USGS_IA_Western_1_2020_D21 Lidar 2020 Final Report

Report Produced for U.S. Geological Survey
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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 2691 square miles of USGS_IA_WesternIA_2020_D21 referred to as USGS_IA_Western_1_2020_D21 was acquired in the late fall of 2020 and early spring 2021. USGS_IA_Western_1_2020_D21 project area consists of the western most portions of 6 Iowa counties; Lyon, Sioux, Plymouth, Woodbury, Monona, and Harrison. The condition of the ground was good during the collection of the survey.

Acquisition of the USGS_IA_Western_1_2020_D21 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

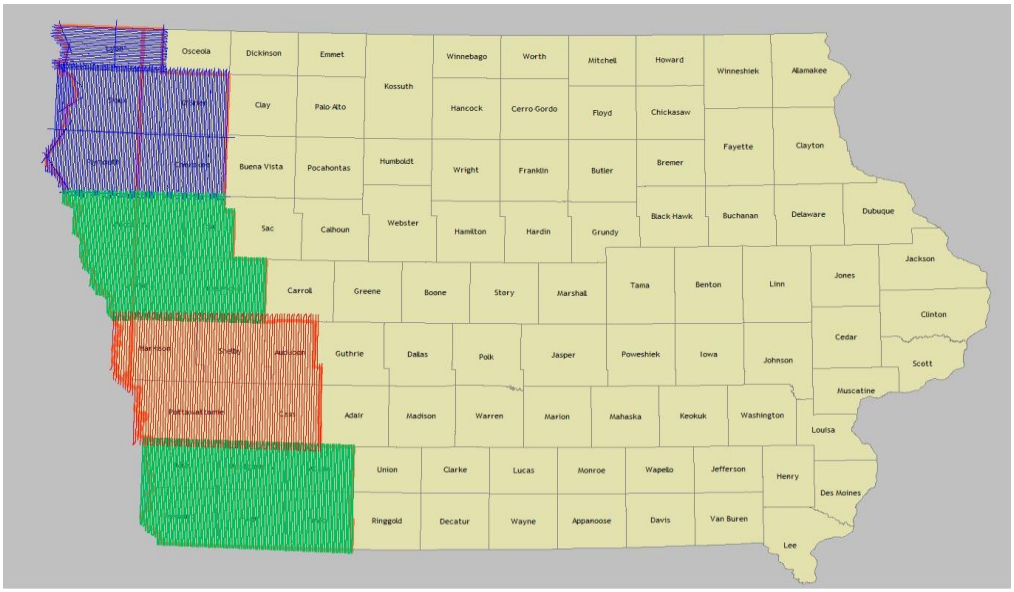

Figure 1: USGS_IA_Western_1_2020_D21 DPA Contractor and Subcontractor Breakout

The LiDAR data for USGS_IA_Western_1_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_1_2020_D21 project area. Data was formatted into

tiles with each tile covering an area of 1000 meters by 1000 meters. A total of 7,321 LAS files, 7,320 DEMs, and 7,321Intensity Images were produced for the project, encompassing the USGS_IA_WESTERN_1_2020_D21 project area approximately 2,691 square miles and formatted into 7,322 total tiles.

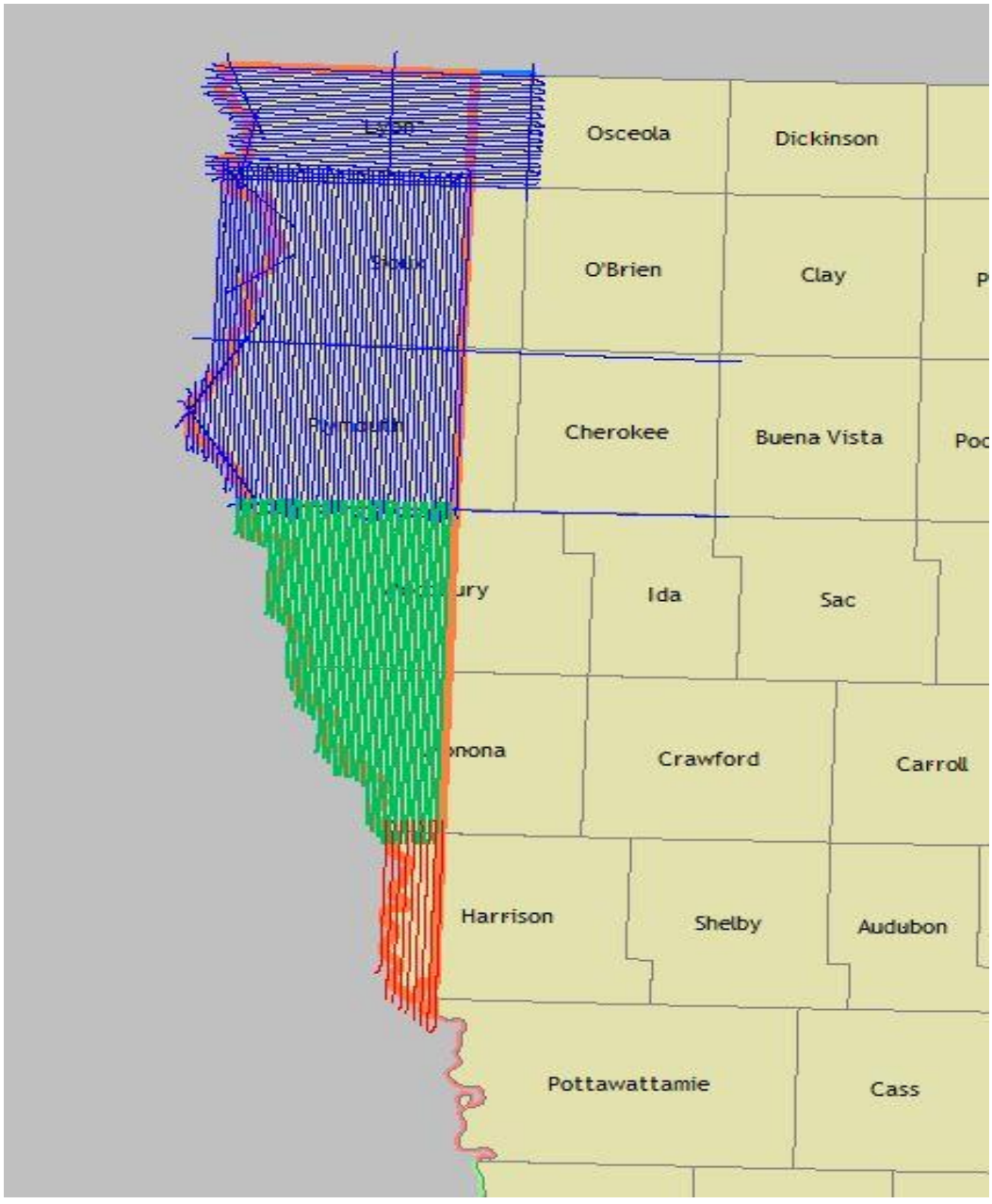

Figure 2: USGS_IA_Western_1_2020_D21 Breakout

Project team

Aerial Services, Inc. (ASI) served as the prime contractor for the project. In addition to project management, ASI was responsible for LIDAR acquisition and calibration of 1776.5 square miles of the northern section and ground filtration of this USGS_IA_Western_1_2020_D21 project area. 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 118.5 square miles of the southern section of this USGS_IA_Western_1_2020_D21 project area. Subcontractor: Technical Applications & Consulting, LLC (TAC) was responsible for LiDAR acquisition and calibration of 795.89 square miles of the central section of this USGS_IA_Western_1_2020_D21 project area. Subcontractor: Michael Backer International collected hydro for the entire USGS_IA_Western_1_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 within the USGS_IA_Western_1_2020_D21 project area consists of the western portions of 6 Iowa counties; Lyon, Sioux, Plymouth, Woodbury, Monona, and Harrison.

Date of survey

LiDAR acquisition for USGS_IA_Western_1_2020_D21 project area was conducted between the dates of November 27, 2020 to March 29, 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 14 North.
Units: Horizontal units are in meters, Vertical units are in meters.
Geoid Model: Geoid18

Lidar vertical accuracy

For the USGS_IA_Western_1_2020_D21 project area, the tested RMSEz of the classified LiDAR data for checkpoints in non-vegetated terrain equaled 0.047 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 0.093 meters compared with the 0.196 meter specification.

For the USGS_IA_Western_1_2020_D21 project area, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to 0.143 meters, compared with the 0.294 meter specification.

This project must meet Non-vegetated Vertical Accuracy (NVA) ≤ 0.0196 meters (19.6 cm) at the 95% confidence level based on RMSEz ≤ 0.100 meters (10 cm) x 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	53	0.047	0.093	0.009	0.006	-0.09	0.047	-0.112	0.133	0.597

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 – GeoTIF format)
- Intensity Images (8-bit gray scale, tiled, TIFF format)
- Breakline Data (File GDB)
- Independent Survey Checkpoint Data (File GDB)
- Calibration Points (File GDB)
- Metadata
- Maximum surface height raster (Raster –GeoTIF format)
- Swath separation Images
- Project Report (Acquisition, Processing, QC)
- Swaths Extents (File GDB)
- Tile Index (File GDB)
- DPA (File GDB)

Project tiling footprint

The LiDAR data for USGS_IA_WesternIA_2020_D21 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_WesternIA_2020_D21 project area. Lidar data was delivered as processed Classified LAS 1.4 files, formatted to 7,321 individual 1000 meter x 1000 meter tiles, 7,319 tiled DSMs and Intensity Imagery, and 7,320 tiled bare earth DEMs; all tiled to the same 1000 meter x 1000 meter schema consisting of 7,322 tiles. Only 7,320 bare earth DEMs were produced due to Blocks w7500n4613 and w6980n4726 being sliver tiles less than 1 meter wide at their widest part, therefore no DEM, DSM, or Intensities could be produced for these Blocks. Lidar point cloud LAS files are created for each tile in the tiling schema in which there is reflected photonic energy. No LAS files are created for tiles in which there is total absorption of photons, such as tiles consisting of all water and in which photonic energy is absorbed. LAS file w7250n4657 was affected by photonic energy absorption. Intensity Images are created for each tile in the tiling schema in which there is reflected photonic energy. No intensity or DSM tiles are created for tiles in which there is total absorption of photons, such as tiles consisting of all water and in which photonic energy is absorbed. DEM w7250n4657 was produced by applied hydro flattening. (See Appendix A for a complete listing of delivered tiles.)

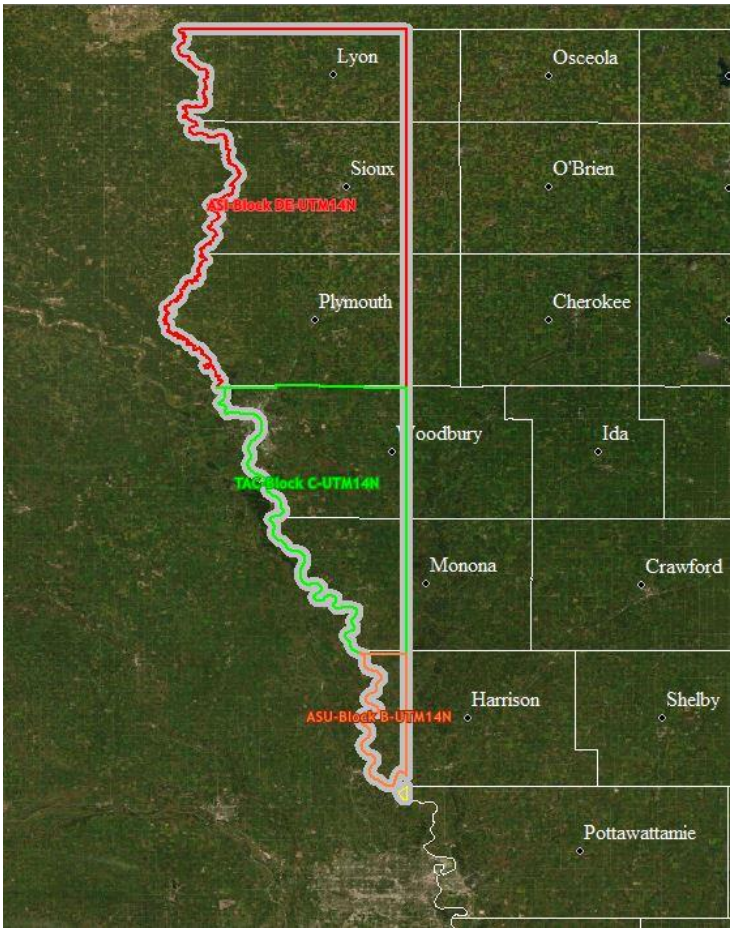

Figure 3: USGS_IA_Western_1_2020_D21 project area of Interest

Project Area Elevation Model

Figure 4 USGS_IA_Western_1_2020_D21 project Elevation DEM

Aerial Services, Inc. LiDAR Acquisition Details and System parameters

Aerial Services, Inc. served as prime contractor for the USGS_IA_Western_1_2020_D21 project and preformed the LiDAR Acquisition and Calibration for Iowa counties; Lyon, Sioux, Plymouth, O'Brien and Cherokee.

The following image is of the Planned Flight Line Overview for the 5 counties of USGS_IA_Western_1_2020_D21 project area.

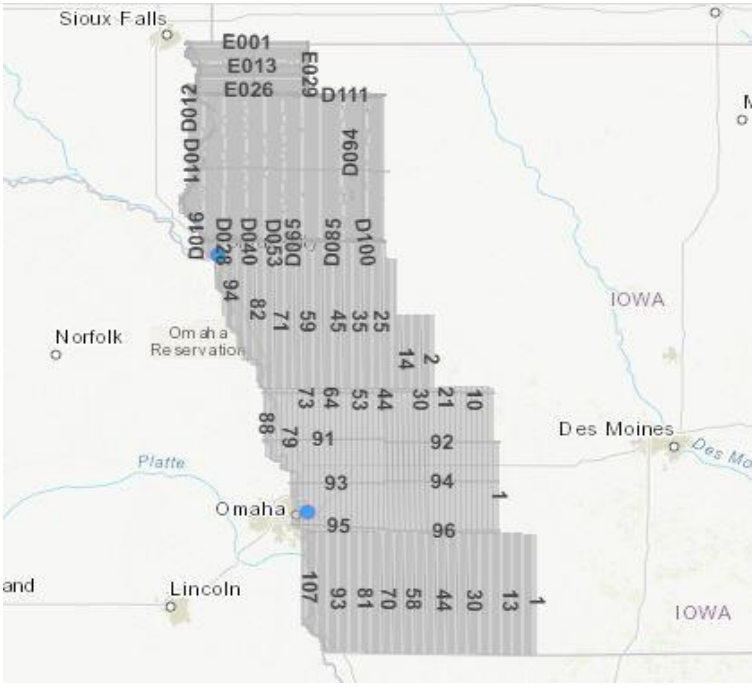

Figure 5: USGS_IA_WesternIA_2020_D21 project area planned flight line overview

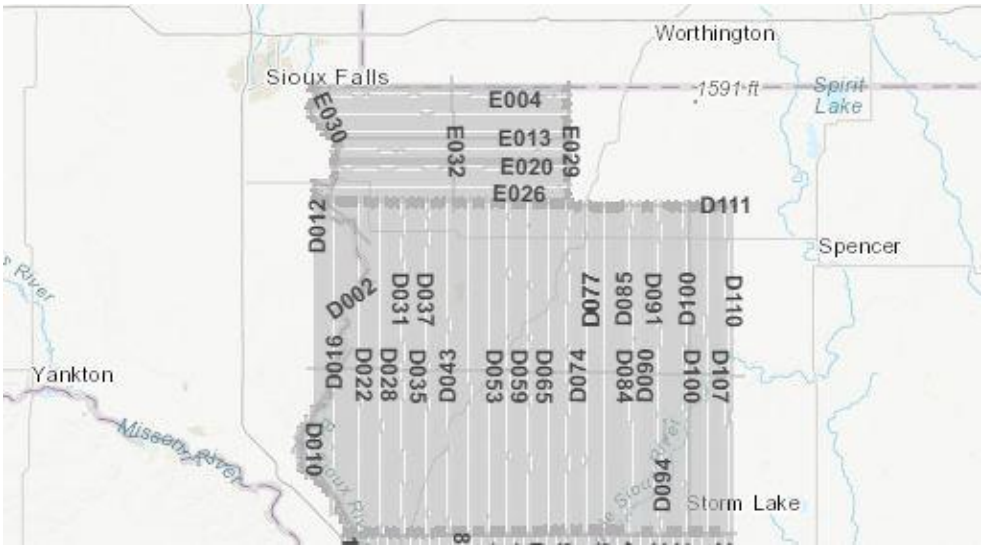

Figure 6: ASI planned flight line overview

Aerial Services, Inc. planned 164 passes for USGS_IA_WesternIA_2020_D21 and a series of cross flightlines for quality control. Of the 164 passes, 83 full or partial passes covered the USGS_IA_Western_2_2020_D21 project area.

In order to reduce any margin for error in the flight plan, Aerial Services, Inc. followed FEMA's Appendix A guidelines for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Leica Mission Pro Flight Management Suite 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.

Lidar System parameters

Aerial Services, Inc. operated a Cessna (Tail # N78AS) outfitted with a LEICA ALS70-HP lidar system during the collection of the study area. The following table illustrates Aerial Services, Inc. system parameters for lidar acquisition on this project. Data was acquired between 27 November 2020 and 08 December 2020.

Item	Parameter
System	Leica ALS-70 HP
Maximum Number of Returns per Pulse	4
Nominal Pulse Spacing (single swath), (m)	0.5
Nominal Pulse Density (single swath) (ppsm), (m)	4
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.5
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	4
Altitude (AGL meters)	1200
Approx. Flight Speed (knots)	125
Total Sensor Scan Angle (degrees)	50
Scan Rate (hz)	47
Scanner Pulse Rate (kHz)	212
Did the Sensor Operate with Multiple Pulses in The Air? (MPiA) (yes/no)	Yes
Nominal Swath Width on the Ground (m)	1119
Swath Overlap (%)	30
Max. Point Spacing Along Track (m)	1.37
Max. Point Spacing Across Track (m)	0.72

Table 3: Aerial Services, Inc. Lidar System Parameters

Calibration Report

Acquisition Control

Aerial Services, Inc. utilized known Iowa RTN base stations to control the lidar acquisition for the USGS_IA_Western_1_2020_D21 project area. The coordinates of the base stations are provided in the table below.

Name	NAD83(2011) DD.MM.SS.SSSSS		Ellipsoid Ht (WGS84, m)
	Easting X	Northing Y	
IARR	43° 26' 00.58447"	-96° 08' 55.47162"	405.9089
IARV	43° 12' 02.87827"'	-96° 25' 56.02407"	379.1871
IAAS	43° 18' 20.16909"	-95° 46' 44.57517"	430.5744
IASL	43° 25' 15.18222'	-95° 08' 09.07761"	414.5607
IASP	43° 07' 41.67611"	-95° 09' 41.81994"	381.8388
IAAK	42° 48' 41.00926"	-96° 32' 54.06877"	369.2826
IASX	42° 33' 00.13888"	-96° 20' 54.47531"	329.1062
IALM	42° 47' 53.00359"	-96° 08' 55.35654"	365.9100
IACK	42° 46' 06.07977"'	-95° 32' 31.86168"	362.3723
IACV	42° 28' 52.77137"	-95° 46' 24.68982"	325.5023
IASP	43° 07' 41.67611"	-95° 09' 41.81994"	381.8388
IASM	42° 38' 53.58626"	-95° 12' 58.68742"	418.849

Table 4: Acquisition control used by ASI for ABGPS processing.

Airborne GPS Kinematic

Aerial Services, Inc. conducted the survey using Novatel, Inc.'s Inertial Explorer Version 8.80.2305 software for processing the GPS/IMU data. All flights were flown with PDOP less than or equal to 3.0 and with at least 6 satellites in common view of both a stationary reference receiver and the airborne GPS. For all flights, the GPS data can be classified as excellent, with GPS residuals no larger than 10 cm being recorded.

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 CloudPro, initially with default values from CloudPro or the last calibration mission flew with the sensor. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch, and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness, acceptable 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.

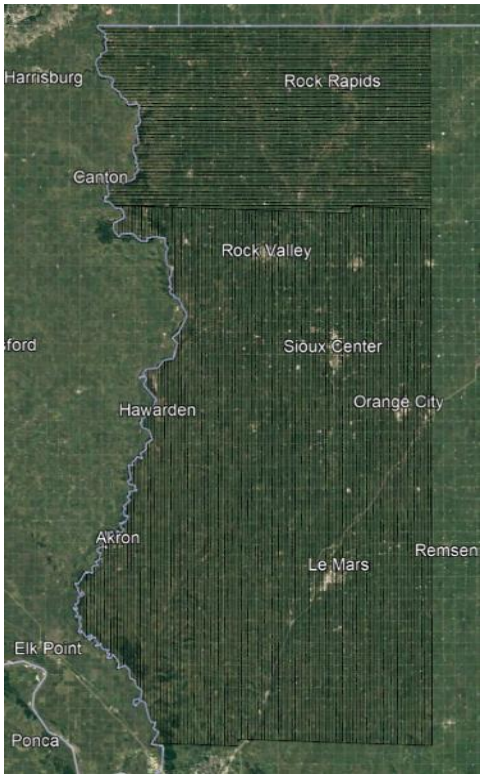

Figure 7: ASI Lidar swath coverage.

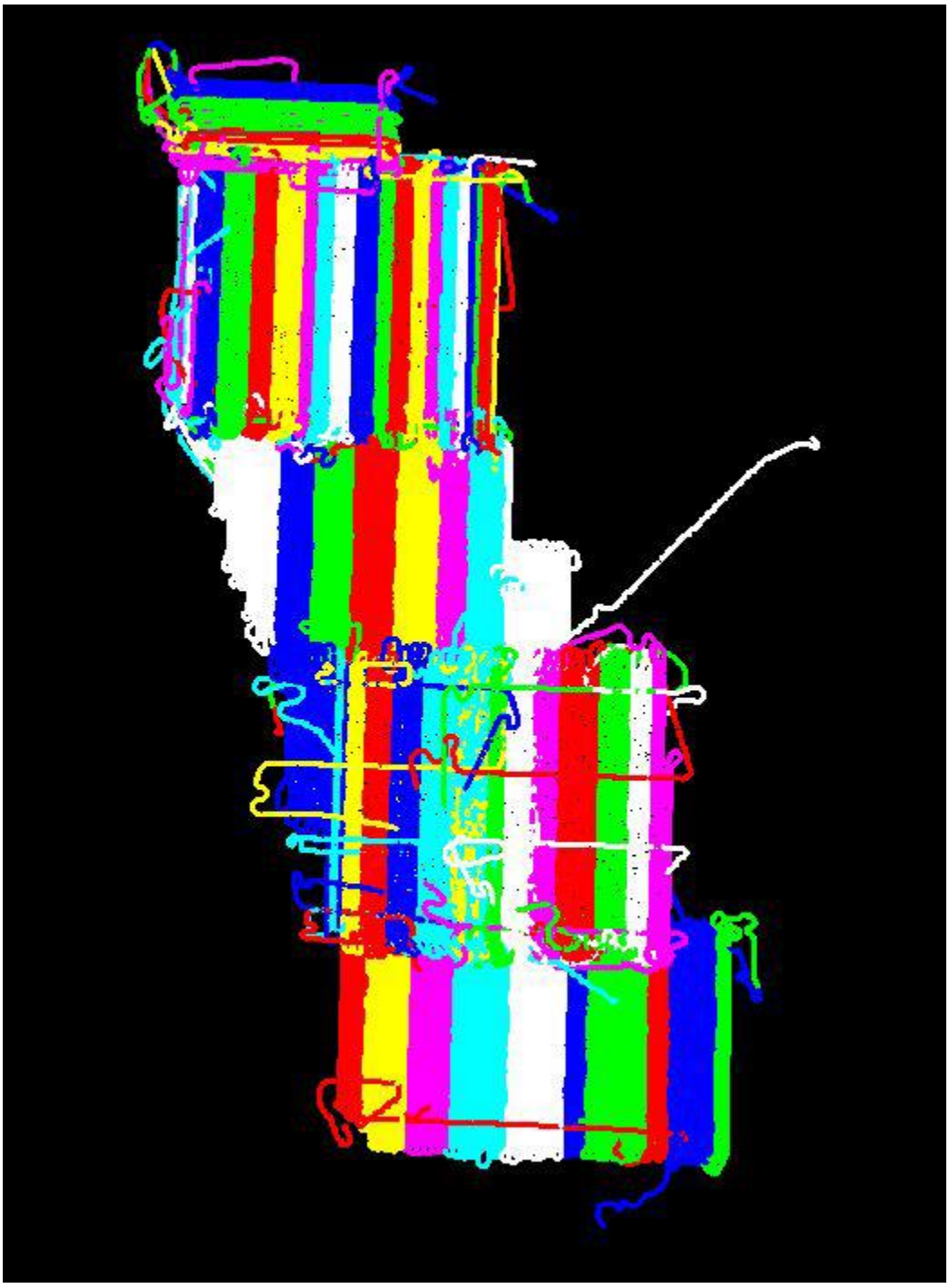

Figure 8: ASI's Combined project SBET

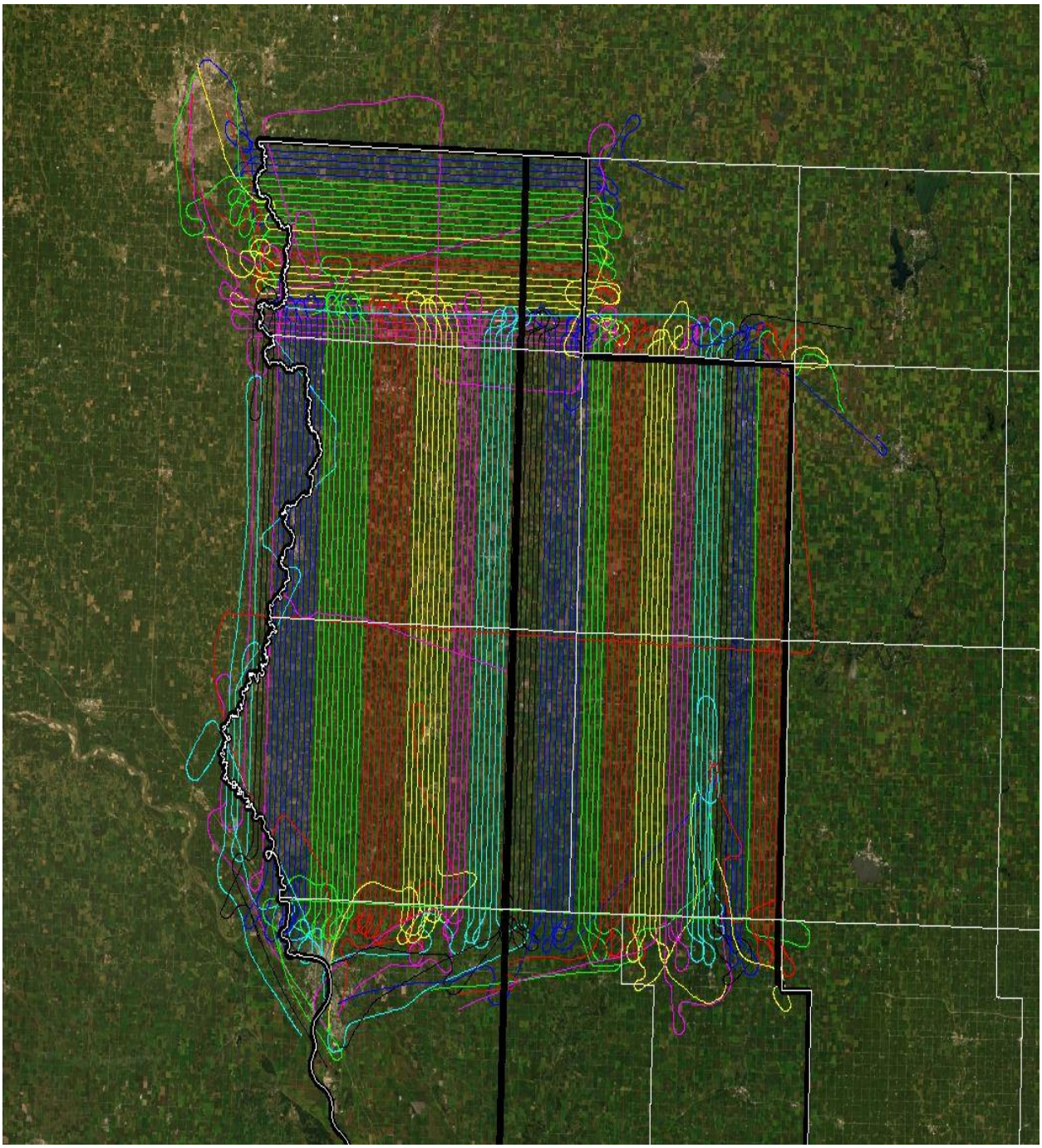

Figure 9: shows the combined trajectory of the flightlines ASI flew by mission over the USGS_IA_Western_1_2020_D21 project area

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

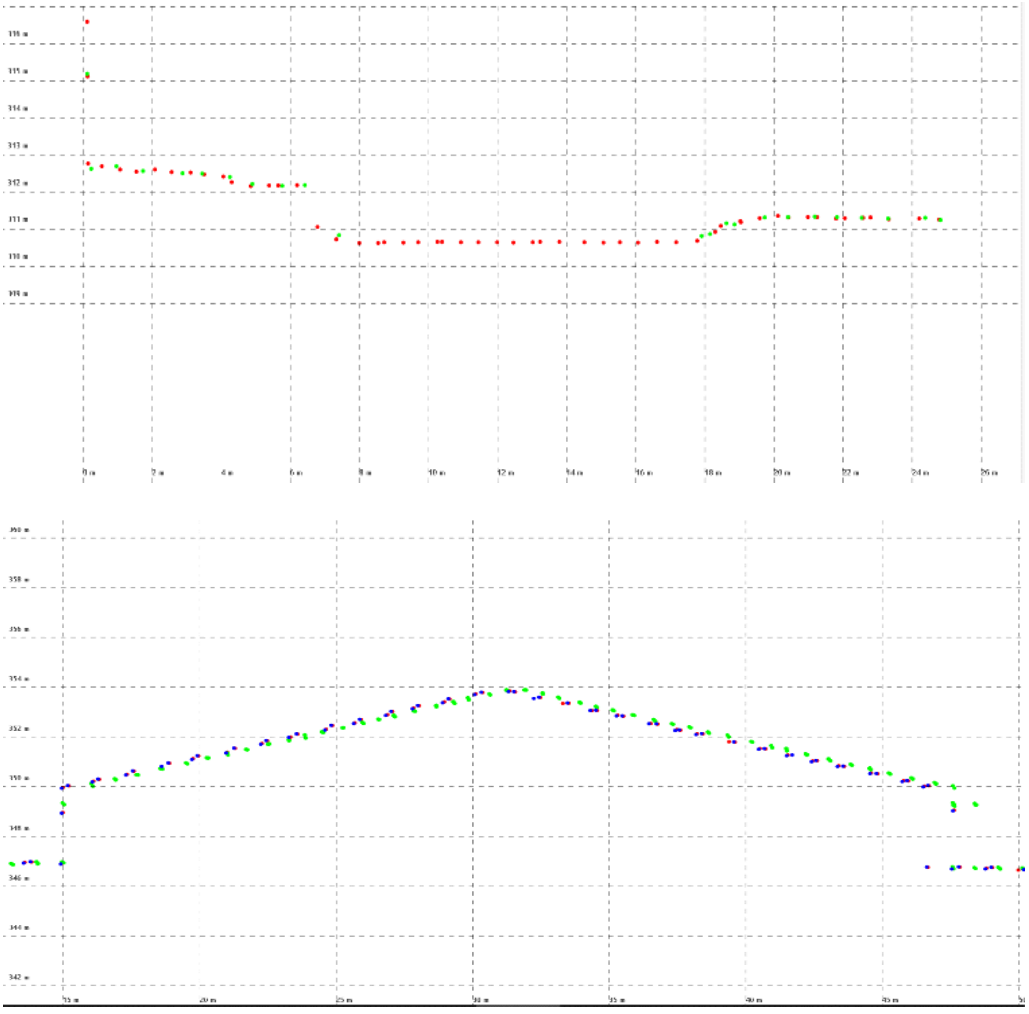

Figure 10: Profile views showing correct roll and pitch adjustments

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, 9 full or partial passes covered the USGS_IA_Western_1_2020_D21 project area.

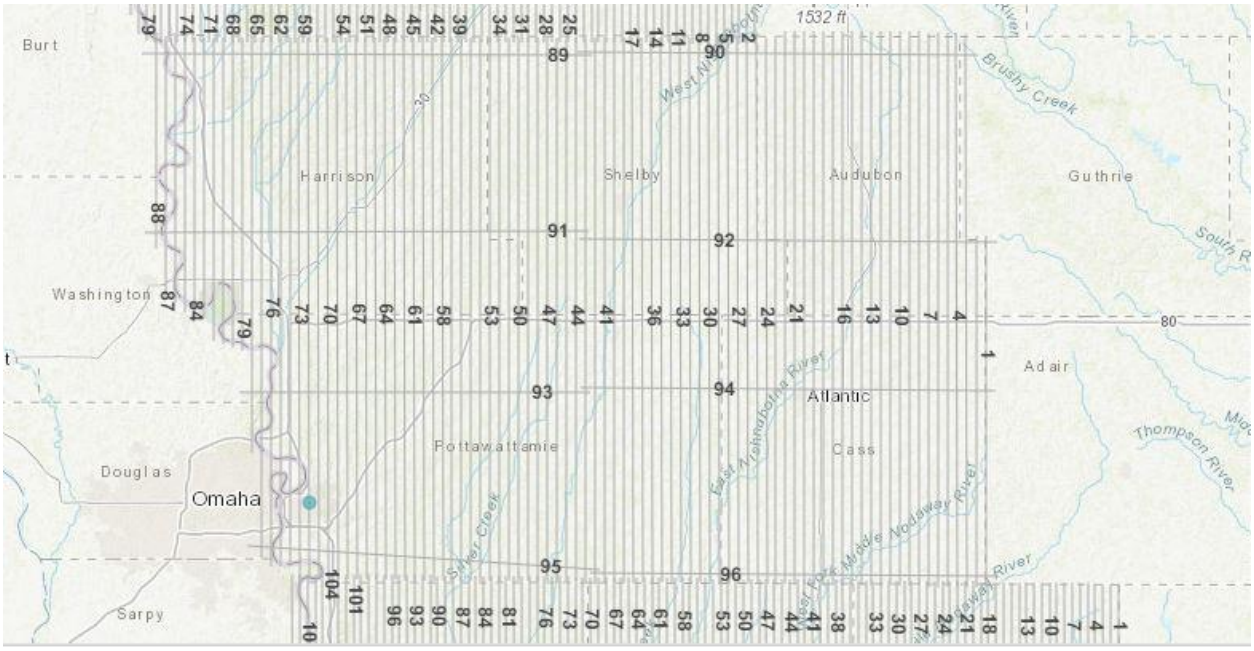

Figure11: Aerial Surveys International, LLC planned flight line overview

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 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 5: 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.

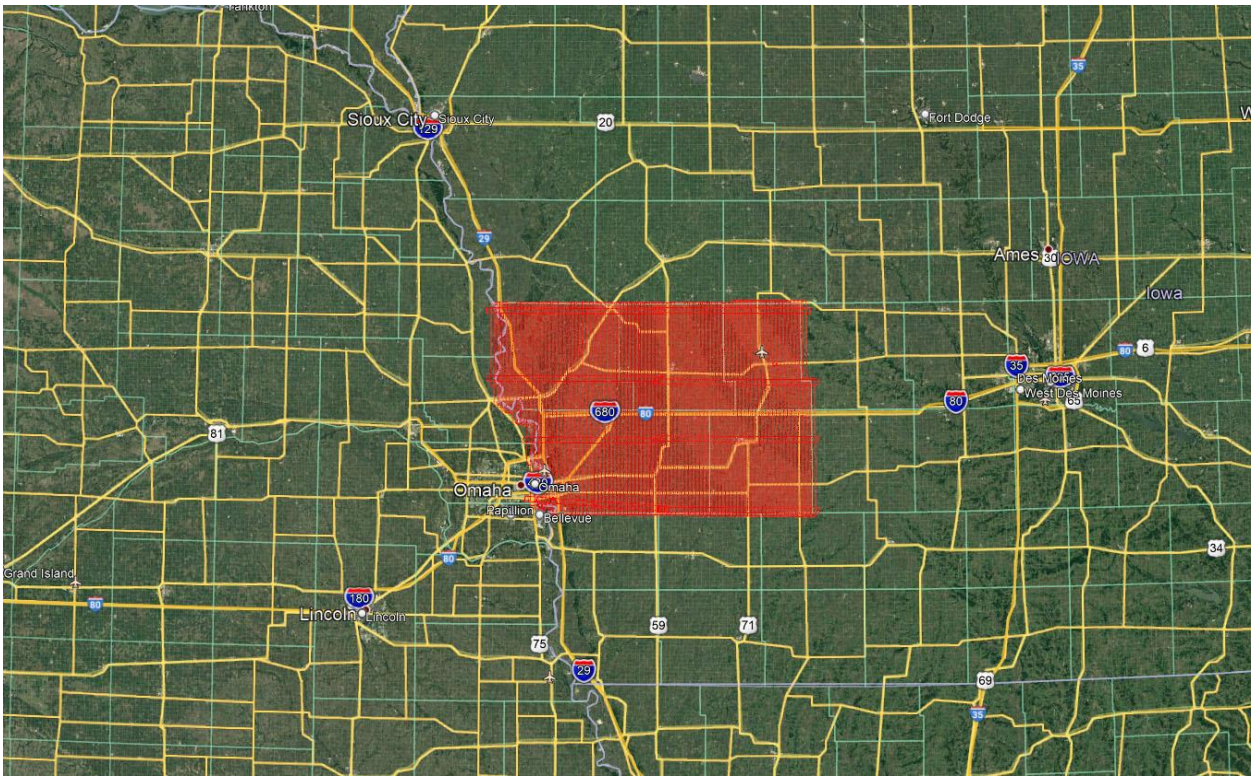

Figure 11: LiDAR swath output showing complete coverage

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) ≤ 6 cm maximum differences within individual swaths and ≤ 8 cm $RMSD_z$ between adjacent and overlapping swaths.

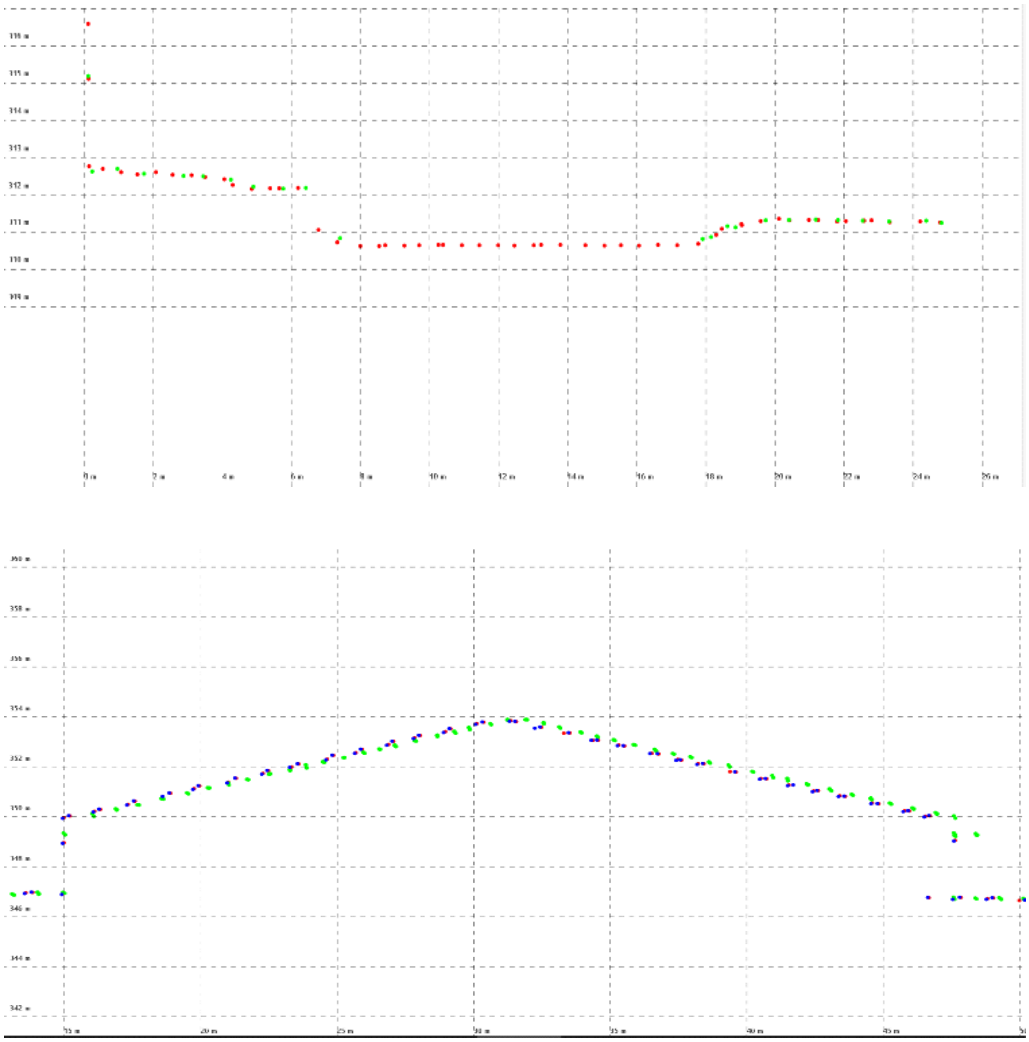

Figure 12: Profile views showing correct roll and pitch adjustments

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, 39 full or partial passes covered the USGS_IA_Western_1_2020_D21 project area.

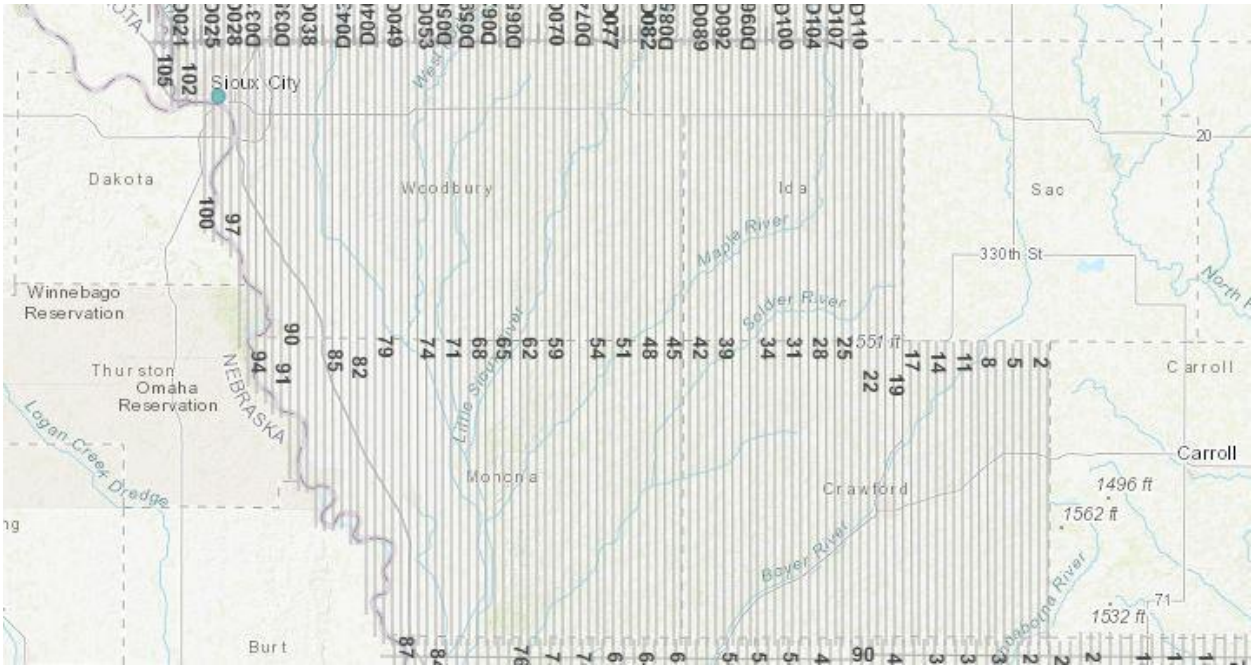

Figure 13: Technical Applications & Consulting, LLC planned flight line overview

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 March 28 and March 29, 2021. 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 6: 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° 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.

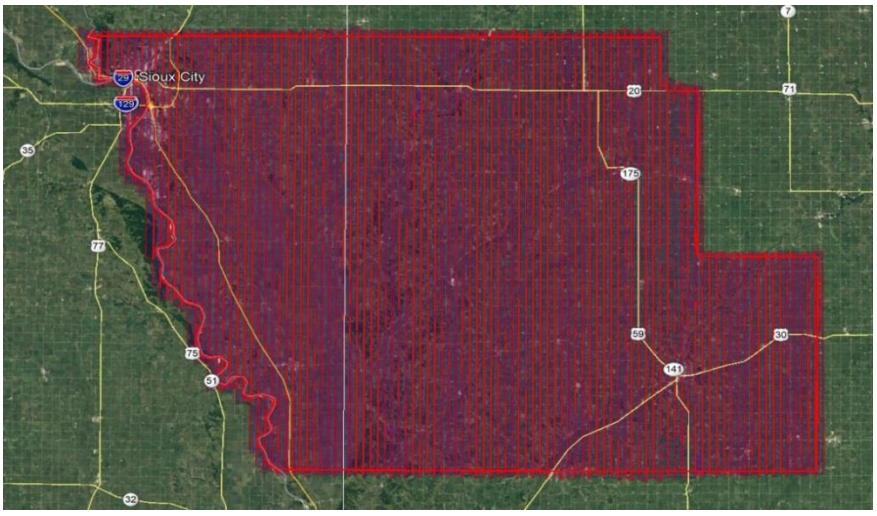

Figure 14: LiDAR swath output showing complete coverage

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

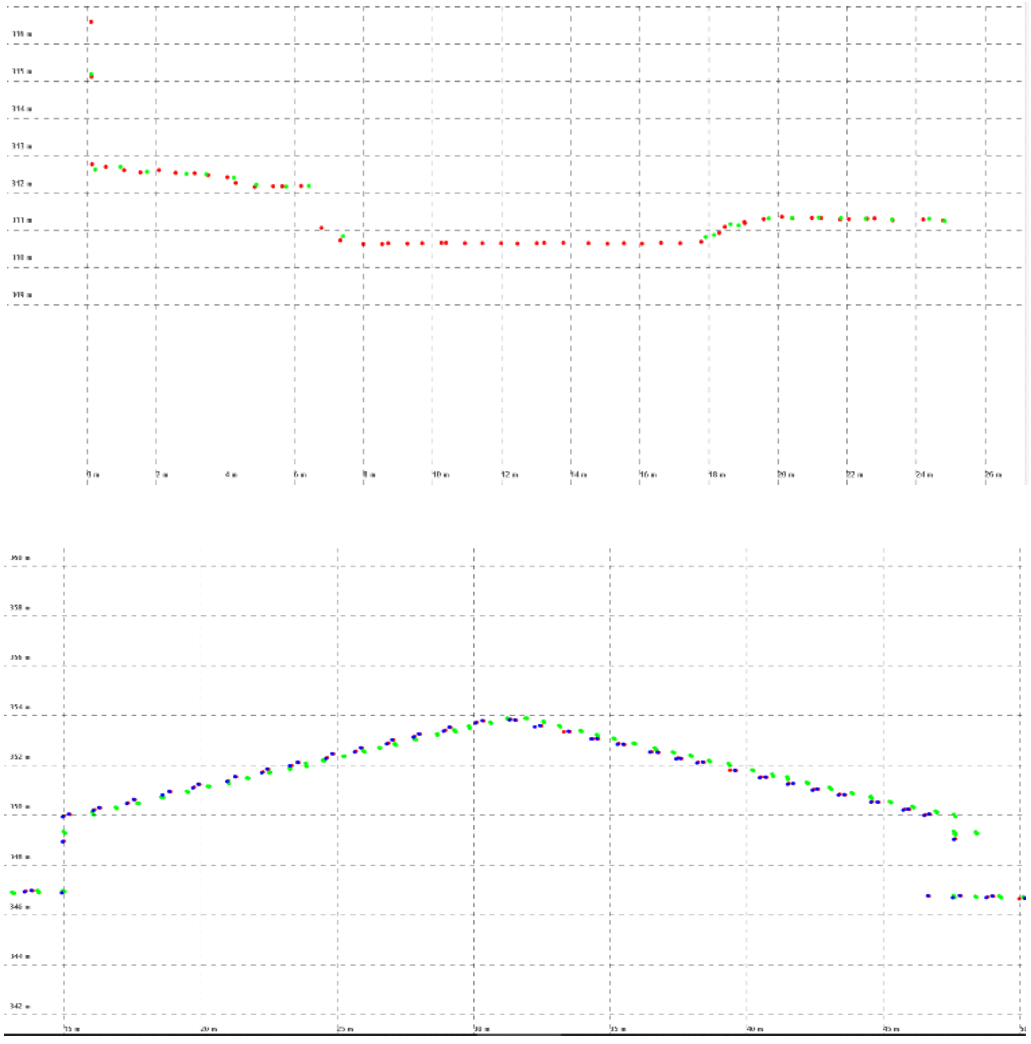

Figure 15: Profile views showing correct roll and pitch adjustments

The following table is a listing of 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
20210328_184656	328_1_z14	03/28/2021	7273	Optech	300992416	300993516
20210328_210639	328_2_z14	03/28/2021	7275	Optech	301000800	301001931
20210328_212903	328_2_z14	03/28/2021	7276	Optech	301002143	301003391
20210328_215149	328_2_z14	03/28/2021	7277	Optech	301003509	301004827
20210328_221535	328_2_z14	03/28/2021	7278	Optech	301004936	301006218
20210328_223952	328_2_z14	03/28/2021	7279	Optech	301006393	301007783
20210328_230525	328_2_z14	03/28/2021	7280	Optech	301007925	301009254
20210328_233014	328_2_z14	03/28/2021	7281	Optech	301009415	301010816
20210328_235506	328_2_z14	03/28/2021	7282	Optech	301010906	301012216
20210329_001912	328_2_z14	03/28/2021	7283	Optech	301012352	301013706
20210329_004317	328_2_z14	03/28/2021	7284	Optech	301013798	301015118
20210329_144336	329_1_z14	03/29/2021	7287	Optech	301064217	301065706
20210329_151123	329_1_z14	03/29/2021	7288	Optech	301065884	301067179
20210329_153546	329_1_z14	03/29/2021	7289	Optech	301067346	301068950
20210329_160456	329_1_z14	03/29/2021	7290	Optech	301069096	301070396
20210329_162926	329_1_z14	03/29/2021	7291	Optech	301070565	301072173
201127_163628	20201127A	11/27/2020	1	ALS 70	290530176	290531406
201127_170208	20201127A	11/27/2020	2	ALS 70	290531717	290532658
201127_172035	20201127A	11/27/2020	3	ALS 70	290532823	290534040
201127_174241	20201127A	11/27/2020	4	ALS 70	290534149	290535077
201127_180053	20201127A	11/27/2020	5	ALS 70	290535242	290536479
201127_192859	20201127A	11/27/2020	6	ALS 70	290540528	290541470
201127_194654	20201127A	11/27/2020	7	ALS 70	290541602	290542833
201127_200918	20201127B	11/27/2020	8	ALS 70	290542947	290543888
201127_202813	20201127B	11/27/2020	9	ALS 70	290544082	290545291
201127_205123	20201127B	11/27/2020	10	ALS 70	290545471	290546378
201127_210824	20201127B	11/27/2020	11	ALS 70	290546492	290547633

201127_212952	20201127B	11/27/2020	12	ALS 70	290547781	290548681
201127_220758	20201127B	11/27/2020	14	ALS 70	290550067	290550905
201127_222434	20201127B	11/27/2020	15	ALS 70	290551063	290552121
201127_235823	20201127C	11/27/2020	16	ALS 70	290556693	290557545
201128_001522	20201127C	11/27/2020	17	ALS 70	290557711	290558796
201128_154011	20201128A	11/28/2020	20	ALS 70	290613200	290614073
201128_155754	20201128A	11/28/2020	21	ALS 70	290614264	290615453
201128_161948	20201128A	11/28/2020	22	ALS 70	290615578	290616443
201128_163657	20201128A	11/28/2020	23	ALS 70	290616607	290617816
201128_165842	20201128A	11/28/2020	24	ALS 70	290617911	290618770
201128_194119	20201128B	11/28/2020	27	ALS 70	290627668	290628603
201128_195919	20201128B	11/28/2020	28	ALS 70	290628748	290629937
201128_202115	20201128B	11/28/2020	29	ALS 70	290630065	290630992
201128_203914	20201128B	11/28/2020	30	ALS 70	290631144	290632312
201128_210025	20201128B	11/28/2020	31	ALS 70	290632414	290633334
201128_211857	20201128B	11/28/2020	32	ALS 70	290633525	290634673
201128_224920	20201128B	11/28/2020	37	ALS 70	290638949	290640000
201128_230832	20201128B	11/28/2020	38	ALS 70	290640101	290640319
201129_154023	20201129A	11/29/2020	40	ALS 70	290699613	290699969
201129_154922	20201129A	11/29/2020	41	ALS 70	290700152	290700466
201129_155800	20201129A	11/29/2020	42	ALS 70	290700669	290701879
201129_162709	20201129A	11/29/2020	43	ALS 70	290702419	290702651
201130_002911	20201130A	11/30/2020	44	ALS 70	290731341	290732874
201130_005613	20201130A	11/30/2020	45	ALS 70	290732963	290733181
201130_010833	20201130A	11/30/2020	46	ALS 70	290733703	290734768
201130_161312	20201130A	11/30/2020	48	ALS 70	290787981	290789102
201130_163417	20201130A	11/30/2020	49	ALS 70	290789246	290790566
201130_165811	20201130A	11/30/2020	50	ALS 70	290790680	290791876
201130_172029	20201130A	11/30/2020	51	ALS 70	290792018	290793358
201130_174409	20201130A	11/30/2020	52	ALS 70	290793438	290794634

201130_180532	20201130A	11/30/2020	53	ALS 70	290794721	290796034
201130_182915	20201130A	11/30/2020	54	ALS 70	290796145	290797341
201130_185118	20201130A	11/30/2020	55	ALS 70	290797468	290798760
201130_200946	20201130B	11/30/2020	56	ALS 70	290802175	290803385
201130_203127	20201130B	11/30/2020	57	ALS 70	290803476	290804734
201130_205420	20201130B	11/30/2020	58	ALS 70	290804849	290806058
201130_211611	20201130B	11/30/2020	59	ALS 70	290806160	290807418
201130_213847	20201130B	11/30/2020	60	ALS 70	290807516	290808726
201130_220042	20201130B	11/30/2020	61	ALS 70	290808831	290810068
201130_222353	20201130B	11/30/2020	62	ALS 70	290810223	290811426
201130_224549	20201130B	11/30/2020	63	ALS 70	290811539	290812776
201130_230828	20201130B	11/30/2020	64	ALS 70	290812897	290814107
201201_154500	20201201A	12/01/2020	65	ALS 70	290872691	290873887
201201_160652	20201201A	12/01/2020	66	ALS 70	290874003	290875384
201201_163337	20201201A	12/01/2020	67	ALS 70	290875608	290876804
201201_165534	20201201A	12/01/2020	68	ALS 70	290876925	290878334
201201_172043	20201201A	12/01/2020	69	ALS 70	290878434	290879650
201201_174334	20201201A	12/01/2020	70	ALS 70	290879805	290881207
201201_180900	20201201A	12/01/2020	71	ALS 70	290881331	290882506
201201_183054	20201201A	12/01/2020	72	ALS 70	290882644	290884040
201201_202105	20201201B	12/01/2020	73	ALS 70	290889254	290890457
201201_204409	20201201B	12/01/2020	74	ALS 70	290890638	290892006
201201_210855	20201201B	12/01/2020	75	ALS 70	290892124	290893313
201201_213103	20201201B	12/01/2020	76	ALS 70	290893453	290894800
201201_215529	20201201B	12/01/2020	77	ALS 70	290894918	290896093
201201_221740	20201201B	12/01/2020	78	ALS 70	290896249	290897568
201201_224109	20201201B	12/01/2020	79	ALS 70	290897659	290898848
201201_230246	20201201B	12/01/2020	80	ALS 70	290898955	290900275
201202_002352	20201201C	12/01/2020	81	ALS 70	290903821	290905031
201202_004600	20201201C	12/01/2020	82	ALS 70	290905150	290906449

201202_010855	20201201C	12/01/2020	83	ALS 70	290906525	290907694
201202_013108	20201201C	12/01/2020	84	ALS 70	290907857	290909143
201202_153033	20201202A	12/02/2020	85	ALS 70	290958223	290959467
201202_155341	20201202A	12/02/2020	86	ALS 70	290959611	290960924
201202_161719	20201202A	12/02/2020	87	ALS 70	290961028	290962292
201202_164050	20201202A	12/02/2020	88	ALS 70	290962439	290963717
201202_170407	20201202A	12/02/2020	89	ALS 70	290963836	290965129
201202_172815	20201202A	12/02/2020	90	ALS 70	290965284	290966570
201202_224529	20201202B	12/02/2020	91	ALS 70	290984319	290985611
201202_230926	20201202B	12/02/2020	92	ALS 70	290985755	290987013
201207_215452	20201207B	12/07/2020	155	ALS 70	291413281	291414284
201208_173728	20201208A	12/08/2020	156	ALS 70	291484238	291485413
20210319_192707	210319_448B	03/19/2021	4011	Optech	300217227	300217728
20210319_193826	210319_448B	03/19/2021	4012	Optech	300217906	300218449
20210319_195025	210319_448B	03/19/2021	4013	Optech	300218625	300219216
20210319_200254	210319_448B	03/19/2021	4014	Optech	300219374	300219946
20210319_201517	210319_448B	03/19/2021	4015	Optech	300220117	300220730
20210319_202801	210319_448B	03/19/2021	4016	Optech	300220881	300221491
20210319_204120	210319_448B	03/19/2021	4017	Optech	300221680	300222330
20210319_205442	210319_448B	03/19/2021	4018	Optech	300222482	300223131
20210319_210826	210319_448B	03/19/2021	4019	Optech	300223306	300223978
20210328_133160	328_1_z14	03/28/2021	7250	Optech	300973520	300973660
20210328_133541	328_1_z14	03/28/2021	7251	Optech	300973741	300973902
20210328_134041	328_1_z14	03/28/2021	7252	Optech	300974042	300974228
20210328_134558	328_1_z14	03/28/2021	7253	Optech	300974359	300974543
20210328_135131	328_1_z14	03/28/2021	7254	Optech	300974691	300974881
20210328_135610	328_1_z14	03/28/2021	7255	Optech	300974971	300975174
20210328_140244	328_1_z14	03/28/2021	7256	Optech	300975365	300975823
20210328_141231	328_1_z14	03/28/2021	7257	Optech	300975951	300976458
20210328_142413	328_1_z14	03/28/2021	7258	Optech	300976653	300977137

20210328_143349	328_1_z14	03/28/2021	7259	Optech	300977230	300977756
20210328_144528	328_1_z14	03/28/2021	7260	Optech	300977928	300978603
20210328_145921	328_1_z14	03/28/2021	7261	Optech	300978761	300979555
20210328_151539	328_1_z14	03/28/2021	7262	Optech	300979740	300980547
20210328_153100	328_1_z14	03/28/2021	7263	Optech	300980661	300981533
20210328_154758	328_1_z14	03/28/2021	7264	Optech	300981678	300982488
20210328_160249	328_1_z14	03/28/2021	7265	Optech	300982570	300983482
20210328_162029	328_1_z14	03/28/2021	7266	Optech	300983630	300984600
20210328_163801	328_1_z14	03/28/2021	7267	Optech	300984681	300985762
20210328_165830	328_1_z14	03/28/2021	7268	Optech	300985910	300986919
20210328_171913	328_1_z14	03/28/2021	7269	Optech	300987153	300988290
20210328_174249	328_1_z14	03/28/2021	7270	Optech	300988570	300989654
20210328_180530	328_1_z14	03/28/2021	7271	Optech	300989931	300991042
20210328_182629	328_1_z14	03/28/2021	7272	Optech	300991189	300992258
20210328_184656	328_1_z14	03/28/2021	7273	Optech	300992416	300993516
20210328_210639	328_2_z14	03/28/2021	7275	Optech	301000800	301001931
20210328_212903	328_2_z14	03/28/2021	7276	Optech	301002143	301003391
20210328_215149	328_2_z14	03/28/2021	7277	Optech	301003509	301004827
20210328_221535	328_2_z14	03/28/2021	7278	Optech	301004936	301006218
20210328_223952	328_2_z14	03/28/2021	7279	Optech	301006393	301007783
20210328_230525	328_2_z14	03/28/2021	7280	Optech	301007925	301009254
20210328_233014	328_2_z14	03/28/2021	7281	Optech	301009415	301010816
20210328_235506	328_2_z14	03/28/2021	7282	Optech	301010906	301012216
20210329_001912	328_2_z14	03/28/2021	7283	Optech	301012352	301013706
20210329_004317	328_2_z14	03/28/2021	7284	Optech	301013798	301015118
20210329_144336	329_1_z14	03/29/2021	7287	Optech	301064217	301065706
20210329_151123	329_1_z14	03/29/2021	7288	Optech	301065884	301067179
20210329_153546	329_1_z14	03/29/2021	7289	Optech	301067346	301068950
20210329_160456	329_1_z14	03/29/2021	7290	Optech	301069096	301070396
20210329_162926	329_1_z14	03/29/2021	7291	Optech	301070565	301072173

Table 7: USGS_IA_Western_1_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 42 were use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided in 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.

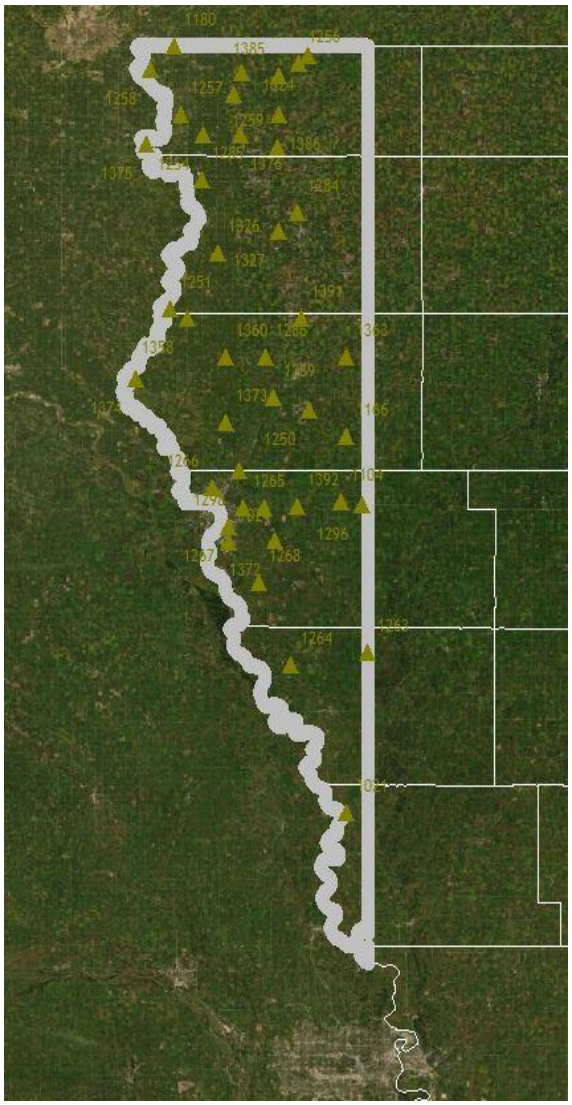

Figure 16: surveyed Ground Control Point Locations

Point ID	NAD83 (2011 adj) UTM Zone 14 N		NAVD88 (Geoid 12B)		
	Easting X (M)	Northing Y (M)	Z-Survey (M)	Z-LiDAR (M)	Dz (M)
GCP1024	716808.601	4697594.764	338.239	338.210	-0.029
GCP1104	740584.986	4708202.175	358.915	358.900	-0.015
GCP1166	741388.322	4724326.506	409.081	409.050	-0.031
GCP1180	701651.842	4819076.110	440.034	440.140	0.106
GCP1250	733043.833	4730593.090	424.276	424.280	0.004
GCP1251	702711.804	4754500.126	355.155	355.210	0.055
GCP1256	727996.266	4815949.769	414.910	414.930	0.020
GCP1257	703713.730	4802389.617	443.881	443.810	-0.071
GCP1258	696954.855	4813407.531	440.877	440.970	0.093
GCP1265	719791.051	4706062.898	385.599	385.590	-0.009
GCP1267	716897.943	4701467.628	333.713	333.740	0.027
GCP1268	723752.500	4687595.975	329.997	330.080	0.083
GCP1284	728852.577	4778852.760	441.640	441.620	-0.020
GCP1285	708598.859	4786418.543	405.221	405.260	0.039
GCP1286	723263.869	4743302.911	383.941	383.920	-0.021
GCP1296	745148.873	4707638.452	390.550	390.630	0.080
GCP1297	724205.698	4706201.627	389.984	389.950	-0.034
GCP1298	718508.988	4715178.517	342.303	342.330	0.027
GCP1324	729977.501	4817661.664	419.513	419.450	-0.063
GCP1325	714643.024	4807477.859	430.039	430.130	0.091
GCP1326	712457.033	4768614.912	395.298	395.330	0.032
GCP1358	706592.962	4752225.036	381.405	381.420	0.015

GCP1359	725521.695	4733381.708	358.245	358.240	-0.005
GCP1360	714989.020	4742809.004	432.053	432.070	0.017
GCP1363	740652.935	4743726.044	405.949	405.910	-0.039
GCP1372	726762.745	4698135.796	332.835	332.810	-0.025
GCP1373	715420.011	4726772.977	387.984	387.970	-0.014
GCP1374	696054.127	4737127.932	345.047	345.170	0.123
GCP1375	696639.554	4794915.786	378.059	378.100	0.041
GCP1376	716391.603	4797756.846	452.393	452.450	0.057
GCP1385	723913.775	4812613.343	443.951	443.970	0.019
GCP1386	724194.210	4802967.427	436.161	436.150	-0.011
GCP1391	730610.018	4752978.958	390.237	390.190	-0.047
GCP1392	731467.924	4706774.174	361.016	361.010	-0.006
GCP1021	744437.997	4631862.556	315.451	315.450	-0.001
GCP1254	708369.652	4797373.094	438.614	438.600	-0.014
GCP1255	716163.867	4813086.959	427.370	427.420	0.050
GCP1259	724297.411	4795126.649	391.459	391.470	0.011
GCP1263	747630.229	4671244.590	333.860	333.850	-0.010
GCP1264	731296.682	4667750.636	327.023	326.990	-0.033
GCP1266	713132.299	4710601.793	391.249	391.210	-0.039
GCP1327	725116.641	4774252.031	425.340	425.310	-0.030

Table 8: USGS_IA_Western_1_2020_D21 surveyed ground control points (GCPs).

This project meets Ground Control Vertical Accuracy ≤ 19.6 cm at the 95% confidence level based on RMSEz ≤ 10 cm x 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
GCP	42	0.047	0.093	0.010	-0.003	0.65	0.047	-0.071	0.123	-0.193

Table 9: USGS_IA_Western_1_2020_D21 Ground Control Vertical Accuracy (GCP) results

NVA was run on the unclassified point cloud which met the Non-Vegetated Accuracy (NVA) of ≤ 19.6 cm at the 95% confidence level based on RMSEz ≤ 10 cm x 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	53	0.047	0.093	0.009	0.006	-0.09	0.047	-0.112	0.133	0.597

Table 10: USGS_IA_Western_1_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).

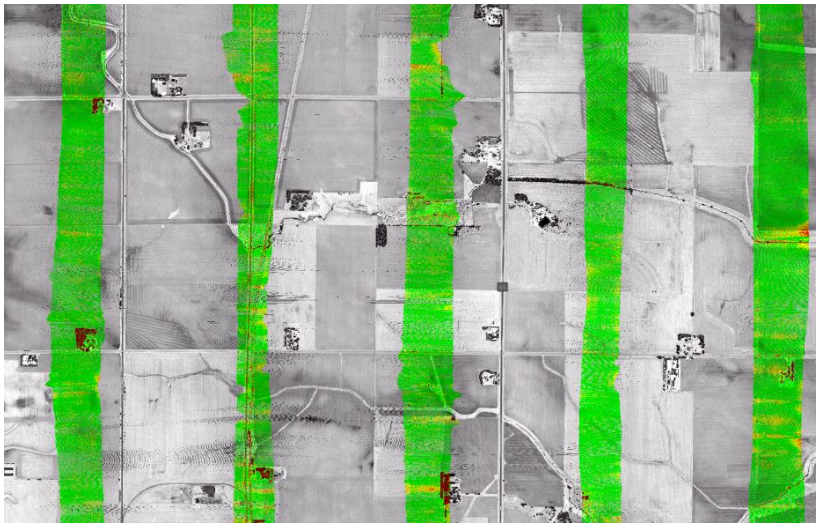

Figure 17: DZ Ortho of inter-swath

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.

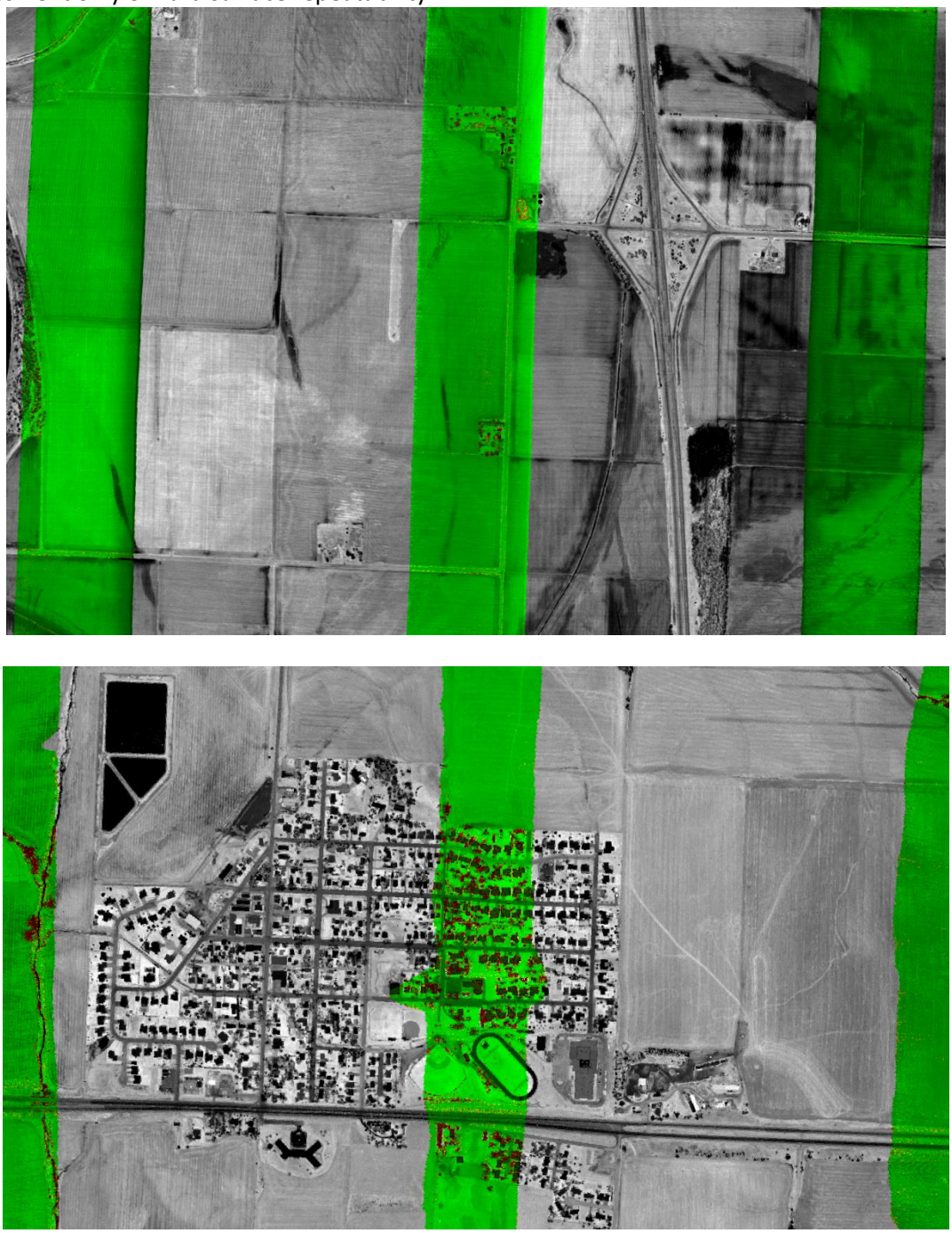

Figure 18: Intra-swath DZ ortho

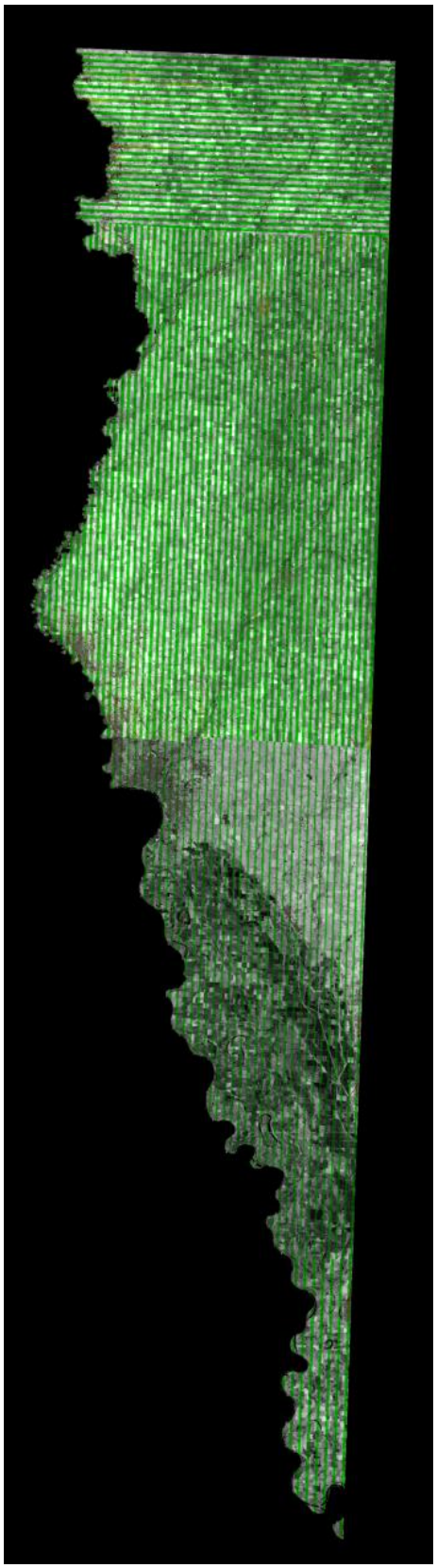

Figure 19: USGS_IA_Western_1_2020_D21 Project Area Delta-z raster image.

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.

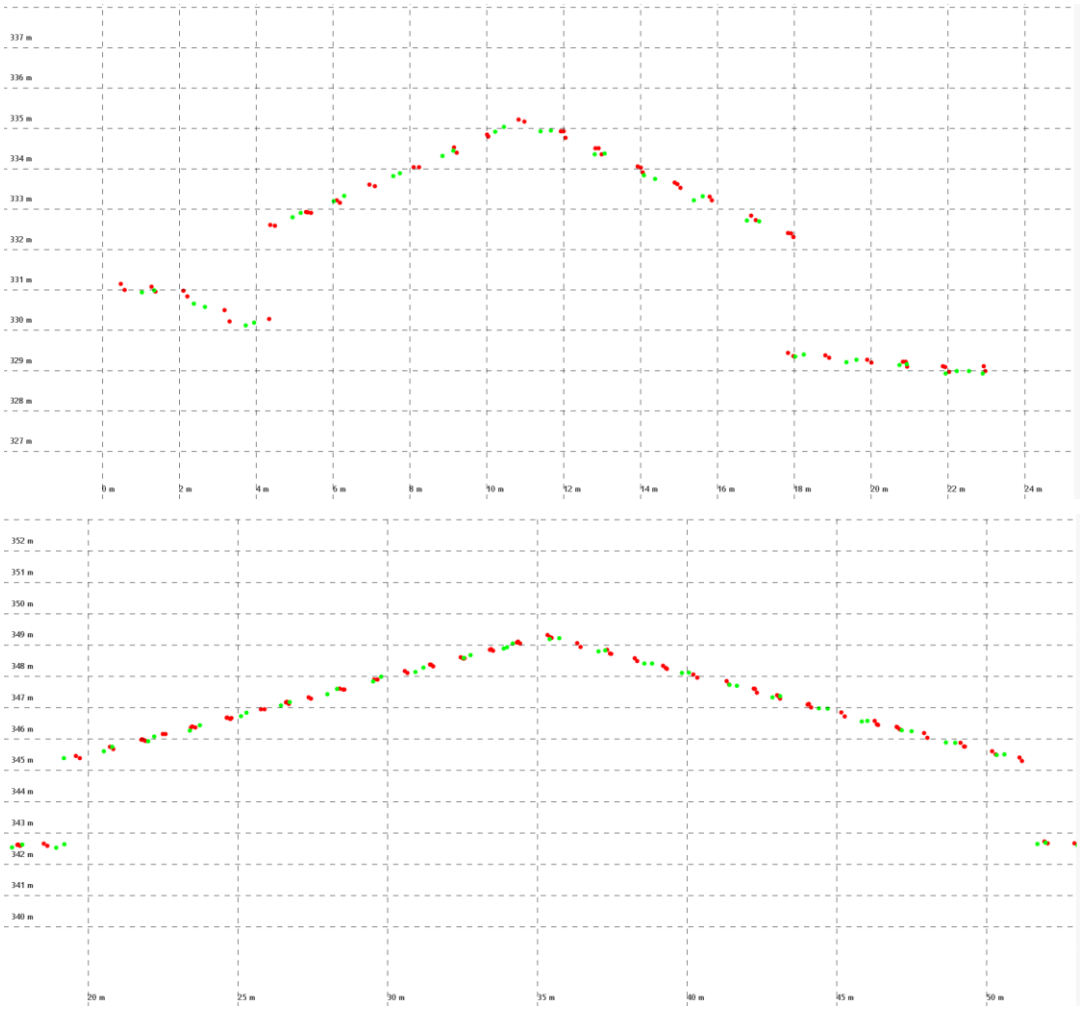

Figure 20: Profile views showing alignment checks

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. Theses 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:

- Class 1 – Default, Processed, but unclassified
- Class 2 – Ground, Bare-earth
- Class 7 – Low Noise (low and manually identified)
- Class 9 – Water
- Class 17 – Bridge Decks
- Class 18 – High Noise (high, manually identified)
- 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 41,196,791,765 lidar points the table below shows the total number of points for every class.

Project Count by Class		
Class 1	Processed, unclassified	2081551242
Class 2	Bare-earth ground	24688968381
Class Withheld 7	Withheld low Noise	7036
Class 9	Water	60155393
Class 17	Bridge Decks	2458044
Class 20	Ignored-Ground	2957487
Class Withheld 18	Withheld High Noise	5475299233
Class Overlap 1	Overlap Processed, unclassified	3431852330
Class Overlap 2	Overlap Bare-earth ground	5448428796
Class Overlap 9	Overlap Water	3020020
Class Overlap 17	Overlap Bridge Decks	1314783
Class Overlap 20	Overlap Ignored-Ground	779020
Project Total Count		41196791765

Table 11: 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 for USGS_IA_Western_1_2020_D21 UTM 14N project.

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. Three small areas obscured by plant stack emissions are present in the USGS_IA_Western_1_2020_D21 UTM 14N project area, affecting tiles w7160n4690, w7160n4690 and w7160n4689. These obscured areas are the result of aerosol clouds emitting from a chemical plant and the LiDAR pulses were absorbed by the clouds. Total area of the three obscured areas is approximately 3 hectares. Break lines were used define the surface for generation of the DEM products. The obscured areas will be delineated with polygons and attributed as "obscured".

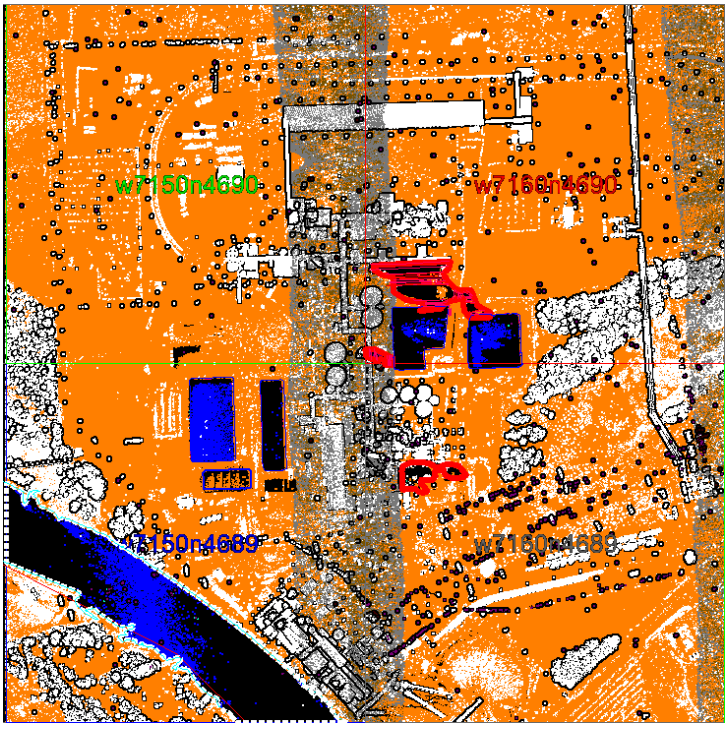

Figure 21: Obscured areas outlined in red. LiDAR pules absorbed by aerosol clouds.

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).

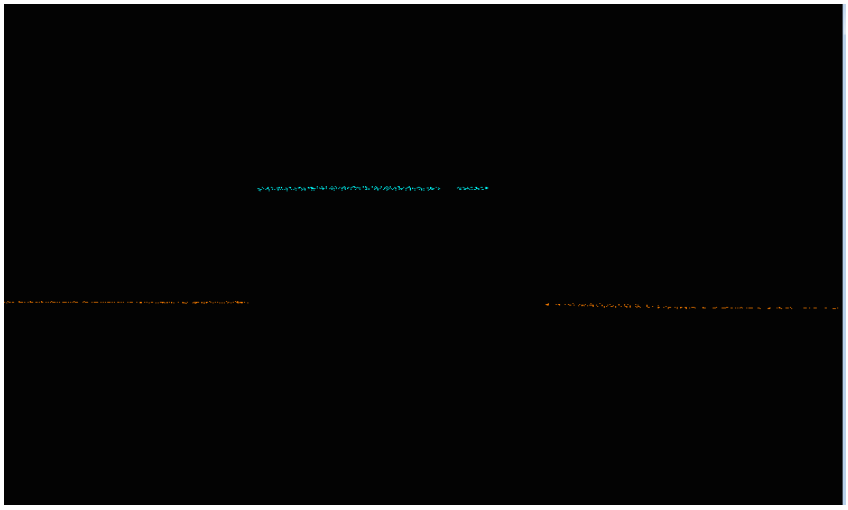

Figure 22: Profile view of a classified bridge deck (blue) and ground (orange).

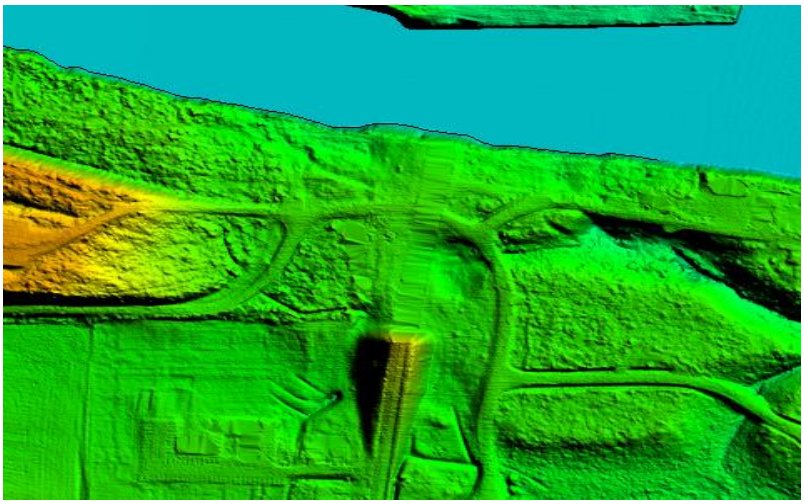

Figure 23: DEM with bridge removed from surface model.

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.

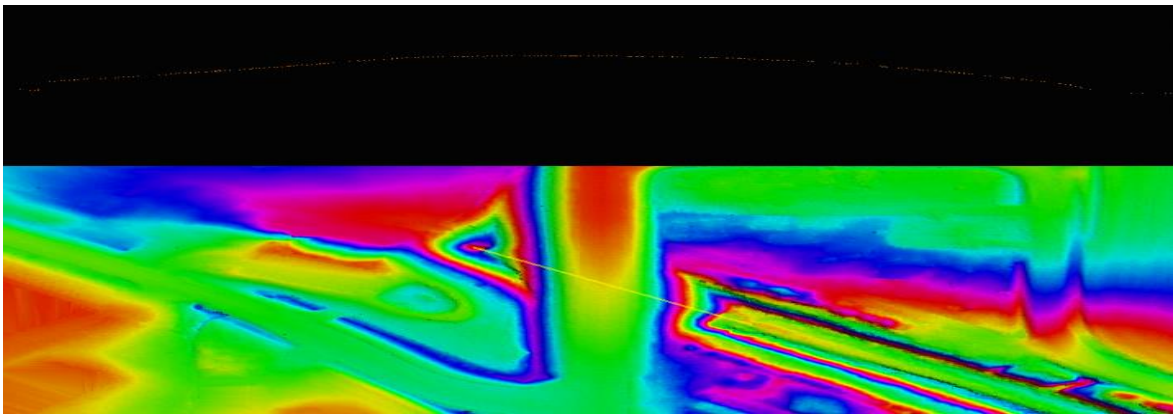

Figure 24: Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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.

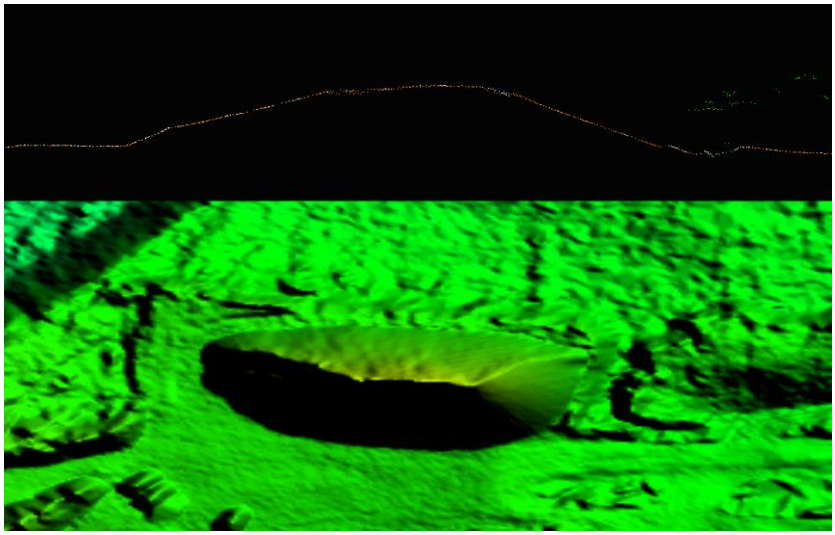

Figure 25: Profile with the points colored by class (unclassified points are white, ground points are orange) is shown on the right and a DEM of the surface is shown to the left. These features are correctly included in the ground classification.

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.

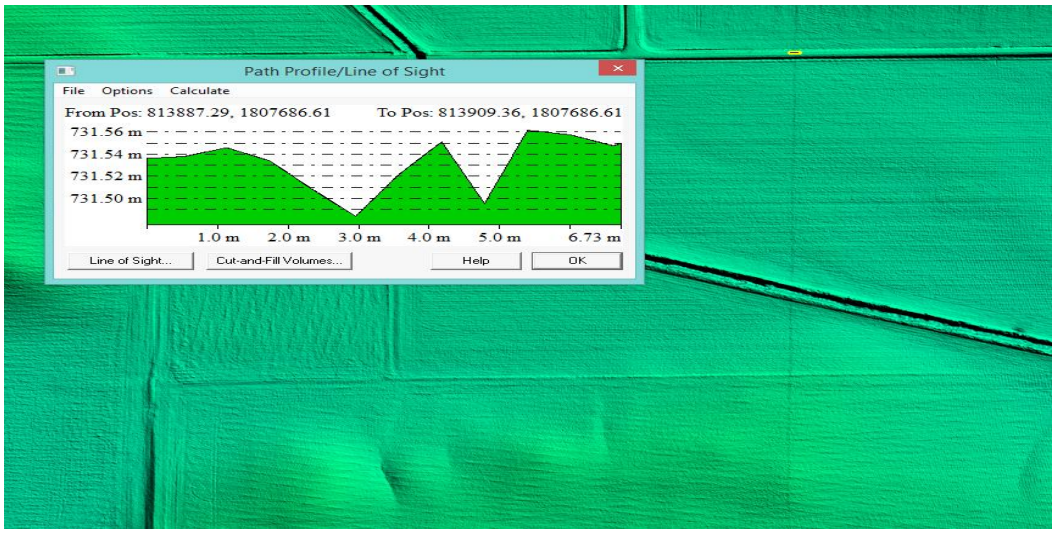

Figure 26: The flight line ridge is less than 8 cm. Overall; this project data meets the project specifications for 8 cm RMSDz relative accuracy requirement.

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_1_2020_D21 project area.

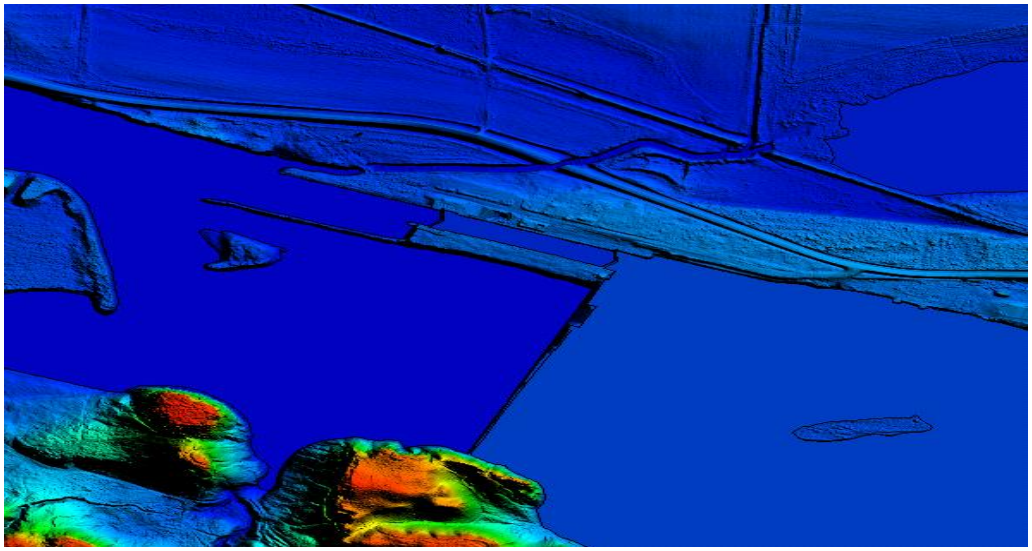

Figure 27: DEM shows Large Dam structure that disrupts natural monotonic river flow, coupled with a lock system.

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 discreet measurement of the survey checkpoints to that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However, there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. 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_1_2020_D21 UTM 14N project, one hundred forty one check points were surveyed. All of those check points are located within bare earth/open terrain (141 NVA points). 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 14 North Easting (M)	NAD83 (2011) UTM Zone 14 North Northing (M)	NAVD88 (Geoid12B) Elevation (M)
NVA1002	694708.41	4819231.156	397.281
NVA1025	699177.163	4743940.101	349.263
NVA1026	704098.076	4763511.523	358.93
NVA1027	708824.109	4778975.012	370.963
NVA1028	703762.194	4789036.279	381.485
NVA1029	700805.023	4807131.763	397.177
NVA1030	706658.412	4715711.686	343.596
NVA1032	705872.393	4819537.687	430.774
NVA1033	726414.088	4820184.126	422.373
NVA1034	741057.247	4820691.39	438.075
NVA1047	728637.737	4812628.826	413.467
NVA1048	743054.643	4803677.272	419.742
NVA1049	743493.456	4793864.796	423.355
NVA1050	743767.06	4785861.325	432.557
NVA1101	739770.587	4679021.369	325.626
NVA1105	721817.979	4722645.073	358.592
NVA1106	729612.74	4739847.781	364.394
NVA1109	730014.842	4771376.569	431.965
NVA1110	715216.611	4736383.473	443.16
NVA1111	731914.057	4695020.433	335.635
NVA1117	740818.231	4737260.389	429.733
NVA1120	719913.329	4786572.453	385.308
NVA1122	708082.298	4812126.463	436.188

NVA1123	719456.988	4752593.967	432.894
NVA1124	719105.534	4764000.749	427.952
NVA1125	733556.572	4716045.812	394.821
NVA1129	740586.363	4696769.328	347.52
NVA1130	738418.04	4754906.904	385.452
NVA1169	730355.525	4761137.125	402.823
NVA1171	732889.328	4785550.617	437.342
NVA1173	735192	4807632.649	429.801
NVA1181	714160.13	4819778.065	437.313
NVA1183	730056.225	4820303.882	446.504
NVA1185	728867.442	4803624.308	399.8
NVA1187	735480.922	4795103.088	433.364
NVA1188	739344.647	4777625.119	433.644
NVA1214	727819.333	4678849.939	328.592
NVA1215	703533.88	4723015.983	340.836
NVA1216	705157.979	4728923.036	353.434
NVA1217	708608.035	4742648.96	423.03
NVA1218	714592.981	4752478.041	417.722
NVA1237	734093.484	4748785.699	386.905
NVA1393	720281.79	4773725.8	431.973
NVA1121	718630.252	4802314.048	404.637
NVA1022	728898.457	4654116.372	325.321
NVA1023	718305.796	4676152.449	325.075
NVA1098	740287.506	4646157.969	322.547

NVA1099	739759.376	4656115.745	320.32
NVA1107	739922.505	4763901.292	428.104
NVA1127	739562.32	4671146.557	323.132
NVA1170	715008.26	4775162.764	413.545
NVA1172	728833.96	4796482.417	394.105
NVA1527	705331.474	4789240.353	438.115
VVA1550	735824.334	4803377.076	424.519
VVA1546	716025.533	4813920.575	434.444
VVA1545	719338.563	4801813.872	400.739
VVA1475	729608.27	4690183.053	327.882
VVA1472	729730.704	4670508.537	325.162
VVA1471	734261.519	4658768.299	319.149
VVA1458	737696.256	4645389.401	316.4
VVA1457	745765.822	4622027.361	309.722
VVA1456	744168.371	4612138.459	305.936
VVA1455	749668.223	4597658.4	303.846
VVA1548	705878.737	4819558.464	429.741
VVA1547	714120.617	4819789.66	437.52
VVA1544	707882.94	4814244.635	448.369
VVA1543	694780.557	4818820.376	393.644
VVA1542	693979.066	4813386.444	386.279
VVA1539	703605.649	4804899.179	431.684
VVA1538	708014.299	4798311.761	446.807
VVA1537	727842.314	4820205.889	416.704

VVA1536	728109.723	4812539.623	421.377
VVA1534	741302.927	4820672.602	434.892
VVA1529	724252.49	4798113.745	388.59
VVA1528	700818.791	4797981.197	379.249
VVA1526	718727.231	4787979.444	376.917
VVA1524	733415.252	4786021.099	441.84
VVA1523	707953.965	4778890.703	362.746
VVA1522	714986.707	4775168.663	412.398
VVA1521	729552.383	4772809.467	445.11
VVA1520	734733.951	4772239.025	404.489
VVA1511	743973.655	4764529.825	393.805
VVA1510	719123.349	4761170.4	435.126
VVA1509	704763.717	4764117.224	355.752
VVA1508	702653.332	4754489.079	354.642
VVA1507	713235.417	4752396.322	403.742
VVA1506	729197.991	4752956.024	385.09
VVA1502	734126.347	4743526.378	374.476
VVA1501	711751.964	4742751.008	395.79
VVA1500	697425.876	4741488.204	344.784
VVA1499	708368.021	4728980.001	411.608
VVA1498	701187.956	4726382.014	336.286
VVA1497	706144.815	4719747.767	349.861
VVA1496	728378.738	4737319.545	365.163
VVA1495	733172.485	4728401.109	401.065

VVA1483	741342.882	4707715.575	364.965
VVA1482	719775.17	4723637.193	384.012
VVA1481	706207.317	4710137.811	334.641
VVA1480	715116.092	4710132.367	335.942
VVA1479	729274.64	4698996.956	338.445
VVA1474	718170.844	4697213.901	332.711
VVA1473	729104.383	4679948.696	326.644

Table 12: USGS_IA_Western_1_2020_D21 Project Area LiDAR Validation Checkpoints.

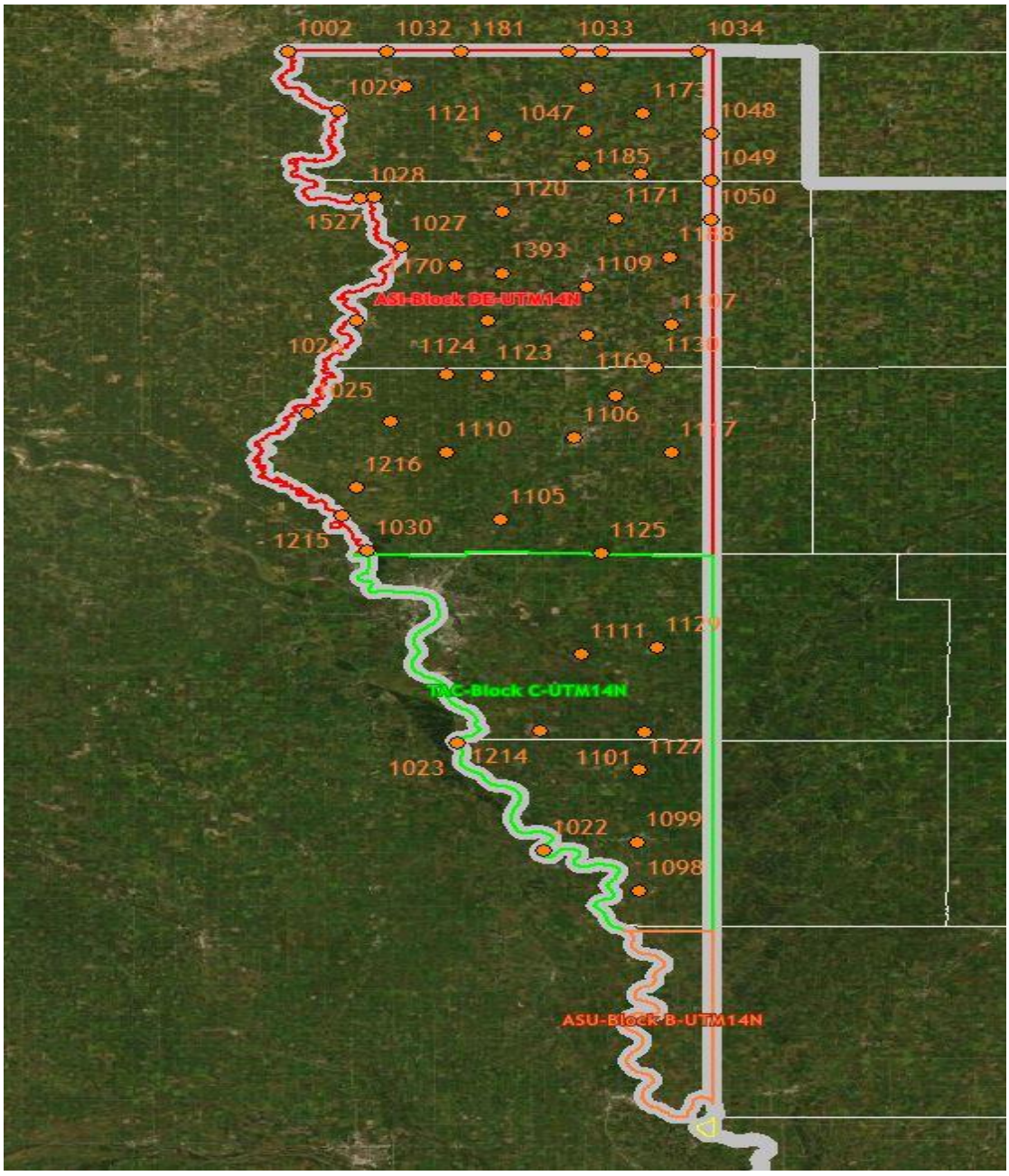

Figure 28: Location of USGS_IA_Western_1_2020_D21 project area LiDAR NVA Checkpoints

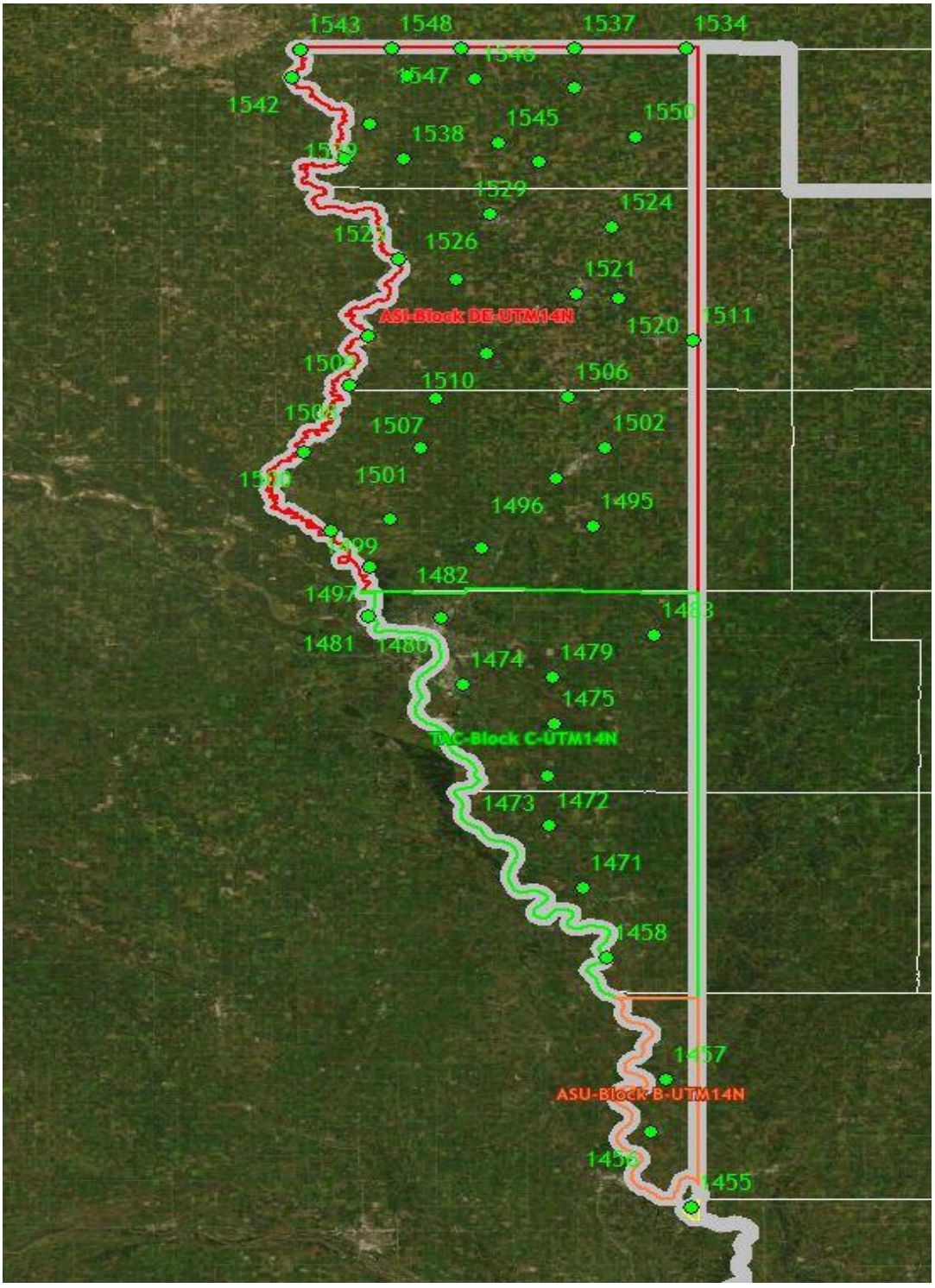

Figure 29: VVA Checkpoints were located in USGS_IA_Western_1_2020_D21 project area

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_1_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) x 1.9600. VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The USGS_IA_Western_1_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 95th Percentile error	29.4 cm (based on combined 95th percentile)

Table 13: 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 (95th Percentile) spec = 0.294 m
NVA	53	0.093	
VVA	48		0.143

Table 14: Tested NVA and VVA.

HORIZONTAL ACCURACY TEST PROCEDURES

The USGS_IA_WesternIA_2020_D21 project data set was produced to meet ASPRS "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a 32.72 (cm) RMSEx / RMSEy 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 check 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 4000m² (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 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 30: 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 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.

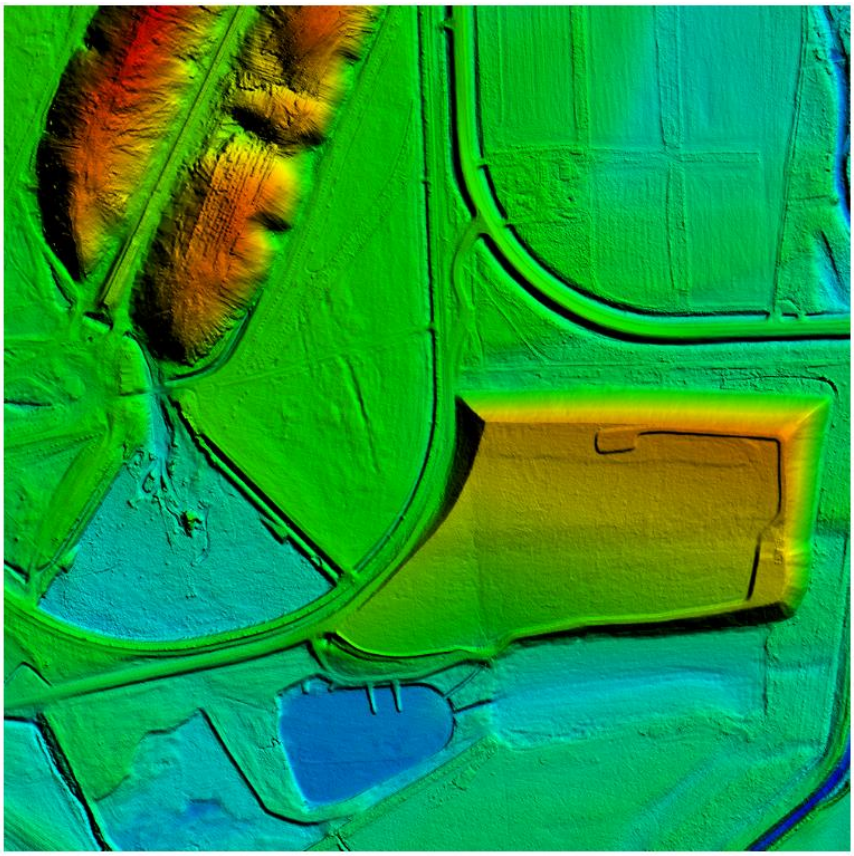

Figure 31: Bare earth DEM example

DEM VERTICAL ACCURACY RESULTS

The same 101 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 (95th percentile)
NVA	53	0.092	
VVA	48		0.050

Table 15: 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 = 0.047 meters with a 0.092 meters accuracy at 95 % confidence level. Actual VVA accuracy tested 0.092 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_1_2020_D21 project area project satisfies the project's pre-defined vertical accuracy criteria.

Appendix A: List of Delivered LAS File

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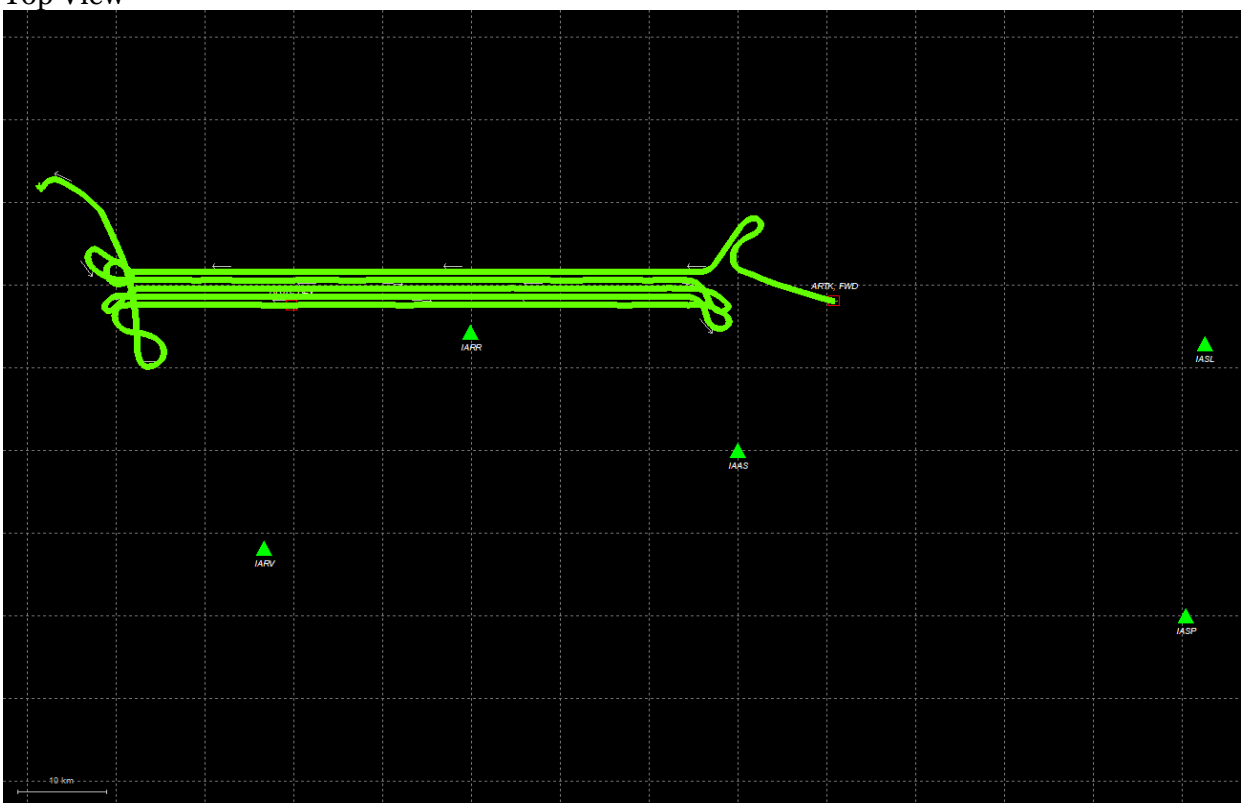
Appendix B: GPS and IMU Processing Report

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

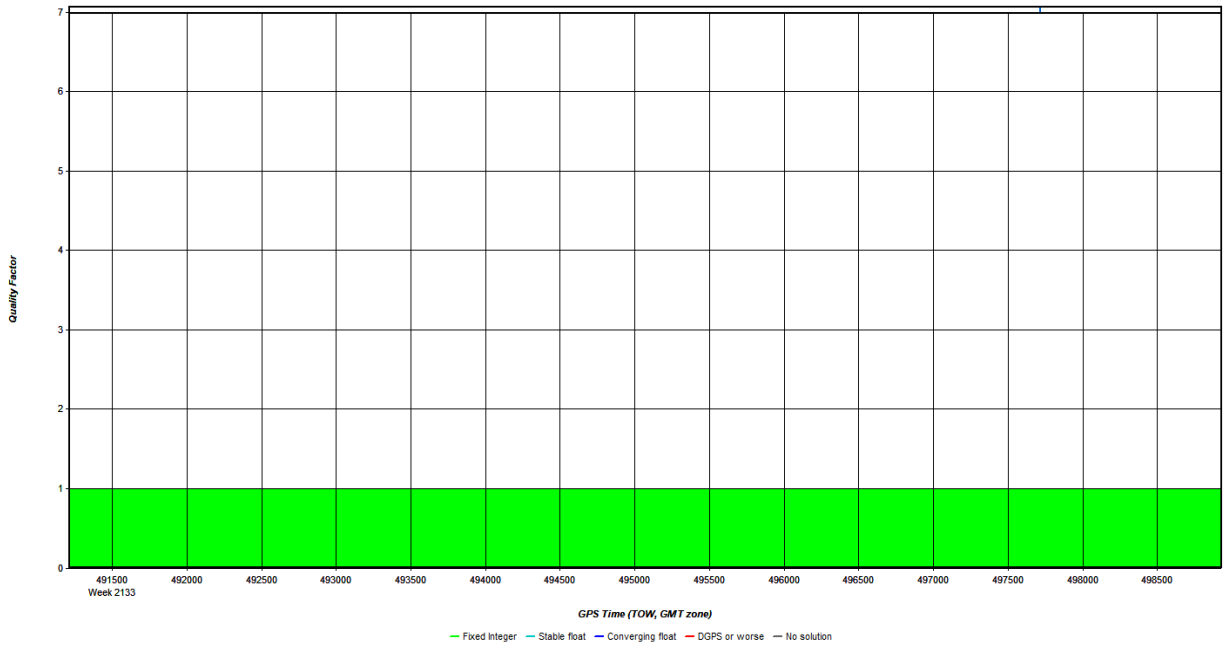
Smoothed Trajectory Information

Top View

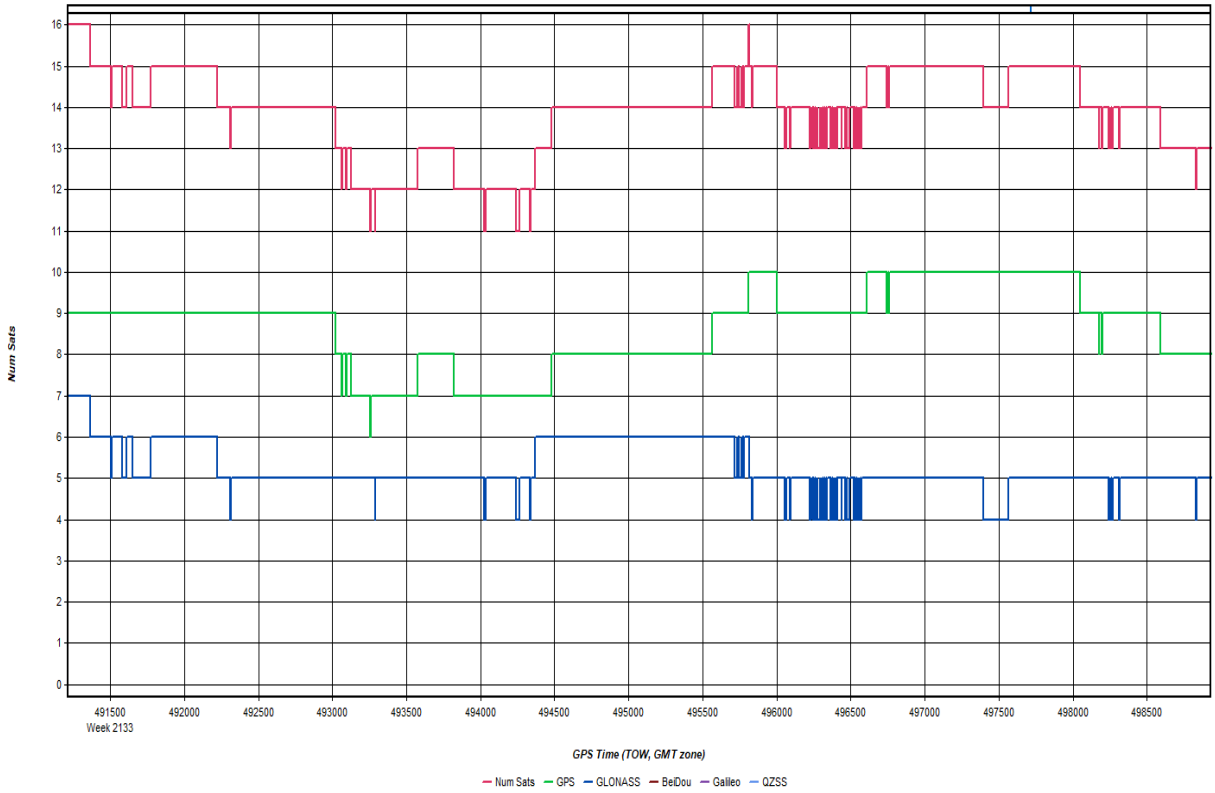


GNSS QC

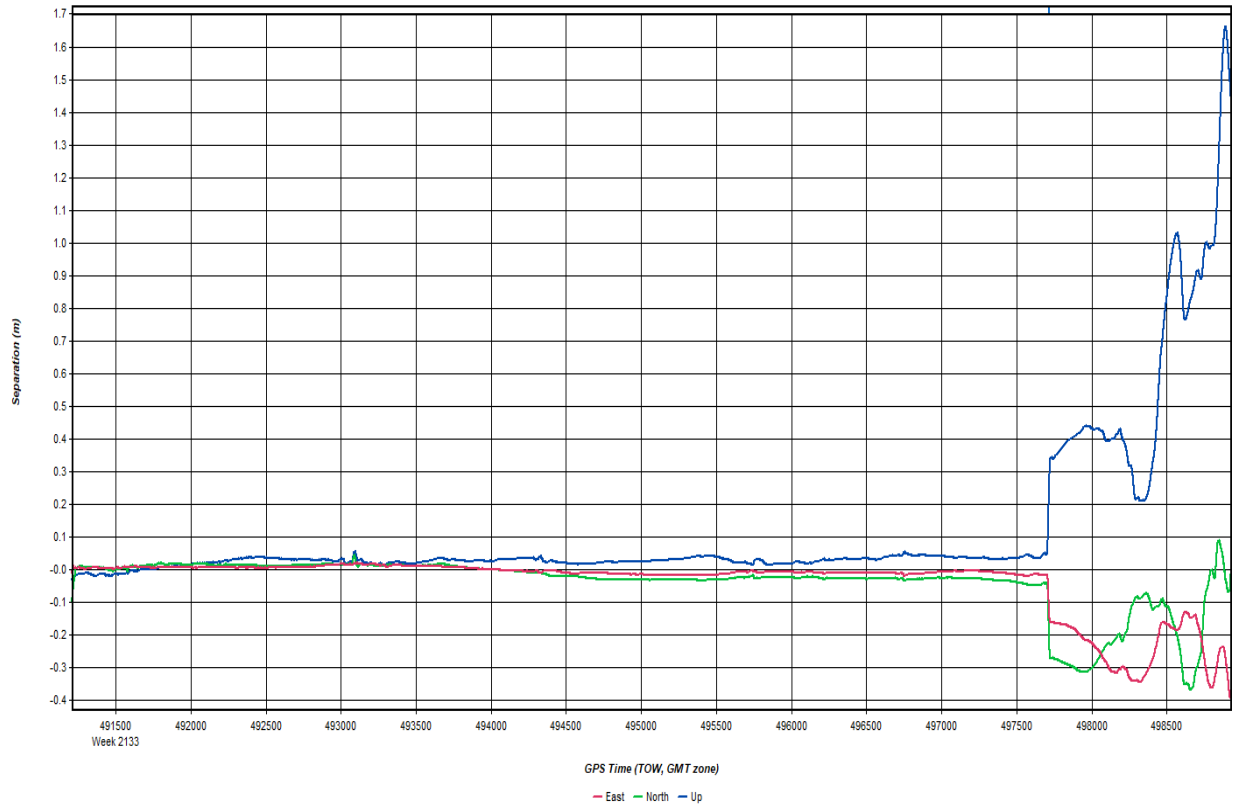
Quality Factor Plot



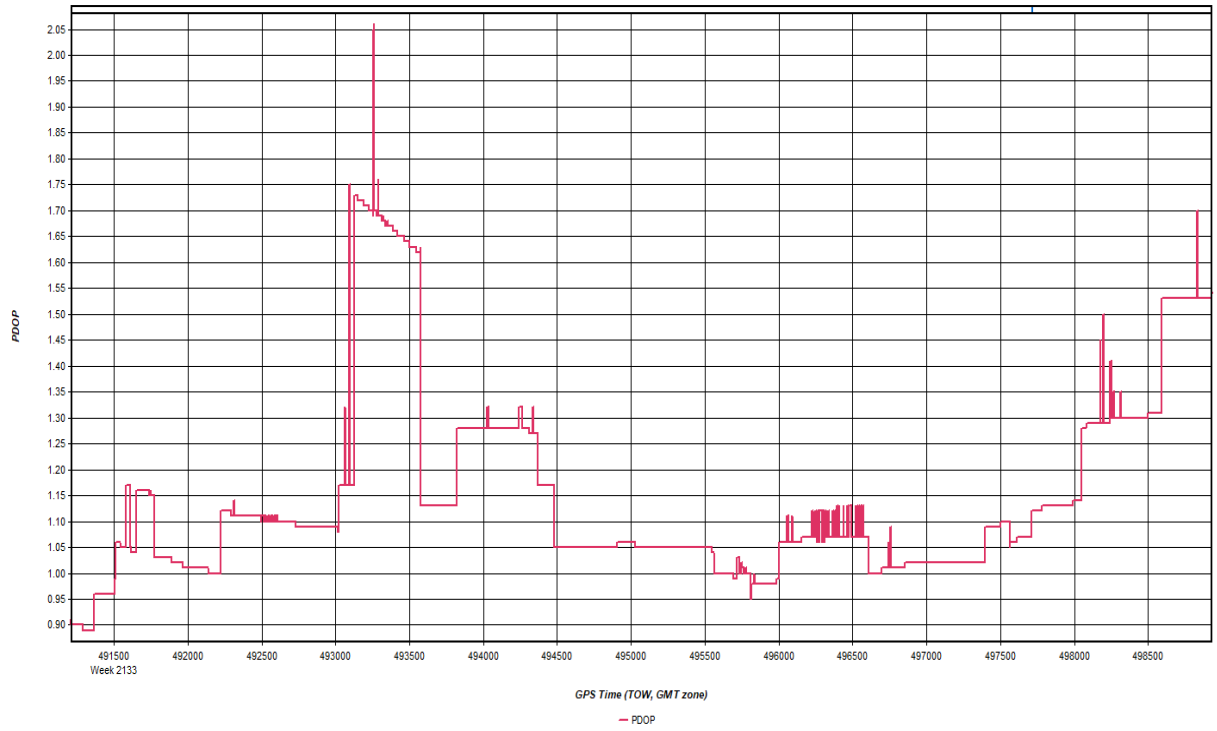
Number of Satellites Plot



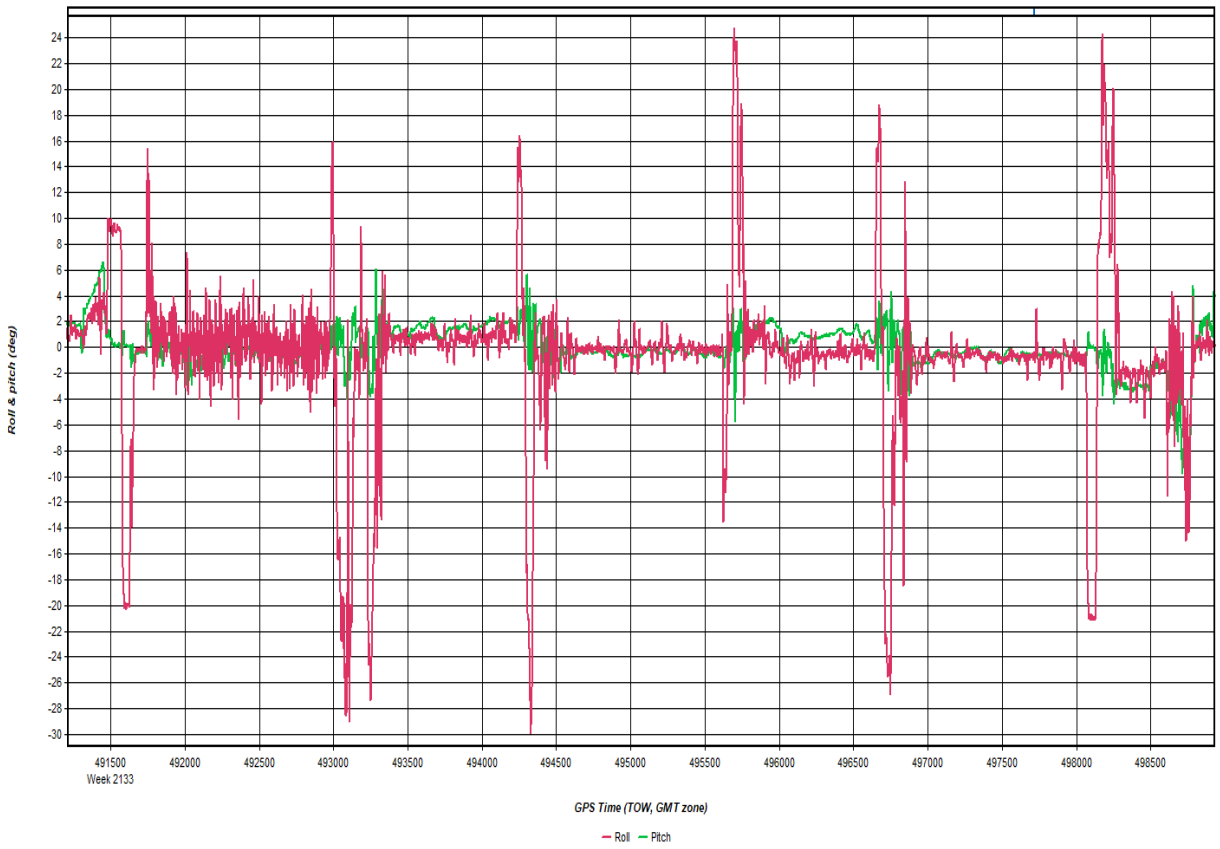
Forward/Reverse or Combined Separation Plot



PDOP Plot



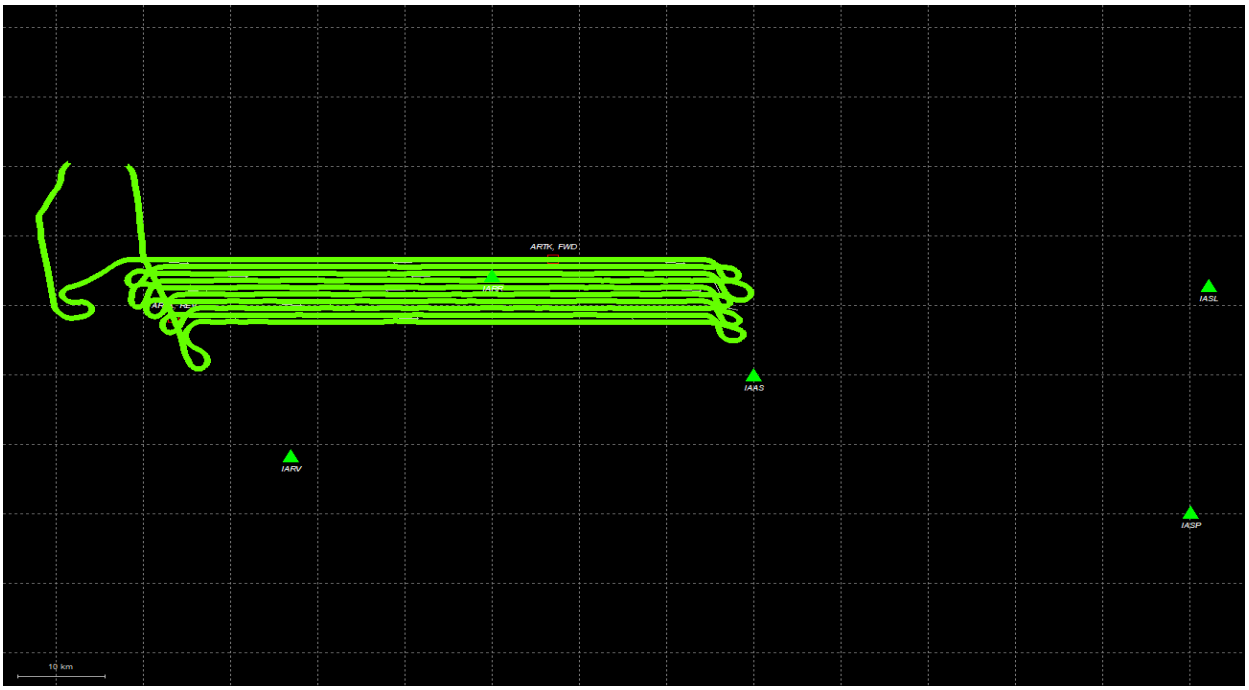
Roll & Pitch Plot



20201127-190707.docx QC Report - 06/22/2021 09:07:25

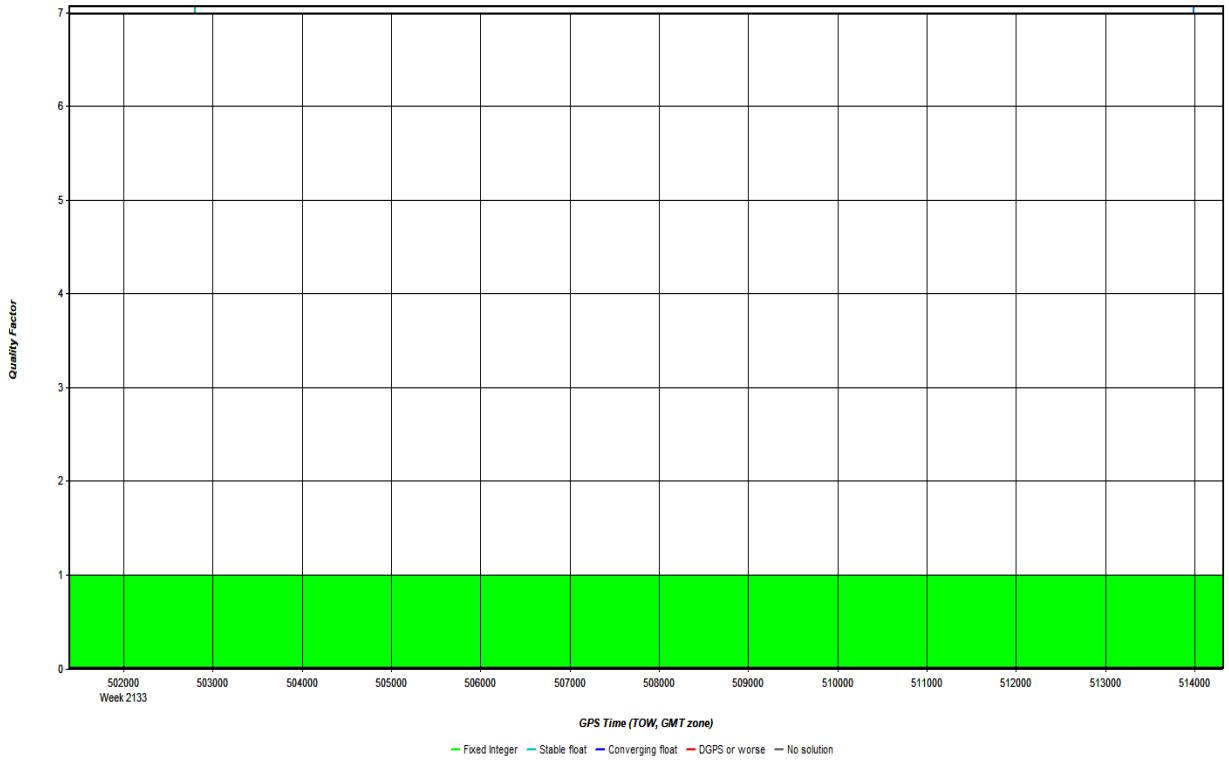
Smoothed Trajectory Information

Top View

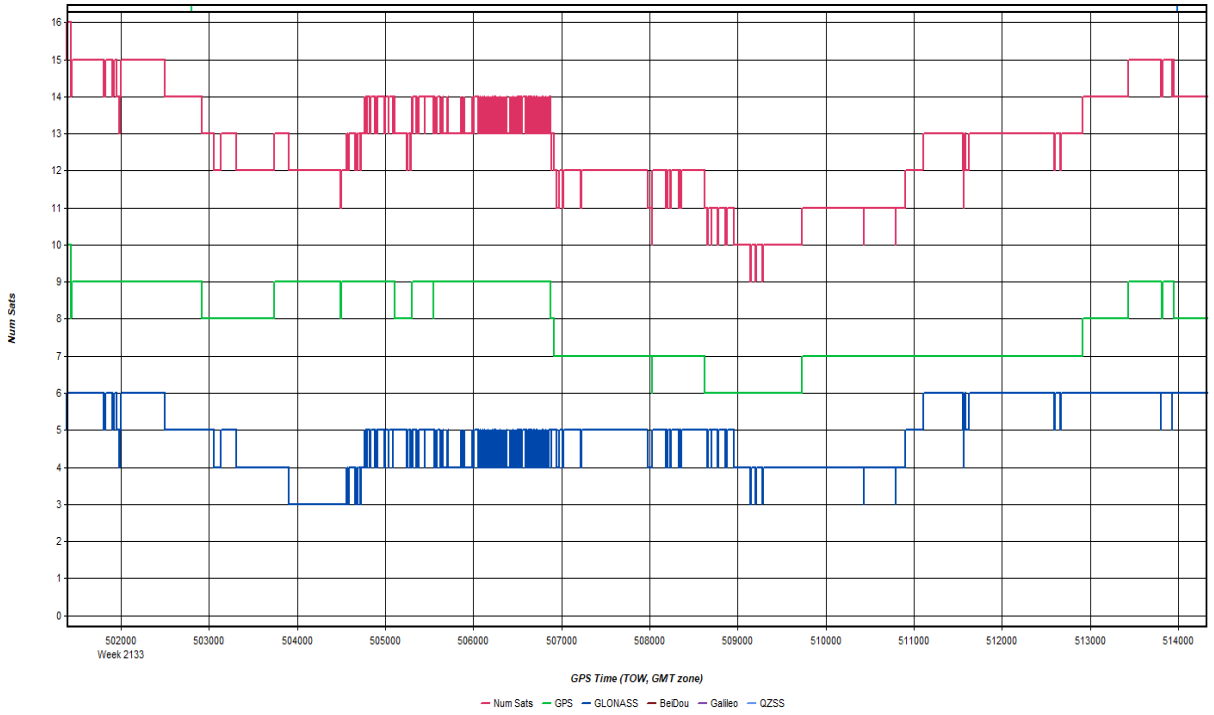


GNSS QC

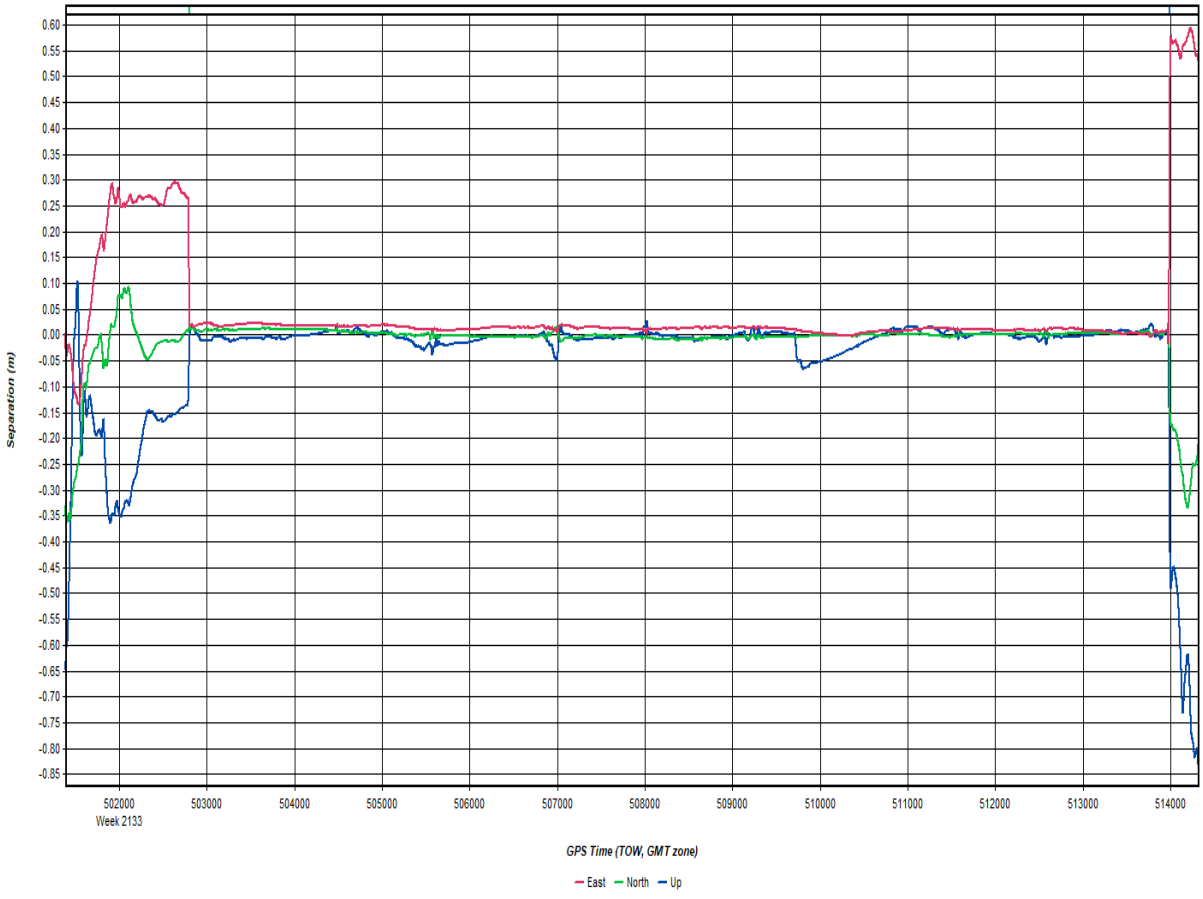
Quality Factor Plot



Number of Satellites Plot



Forward/Reverse or Combined Separation Plot



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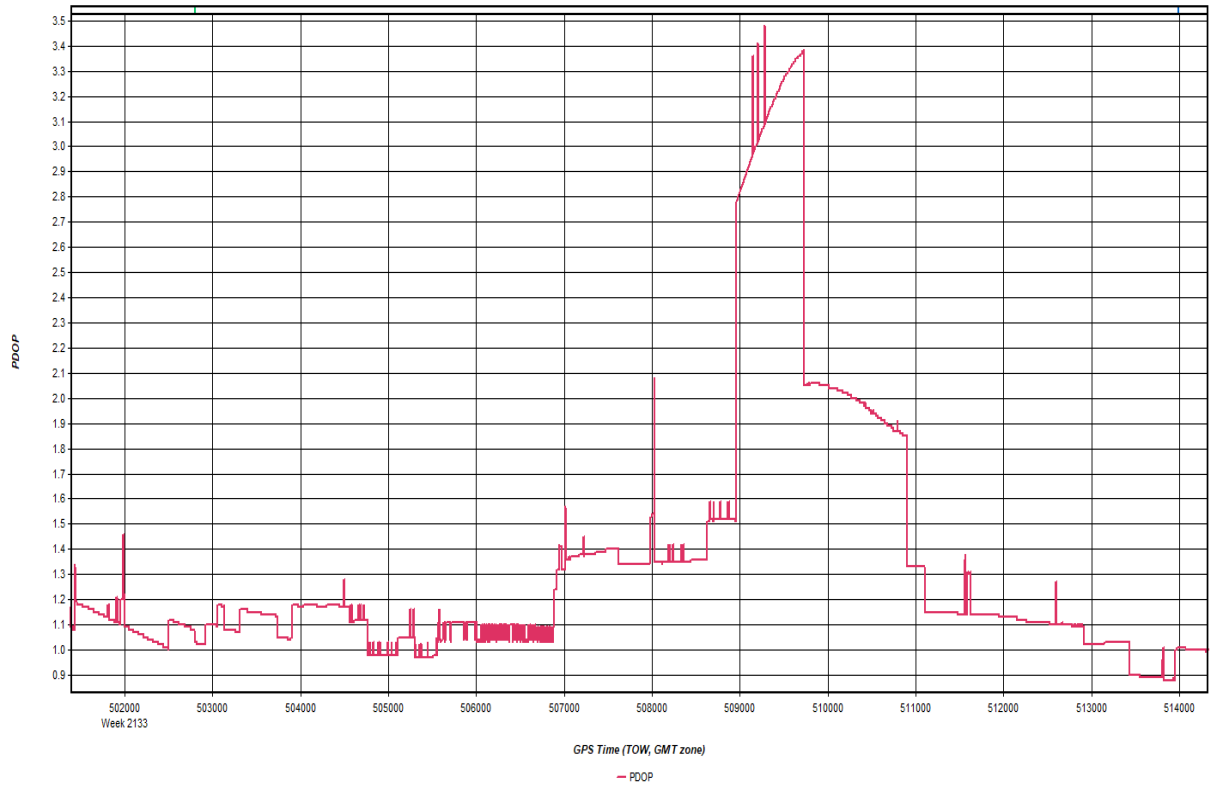
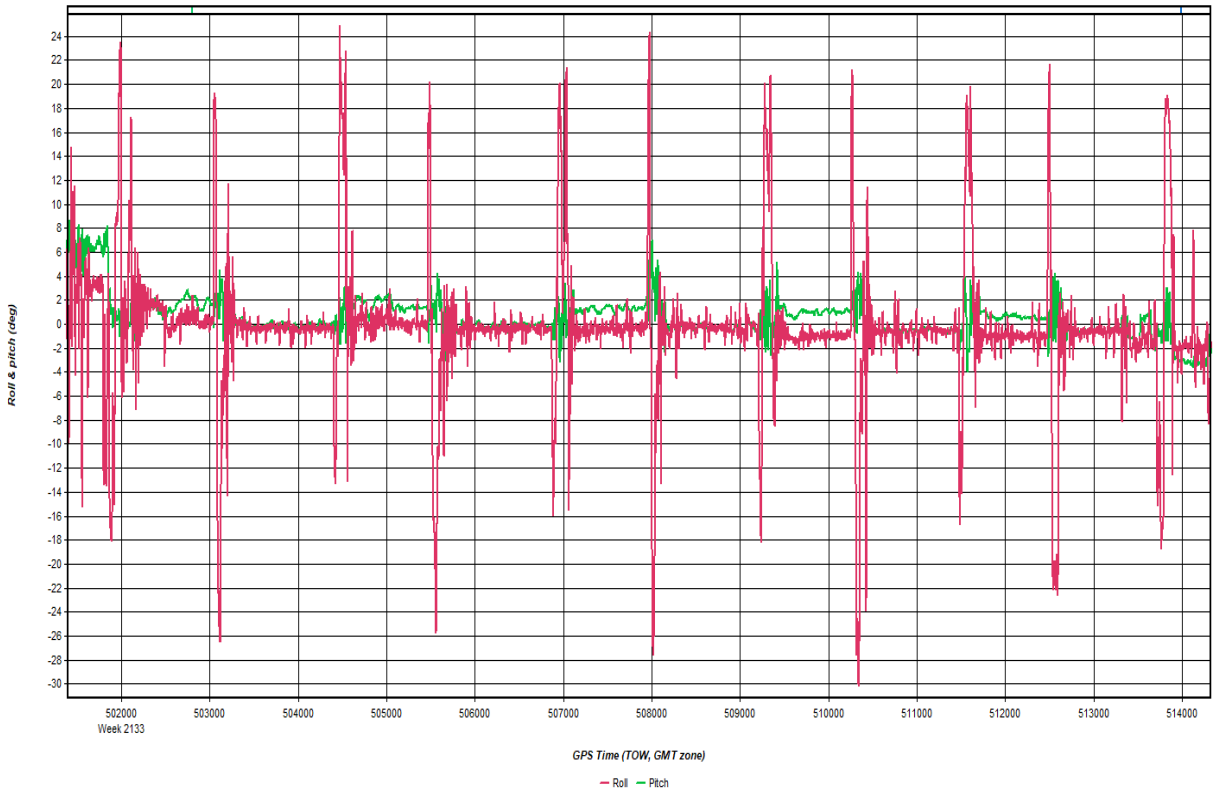


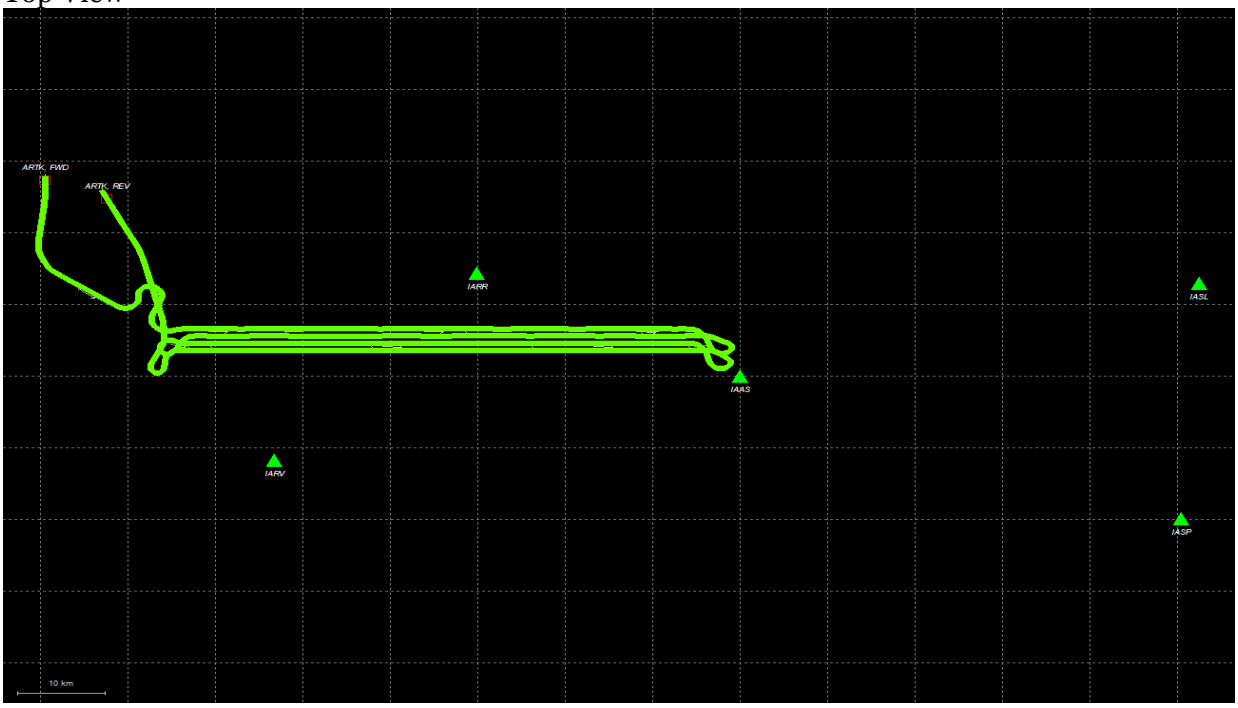
Roll & Pitch Plot



20201127-233917.docx QC Report - 06/22/2021 09:12:25

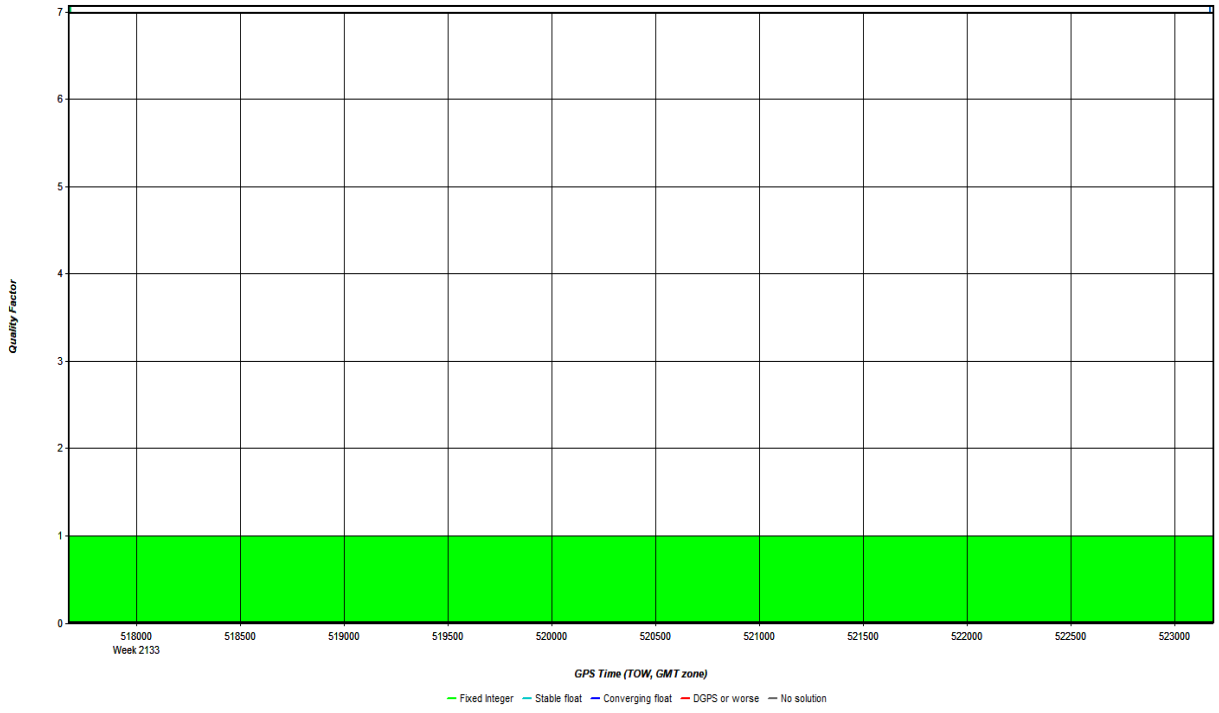
Smoothed Trajectory Information

Top View

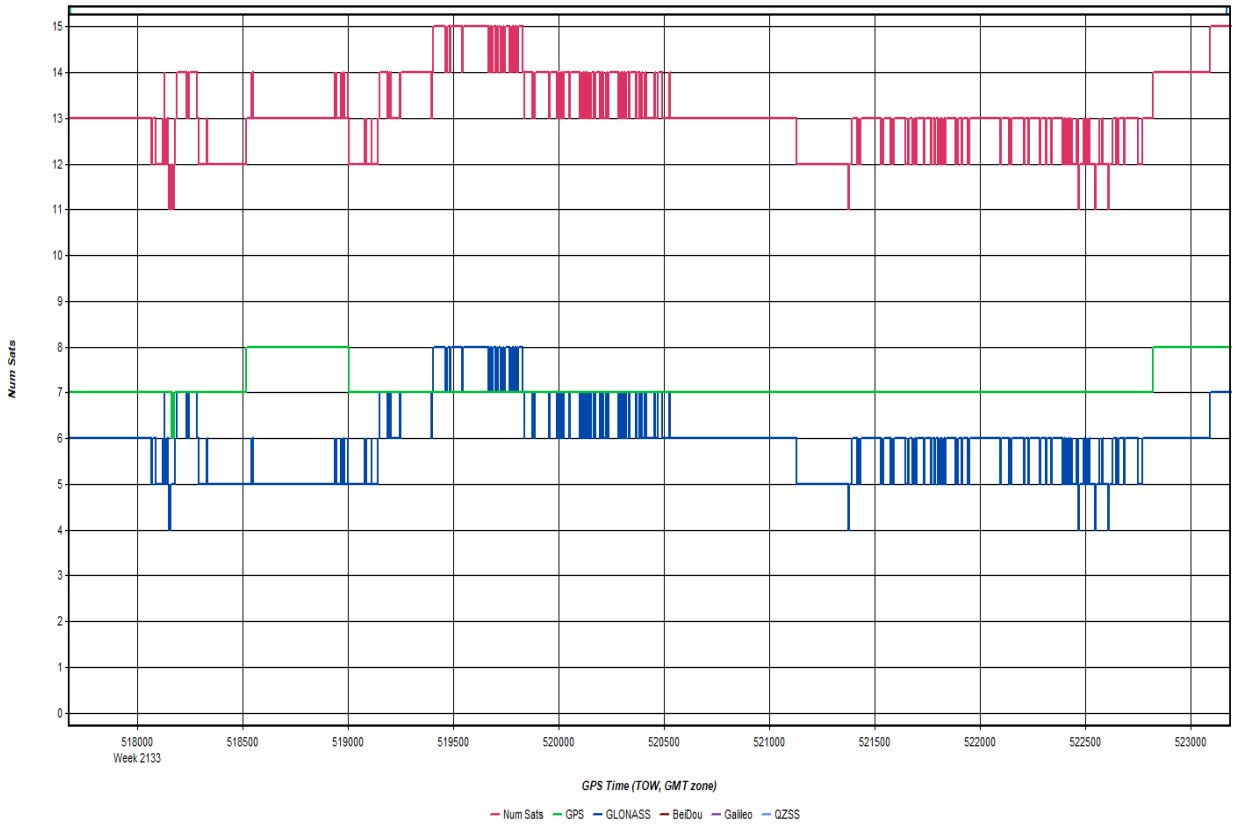


GNSS QC

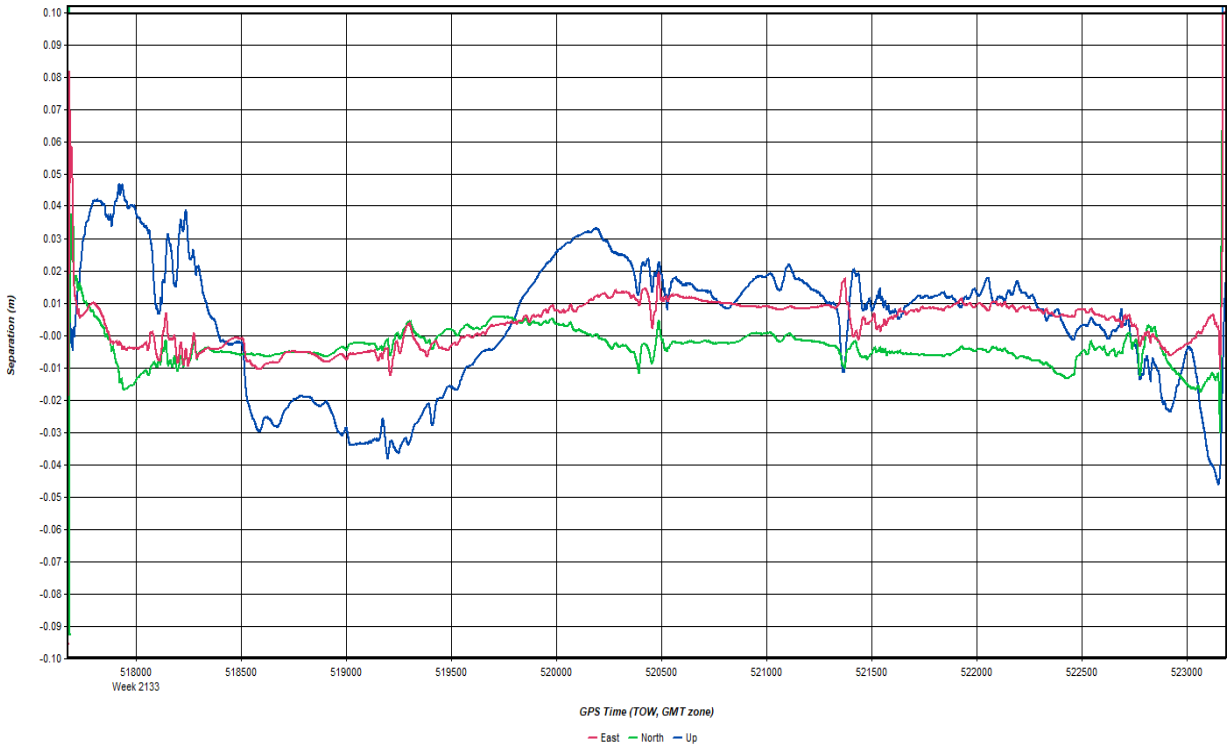
Quality Factor Plot



Number of Satellites Plot



Forward/Reverse or Combined Separation Plot



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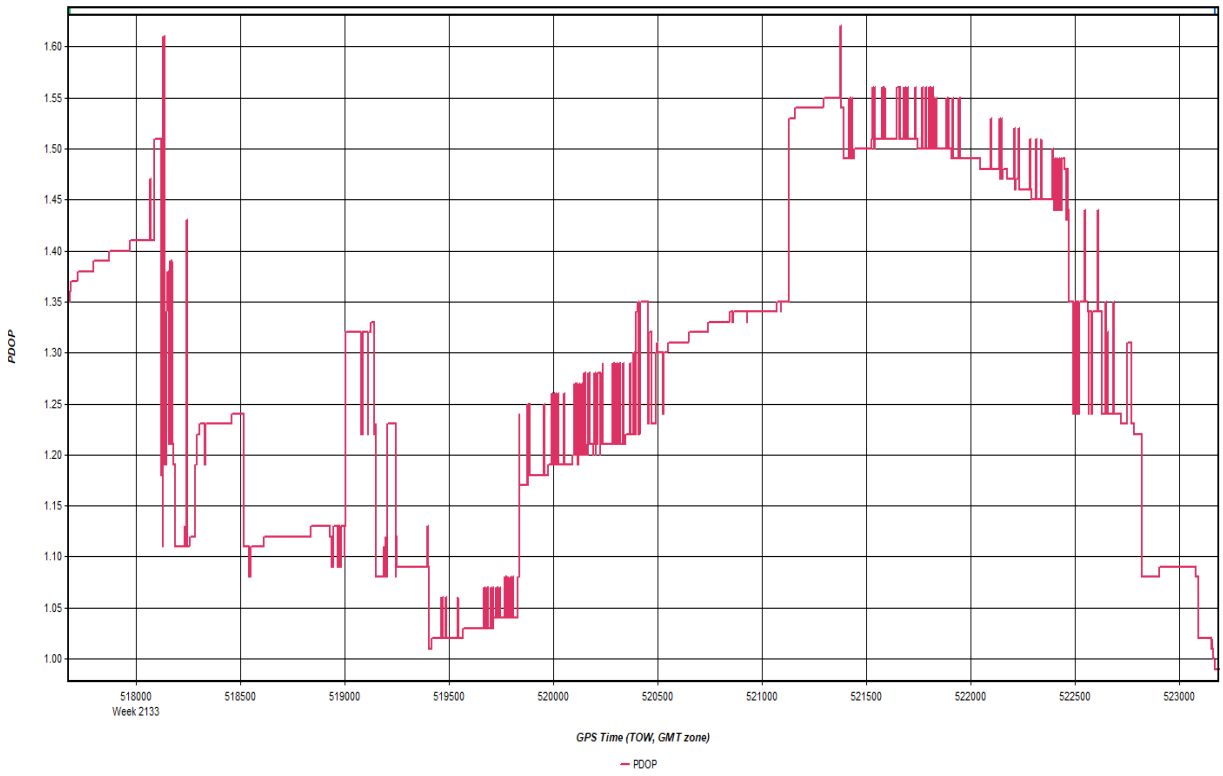
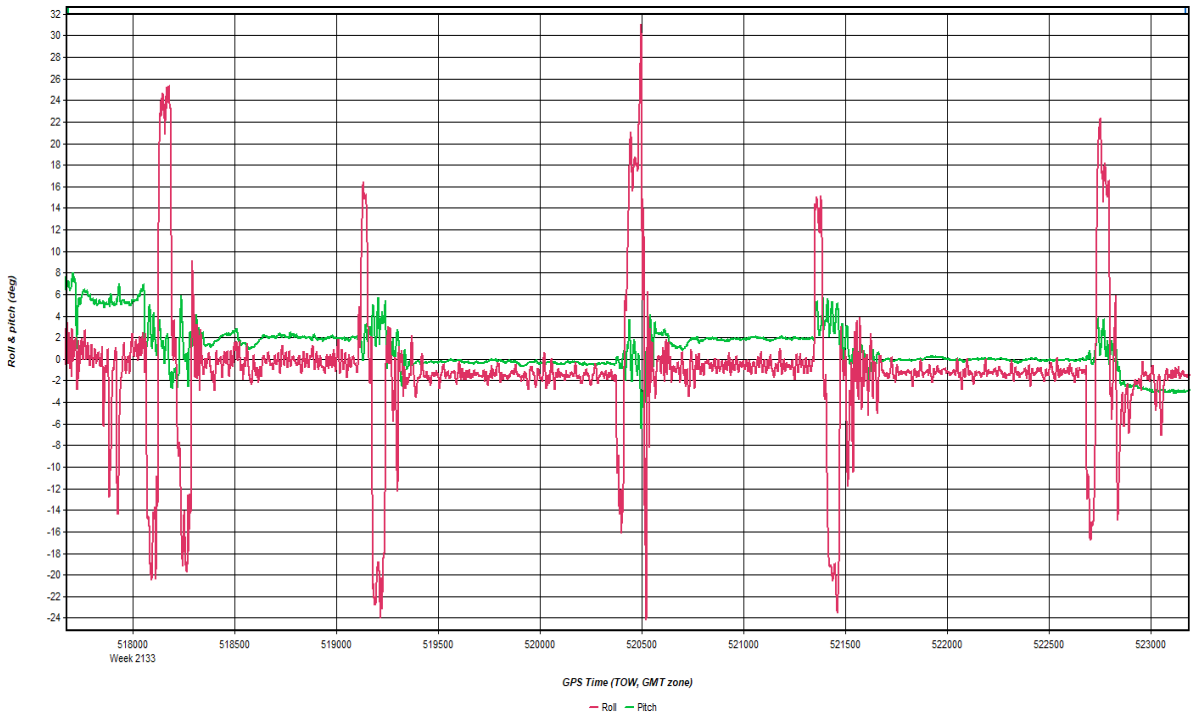


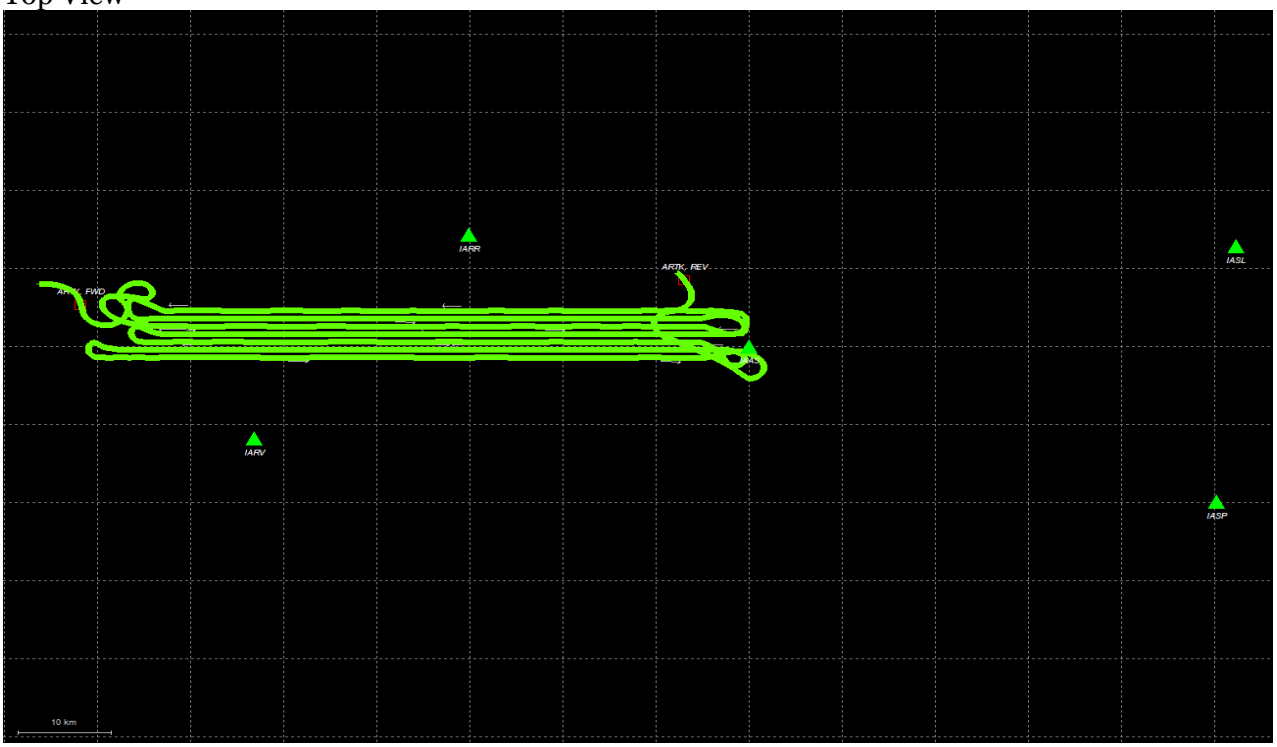
Roll & Pitch Plot



20201128-152926.docx QC Report - 06/22/2021 09:39:12

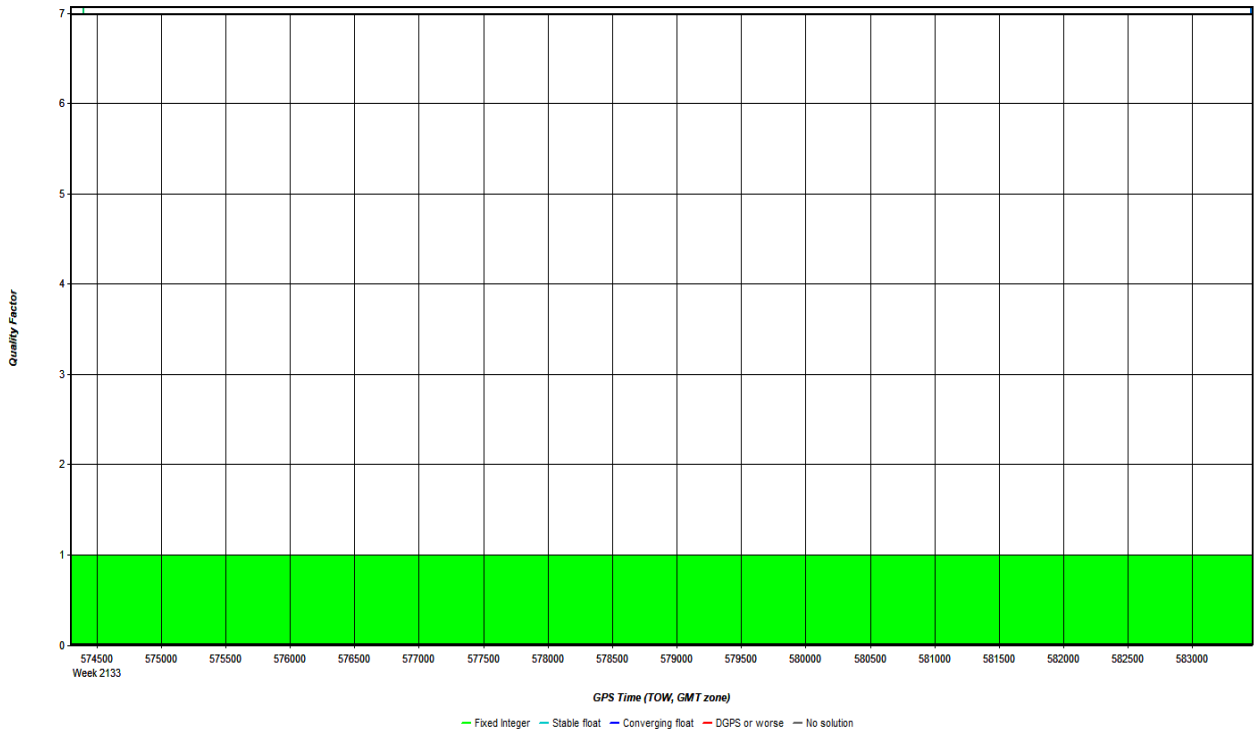
Smoothed Trajectory Information

Top View

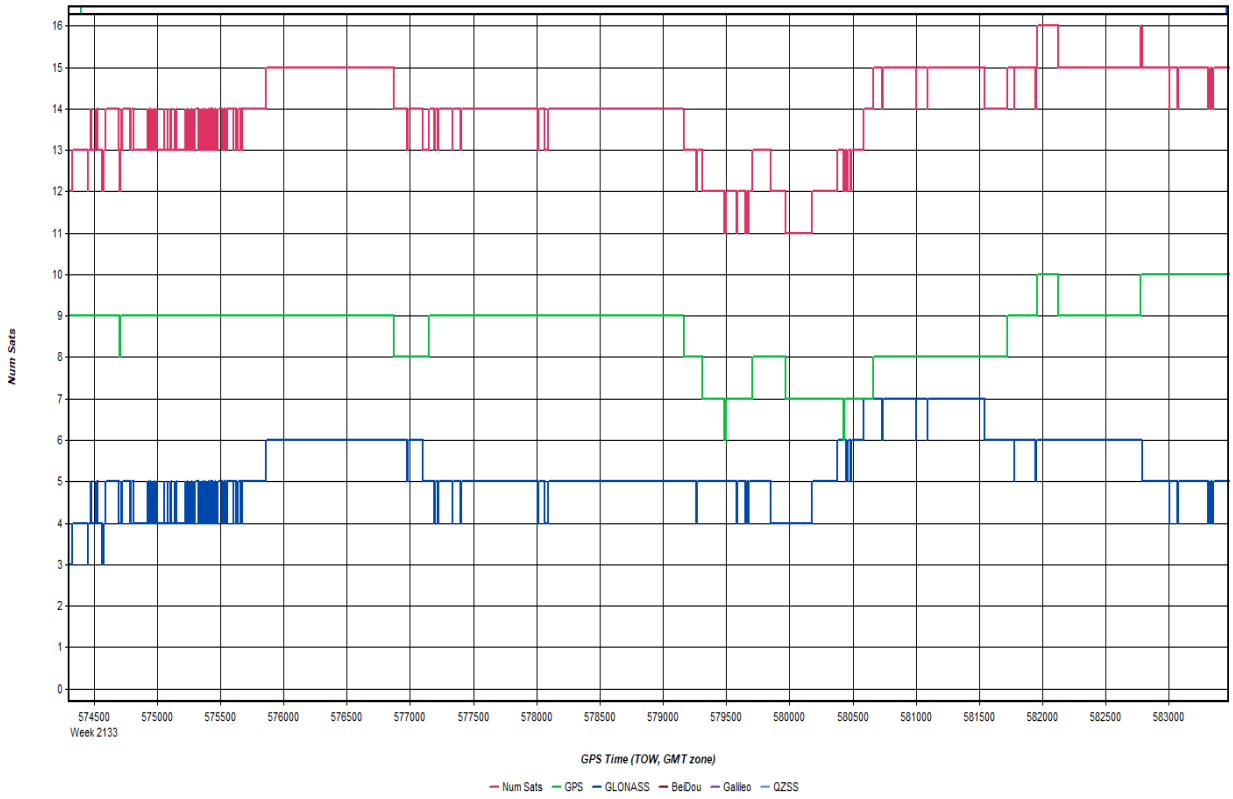


GNSS QC

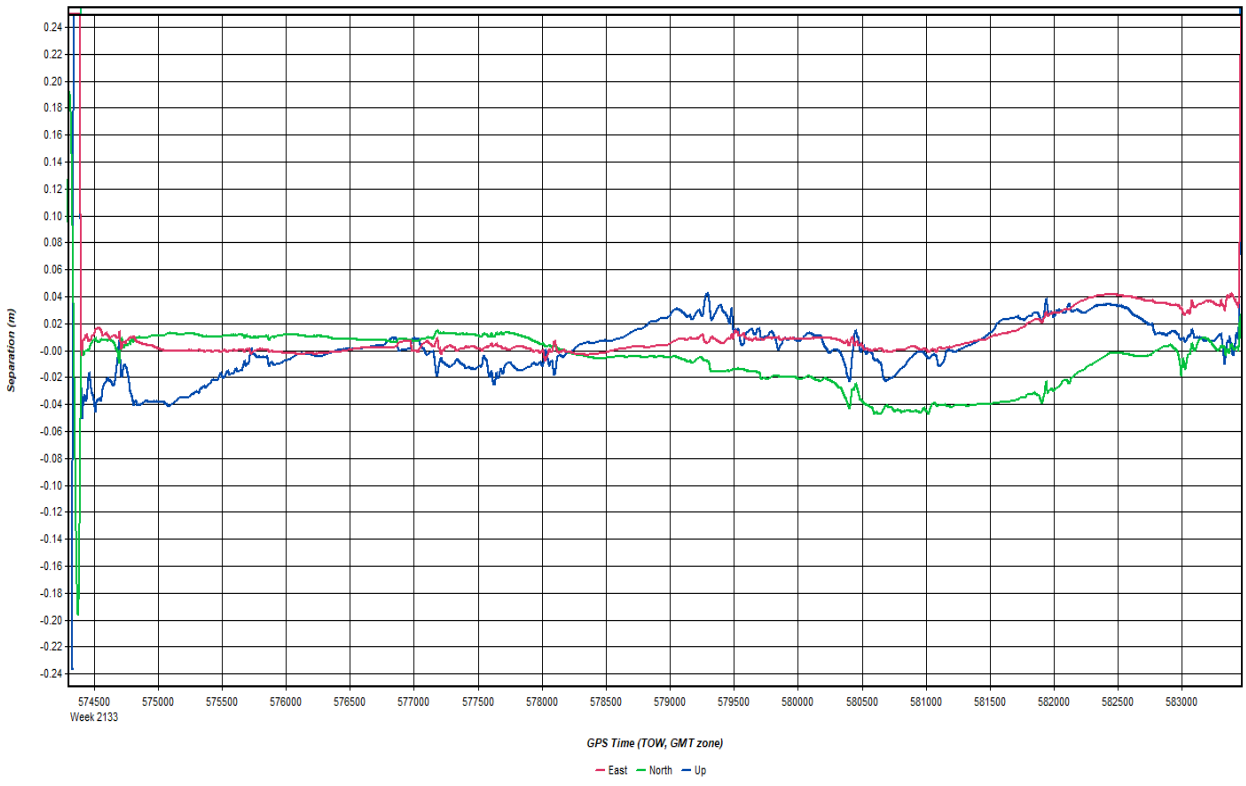
Quality Factor Plot



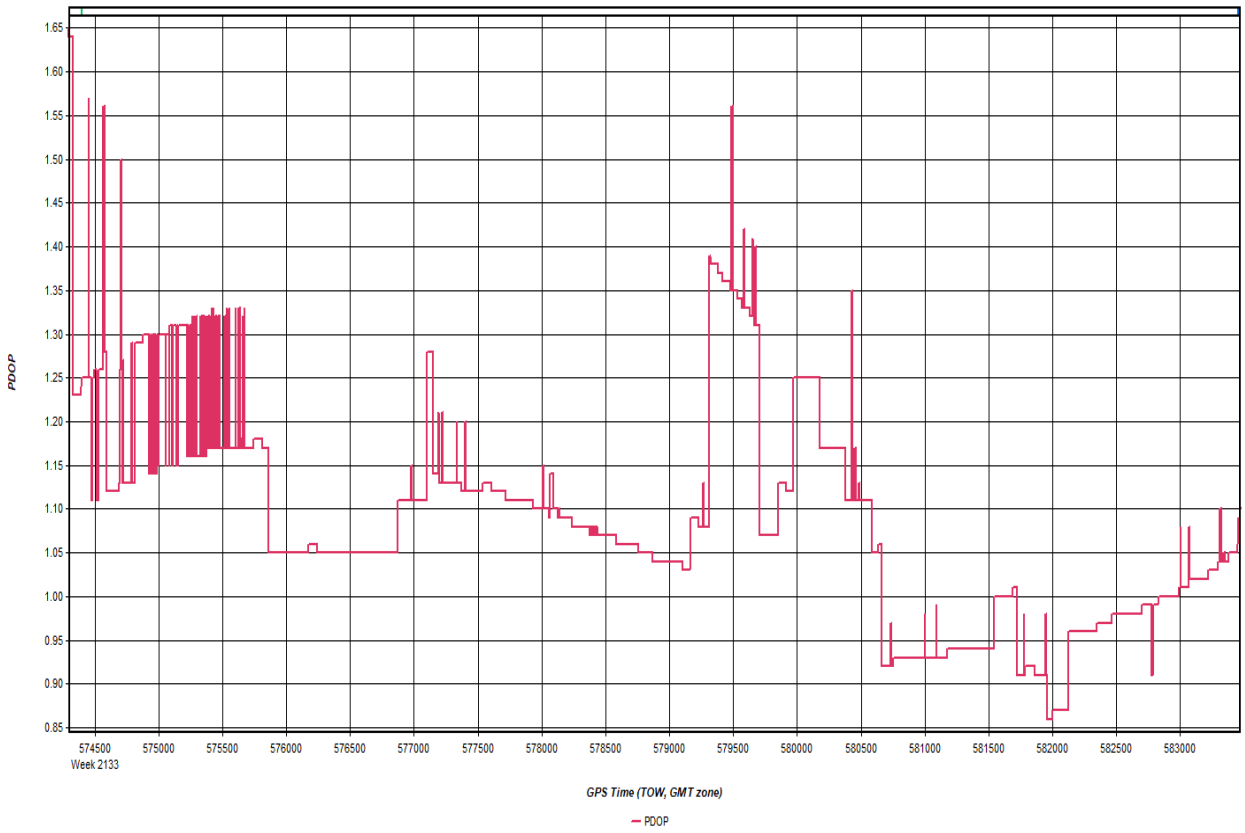
Number of Satellites Plot



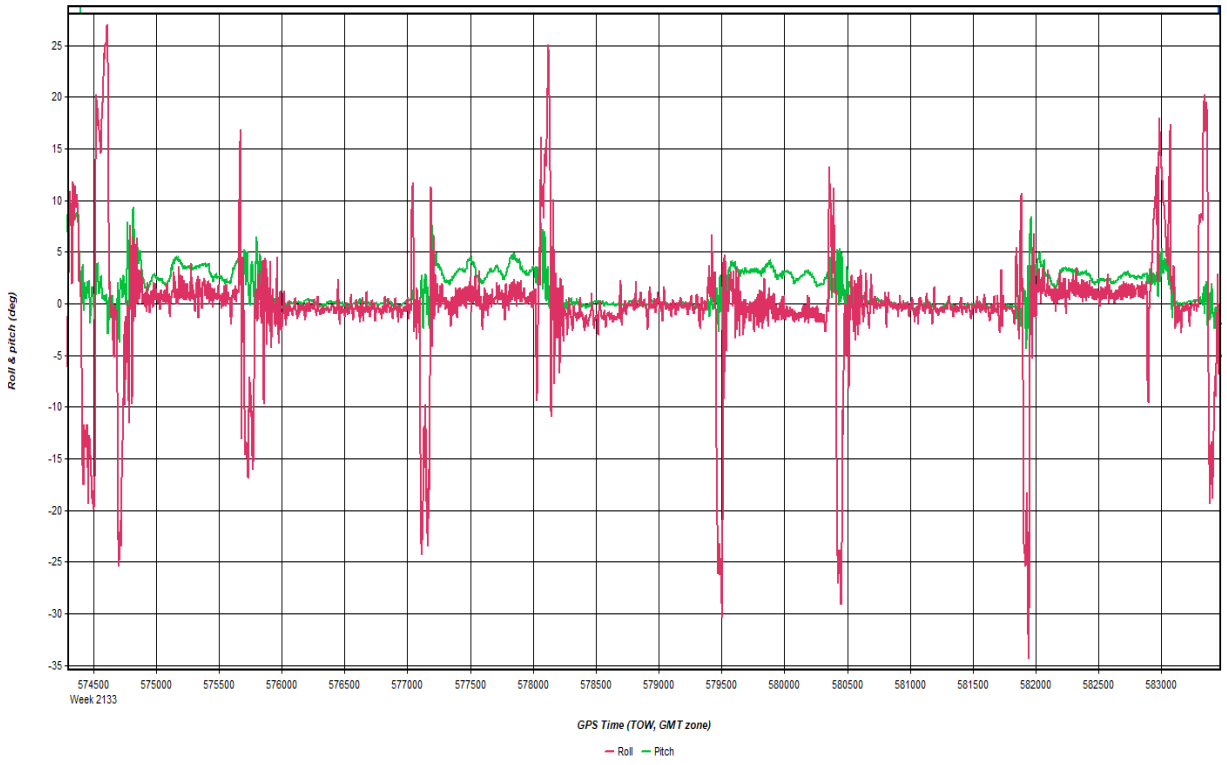
Forward/Reverse or Combined Separation Plot



PDOP Plot



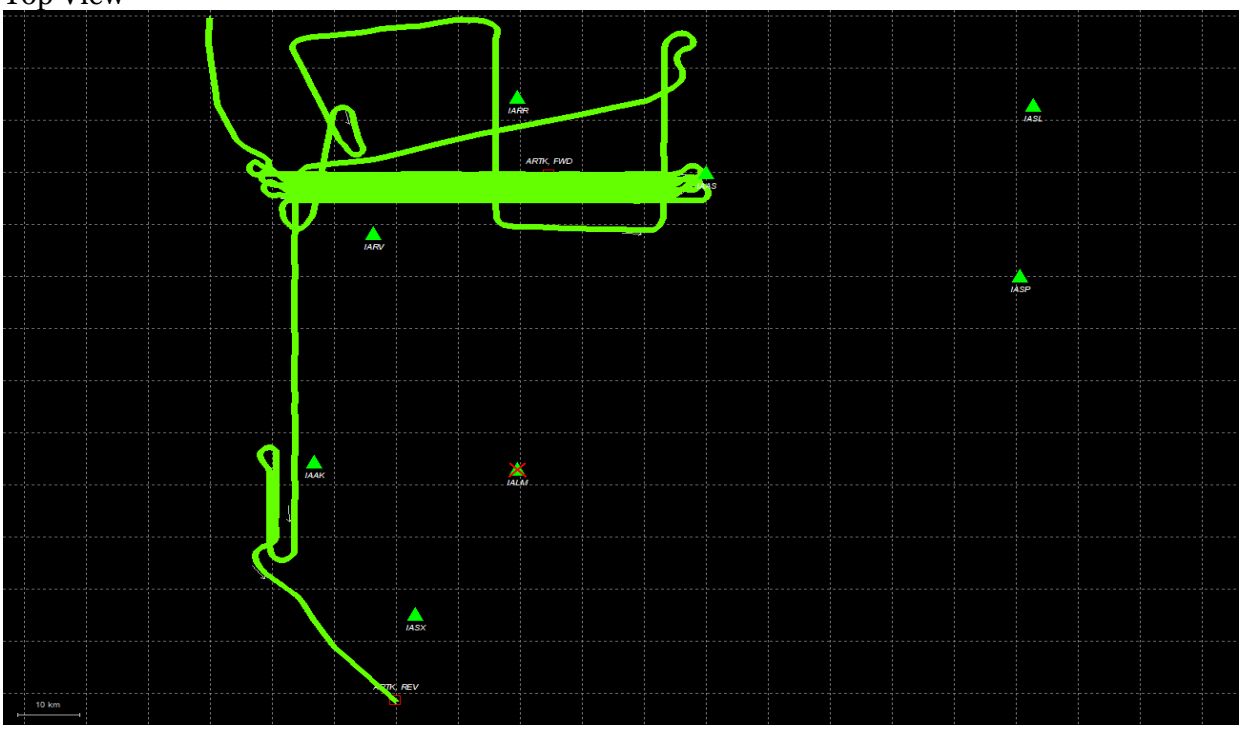
Roll & Pitch Plot



20201128-192627.docx QC Report - 06/22/2021 09:4:12

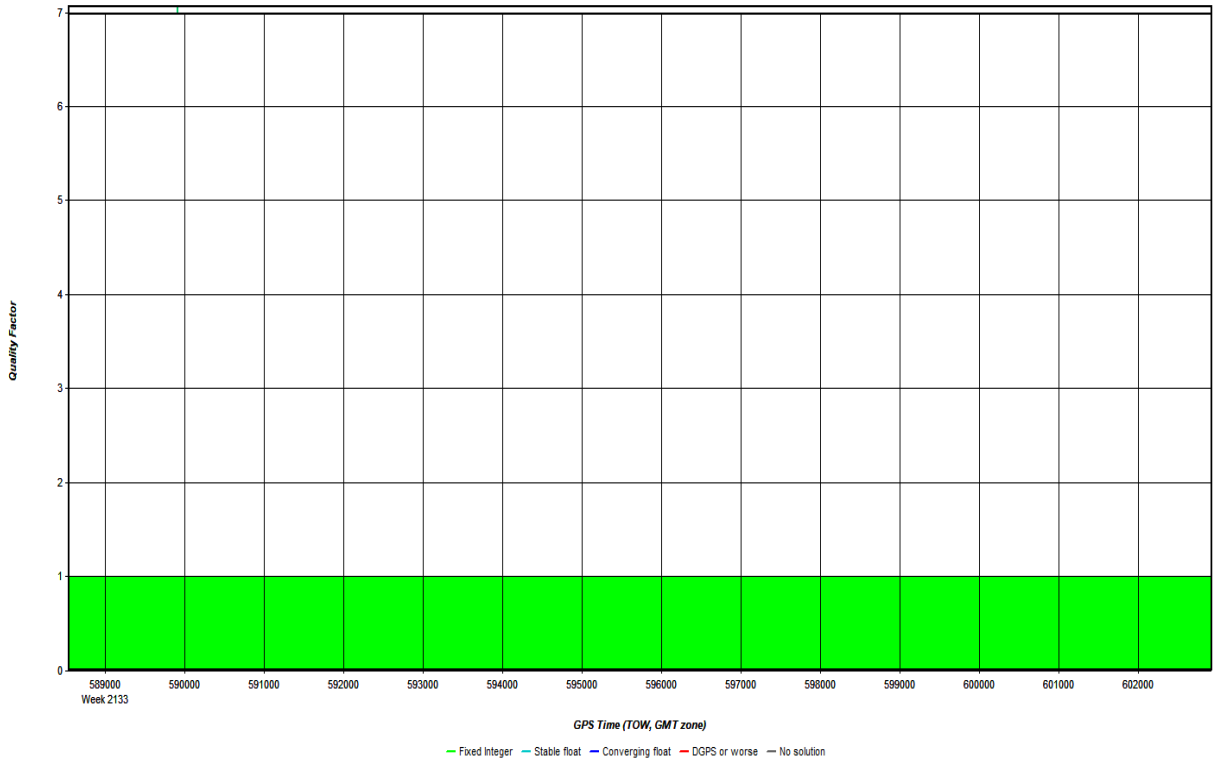
Smoothed Trajectory Information

Top View

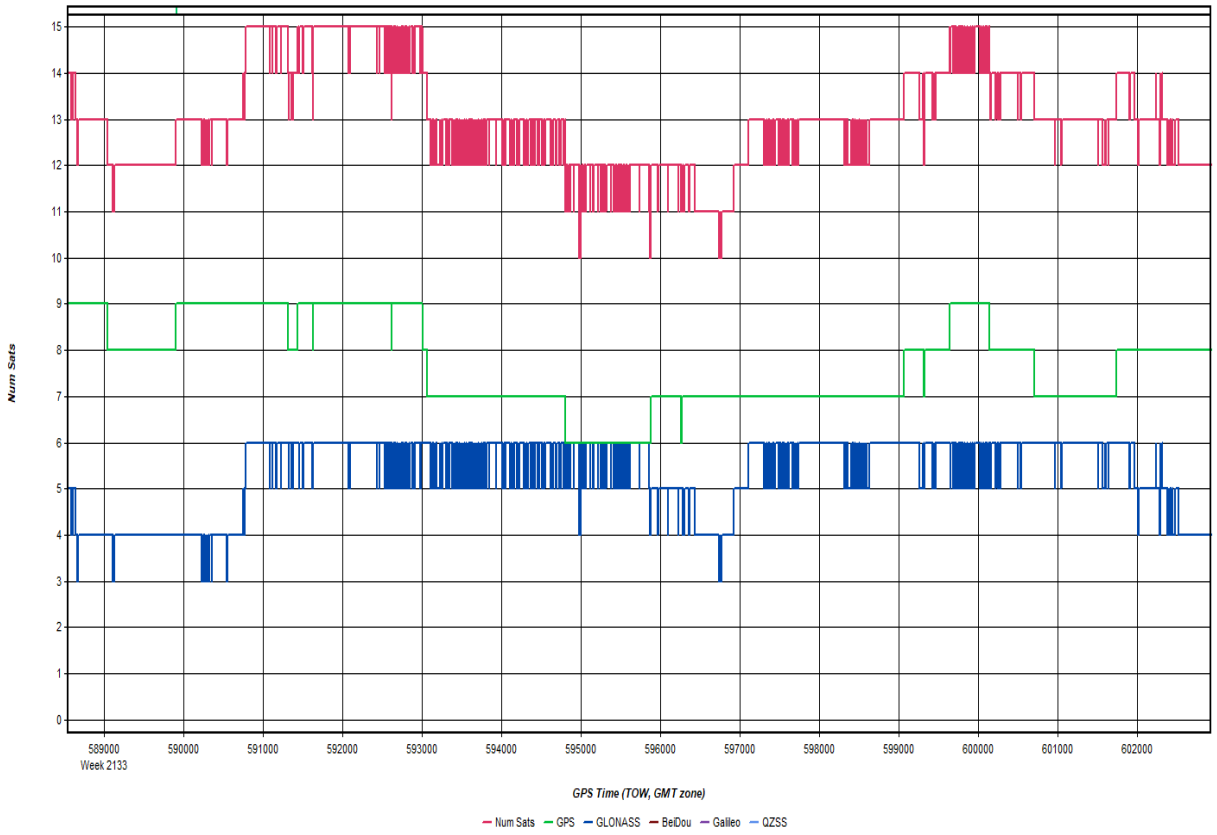


GNSS QC

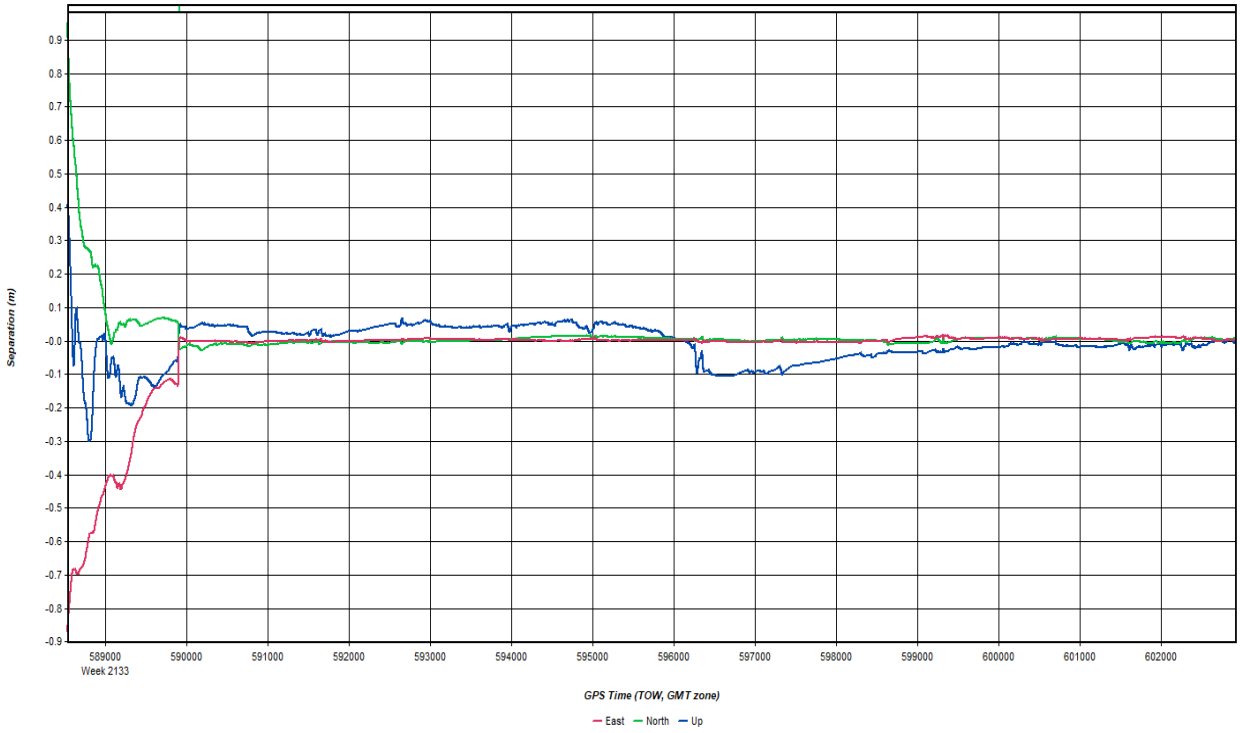
Quality Factor Plot



Number of Satellites Plot



Forward/Reverse or Combined Separation Plot



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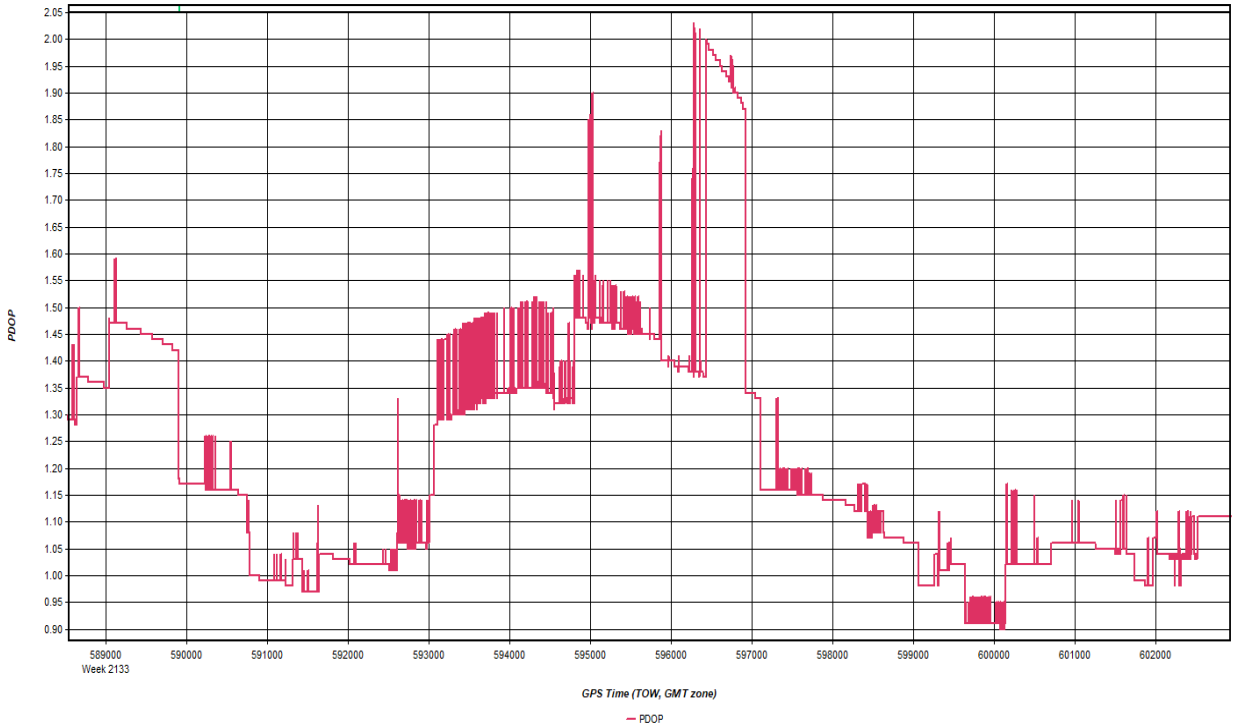
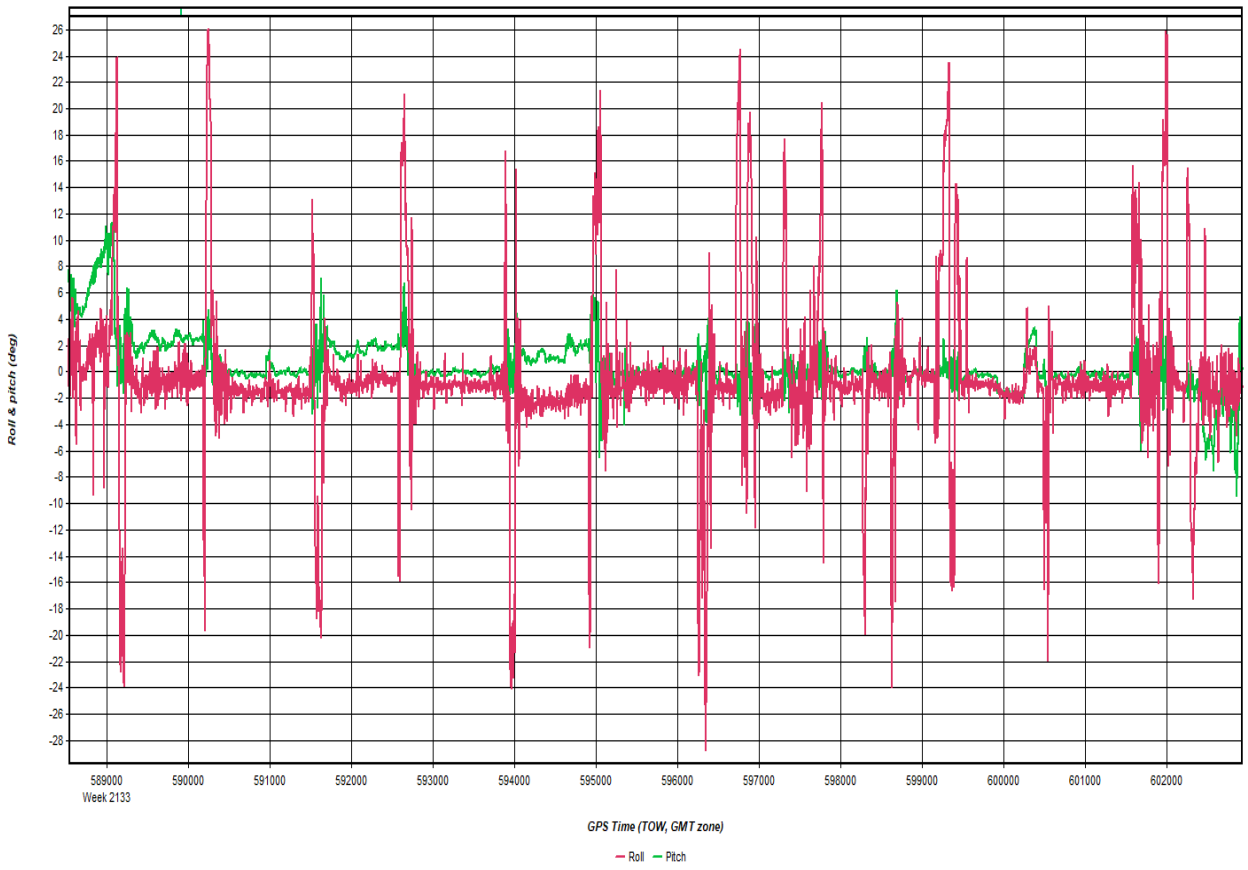


Roll & Pitch Plot



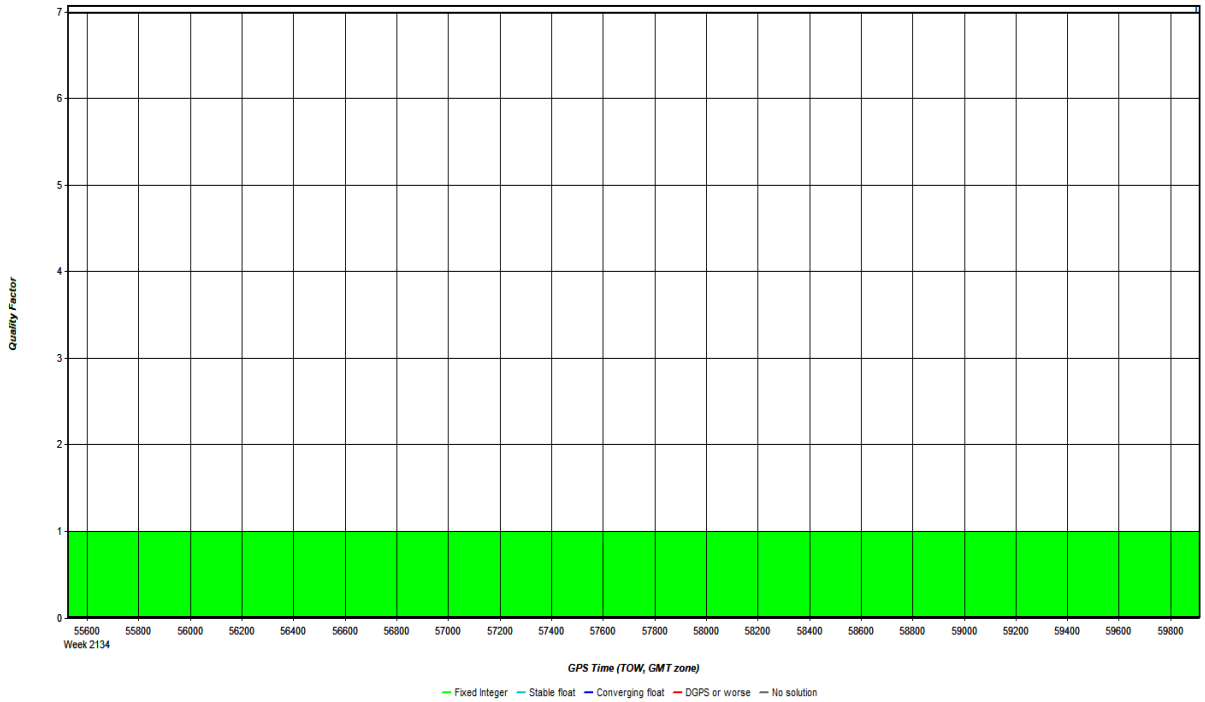
20201129-152321.docx QC Report - 06/22/2021 09:55:12

Smoothed Trajectory Information

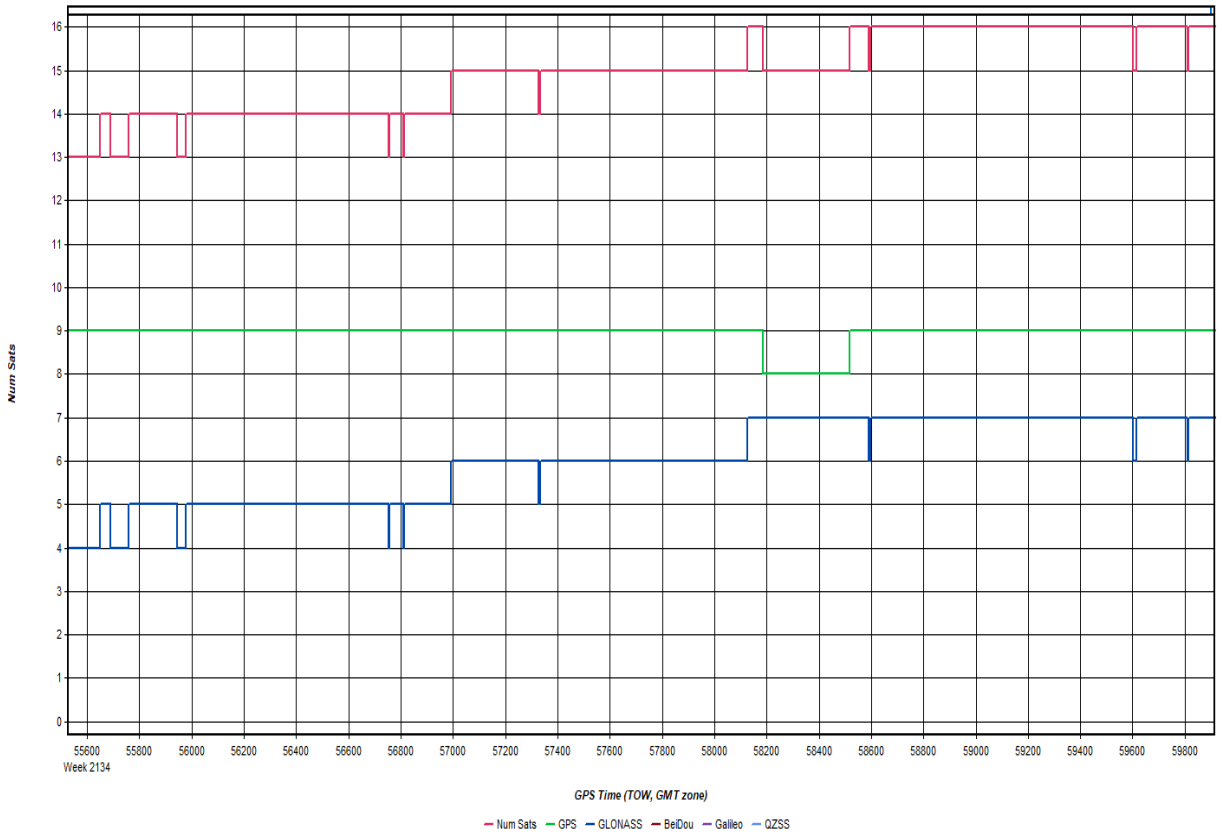
Top View

GNSS QC

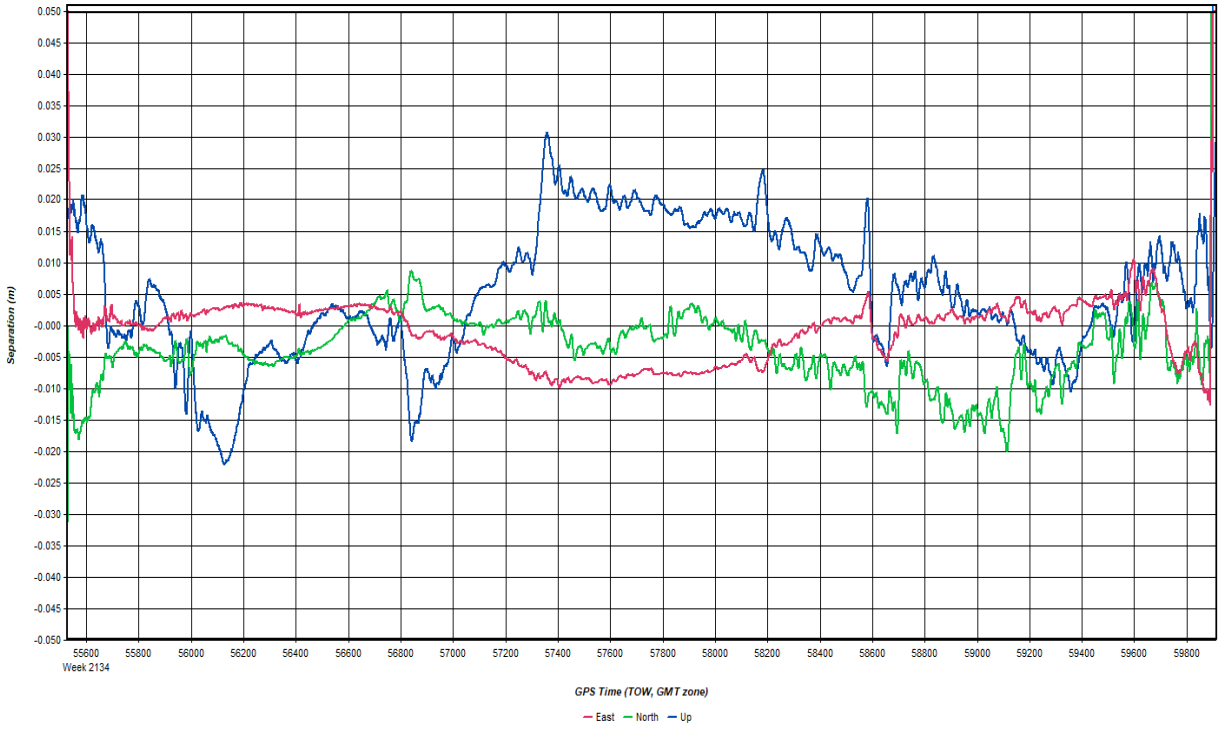
Quality Factor Plot



Number of Satellites Plot



Forward/Reverse or Combined Separation Plot



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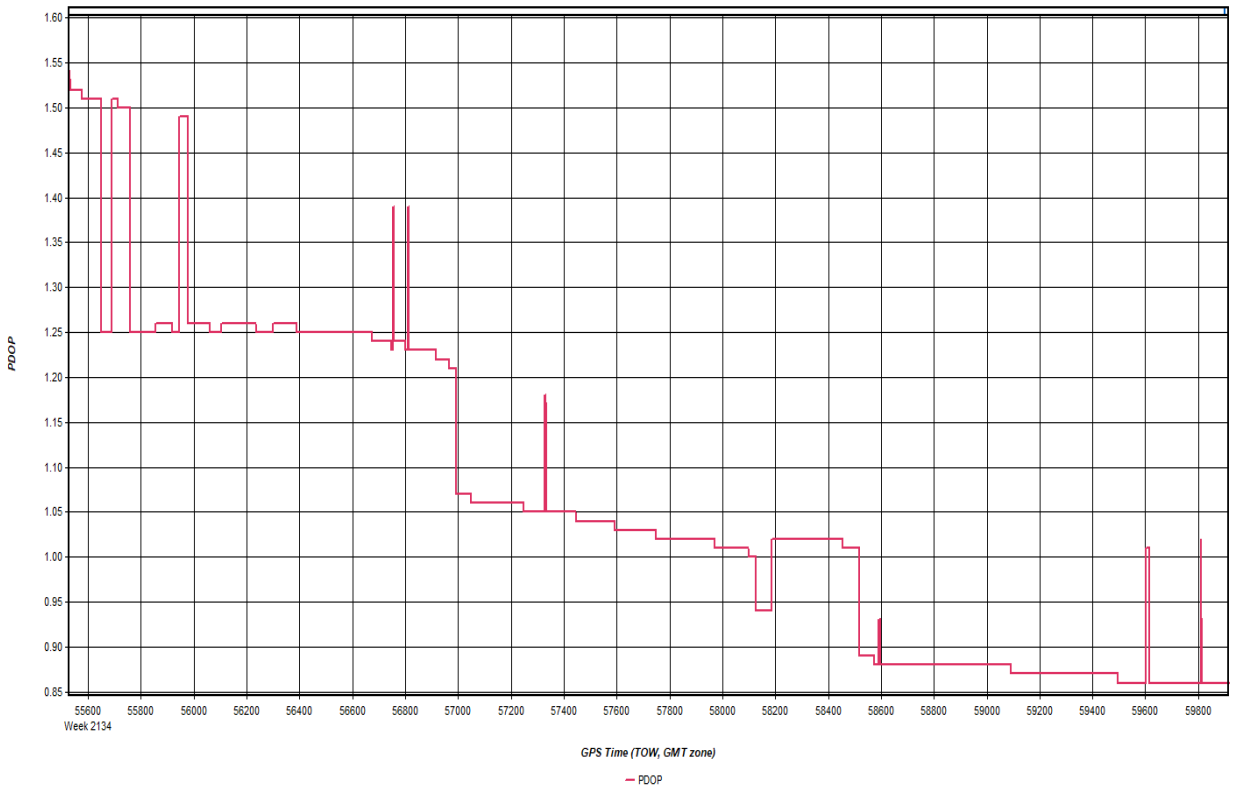
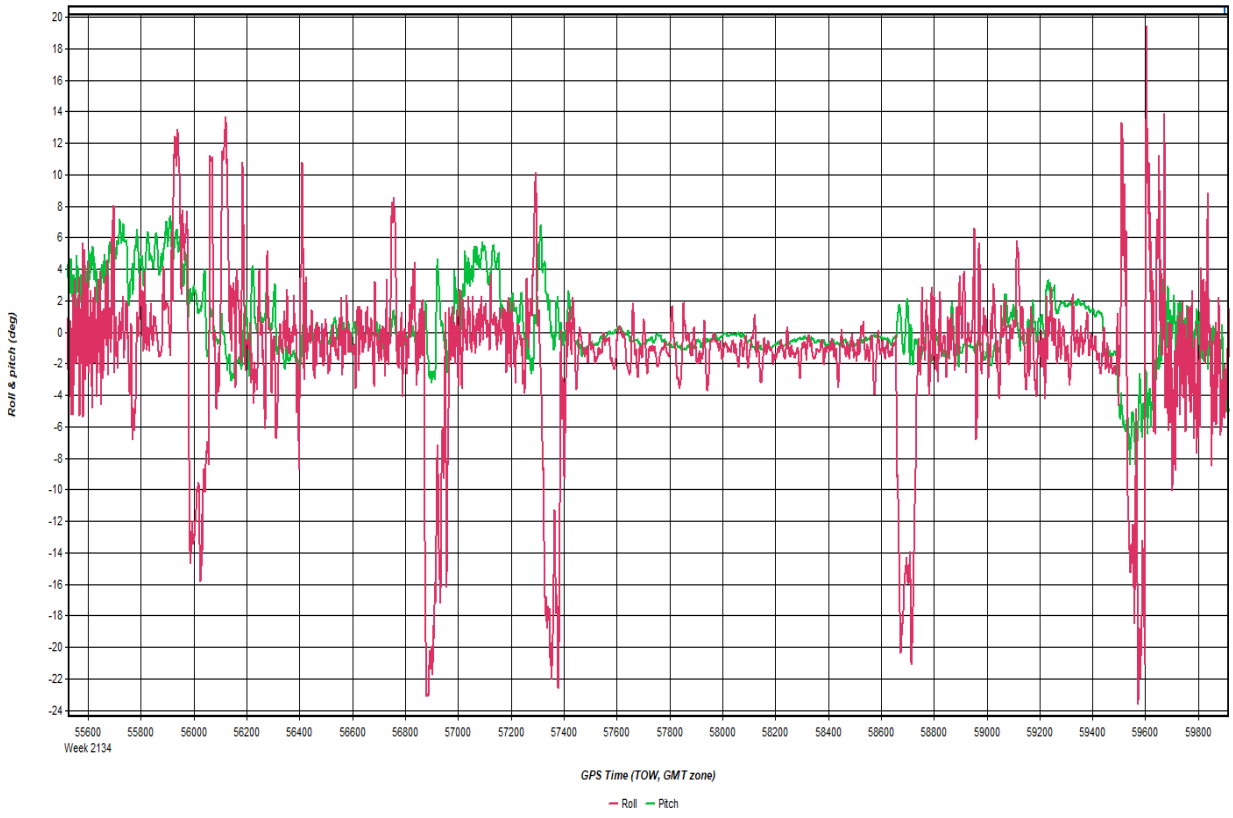


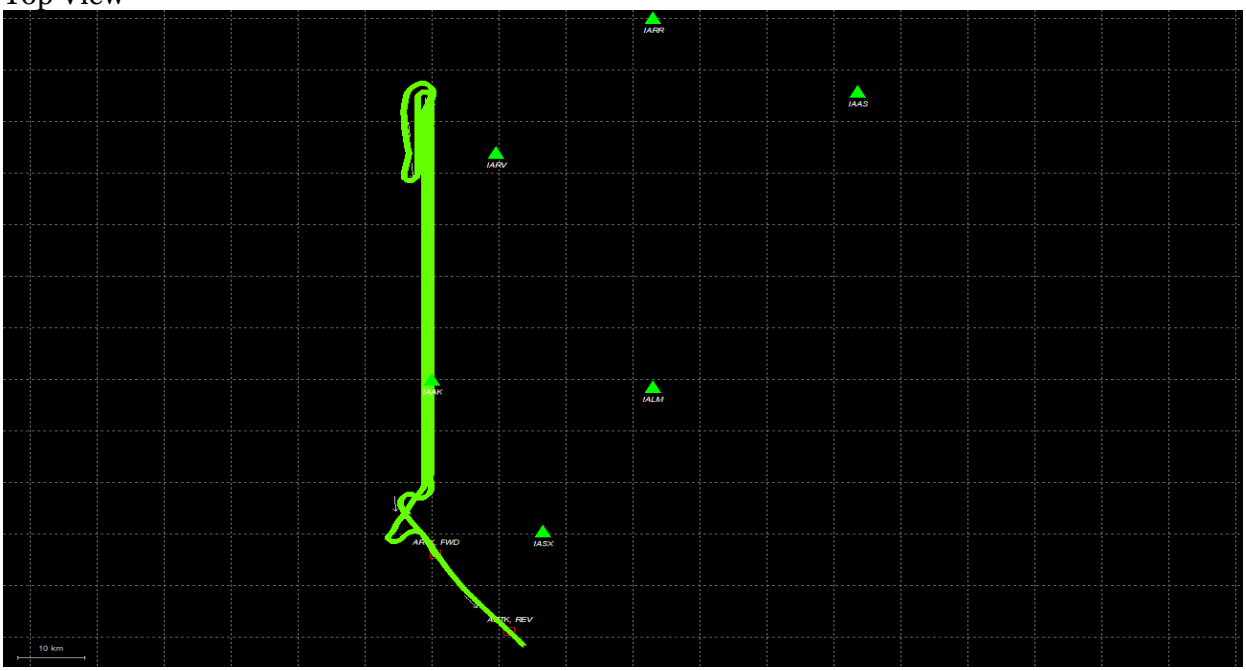
Roll & Pitch Plot



20201130_001852.docx QC Report - 06/22/2021 09:58:40

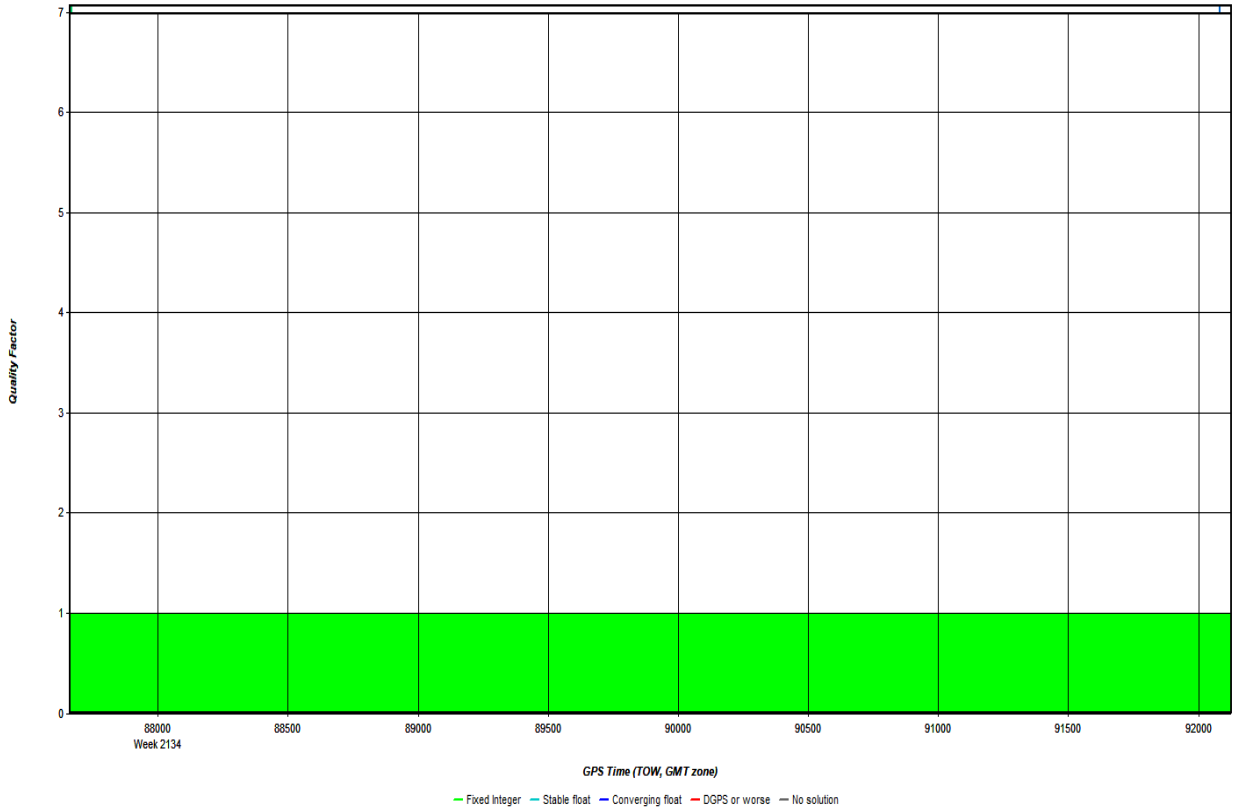
Smoothed Trajectory Information

Top View

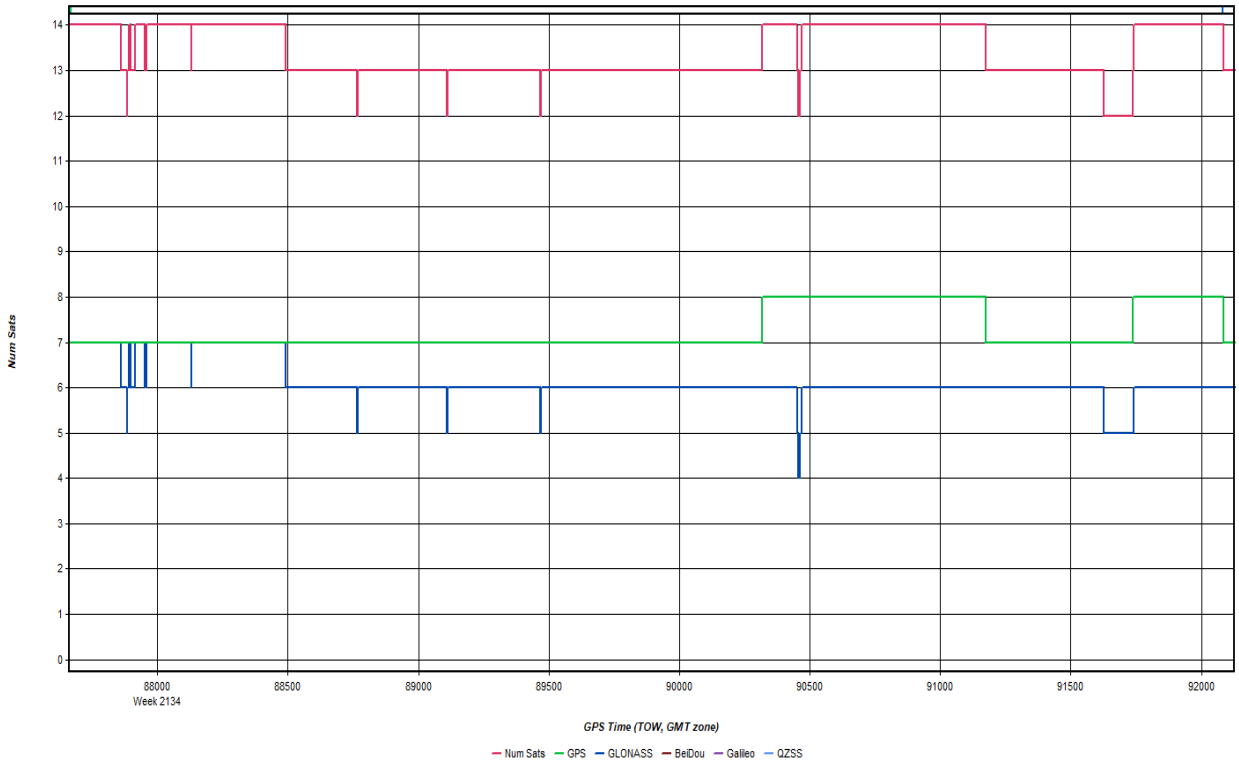


GNSS QC

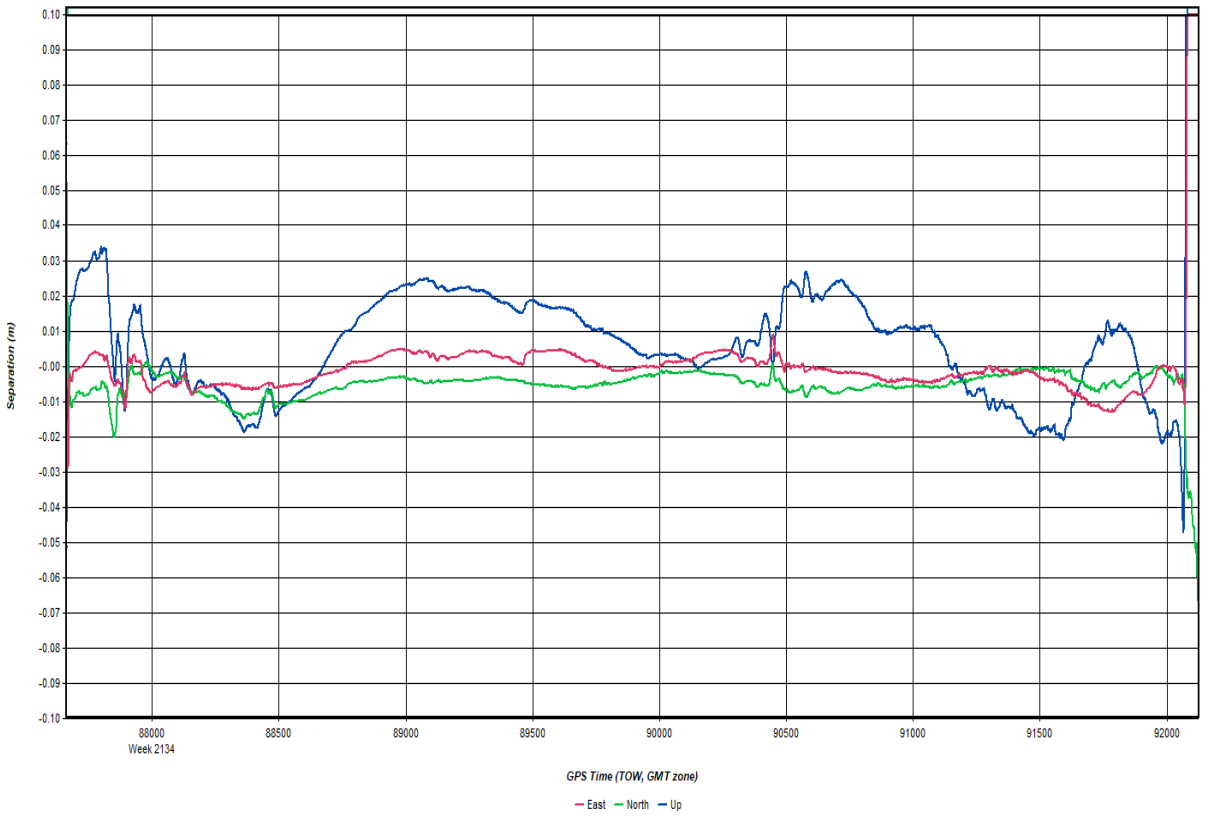
Quality Factor Plot



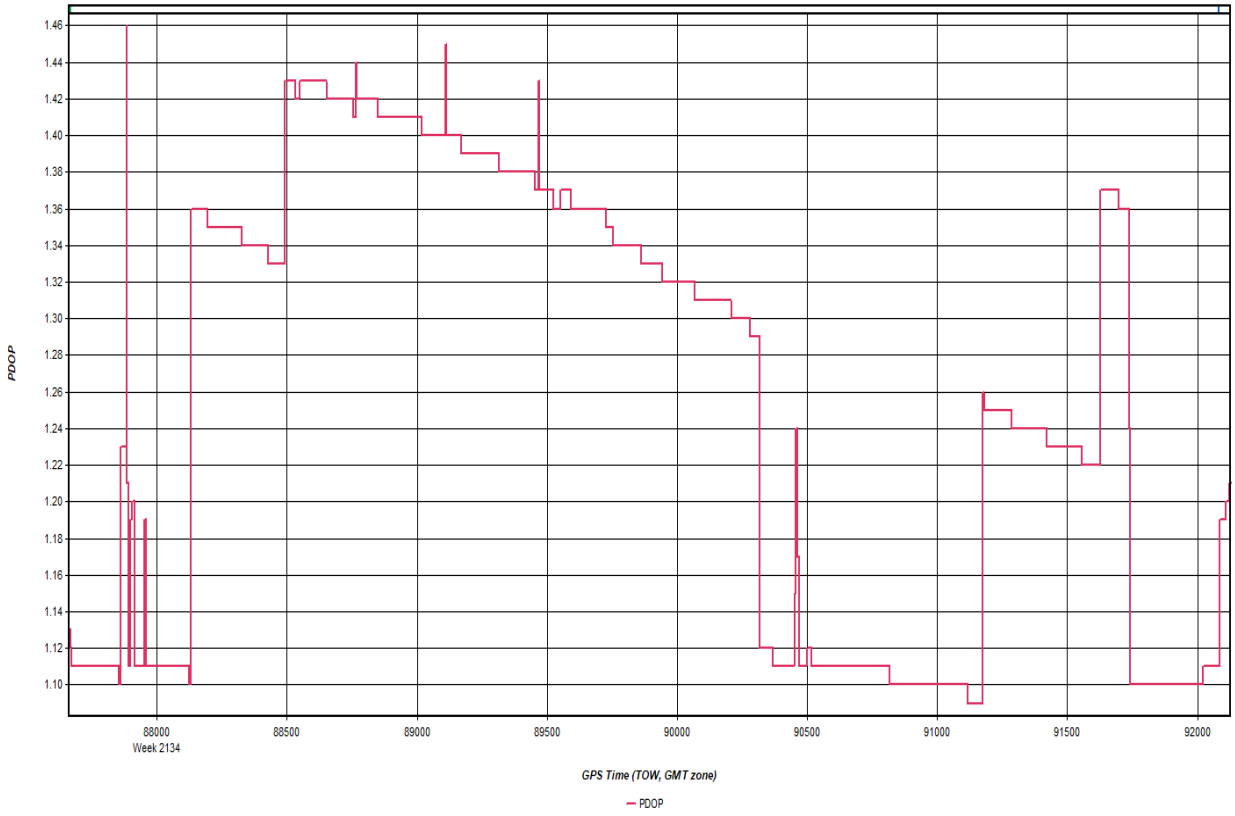
Number of Satellites Plot



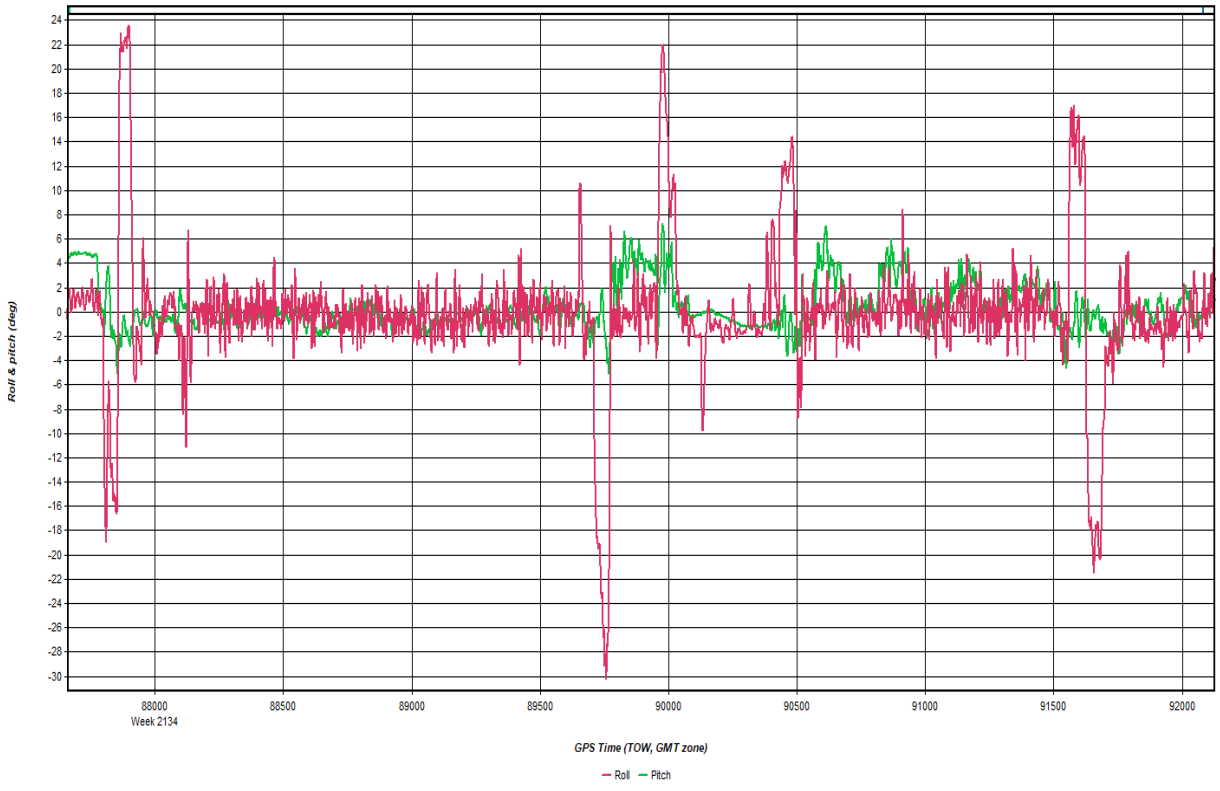
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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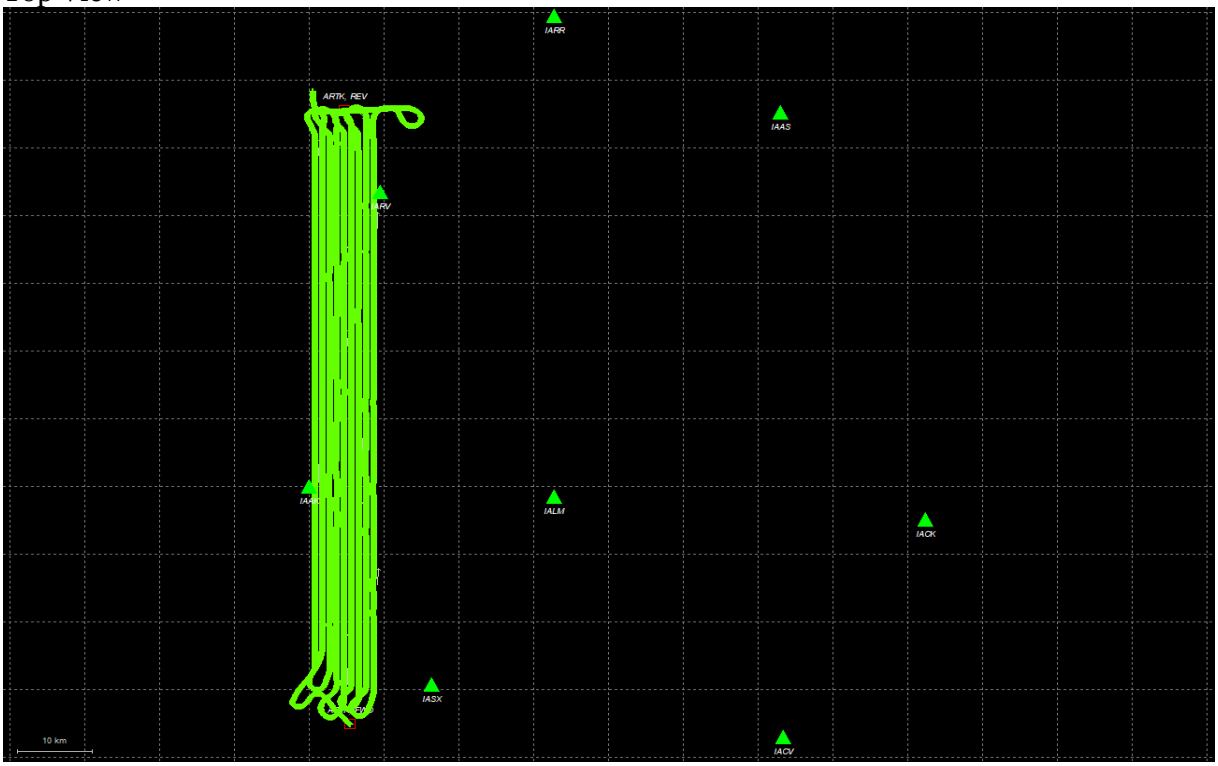
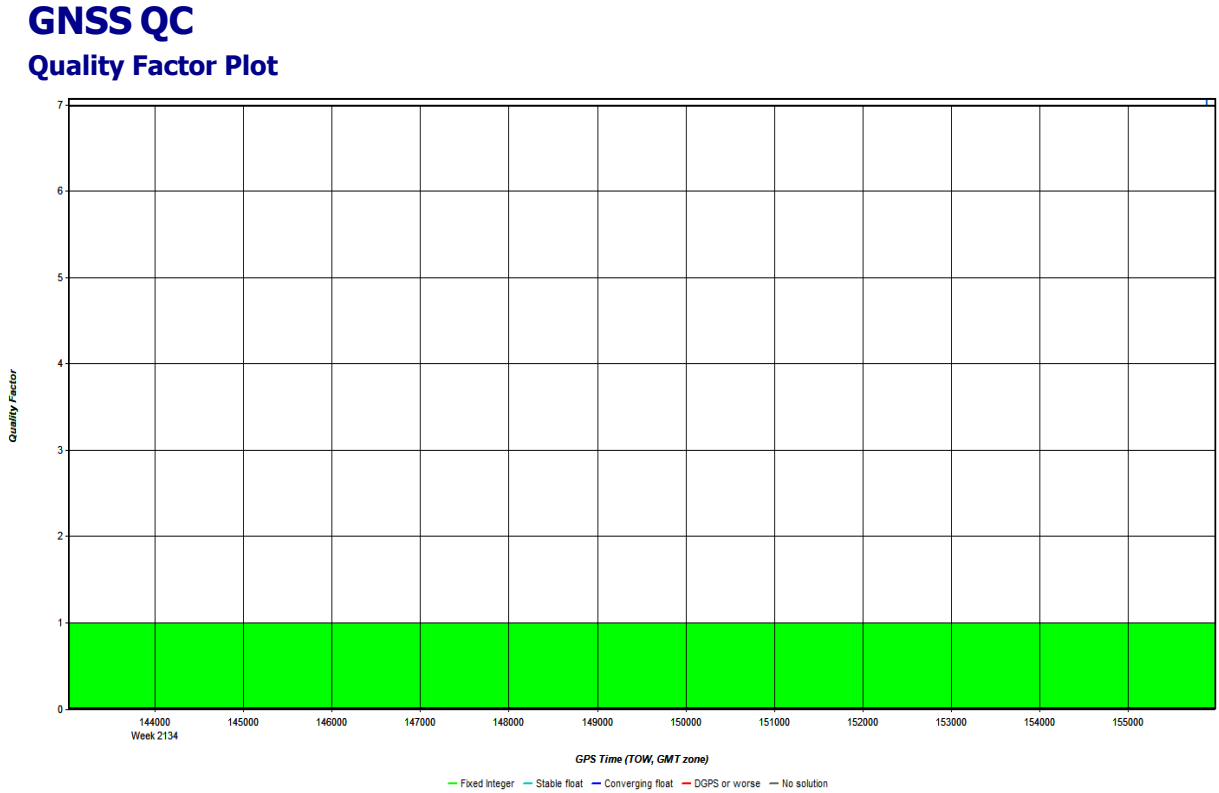
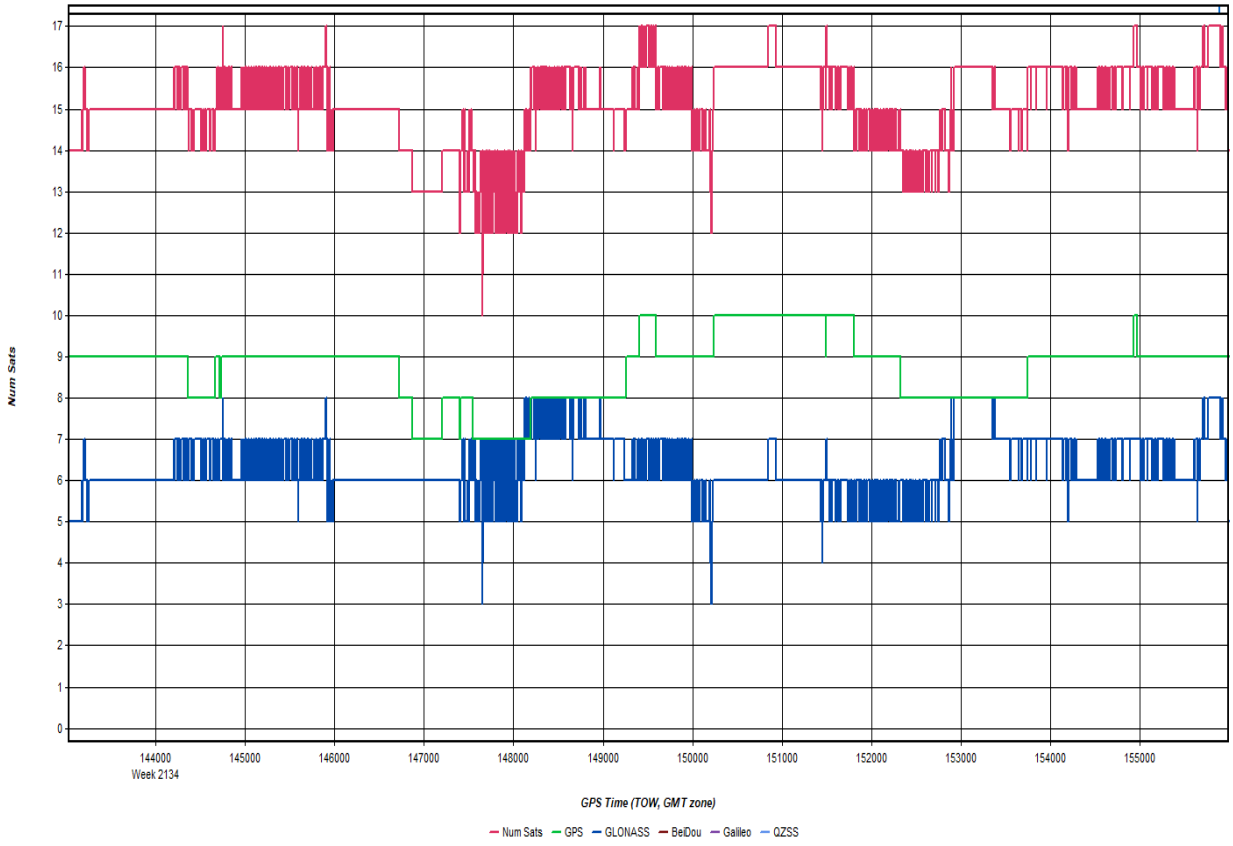
Smoothed Trajectory Information

Top View

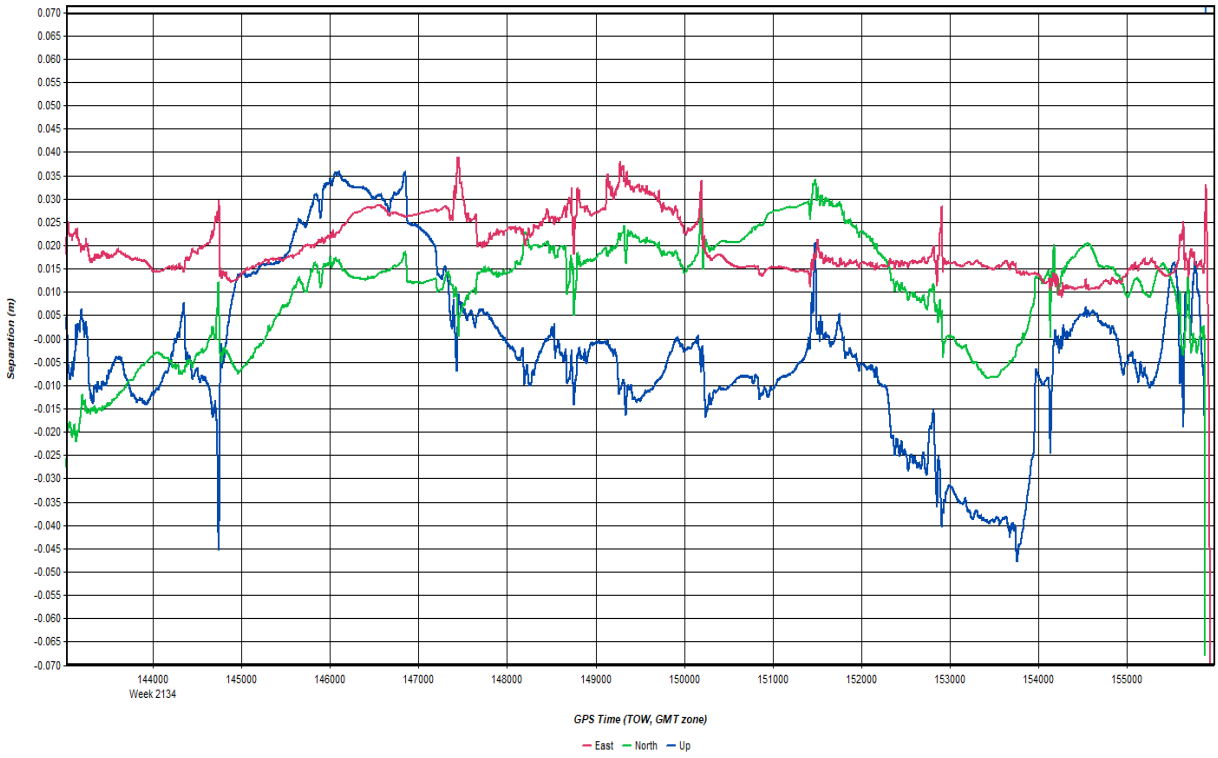




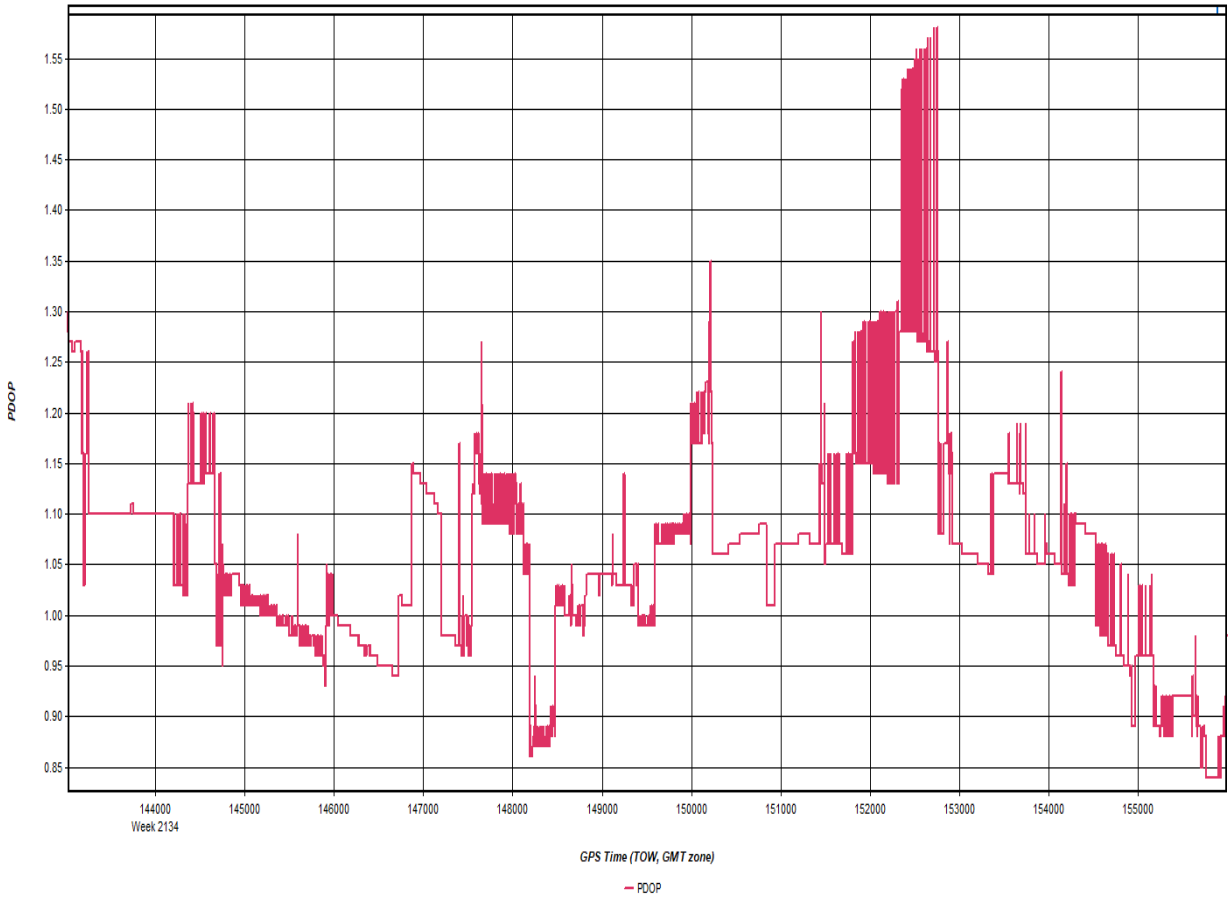
Number of Satellites Plot



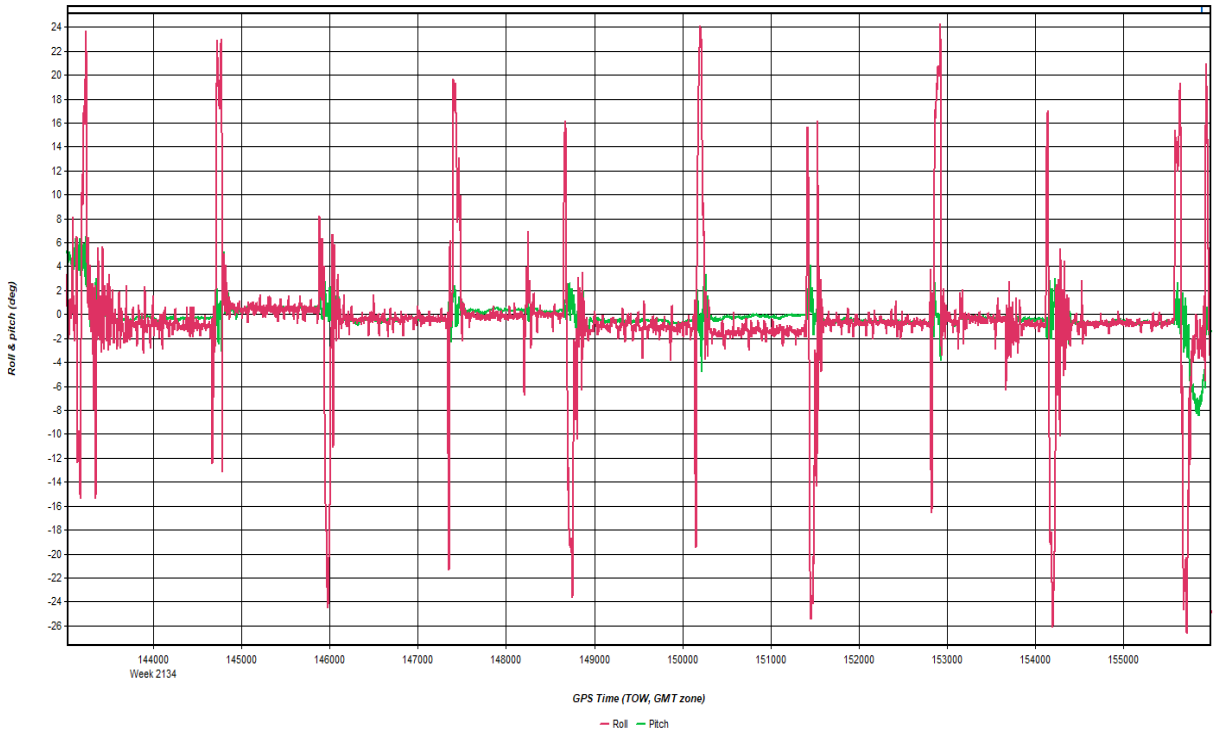
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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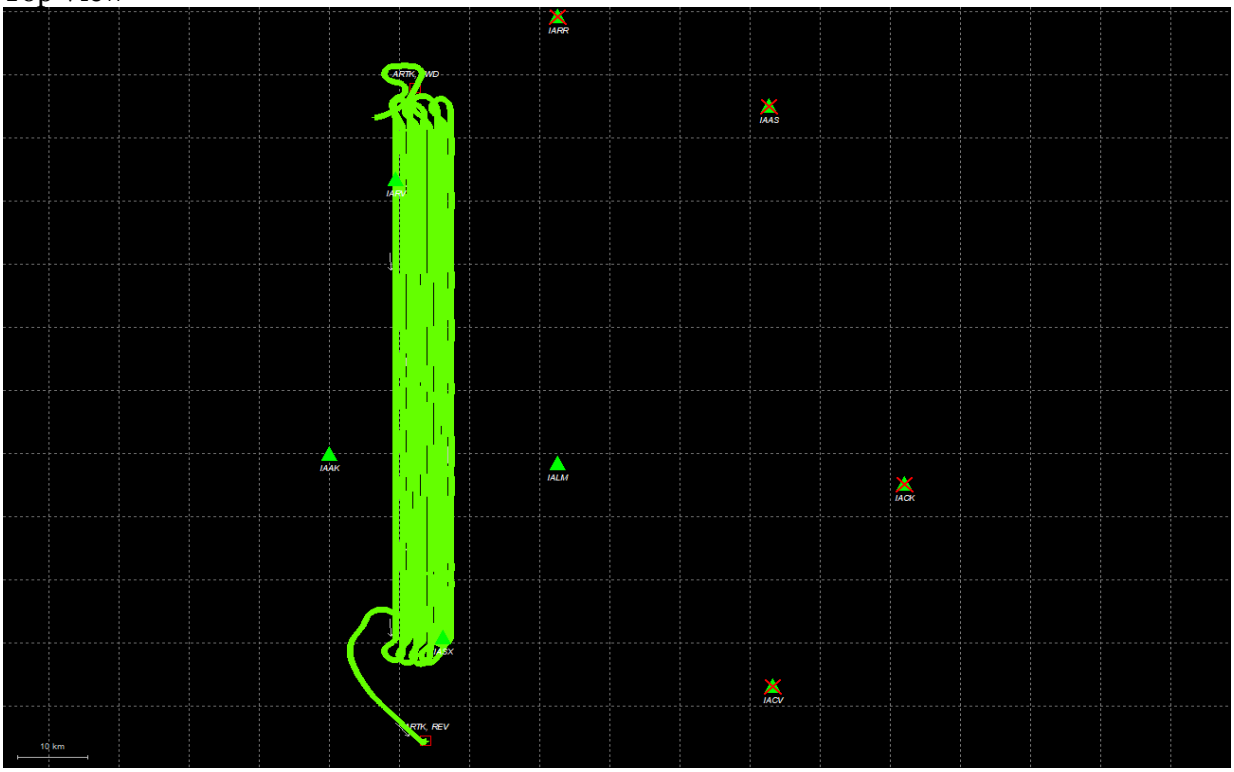
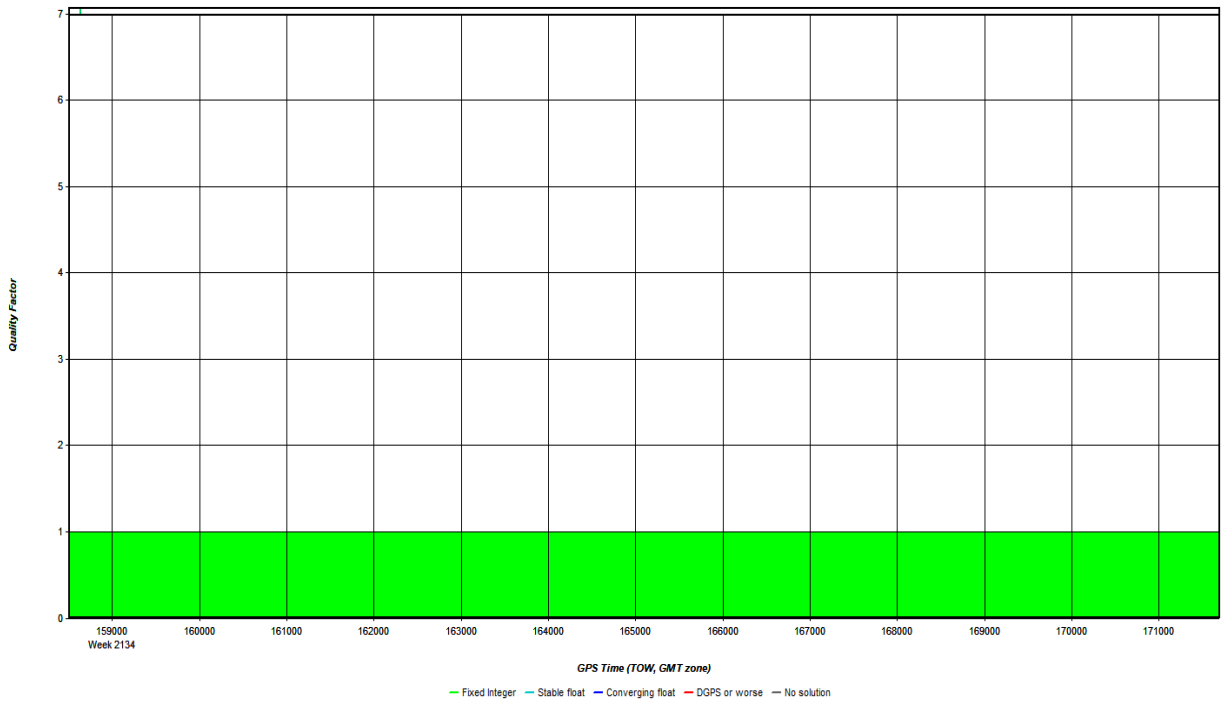
Smoothed Trajectory Information

Top View

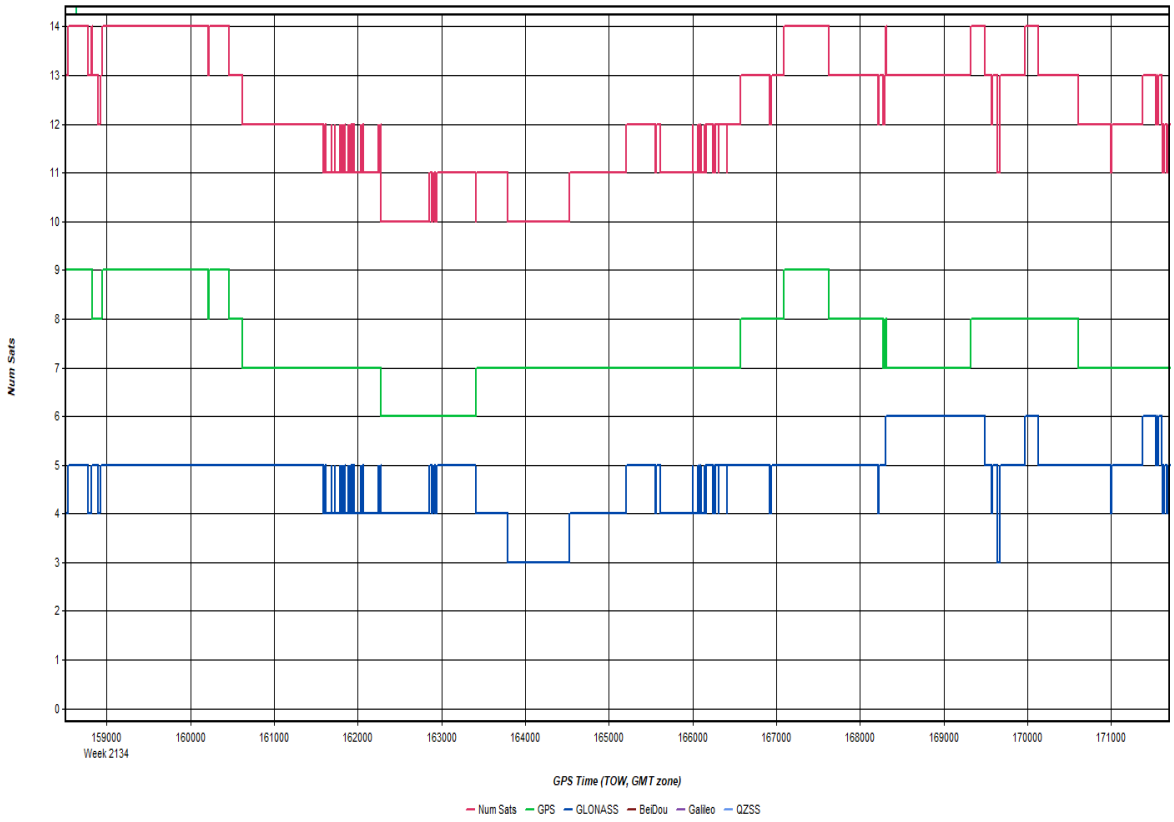


GNSS QC

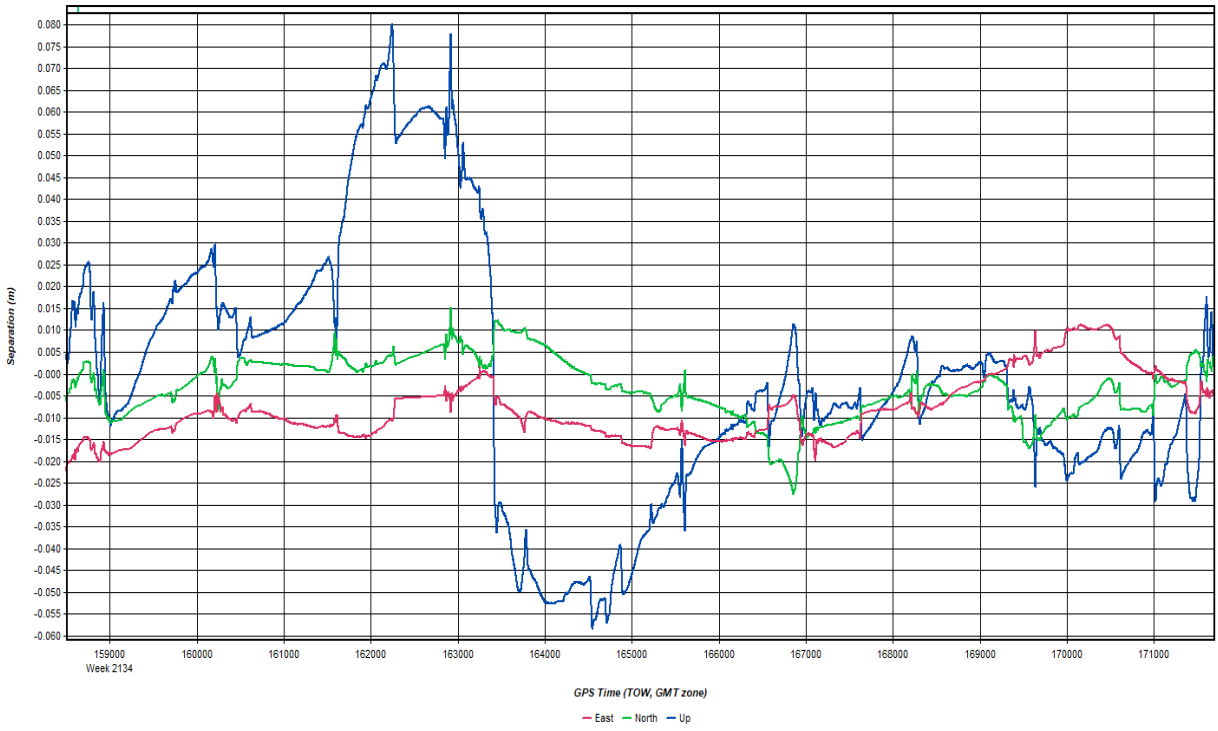
Quality Factor Plot



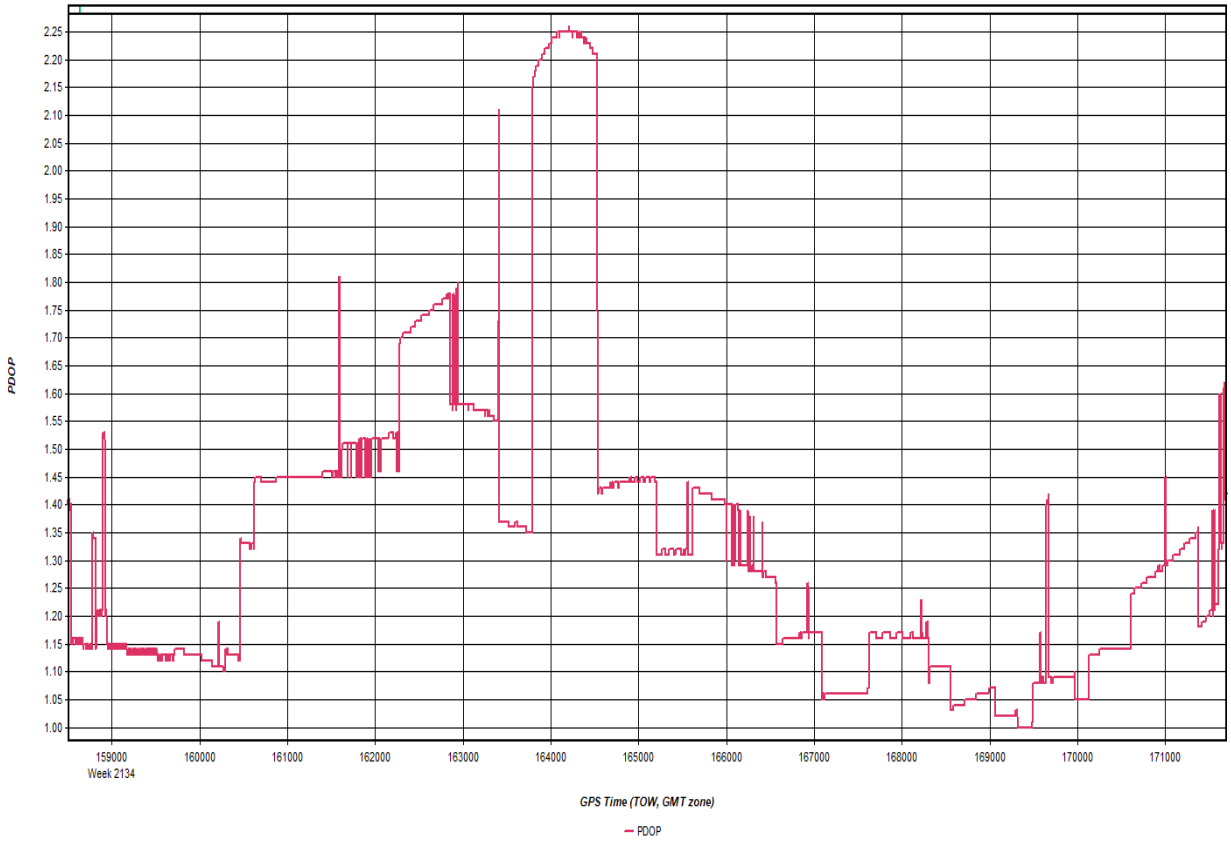
Number of Satellites Plot



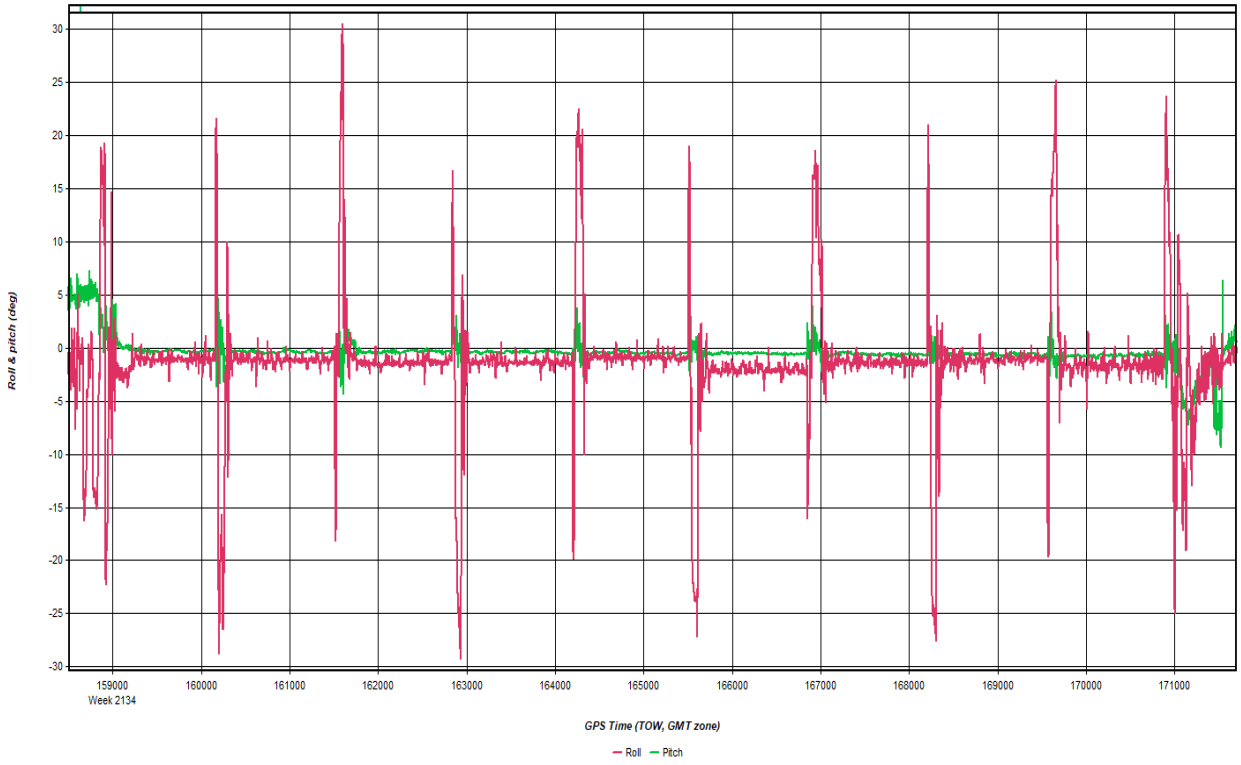
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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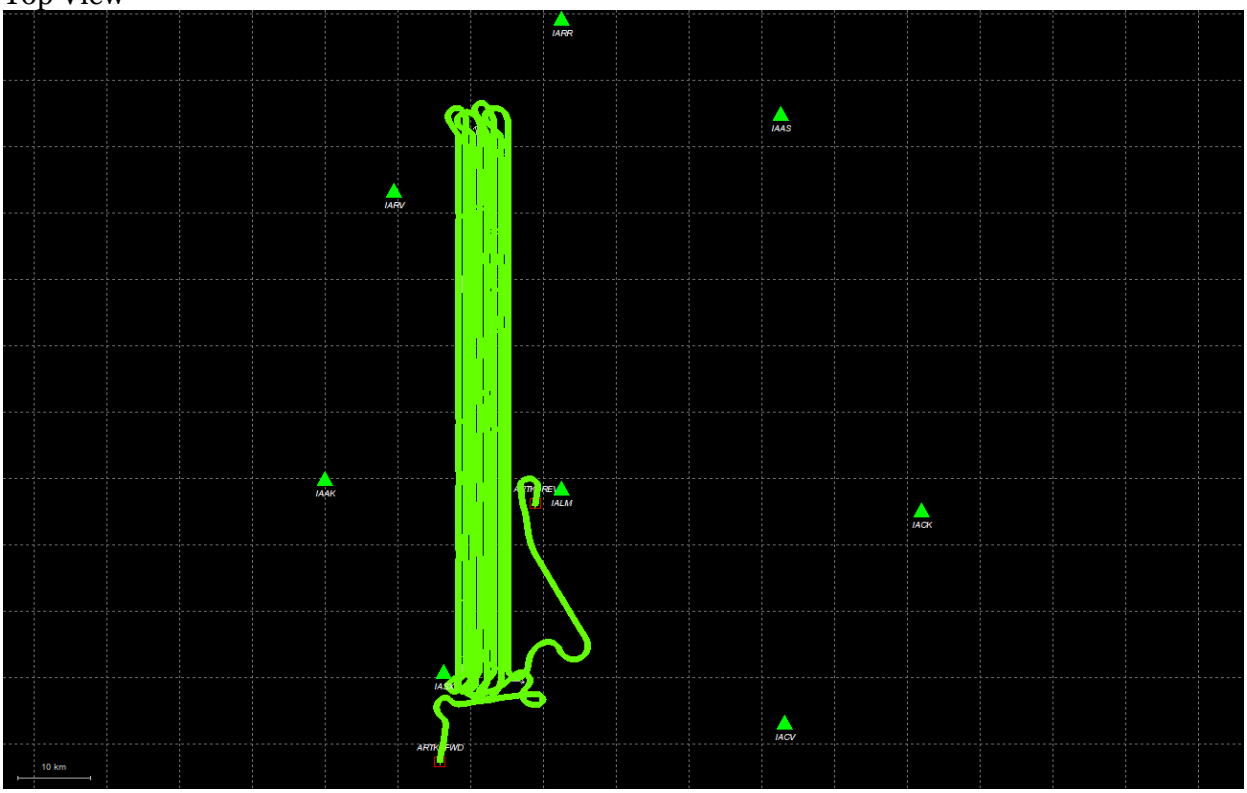
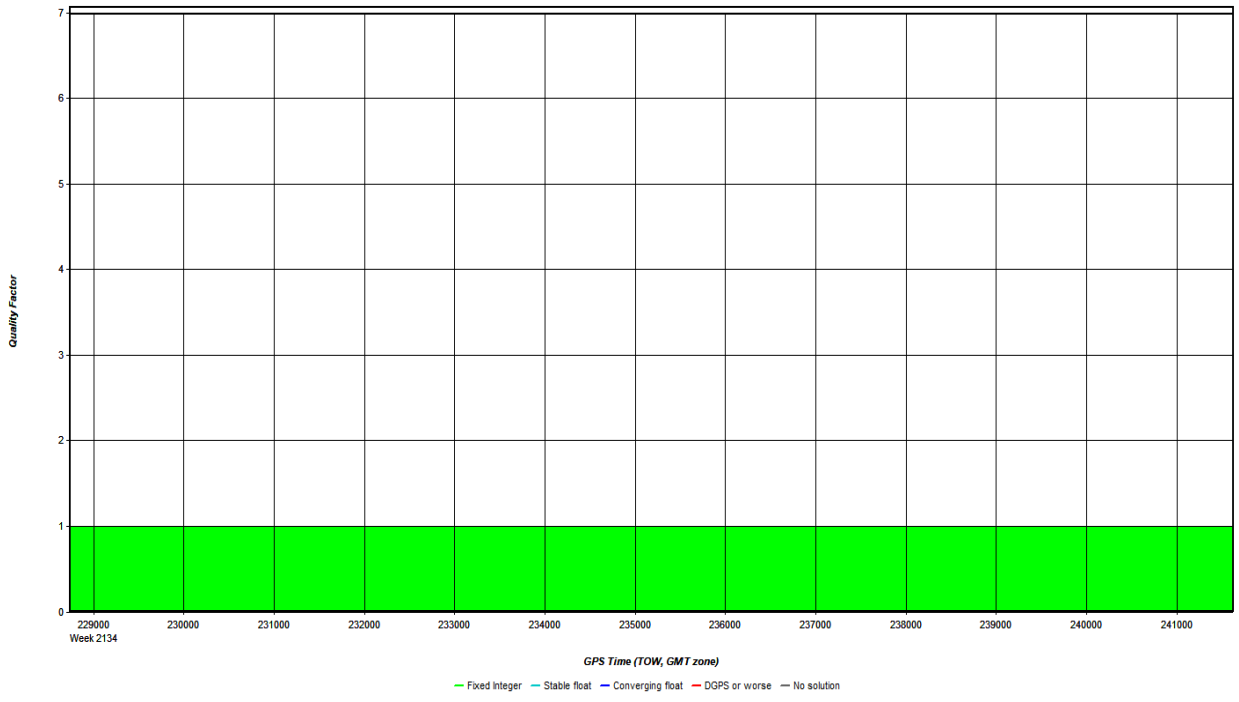
Smoothed Trajectory Information

Top View

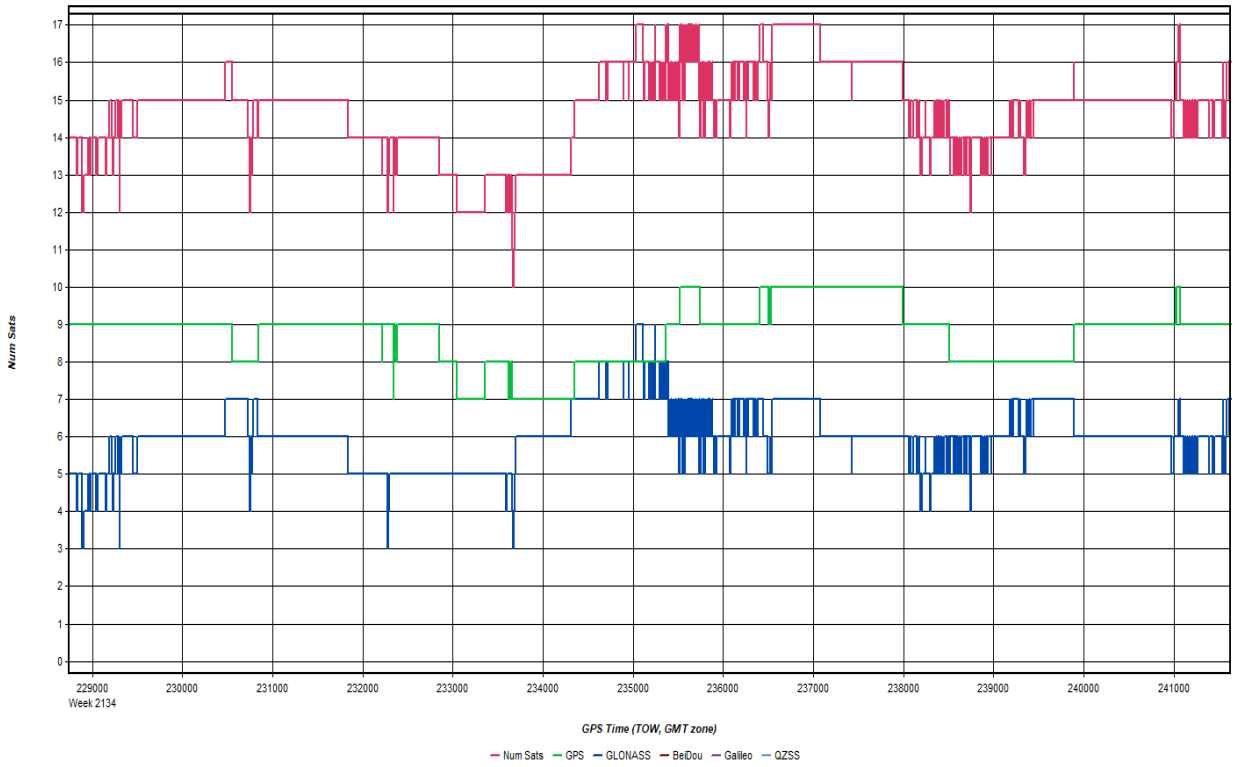


GNSS QC

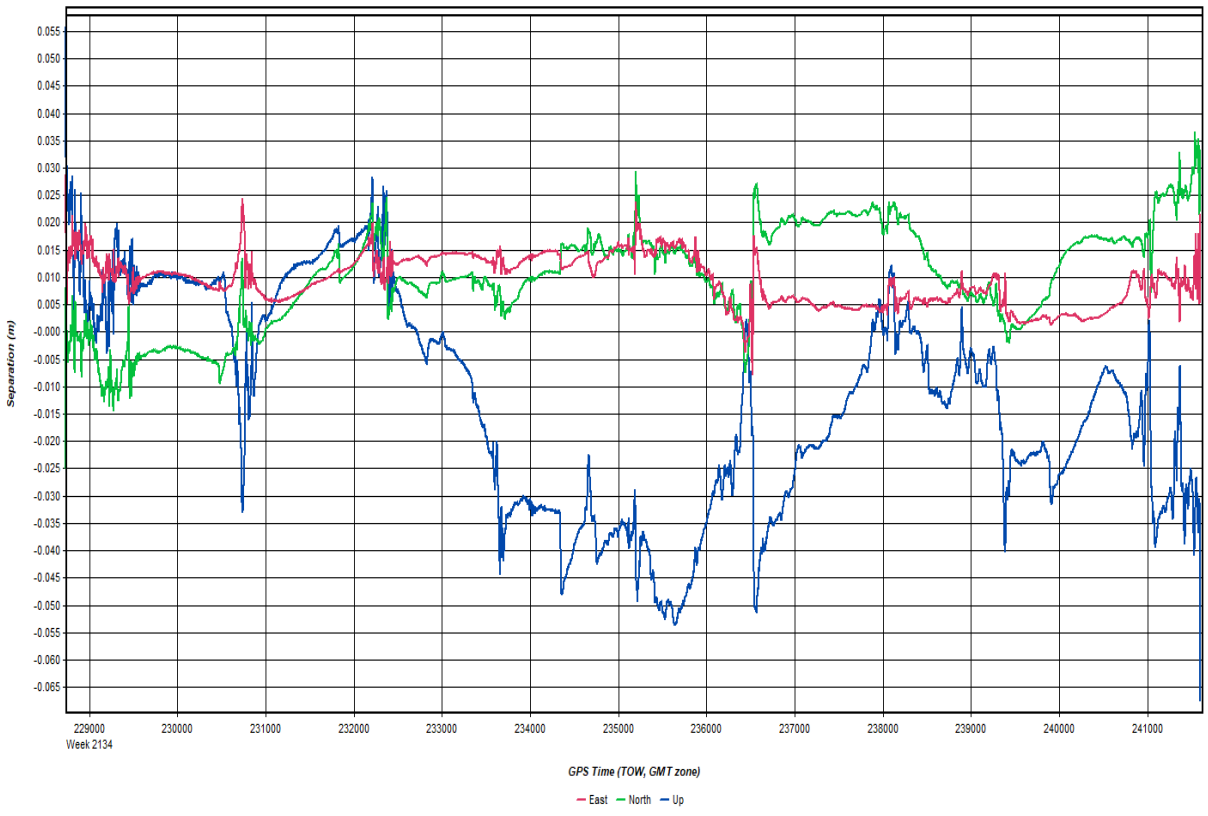
Quality Factor Plot



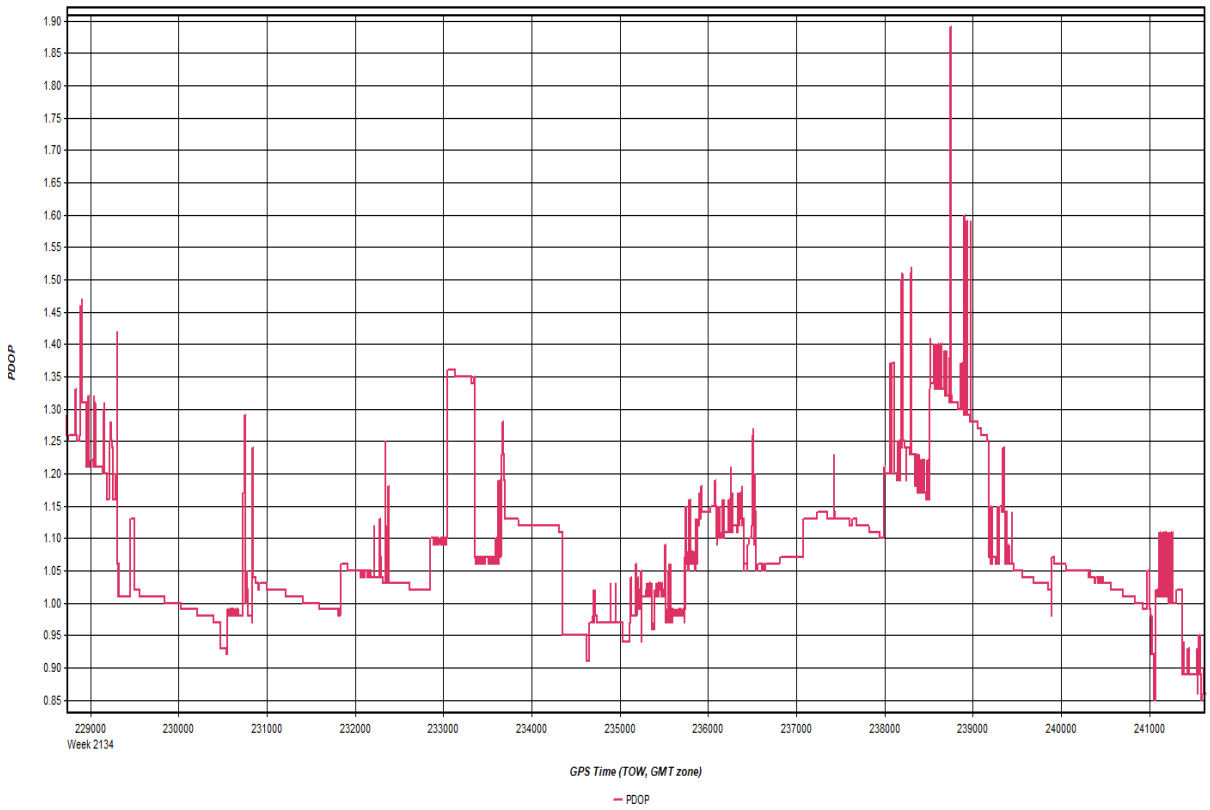
Number of Satellites Plot



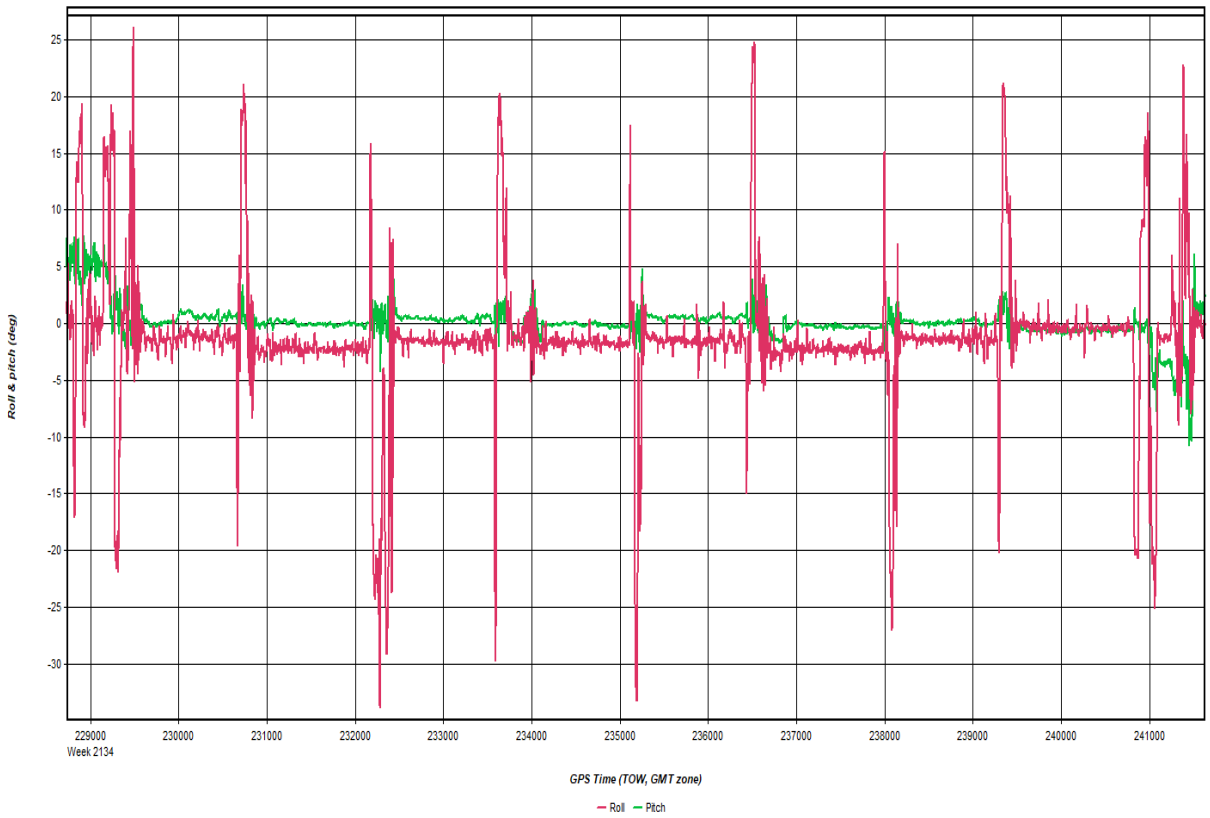
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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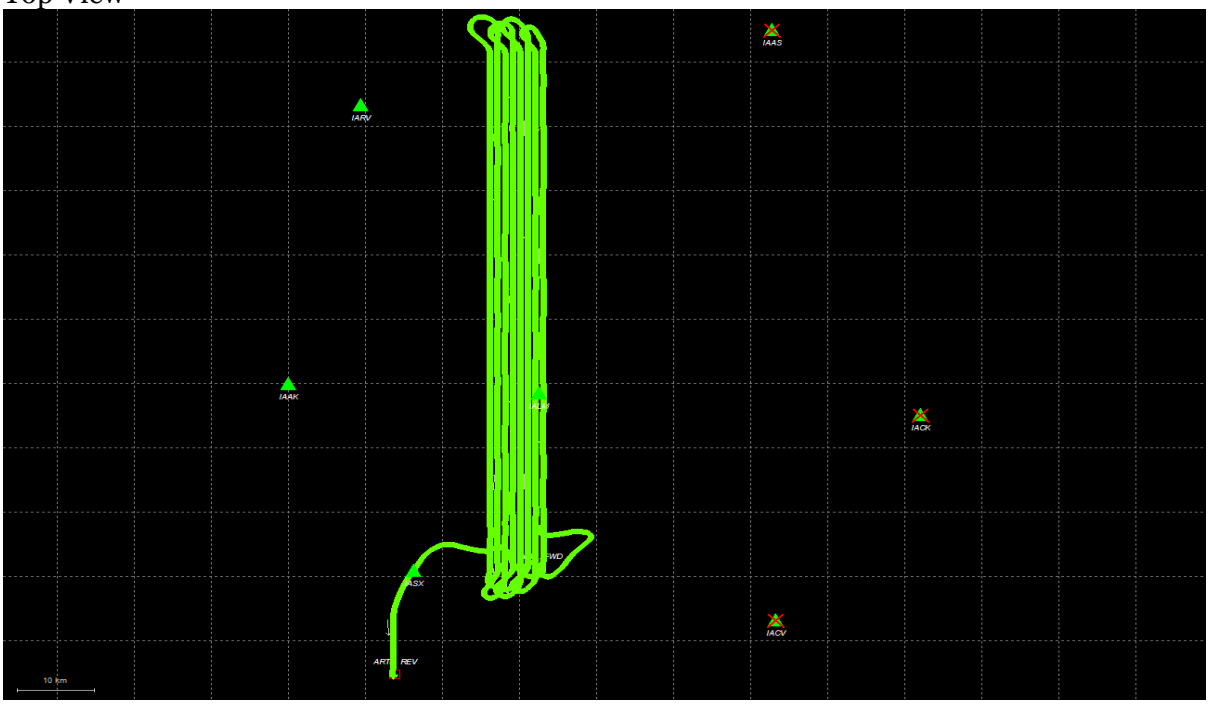
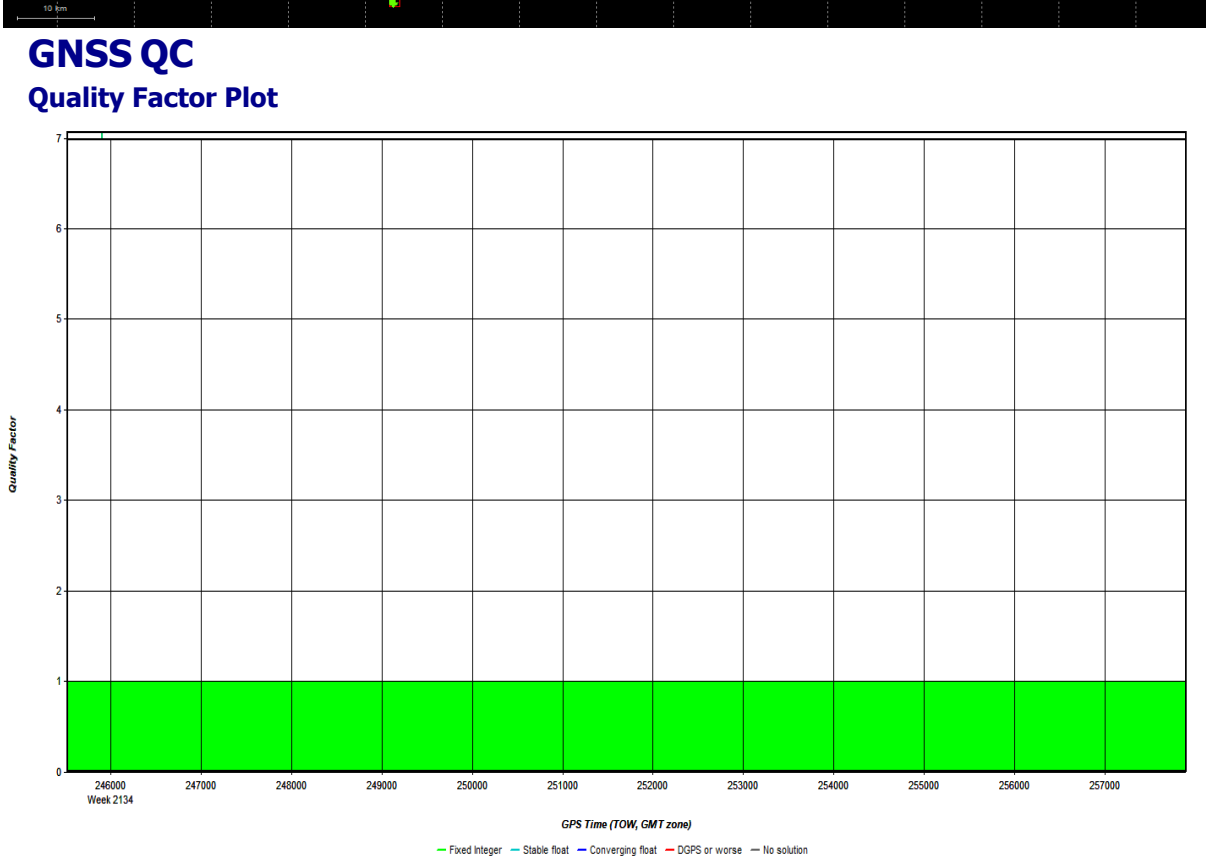
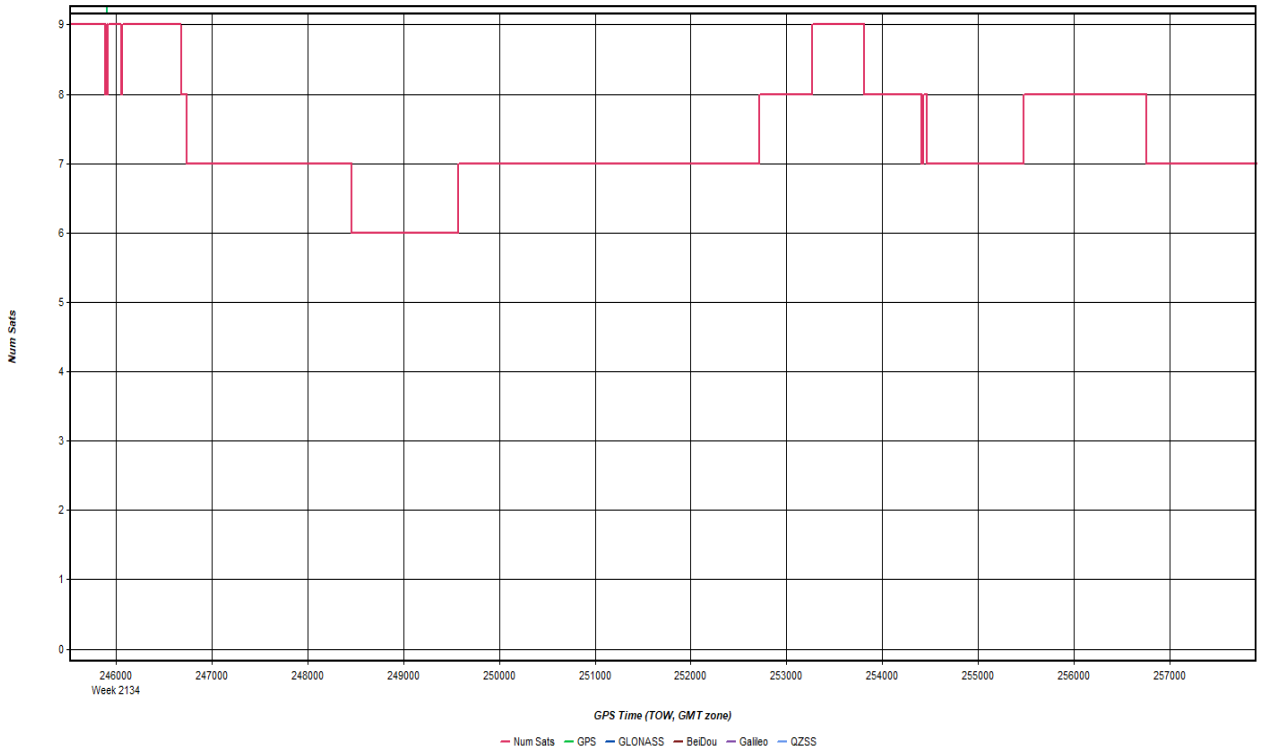
Smoothed Trajectory Information

Top View



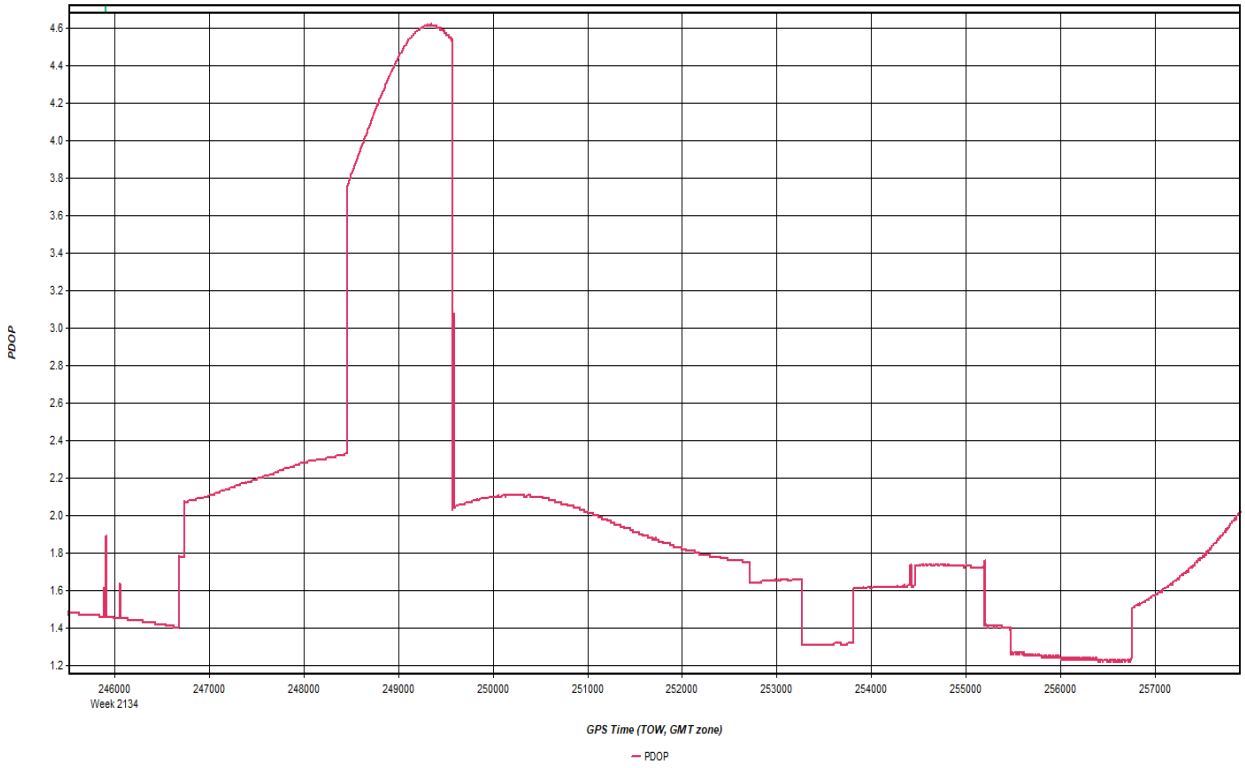


Number of Satellites Plot

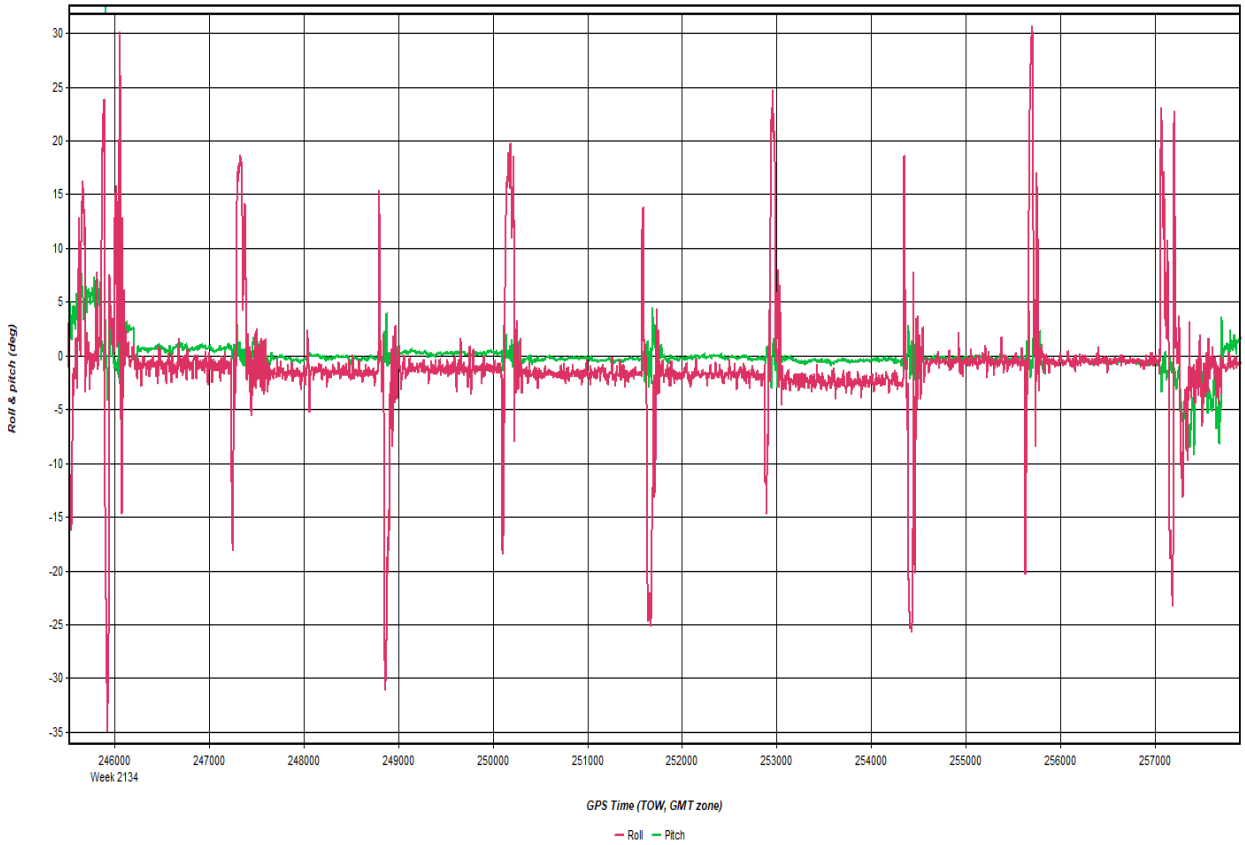


Forward/Reverse or Combined Separation Plot

PDOP Plot



Roll & Pitch Plot



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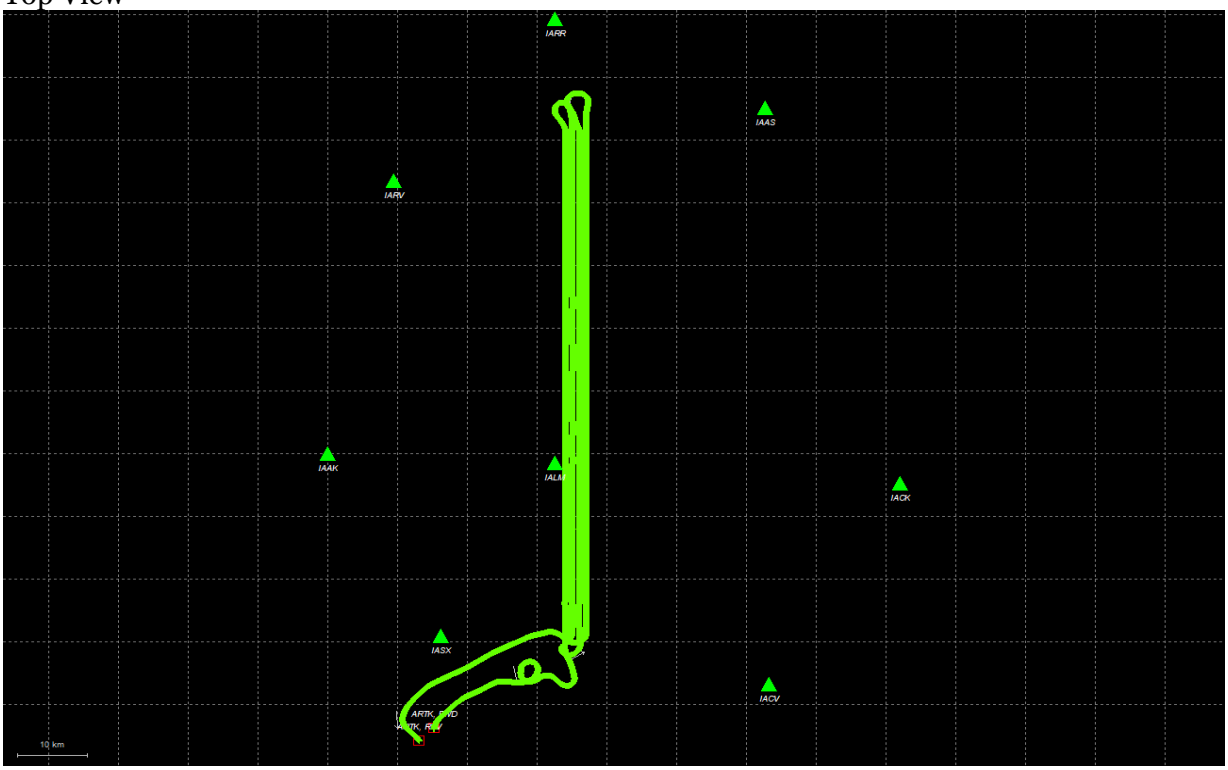
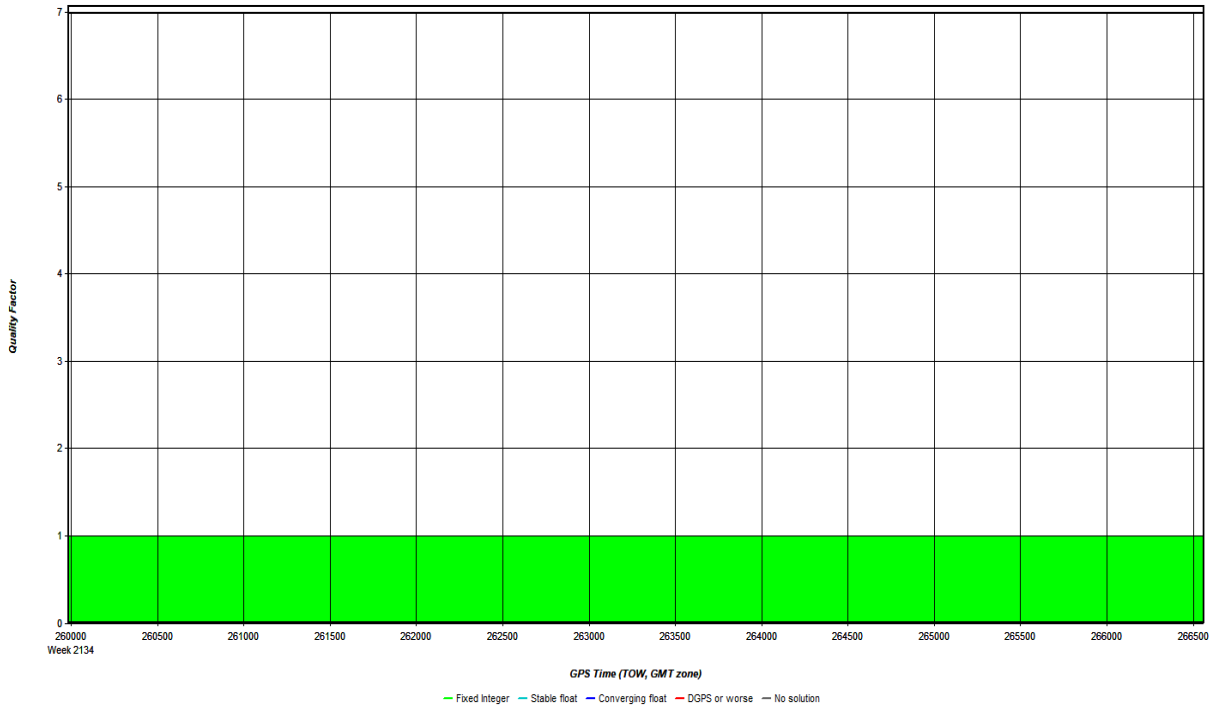
Smoothed Trajectory Information

Top View

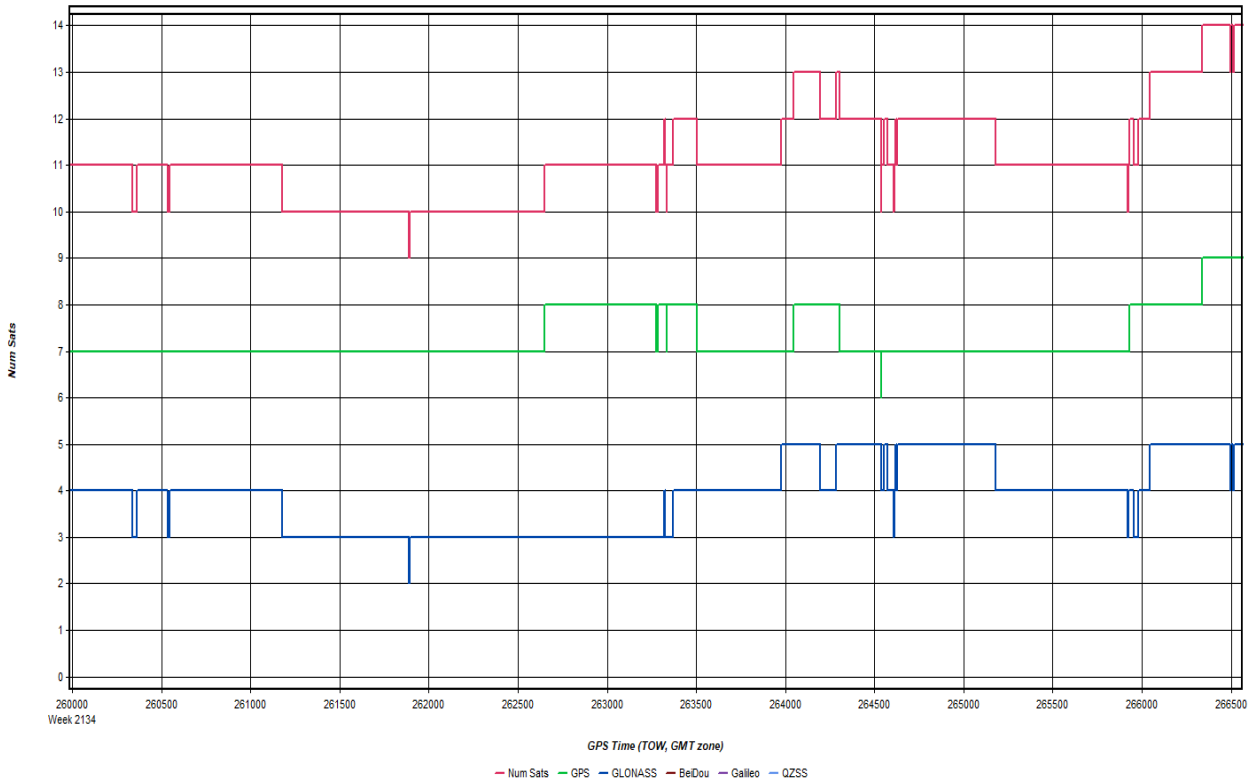


GNSS QC

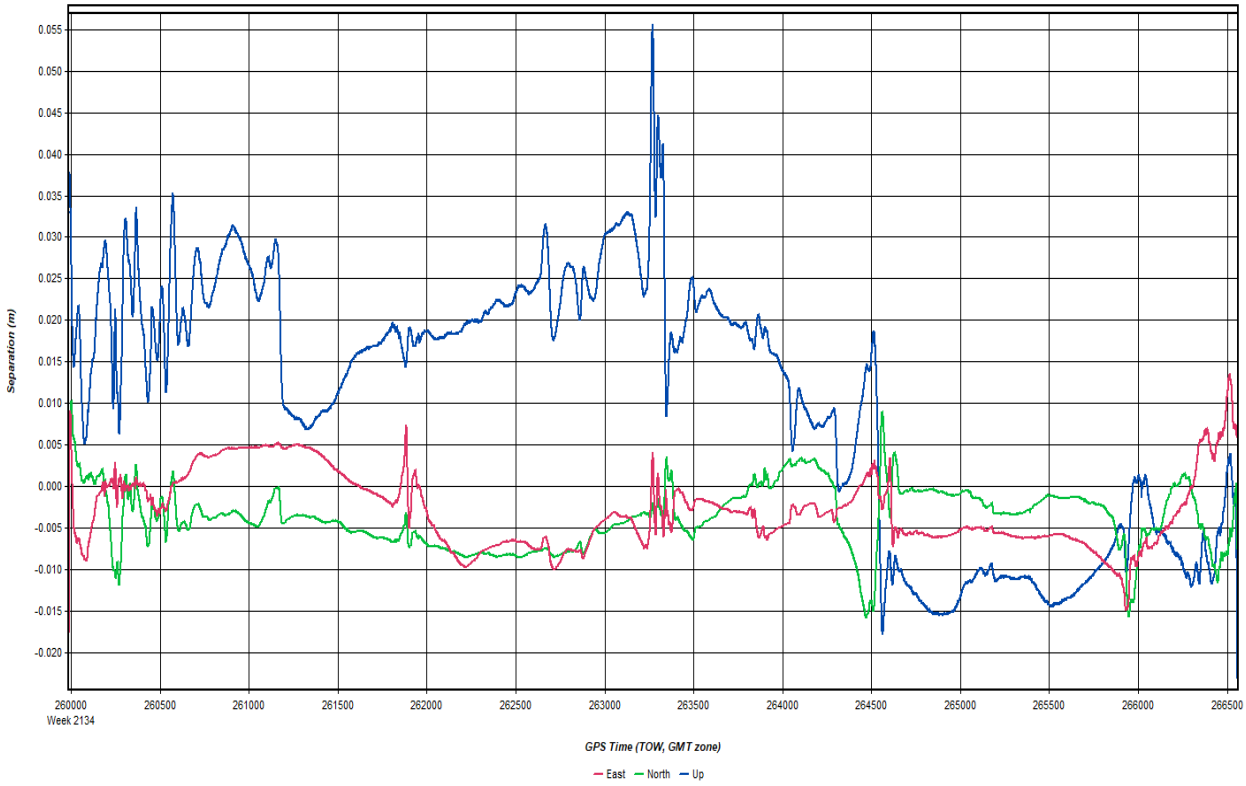
Quality Factor Plot



Number of Satellites Plot



Forward/Reverse or Combined Separation Plot



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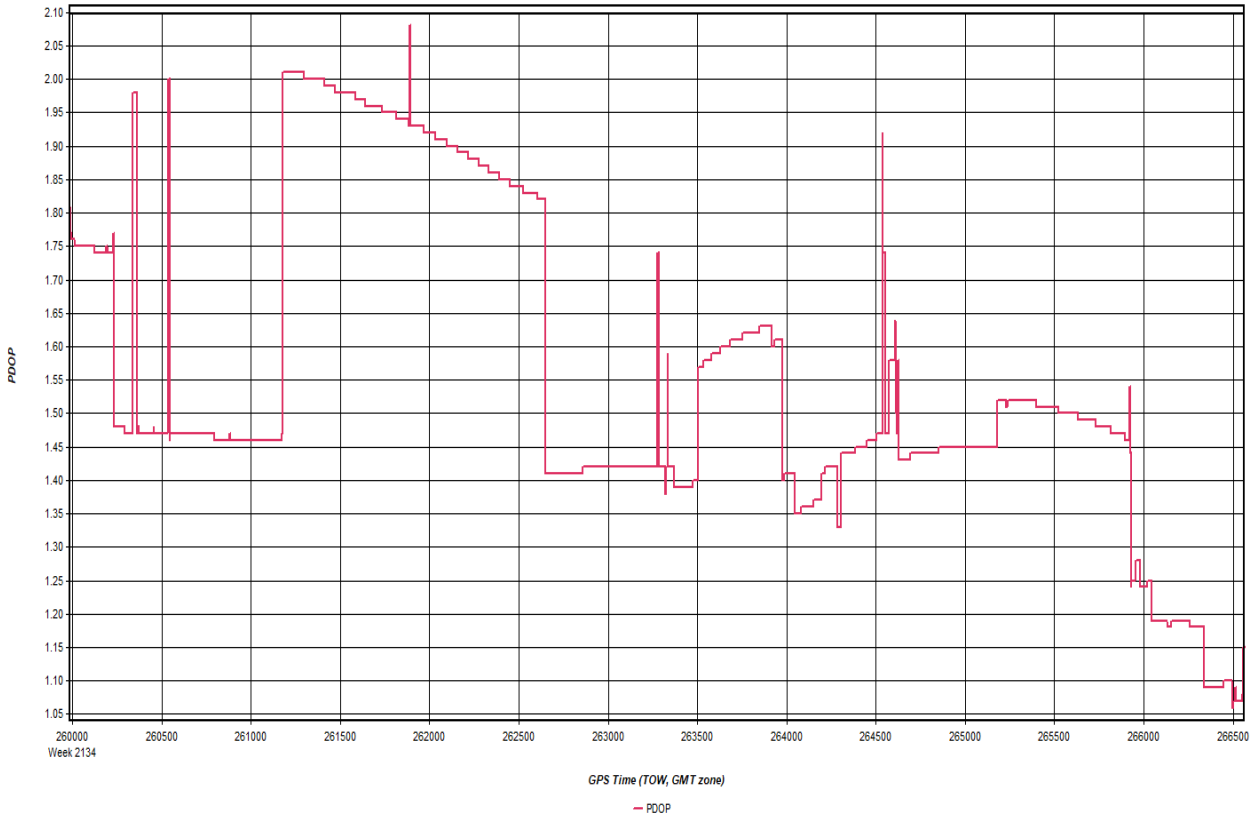
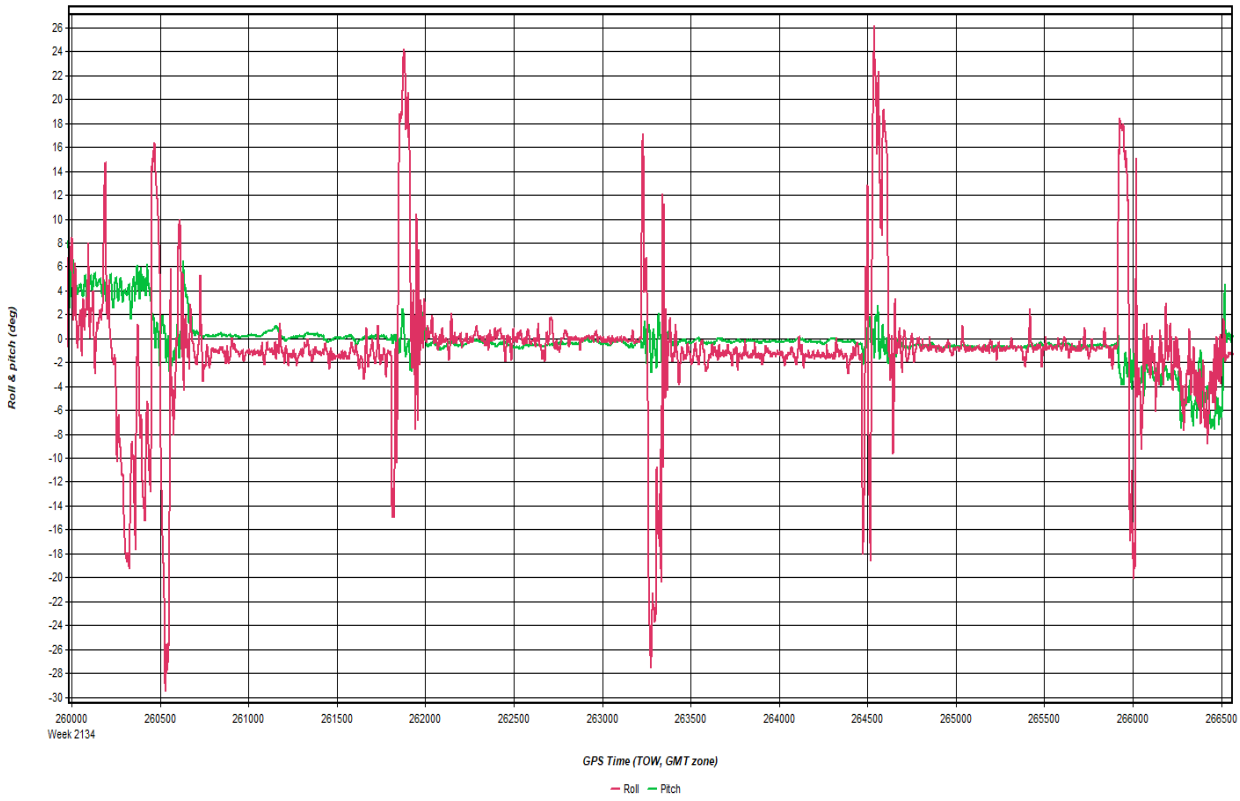


Roll & Pitch Plot



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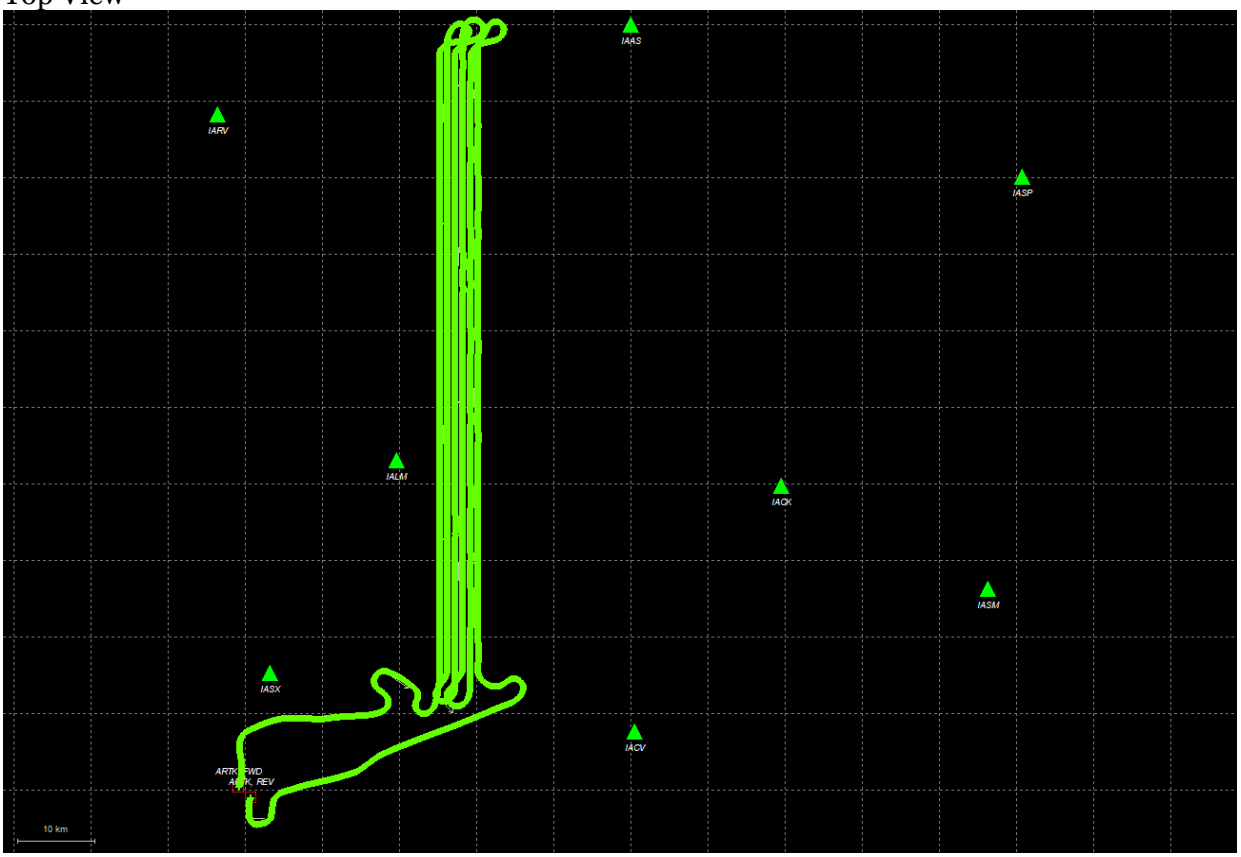
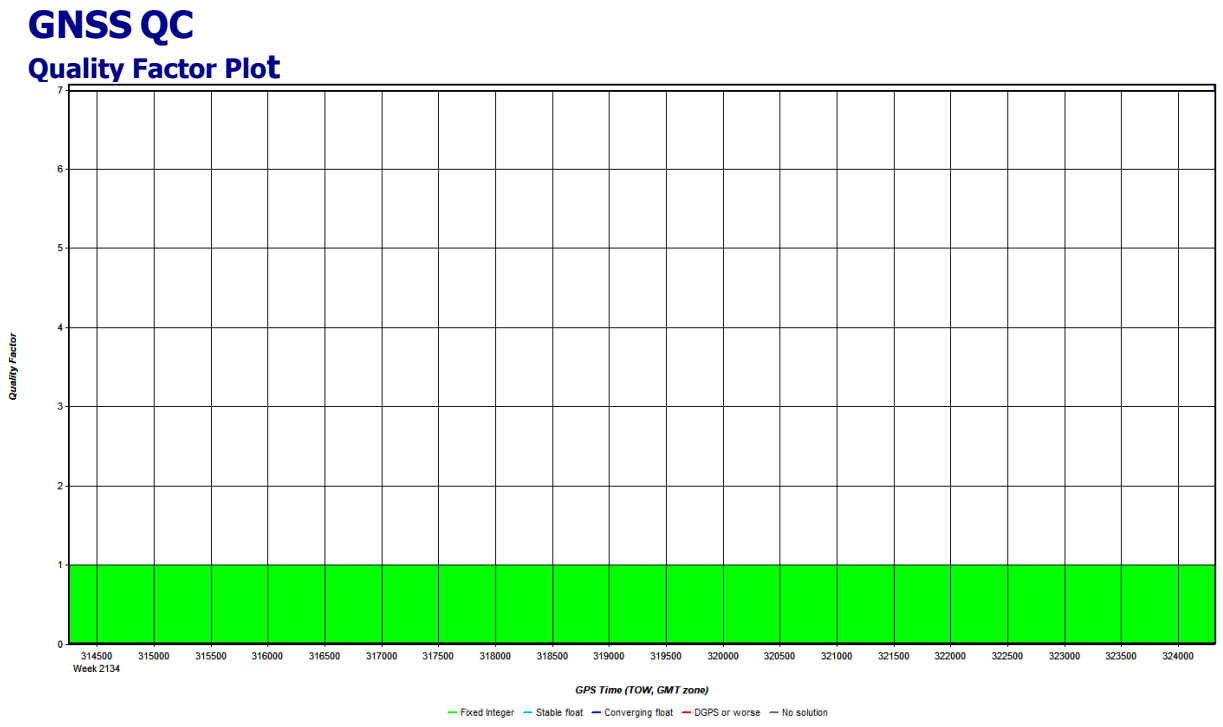
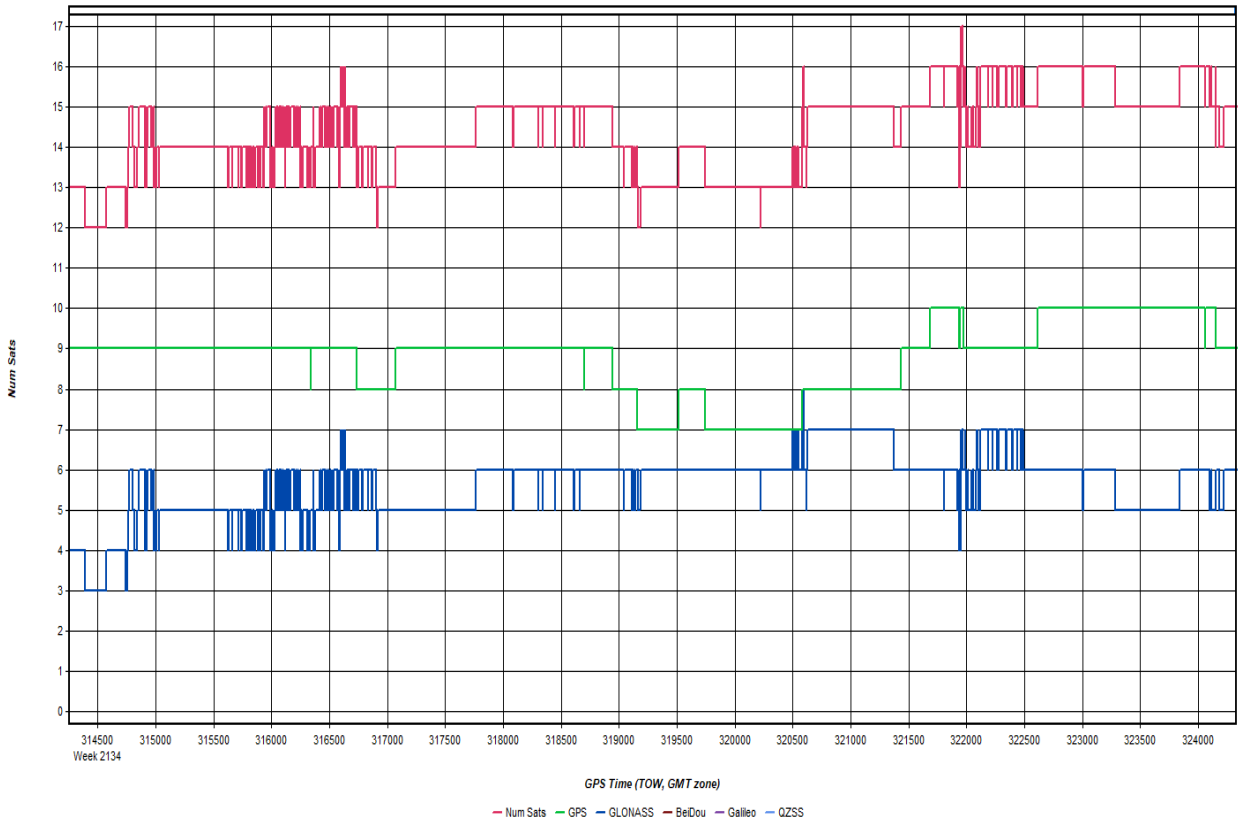
Smoothed Trajectory Information

Top View

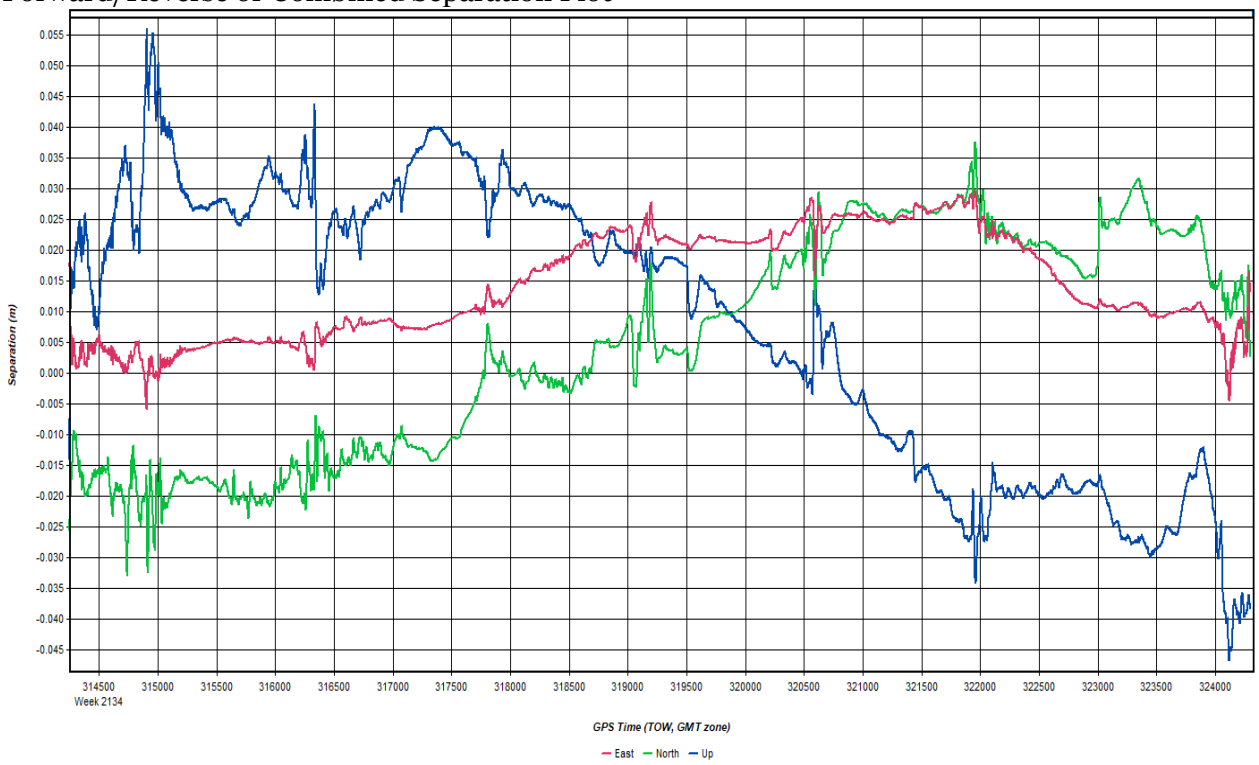




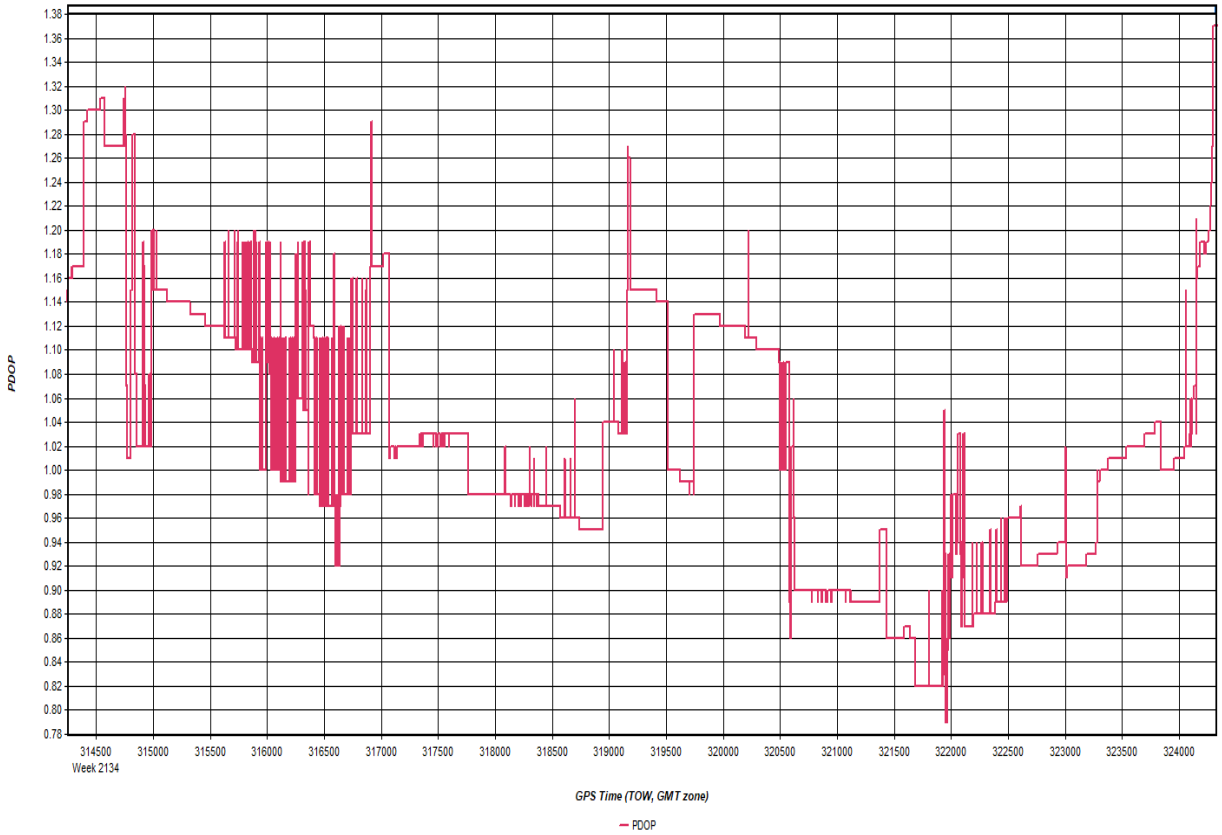
Number of Satellites Plot



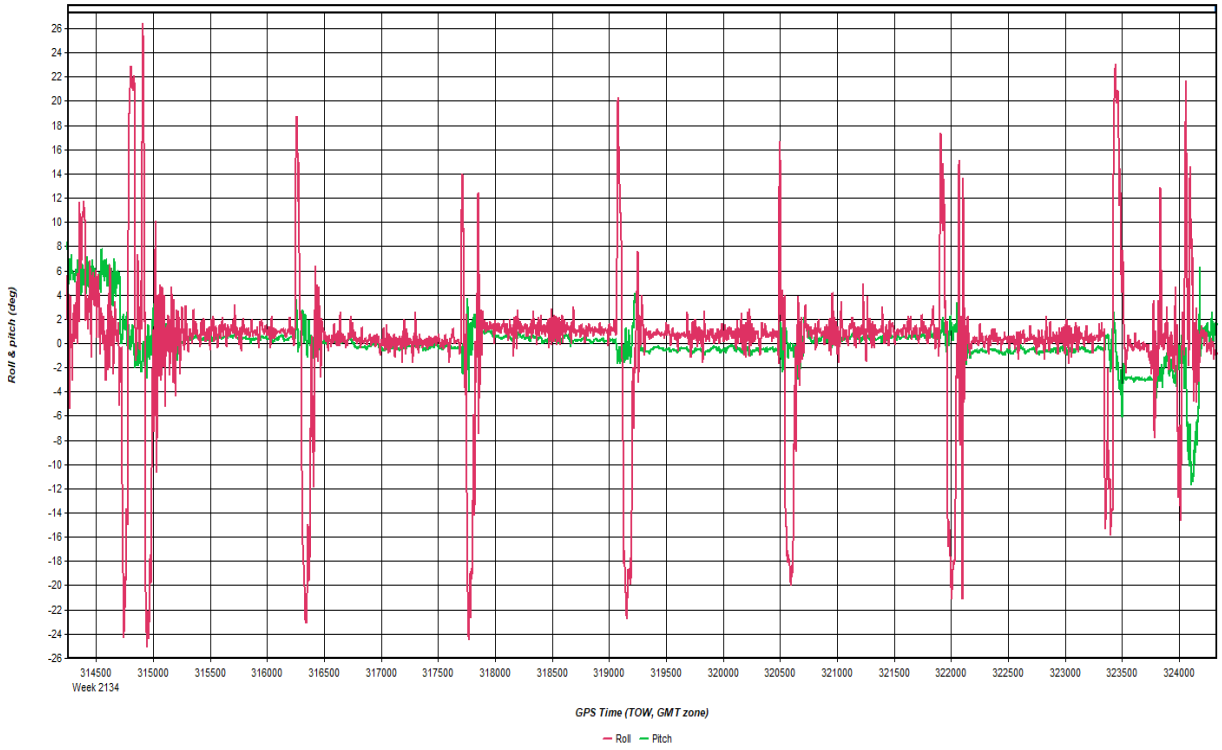
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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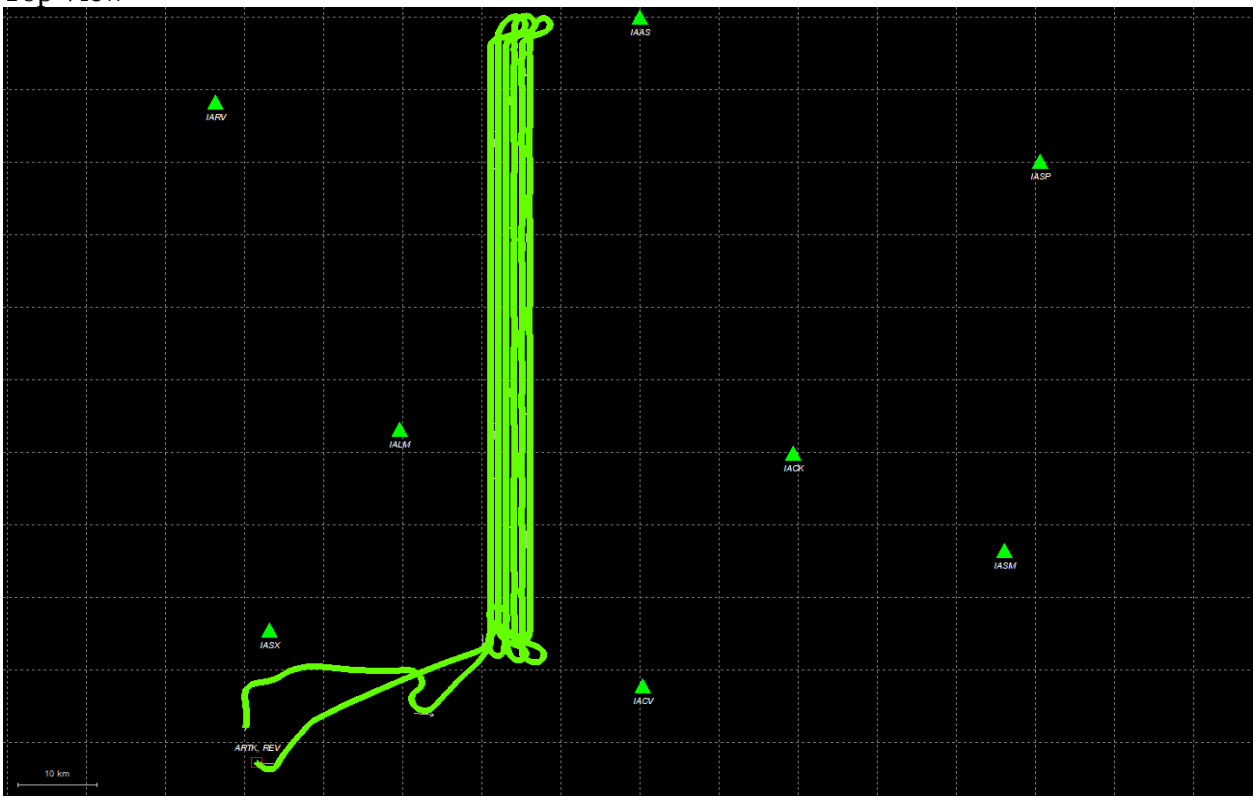
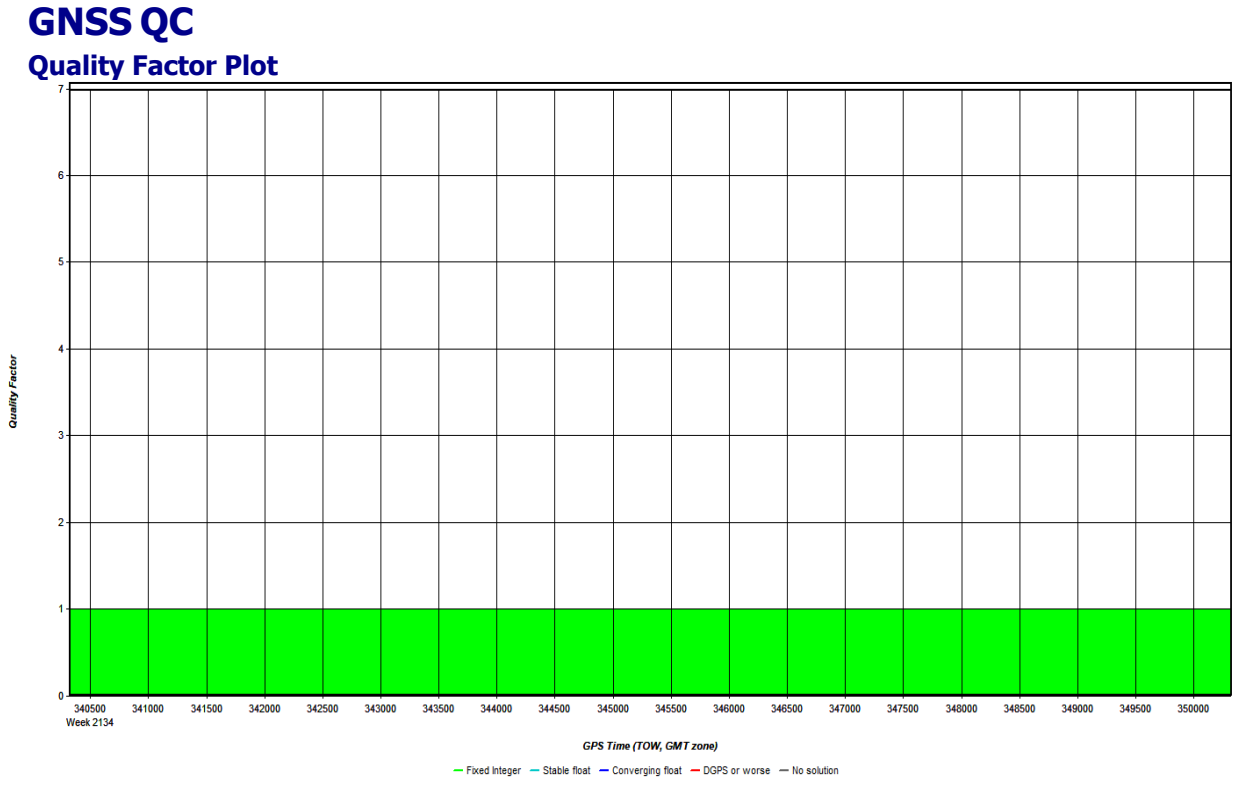
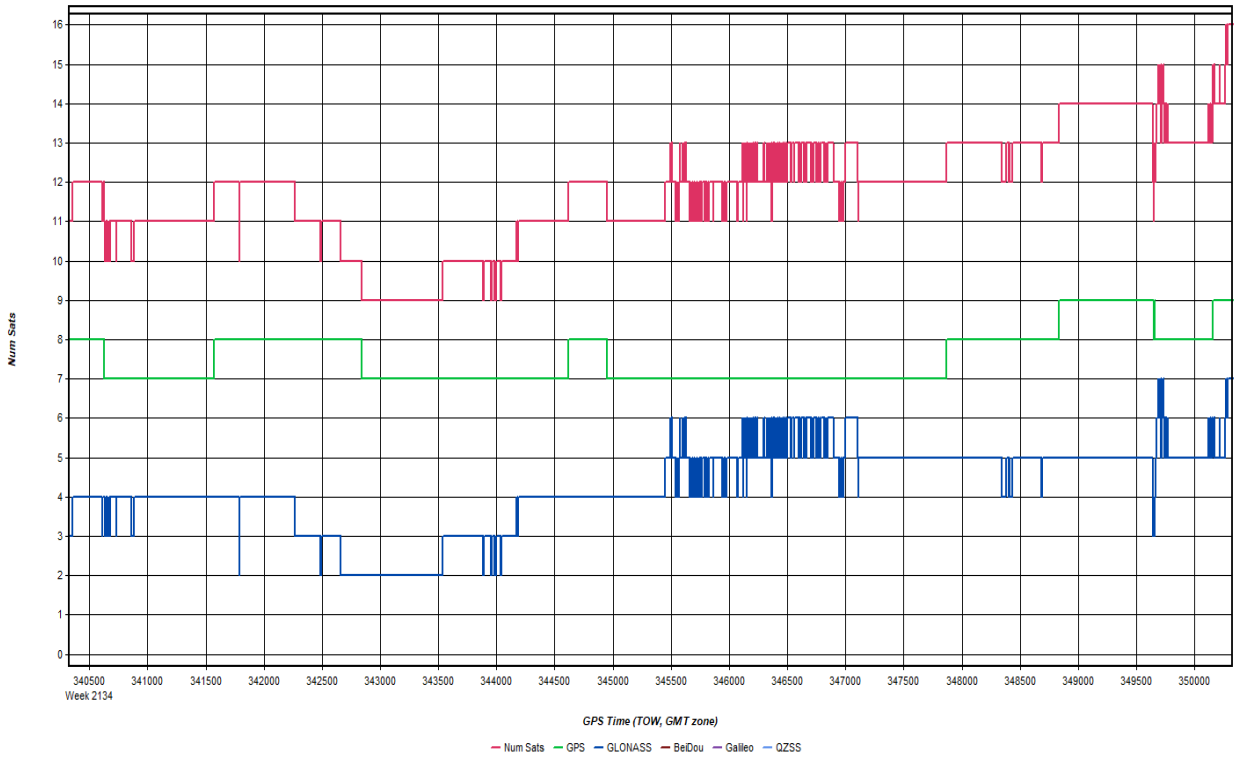
Smoothed Trajectory Information

Top View

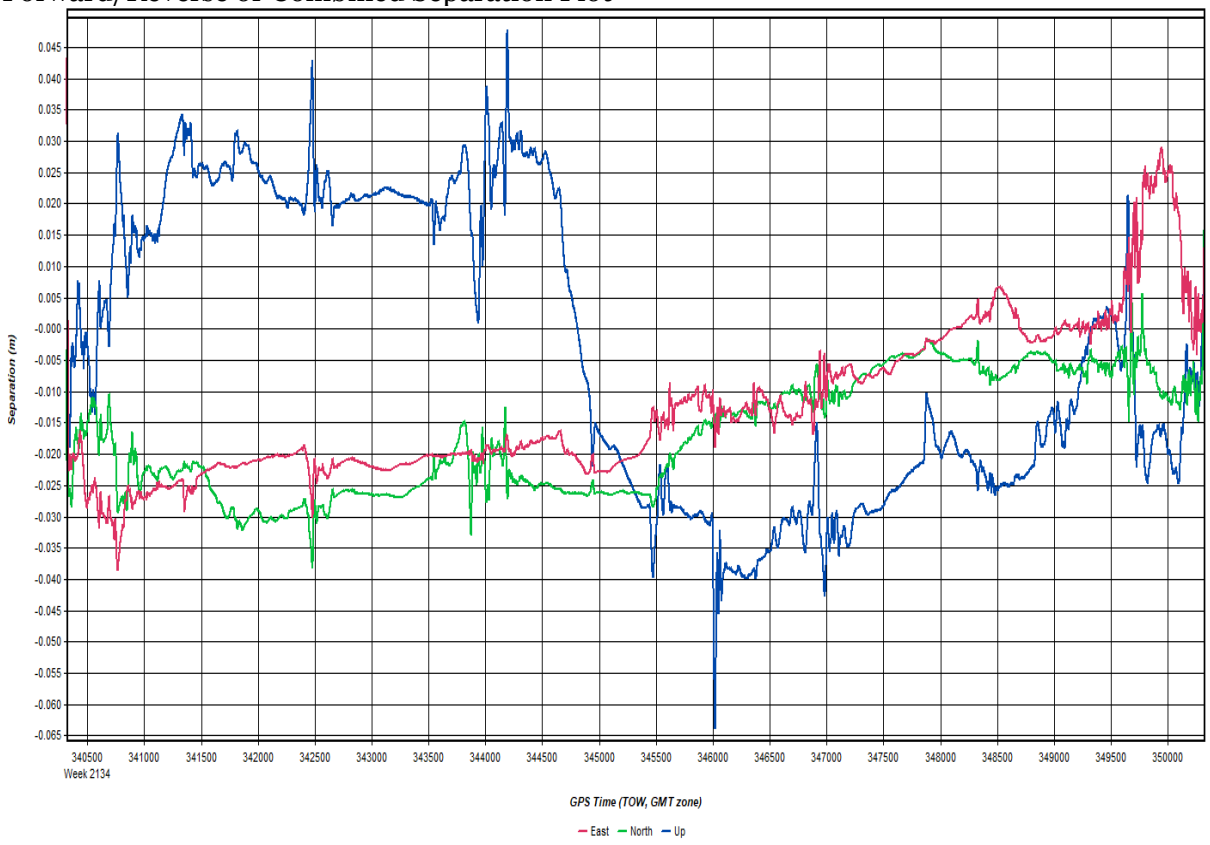




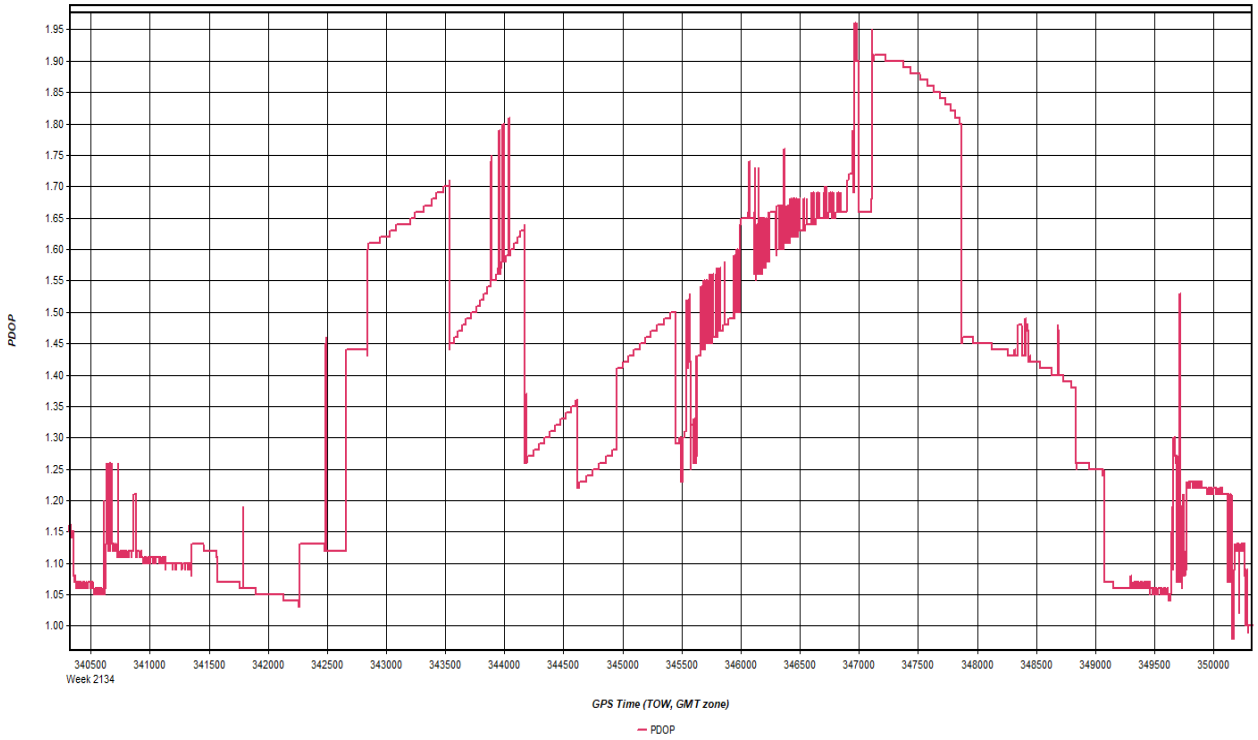
Number of Satellites Plot



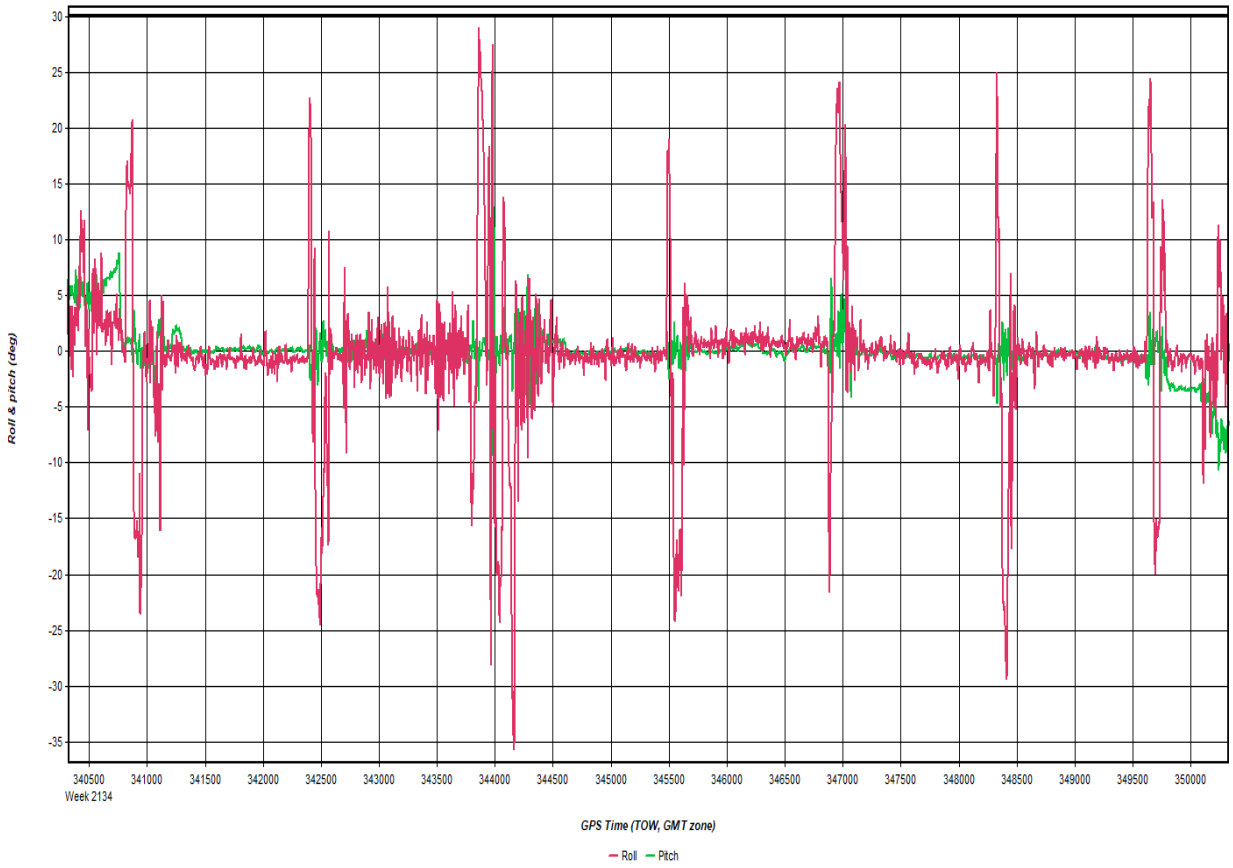
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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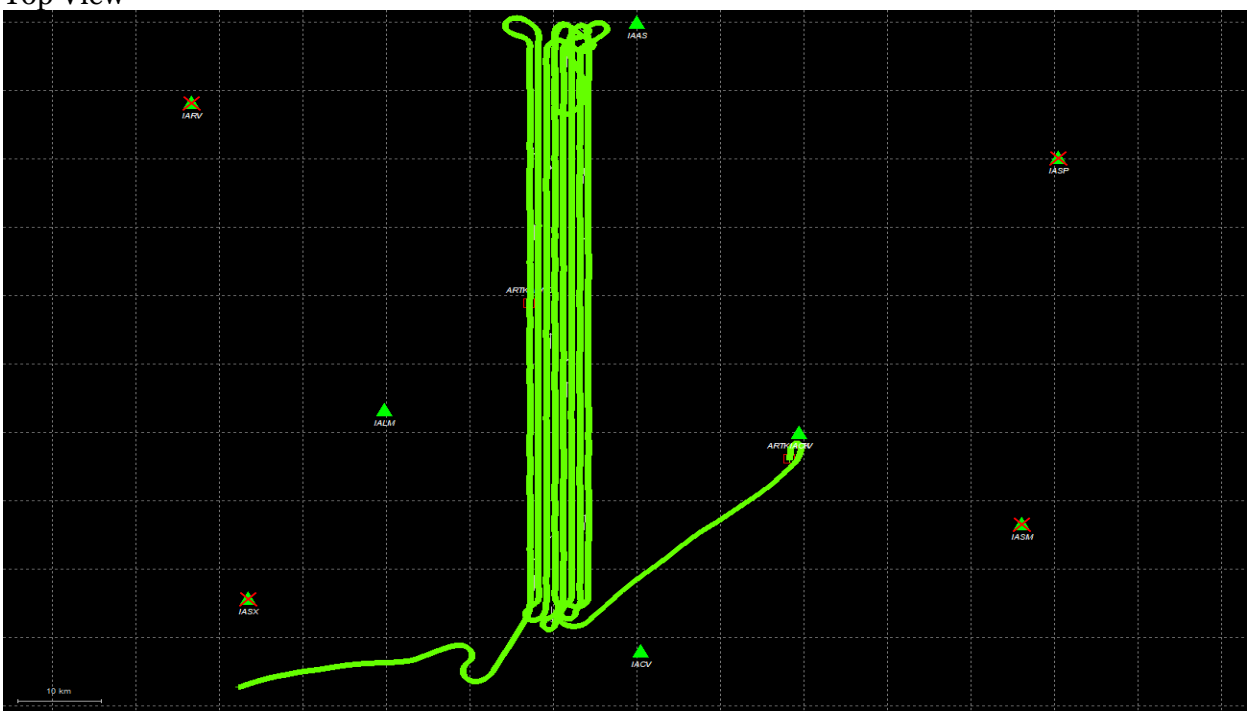
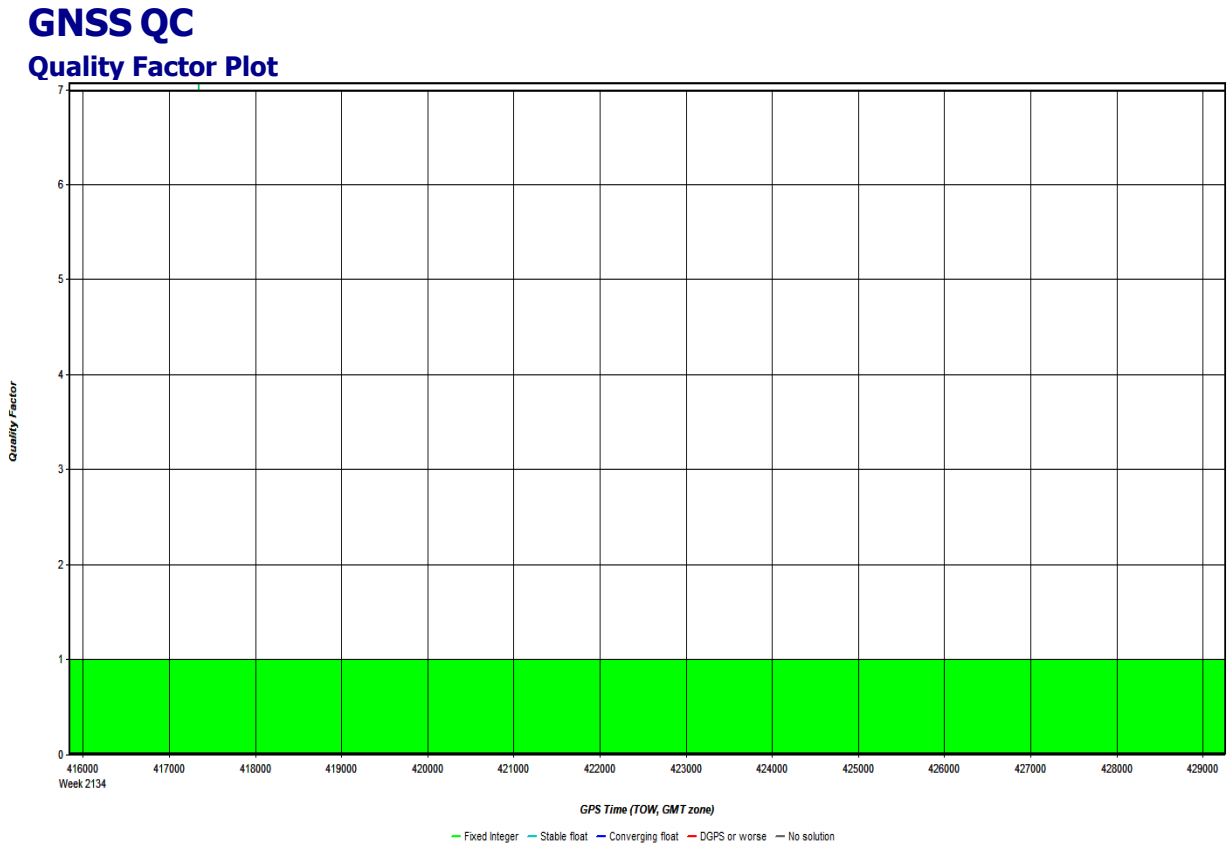
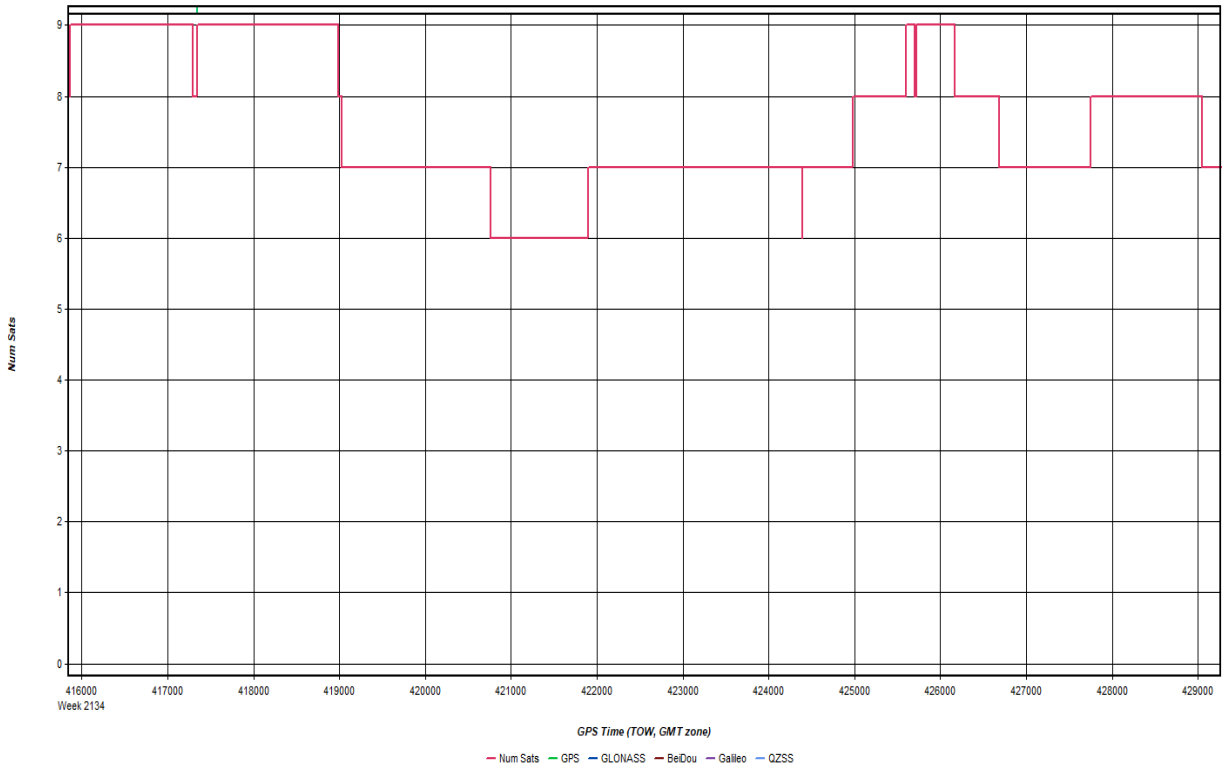
Smoothed Trajectory Information

Top View

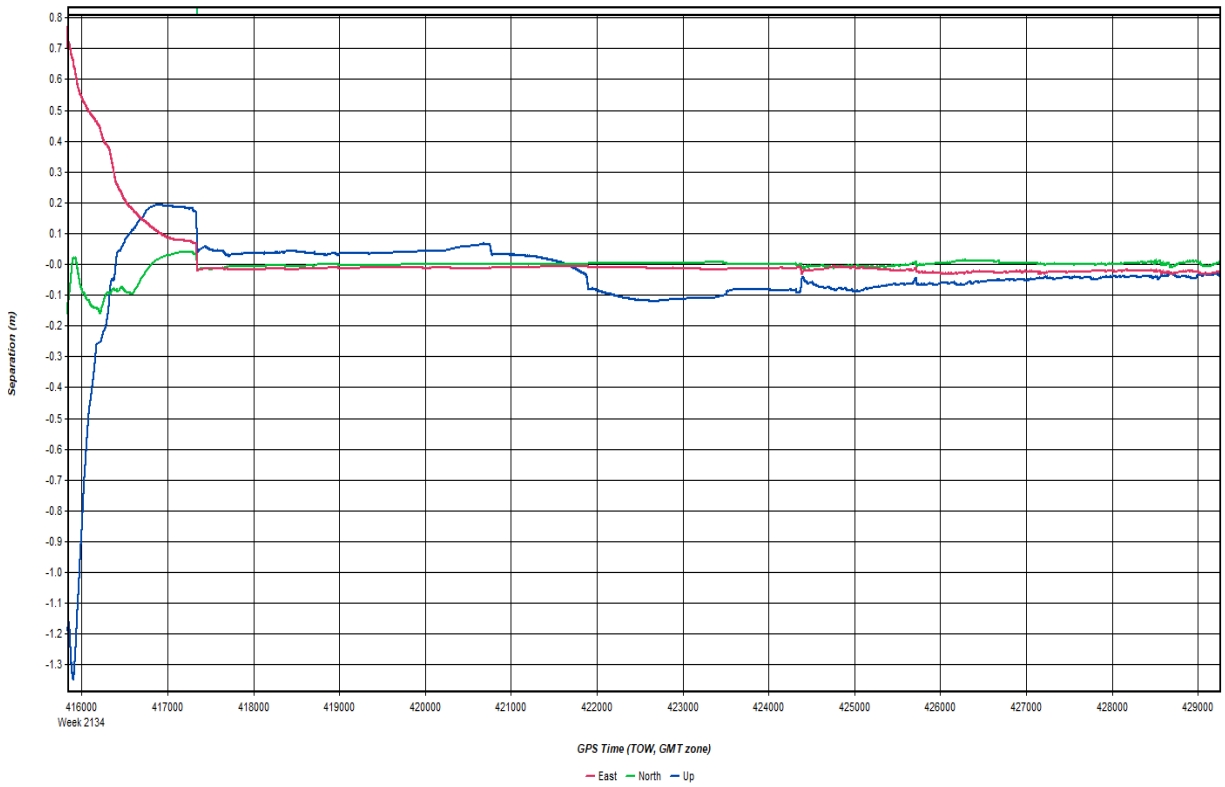




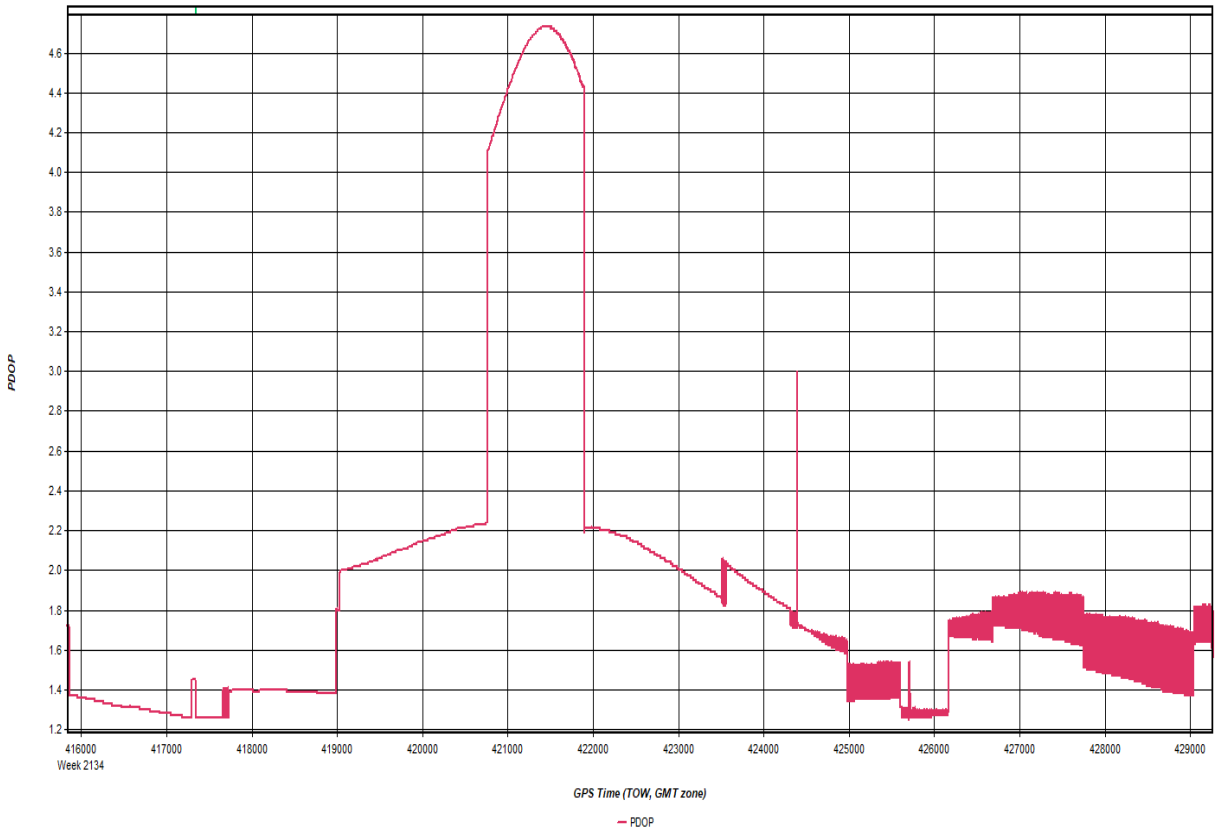
Number of Satellites Plot



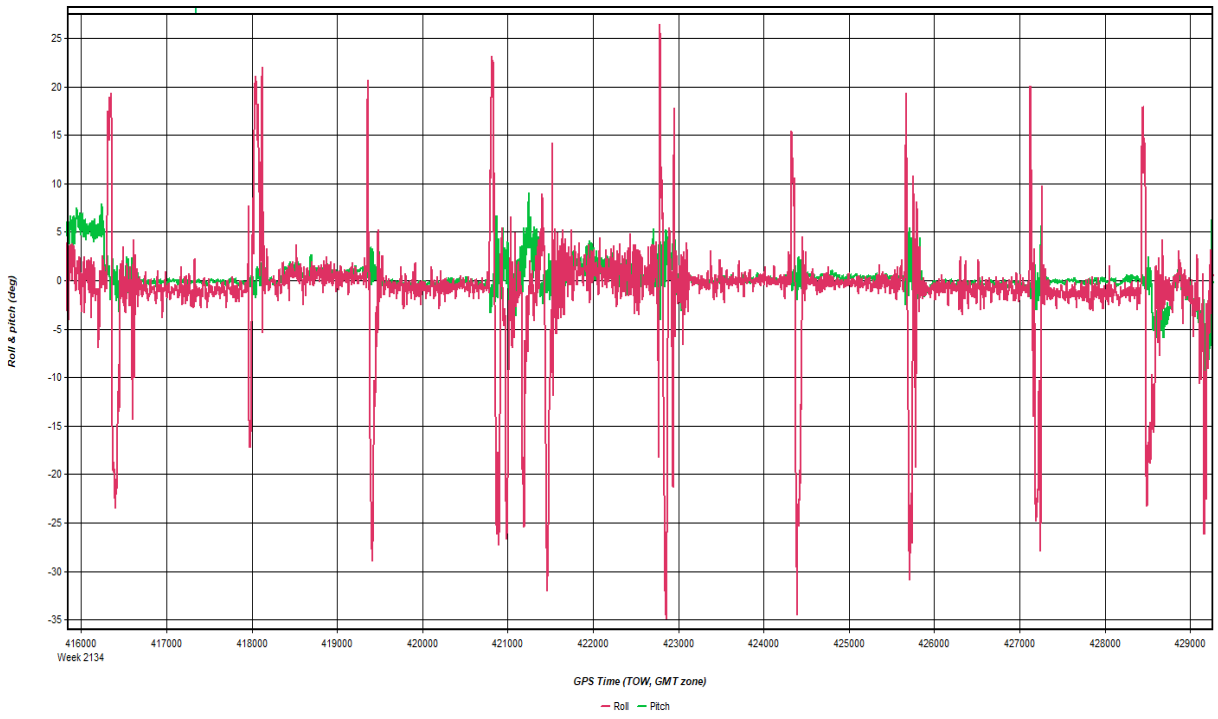
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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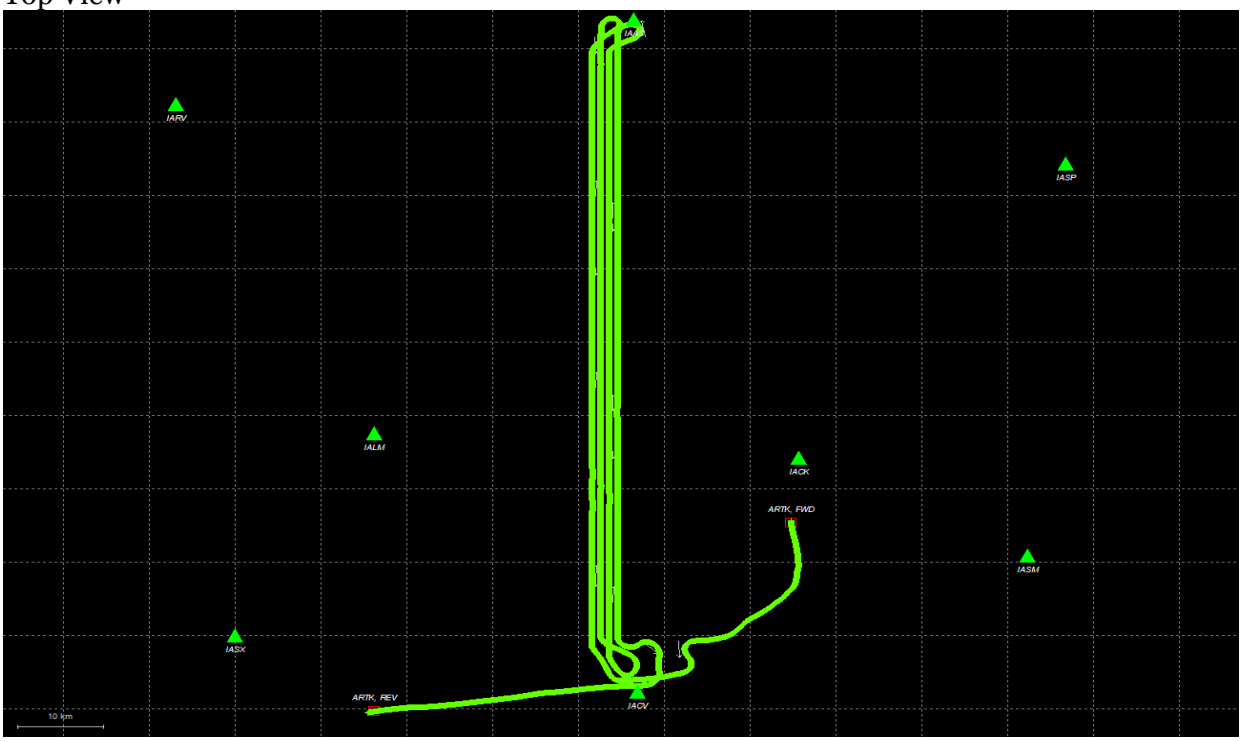
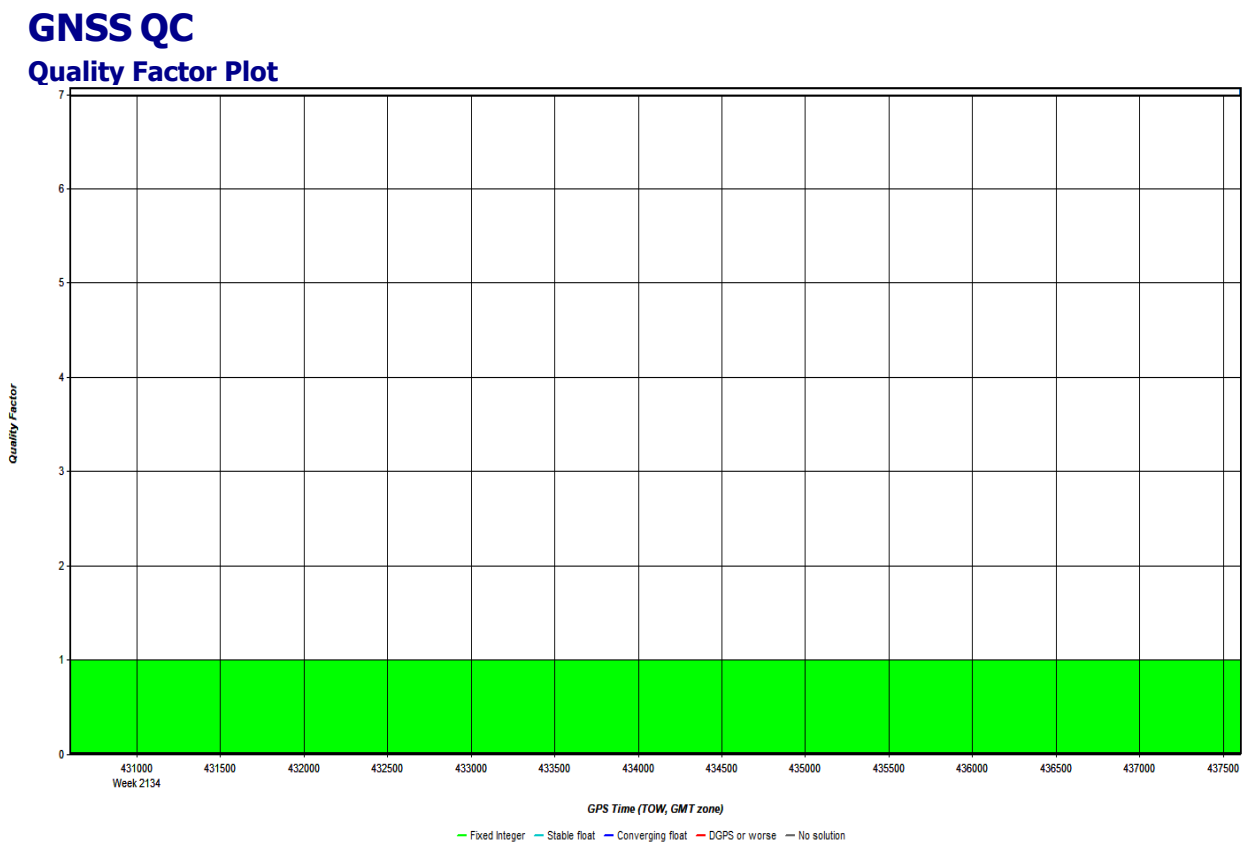
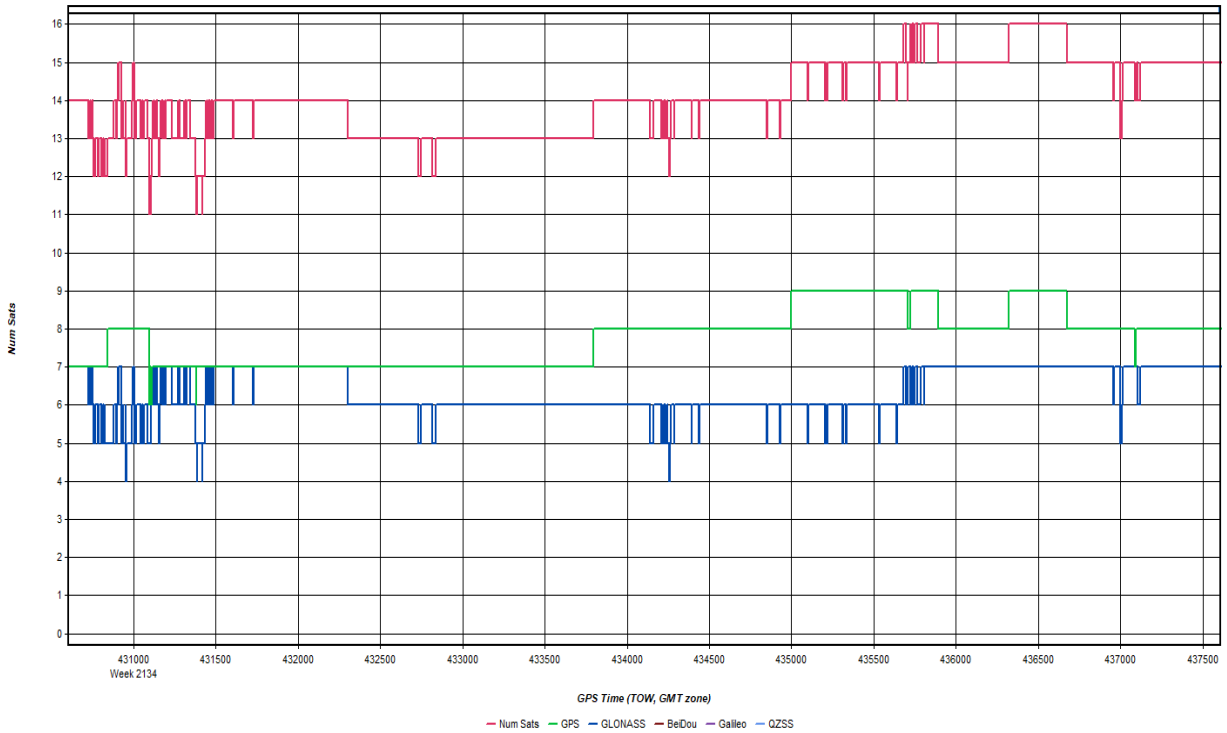
Smoothed Trajectory Information

Top View

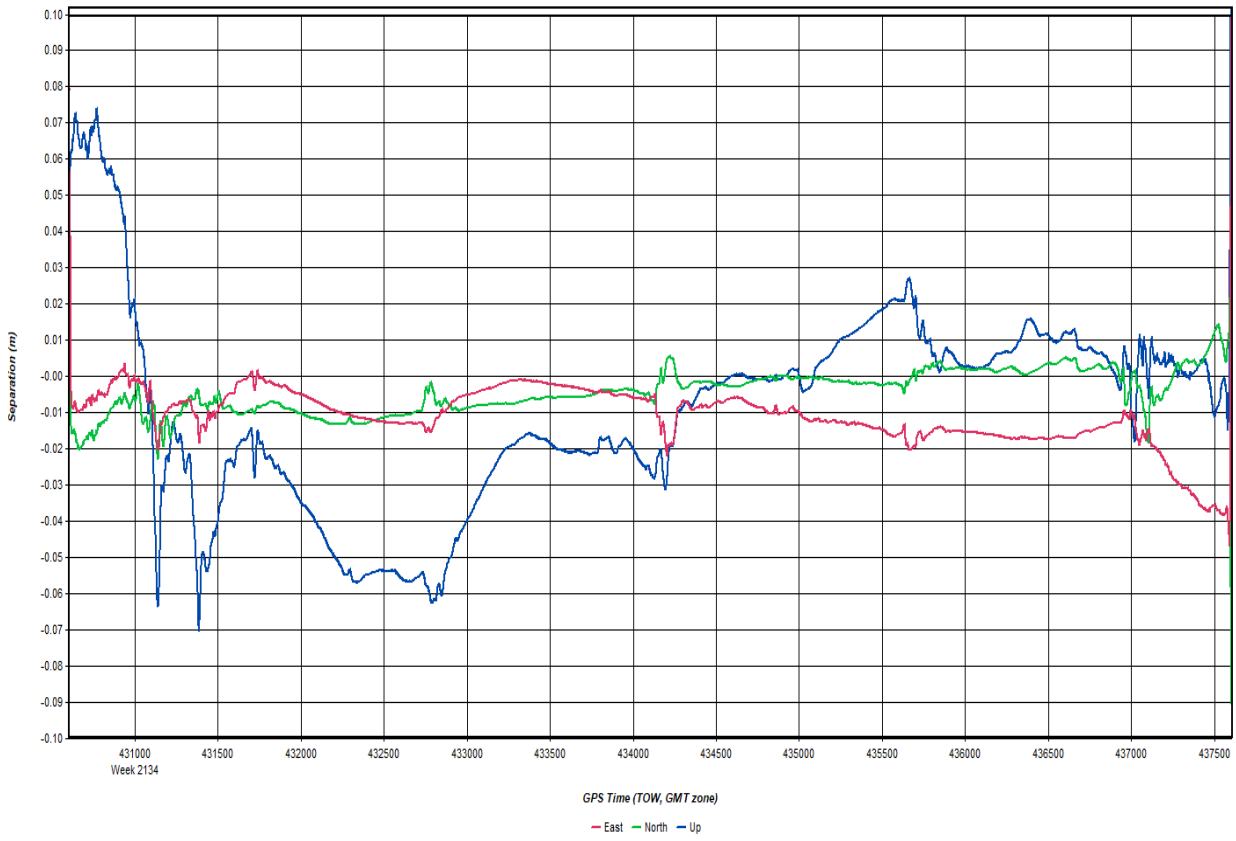




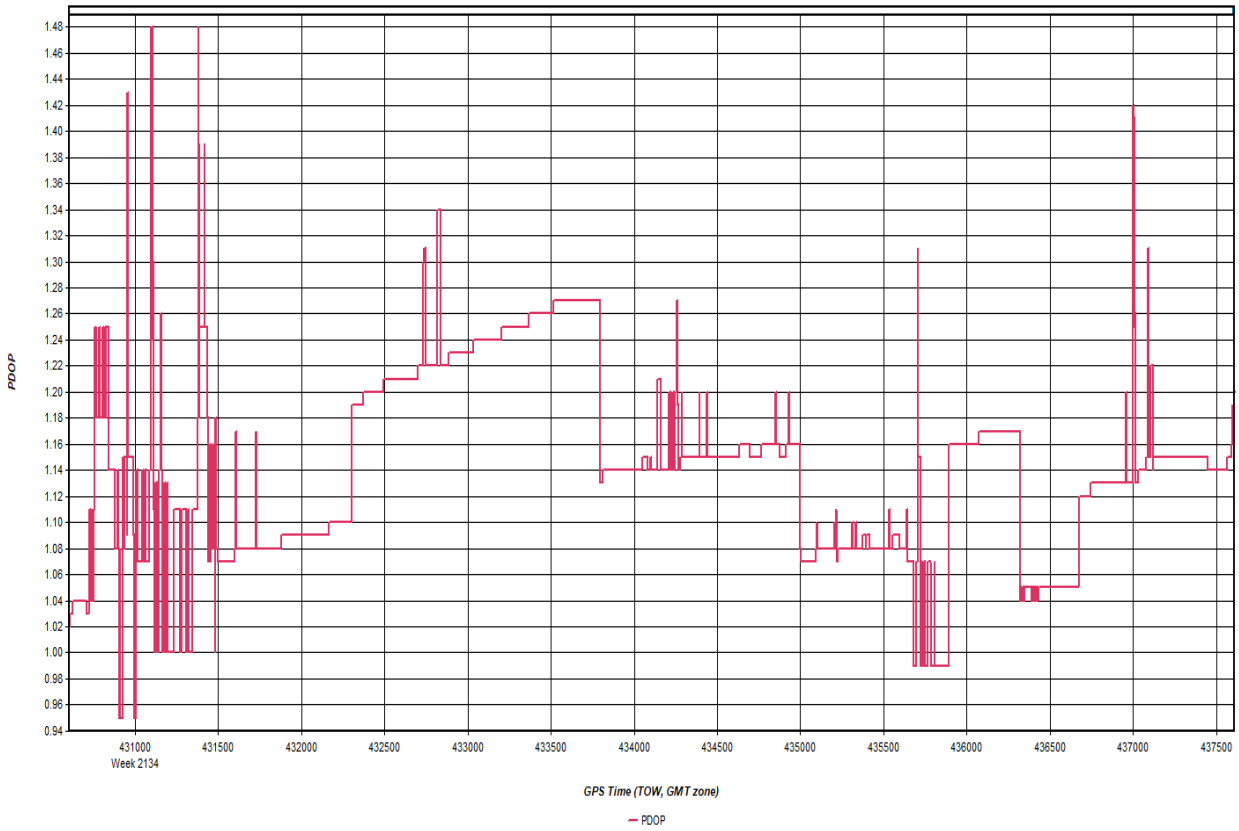
Number of Satellites Plot



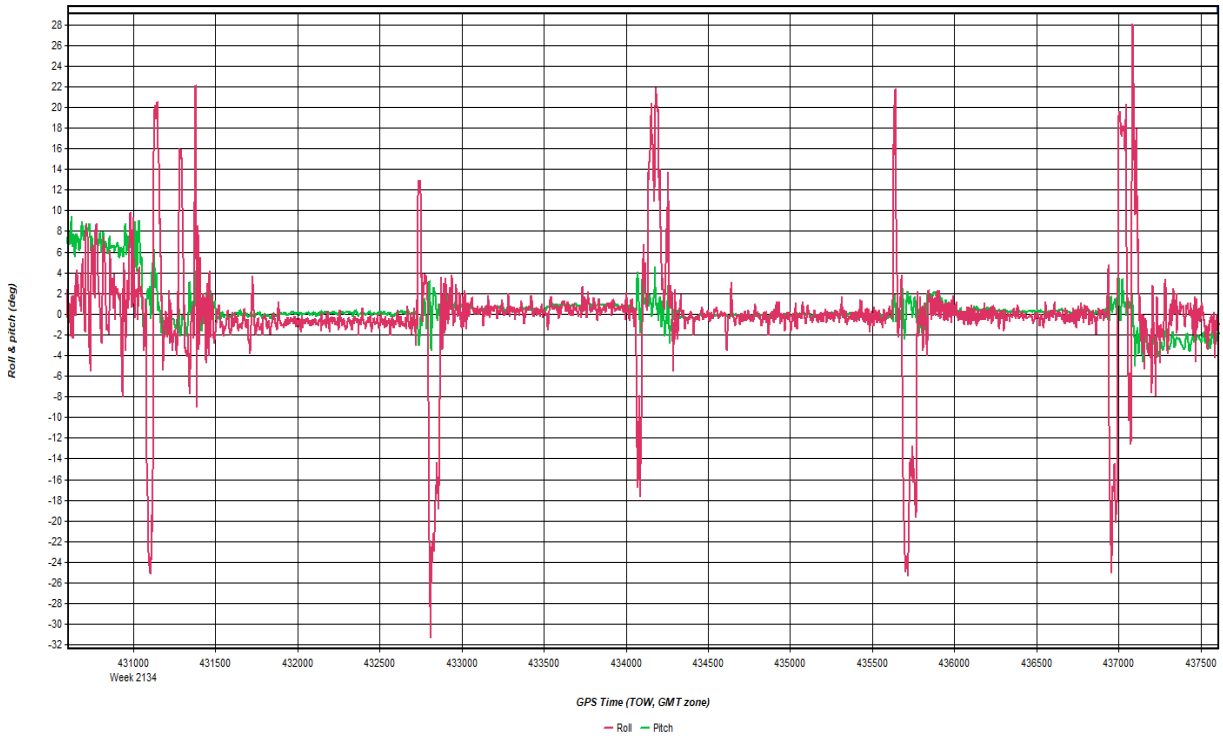
Forward/Reverse or Combined Separation Plot



PDOP Plot



Roll & Pitch Plot



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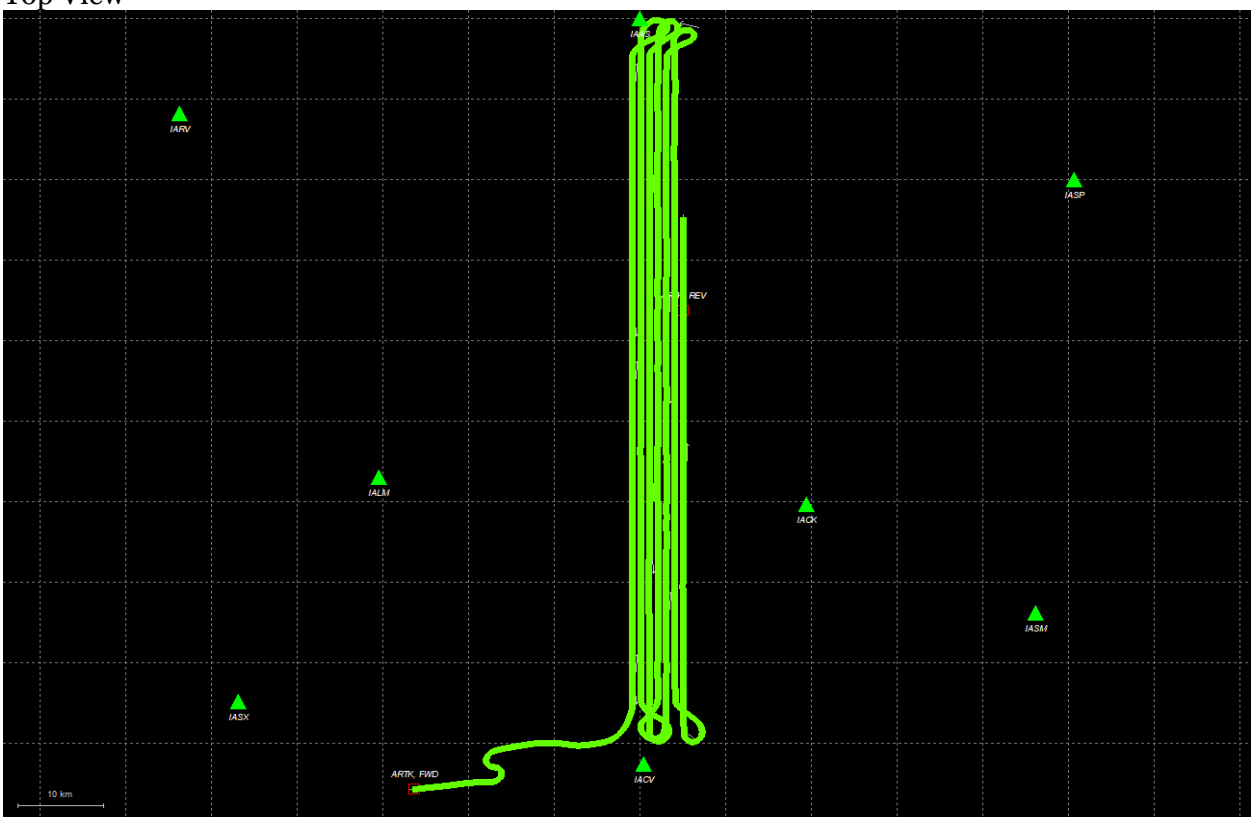
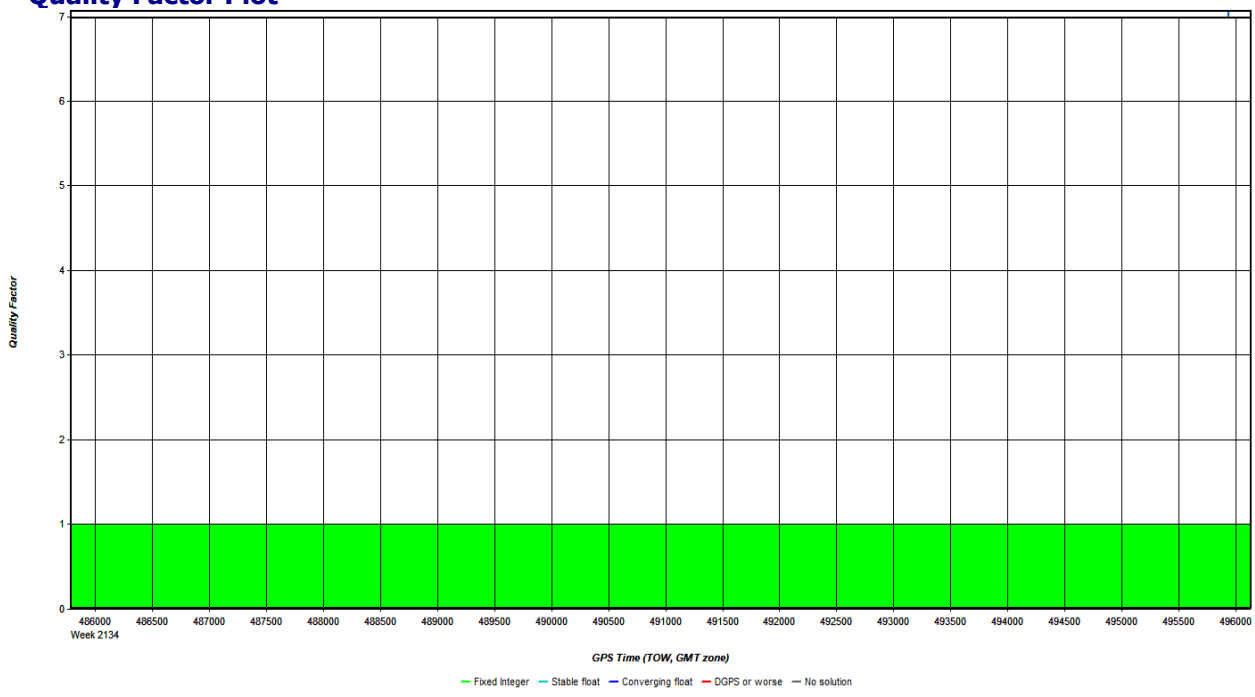
Smoothed Trajectory Information

Top View

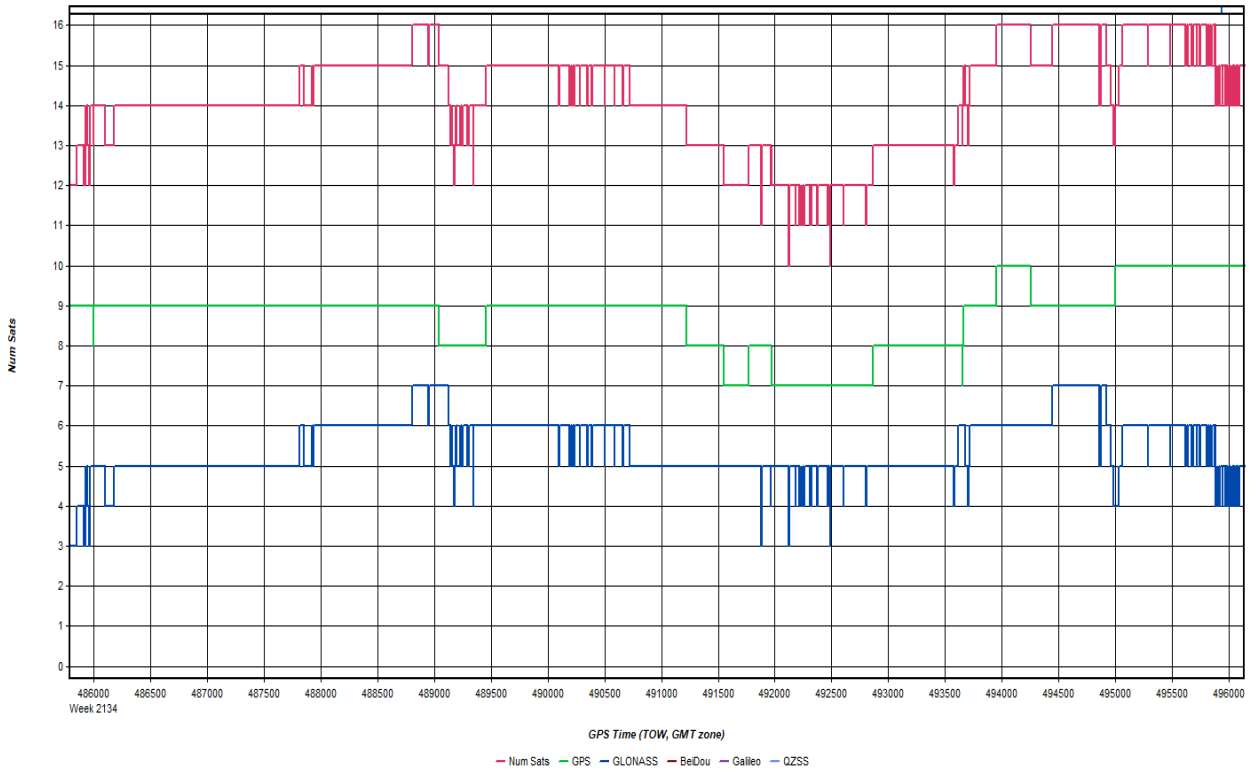


GNSS QC

Quality Factor Plot

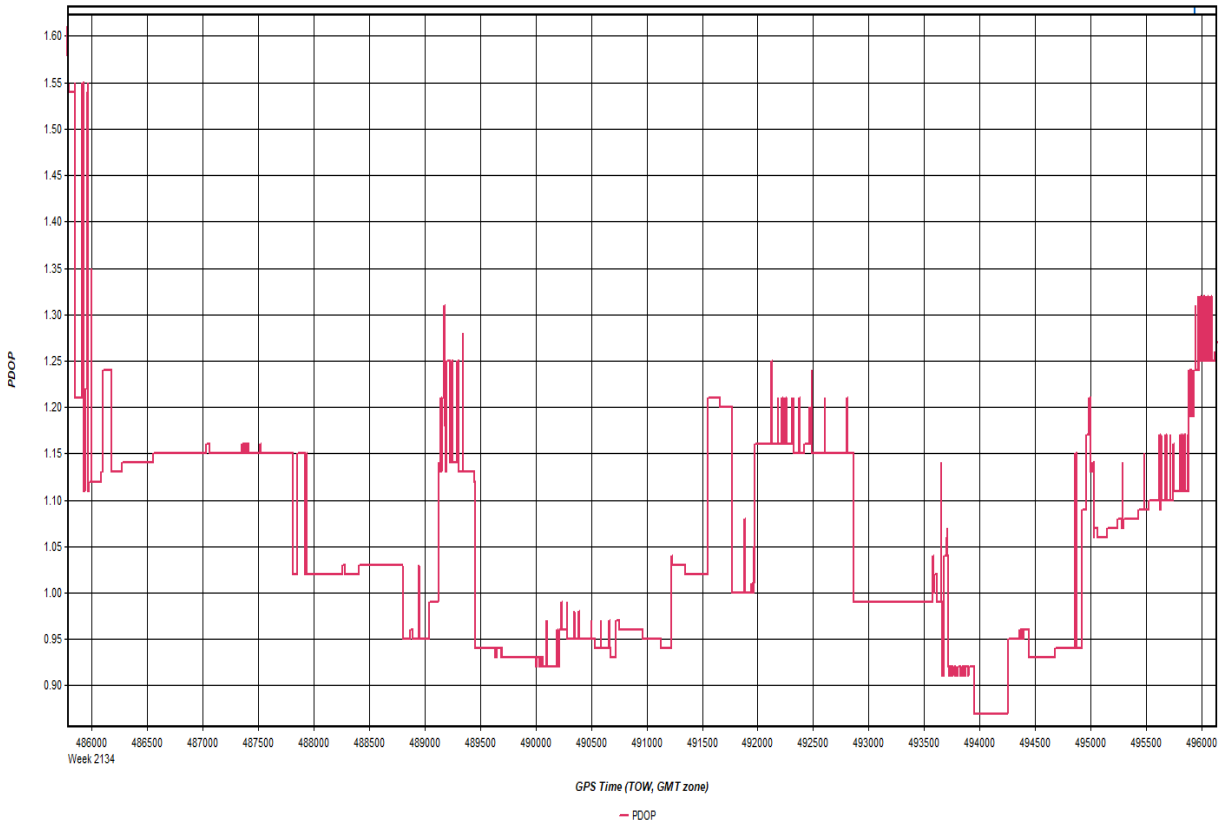


Number of Satellites Plot

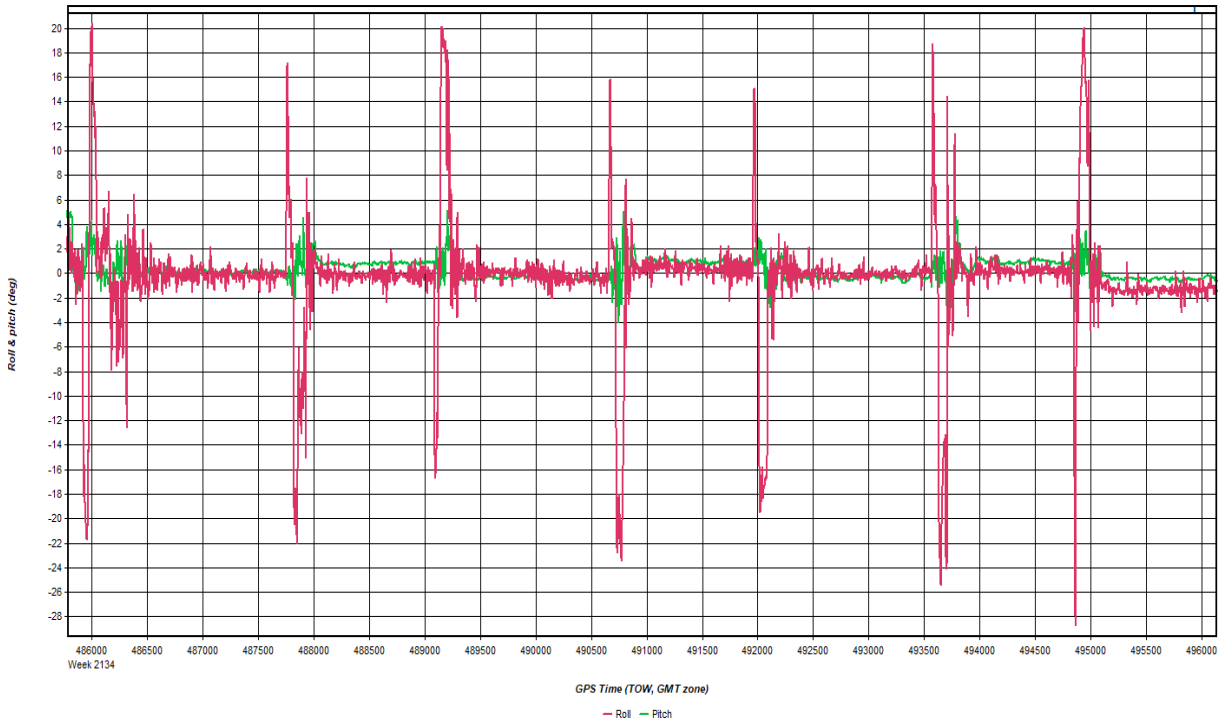


Forward/Reverse or Combined Separation Plot

PDOP Plot



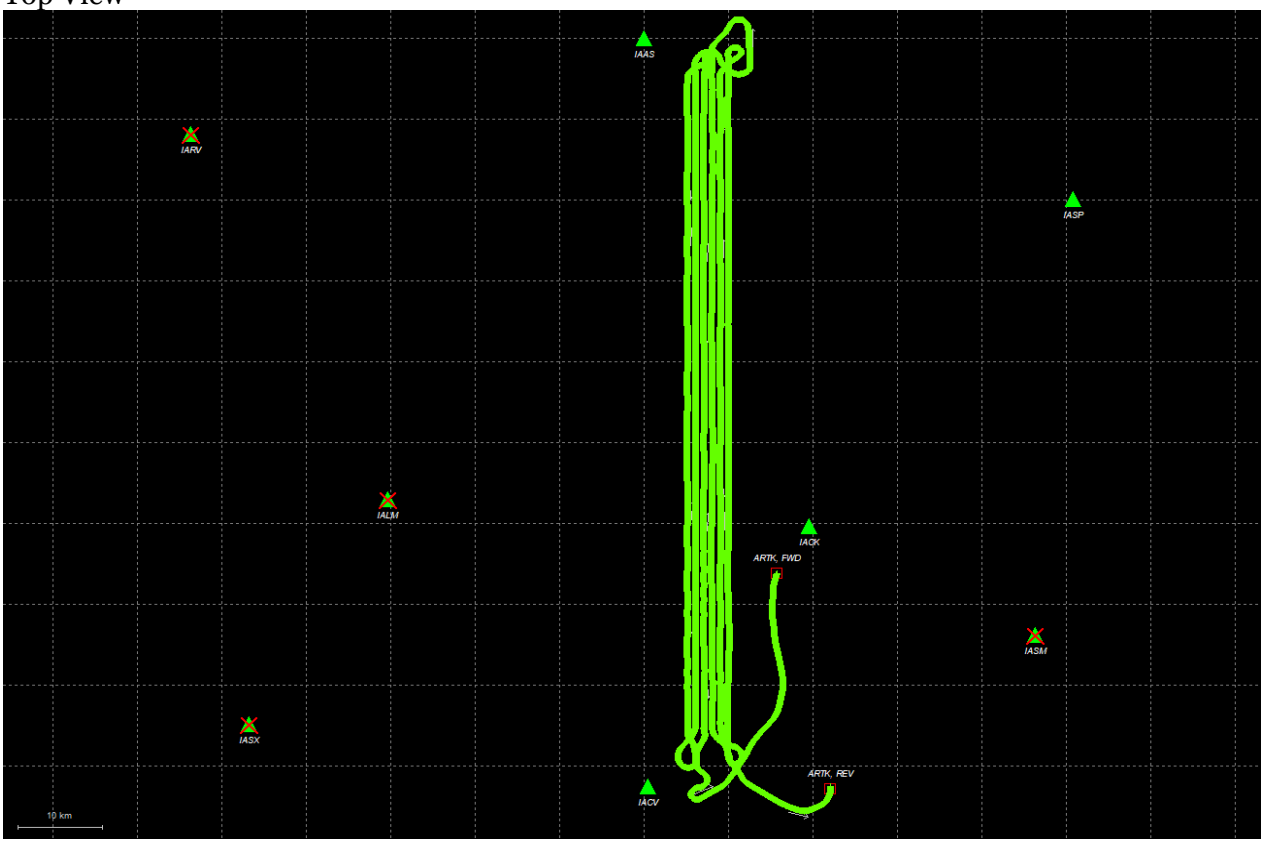
Roll & Pitch Plot



20201204_194301.docx QC Report - 06/22/2021 10:41:18

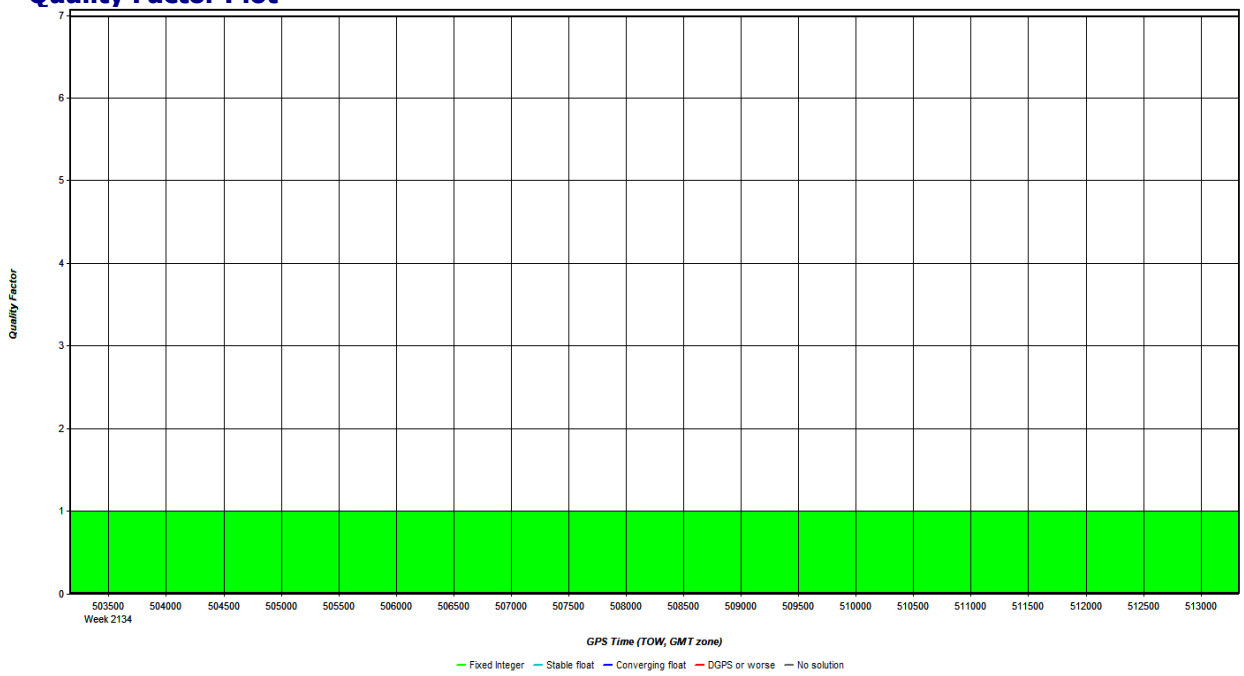
Smoothed Trajectory Information

Top View

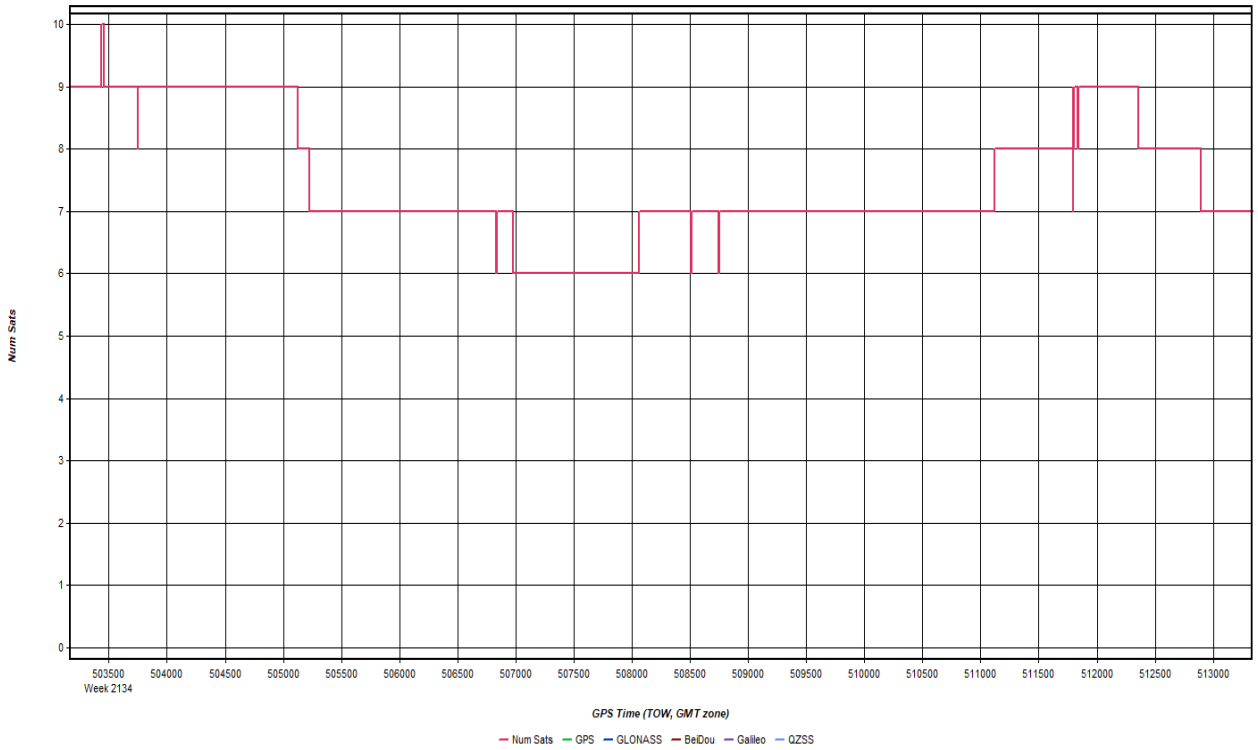


GNSS QC

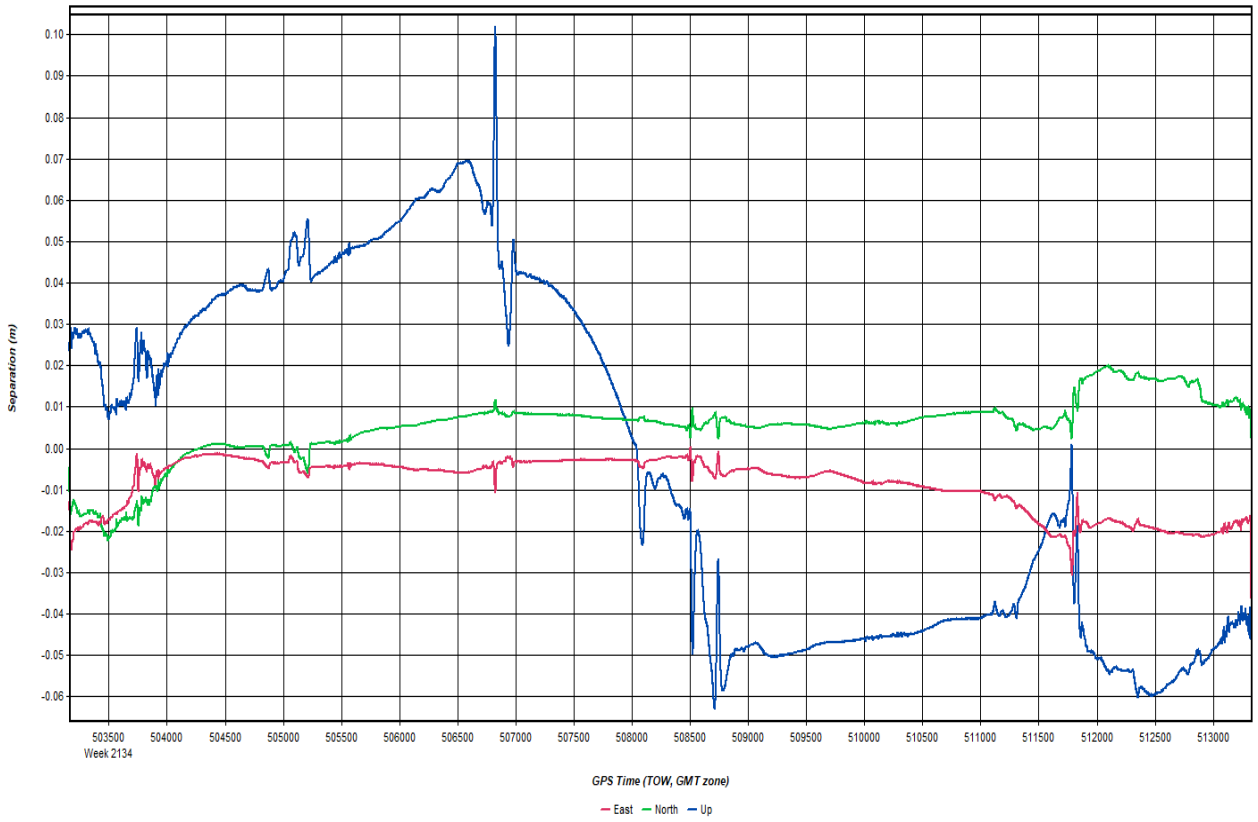
Quality Factor Plot



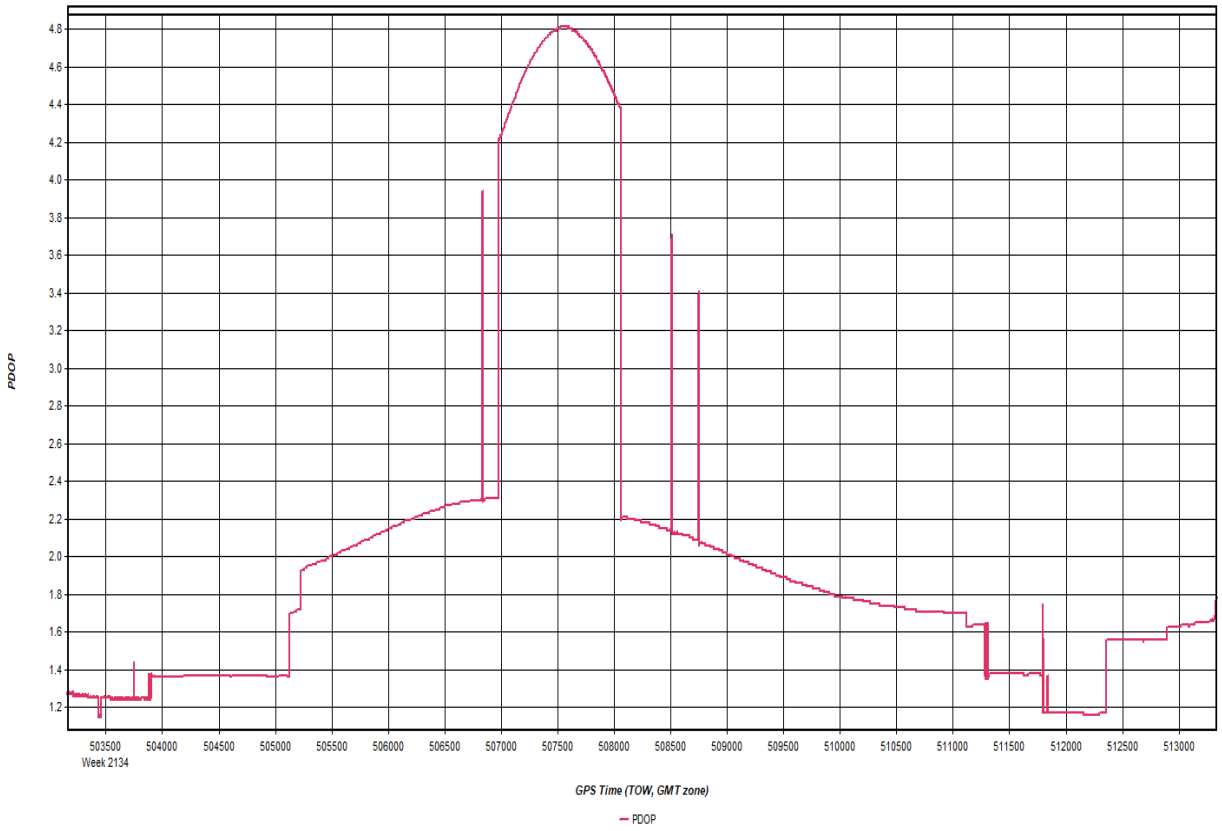
Number of Satellites Plot



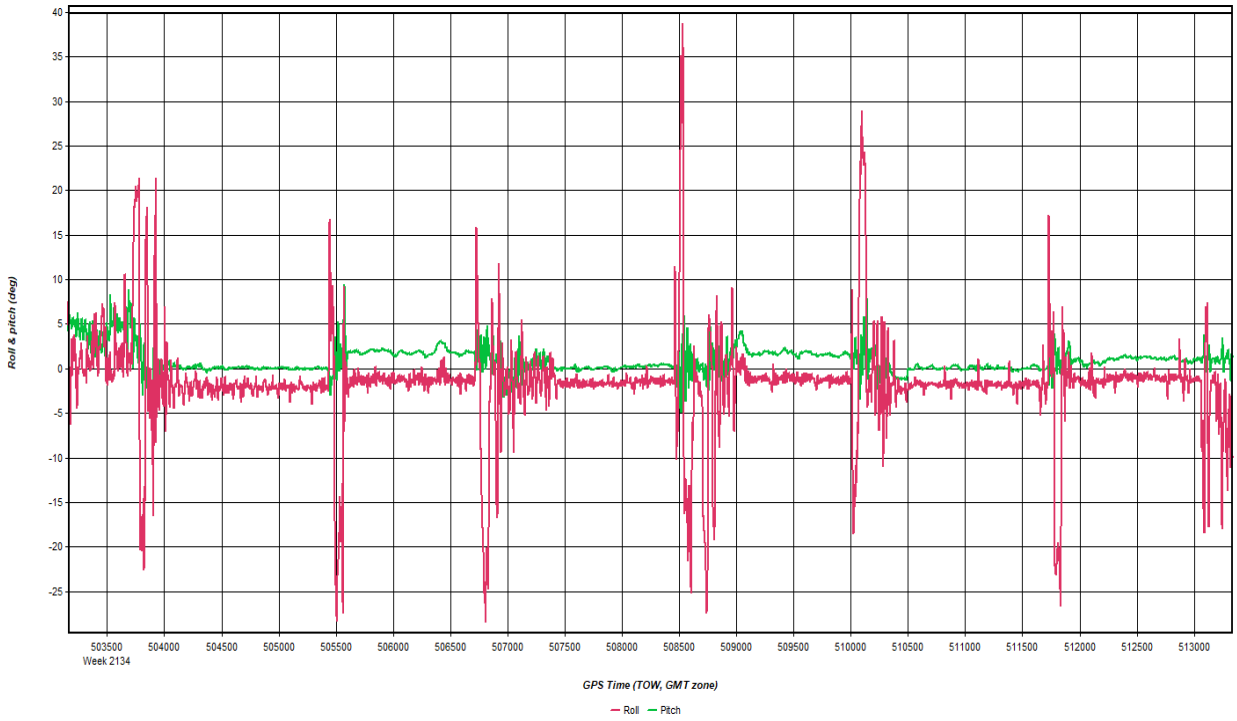
Forward/Reverse or Combined Separation Plot



PDOP Plot



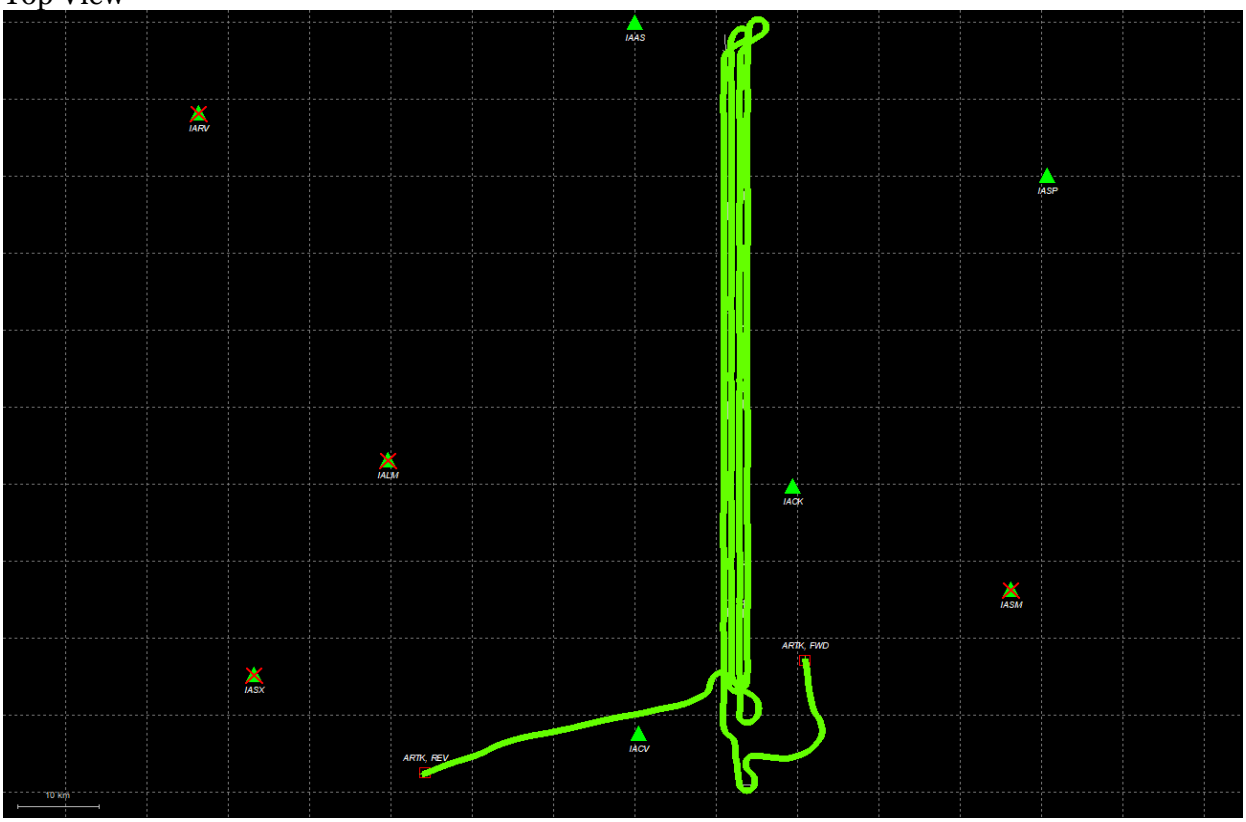
Roll & Pitch Plot



20201204_231634.docx QC Report - 06/22/2021 10:45:25

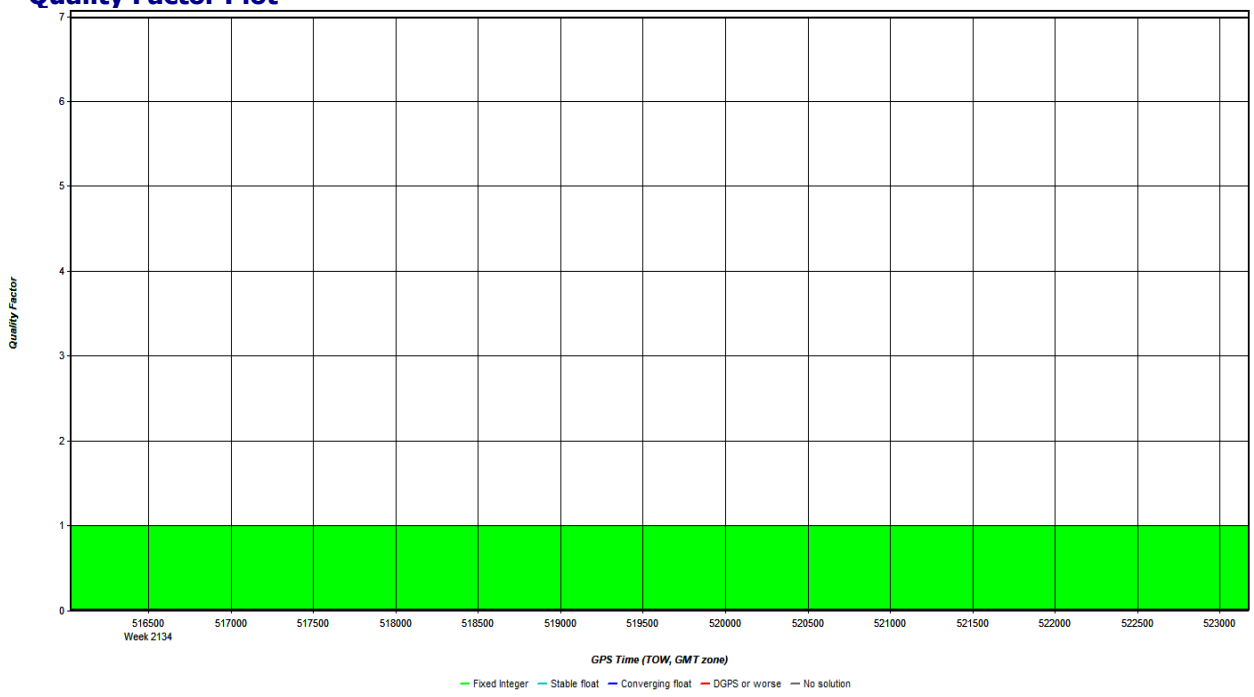
Smoothed Trajectory Information

Top View

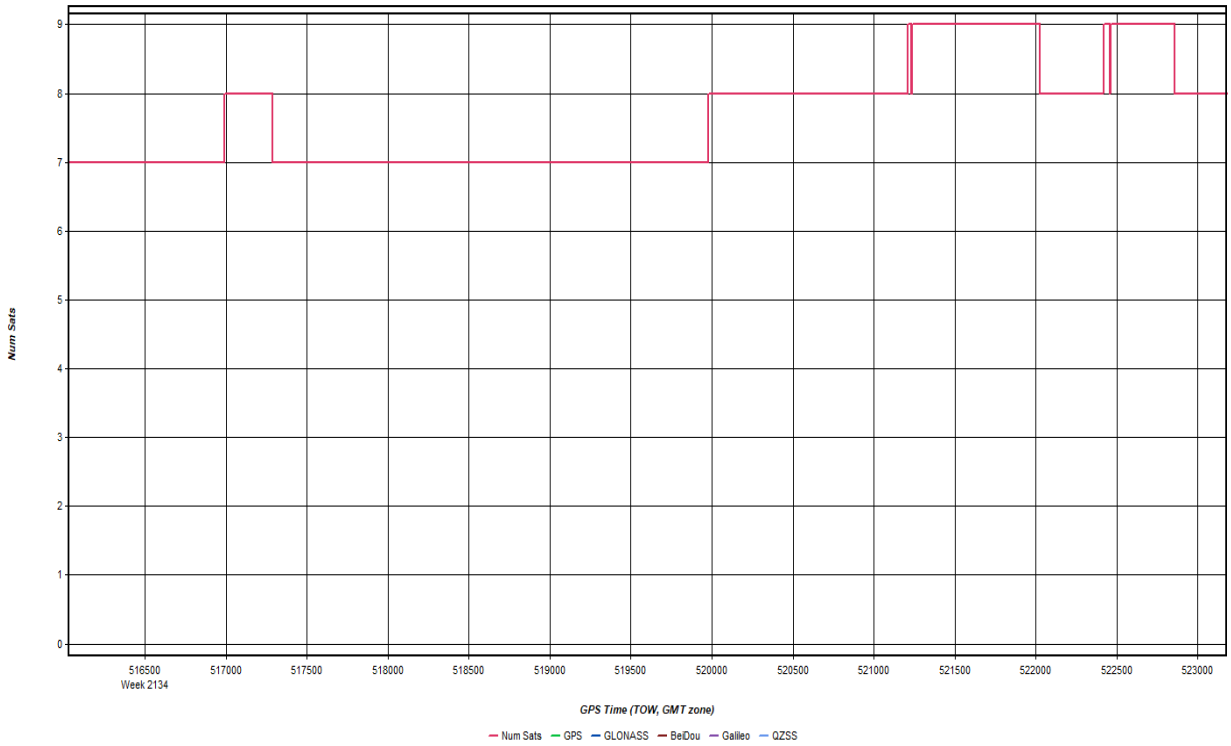


GNSS QC

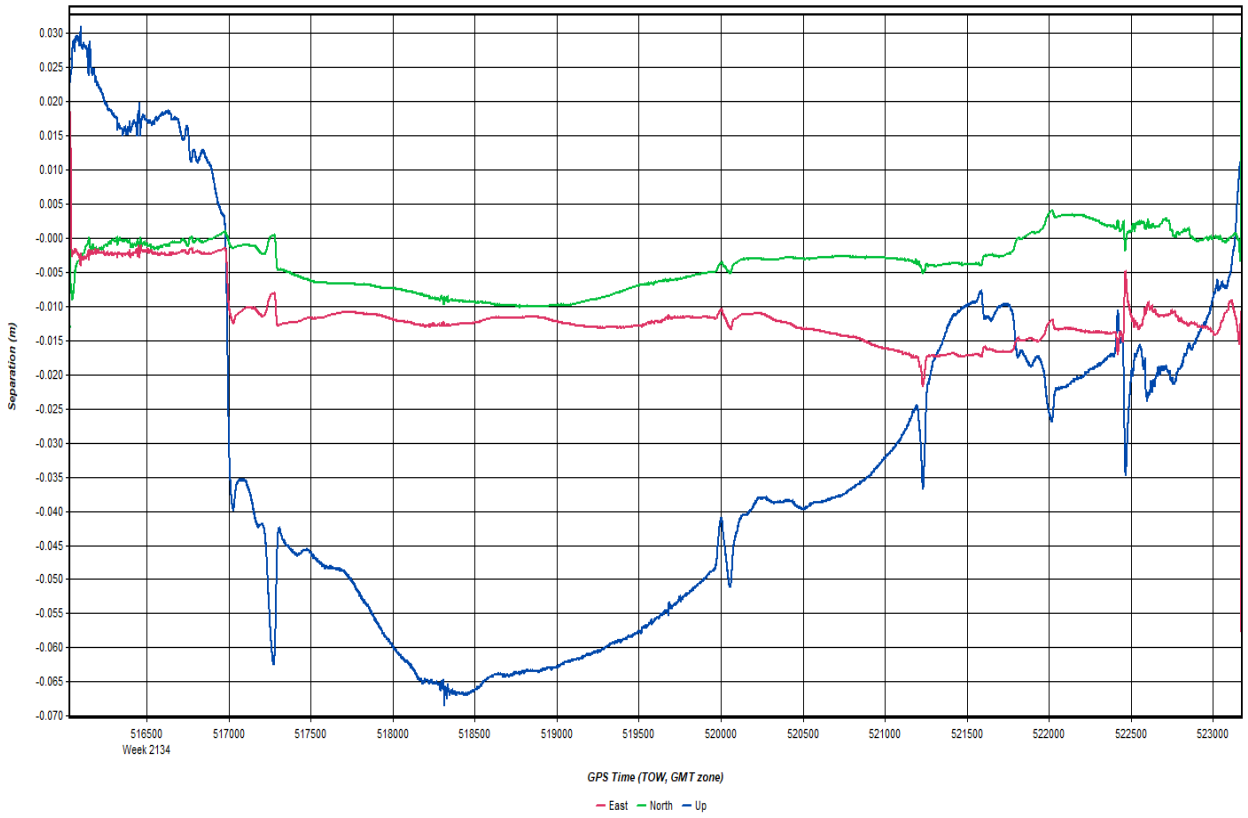
Quality Factor Plot



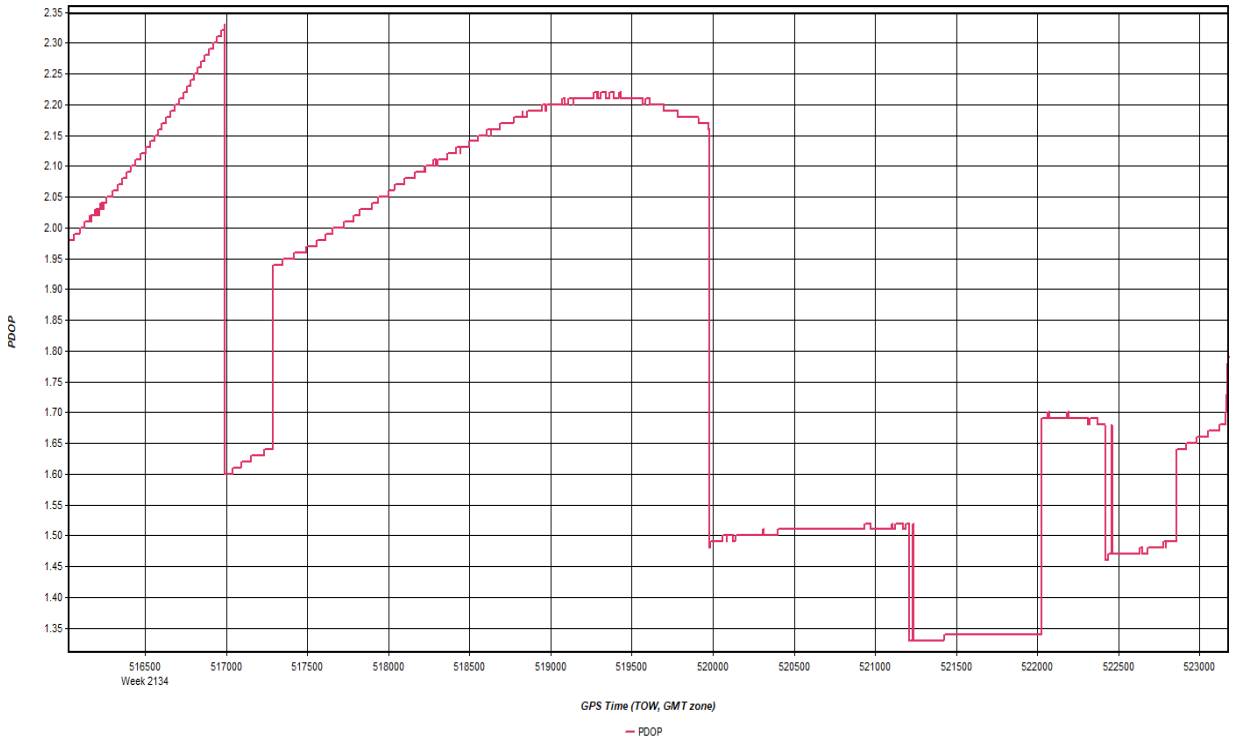
Number of Satellites Plot



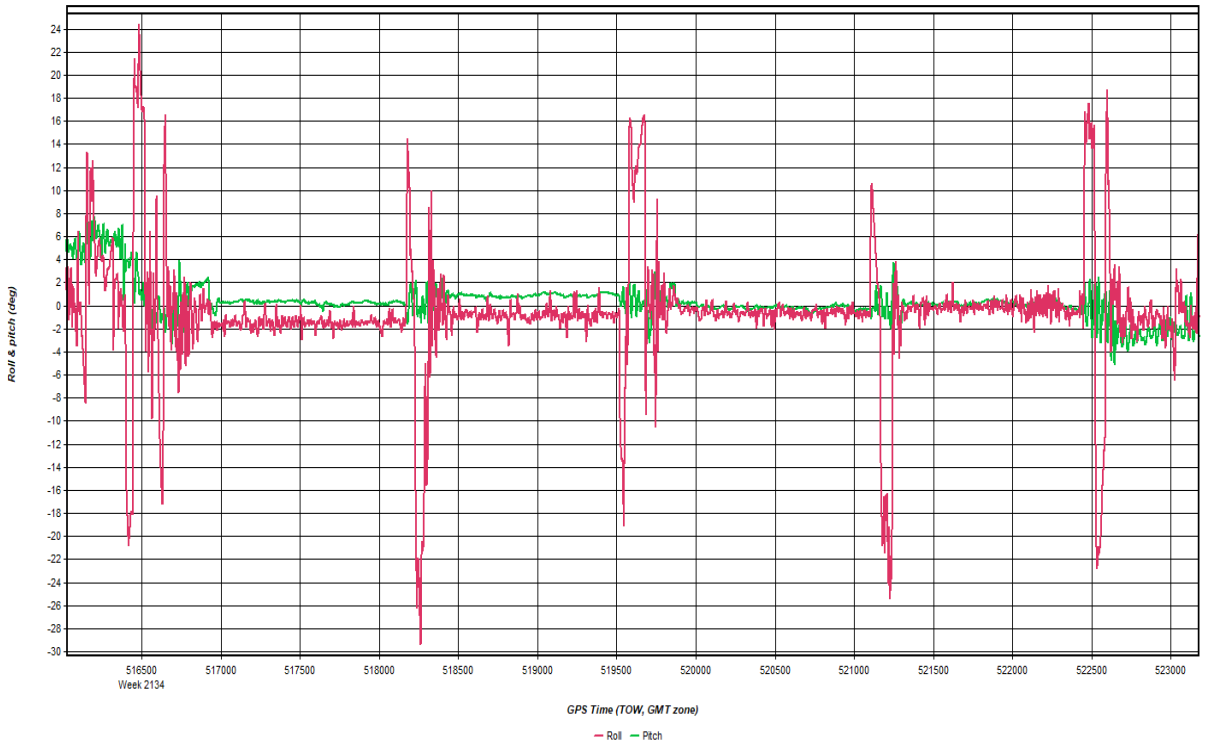
Forward/Reverse or Combined Separation Plot



PDOP Plot



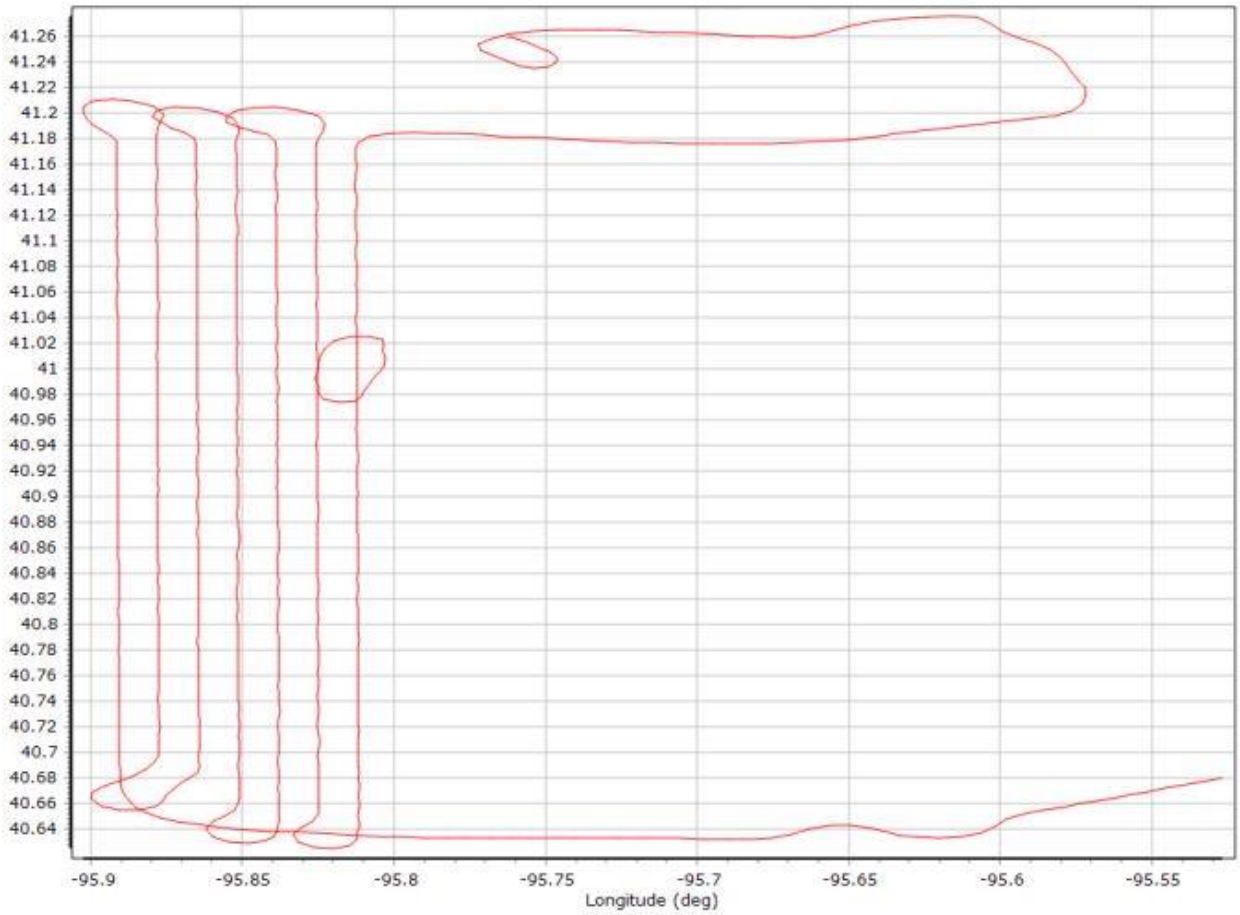
Roll & Pitch Plot



TAC Reports for Block A.

20201205_1_QC Report.docx QC Report – 8/27/2021 07:28:24
Smoothed Trajectory Information

Top View

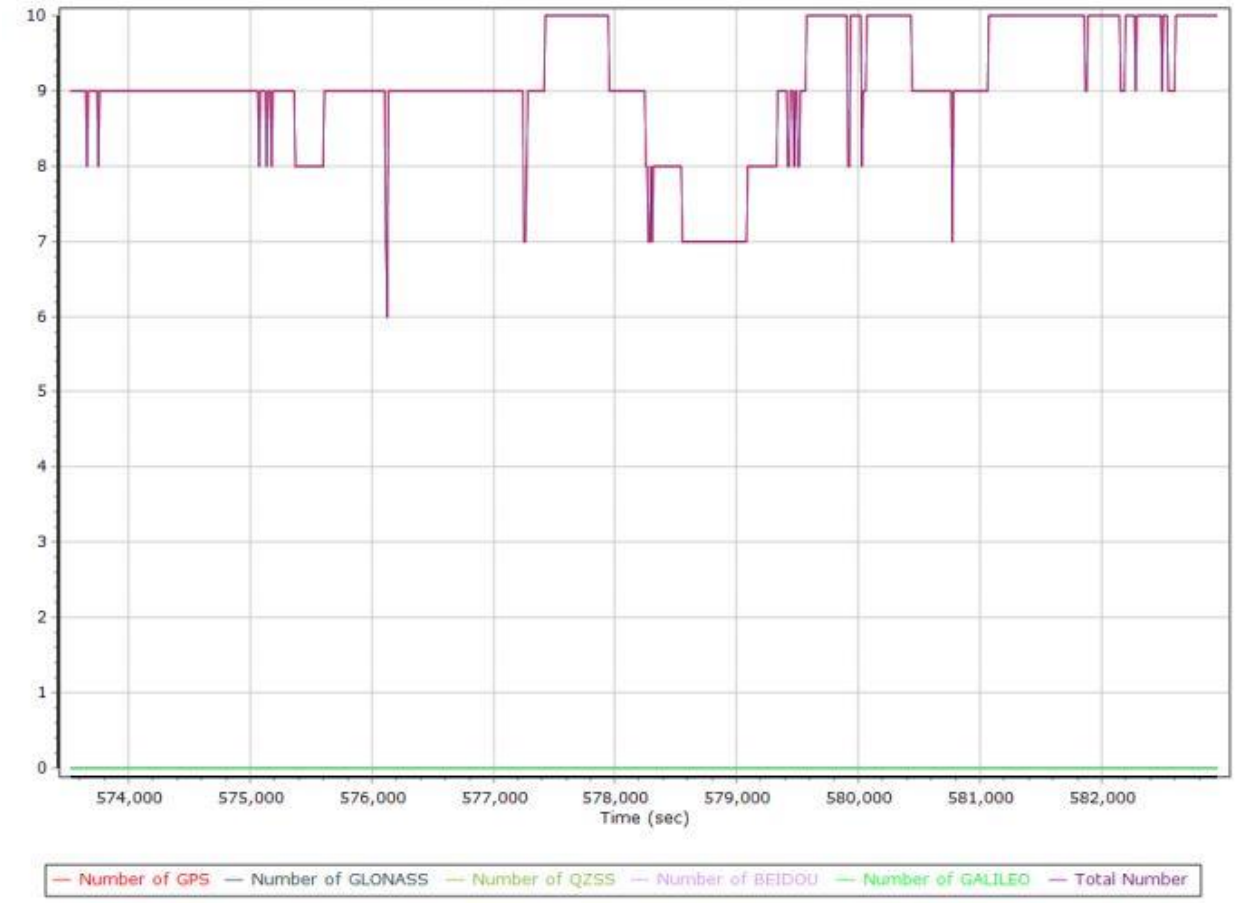


GNSS QC

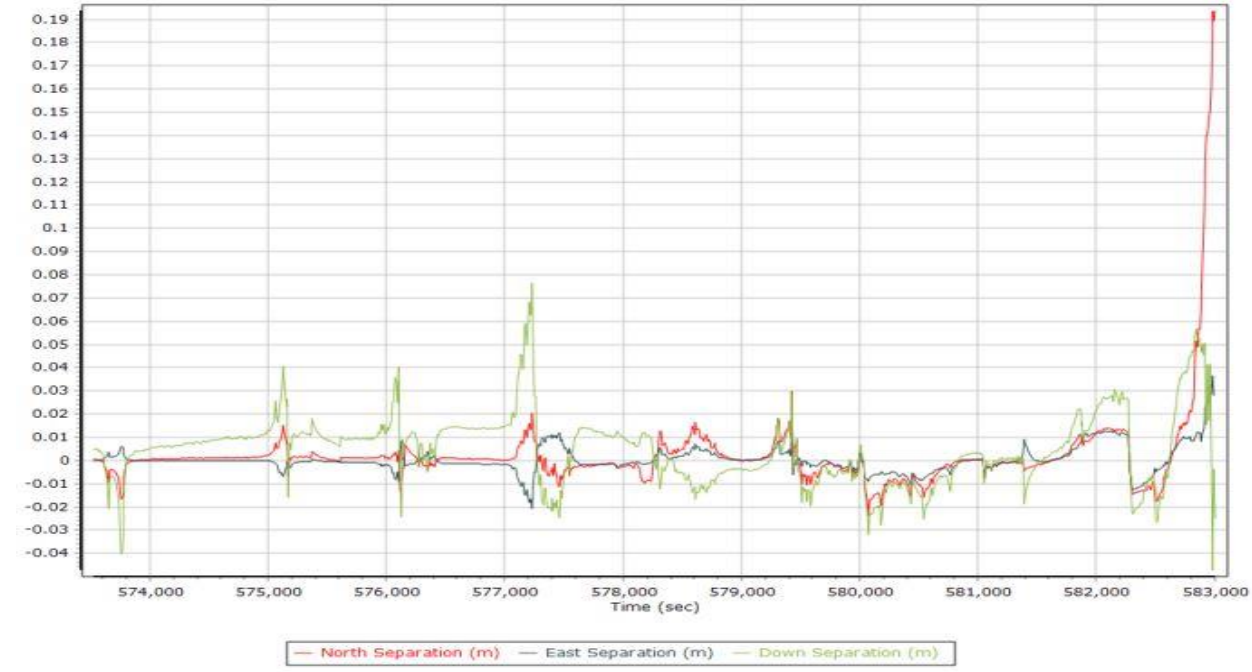
GNSS QC Statistics

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

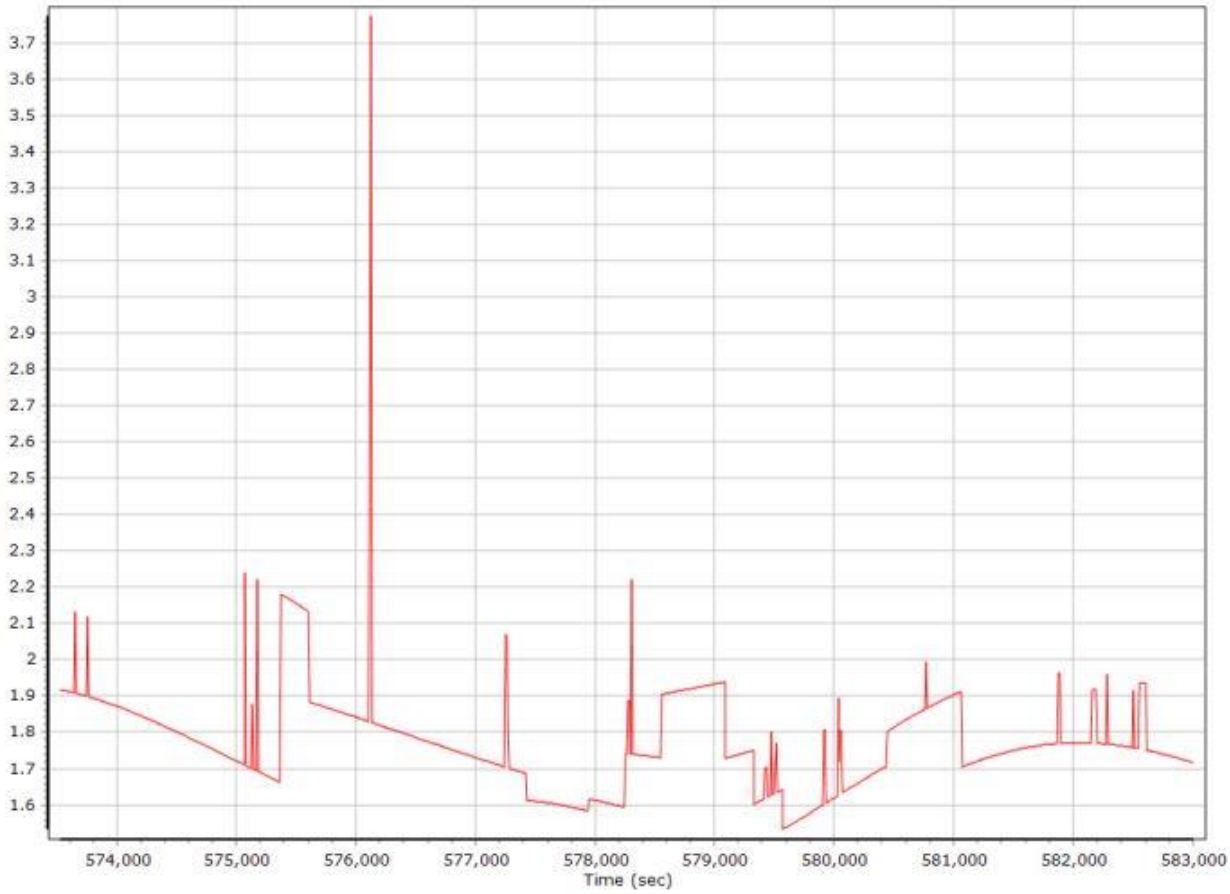
Number of Satellites



Forward/Reverse Separation



PDOP


3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
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576,000
577,000
578,000
579,000
580,000
581,000
582,000
583,000
Time (sec)

20201205_2_QC Report.docx QC Report – 8/27/2021 07:28:24
Smoothed Trajectory Information

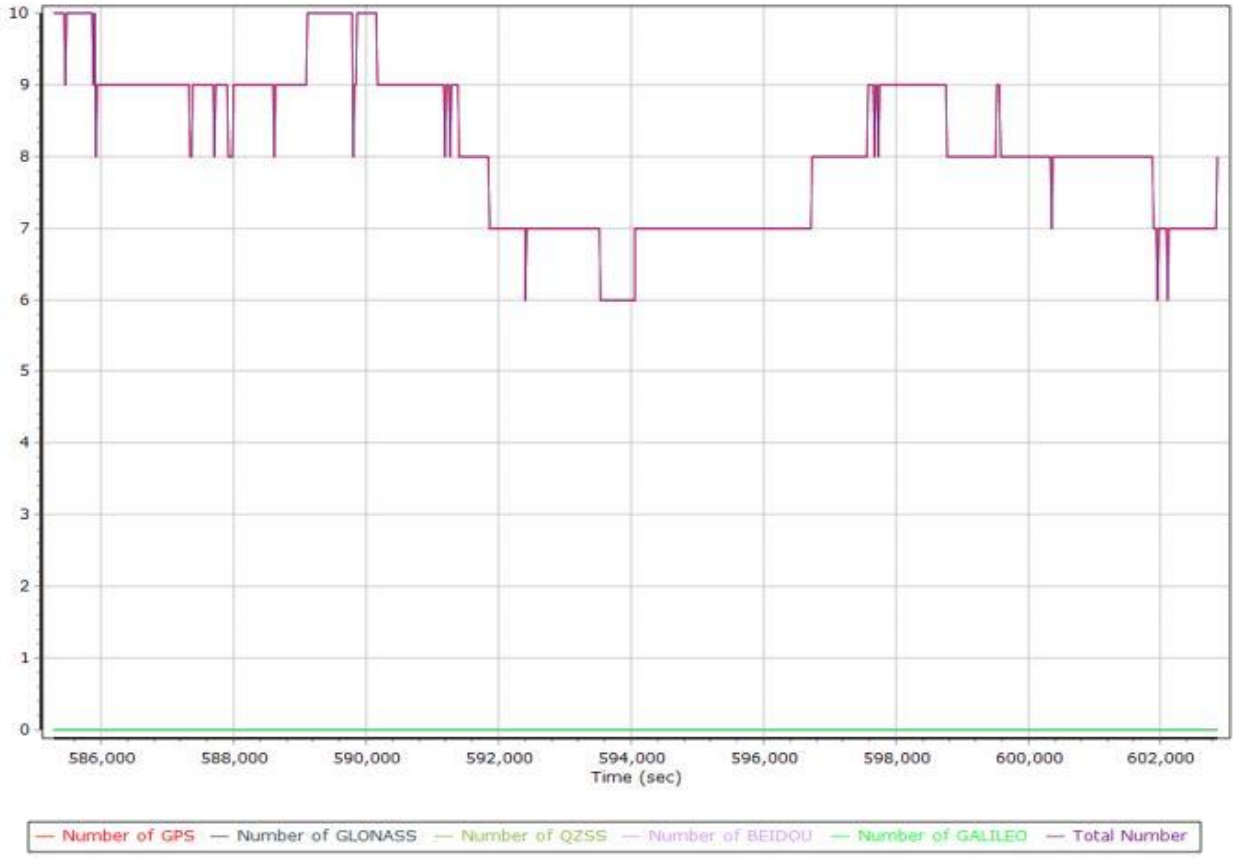
Top View

GNSS QC

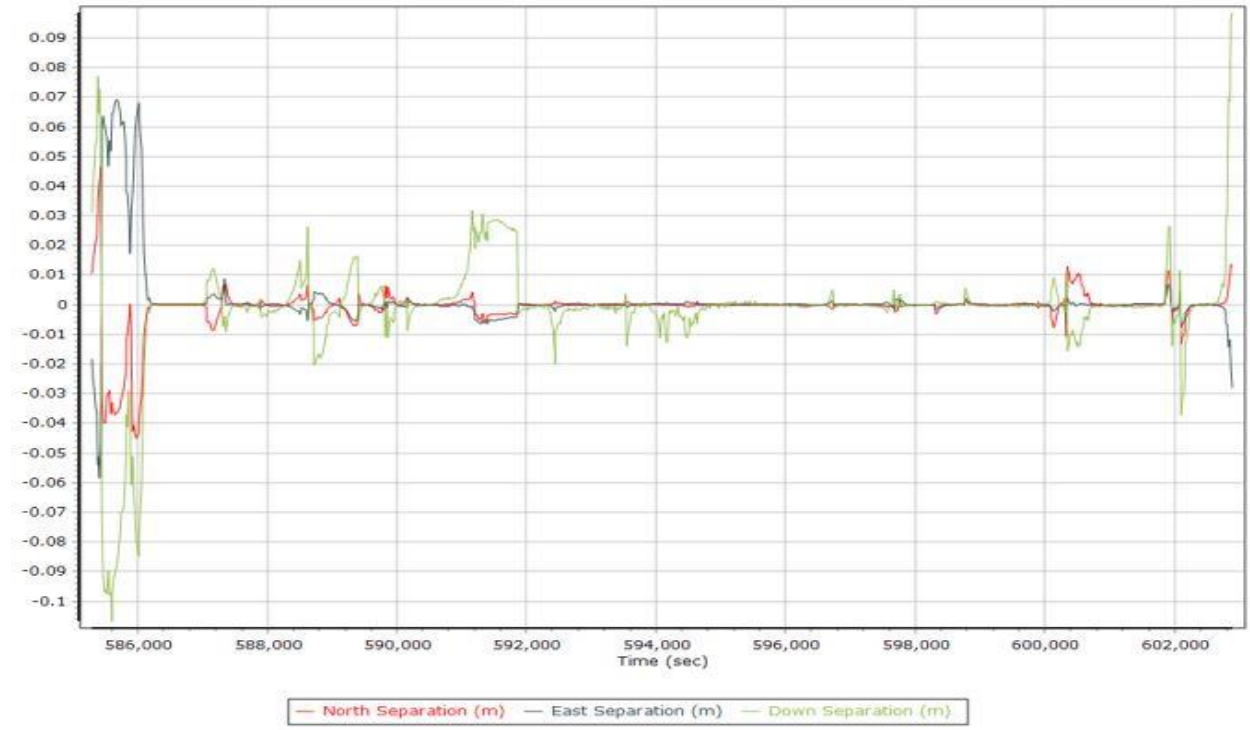
GNSS QC Statistics

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

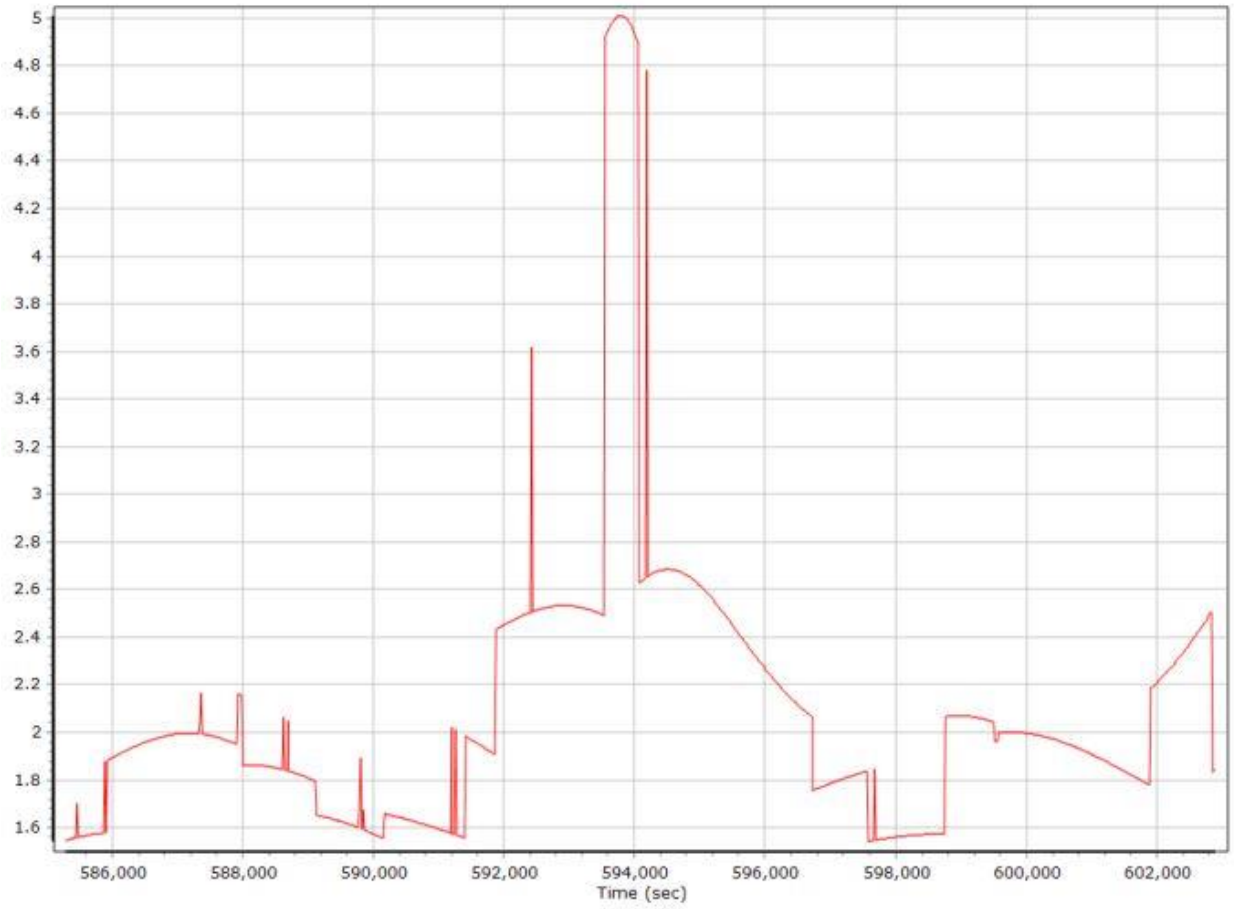
Number of Satellites



Forward/Reverse Separation



PDOP


5
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4.6
4.4
4.2
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3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
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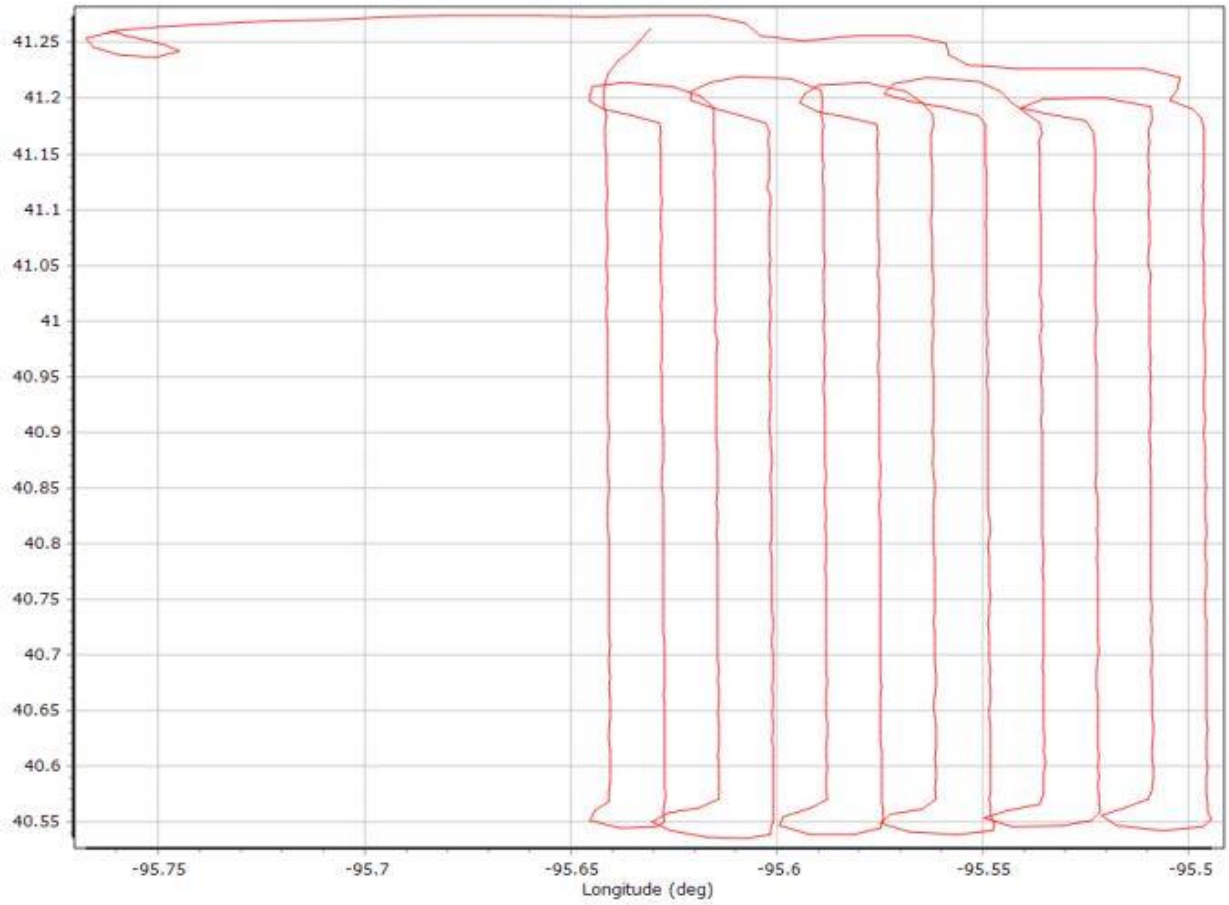
592,000
594,000
596,000
598,000
600,000
602,000
Time (sec)

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

Top View

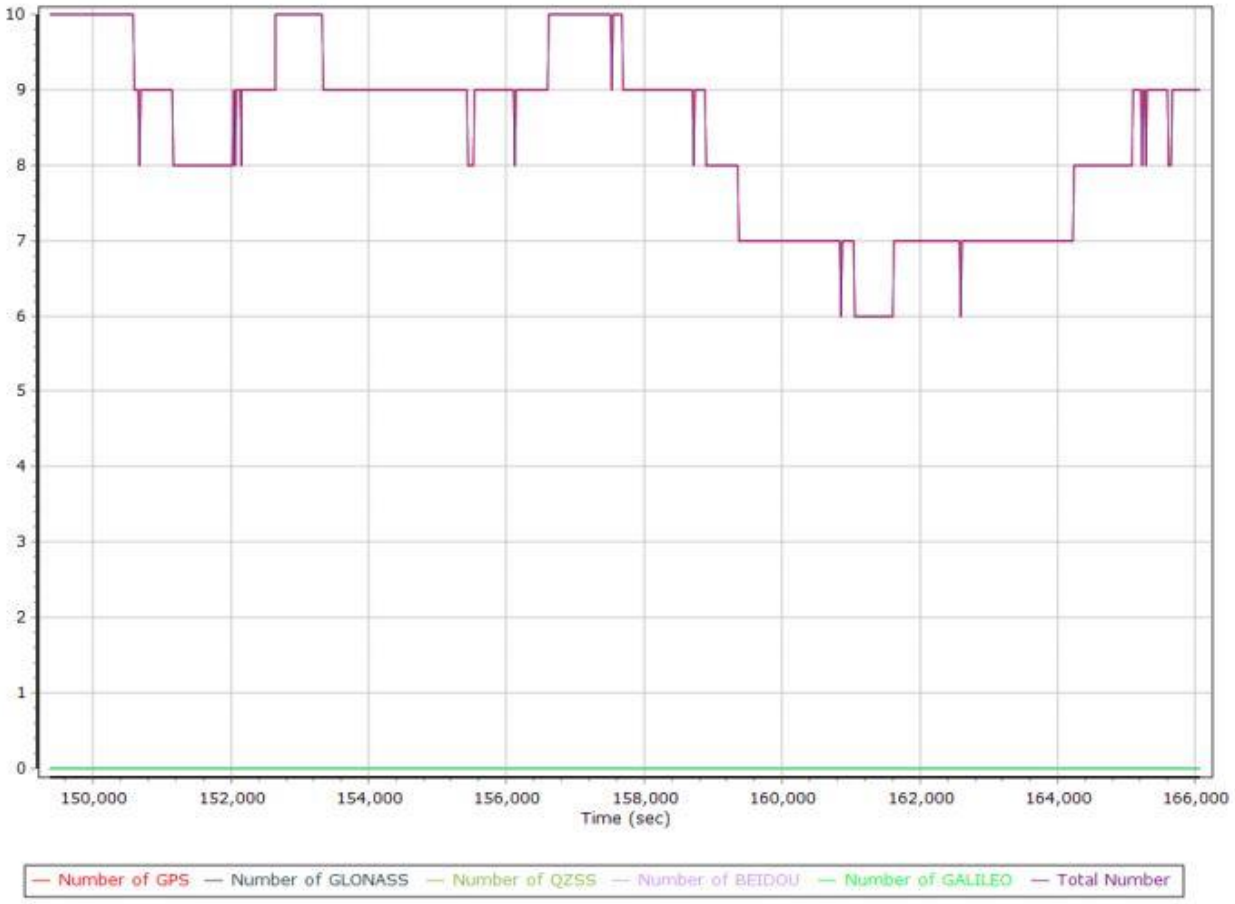


GNSS QC

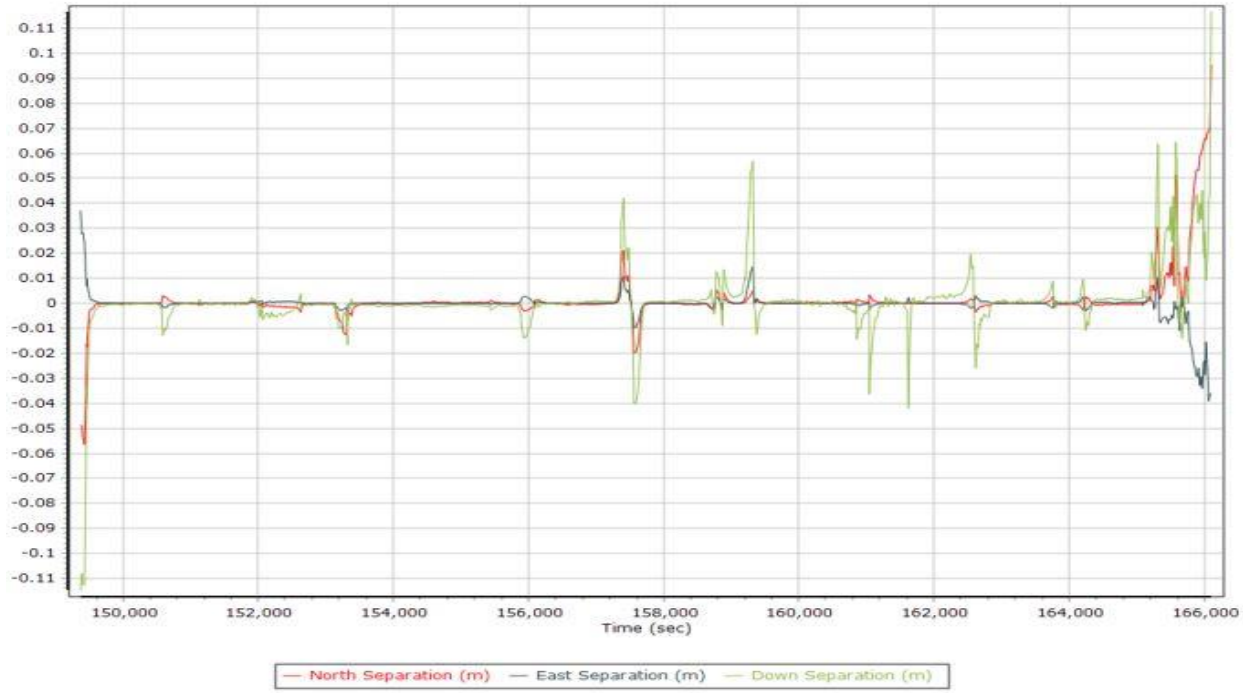
GNSS QC Statistics

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

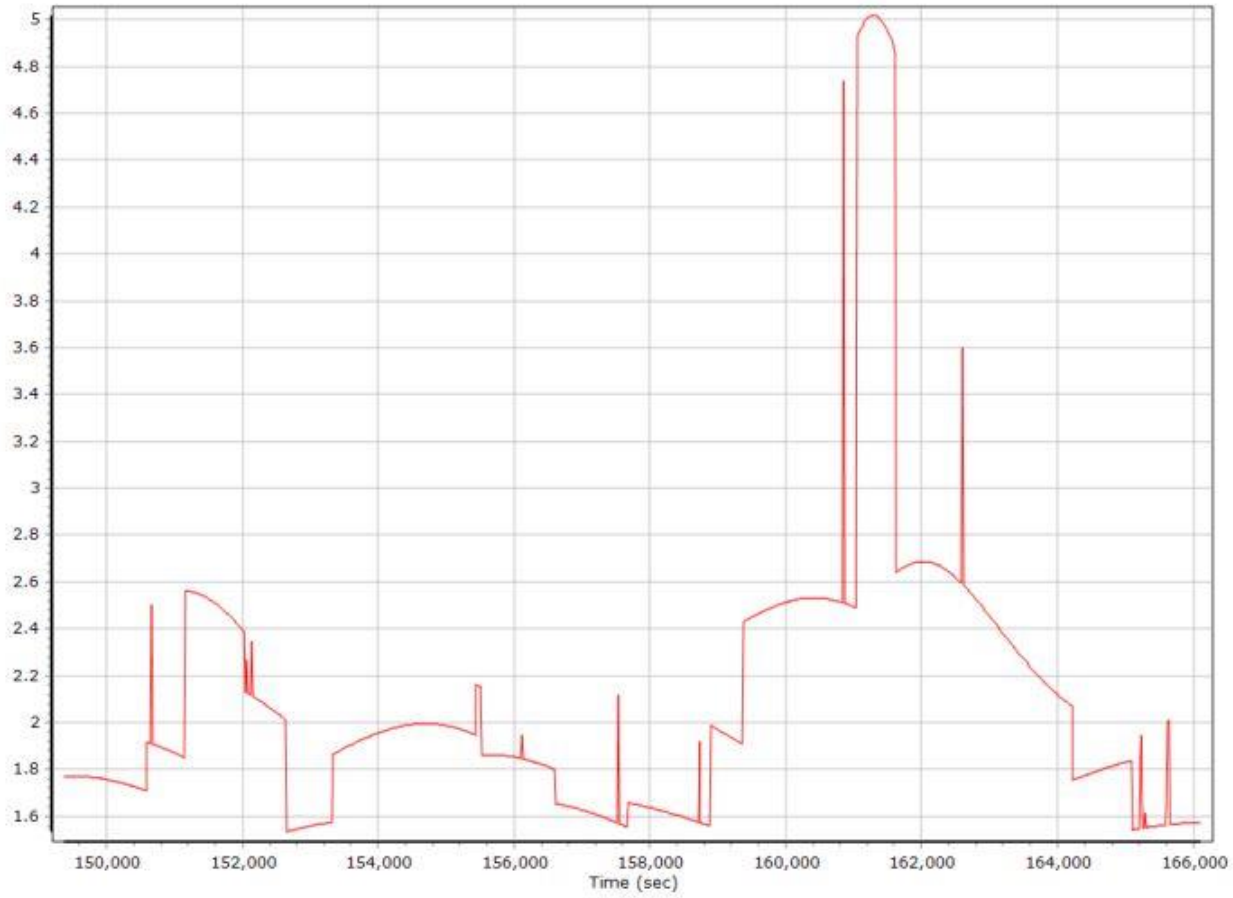
Number of Satellites



Forward/Reverse Separation



PDOP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4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
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1.8
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156,000
158,000
160,000
162,000
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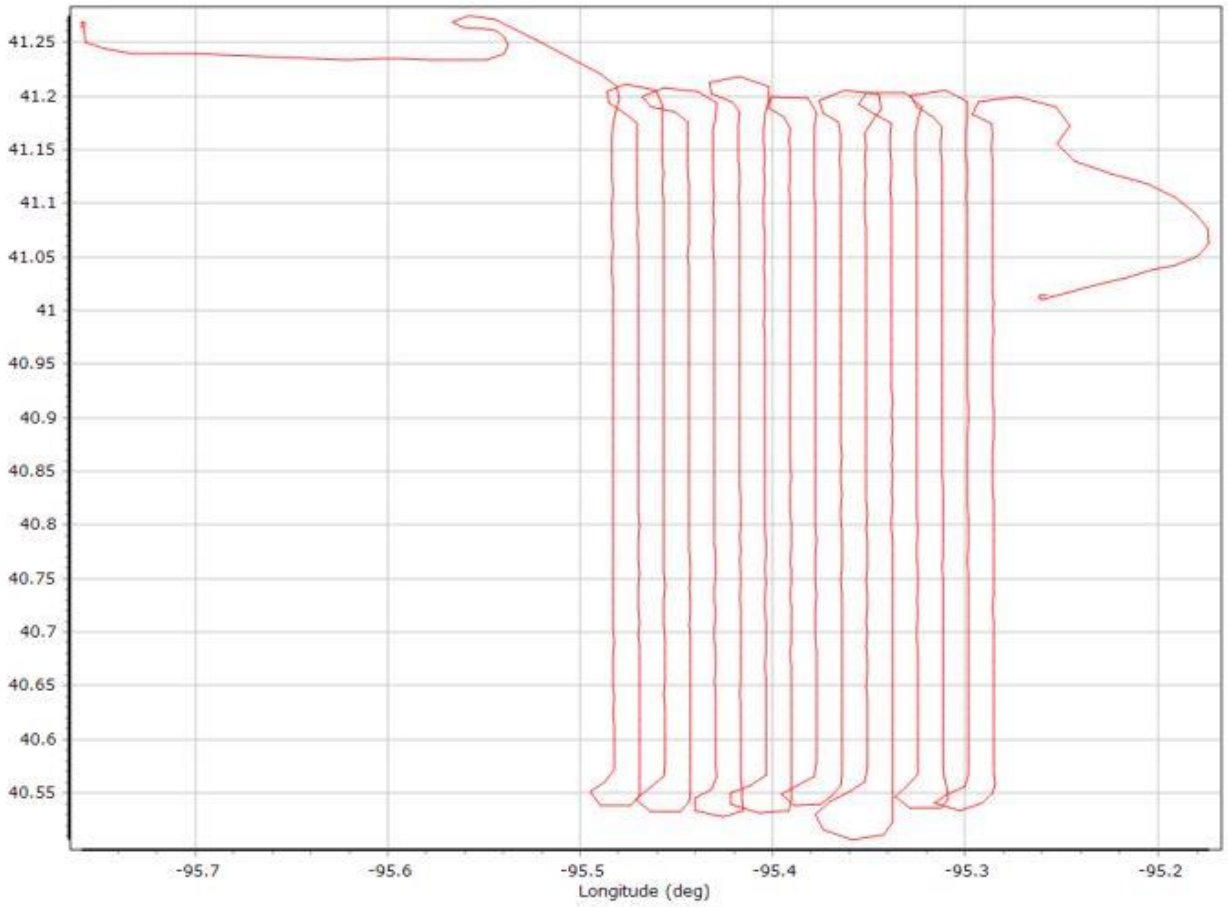
166,000
Time (sec)

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

Top View

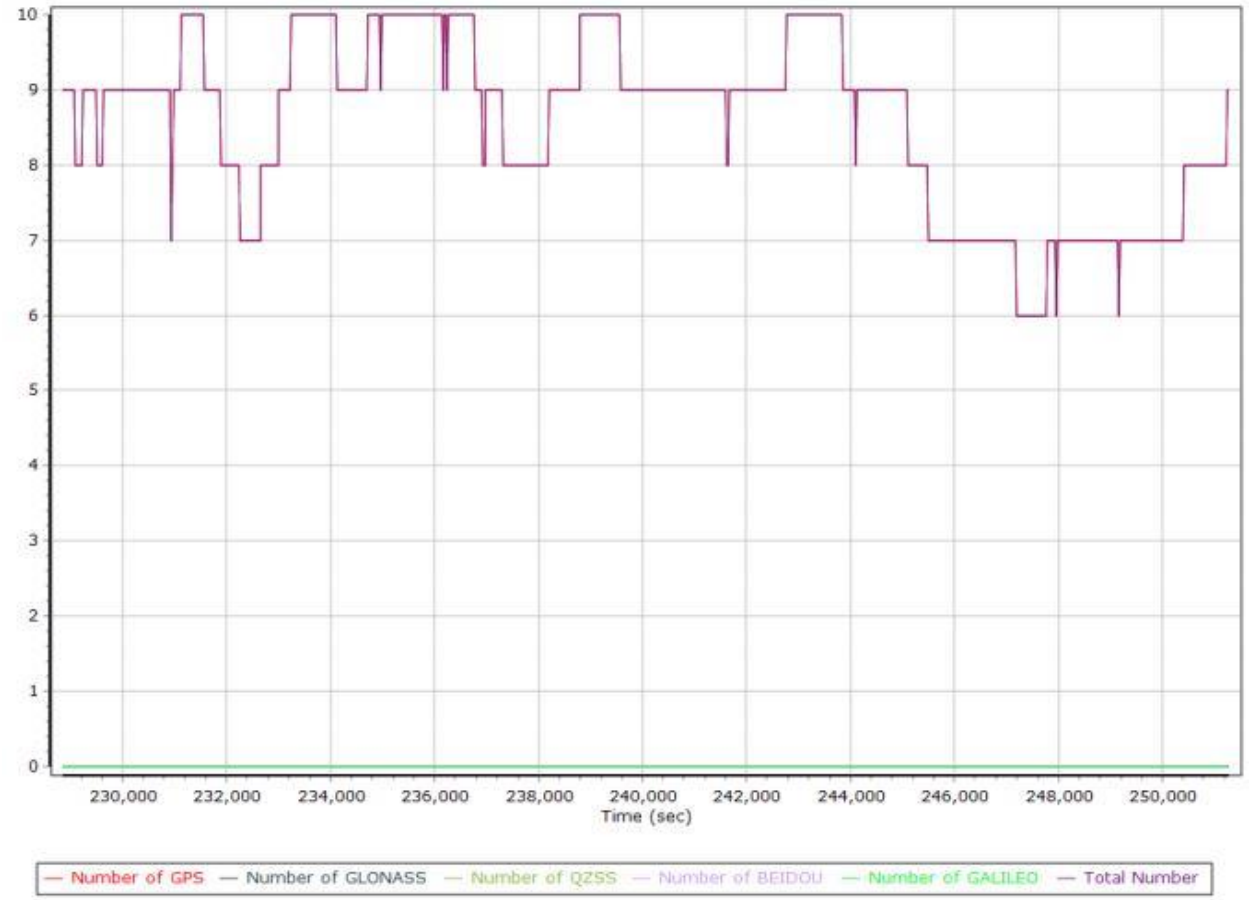


GNSS QC

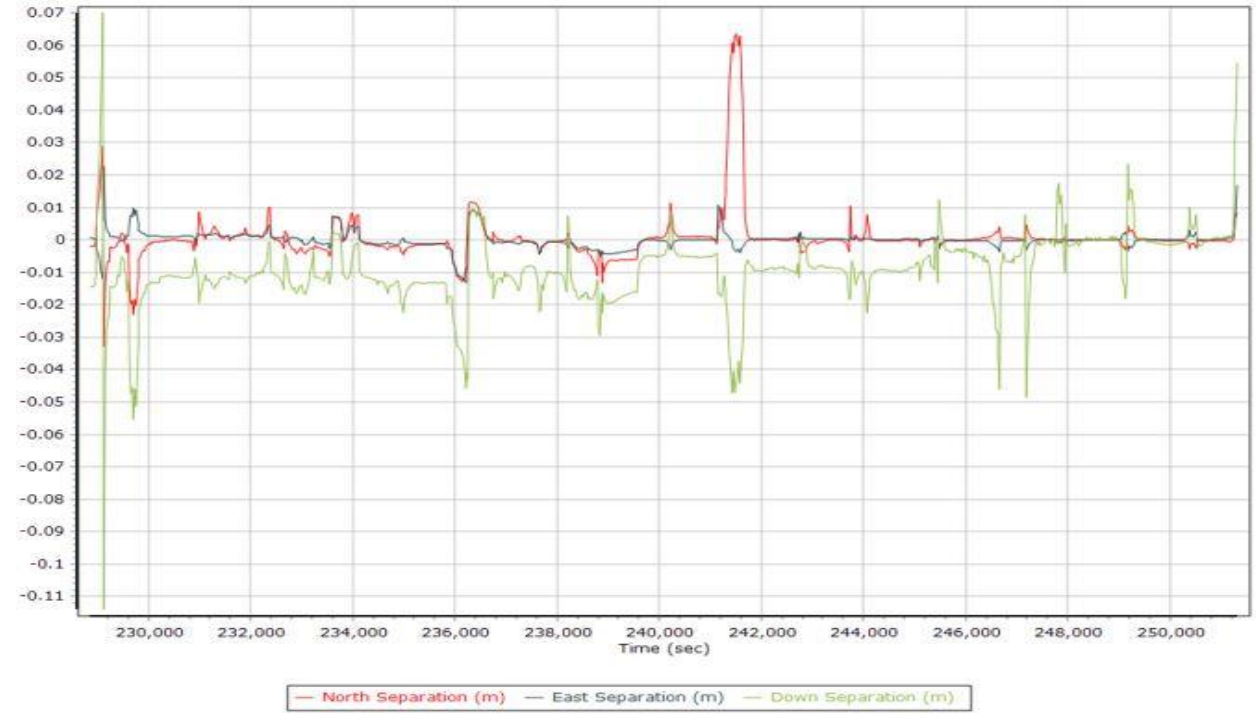
GNSS QC Statistics

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

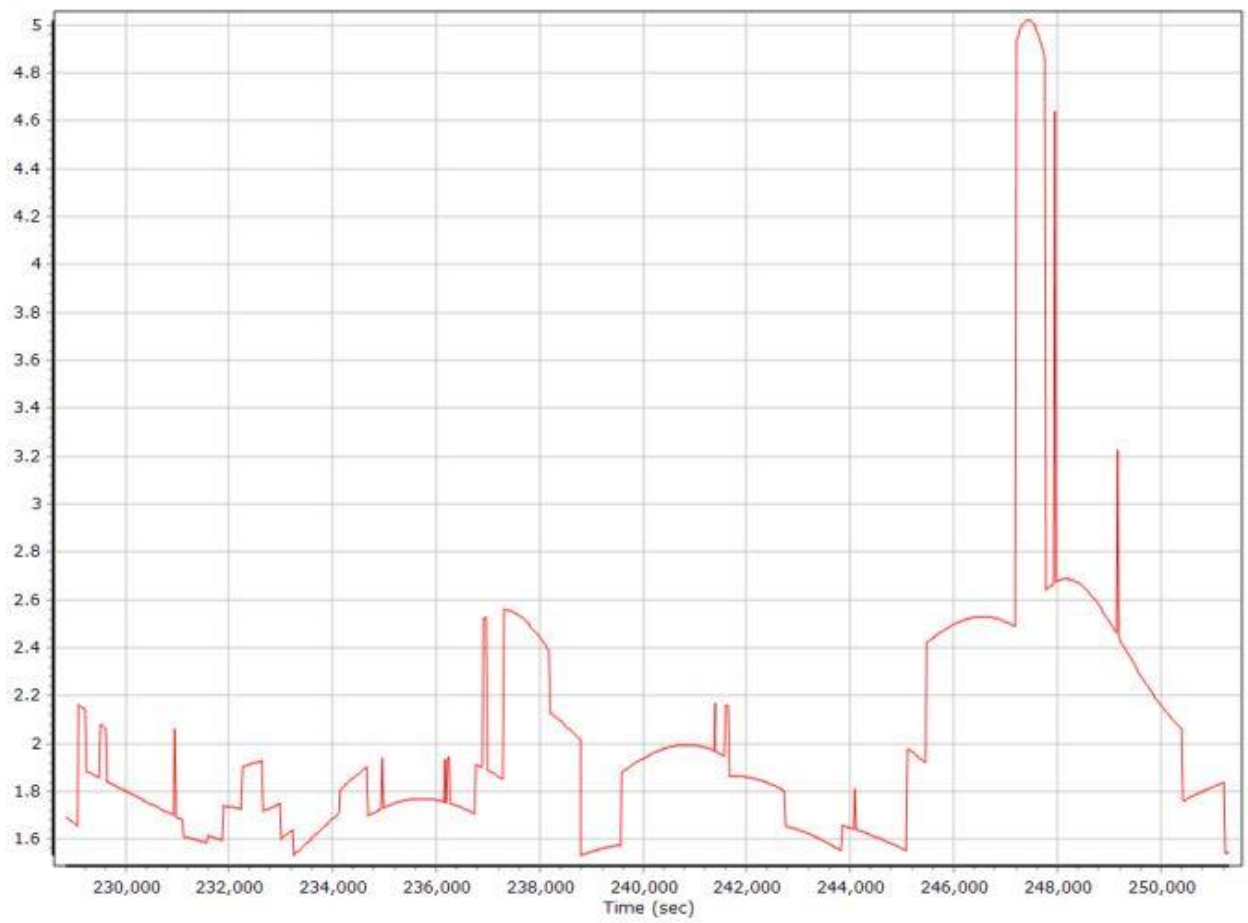
Number of Satellites



Forward/Reverse Separation



PDOP


5
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4.6
4.4
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3.4
3.2
3
2.8
2.6
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240,000
242,000
244,000
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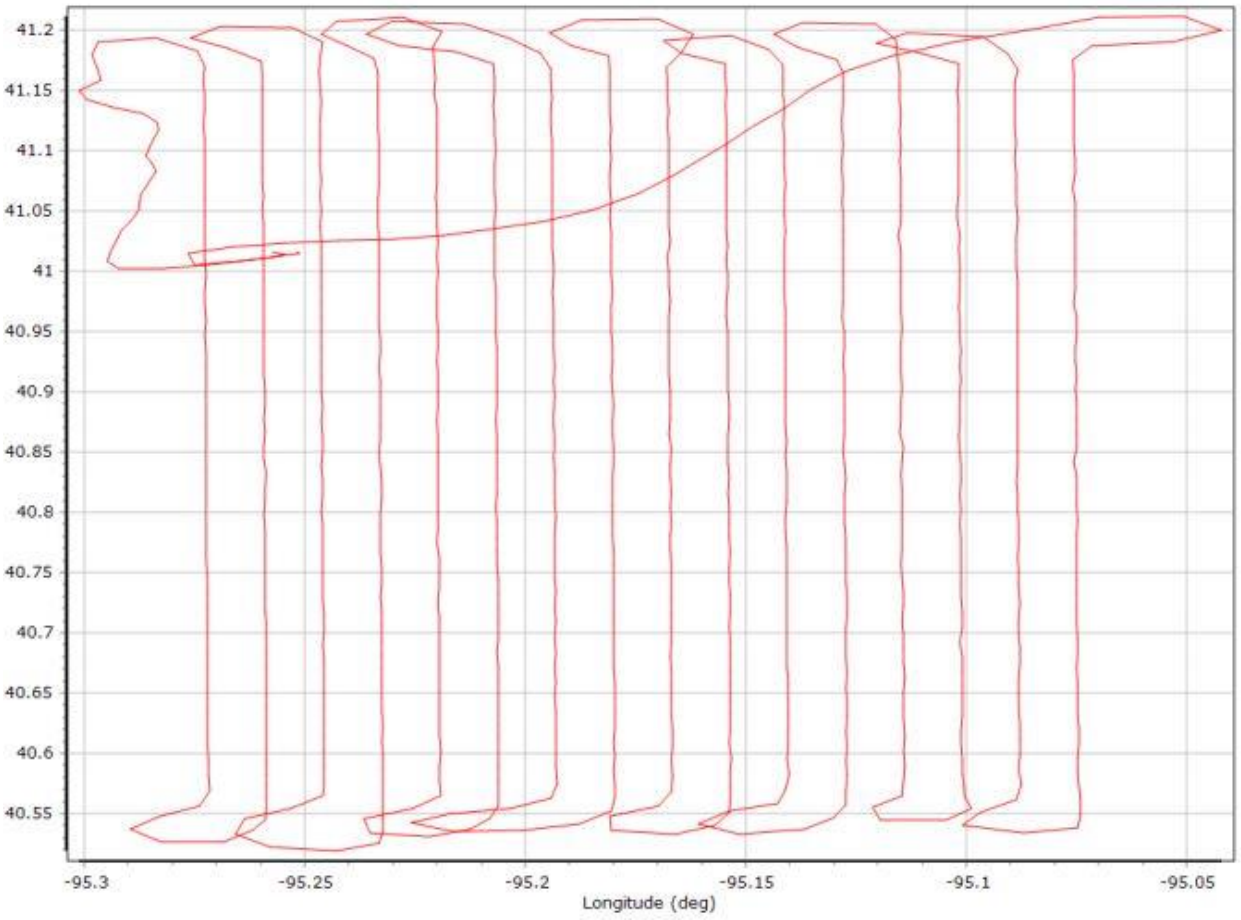
250,000
Time (sec)

20201209_1_QC Report.docx QC Report – 8/27/2021 07:53:24
Smoothed Trajectory Information

Top View

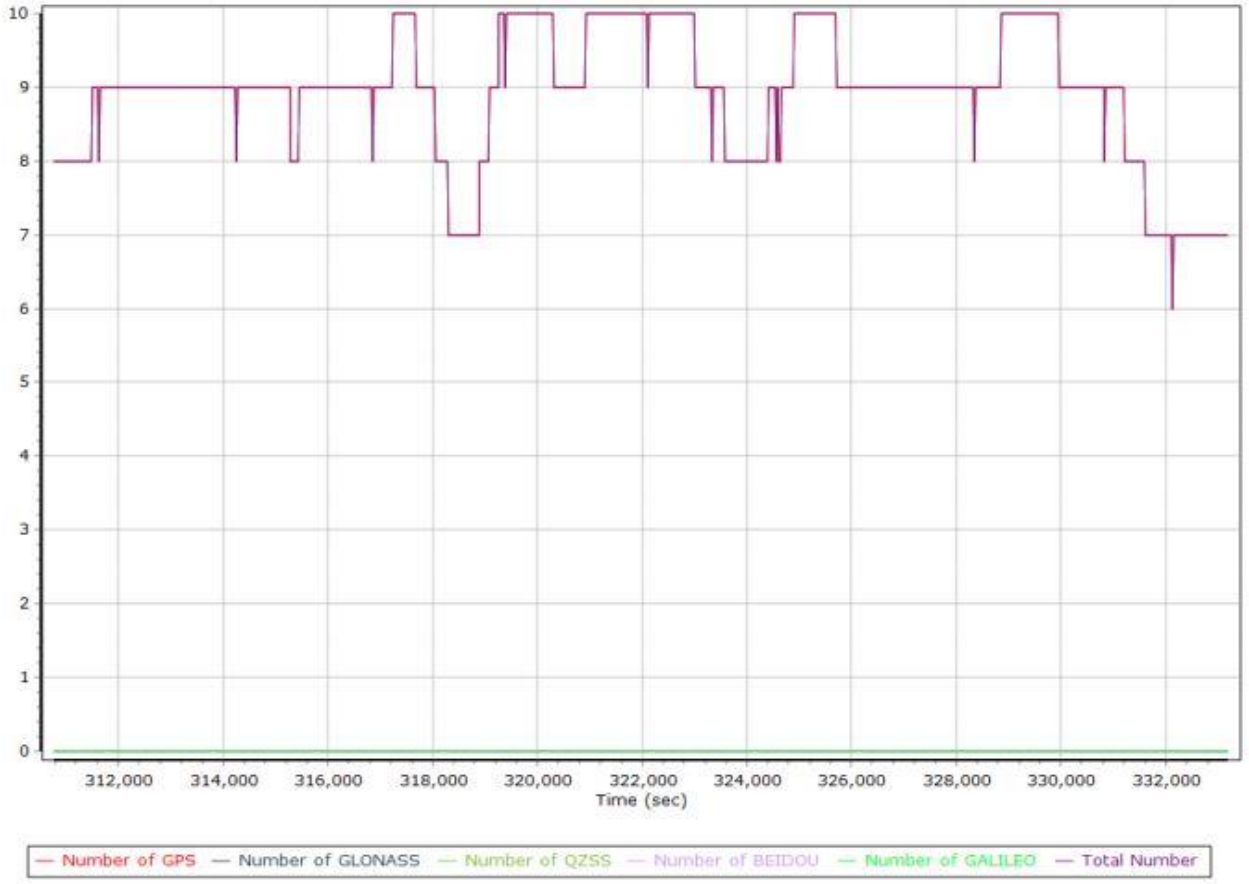


GNSS QC

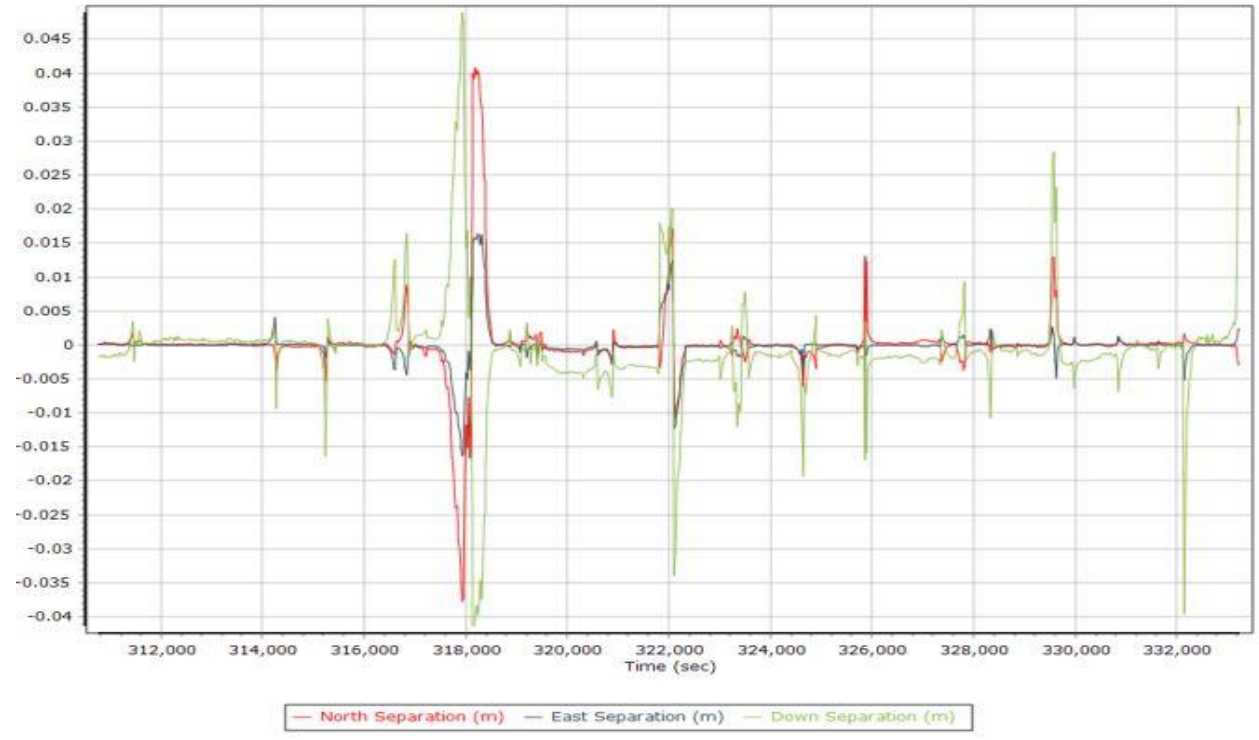
GNSS QC Statistics

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

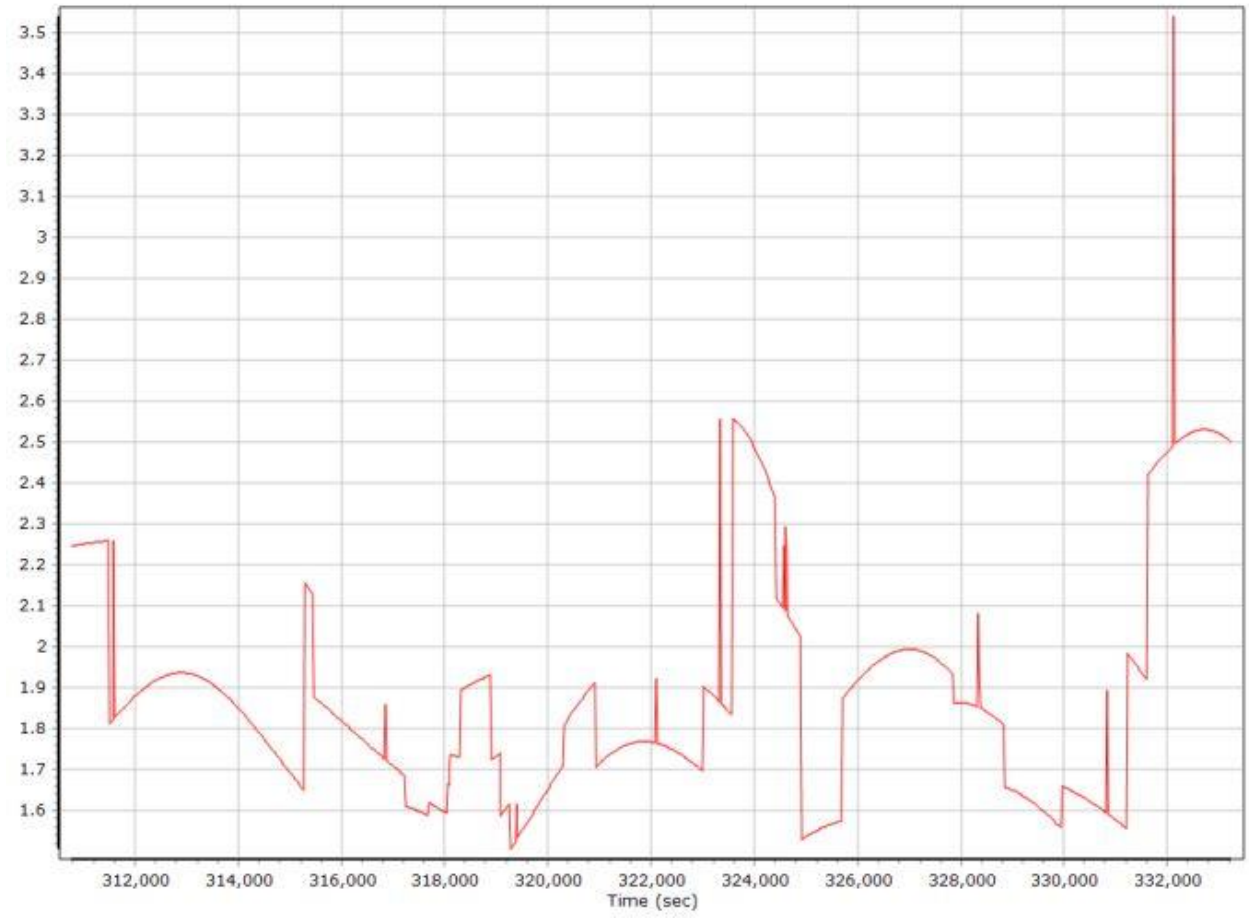
Number of Satellites



Forward/Reverse Separation



PDOP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3.2
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2.2
2.1
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1.8
1.7
1.6
312,000
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322,000
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326,000
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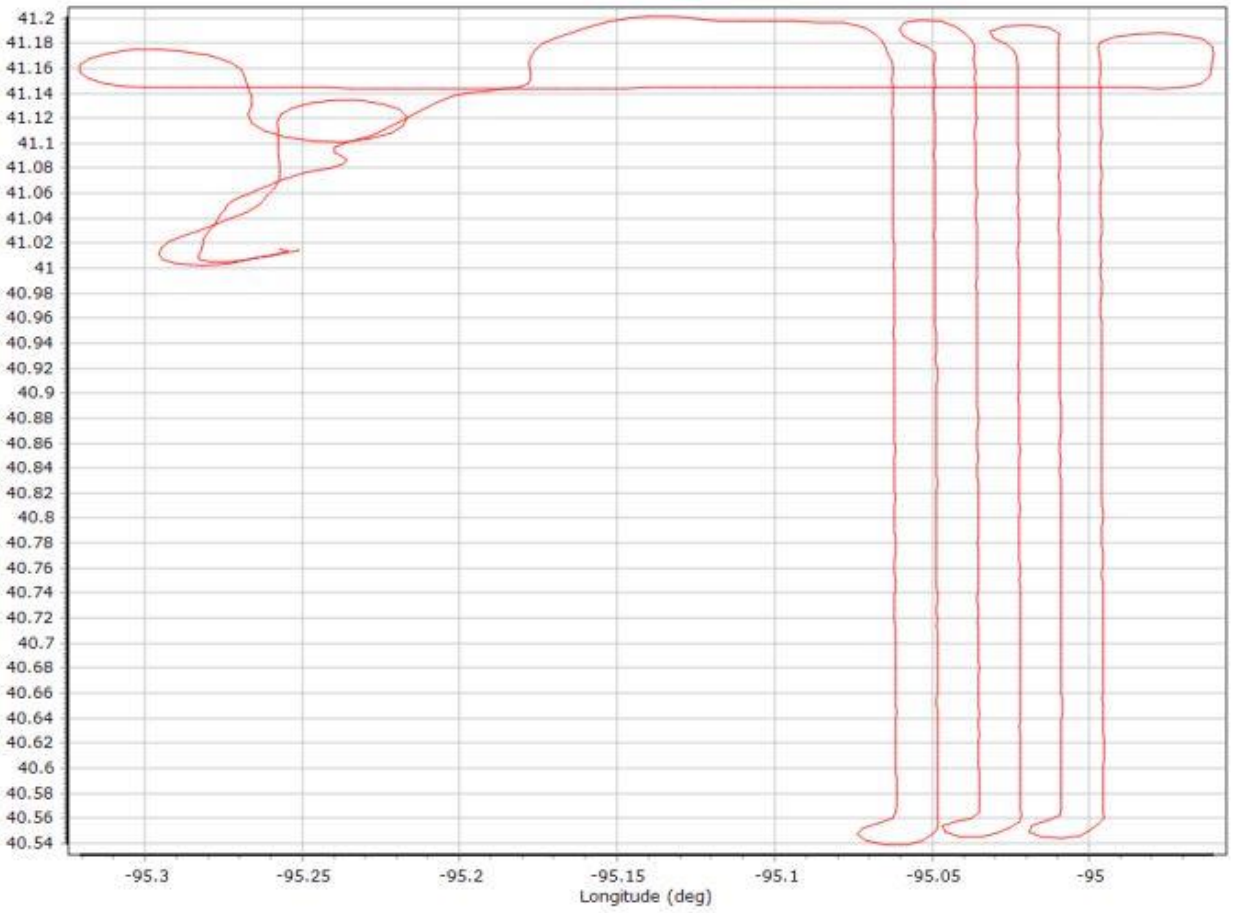
330,000
332,000
Time (sec)

20201209_2_QC Report.docx QC Report – 8/27/2021 08:01:24
Smoothed Trajectory Information

Top View

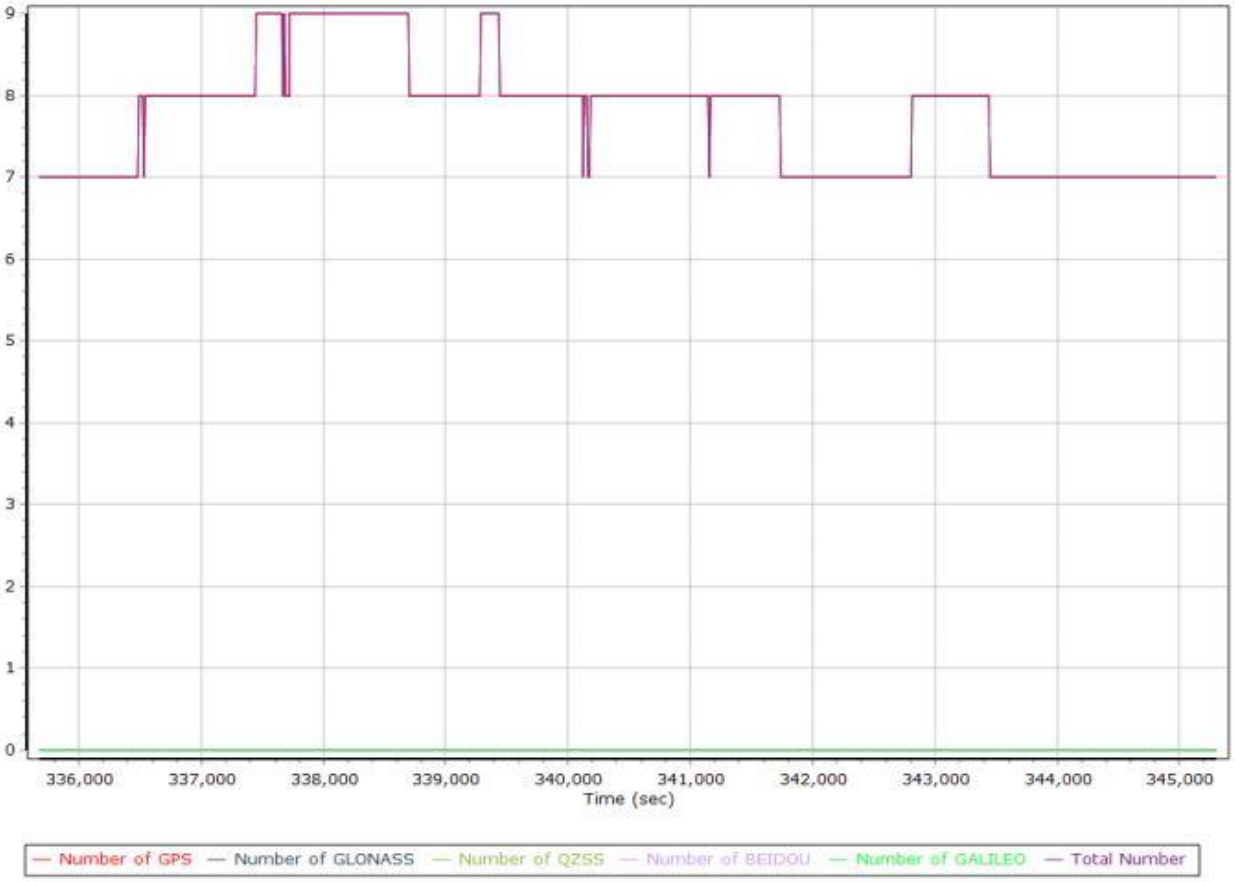


GNSS QC

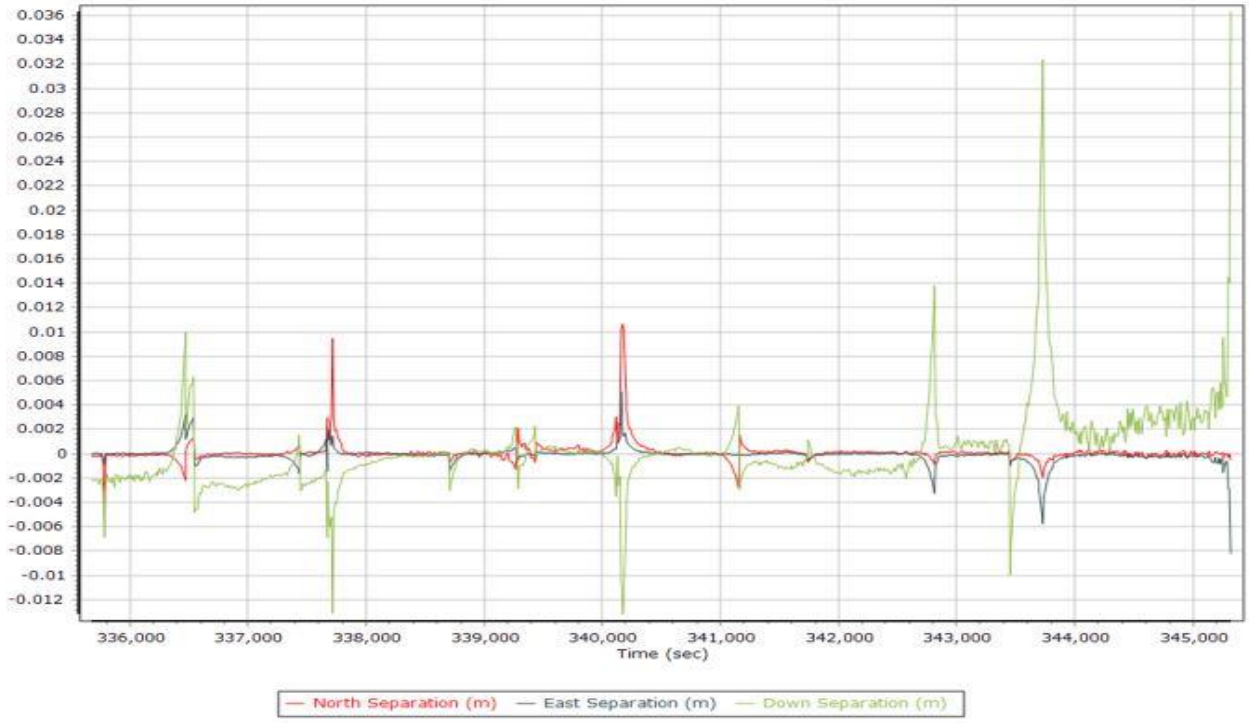
GNSS QC Statistics

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

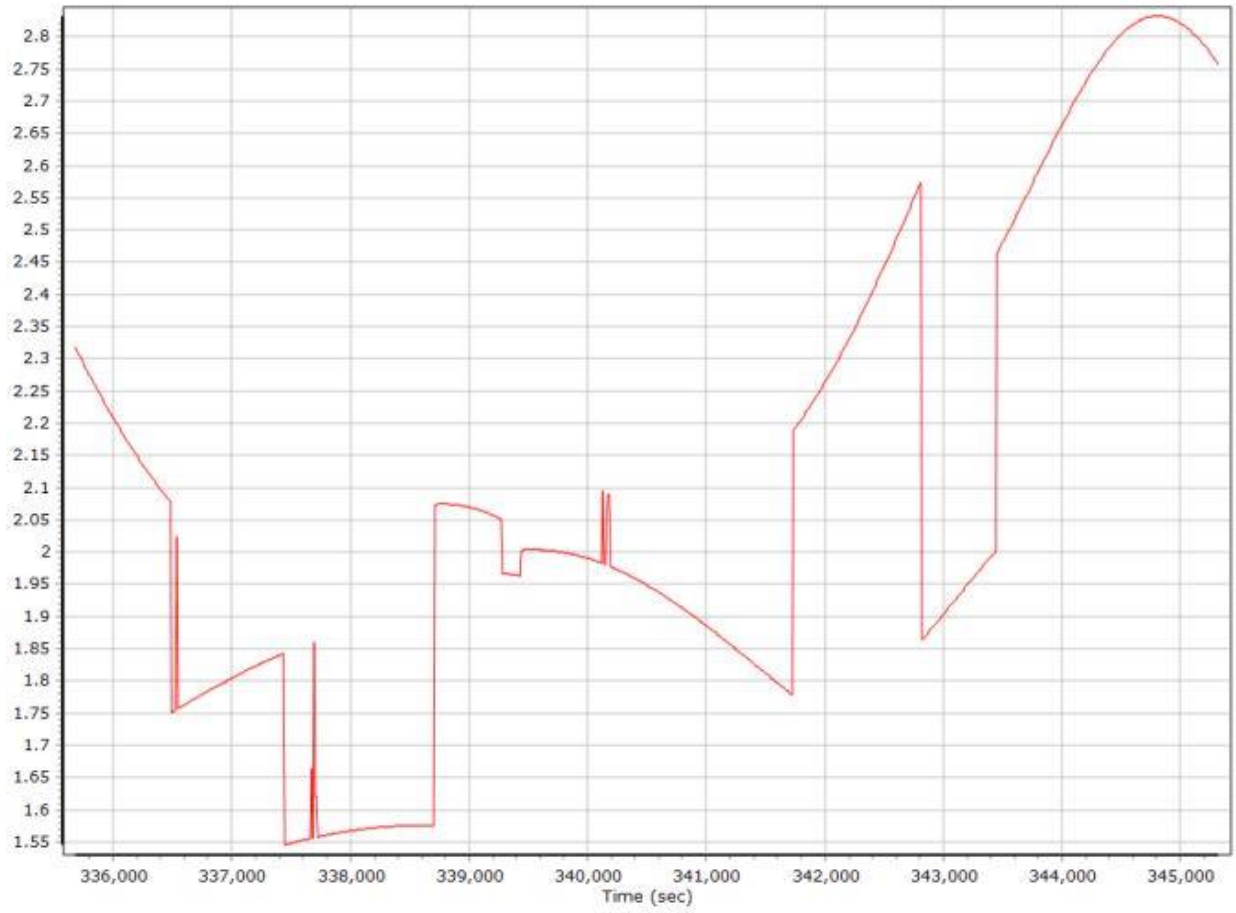
Number of Satellites



Forward/Reverse Separation



PDOP


2.8
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2.55
2.5
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
336,000
337,000
338,000
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340,000
341,000
342,000
343,000
344,000
345,000
Time (sec)

20201210_1_QC Report.docx QC Report – 8/27/2021 08:08:14
Smoothed Trajectory Information

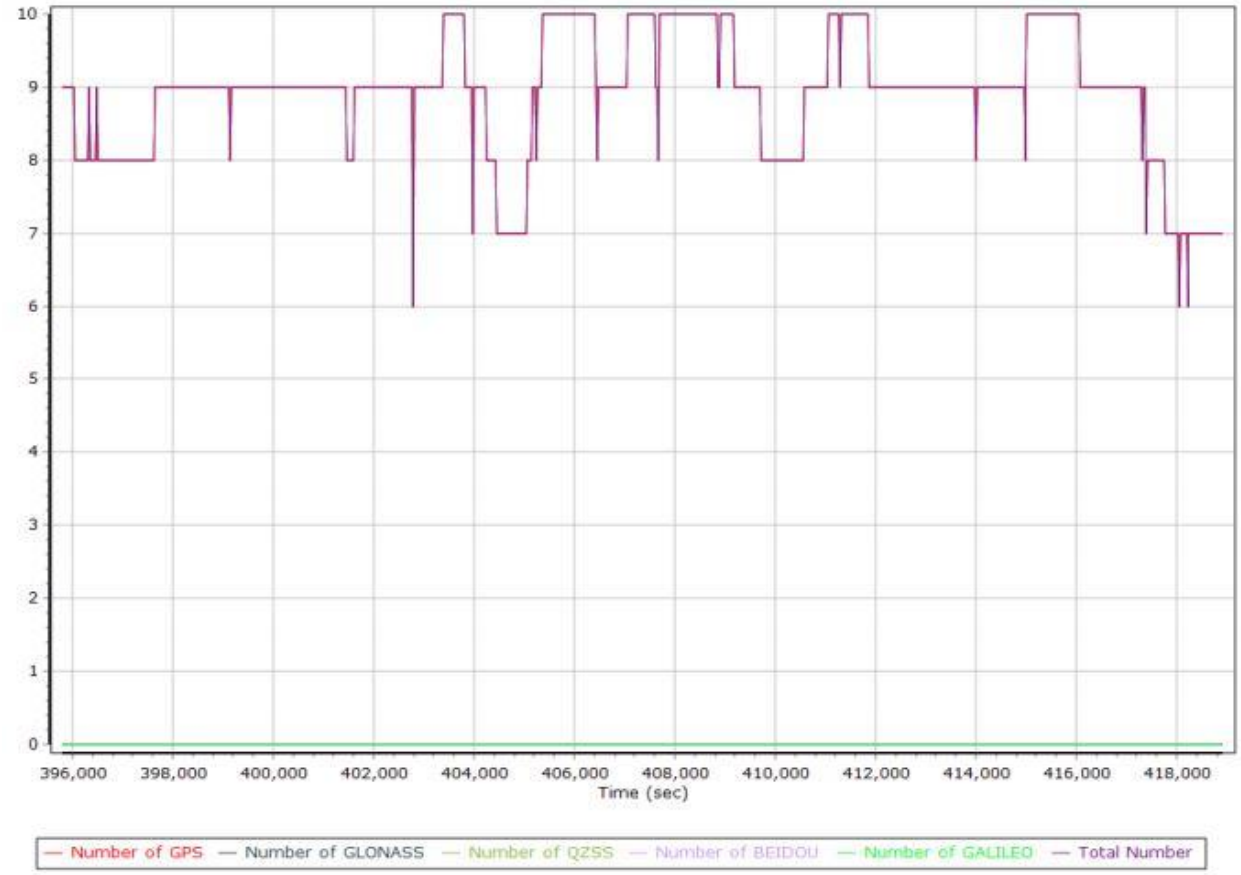
Top View

GNSS QC

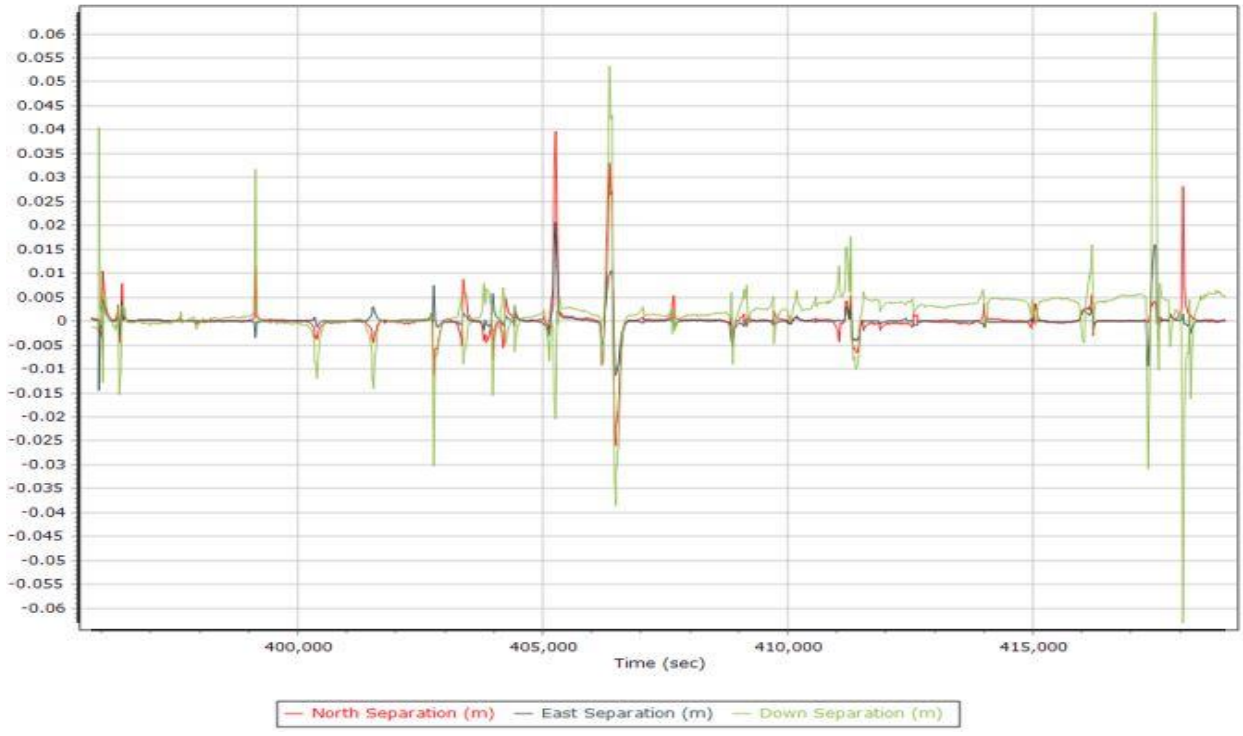
GNSS QC Statistics

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

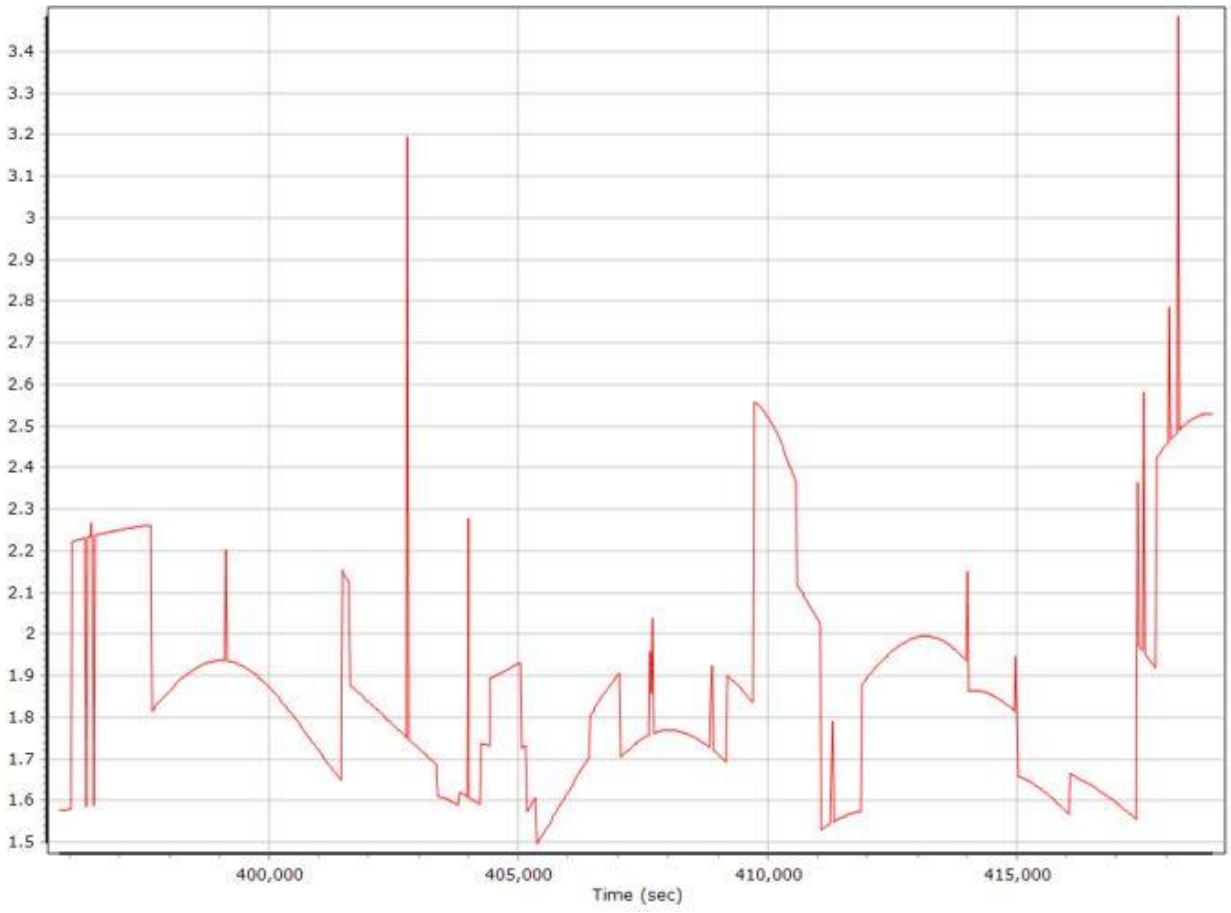
Number of Satellites



Forward/Reverse Separation

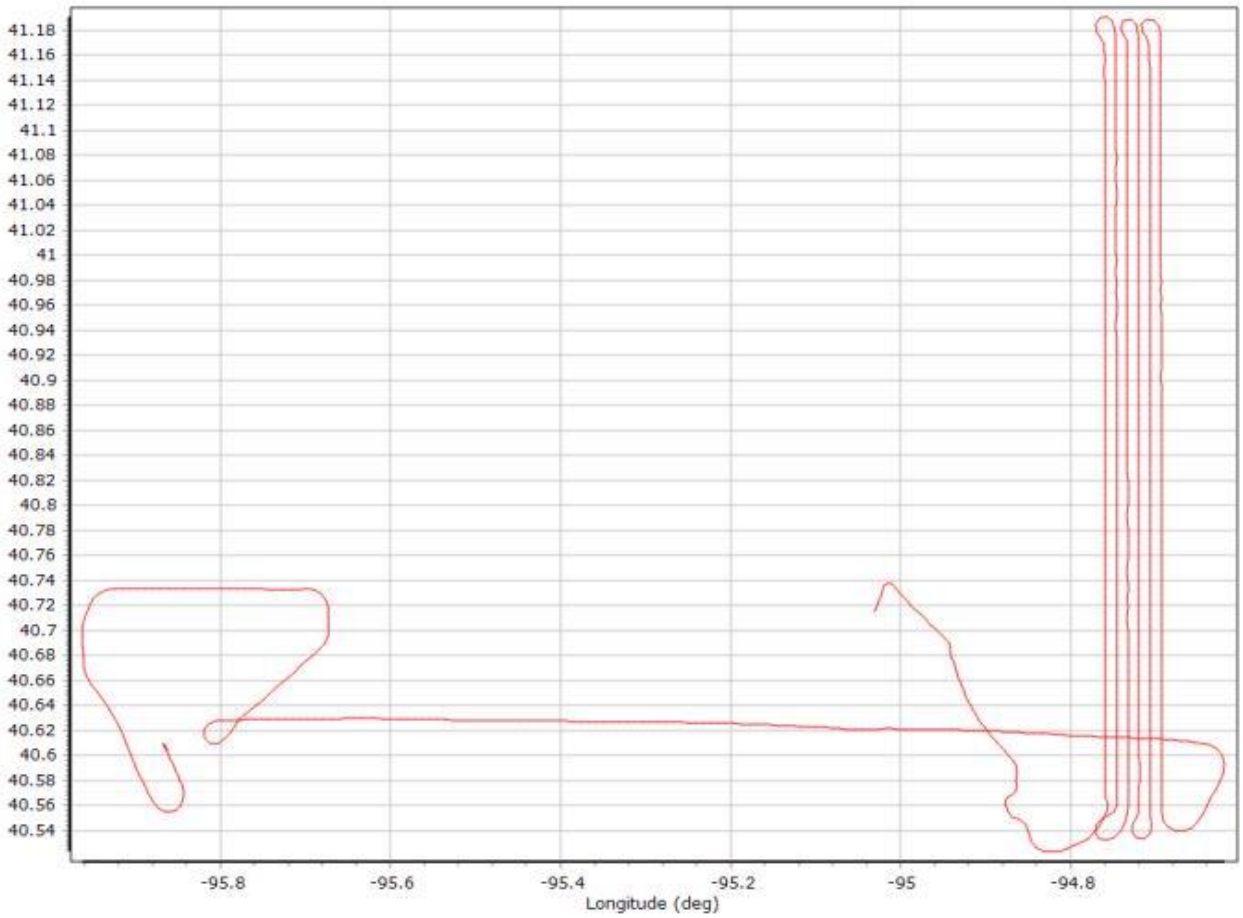


PDOP


3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
400,000
405,000
410,000
415,000
Time (sec)

20201210_2_QC Report.docx QC Report – 8/27/2021 08:15:12
Smoothed Trajectory Information

Top View

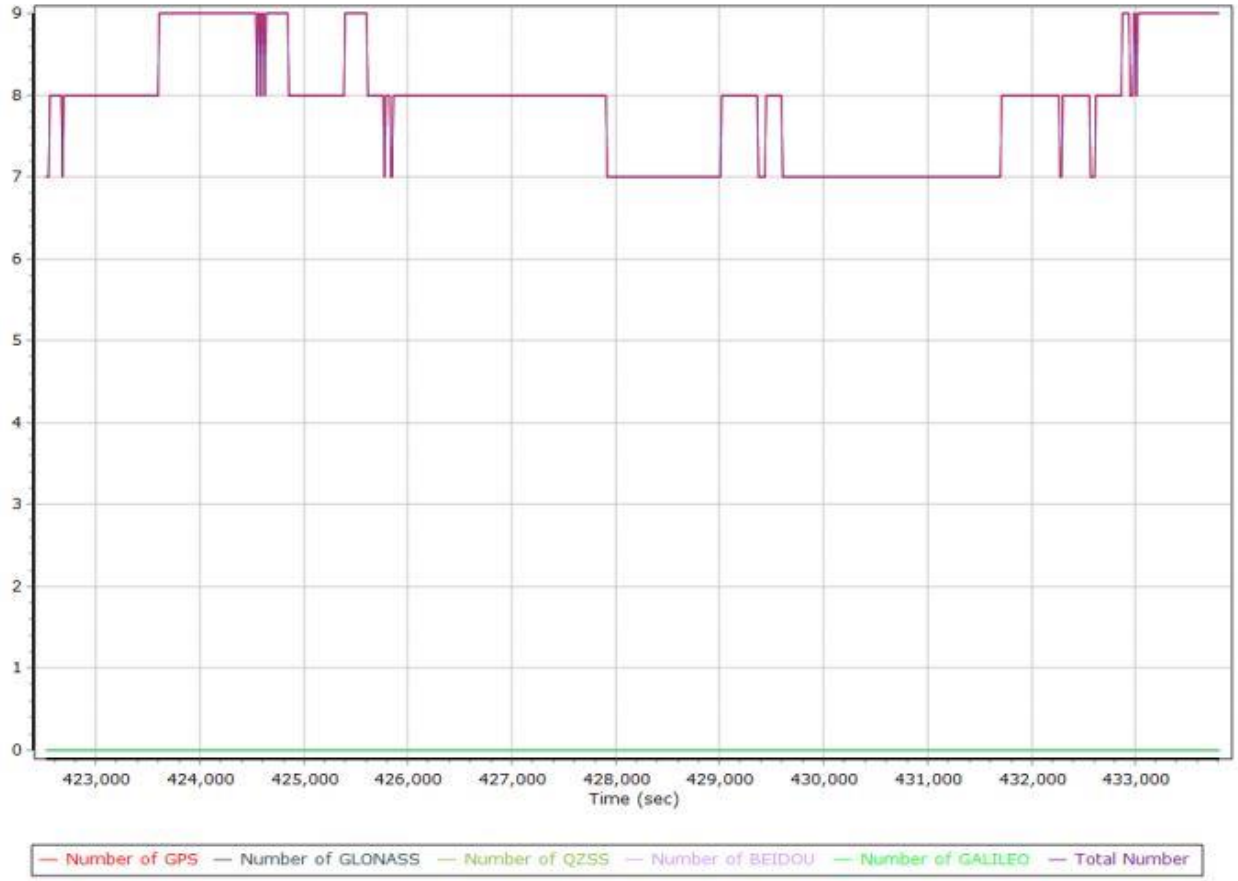


GNSS QC

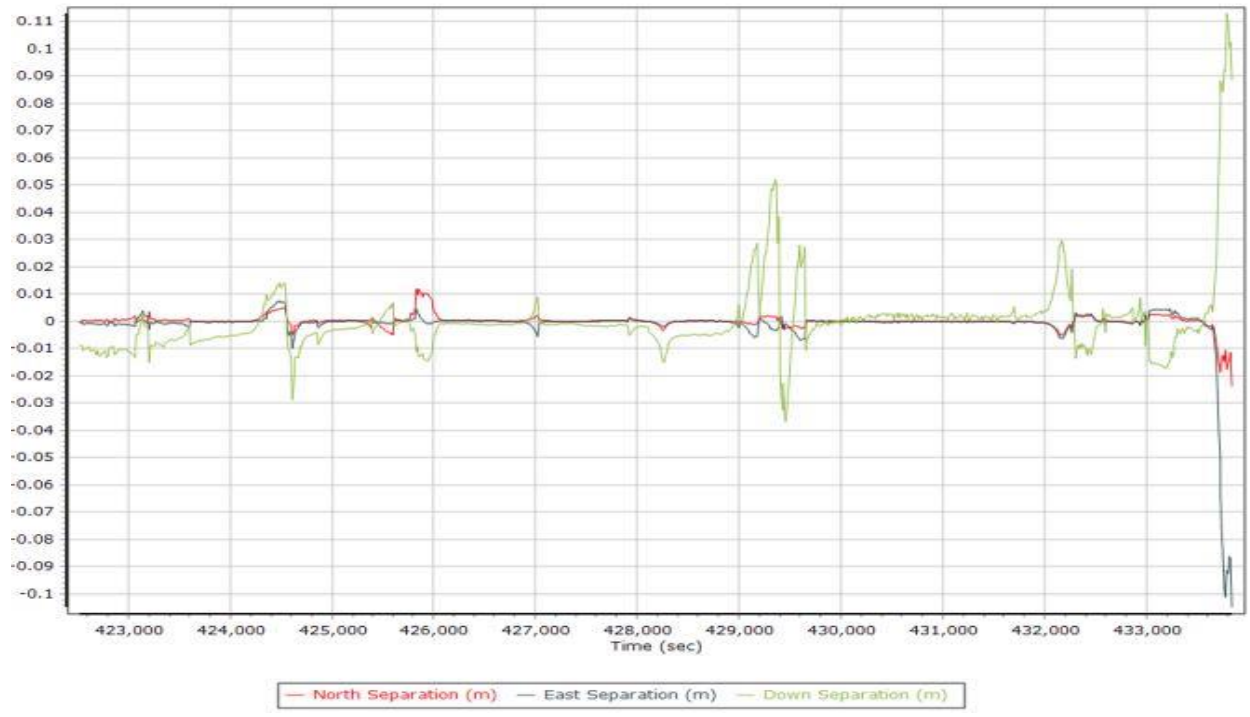
GNSS QC Statistics

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

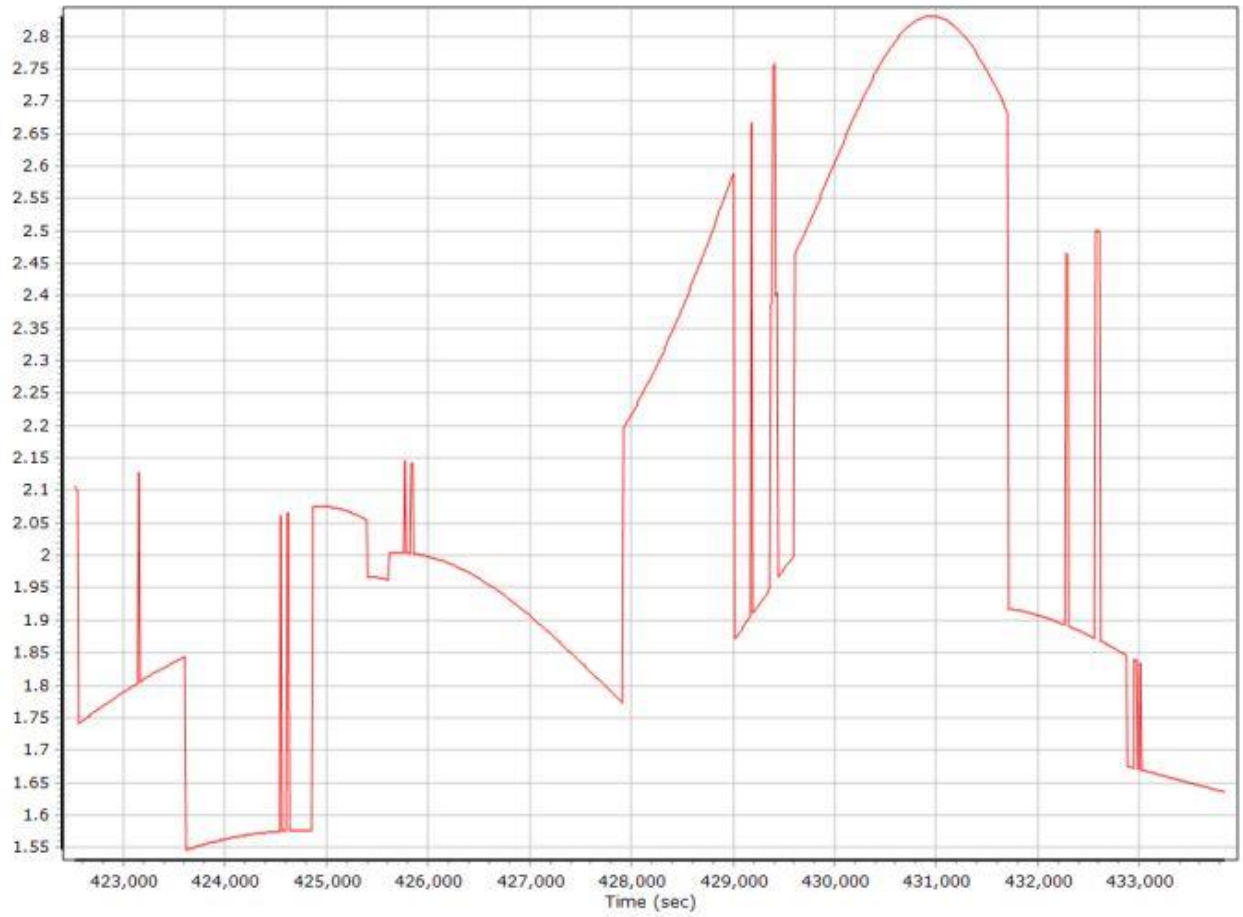
Number of Satellites



Forward/Reverse Separation

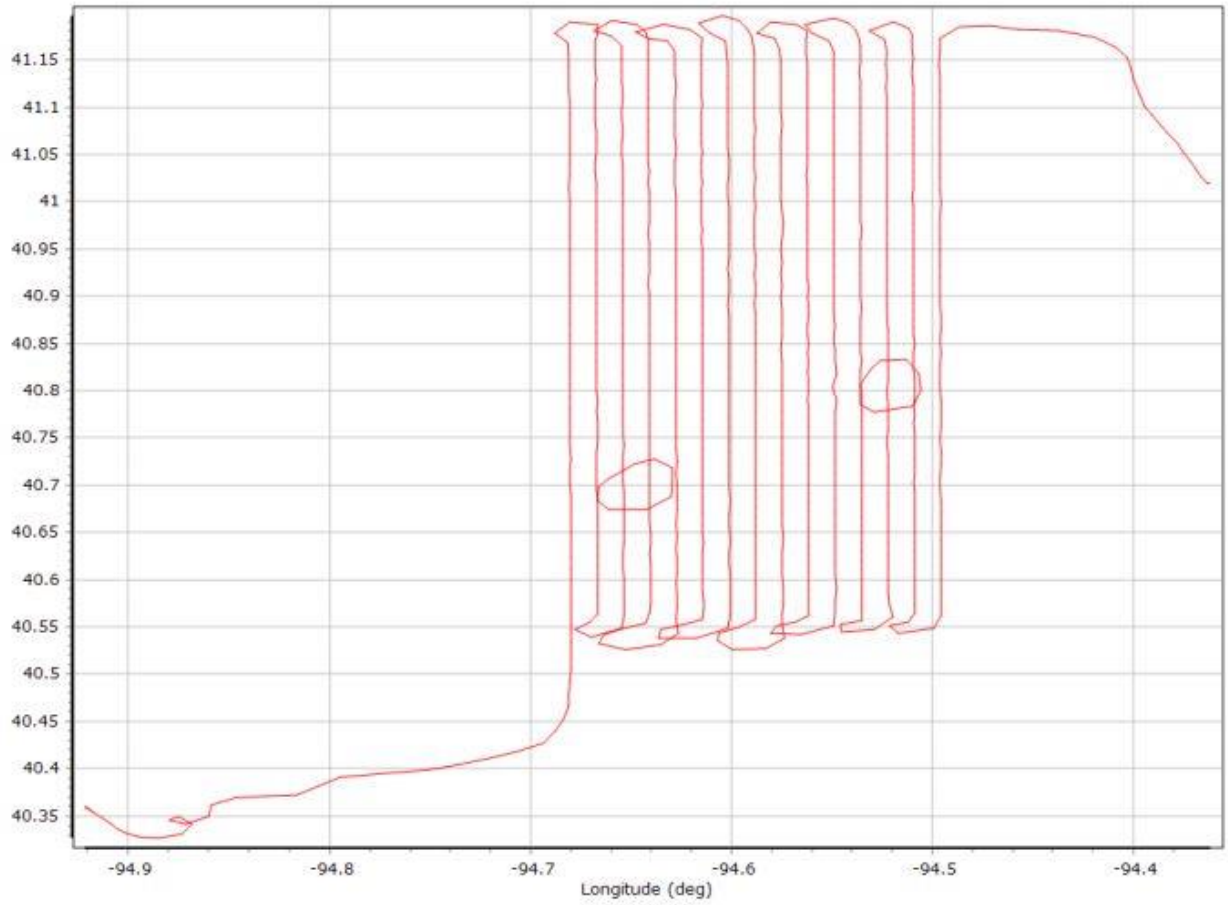


PDOP


2.8
2.75
2.7
2.65
2.6
2.55
2.5
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
423,000
424,000
425,000
426,000
427,000
428,000
429,000
430,000
431,000
432,000
433,000
Time (sec)

20201222_1_QC Report.docx QC Report – 8/27/2021 08:32:12
Smoothed Trajectory Information

Top View

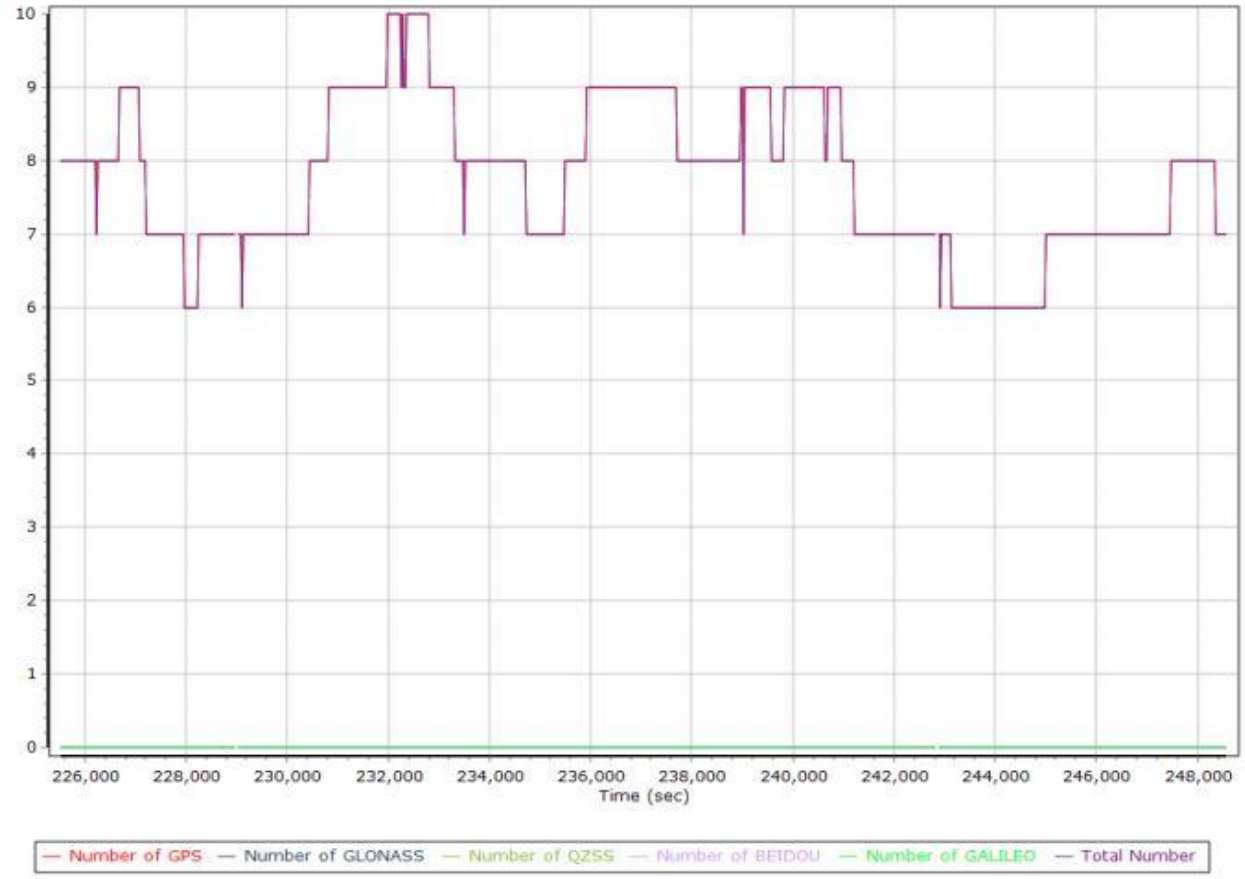


GNSS QC

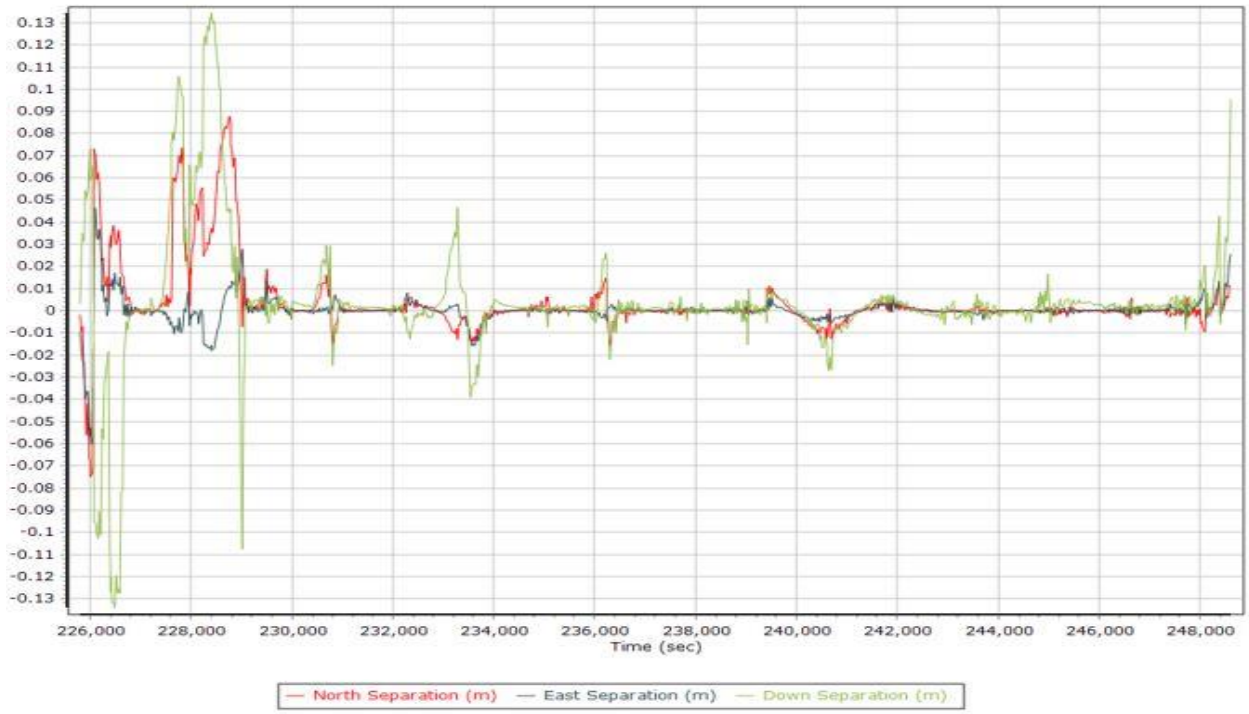
GNSS QC Statistics

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

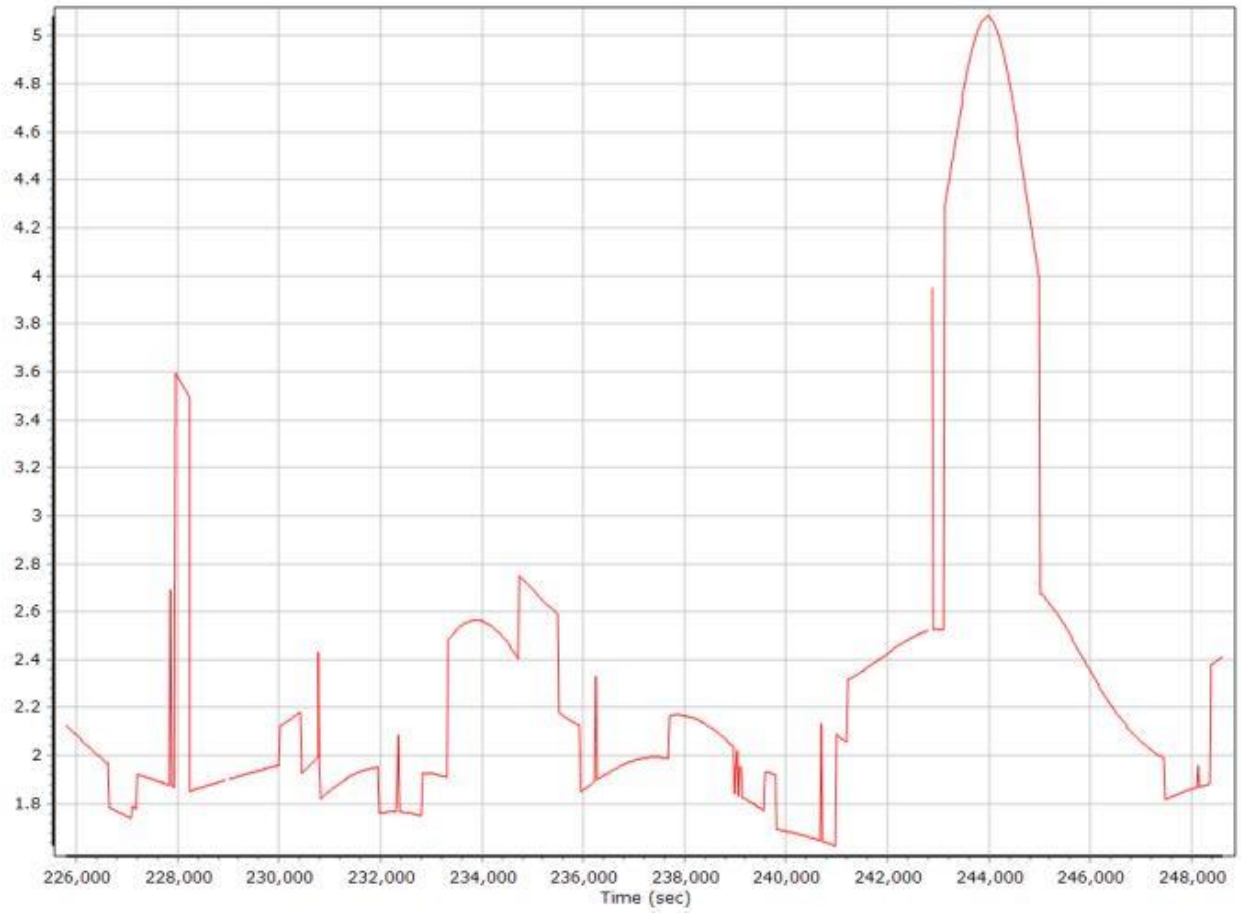
Number of Satellites



Forward/Reverse Separation

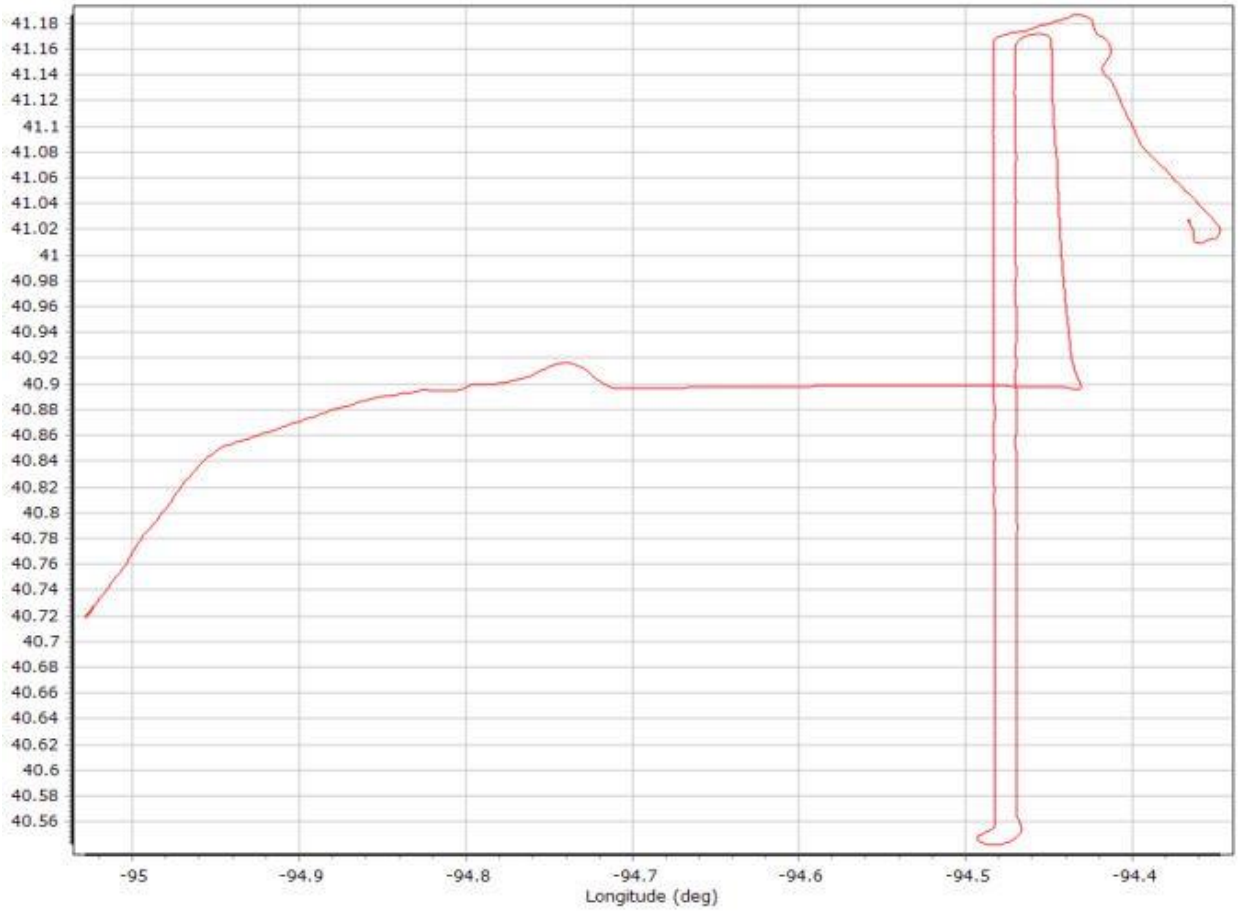


PDOP


5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
242,000
244,000
246,000
248,000
Time (sec)

20201222_2_QC Report.docx QC Report – 8/27/2021 08:38:52
Smoothed Trajectory Information

Top View

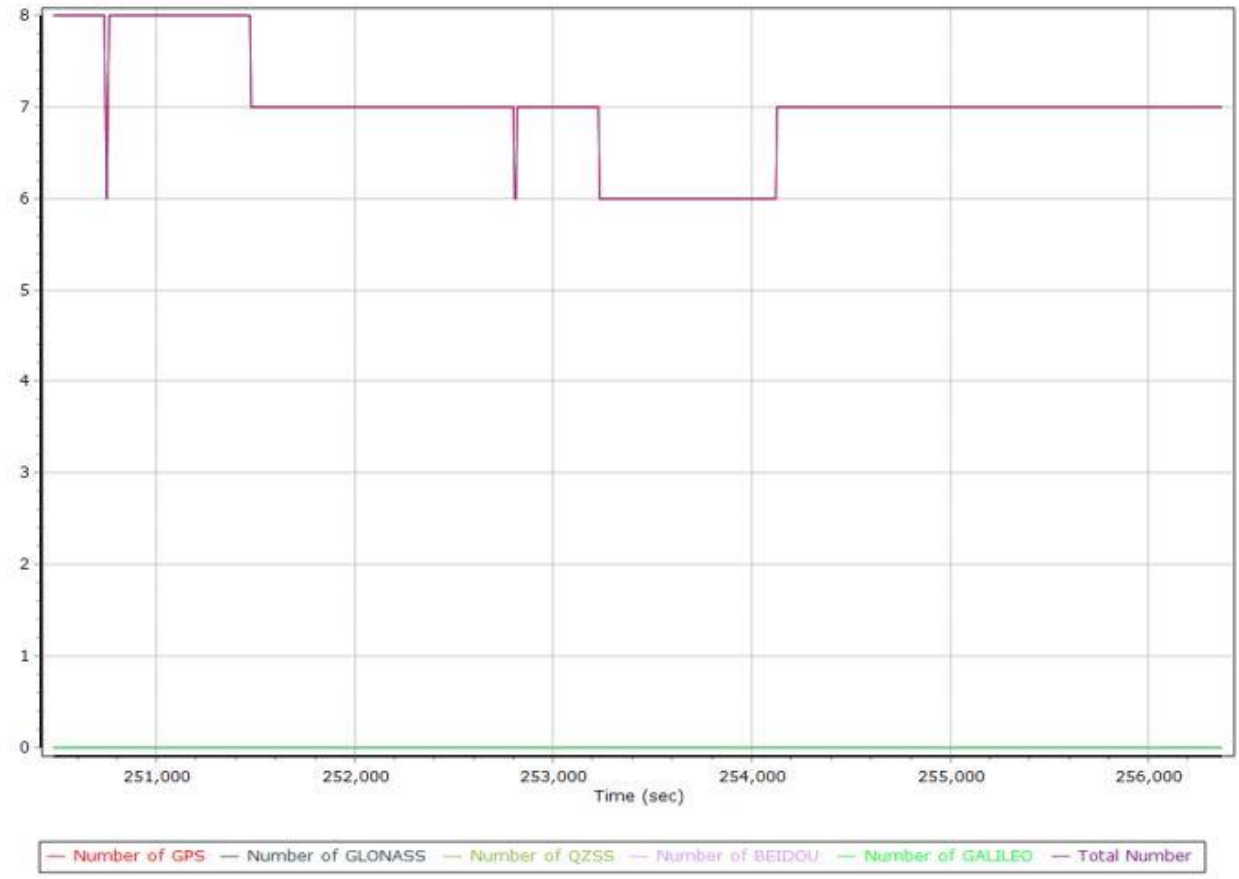


GNSS QC

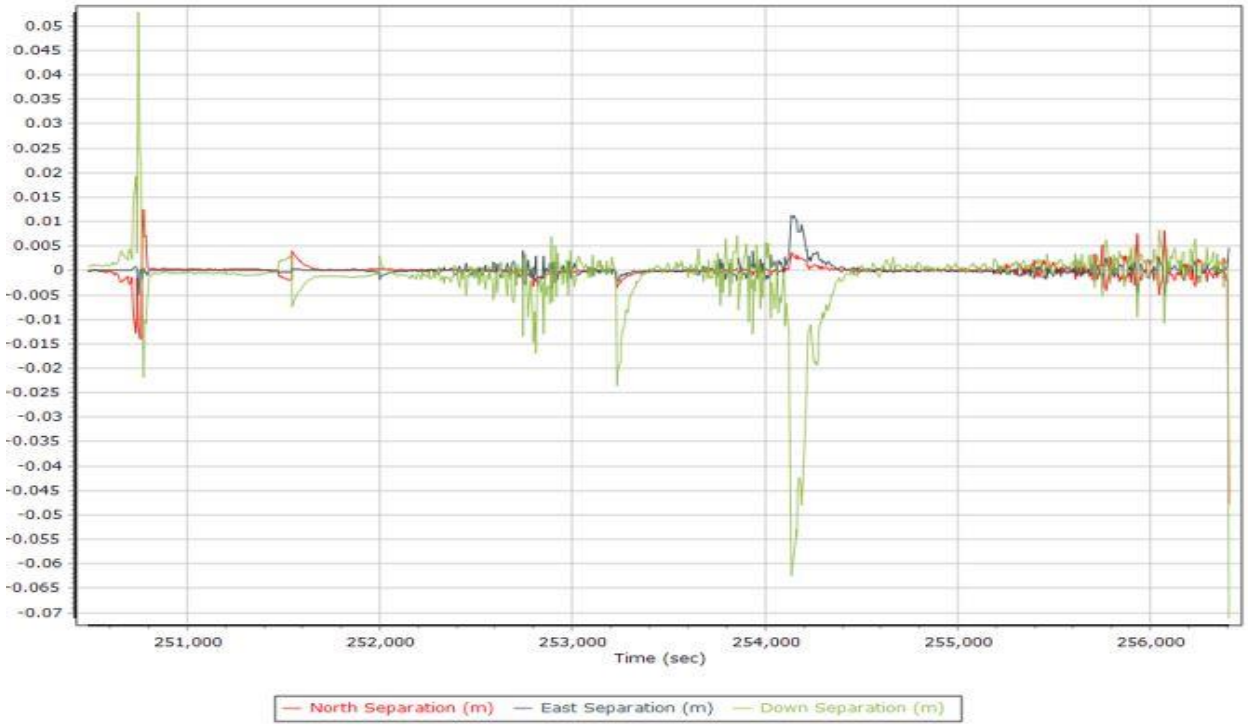
GNSS QC Statistics

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

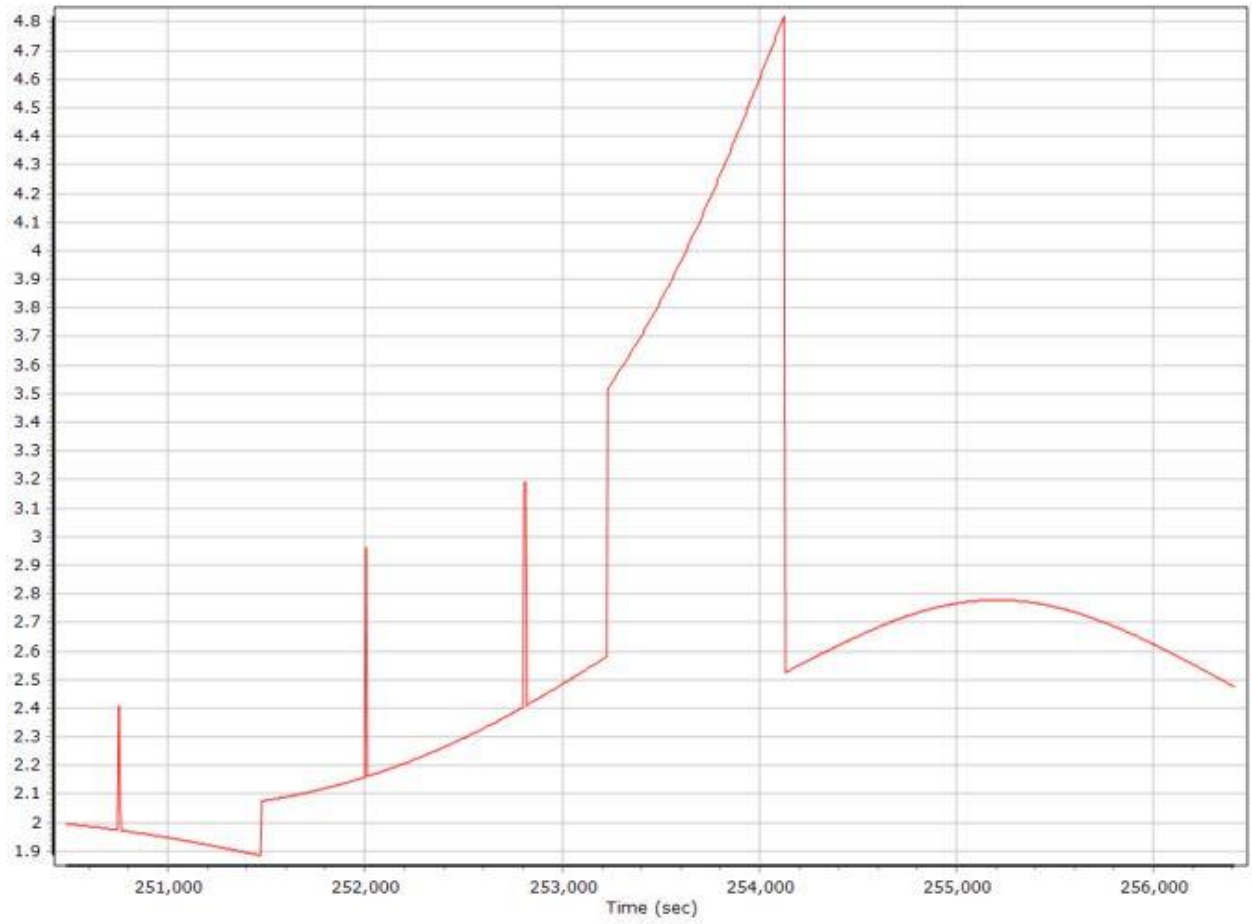
Number of Satellites



Forward/Reverse Separation

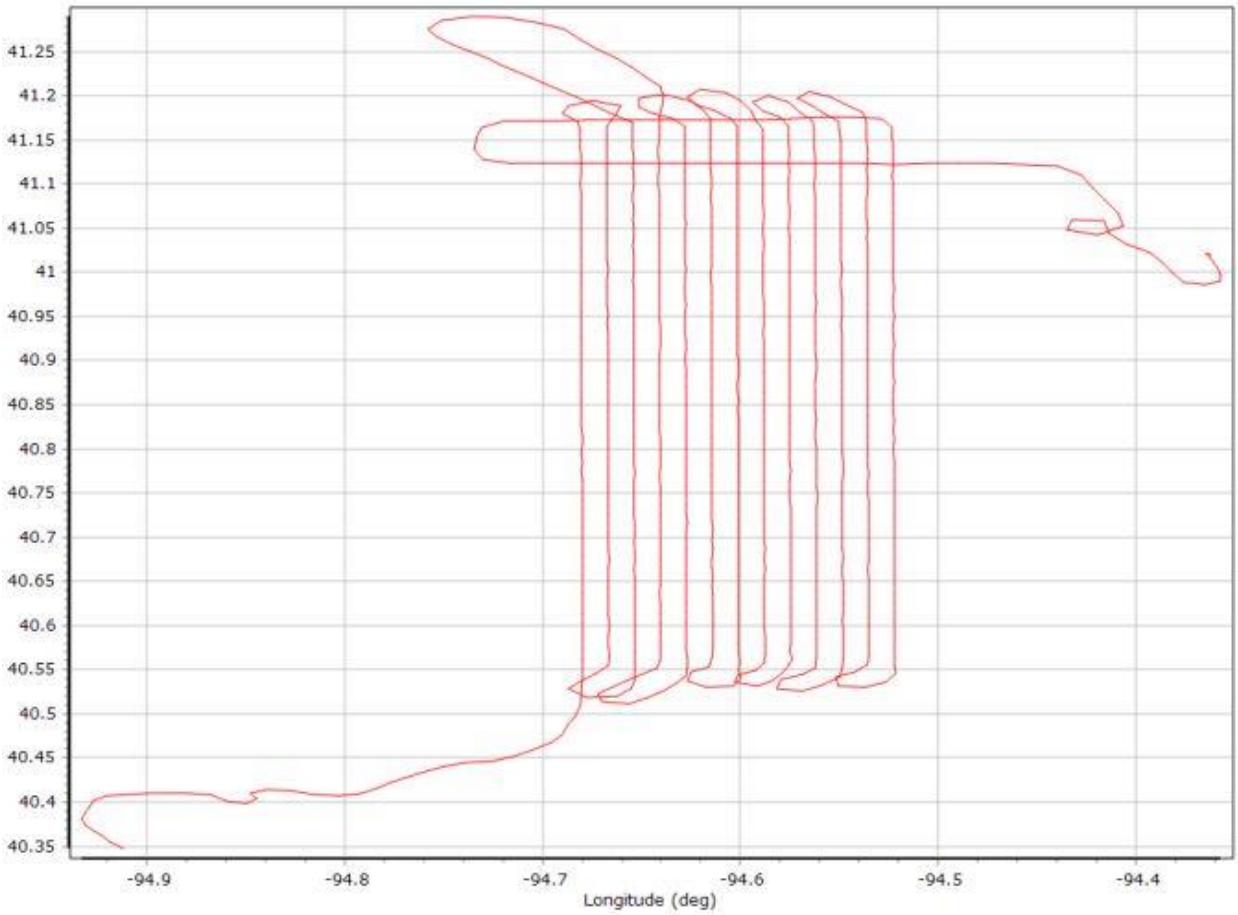


PDOP


4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
251,000
252,000
253,000
254,000
255,000
256,000
Time (sec)

20210311_1_QC Report.docx QC Report – 8/27/2021 08:44:02
Smoothed Trajectory Information

Top View

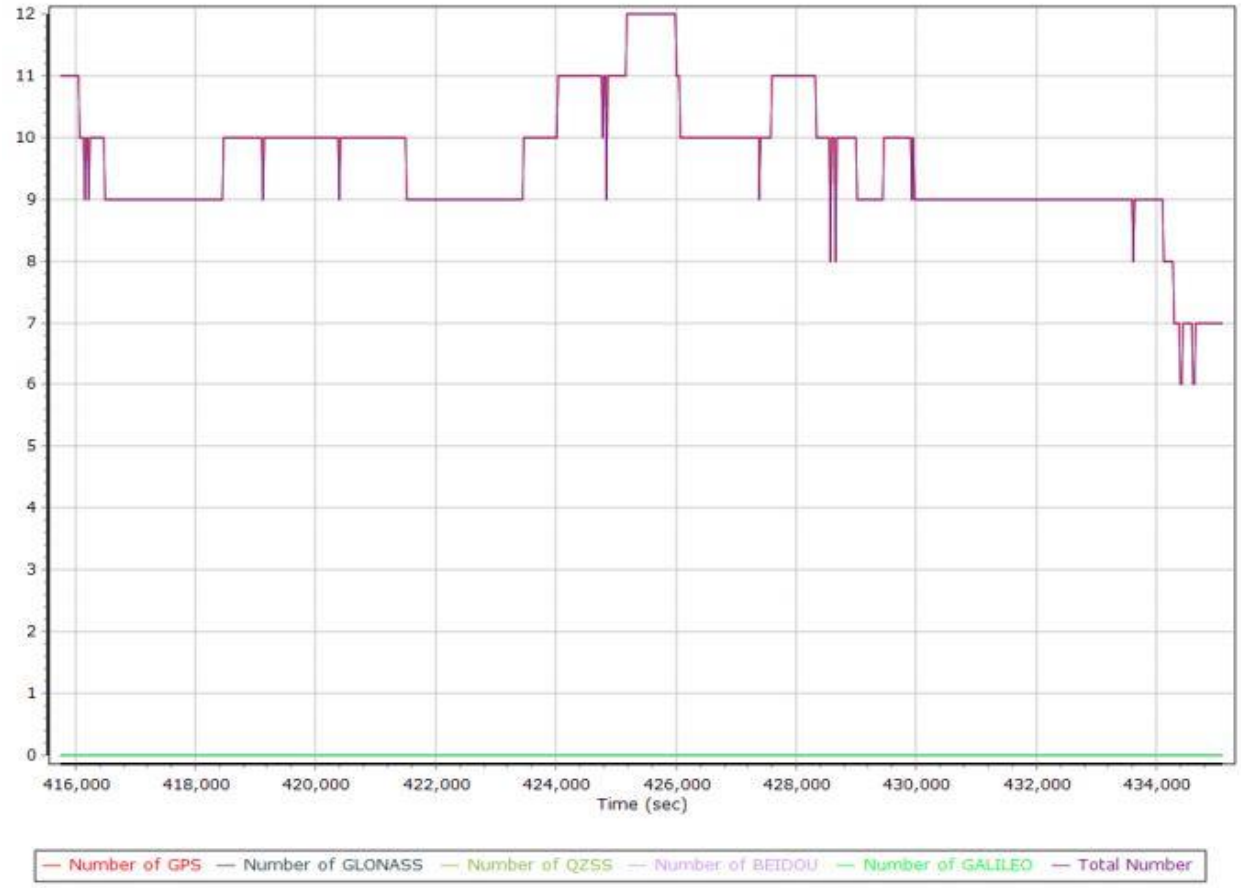


GNSS QC

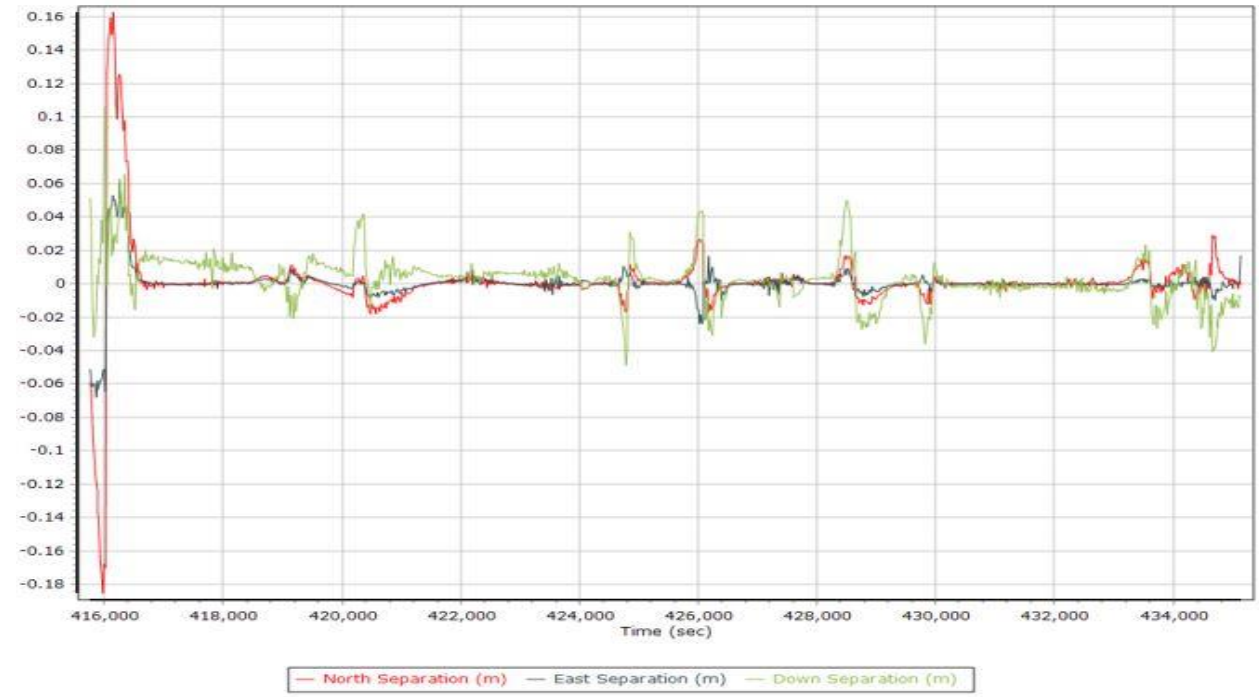
GNSS QC Statistics

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

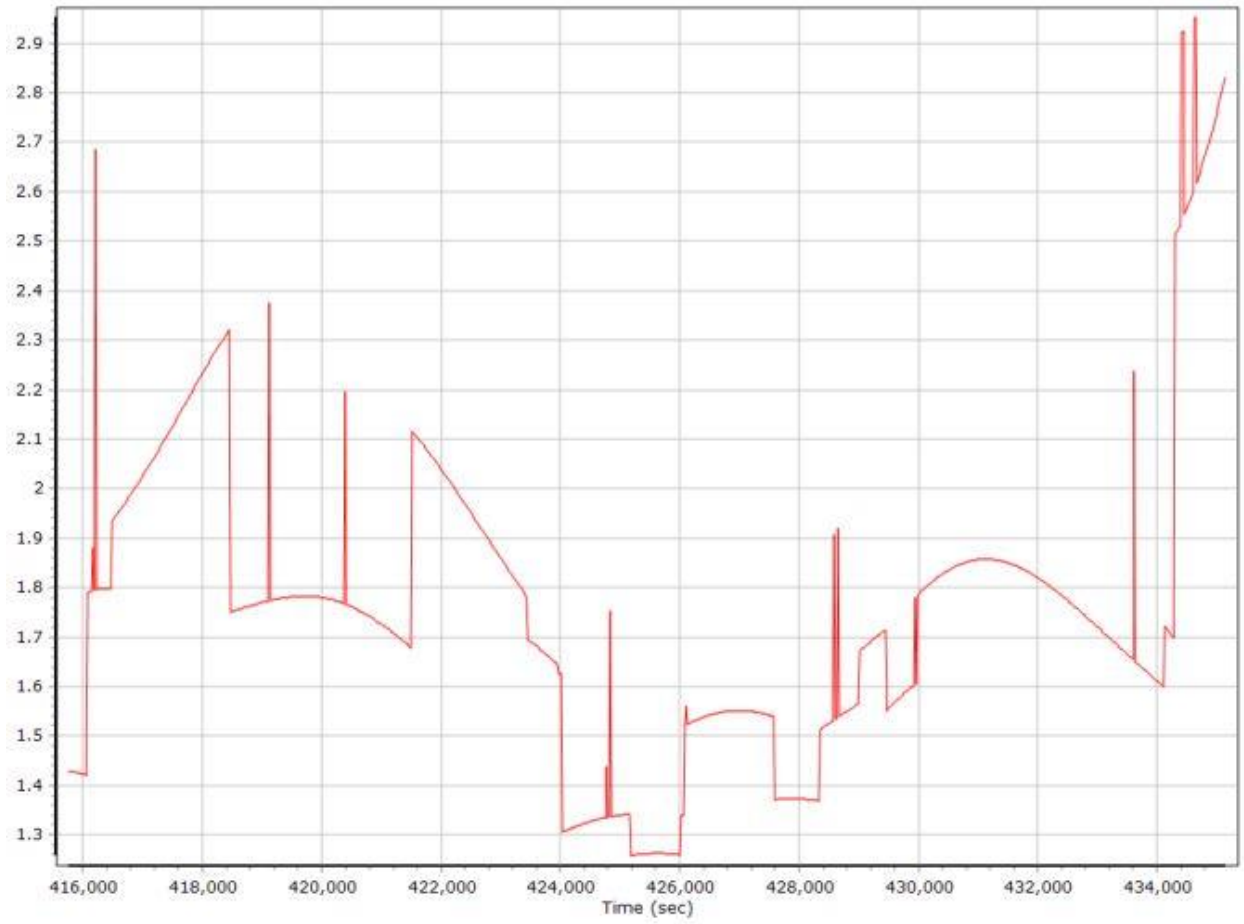
Number of Satellites



Forward/Reverse Separation

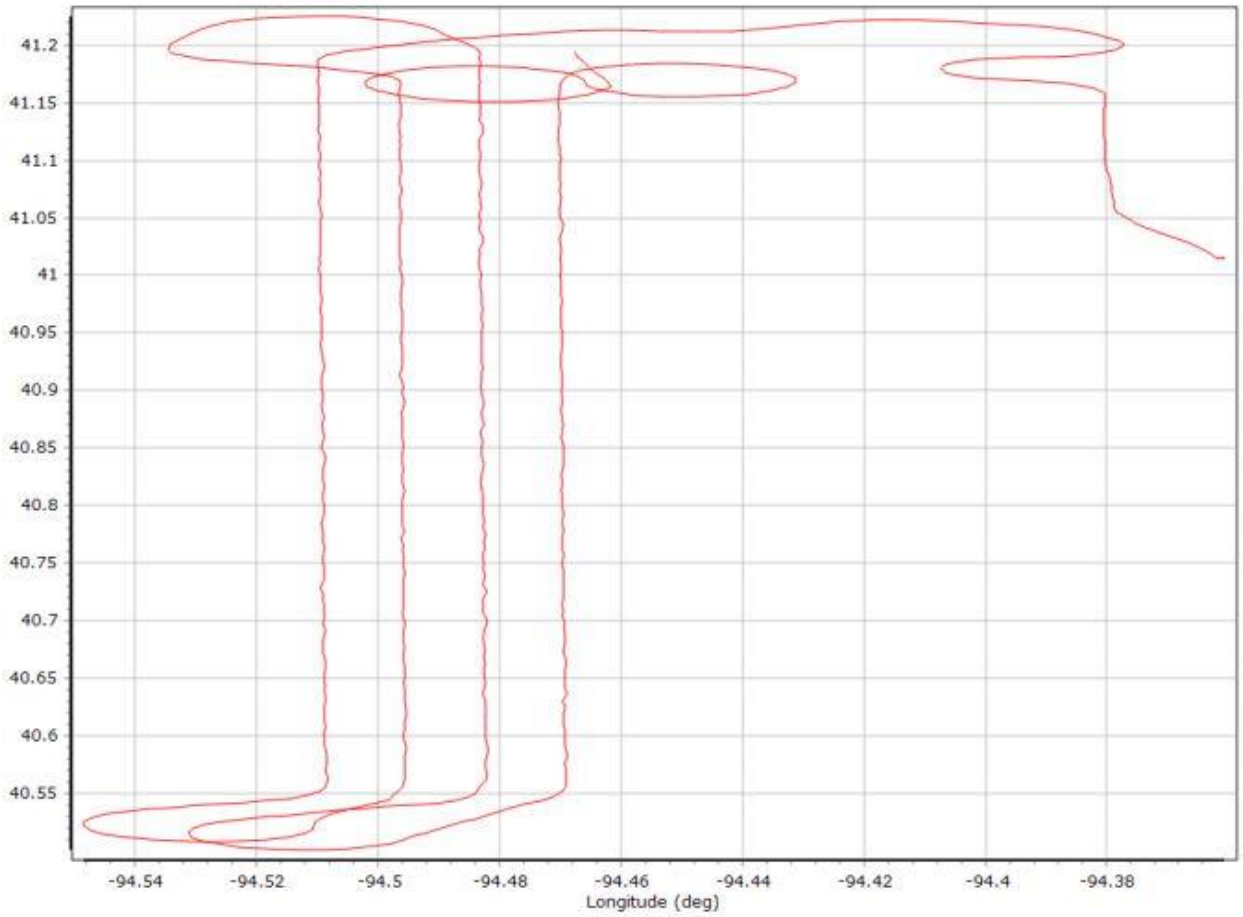


PDOP


2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
416,000
418,000
420,000
422,000
424,000
426,000
428,000
430,000
432,000
434,000
Time (sec)

20210311_2_QC Report.docx QC Report – 8/27/2021 09:35:02
Smoothed Trajectory Information

Top View

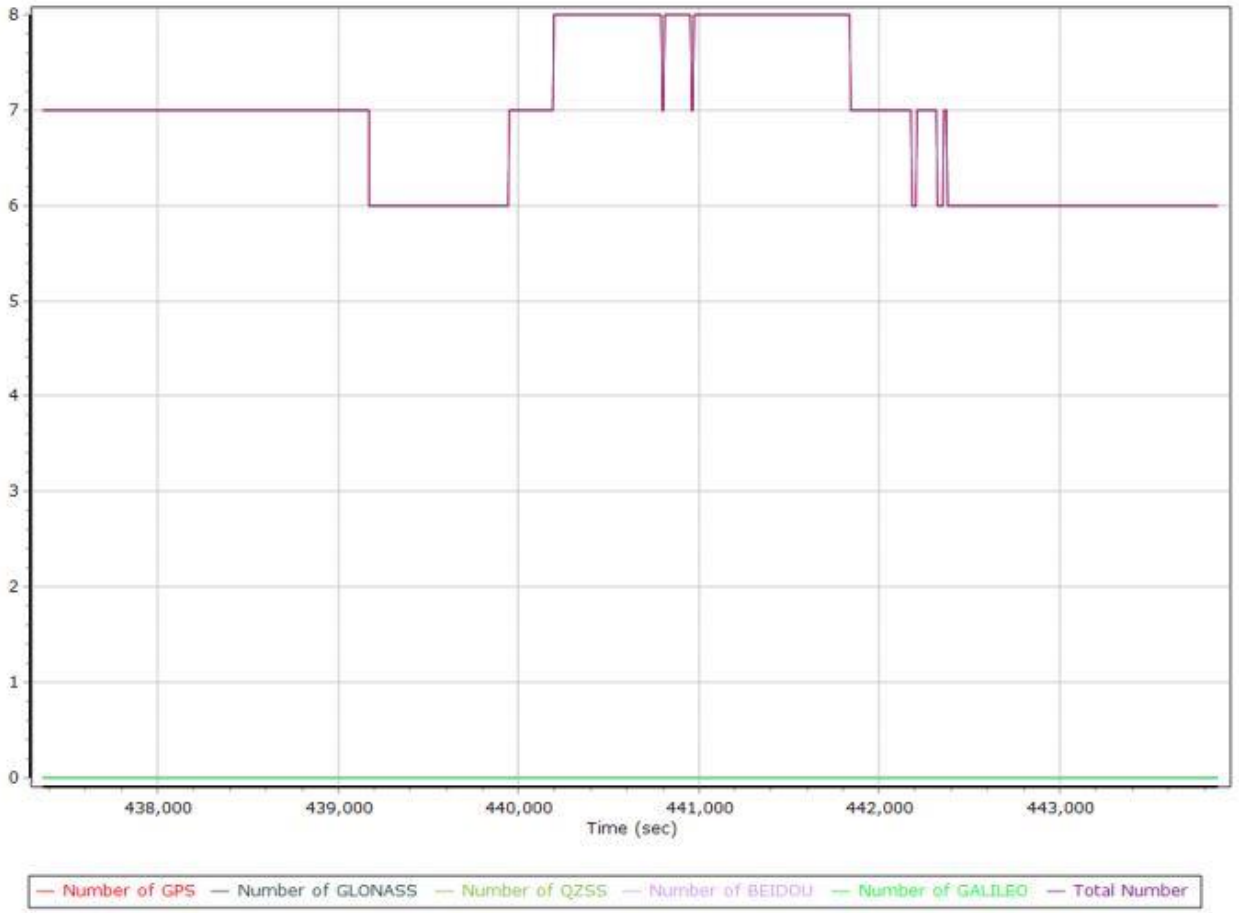


GNSS QC

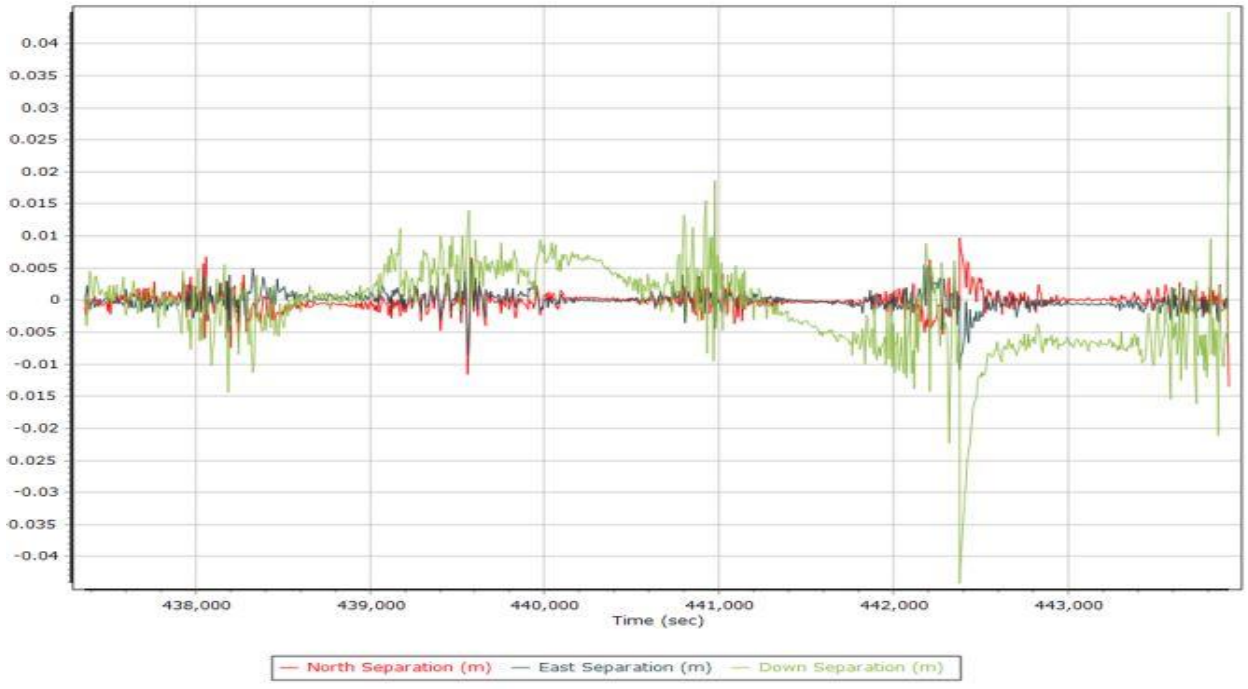
GNSS QC Statistics

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

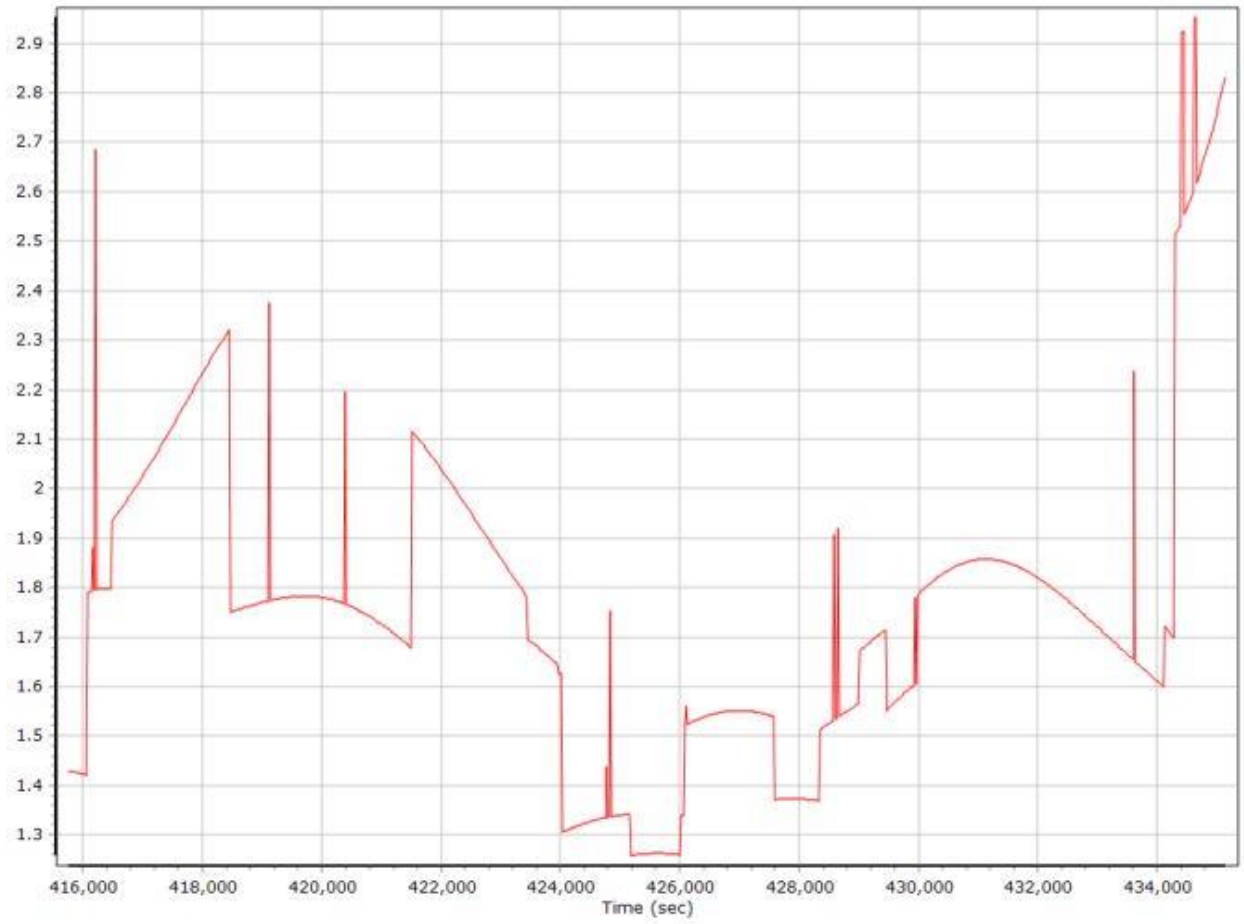
Number of Satellites



Forward/Reverse Separation

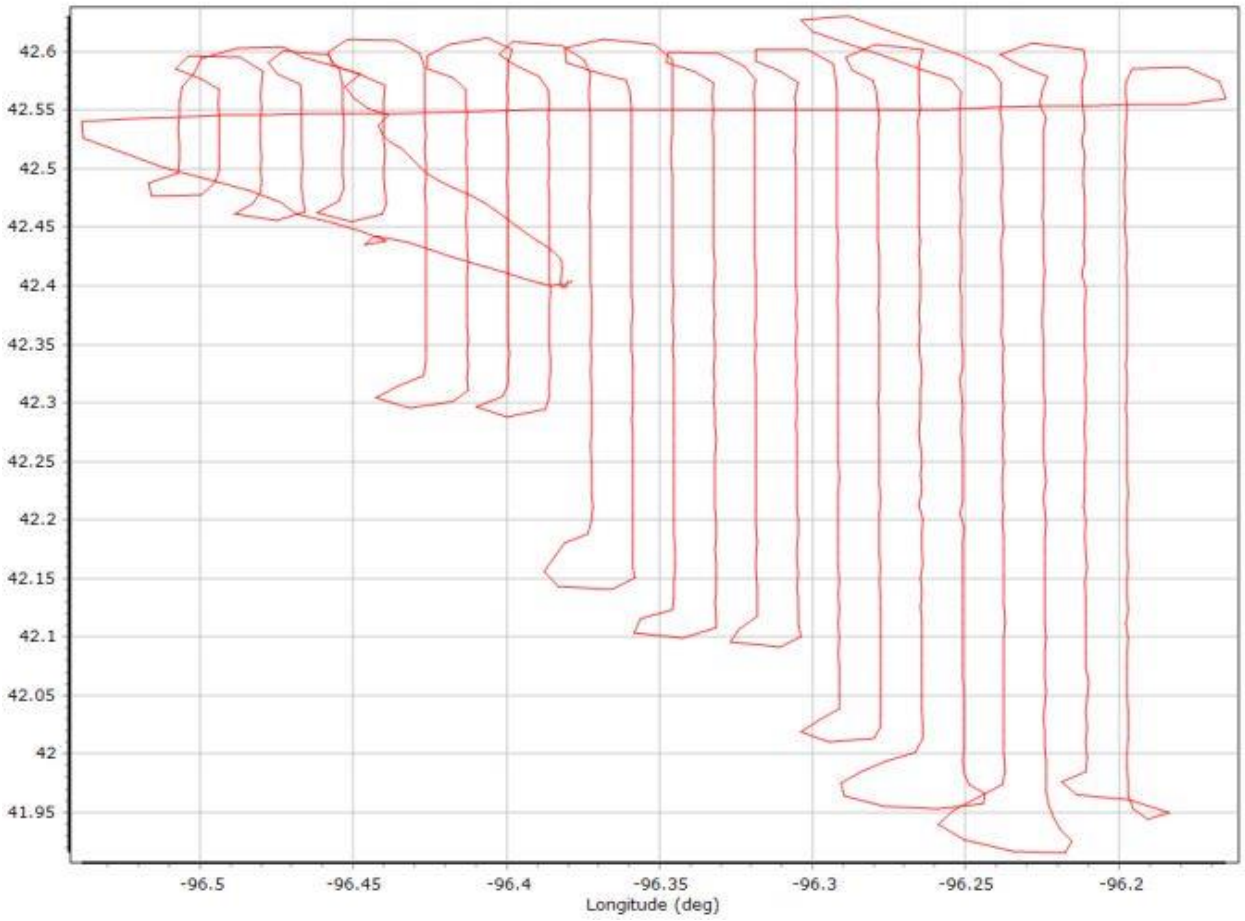


PDOP


2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
416,000
418,000
420,000
422,000
424,000
426,000
428,000
430,000
432,000
434,000
Time (sec)

Block C 20210328_1_QC Report.docx QC Report – 8/27/2021 09:50:02
Smoothed Trajectory Information

Top View

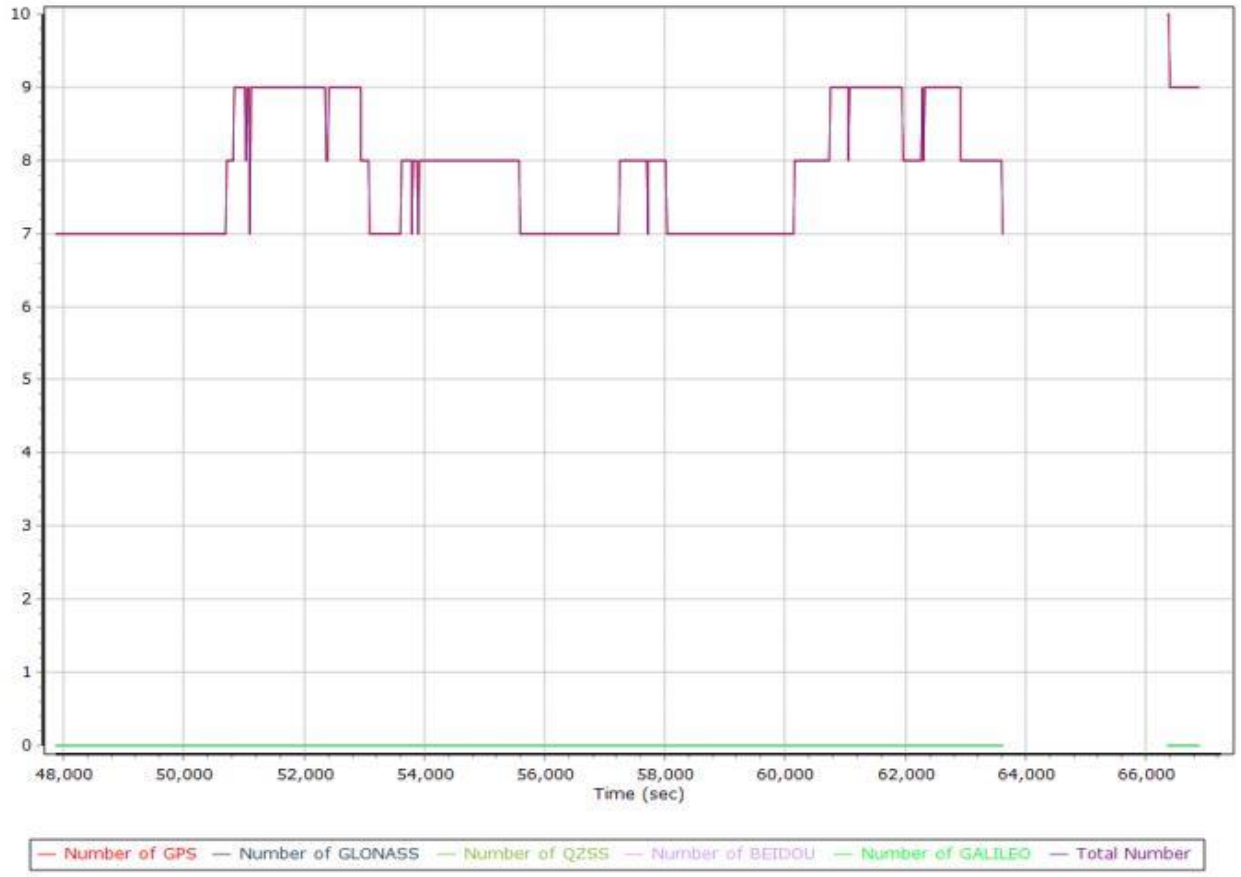


GNSS QC

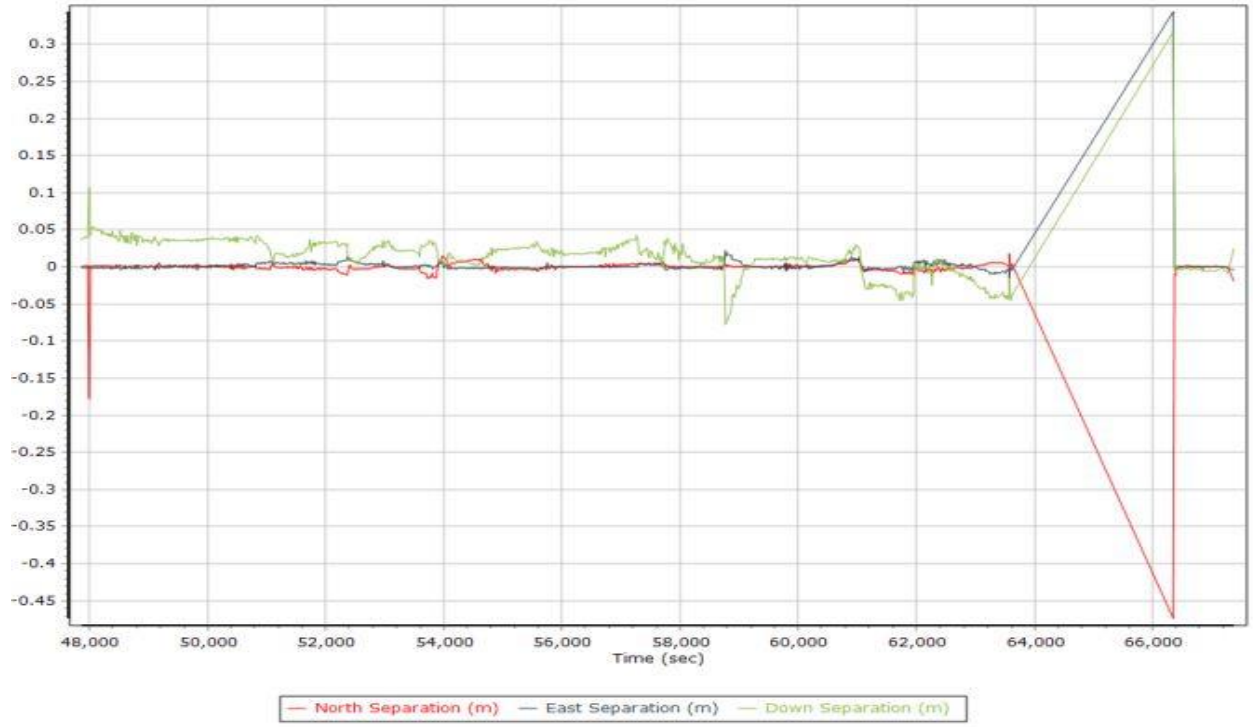
GNSS QC Statistics

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

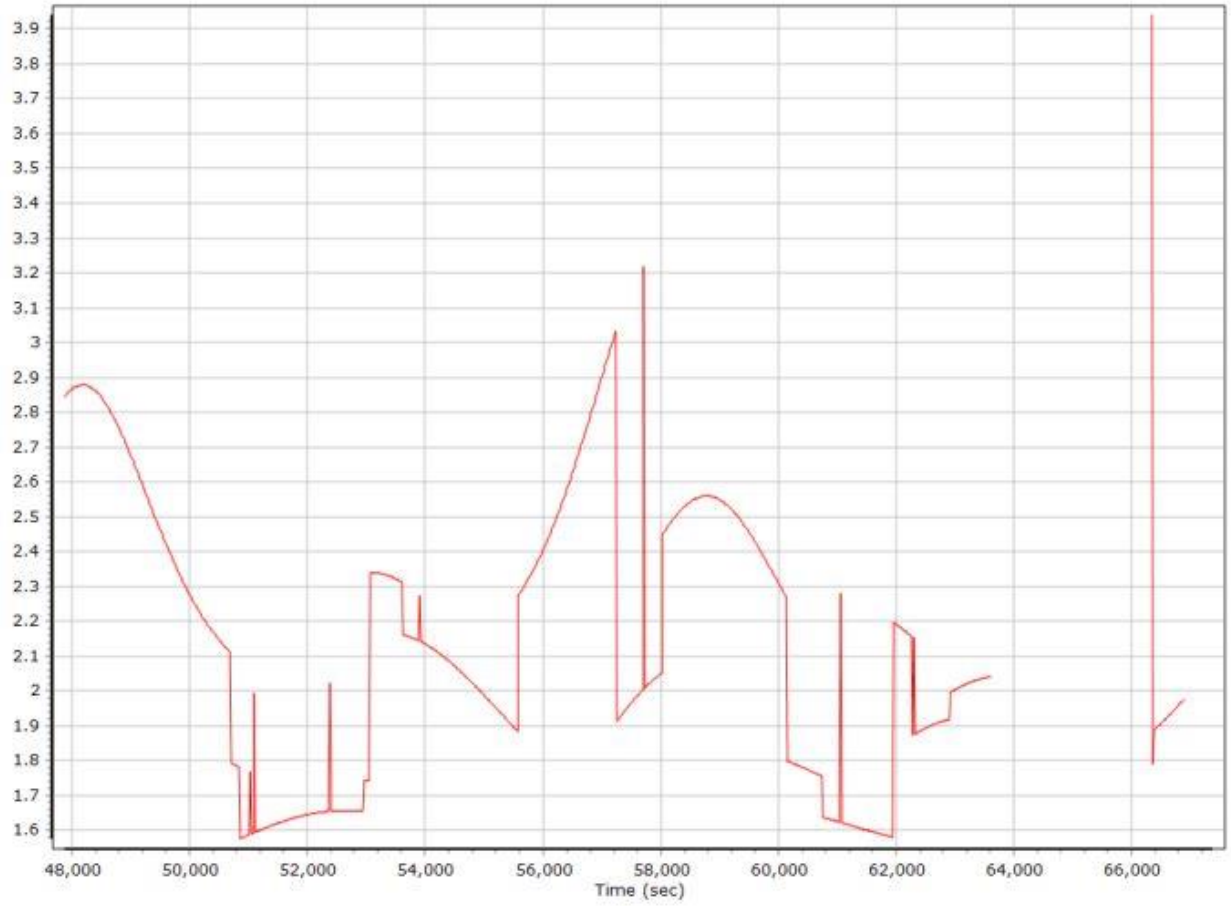
Number of Satellites



Forward/Reverse Separation



PDOP


3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
48,000
50,000
52,000
54,000
56,000
58,000
60,000
62,000
64,000
66,000
Time (sec)

20210328_2_QC Report.docx QC Report – 8/27/2021 09:58:33
Smoothed Trajectory Information

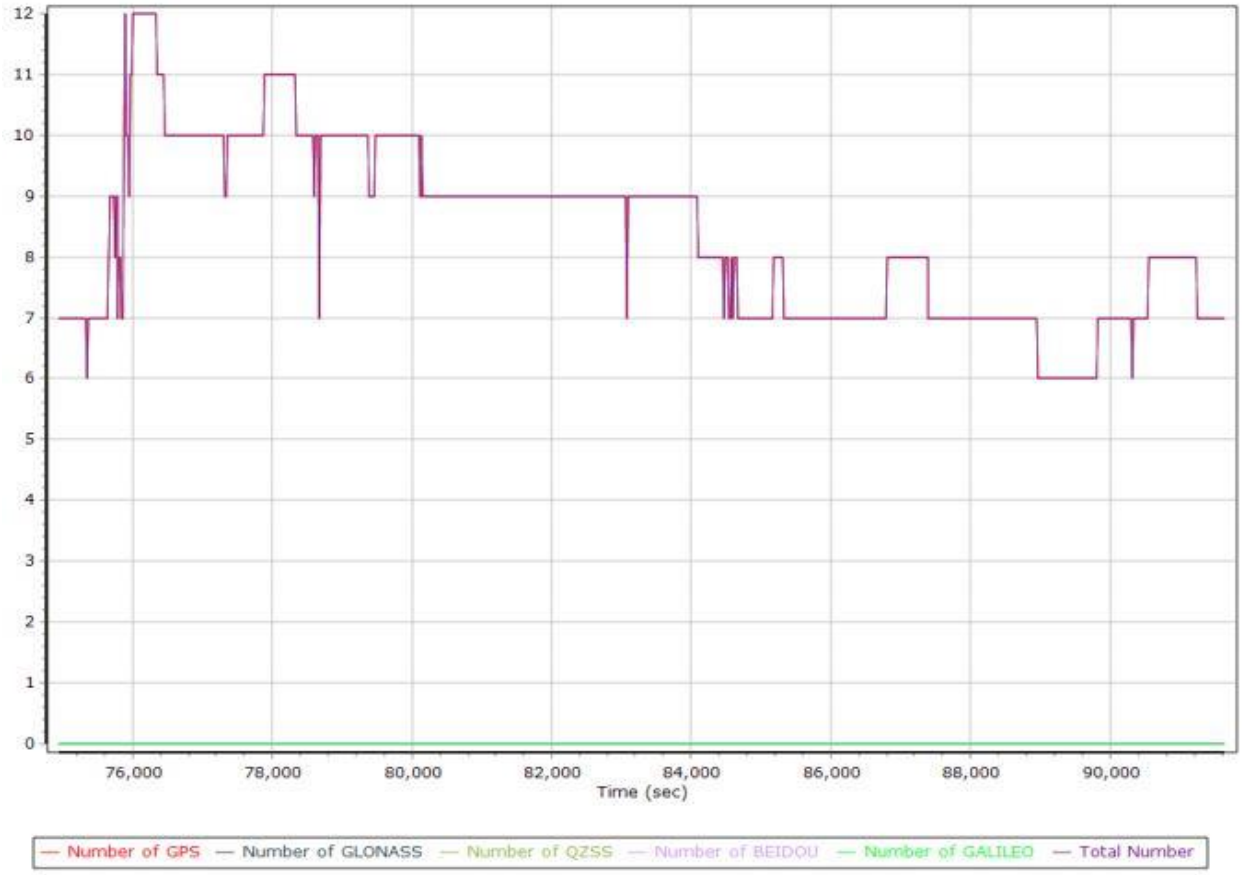
Top View

GNSS QC

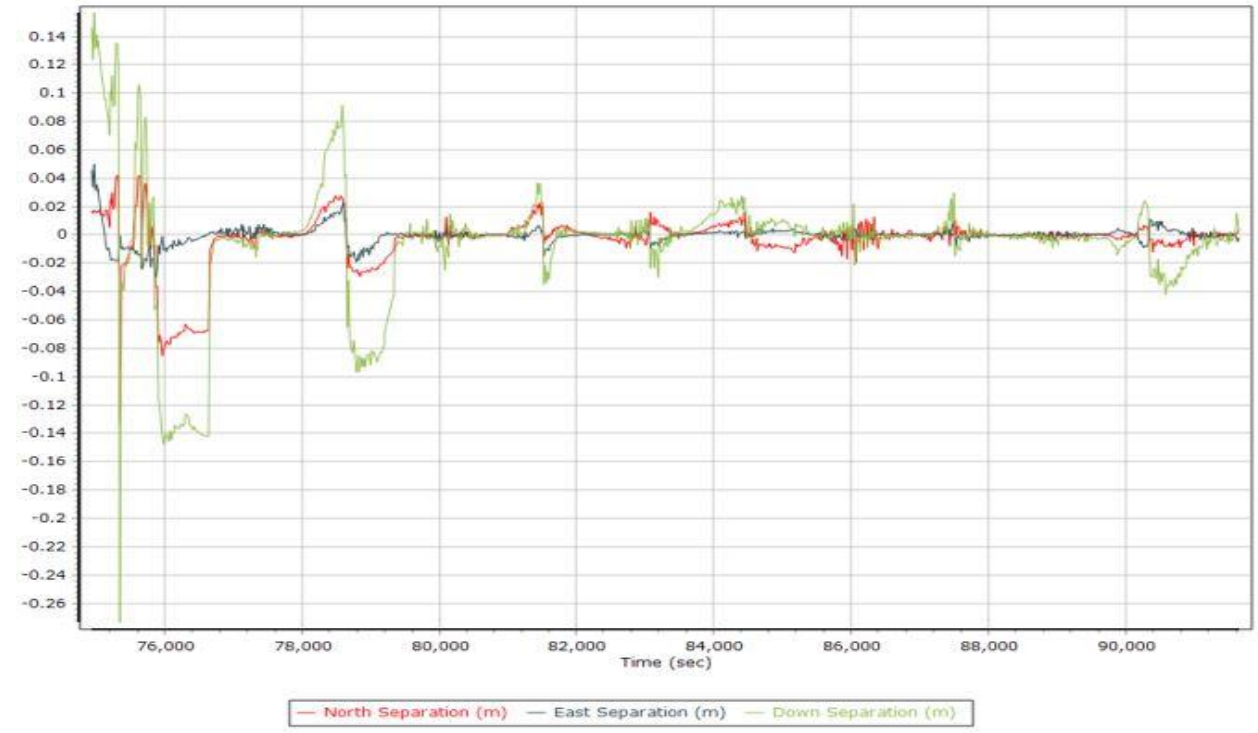
GNSS QC Statistics

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

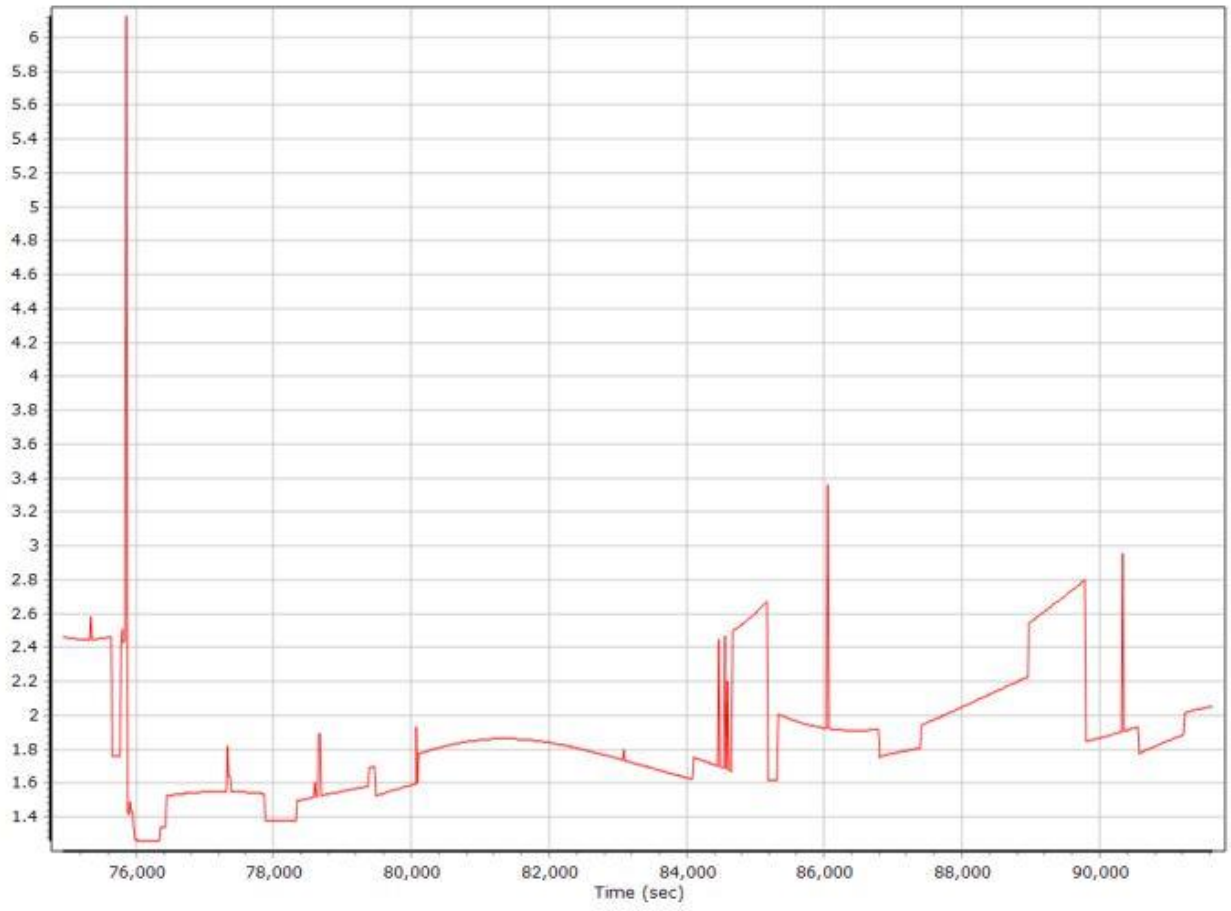
Number of Satellites



Forward/Reverse Separation

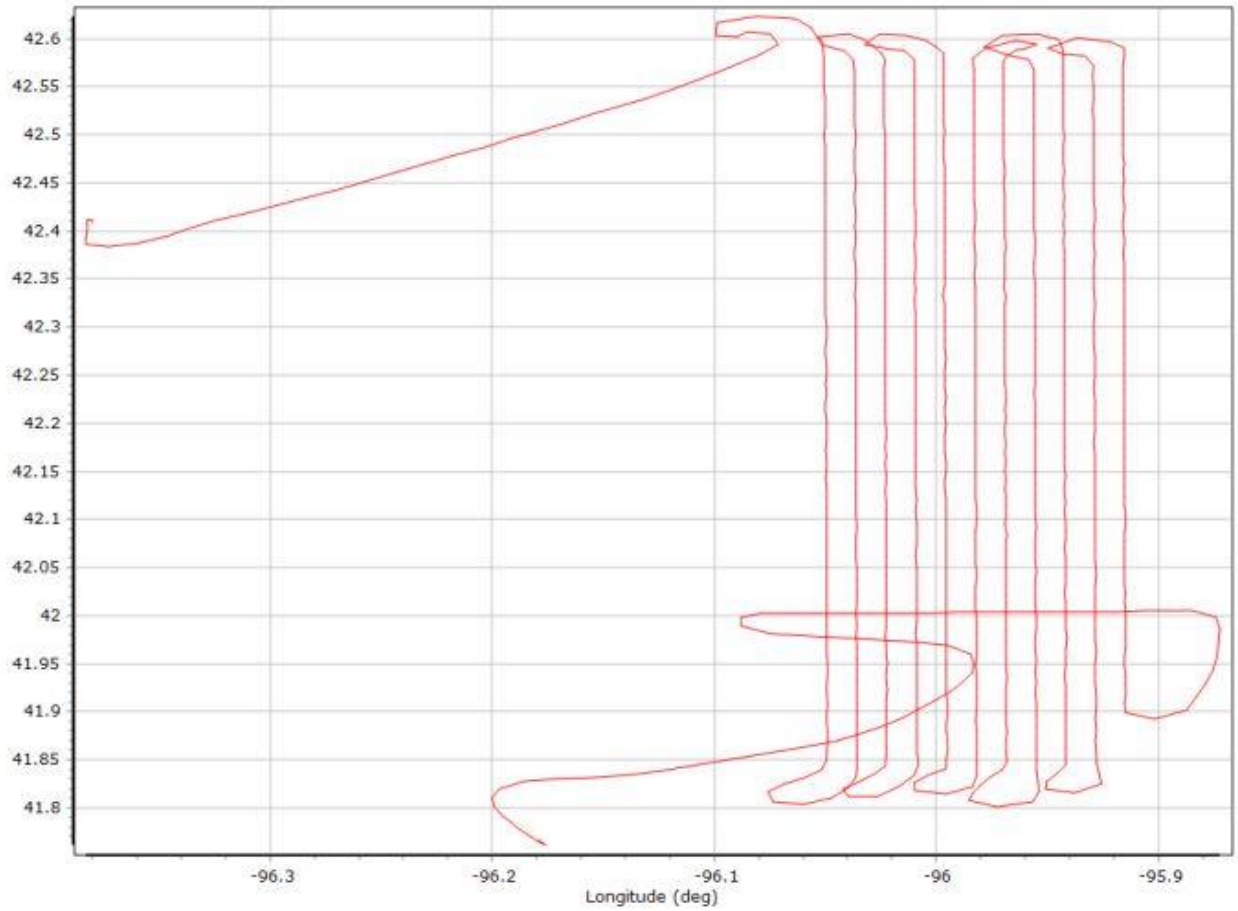


PDOP


6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
76,000
78,000
80,000
82,000
84,000
86,000
88,000
90,000
Time (sec)

20210329_1_QC Report.docx QC Report – 8/27/2021 10:07:14
Smoothed Trajectory Information

Top View

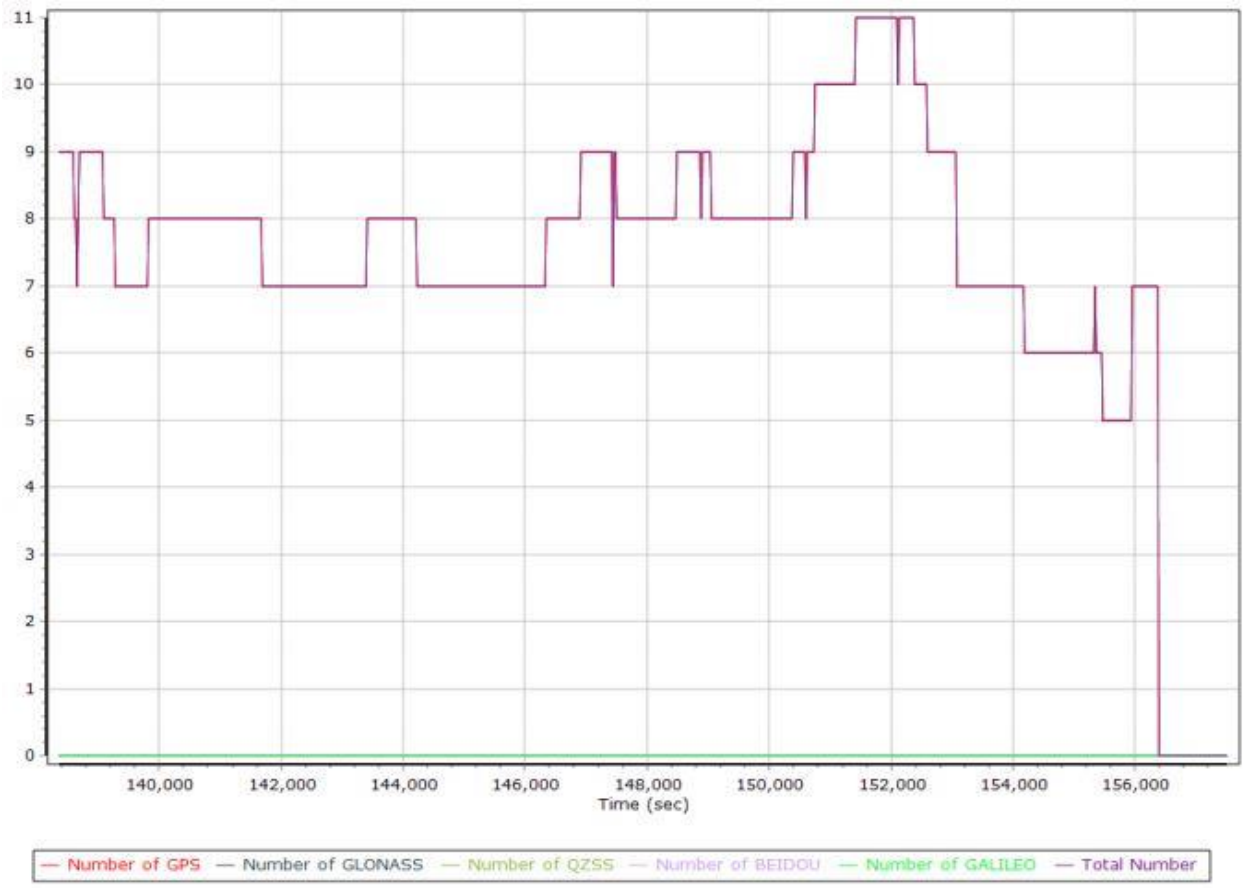


GNSS QC

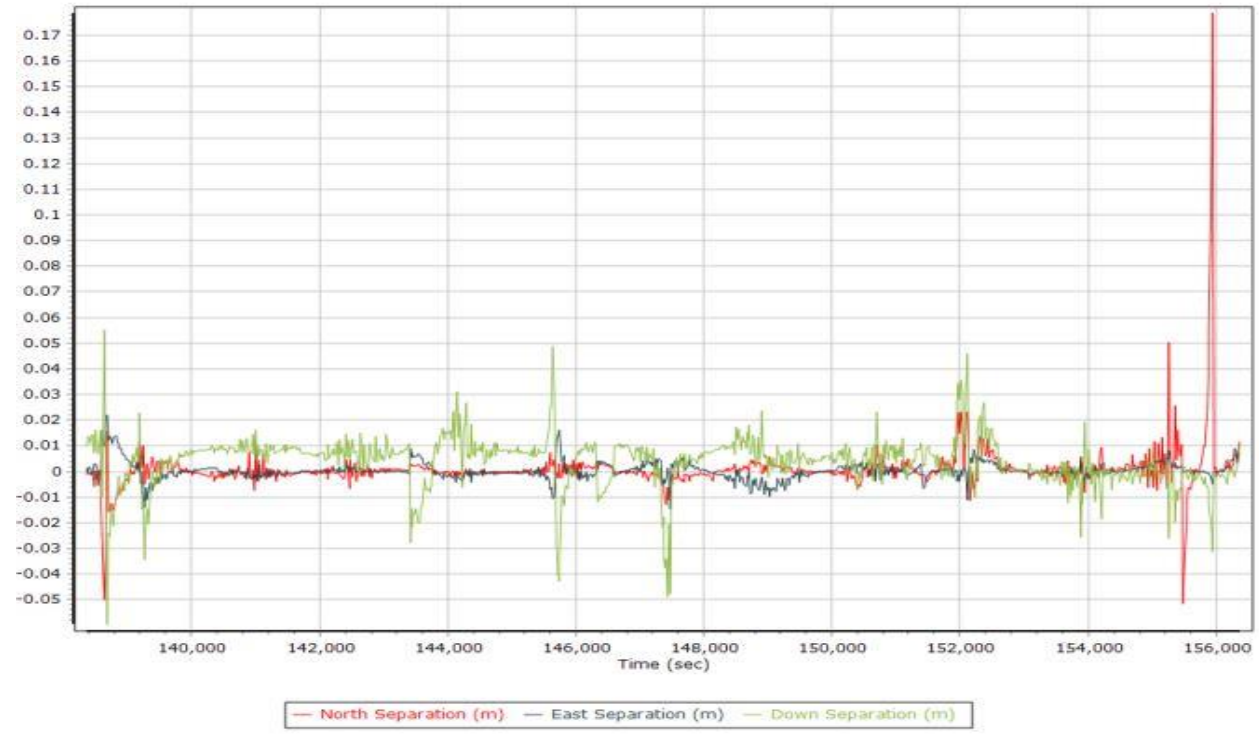
GNSS QC Statistics

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

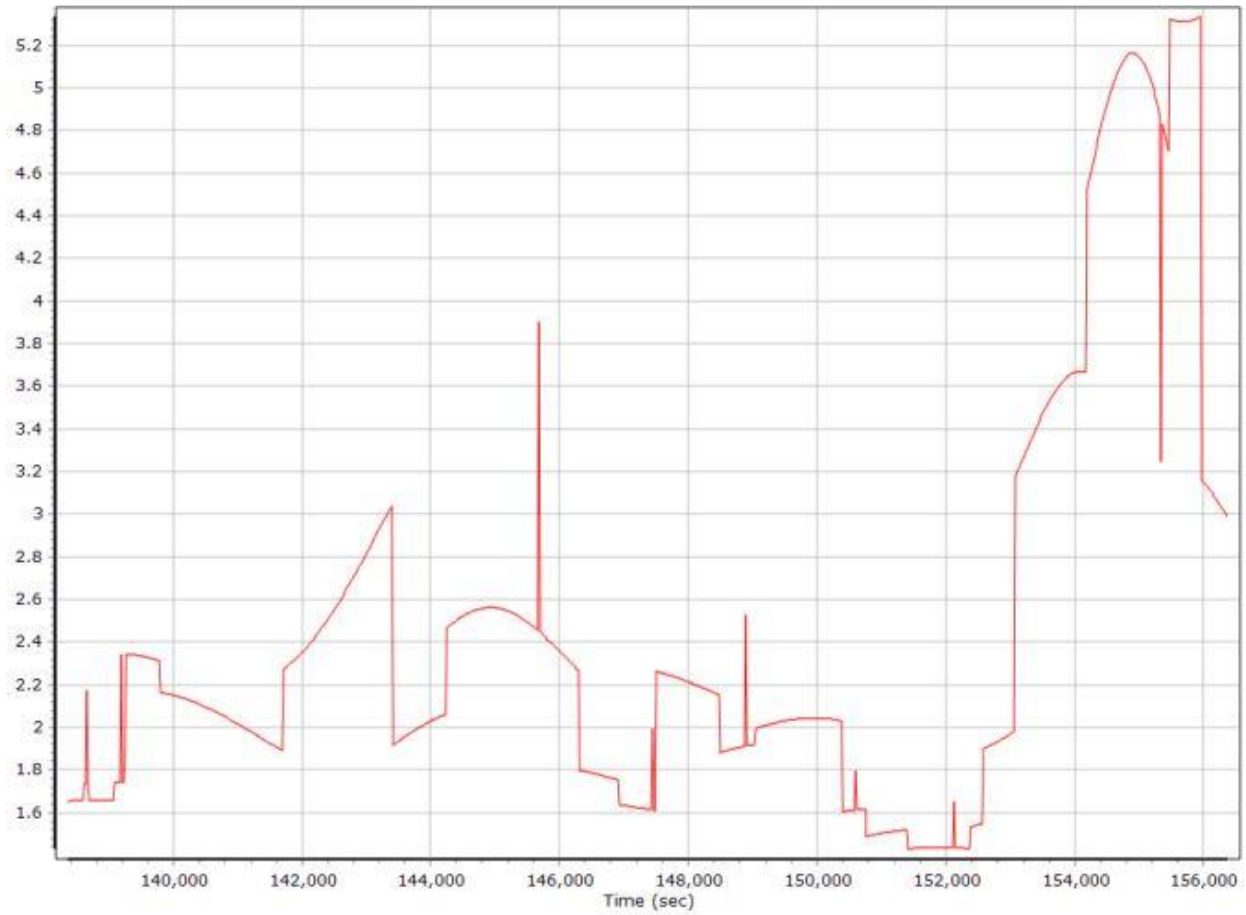
Number of Satellites



Forward/Reverse Separation

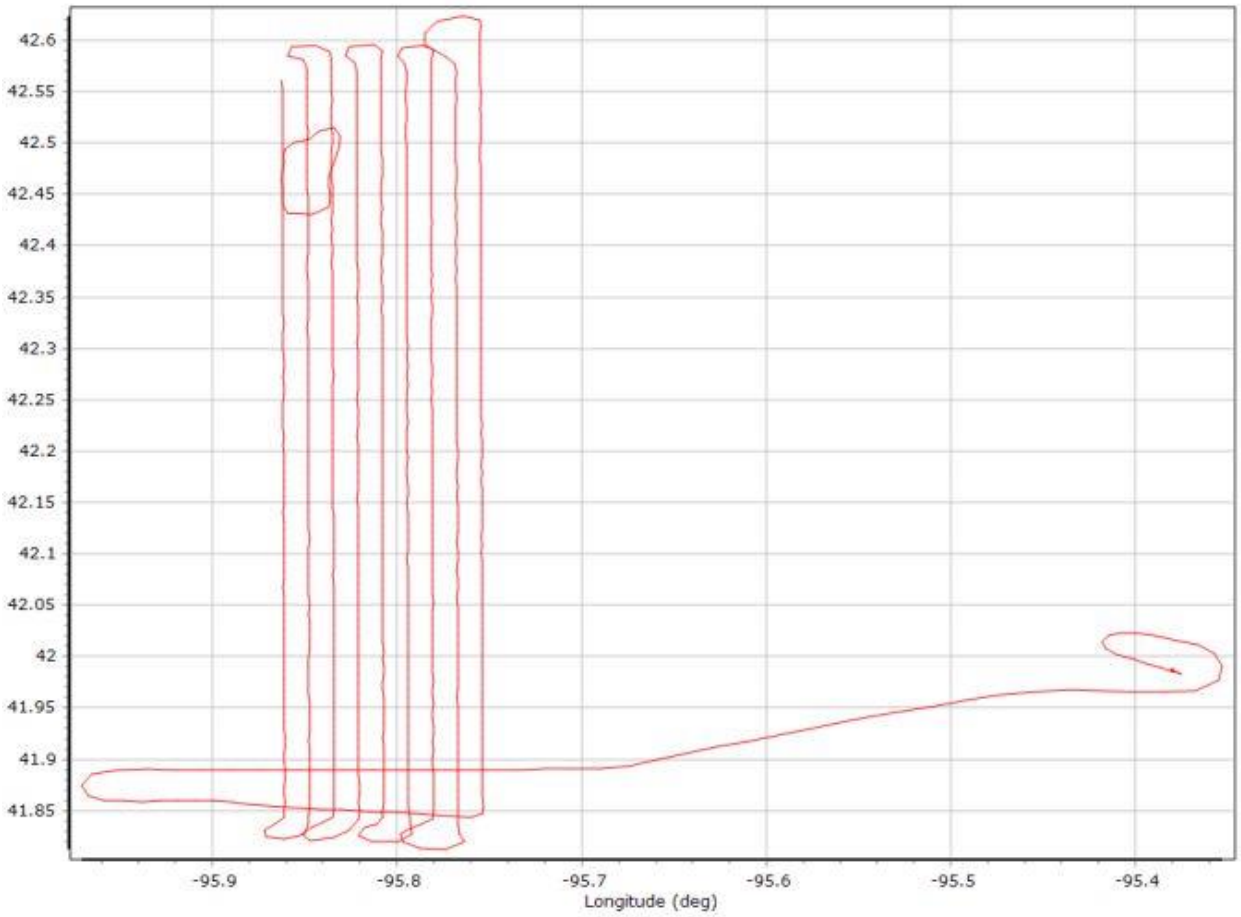


PDOP


5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
140,000
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
Time (sec)

20210329_2_QC Report.docx QC Report – 8/27/2021 1014:24
Smoothed Trajectory Information

Top View

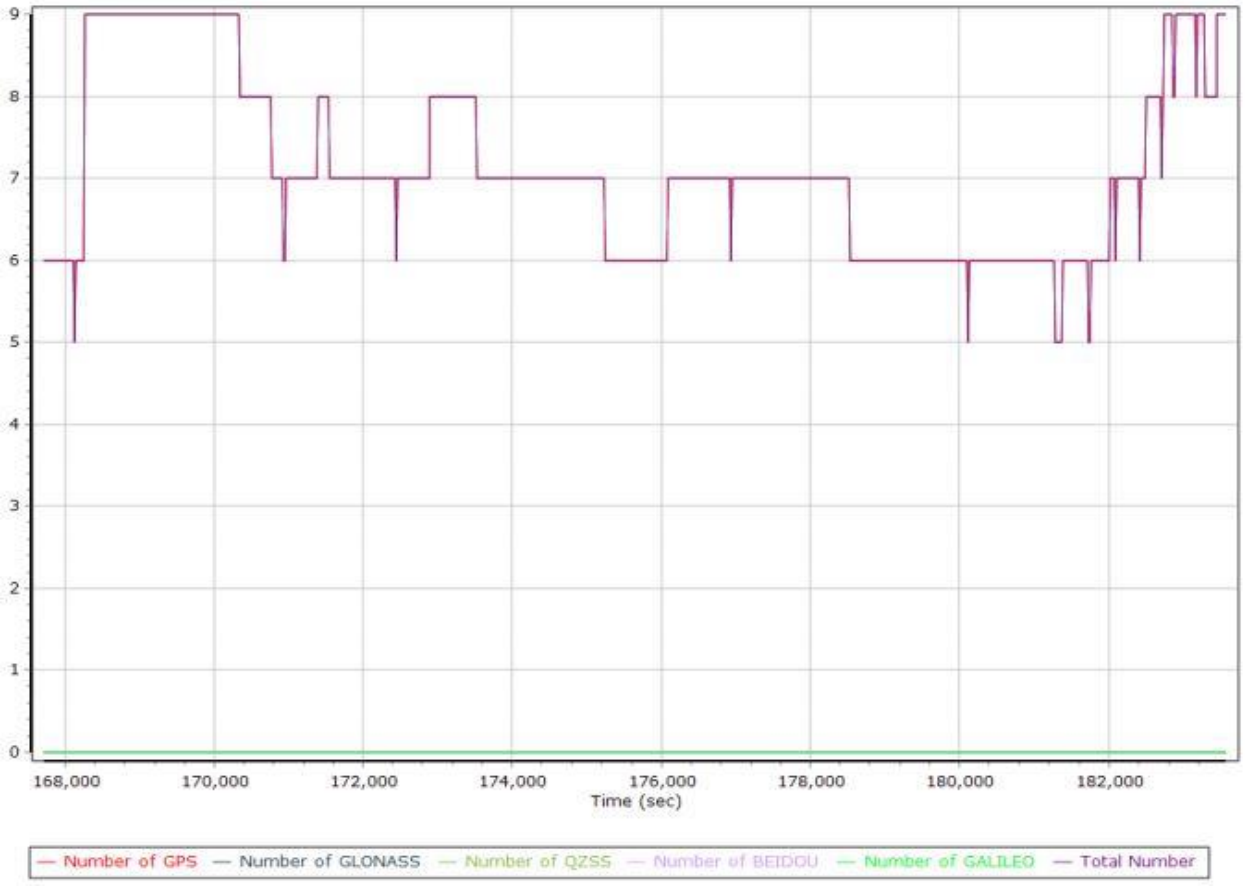


GNSS QC

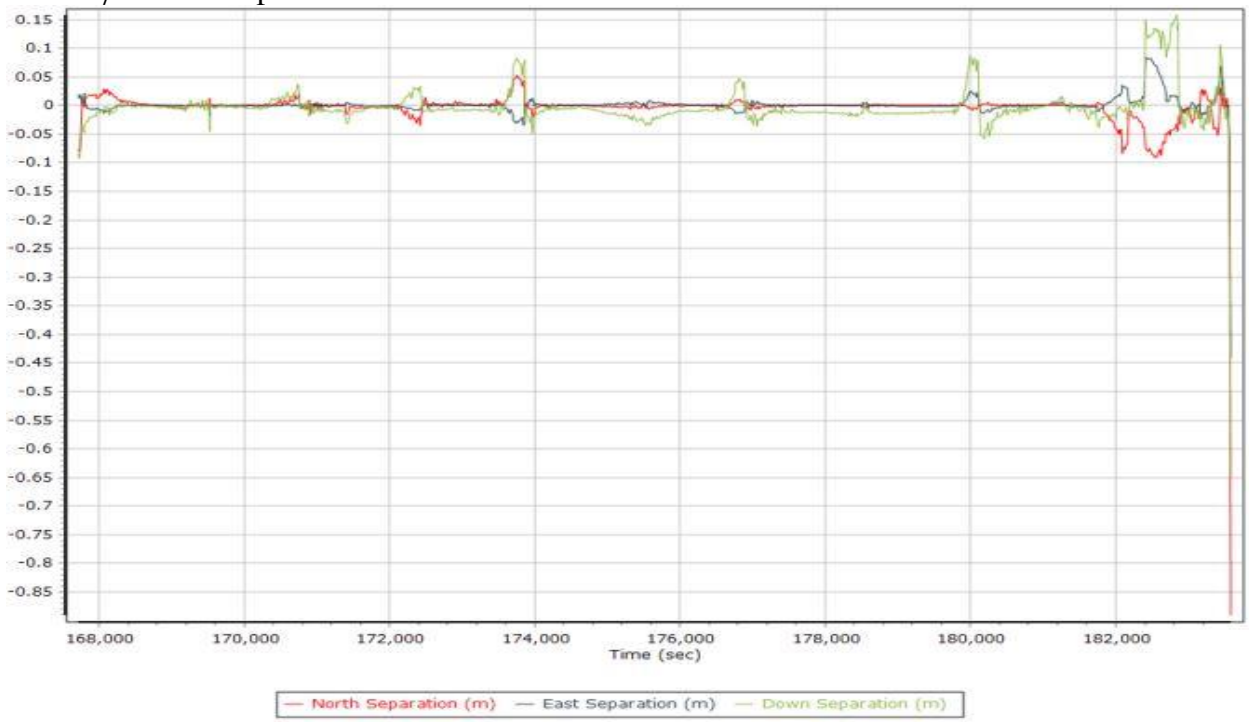
GNSS QC Statistics

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

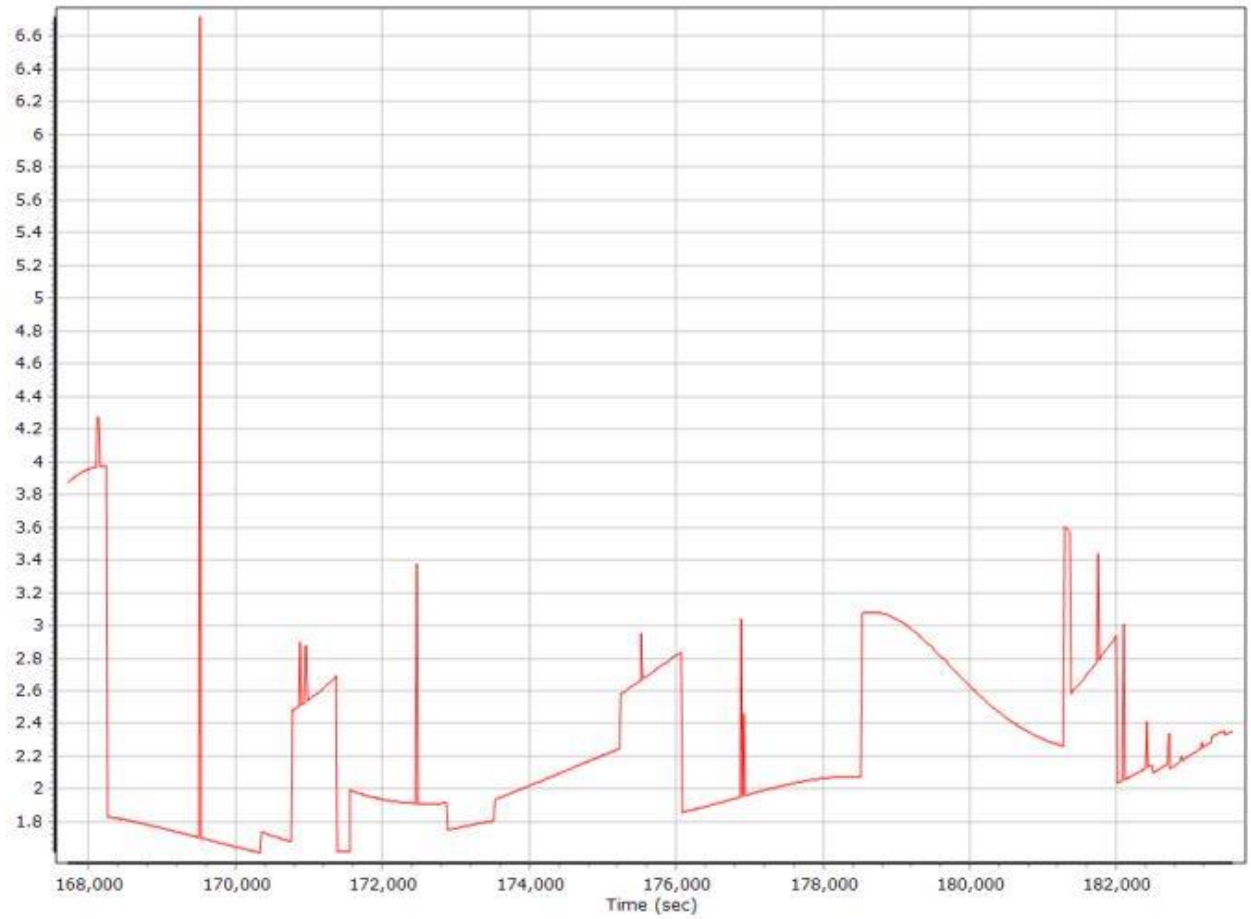
Number of Satellites



Forward/Reverse Separation

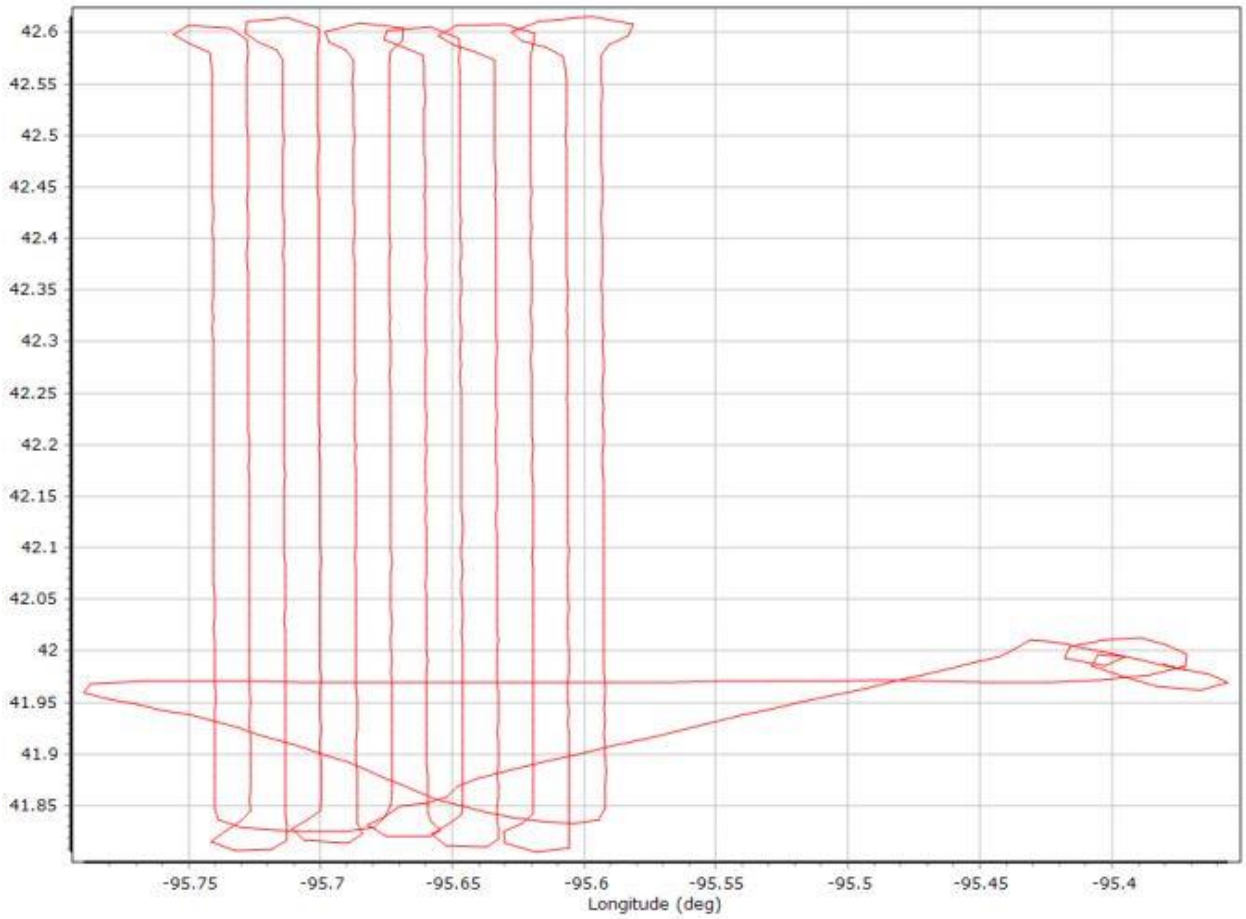


PDOP


6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
168,000
170,000
172,000
174,000
176,000
178,000
180,000
182,000
Time (sec)

20210330_1_QC Report.docx QC Report – 8/27/2021 10:20:22
Smoothed Trajectory Information

Top View

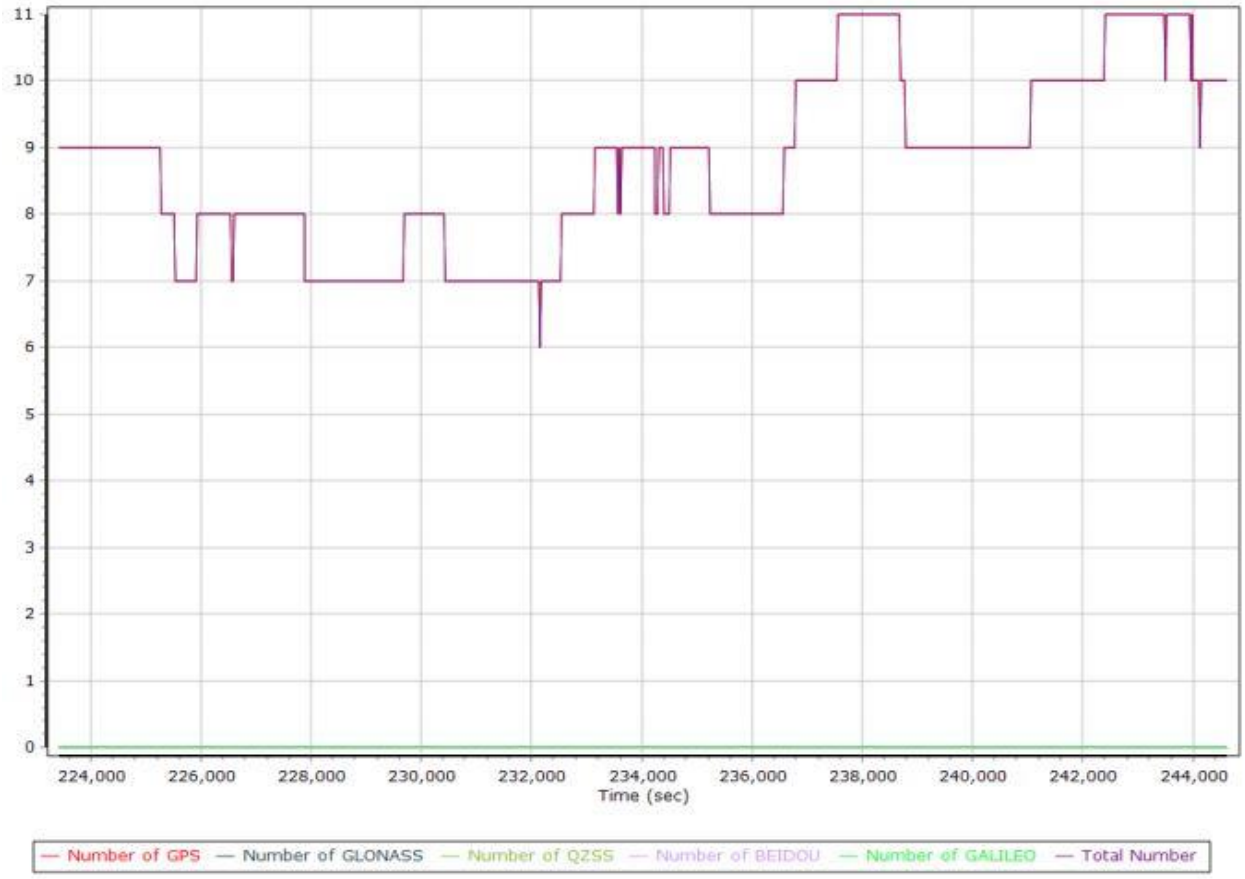


GNSS QC

GNSS QC Statistics

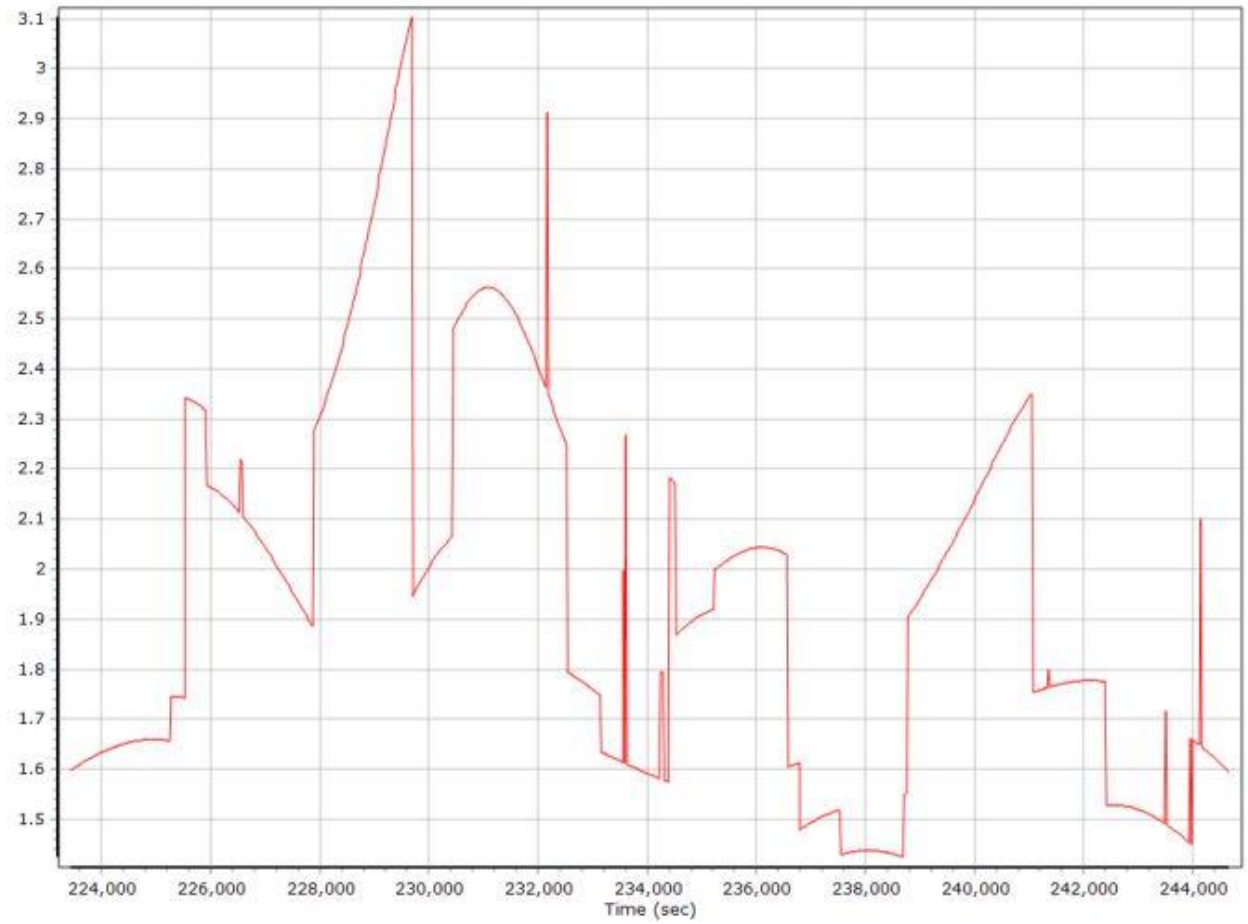
Statistics	Min	Max	Mean
Baseline length (km)	0.26	49.38	
Number of GPS SV	6	11	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	6	11	9
PDOP	1.42	3.95	1.94
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites



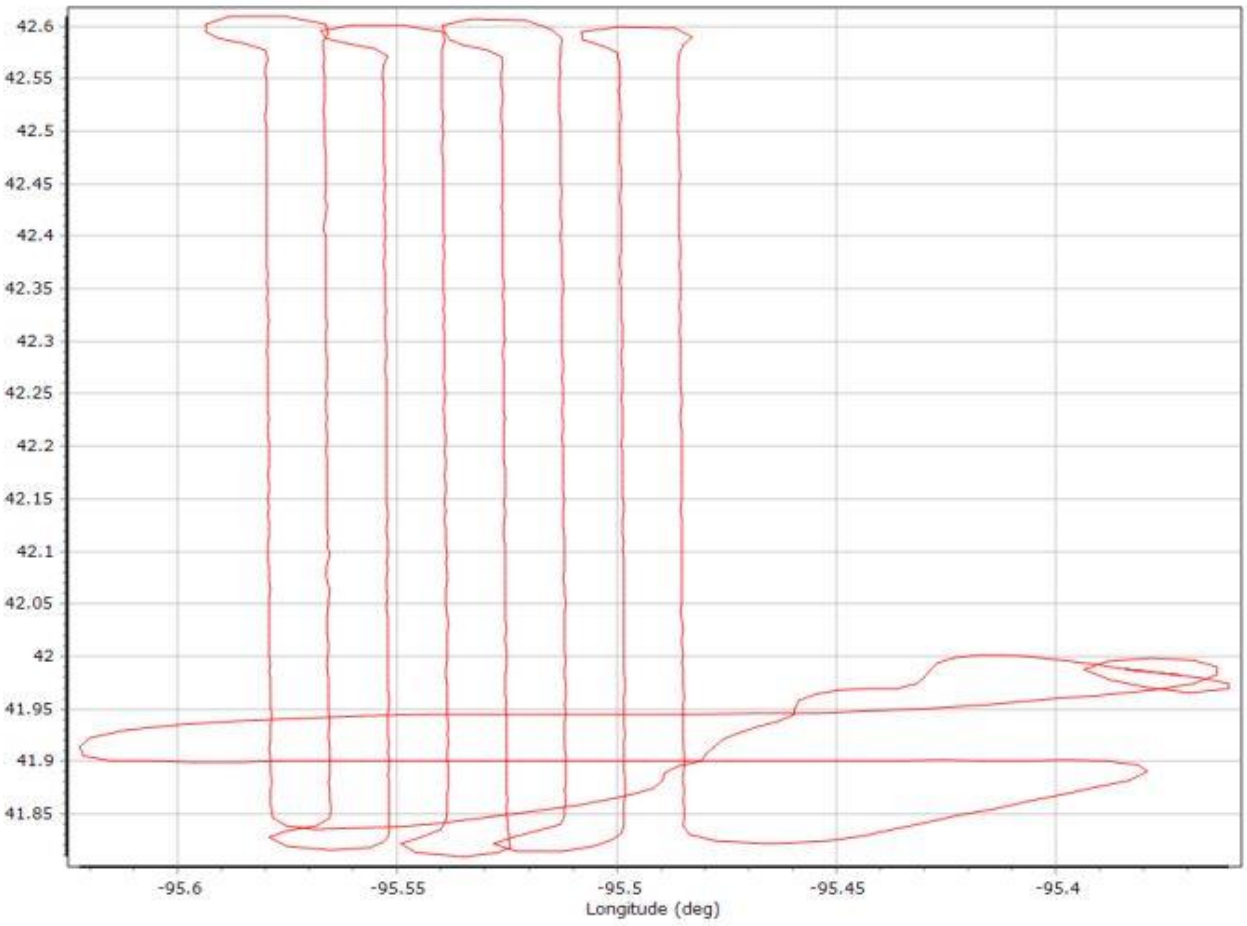
Forward/Reverse Separation

PDOP


3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
224,000
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
242,000
244,000
Time (sec)

20210330_2_QC Report.docx QC Report – 8/27/2021 10:26:41
Smoothed Trajectory Information

Top View

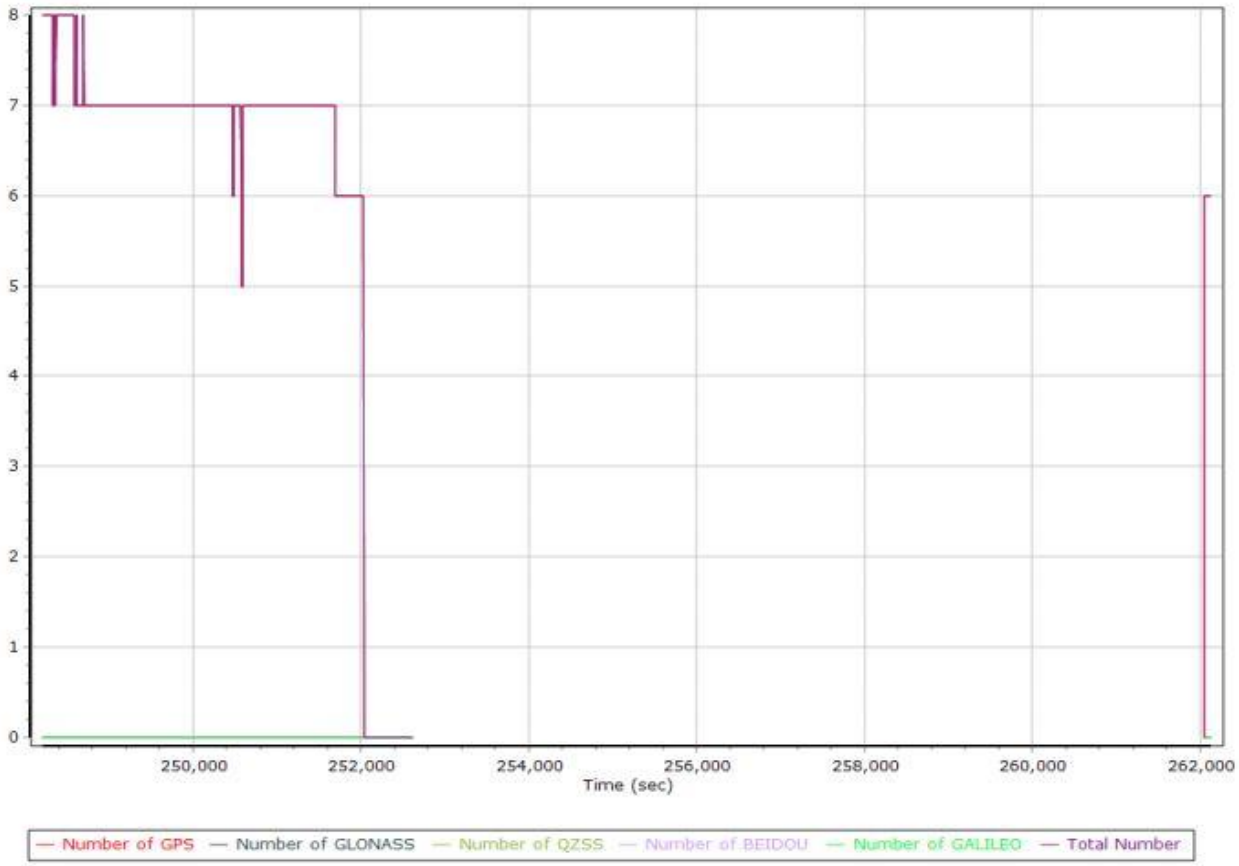


GNSS QC

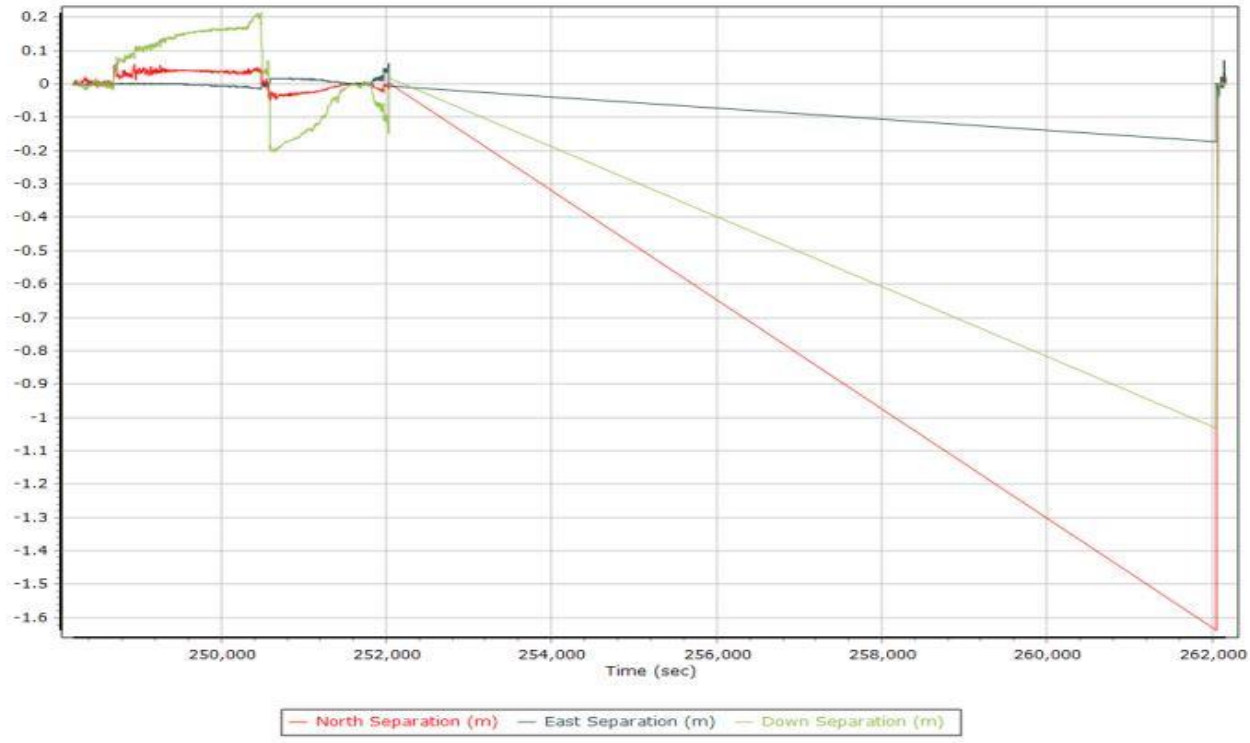
GNSS QC Statistics

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

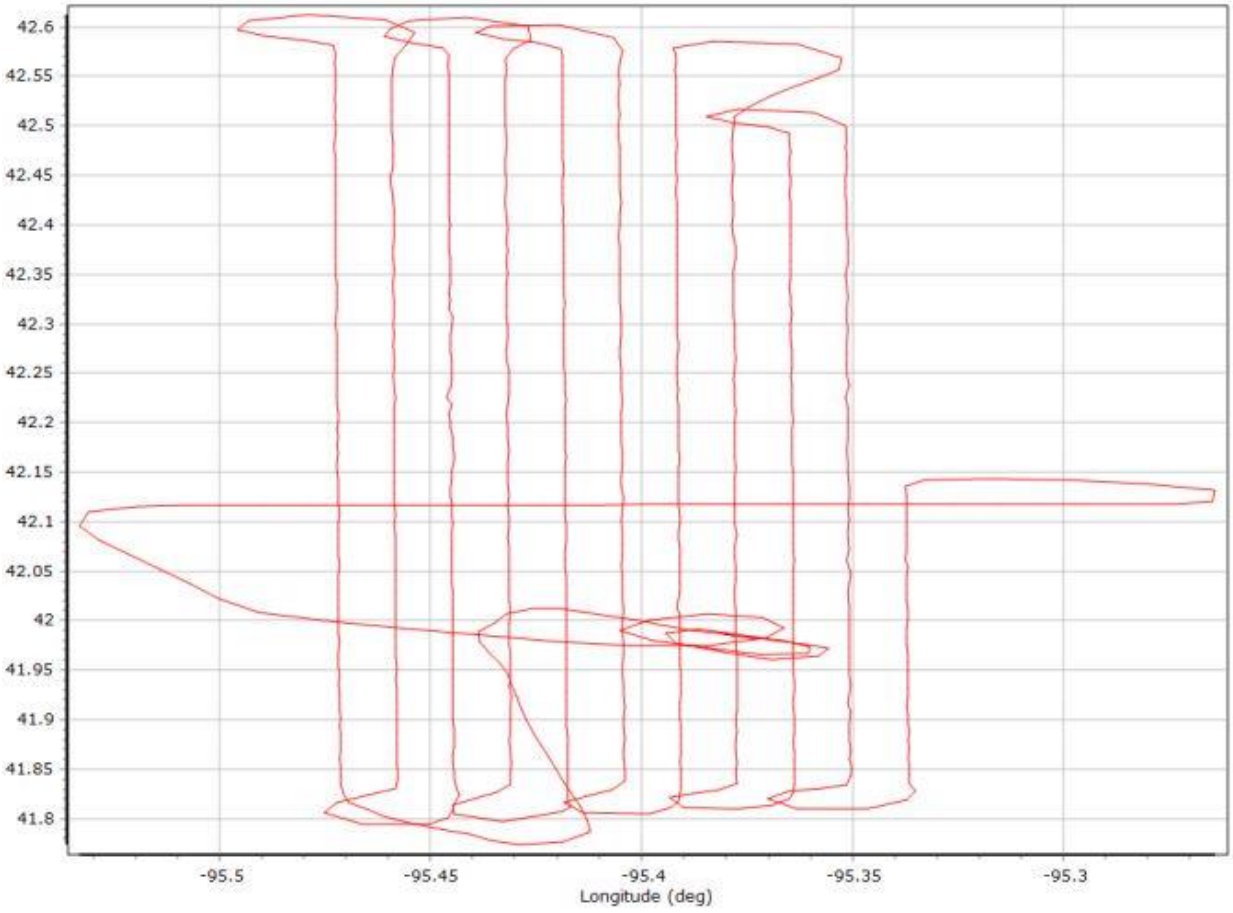


PDOP


5.5
5.4
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
250,000
252,000
254,000
256,000
258,000
260,000
262,000
Time (sec)

20210331_1_QC Report.docx QC Report – 8/27/2021 10:34:23
Smoothed Trajectory Information

Top View

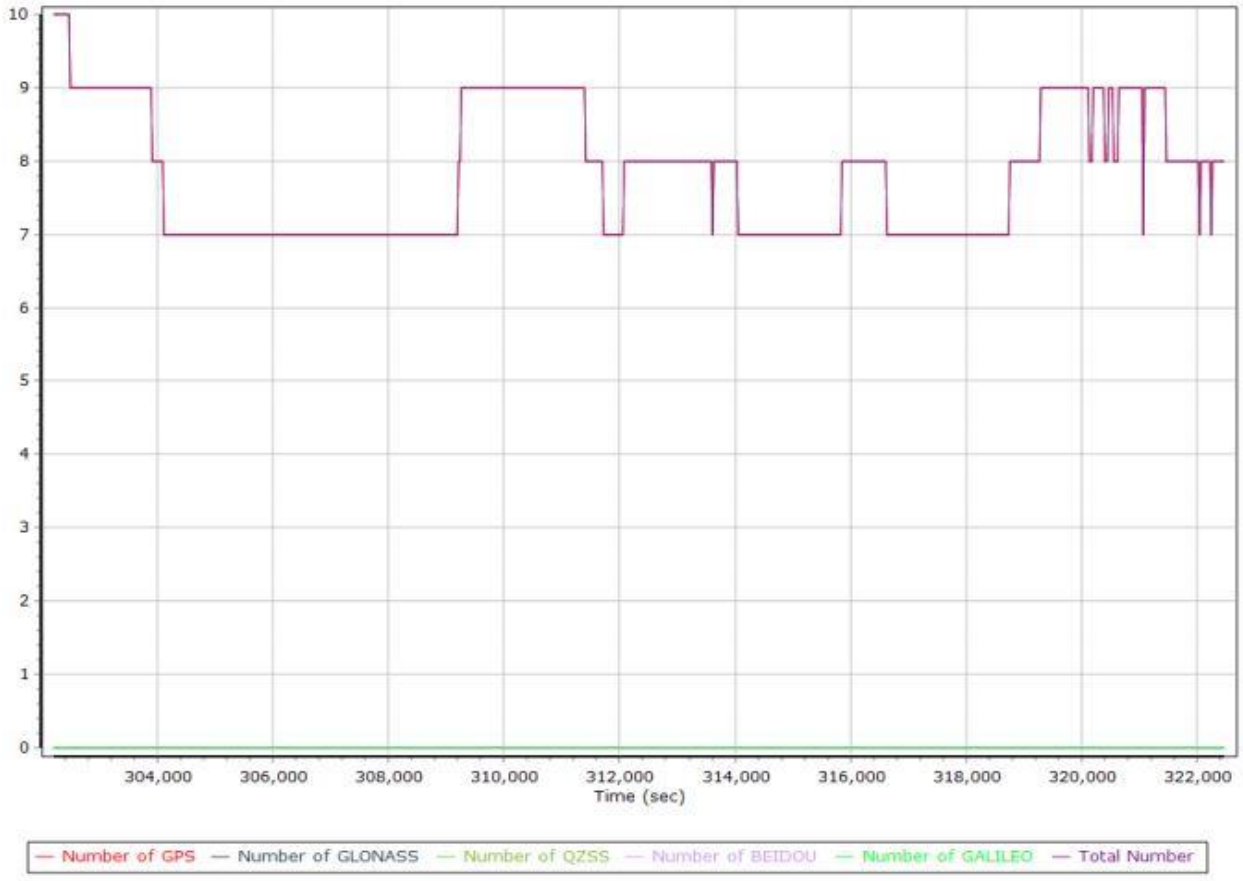


GNSS QC

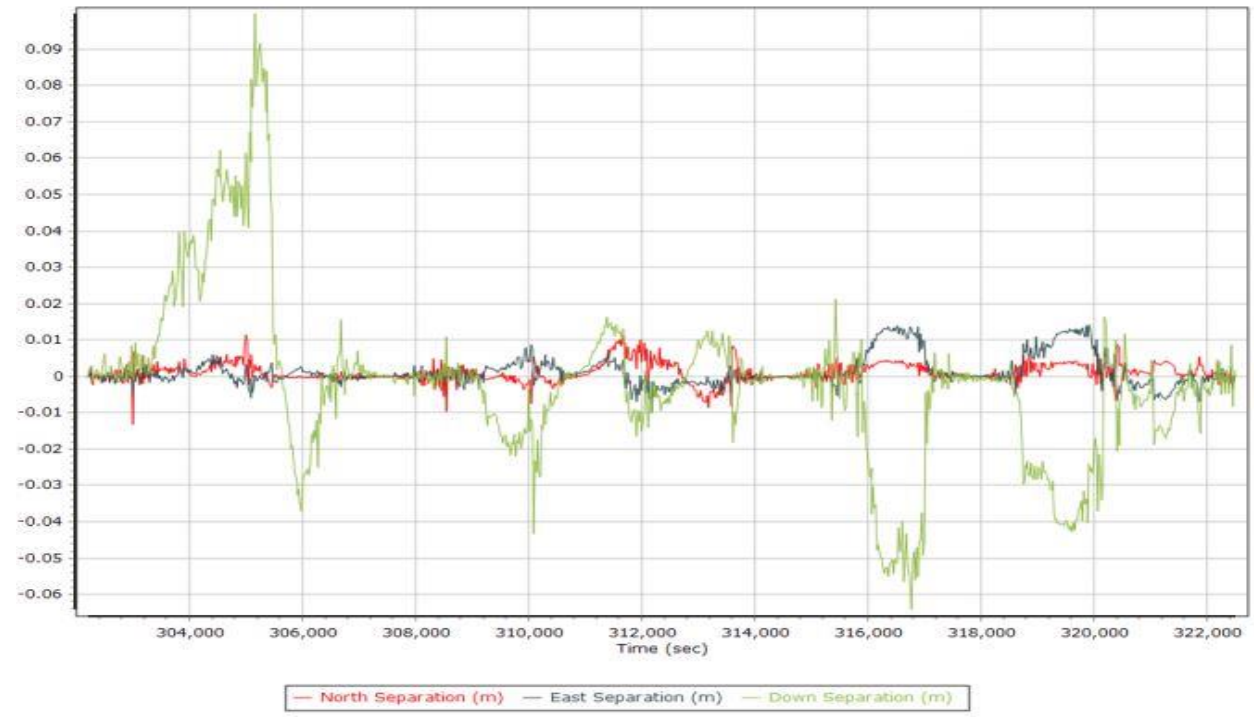
GNSS QC Statistics

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

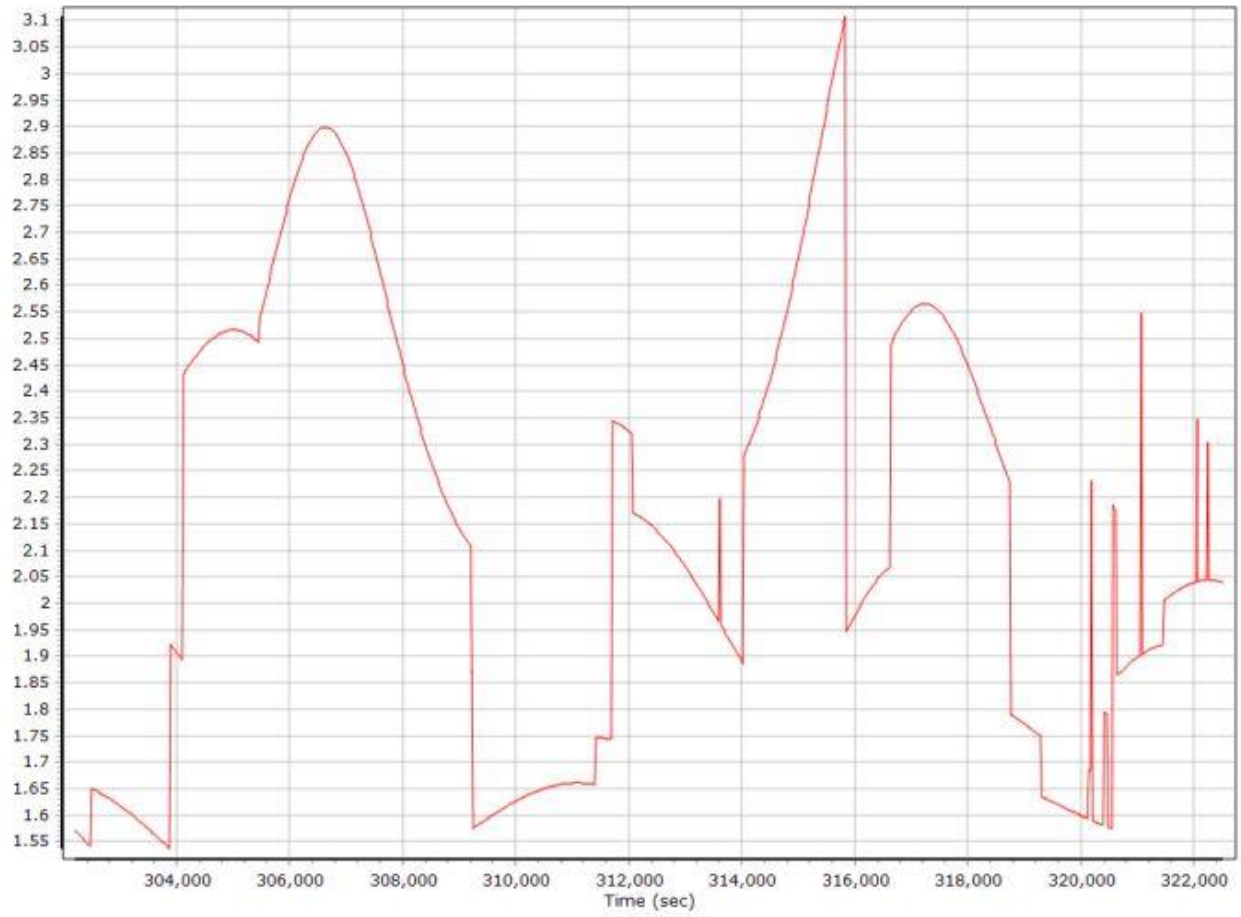
Number of Satellites



Forward/Reverse Separation



PDOP


3.1
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
2.65
2.6
2.55
2.5
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
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306,000
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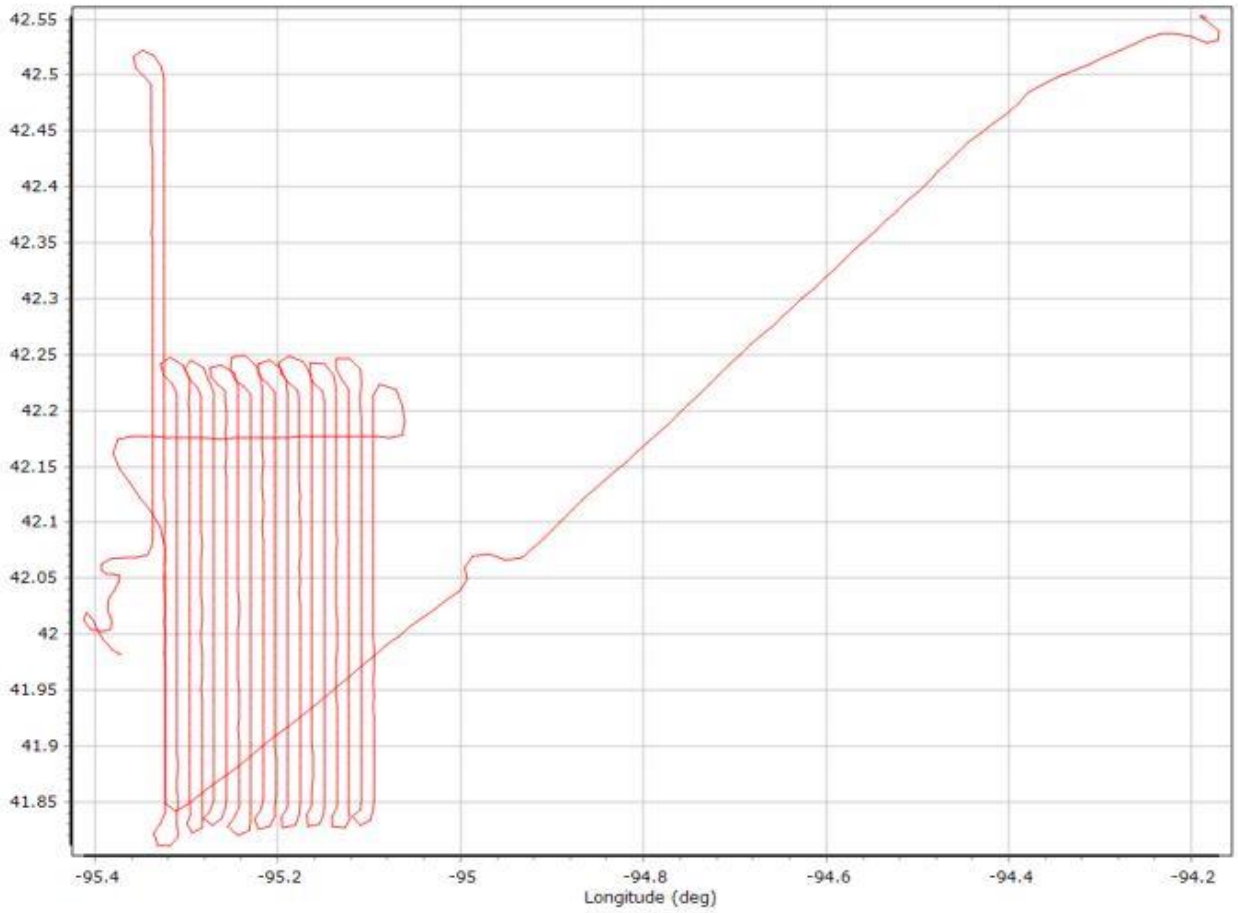
312,000
314,000
316,000
318,000
320,000
322,000
Time (sec)

20210331_2_QC Report.docx QC Report – 8/27/2021 10:47:22
Smoothed Trajectory Information

Top View



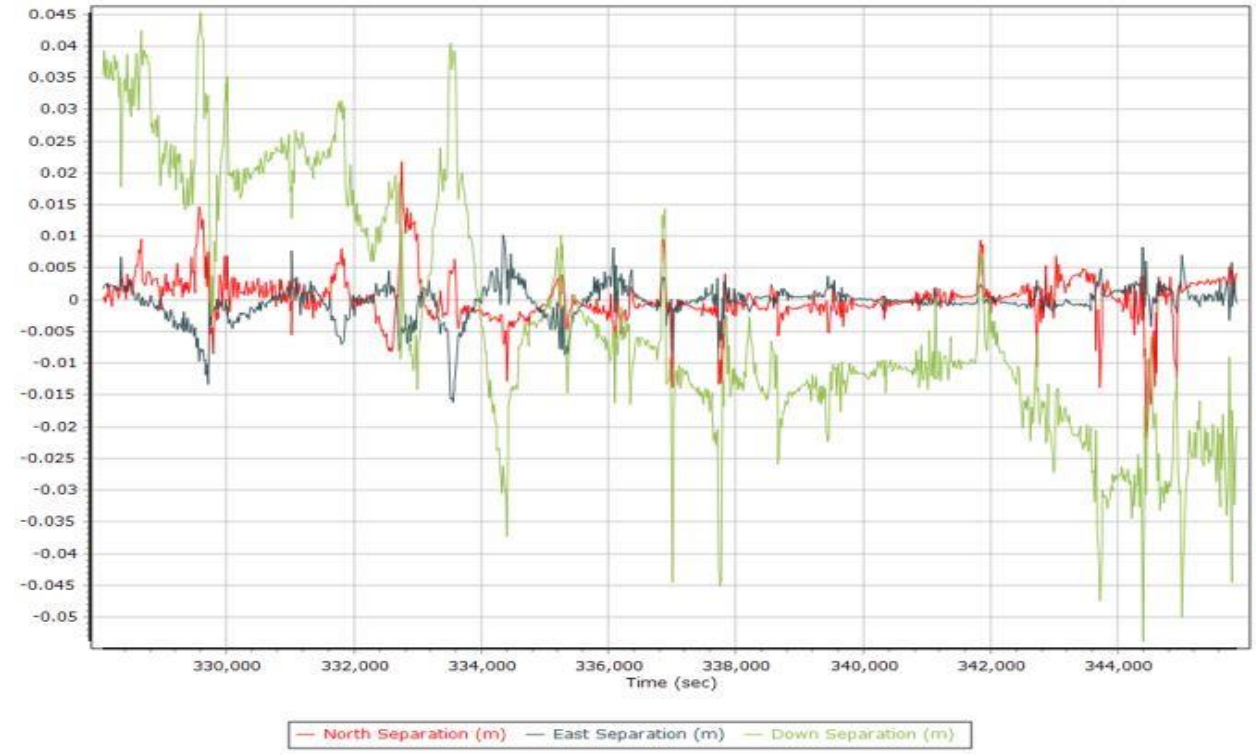
GNSS QC

GNSS QC Statistics

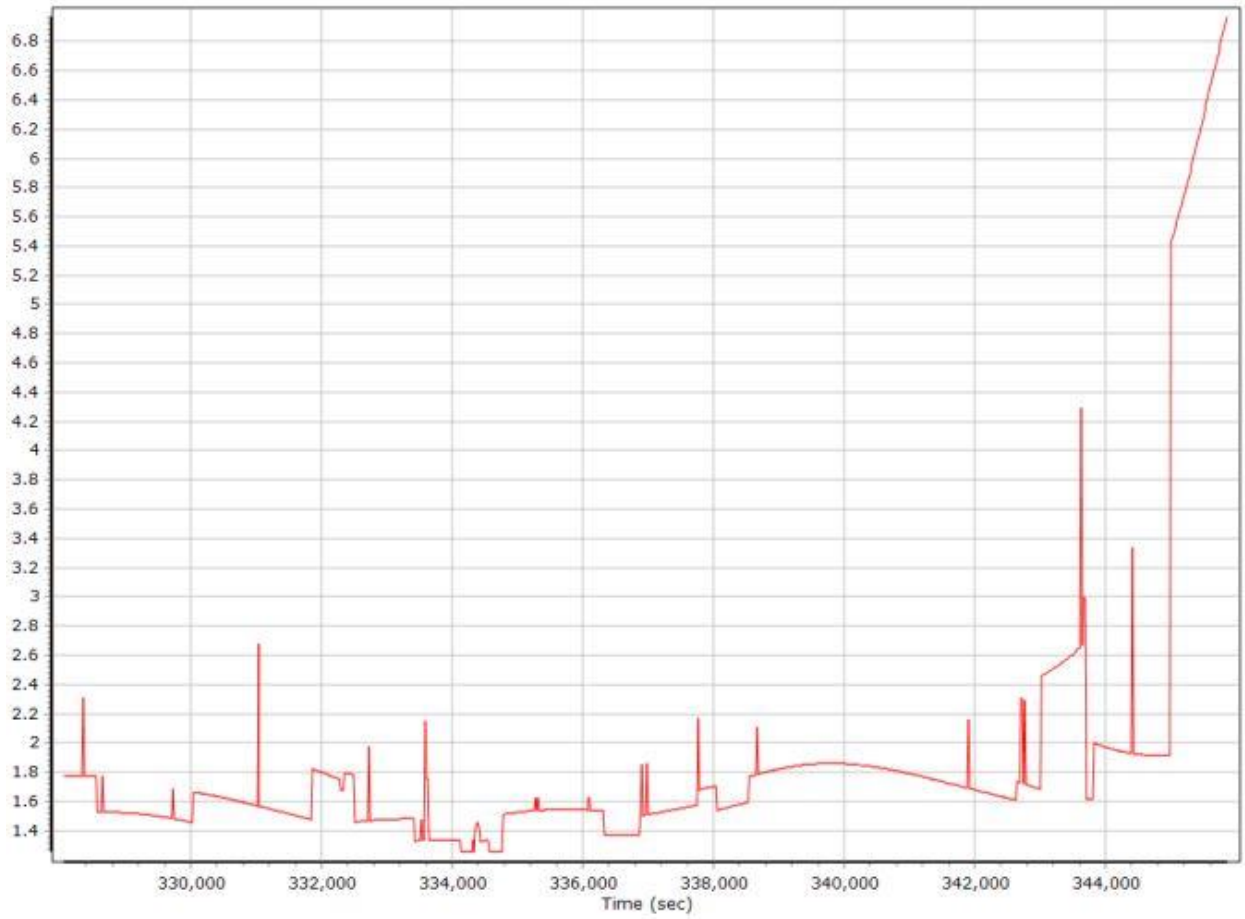
Statistics	Min	Max	Mean
Baseline length (km)	0.38	50.92	
Number of GPS SV	5	12	9
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	5	12	9
PDOP	1.26	7.00	1.90
QC Solution Gaps	1.00	20.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation



PDOP


6.8
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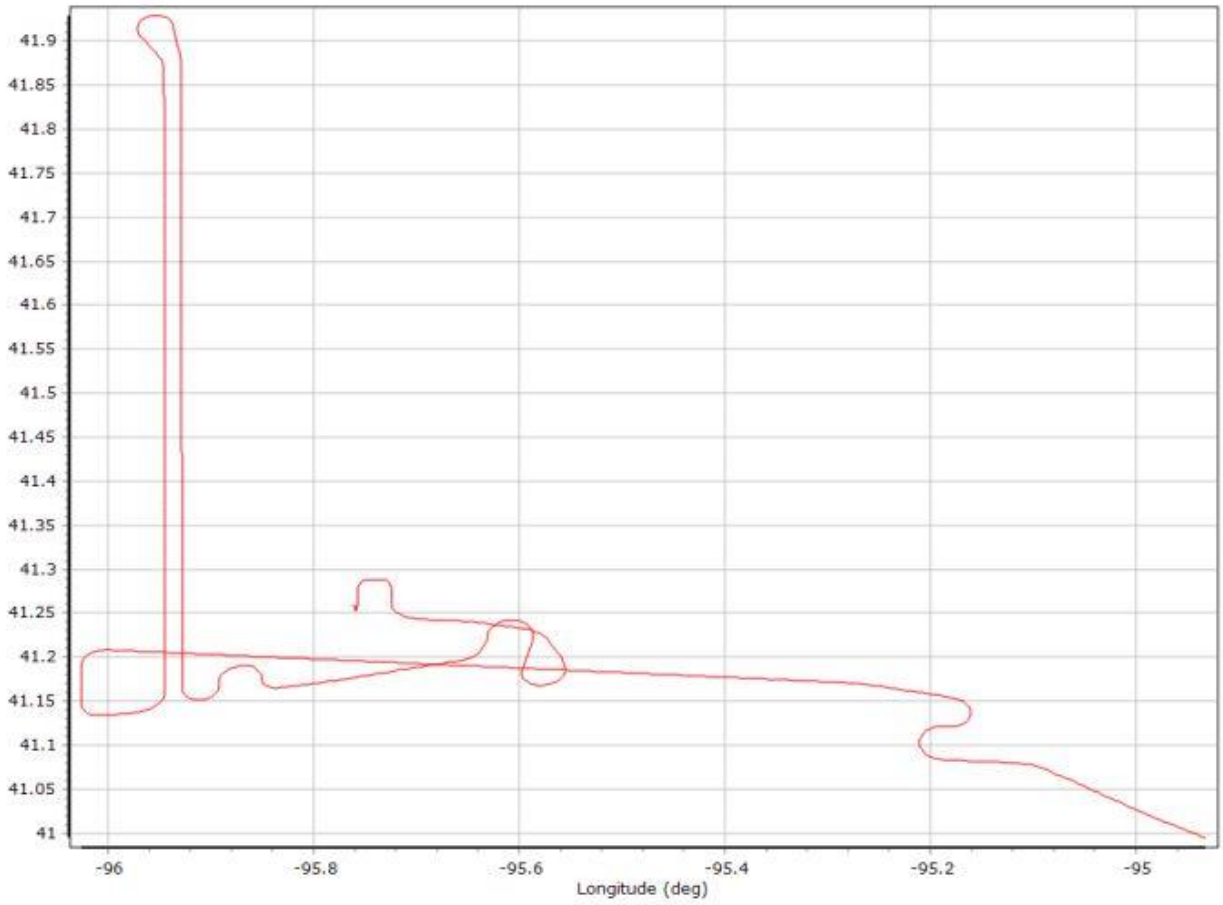
6.4
6.2
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
330,000
332,000
334,000
336,000
338,000
340,000
342,000
344,000
Time (sec)

Aerial Services, Inc. QC Reports.

0319a448_QC Report.docx QC Report - 8/25/2021 14:45:25
Smoothed Trajectory Information

Top View



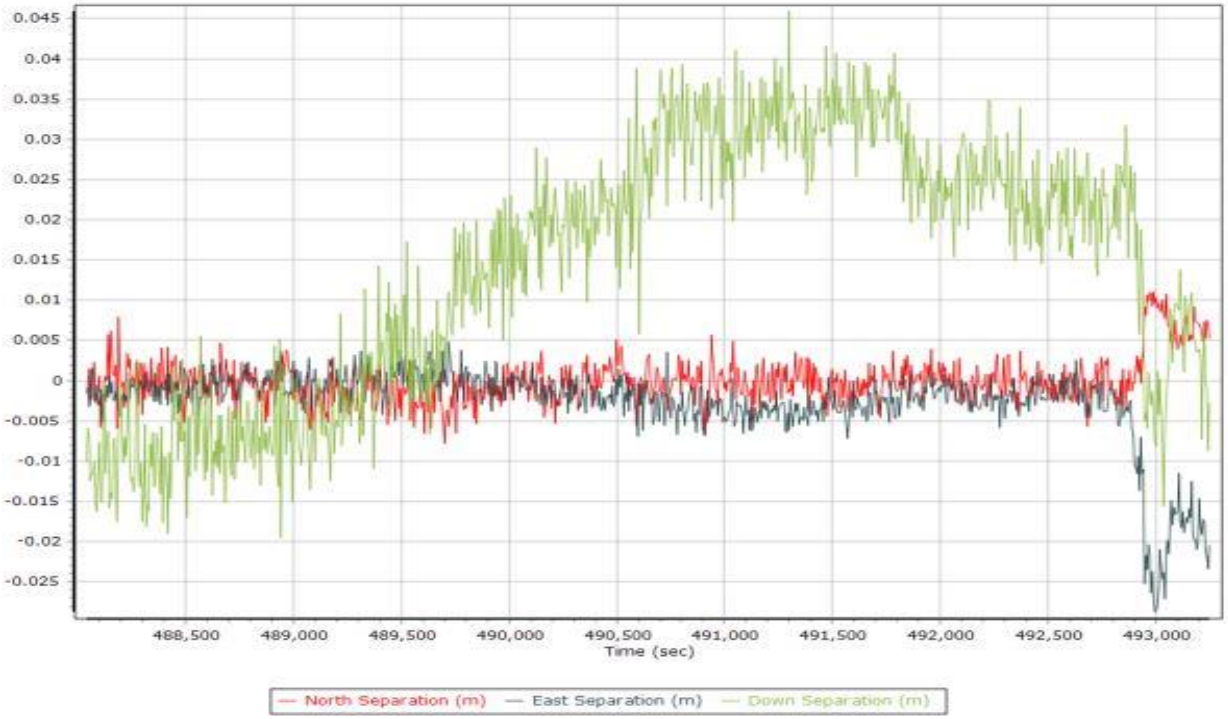
GNSS QC

GNSS QC Statistics

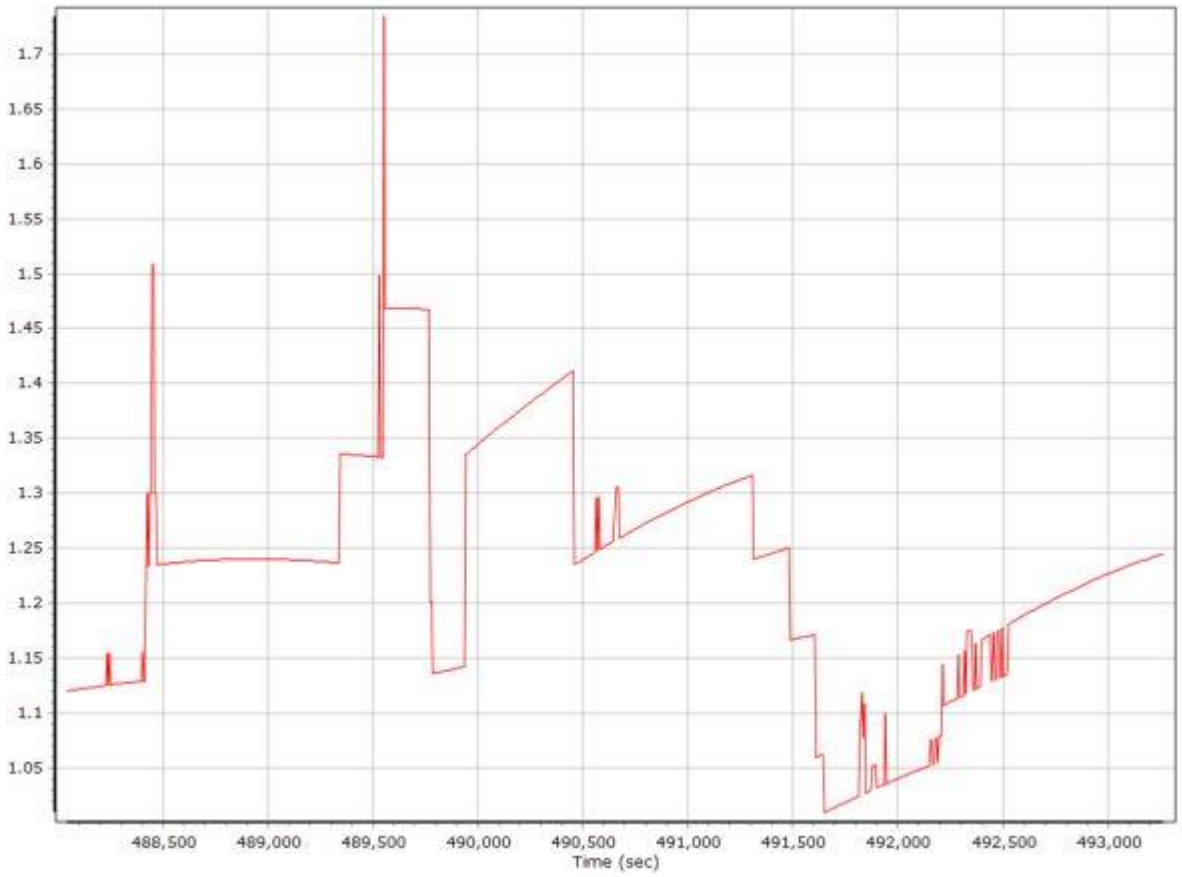
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	9	8
Number of GLONASS SV	4	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	7	6
Total number of SV	16	23	20
PDOP	1.01	1.73	1.20
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation

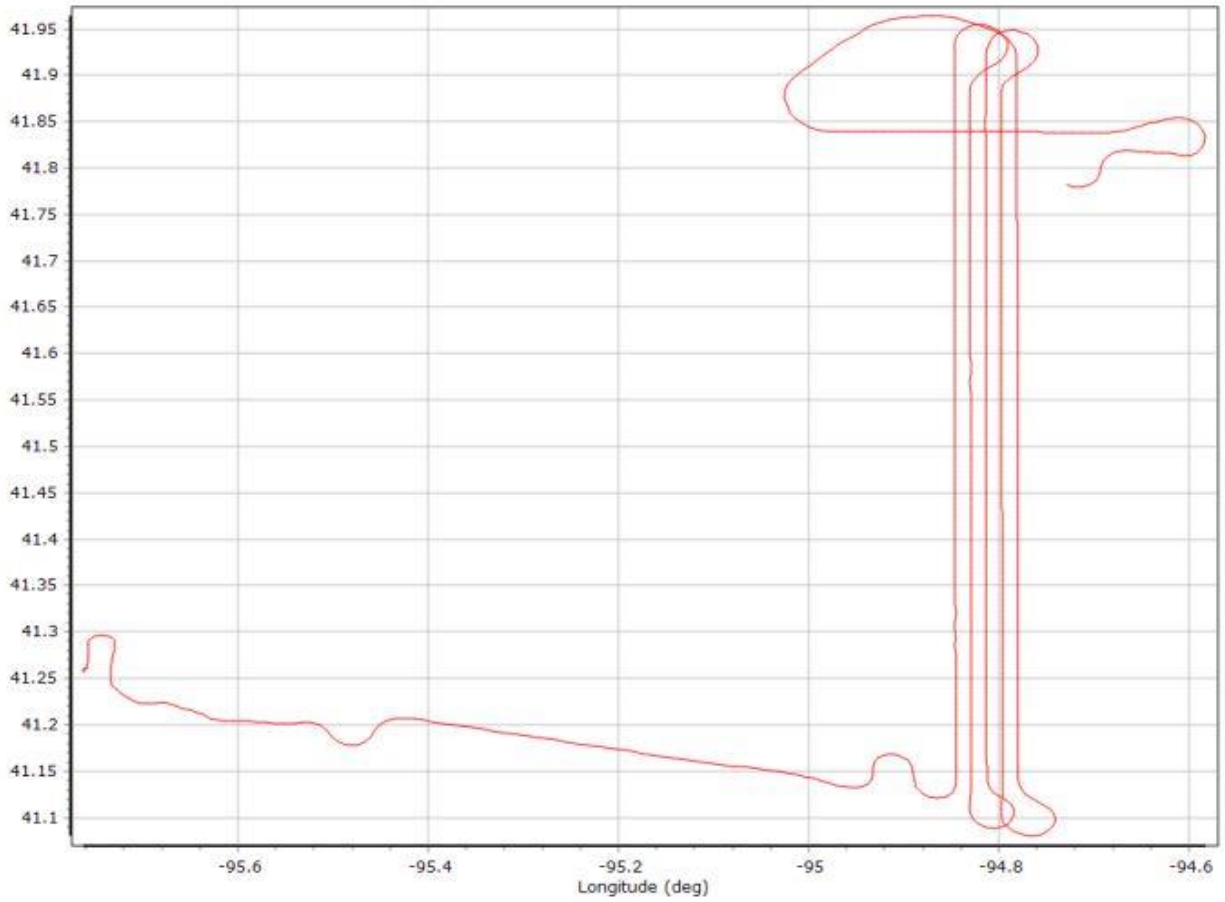


PDOP


1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
488,500
489,000
489,500
490,000
490,500
491,000
491,500
492,000
492,500
493,000
Time (sec)

0319b386_QC Report.docx QC Report – 8/25/2021 09:32:25
Smoothed Trajectory Information

Top View
`

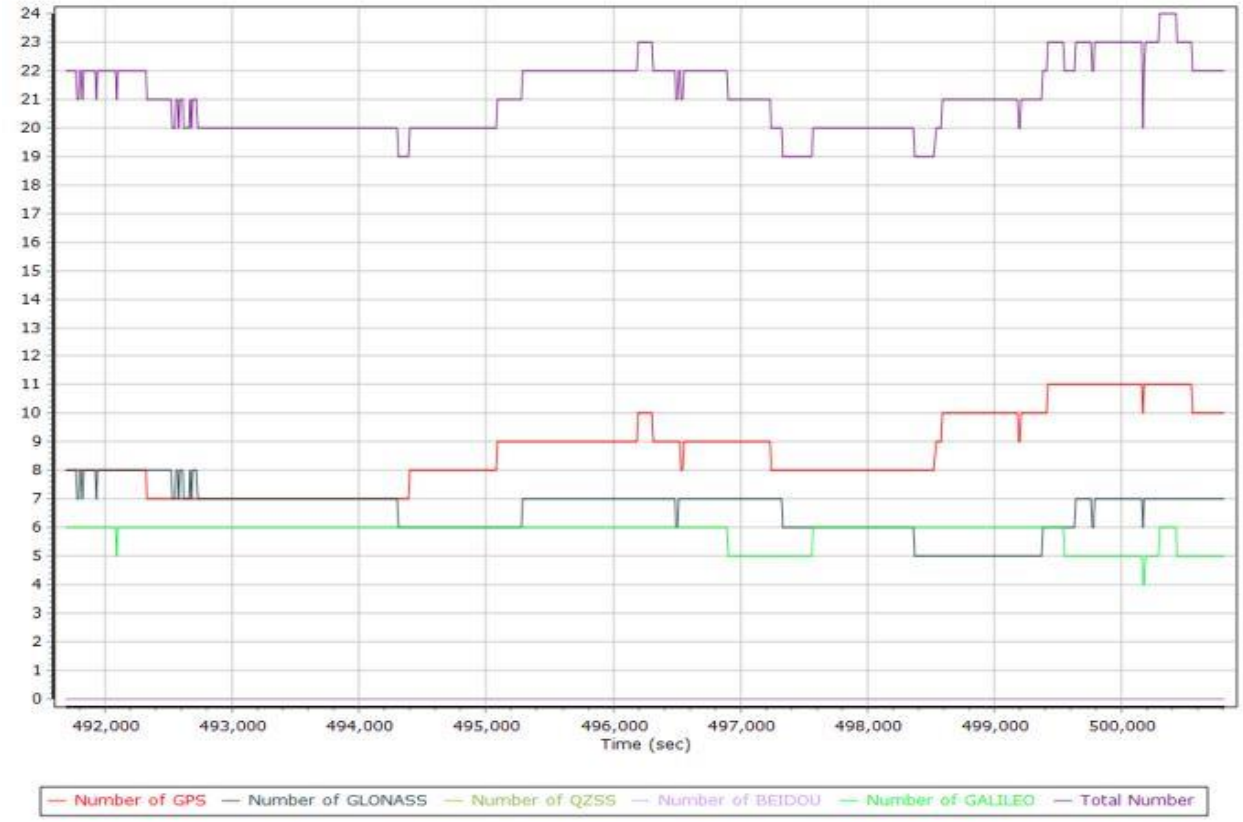


GNSS QC

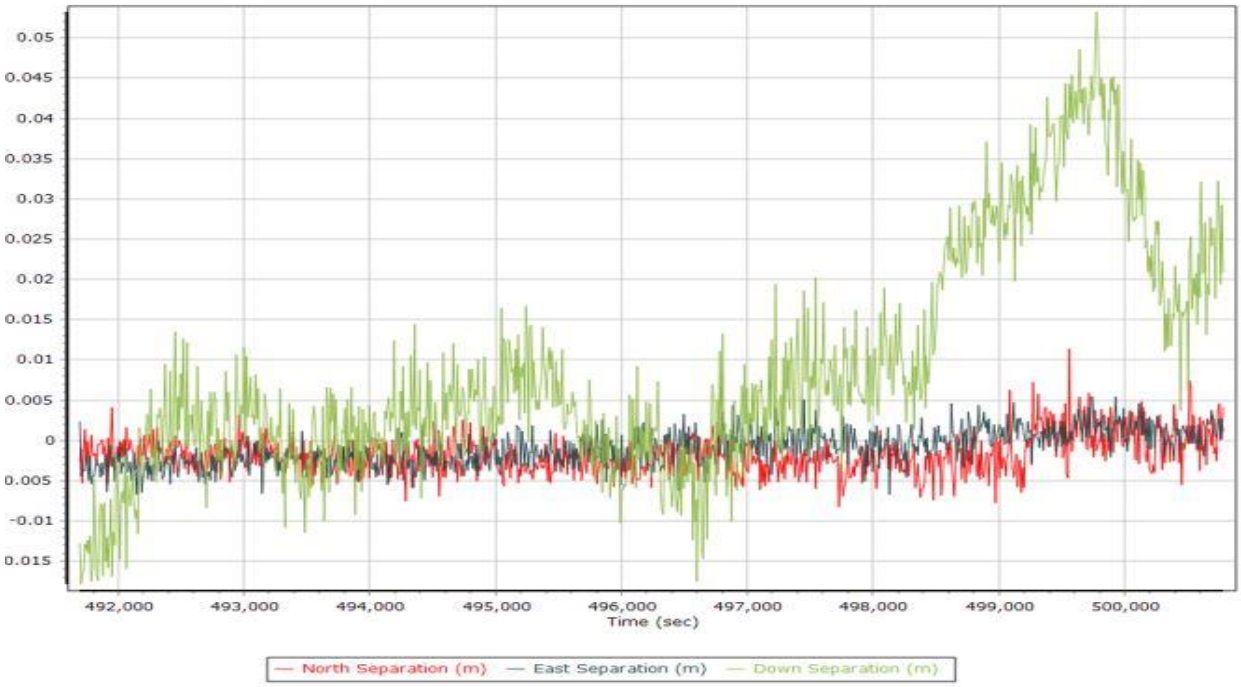
GNSS QC Statistics

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

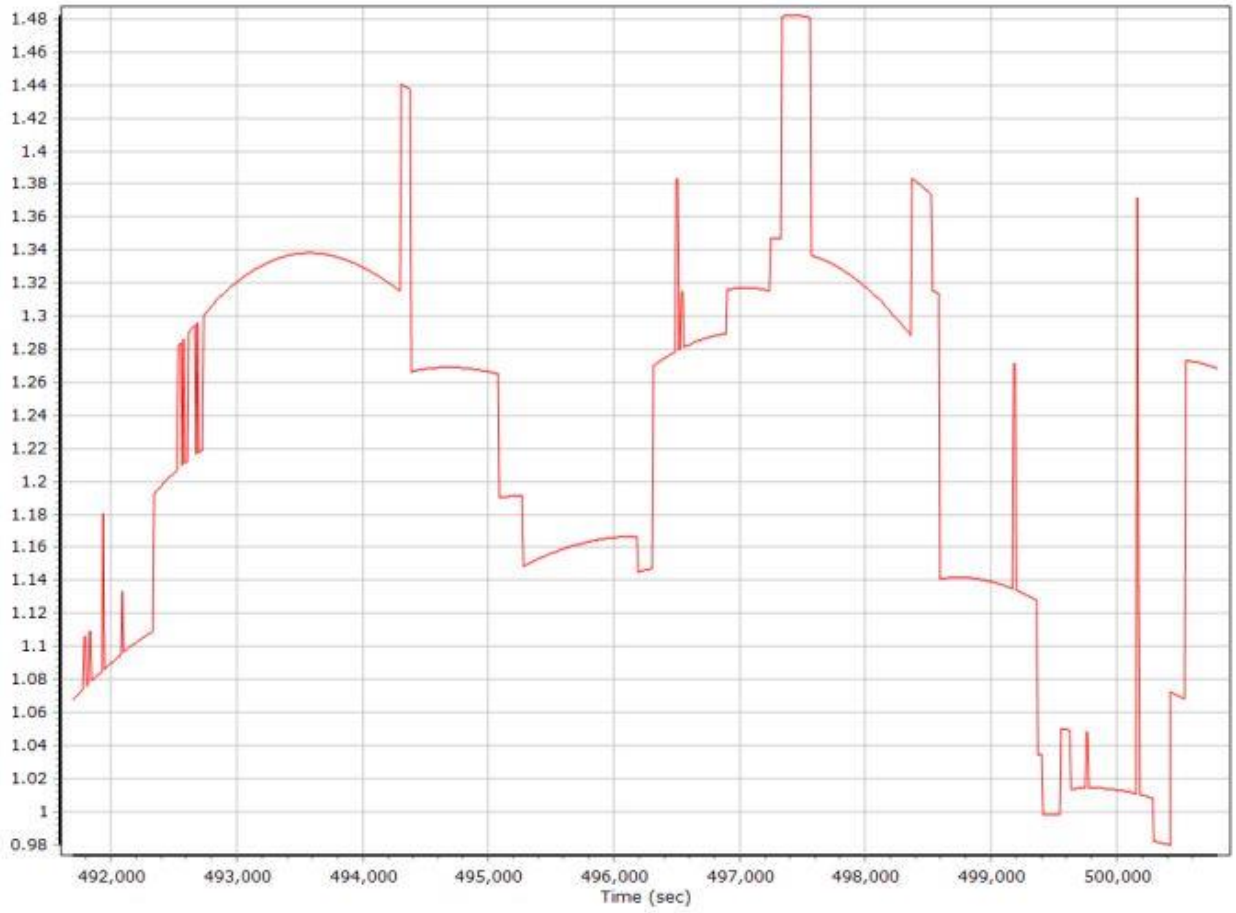
Number of Satellites



Forward/Reverse Separation



PDOP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1.46
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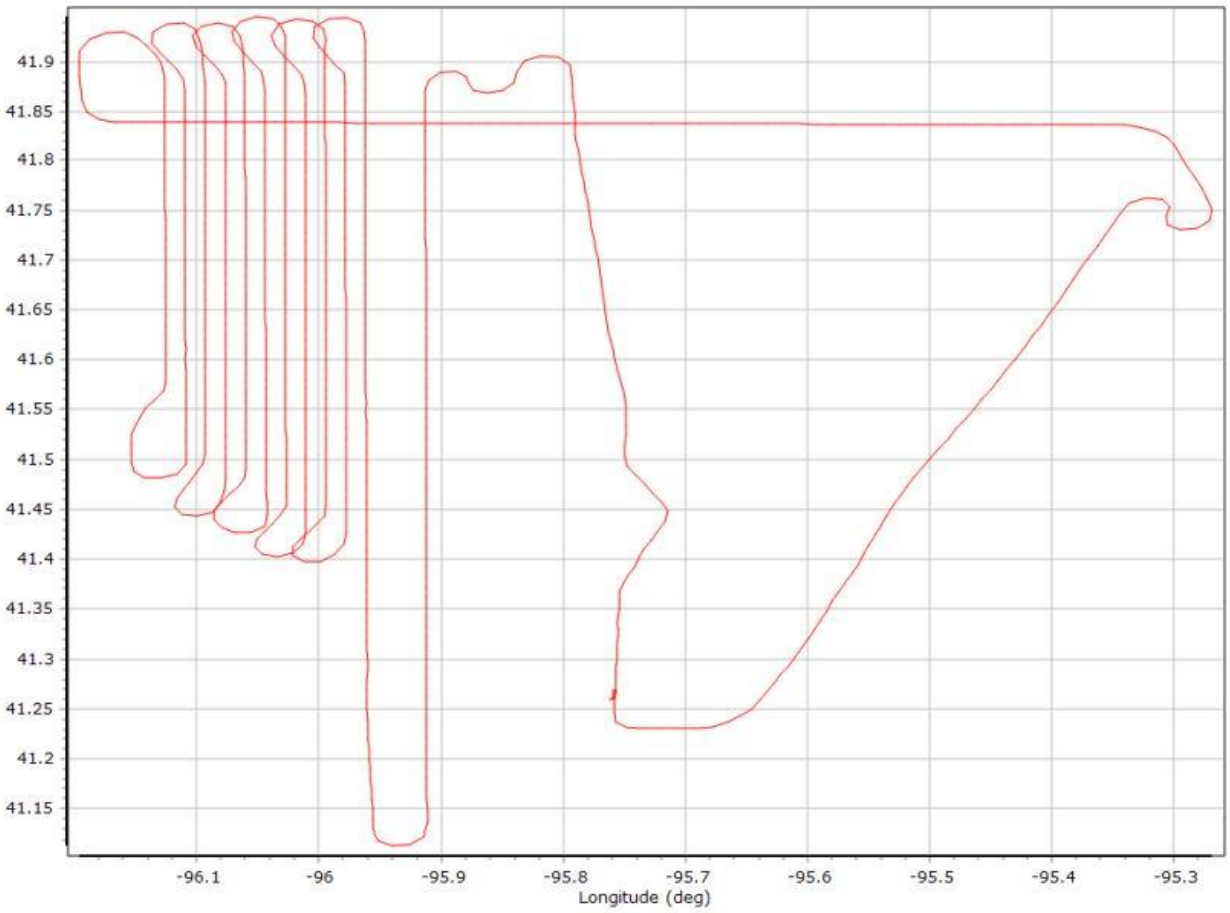
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
492,000
493,000
494,000
495,000
496,000
497,000
498,000
499,000
500,000
Time (sec)

0319b448_QC Report.docx QC Report – 8/25/2021 09:54:33
Smoothed Trajectory Information

Top View



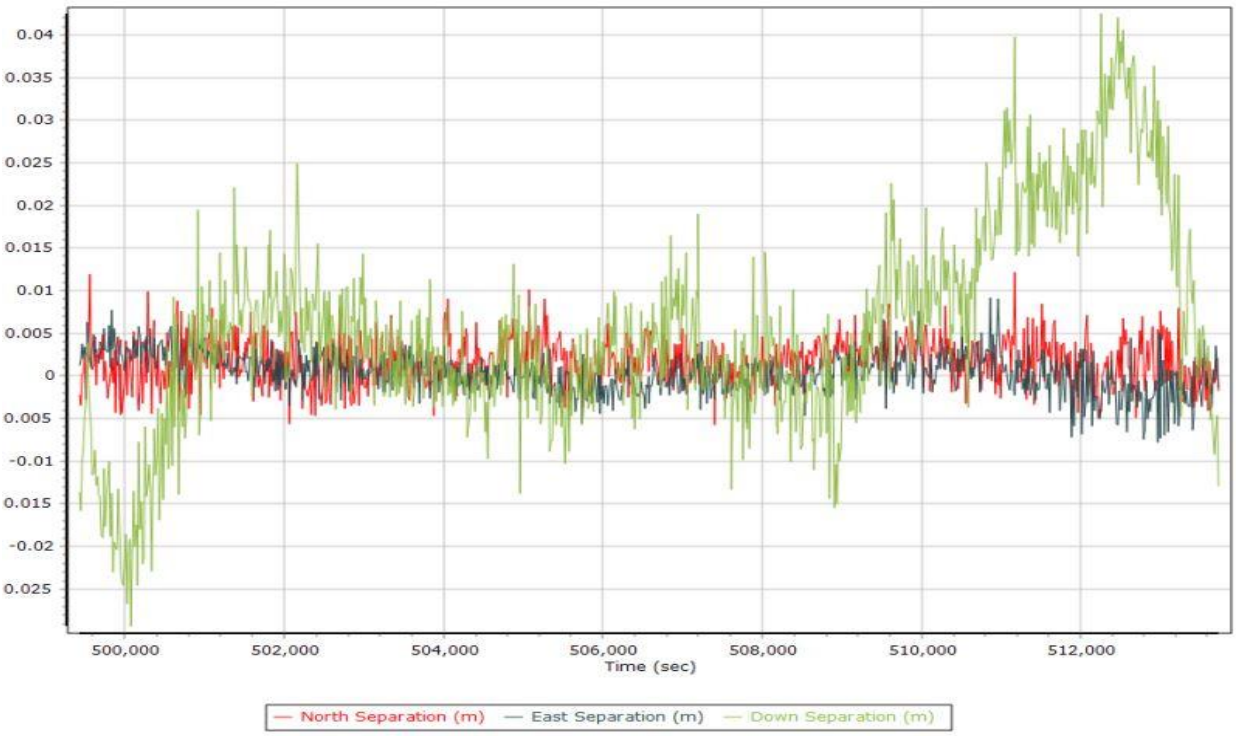
GNSS QC

GNSS QC Statistics

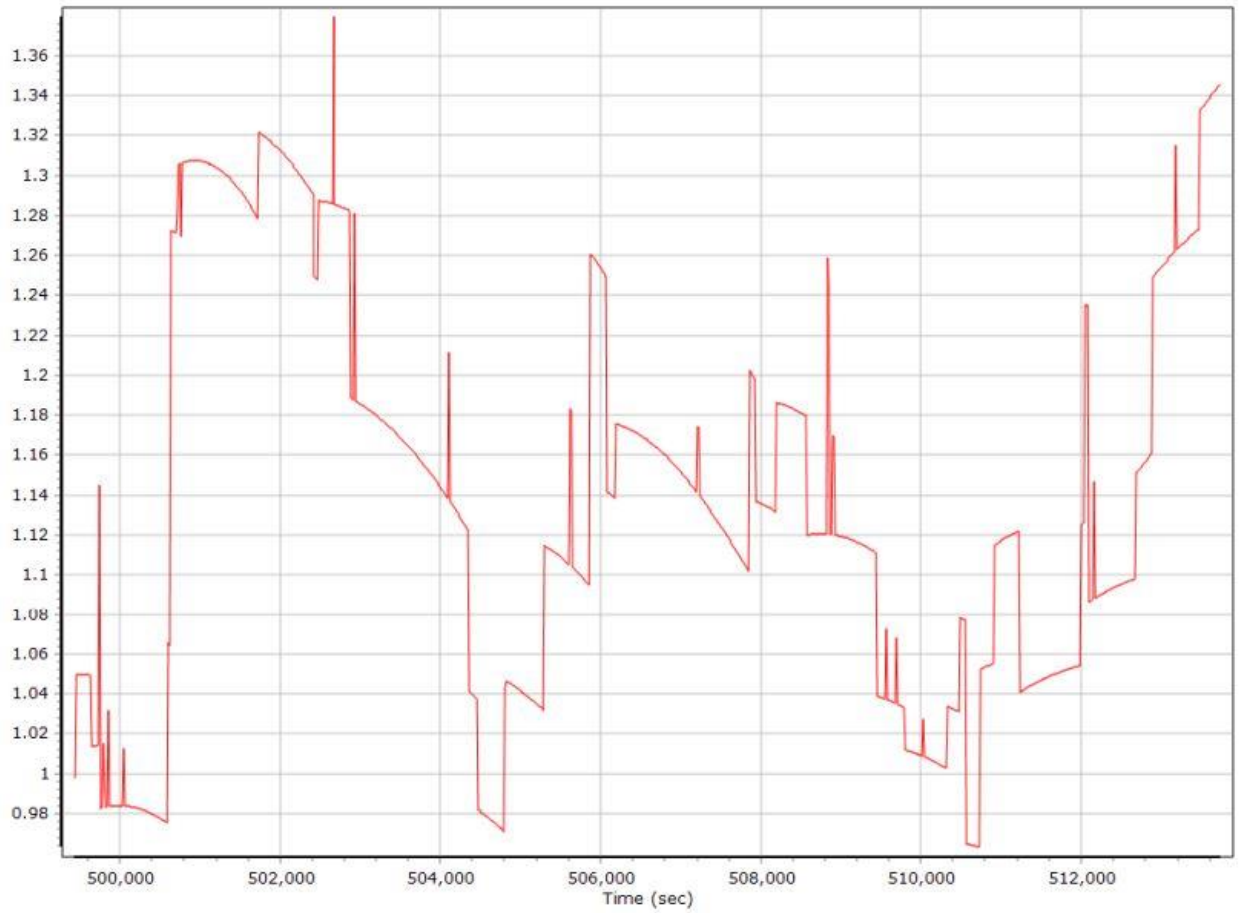
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	8	11	10
Number of GLONASS SV	3	7	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	6	5
Total number of SV	17	24	21
PDOP	0.96	1.41	1.14
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation

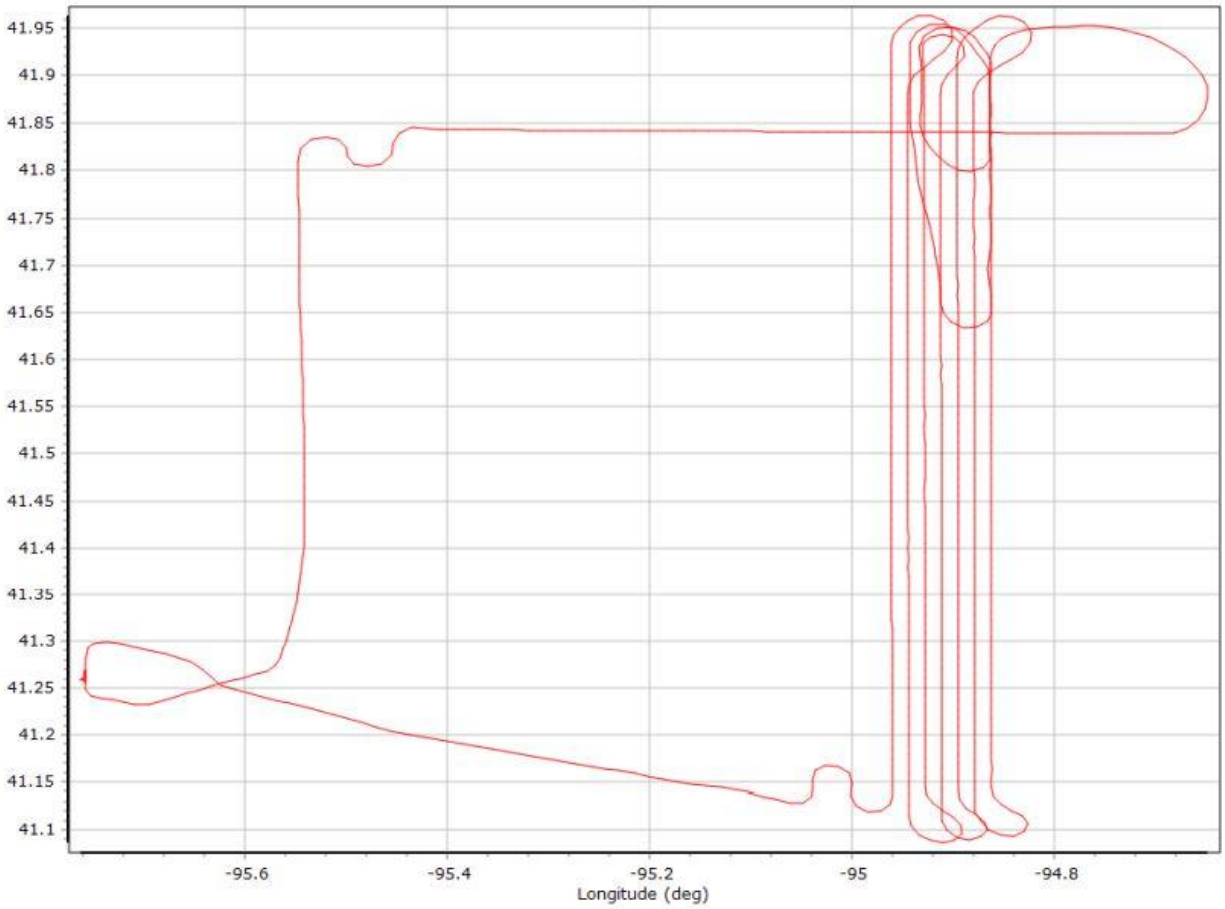


PDOP


1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
500,000
502,000
504,000
506,000
508,000
510,000
512,000
Time (sec)

0319c386_QC Report.docx QC Report – 8/25/2021 10:03:59
Smoothed Trajectory Information

Top View



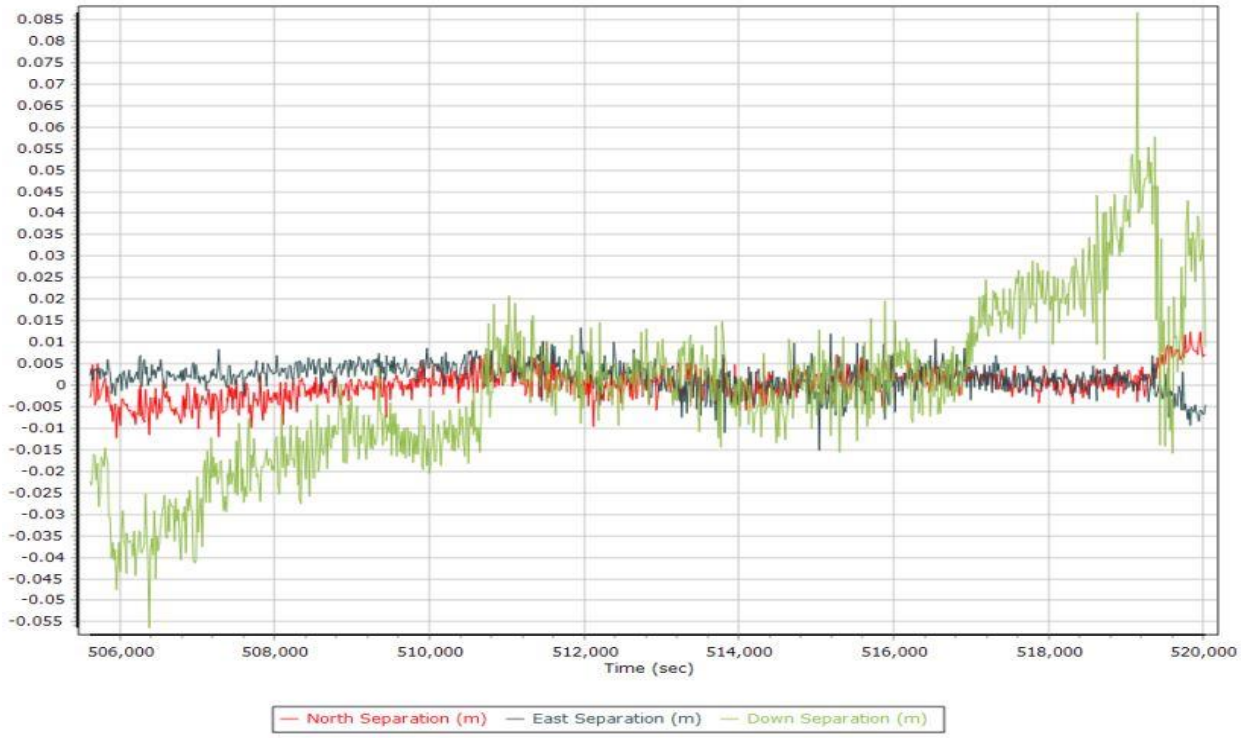
GNSS QC

GNSS QC Statistics

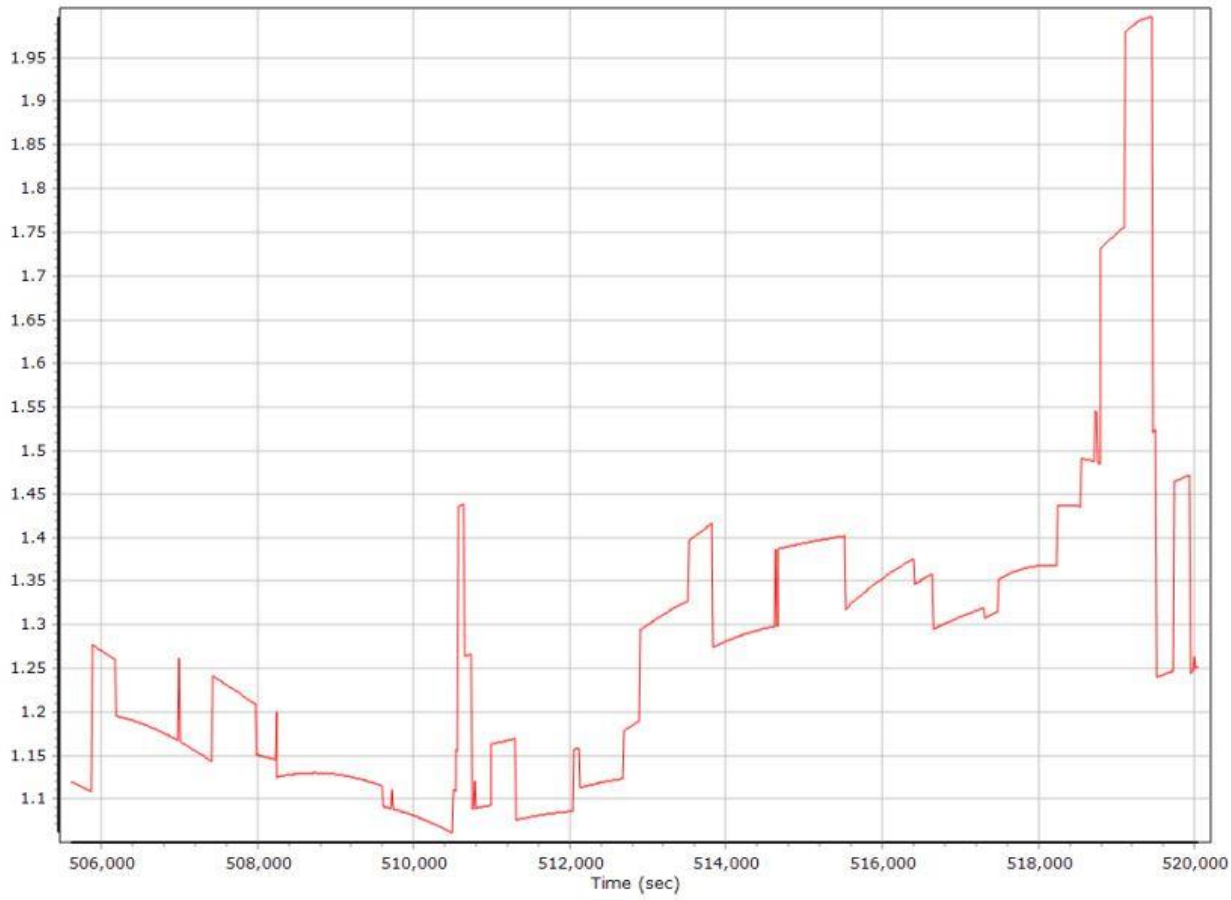
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	11	9
Number of GLONASS SV	0	7	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	0
Number of GALILEO SV	2	5	4
Total number of SV	14	21	18
PDOP	1.04	2.00	1.27
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation



PDOP


1.95
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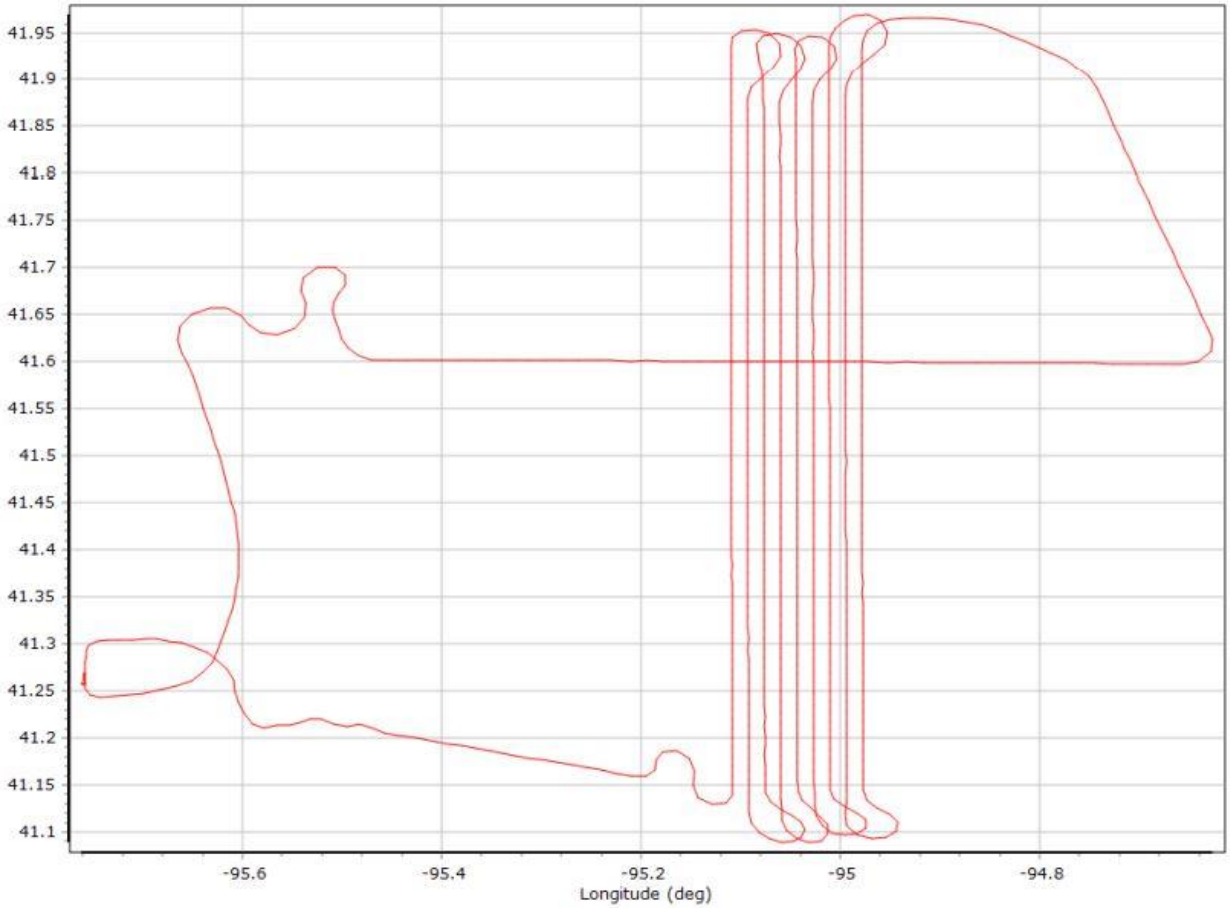
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
506,000
508,000
510,000
512,000
514,000
516,000
518,000
520,000
Time (sec)

0320a386_QC Report.docx QC Report – 8/25/2021 10:11:45
Smoothed Trajectory Information

Top View

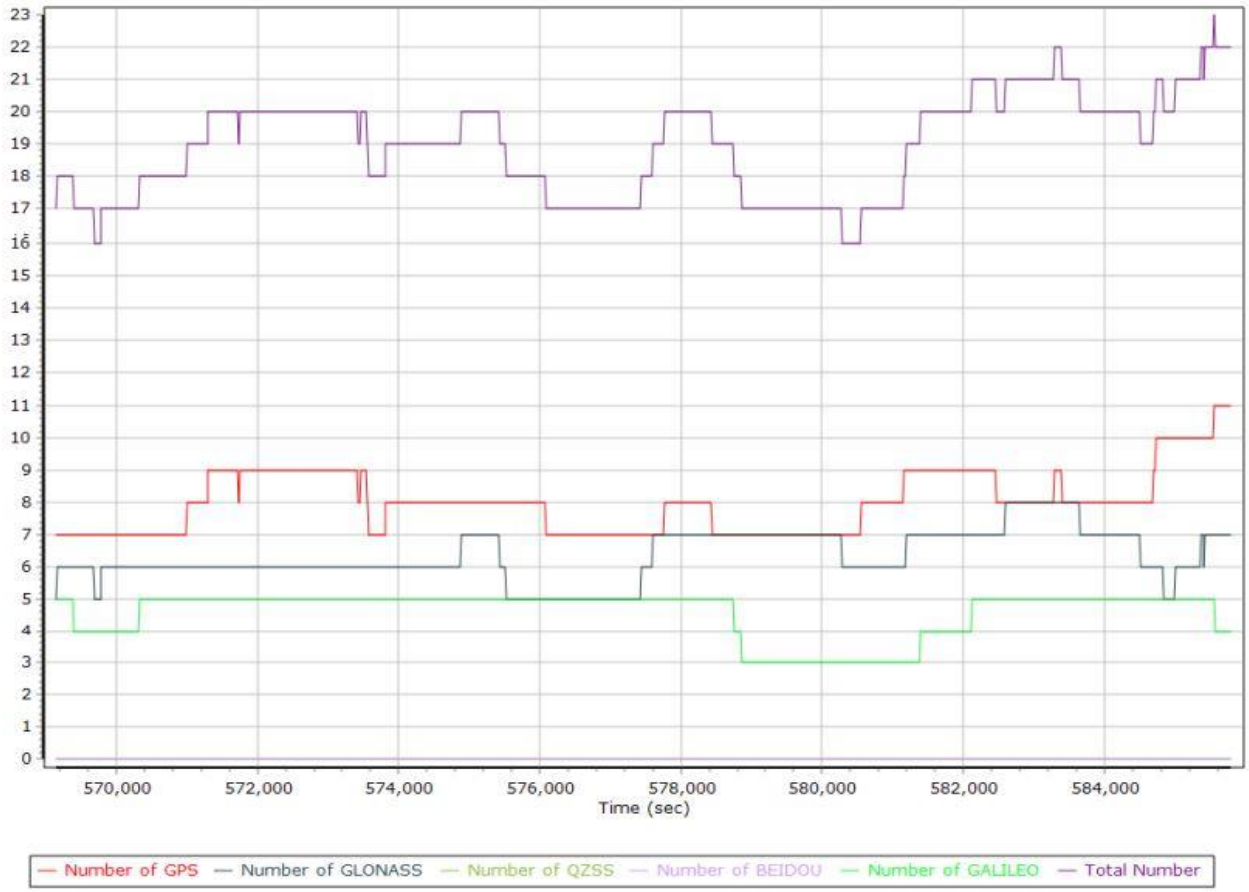


GNSS QC

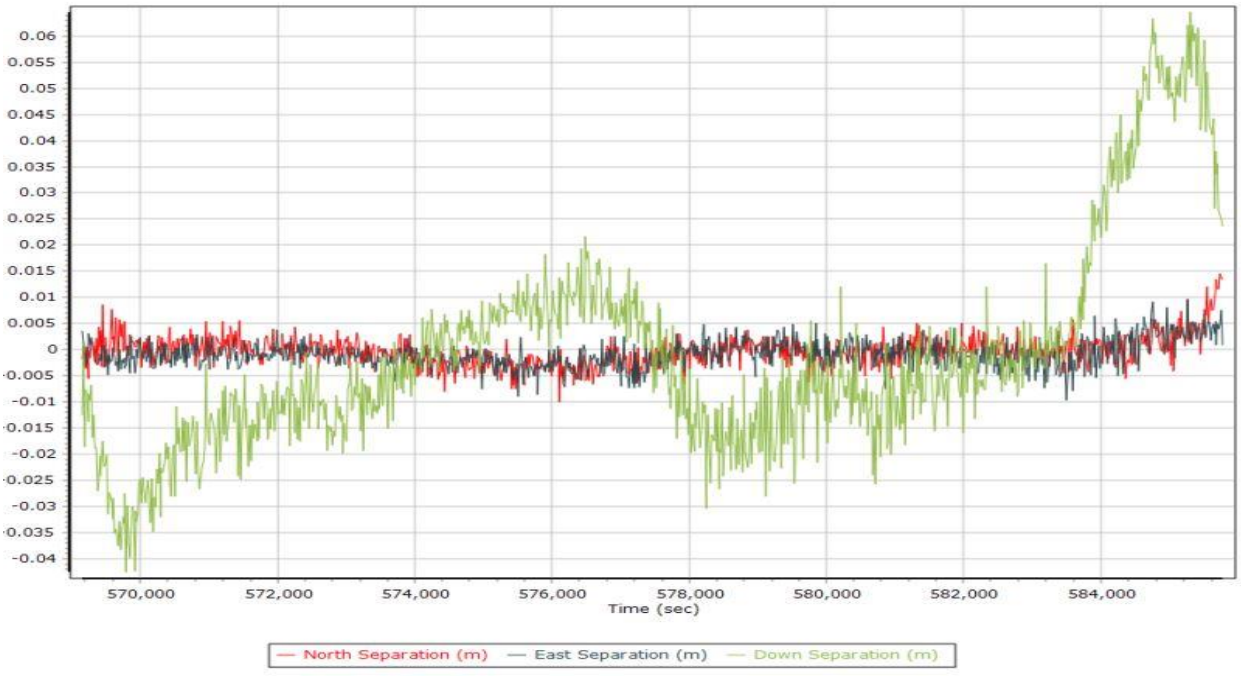
GNSS QC Statistics

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

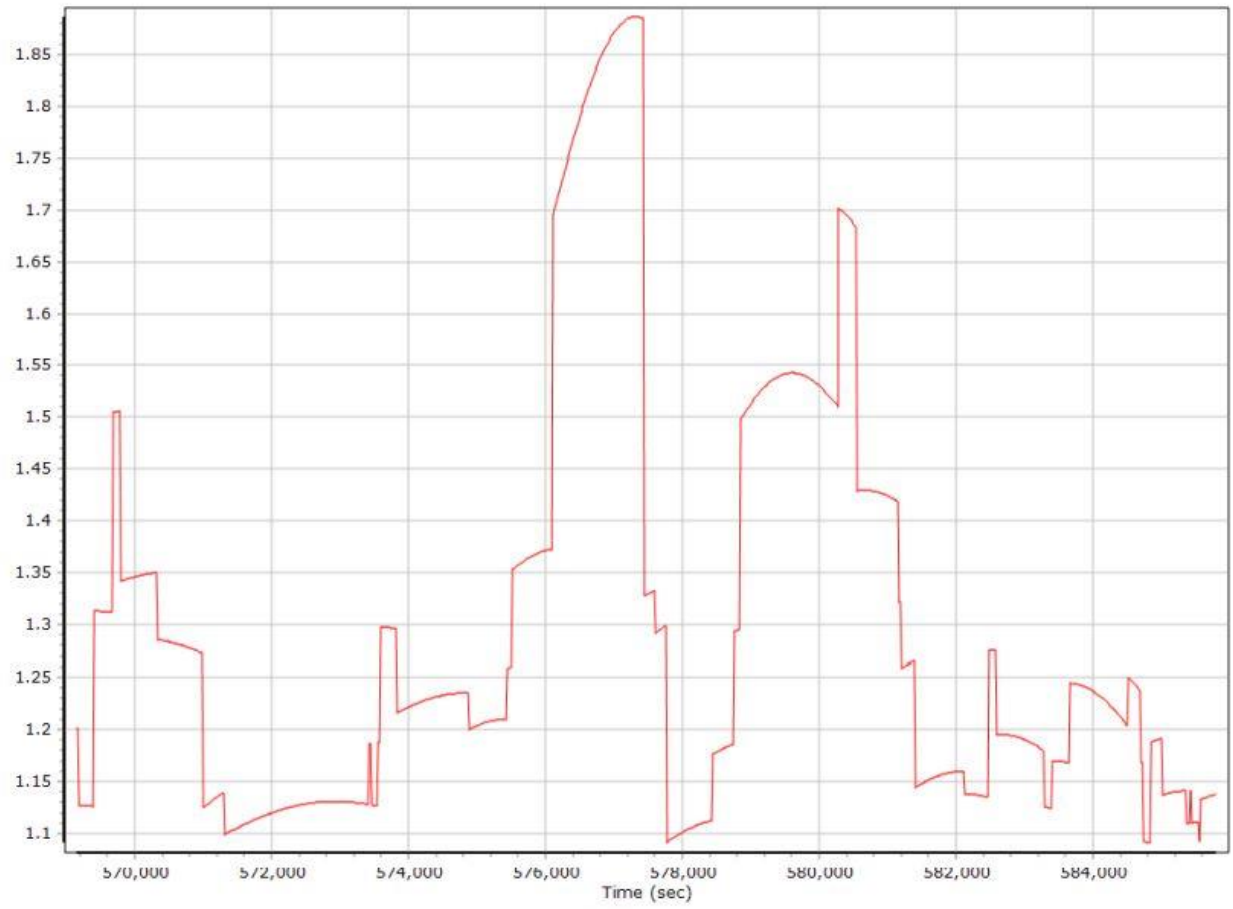
Number of Satellites



Forward/Reverse Separation

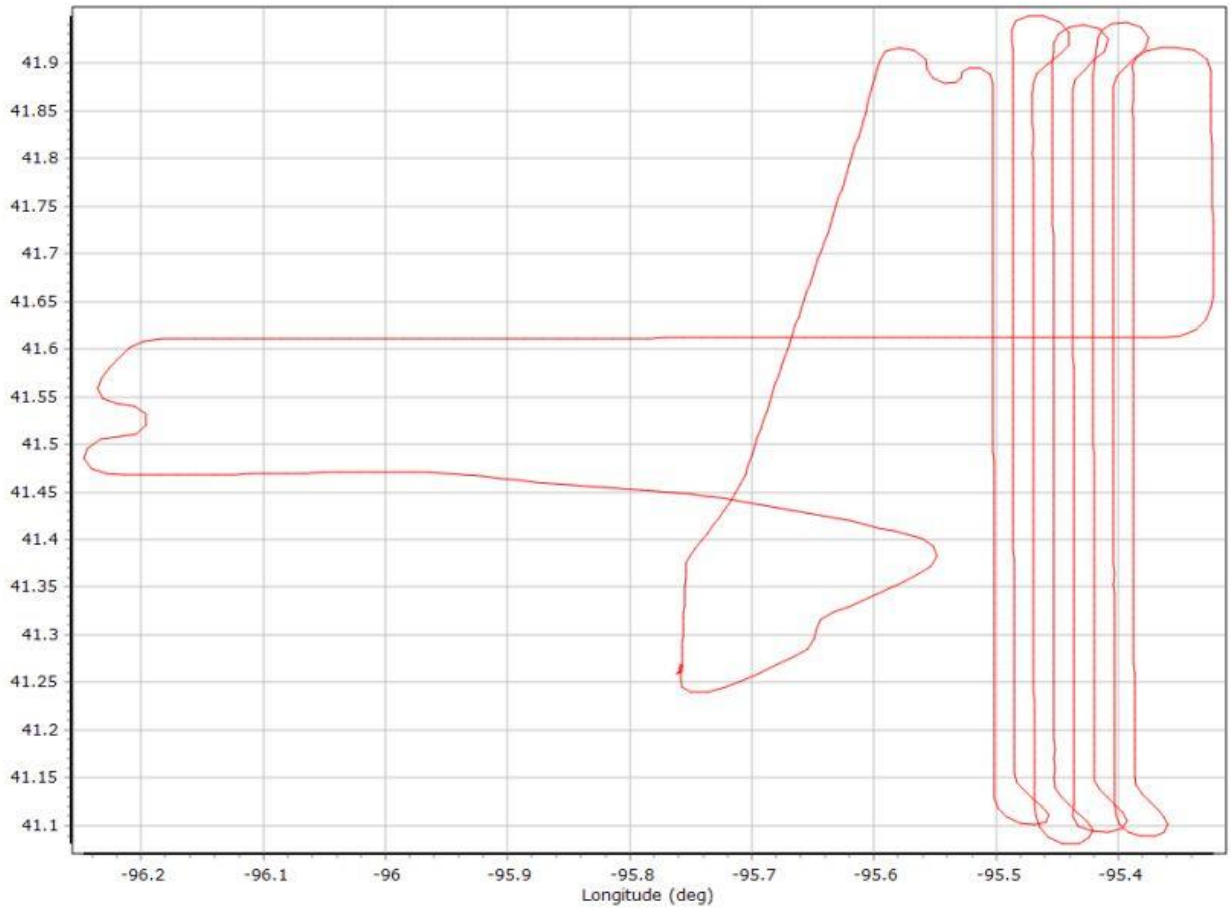


PDOP


1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
570,000
572,000
574,000
576,000
578,000
580,000
582,000
584,000
Time (sec)

0320a448_QC Report.docx QC Report – 8/25/2021 11:13:25
Smoothed Trajectory Information

Top View

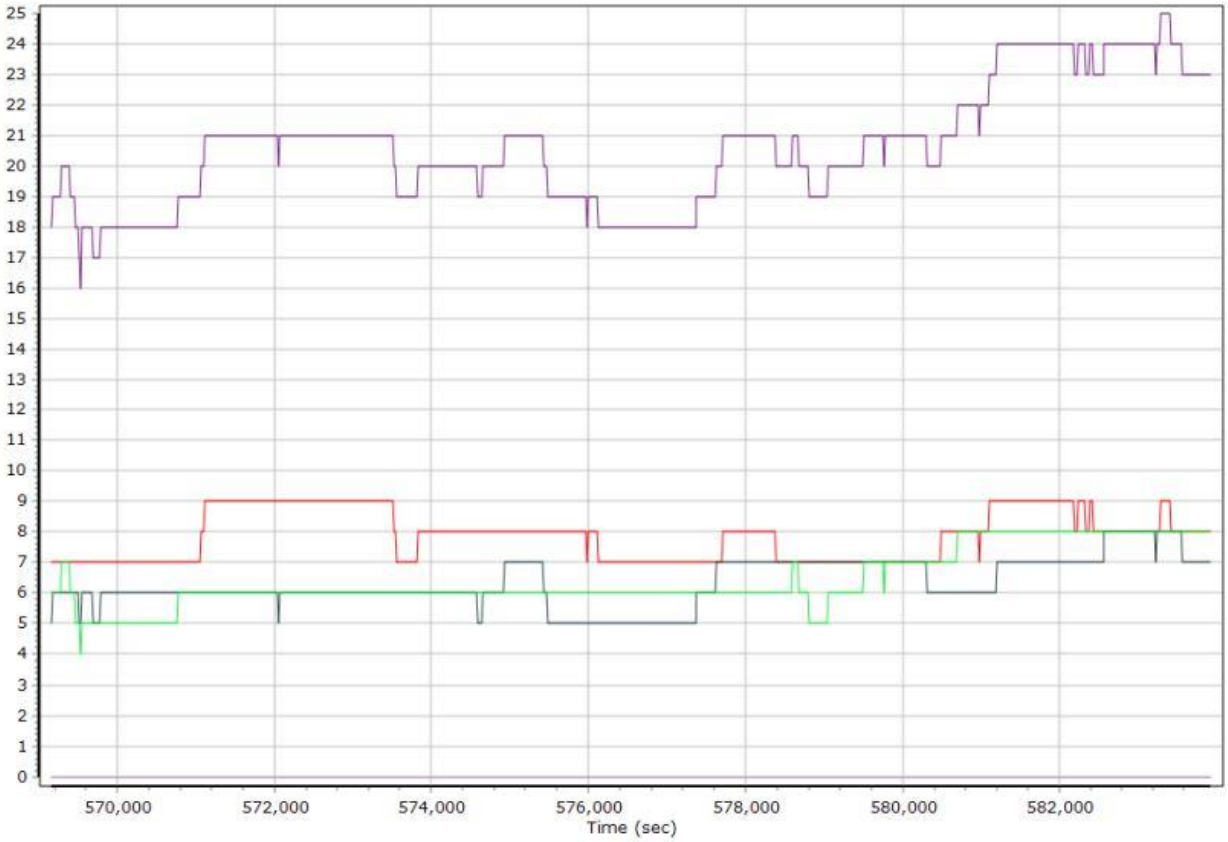


GNSS QC

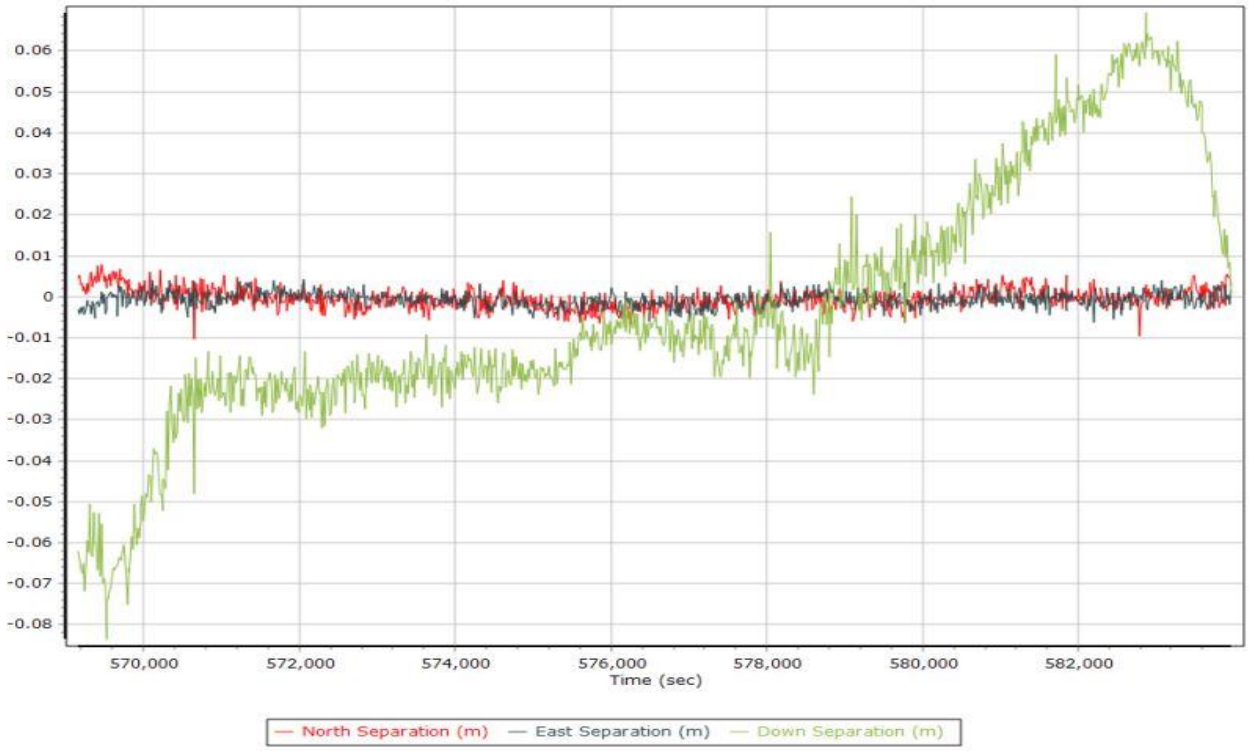
GNSS QC Statistics

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

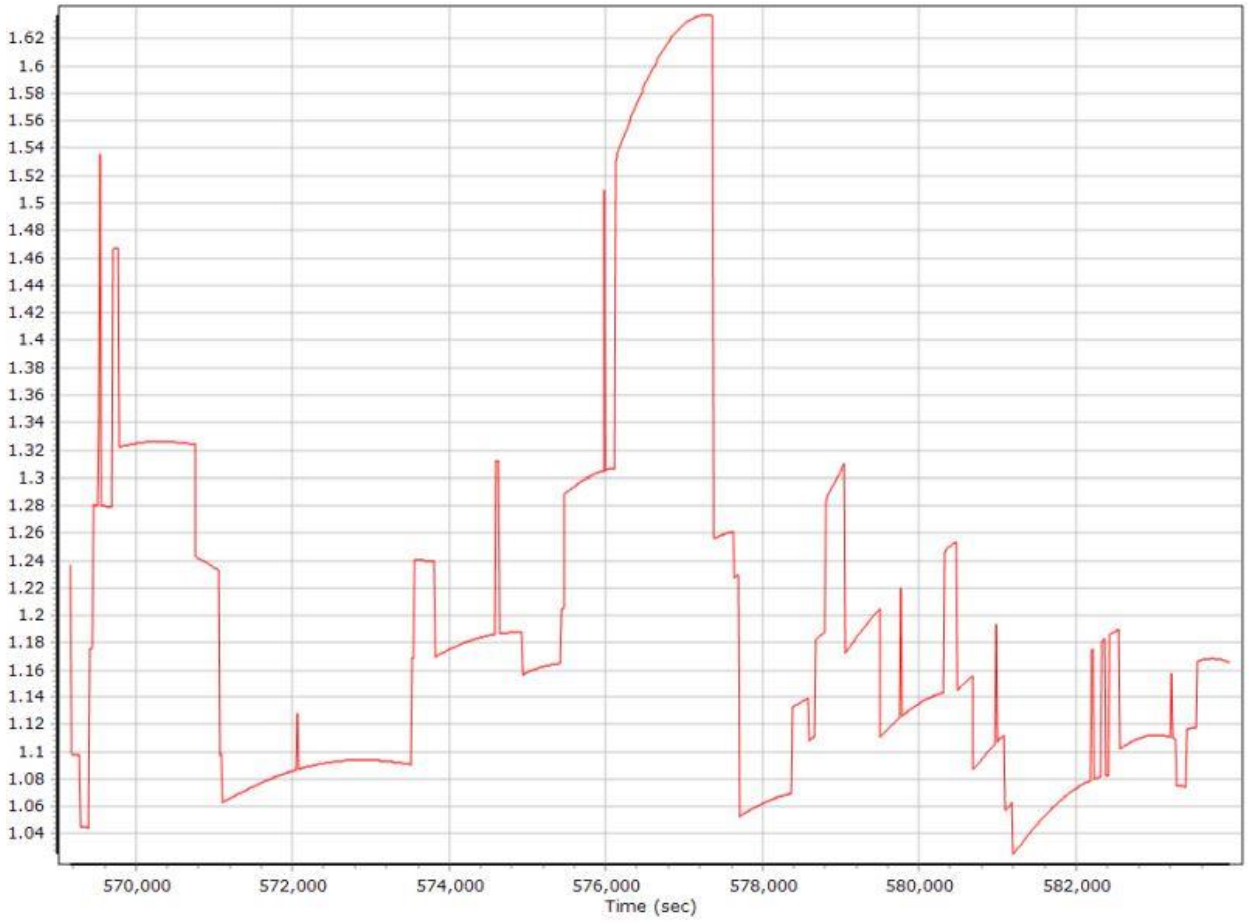
Number of Satellites



Forward/Reverse Separation

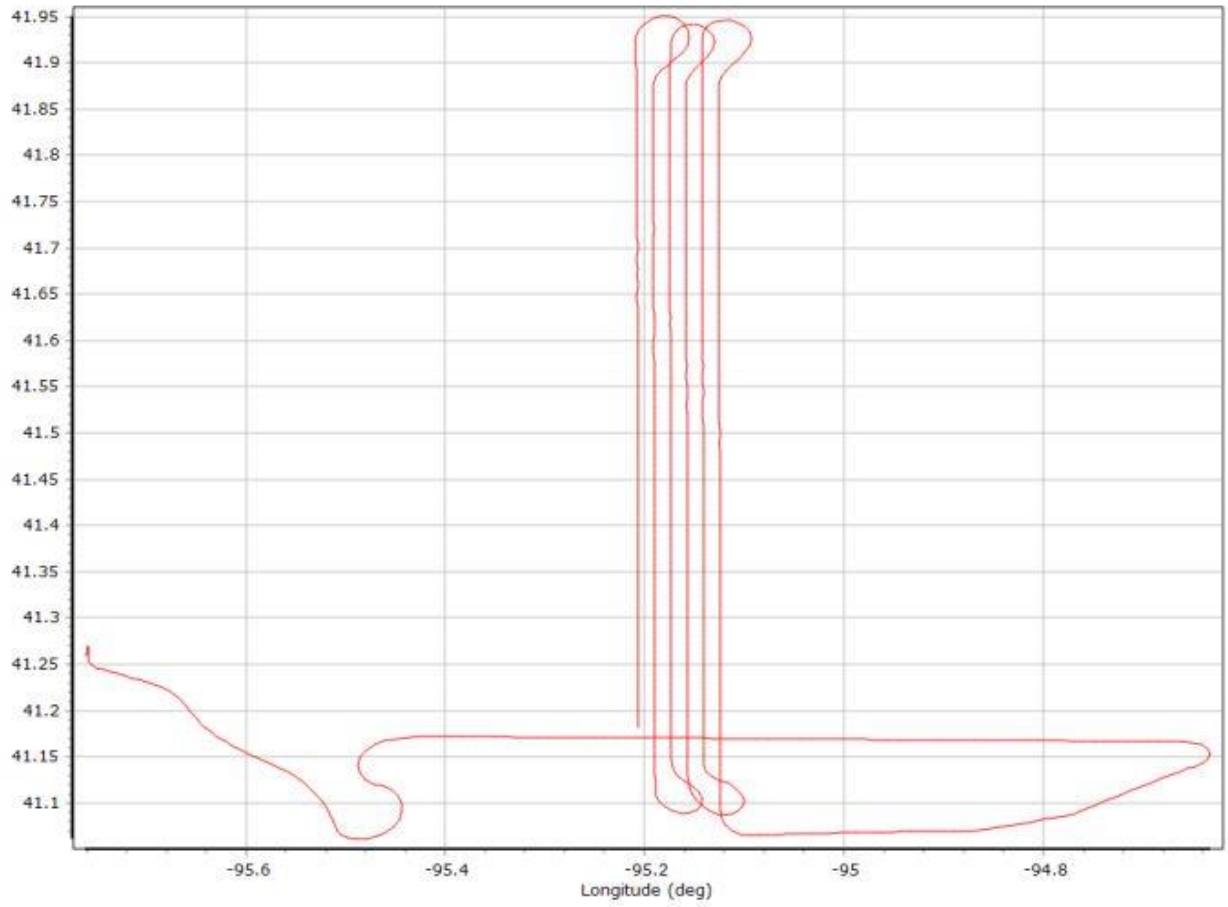


PDOP


1.62
1.6
1.58
1.56
1.54
1.52
1.5
1.48
1.46
1.44
1.42
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
570,000
572,000
574,000
576,000
578,000
580,000
582,000
Time (sec)

0320b386_QC Report.docx QC Report – 8/25/2021 12:50:46
Smoothed Trajectory Information

Top View

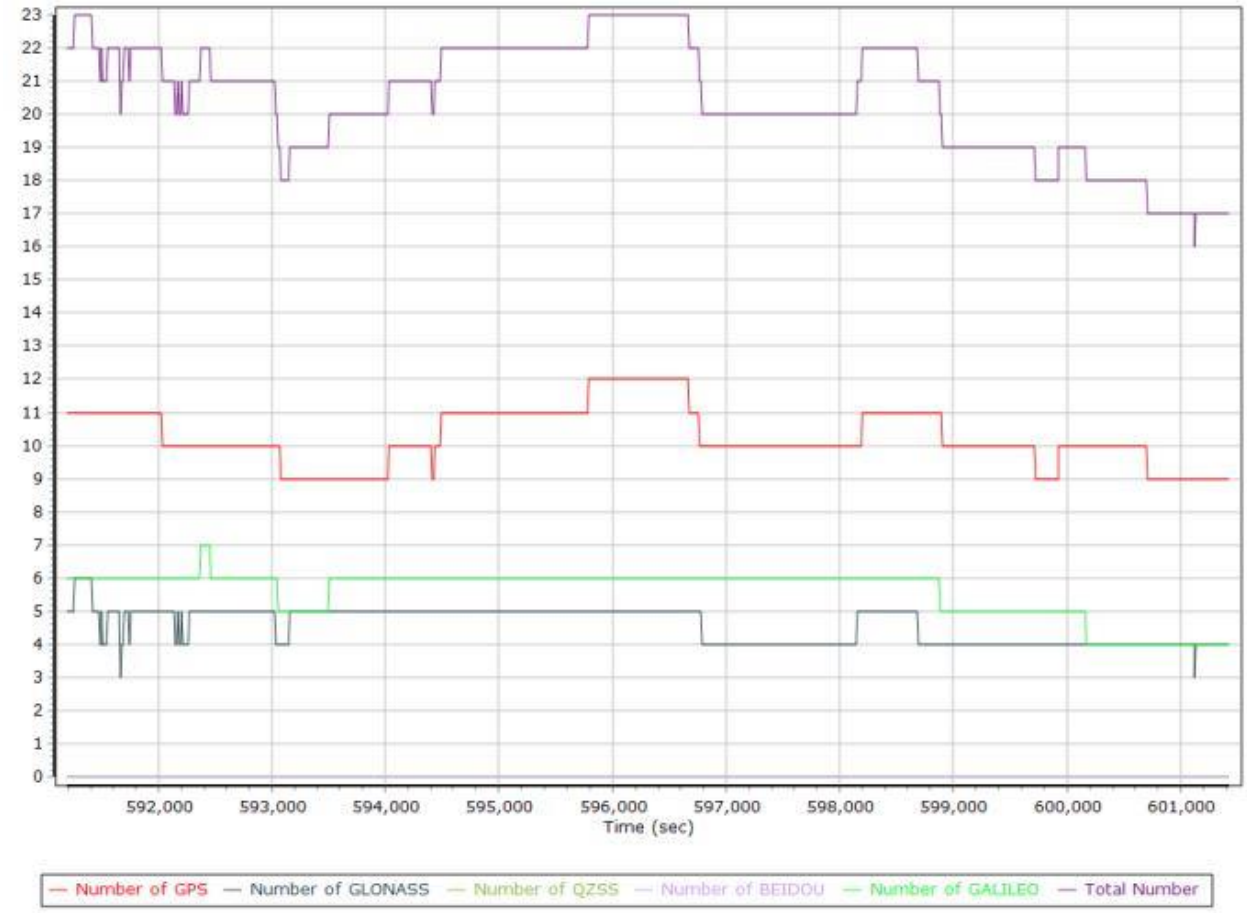


GNSS QC

GNSS QC Statistics

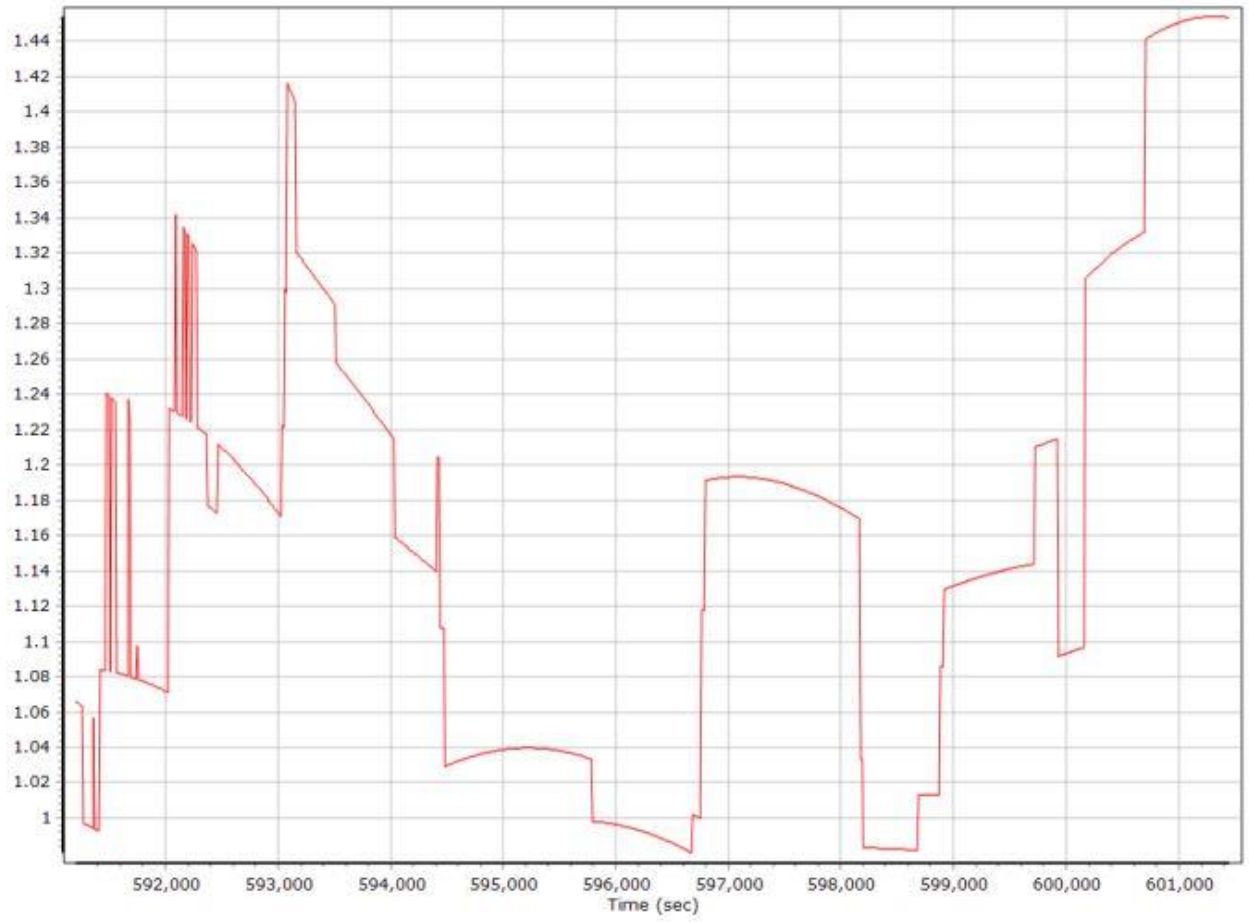
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	9	12	10
Number of GLONASS SV	0	6	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	7	6
Total number of SV	16	23	20
PDOP	0.98	1.55	1.15
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites



Forward/Reverse Separation

PDOP


1.44
1.42
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
592,000
593,000
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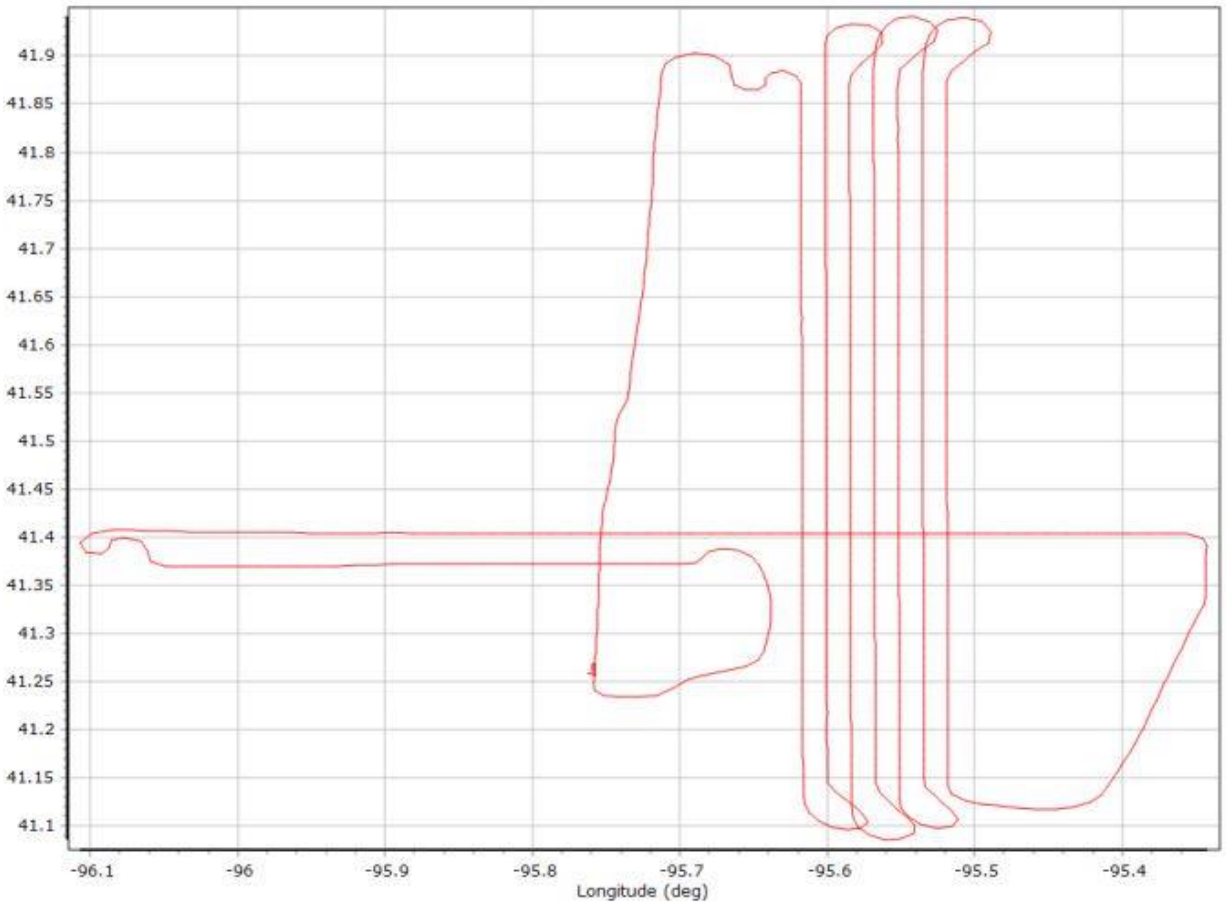
596,000
597,000
598,000
599,000
600,000
601,000
Time (sec)

0320b448_QC Report.docx QC Report – 8/25/2021 13:04:32
Smoothed Trajectory Information

Top View

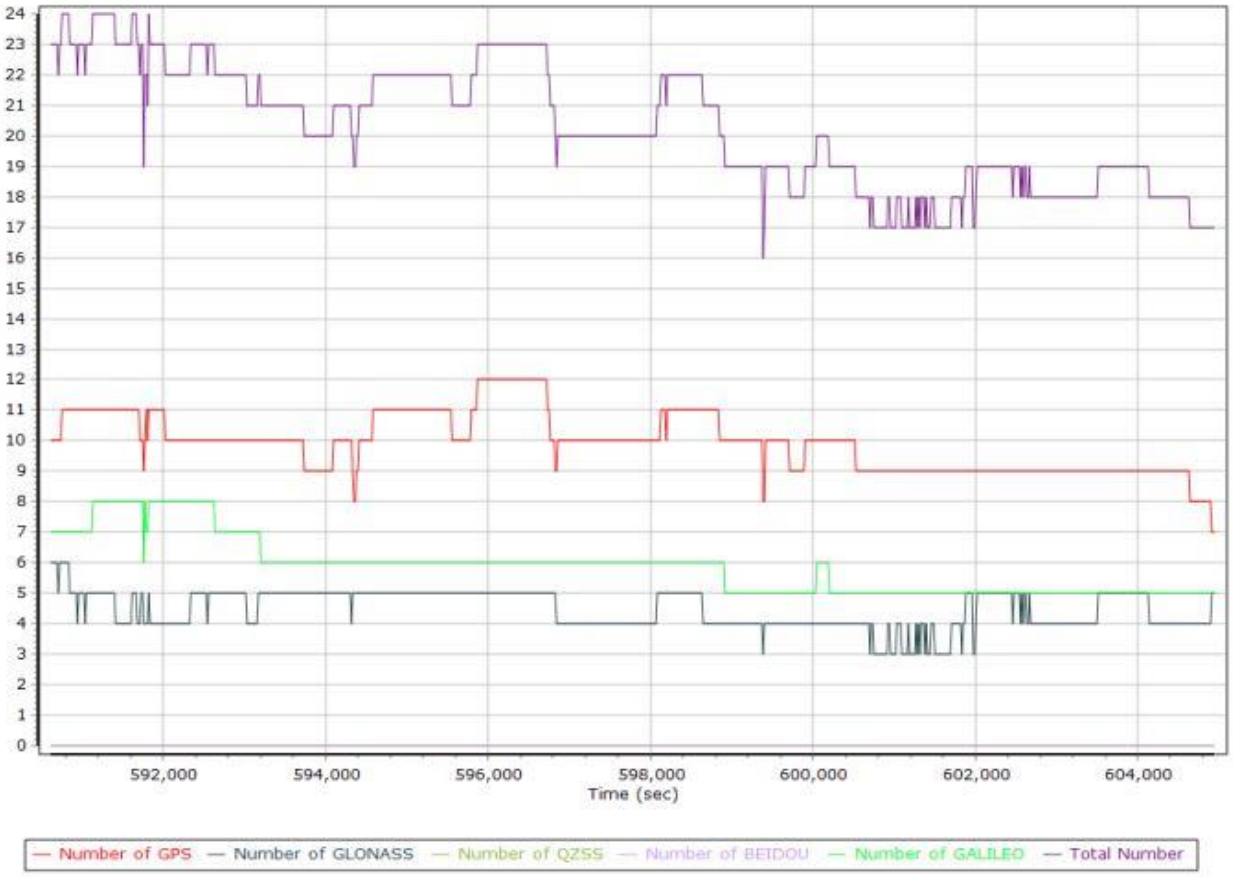


GNSS QC

GNSS QC Statistics

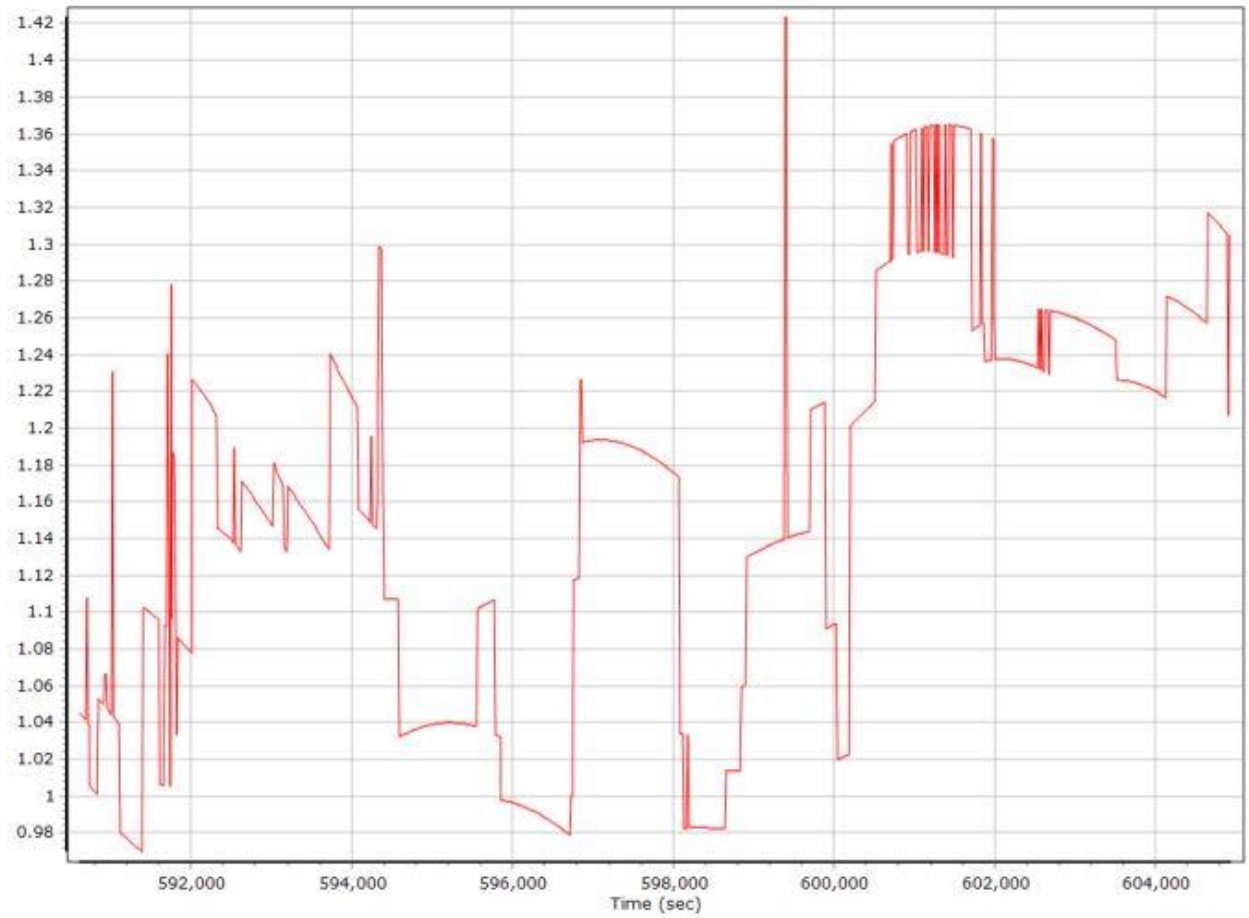
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	12	10
Number of GLONASS SV	2	8	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	5	8	6
Total number of SV	16	24	20
PDOP	0.96	1.51	1.15
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites



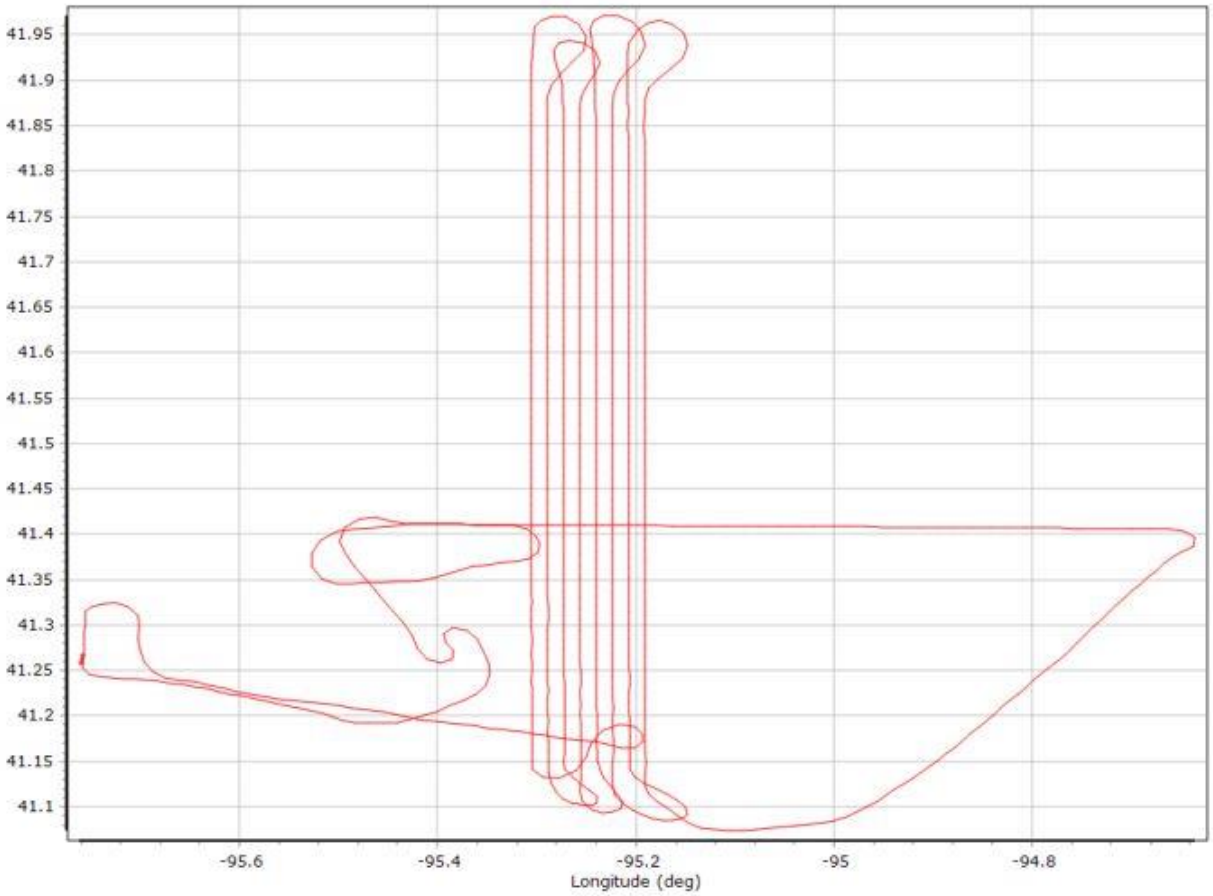
Forward/Reverse Separation

PDOP


1.42
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
592,000
594,000
596,000
598,000
600,000
602,000
604,000
Time (sec)

0321a386_QC Report.docx QC Report – 8/25/2021 13:13:01
Smoothed Trajectory Information

Top View



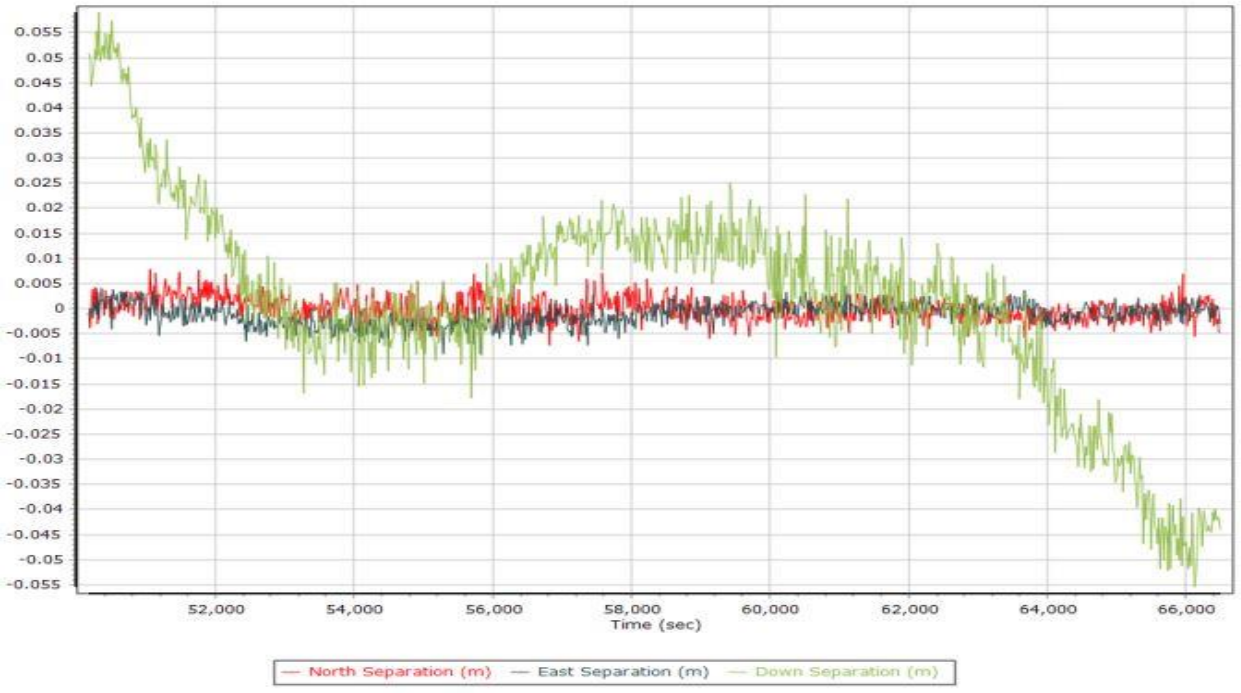
GNSS QC

GNSS QC Statistics

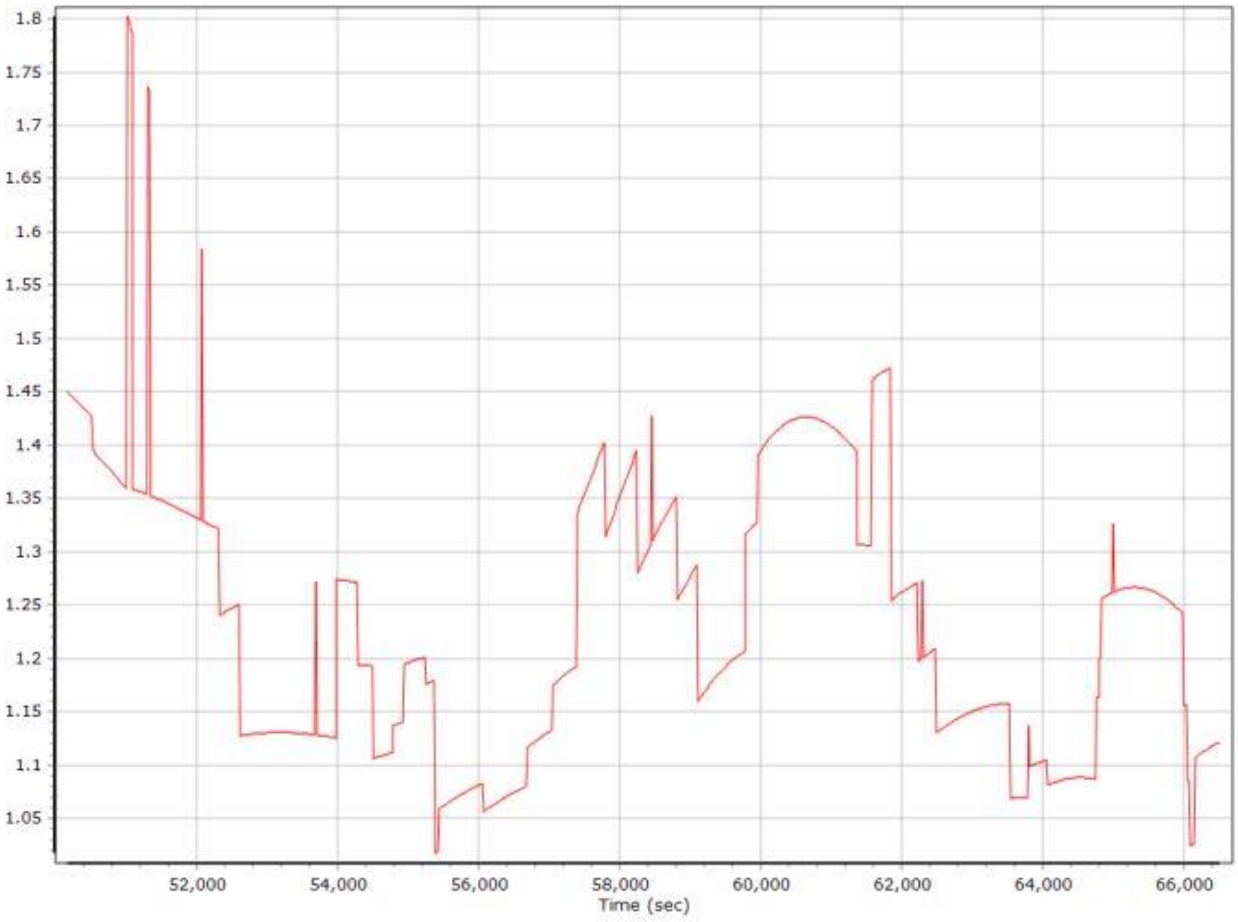
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	10	8
Number of GLONASS SV	0	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	3	7	5
Total number of SV	12	24	20
PDOP	1.02	1.93	1.24
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation

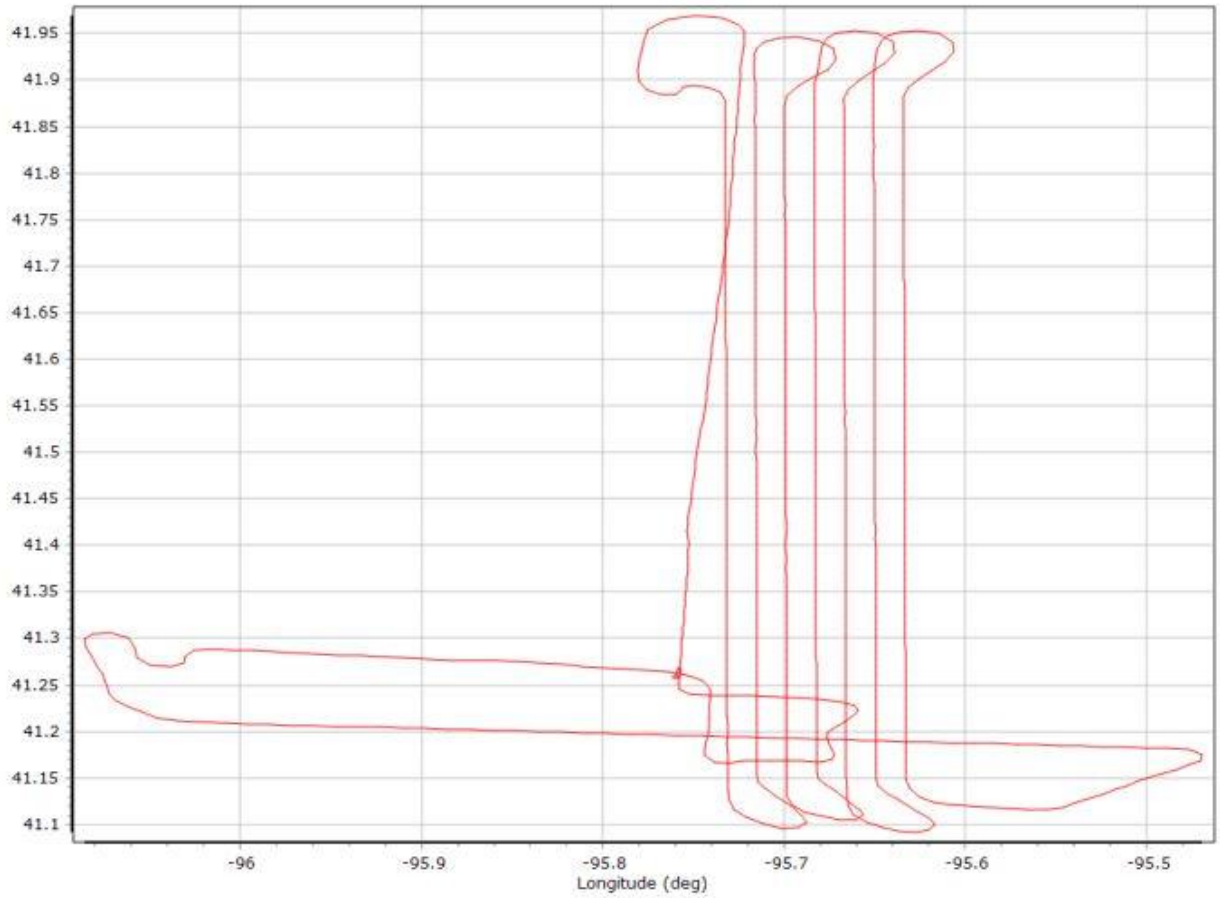


PDOP


1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
52,000
54,000
56,000
58,000
60,000
62,000
64,000
66,000
Time (sec)

0321a448_QC Report.docx QC Report -08/26/2021 13:27:25
Smoothed Trajectory Information

Top View

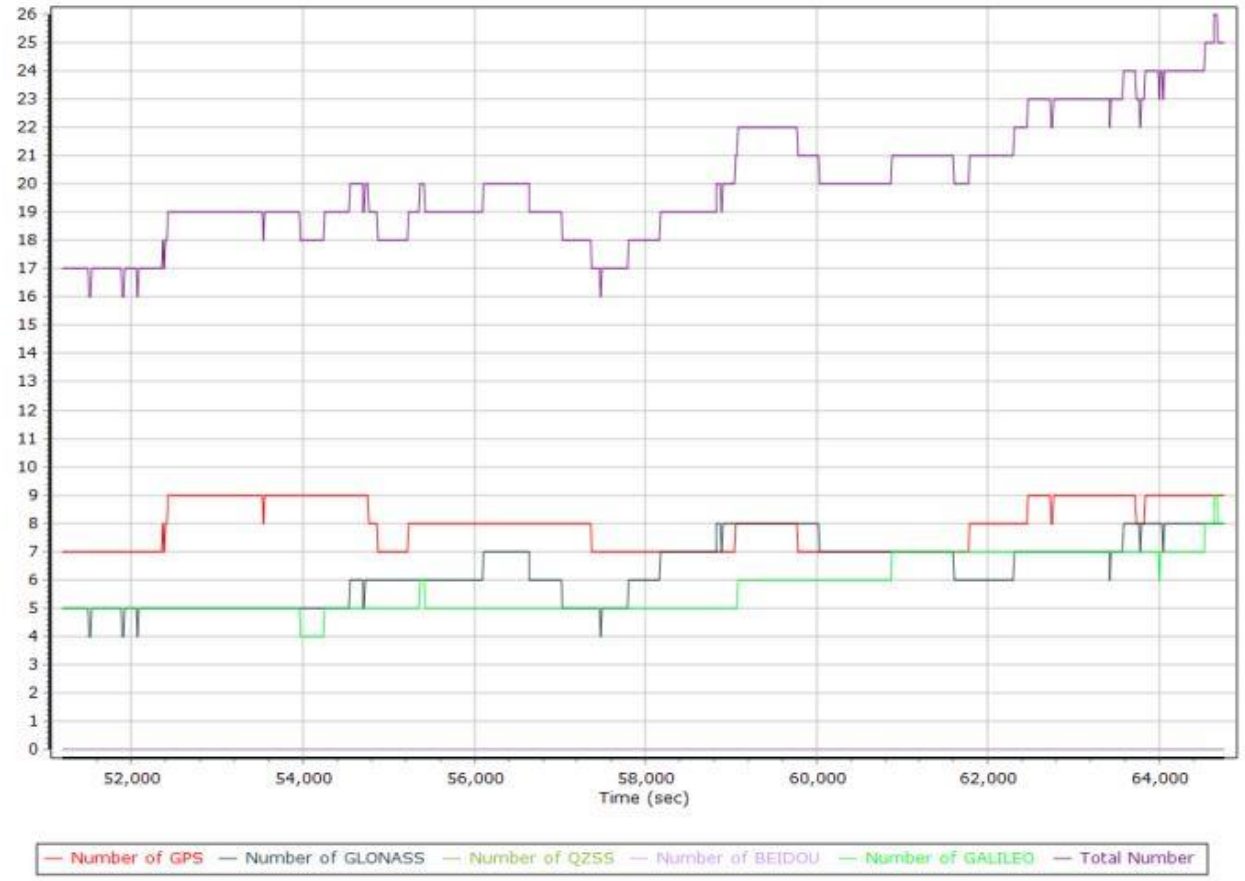


GNSS QC

GNSS QC Statistics

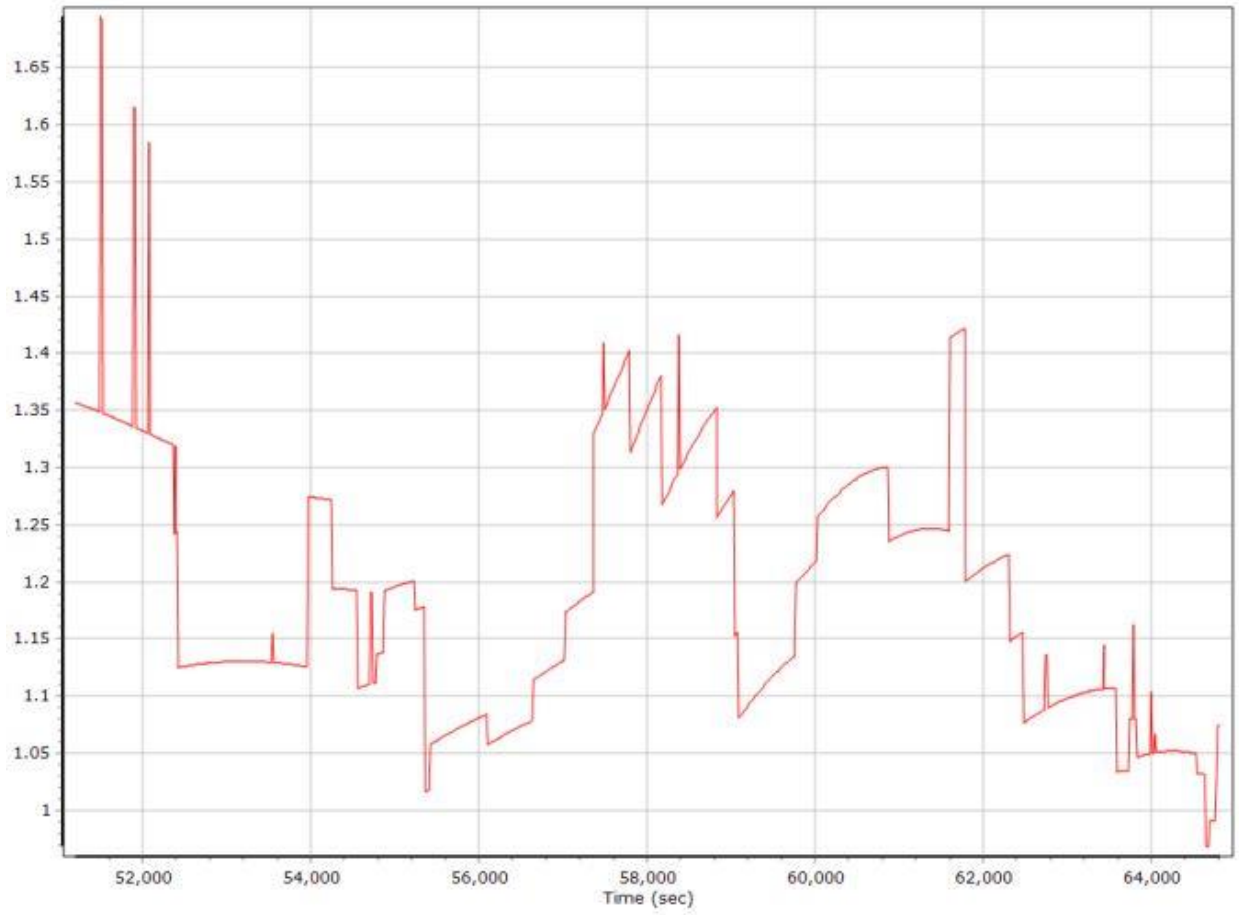
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	9	8
Number of GLONASS SV	3	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	4	9	6
Total number of SV	14	26	20
PDOP	0.97	1.98	1.20
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites



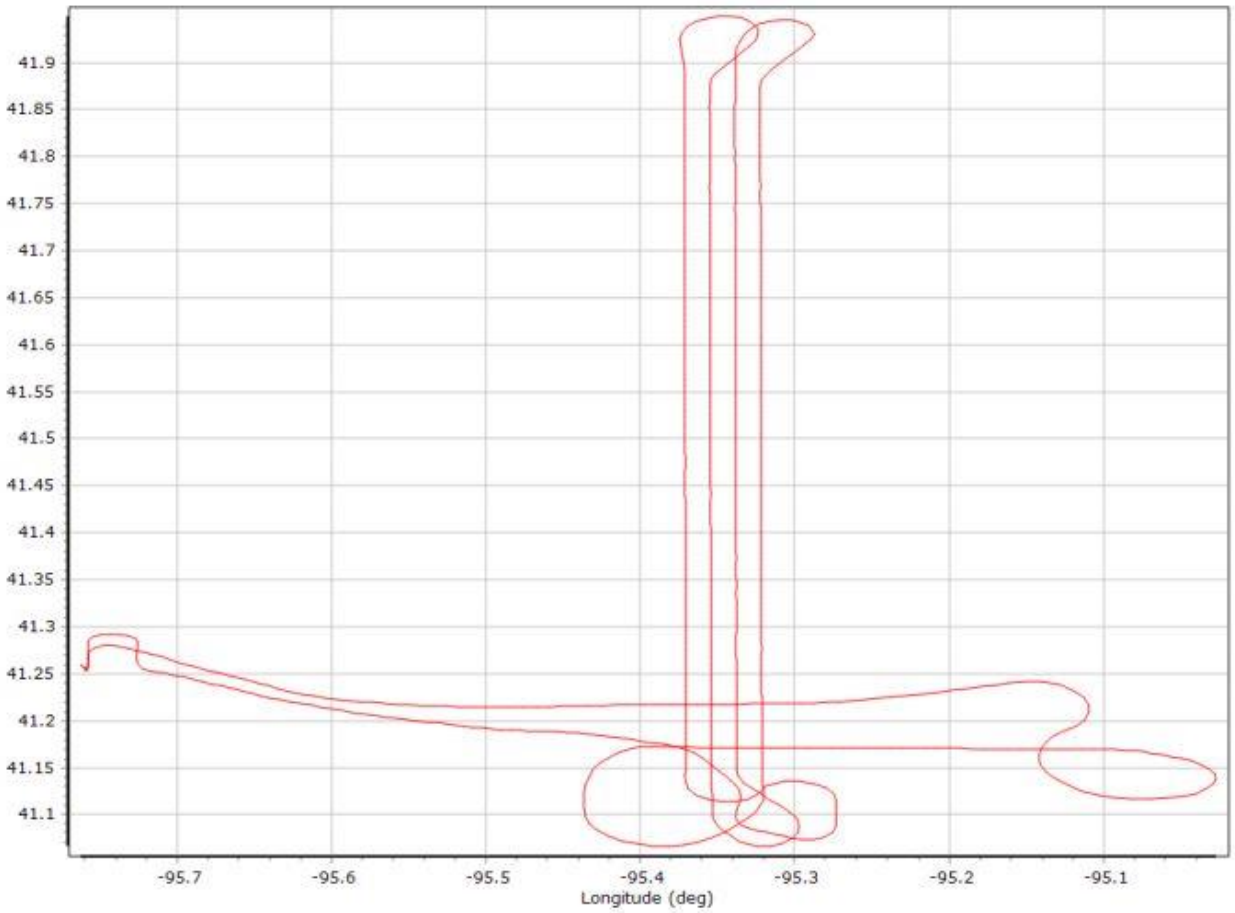
Forward/Reverse Separation

PDOP


1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
52,000
54,000
56,000
58,000
60,000
62,000
64,000
Time (sec)

0328a386_QC Report.docx QC Report – 8/26/2021 13:35:30
Smoothed Trajectory Information

Top View



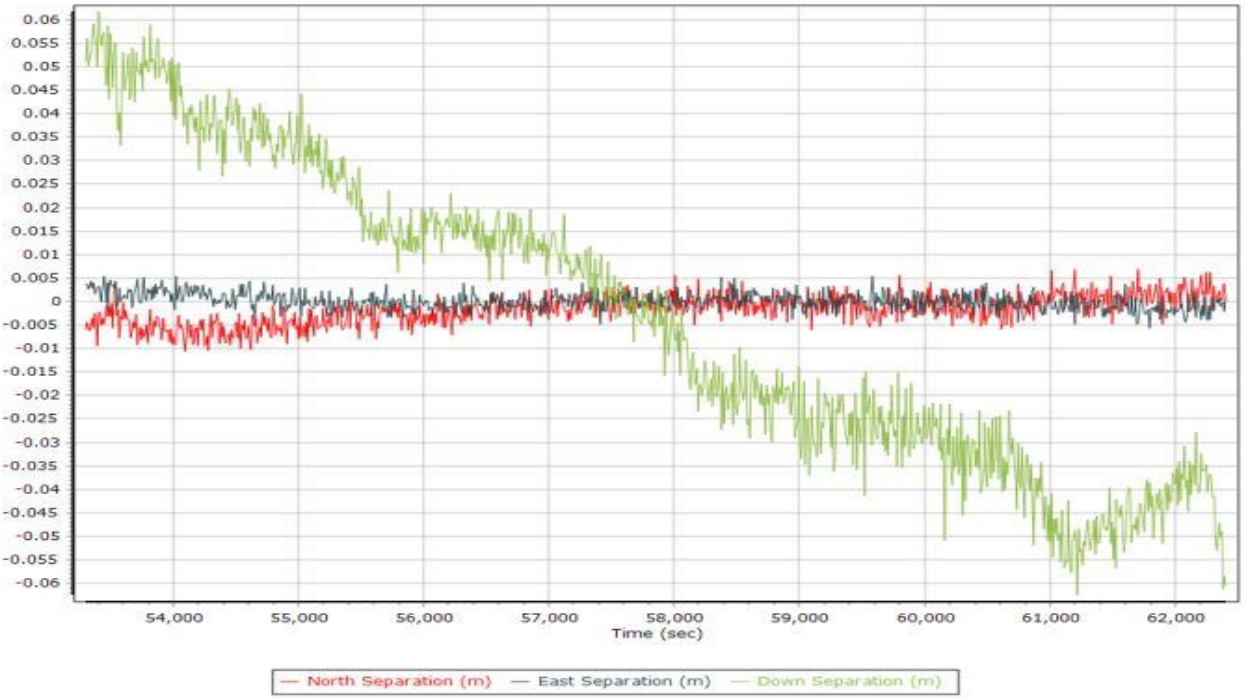
GNSS QC

GNSS QC Statistics

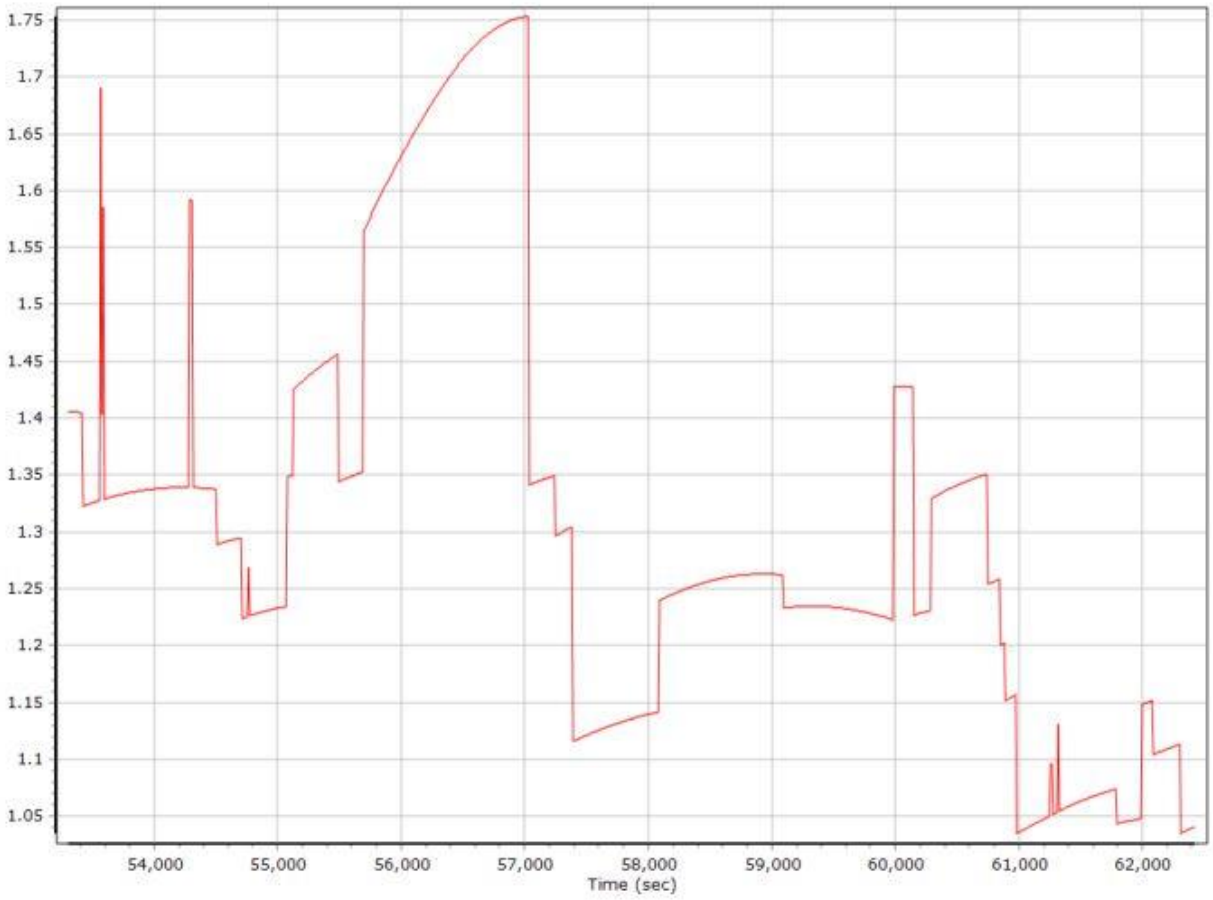
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	3	9	8
Number of GLONASS SV	0	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	7	5
Total number of SV	9	24	19
PDOP	1.03	3.58	1.31
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation

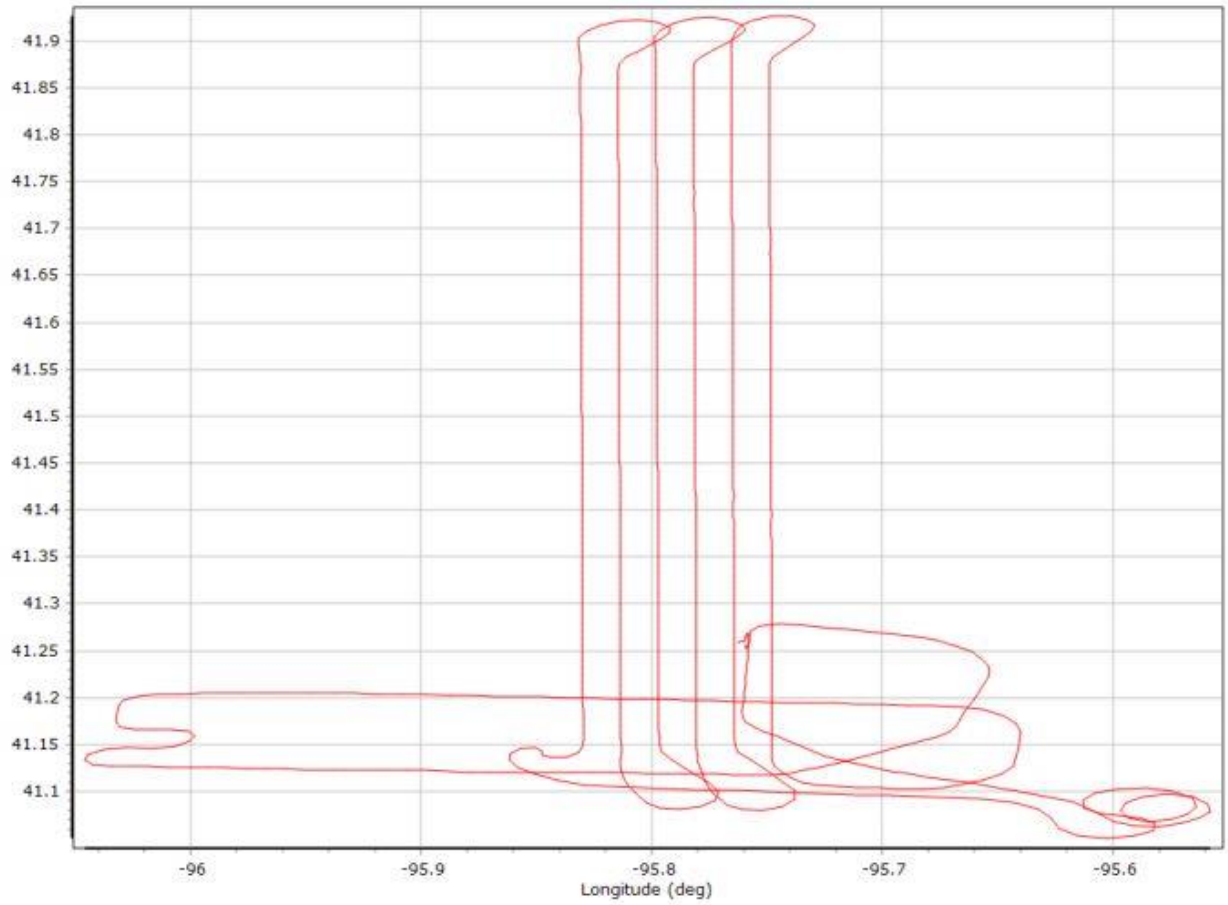


PDOP


1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
54,000
55,000
56,000
57,000
58,000
59,000
60,000
61,000
62,000
Time (sec)

0328a448_QC Report.docx QC Report – 8/26/2021 13:43:38
Smoothed Trajectory Information

Top View



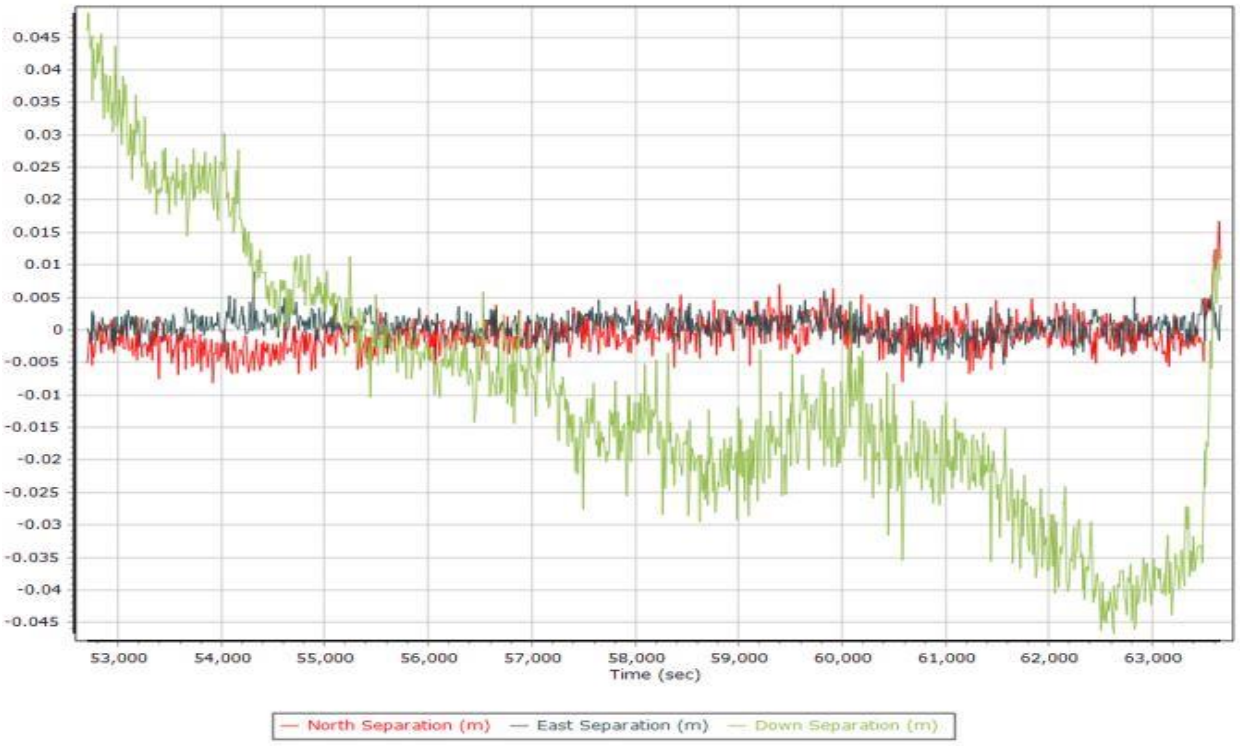
GNSS QC

GNSS QC Statistics

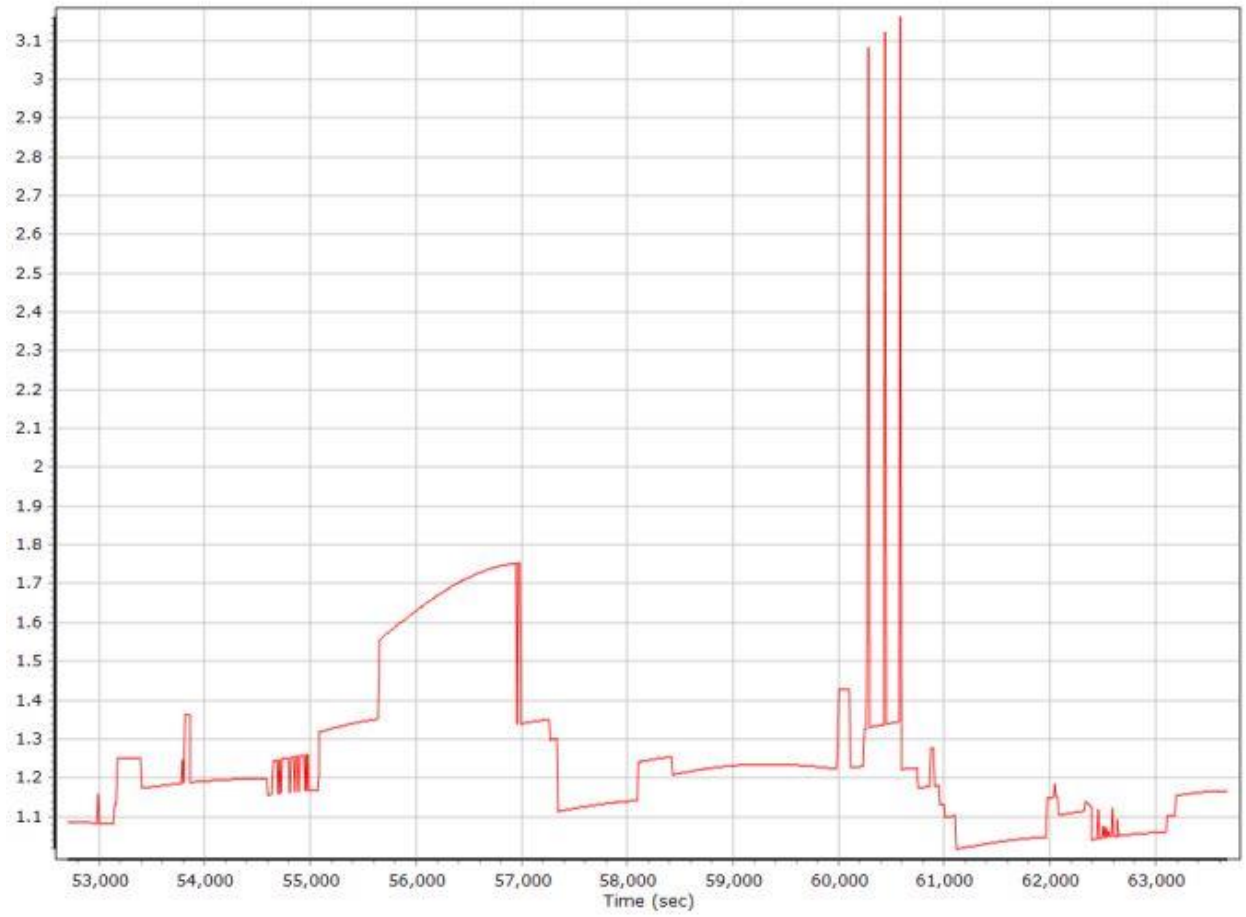
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	3	9	8
Number of GLONASS SV	2	8	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	7	6
Total number of SV	9	24	20
PDOP	1.02	3.16	1.24
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch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

Number of Satellites

Forward/Reverse Separation



PDOP


3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
53,000
54,000
55,000
56,000
57,000
58,000
59,000
60,000
61,000
62,000
63,000
Time (sec)

0328c448_QC Report.docx QC Report – 8/25/2021 13:52:41
Smoothed Trajectory Information

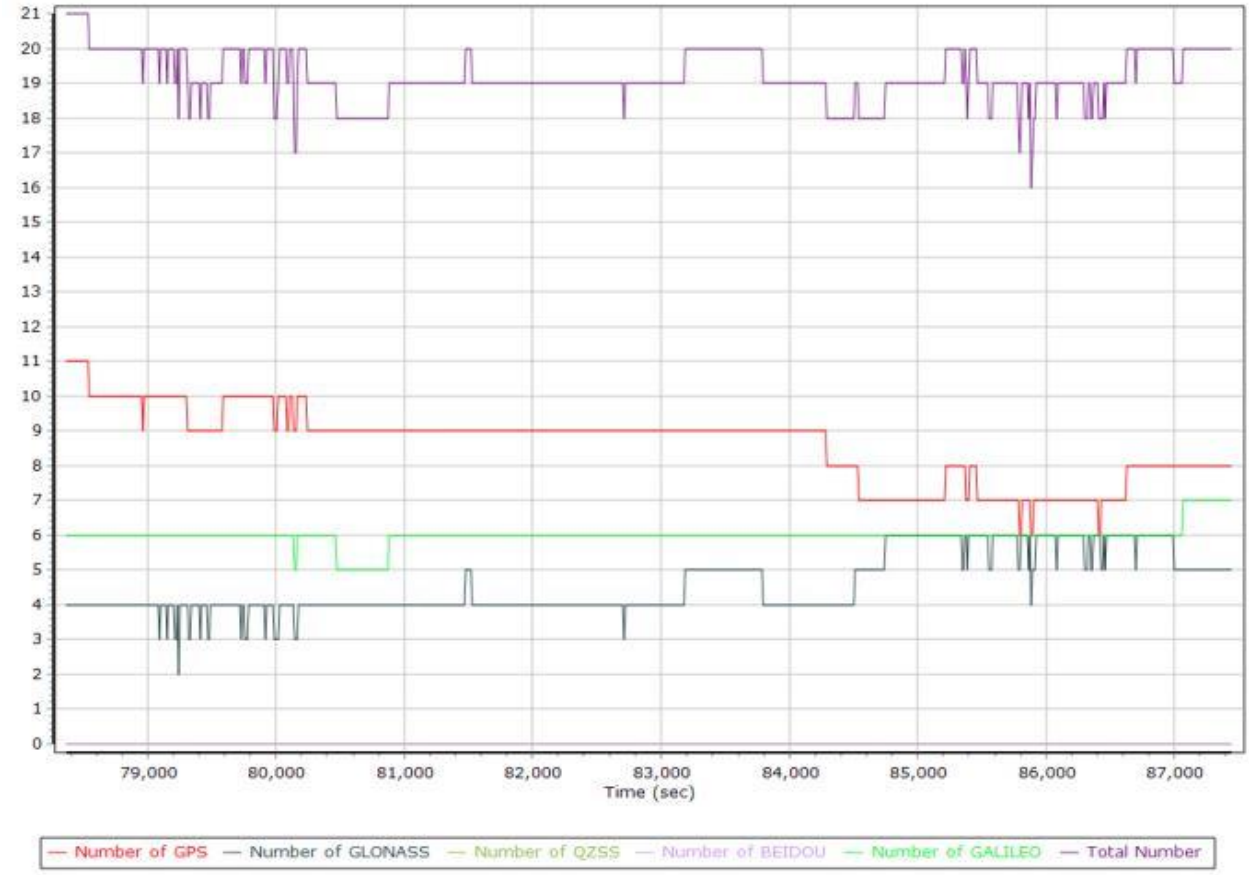
Top View

GNSS QC

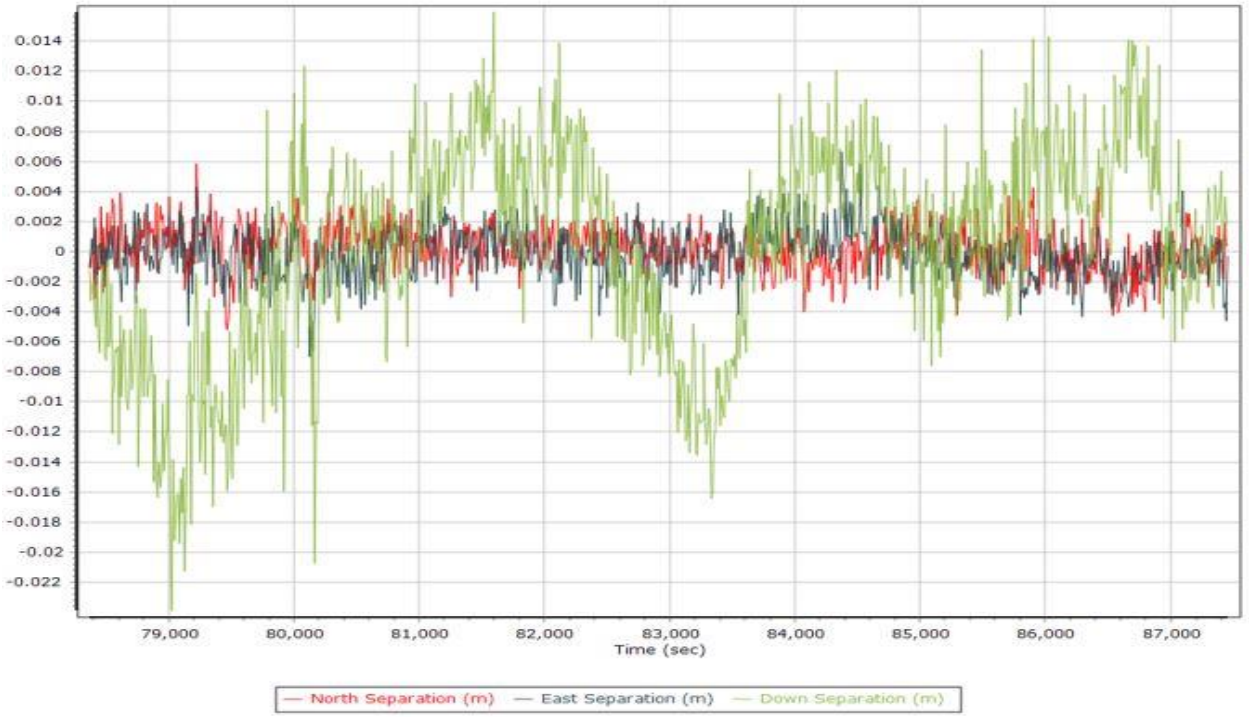
GNSS QC Statistics

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

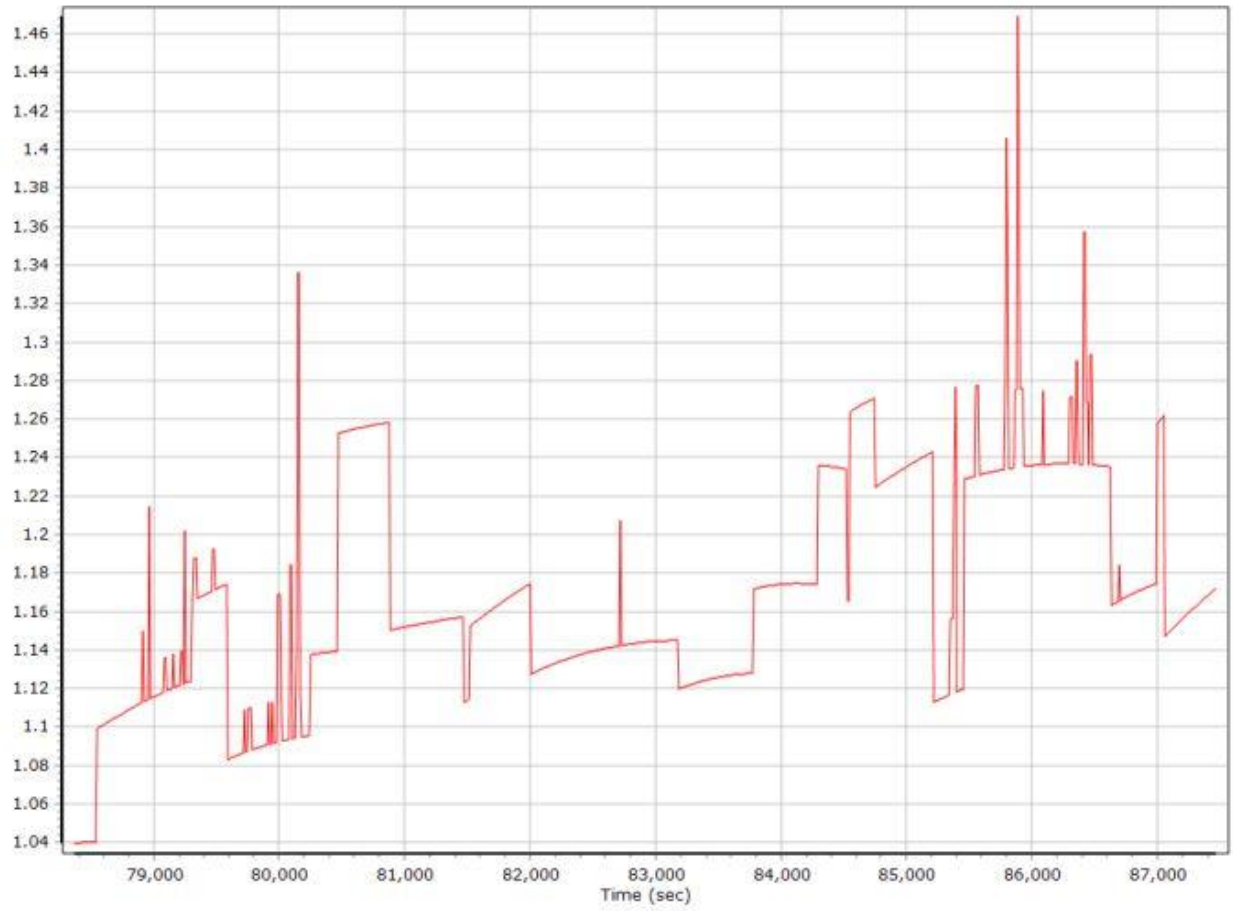
Number of Satellites



Forward/Reverse Separation

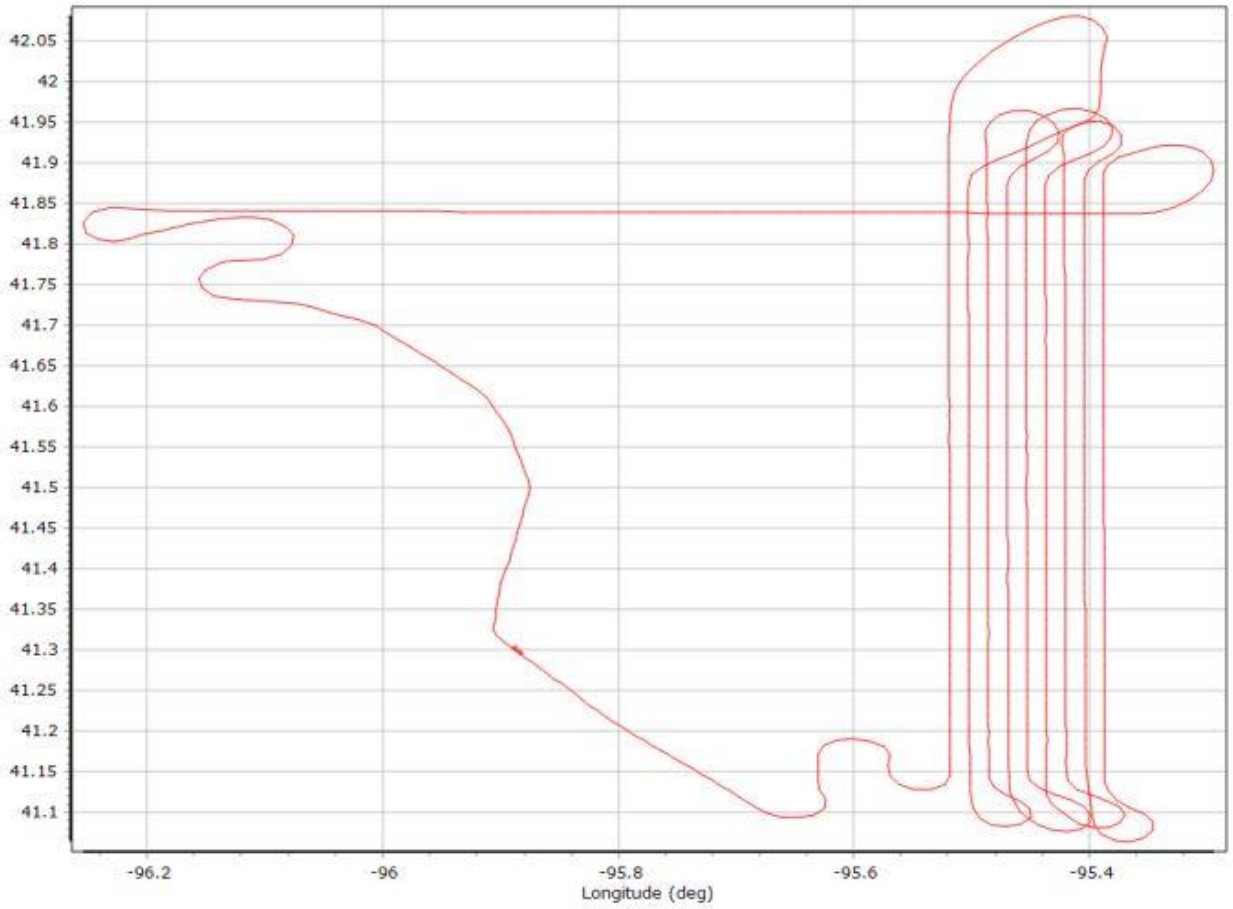


PDOP


1.46
1.44
1.42
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
1.06
1.04
79,000
80,000
81,000
82,000
83,000
84,000
85,000
86,000
87,000
Time (sec)

1210a386_QC Report.docx QC Report – 8/26/2021 14:00:11
Smoothed Trajectory Information

Top View

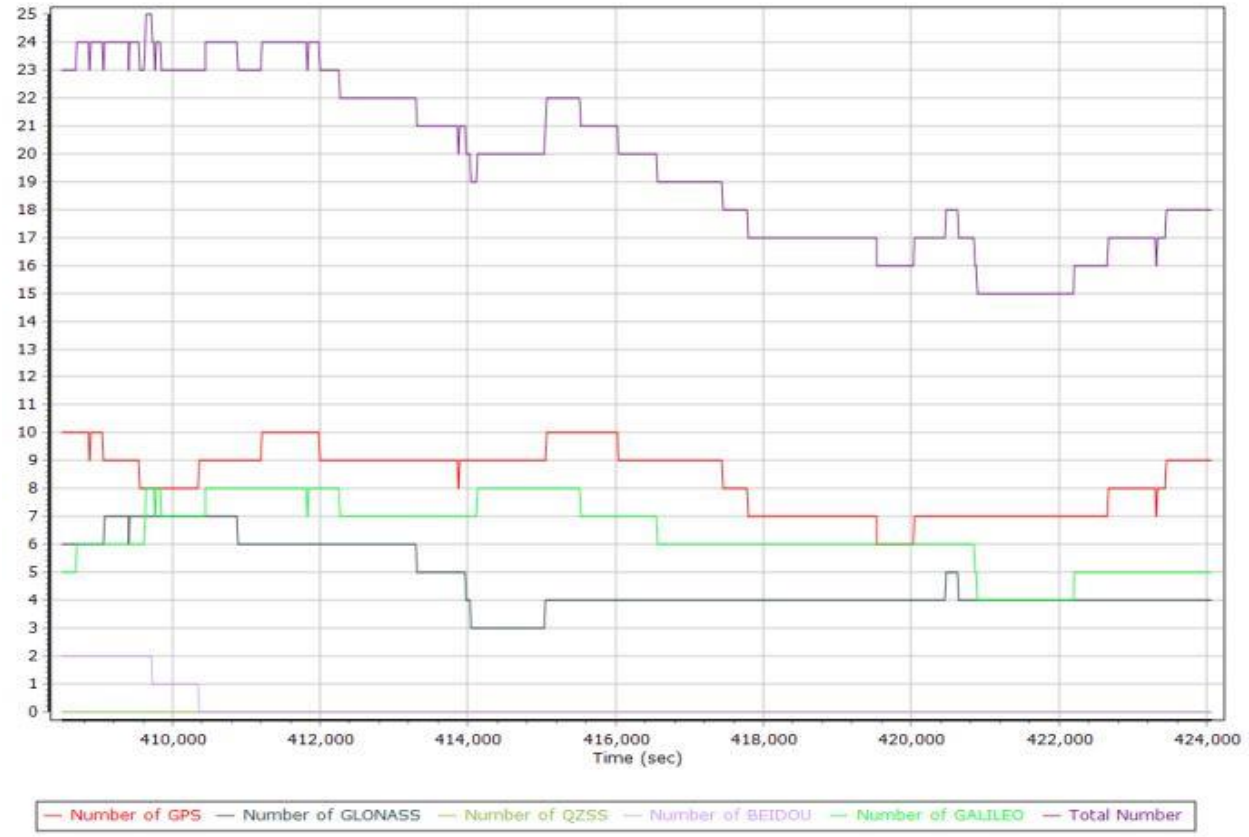


GNSS QC

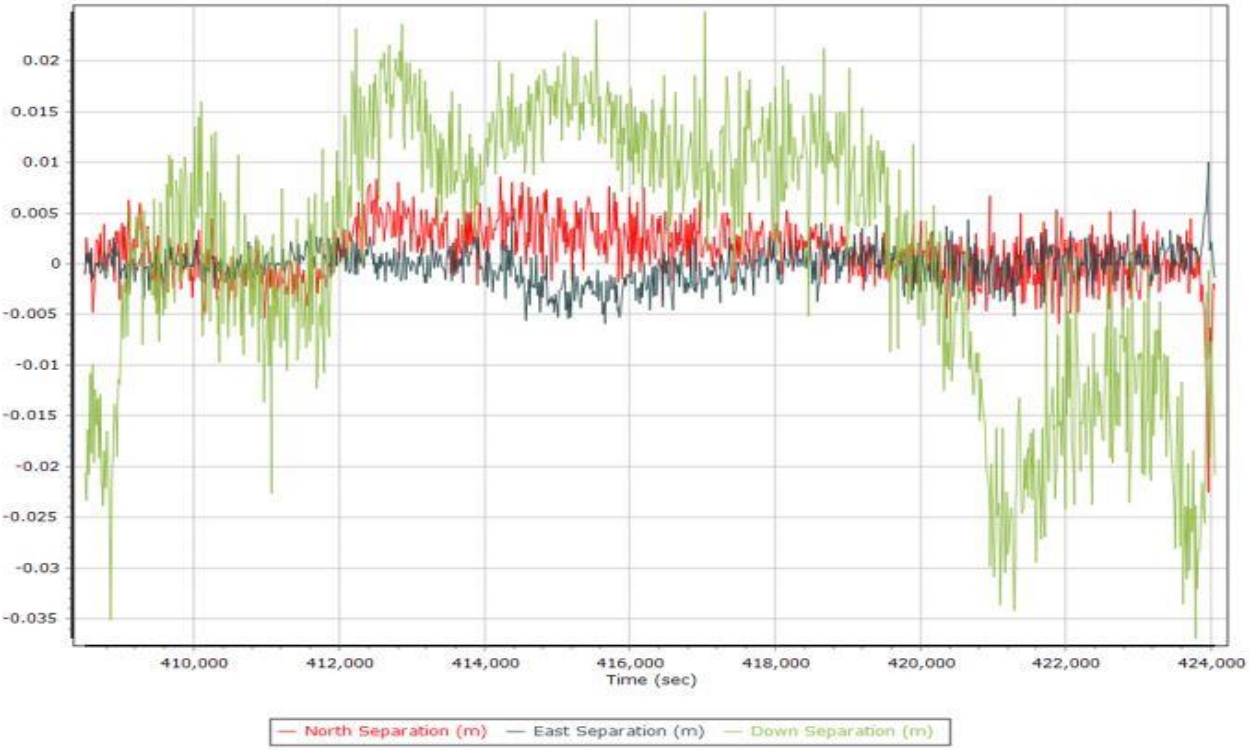
GNSS QC Statistics

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

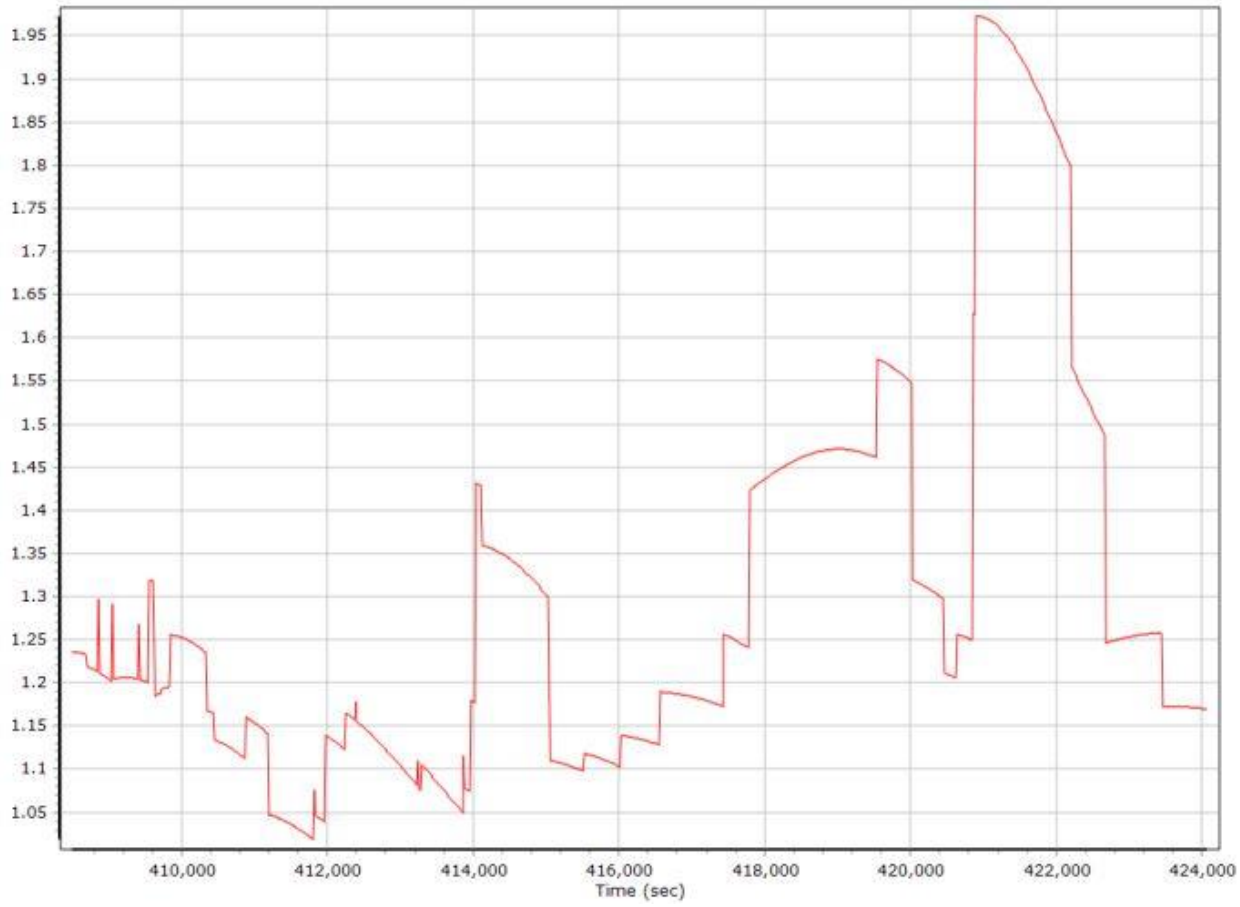
Number of Satellites



Forward/Reverse Separation

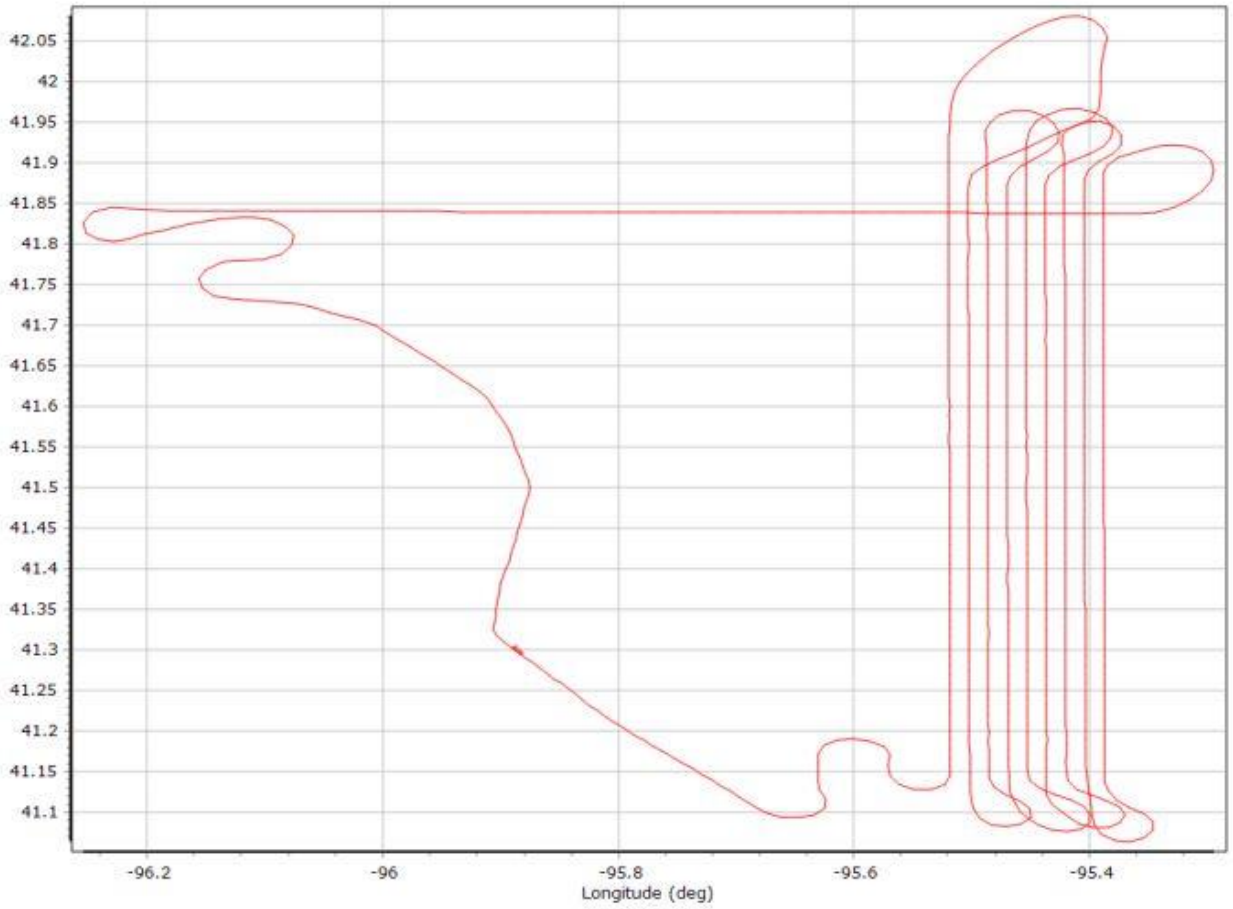


PDOP


1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
410,000
412,000
414,000
416,000
418,000
420,000
422,000
424,000
Time (sec)

1210a448_QC Report.docx QC Report - 8/26/2021 14:10:44
Smoothed Trajectory Information

Top View

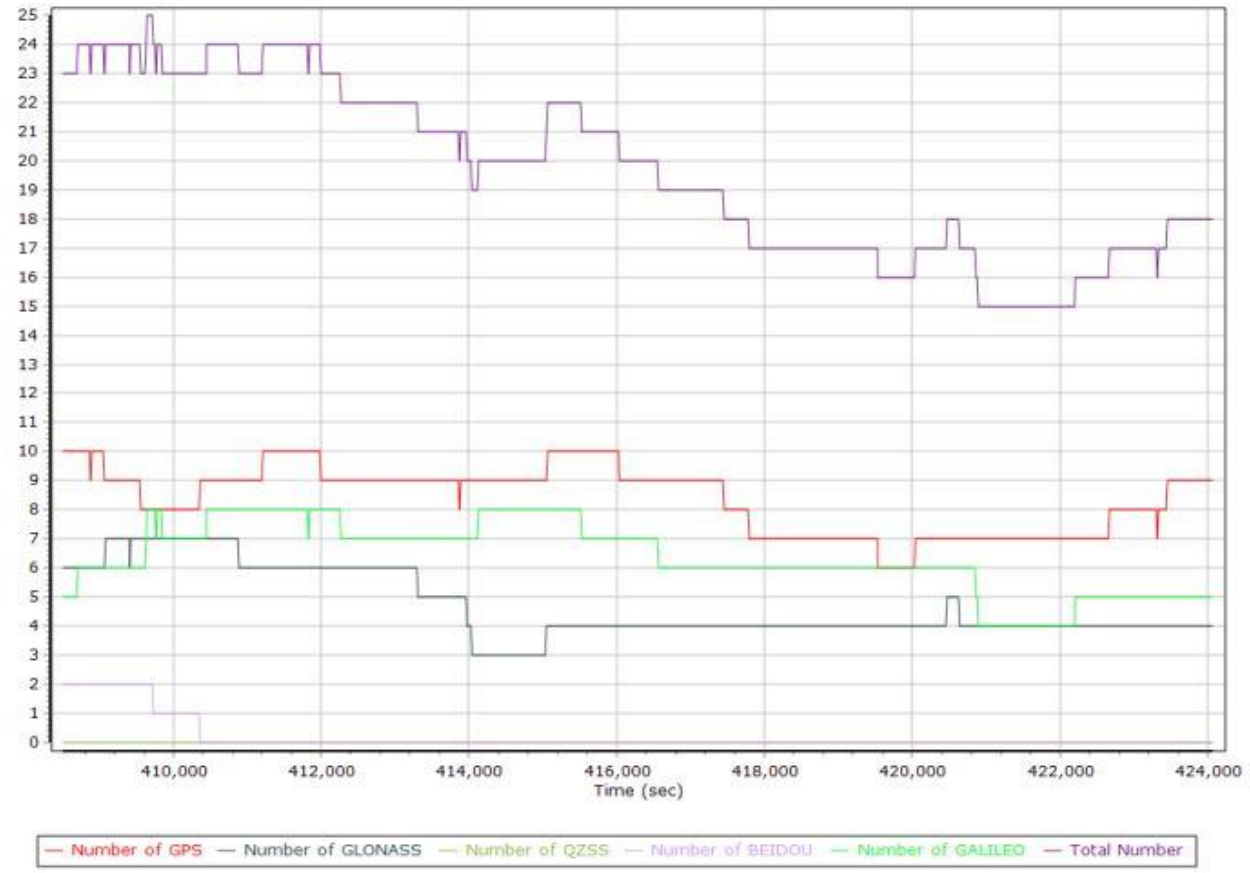


GNSS QC

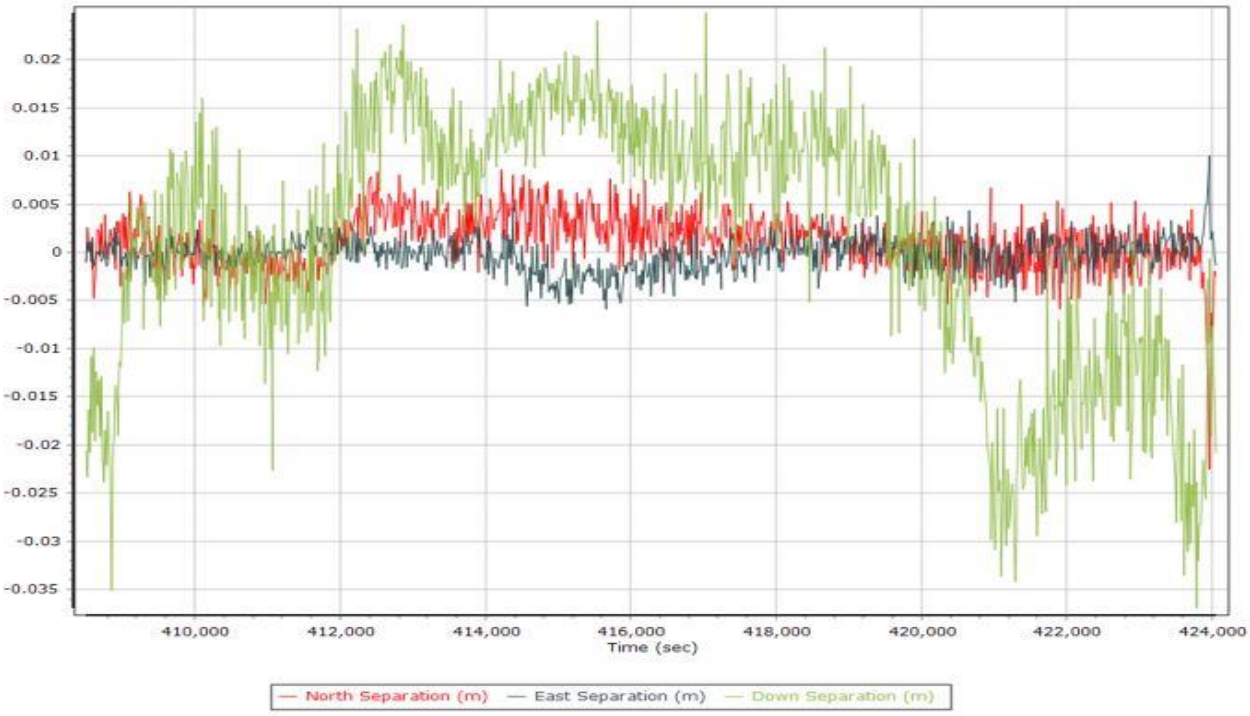
GNSS QC Statistics

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

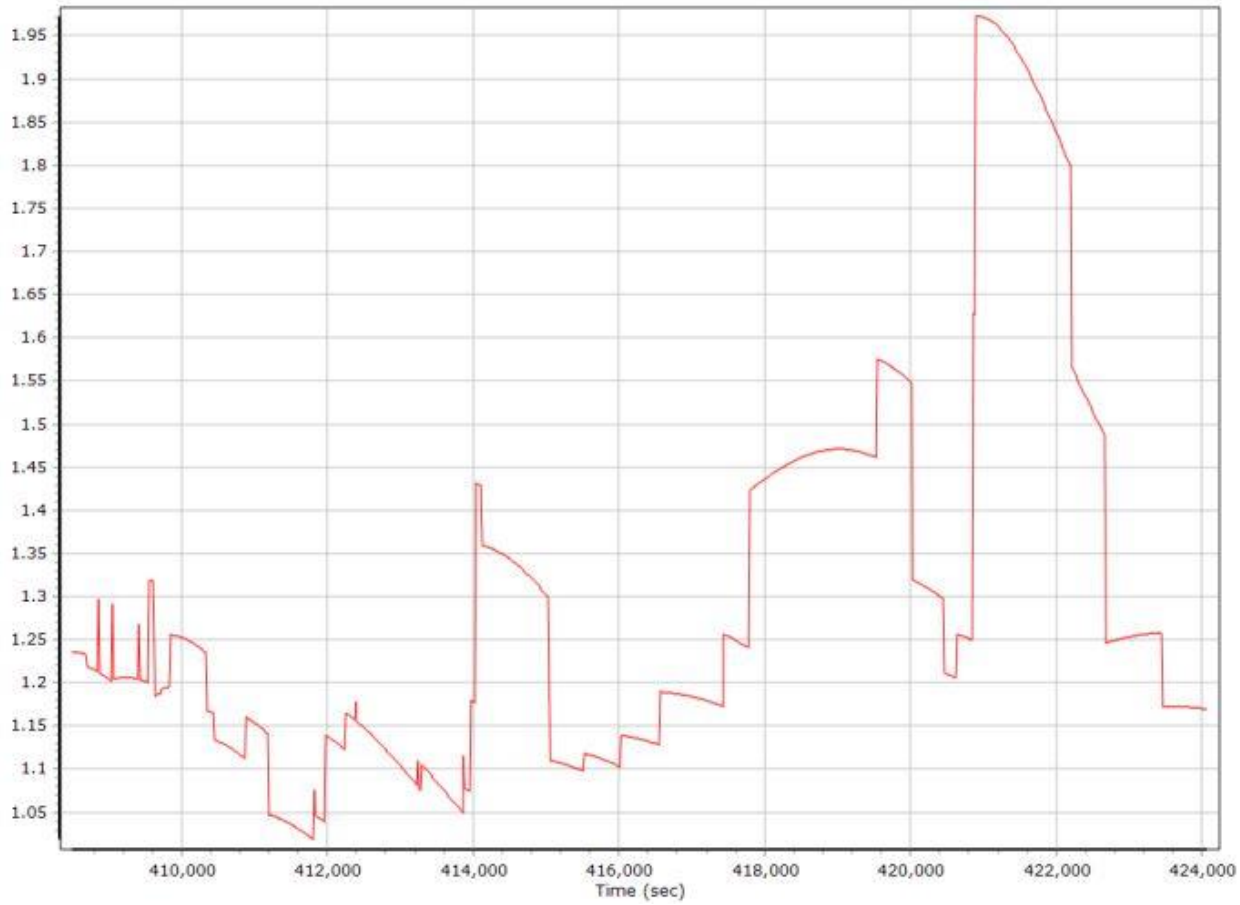
Number of Satellites



Forward/Reverse Separation



PDOP


1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
410,000
412,000
414,000
416,000
418,000
420,000
422,000
424,000
Time (sec)