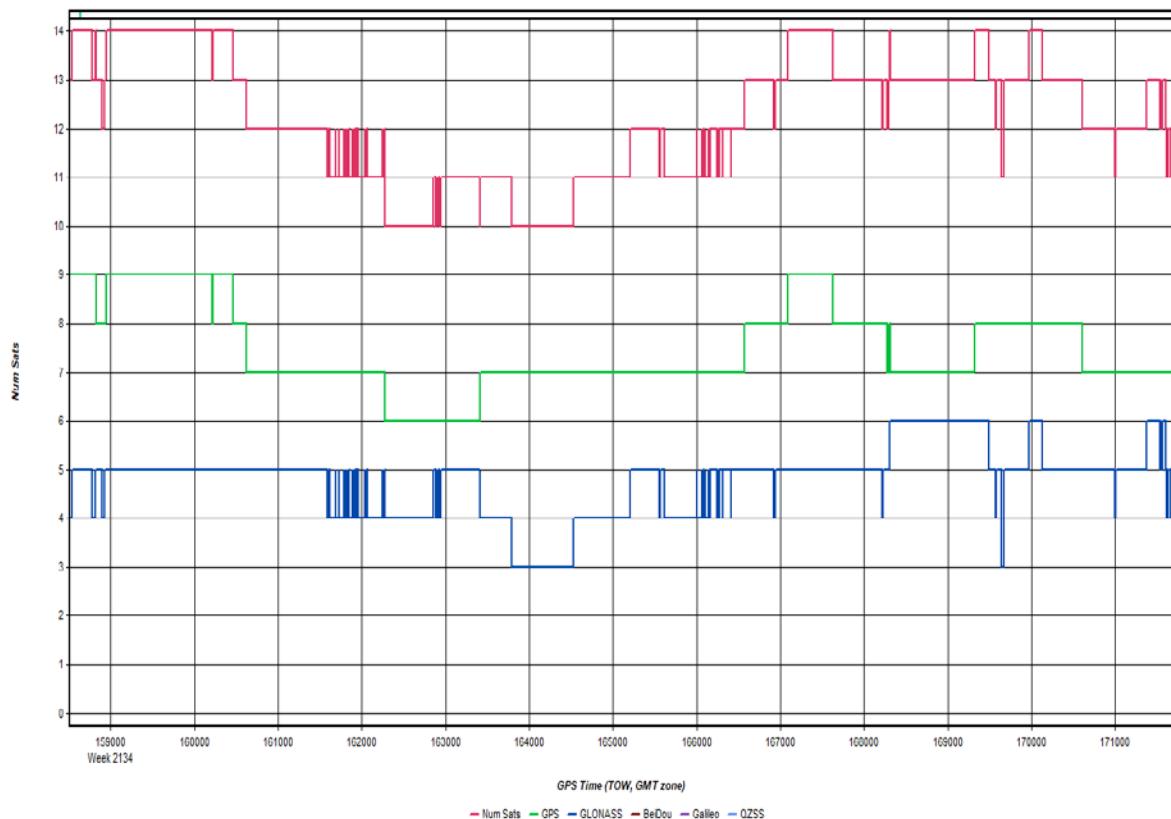


**GNSS QC**

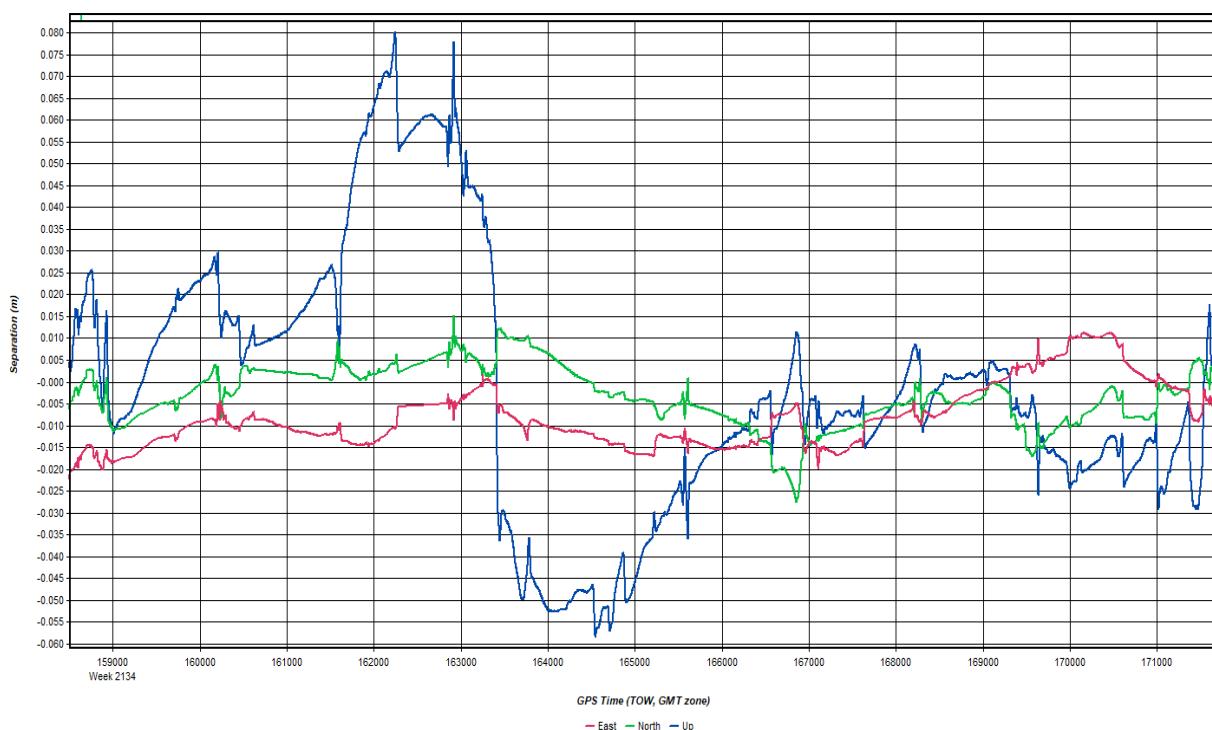
**Quality Factor Plot**



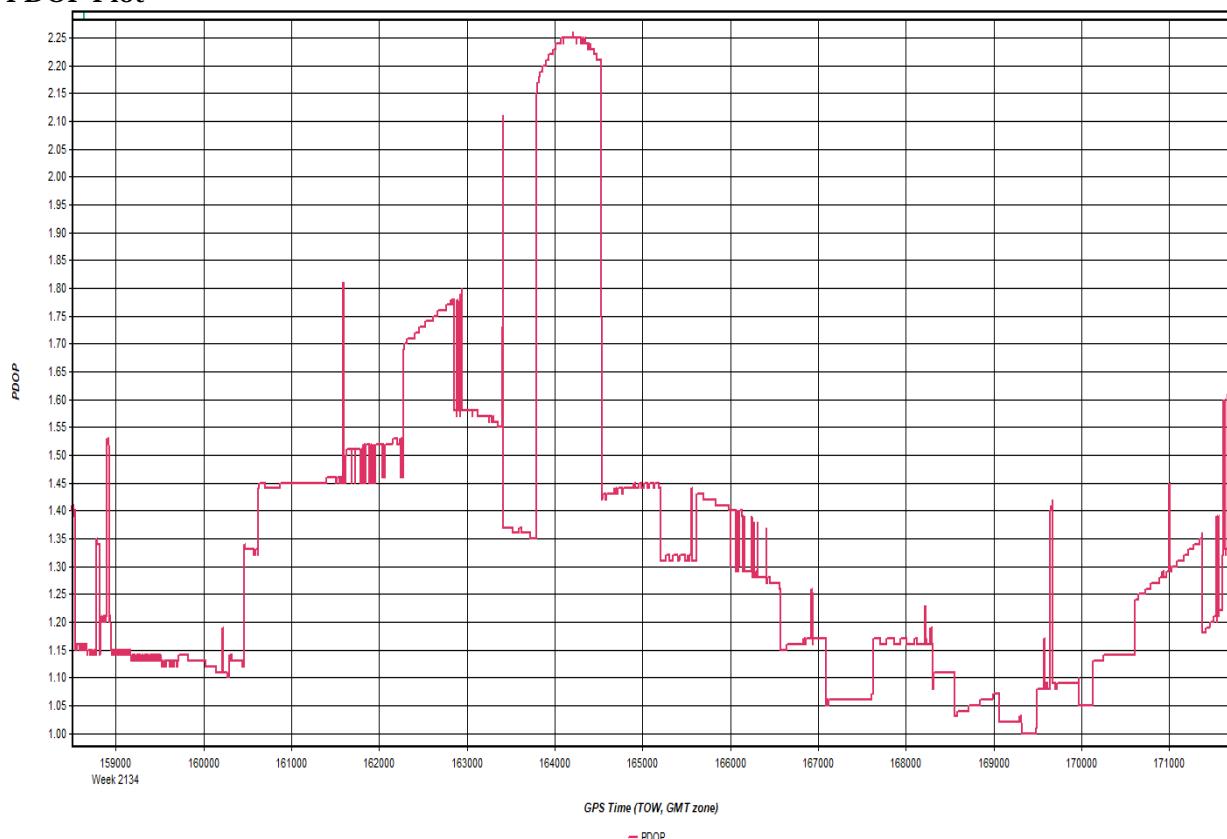
### Number of Satellites Plot



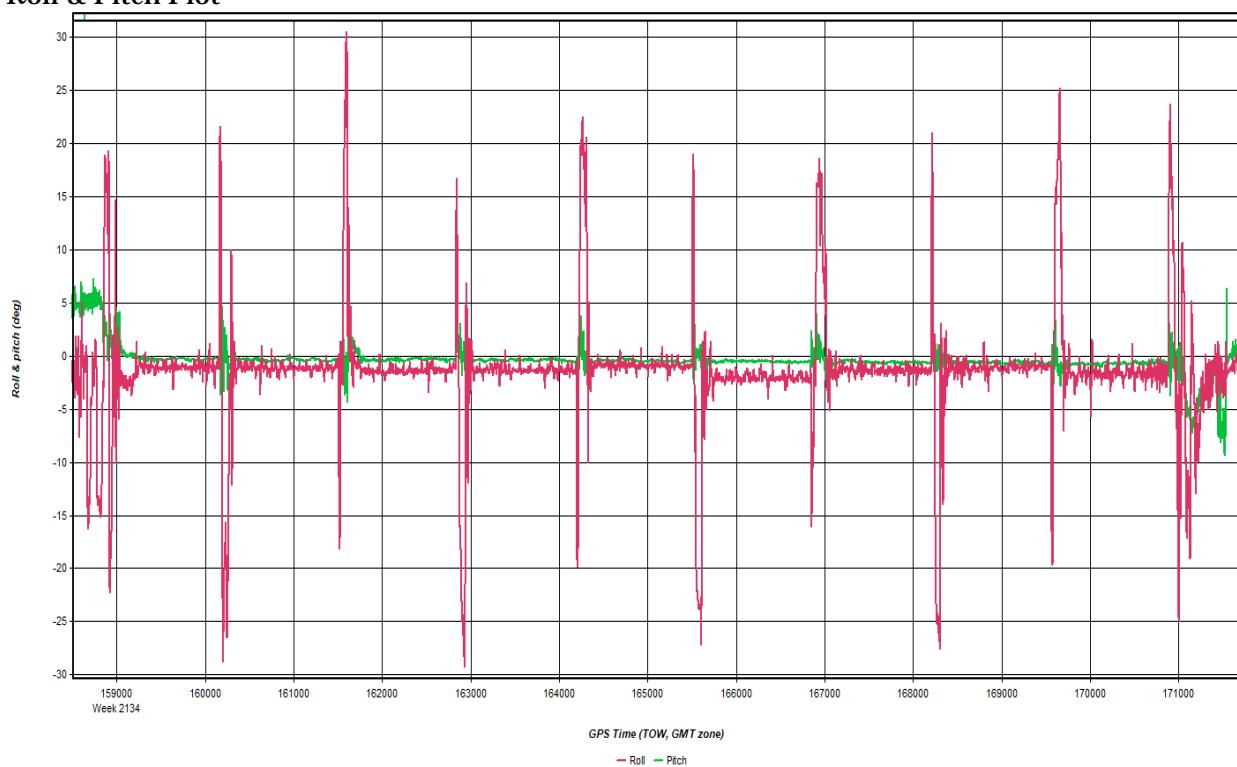
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

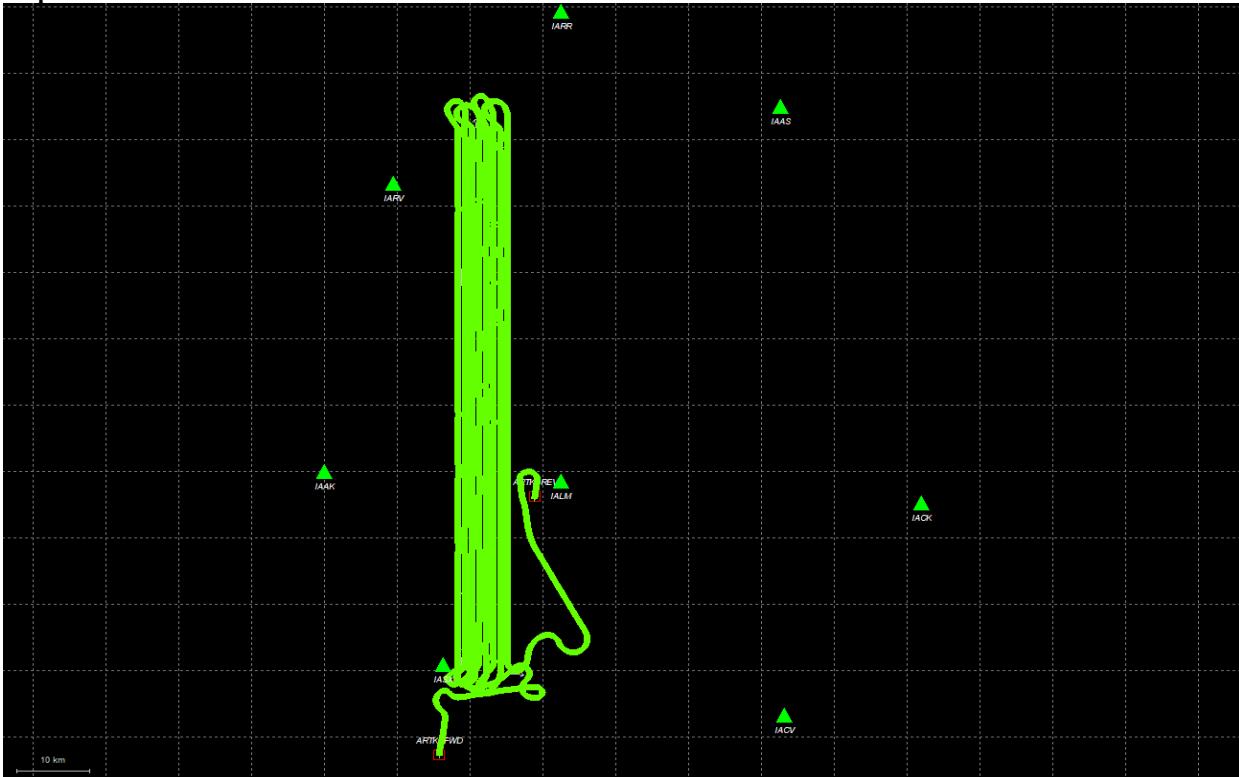


### Roll & Pitch Plot



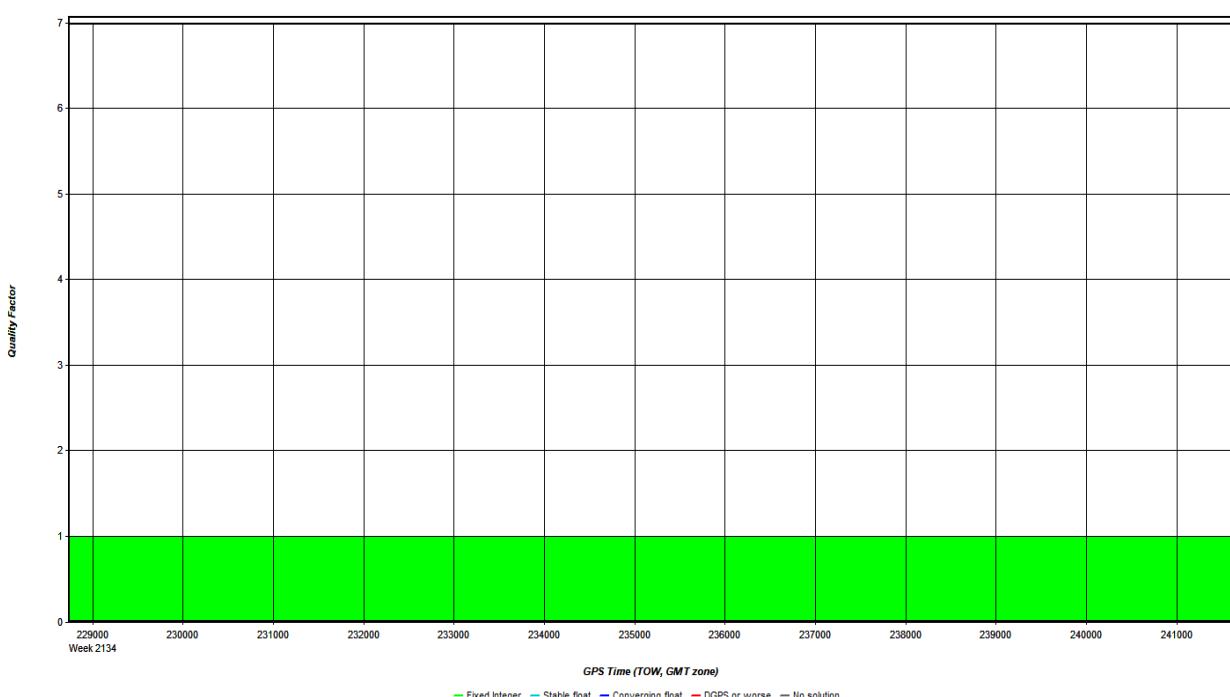
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**Smoothed Trajectory Information**

## Top View

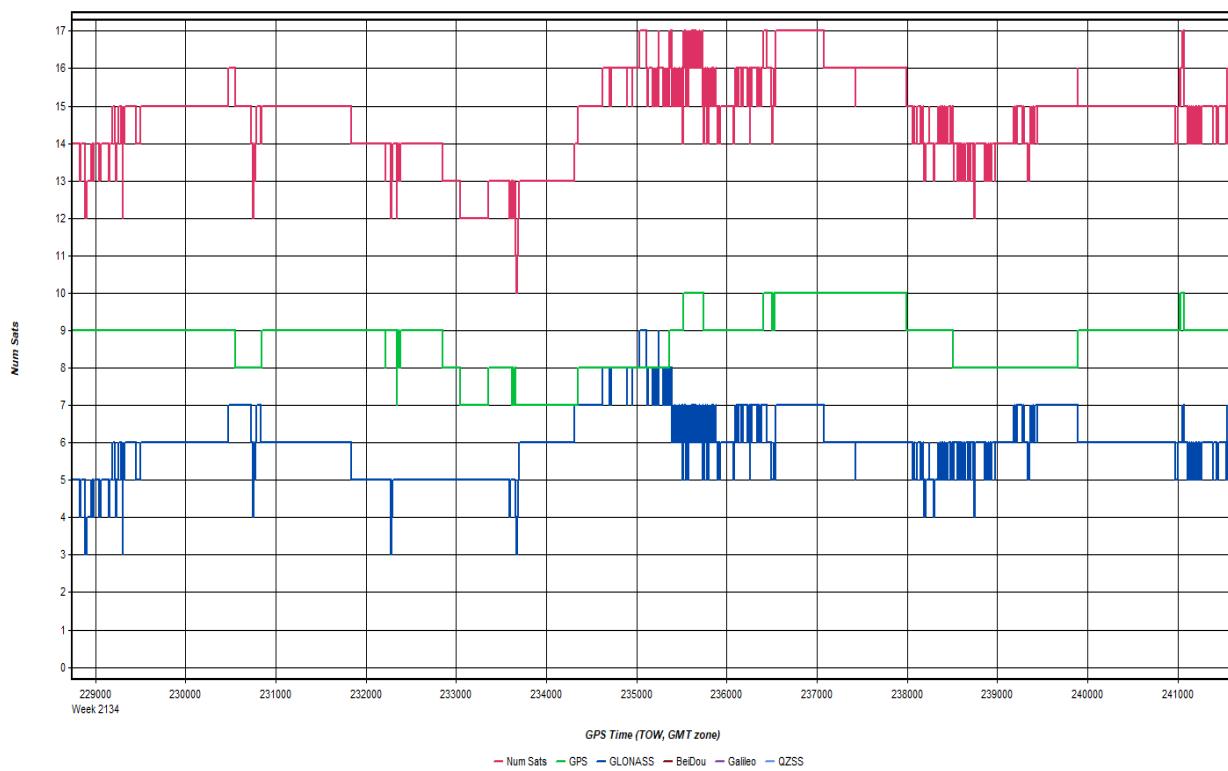


GNSS QC

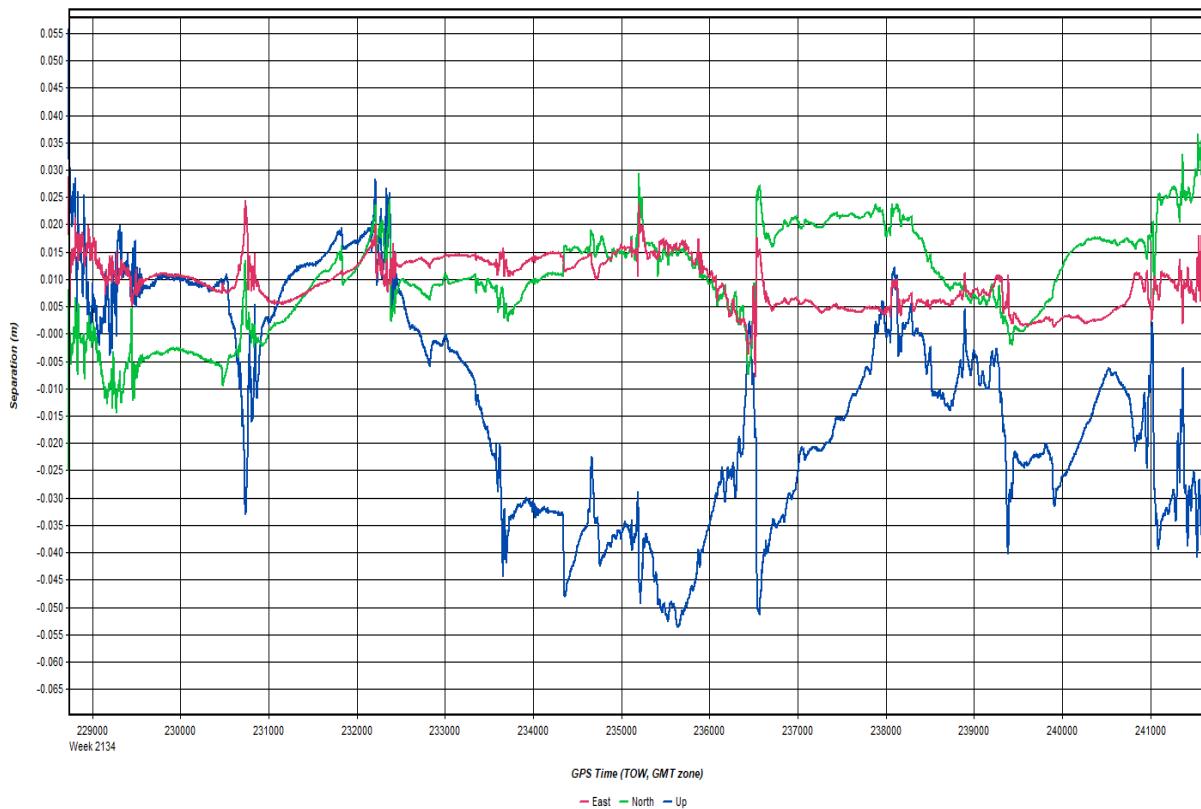
## Quality Factor Plot



### Number of Satellites Plot

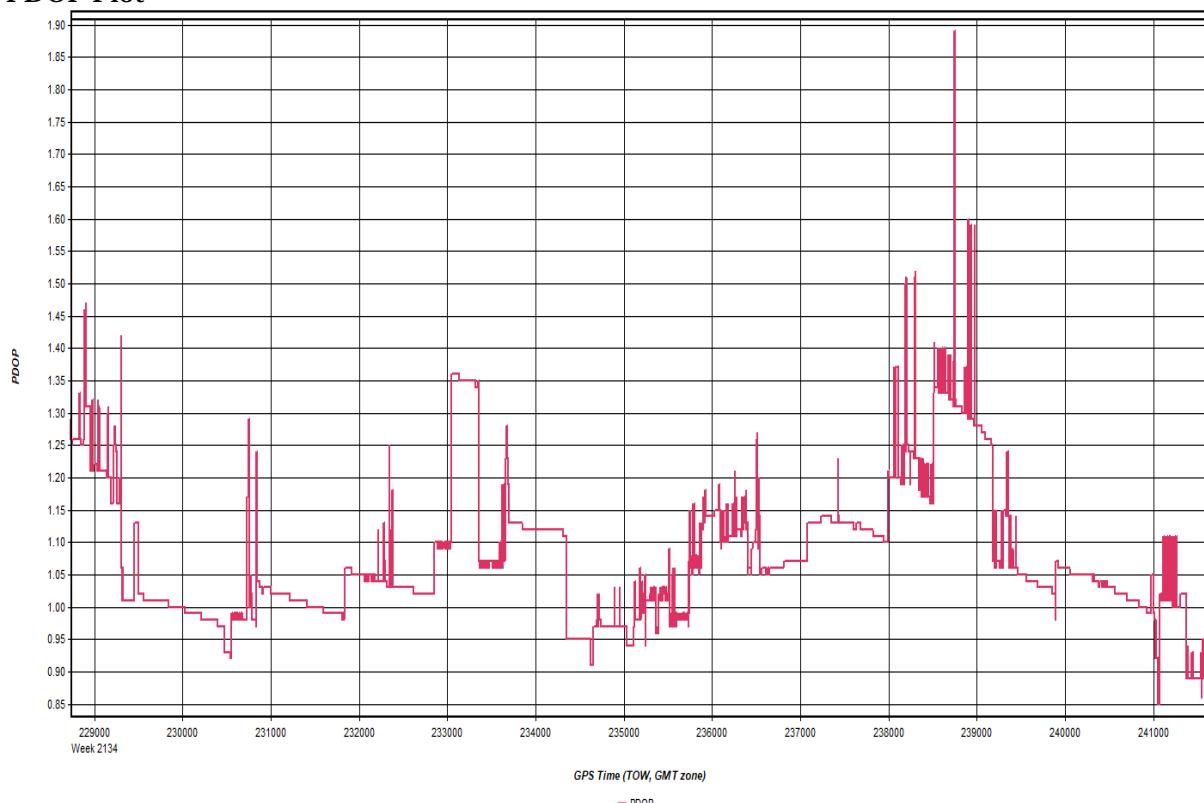


### Forward/Reverse or Combined Separation Plot

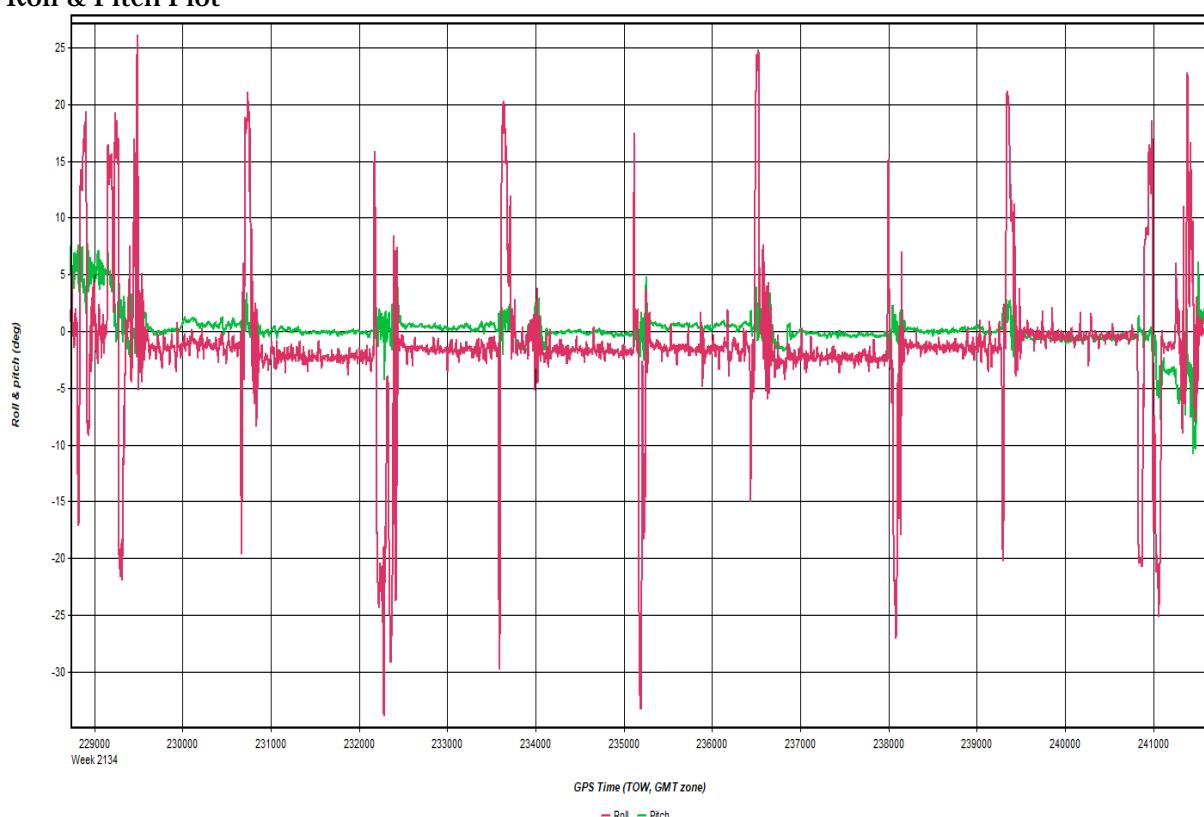


IA West 2020  
11/24/2021

### PDOP Plot

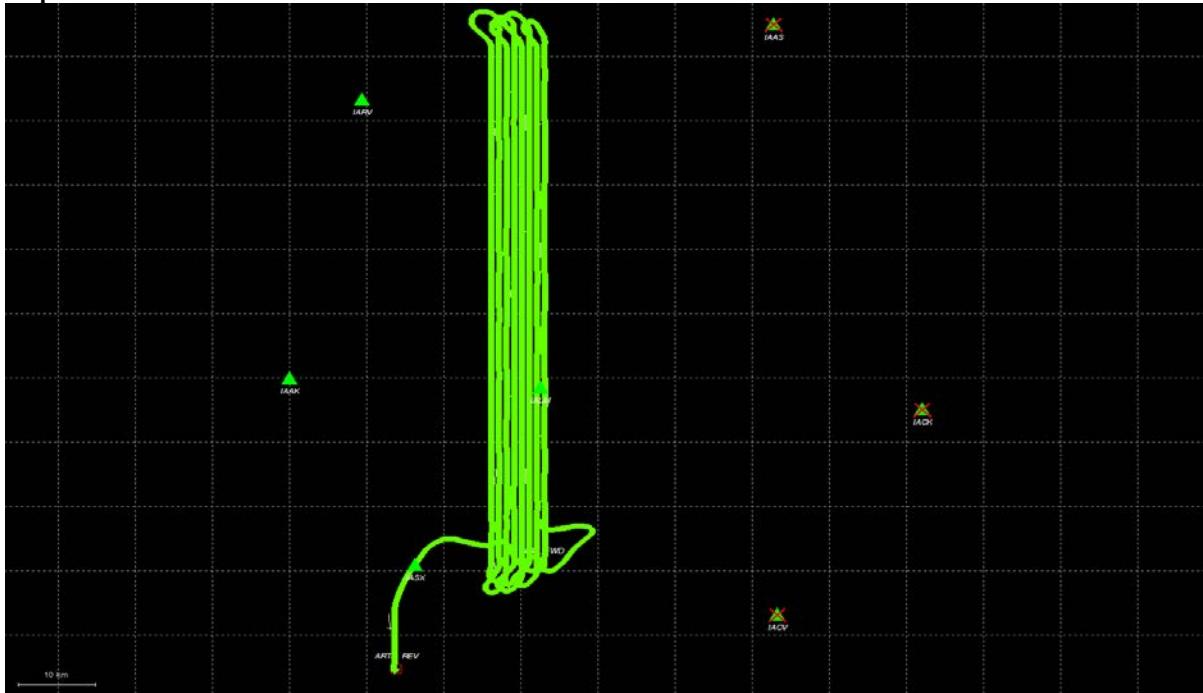


### Roll & Pitch Plot



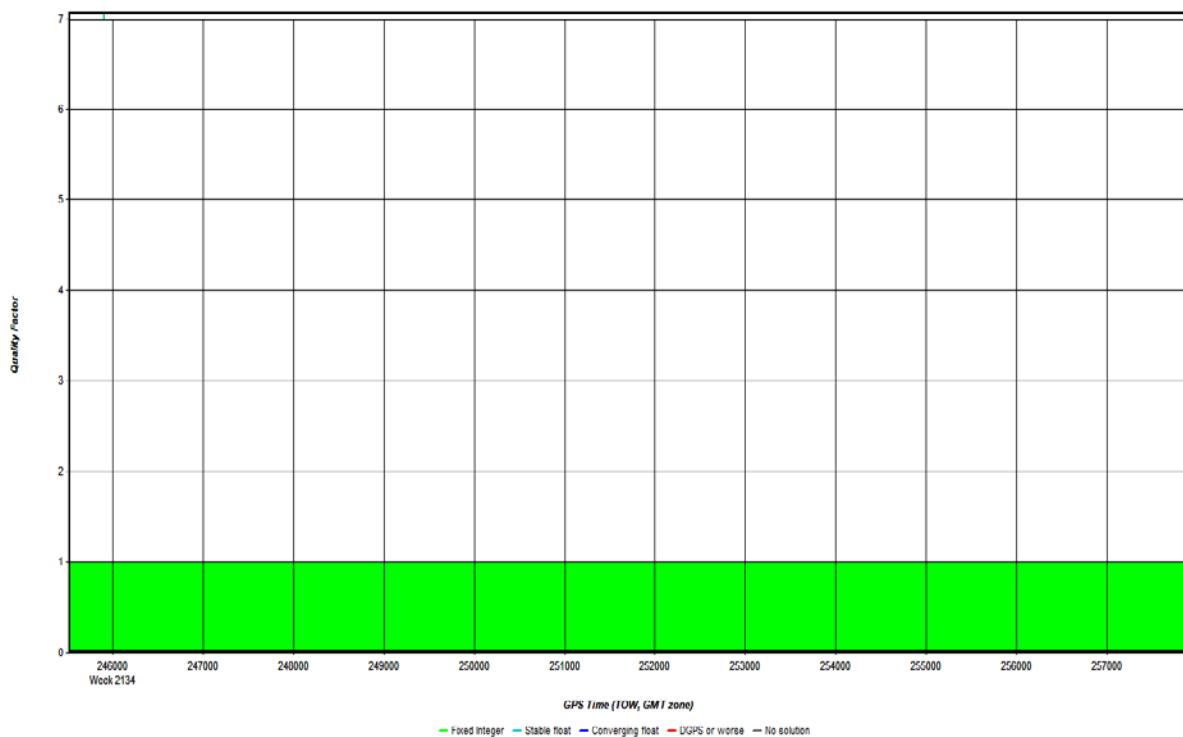
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**Smoothed Trajectory Information**

## Top View

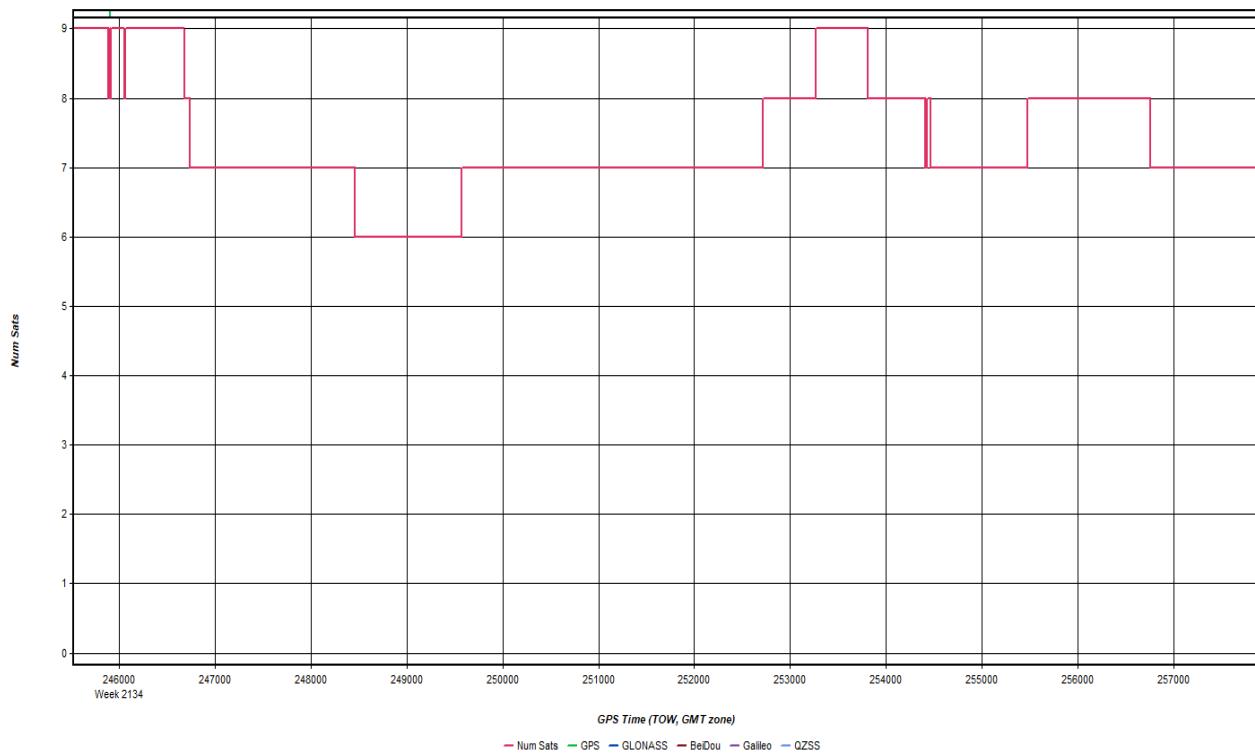


GNSS QC

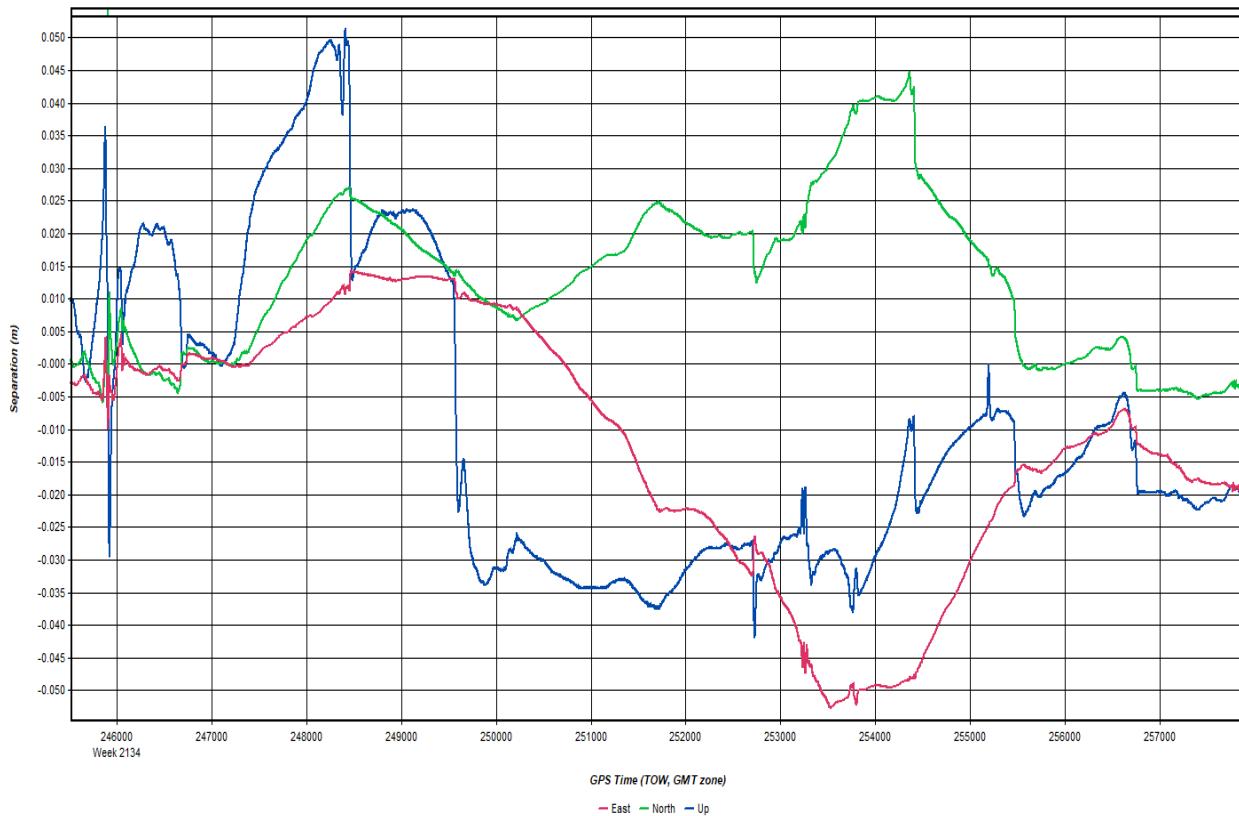
## Quality Factor Plot



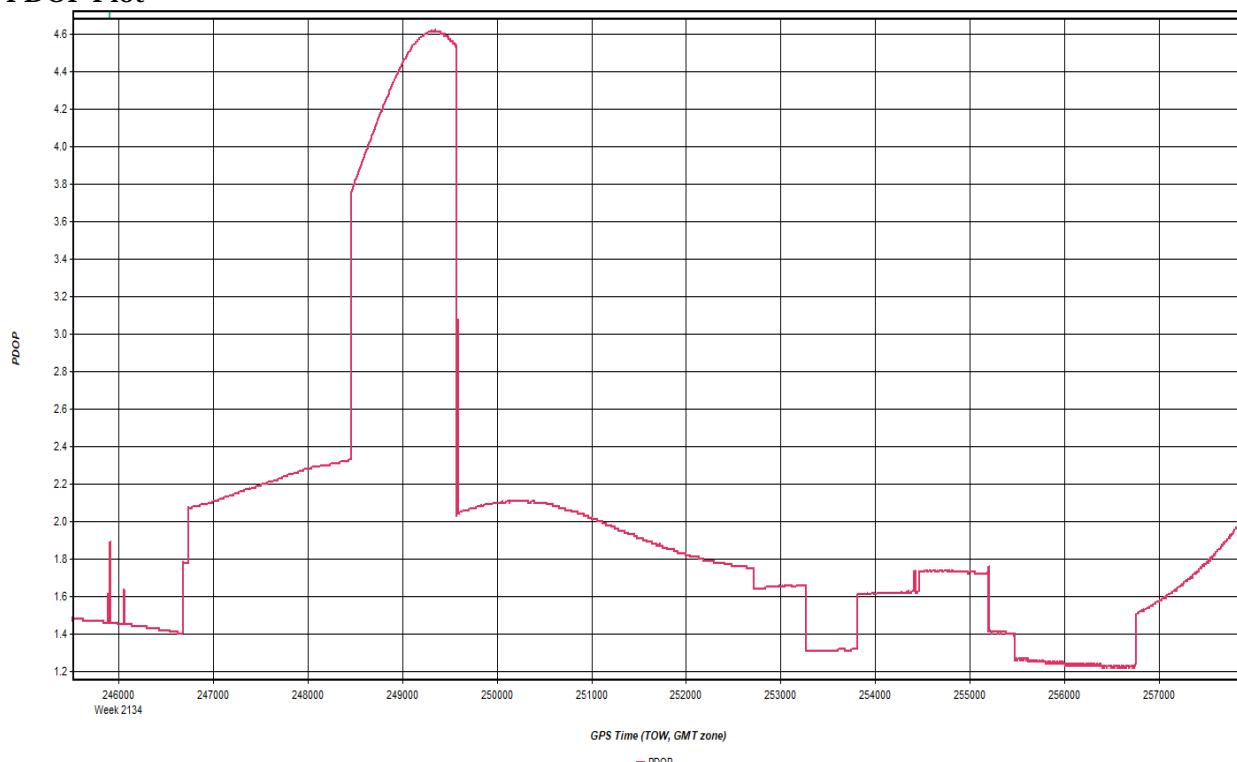
### Number of Satellites Plot



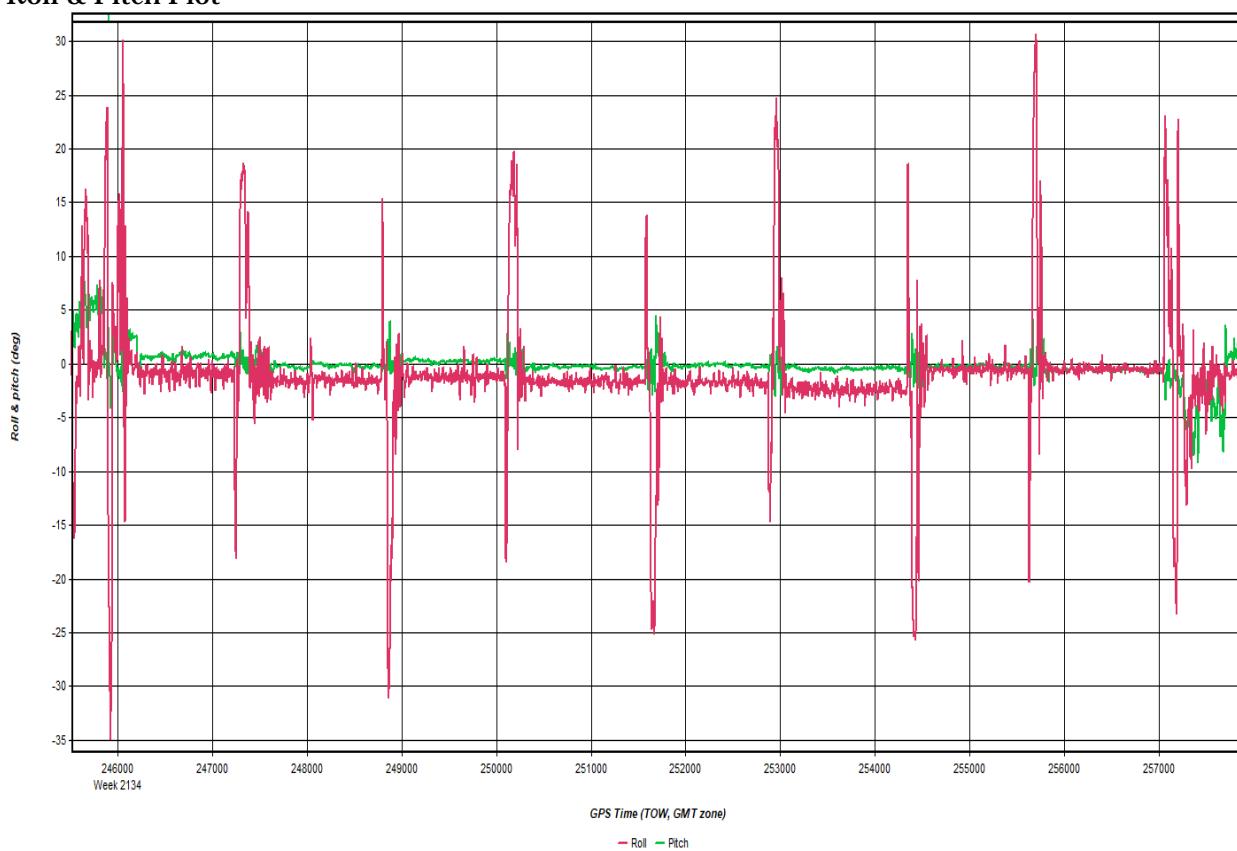
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

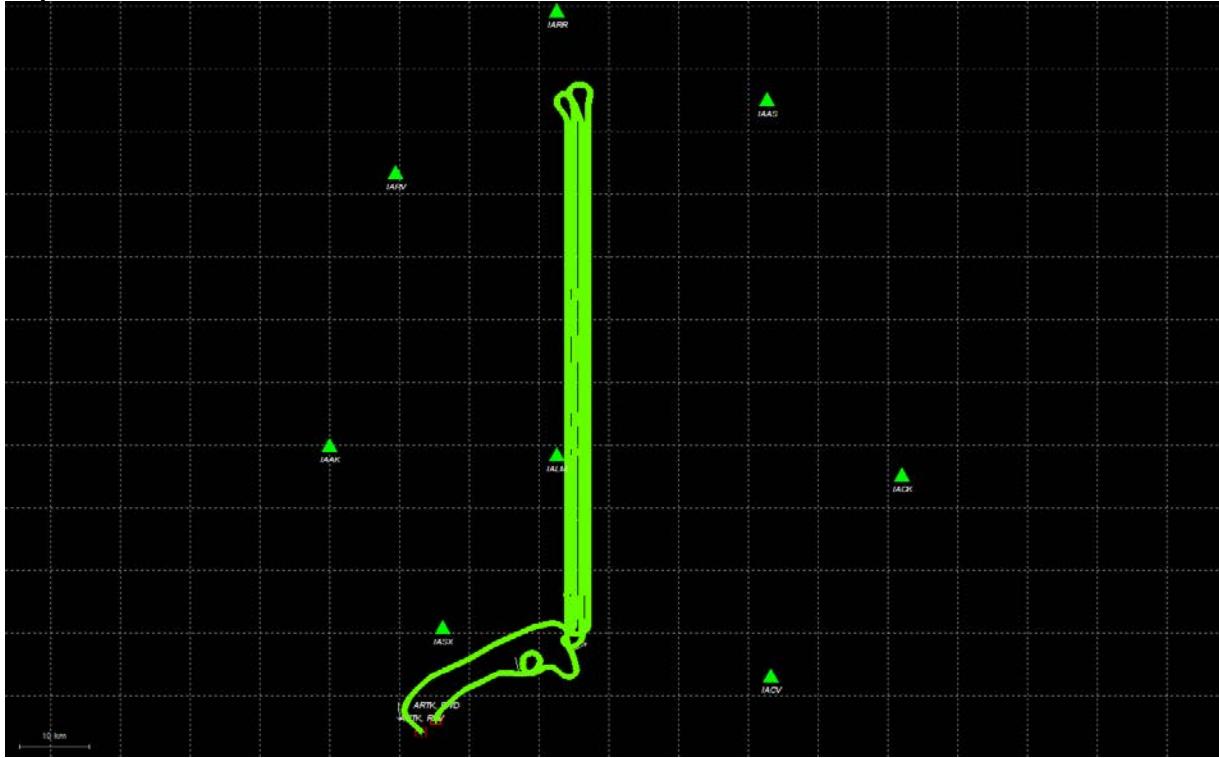


### Roll & Pitch Plot



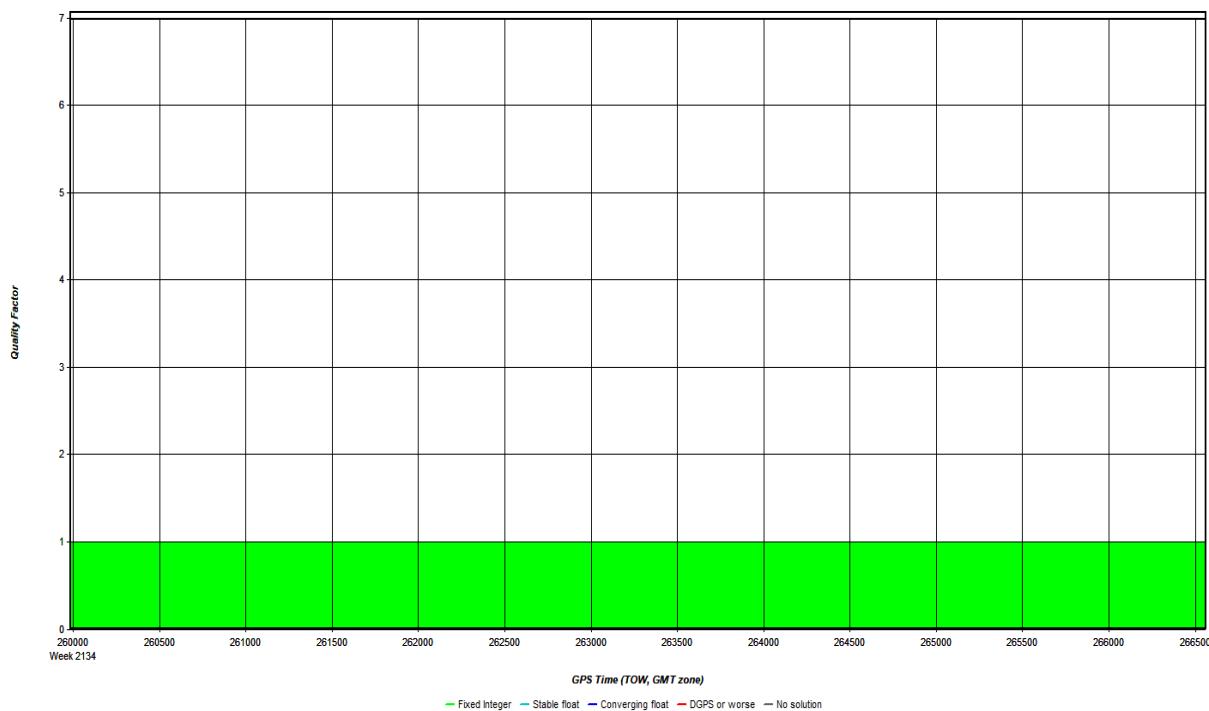
20201202\_001014.docx QC Report - 06/22/2021 10:19:08  
**Smoothed Trajectory Information**

## Top View

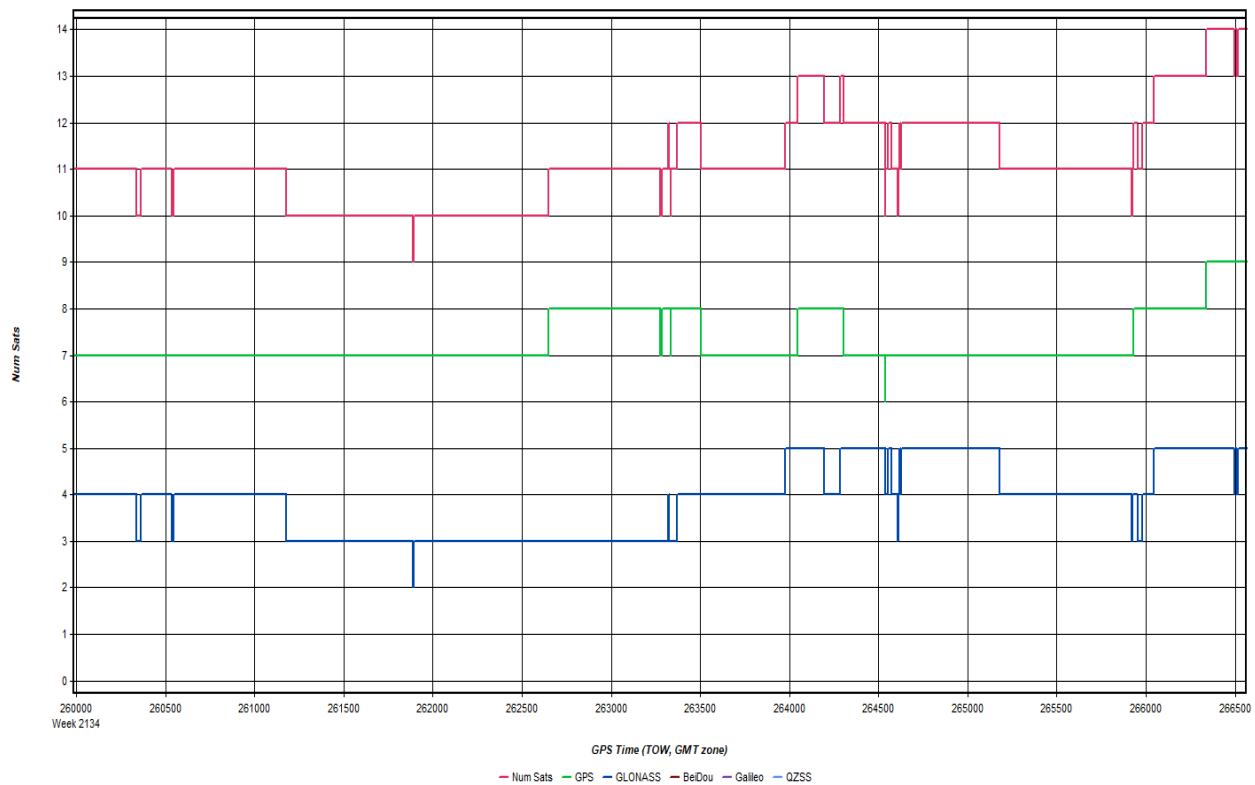


GNSS QC

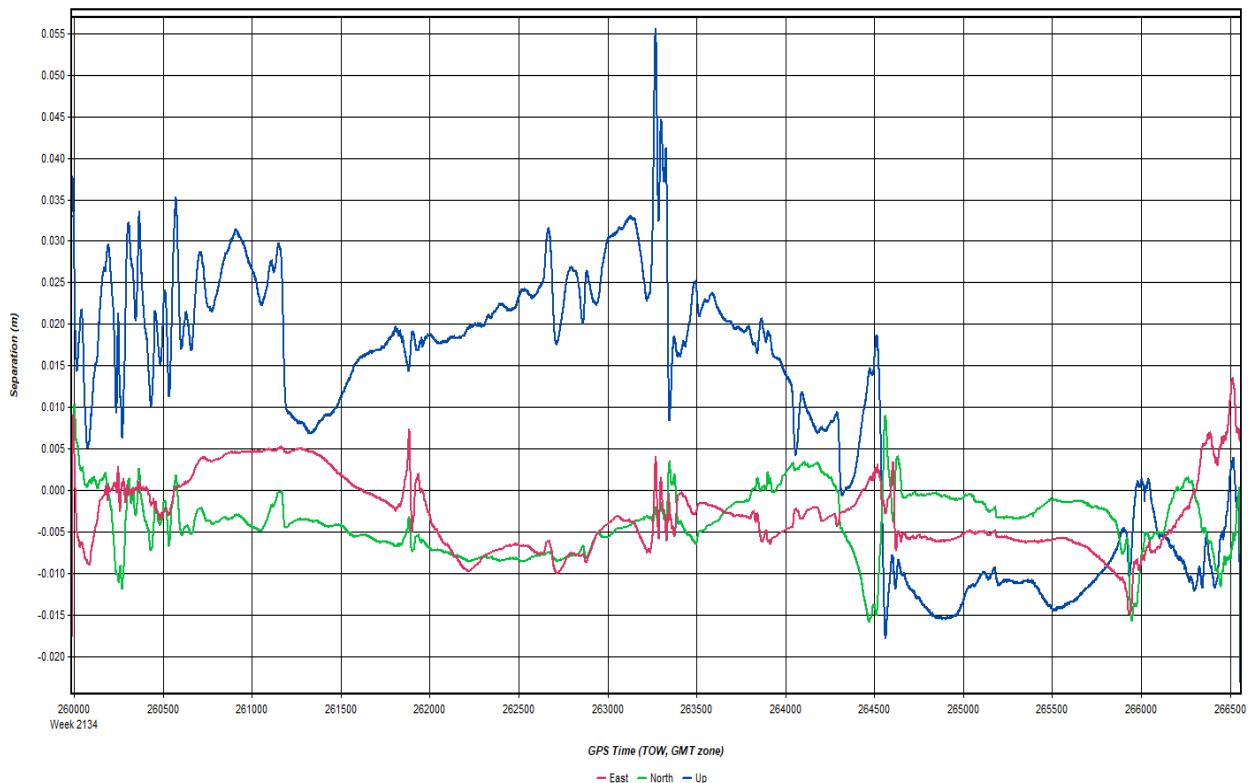
## Quality Factor Plot



### Number of Satellites Plot

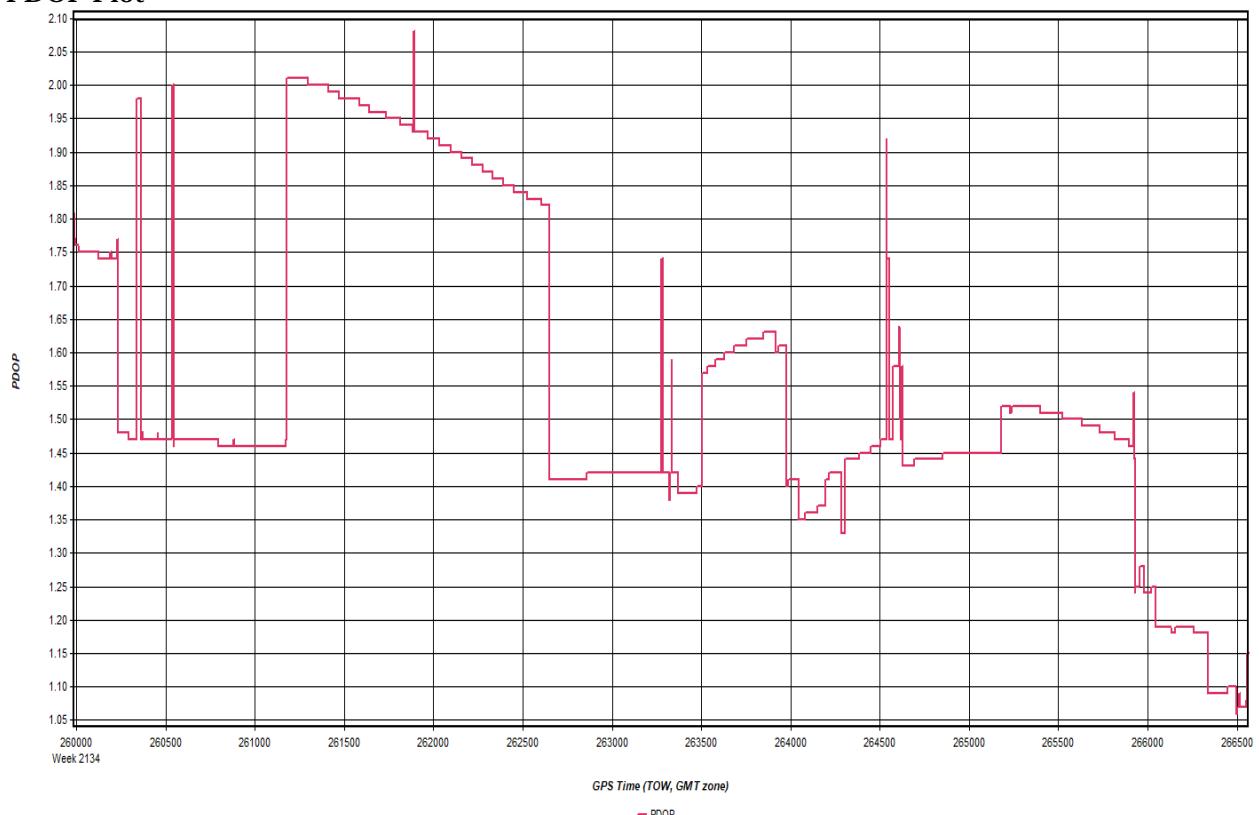


### Forward/Reverse or Combined Separation Plot

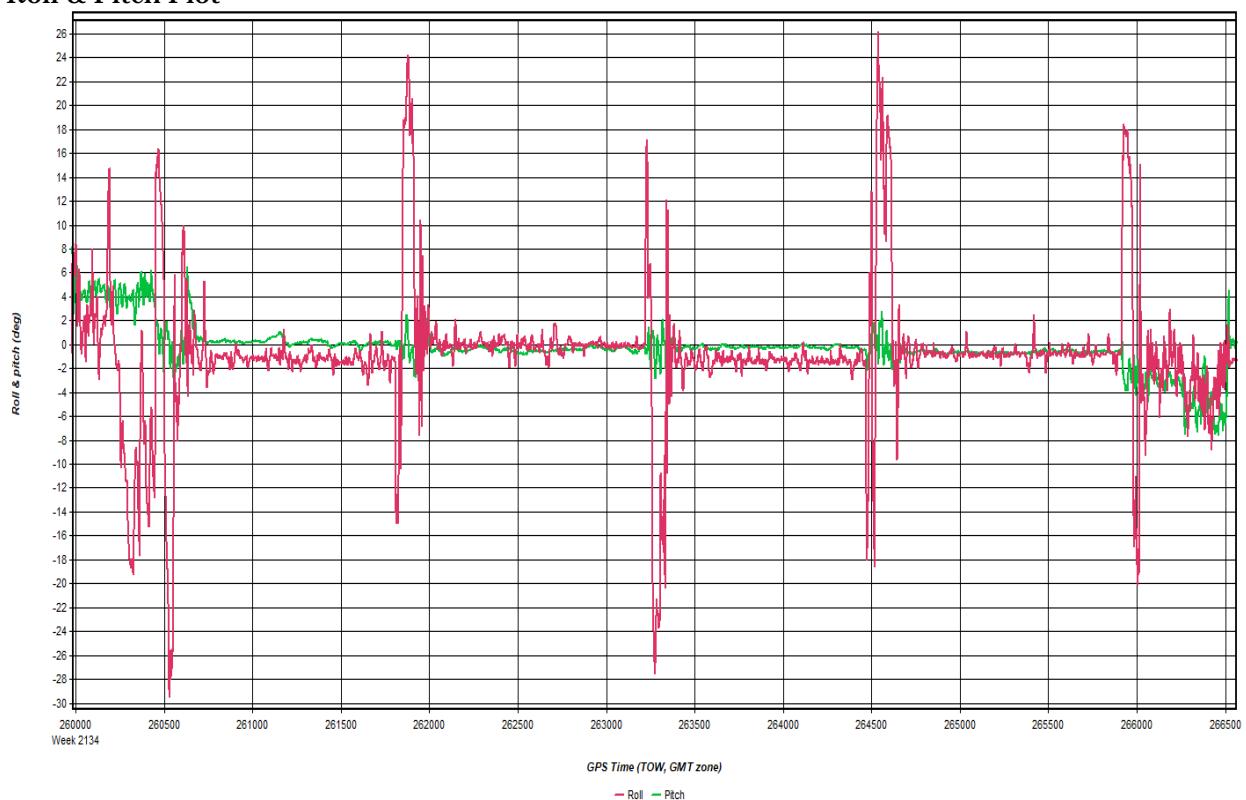


IA West 2020  
11/24/2021

### PDOP Plot

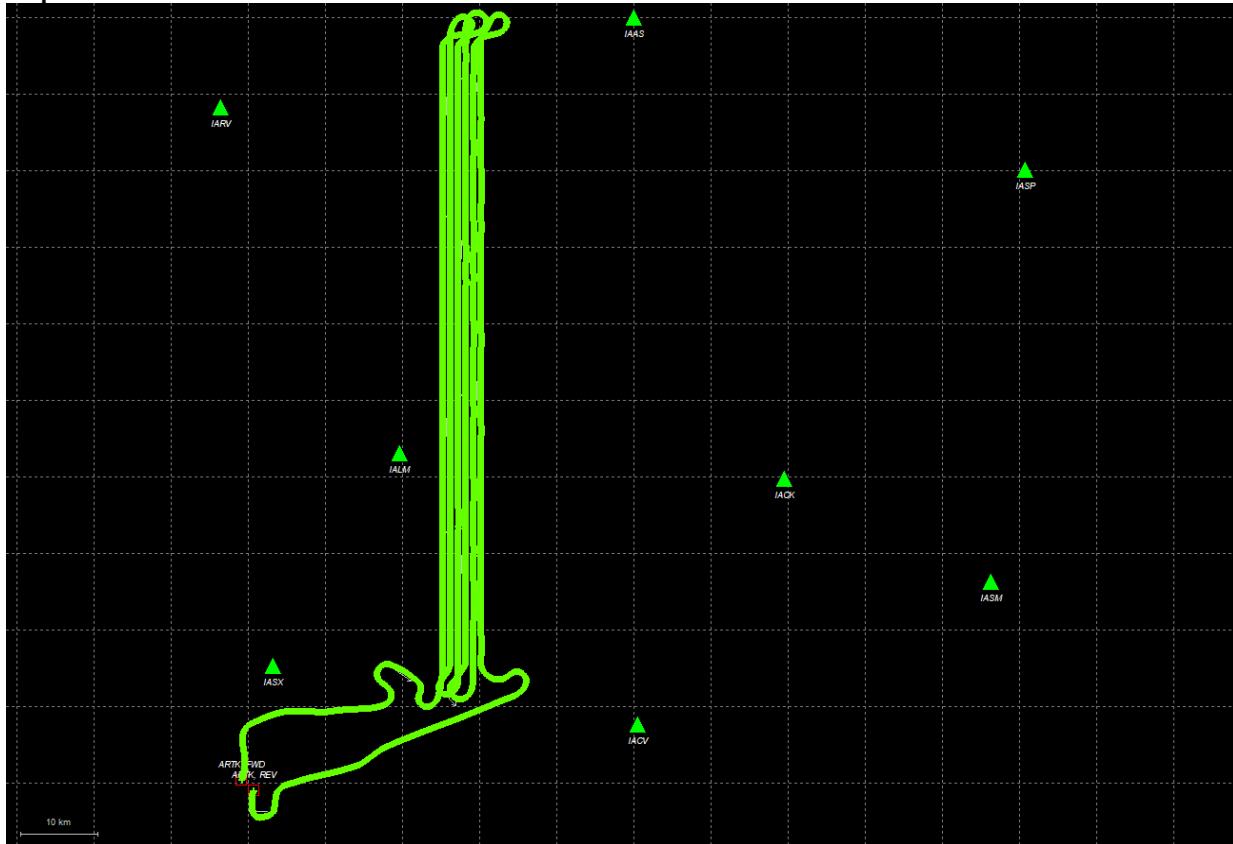


### Roll & Pitch Plot



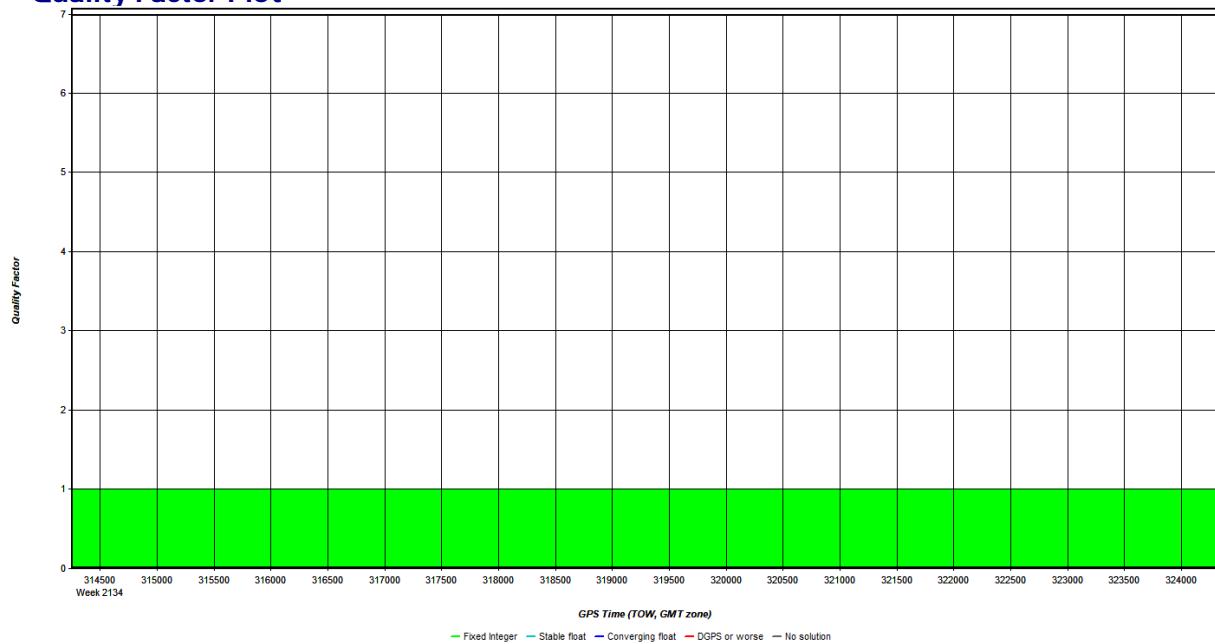
20201202\_151519.docx QC Report - 06/22/2021 10:22:43  
Smoothed Trajectory Information

Top View

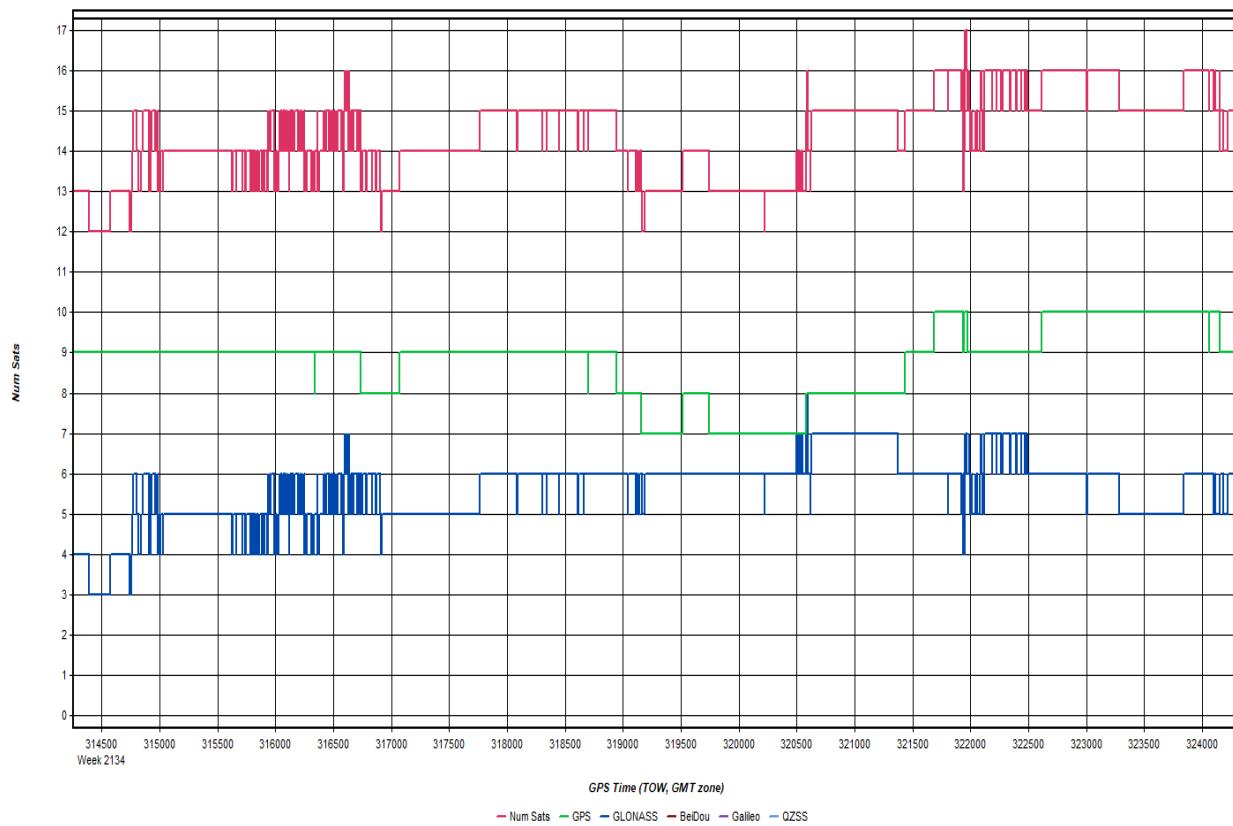


GNSS QC

Quality Factor Plot



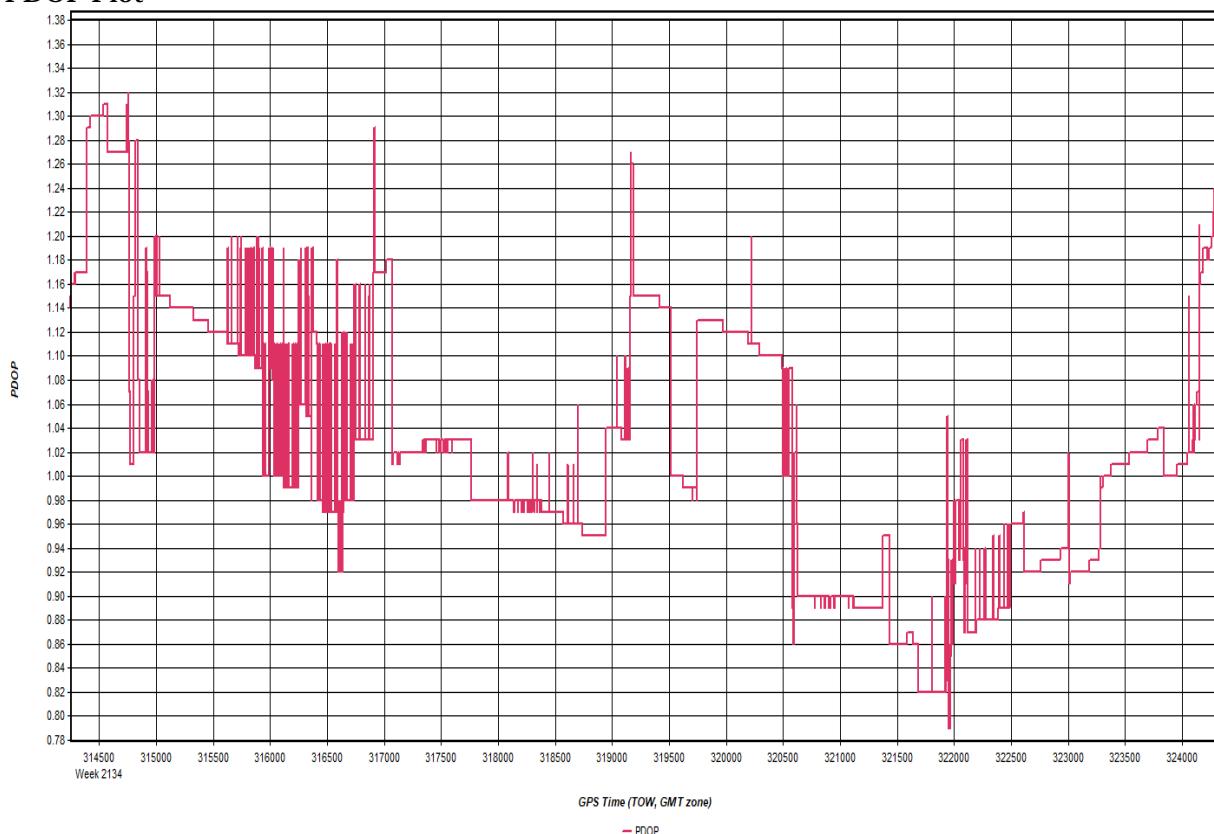
### Number of Satellites Plot



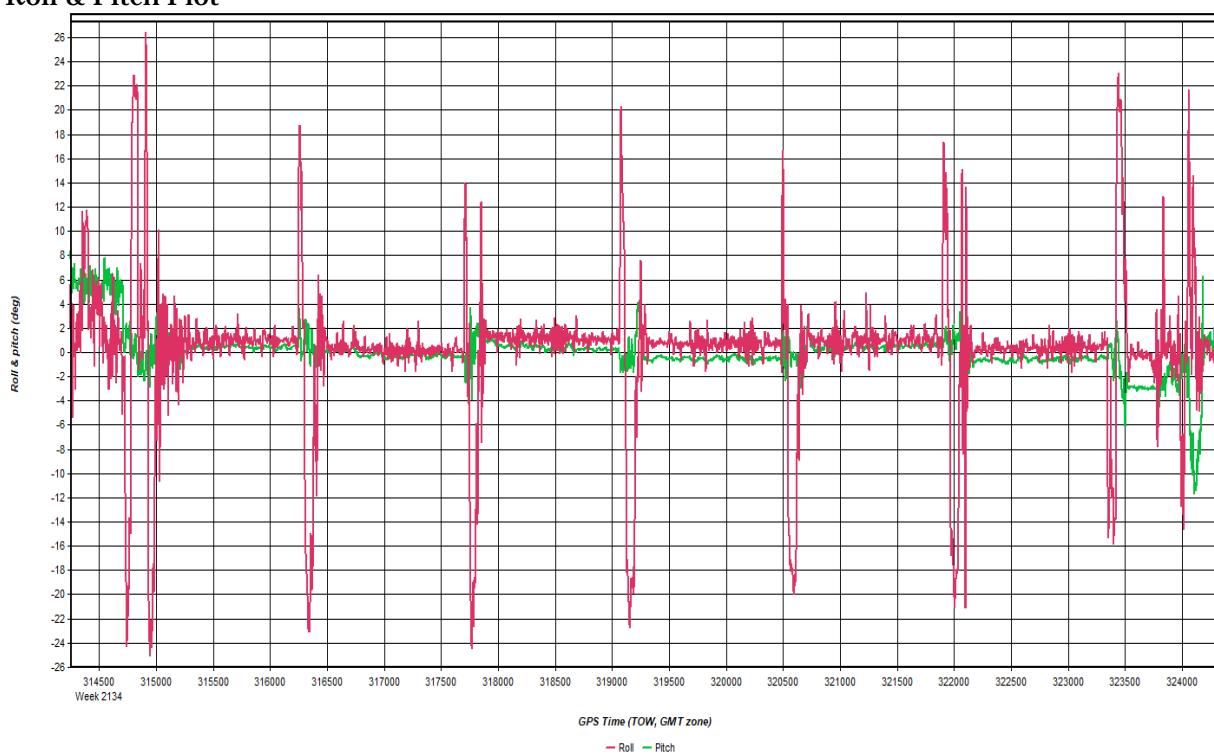
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

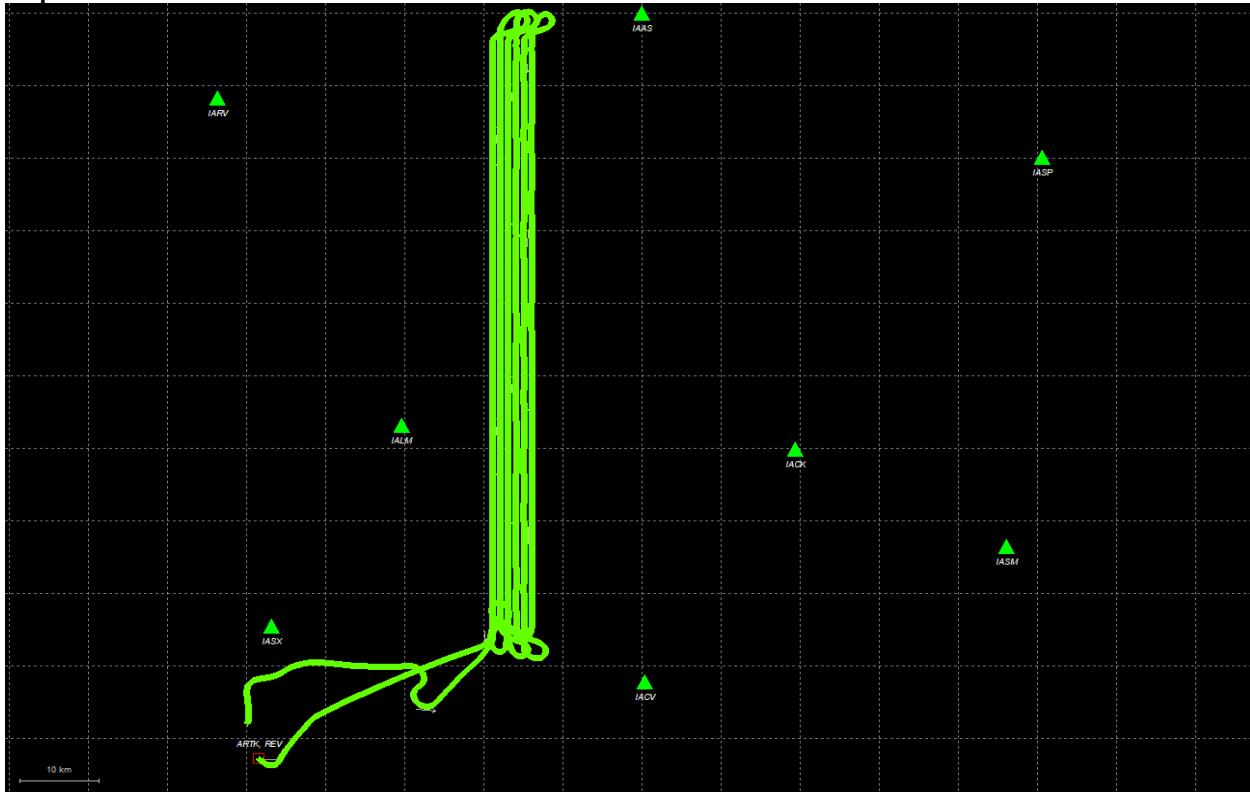


### Roll & Pitch Plot



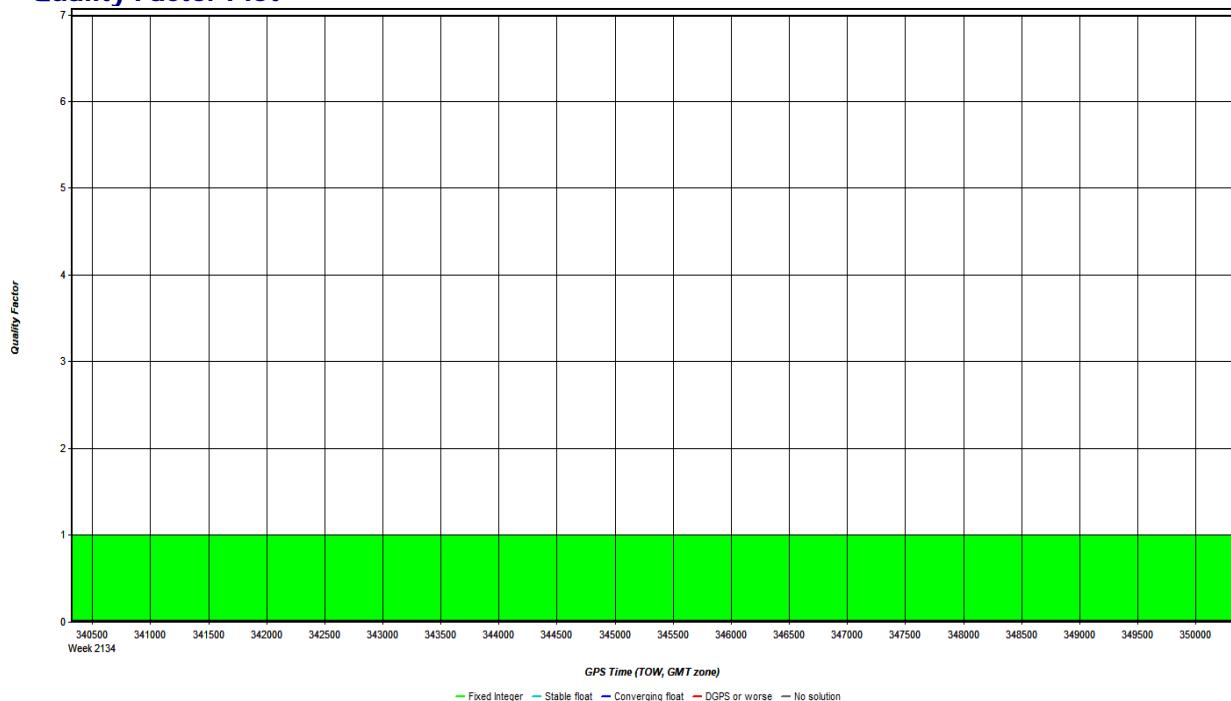
20201202\_222959.docx QC Report - 06/22/2021 10:26:33  
Smoothed Trajectory Information

Top View

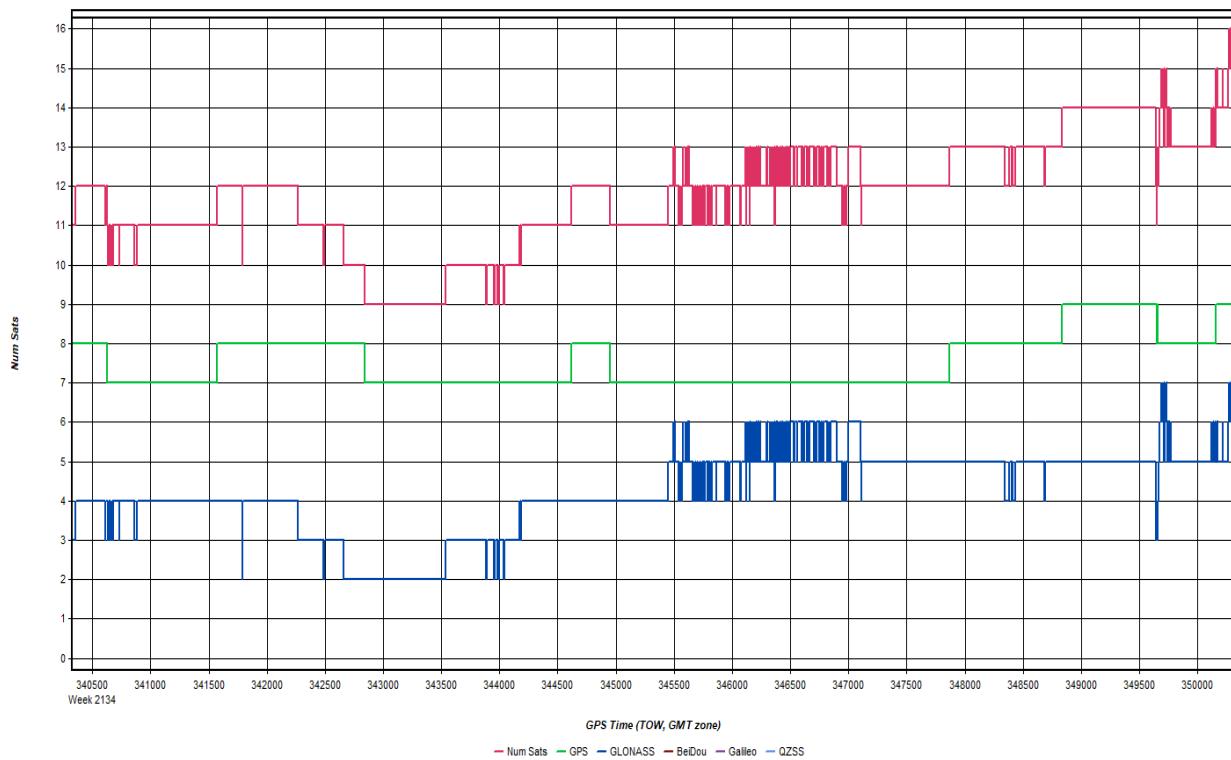


**GNSS QC**

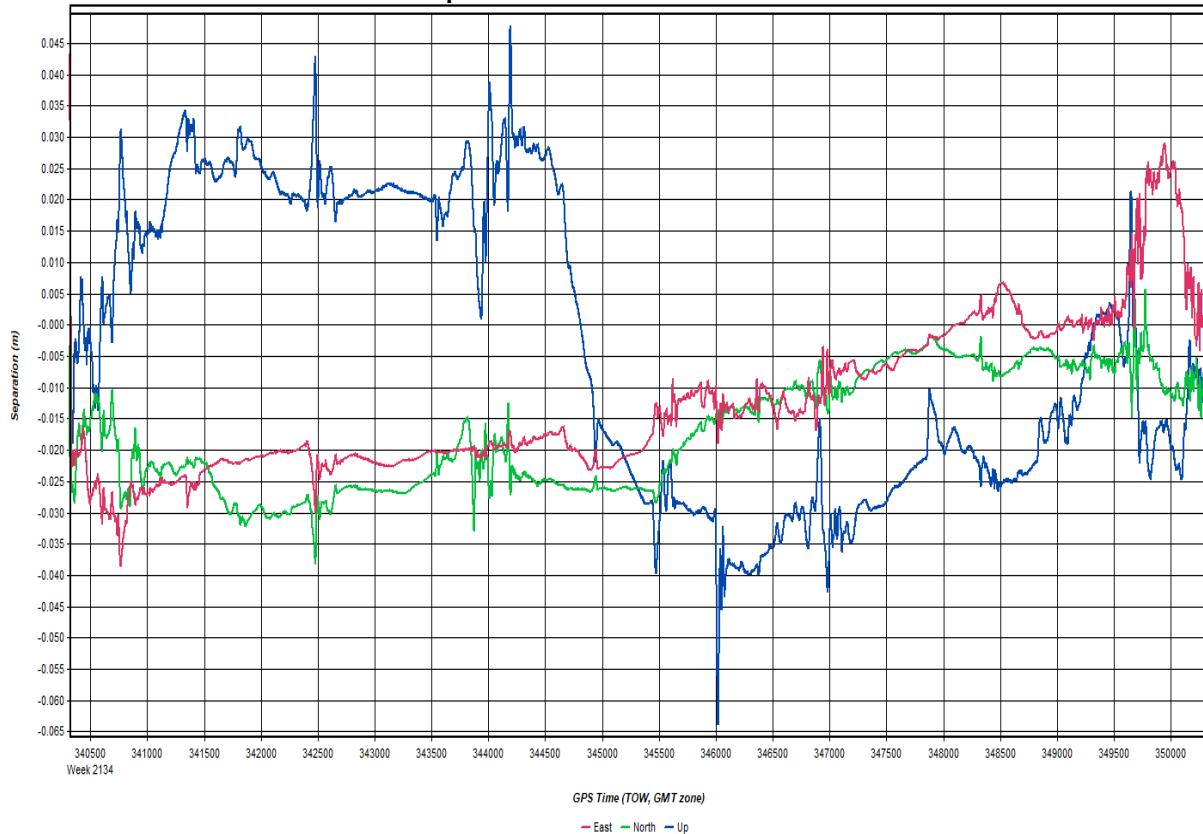
**Quality Factor Plot**



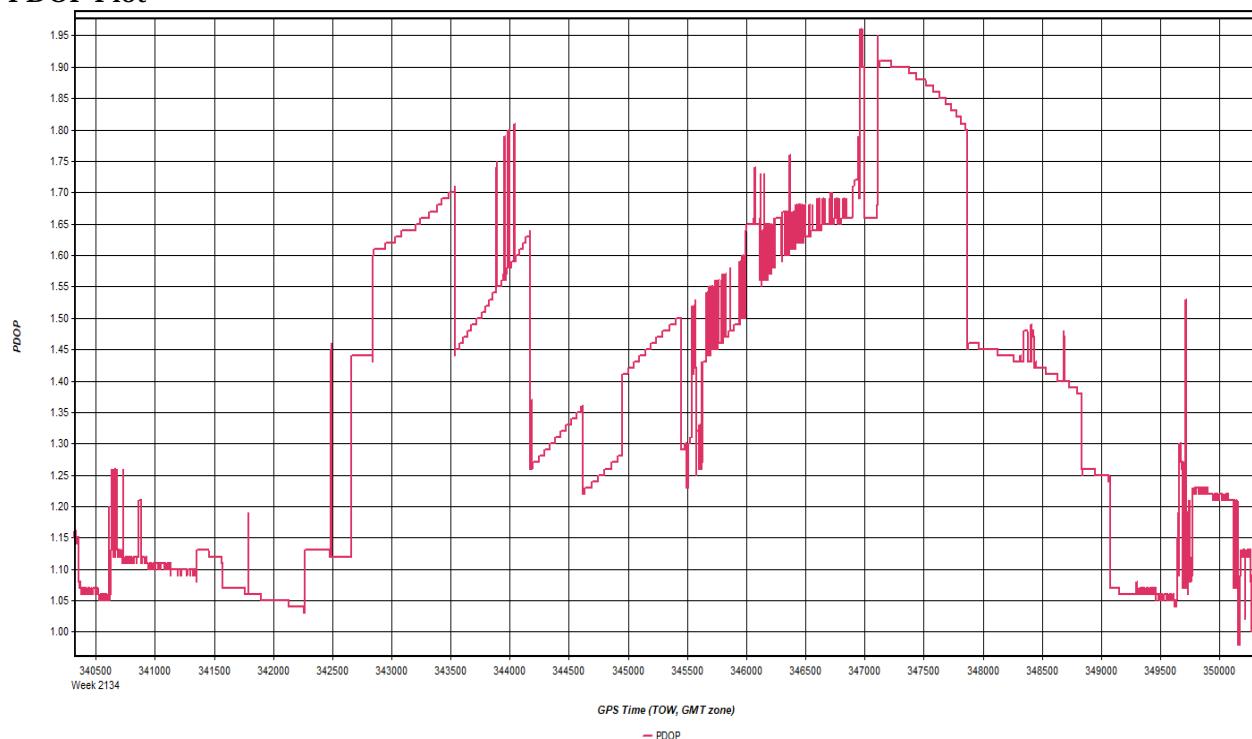
### Number of Satellites Plot



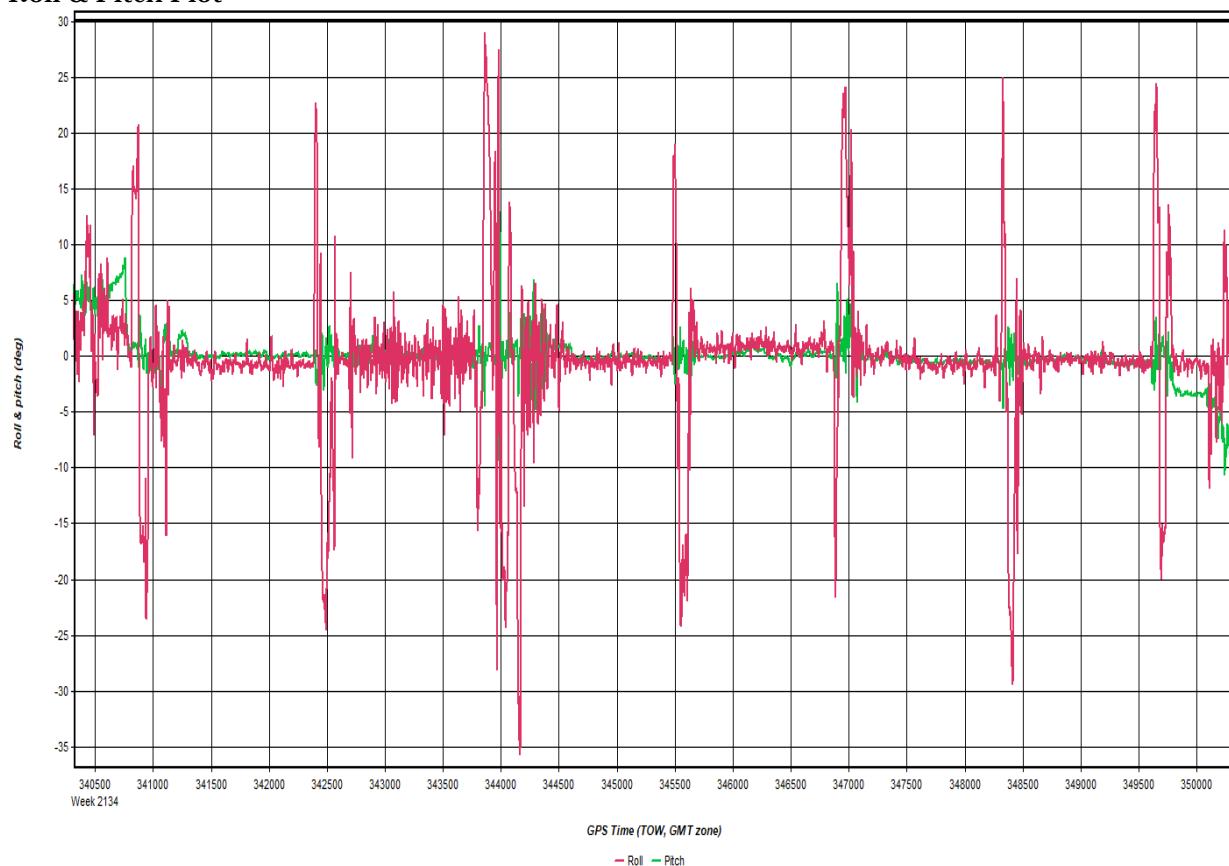
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

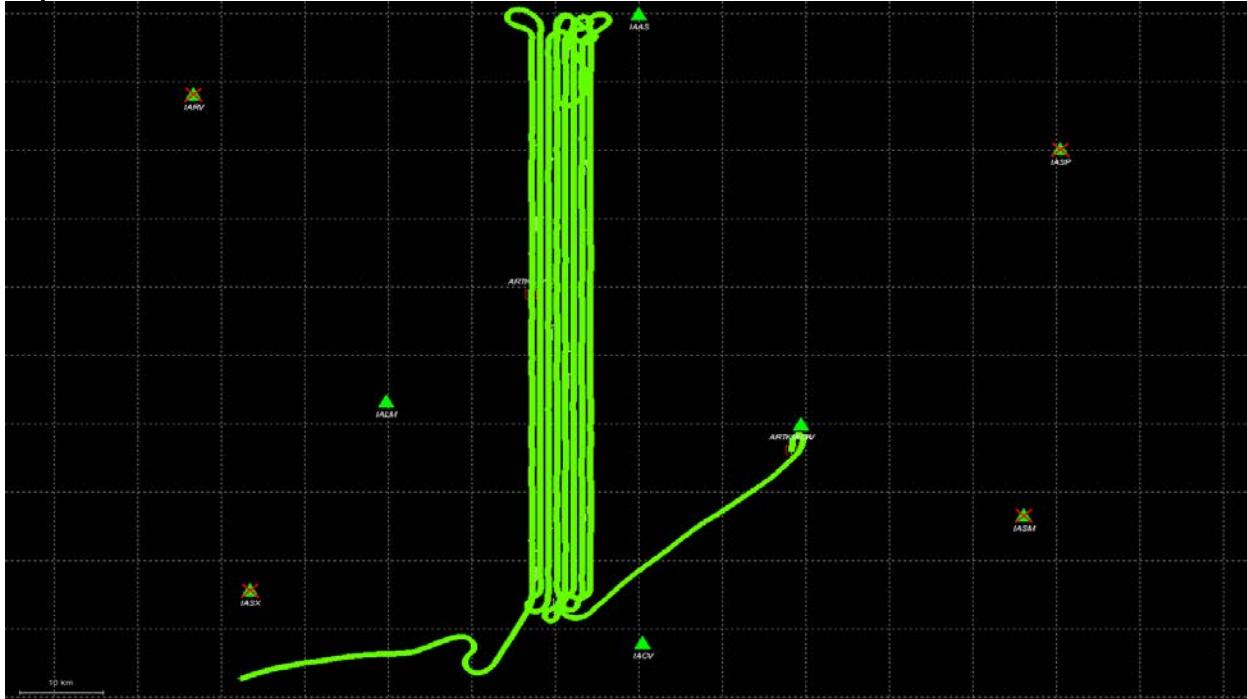


### Roll & Pitch Plot



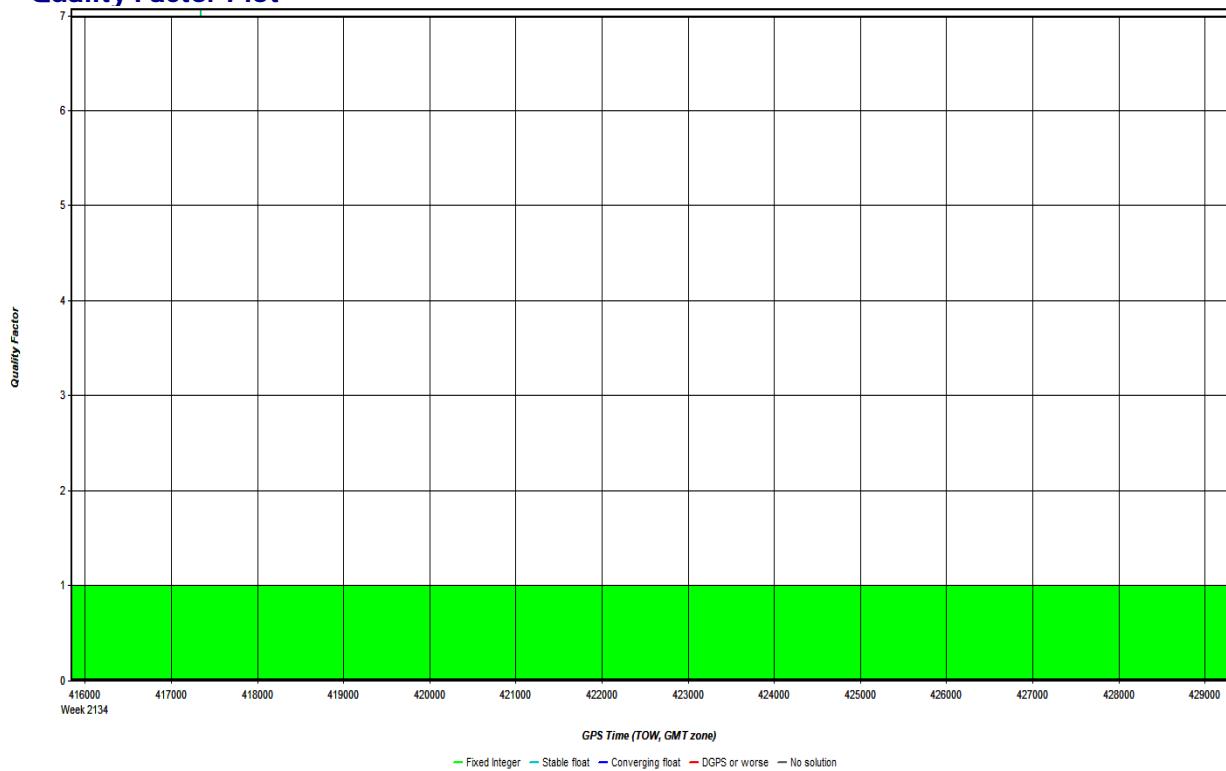
20201203\_192805.docx QC Report - 06/22/2021 10:31:54  
Smoothed Trajectory Information

Top View

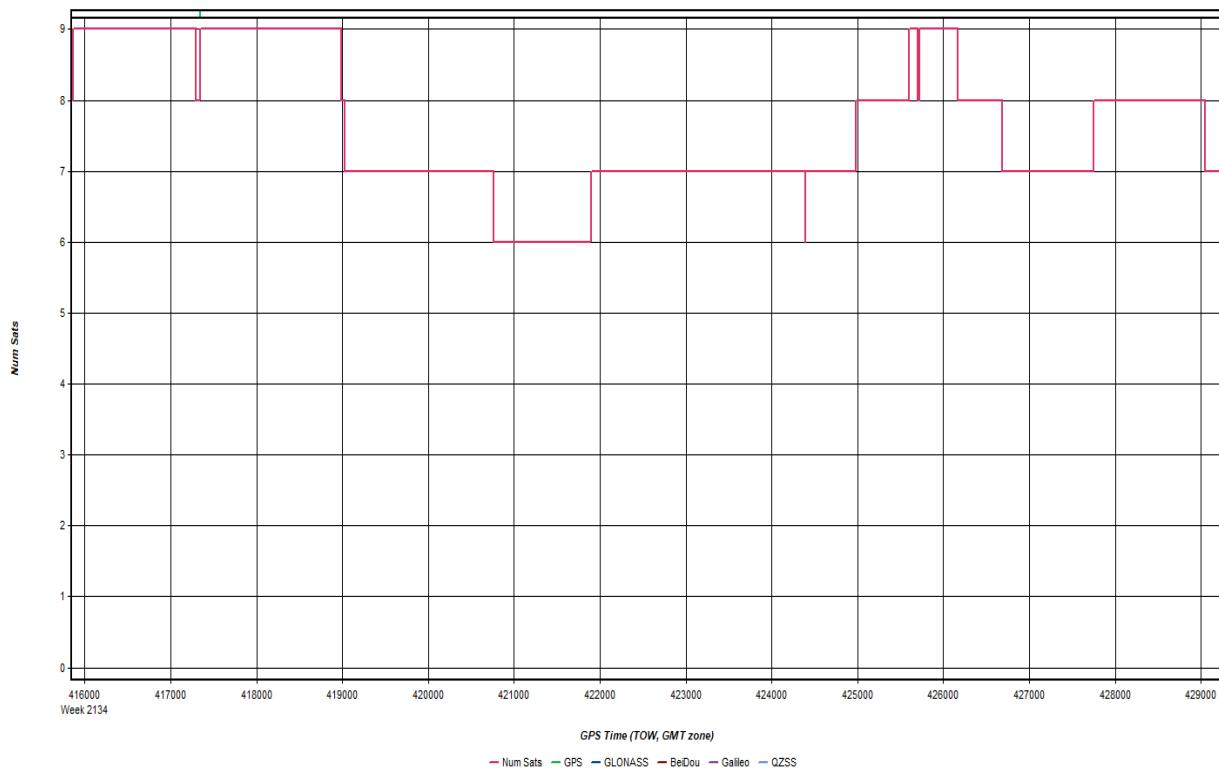


GNSS QC

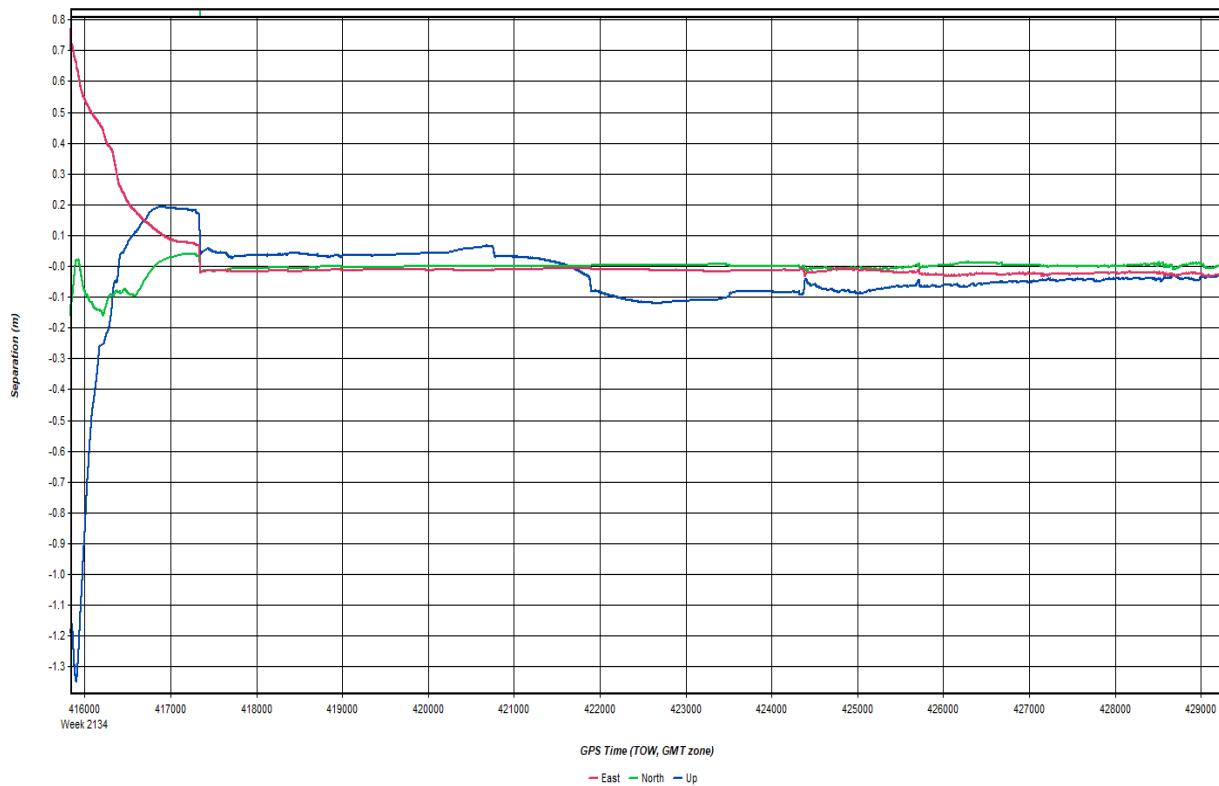
Quality Factor Plot



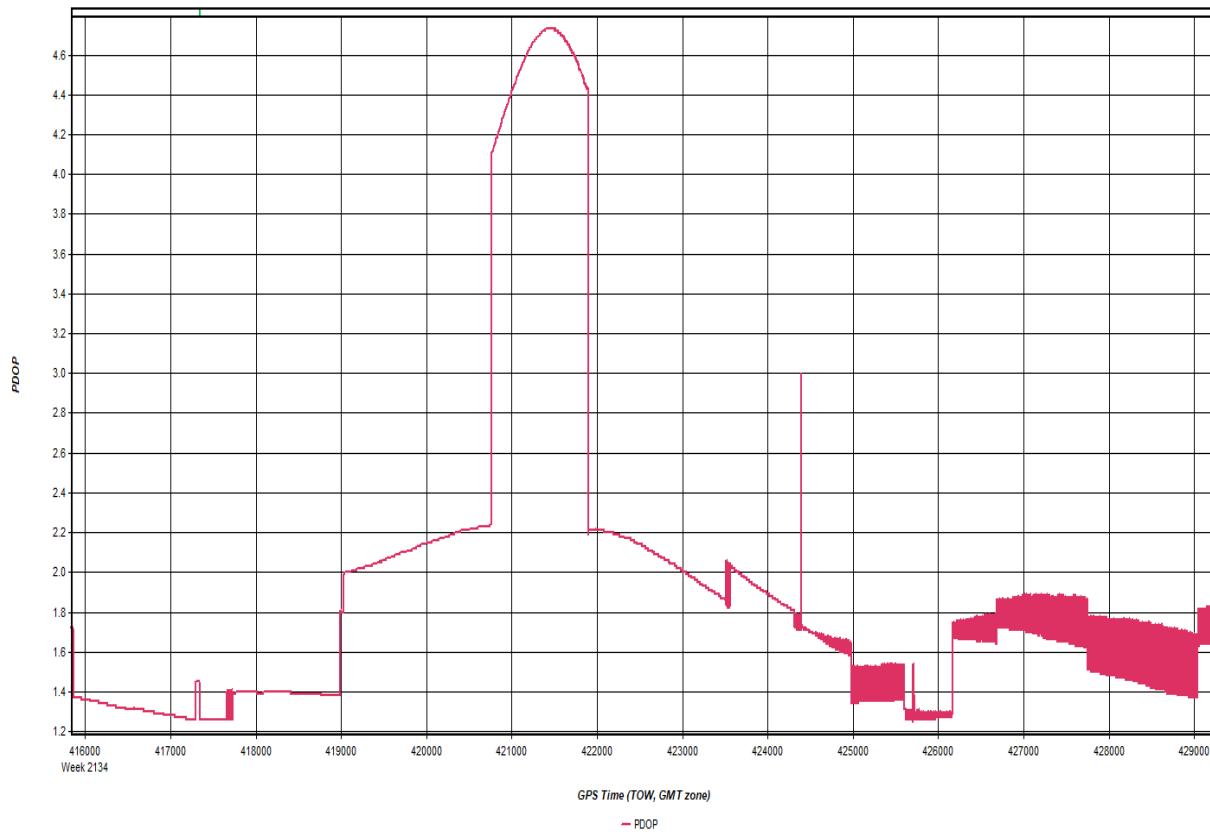
### Number of Satellites Plot



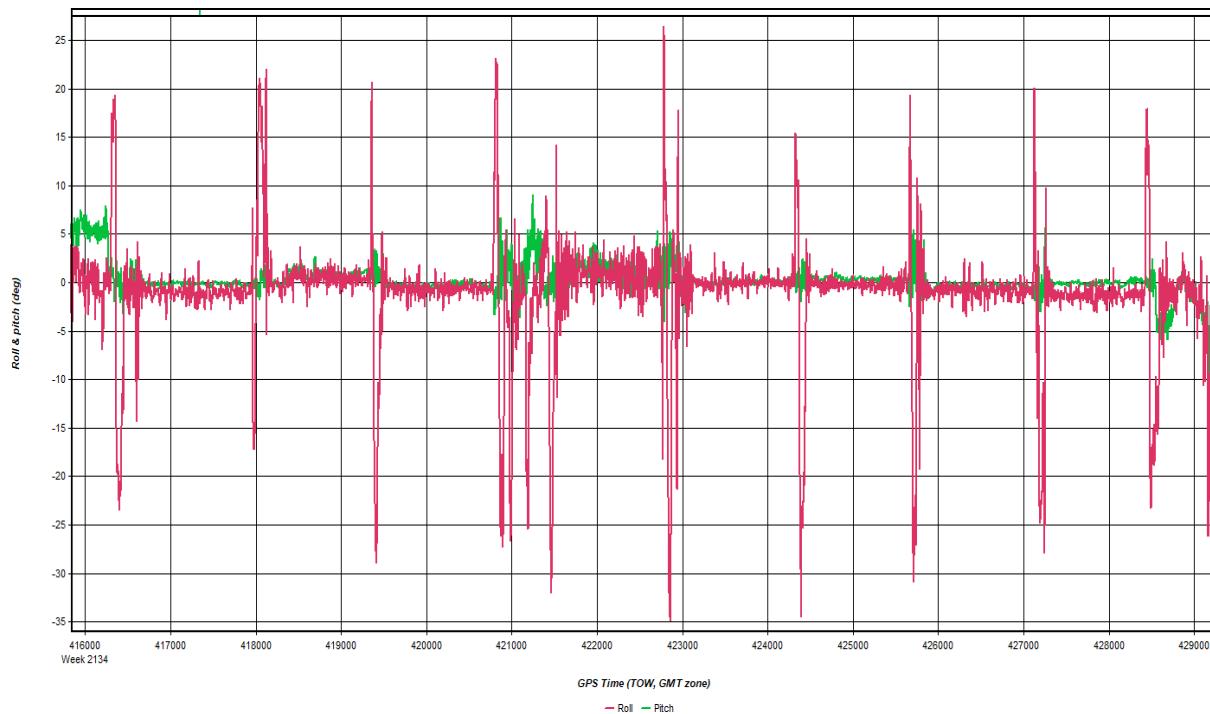
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

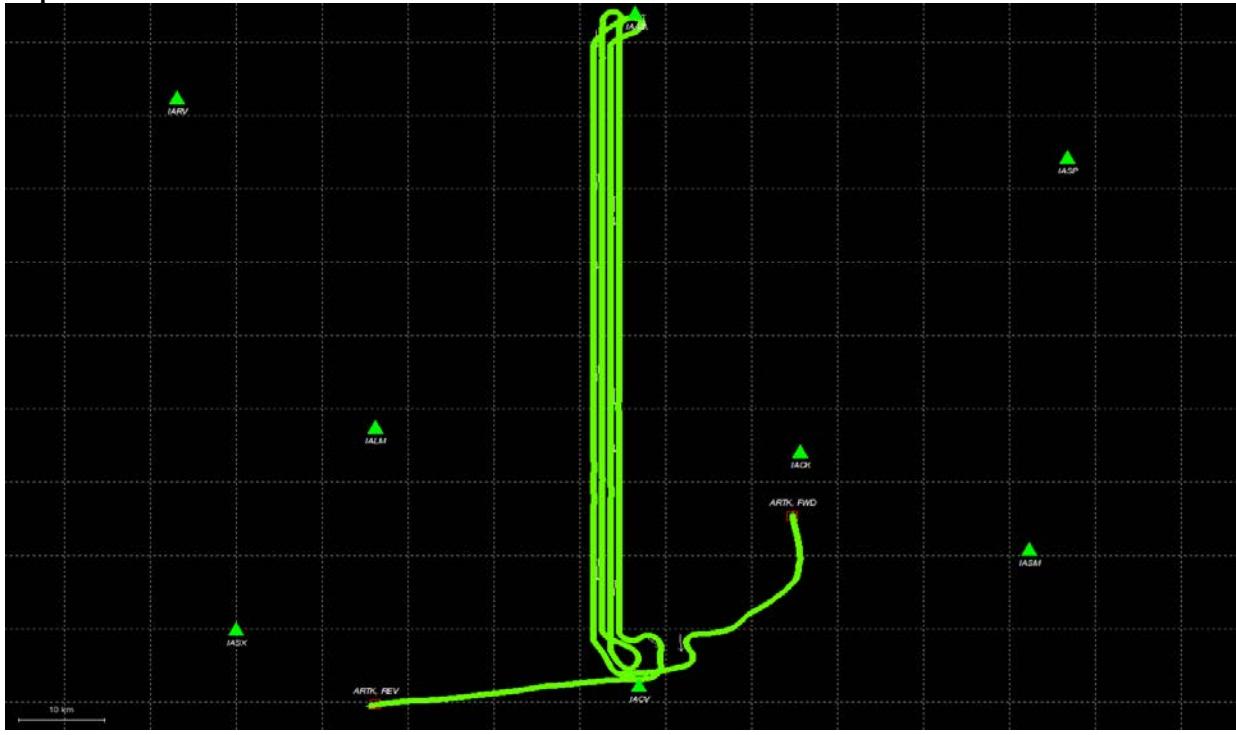


### Roll & Pitch Plot



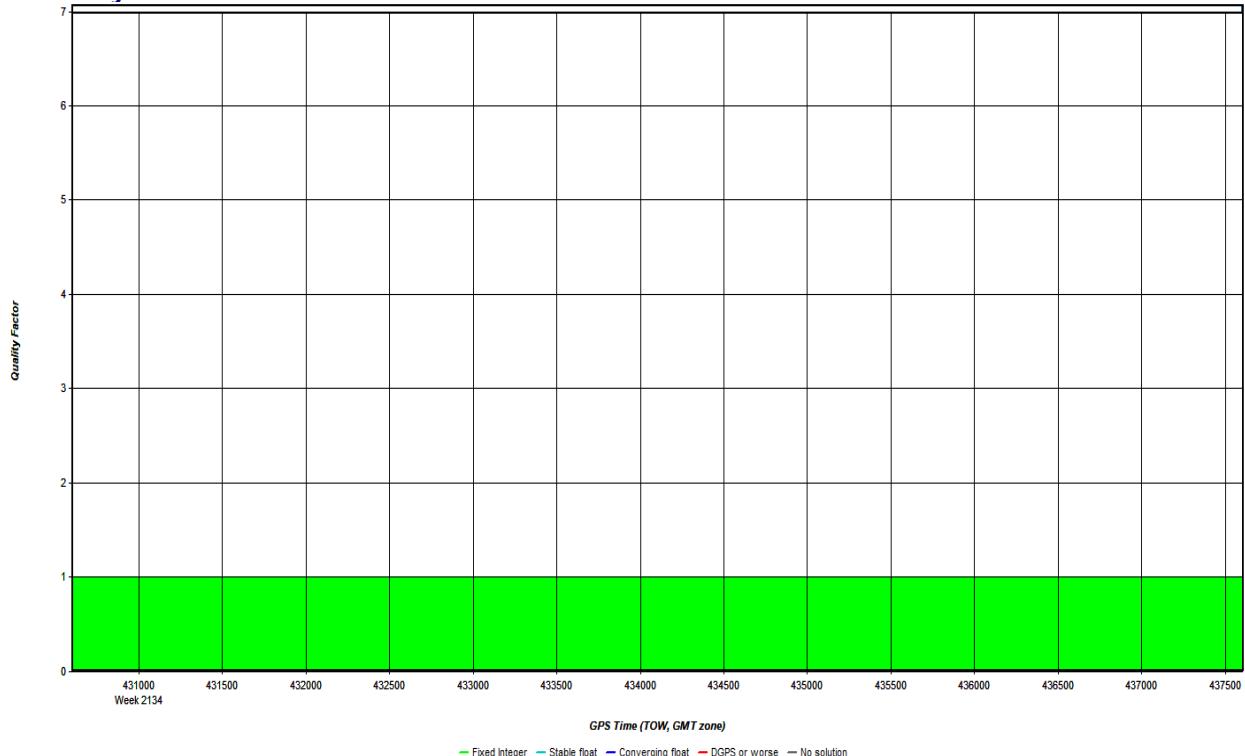
20201203\_233430.docx QC Report - 06/22/2021 10:34:32  
Smoothed Trajectory Information

Top View

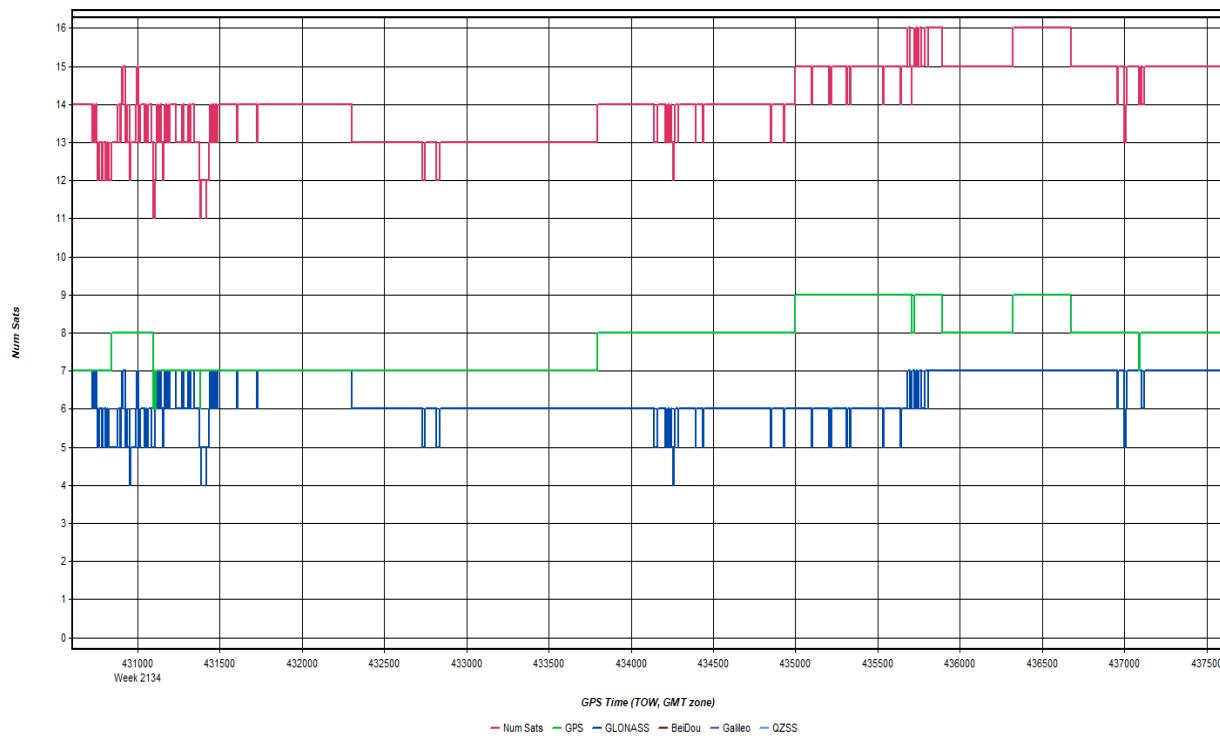


**GNSS QC**

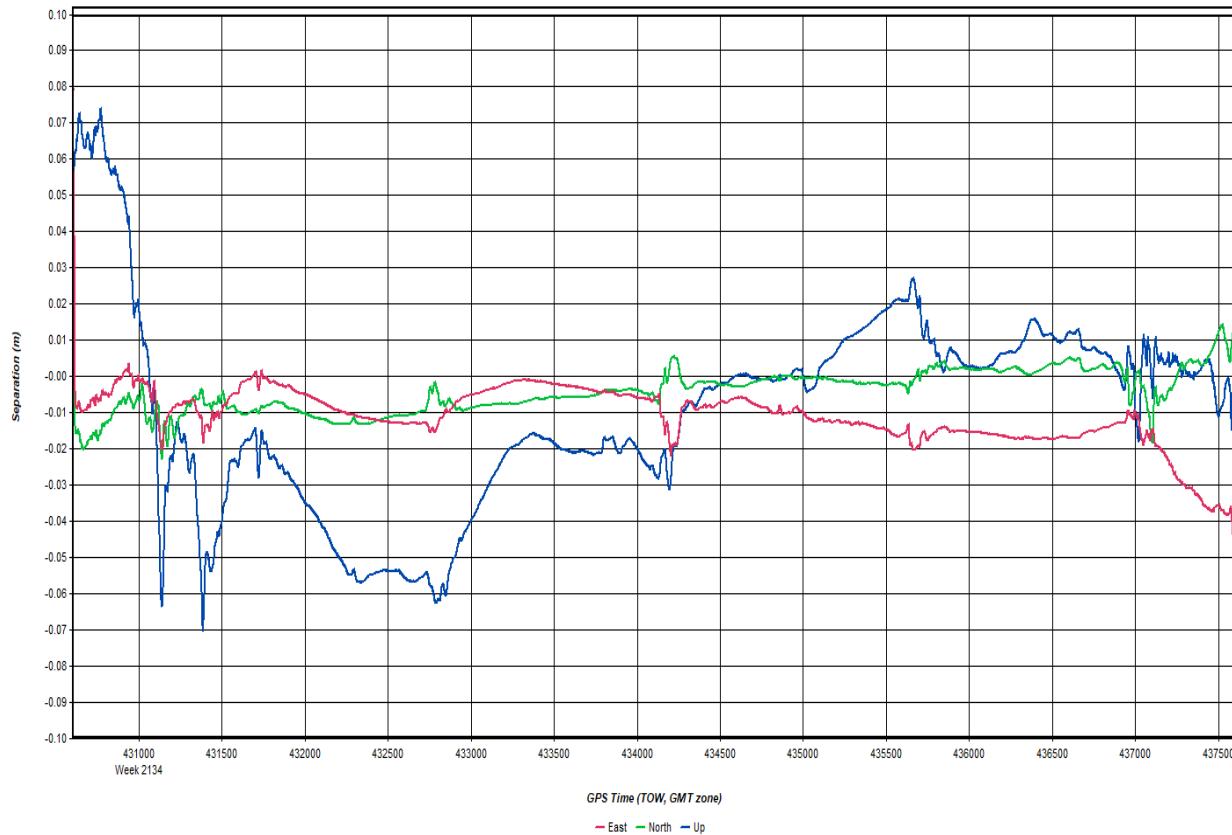
**Quality Factor Plot**



### Number of Satellites Plot

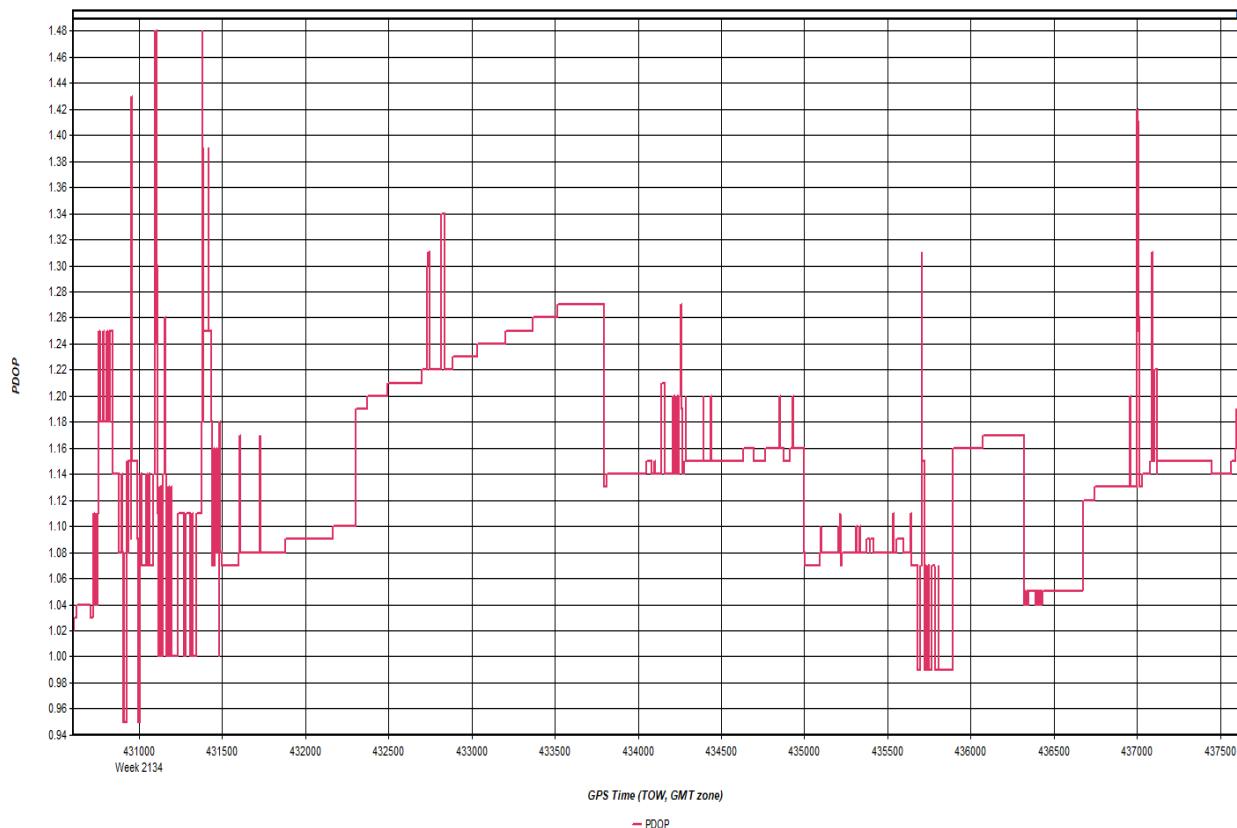


### Forward/Reverse or Combined Separation Plot

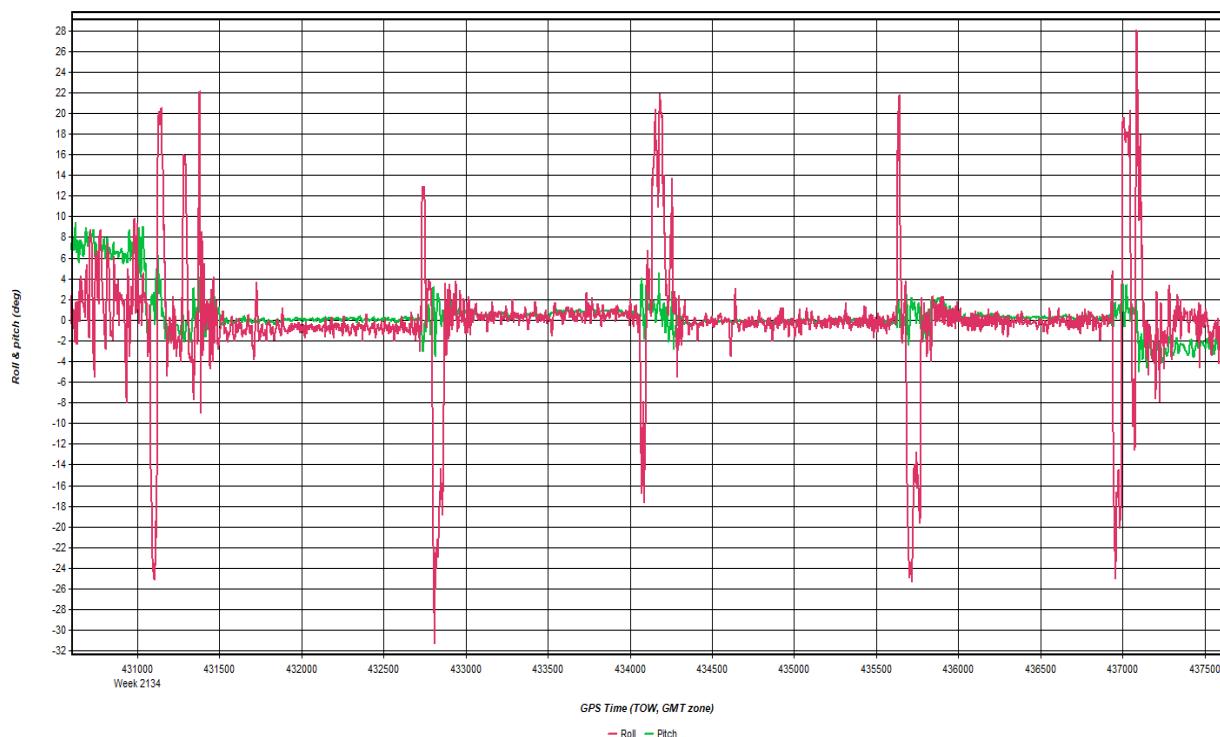


IA West 2020  
11/24/2021

## PDOP Plot

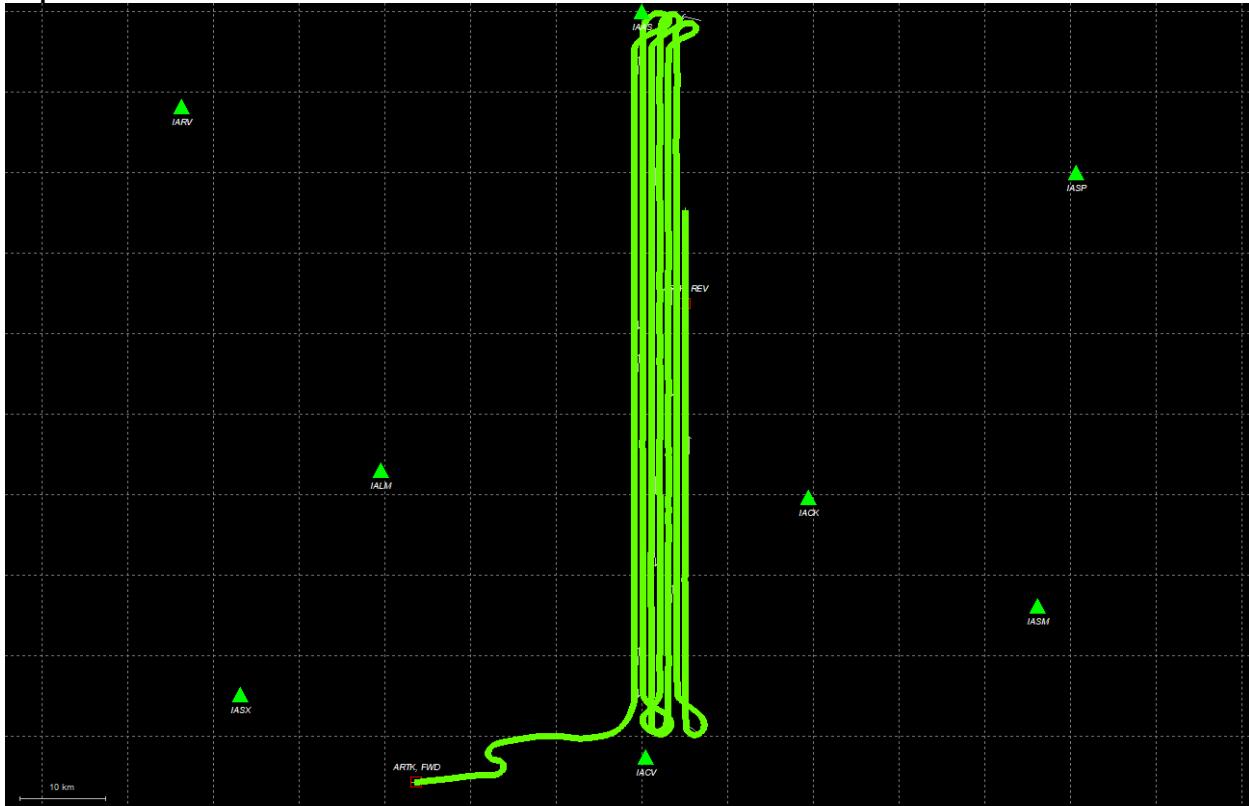


## Roll & Pitch Plot



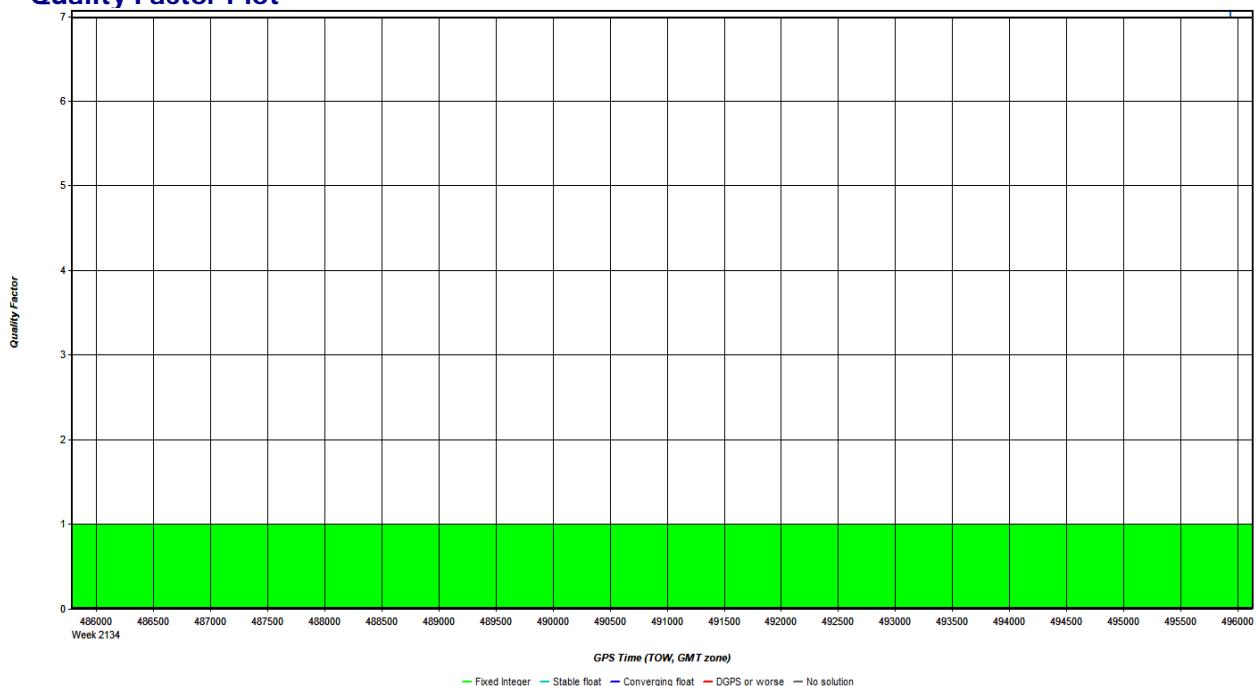
20201204\_145345.docx QC Report - 06/22/2021 10:34:32  
Smoothed Trajectory Information

Top View

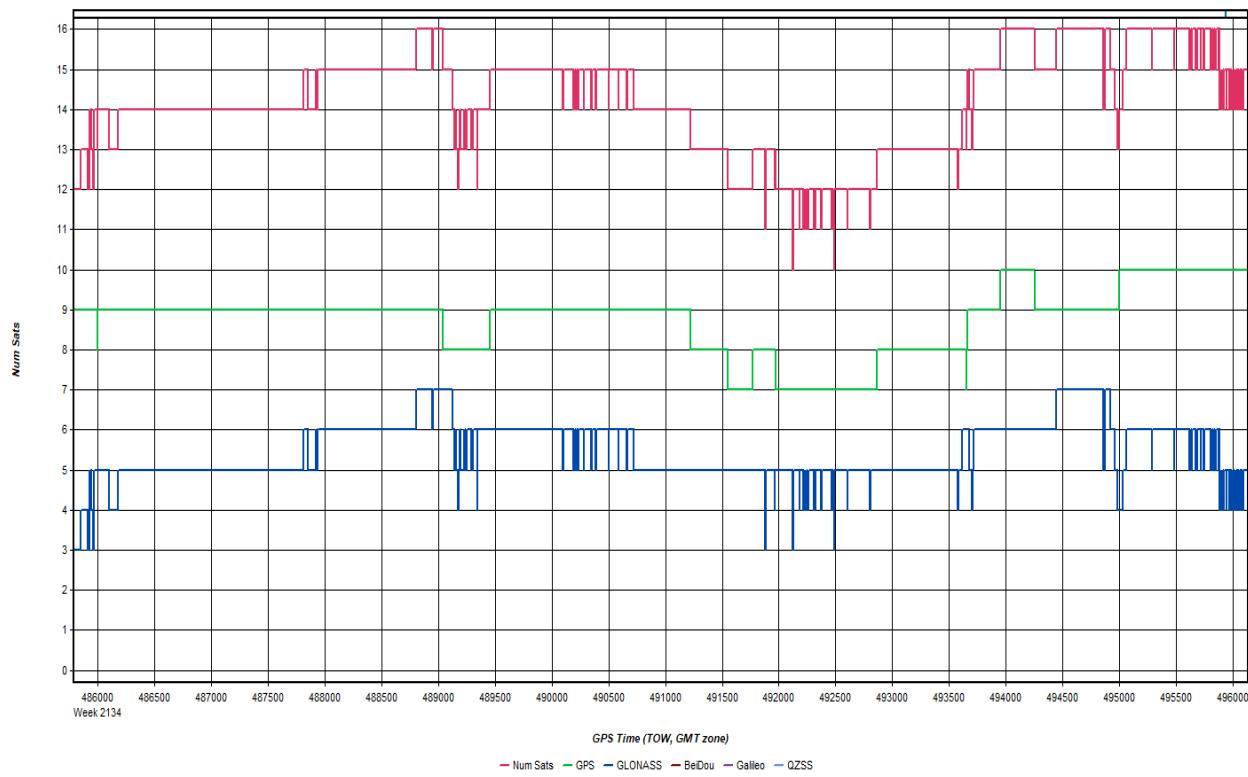


GNSS QC

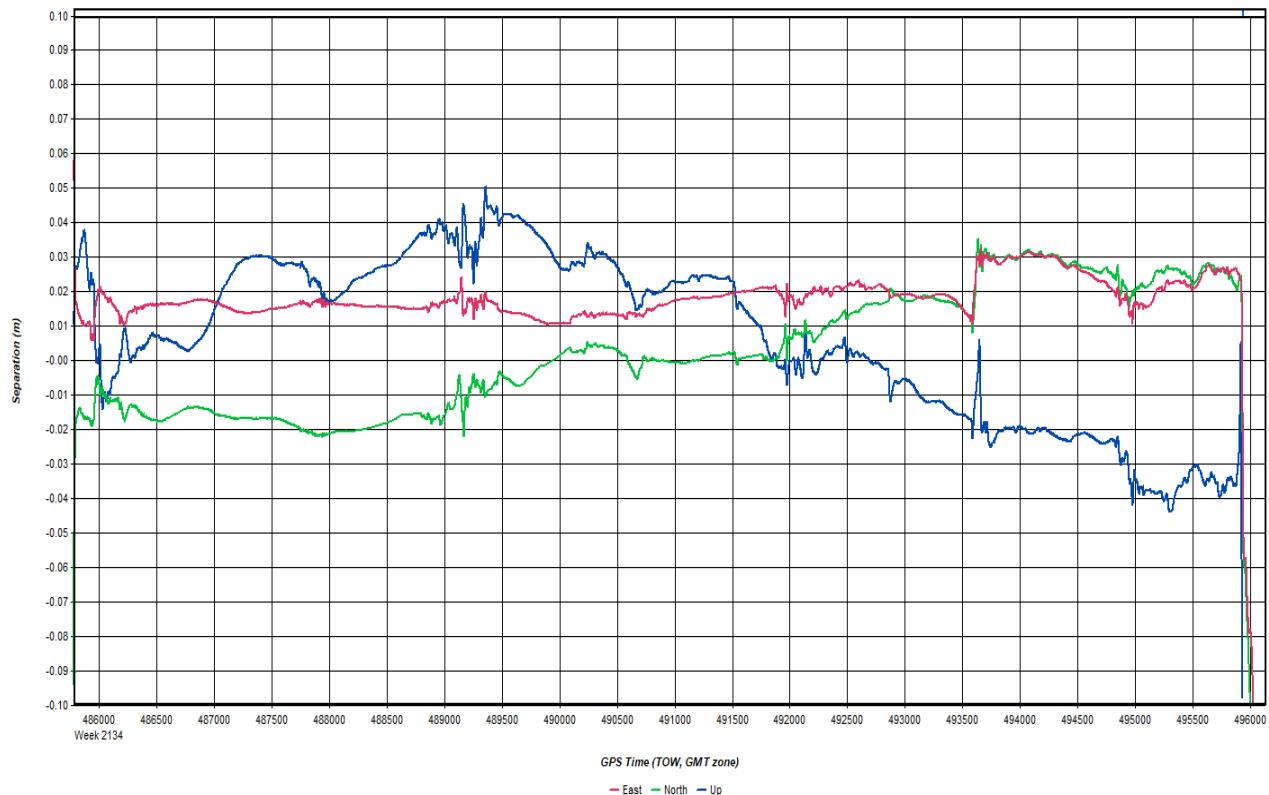
Quality Factor Plot



### Number of Satellites Plot

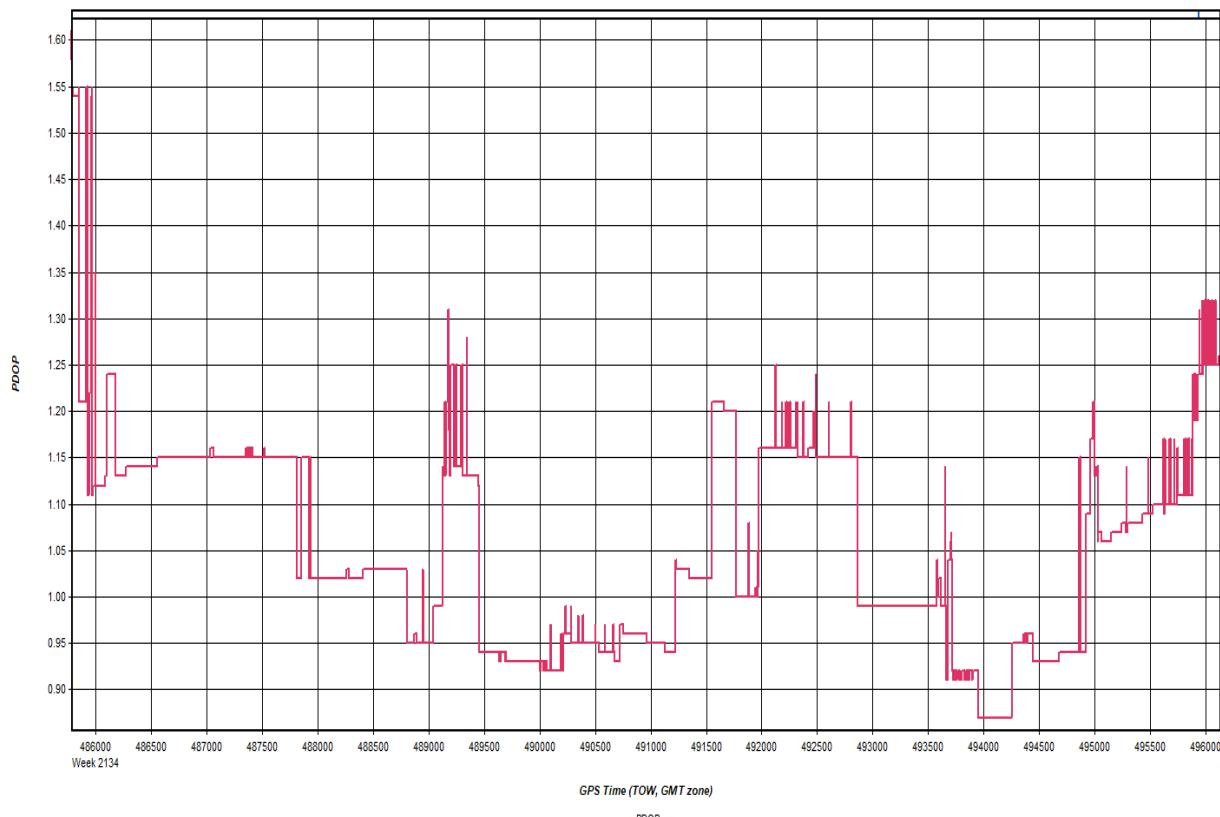


### Forward/Reverse or Combined Separation Plot

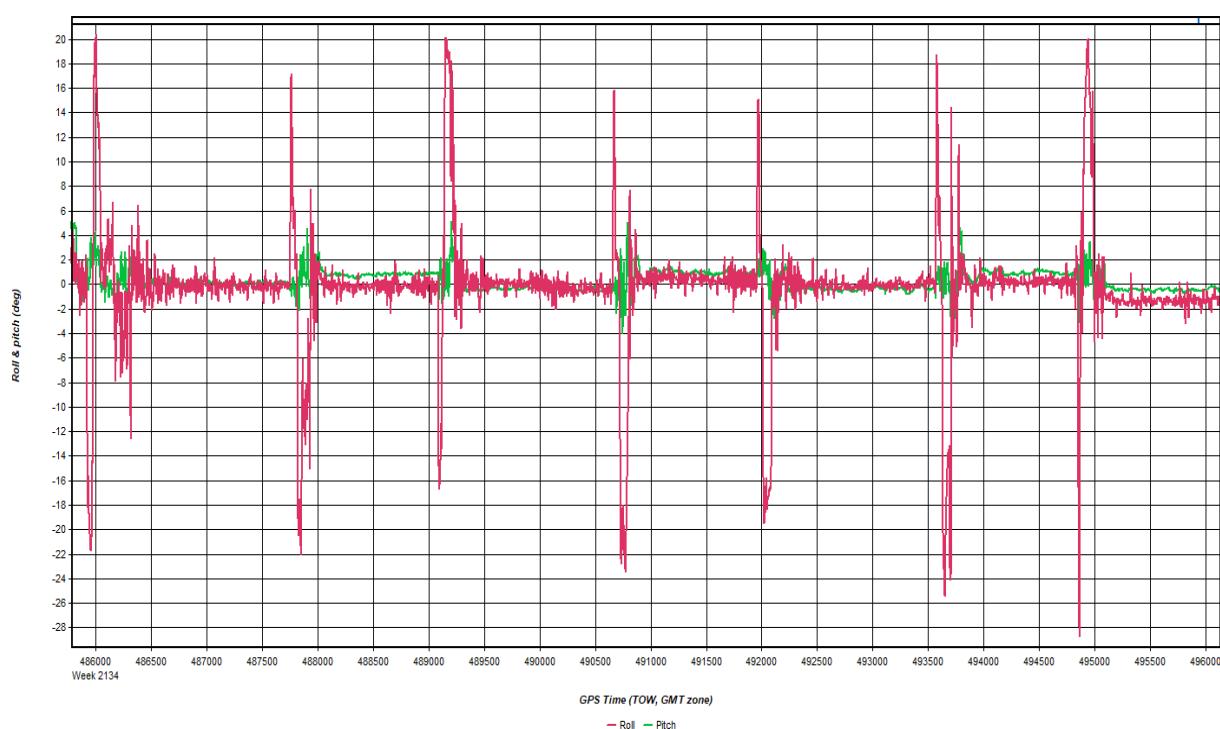


IA West 2020  
11/24/2021

### PDOP Plot

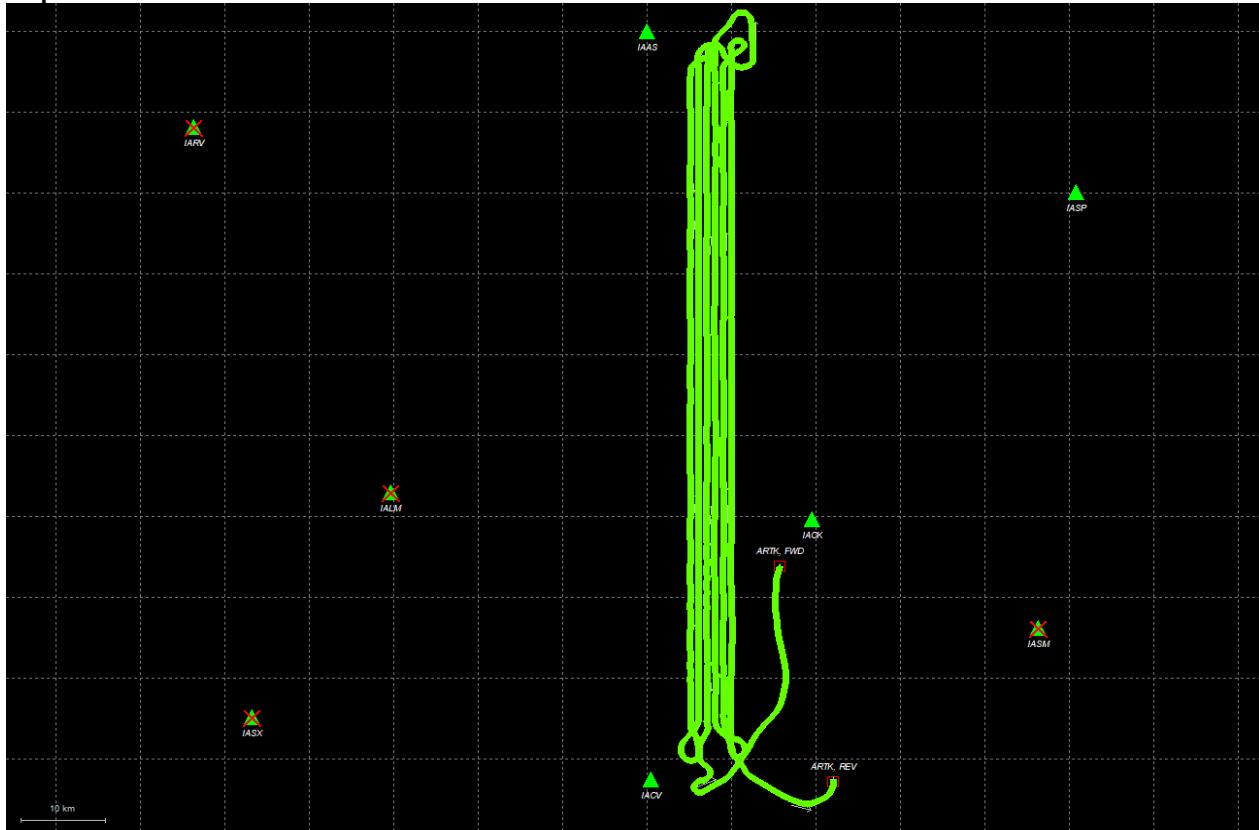


### Roll & Pitch Plot



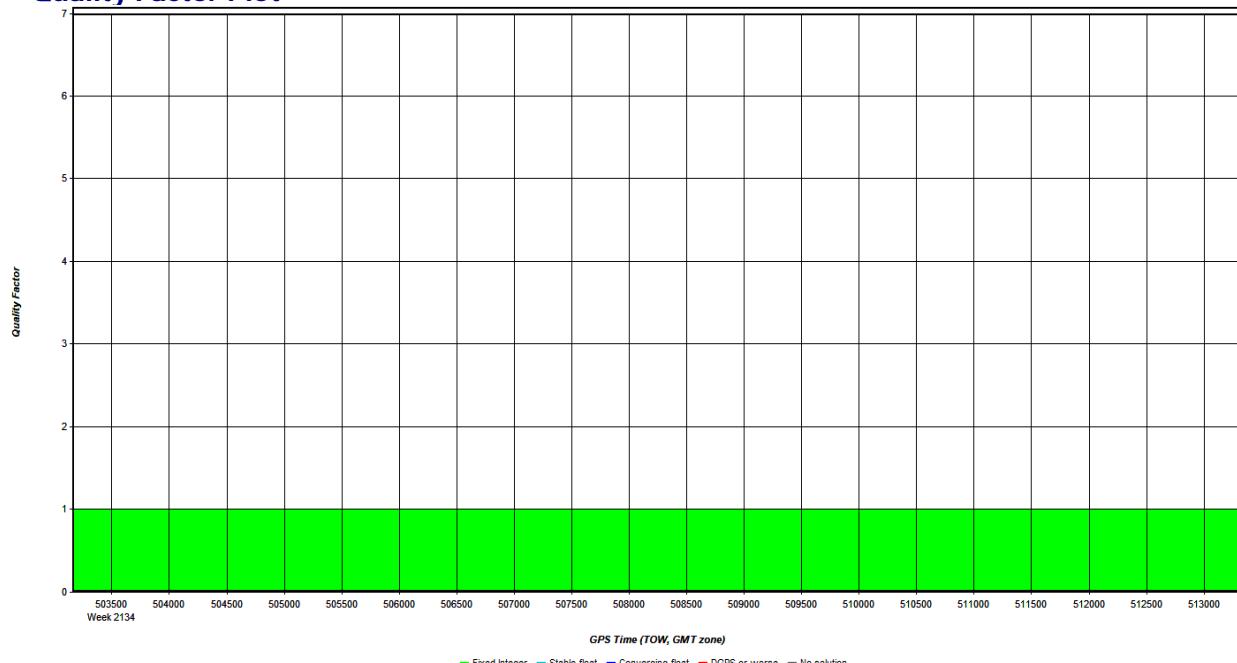
20201204\_194301.docx QC Report - 06/22/2021 10:41:18  
Smoothed Trajectory Information

Top View

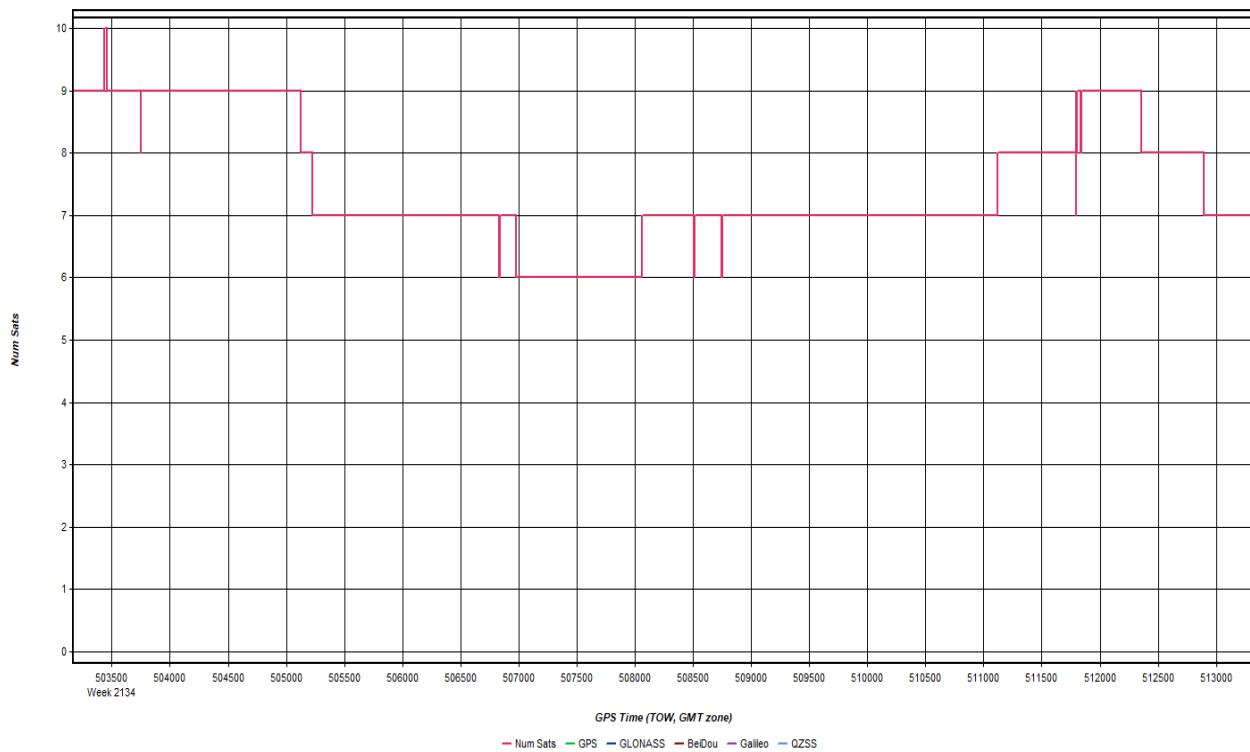


**GNSS QC**

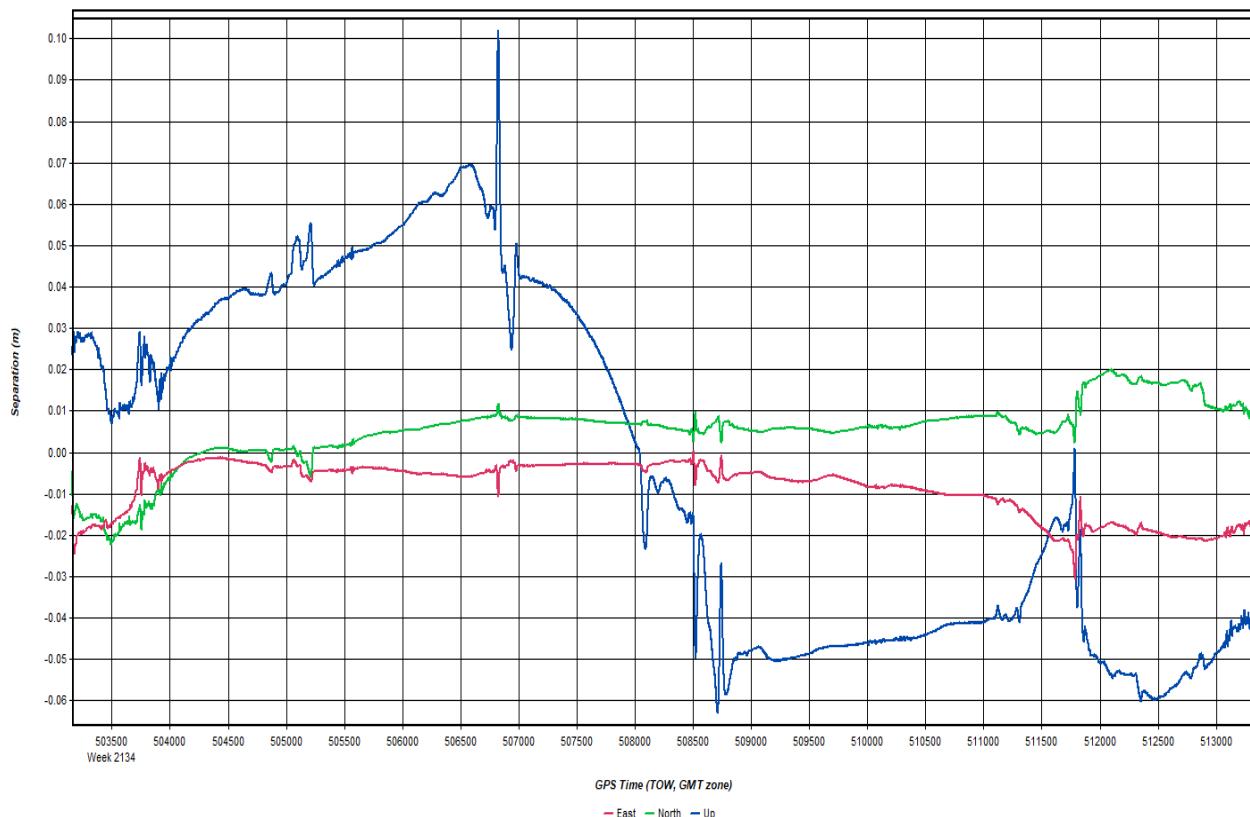
**Quality Factor Plot**



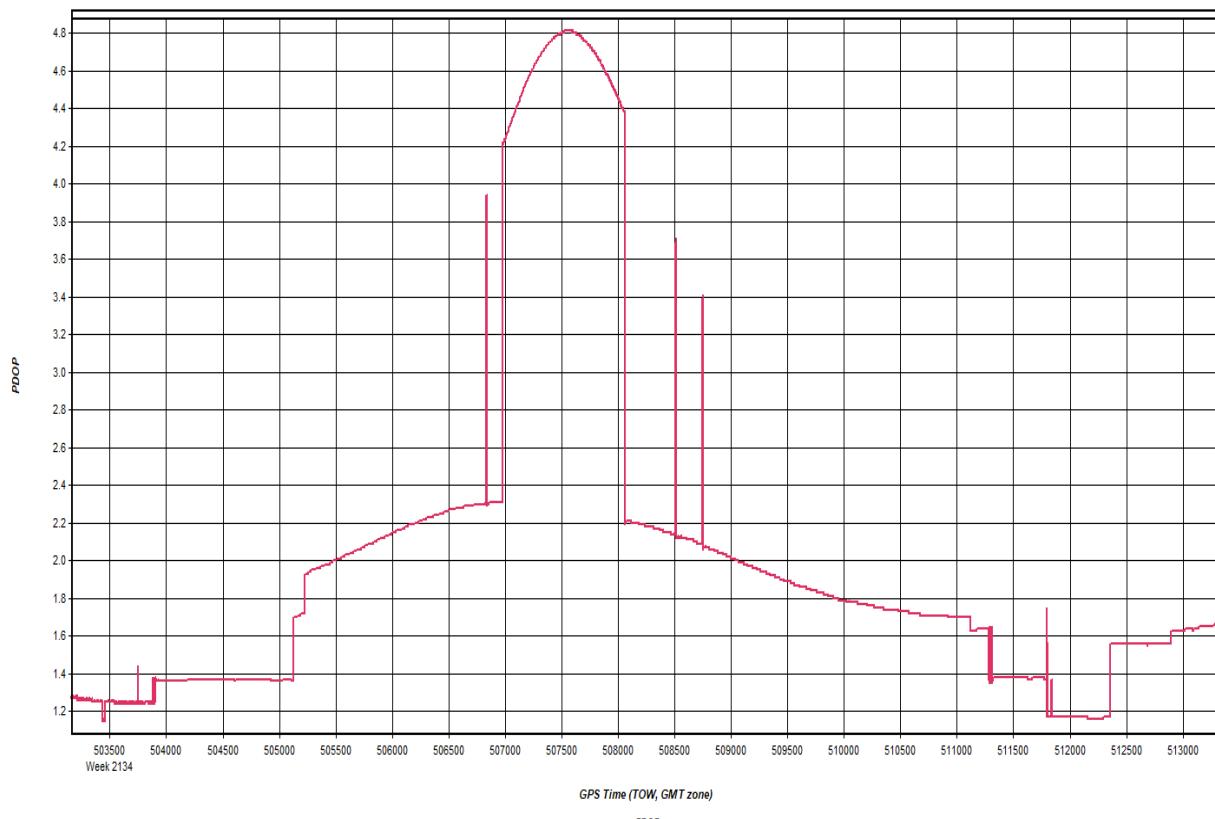
### Number of Satellites Plot



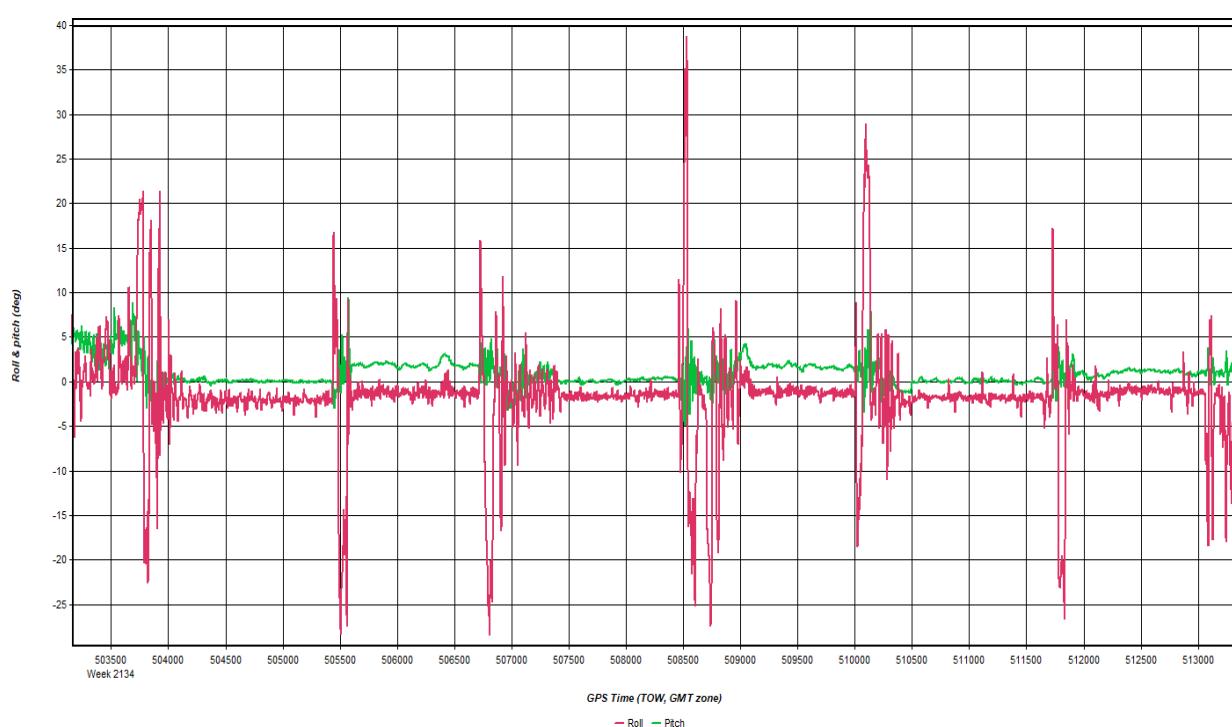
### Forward/Reverse or Combined Separation Plot



### PDOP Plot

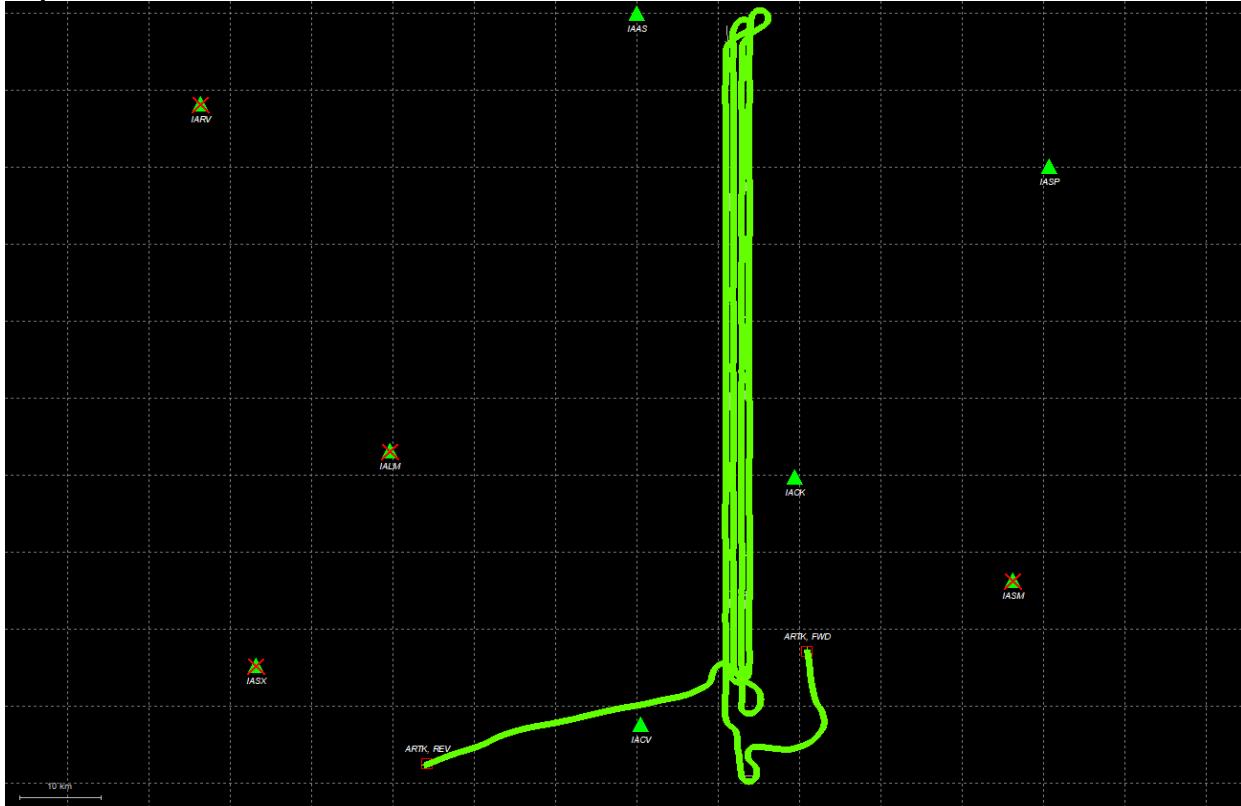


### Roll & Pitch Plot



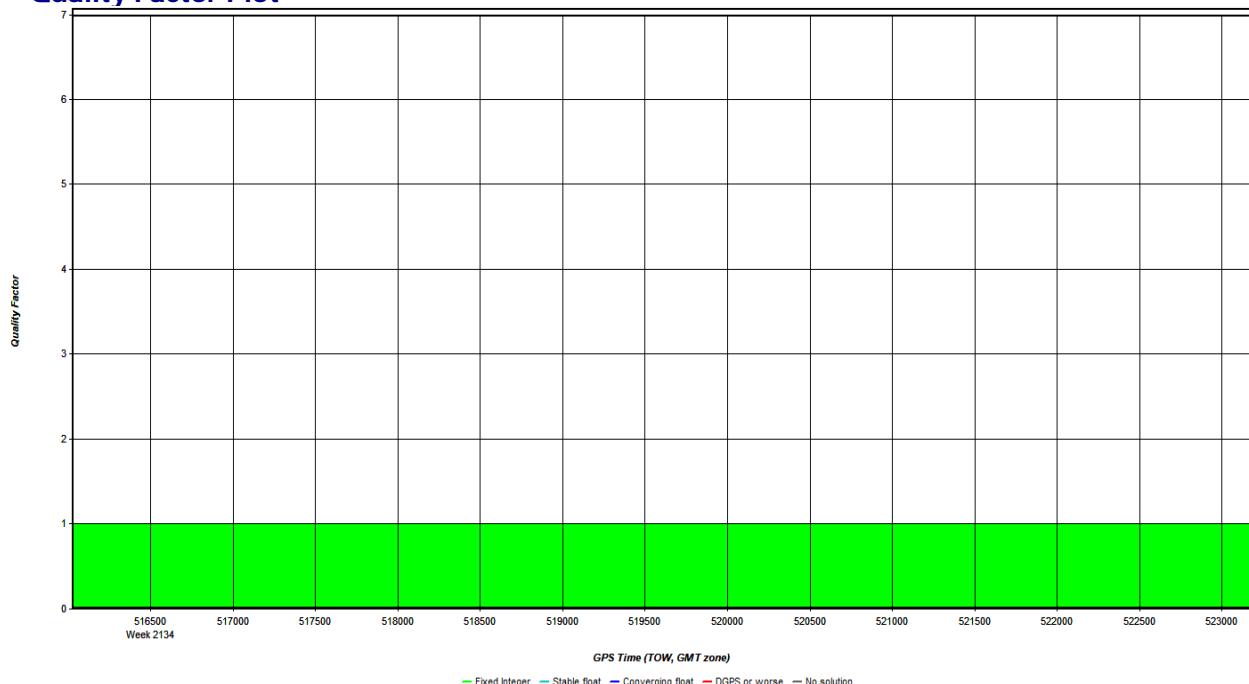
20201204\_231634.docx QC Report - 06/22/2021 10:45:25  
Smoothed Trajectory Information

Top View

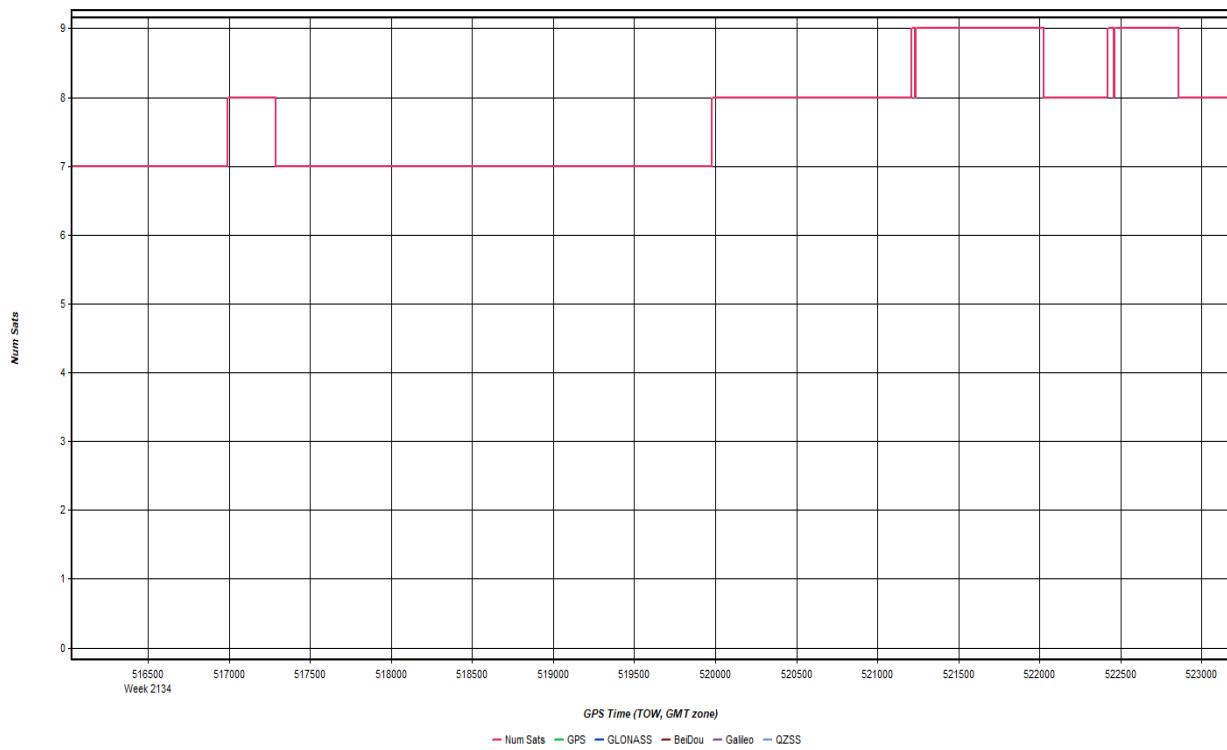


**GNSS QC**

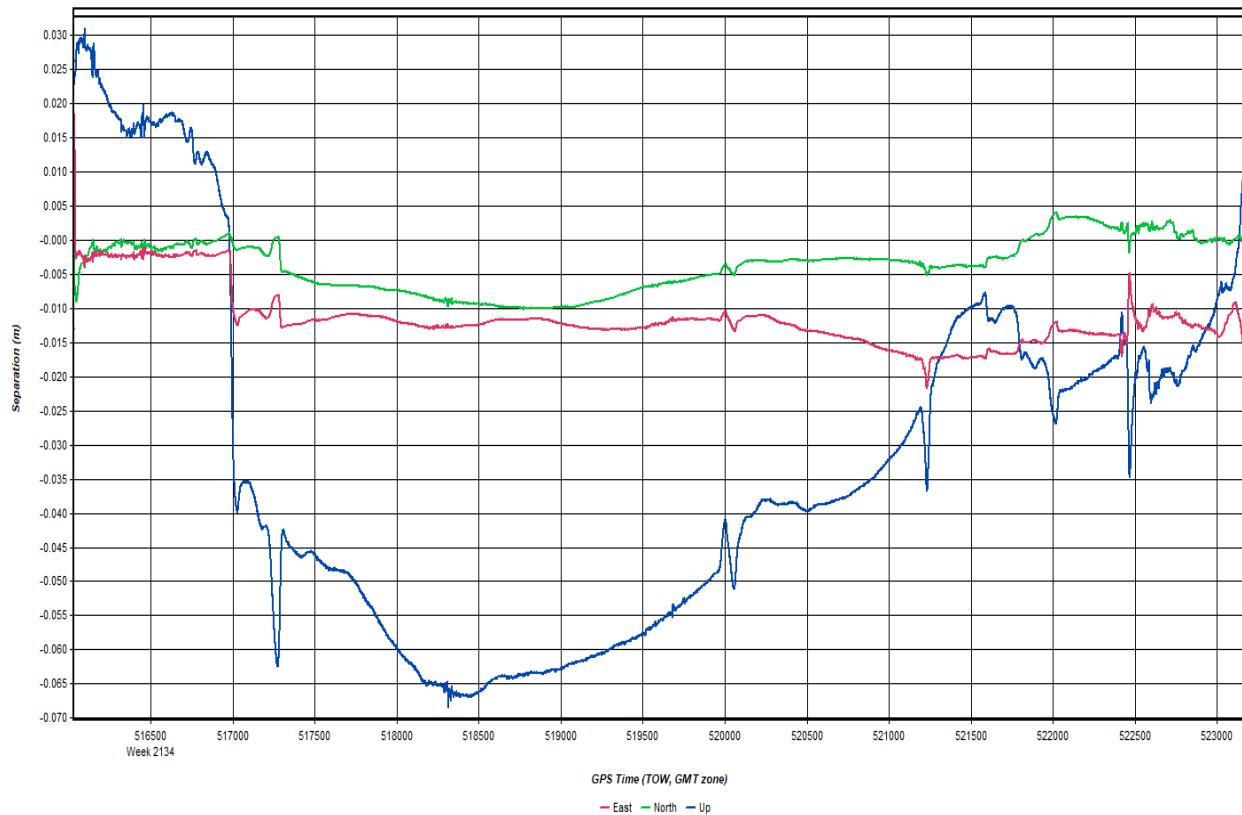
**Quality Factor Plot**



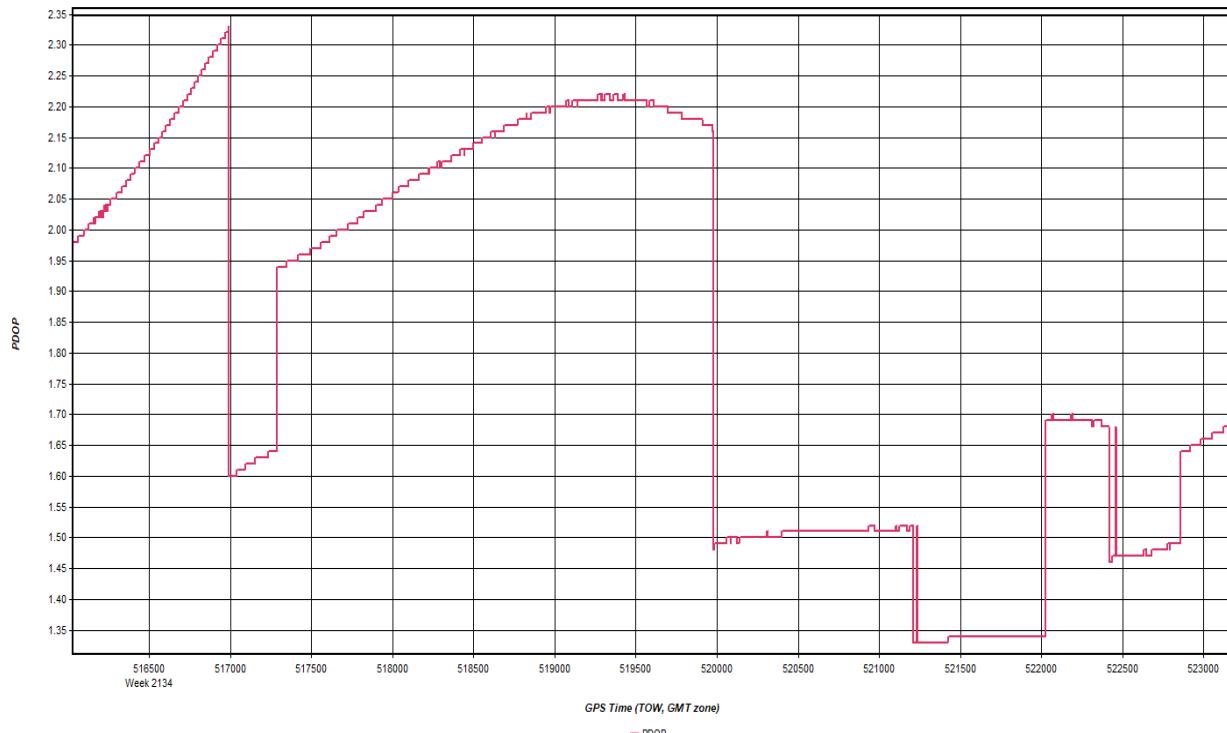
### Number of Satellites Plot



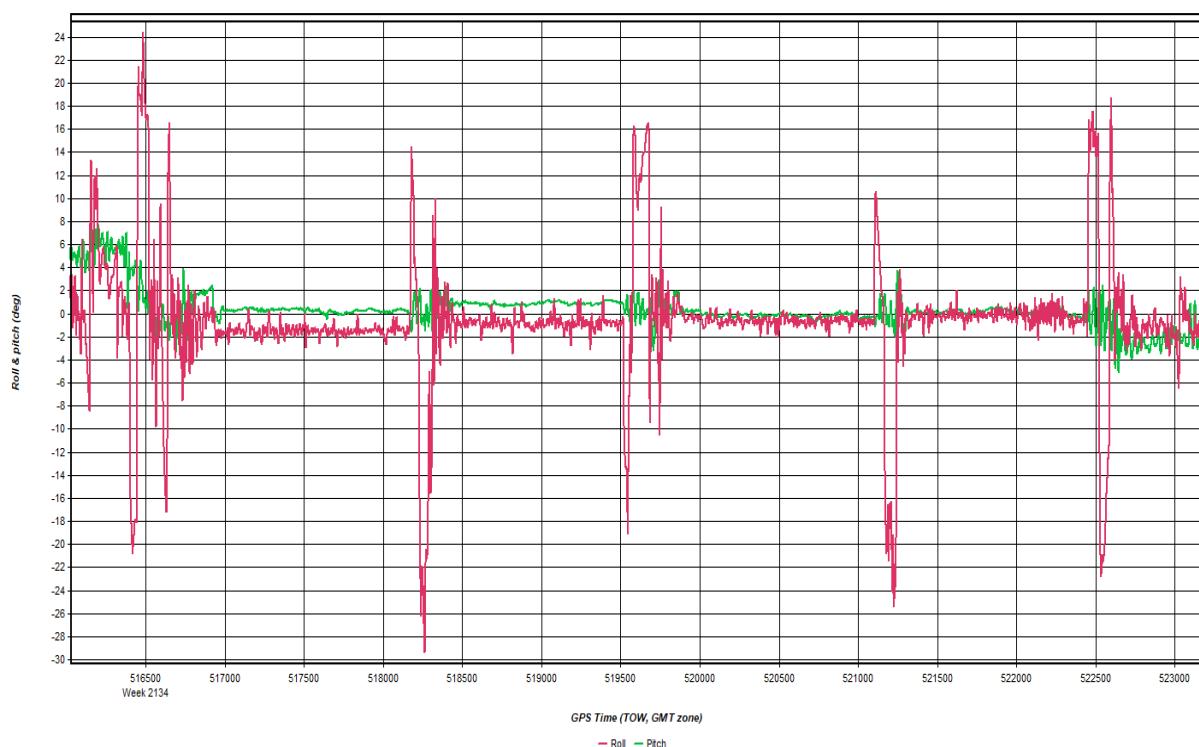
### Forward/Reverse or Combined Separation Plot



### PDOP Plot



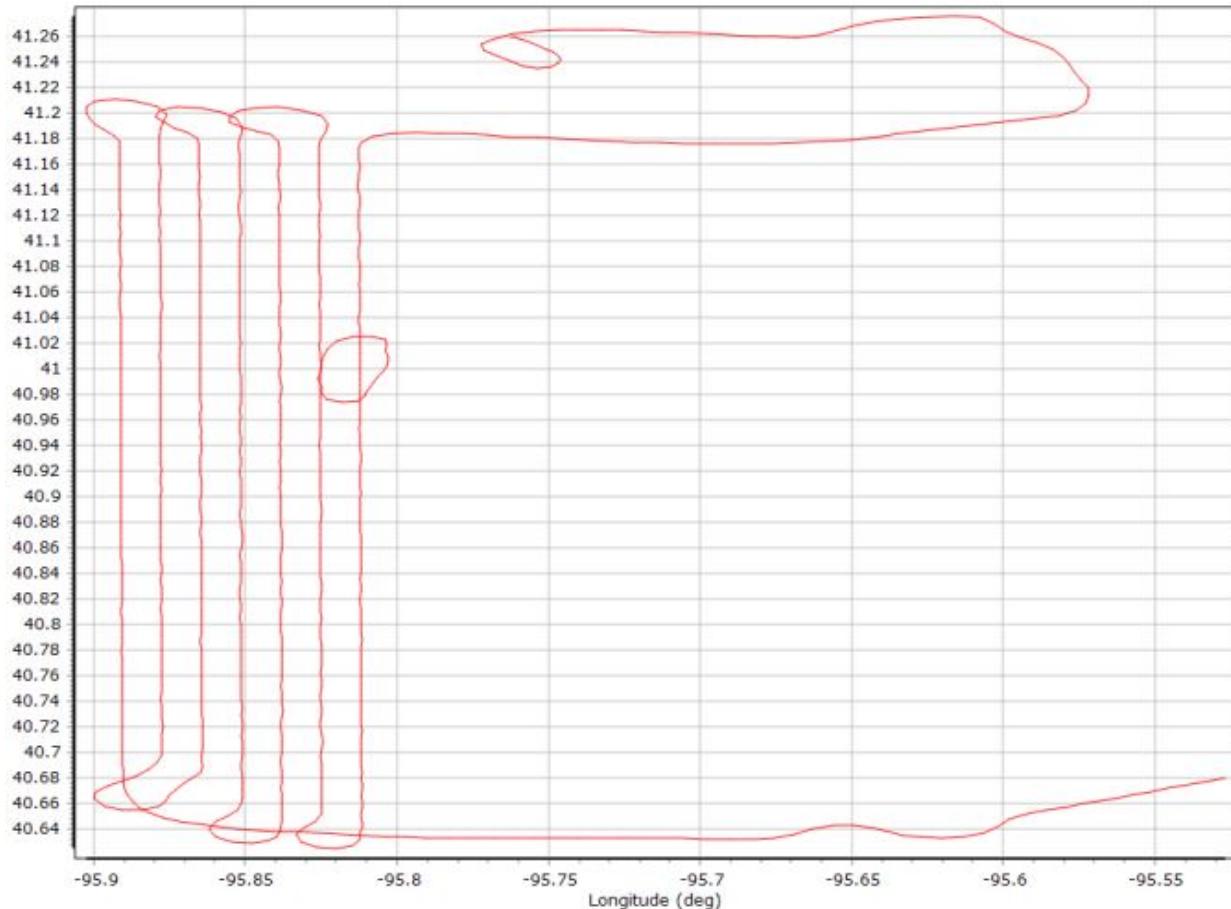
### Roll & Pitch Plot



**TAC Reports for Block A.**

20201205\_1\_QC Report.docx QC Report – 8/27/2021 07:28:24  
Smoothed Trajectory Information

Top View

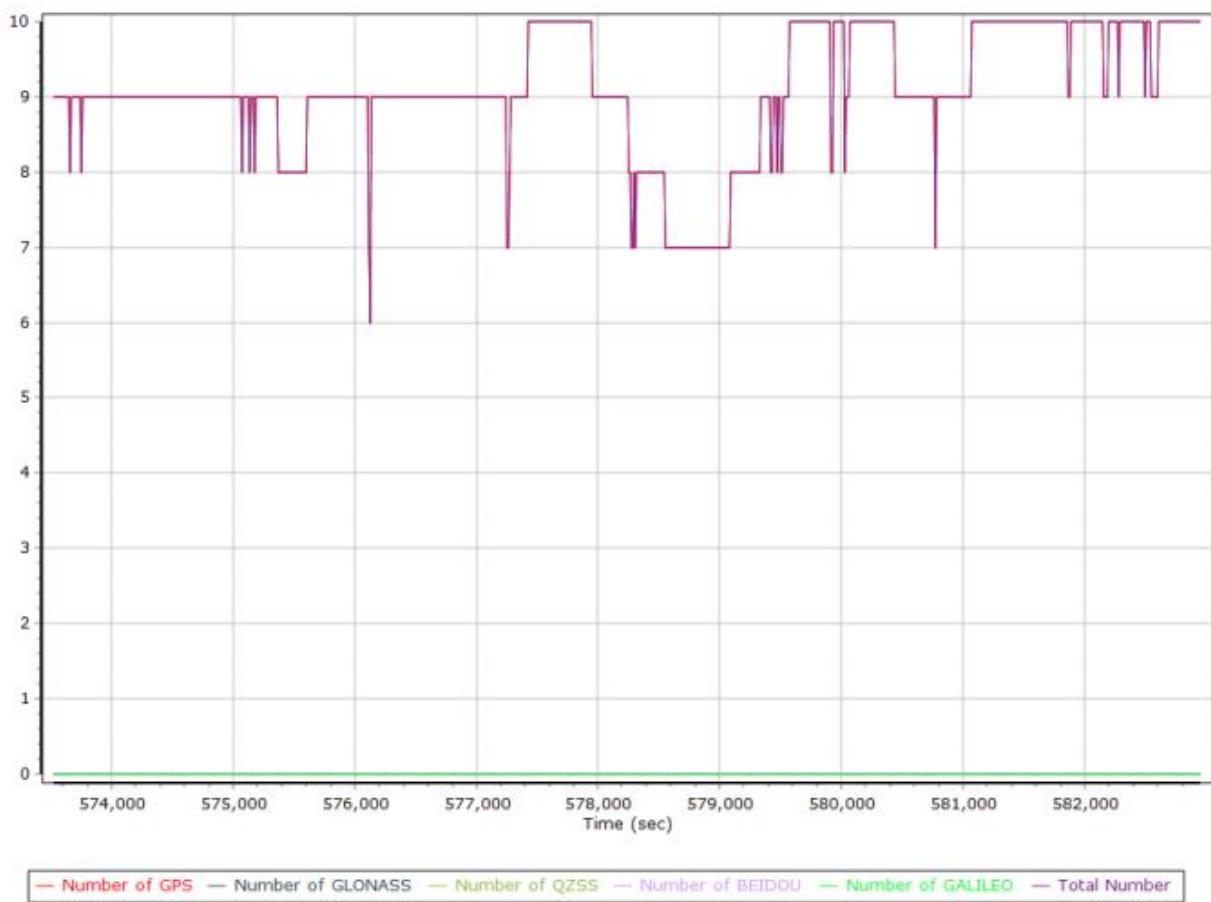


## GNSS QC

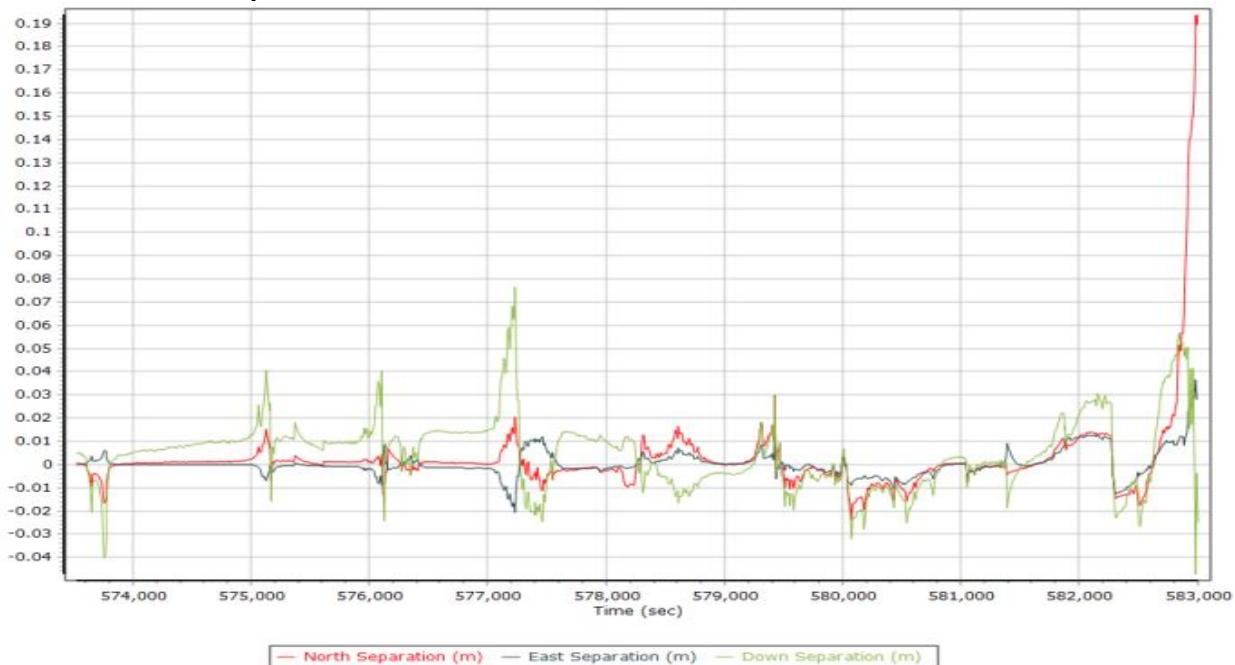
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.28	41.81	
Number of GPS SV	5	10	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	10	9
PDOP	1.53	6.02	1.78
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	9499.00	0.00	0.00
Percentage	100.00	0.00	0.00

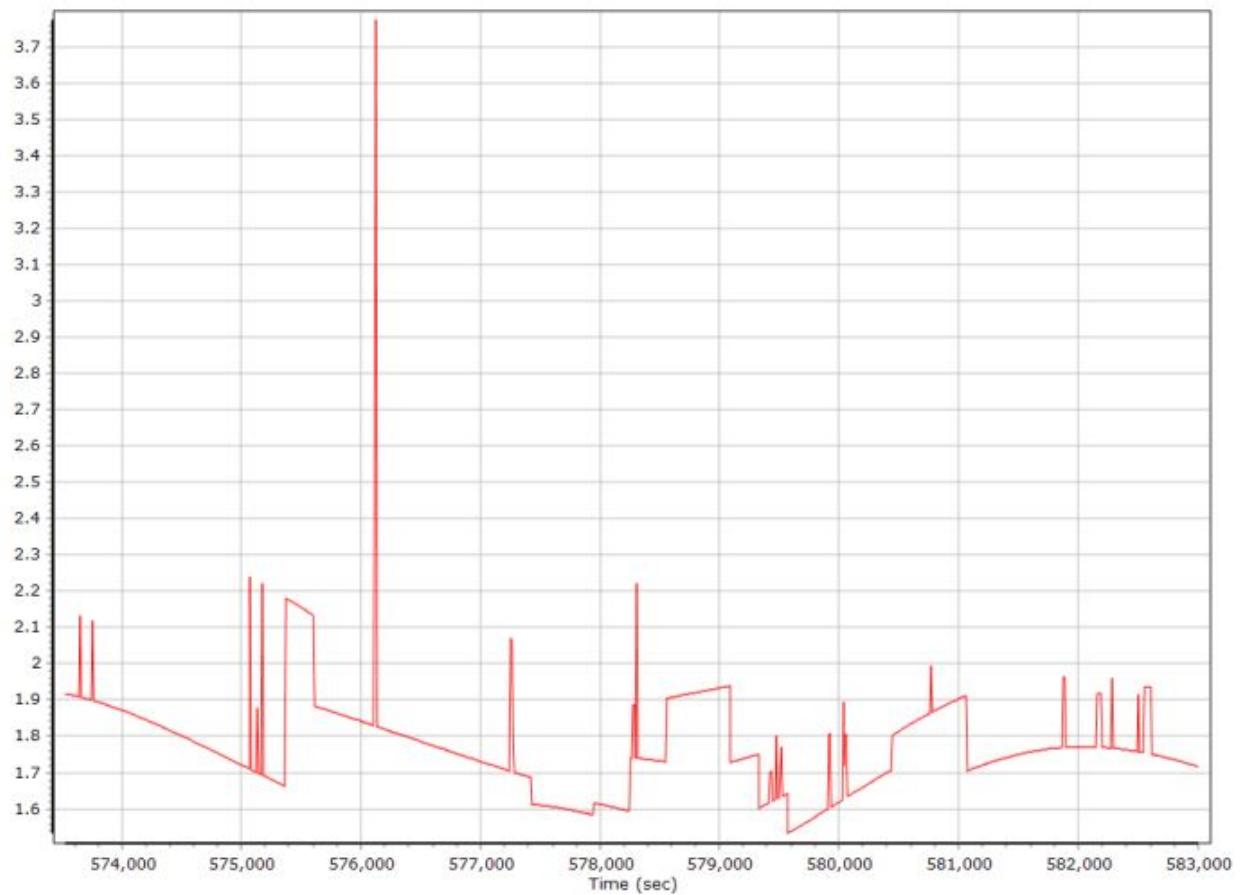
### Number of Satellites



### Forward/Reverse Separation

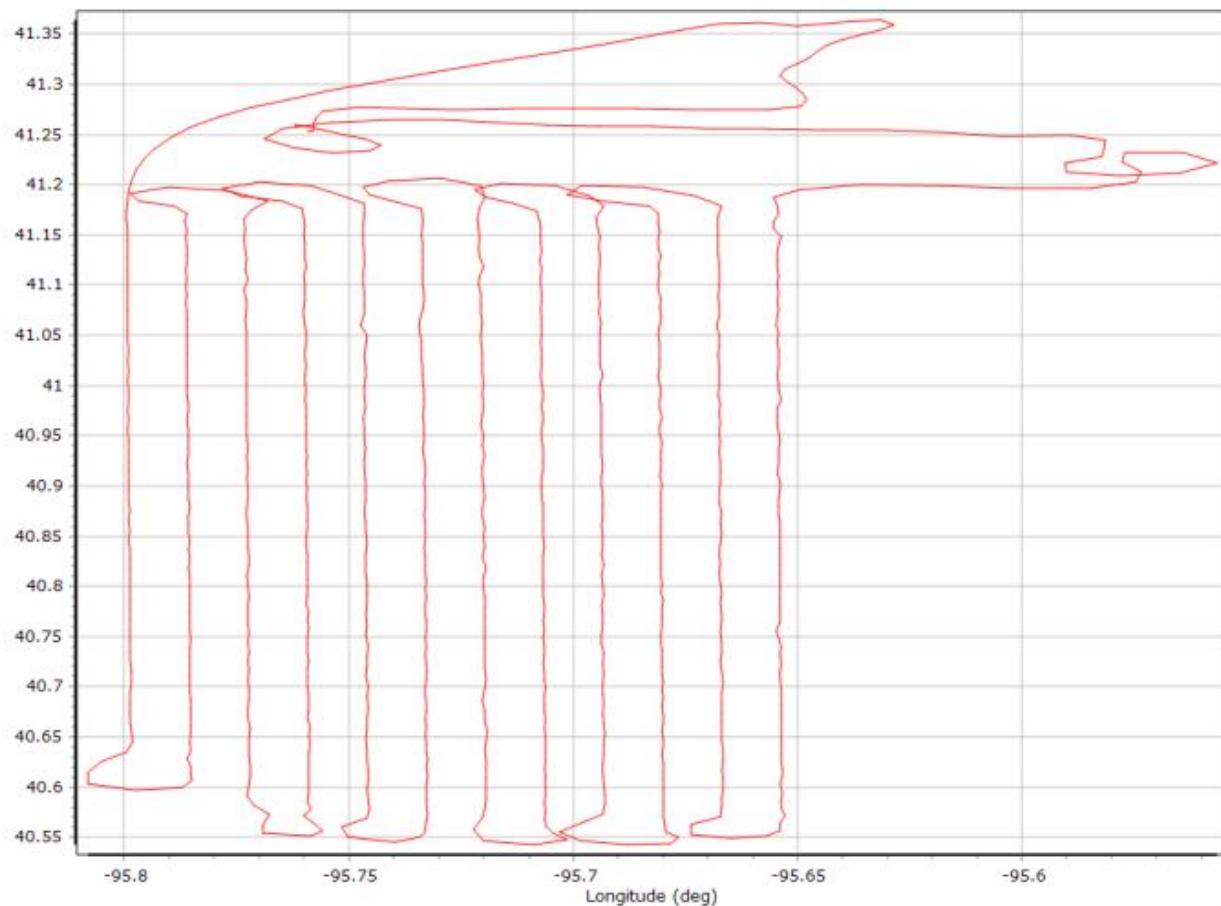


### PDOP



20201205\_2\_QC Report.docx QC Report – 8/27/2021 07:28:24  
Smoothed Trajectory Information

Top View



**GNSS QC**

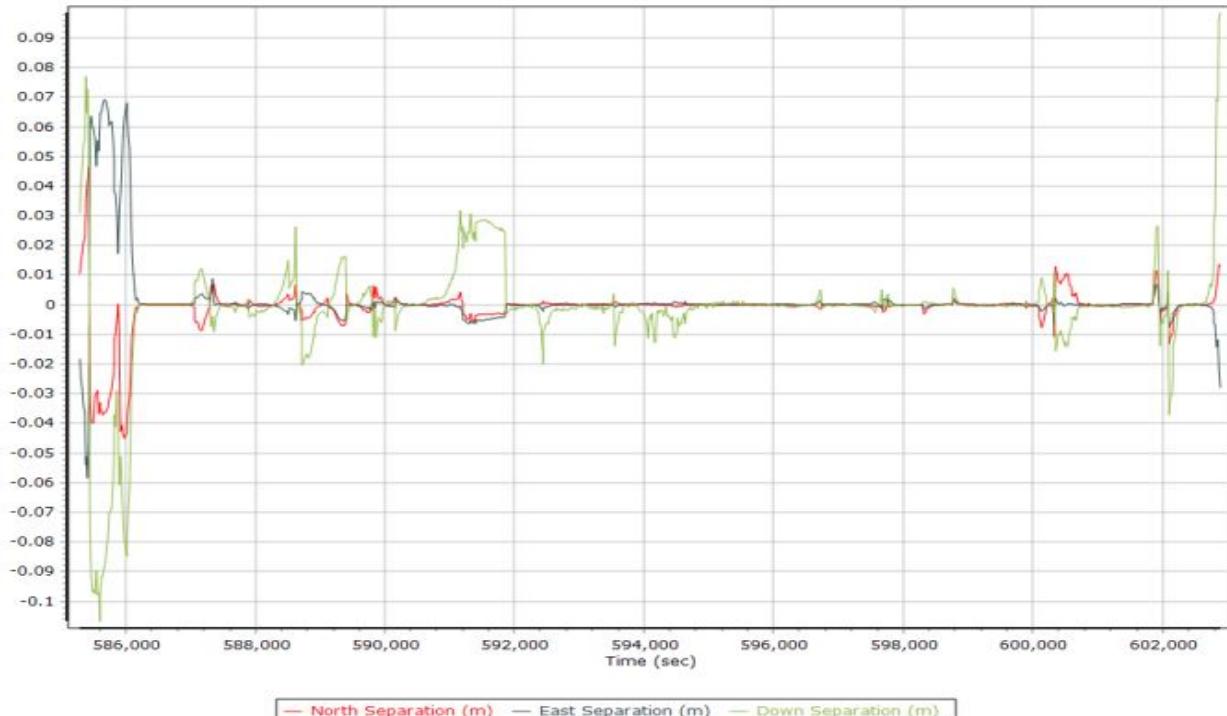
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.30	48.79	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	10	8
PDOP	1.53	5.01	2.09
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17843.00	188.00	1.00
Percentage	98.95	1.04	0.01

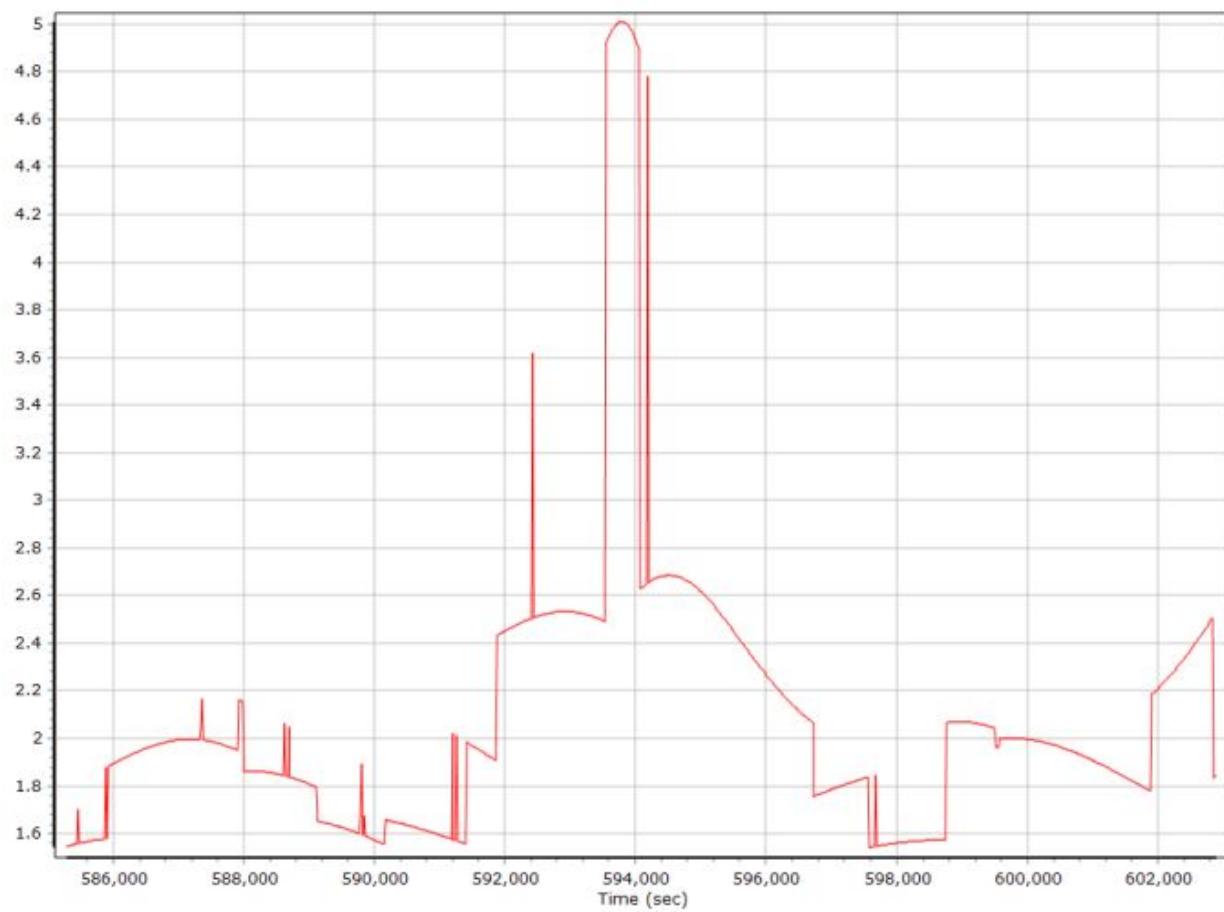
### Number of Satellites



### Forward/Reverse Separation

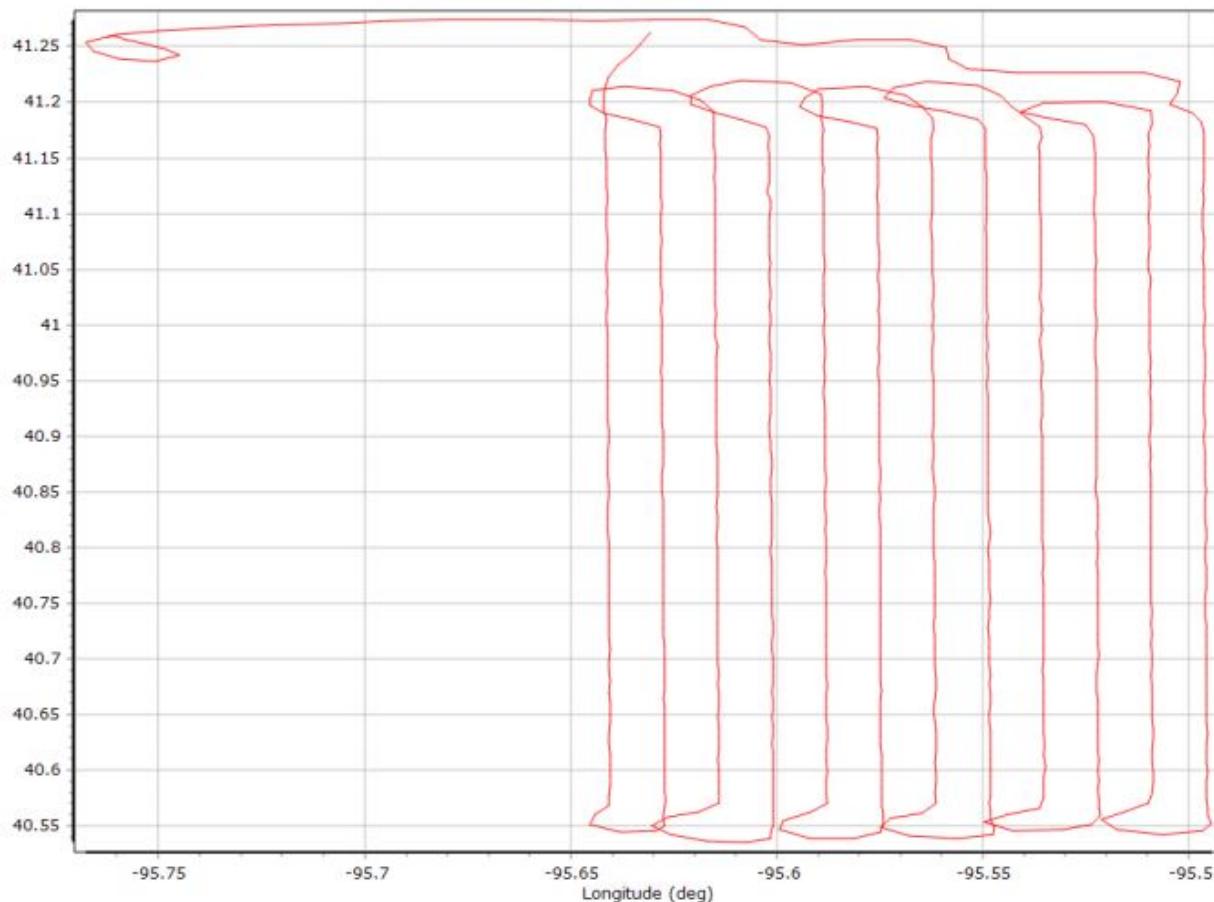


### PDOP



20201207\_QC Report.docx QC Report – 8/27/2021 07:39:22  
Smoothed Trajectory Information

Top View

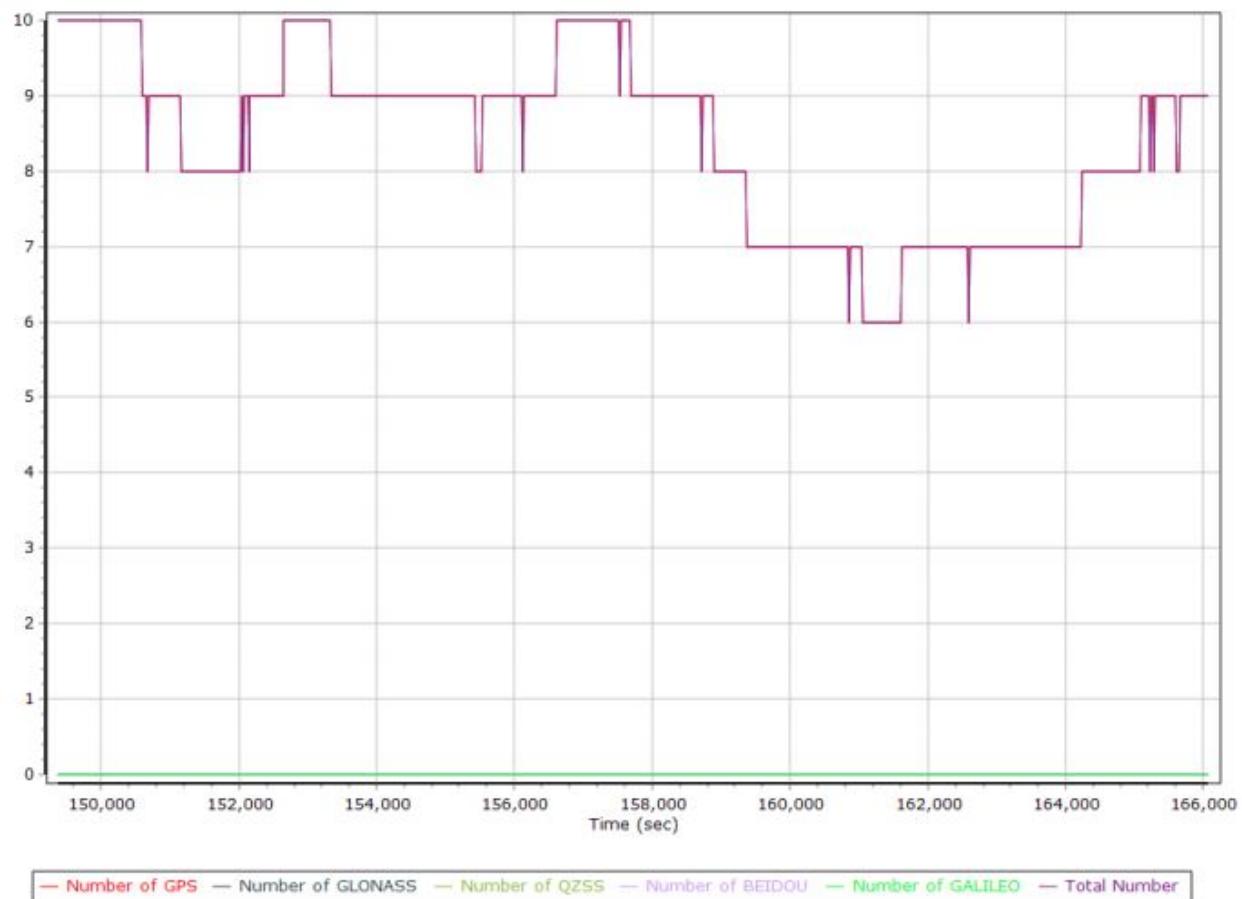


## GNSS QC

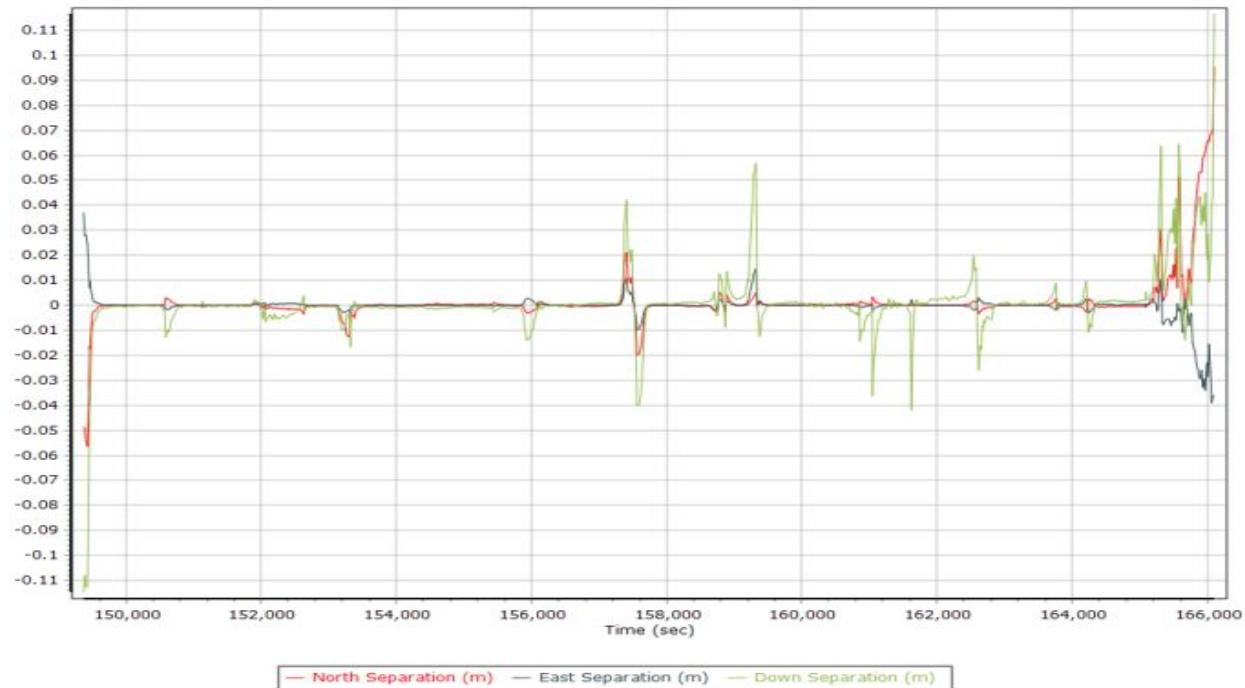
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.38	42.41	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	10	8
PDOP	1.53	5.02	2.10
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17121.00	0.00	1.00
Percentage	99.99	0.00	0.01

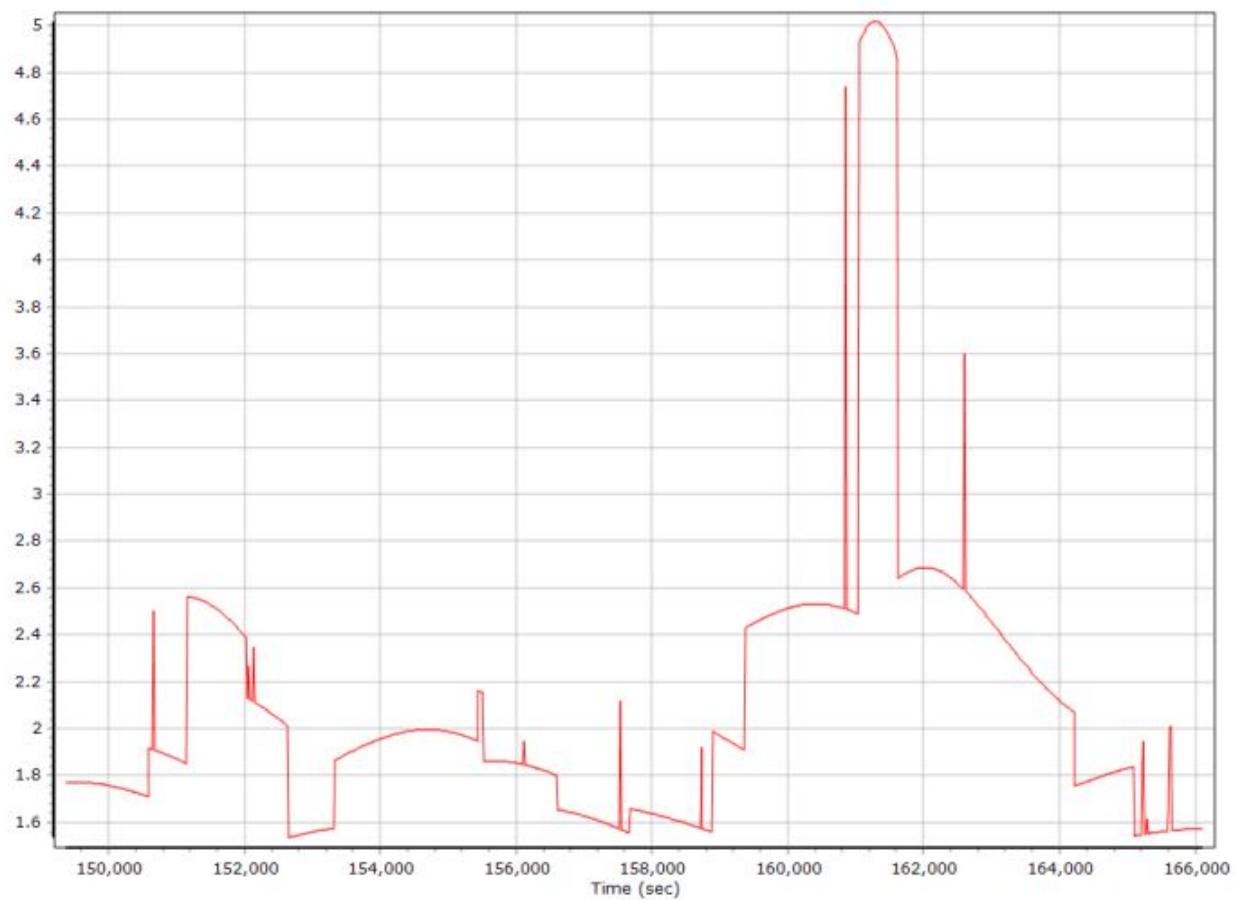
### Number of Satellites



### Forward/Reverse Separation

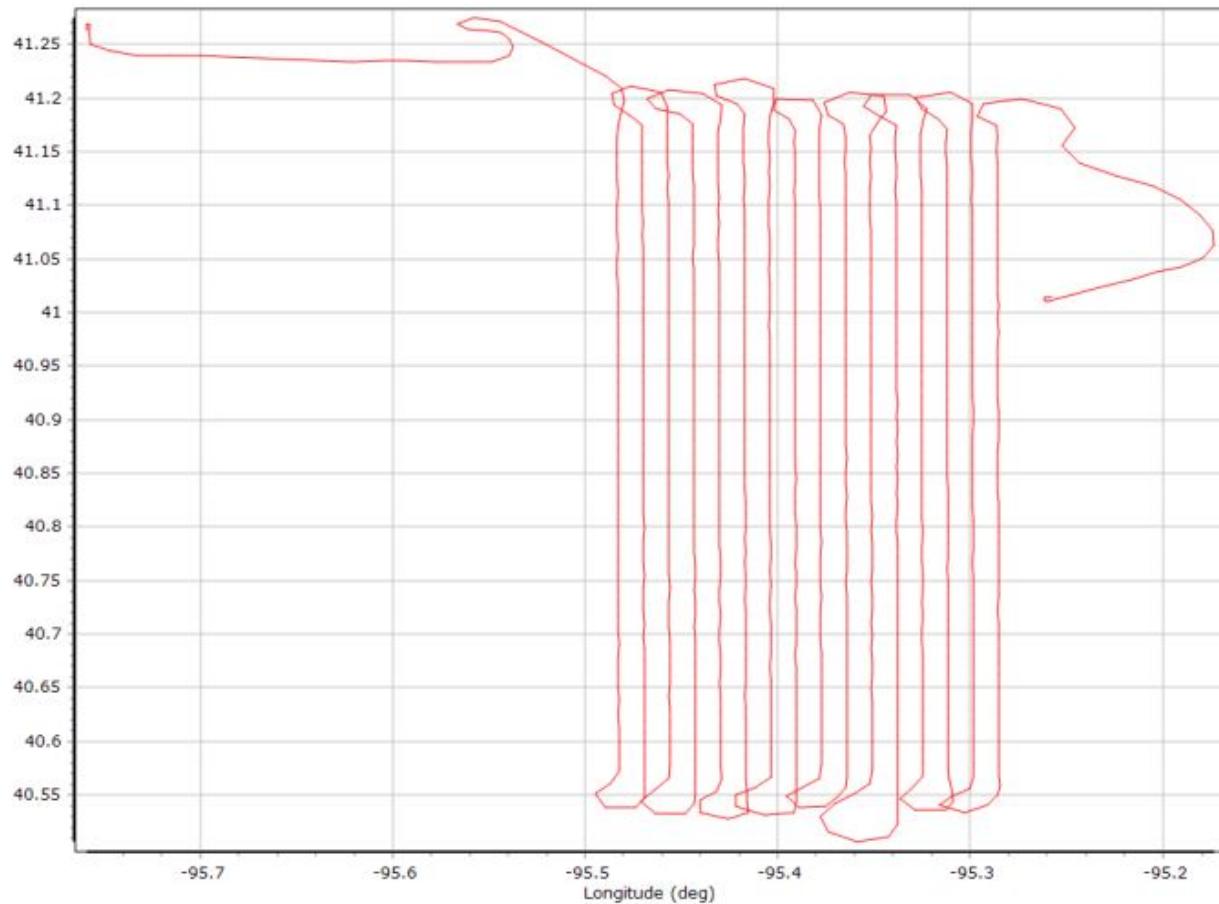


**PDOP**



20201208\_QC Report.docx QC Report – 8/27/2021 07:43:44  
Smoothed Trajectory Information

Top View

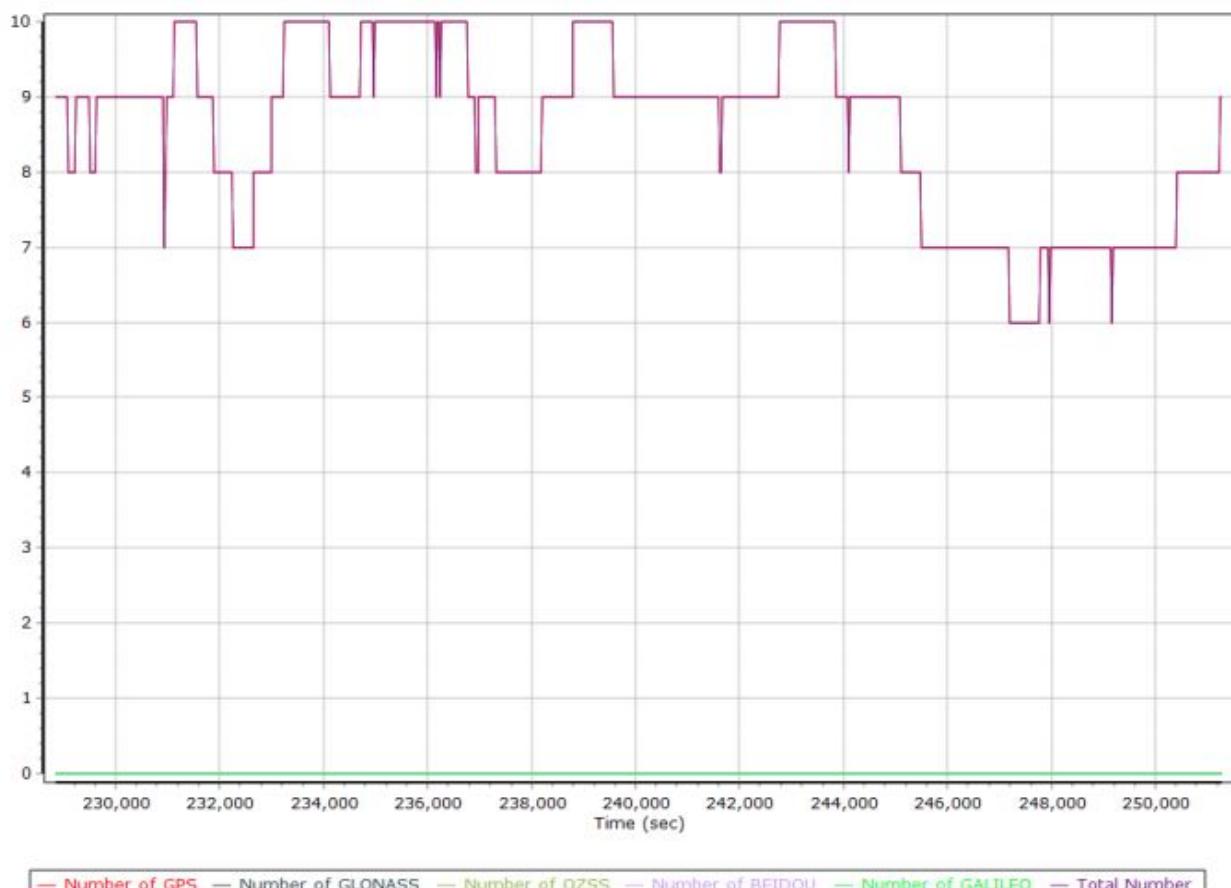


**GNSS QC**

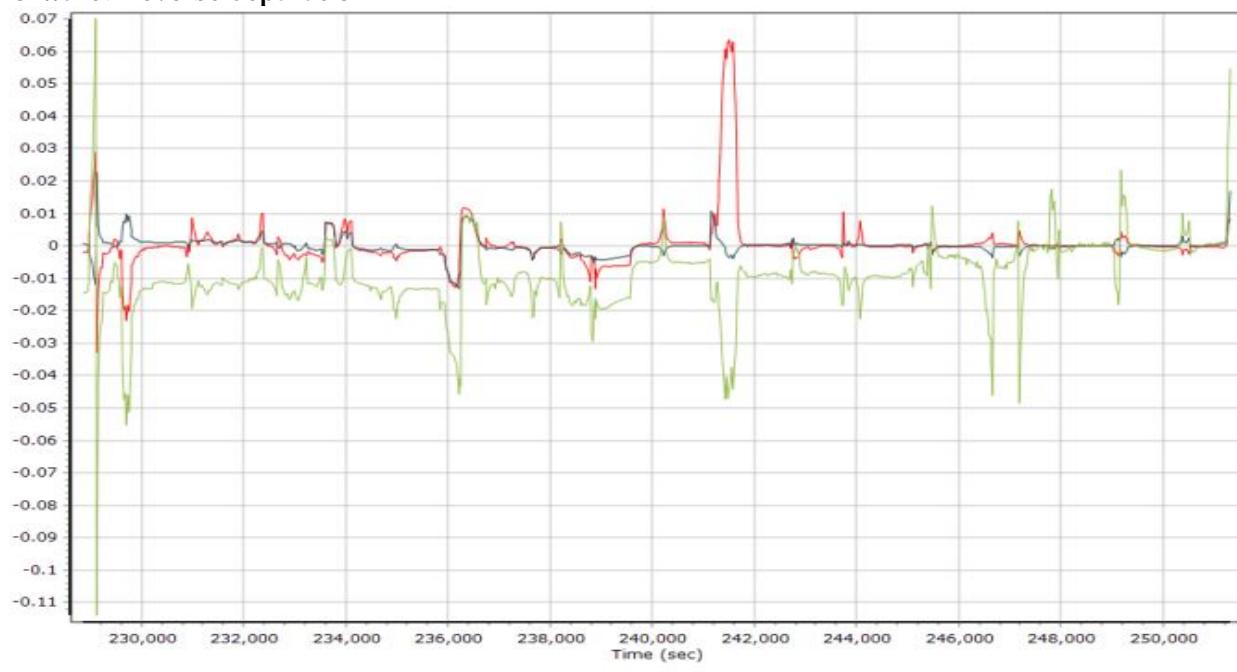
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.53	51.24	
Number of GPS SV	6	10	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	10	9
PDOP	1.53	5.02	2.02
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	22924.00	0.00	1.00
Percentage	100.00	0.00	0.00

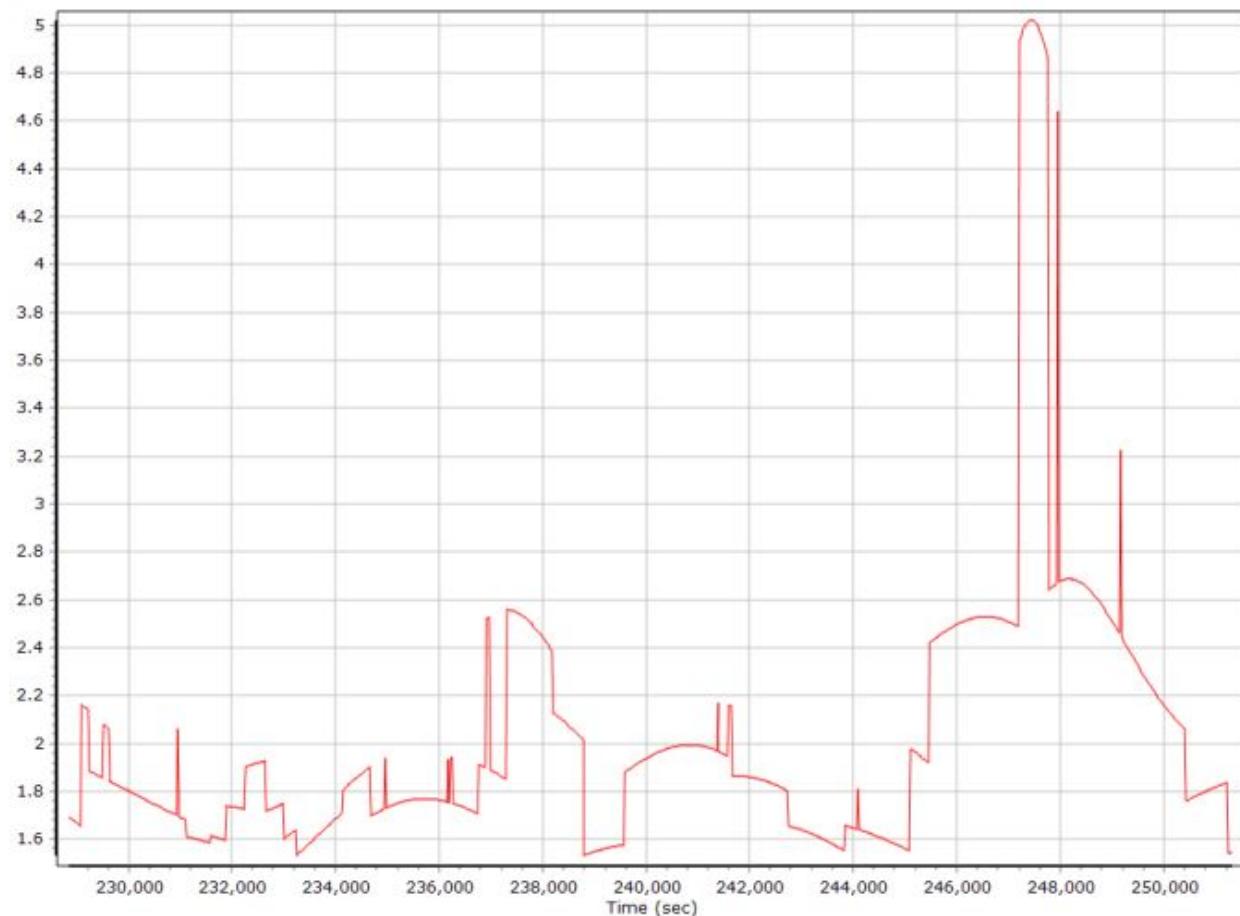
### Number of Satellites



### Forward/Reverse Separation

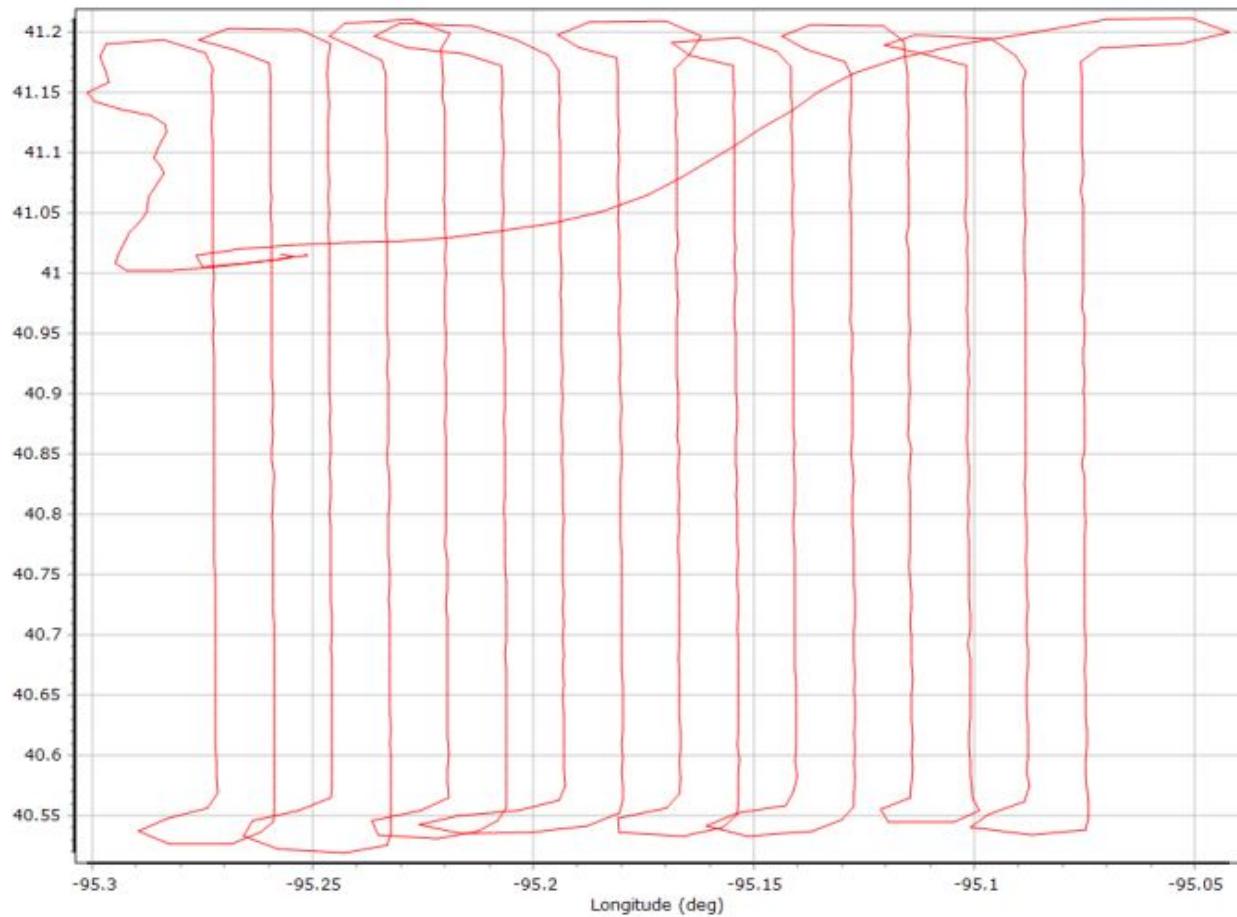


**PDOP**



20201209\_1\_QC Report.docx QC Report – 8/27/2021 07:53:24  
Smoothed Trajectory Information

Top View

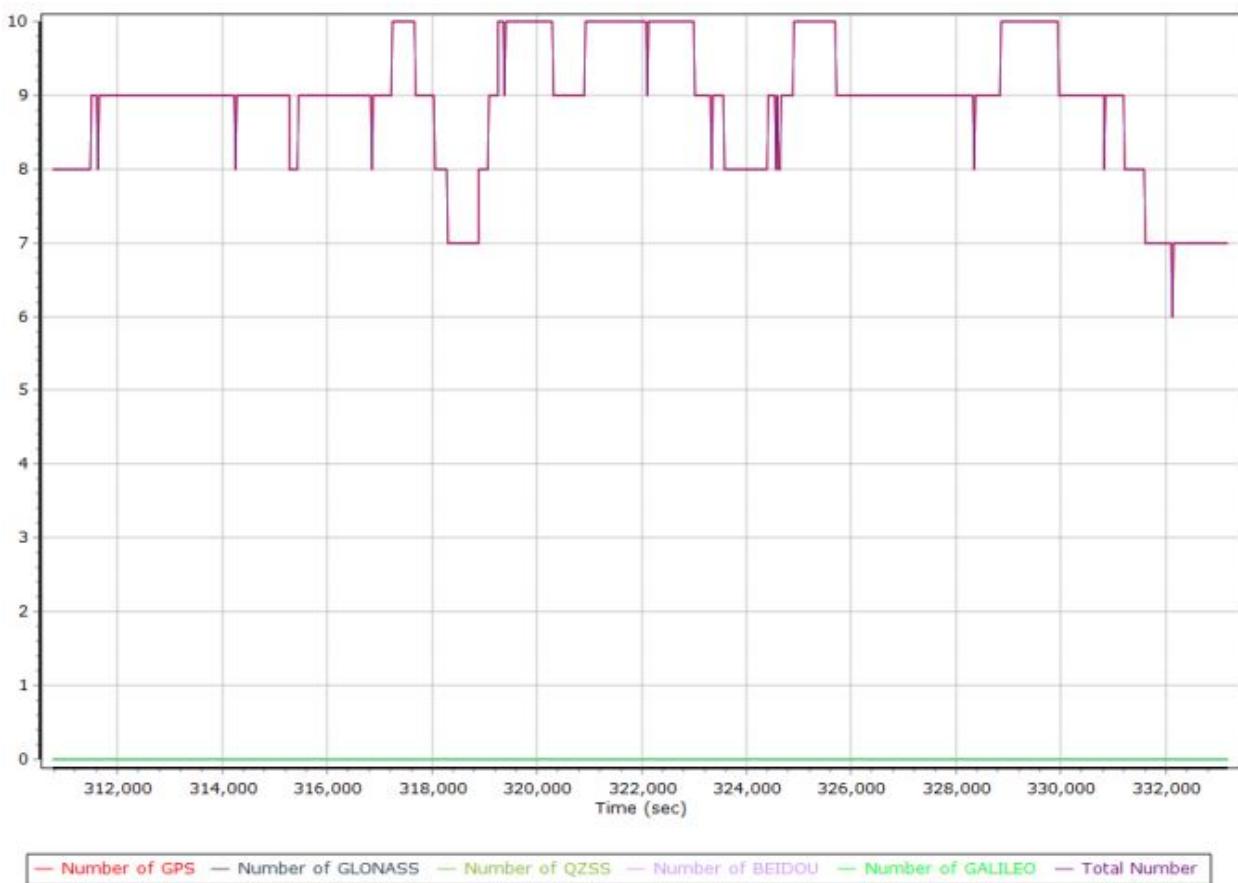


## GNSS QC

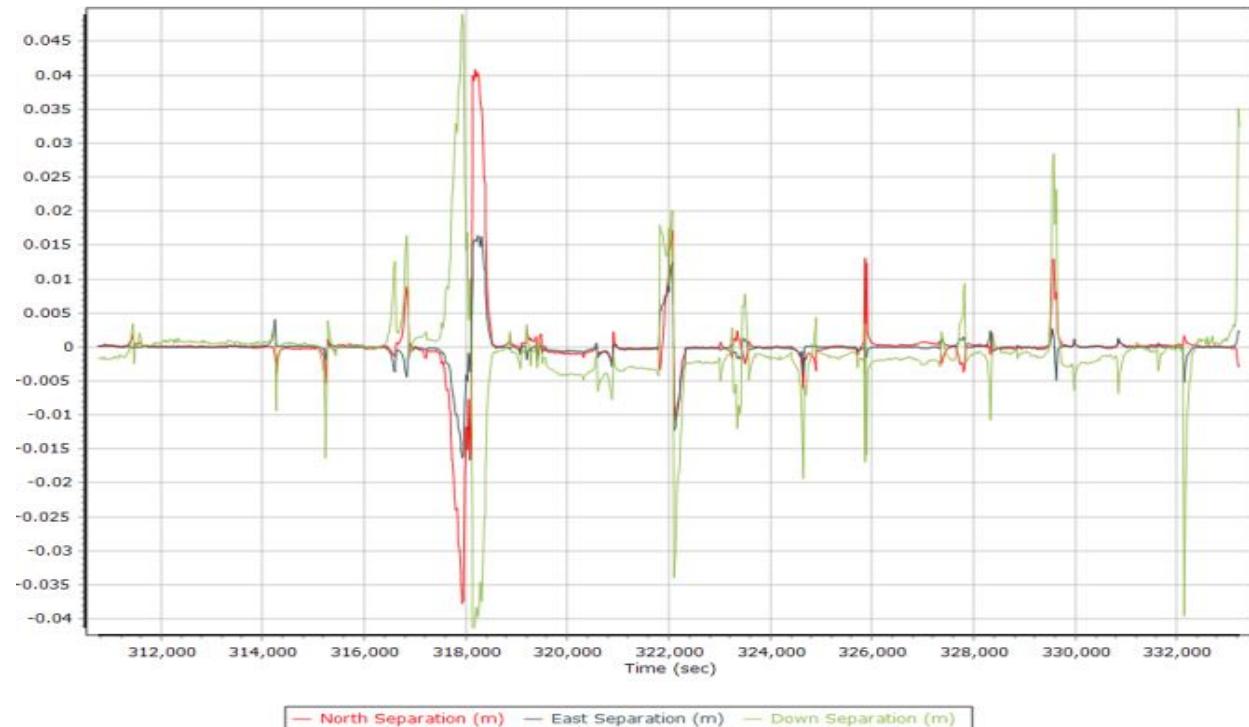
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.28	40.98	
Number of GPS SV	6	10	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	10	9
PDOP	1.51	3.55	1.89
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	22867.00	0.00	1.00
Percentage	100.00	0.00	0.00

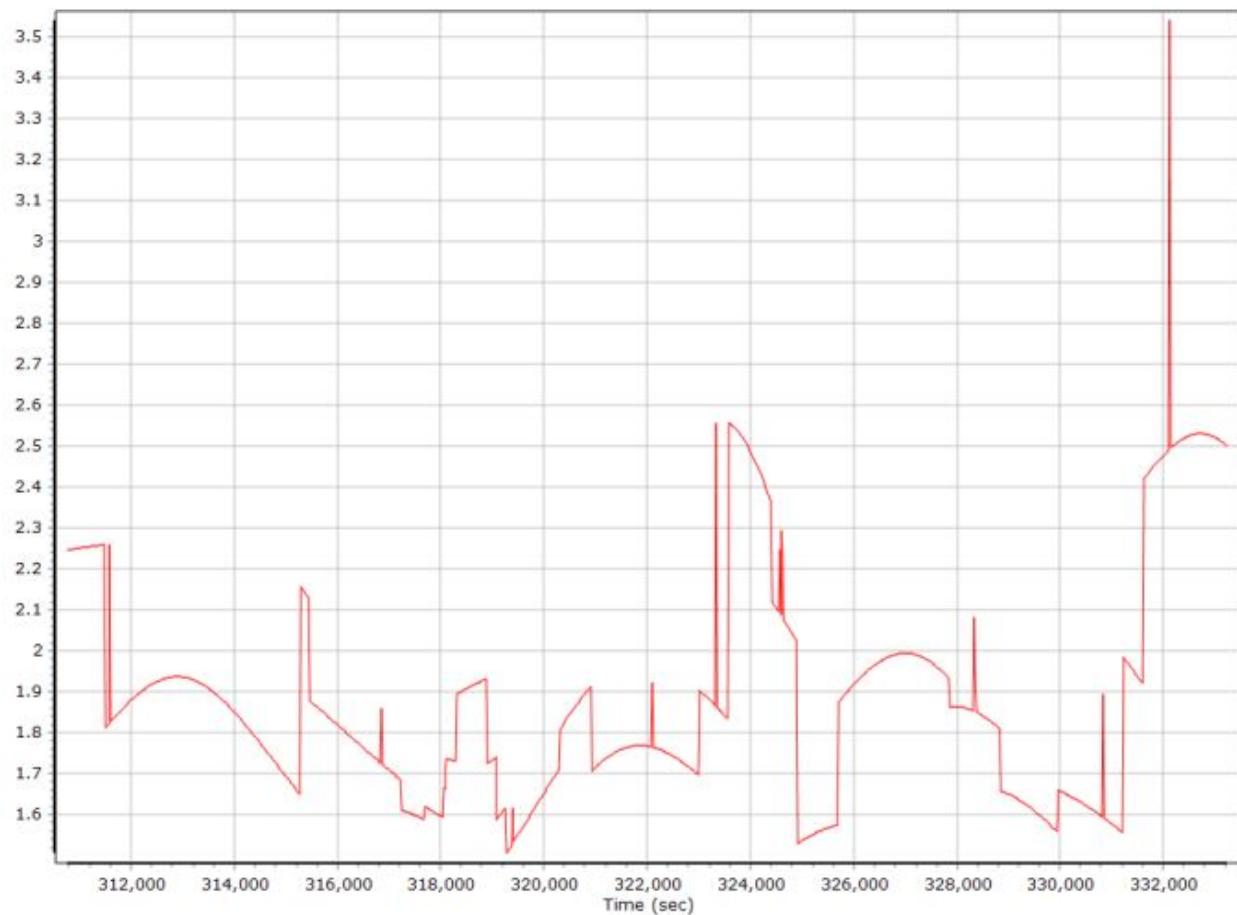
### Number of Satellites



### Forward/Reverse Separation

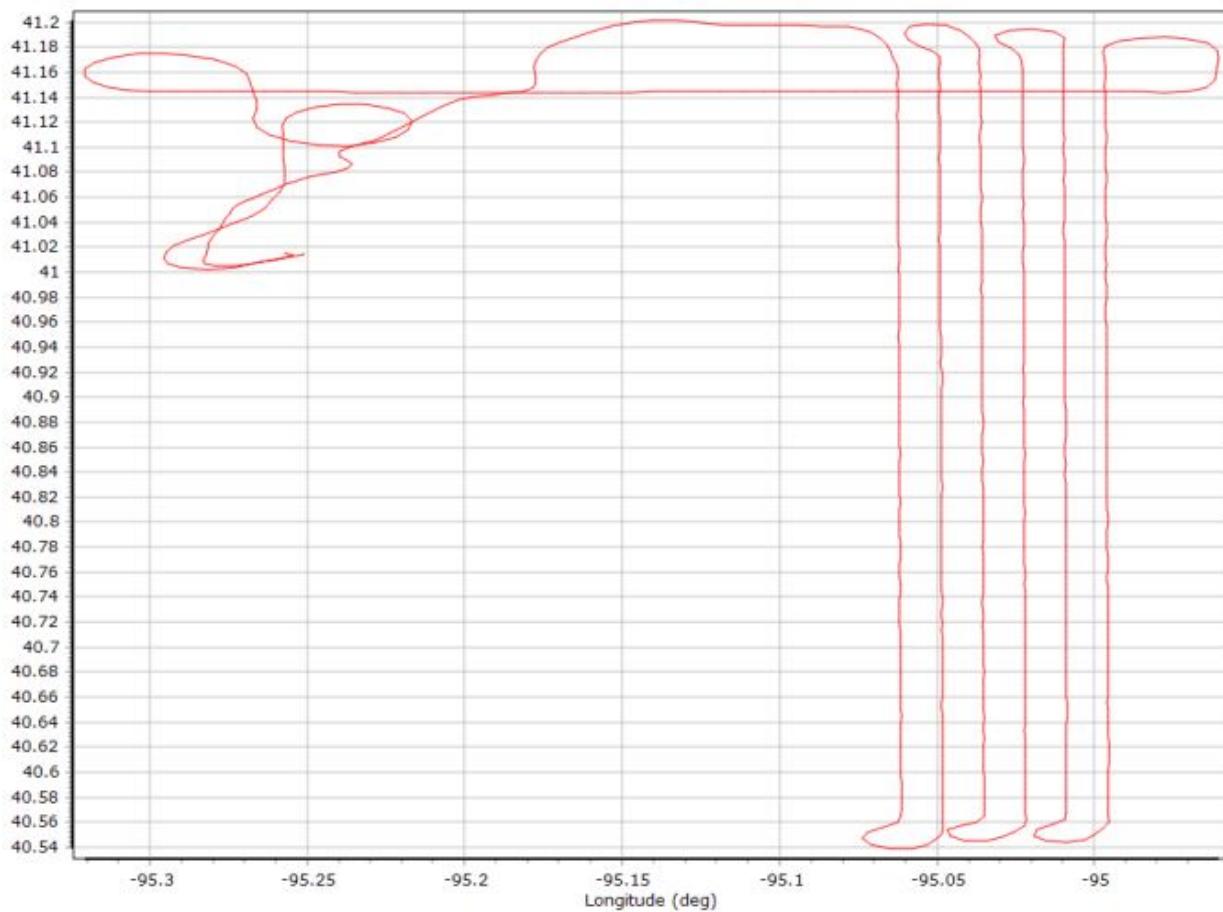


### PDOP



20201209\_2\_QC Report.docx QC Report – 8/27/2021 08:01:24  
Smoothed Trajectory Information

Top View

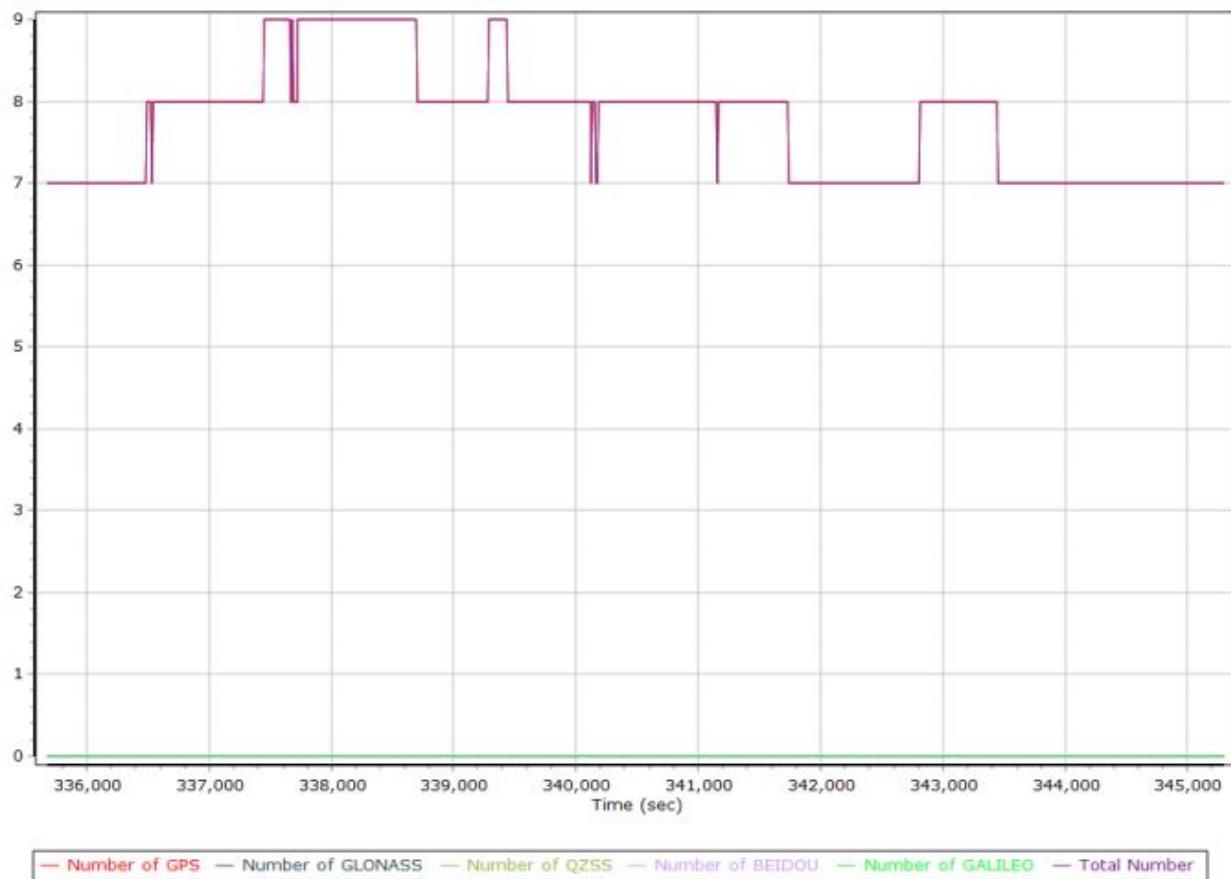


## GNSS QC

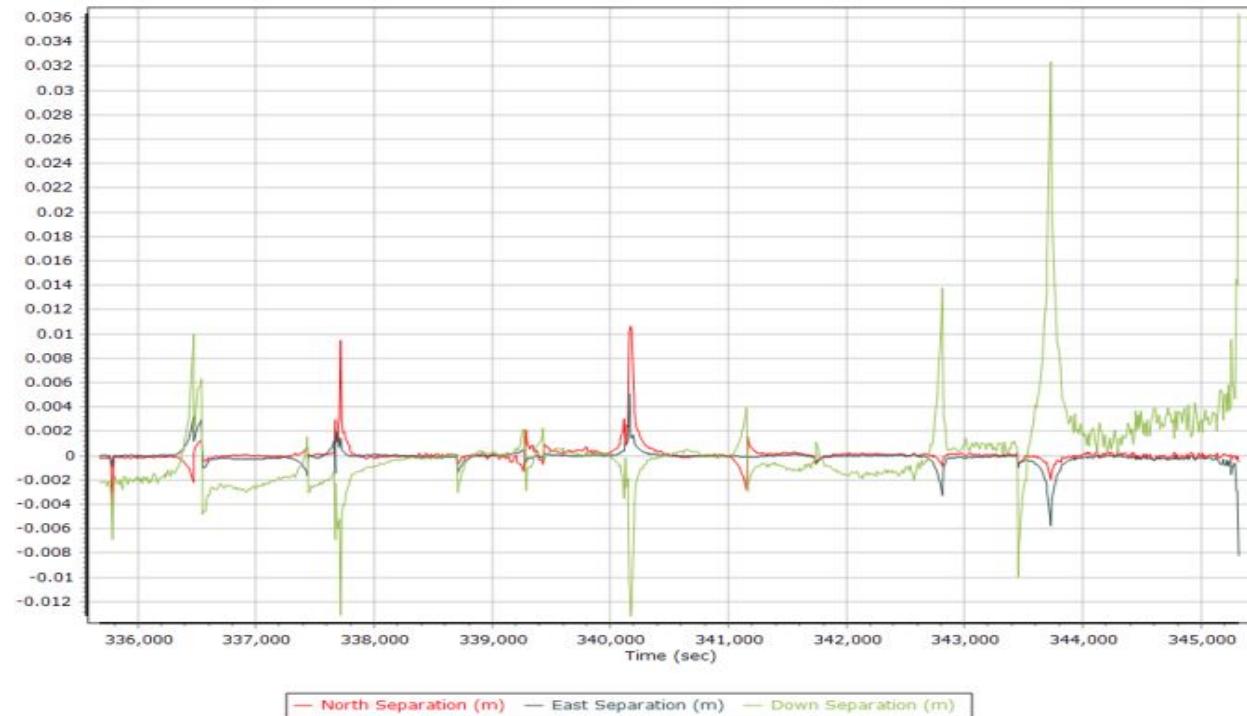
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	1.86	43.19	
Number of GPS SV	6	9	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	9	8
PDOP	1.55	4.87	2.11
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	10067.00	0.00	1.00
Percentage	99.99	0.00	0.01

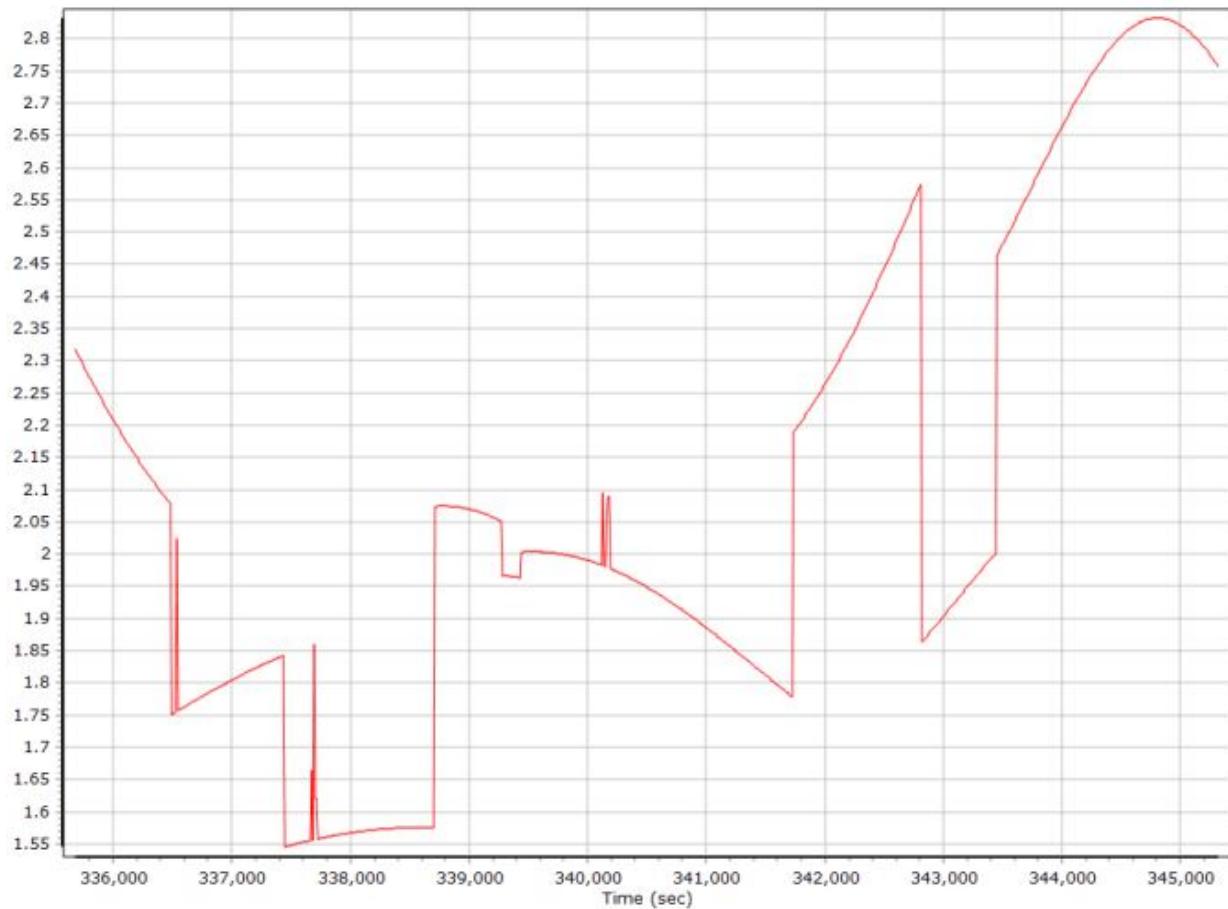
### Number of Satellites



### Forward/Reverse Separation

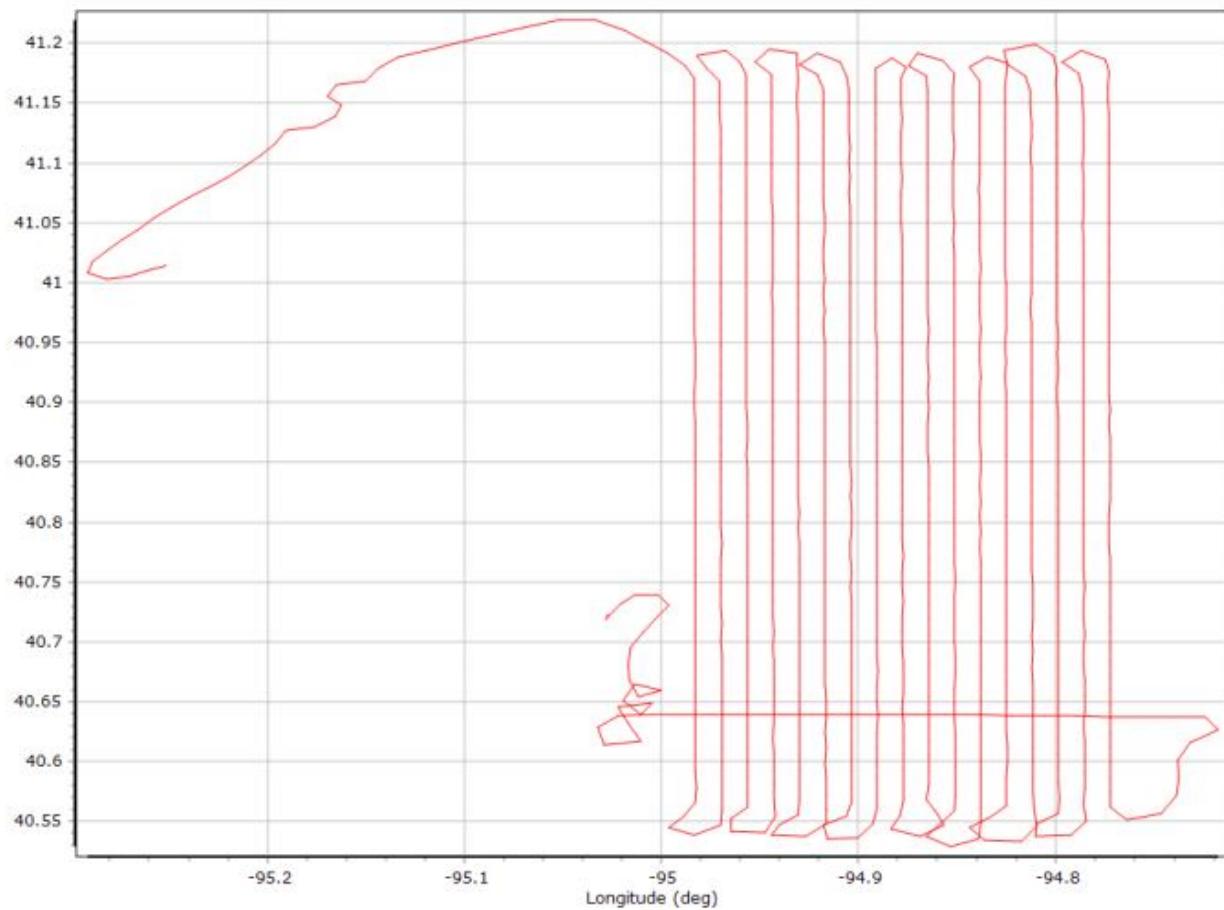


PDOP



20201210\_1\_QC Report.docx QC Report – 8/27/2021 08:08:14  
Smoothed Trajectory Information

Top View

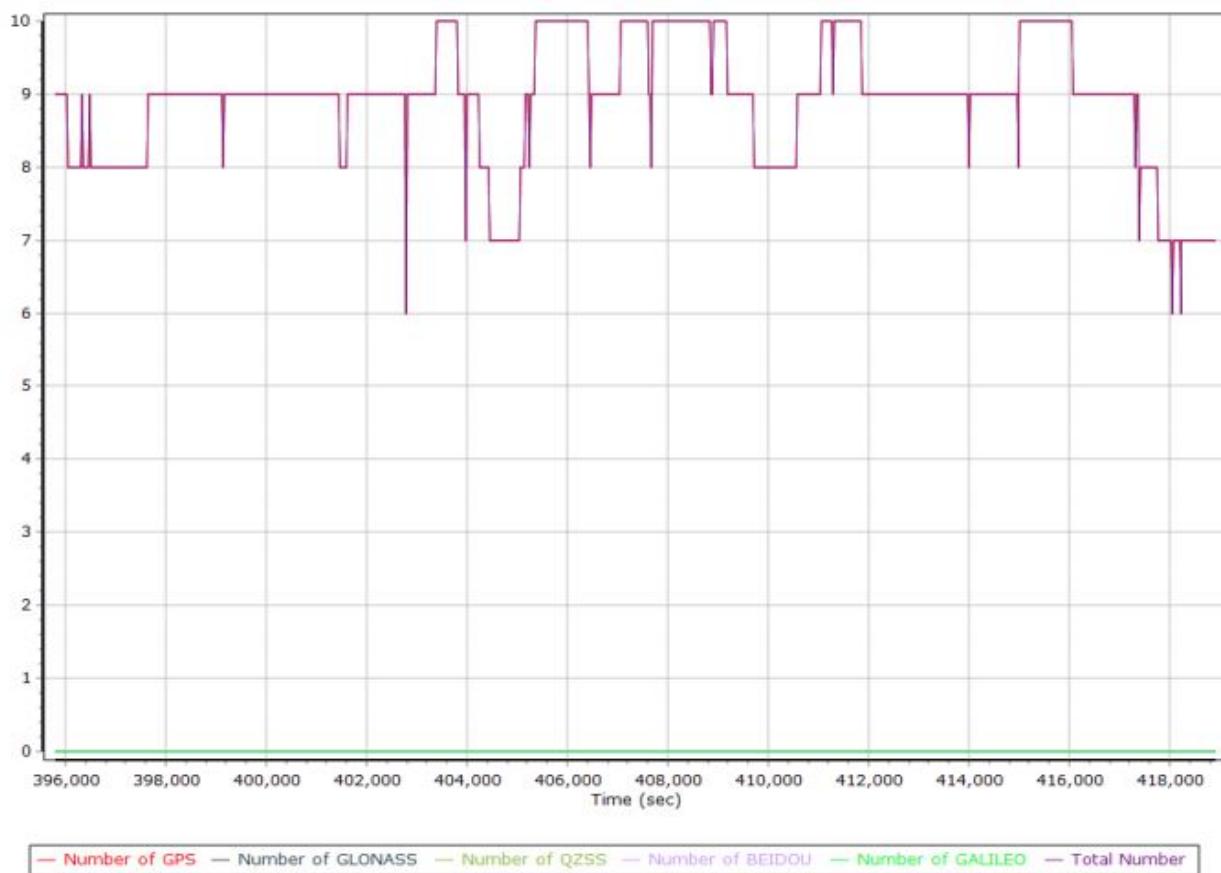


## GNSS QC

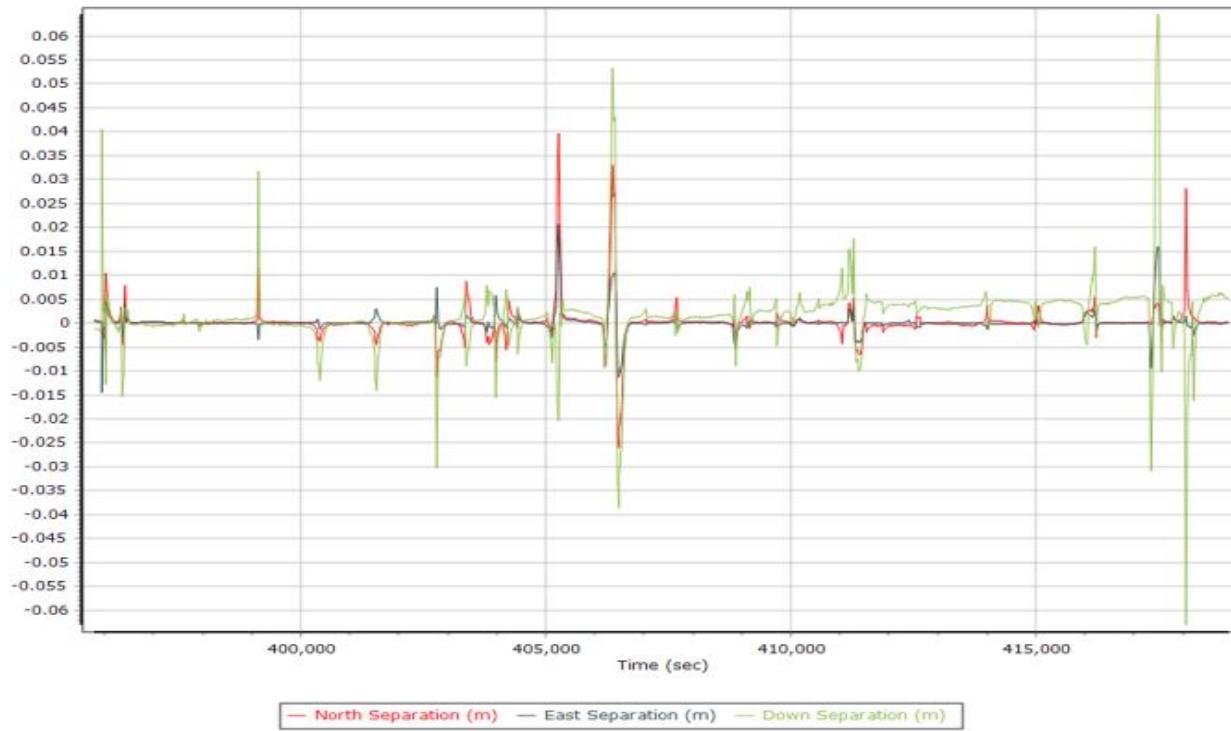
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.23	41.43	
Number of GPS SV	6	10	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	10	9
PDOP	1.47	4.26	1.87
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	23550.00	0.00	1.00
Percentage	100.00	0.00	0.00

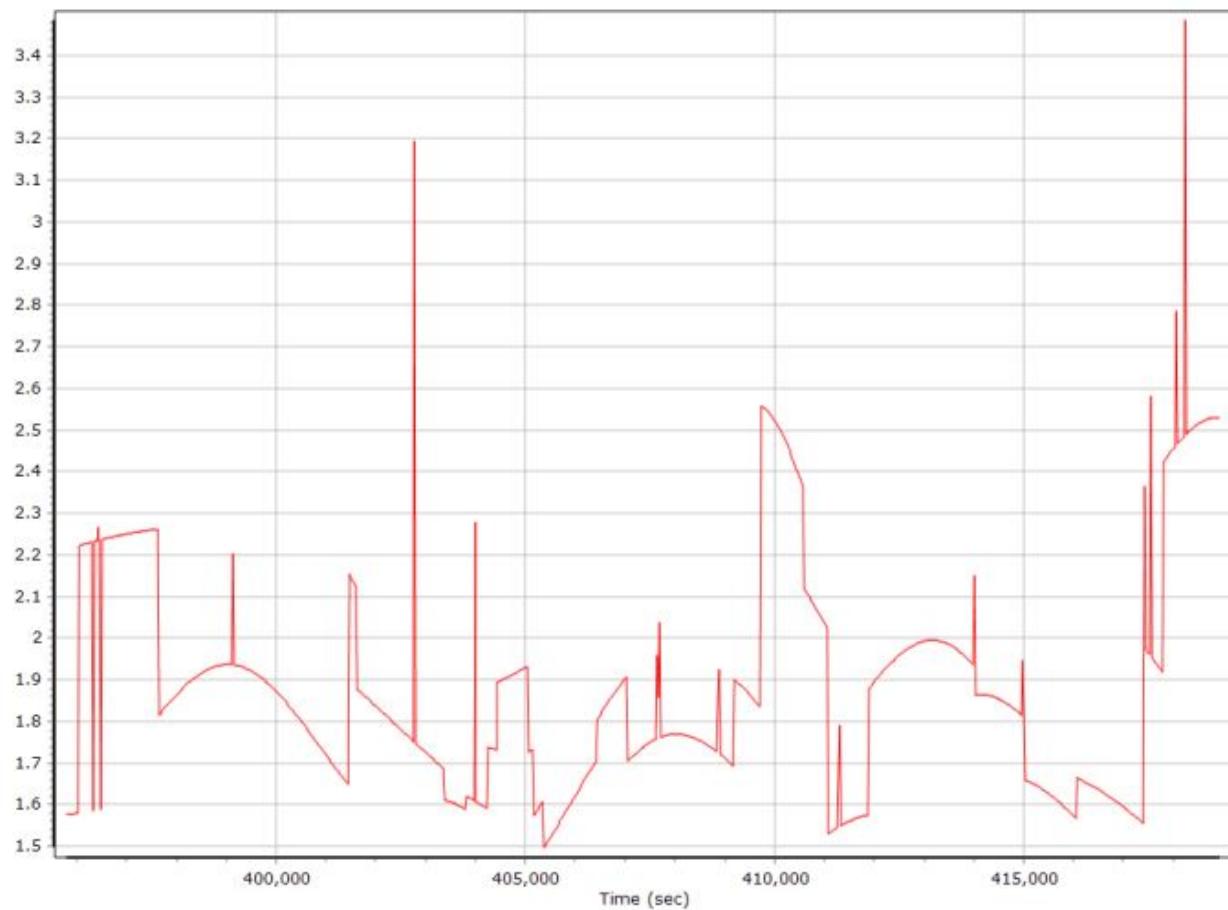
### Number of Satellites



### Forward/Reverse Separation

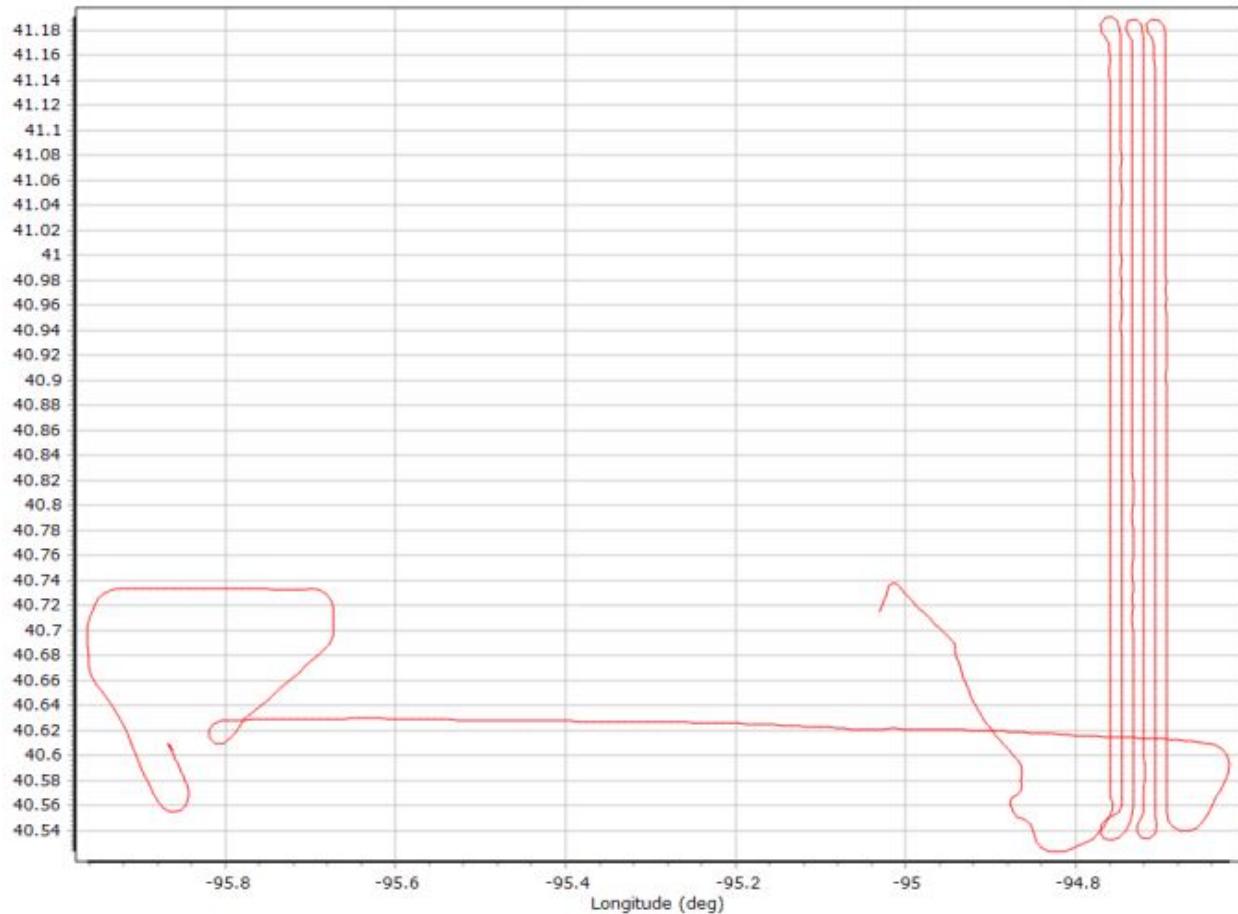


### PDOP



20201210\_2\_QC Report.docx QC Report – 8/27/2021 08:15:12  
Smoothed Trajectory Information

Top View

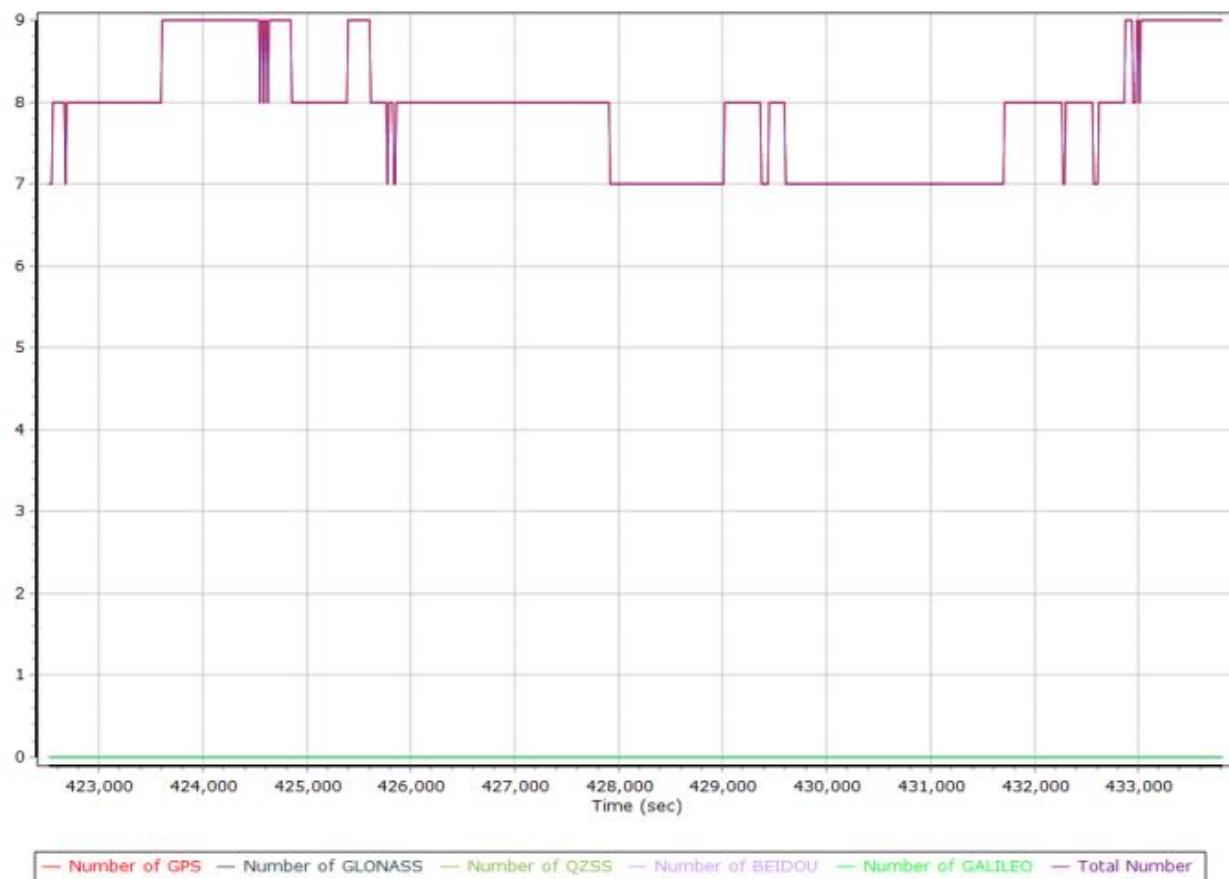


## GNSS QC

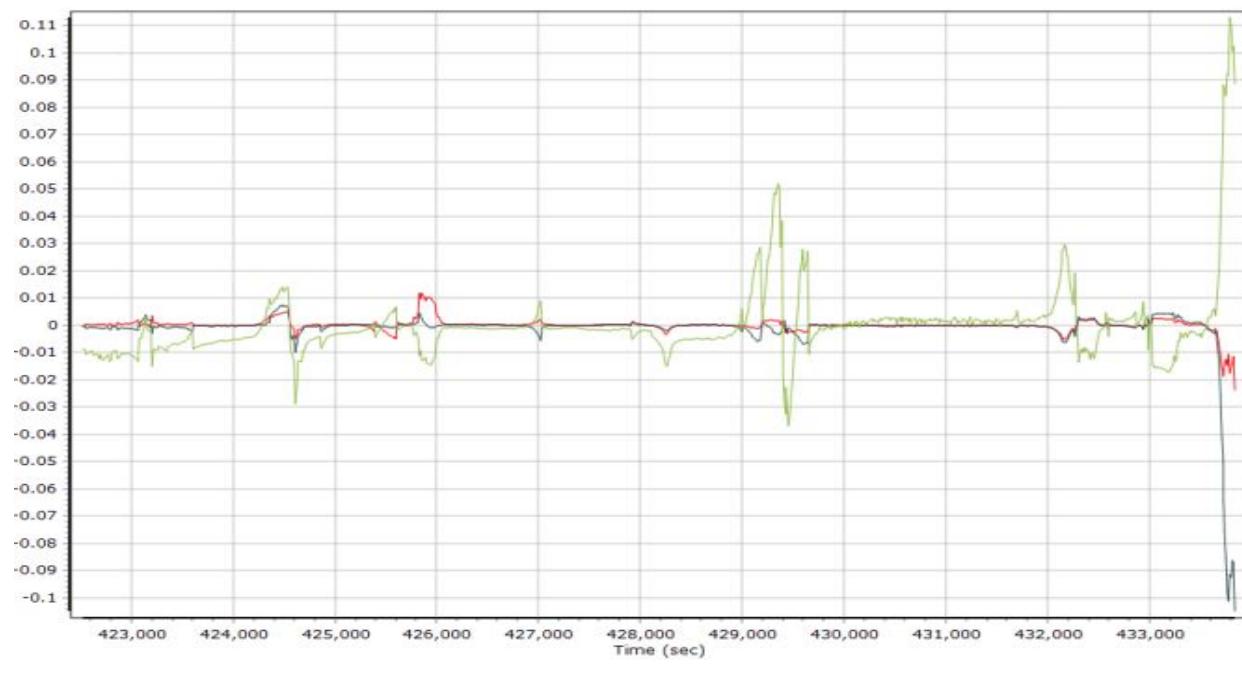
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	5.93	85.00	
Number of GPS SV	6	9	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	9	8
PDOP	1.55	4.45	2.06
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	11717.00	0.00	1.00
Percentage	99.99	0.00	0.01

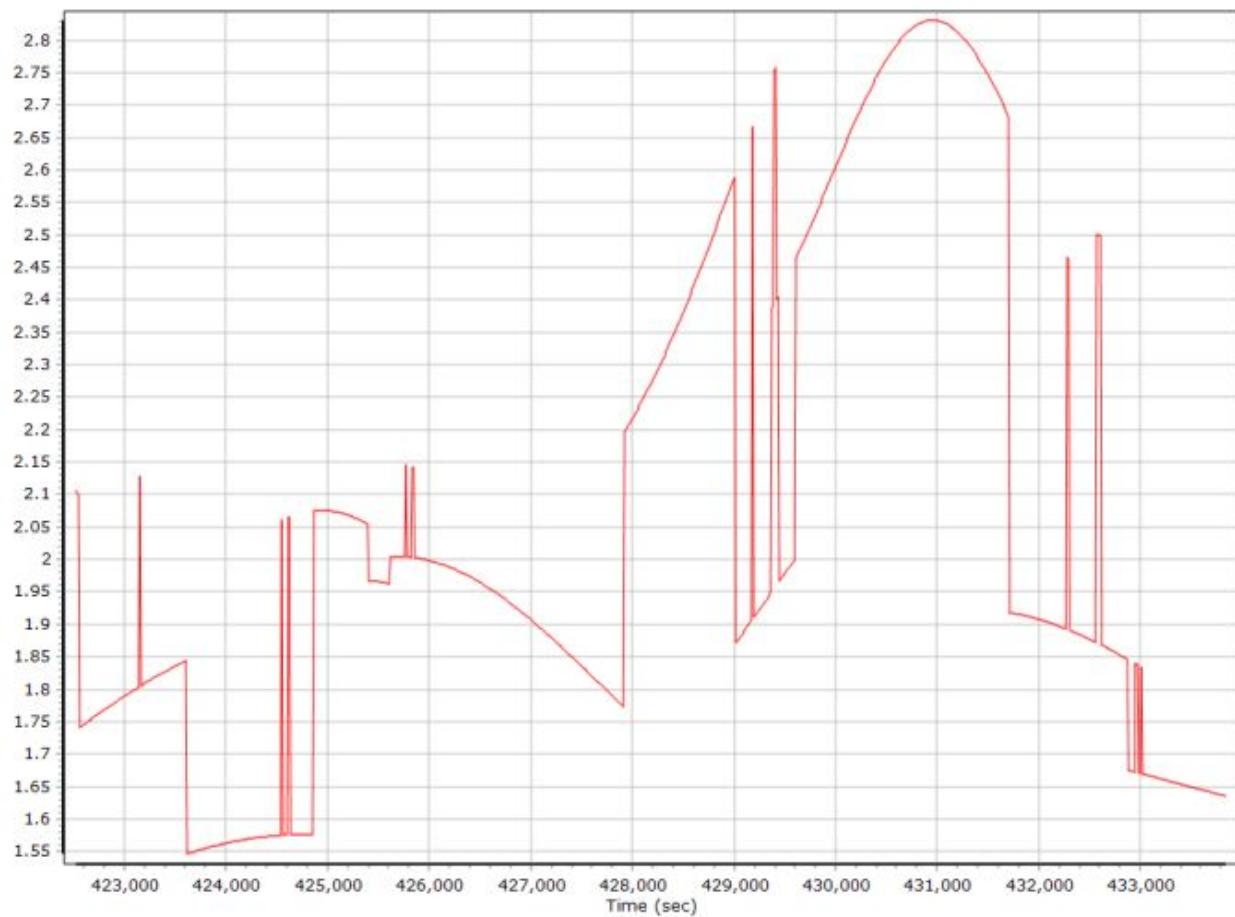
### Number of Satellites



### Forward/Reverse Separation

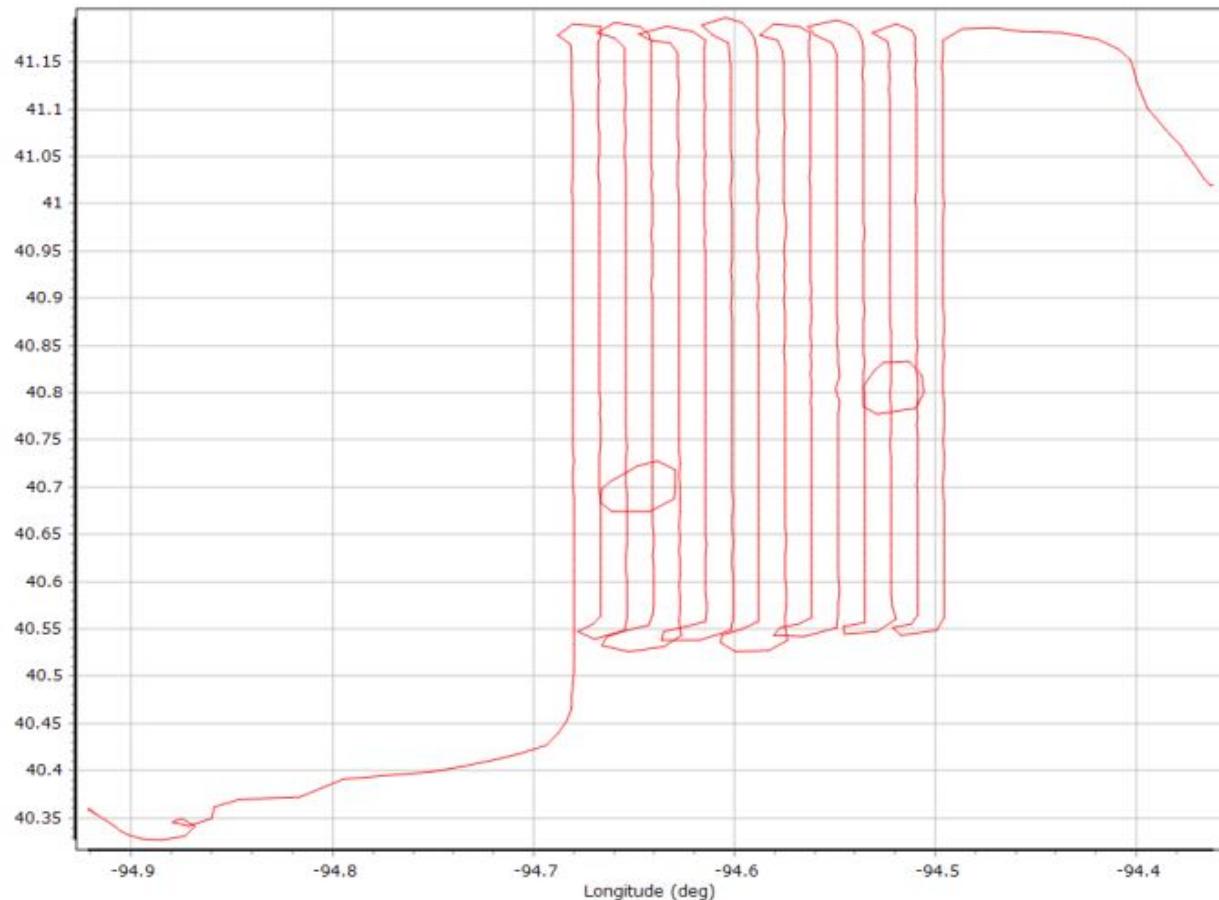


### PDOP



20201222\_1\_QC Report.docx QC Report – 8/27/2021 08:32:12  
Smoothed Trajectory Information

Top View

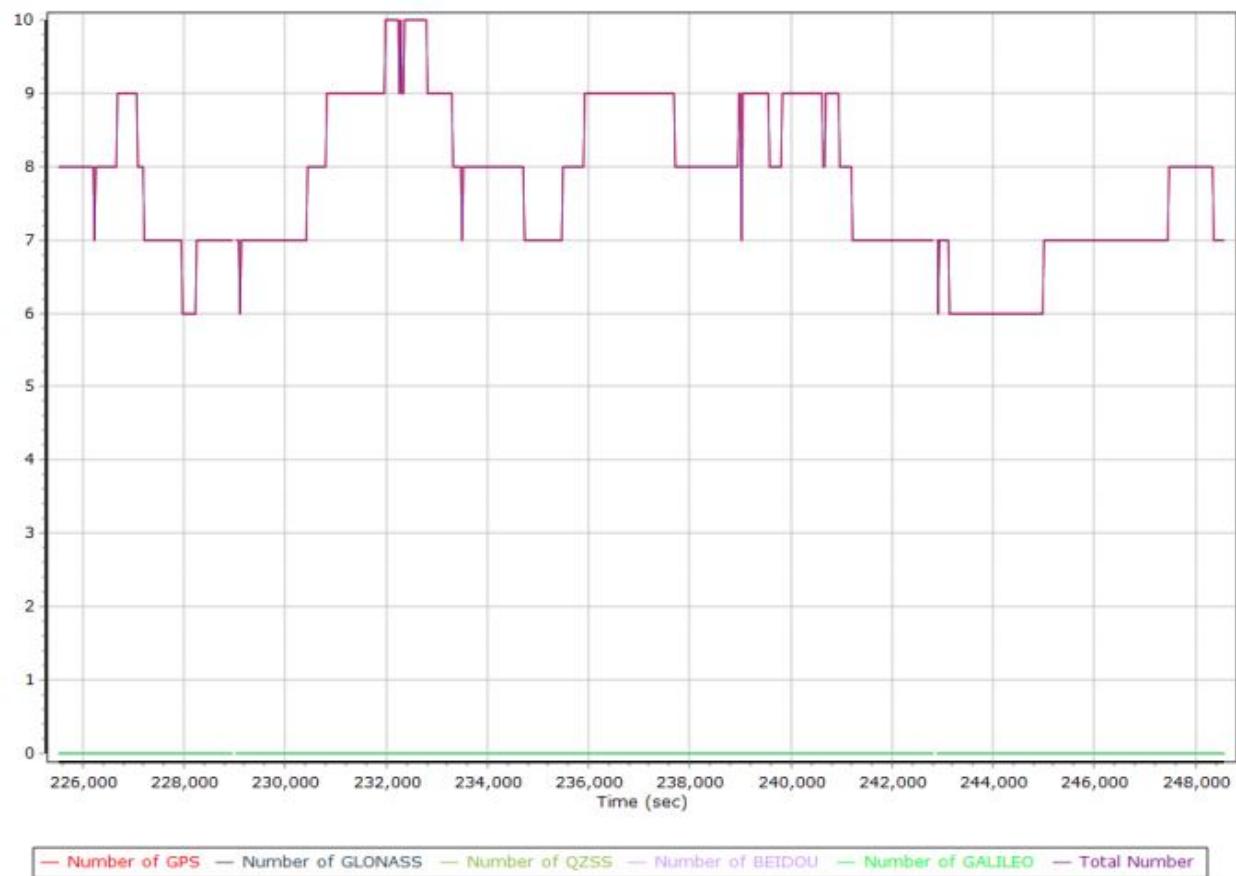


**GNSS QC**

**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.48	62.39	
Number of GPS SV	5	10	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	10	8
PDOP	1.62	5.60	2.32
QC Solution Gaps	1.00	41.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	23199.00	0.00	352.00
Percentage	98.51	0.00	1.49

### Number of Satellites

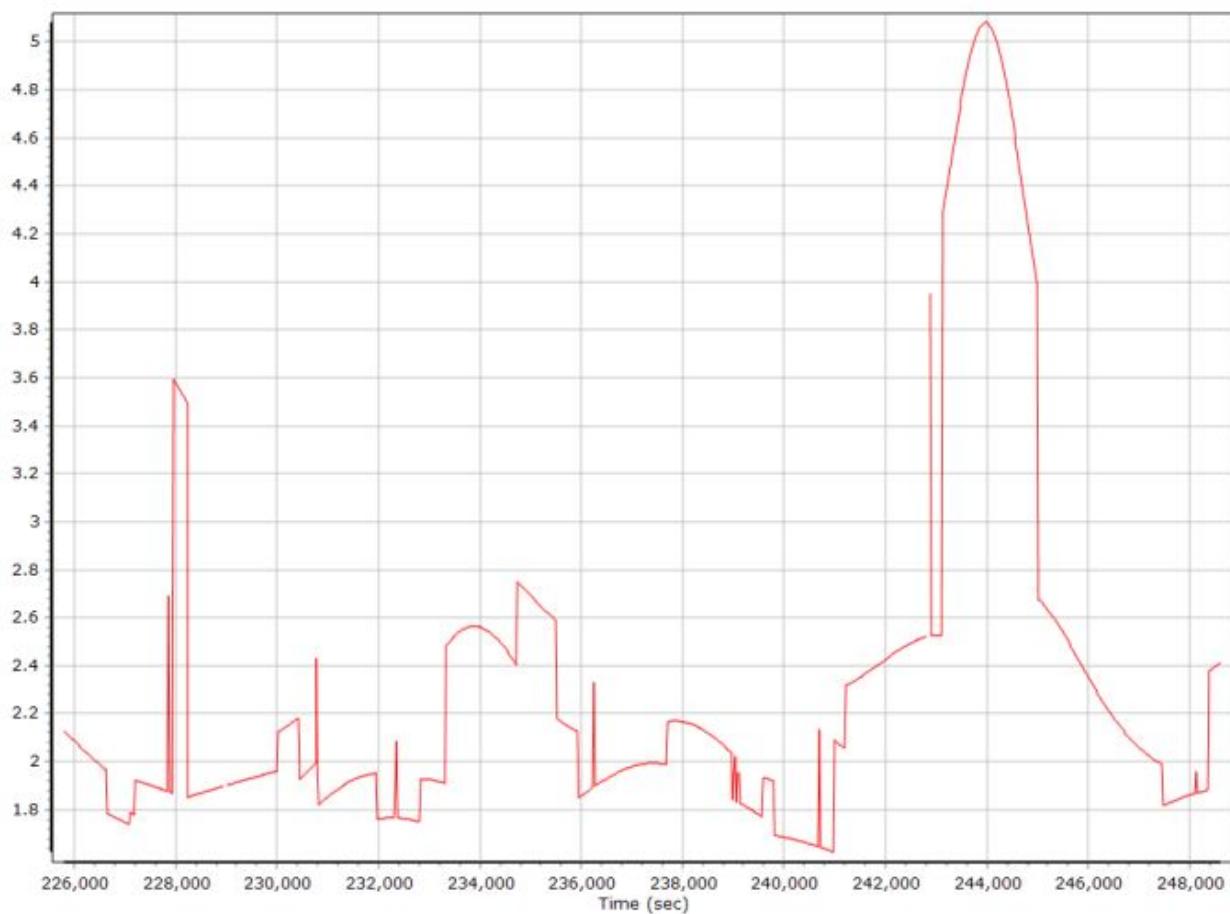


### Forward/Reverse Separation



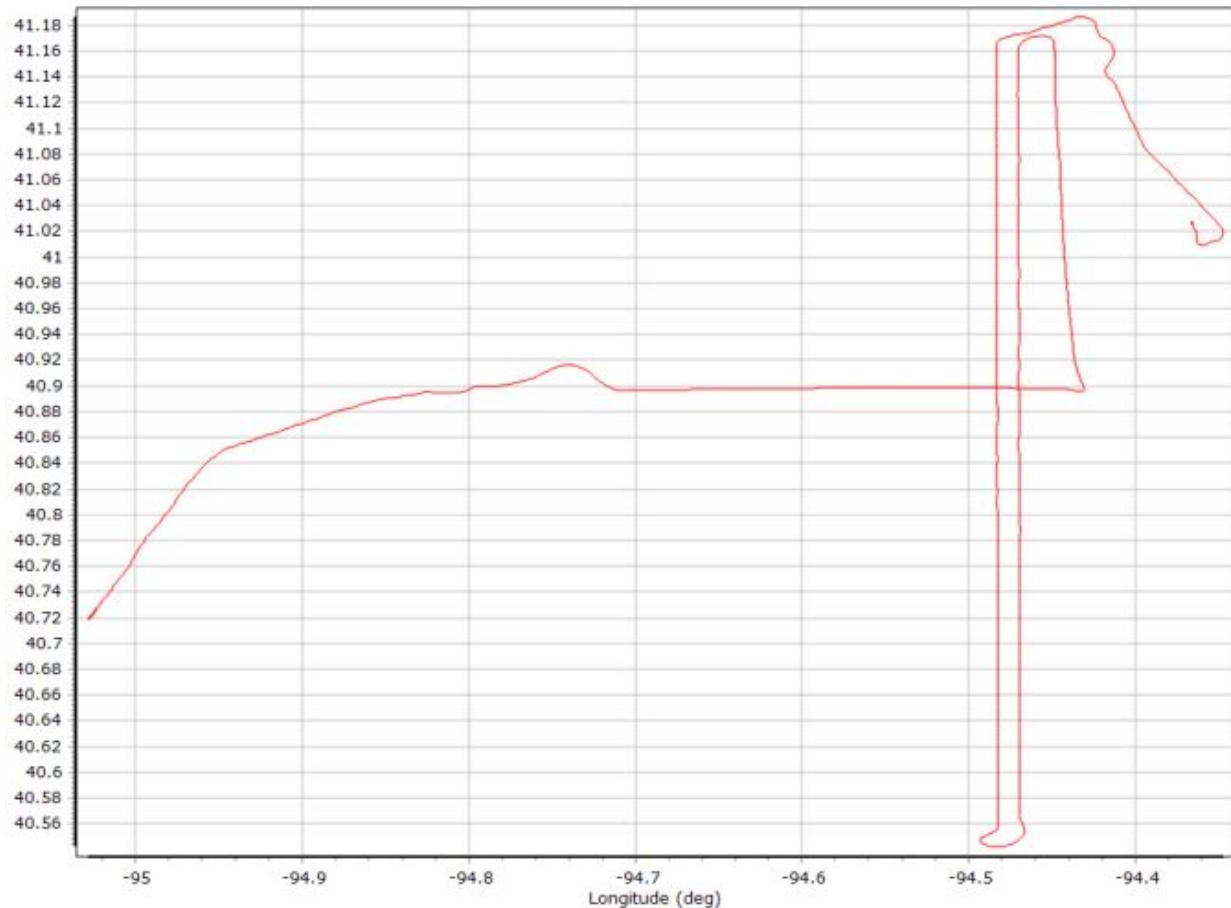
IA West 2020  
11/24/2021

### PDOP



20201222\_2\_QC Report.docx QC Report – 8/27/2021 08:38:52  
Smoothed Trajectory Information

Top View

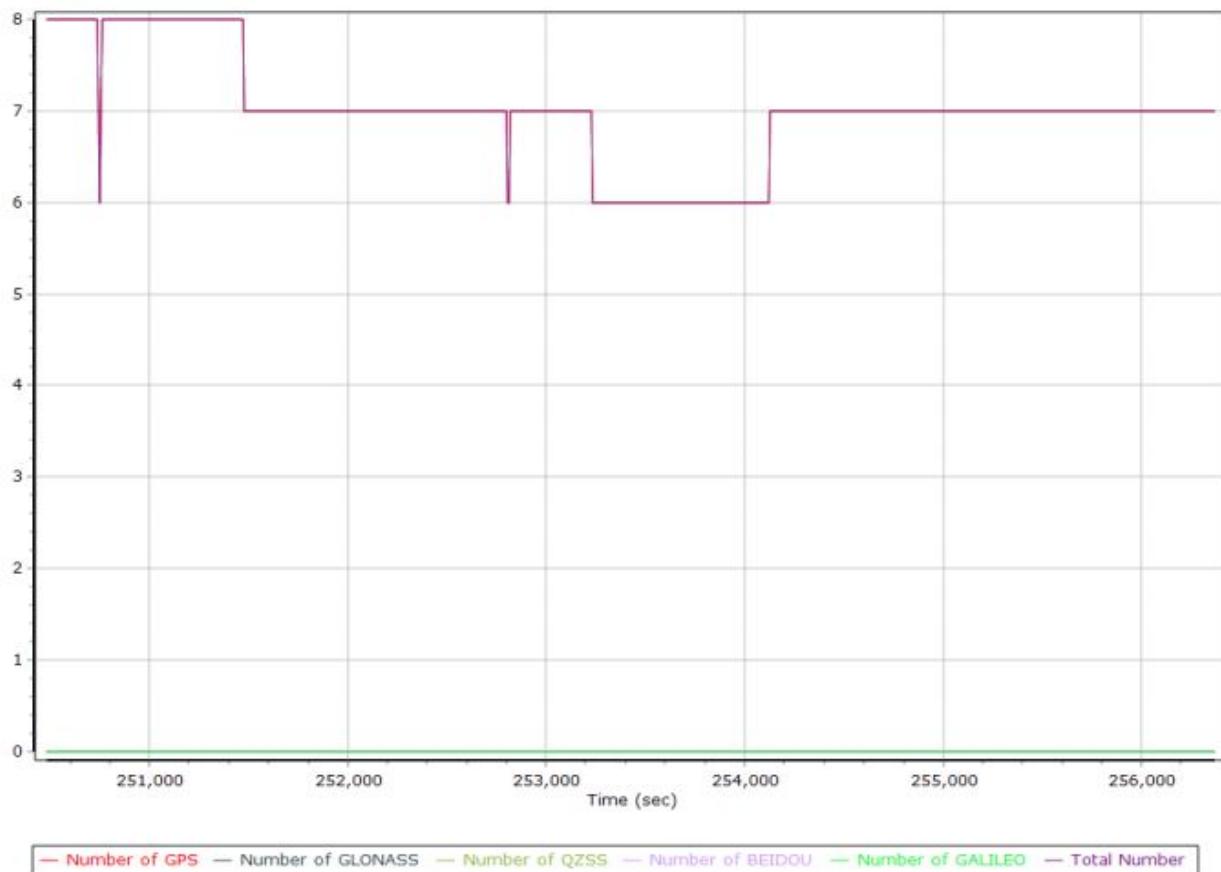


## GNSS QC

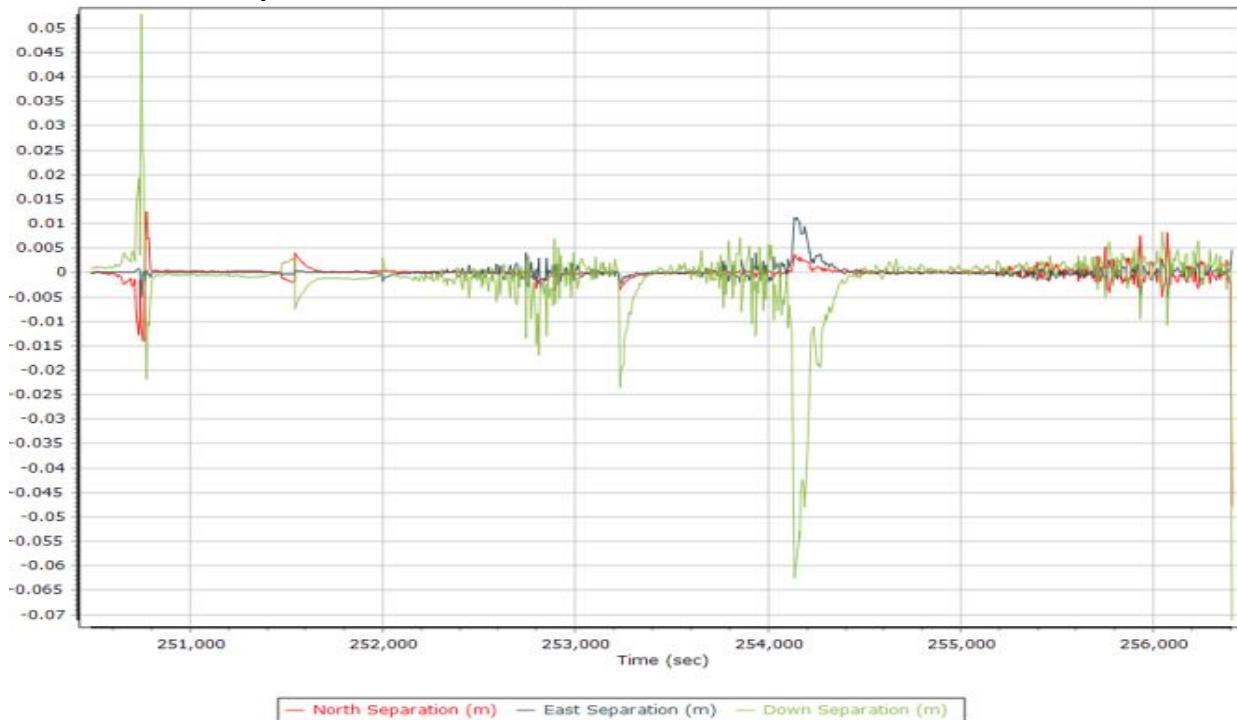
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	1.50	45.65	
Number of GPS SV	6	8	7
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	8	7
PDOP	1.88	4.83	2.61
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	6369.00	0.00	1.00
Percentage	99.98	0.00	0.02

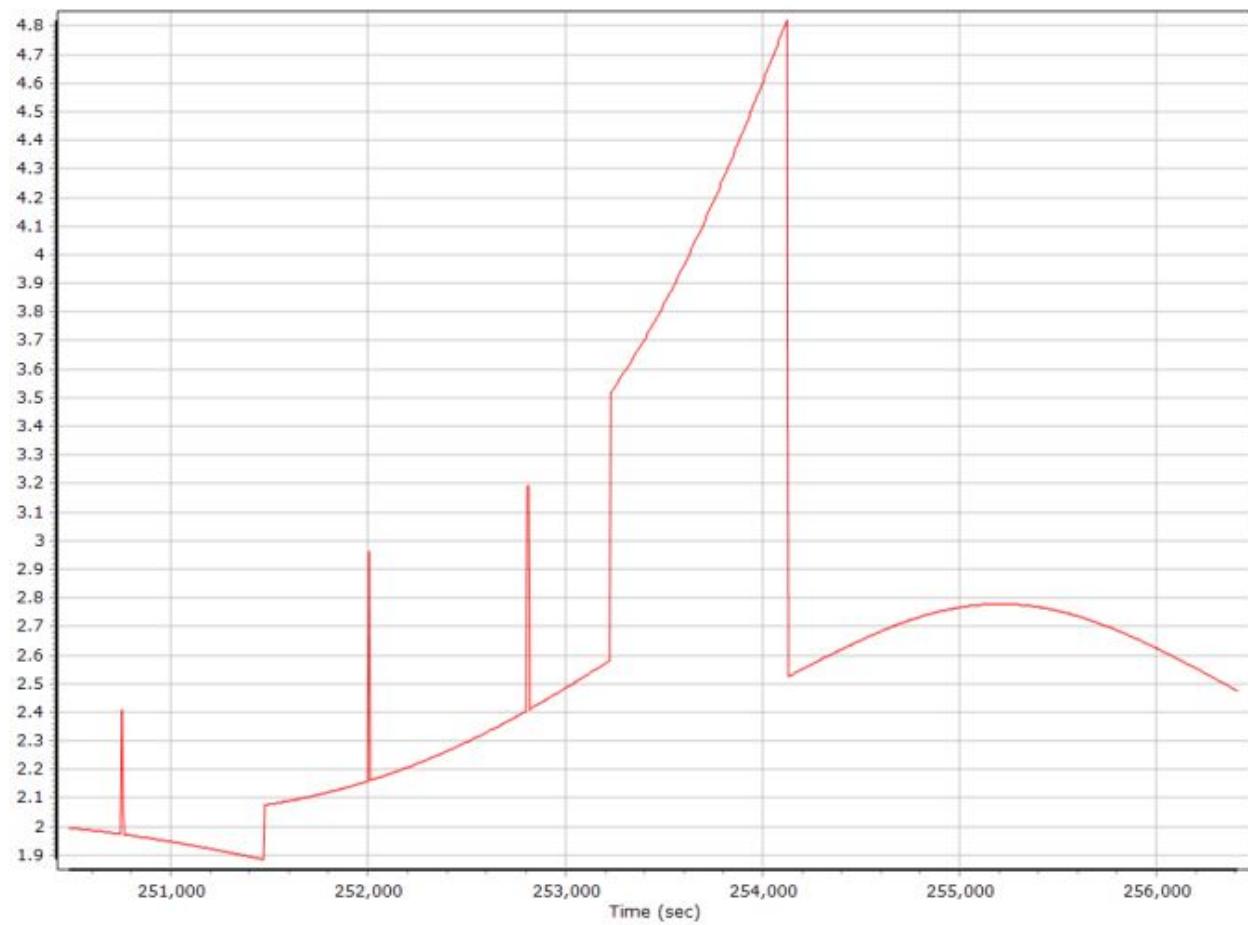
### Number of Satellites



### Forward/Reverse Separation

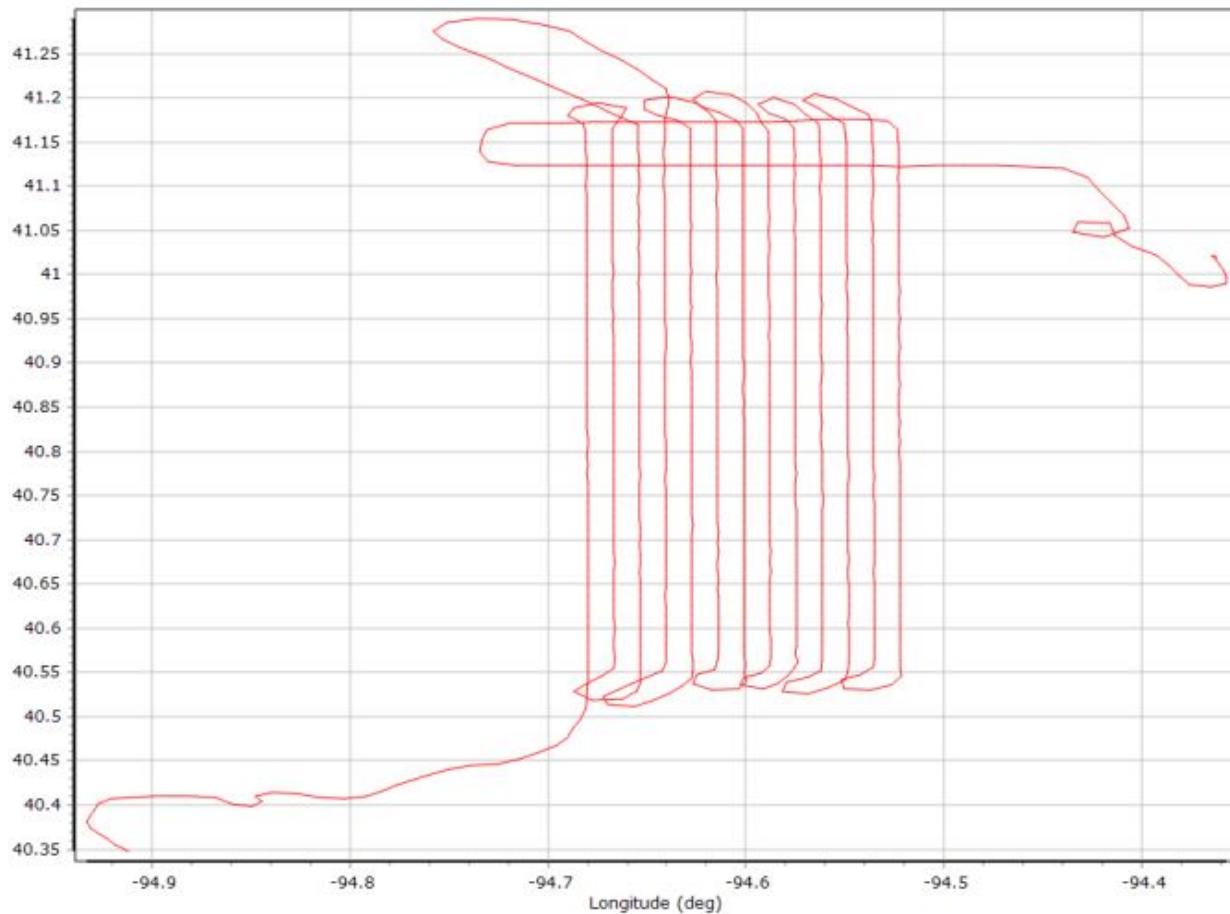


## PDOP



20210311\_1\_QC Report.docx QC Report – 8/27/2021 08:44:02  
Smoothed Trajectory Information

Top View

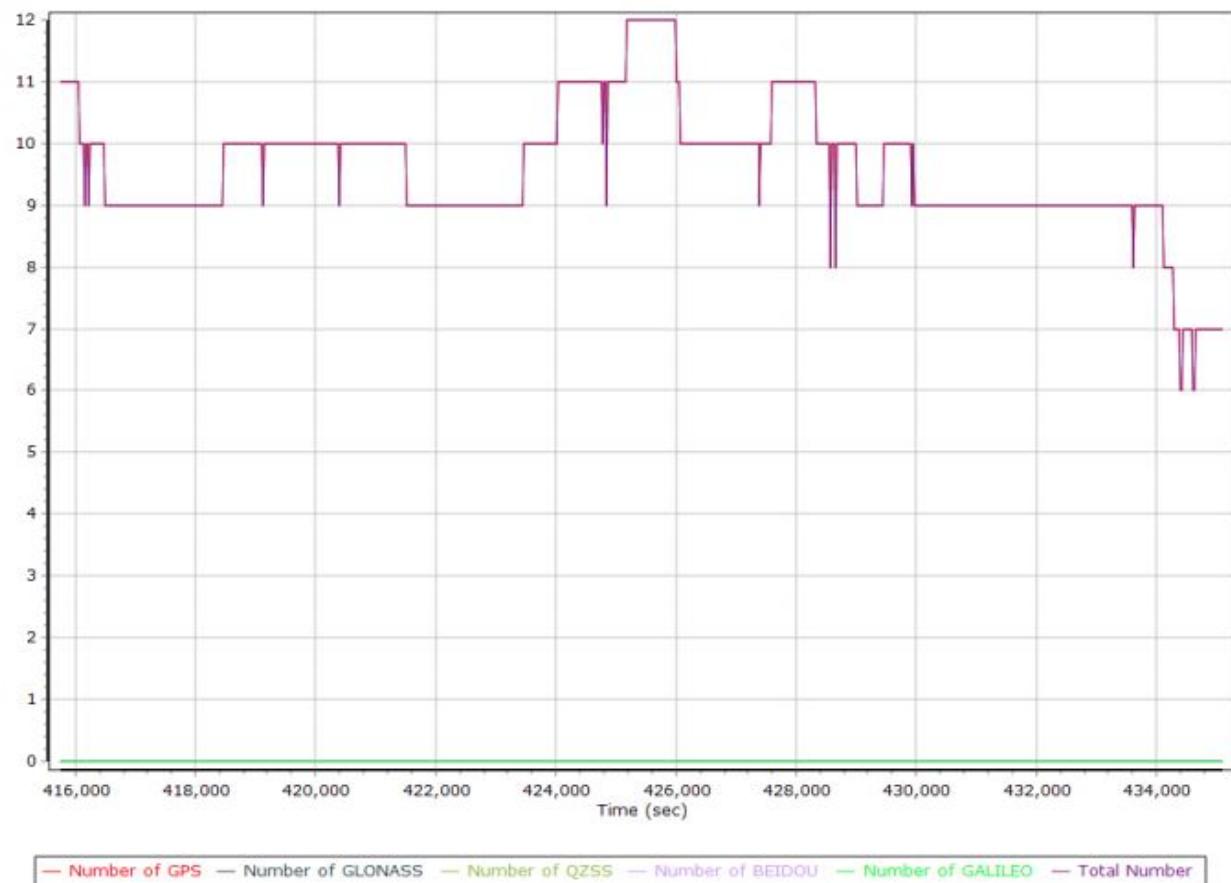


## GNSS QC

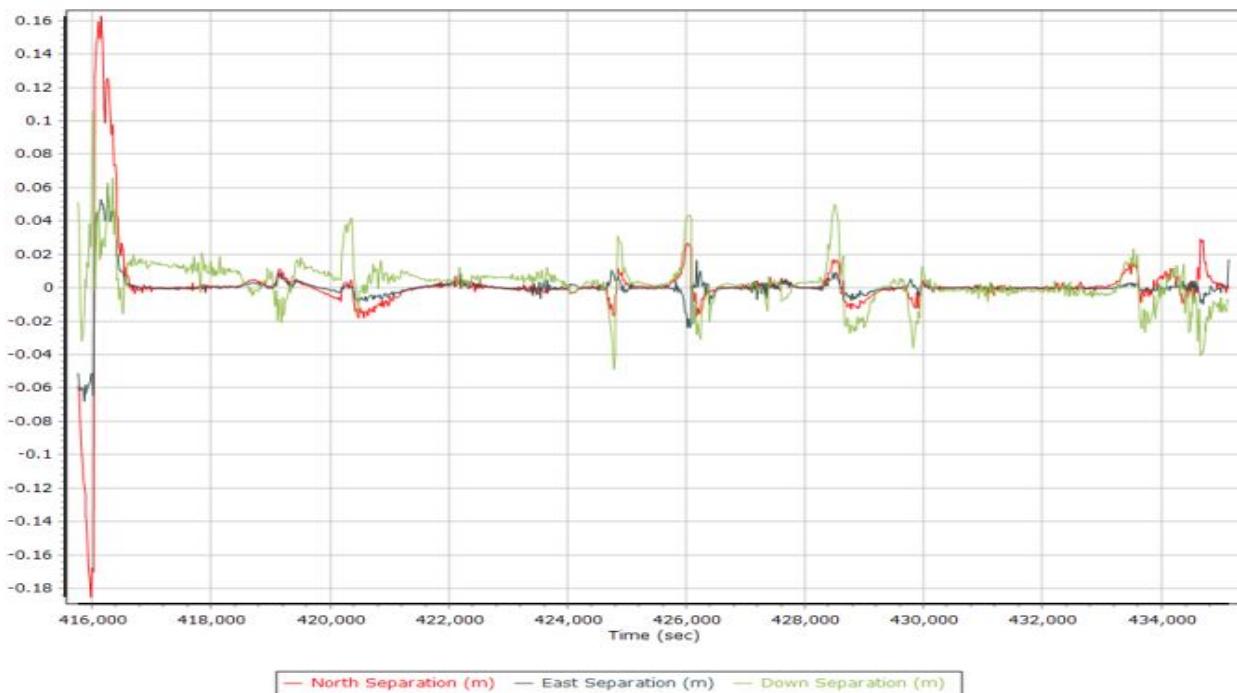
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.20	61.75	
Number of GPS SV	6	12	10
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	12	10
PDOP	1.26	3.11	1.75
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	19795.00	0.00	1.00
Percentage	99.99	0.00	0.01

### Number of Satellites

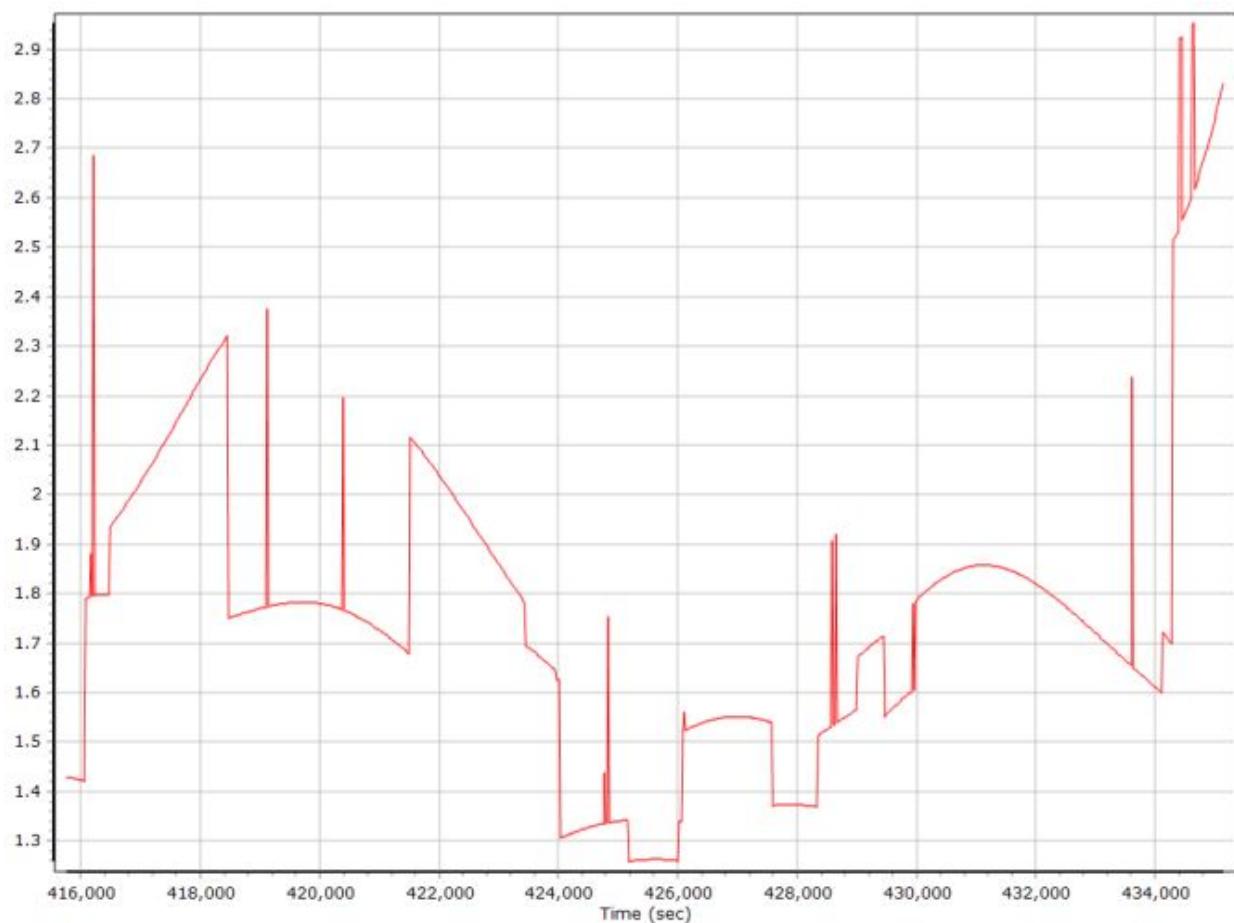


### Forward/Reverse Separation



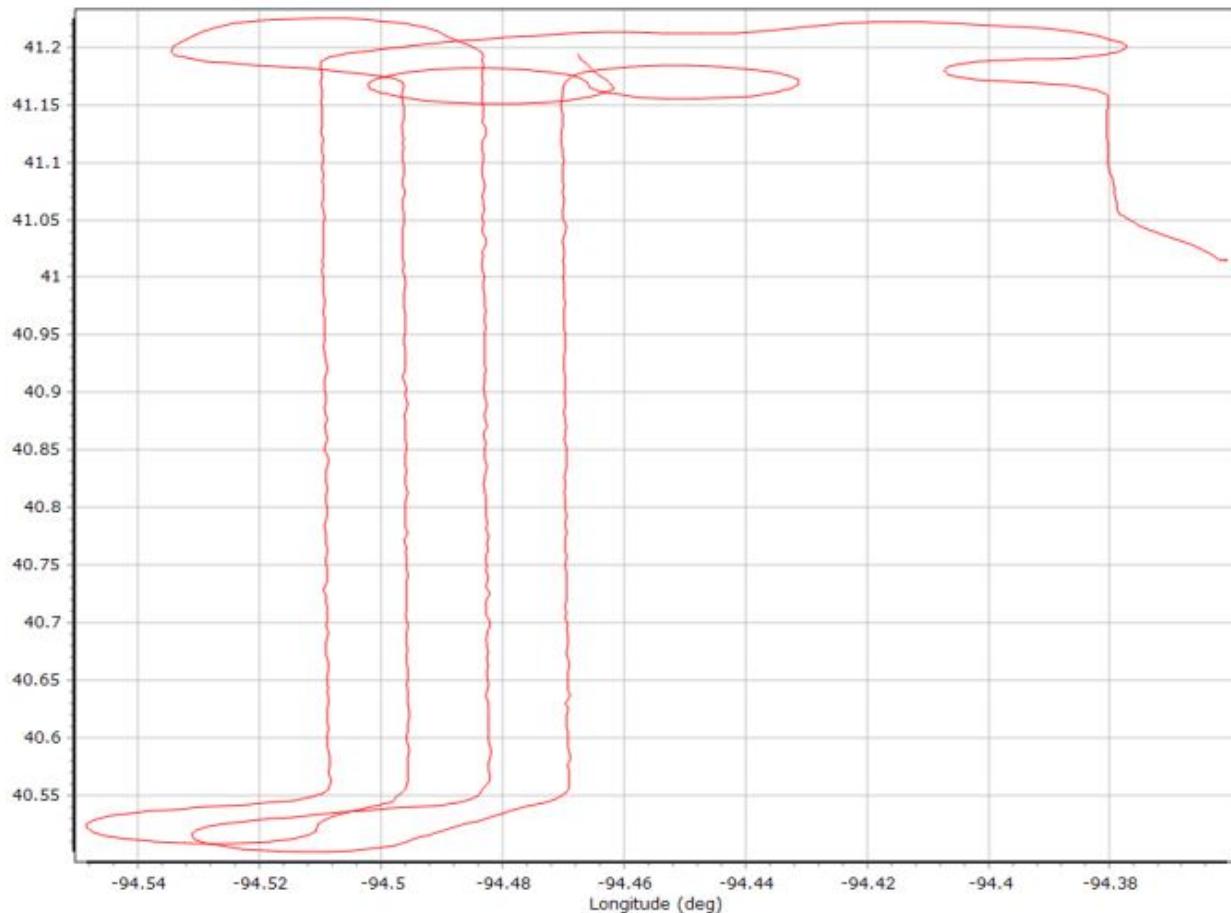
IA West 2020  
11/24/2021

### PDOP



20210311\_2\_QC Report.docx QC Report – 8/27/2021 09:35:02  
Smoothed Trajectory Information

Top View

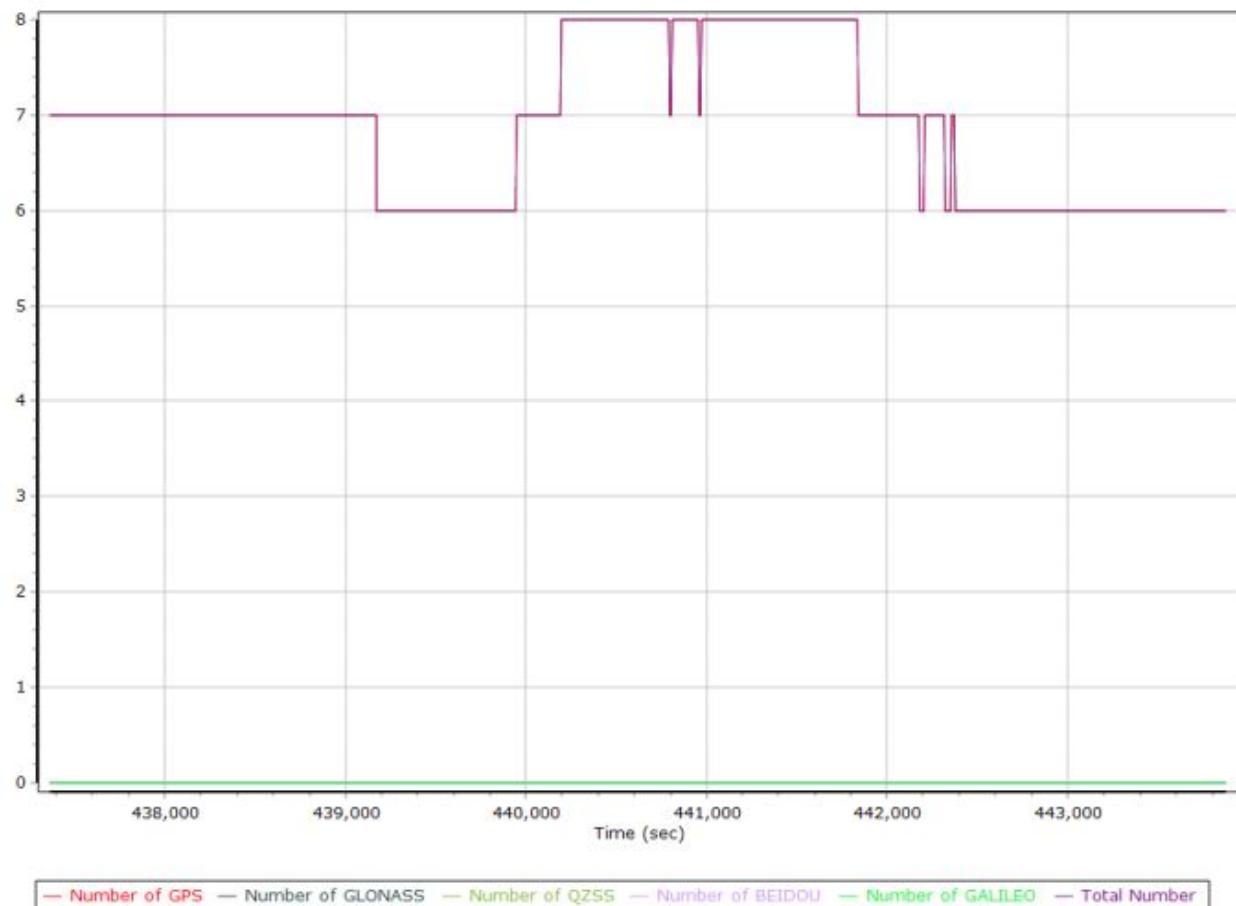


## GNSS QC

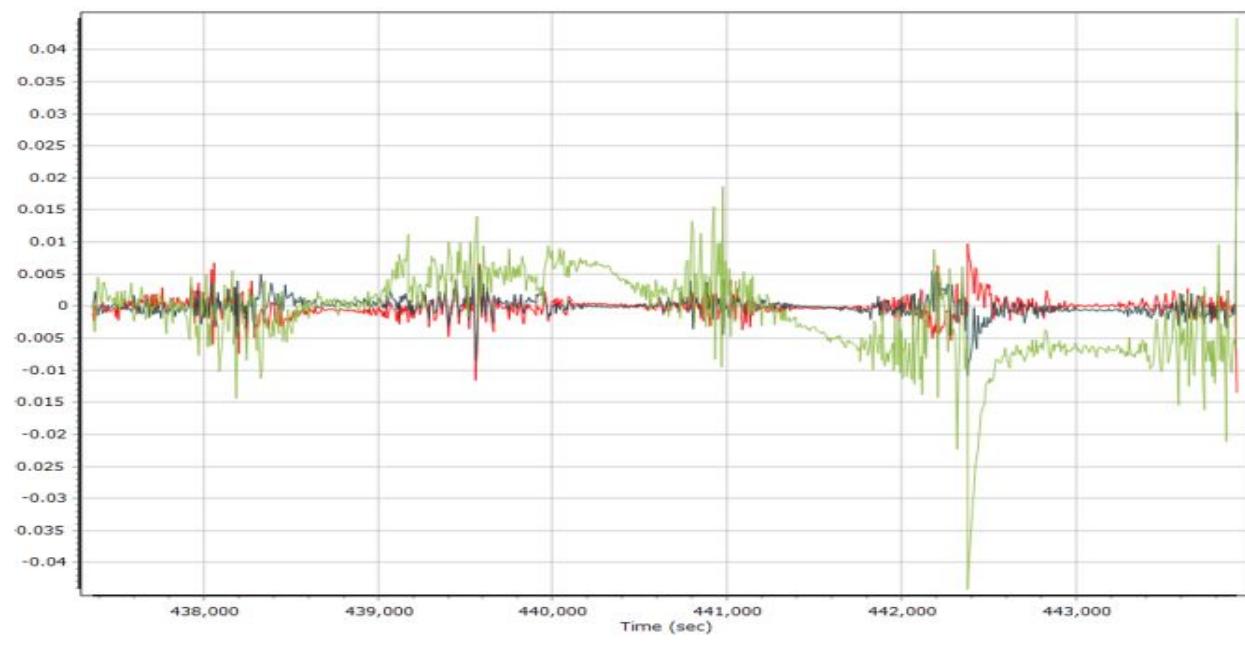
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.23	45.80	
Number of GPS SV	6	8	7
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	8	7
PDOP	1.77	3.04	2.27
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	6995.00	0.00	1.00
Percentage	99.99	0.00	0.01

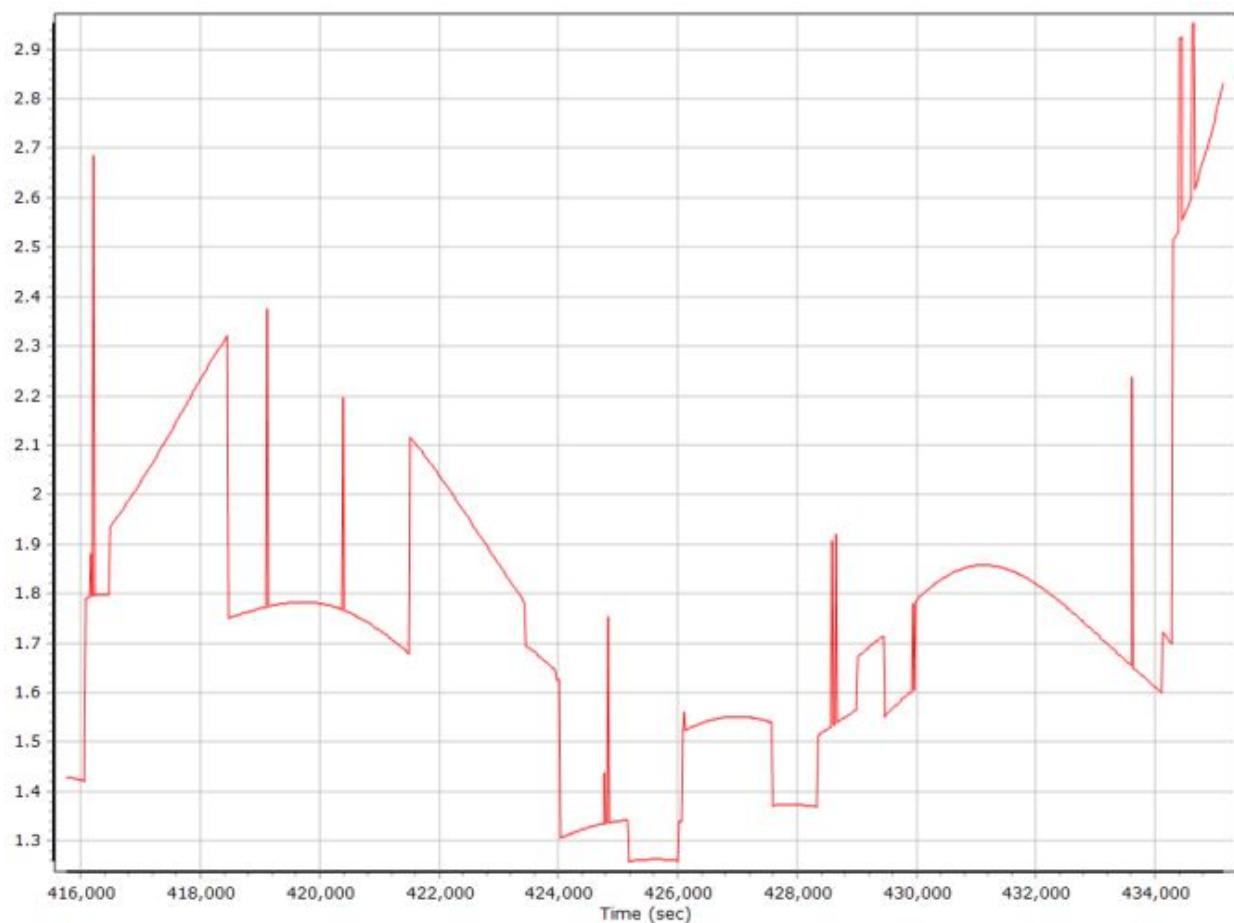
### Number of Satellites



### Forward/Reverse Separation

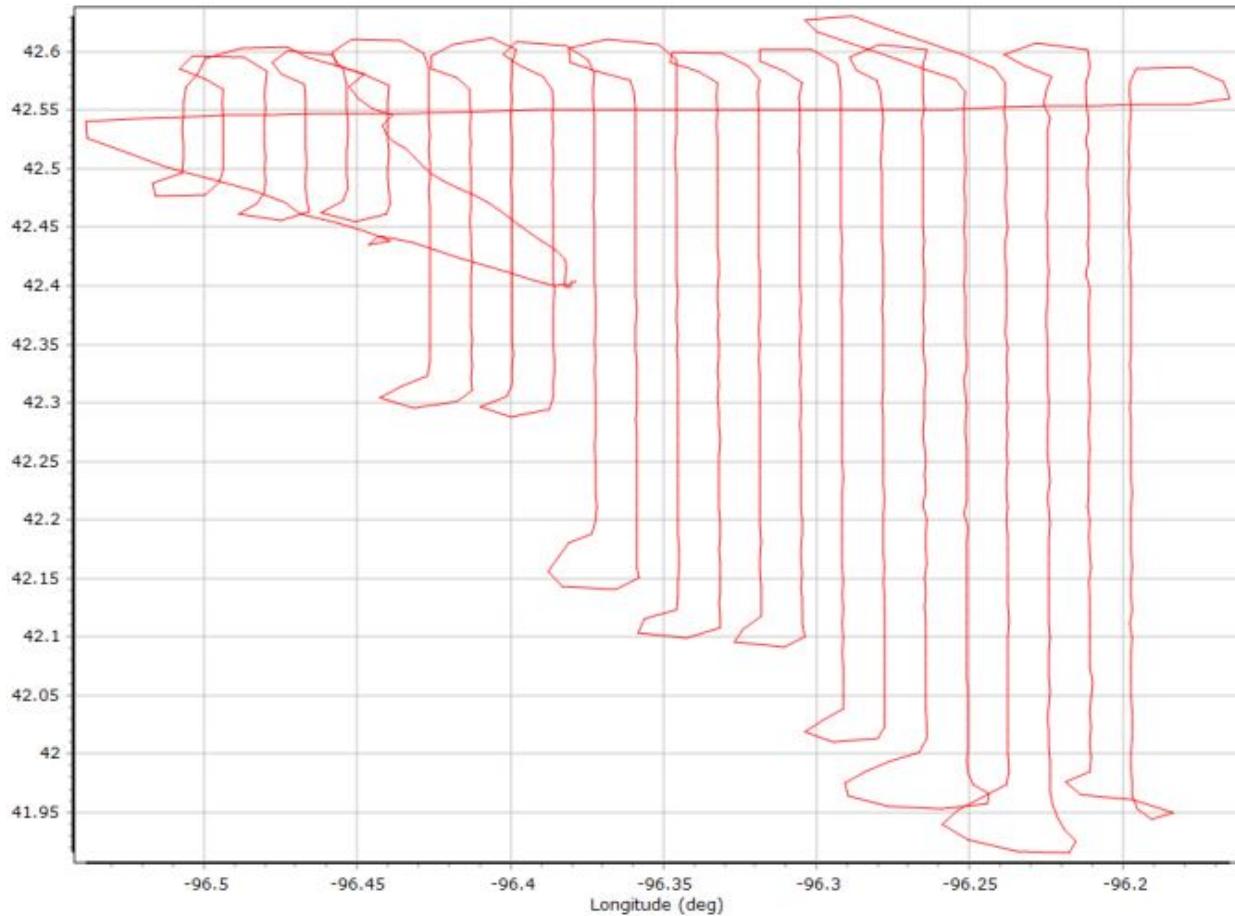


PDOP



**Block C** 20210328\_1\_QC Report.docx QC Report – 8/27/2021 09:50:02  
Smoothed Trajectory Information

Top View

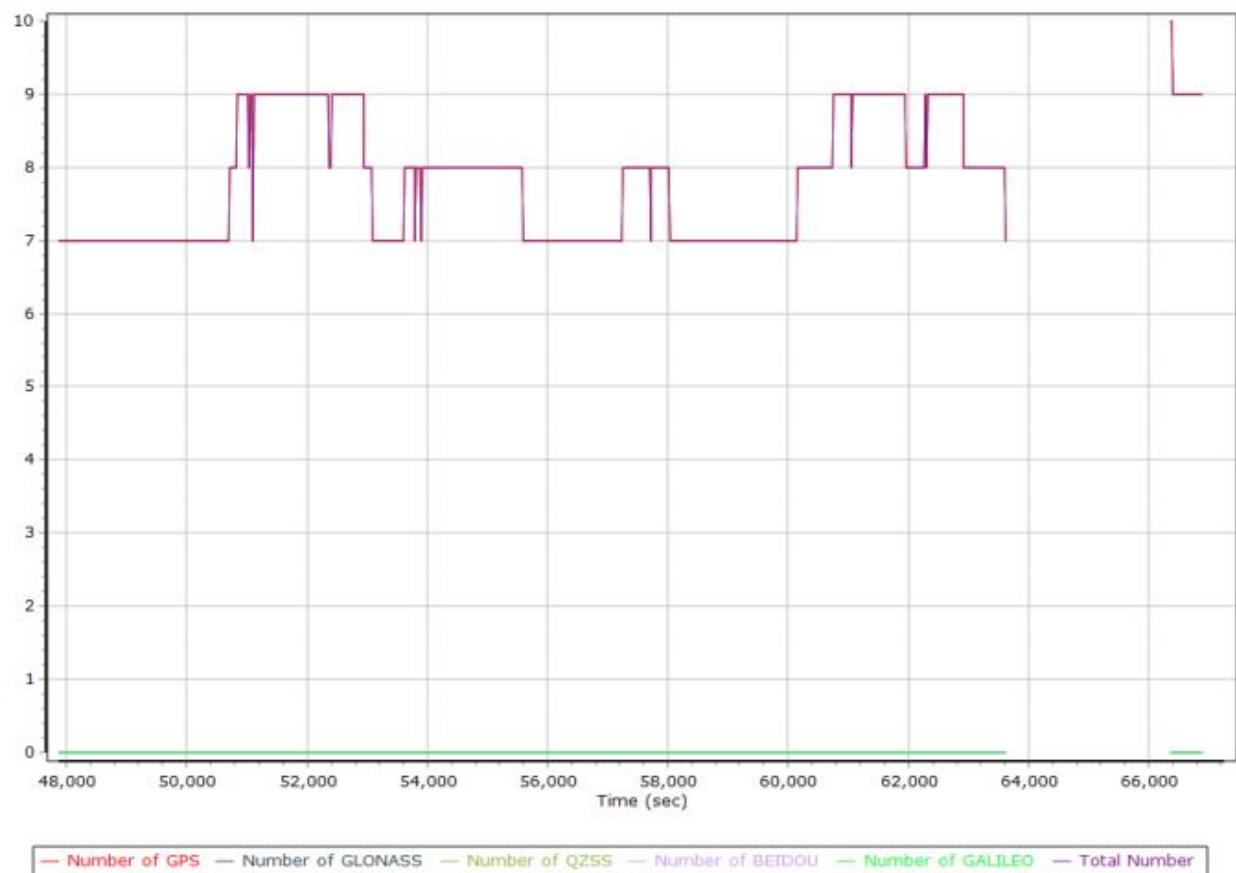


## GNSS QC

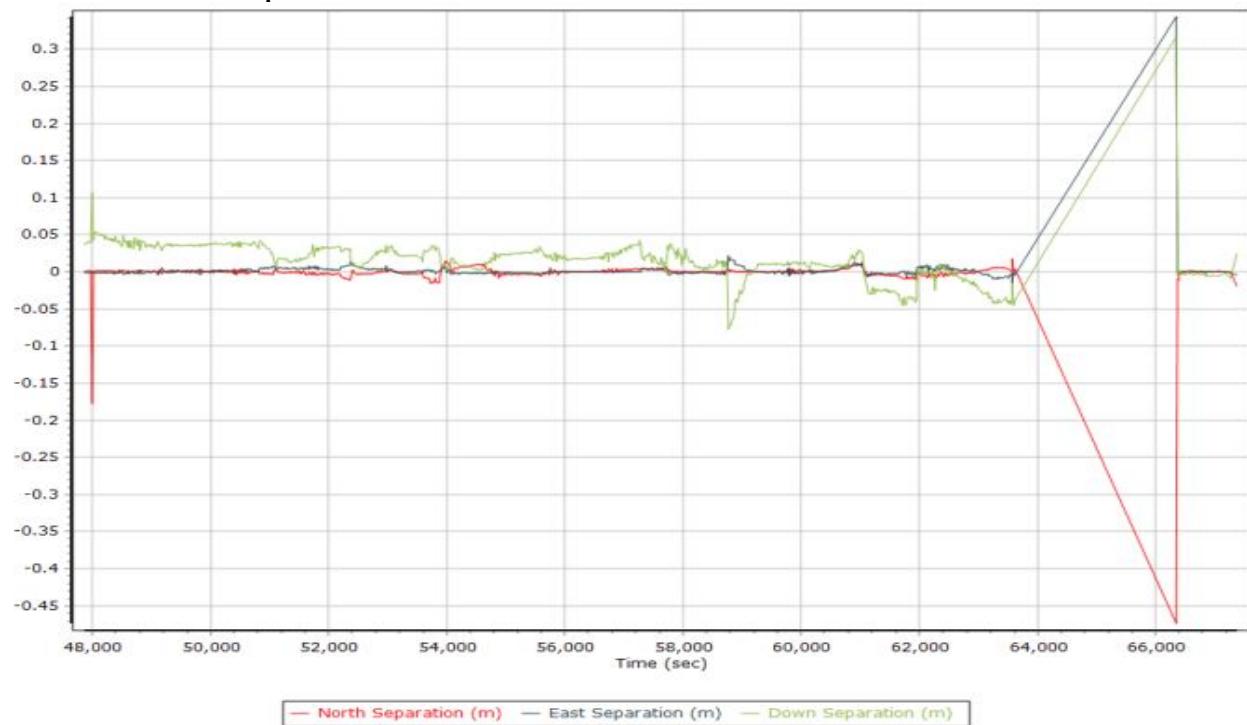
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.35	45.72	
Number of GPS SV	5	11	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	11	8
PDOP	1.42	5.19	2.17
QC Solution Gaps	1.00	2719.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	16948.00	0.00	3050.00
Percentage	84.75	0.00	15.25

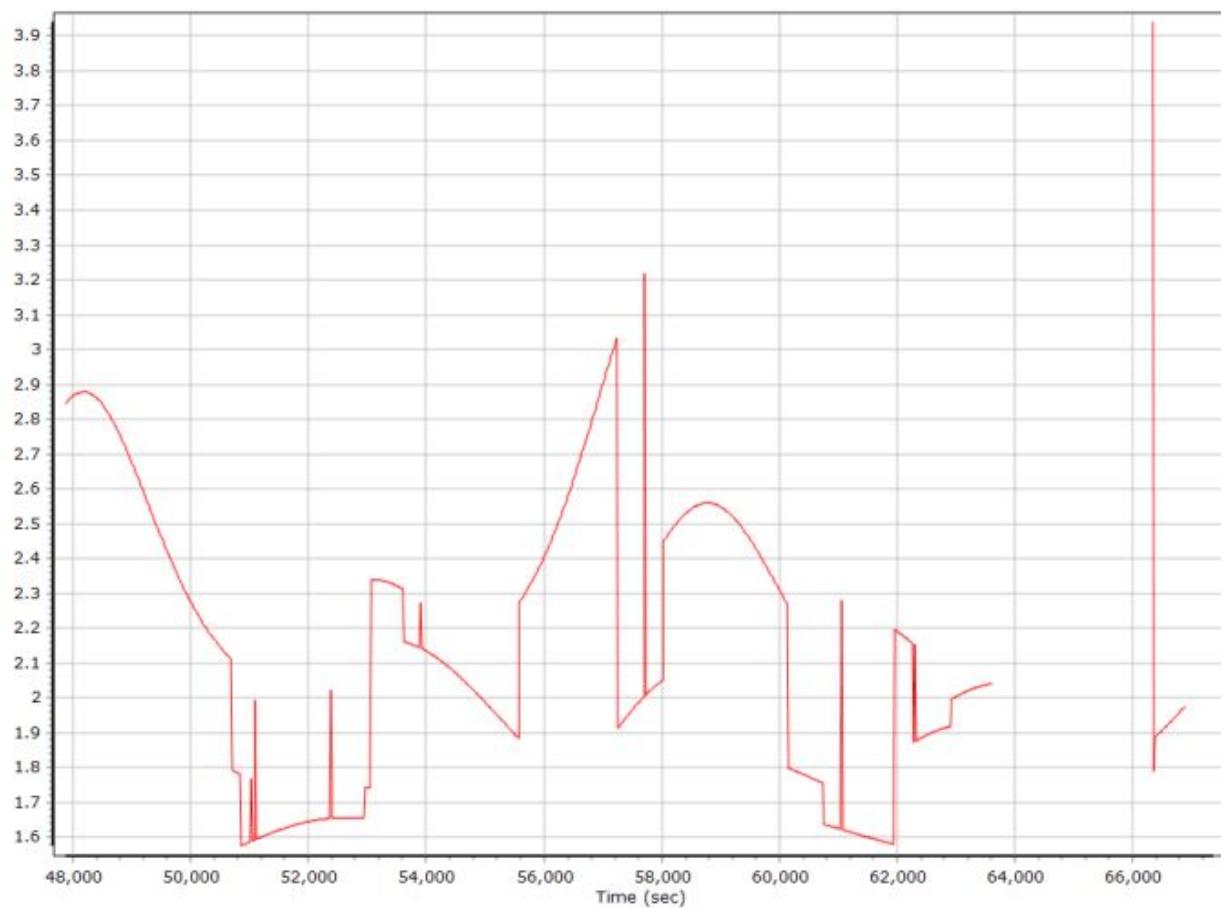
### Number of Satellites



### Forward/Reverse Separation

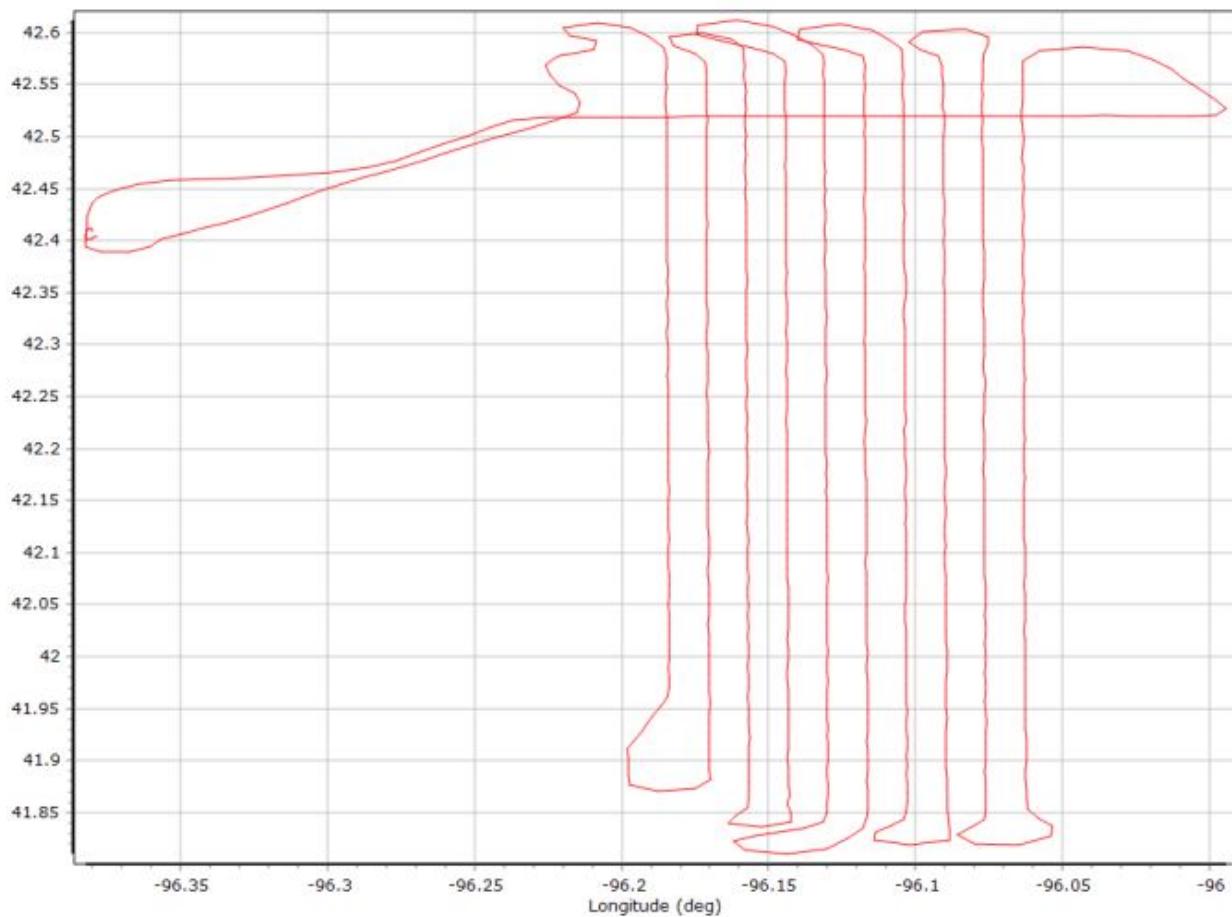


### PDOP



20210328\_2\_QC Report.docx QC Report – 8/27/2021 09:58:33  
Smoothed Trajectory Information

Top View

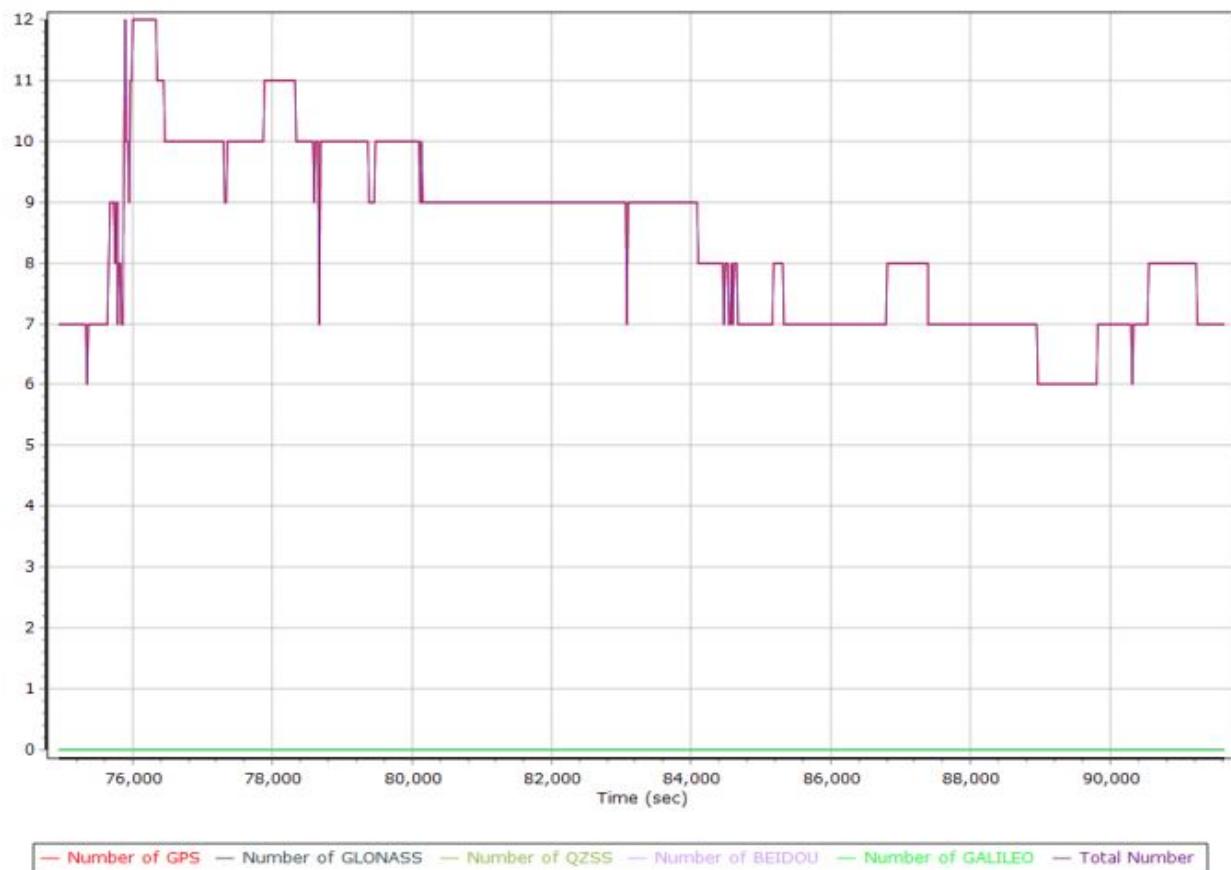


## GNSS QC

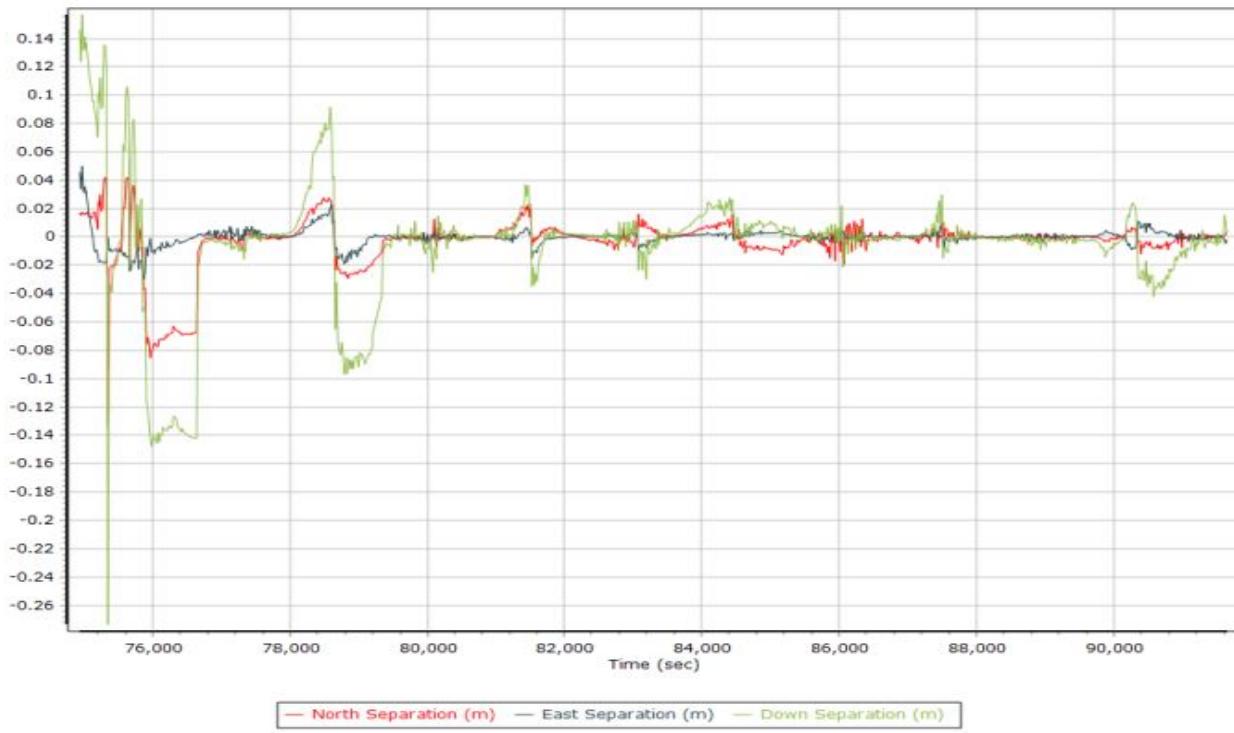
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.50	49.46	
Number of GPS SV	5	12	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	12	8
PDOP	1.26	6.23	1.88
QC Solution Gaps	1.00	4.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17173.00	0.00	6.00
Percentage	99.97	0.00	0.03

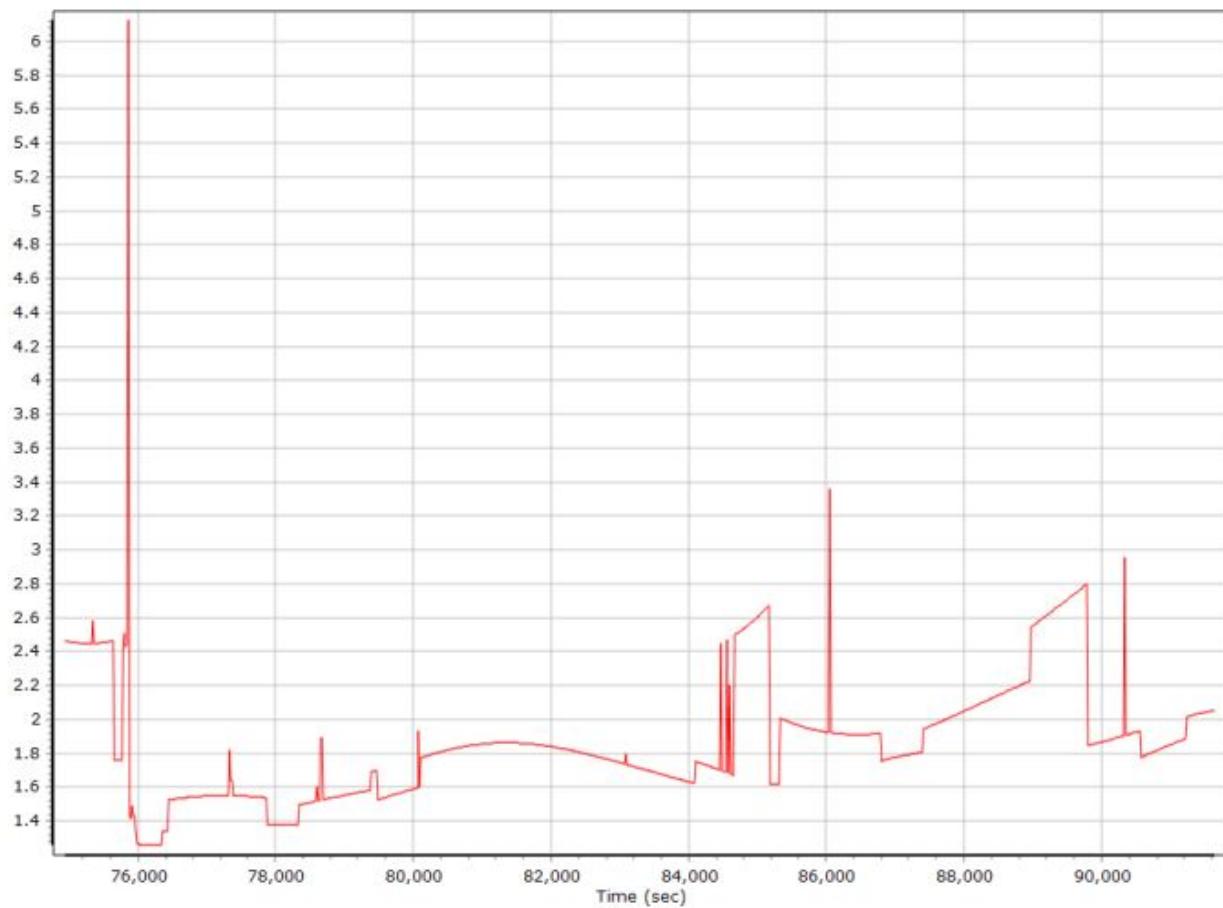
### Number of Satellites



### Forward/Reverse Separation

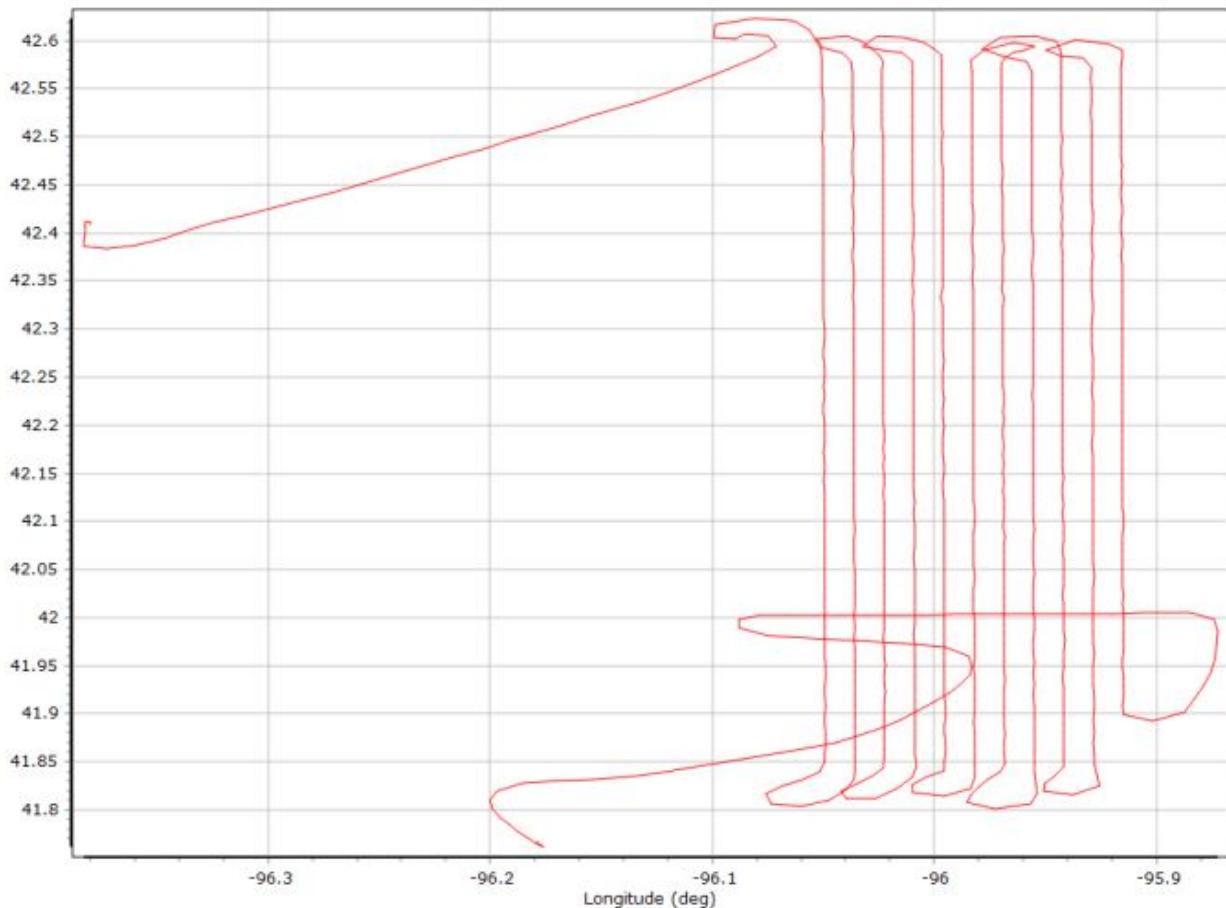


### PDOP



20210329\_1\_QC Report.docx QC Report – 8/27/2021 10:07:14  
Smoothed Trajectory Information

Top View



## GNSS QC

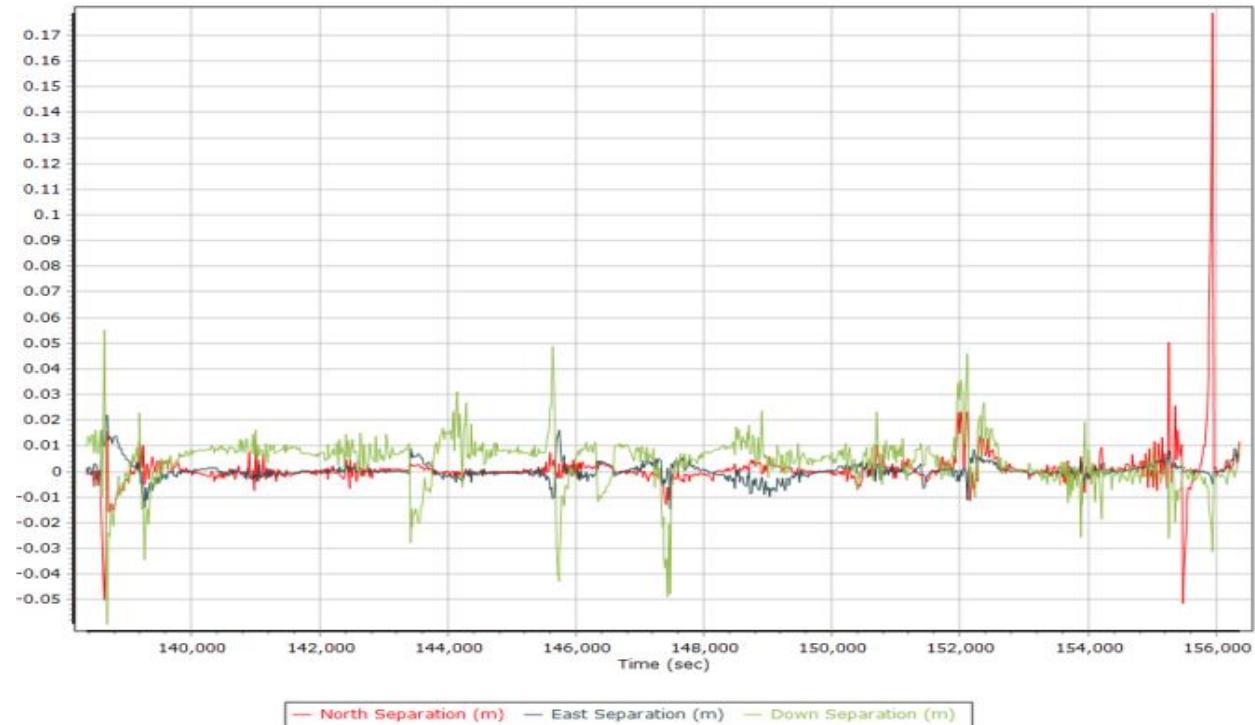
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.41	46.68	
Number of GPS SV	5	11	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	11	8
PDOP	1.43	5.34	2.43
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	18610.00	0.00	1.00
Percentage	99.99	0.00	0.01

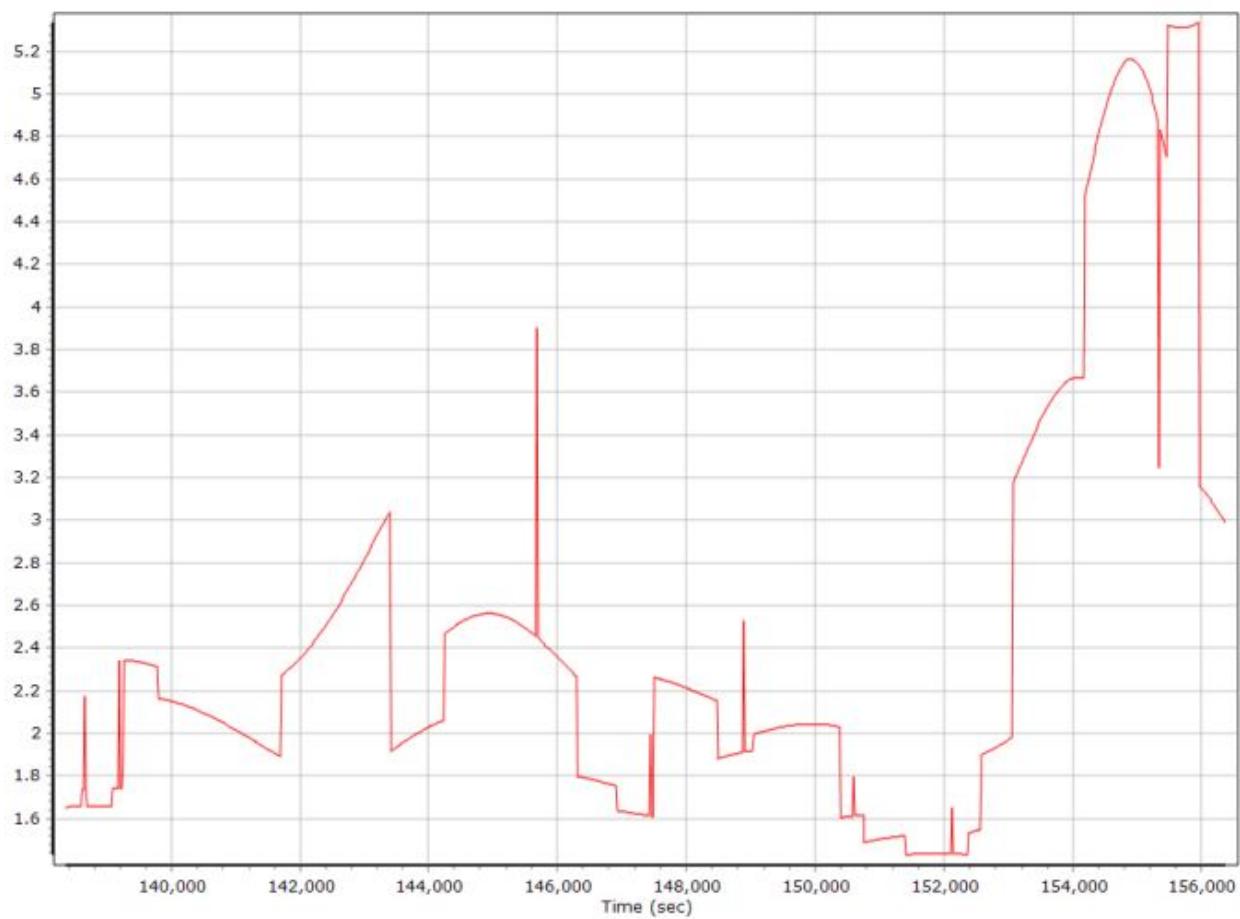
### Number of Satellites



### Forward/Reverse Separation

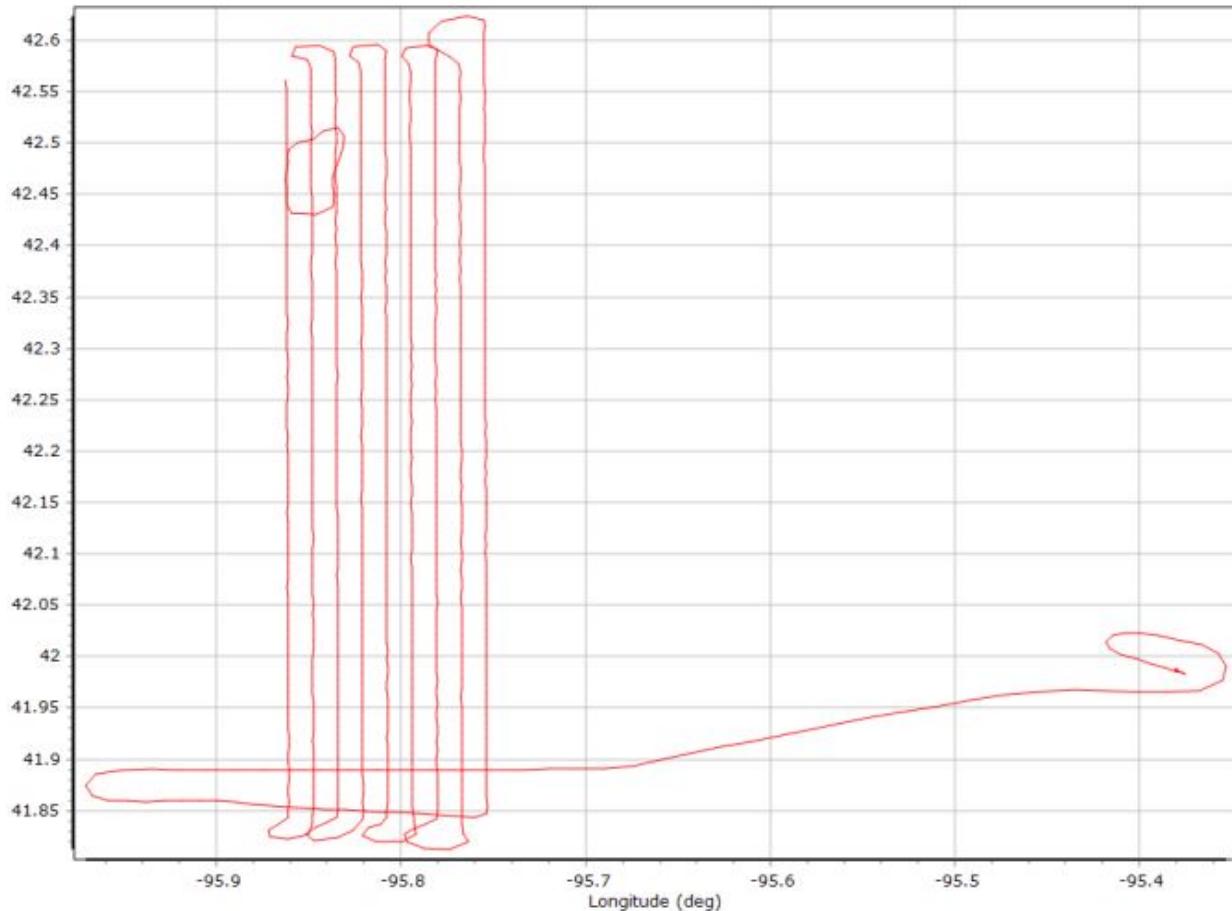


PDOP



20210329\_2\_QC Report.docx QC Report – 8/27/2021 1014:24  
Smoothed Trajectory Information

Top View

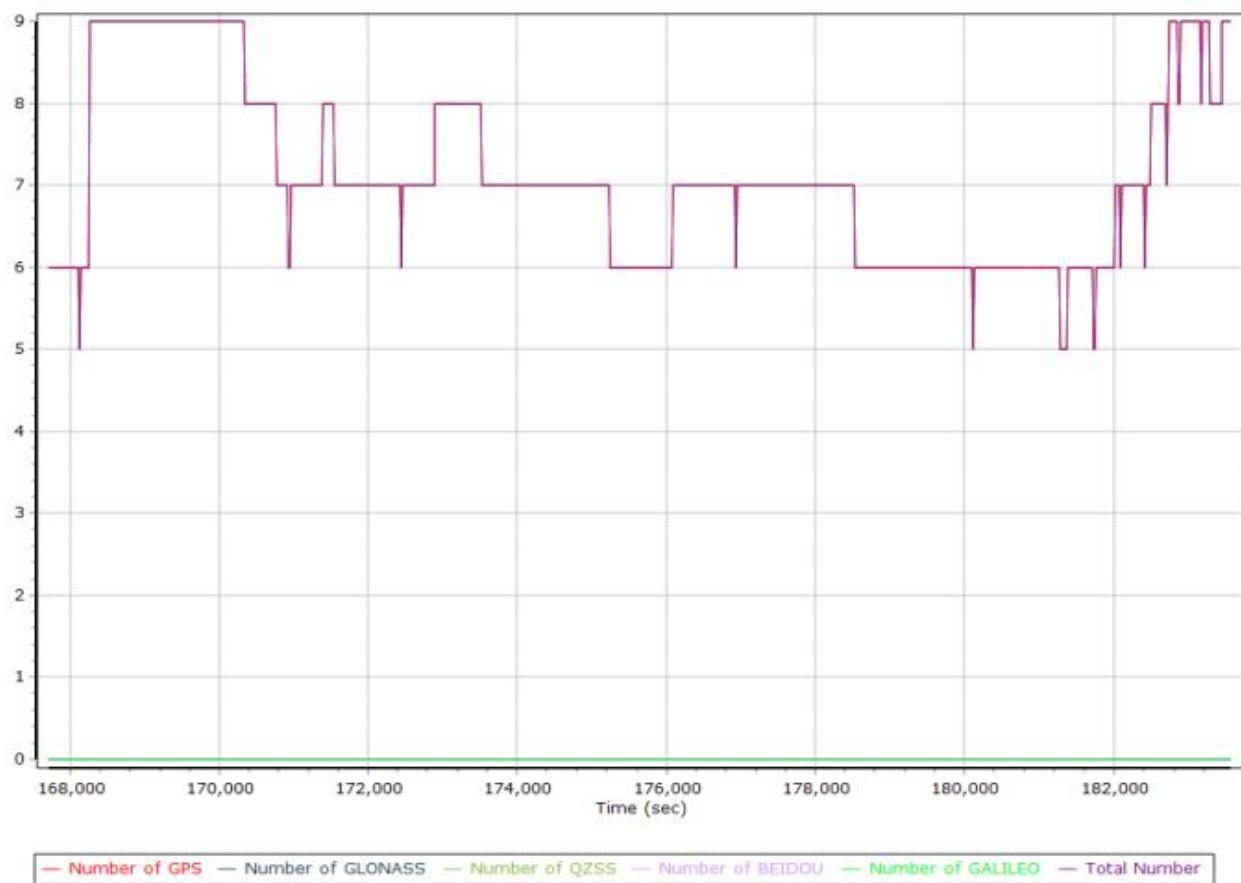


## GNSS QC

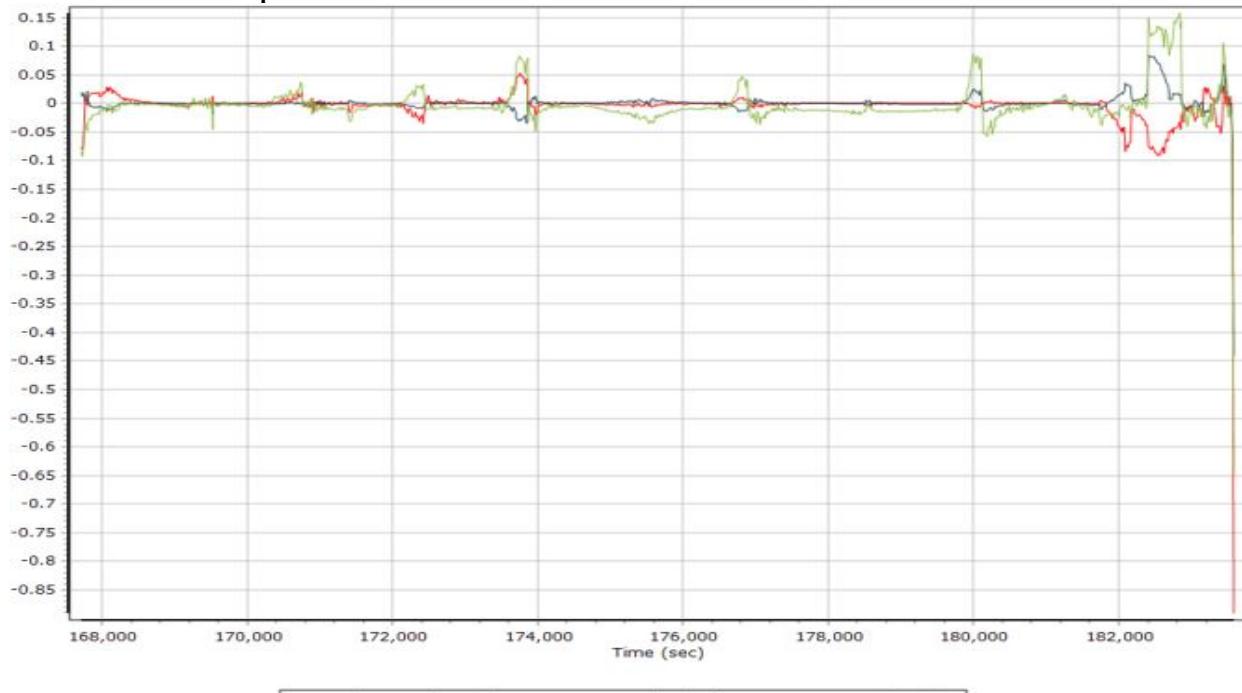
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.31	51.94	
Number of GPS SV	5	9	7
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	9	7
PDOP	1.61	6.96	2.26
QC Solution Gaps	3.00	9.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	15914.00	0.00	12.00
Percentage	99.92	0.00	0.08

### Number of Satellites

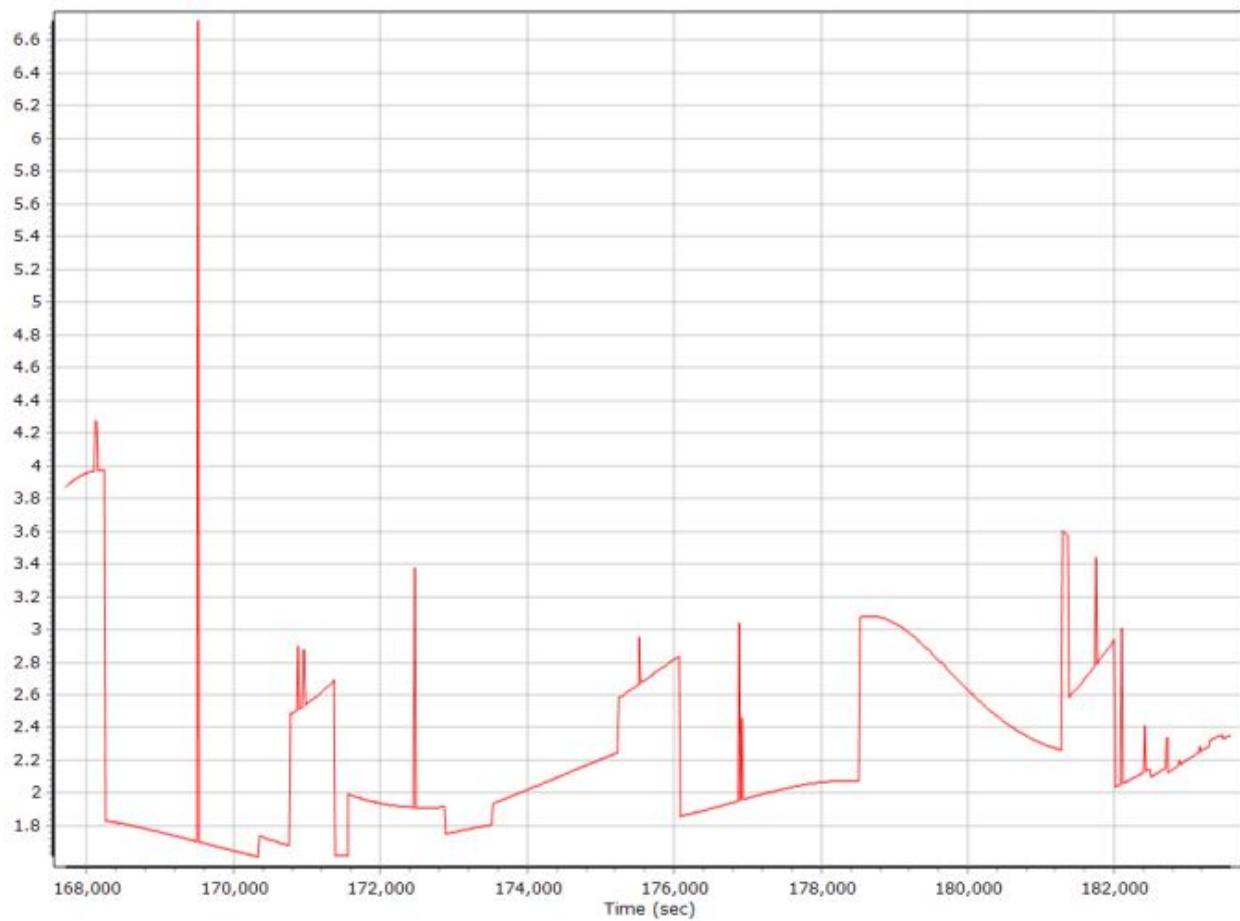


### Forward/Reverse Separation



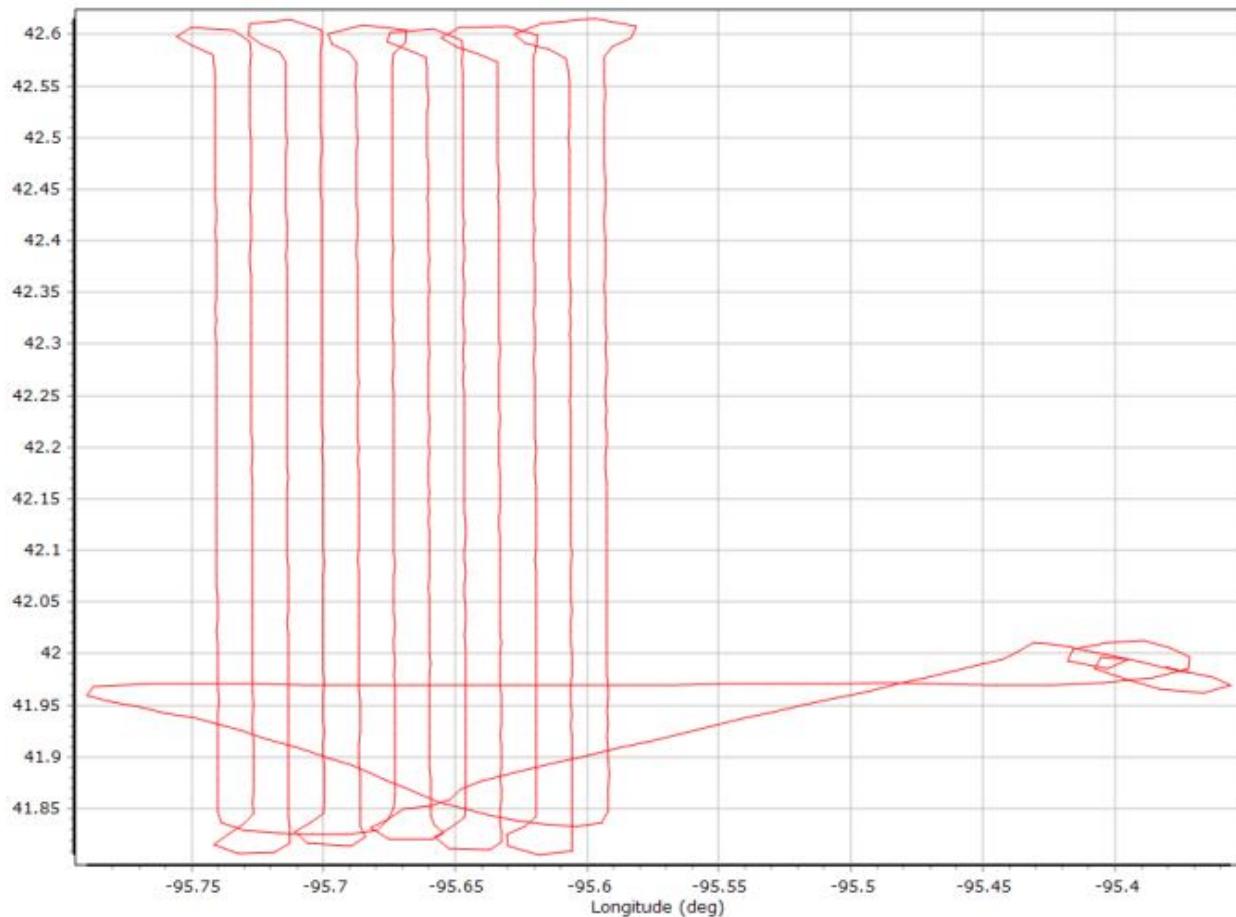
IA West 2020  
11/24/2021

### PDOP



20210330\_1\_QC Report.docx QC Report – 8/27/2021 10:20:22  
Smoothed Trajectory Information

Top View

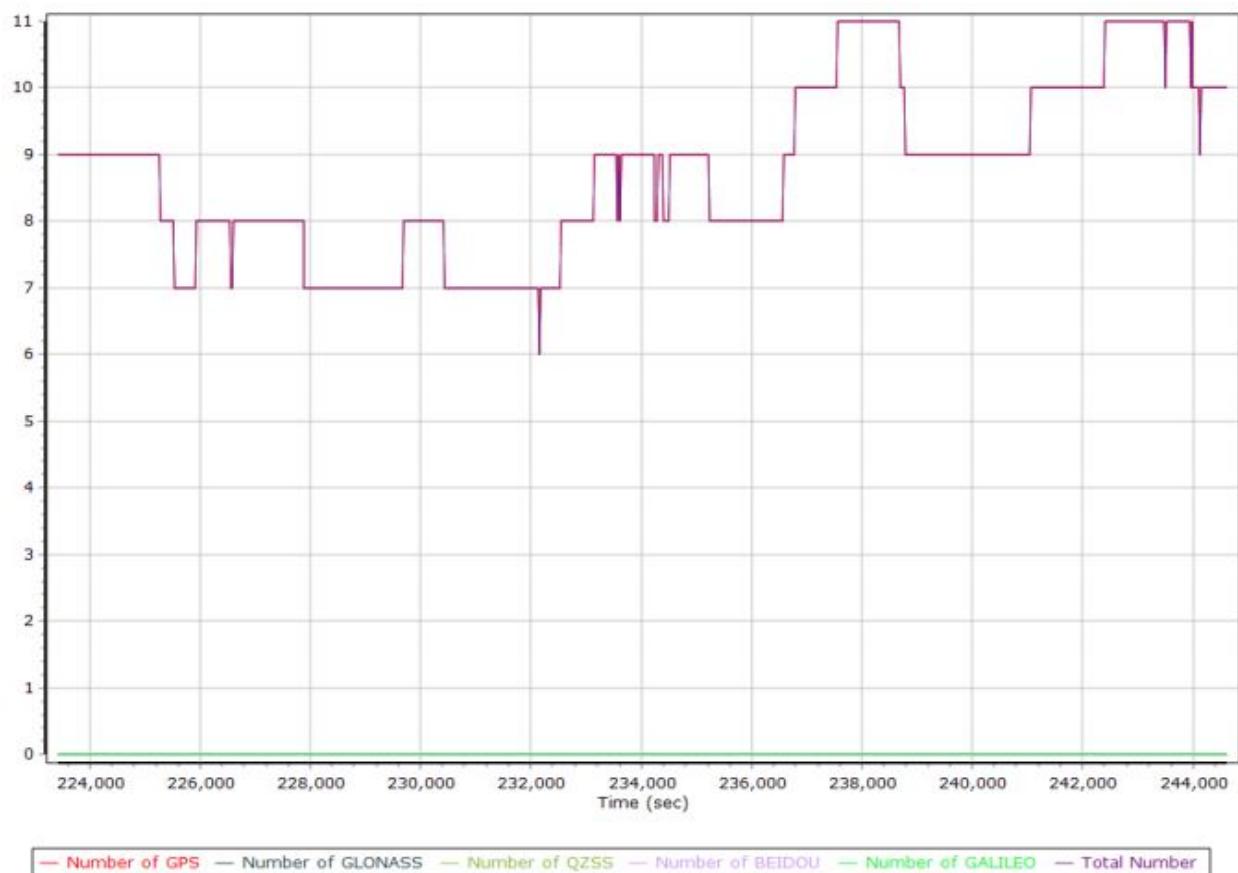


## GNSS QC

### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.26	49.38	
Number of GPS SV	6	11	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	11	9
PDOP	1.42	3.95	1.94
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	21672.00	0.00	1.00
Percentage	100.00	0.00	0.00

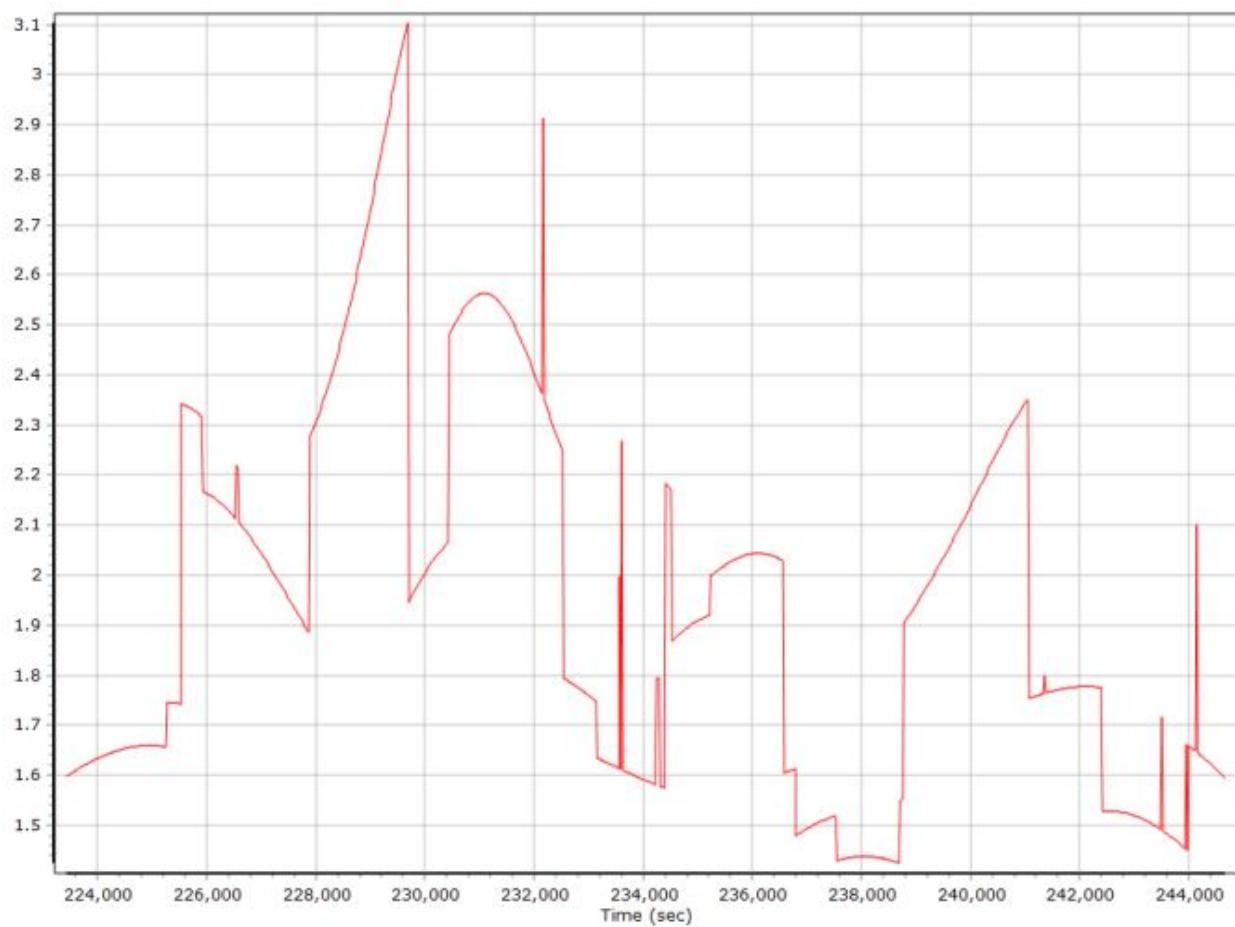
### Number of Satellites



### Forward/Reverse Separation

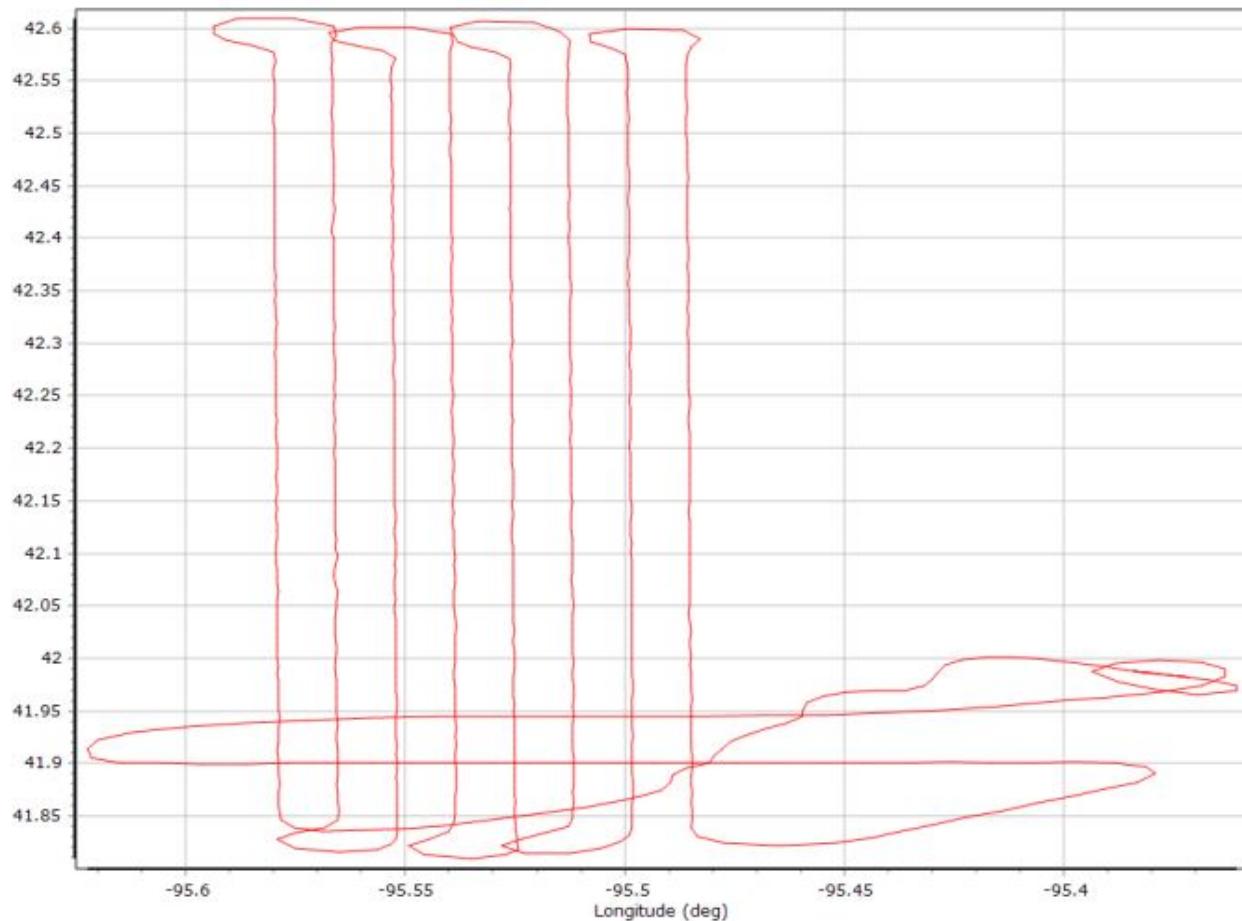


PDOP



20210330\_2\_QC Report.docx QC Report – 8/27/2021 10:26:41  
Smoothed Trajectory Information

Top View

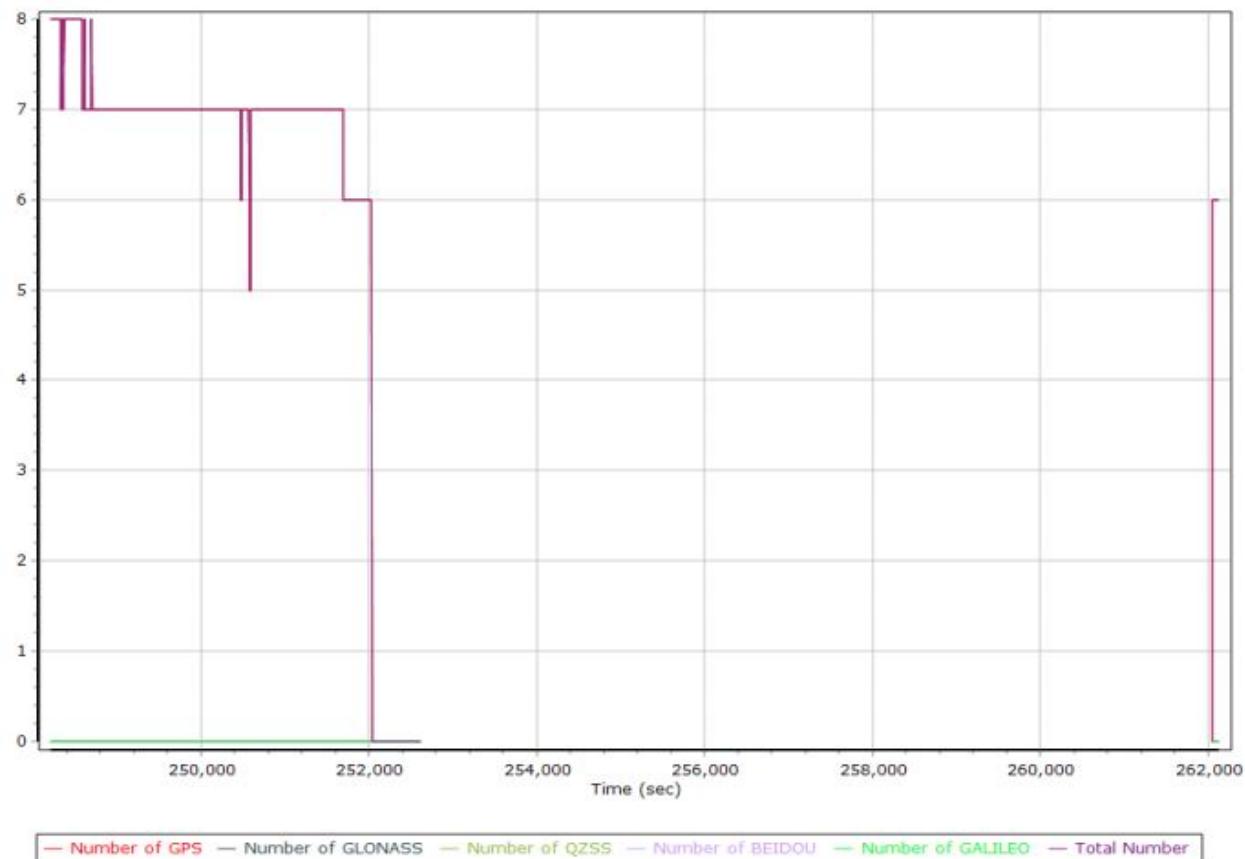


## GNSS QC

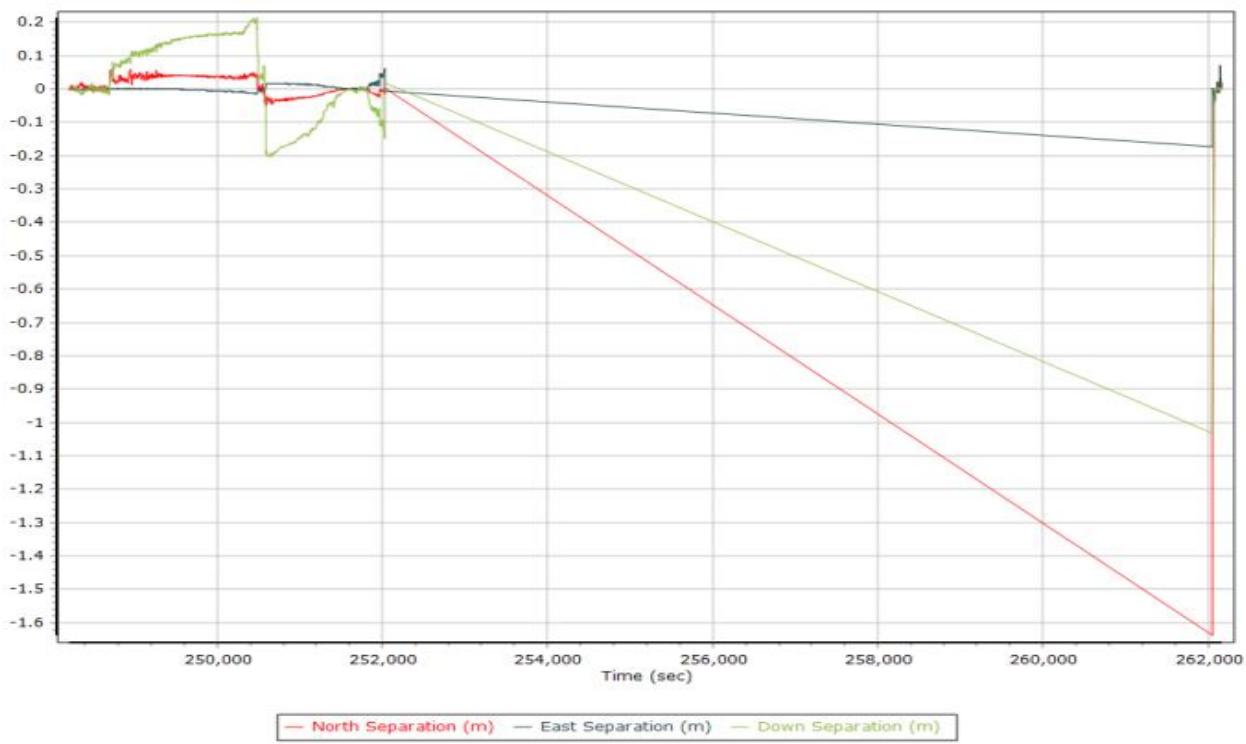
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	4.15	49.91	
Number of GPS SV	5	9	7
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	9	7
PDOP	1.80	6.99	4.07
QC Solution Gaps	1.00	9405.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	4270.00	39.00	10010.00
Percentage	29.82	0.27	69.91

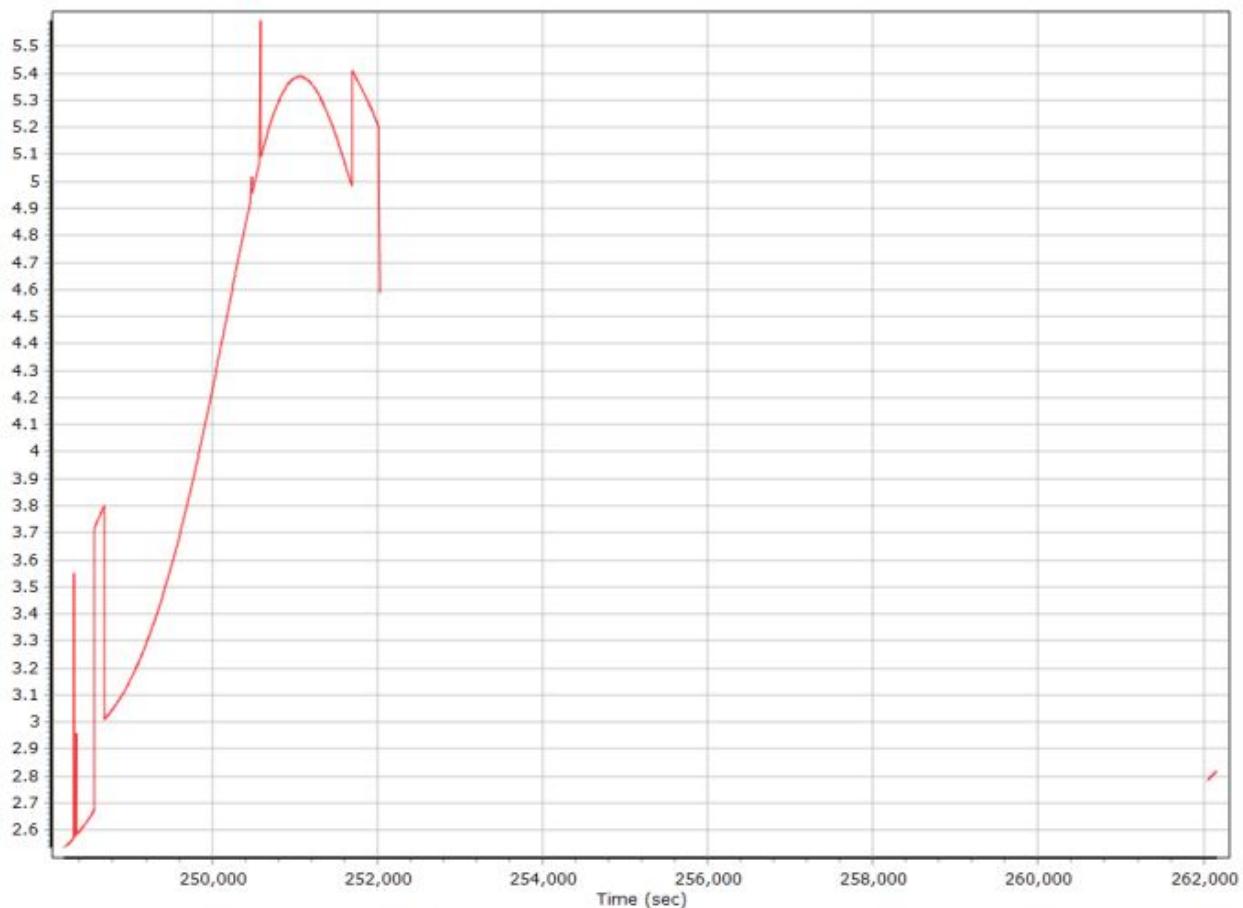
### Number of Satellites



### Forward/Reverse Separation

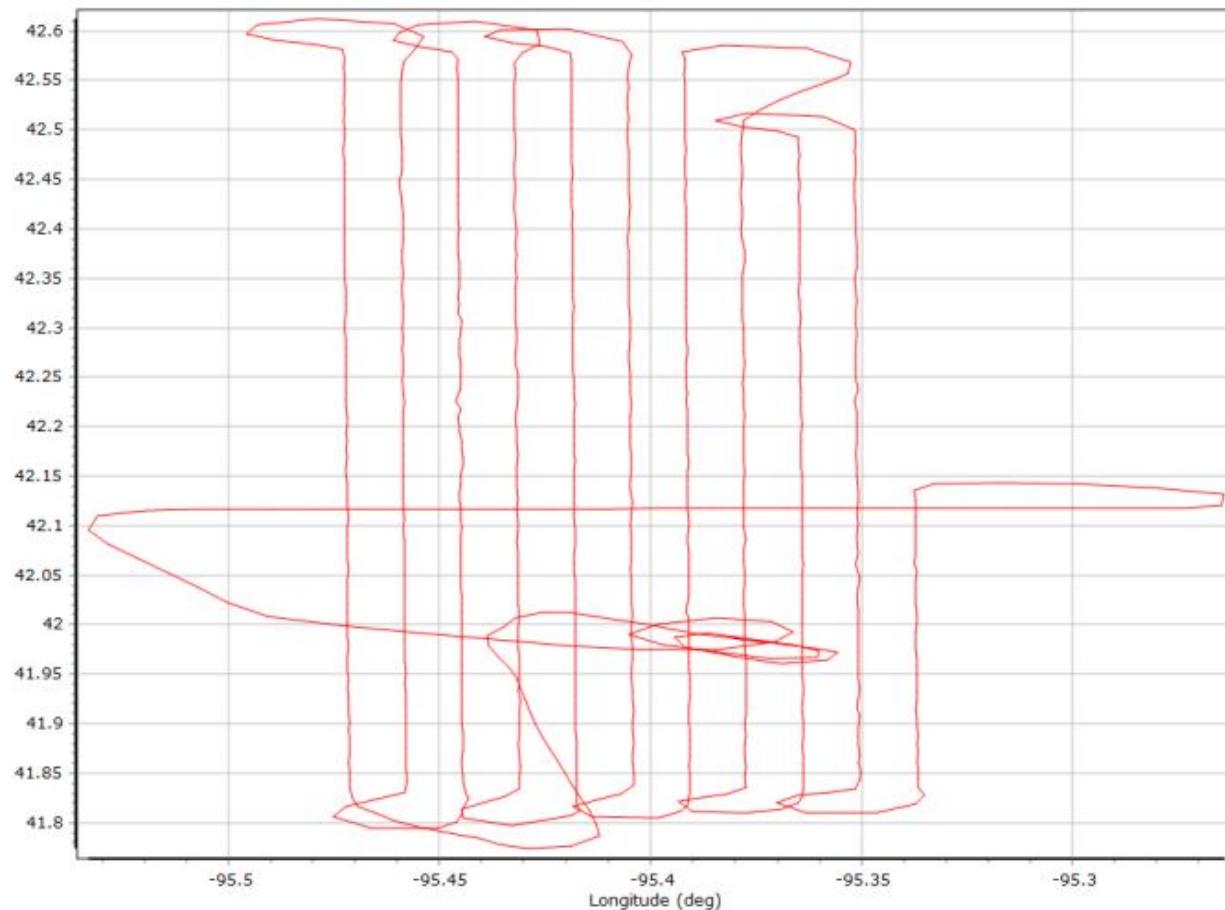


### PDOP



20210331\_1\_QC Report.docx QC Report – 8/27/2021 10:34:23  
Smoothed Trajectory Information

Top View

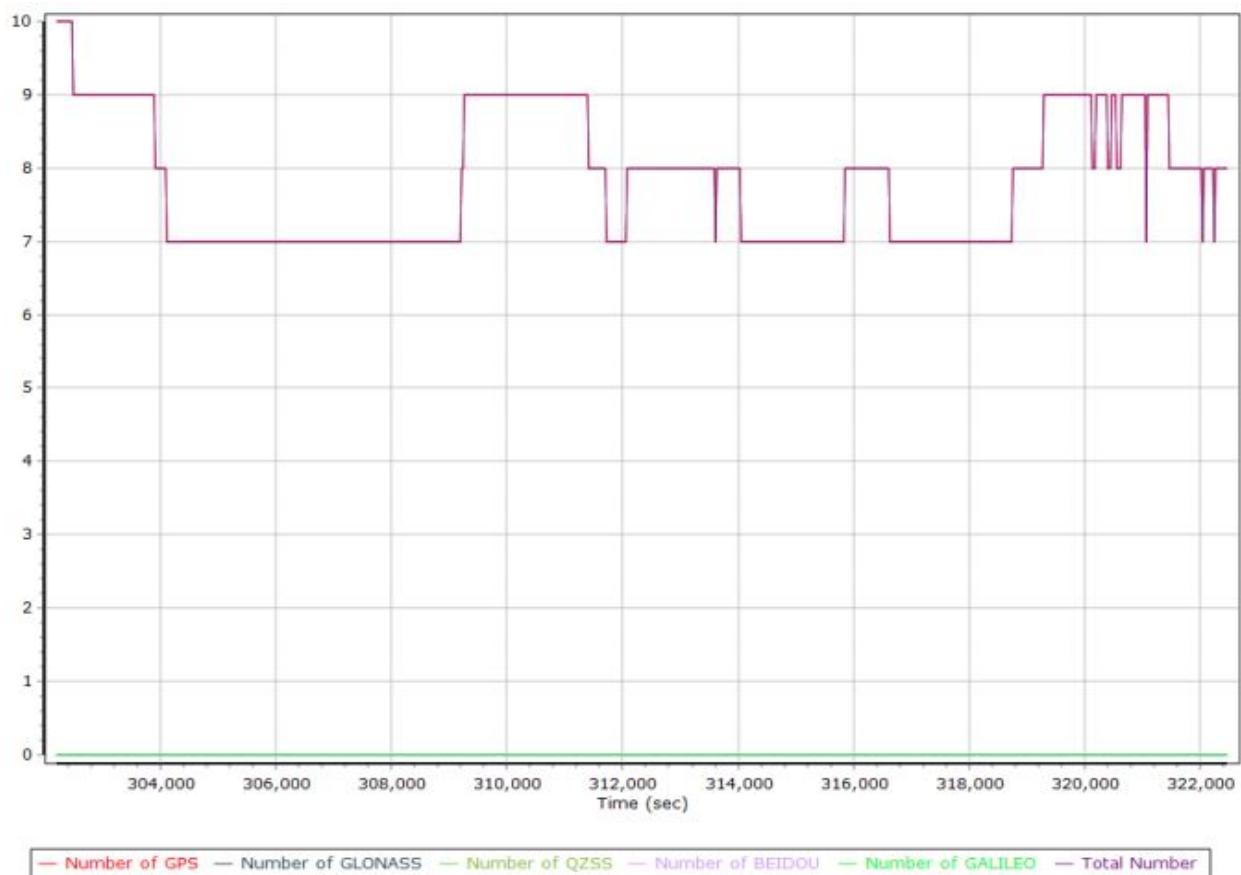


## GNSS QC

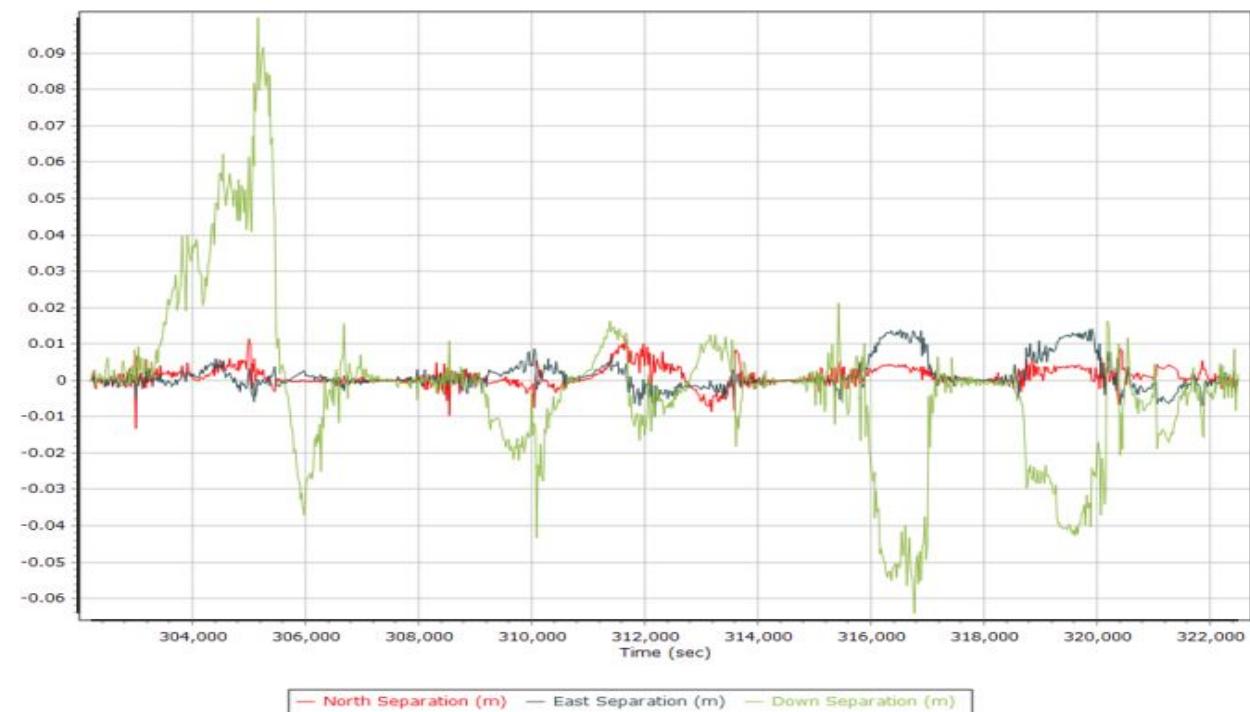
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.37	51.20	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	10	8
PDOP	1.53	5.50	2.14
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	20705.00	0.00	1.00
Percentage	100.00	0.00	0.00

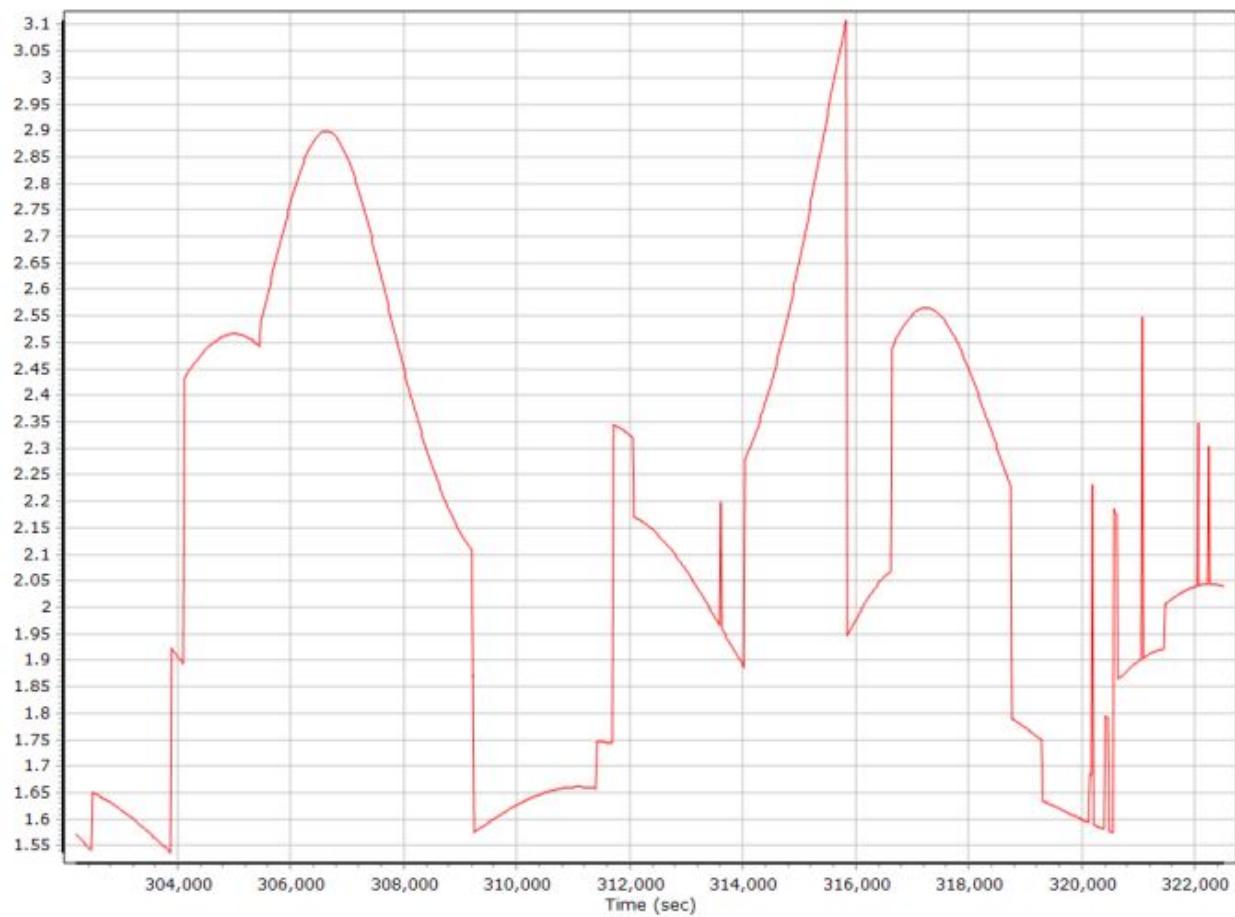
### Number of Satellites



### Forward/Reverse Separation

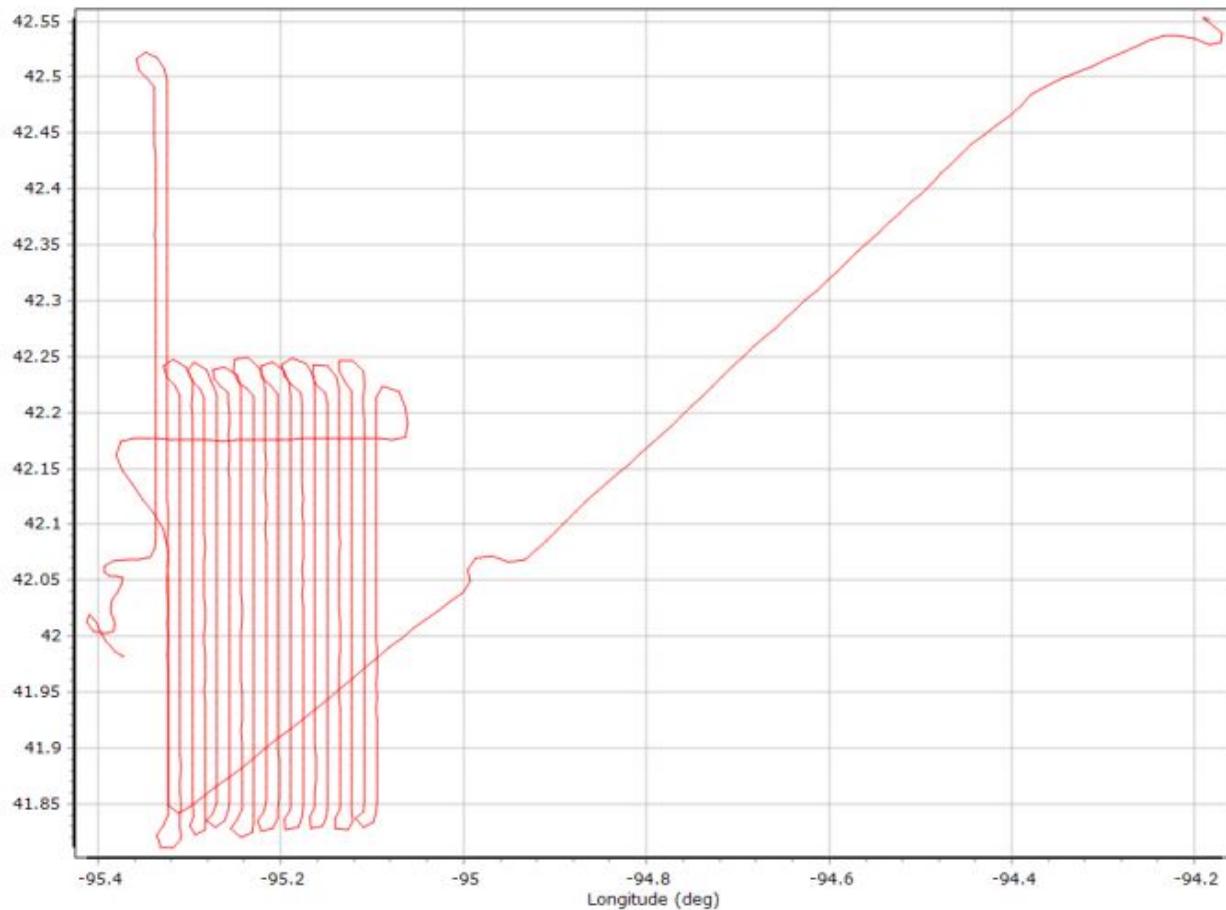


### PDOP



20210331\_2\_QC Report.docx QC Report – 8/27/2021 10:47:22  
Smoothed Trajectory Information

Top View

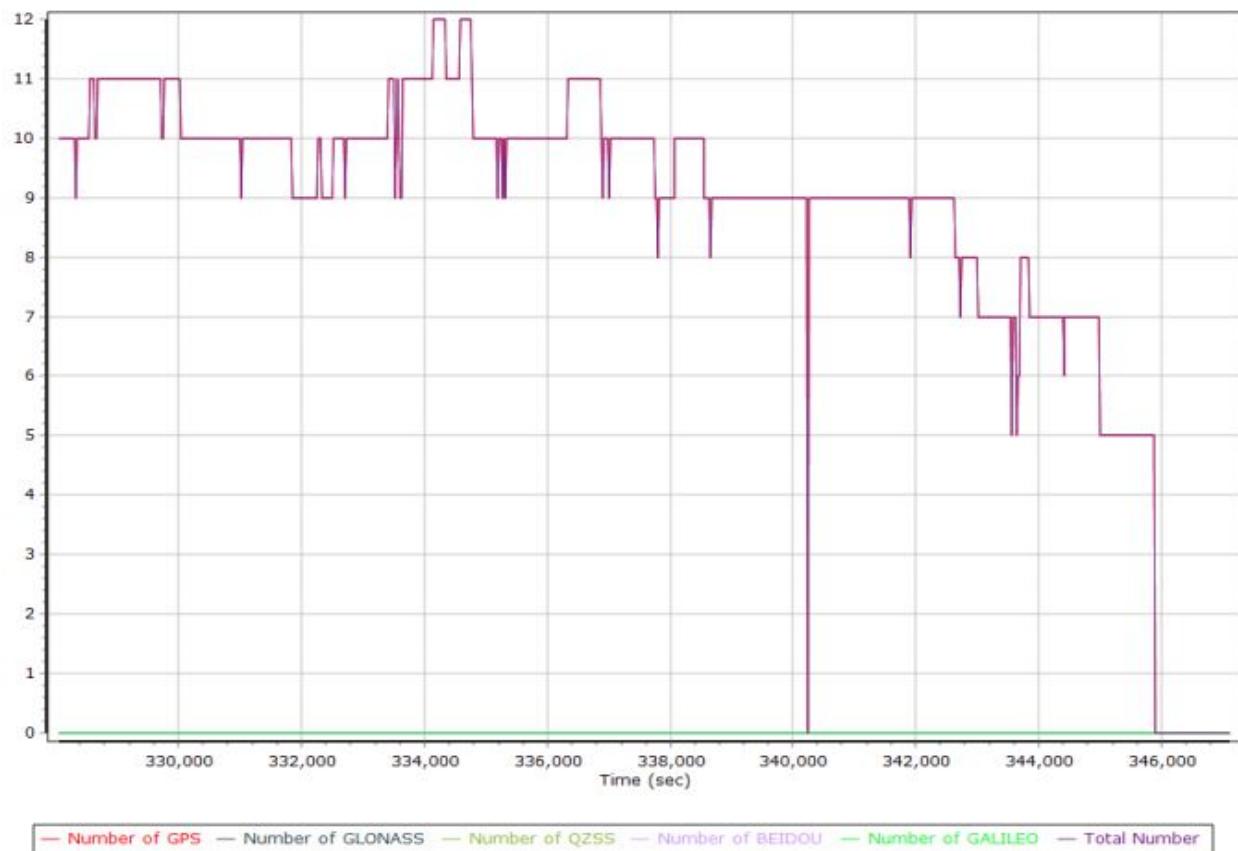


## GNSS QC

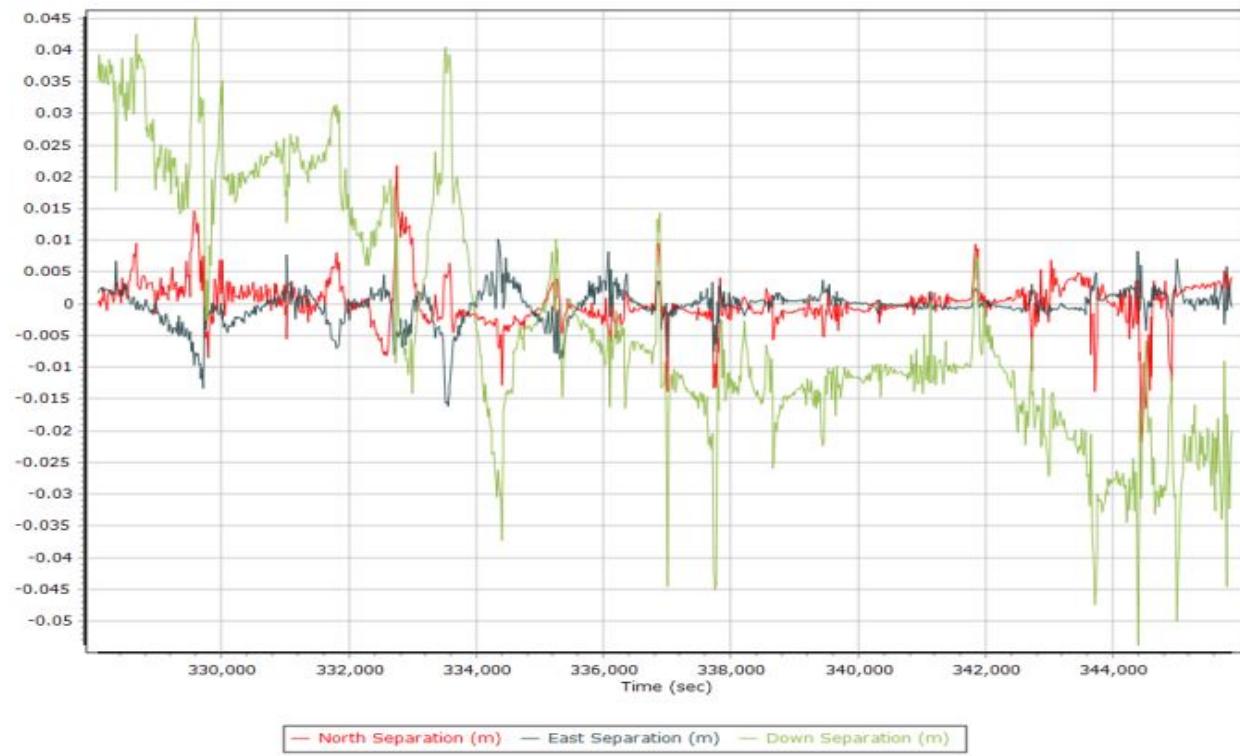
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.38	50.92	
Number of GPS SV	5	12	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	12	9
PDOP	1.26	7.00	1.90
QC Solution Gaps	1.00	20.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	18200.00	0.00	22.00
Percentage	99.88	0.00	0.12

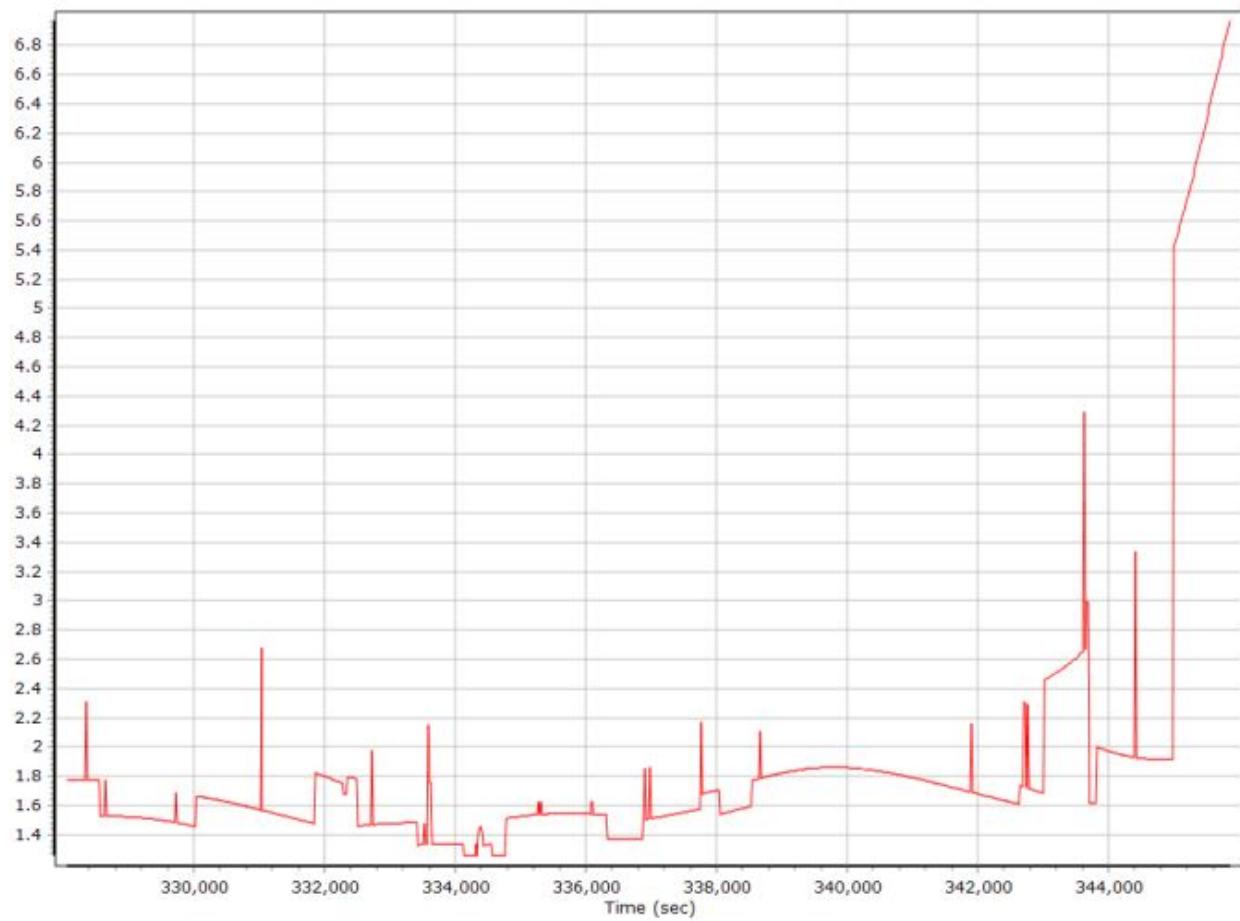
### Number of Satellites



### Forward/Reverse Separation



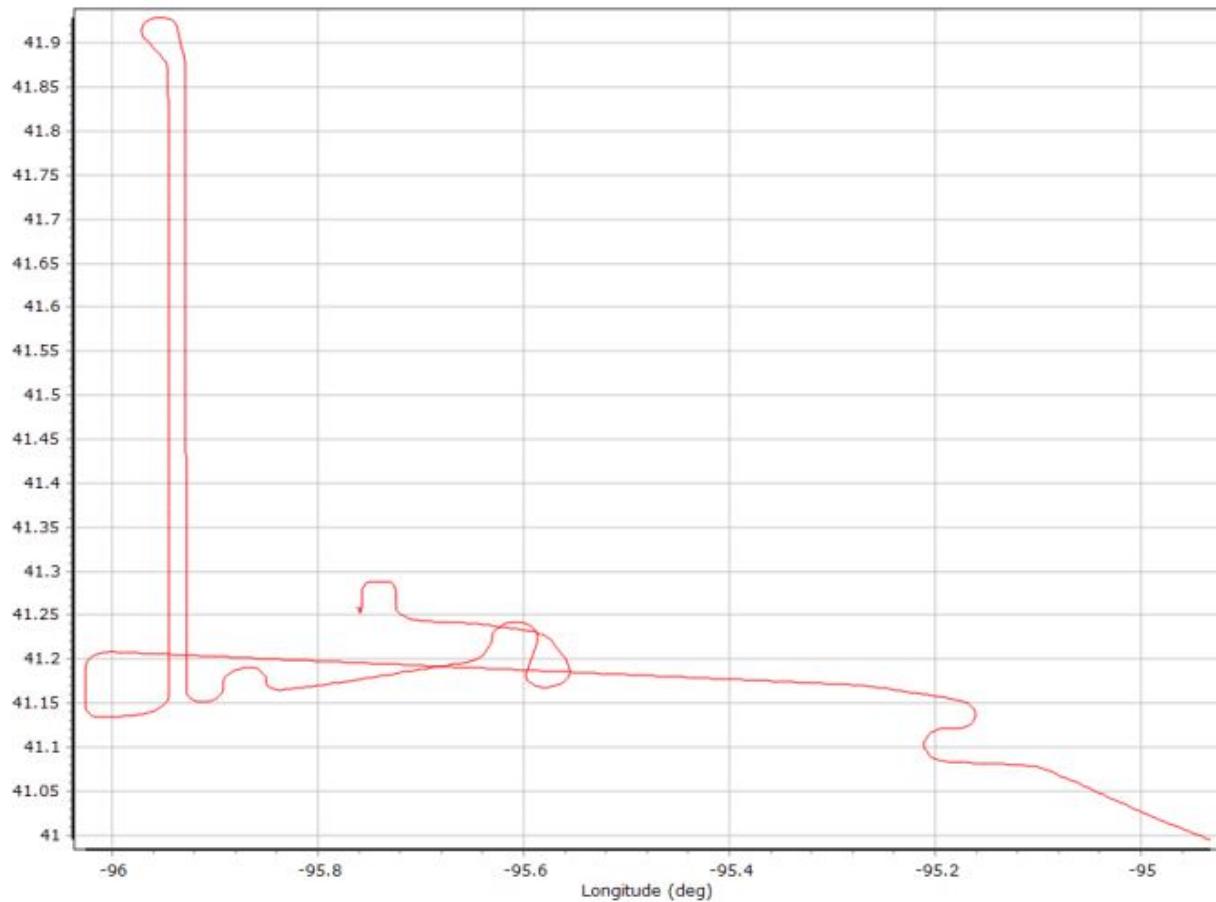
PDOP



Aerial Services, Inc. QC Reports.

0319a448\_QC Report.docx QC Report - 8/25/2021 14:45:25  
Smoothed Trajectory Information

Top View



**GNSS QC**

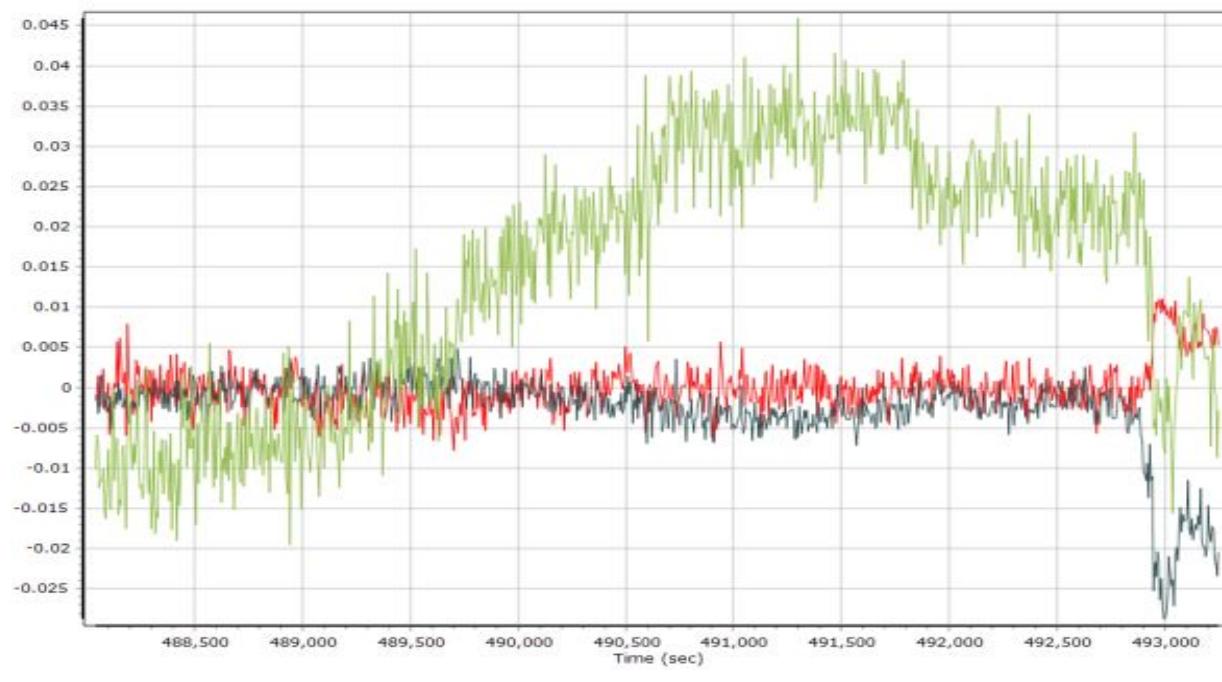
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	9	8
Number of GLONASS SV	4	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	7	6
Total number of SV	16	23	20
PDOP	1.01	1.73	1.20
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	11088.00	0.00	0.00
Percentage	100.00	0.00	0.00

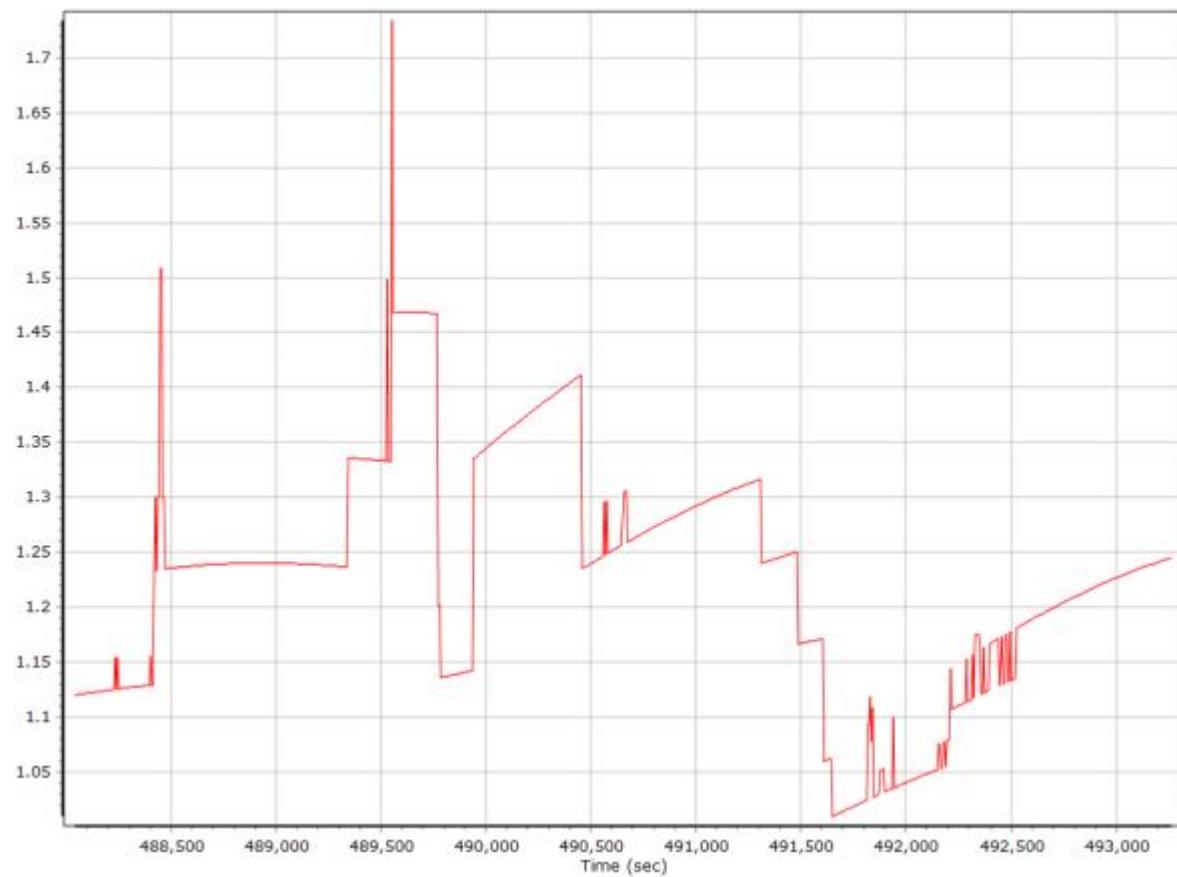
### Number of Satellites



### Forward/Reverse Separation

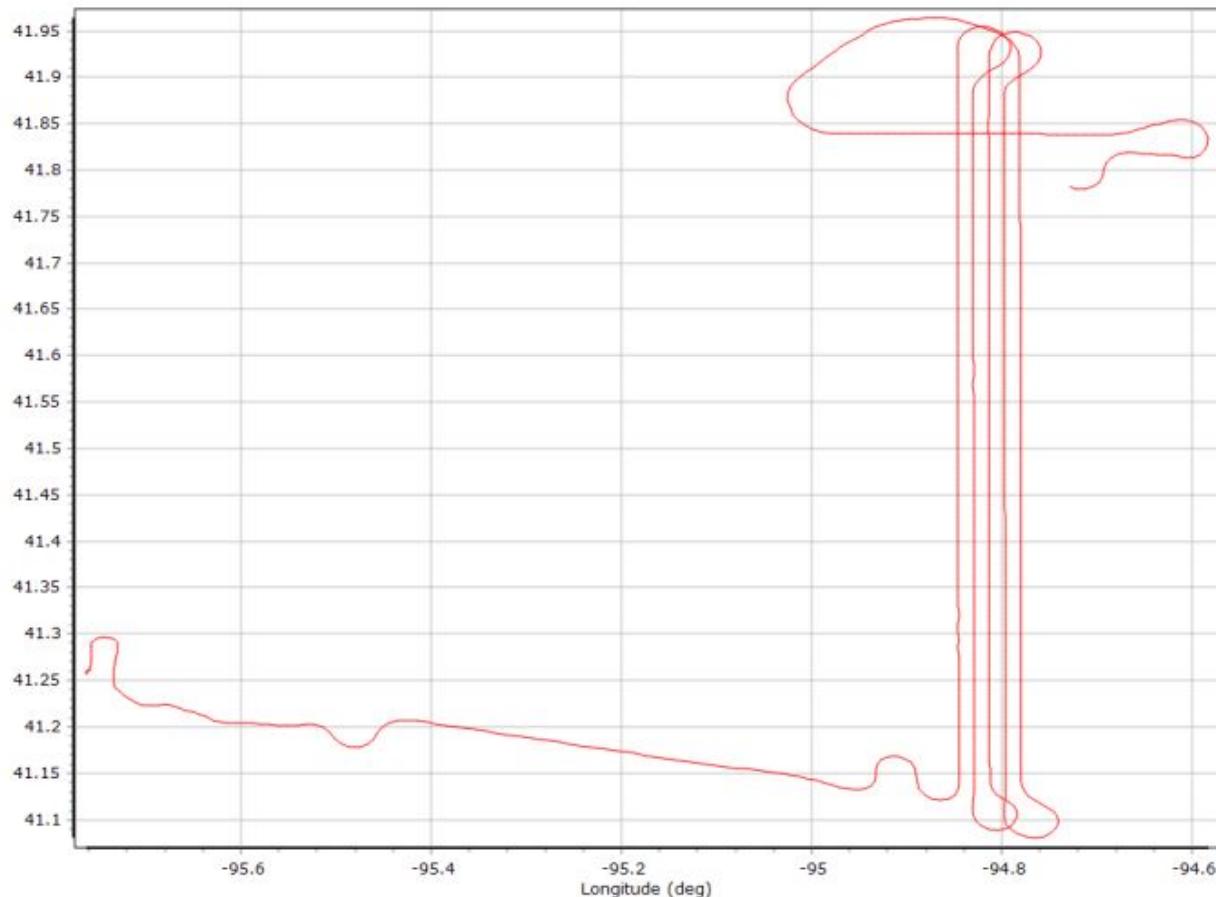


**PDOP**



0319b386\_QC Report.docx QC Report – 8/25/2021 09:32:25  
Smoothed Trajectory Information

Top View

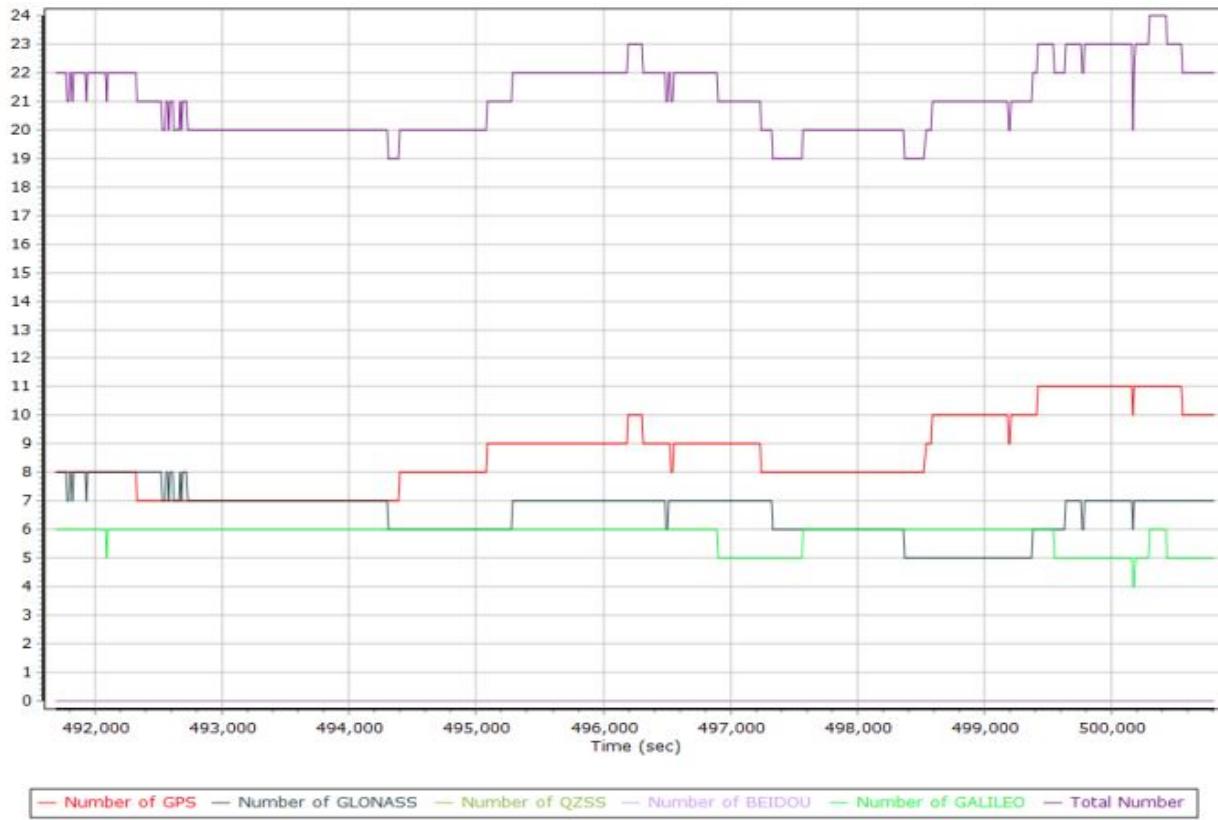


**GNSS QC**

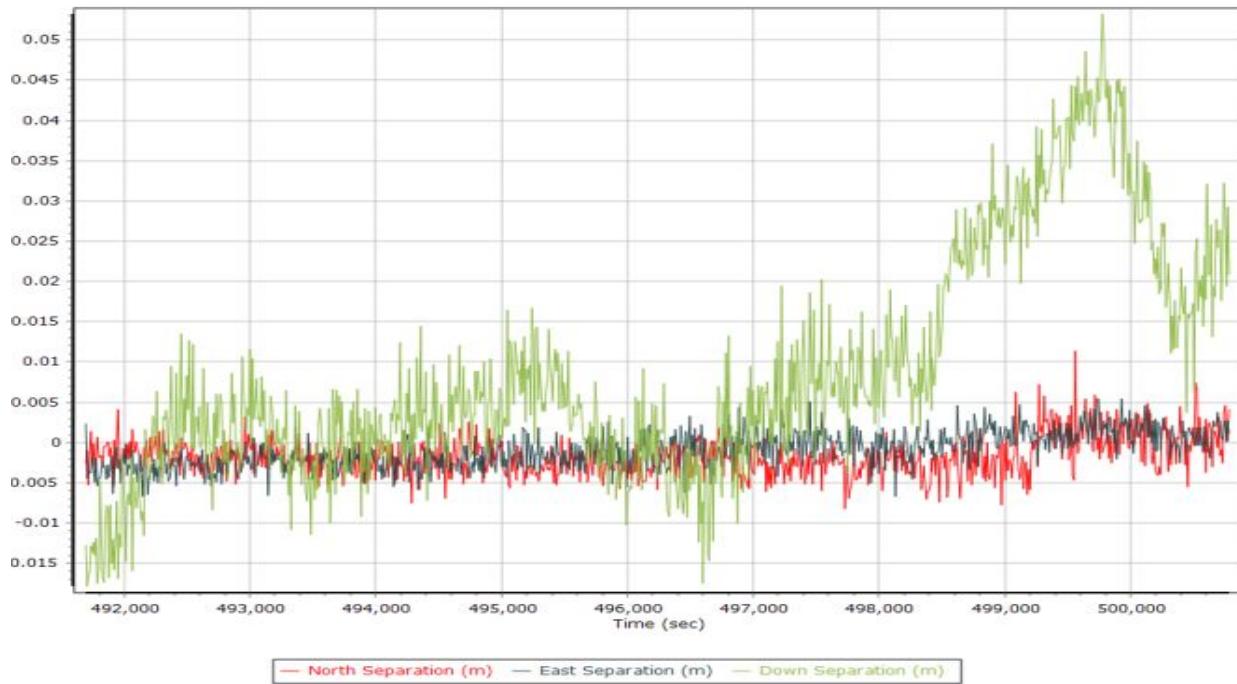
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	11	9
Number of GLONASS SV	5	8	7
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	3	6	6
Total number of SV	17	24	21
PDOP	0.98	1.52	1.23
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	9552.00	0.00	0.00
Percentage	100.00	0.00	0.00

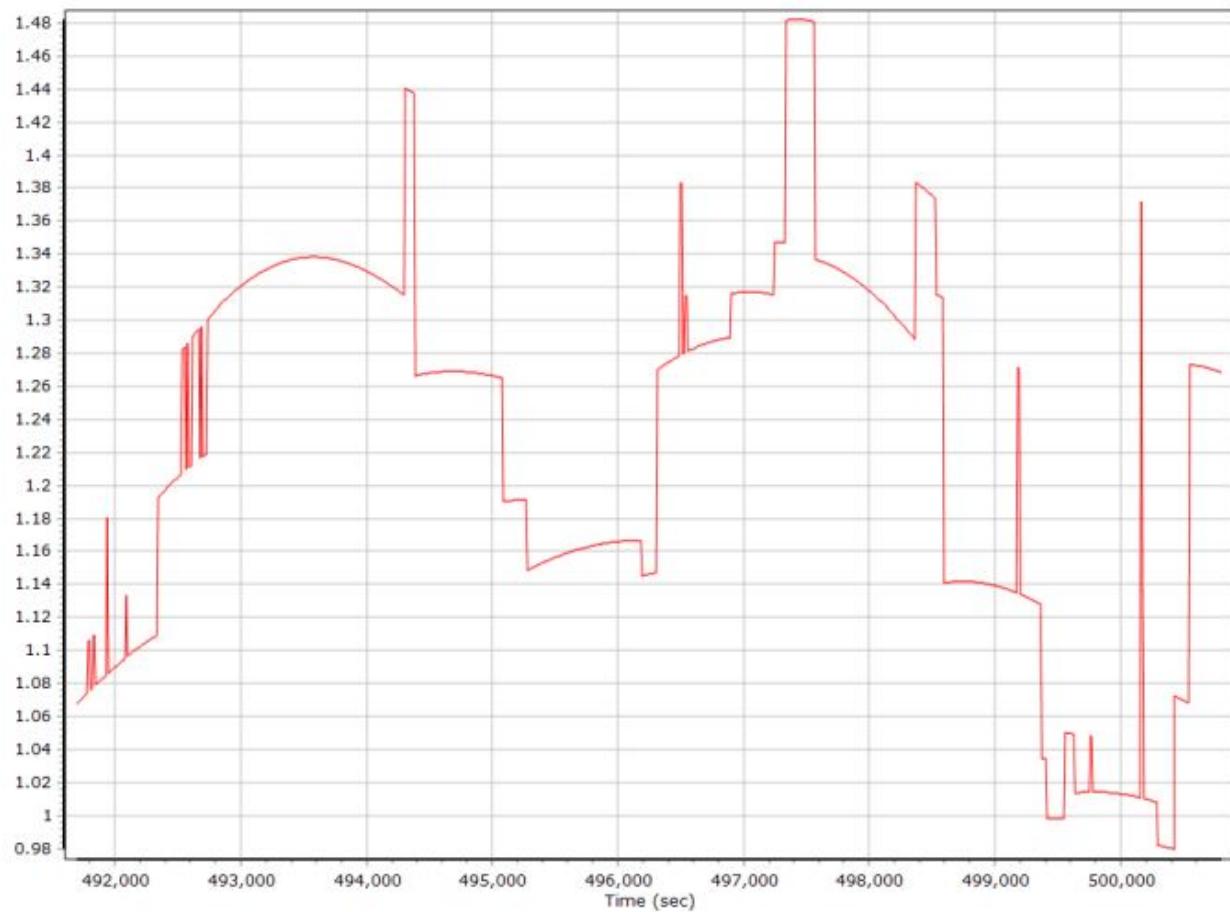
### Number of Satellites



### Forward/Reverse Separation

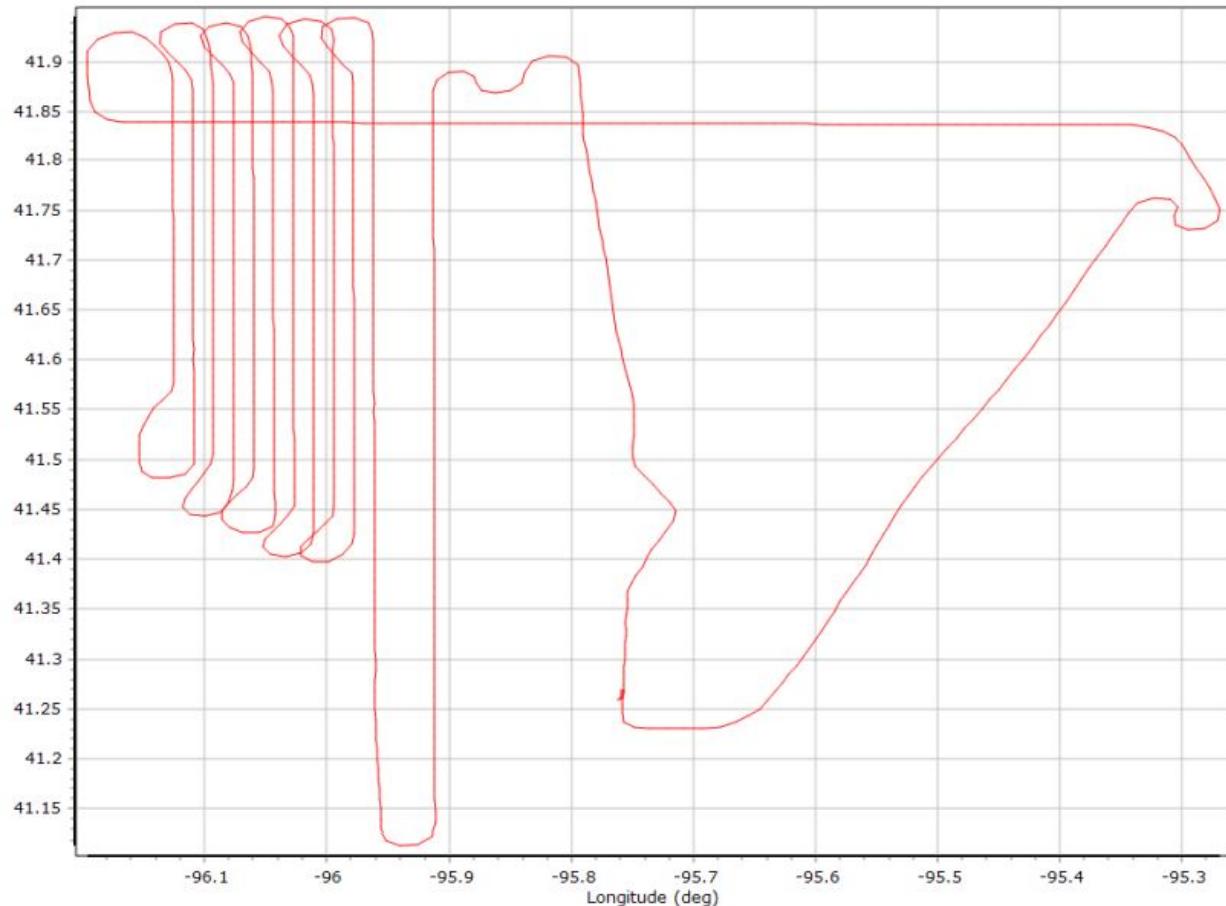


PDOP



0319b448\_QC Report.docx QC Report – 8/25/2021 09:54:33  
Smoothed Trajectory Information

Top View

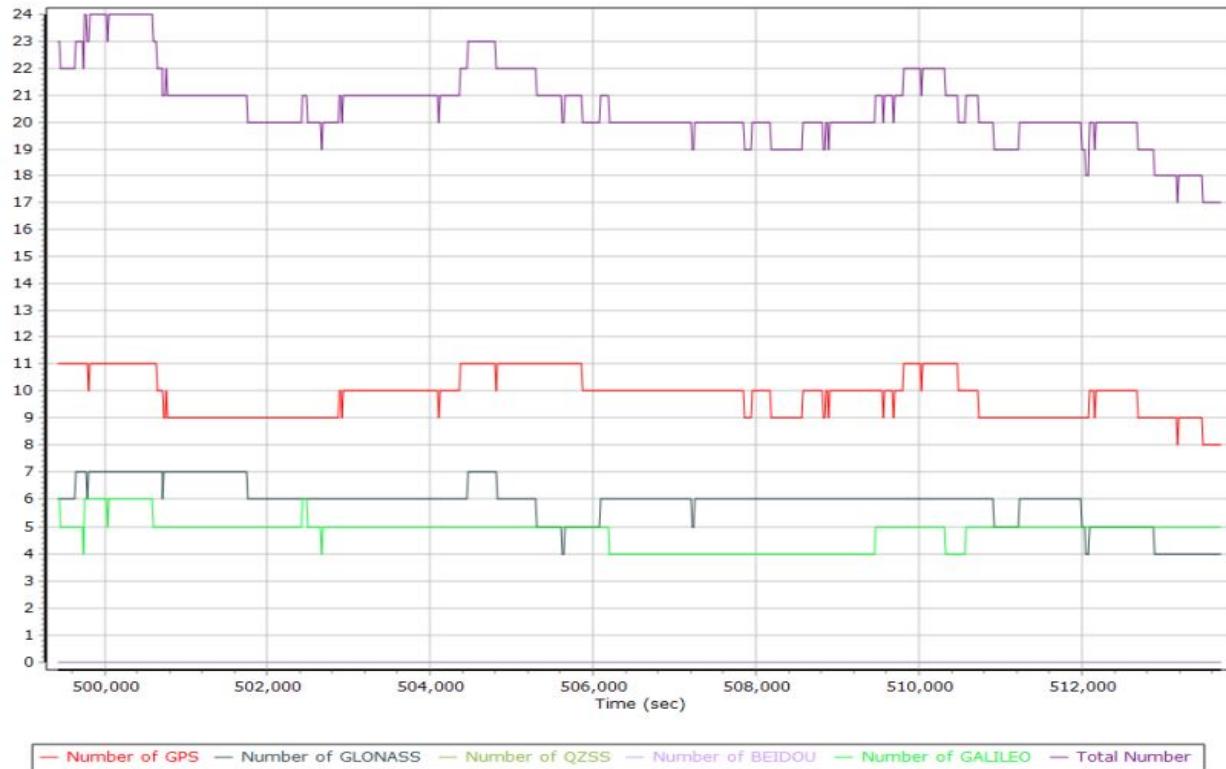


## GNSS QC

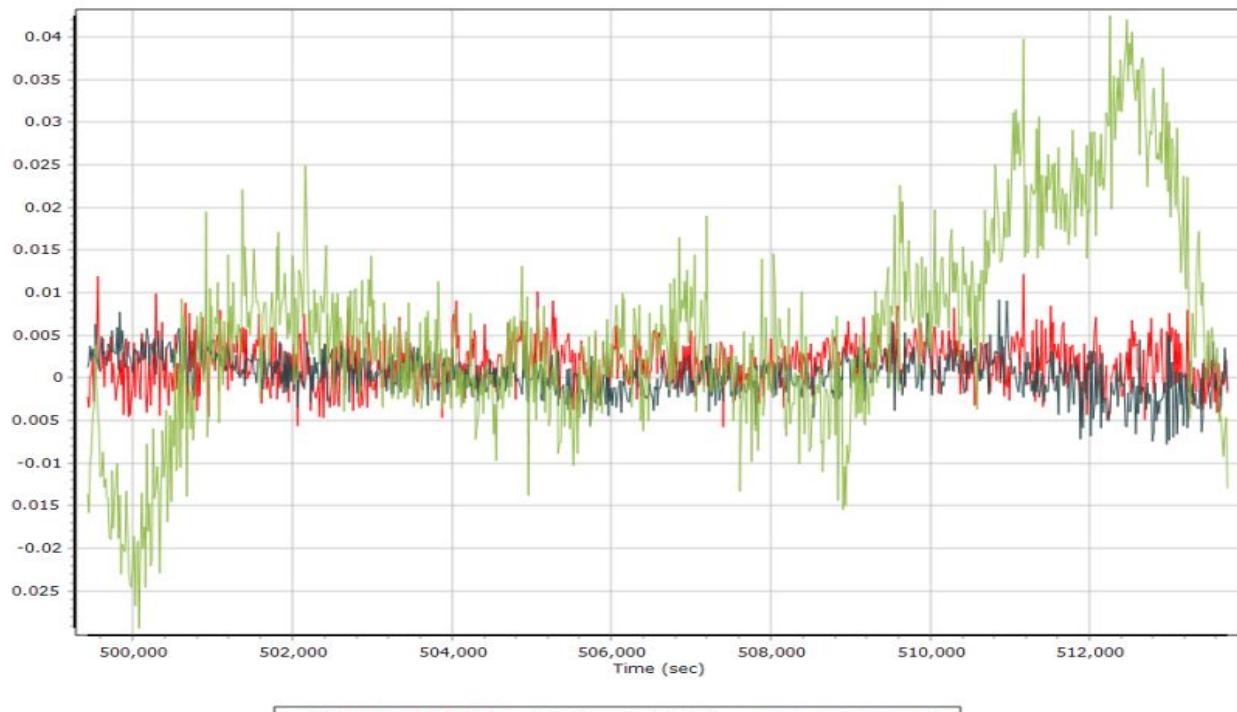
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	8	11	10
Number of GLONASS SV	3	7	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	6	5
Total number of SV	17	24	21
PDOP	0.96	1.41	1.14
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	14786.00	0.00	0.00
Percentage	100.00	0.00	0.00

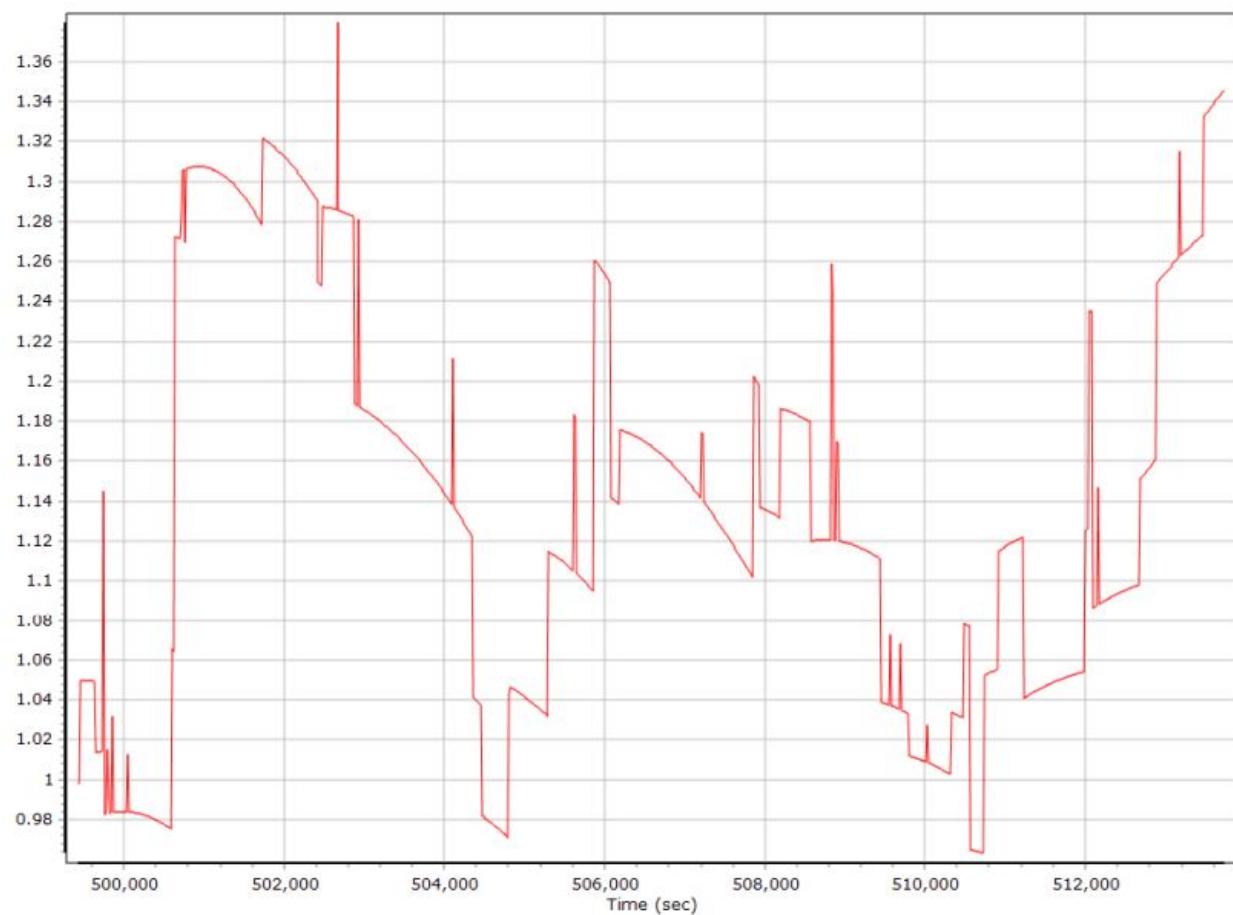
### Number of Satellites



### Forward/Reverse Separation

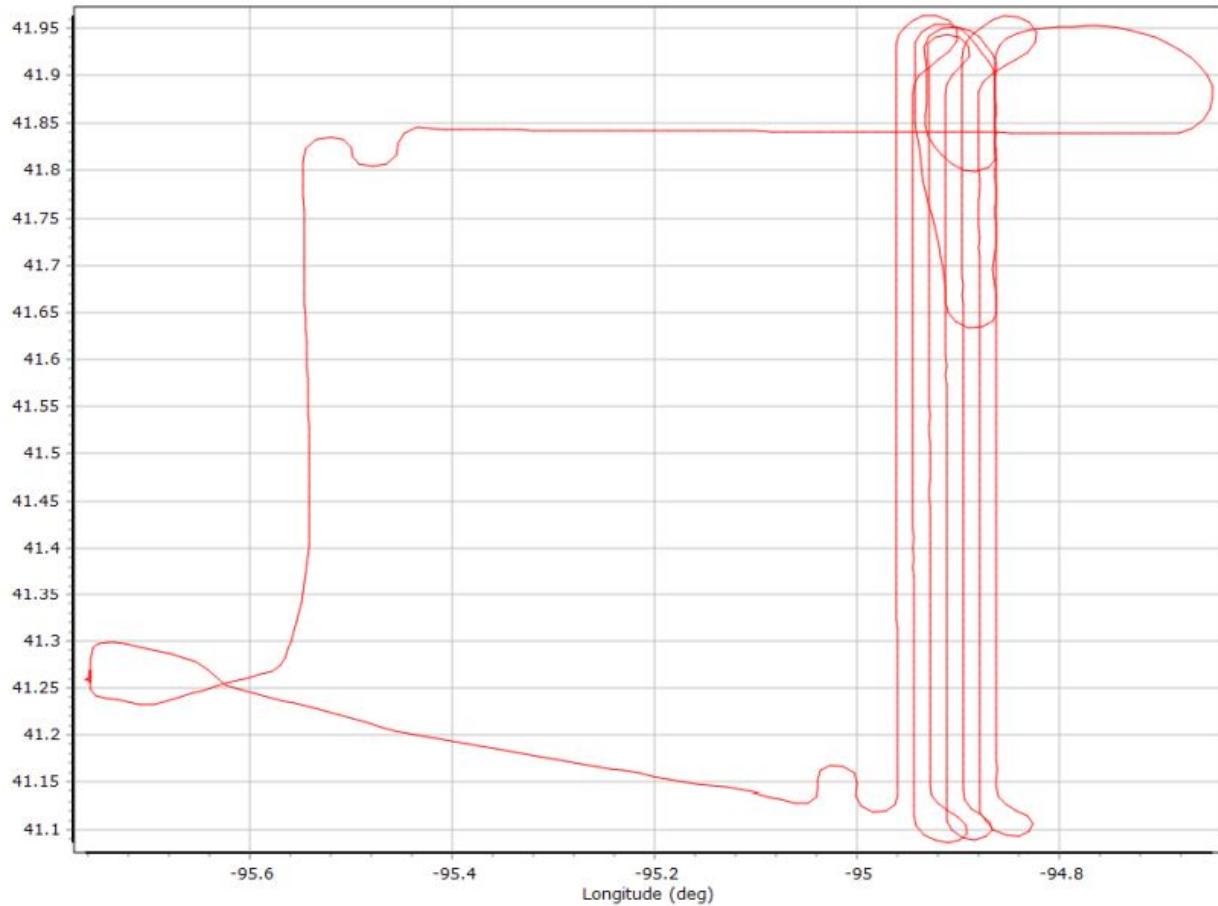


PDOP



0319c386\_QC Report.docx QC Report – 8/25/2021 10:03:59  
Smoothed Trajectory Information

Top View

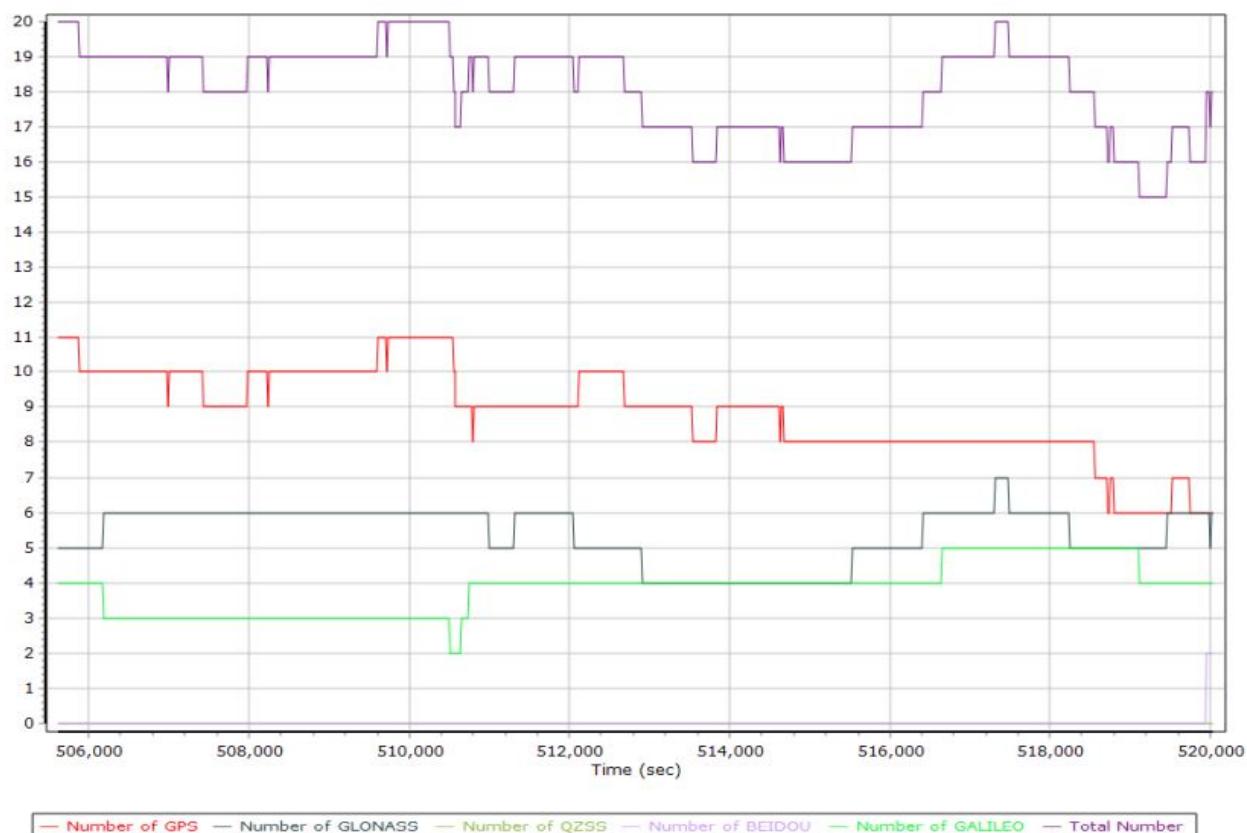


**GNSS QC**

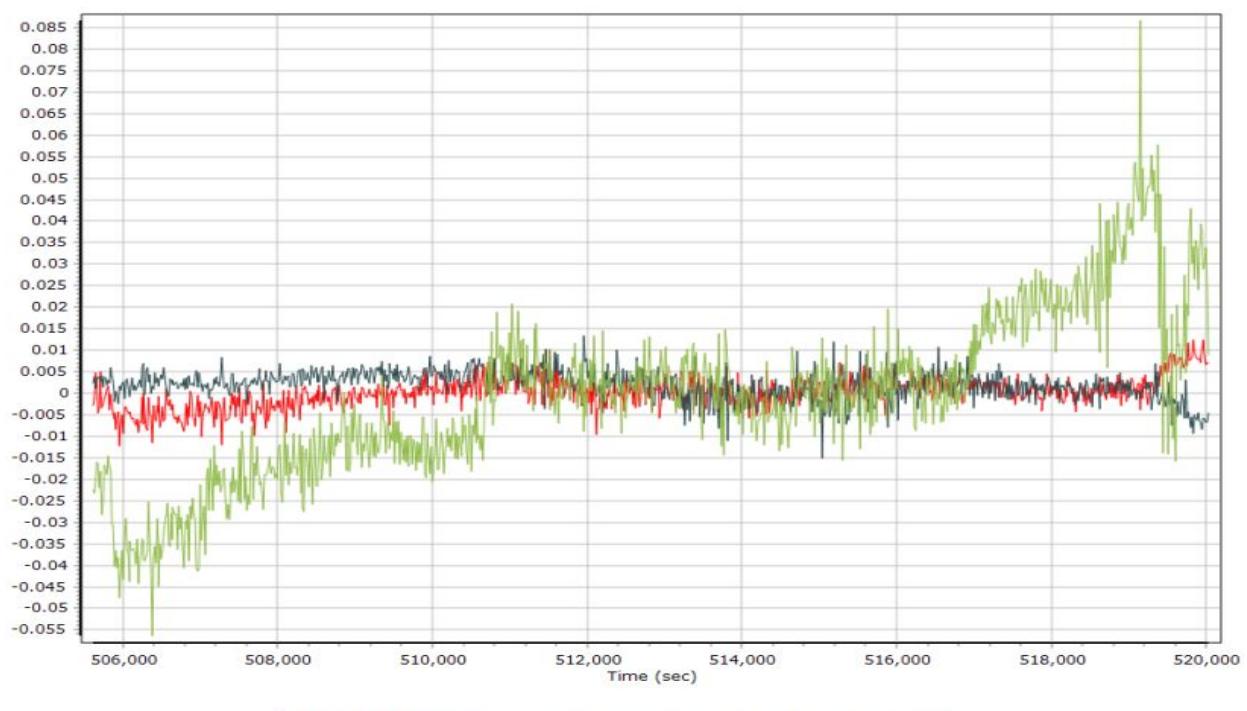
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	11	9
Number of GLONASS SV	0	7	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	0
Number of GALILEO SV	2	5	4
Total number of SV	14	21	18
PDOP	1.04	2.00	1.27
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	14843.00	0.00	0.00
Percentage	100.00	0.00	0.00

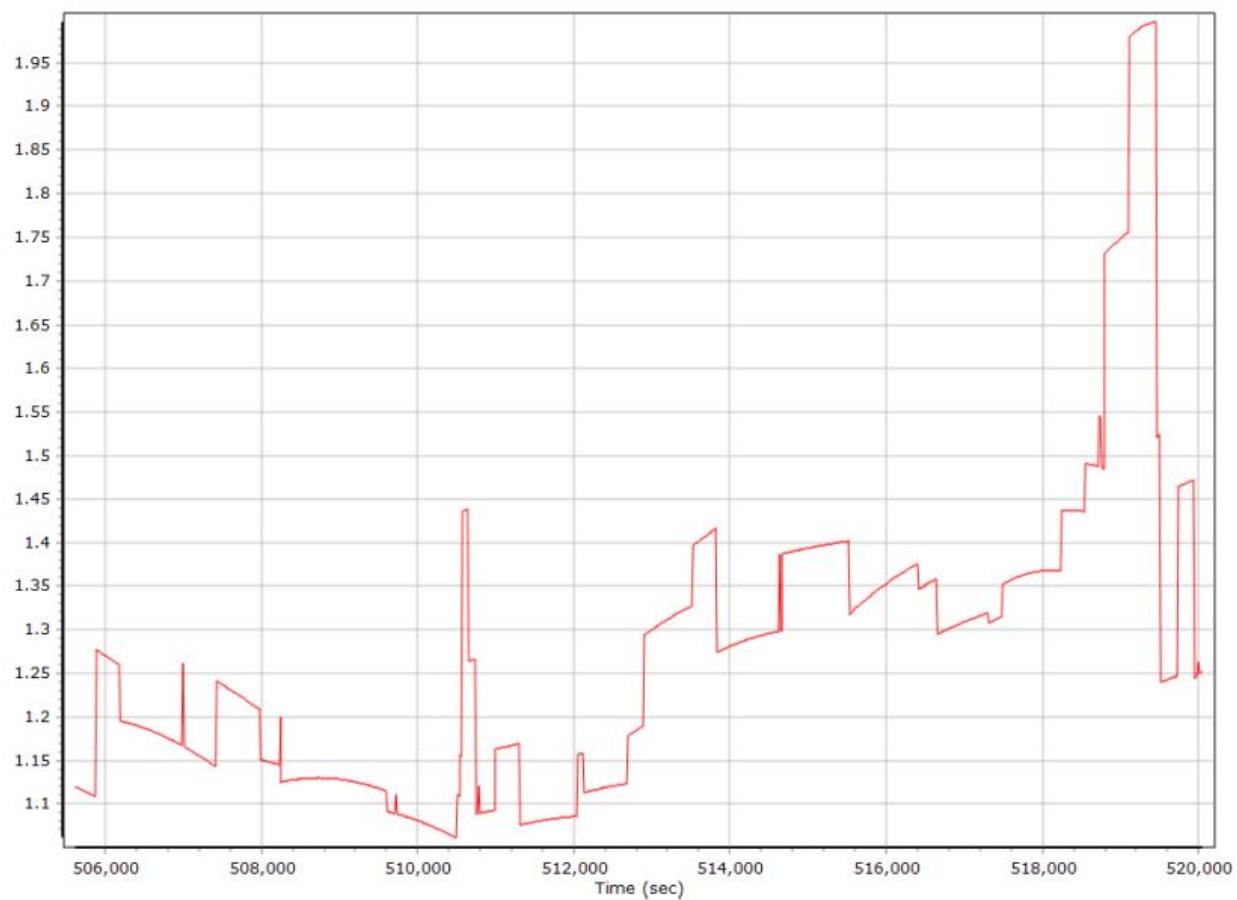
### Number of Satellites



### Forward/Reverse Separation

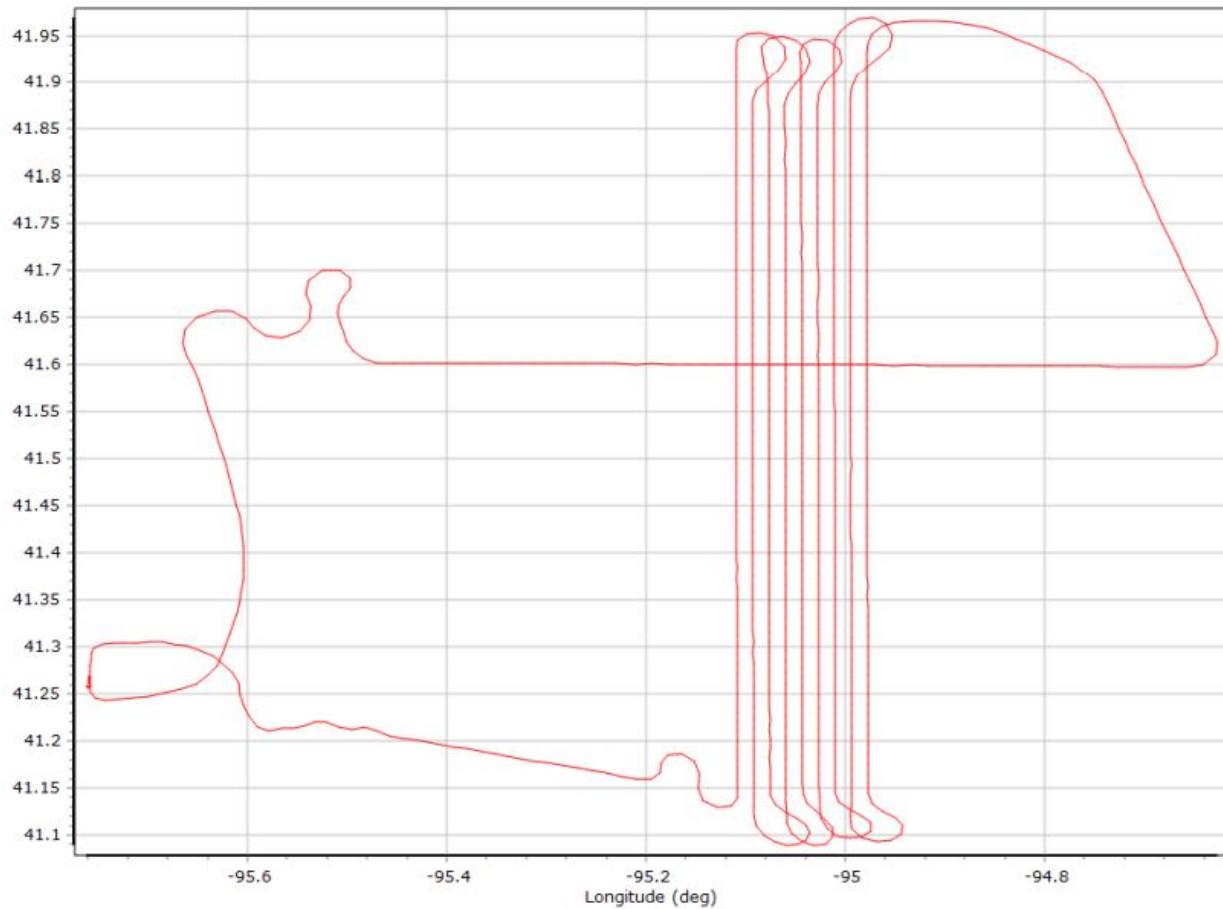


### PDOP



0320a386\_QC Report.docx QC Report – 8/25/2021 10:11:45  
Smoothed Trajectory Information

Top View

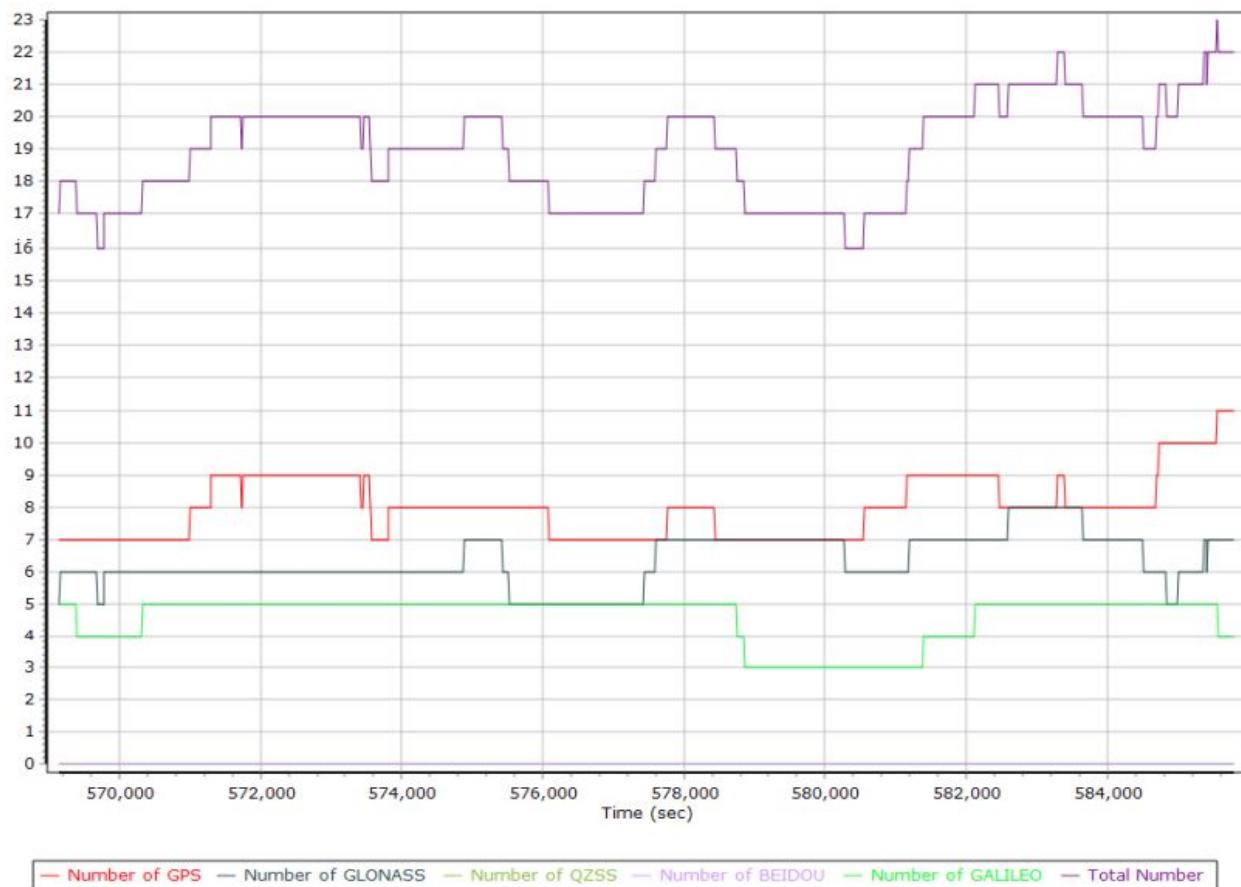


## GNSS QC

### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	11	8
Number of GLONASS SV	0	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	5	5
Total number of SV	11	23	19
PDOP	1.09	1.89	1.30
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17175.00	0.00	0.00
Percentage	100.00	0.00	0.00

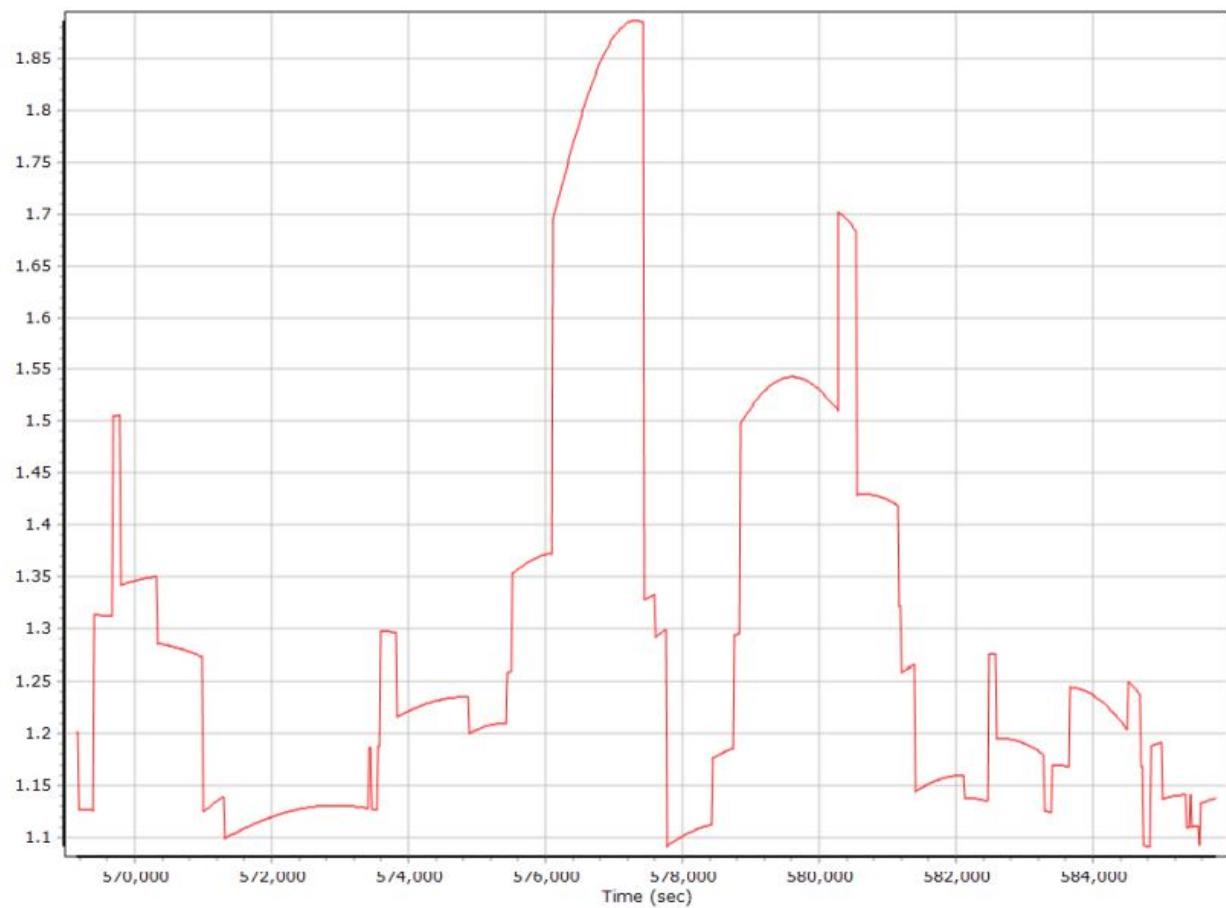
### Number of Satellites



### Forward/Reverse Separation

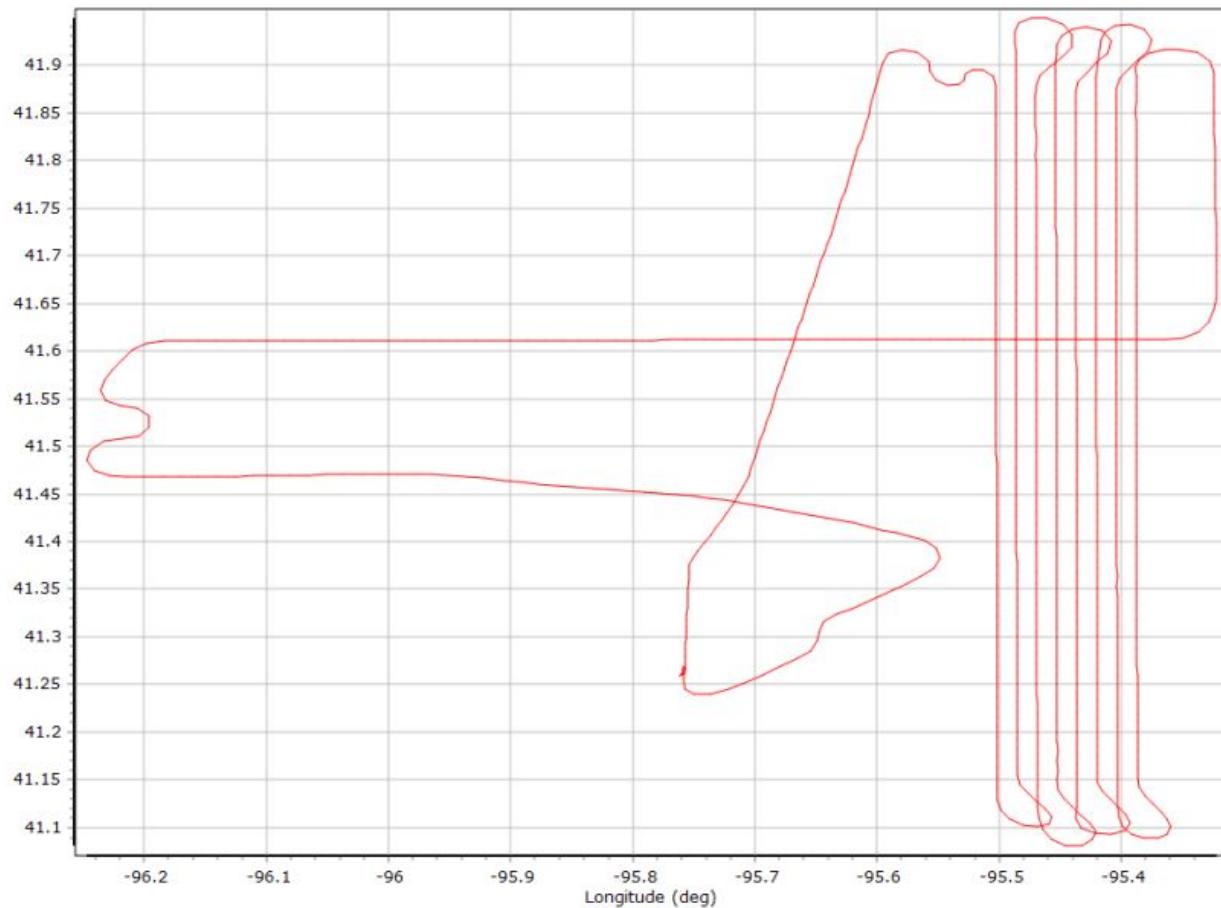


PDOP



0320a448\_QC Report.docx QC Report – 8/25/2021 11:13:25  
Smoothed Trajectory Information

Top View

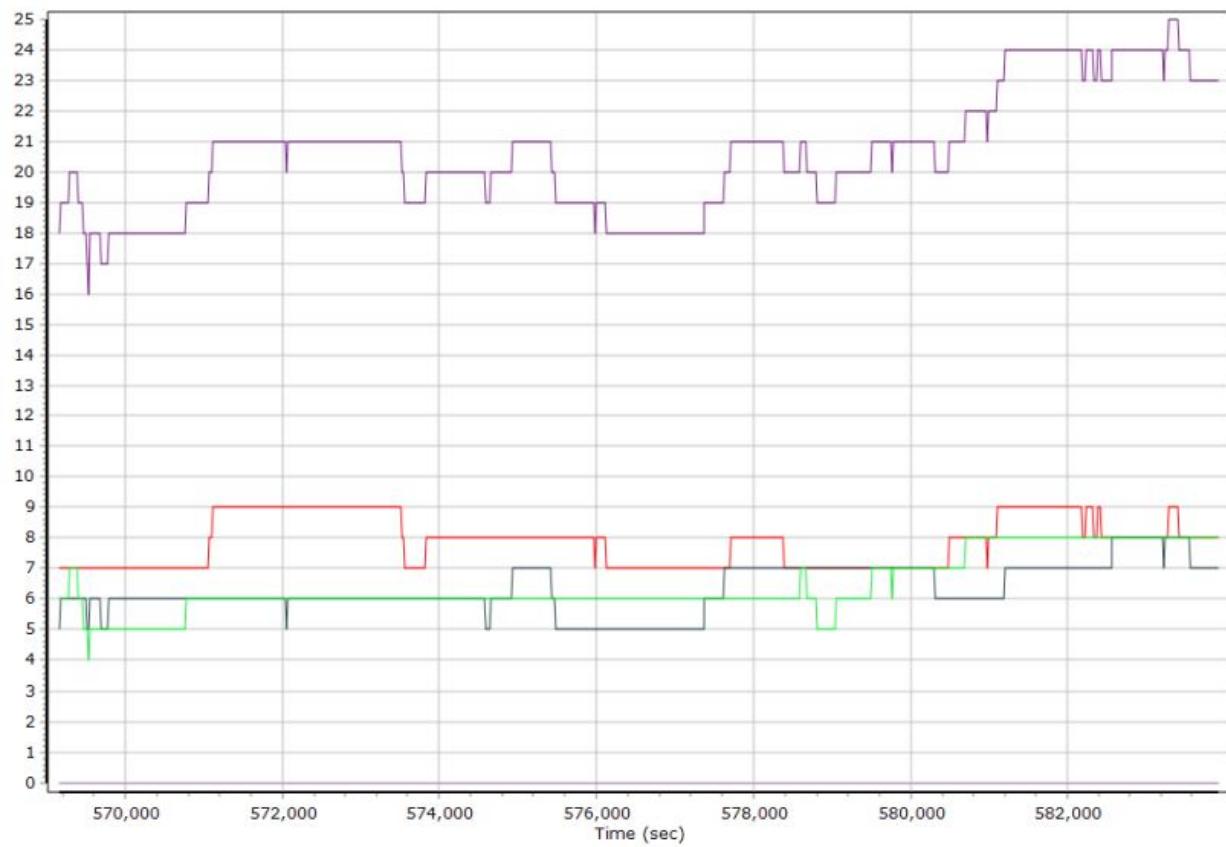


## GNSS QC

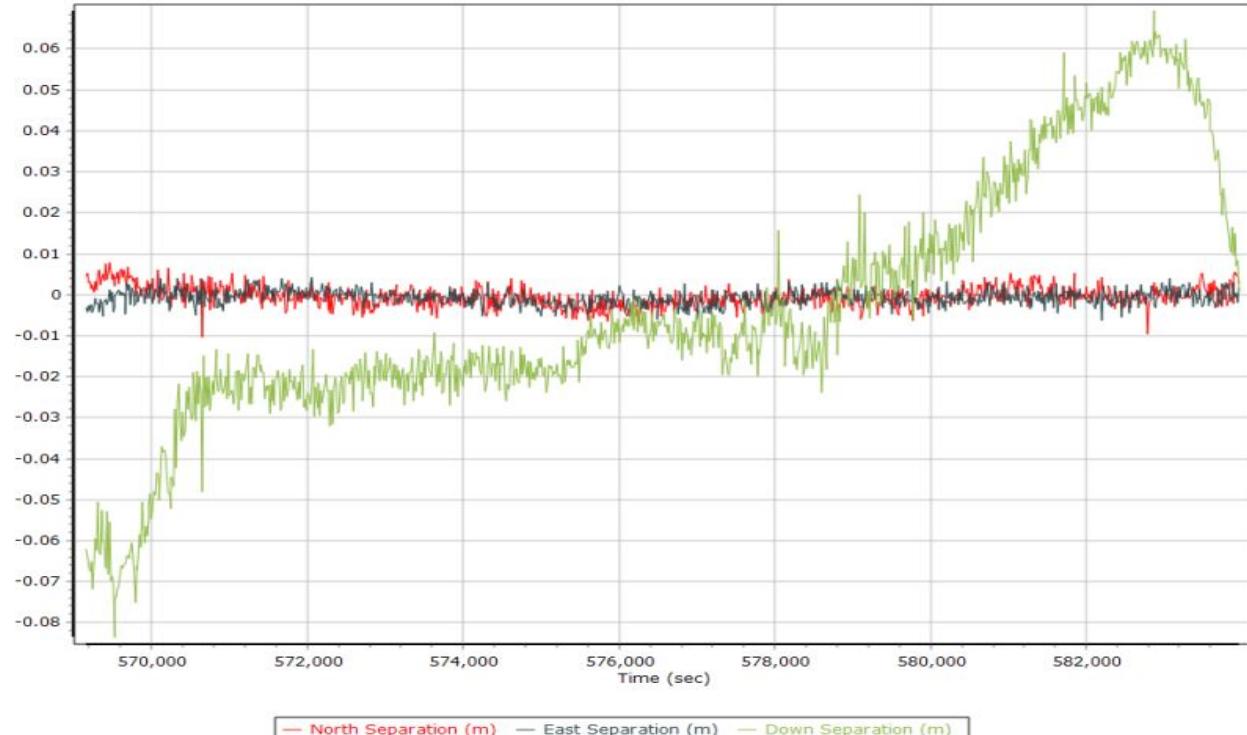
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	9	8
Number of GLONASS SV	4	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	8	6
Total number of SV	15	25	21
PDOP	1.03	1.77	1.20
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	15298.00	0.00	0.00
Percentage	100.00	0.00	0.00

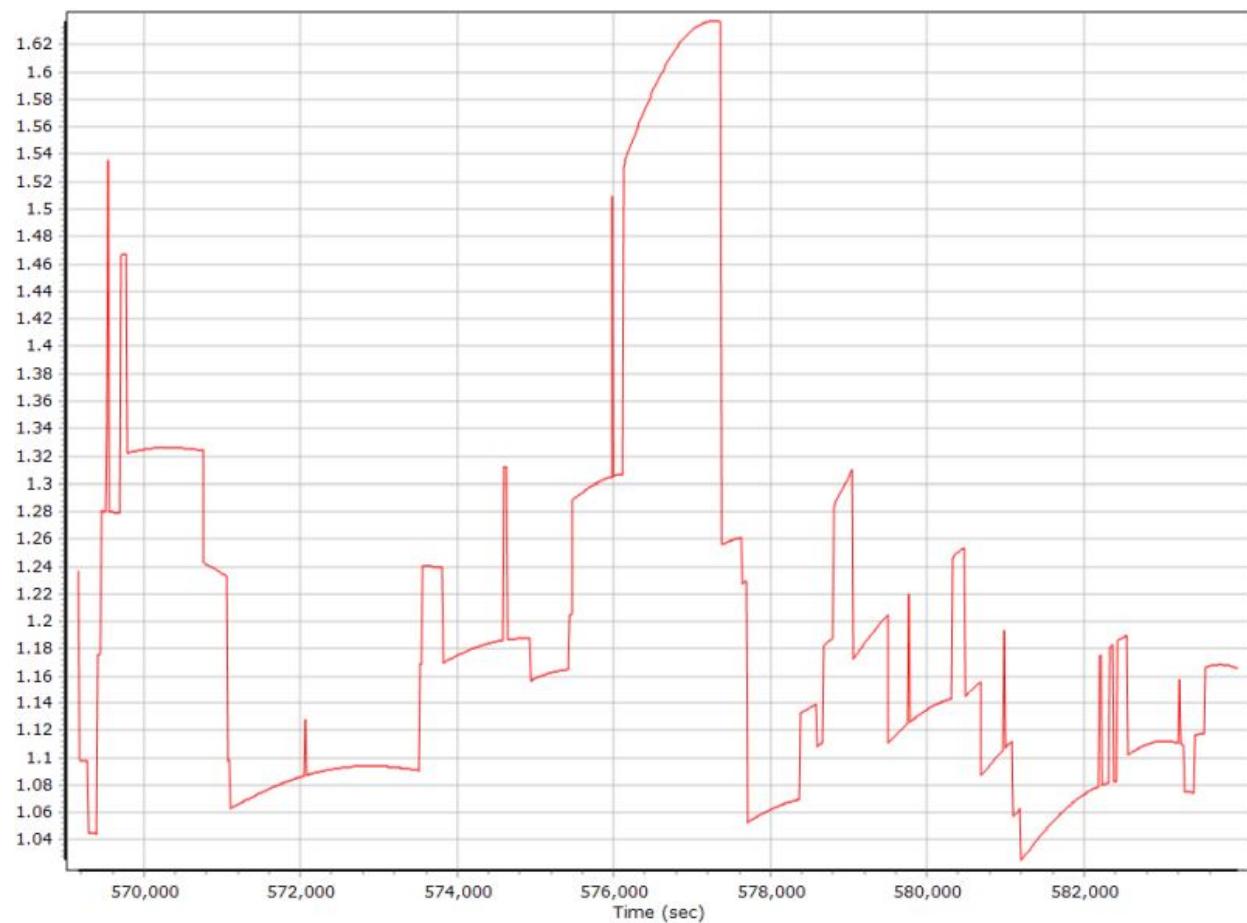
### Number of Satellites



### Forward/Reverse Separation

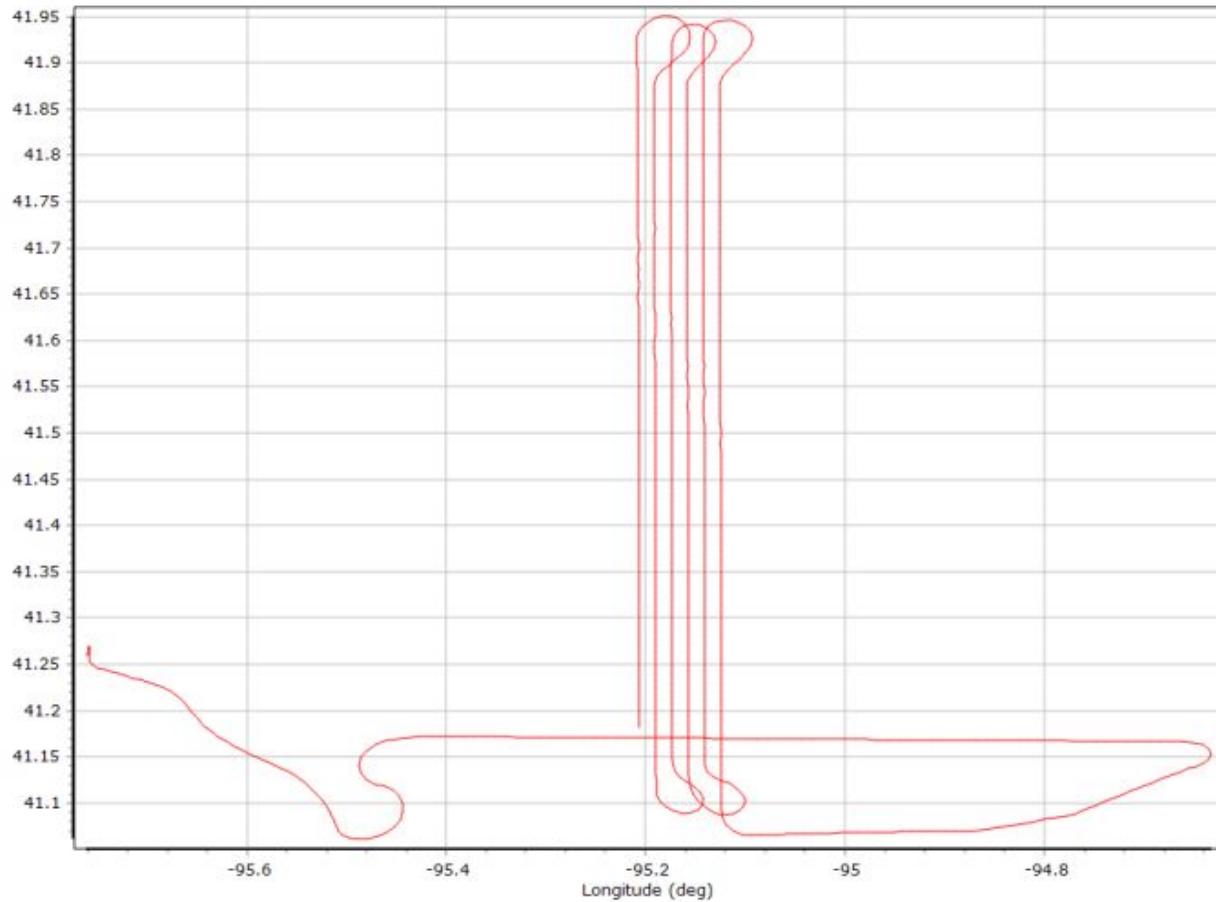


PDOP



0320b386\_QC Report.docx QC Report – 8/25/2021 12:50:46  
Smoothed Trajectory Information

Top View

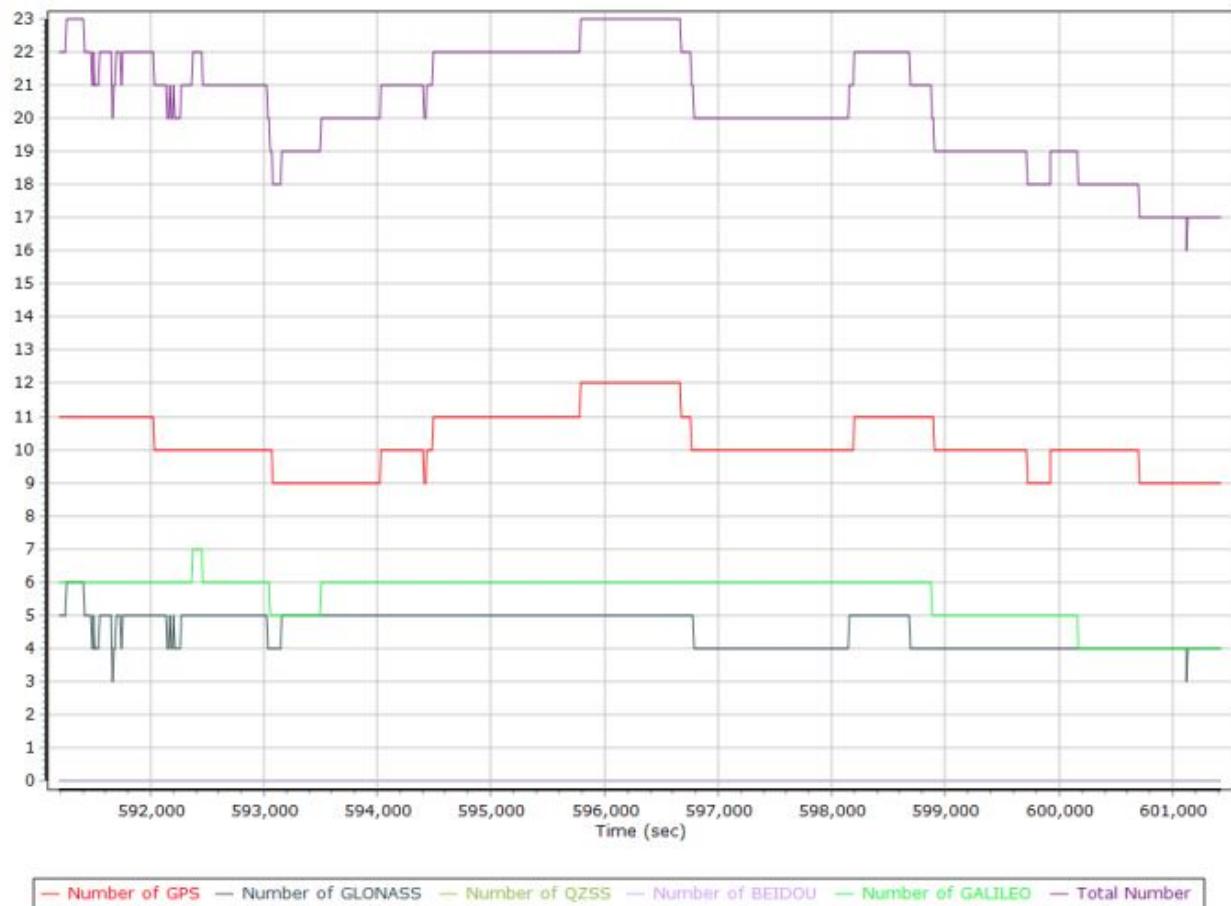


**GNSS QC**

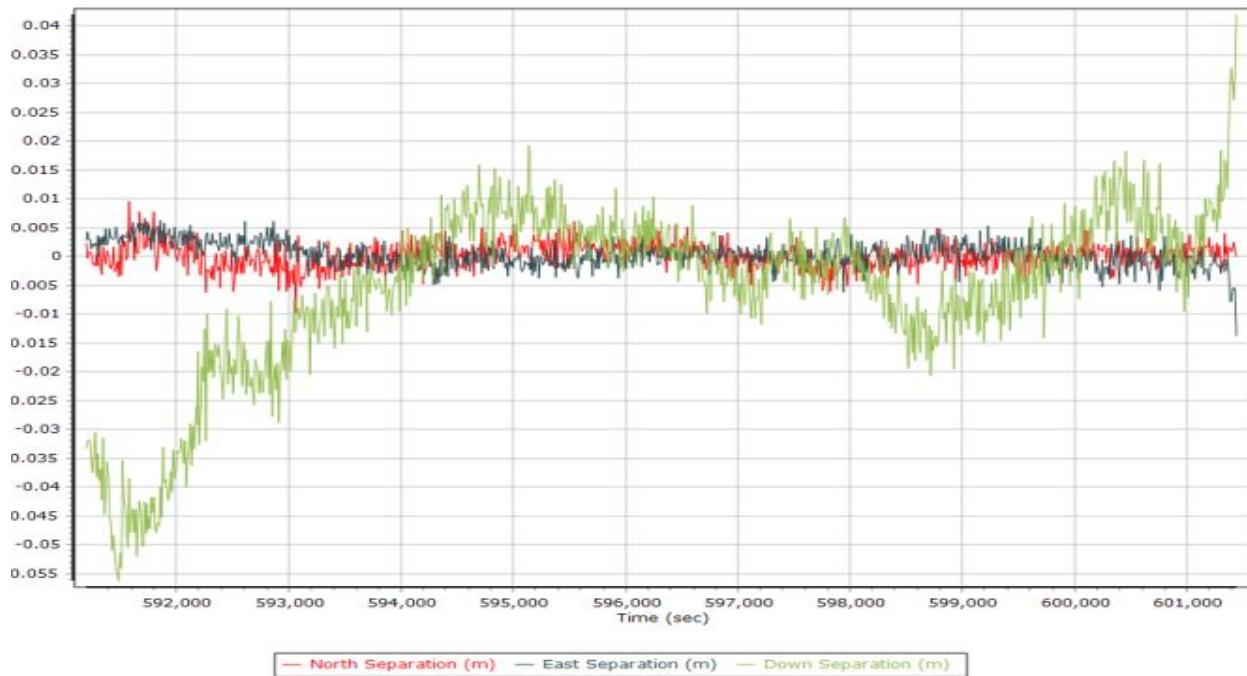
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	9	12	10
Number of GLONASS SV	0	6	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	7	6
Total number of SV	16	23	20
PDOP	0.98	1.55	1.15
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	10633.00	0.00	0.00
Percentage	100.00	0.00	0.00

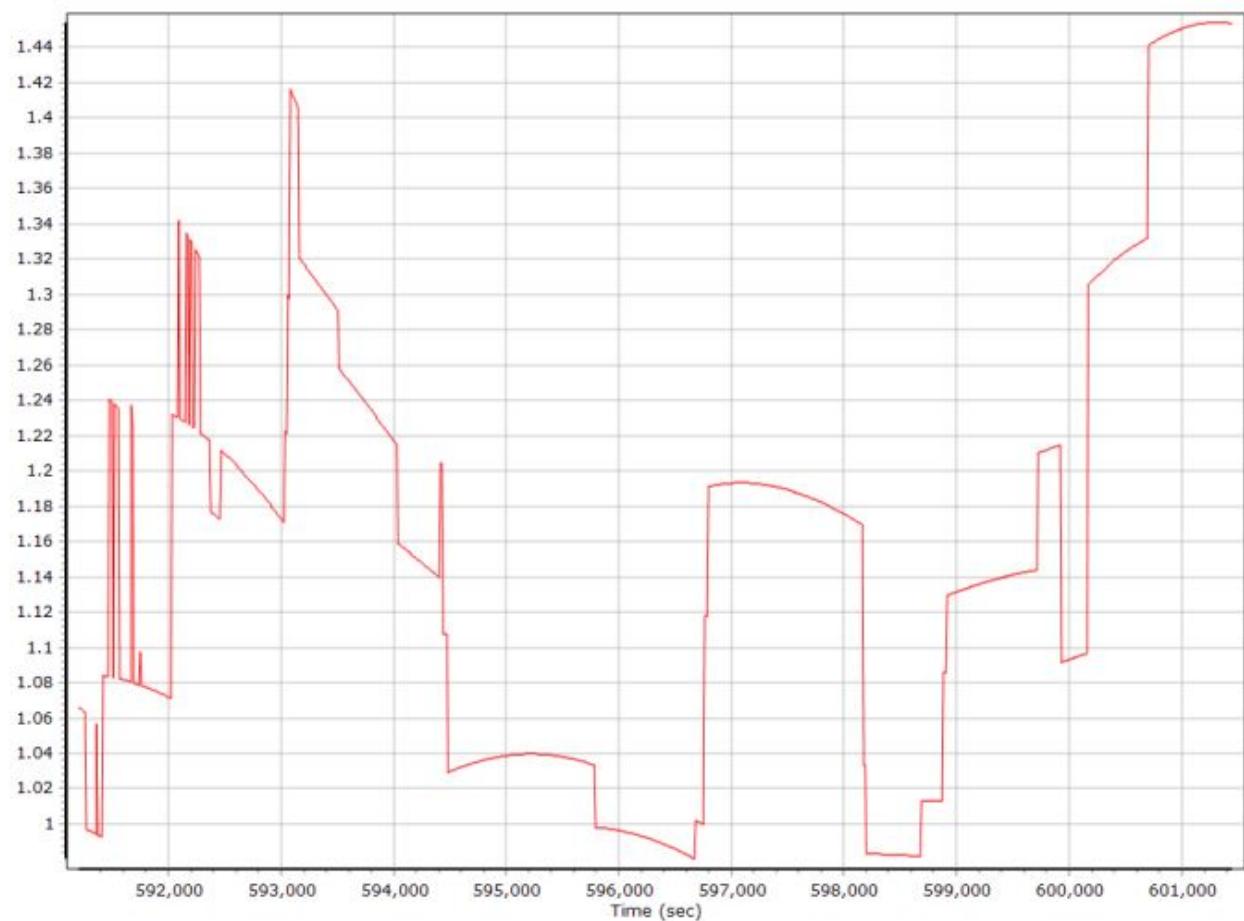
### Number of Satellites



### Forward/Reverse Separation



PDOP



0320b448\_QC Report.docx QC Report – 8/25/2021 13:04:32  
Smoothed Trajectory Information

Top View

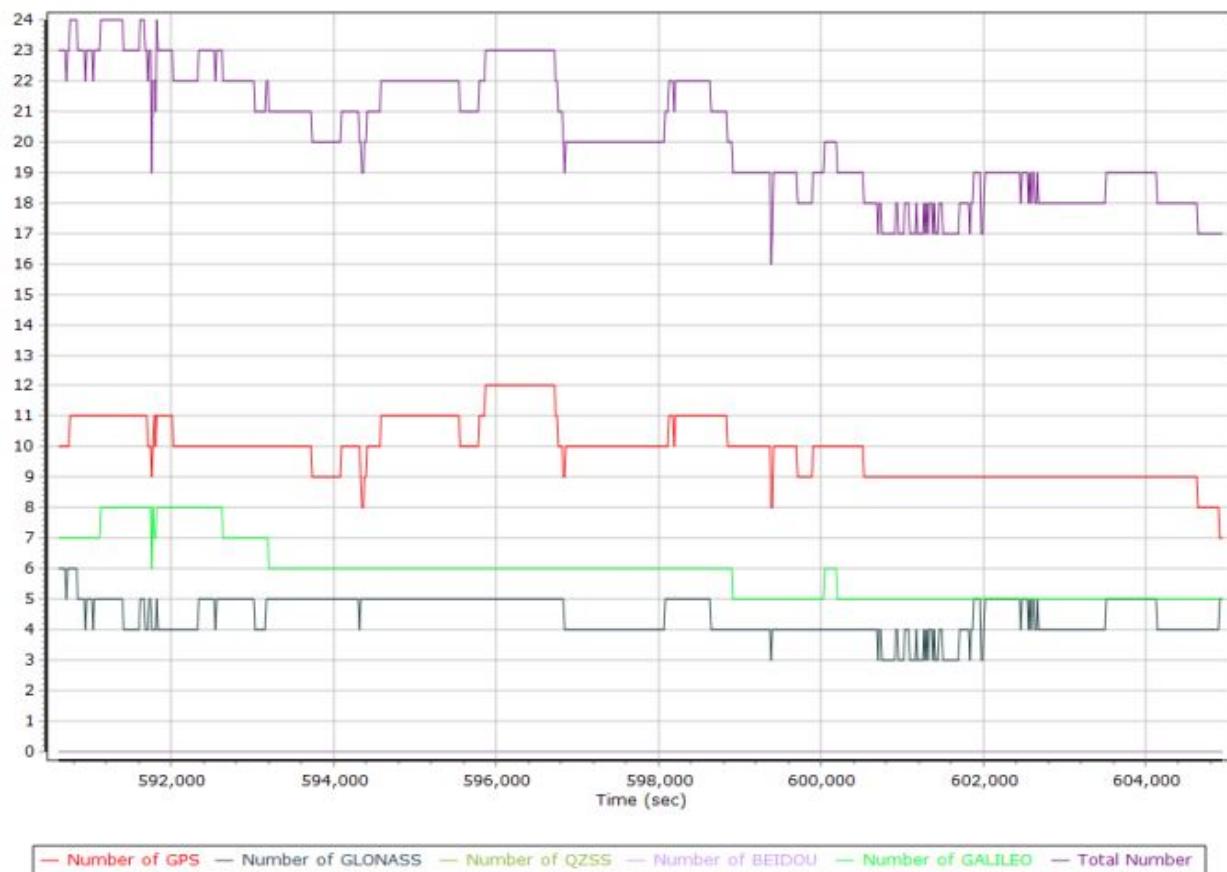


**GNSS QC**

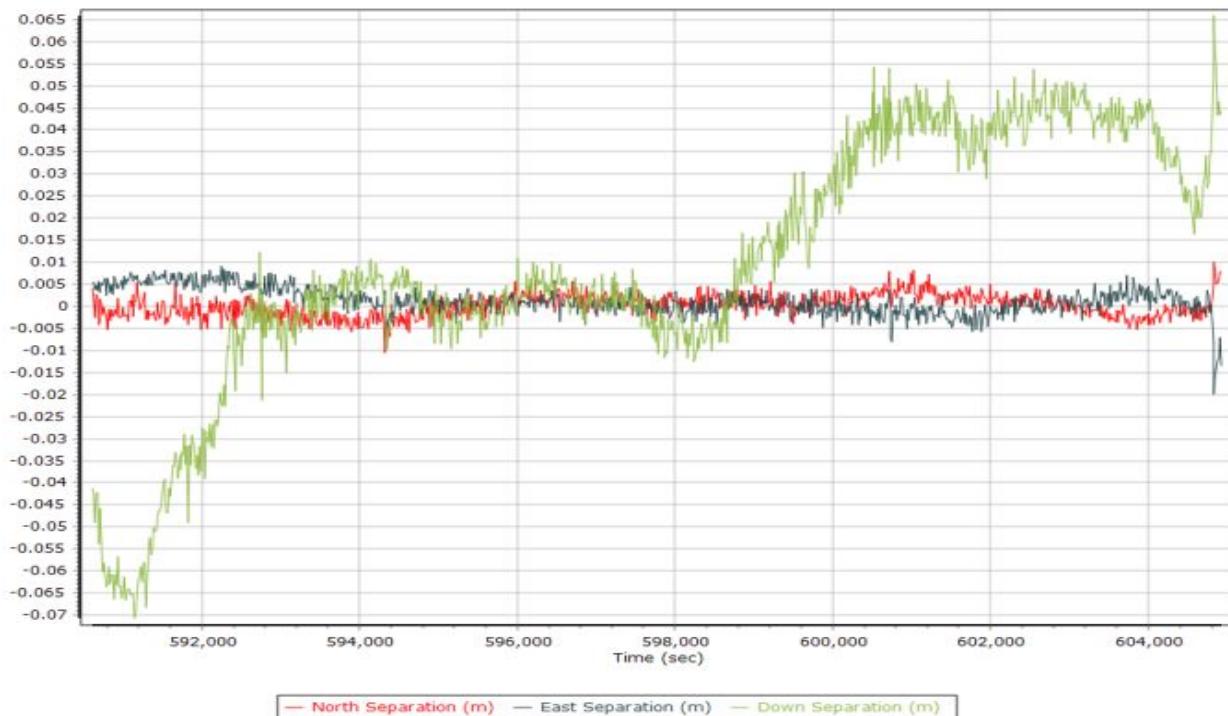
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	12	10
Number of GLONASS SV	2	8	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	5	8	6
Total number of SV	16	24	20
PDOP	0.96	1.51	1.15
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	14729.00	0.00	0.00
Percentage	100.00	0.00	0.00

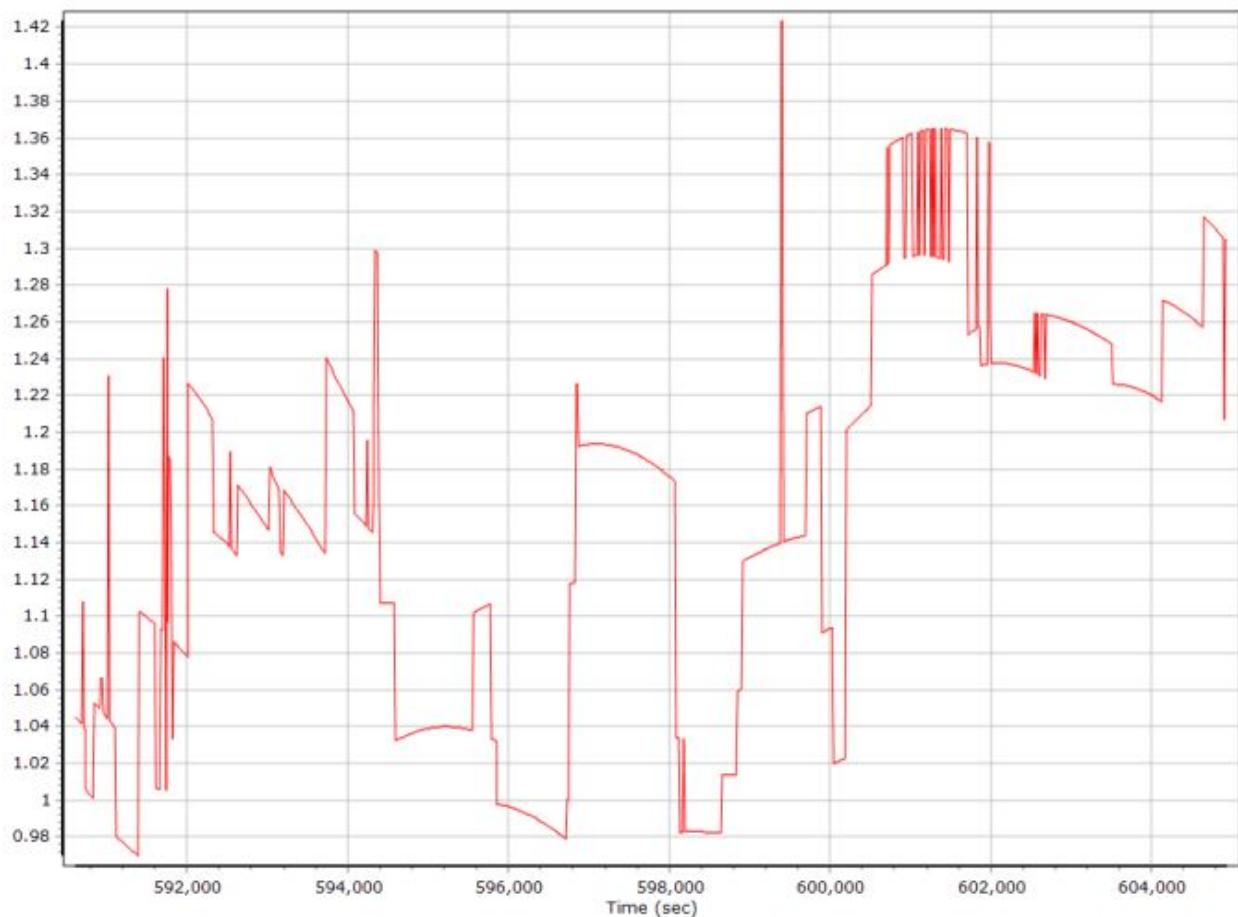
### Number of Satellites



### Forward/Reverse Separation

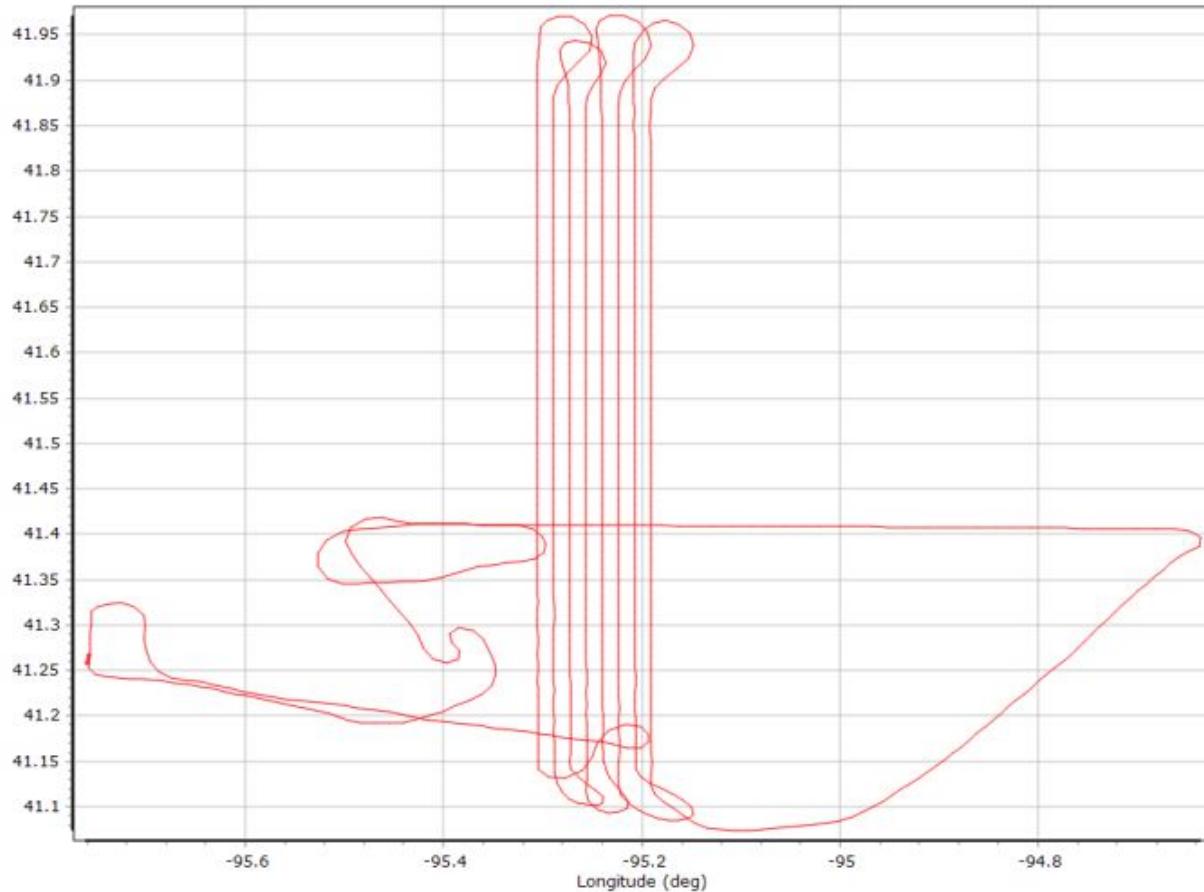


PDOP



0321a386\_QC Report.docx QC Report – 8/25/2021 13:13:01  
Smoothed Trajectory Information

Top View



## GNSS QC

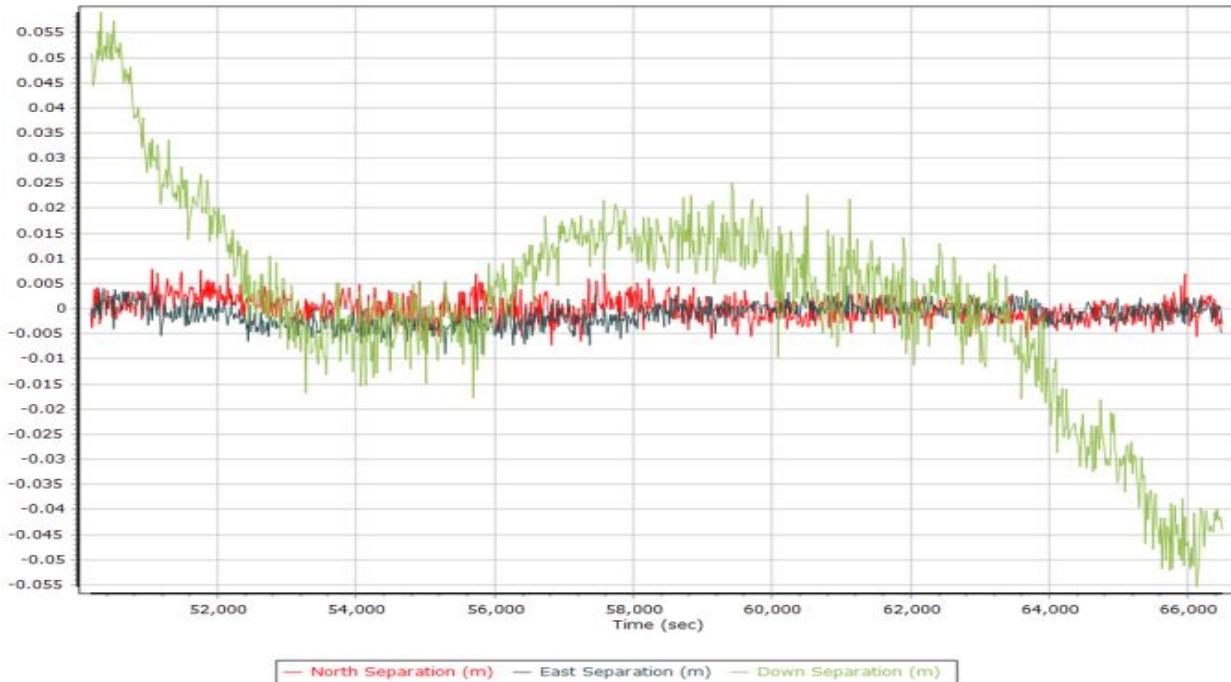
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	10	8
Number of GLONASS SV	0	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	3	7	5
Total number of SV	12	24	20
PDOP	1.02	1.93	1.24
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	16777.00	0.00	0.00
Percentage	100.00	0.00	0.00

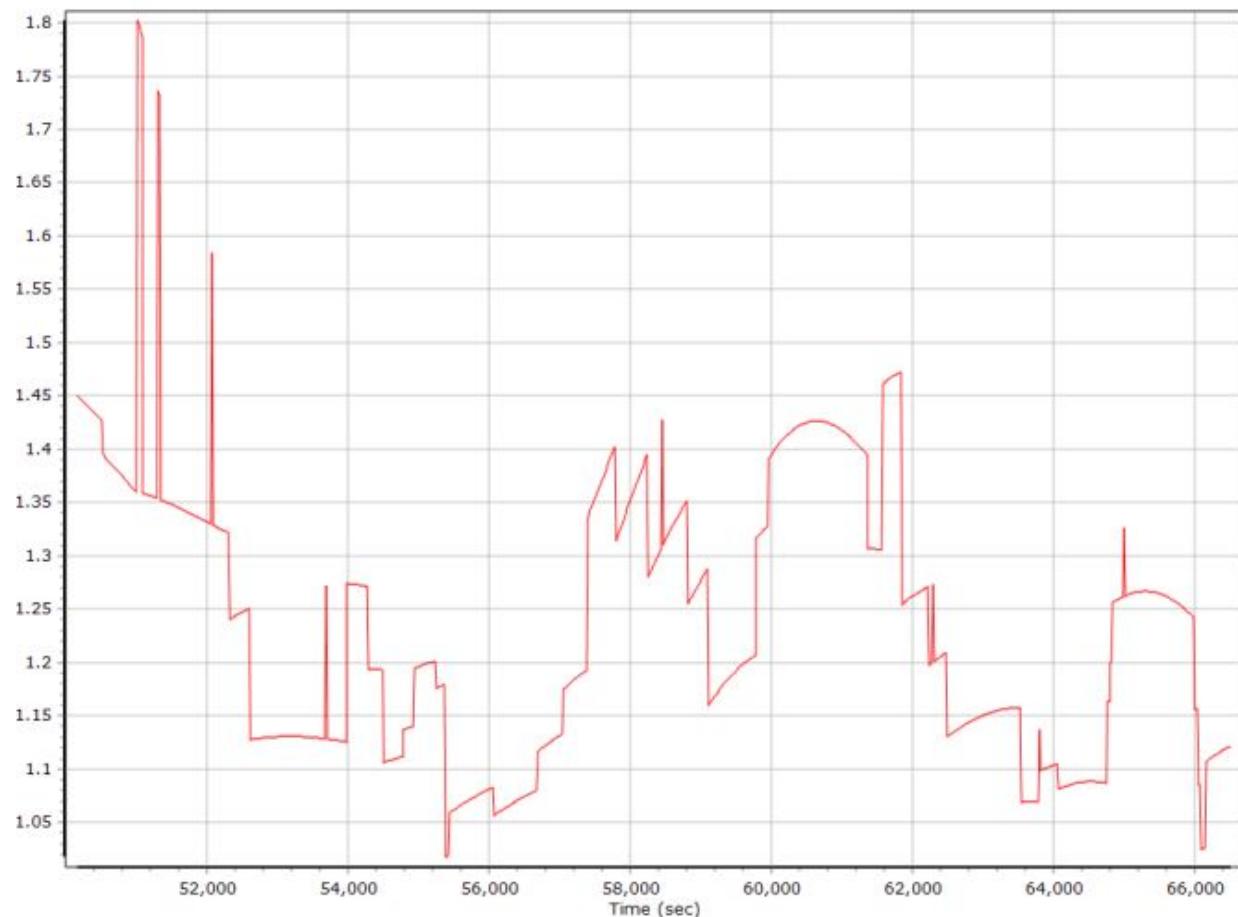
### Number of Satellites



### Forward/Reverse Separation

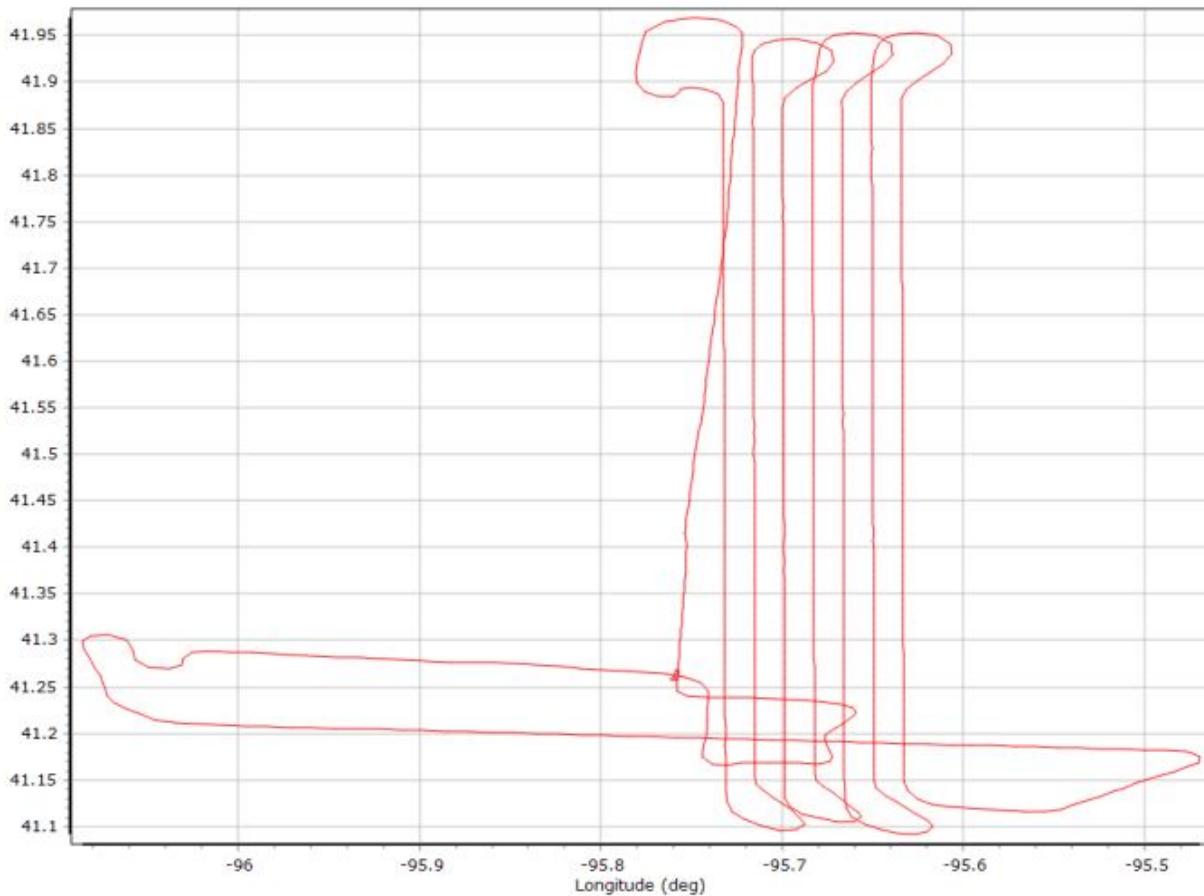


## PDOP



0321a448\_QC Report.docx QC Report -08/26/2021 13:27:25  
Smoothed Trajectory Information

Top View

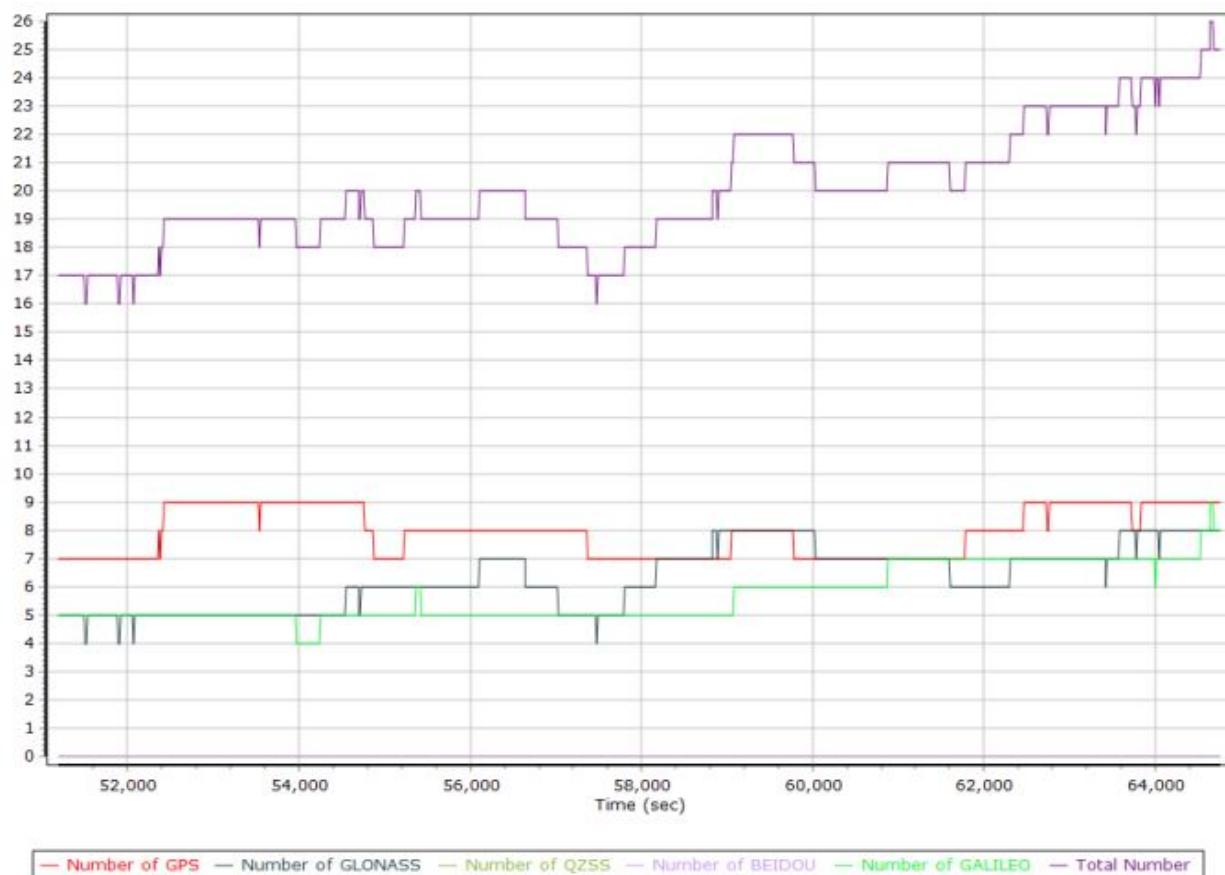


**GNSS QC**

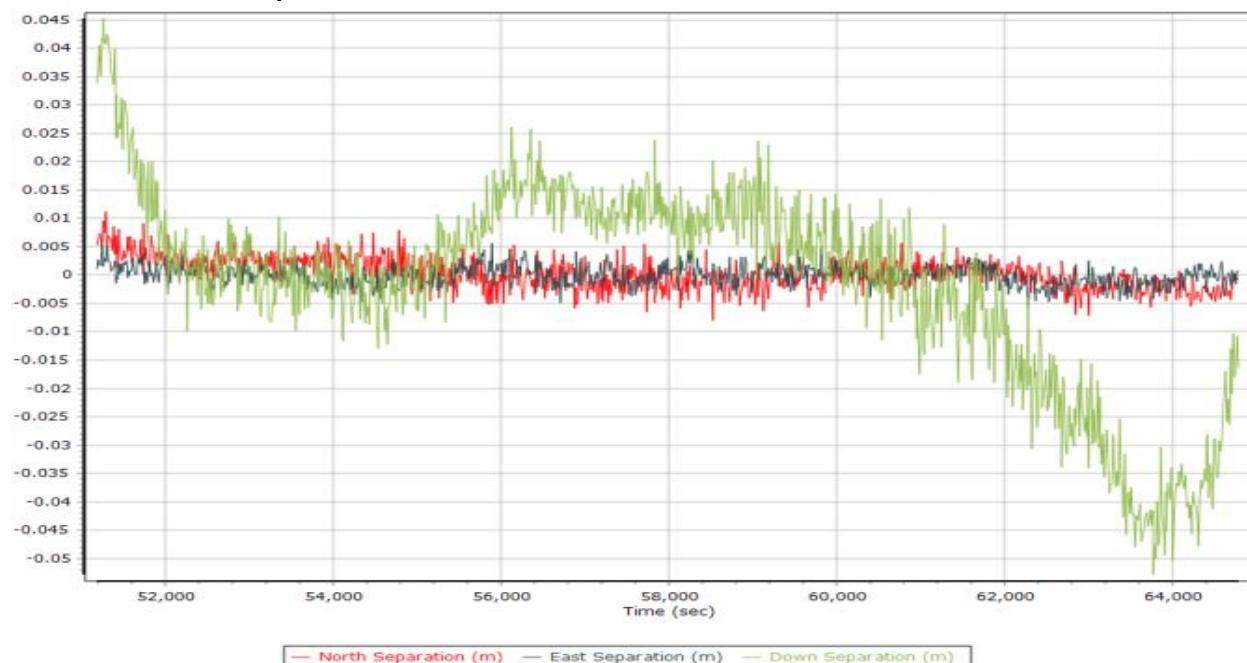
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	9	8
Number of GLONASS SV	3	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	9	6
Total number of SV	14	26	20
PDOP	0.97	1.98	1.20
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	13989.00	0.00	0.00
Percentage	100.00	0.00	0.00

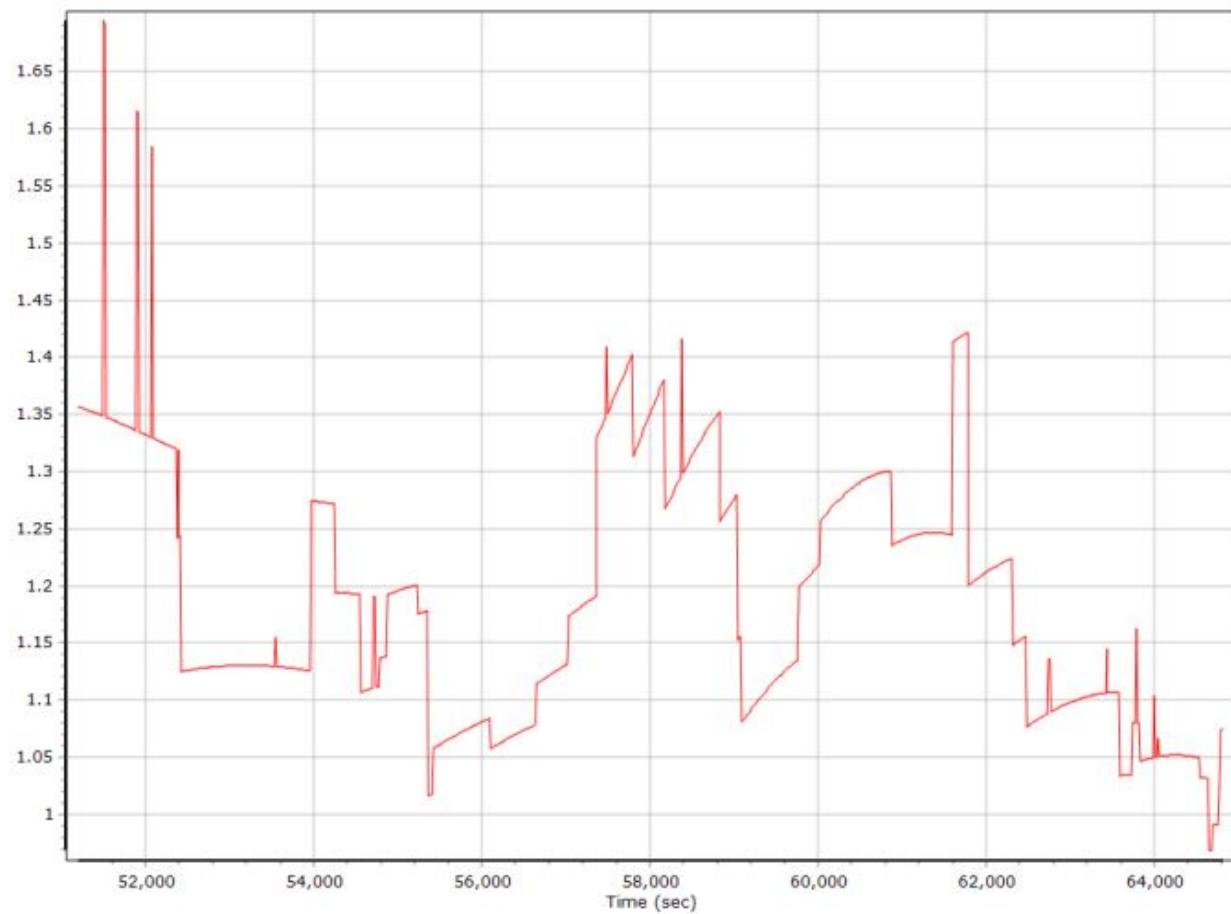
### Number of Satellites



### Forward/Reverse Separation

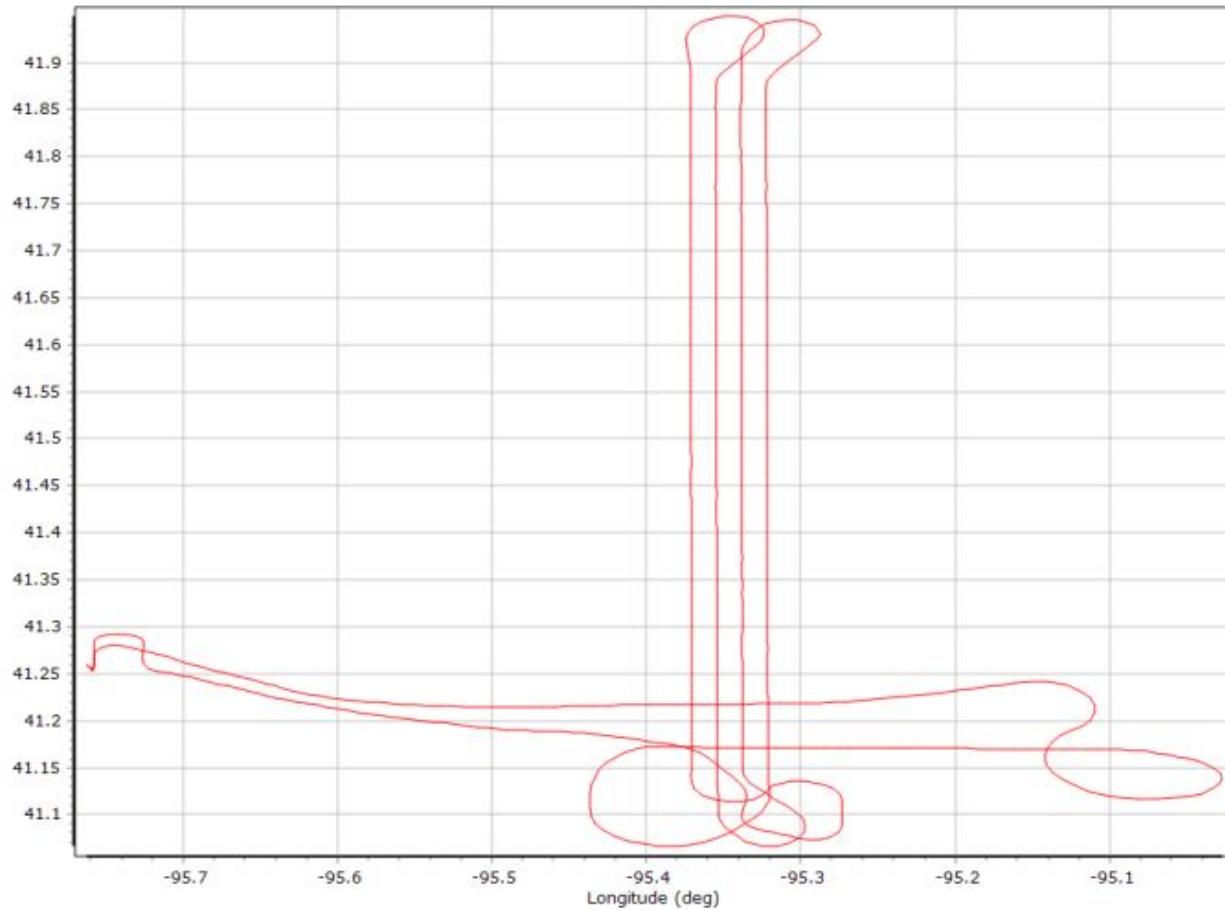


PDOP



0328a386\_QC Report.docx QC Report – 8/26/2021 13:35:30  
Smoothed Trajectory Information

Top View

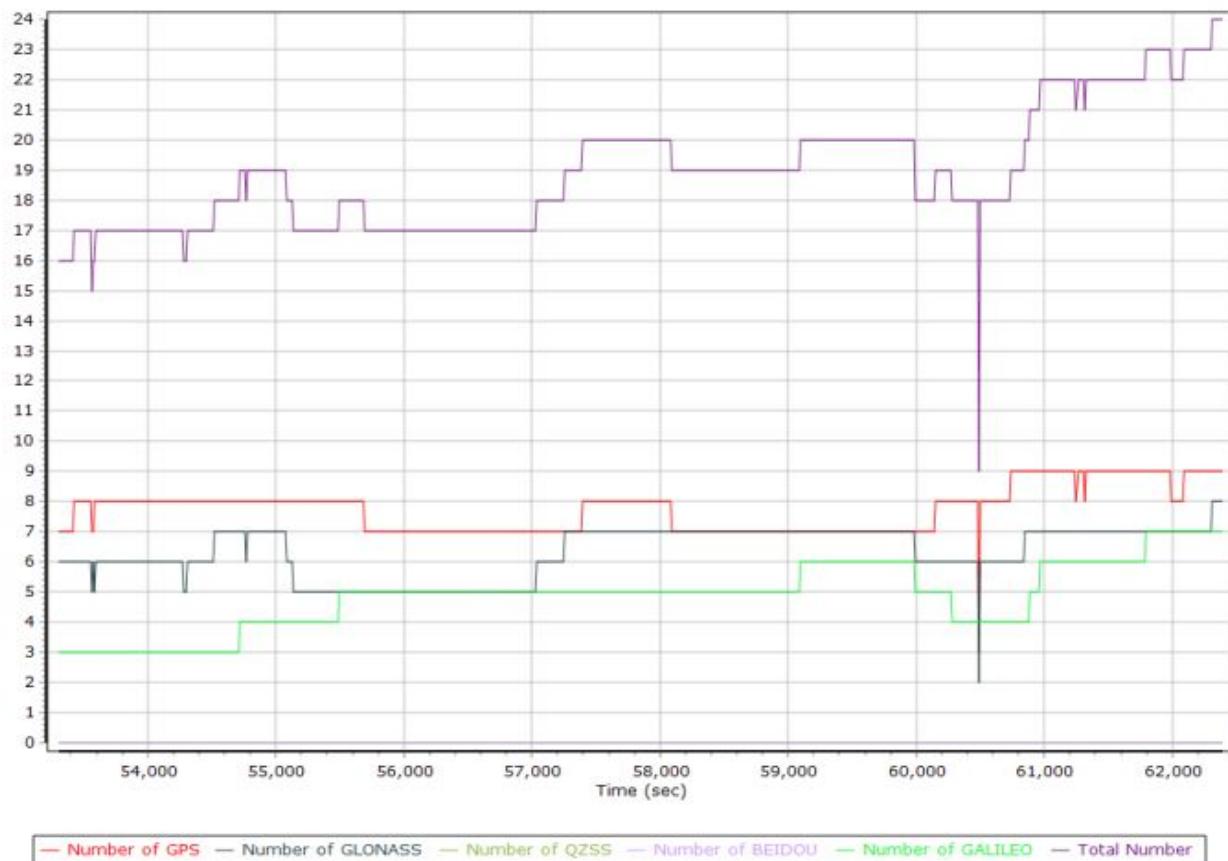


## GNSS QC

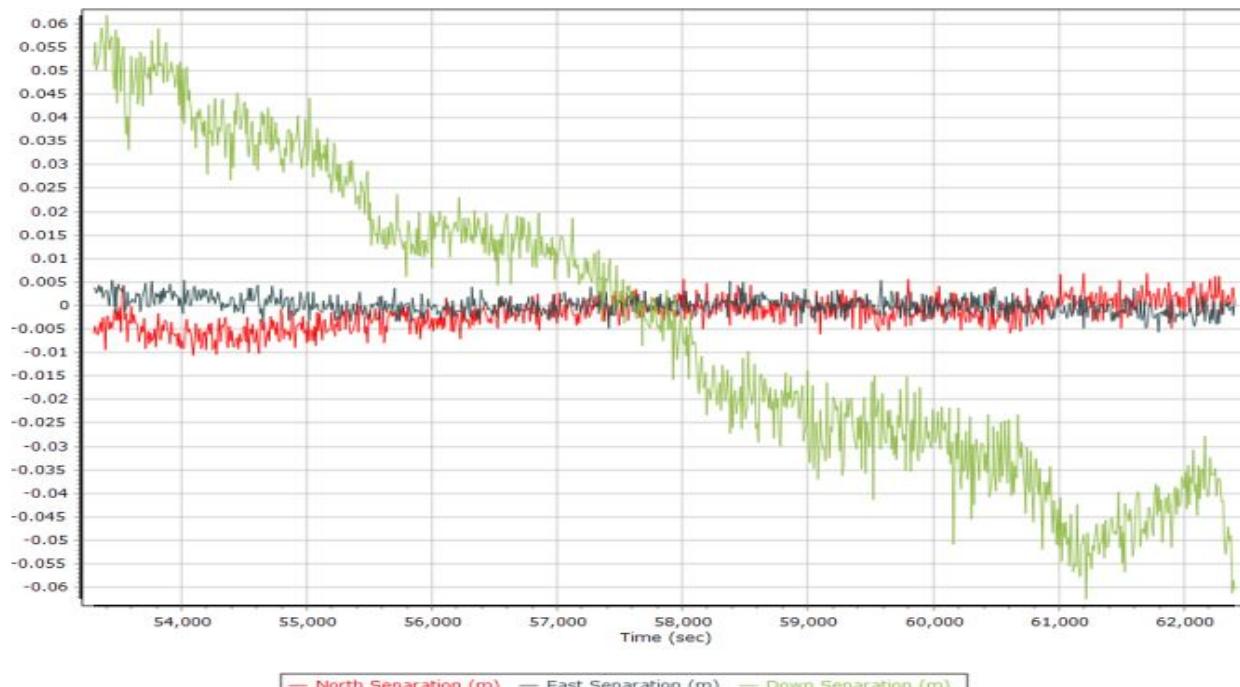
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	3	9	8
Number of GLONASS SV	0	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	7	5
Total number of SV	9	24	19
PDOP	1.03	3.58	1.31
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	9609.00	0.00	0.00
Percentage	100.00	0.00	0.00

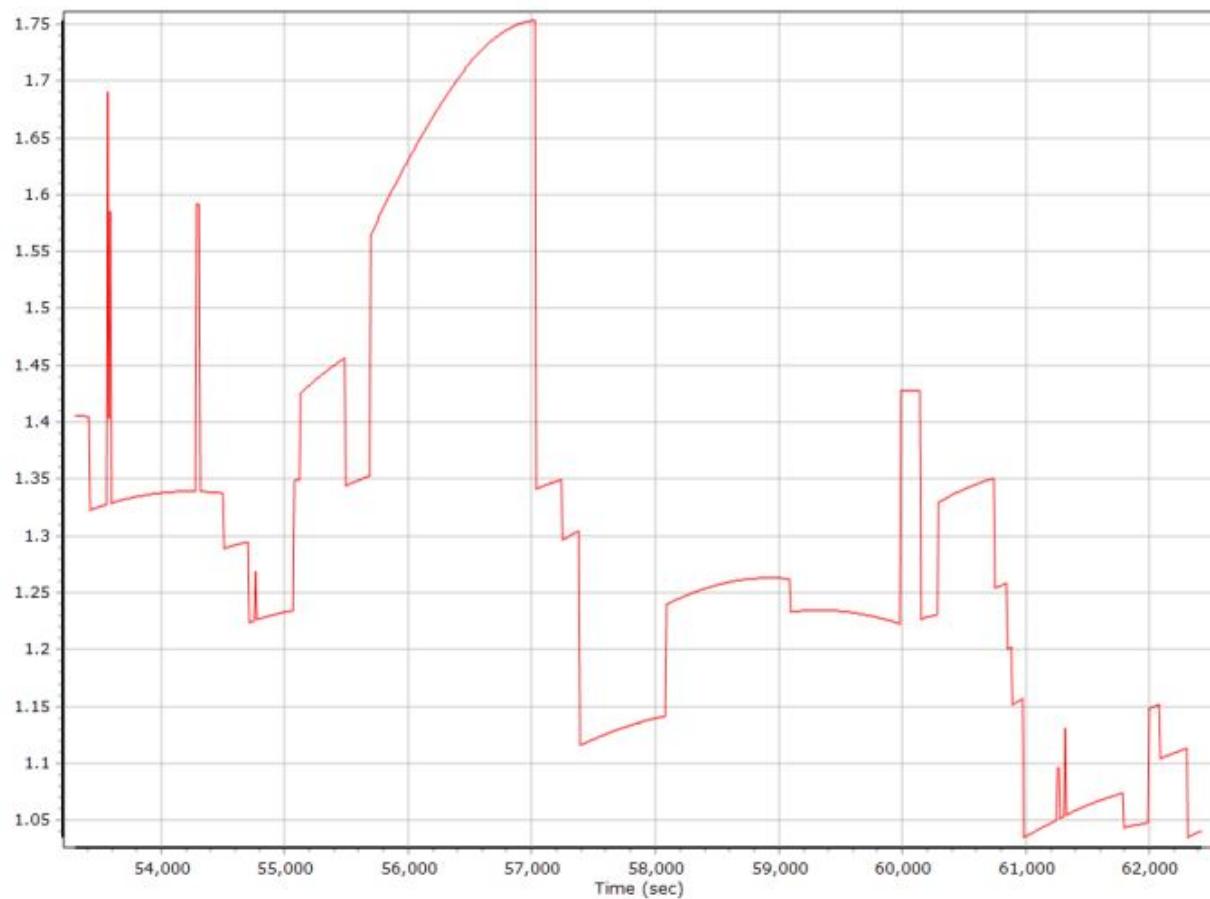
### Number of Satellites



### Forward/Reverse Separation

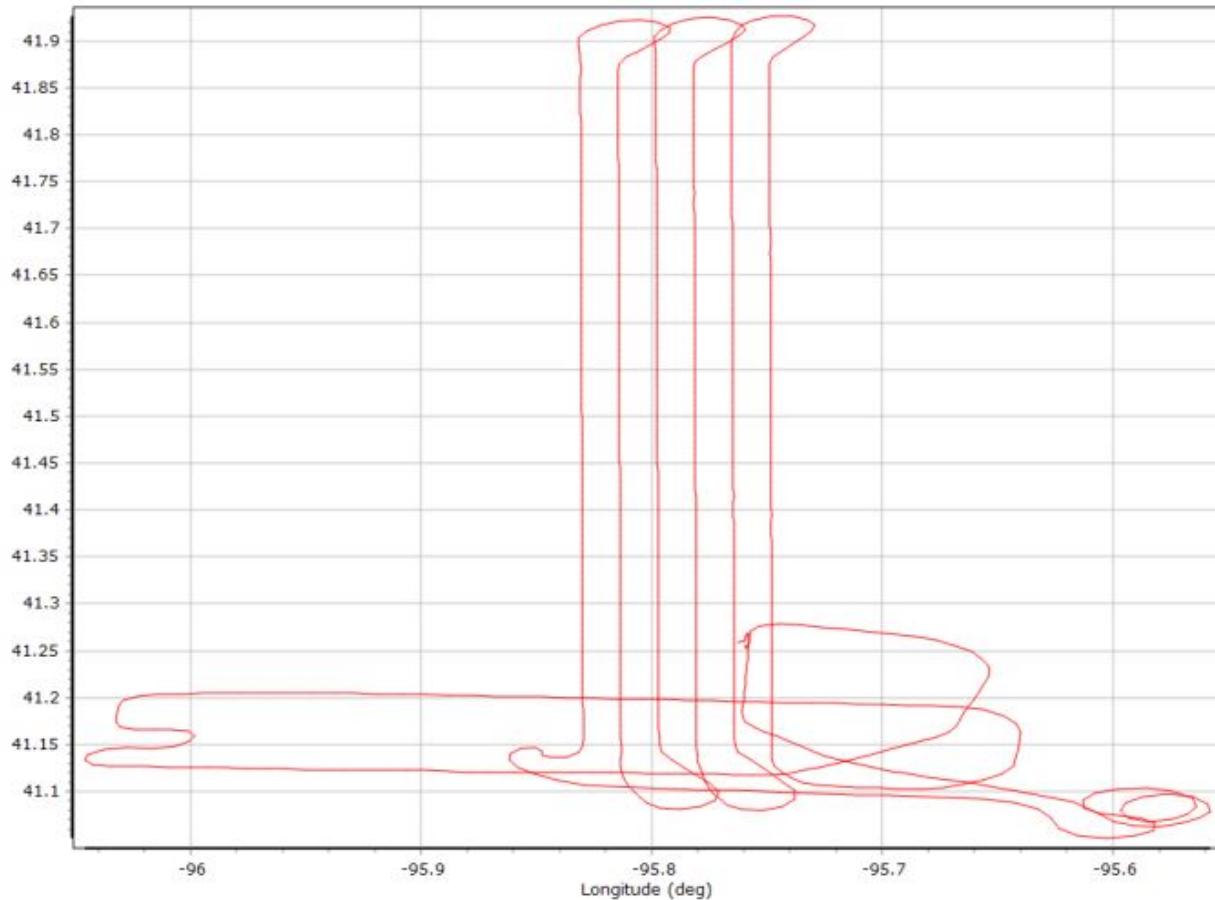


PDOP



0328a448\_QC Report.docx QC Report – 8/26/2021 13:43:38  
Smoothed Trajectory Information

Top View



**GNSS QC**

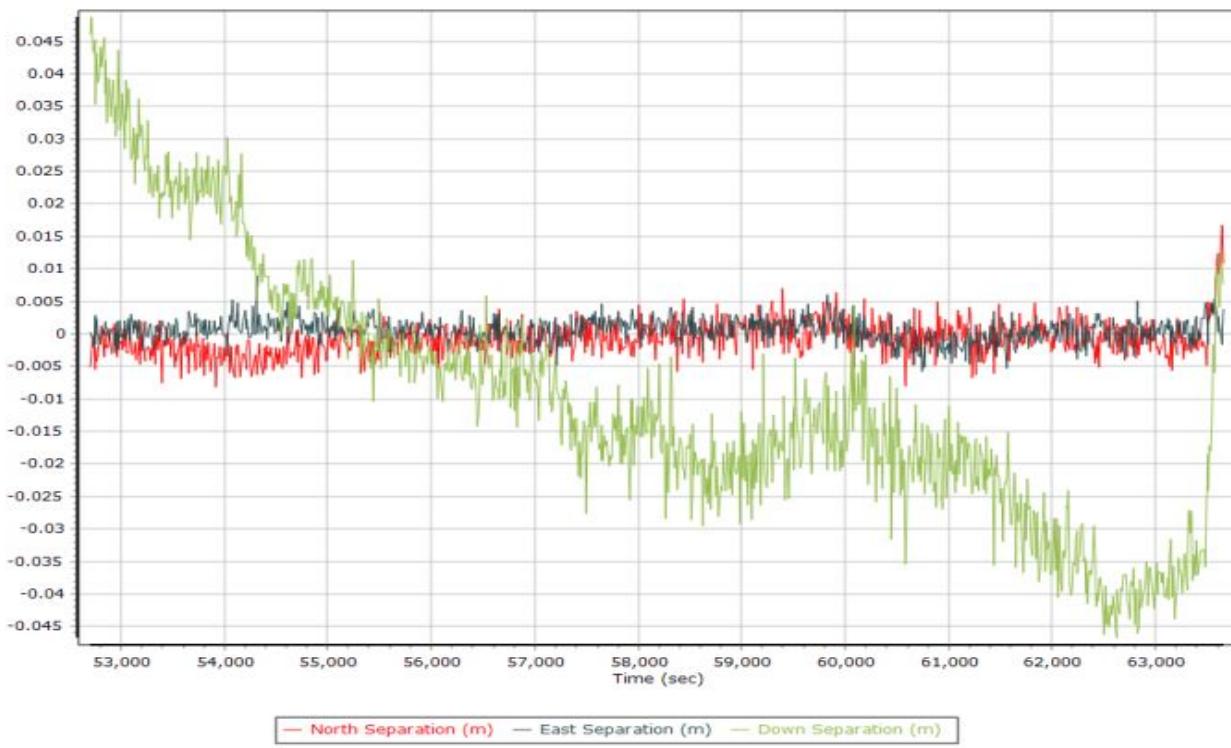
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	3	9	8
Number of GLONASS SV	2	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	7	6
Total number of SV	9	24	20
PDOP	1.02	3.16	1.24
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	11372.00	0.00	0.00
Percentage	100.00	0.00	0.00

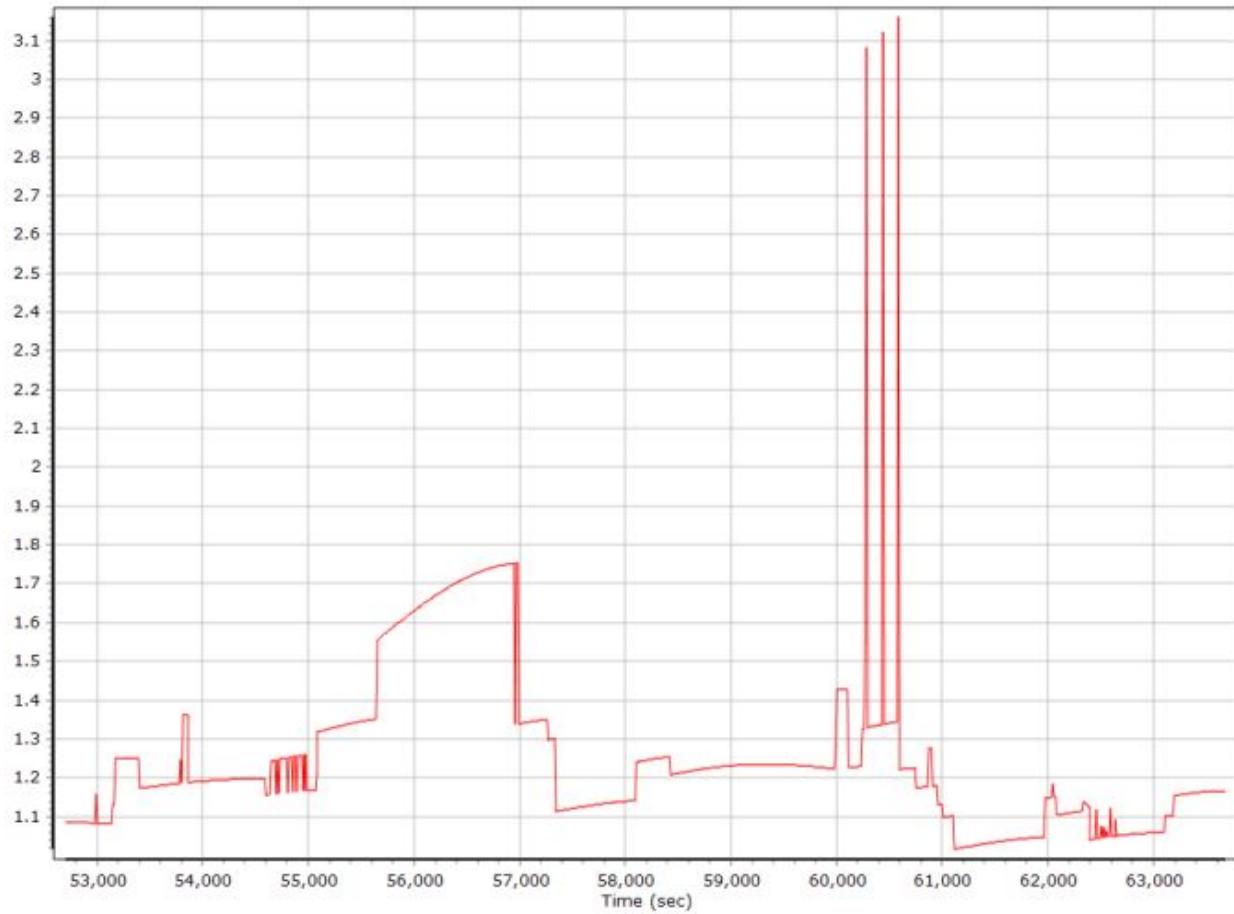
### Number of Satellites



### Forward/Reverse Separation

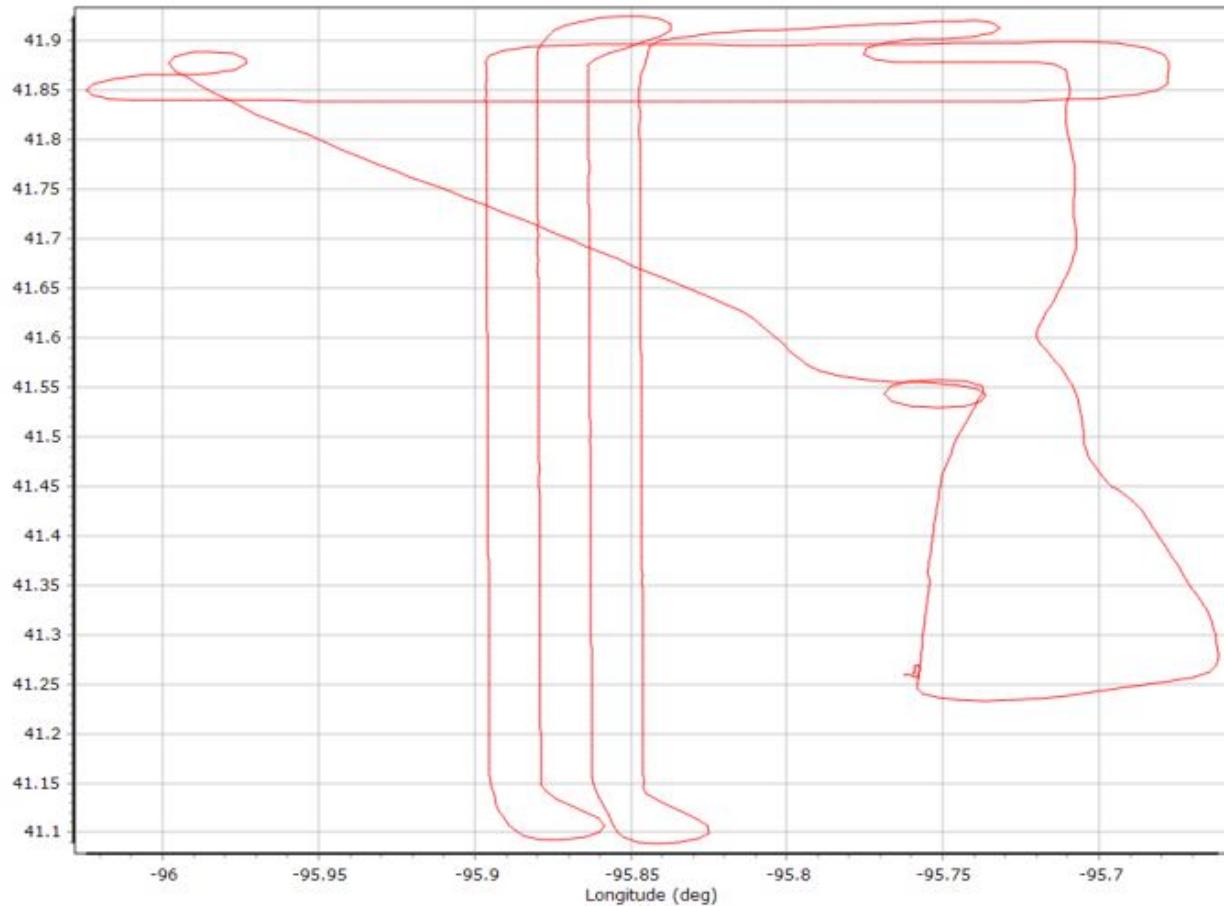


**PDOP**



0328c448\_QC Report.docx QC Report – 8/25/2021 13:52:41  
Smoothed Trajectory Information

Top View

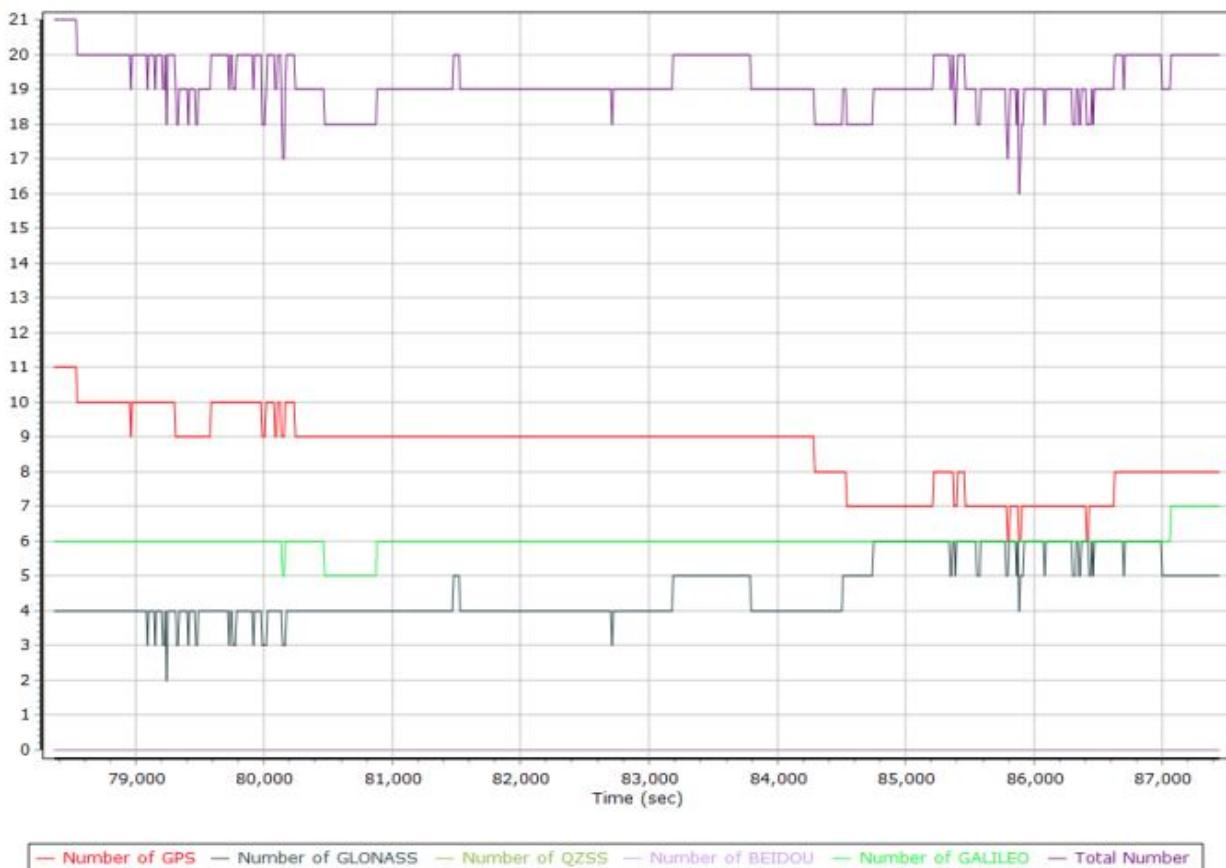


## GNSS QC

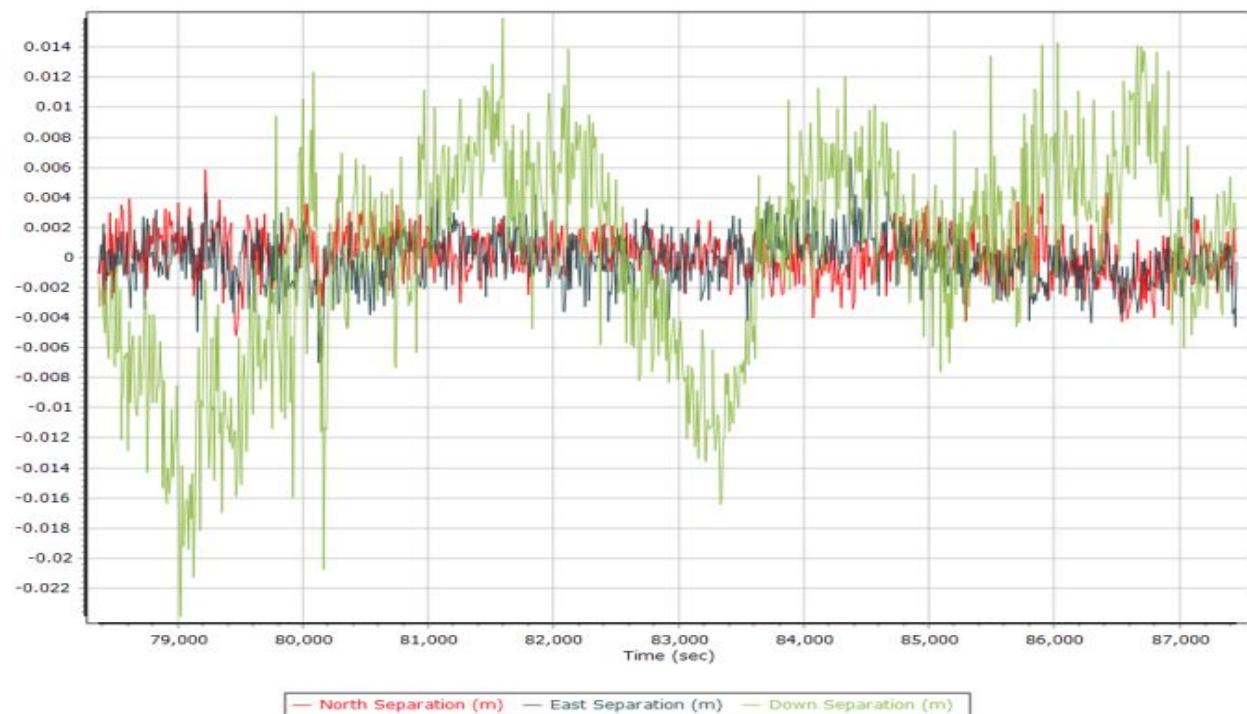
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	11	9
Number of GLONASS SV	2	6	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	5	7	6
Total number of SV	16	22	19
PDOP	1.00	1.54	1.16
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	9495.00	0.00	0.00
Percentage	100.00	0.00	0.00

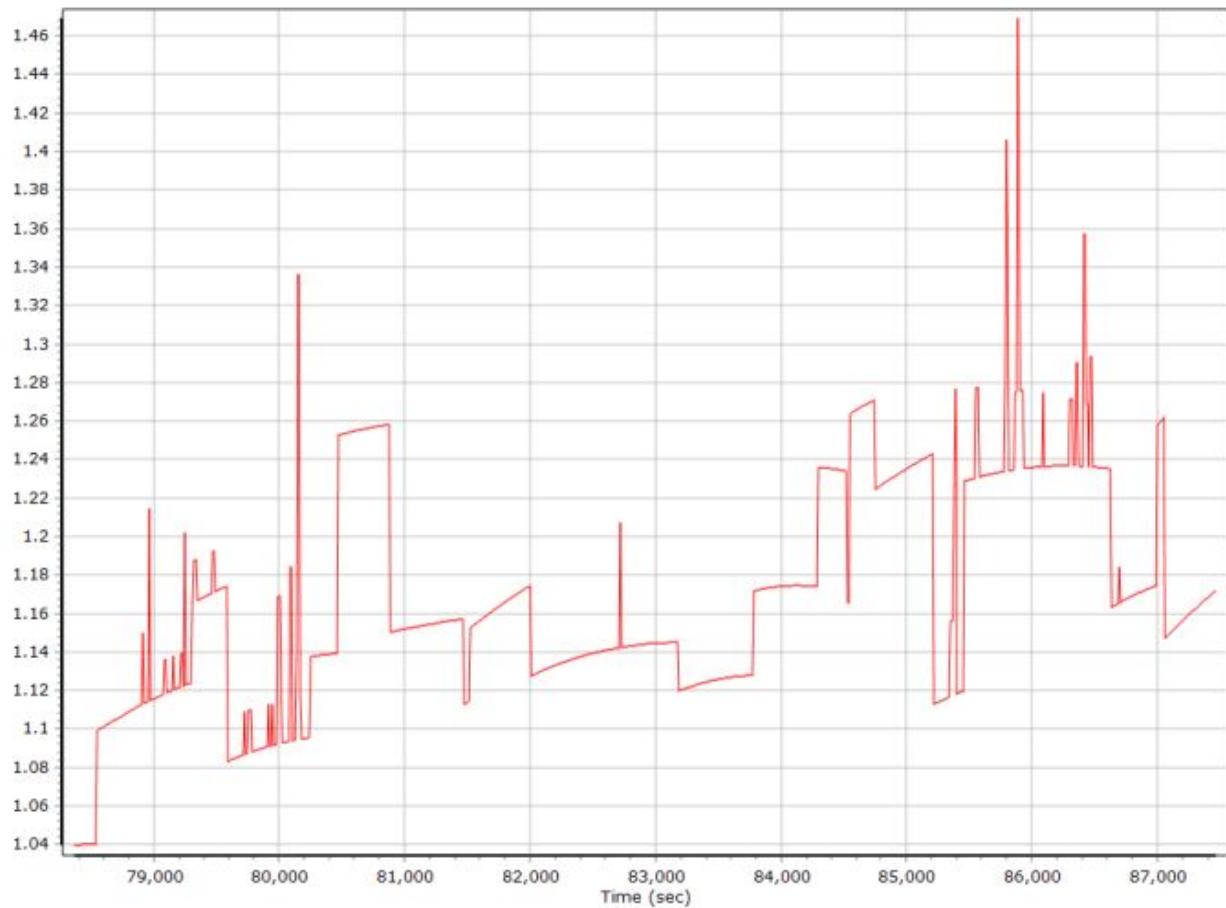
### Number of Satellites



### Forward/Reverse Separation



**PDOP**



1210a386\_QC Report.docx QC Report – 8/26/2021 14:00:11  
Smoothed Trajectory Information

Top View

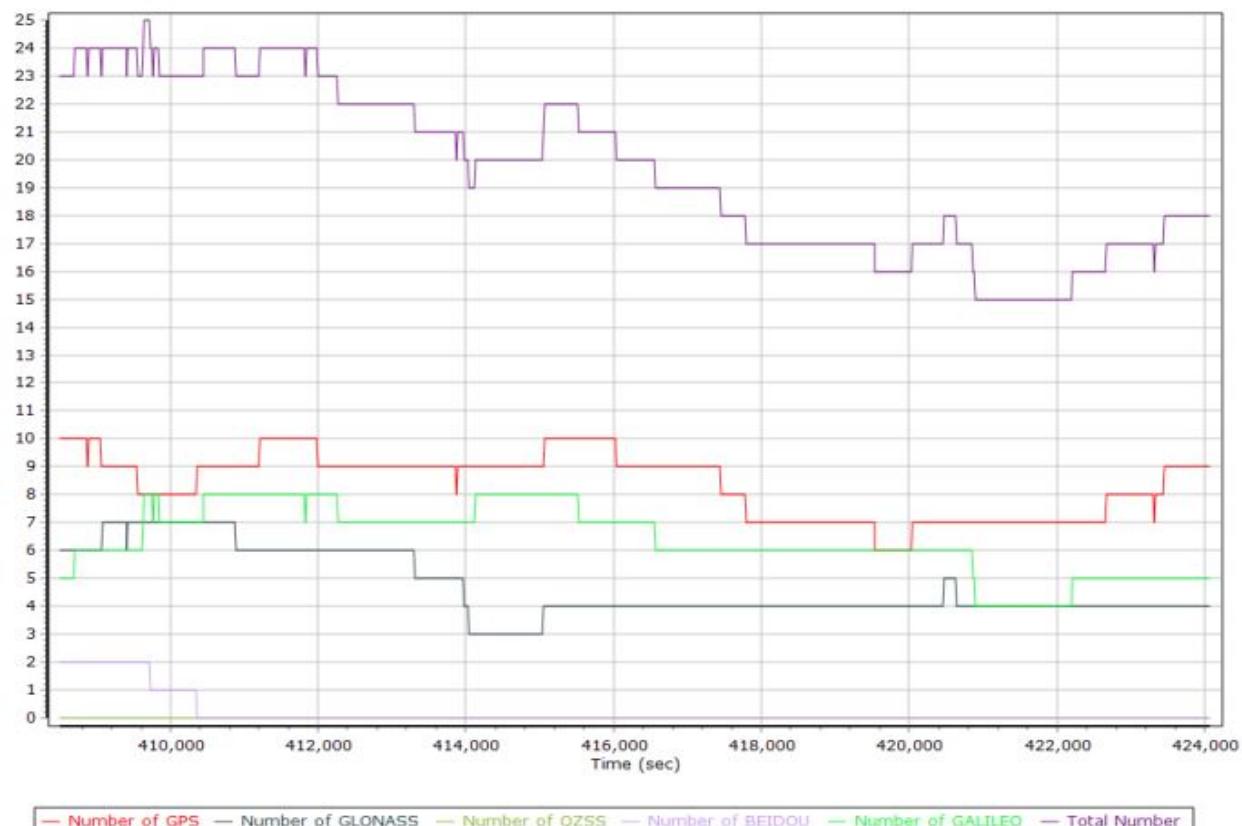


## GNSS QC

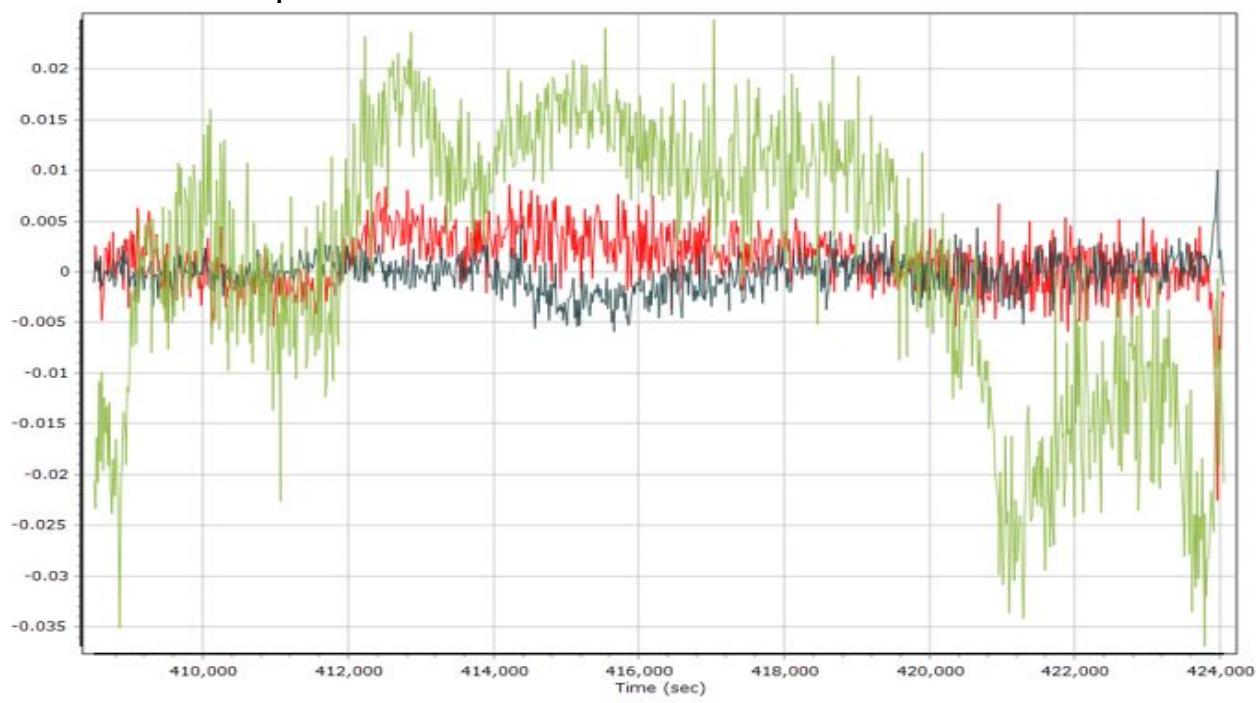
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	7	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	0
Number of GALILEO SV	0	8	6
Total number of SV	15	25	20
PDOP	1.02	1.97	1.30
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	16265.00	0.00	0.00
Percentage	100.00	0.00	0.00

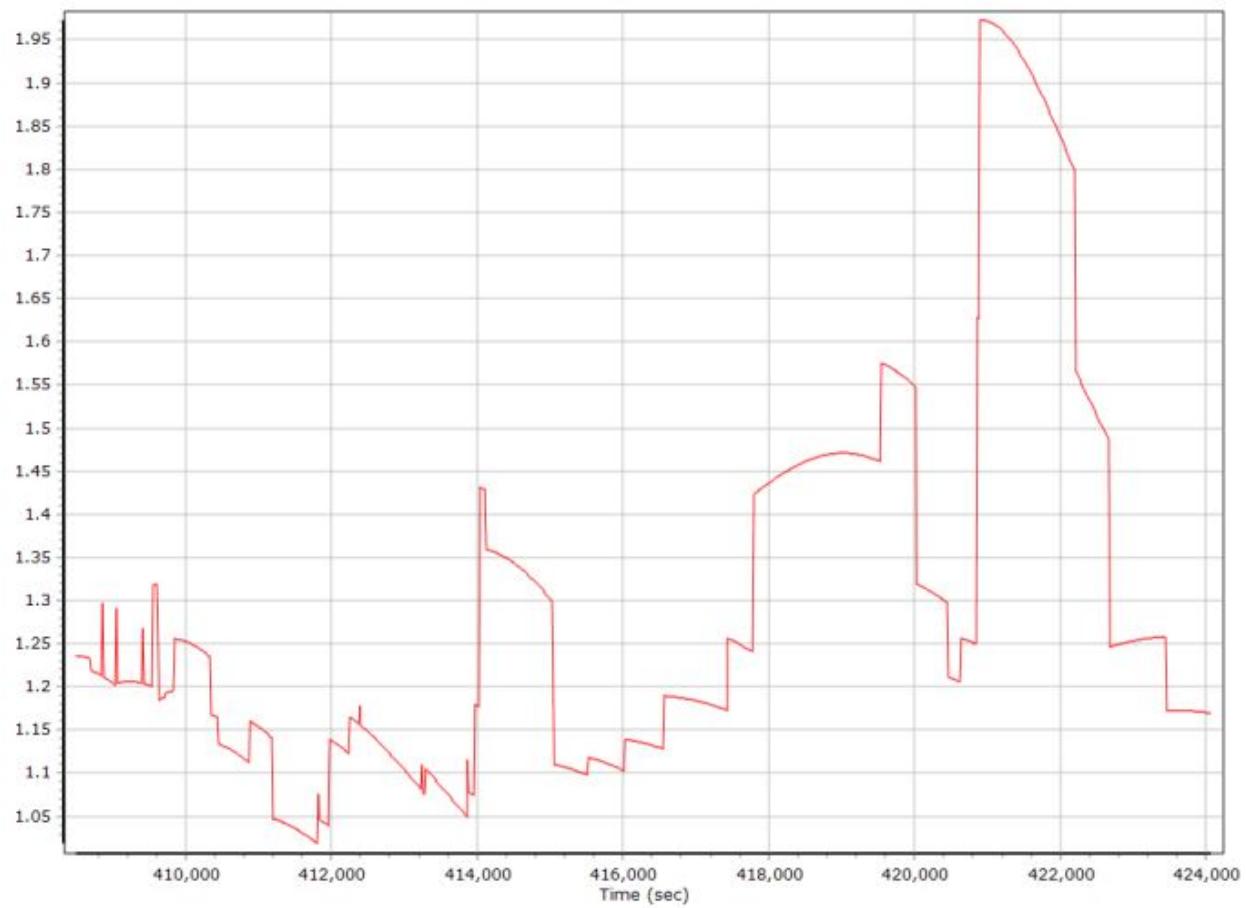
### Number of Satellites



### Forward/Reverse Separation



**PDOP**



1210a448\_QC Report.docx QC Report - 8/26/2021 14:10:44  
Smoothed Trajectory Information

Top View

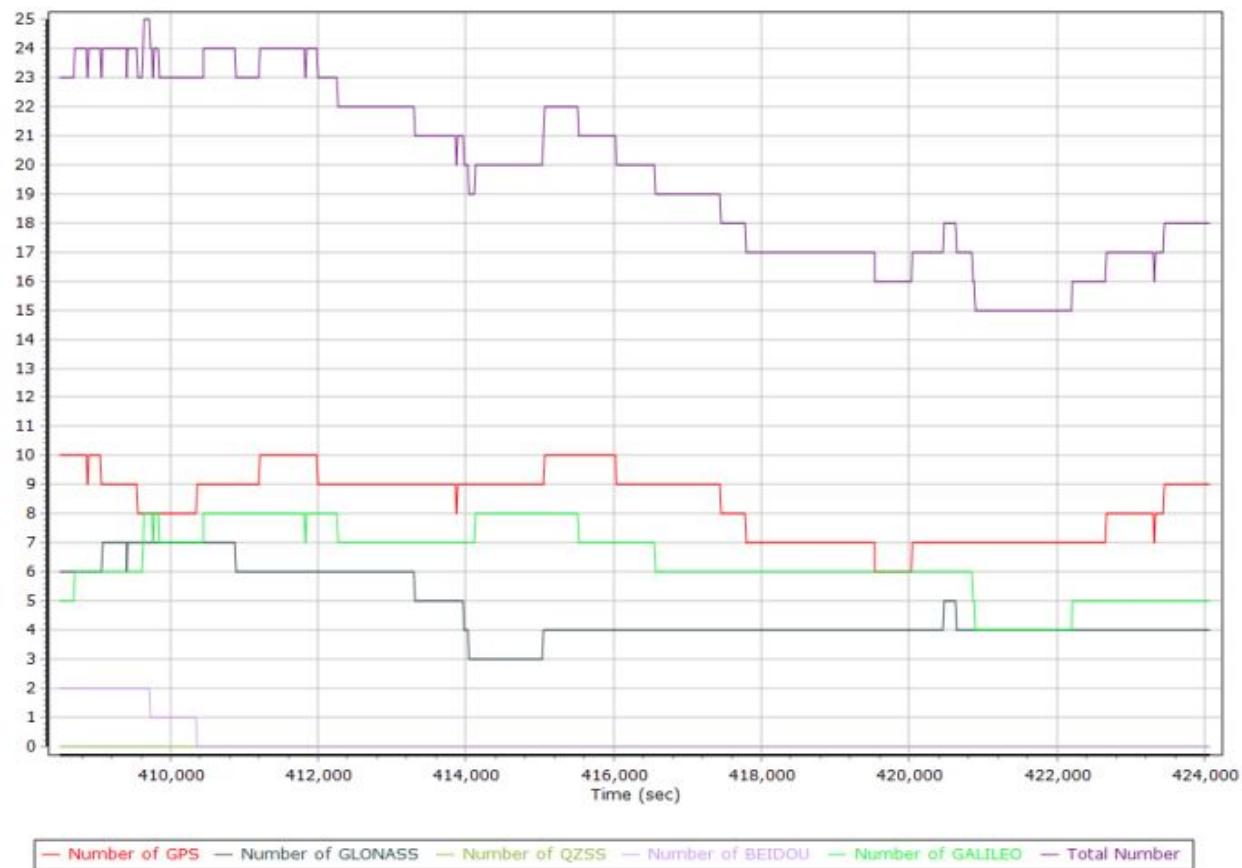


## GNSS QC

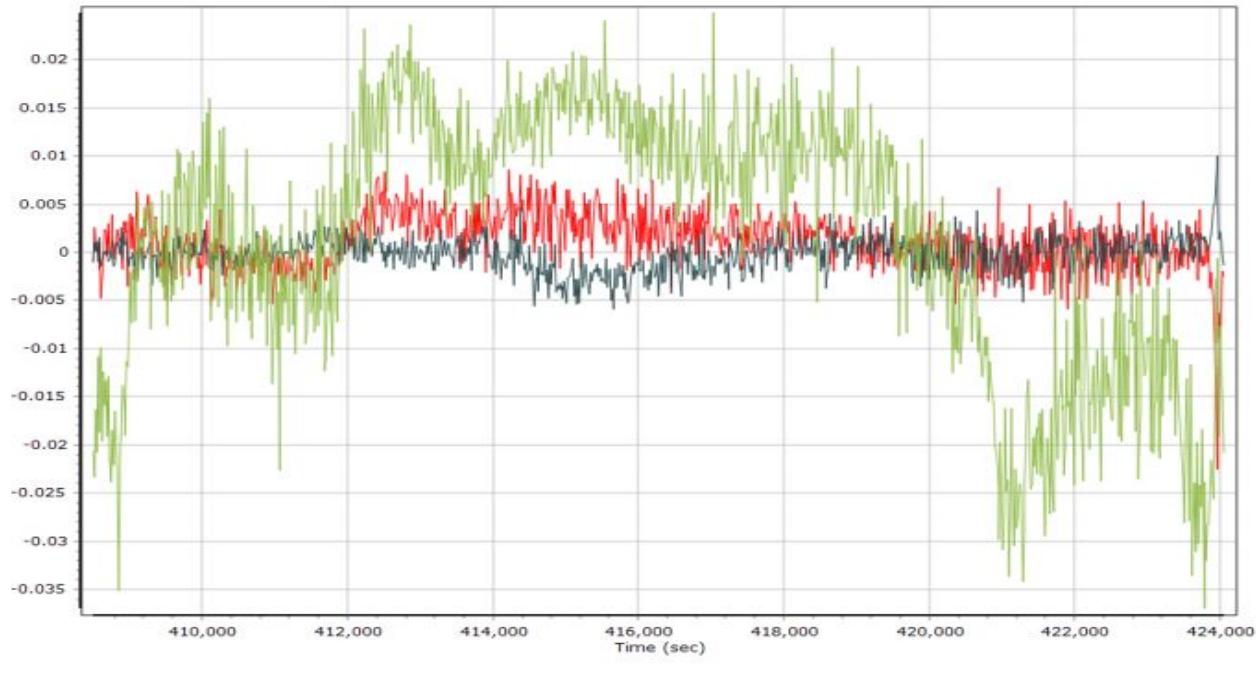
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	7	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	0
Number of GALILEO SV	0	8	6
Total number of SV	15	25	20
PDOP	1.02	1.97	1.30
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	16265.00	0.00	0.00
Percentage	100.00	0.00	0.00

### Number of Satellites



### Forward/Reverse Separation



PDOP

