

# **USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019\_D19 Final Report**

Report Produced for U.S. Geological Survey

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## Overview

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019\_D19 project Area.

USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 area of interest (AOI) covered approximately 2685 square miles in total and includes the counties of St. Clair, Monroe, Randolph, Union, Alexander and Pulaski. USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 was planned for the acquisition, processing, and derivative products of LiDAR data to be collected at an aggregate nominal pulse spacing (ANPS) of  $\leq 0.5$  meters. Adverse ground conditions during the fall 2019 flight season pushed Lidar acquisition to early spring and late fall of 2020.

USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 is the only portion of the USGS IL\_HicksDome\_FluorsparDistrict\_2019 project area that has been acquired at that time.

The LiDAR data for USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 was processed and classified according to project specifications. Detailed breaklines, bare earth Digital Elevation Models (DEMs), and Intensity Images were produced for the

USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project area. Data was formatted into tiles with each tile covering an area of 2000 US survey feet by 2000 US survey feet. A total of 19,250 LAS files, 19,255 DEMs, and 19,250 Intensity Images were produced for the project, encompassing the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 AOI of approximately 2685 square miles and formatted into 19,255 total tiles. DEMs were created with a 2 foot cell size. 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 files affected by photonic energy absorption: 2295\_5090, 2483\_2210, 2655\_2050, 2657\_2050 and 2643\_2030.

## PROJECT TEAM

Aerial Services, Inc. (ASI) served as the prime contractor for the project. In addition to project and subcontractor management ASI was responsible for LiDAR acquisition and calibration, LiDAR products, Digital Elevation Models (DEM) production, Intensity Image production, and quality assurance. Subcontractors: SurvTech Solutions and Aerial Surveys International, LLC assisted ASI with LiDAR acquisition and calibration. SurvTech Solutions and GRW assisted ASI with manually editing, bare earth surface cleanup, and performed hydro collection. ASI consolidated the hydrologic features and performed hydro flattening for all of project USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019. All follow-on processing was completed by the prime contractor.

Surveying and Mapping, LLC (SAM) completed ground surveying for the project and delivered surveyed checkpoints. SAM was to acquire surveyed checkpoints for the project to be used 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 created for this portion of the project.



**SURVEY AREA**

The project area addressed by this report falls within the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 covering the counties of St. Clair, Monroe, Randolph, Union, Alexander and Pulaski, Illinois.

**DATE OF SURVEY**

LiDAR acquisition for USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 was conducted from March 5, 2020 through December 10, 2020.

**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:** Illinois State Plane West (FIPS 1202) (EPSG 6457).

**Units:** Horizontal units are in US Survey Feet, Vertical units are in US Survey feet.

**Geoid Model:** Geoid 12B

**LIDAR VERTICAL ACCURACY**

For the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project, the tested RMSEz of the data for checkpoints in non-vegetated terrain equaled 0.057 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 0.111 meters compared with the 19.6 cm specification.

For the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project, the tested VVA of the classified data computed using the 95<sup>th</sup> percentile was equal to 0.089 meters, compared with the 29.4 cm specification.

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	97	0.057	0.111	-0.027	-0.027	0.506	0.050	-0.308	0.082	2.759

Table 1: Non-vegetated Vertical Accuracy (NVA) results.

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

### PROJECT DELIVERABLES

The deliverables for the project are listed below.

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

### PROJECT TILING FOOTPRINT

19,255 tiles, 19,250 LAS files, 19,255 DEM tiles, and 19,250 Intensity Image tiles were delivered for the project. Each tile's extent is 2000 US Survey feet by 2000 US Survey feet. (See Appendix A for a complete listing of delivered tiles.)

USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project Area

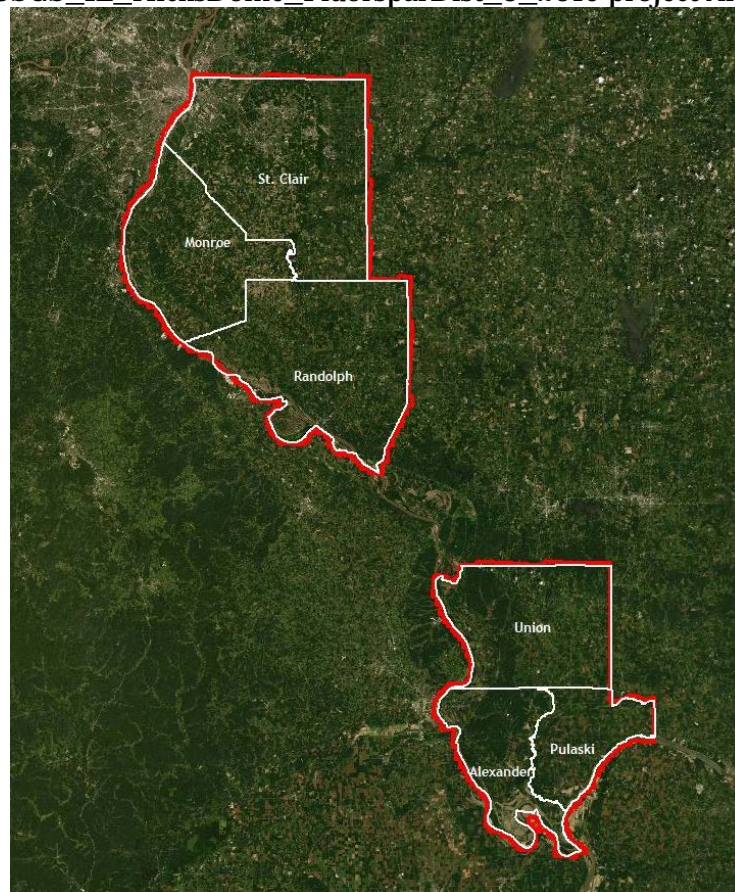
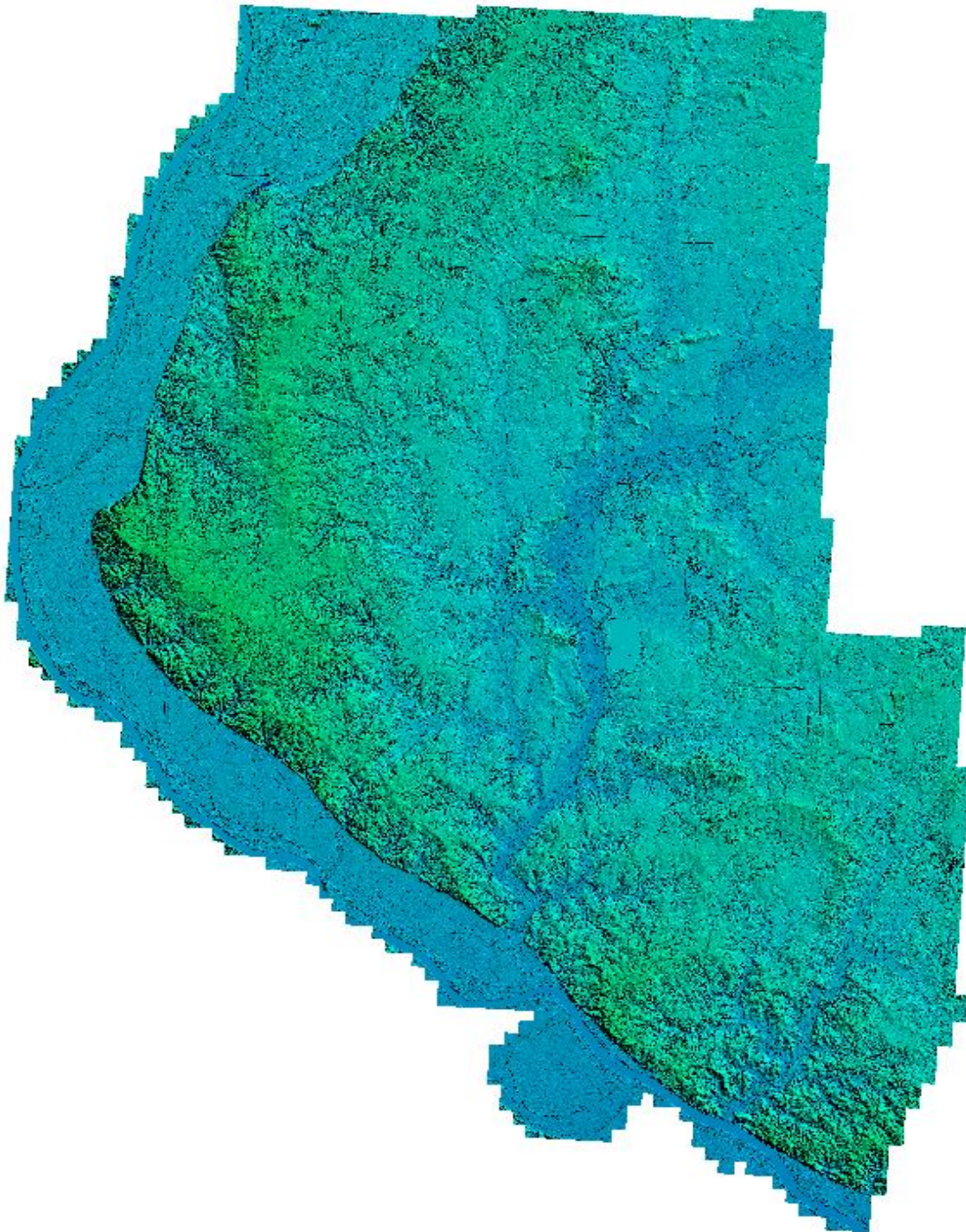


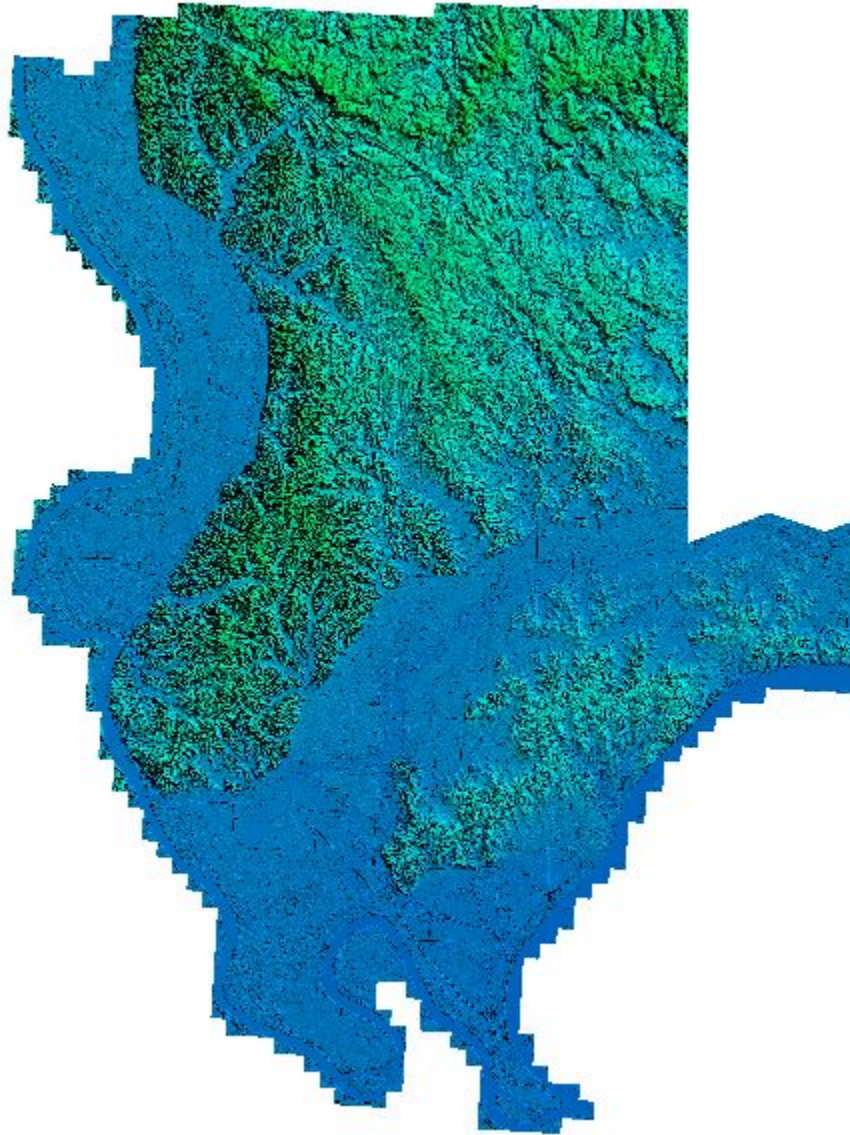
Figure 1: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 Area of Interest



**PROJECT AREA ELEVATION MODEL.**



**Figure 2: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 St. Clair, Monroe and Randolph counties DEM.**



**Figure 3: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 Union, Alexander and Pulaski counties  
DEM.**



## Lidar Acquisition Details – Aerial Services, Incorporated

Aerial Services, Inc. (ASI) served as prime contractor for the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project and performed the LiDAR Acquisition and Calibration.

Aerial Services, Inc. acquired 113 passes for the project area as well as three additional cross flightlines for the purposes of quality control in our own processing which are not included in delivery. 3 of the 113 passes flown by ASI covered the Block 2 West area. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, 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 design software for direct integration into the aircraft flight navigation system, and planned flight lines; flight line numbers; and coverage area.

Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.

Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Aerial Services, Inc. will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Aerial Services, Inc. monitored weather and atmospheric conditions and conducted LiDAR missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Aerial Services, Inc. accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Aerial Services, Inc. closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Aerial Services, Inc. LiDAR sensors are calibrated at a designated site located at the Waverly Municipal Airport in Waverly, Iowa and are periodically checked and adjusted to minimize corrections at project sites.

**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. Data was acquired between March 5, 2020 and March 6, 2020. The Table below illustrates Aerial Services, Inc. system parameters for LiDAR acquisition on this project.

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 (degree)	50
Scan Frequency (hz)	47
Scanner Pulse Rate (kHz)	212
Did the Sensor Operate with Multiple Pulses in The Air? (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 2: Aerial Services, Inc. Lidar System Parameters**

## Lidar Acquisition Details – SurvTech Solutions

Under Aerial Services, Inc. direction, SurvTech Solutions served as subcontractor for the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project and performed the LiDAR Acquisition and Calibration.

SurvTech Solutions planned 74 passes for the project area as well as a series of cross flightlines for quality control. In order to reduce any margin for error in the flight plan, SurvTech Solutions followed FEMA's Appendix A guidelines for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Optech's FMS 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.

Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.

Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, SurvTech Solutions filed our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

SurvTech Solutions monitored weather and atmospheric conditions and conducted LiDAR missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. SurvTech Solutions accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, SurvTech Solutions closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

### LIDAR SYSTEM PARAMETERS

SurvTech Solutions operated a CESSA 401 (Registration N41GD) equipped with an Optech Galaxy T2000 Lidar system during the collection of this task order. Data was acquired between December 2, 2020 and December 10, 2020.

Item	Parameter
System	Optech T2000
Maximum Number of Returns per Pulse	8
Nominal Pulse Spacing (single swath), (m)	0.41
Nominal Pulse Density (single swath) (ppsm), (m)	5.76
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.41
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	5.76
Altitude (AGL meters)	2286
Approx. Flight Speed (knots)	145
Total Sensor Scan Angle (degrees)	45
Scan Rate (hz)	88
Scanner Pulse Rate (kHz)	1000
Did the Sensor Operate with Multiple Pulses in The Air? (MPiA) (yes/no)	YES
Beam Divergence (mRADs)	0.23
Nominal Swath Width on the Ground (m)	1894
Swath Overlap (%)	30
Computed Down Track spacing (m) per beam	0.42
Computed Cross Track Spacing (m) per beam	0.41

**Table 3: Survtech Solutions Lidar System Parameters**



## Lidar Acquisition Details – Aerial Surveys International, LLC.

Aerial Surveys International, LLC planned 77 passes for the project area as well as a series of cross flightlines for quality control. 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) equipped with an Optech T2000 Lidar system during the collection of this task order. Data was acquired between April 5, 2021 and April 10, 2021.

Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.

Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Aerial Surveys International, LLC filed flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Aerial Surveys International, LLC monitored weather and atmospheric conditions and conducted LiDAR missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Aerial Surveys International, LLC accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Aerial Surveys International, LLC closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, aircraft were mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

**LIDAR SYSTEM PARAMETERS**

Item	Parameter
System	Optech T2000
Maximum Number of Returns per Pulse	8
Nominal Pulse Spacing (single swath), (m)	0.43
Nominal Pulse Density (single swath) (ppsm), (m)	5.28
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)	5.28
Altitude (AGL meters)	2500
Approx. Flight Speed (knots)	160
Total Sensor Scan Angle (degrees)	32
Scan Rate (hz)	92
Scanner Pulse Rate (kHz)	800
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)	1434
Swath Overlap (%)	30
Computed Down Track spacing (m) per beam	0.45
Computed Cross Track Spacing (m) per beam	0.42

**Table 4: Aerial Surveys International, LLC LiDAR system parameters**

### ACQUISITION STATUS REPORT AND FLIGHTLINES

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

The Figure below shows the combined trajectory of the flightlines by mission.

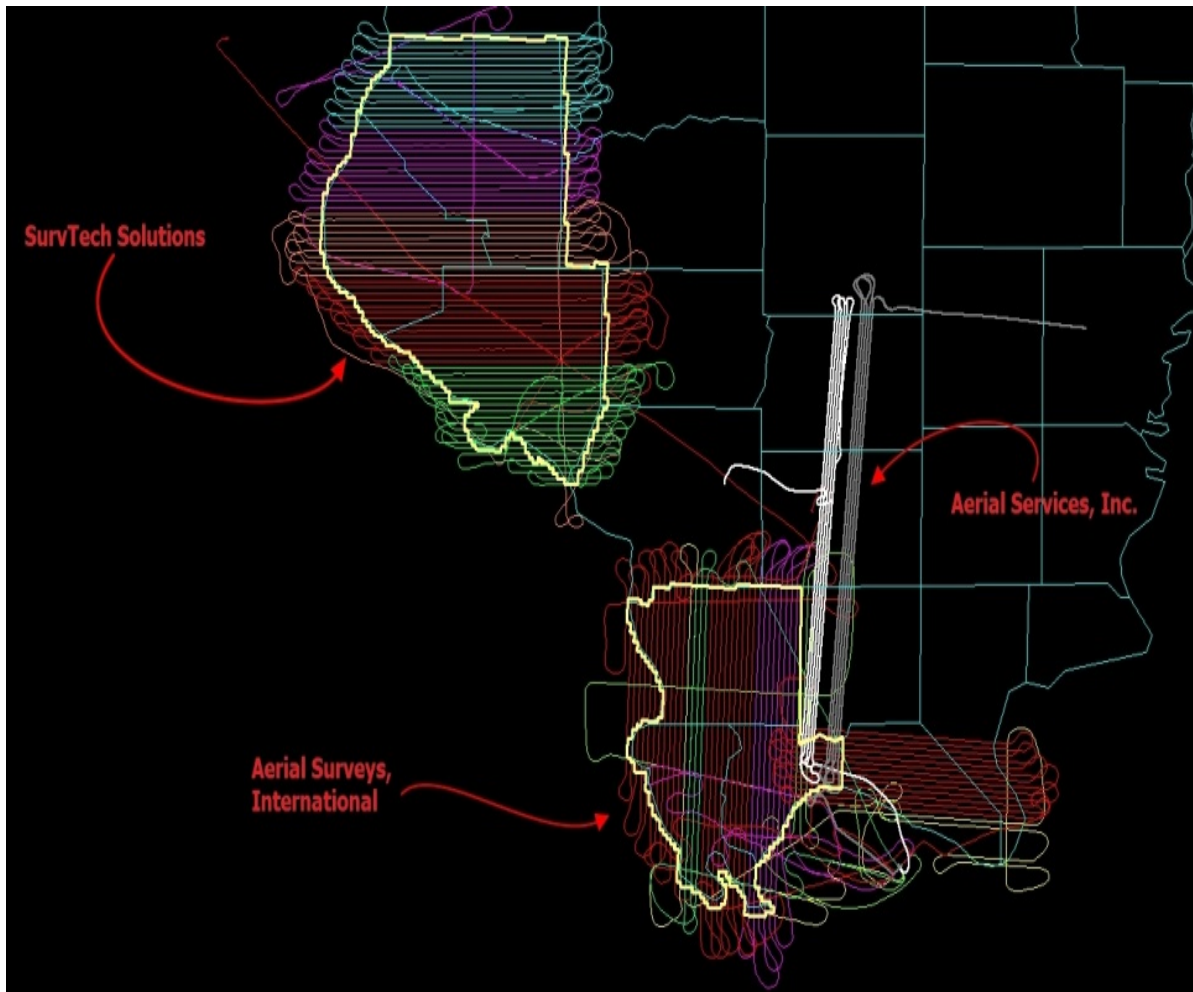


Figure 4: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 trajectories by mission as flown by Aerial Services, Inc.

Name	Lift_ID	PT Source ID	Scanner	Start Time	End Time
20201202_140412	201202a	3001	Optech	290953052.4	290953714.8
20201202_141748	201202a	3002	Optech	290953867.9	290954537.5
20201202_143213	201202a	3003	Optech	290954733.1	290955412.2
20201202_144607	201202a	3004	Optech	290955566.8	290956255
20201202_150030	201202a	3005	Optech	290956430.1	290957126.3
20201202_151416	201202a	3006	Optech	290957256.4	290957960.7
20201202_152828	201202a	3007	Optech	290958107.8	290958831.8
20201202_154306	201202a	3008	Optech	290958985.6	290959709.1
20201202_155724	201202a	3009	Optech	290959844.4	290960583.9
20201202_161237	201202a	3010	Optech	290960756.6	290961489.4
20201202_162717	201202a	3011	Optech	290961636.8	290962396.2
20201202_164204	201202a	3012	Optech	290962523.9	290963264.8
20201202_165748	201202a	3013	Optech	290963468.4	290964242.6
20201202_171319	201202a	3014	Optech	290964399.1	290965160.7
20201202_172826	201202a	3015	Optech	290965305.5	290966100
20201202_174325	201202a	3016	Optech	290966205	290966963.5
20201202_200208	201202b	3017	Optech	290974528.2	290975330.1
20201202_201742	201202b	3018	Optech	290975462.3	290976268
20201202_203333	201202b	3019	Optech	290976413.2	290977232.9
20201202_204854	201202b	3020	Optech	290977334.2	290978167.5
20201202_210505	201202b	3021	Optech	290978304.8	290979144.6
20201202_212111	201202b	3022	Optech	290979270.9	290980120.7
20201202_213709	201202b	3023	Optech	290980228.7	290981090.7
20201202_215315	201202b	3024	Optech	290981195.4	290982058
20201202_220941	201202b	3025	Optech	290982181	290983060.2
20201202_222601	201202b	3026	Optech	290983160.7	290984052.2
20201202_224239	201202b	3027	Optech	290984158.6	290985071.1

20201202_225956	201202b	3028	Optech	290985196.2	290986136.7
20201202_231712	201202b	3029	Optech	290986231.6	290987109.7
20201204_221213	201204A	3030	Optech	291155132.7	291156013.5
20201204_222845	201204A	3031	Optech	291156125.4	291157056.1
20201204_224702	201204A	3032	Optech	291157222	291158087.4
20201204_230428	201204A	3033	Optech	291158267.7	291159177.4
20201204_232151	201204A	3034	Optech	291159311	291160221.3
20201204_233932	201204A	3035	Optech	291160372.4	291161272.2
20201204_235743	201204A	3036	Optech	291161462.9	291162374
20201205_001524	201204A	3037	Optech	291162523.7	291163488.4
20201205_003514	201204A	3038	Optech	291163713.5	291164651
20201205_005529	201204A	3039	Optech	291164929	291165924.7
20201205_011529	201204A	3040	Optech	291166129.1	291167080
20201205_145919	201205A	3041	Optech	291215558.6	291216543.7
20201205_151937	201205A	3042	Optech	291216776.6	291217664.1
20201205_153842	201205A	3043	Optech	291217922.1	291218864.7
20201205_155758	201205A	3044	Optech	291219078.2	291219971.1
20201205_161647	201205A	3045	Optech	291220206.8	291221101.8
20201205_163532	201205A	3046	Optech	291221331.6	291222181.2
20201205_165340	201205A	3047	Optech	291222420.2	291223274.8
20201205_171146	201205A	3048	Optech	291223505.9	291224306.3
20201205_172903	201205A	3049	Optech	291224543.5	291225359.3
20201205_174726	201205A	3050	Optech	291225646.5	291226411.2
20201205_180422	201205A	3051	Optech	291226662.4	291227440.8
20201205_182113	201205A	3052	Optech	291227672.9	291228408.9
20201205_183638	201205A	3053	Optech	291228597.6	291229338.6
20201205_185158	201205A	3054	Optech	291229517.7	291230197.6
20201205_212137	201205B	3055	Optech	291238497.2	291239216.2
20201205_213603	201205B	3056	Optech	291239363.3	291240051.7

20201205_214944	201205B	3057	Optech	291240184.1	291240954
20201205_220346	201205B	3058	Optech	291241025.9	291241671.9
20201205_221811	201205B	3059	Optech	291241890.7	291242616.7
20201205_223059	201205B	3060	Optech	291242658.8	291243281.7
20201205_224458	201205B	3061	Optech	291243498	291244192.6
20201205_225716	201205B	3062	Optech	291244236.5	291244839.6
20201205_231105	201205B	3063	Optech	291245065.5	291245604.5
20201205_232932	201205B	3064	Optech	291246172.5	291246697.9
20201205_234150	201205B	3065	Optech	291246910.3	291247519.8
20201205_235308	201205B	3066	Optech	291247588.3	291248089.1
20201206_000440	201205B	3067	Optech	291248280	291248826.6
20201206_001517	201205B	3068	Optech	291248916.7	291249385.5
20201206_002527	201205B	3069	Optech	291249527.1	291249991.2
20201206_003644	201205B	3070	Optech	291250204	291250457.4
20201206_004400	201205B	3071	Optech	291250640.3	291250910.4
20201206_004951	201205B	3072	Optech	291250991.5	291251235.8
20201206_005643	201205B	3073	Optech	291251403.2	291251584.1
20201206_010119	201205B	3074	Optech	291251678.8	291251846
20201209_231203	2020_1209b448	2085	Optech	291590723.6	291591454.2
20201209_231904	2020_1209b386	2086	Optech	291591144.7	291592069.1
20201209_232639	2020_1209b448	2087	Optech	291591599.4	291592358.9
20201209_234107	2020_1209b386	2088	Optech	291592466.9	291593381.3
20201209_234137	2020_1209b448	2089	Optech	291592497.7	291593230.2
20201210_000105	2020_1209b386	2090	Optech	291593665.3	291594626
20201210_005955	2020_1210a386	2092	Optech	291597195.9	291598097.8
20201210_011737	2020_1210a386	2093	Optech	291598257.6	291599120.2
20201210_013519	2020_1210a386	2094	Optech	291599319.9	291600189.1
20200305_160022	20200305_ALS70	53	ALS70	267459211.1	267460722
20200305_162632	20200305_ALS70	54	ALS70	267460781.1	267462273

20200306_004903	20200306_ALS70	63	ALS70	267490931.1	267492396
20201205_221923	2020_1205a448	2002	Optech	291241963.4	291242172.7
20201205_222602	2020_1205a448	2003	Optech	291242362.5	291242870.1
20201205_223656	2020_1205a448	2004	Optech	291243017.2	291243557.8
20201205_224801	2020_1205a448	2005	Optech	291243681.1	291244271.5
20201205_230125	2020_1205a448	2006	Optech	291244485	291245120.7
20201205_231460	2020_1205a448	2007	Optech	291245299.9	291245958.6
20201205_232921	2020_1205a448	2008	Optech	291246161.5	291246851.6
20201205_234355	2020_1205a448	2009	Optech	291247036.1	291247735.3
20201205_235840	2020_1205a448	2010	Optech	291247920.8	291248673.2
20201206_001453	2020_1205a448	2011	Optech	291248893.6	291249638.2
20201206_002933	2020_1205a448	2012	Optech	291249773.3	291250634
20201206_004658	2020_1205a448	2013	Optech	291250819	291251667.4
20201206_155709	2020_1206a448	2015	Optech	291305429.3	291306287.7
20201206_161457	2020_1206a448	2016	Optech	291306497.2	291307351.9
20201208_213038	2020_1208a386	2030	Optech	291498238.4	291498882.1
20201208_214524	2020_1208a386	2032	Optech	291499125.1	291499763.3
20201208_220021	2020_1208a386	2034	Optech	291500021.8	291500692.3
20201209_155735	2020_1209a386	2045	Optech	291564655.7	291565406.3
20201209_161418	2020_1209a386	2047	Optech	291565658.4	291566394.6
20201209_163212	2020_1209a386	2049	Optech	291566732.1	291567725.7
20201209_165316	2020_1209a386	2052	Optech	291567996.4	291568935.6
20201209_171355	2020_1209a386	2055	Optech	291569235.7	291570201.4
20201209_173404	2020_1209a386	2058	Optech	291570444.5	291571383.2
20201209_175624	2020_1209a386	2062	Optech	291571784.8	291572729
20201209_181705	2020_1209a386	2064	Optech	291573025.1	291573968.2
20201209_205315	2020_1209b448	2069	Optech	291582395.6	291583092.7
20201209_210718	2020_1209b448	2070	Optech	291583238.3	291583918.4
20201209_212028	2020_1209b386	2072	Optech	291584028.5	291584999.8

20201209_212141	2020_1209b448	2073	Optech	291584101.4	291584807.1
20201209_213658	2020_1209b448	2074	Optech	291585018.2	291585717.7
20201209_214129	2020_1209b386	2075	Optech	291585289.8	291586221
20201209_215203	2020_1209b448	2076	Optech	291585924.4	291586661.6
20201209_220056	2020_1209b386	2077	Optech	291586456.6	291587386.3
20201209_220815	2020_1209b448	2078	Optech	291586895.6	291587613.8
20201209_222008	2020_1209b386	2079	Optech	291587608.4	291588521.8
20201209_222421	2020_1209b448	2080	Optech	291587861.9	291588612.9
20201209_223918	2020_1209b386	2081	Optech	291588758.6	291589688.7
20201209_224014	2020_1209b448	2082	Optech	291588814.6	291589552.3
20201209_225606	2020_1209b448	2083	Optech	291589766.3	291590517.5
20201209_225927	2020_1209b386	2084	Optech	291589967.2	291590879.6

**Table 5: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019, Illinois Project flightline by Mission**



**ACQUISITION CONTROL**

**Aerial Services, Inc.** conducted the survey which provided the established base stations used to control the lidar acquisition for the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project area. The coordinates of the base stations are provided in the table below.

Name	NAD83(2011) Decimal Degrees		Ellipsoid Ht (WGS84, m)
	Easting X	Northing Y	
MOCH	36.91805	-89.31888	70.084
MOJK	37.41222	-89.65	115.82
MOSG	37.9375	-90.13555	167.739
INES	38.12944	-87.55055	111.475
INDA	38.195	-86.97388	126.116
INVI	38.6275	-87.53055	101
VINU	38.68916	-87.52305	105.509
KYTB	37.35333	-87.49666	133.959

**Table 6: Base station used to control lidar acquisition for the Project.**

**SurvTech Solutions**, utilized location listed in the Table below to control the lidar acquisition for Hicks Dome project area.

Name	NAD83(2011) Decimal Degrees		Ellipsoid Ht (WGS84, m)
	Easting X	Northing Y	
KCPS-REBAR	90.158958	38.575625	91.617
KPCD-REBAR	89.867668	37.862867	81.424

**Table 7: Base station used to control lidar acquisition for the Project.**

**Aerial Surveys International, LLC**, utilized POSPac PP-RTX to control the lidar acquisition for the Hicks Dome project area. 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 Waypoint's Inertial Explorer version 8.80.2503 software suite. 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.

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

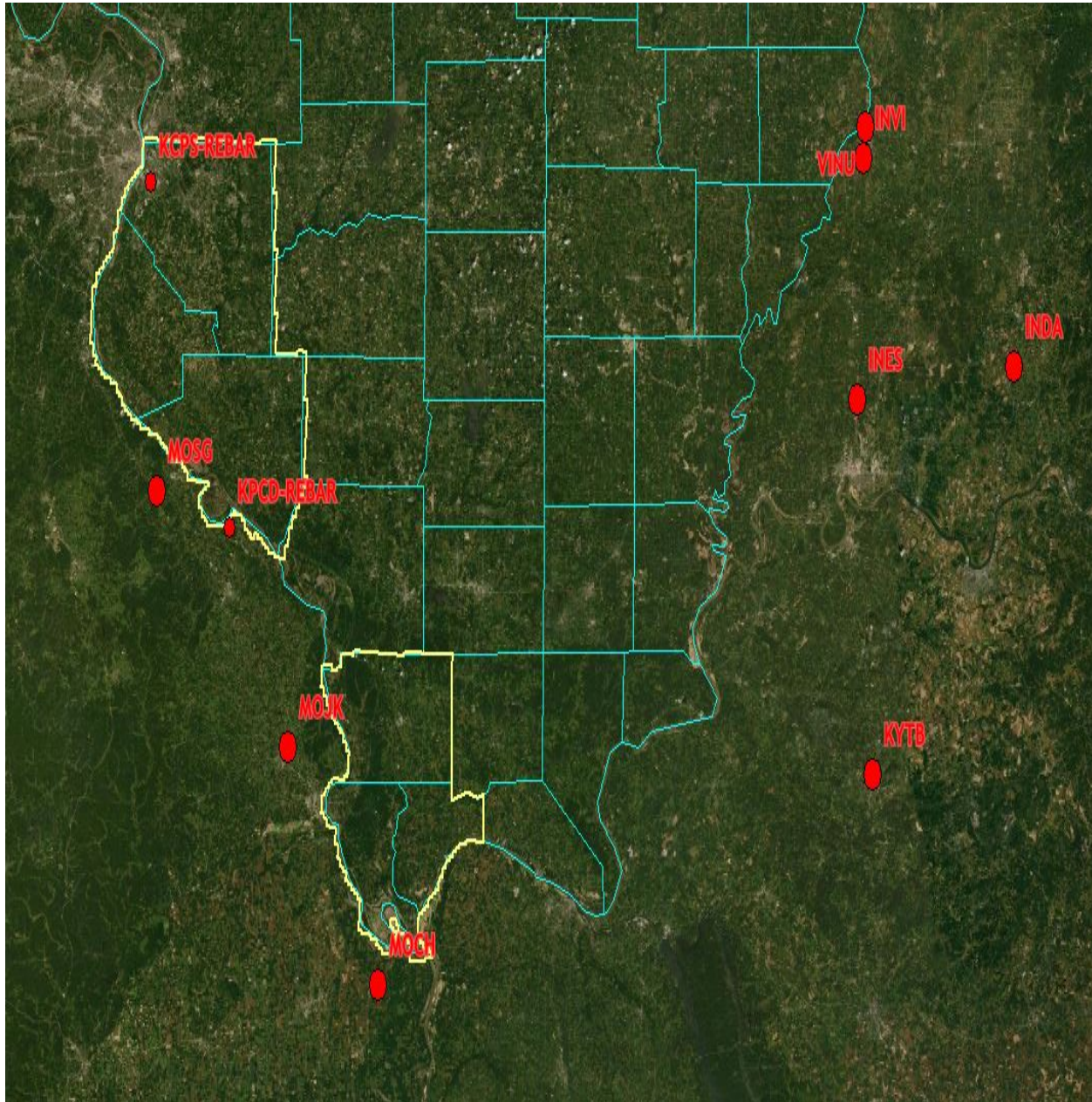


figure 5: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 Base station location

**SurvTech Solutions** Airborne GPS data was processed through POSPAC 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 B.

**Aerial Surveys International, LLC's** 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 within the Block 2\_West are included in Appendix B.

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

After **Aerial Services Incorporated (ASI)** processes the GNSS/GPS and IMU data in Inertial Explorer, the data is then exported to raw LAS files using Leica's CloudPro software. CloudPro combines the raw data collected with the ALS 70 HP sensor, combines it with the airborne trajectory data, applies the sensor's calculated boresight correction angles, and then outputs the point cloud to the specified coordinate reference system and file format.

The initial step of calibration is to verify the complete coverage of the AOI with no internal voids present, as well as ensuring that minimum point density of 4.0 ppsm has been achieved. SurvTech Solutions and Aerial Surveys International initial calibration step 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 LMS, initially with default values from Optech's LMS or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch, and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness, acceptable 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 6: LiDAR swath output showing complete coverage**

## Boresight and Relative Accuracy

Aerial Services Incorporation lidar analysts load the project's data into MicroStation/TerraScan for viewing and post-processing of calibration errors. Roll, pitch, and heading corrections are calculated to produce the best relative accuracy that can be achieved, with a maximum interswath RMSDz of 8 cm. Tested interswath RMSDz was 2.4 cm.

The relative accuracy of every swath is checked and QC'd at 3 different points along its length. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement to verify that the project meet the specifications.

For this project the specifications used are as follow

Relative accuracy  $\leq 6$  cm maximum differences within individual swaths and  $\leq 8$  cm RMSDz between adjacent and overlapping swaths.

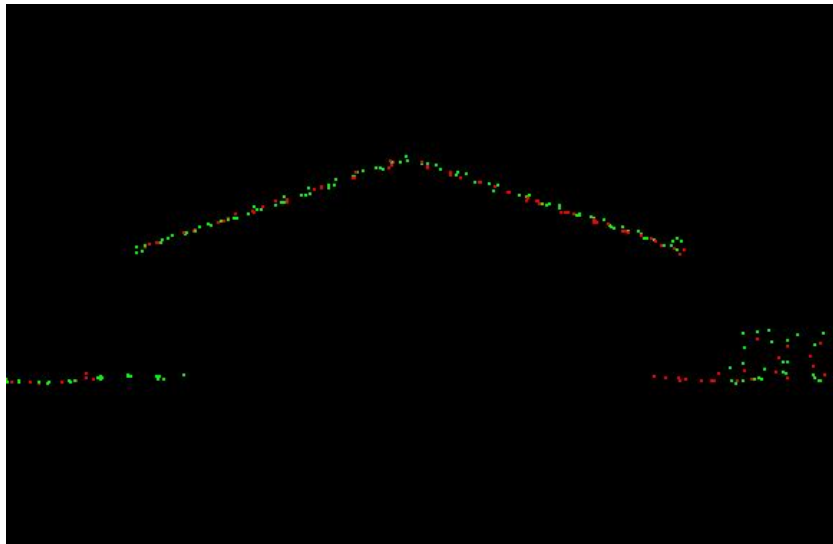


Figure 7: Profile view showing proper interswath calibration.

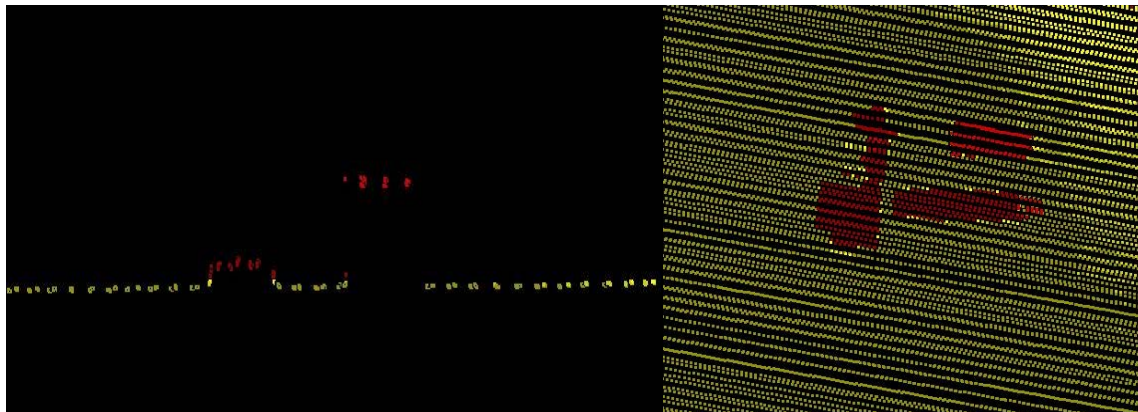


Figure 8: Top view showing a parking lot with a car and raised feature on a single swath demonstrating intraswath accuracy. Yellow color is scaled to a range of 6 cm in elevation. Points are within 6 cm of variation until the raised curb and car. Also shown is a profile view showing low variability of ranges within the swath.

**SurvTech Solutions** analysts inspect the initial points for each mission calibration 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 specification 2.1, QL2):

Relative accuracy (smooth surface repeatability)  $\leq 6$  cm maximum differences within individual swaths and  $\leq 8$  cm RMSD<sub>z</sub> between adjacent and overlapping swaths.

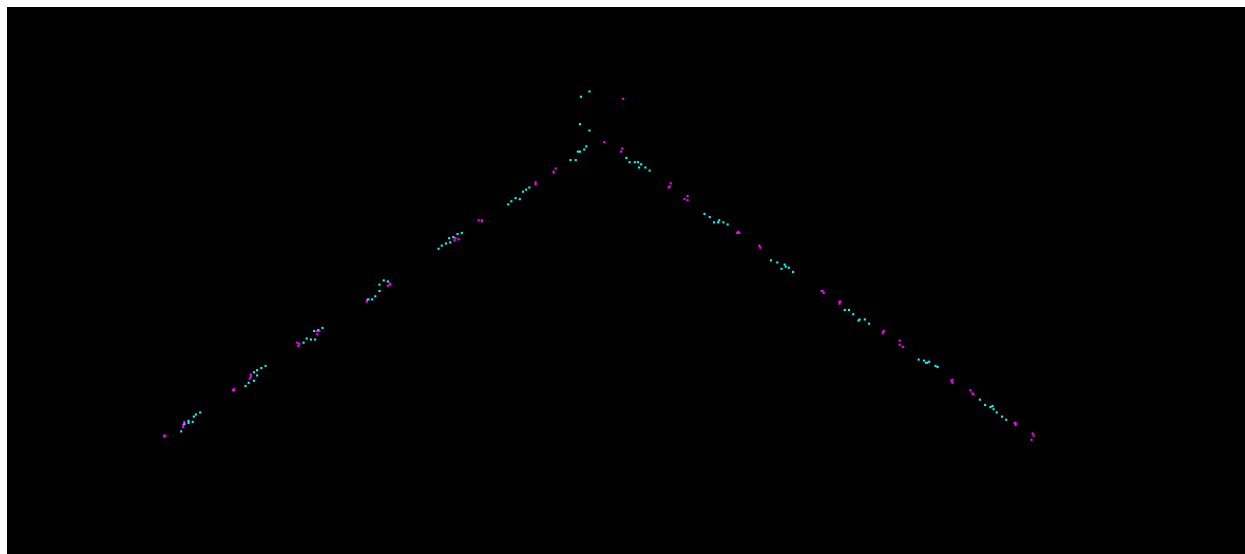
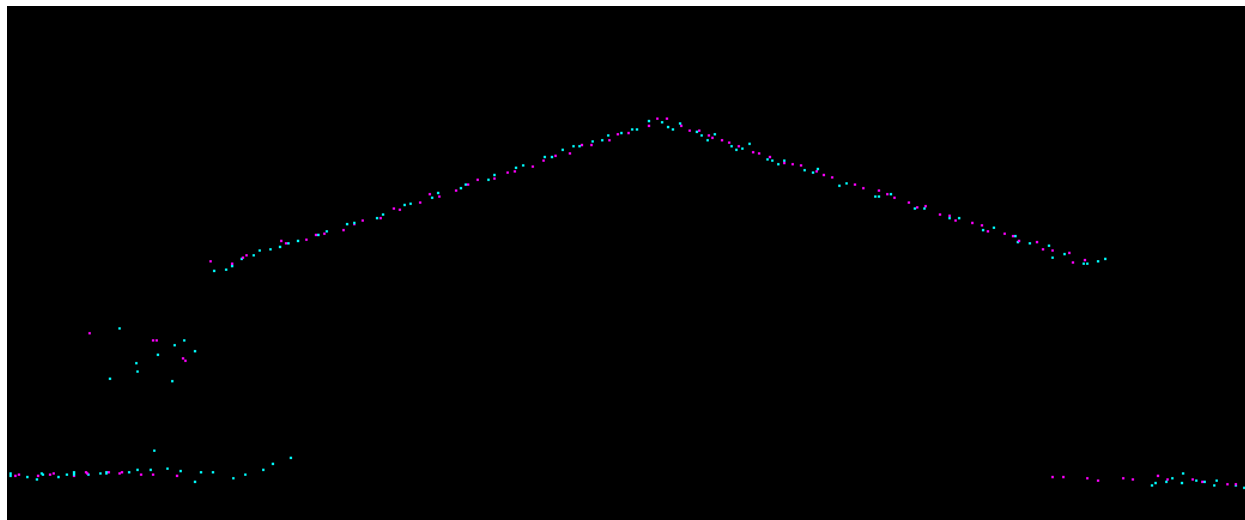


Figure 9: Profile views showing correct roll and pitch adjustments

**Aerial Surveys International's** analysts inspect the initial points for each mission calibration for flight line errors, flight line overlap, slivers, or gaps in the data, point density 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 vertical errors greater than the required 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 specification 2.1, QL2):

Relative accuracy (smooth surface repeatability)  $\leq 6$  cm maximum differences within individual swaths and  $\leq 8$  cm RMSD<sub>z</sub> between adjacent and overlapping swaths.

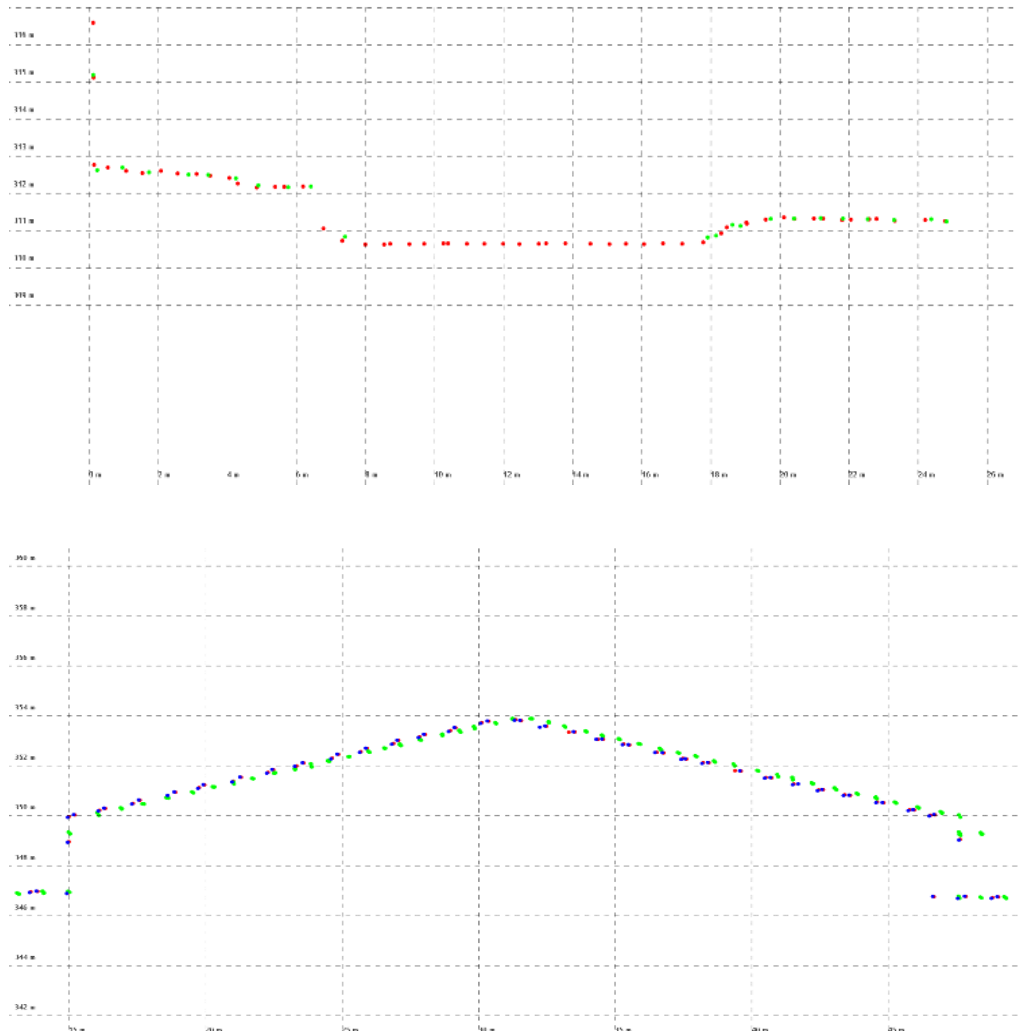


Figure 10: Profile views showing correct roll and pitch adjustments

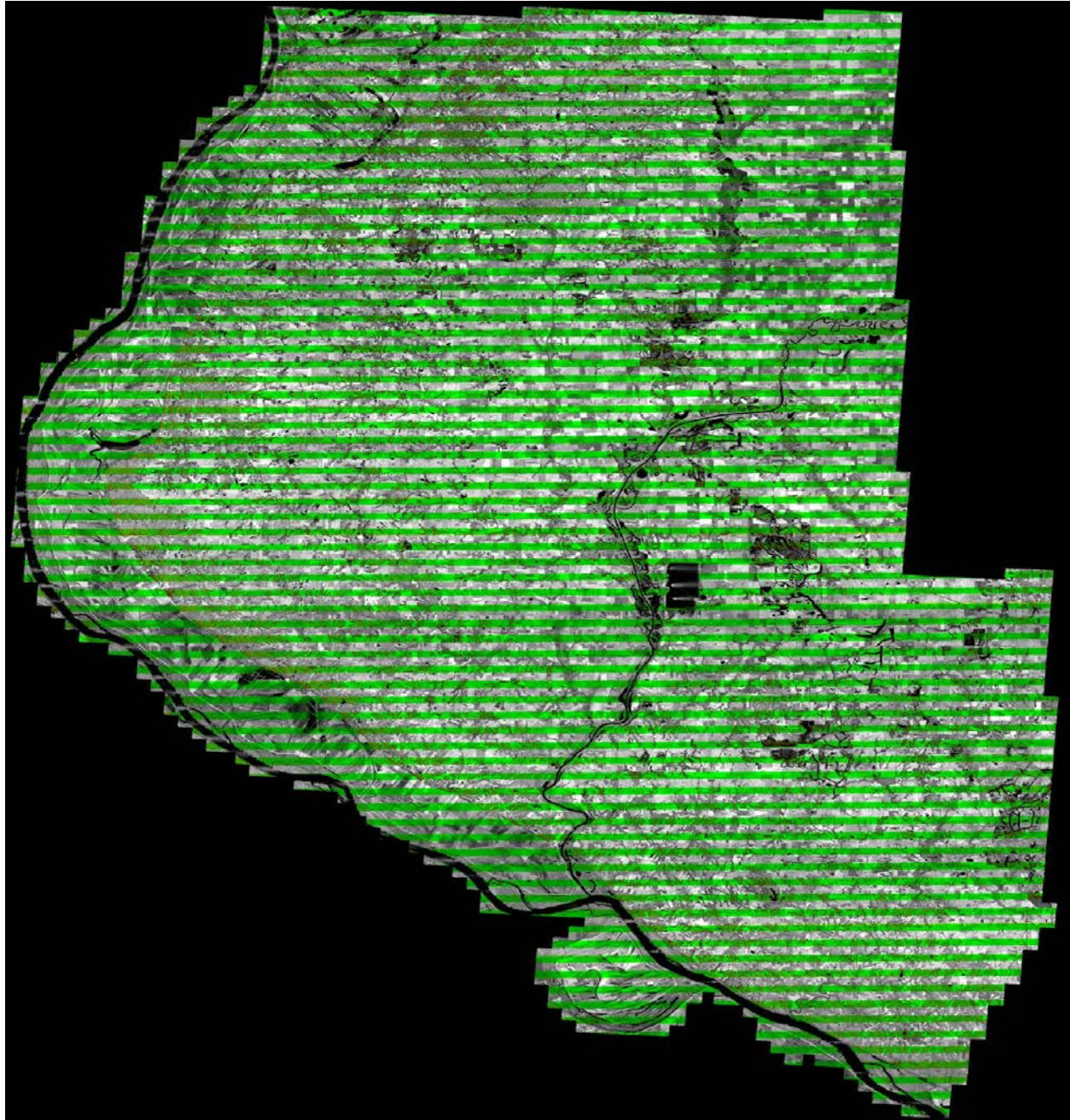
### DELTA-Z ACCURACY ASSESSMENT

Swath-to-swath relative accuracy is assessed by comparing the elevations of overlapping swaths. Delta-z is a raster file representing the differences in elevation of overlapping swaths and is generated from the subtraction of the two raster files created from each swath over the entire area of interest. It is then used to calculate the RMSD<sub>z</sub>, which in turn is displayed as a visual representation of error distribution.

The image below is a LIDAR “ortho” image created from the laser return intensity, Z (elevation) and swath number. The image is rendered as grayscale where there is no overlap between data from different flight lines (swath). Where two (or more) flight lines overlap, a color rendering is constructed base on the average maximum elevation difference between points in the overlapping swath. The distance (dZ) is indexed into a user-defined color. In the image below,



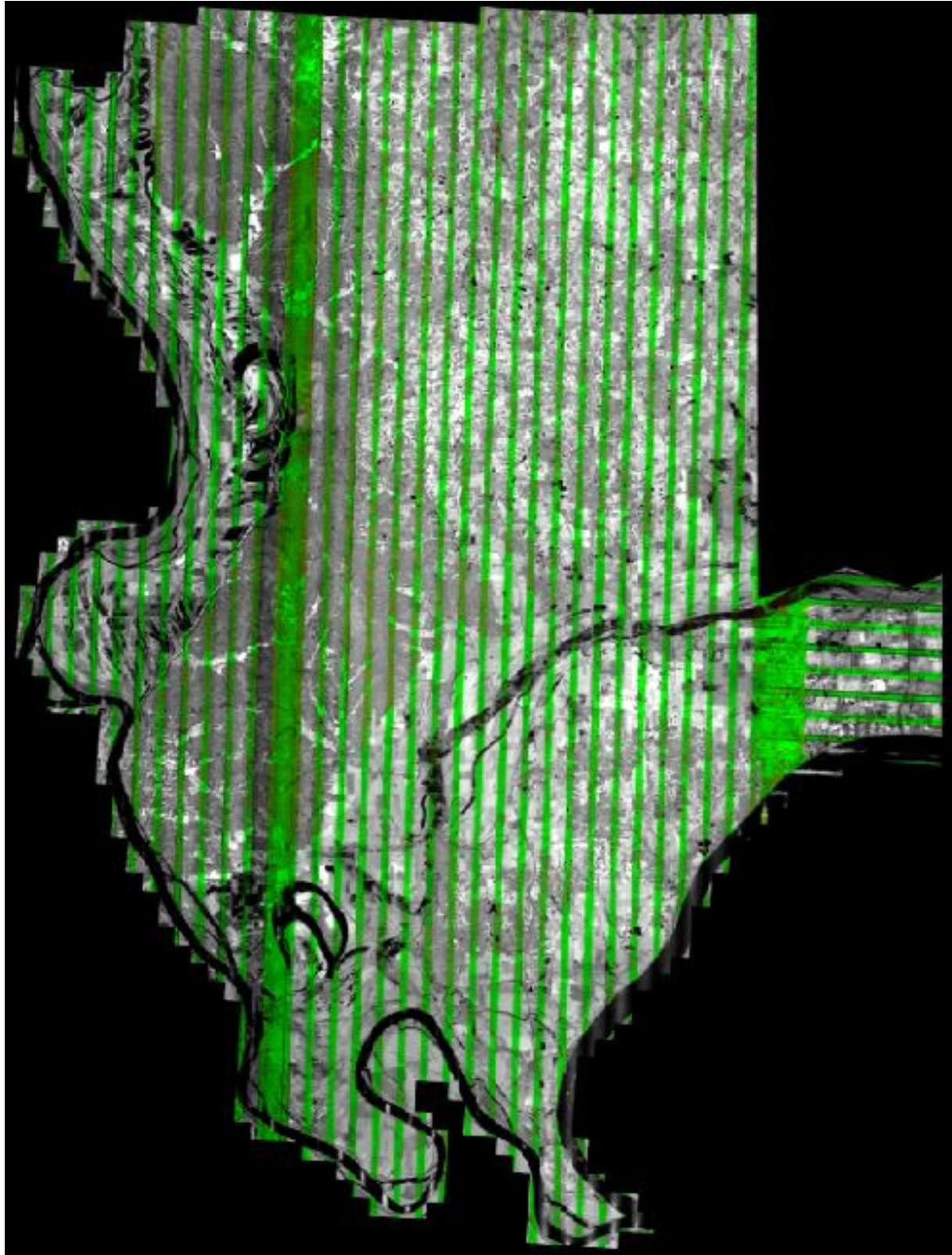
four-color bands were separated into 8 cm increments. Thus green represents dZs from 0 to 8 cm, yellow from 8 cm to 16 cm, orange from 16 cm to 24 cm and red for dZ greater than 24 cm. The dZ image provides a quick method of quickly assessing the relative vertical accuracy of a LiDAR project.



St. Clair, Monroe and Randolph counties.

Figure 11: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019, Illinois Project Delta-z raster image.





**Union, Alexander, and Pulaski Counties**

**Figure 12: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019, Illinois Project Delta-z raster image.**

## Final Calibration Verification

Surveying and Mapping, LLC (SAM) conducted the survey for 61 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 61 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided in the following table and the accuracy results from testing the calibrated swath data against the GCPs is provided in table below; no further adjustments to the swath data were required based on the accuracy results of the GCPs. Accuracy of the raw point cloud against GCP: 0.042 meters with a 95% confidence value of 0.083 meters.

Point ID	NAD83 (2011 adj) IL East		NAVD88 (Geoid 12B)		Dz (USft)
	Easting X (USft)	Northing Y (USft)	Z-Survey (USft)	Z-LiDAR (USft)	
GCP101	2297643	724615.49	410.363	410.25	-0.113
GCP102	2330936.9	708711.17	433.652	433.76	0.108
GCP103	2376675.7	712266.32	509.003	509	-0.003
GCP104	2398869.7	721907.85	527.881	527.91	0.029
GCP105	2289266	690827.18	405.118	405.23	0.112
GCP106	2373419.8	688091.13	650.037	649.94	-0.097
GCP107	2415085.9	703477.02	479.819	479.65	-0.169
GCP108	2348999.1	668784.91	474.541	474.16	-0.381
GCP109	2315442.6	681373.22	535.452	535.62	0.168
GCP110	2426572	680687.37	465.976	466.05	0.074
GCP111	2401395.4	664715.77	425.839	425.72	-0.119
GCP112	2283621.4	650037.36	495.528	495.27	-0.258
GCP113	2316090.6	653482.26	609.996	609.89	-0.106
GCP114	2369102.1	644027.97	511.867	511.64	-0.227
GCP115	2403481.2	645382.93	439.676	439.41	-0.266
GCP116	2345635.6	619728.56	445.255	445.13	-0.125

GCP117	2249589.7	620341.52	402.632	402.39	-0.242
GCP118	2254665.1	592776.24	398.42	398.15	-0.27
GCP119	2295855.6	627259.85	684.256	684.28	0.024
GCP120	2303676.3	592595.71	671.756	671.63	-0.126
GCP121	2427935	619302.03	426.564	426.36	-0.204
GCP122	2299716.3	566877.06	688.343	688.36	0.017
GCP123	2346261.3	560120.55	468.772	468.91	0.138
GCP124	2379003.1	600789.01	419.796	419.8	0.004
GCP125	2345992.1	596605.55	474.971	474.88	-0.091
GCP126	2277801.7	570547.57	606.705	606.63	-0.075
GCP127	2418859.6	576213.84	472.759	472.85	0.091
GCP128	2284261.4	544726.41	396.338	396.44	0.102
GCP130	2345093.6	533670.32	456.631	456.75	0.119
GCP131	2389728.6	552291.49	460.907	460.85	-0.057
GCP132	2433474.6	531060.12	514.809	514.98	0.171
GCP133	2458342.7	553773.81	545.746	545.78	0.034
GCP134	2316071	516433.94	392.538	392.52	-0.018
GCP135	2387573.7	518121.16	479.009	478.93	-0.079
GCP136	2440233.7	512748.71	492.987	492.99	0.003
GCP137	2355760.7	491599.96	404.075	404.24	0.165
GCP138	2379086.5	477001.41	659.876	659.81	-0.066
GCP139	2406968.8	488747.07	515.596	515.68	0.084
GCP140	2438302.4	489956.11	442.039	442.11	0.071
GCP141	2358076.4	451440.73	378.062	377.9	-0.162

GCP142	2398862.9	456888.4	600.75	600.89	0.14
GCP143	2426850.5	469882.58	410.45	410.46	0.01
GCP144	2438114.9	455376.87	554.746	554.8	0.054
GCP145	2439664.2	423105.68	374.32	374.47	0.15
GCP261	2612275.3	313357.02	506.555	506.52	-0.035
GCP262	2560500.8	318778.51	627.267	627.24	-0.027
GCP263	2507497.8	306883.21	353.361	353.49	0.129
GCP264	2546331.7	292556.78	402.795	402.94	0.145
GCP265	2570509.1	291884.61	634.218	634.35	0.132
GCP266	2607731.8	284524.03	532.072	531.96	-0.112
GCP274	2576275.9	276706.63	566.534	566.54	0.006
GCP275	2522461.7	271584.01	345.992	346.04	0.048
GCP276	2510235.1	239355.07	339.81	339.69	-0.12
GCP277	2559726	231545.1	372.201	372.16	-0.041
GCP278	2587443.4	240936.31	356.353	356.25	-0.103
GCP286	2629187.3	215286.2	378.749	378.58	-0.169
GCP287	2576156.8	200231.89	342.626	342.49	-0.136
GCP288	2523764.8	187997.7	363.319	363.23	-0.089
GCP289	2532704.8	161939.46	331.94	331.59	-0.35
GCP290	2592596.5	169874.52	336.736	336.77	0.034
GCP292	2582573.1	132304.82	313.983	313.88	-0.103

**Table8: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019, Illinois Project surveyed ground control points (GCPs).**

This project met Ground Control Point Vertical Accuracy (GCP)  $\leq 19.6$  cm at the 95% confidence level based on  $RMSE_z \leq 10$  cm  $\times 1.9600$ .

100 % of Totals	# of Points	RMSEz GCP (m)	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600)m
GCP	61	0.042	0.083

Table 9: Ground Control Points (GCP) vertical Accuracy of the RAW vertical accuracy results.

## DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, SurvTech Solutions and GRW 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.

Once the ground surface had been deduced through the filtering process a vegetation class was then extracted by distance from ground from the remaining class 1. Vegetation points were filtered by distance into Low Vegetation is 0.5-5 feet, Medium Vegetation is 5-20 feet, High Vegetation is >20 feet from the ground. Classes 3, 4, and 5 define low, medium, and high vegetation points respectively and were classified using an automated method. These vegetation classes represent all non-noise points that fall into the distances above the ground surface, and will likely include buildings, utility poles, powerlines, and other infrastructure.

In TerraScan surface models for each tile was created to examine the ground classification. ASI analysts visually reviewed the ground surface model for artifacts left in the ground classification. These artifacts consist of vegetation, buildings, and bridges that were still present in the ground after initial processing. ASI analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that errant points are removed from the ground classification. Bridge decks are manually classified to class 17. After the ground classification had been completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by the 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. No points were identified as withheld during the



classification so withheld bit was not applied. The LiDAR tiles were classified to the following classification schema:

- o Class 1 – Default, Processed, but unclassified
- o Class 2 – Ground, Bare-earth
- o Class 3 – Low Vegetation is 0.5-5 feet
- o Class 4 – Medium Vegetation is 5-20 feet
- o Class 5 – High Vegetation is >20 feet
- o Class 7 – Low Noise (low and manually identified)
- o Class 9 – Water
- o Class 17 – Bridge Decks
- o Class 18 – High Noise (high, manually identified)
- o Class 20 – Ignored Ground (Breakline Proximity)

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, the LAS files were then converted from LAS v1.2 to LAS v1.4 using TerraScan software to flag the overlap bit and withheld bit. LP360 64bit was used to deduce the Well Known Text (WKT) and an 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 62219693555 lidar points the following table shows the total number of points for every class.

Project Count by Class		
Class 1	Processed, unclassified	11245746770
Class 2	Bare-earth ground	21509139031
Class 3	Low vegetation (0.5-5 ft)	427427498
Class 4	Medium vegetation (5-20 ft)	1916893182
Class 5	High vegetation (>20 ft)	3086799794
Class 7	Low Noise	967624
Class 9	Water	144949058

Class 17	Bridge Decks	6389740
Class 18	High Noise	158219
Class 20	Ignored_Ground	1499212
Class Overlap 1	Overlap Processed, unclassified	12769023140
Class Overlap 2	Overlap Bare-earth ground	8001911158
Class Overlap 3	Overlap Low vegetation (0.5-5 ft)	277639293
Class Overlap 4	Overlap Medium vegetation (5-20 ft)	1180932947
Class Overlap 5	Overlap High vegetation (>20 ft)	1636112504
Class Overlap 7	Overlap Low Noise	196208
Class Overlap 9	Overlap Water	8618676
Class Overlap 17	Overlap Bridge Decks	4792551
Class Overlap 18	Overlap High Noise	89863
Class Overlap 20	Overlap Ignored_Ground	406877
Project Total Count		62219693555

Table 10: 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\_IL\_HicksDome\_FluorsparDist\_3\_2019 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. No unacceptable voids are present in the USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project.

### 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).

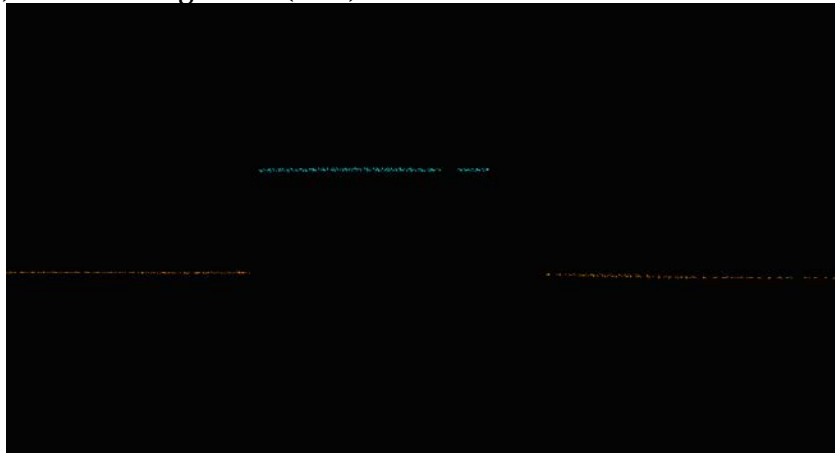


Figure 13: Profile view of a classified bridge deck (blue) and ground (orange).

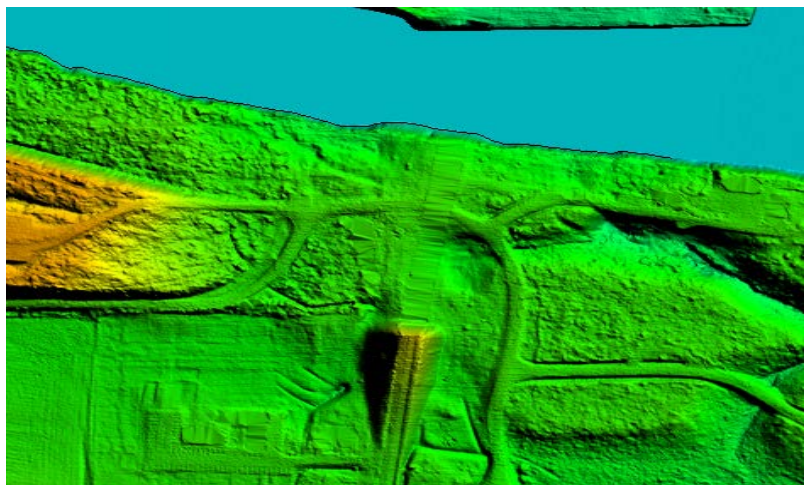
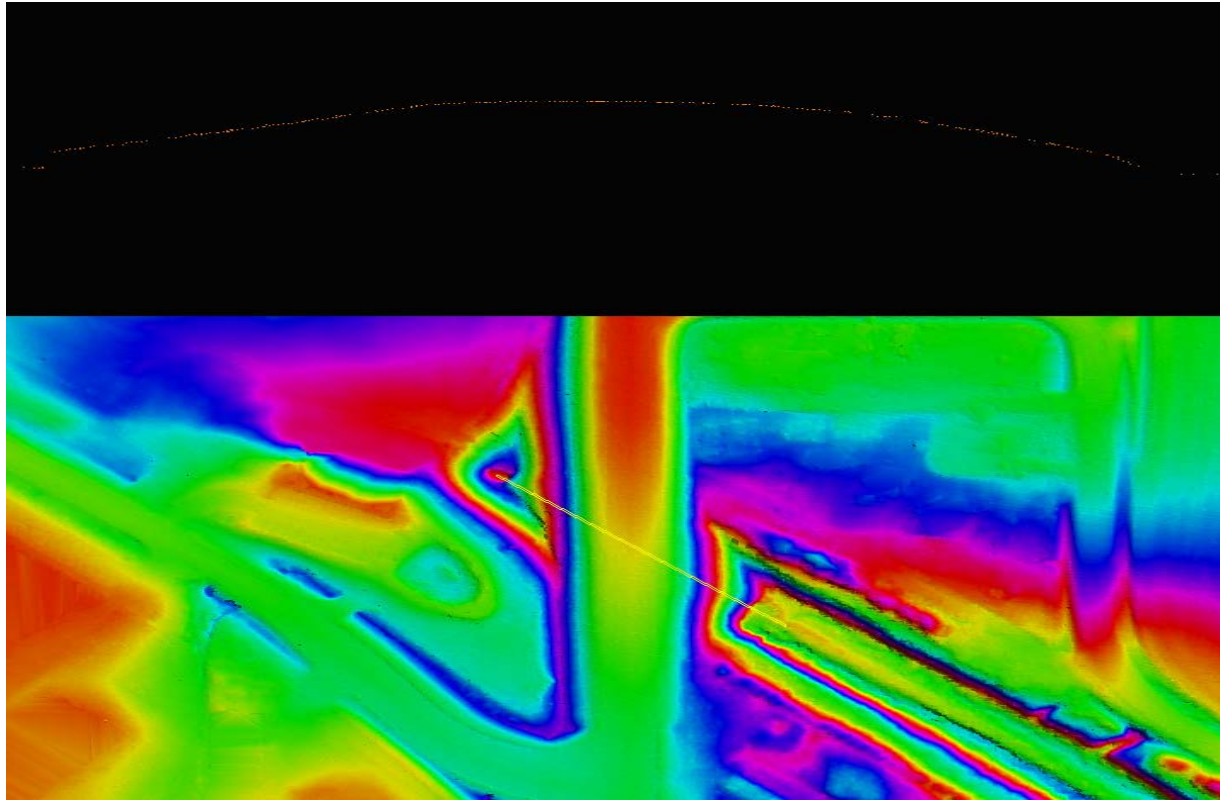


Figure 14: DEM with bridge removed from surface model.



### Culverts

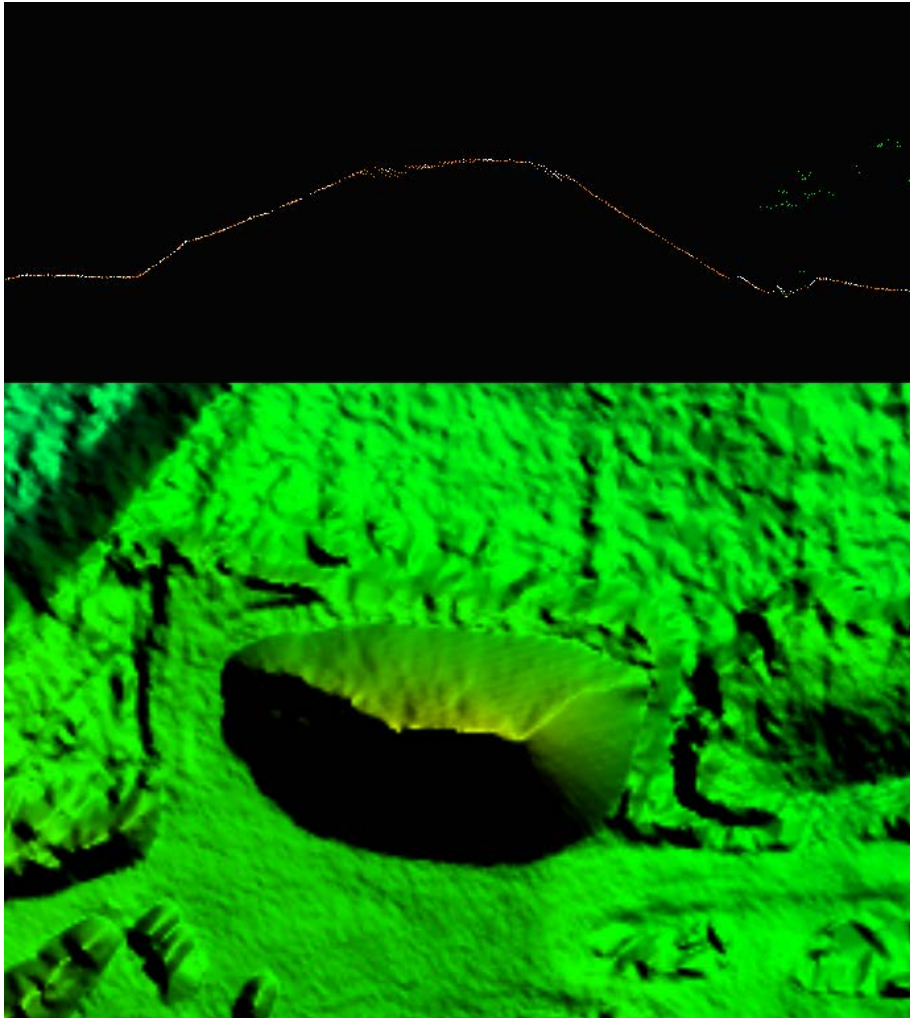
Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, ASI erred on assuming they would be culverts especially if they are on secondary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



**Figure 15: 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

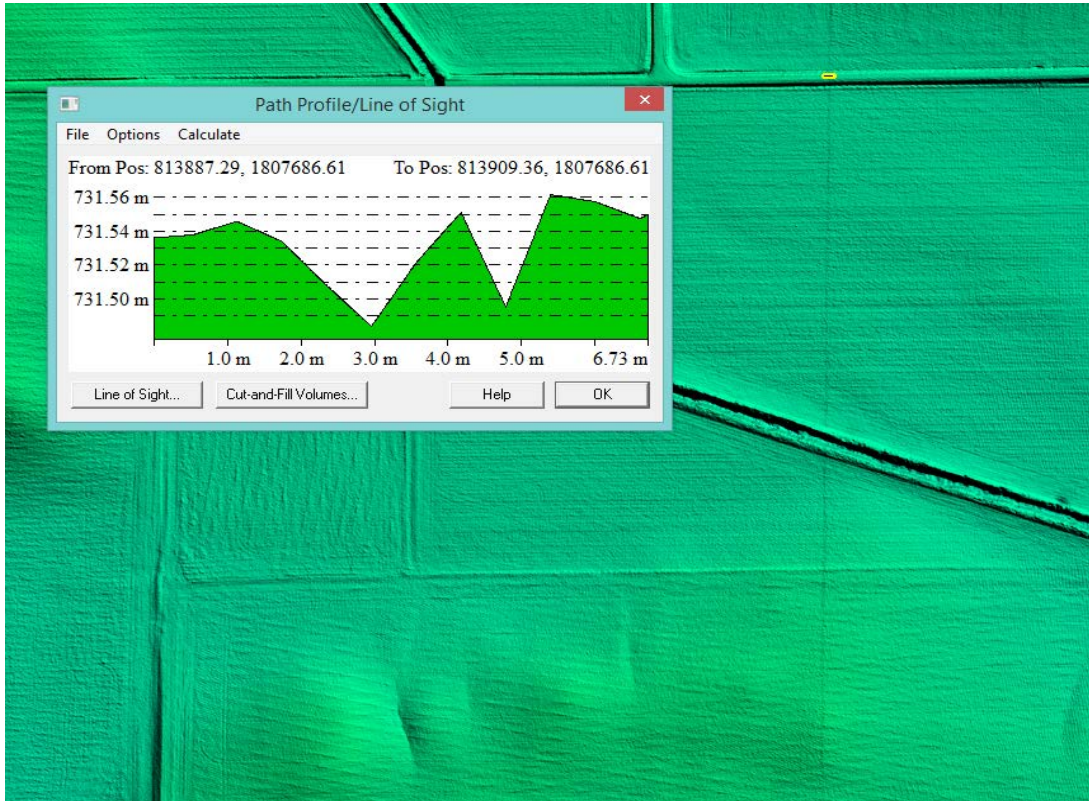
Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.



**Figure 16: 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.

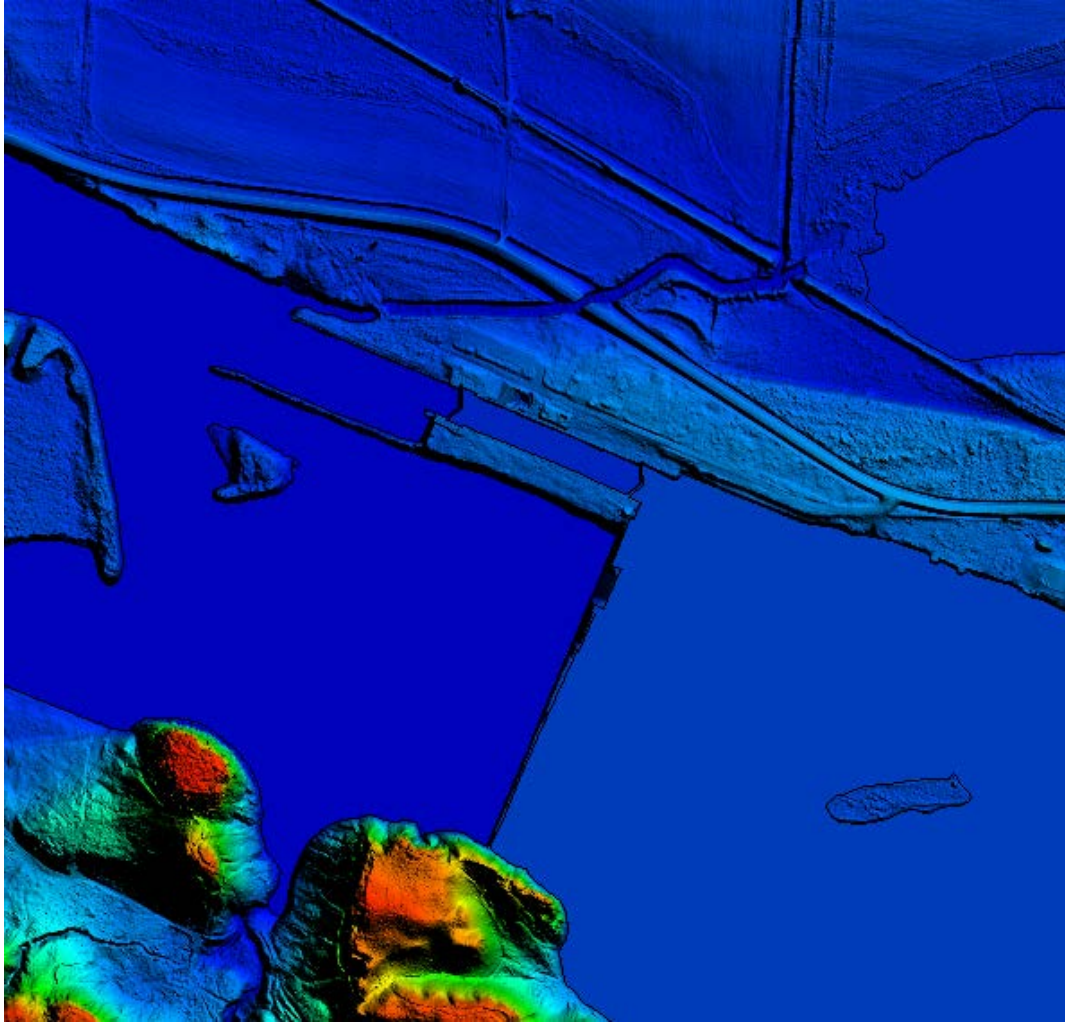


**Figure 17: The flight line ridge is less than 8 cm. Overall; USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project data meets the project specifications for 8 cm RMSDz relative accuracy requirement.**



### 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\_IL\_HicksDome\_FluorsparDist\_3\_2019 Lidar project area.



**Figure 18: DEM shows Large Dam structure that disrupts natural monotonic river flow, coupled with a lock system.**

## **FORMATTING**

After the final QA/QC is performed and all corrections have been applied to the dataset, all LiDAR files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using ASI proprietary tools. ASI routinely reviews for: proper LAS versions, Coordinate Reference System, Global Encoder Bit, Time Stamp, System ID, Multiple Returns, Intensity, Classification, Overlap and Withheld Points, Scan angle, XYZ Coordinates.

## LiDAR Positional Accuracy

### **BACKGROUND**

ASI quantitatively tested the dataset by testing the vertical accuracy of the LiDAR. The vertical accuracy is tested by comparing the discrete measurement of the survey checkpoints to that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. ASI also tests the horizontal accuracy of LiDAR datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the LiDAR. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the LiDAR cannot always be tested.

### **SURVEY VERTICAL ACCURACY CHECKPOINTS**

For the vertical accuracy assessment of USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project, Ninety seven check points were surveyed. All of those check points are located within bare earth/open terrain (97 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) State Plane IL_West	NAD83 (2011) State Plane IL_West	NAVD88 (Geoid192B)
	Easting (USft)	Northing (USft)	Elevation (USft)
101NVA	2296542.34	725746.11	414.32
102NVA	2316308.98	713837.65	421.26
103NVA	2340098.7	705062.28	602.82
104NVA	2348396.23	717709.54	570.18
105NVA	2397409.6	707604.29	475.32
106NVA	2430746.73	727025.92	517.56
107NVA	2399404.09	688205.91	446.73
108NVA	2373085.7	698019.37	537.42
109NVA	2345845.9	687531.73	589.2
110NVA	2313288.39	693401.95	417.17
111NVA	2295687.41	700221.82	409.64
112NVA	2285215.76	672470.62	409.74
113NVA	2264350.8	664211.08	508.24
114NVA	2316750.52	667155.52	540.23
115NVA	2333197.47	674206.61	550.62
116NVA	2361948.46	666077.76	488.25
117NVA	2395818.45	666836.64	431.97
118NVA	2428883.31	660675.88	425.25
119NVA	2415501.37	644708.63	416.03
120NVA	2373235.93	639436.23	496.8
121NVA	2349363.47	647201.81	472.43
122NVA	2325921.22	656519.47	576.03
123NVA	2286143.14	654147.85	458.03
124NVA	2272781.44	633494.63	409.95
125NVA	2296914.05	636029.19	681.78
126NVA	2322737.38	643049.38	586.79
127NVA	2347132.35	625452.29	472.67
128NVA	2370513.45	618723.55	444.06

129NVA	2401907.94	623269.73	412.1
130NVA	2345847.63	603131.3	470.89
131NVA	2327945.15	622087.15	527.98
132NVA	2303504.82	608363.13	681.28
133NVA	2268913.17	618775.54	418.61
135NVA	2264210.09	598252.73	748.7
136NVA	2300651.22	582776.13	653.18
137NVA	2325555.83	597562.97	530.45
138NVA	2346095.69	584924.09	441.68
139NVA	2398959.66	591986.09	446.37
140NVA	2424175.75	597098.6	430.71
141NVA	2429756.51	563262.97	516.3
142NVA	2386362.74	571128.47	419.17
143NVA	2360867.47	557330.77	416.83
144NVA	2324972.12	574642.07	560.45
145NVA	2287443.65	567070.27	738.91
146NVA	2246061.44	569170.17	412.17
147NVA	2260137.99	551045.8	412.51
148NVA	2301818.27	555331.04	676.19
149NVA	2345824.43	547958.18	427.4
150NVA	2389273.00	535433.54	489.54
151NVA	2415002.7	553791.64	503.35
152NVA	2452204.39	543279.92	515.14
153NVA	2461732.34	517927.9	513.97
154NVA	2427487.88	530392.46	536.46
155NVA	2408162.49	518205.88	547.66
156NVA	2357027.48	526909.16	490.74
157NVA	2329949.98	527626.2	588.97
158NVA	2294878.33	528257.59	389.8
159NVA	2333700.24	504086.53	391.03
160NVA	2363240.87	507711.11	522.37
161NVA	2371112.43	491849.48	520.04
162NVA	2392423.94	499338.25	521.98
163NVA	2430895.84	507388.67	494.67
164NVA	2428496.21	490907.18	463.15
165NVA	2454818.47	491990.2	479.65
166NVA	2443856.09	466307.2	533.77
167NVA	2416795.25	474040.49	563.7
168NVA	2359157.37	480469.74	381.55
169NVA	2379782.26	468865.42	698.47
170NVA	2372452.13	450080.28	375.39

171NVA	2393166.45	456700.02	631.43
172NVA	2435378.77	447487.97	560.61
173NVA	2431014.8	427804.62	374.16
174NVA	2349301.35	672918.99	529.53
175NVA	2299800.82	711609.76	412.67
176NVA	2415893.51	580039.03	445.61
292NVA	2570696.98	319518.47	653.88
293NVA	2541698.61	332330.43	763.43
294NVA	2498172.27	326278.79	370.68
295NVA	2520131.7	285224.75	349.66
296NVA	2555410.52	286421.91	527.94
297NVA	2592970.91	286382.7	489.22
307NVA	2590359.36	258302.87	393.07
308NVA	2560640.04	250533.14	388.09
309NVA	2520820.84	255919.9	341.5
310NVA	2505504.3	229660.19	337.58
312NVA	2582328.37	223169.78	338.4
313NVA	2629530.4	227946.06	344.19
322NVA	2600211.84	210841.11	404.78
323NVA	2559939.73	210126.4	338.82
324NVA	2505156.61	202460.22	431.03
325NVA	2532267.37	183896.62	341.83
326NVA	2556773.23	169920.68	333.84
327NVA	2609261.49	189037.32	338.42
332NVA	2578974.34	165778.24	330.03
333NVA	2561954.7	156730.96	335.52
334NVA	2531863.11	155476.72	328.99
336NVA	2592937.37	118837.21	335.24

Table 11: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project NVA LiDAR Checkpoints.

Point ID	NAD83 (2011) State Plane IL_West	NAD83 (2011) State Plane IL_West	NAVD88 (Geoid192B)
	Easting (USft)	Northing (USft)	Elevation (USft)
101VVA	2295779.22	724429.47	414.25
102VVA	2330705.43	724059.7	419.08
103VVA	2374940.42	719058.00	541.52



104VVA	2419461.78	719092.39	499.58
105VVA	2415317.25	685946.41	467.93
106VVA	2380243.53	698564.88	512.56
107VVA	2346339.46	696797.58	573.09
108VVA	2317147.1	690930.76	423.83
109VVA	2286926.13	689343.73	407.33
110VVA	2284965.39	662704.56	498.37
111VVA	2317086.73	667145.55	533.24
112VVA	2359350.1	675036.94	495.48
113VVA	2412766.42	662383.39	418.46
114VVA	2422342.24	646537.65	412.67
115VVA	2378750.56	639211.76	471.81
116VVA	2348292.71	638087.53	454.16
117VVA	2308212.42	646527.6	651.07
118VVA	2279398.25	643837.94	533.36
119VVA	2247964.22	620878.92	404.19
120VVA	2282503.5	616685.61	547.95
121VVA	2308903.1	619343.14	583.57
122VVA	2340535.28	622325.63	491.25
123VVA	2360219.09	620274.34	427.09
124VVA	2403181.34	621974.93	414.12
125VVA	2420968.29	602563.00	417.75
126VVA	2381264.04	599889.11	417.51
127VVA	2342943.47	596619.1	463.64
128VVA	2305105.08	587333.08	633.3
129VVA	2273778.84	597954.58	687.97
130VVA	2245513.58	591932.48	398.79
131VVA	2259547.72	559997.73	385.88
132VVA	2278756.92	574462.95	676.9
133VVA	2301192.41	560479.41	664.66
134VVA	2345379.53	570390.41	444.75
135VVA	2396001.29	575007.8	411.47
136VVA	2408605.19	550240.54	455.62
137VVA	2453783.54	554733.43	555.65
138VVA	2438526.63	530077.13	532.23
139VVA	2421455.59	533275.72	506.00
140VVA	2389462.09	533871.69	448.94
141VVA	2368396.42	554788.05	410.18
142VVA	2328479.6	544895.06	483.77
143VVA	2274870.39	538777.99	393.58
144VVA	2306649.5	529549.01	399.63

145VVA	2333866.91	521877.92	532.97
146VVA	2343162.51	503502.65	578.22
147VVA	2394968.25	499308.37	496.34
148VVA	2418955.44	507753.87	508.32
149VVA	2450101.71	501945.99	460.82
150VVA	2453641.15	489362.55	477.76
151VVA	2418812.48	493217.04	459.51
152VVA	2376826.23	475142.54	652.88
153VVA	2357273.08	451360.15	376.76
154VVA	2406352.13	462019.83	496.58
155VVA	2439384.63	461418.81	525.5
156VVA	2426741.65	444804.88	550.36
157VVA	2439911.6	421818.47	366.91
158VVA	2374535.82	584520.42	398.41
159VVA	2375038.95	626980.98	436.24
260VVA	2613629.06	313504.55	484.57
274VVA	2593780.79	286217.51	484.77
275VVA	2555332.55	286330.85	527.84
276VVA	2542167.36	330613.9	733.76
277VVA	2510407.31	302803.83	349.33
278VVA	2517552.18	255860.91	353.09
279VVA	2587535.2	254080.9	394.89
287VVA	2612445.16	236156.83	347.43
288VVA	2559789.00	231533.61	369.39
289VVA	2492025.08	229062.94	338.48
290VVA	2504148.51	203942.28	460.95
291VVA	2576425.72	200456.52	341.93
296VVA	2579667.2	165849.98	329.9
297VVA	2532931.56	163082.6	332.26
299VVA	2585525.32	122779.16	313.93

**Table 12: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project VVA LiDAR Checkpoints.**

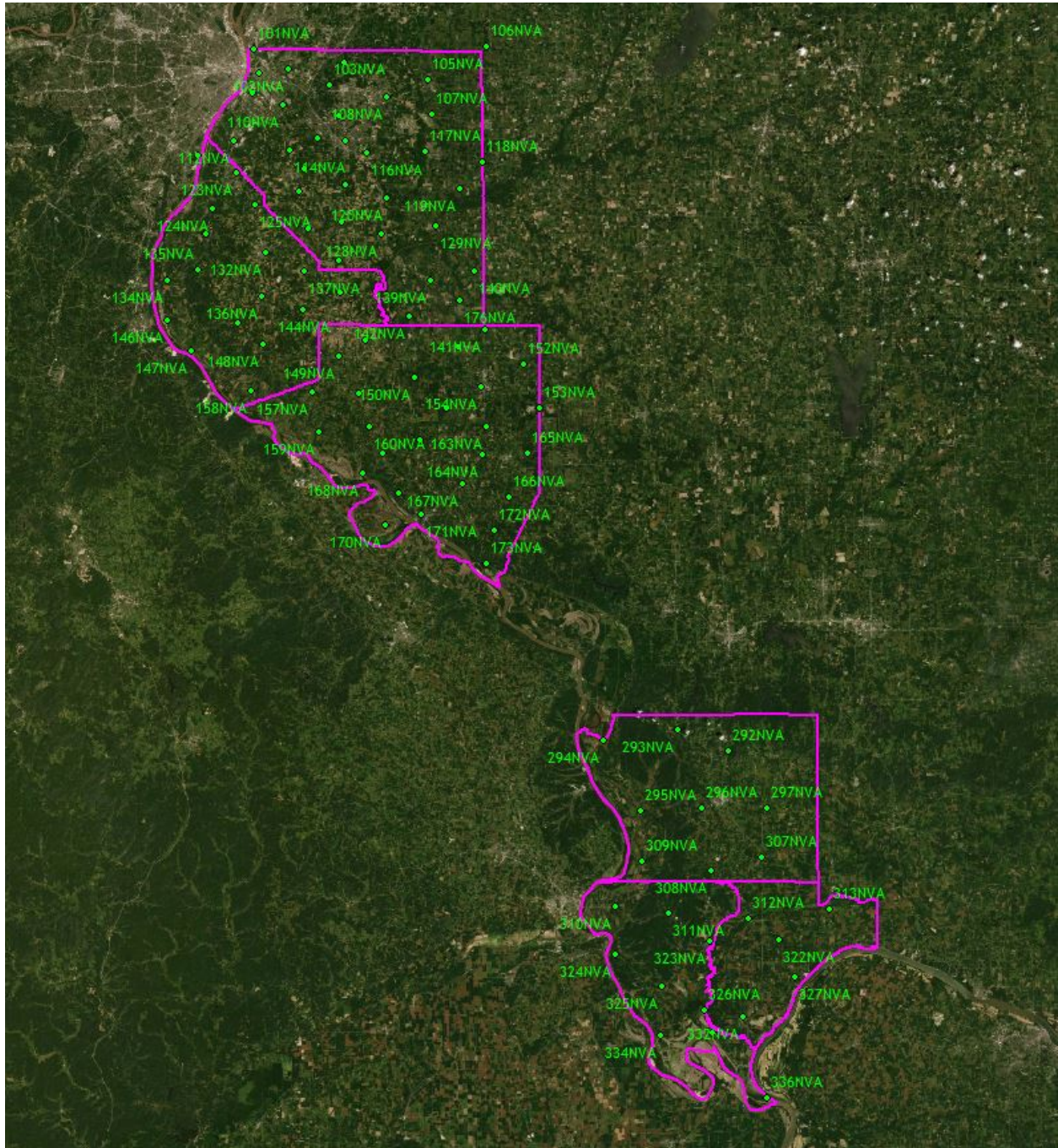


Figure 19: Location of USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 LiDAR NVA Checkpoints



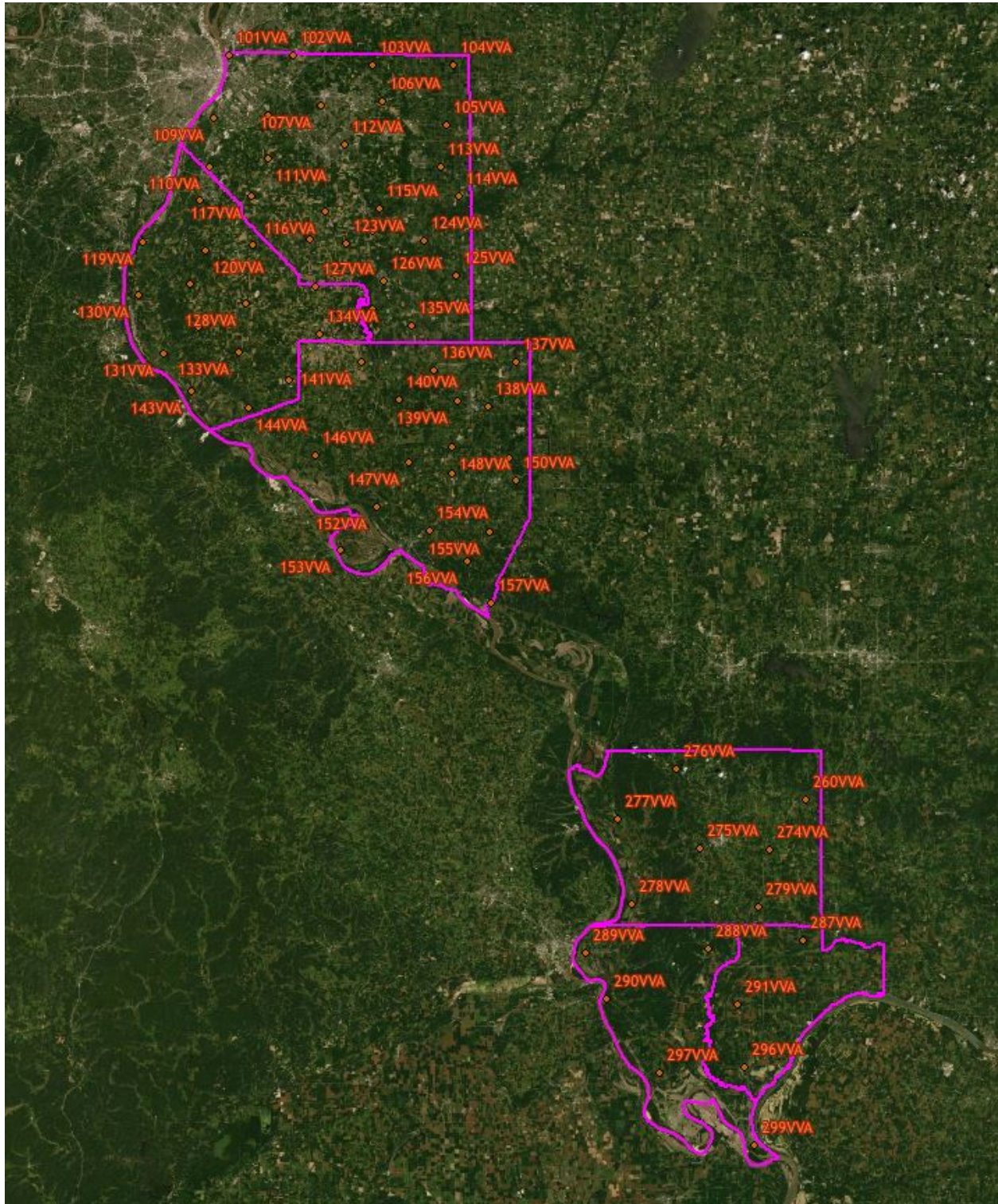


Figure 20: VVA Checkpoints located in USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019

## 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\_IL\_HicksDome\_FluorsparDist\_3\_2019 project, vertical accuracy must be 19.6 cm or less based on an RMSEz of 10 cm x 1.9600. VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 Lidar project VVA standard is 29.4 cm based on the 95th percentile.

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

**Table 13: Acceptance Criteria.**

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

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

## VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (95% confidence)Spec = 0.196 m	VVA – Vegetated Vertical Accuracy (95 <sup>th</sup> Percentile) spec = 0.294 m
NVA	97	0.111	
VVA	74		0.119

Table 14: Tested NVA and VVA.

The following table contains results from vertical testing of Non-vegetated Vertical Accuracy(NVA) checkpoints against elevation values in the classified Lidar LAS files.

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	97	0.057	0.111	-0.027	-0.027	0.506	0.050	-0.308	0.082	2.75

Table 15: Non Vegetated Vertical (NVA) accuracy assessment results.

## HORIZONTAL ACCURACY TEST PROCEDURES

This data set was produced to meet ASPRS “Positional Accuracy Standards for Digital Geospatial Data” (2014) for an overall horizontal accuracy of +/- 29 (cm) RMSE<sub>x</sub> / RMSE<sub>y</sub> Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 57 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 project boundary. Breaklines are in the same coordinate reference system and unit of measure as the LiDAR point delivery. Hydrologic water-surface edges are set at or just below the immediately surrounding terrain. Breaklines are developed to the limit of the project boundary.

### **BREAKLINE QUALITATIVE ASSESSMENT**

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

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

### **FEATURE DEFINITION**

#### **Inland Streams and Rivers**

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

#### **Inland Ponds and Lakes**

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

#### **Islands**

Permanent island 0.4 hectares (1 acre) or larger were delineated within all water bodies. Breaklines have been delivered in PolygonZ format in the final GDB

#### **Bridge Breaklines**

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



## Intensity Imagery Production & Qualitative Assessment

### **INTENSITY PRODUCTION METHODOLOGY**

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

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

### **INTENSITY QUALITATIVE ASSESSMENT**

ASI performed a qualitative assessment of the Intensity deliverables to ensure that all tiled Intensity products were delivered with the proper extents, and contained proper referencing information. This lidar survey was conducted over a span of time consisting of both day and nighttime missions. In this data set Lidar collected during daytime hours tends to have intensity returns of lighter higher range values as opposed to dark lower range value intensity returns of missions flown at night. Lighter daytime and darker nighttime intensity values are evident in the intensities of this dataset. Intensity values vary due to how the intensity value is recorded by each scanner used for the collection. A linear adjustment has been applied to the LAS of this project to help balance the light and dark contrasts between scanners.

The following Figure is an example of an Intensity Image.

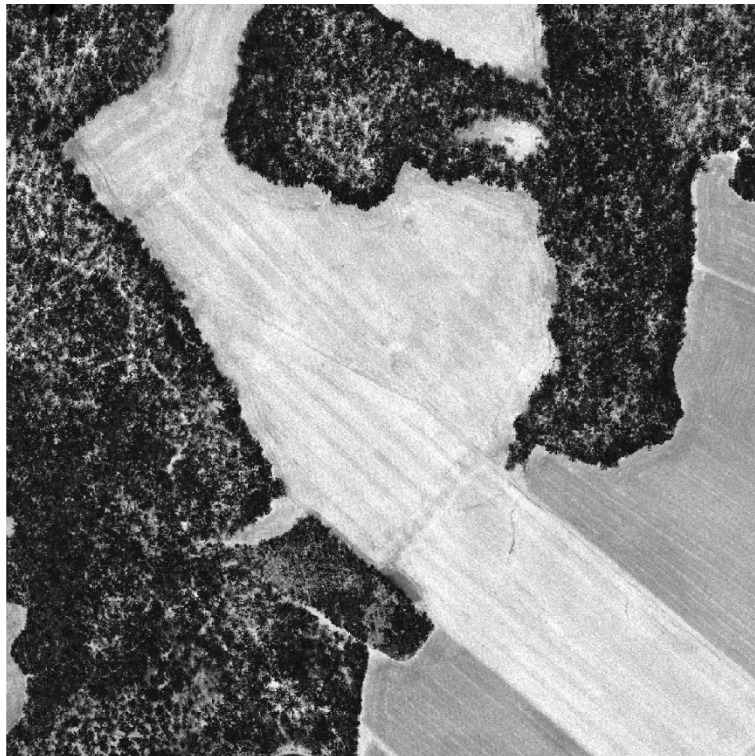


Figure 21: Intensity Image example.

## DEM Production & Qualitative Assessment

### DEM PRODUCTION METHODOLOGY

ASI utilized MicroStation in conjunction with TerraSolid's TerraScan and TerraModeler for DEM production. Global Mapper 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 hydro flattened bare earth DEM.

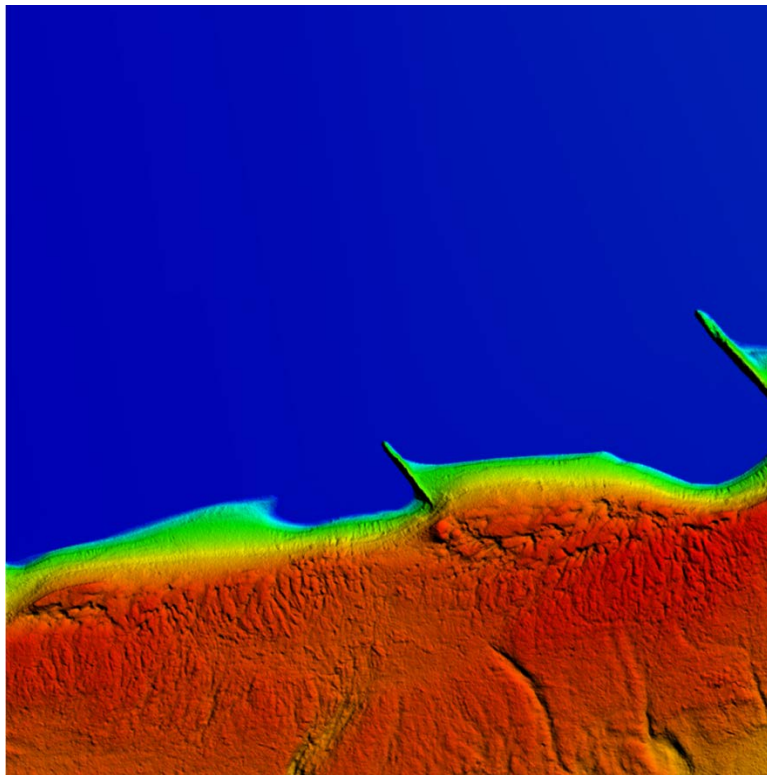


Figure 22: USGS\_IL\_HicksDome\_FluorsparDist\_3\_2019 project bare earth DEM

## DEM VERTICAL ACCURACY RESULTS

The same 97 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 Table below; summarizes the tested vertical accuracy result from a comparison of surveyed checkpoint to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSEz x 1.960)	VVA – Vegetated Vertical Accuracy (95 <sup>th</sup> percentile)
NVA	97	0.126	
VVA	74		0.119

**Table 16: 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 = 0.064 meters with a 0.126 m accuracy at 95 % confidence level. Actual VVA accuracy tested 0.119 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\_IL\_HicksDome\_FluorsparDist\_3\_2019 project satisfies the project's pre-defined vertical accuracy criteria.

## Appendix A: List of Delivered LAS File

2235_5750	2239_5810	2241_5990	2243_6070	2245_6130
2235_5770	2239_5830	2241_6010	2243_6090	2245_6150
2235_5790	2239_5850	2241_6030	2243_6110	2245_6170
2235_5810	2239_5870	2241_6050	2243_6130	2245_6190
2235_5830	2239_5890	2241_6070	2243_6150	2245_6210
2235_5850	2239_5910	2241_6090	2243_6170	2245_6230
2235_5870	2239_5930	2241_6110	2243_6190	2245_6250
2237_5650	2239_5950	2241_6130	2243_6210	2245_6270
2237_5670	2239_5970	2241_6150	2243_6230	2245_6290
2237_5750	2239_5990	2241_6170	2243_6250	2245_6310
2237_5770	2239_6010	2241_6190	2243_6270	2247_5510
2237_5790	2239_6030	2241_6210	2245_5550	2247_5530
2237_5810	2239_6050	2241_6230	2245_5570	2247_5550
2237_5830	2239_6070	2241_6250	2245_5590	2247_5570
2237_5850	2239_6090	2241_6270	2245_5610	2247_5590
2237_5870	2239_6110	2243_5550	2245_5630	2247_5610
2237_5890	2239_6130	2243_5590	2245_5650	2247_5630
2237_5910	2239_6150	2243_5610	2245_5670	2247_5650
2237_5930	2239_6170	2243_5630	2245_5690	2247_5670
2237_5950	2239_6190	2243_5650	2245_5710	2247_5690
2237_5970	2241_5590	2243_5670	2245_5730	2247_5710
2237_5990	2241_5610	2243_5690	2245_5750	2247_5730
2237_6010	2241_5630	2243_5710	2245_5770	2247_5750
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2237_6050	2241_5670	2243_5750	2245_5810	2247_5790
2237_6070	2241_5690	2243_5770	2245_5830	2247_5810
2237_6090	2241_5710	2243_5790	2245_5850	2247_5830
2237_6110	2241_5730	2243_5810	2245_5870	2247_5850
2237_6130	2241_5750	2243_5830	2245_5890	2247_5870
2237_6150	2241_5770	2243_5850	2245_5910	2247_5890
2237_6170	2241_5790	2243_5870	2245_5930	2247_5910
2237_6190	2241_5810	2243_5890	2245_5950	2247_5930
2239_5650	2241_5830	2243_5910	2245_5970	2247_5950
2239_5670	2241_5850	2243_5930	2245_5990	2247_5970
2239_5690	2241_5870	2243_5950	2245_6010	2247_5990
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2239_5750	2241_5930	2243_6010	2245_6070	2247_6050
2239_5770	2241_5950	2243_6030	2245_6090	2247_6070
2239_5790	2241_5970	2243_6050	2245_6110	2247_6090

2247_6110	2249_6130	2251_6070	2253_6010	2255_5910
2247_6130	2249_6150	2251_6090	2253_6030	2255_5930
2247_6150	2249_6170	2251_6110	2253_6050	2255_5950
2247_6170	2249_6190	2251_6130	2253_6070	2255_5970
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2247_6290	2249_6310	2251_6250	2253_6190	2255_6090
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2249_5550	2251_5490	2251_6330	2253_6270	2255_6170
2249_5570	2251_5510	2251_6350	2253_6290	2255_6190
2249_5590	2251_5530	2251_6370	2253_6310	2255_6210
2249_5610	2251_5550	2253_5490	2253_6330	2255_6230
2249_5630	2251_5570	2253_5510	2253_6350	2255_6250
2249_5650	2251_5590	2253_5530	2253_6370	2255_6270
2249_5670	2251_5610	2253_5550	2253_6390	2255_6290
2249_5690	2251_5630	2253_5570	2253_6410	2255_6310
2249_5710	2251_5650	2253_5590	2255_5490	2255_6330
2249_5730	2251_5670	2253_5610	2255_5510	2255_6350
2249_5750	2251_5690	2253_5630	2255_5530	2255_6370
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2249_6070	2251_6010	2253_5950	2255_5850	2257_5710
2249_6090	2251_6030	2253_5970	2255_5870	2257_5730
2249_6110	2251_6050	2253_5990	2255_5890	2257_5750

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2257_5990	2259_5830	2261_5570	2261_6410	2263_6010
2257_6010	2259_5850	2261_5590	2261_6430	2263_6030
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2257_6350	2259_6190	2261_5930	2263_5530	2263_6370
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2257_6430	2259_6270	2261_6010	2263_5610	2263_6450
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2259_5510	2259_6350	2261_6090	2263_5690	2263_6530
2259_5530	2259_6370	2261_6110	2263_5710	2263_6550
2259_5550	2259_6390	2261_6130	2263_5730	2263_6570
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2265_5450	2265_6290	2267_5710	2267_6550	2269_5890
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2265_5550	2265_6390	2267_5810	2267_6650	2269_5990
2265_5570	2265_6410	2267_5830	2267_6670	2269_6010
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2271_5610	2271_6450	2273_5670	2273_6510	2275_5630
2271_5630	2271_6470	2273_5690	2273_6530	2275_5650
2271_5650	2271_6490	2273_5710	2273_6550	2275_5670
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2275_5990	2275_6830	2277_5910	2277_6750	2279_5770
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2603_2390	2603_3230	2605_2250	2605_3090	2607_2130
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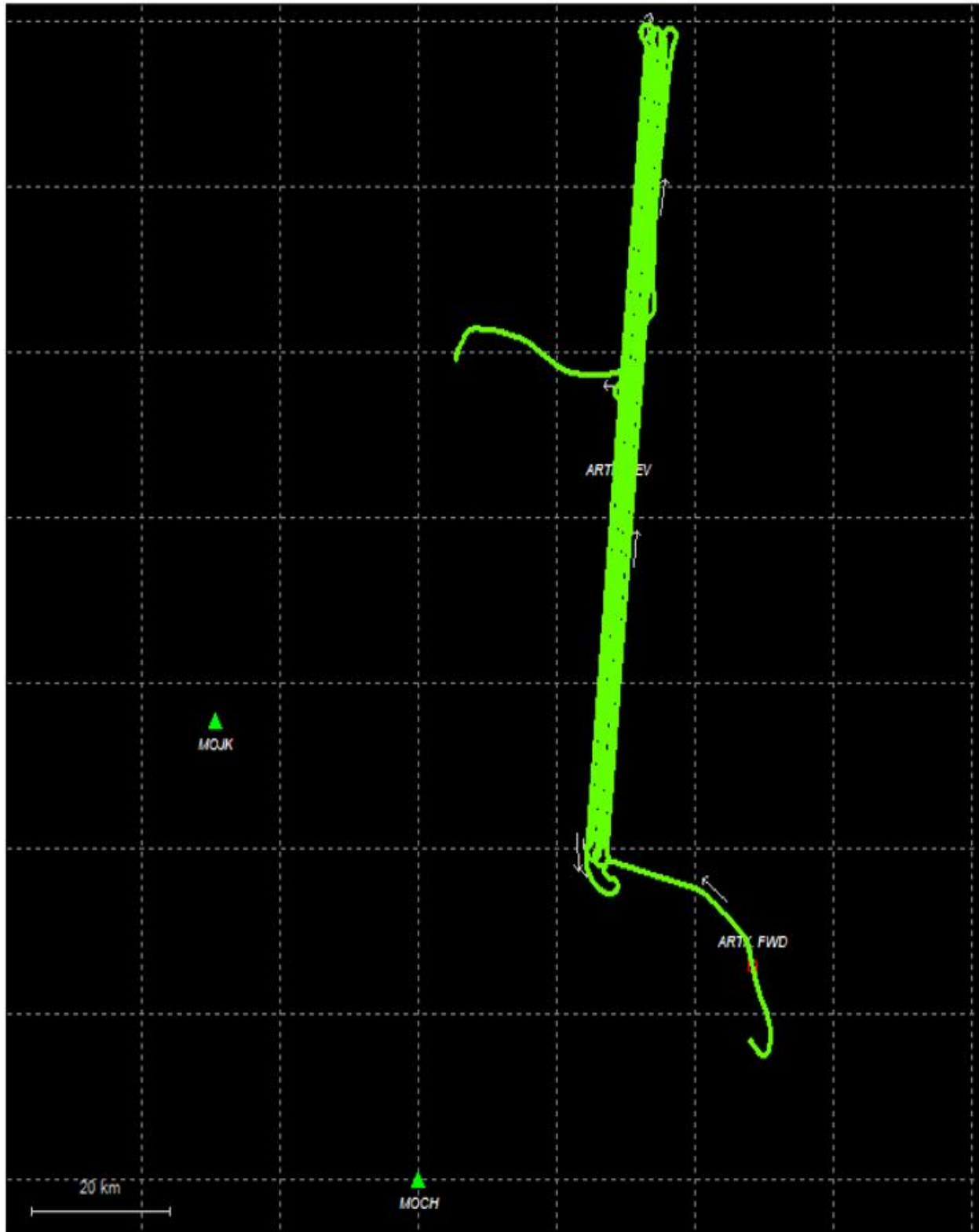
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2641_2330	2645_2210	2649_2090	2651_2350	2655_2210
2641_2350	2645_2230	2649_2110	2651_2370	2655_2230
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2643_2330	2647_2210	2651_2110	2653_2330	2657_2210
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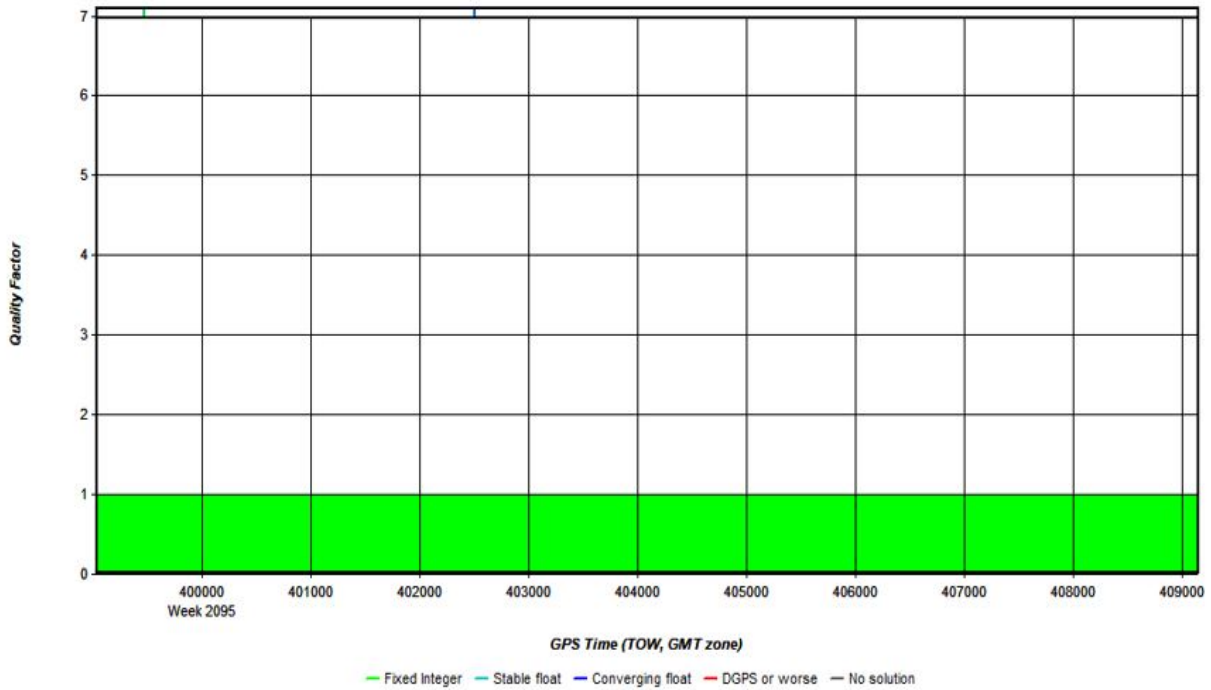
## Appendix B: Mission GPS and IMU Processing Report

Top View

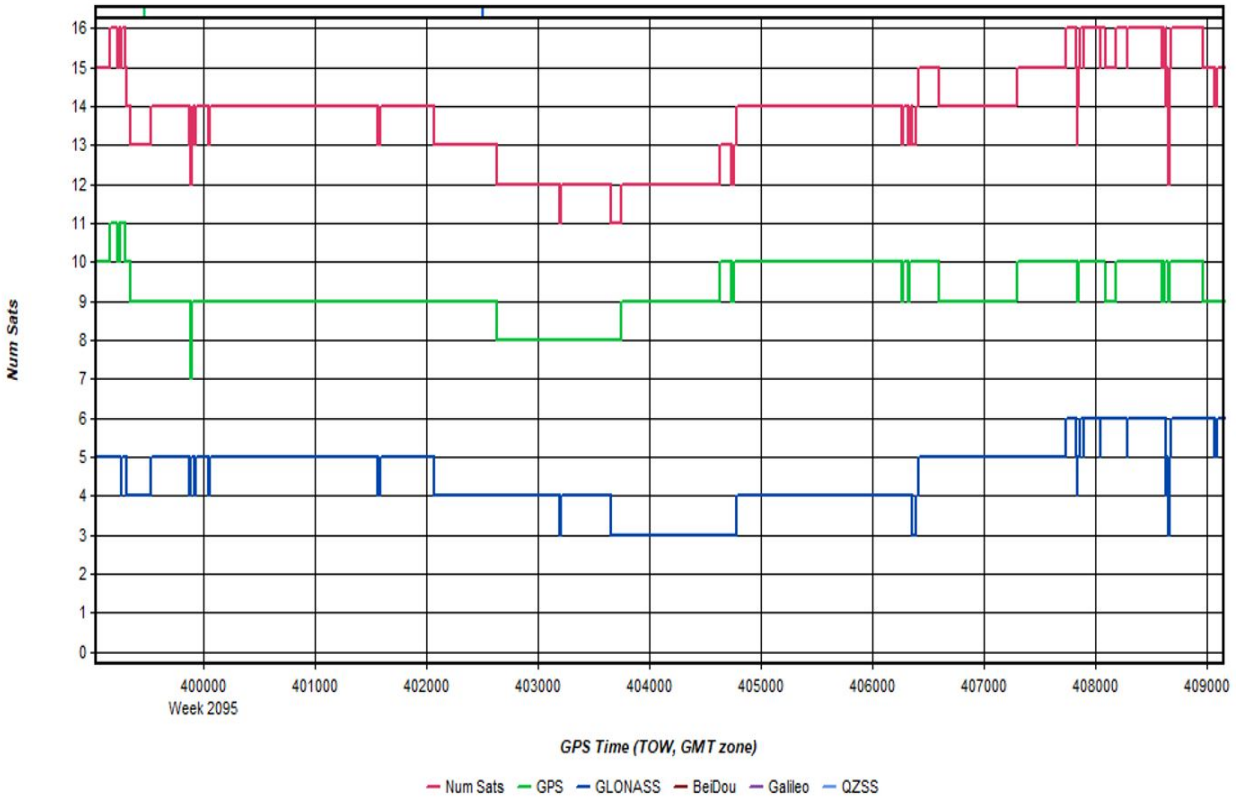


## GNSS QC

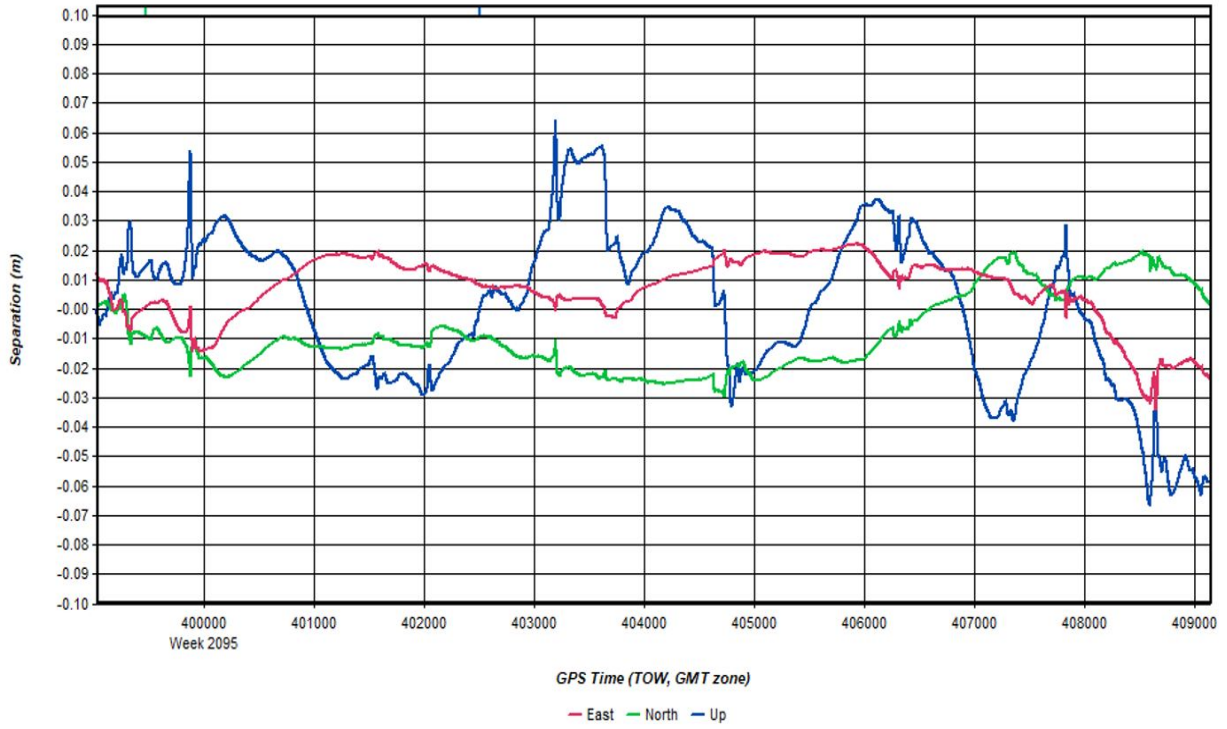
### GNSS Quality Factor



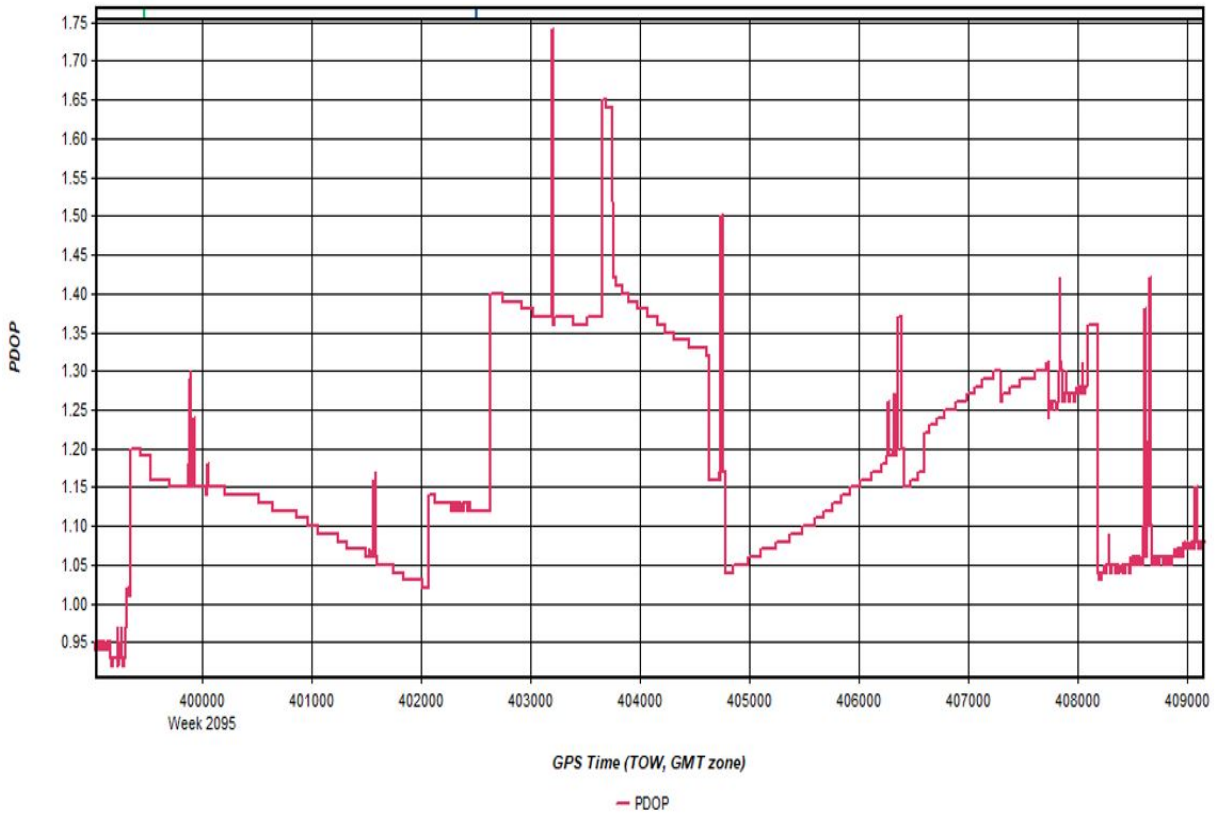
### Number of Satellites



### Forward/Reverse Separation



### PDOP



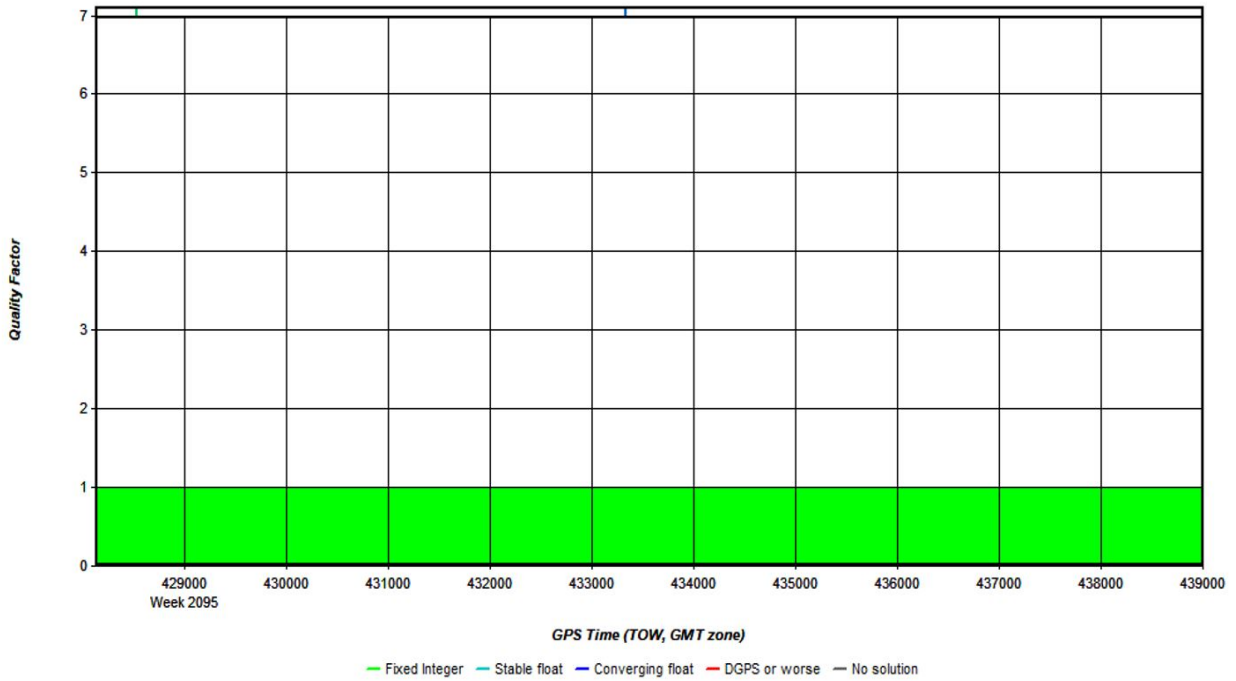
HicksDome\_20200305\_225309.docx QC Report – 5/11/2020 14:55:12  
Smoothed Trajectory Information

Top View

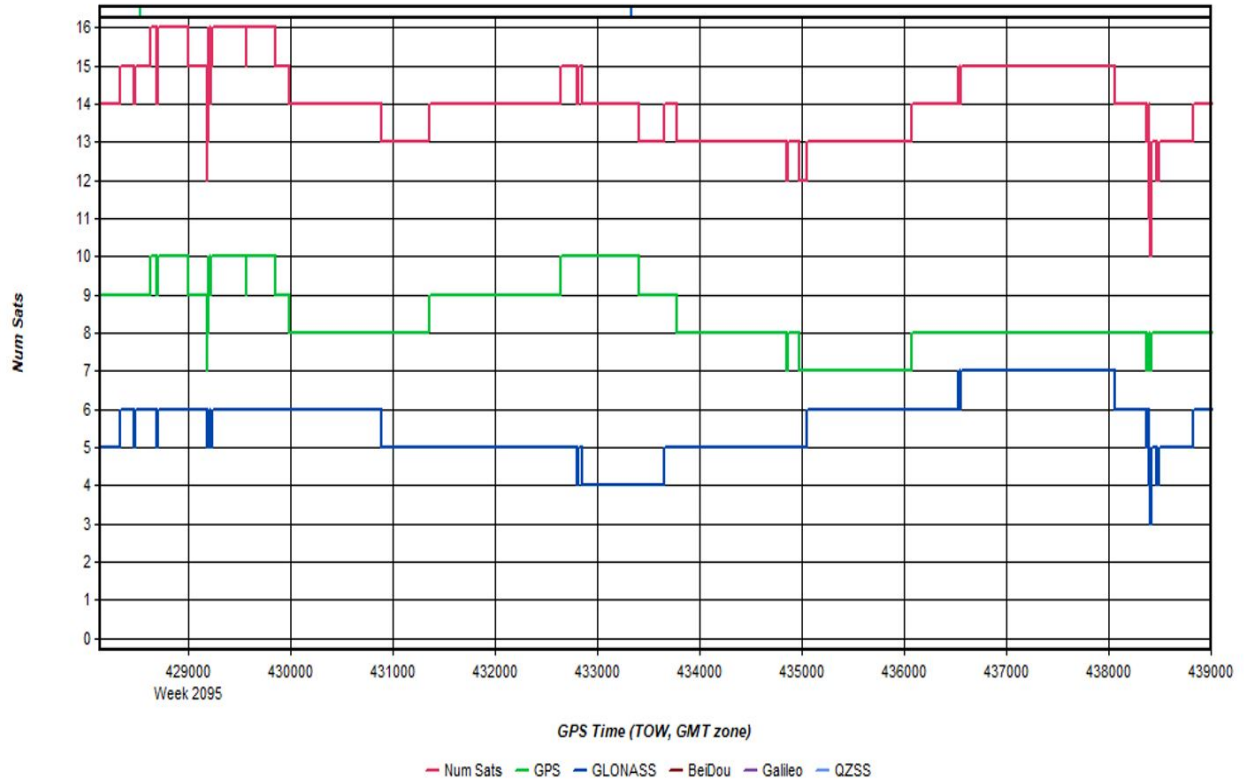


## GNSS QC

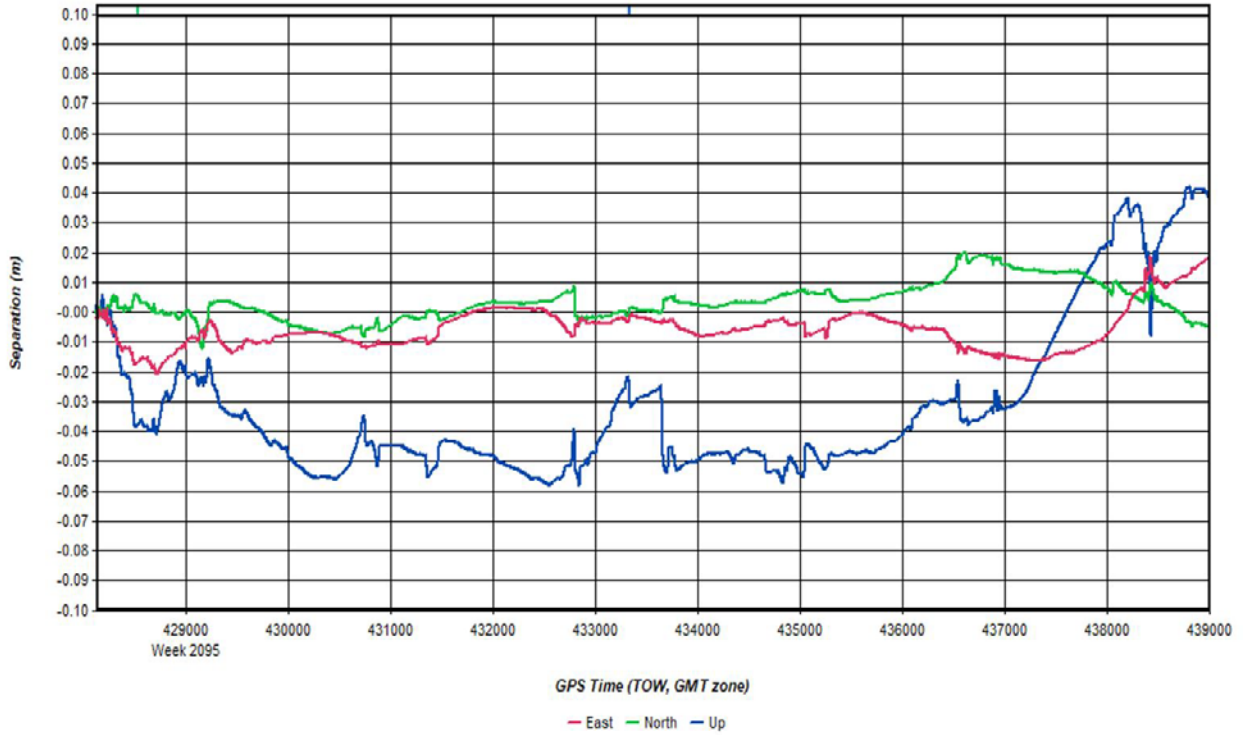
### GNSS Quality Factor



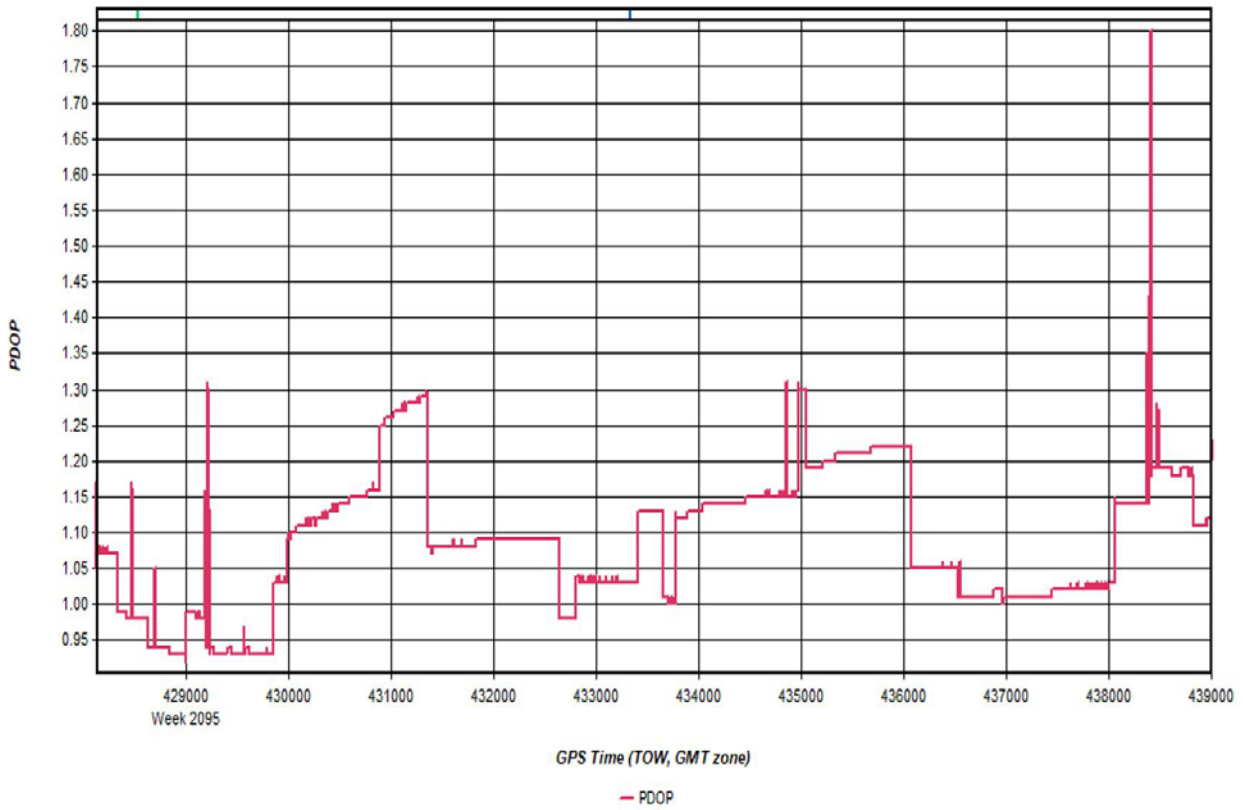
### Number of Satellites



### Forward/Reverse Separation



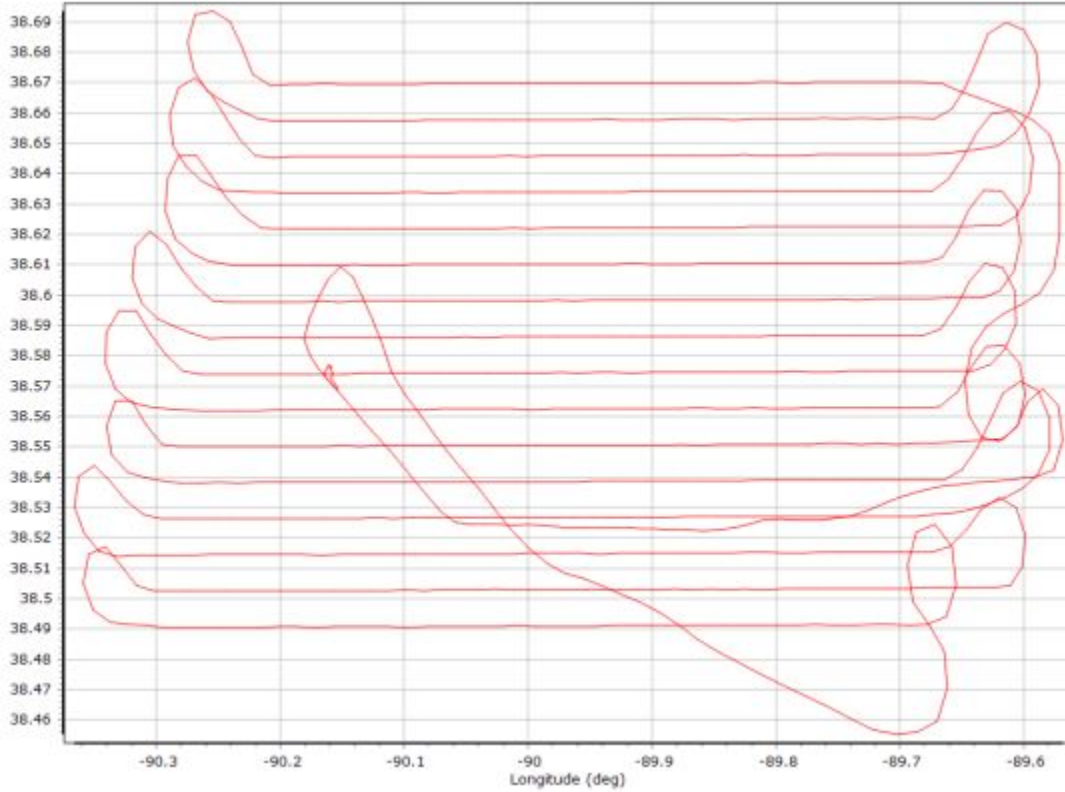
### PDOP





201202A.docx QC Report - 06/21/2021 14:13:25  
**Smoothed Trajectory Information**

Top View

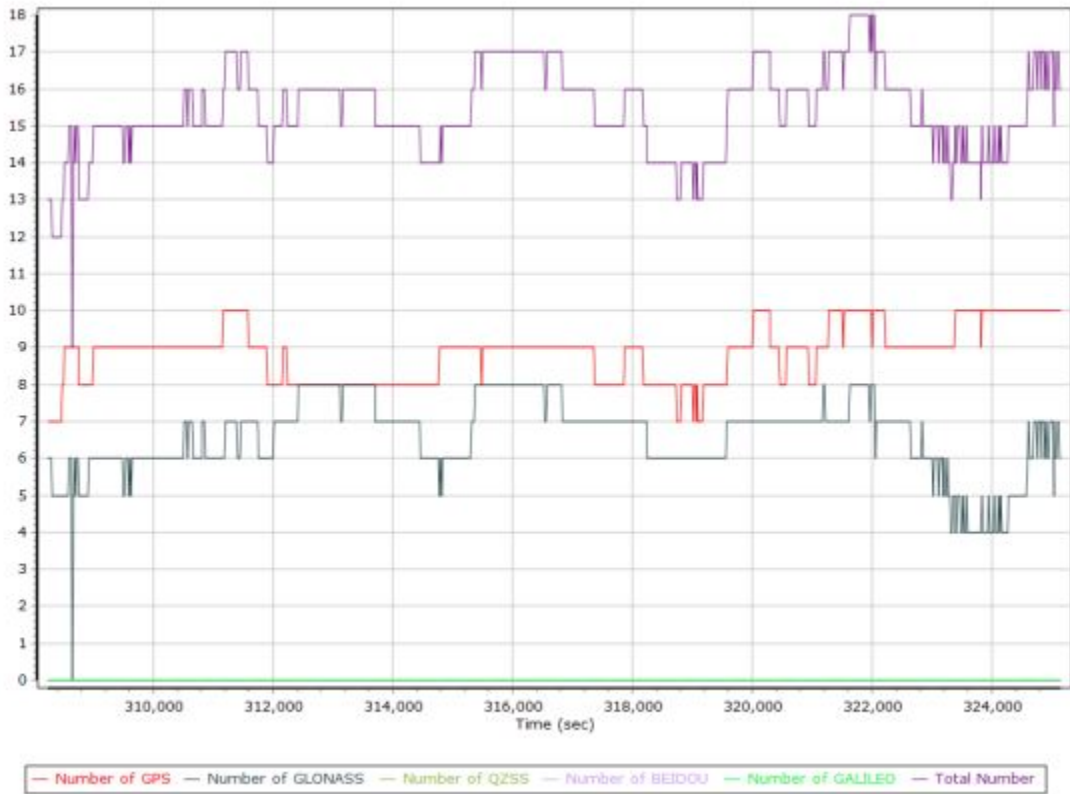


**GNSS QC**

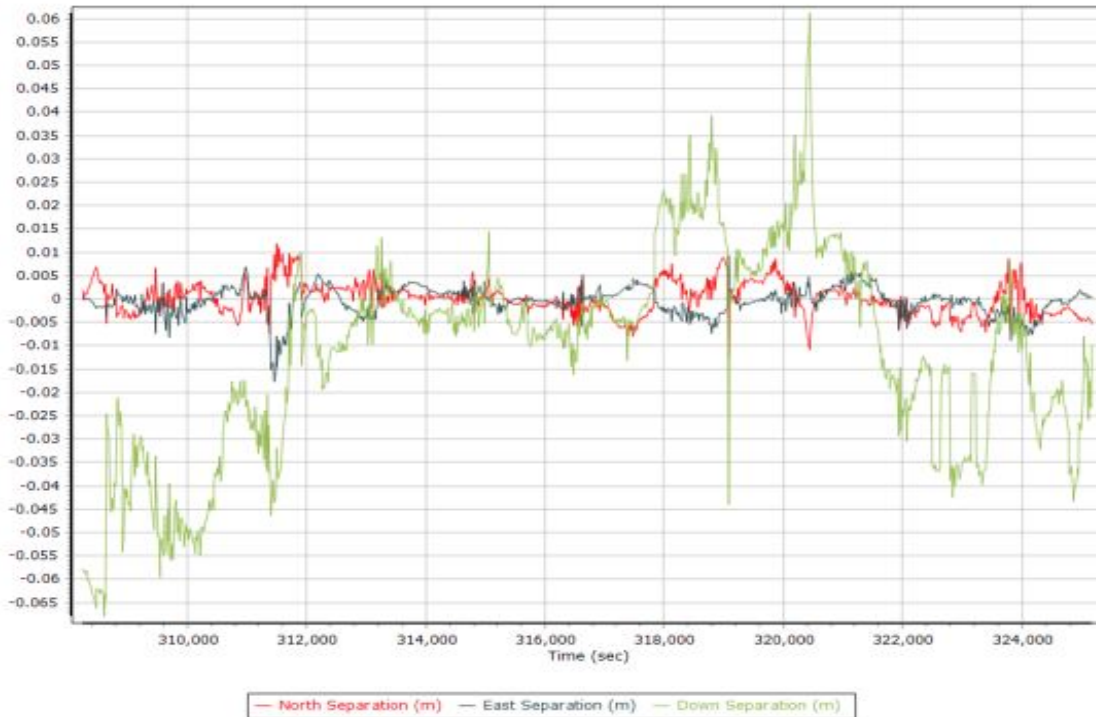
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.05	51.80	
Number of GPS SV	7	10	9
Number of GLONASS SV	0	8	7
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	9	18	15
PDOP	1.13	1.87	1.35
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17406.00	0.00	1.00
Percentage	99.99	0.00	0.01

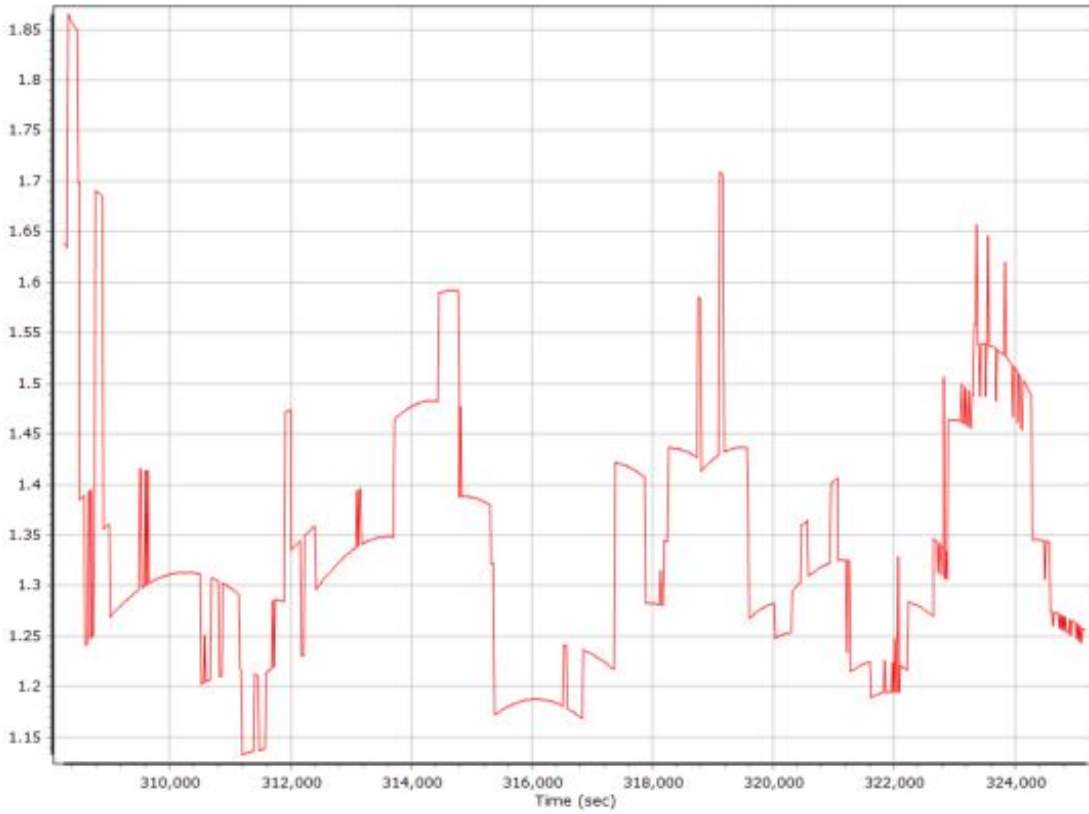
### Number of Satellites



### Forward/Reverse Separation



PDOP



201202B.docx QC Report - 06/21/2021 14:17:25  
 Smoothed Trajectory Information

Top View

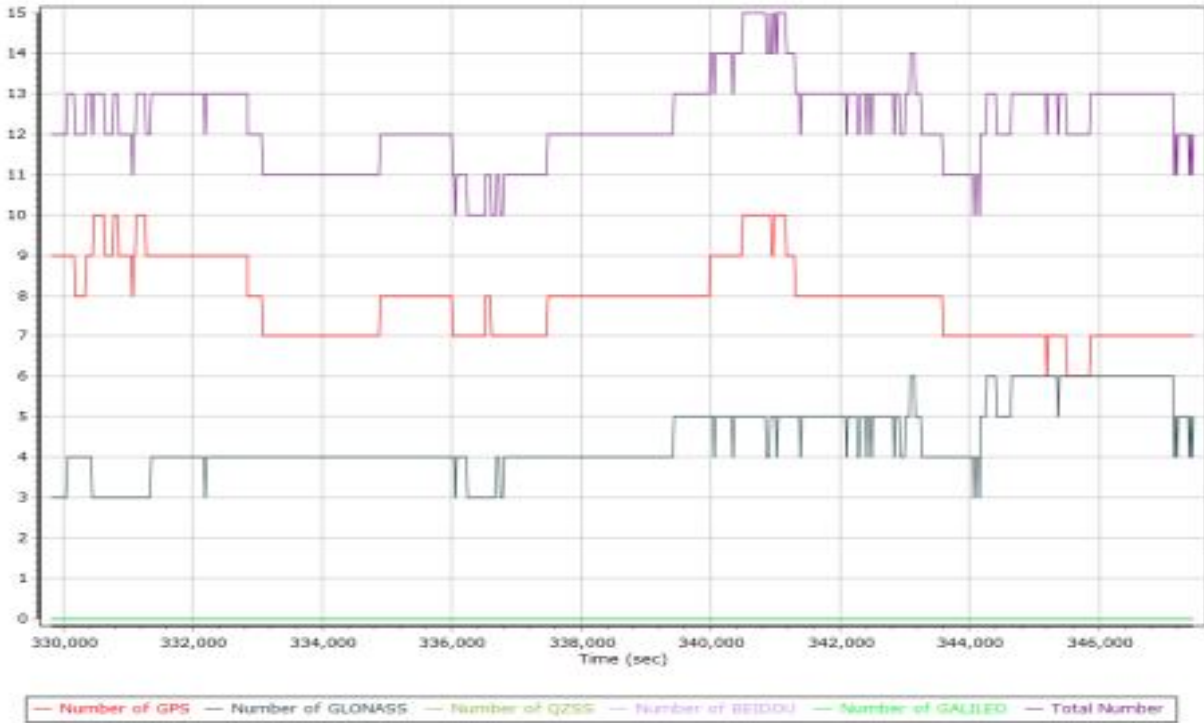


**GNSS QC**

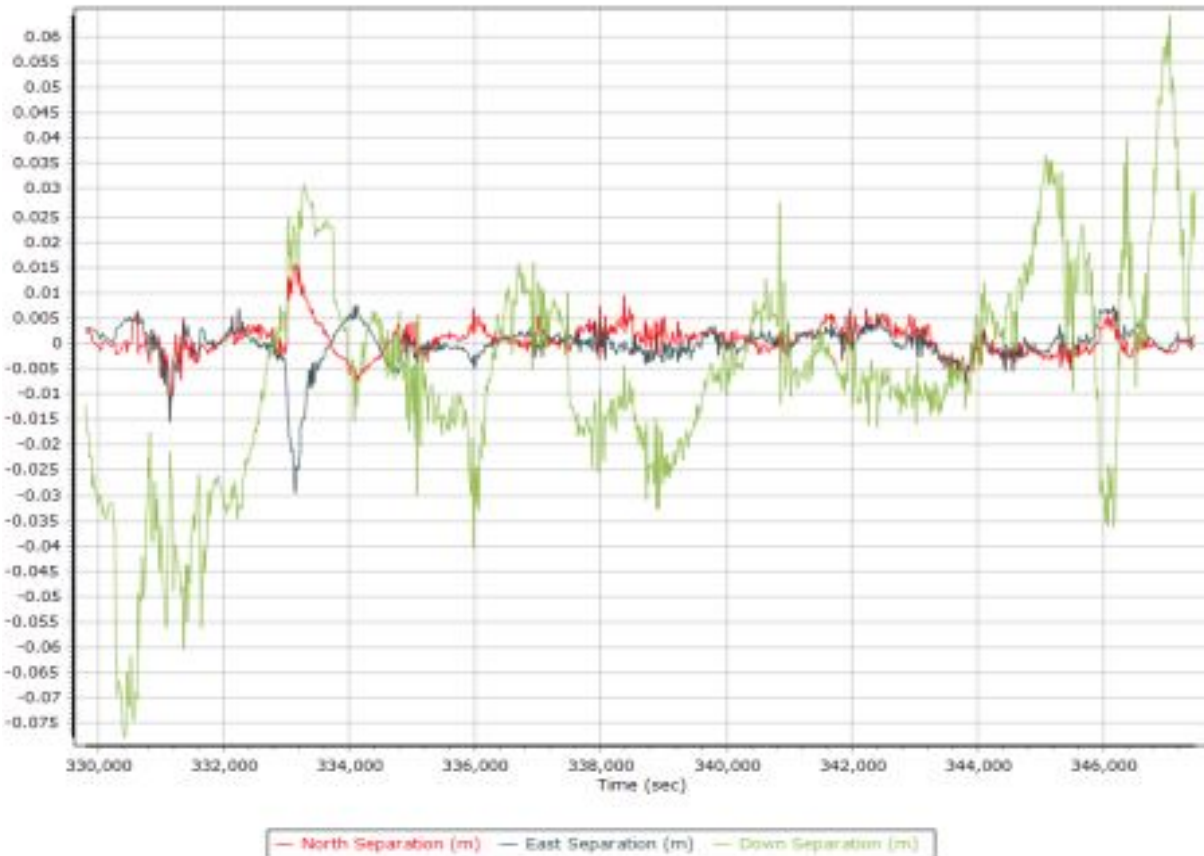
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.05	54.14	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	6	4
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	8	15	12
PDOP	1.21	2.65	1.67
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	18145.00	0.00	1.00
Percentage	99.99	0.00	0.01

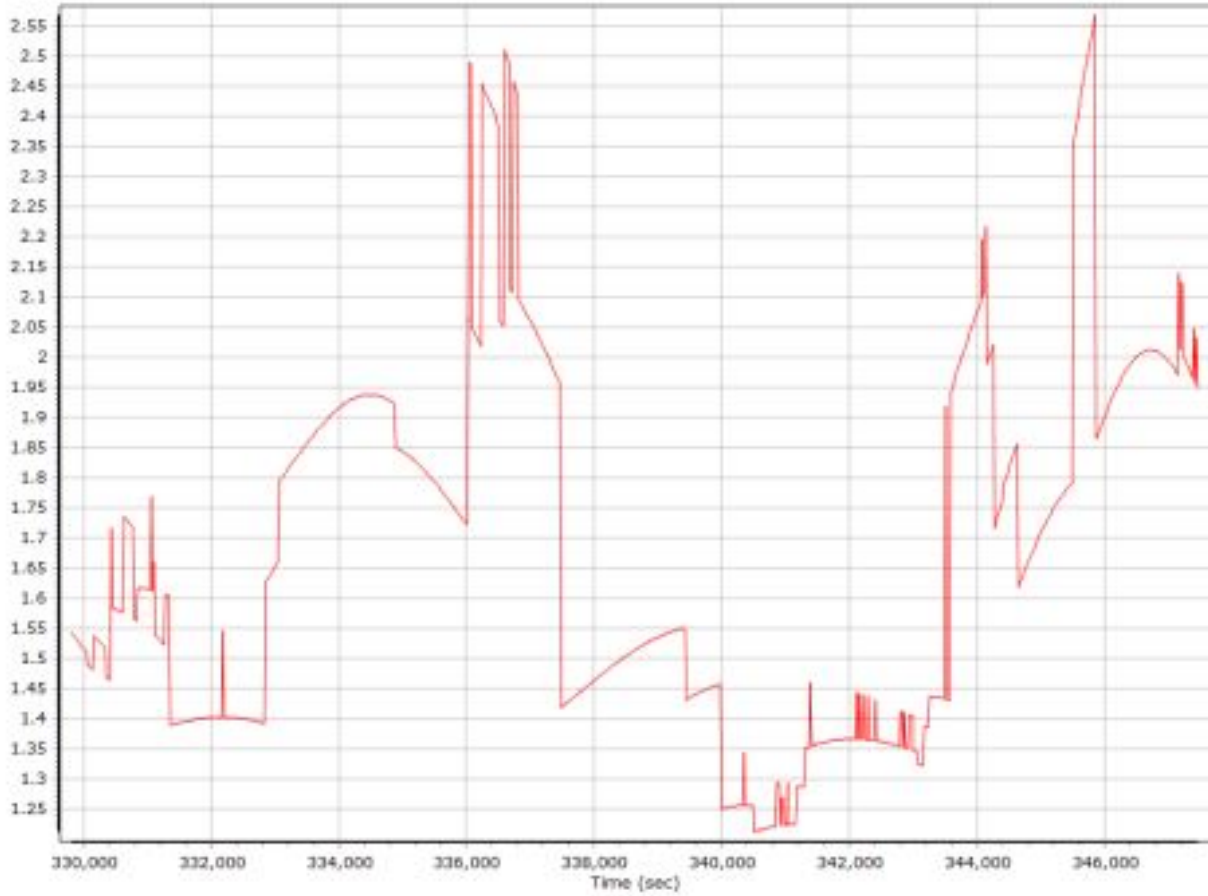
### Number of Satellites



### Forward/Reverse Separation



PDOP





201204A.docx QC Report - 06/21/2021 14:26:25  
 Smoothed Trajectory Information

Top View

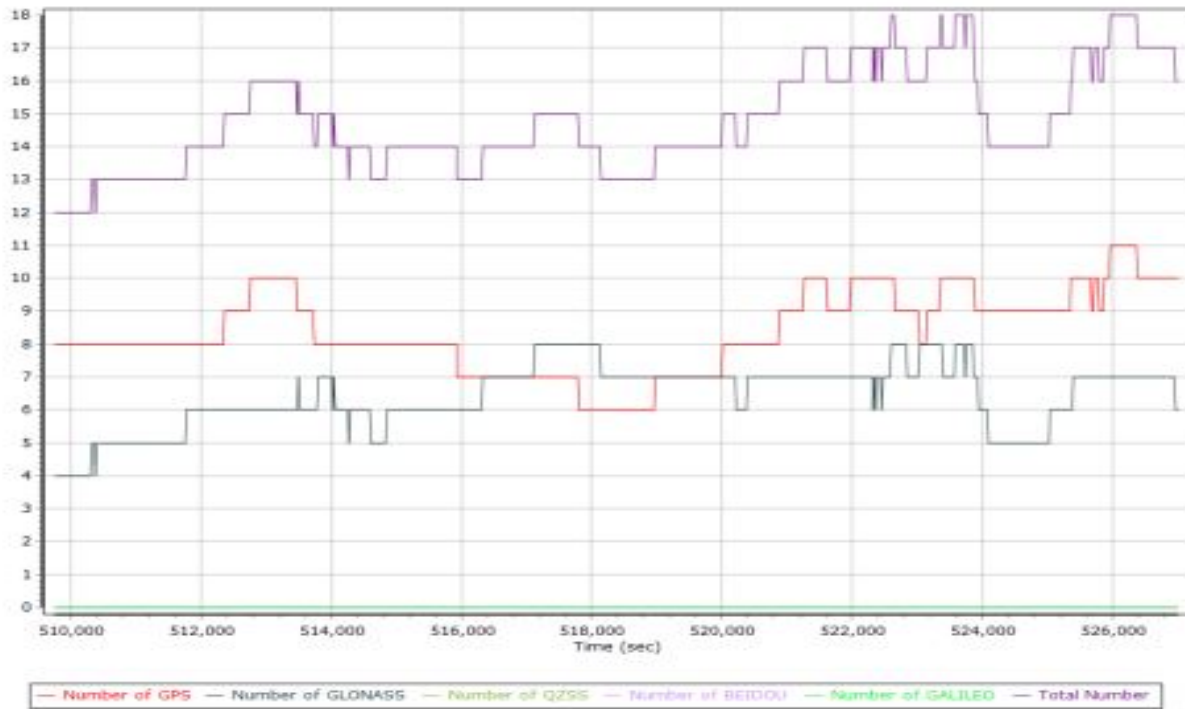


**GNSS QC**

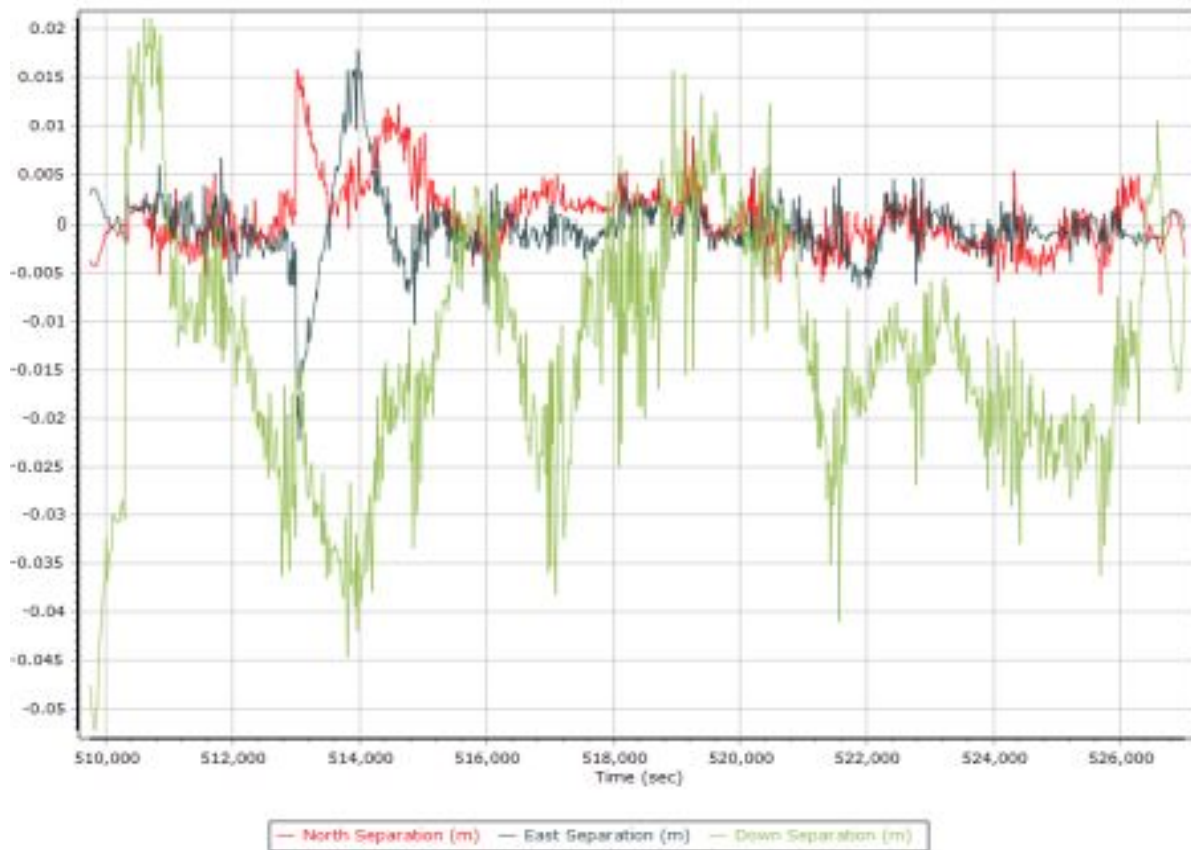
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.13	73.81	
Number of GPS SV	6	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	0	0
Total number of SV	8	18	15
PDOP	1.14	2.07	1.45
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17349.00	0.00	1.00
Percentage	99.99	0.00	0.01

### Number of Satellites

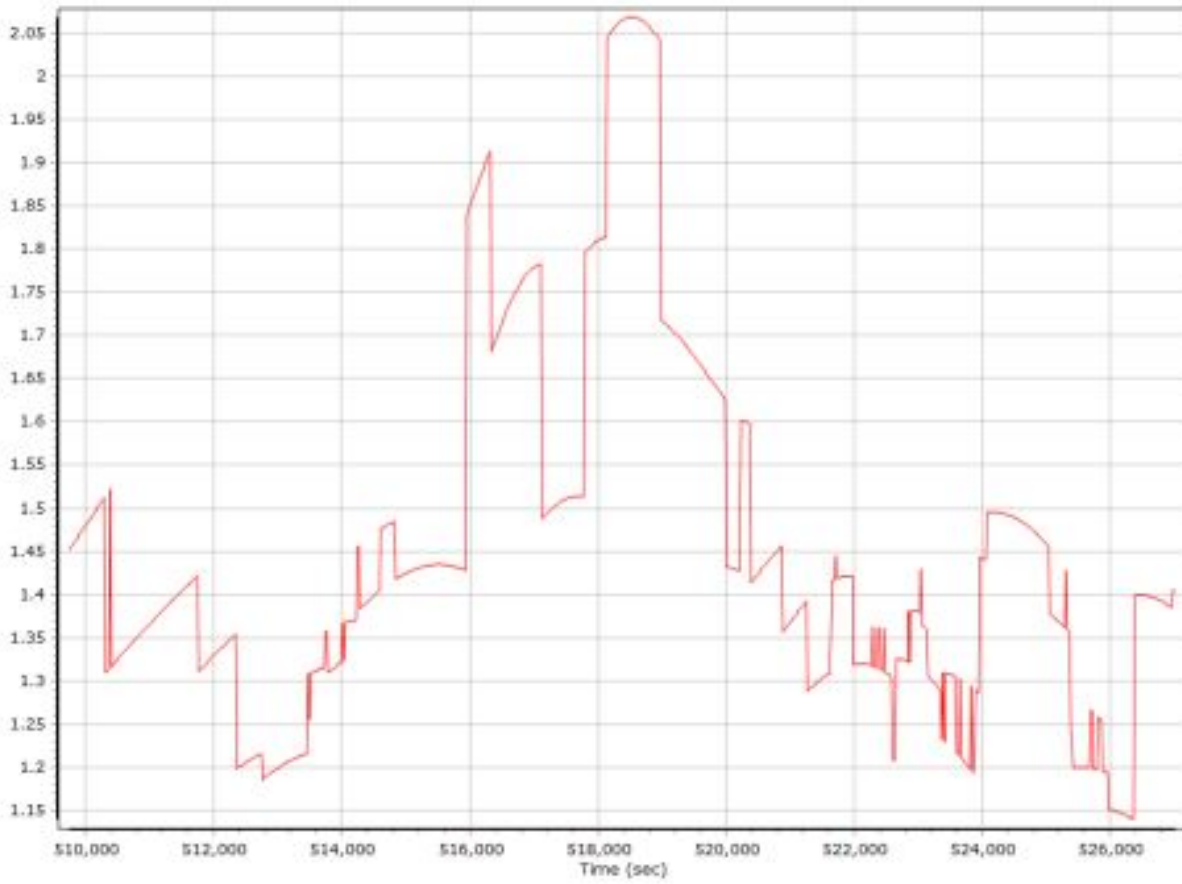


### Forward/Reverse Separation



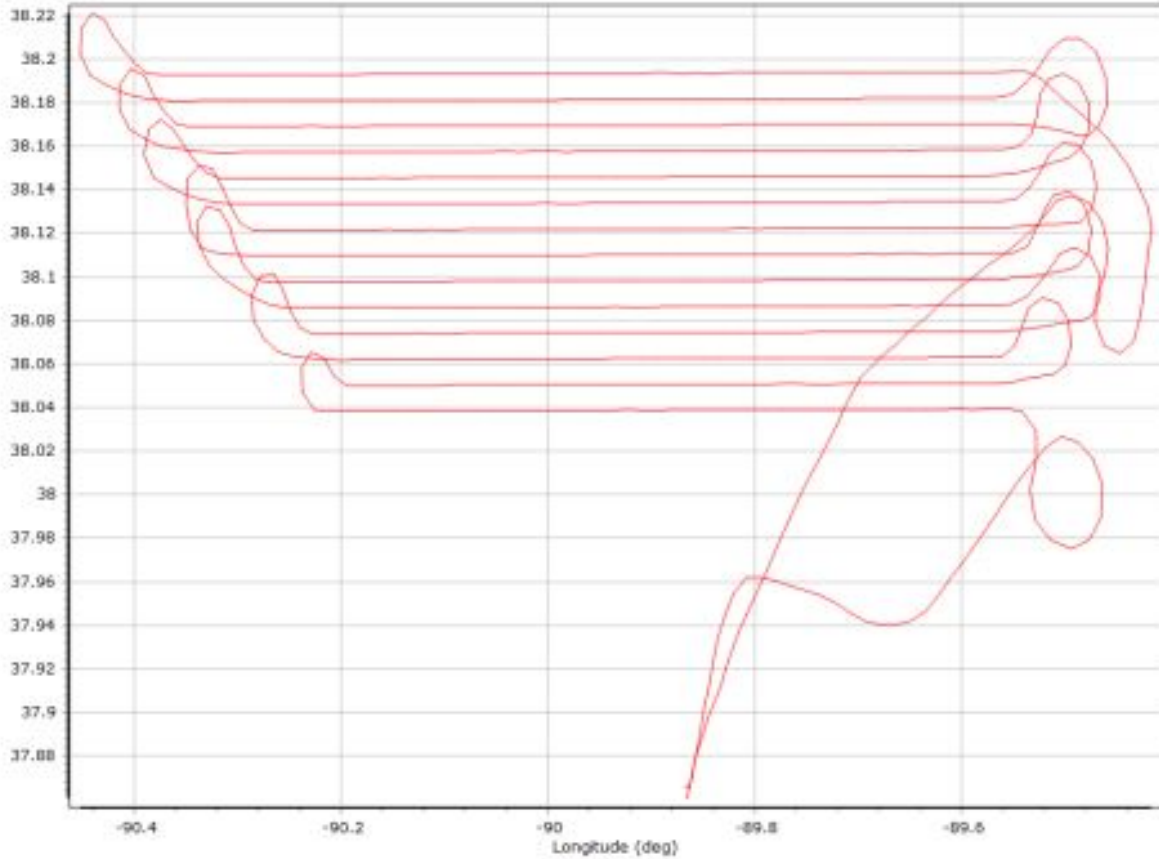


PDOP



201205A.docx QC Report - 06/21/2021 14:26:25  
 Smoothed Trajectory Information

Top View

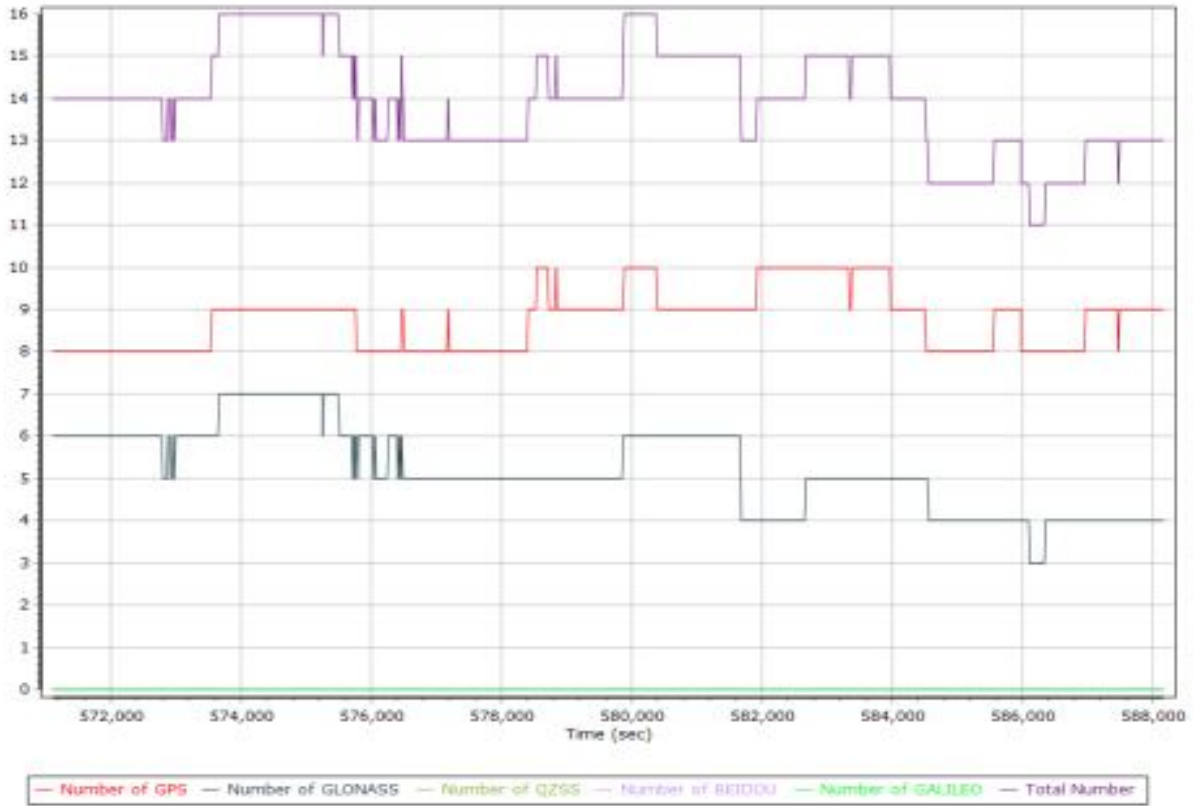


**GNSS QC**

**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.03	64.54	
Number of GPS SV	7	10	9
Number of GLONASS SV	0	7	5
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	8	16	14
PDOP	1.27	2.25	1.48
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17576.00	0.00	1.00
Percentage	99.99	0.00	0.01

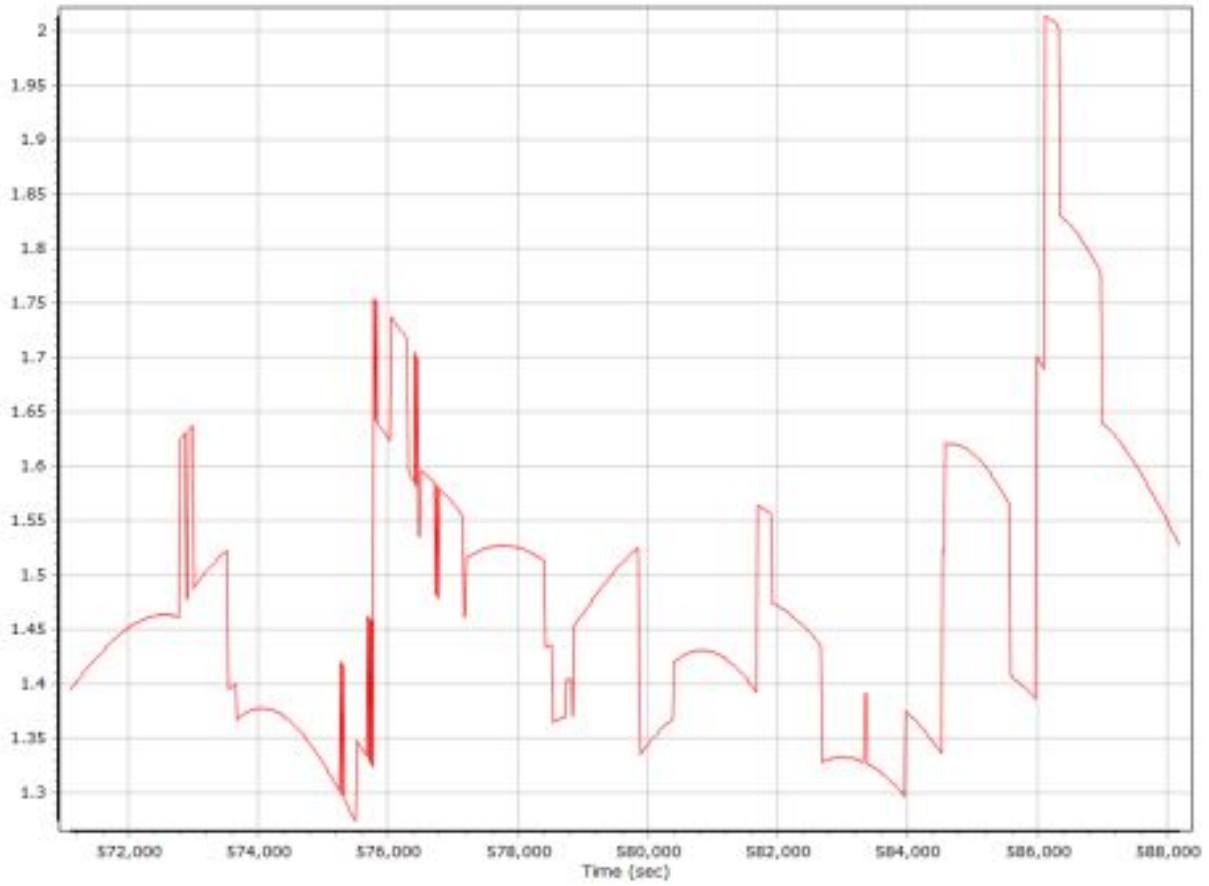
### Number of Satellites



### Forward/Reverse Separation

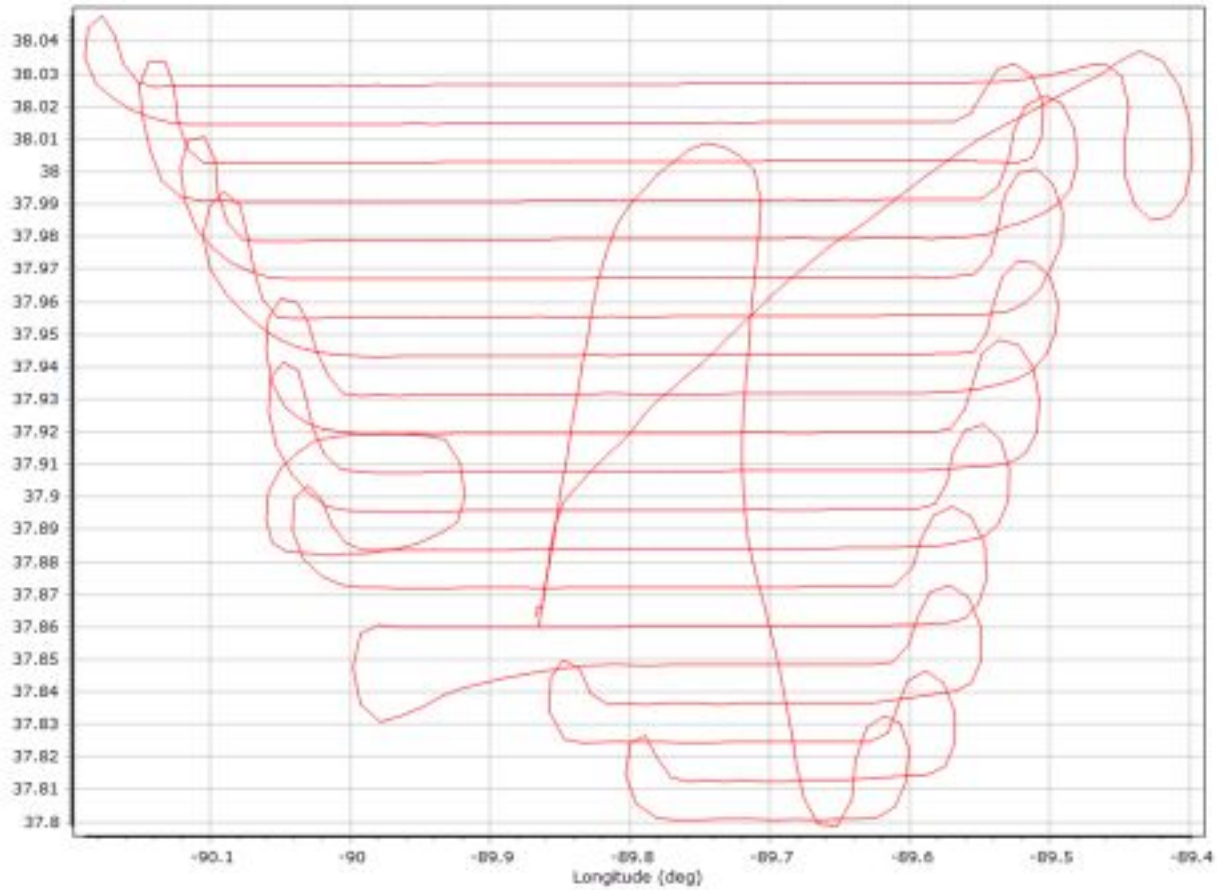


PDOP



201205B.docx QC Report - 06/21/2021 14:42:25  
 Smoothed Trajectory Information

Top View

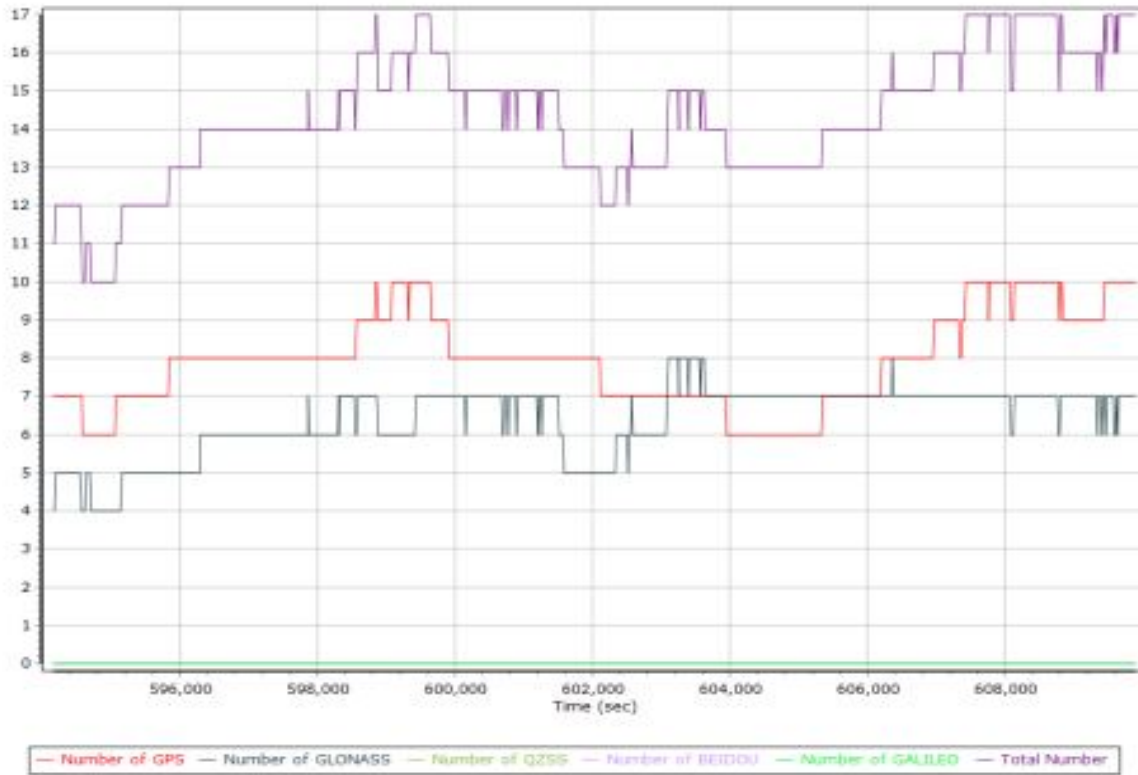


**GNSS QC**

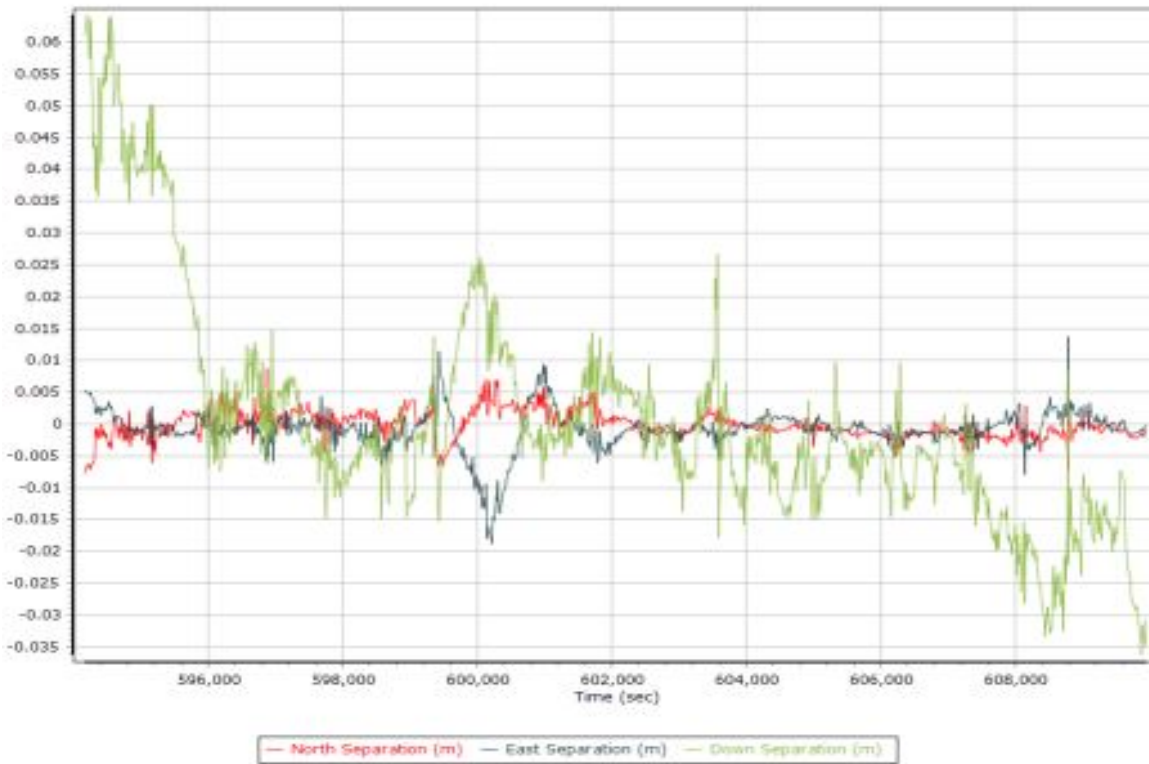
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.04	44.54	
Number of GPS SV	6	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	0	0	0
Total number of SV	7	17	14
PDOP	1.15	3.95	1.55
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	16154.00	0.00	1.00
Percentage	99.99	0.00	0.01

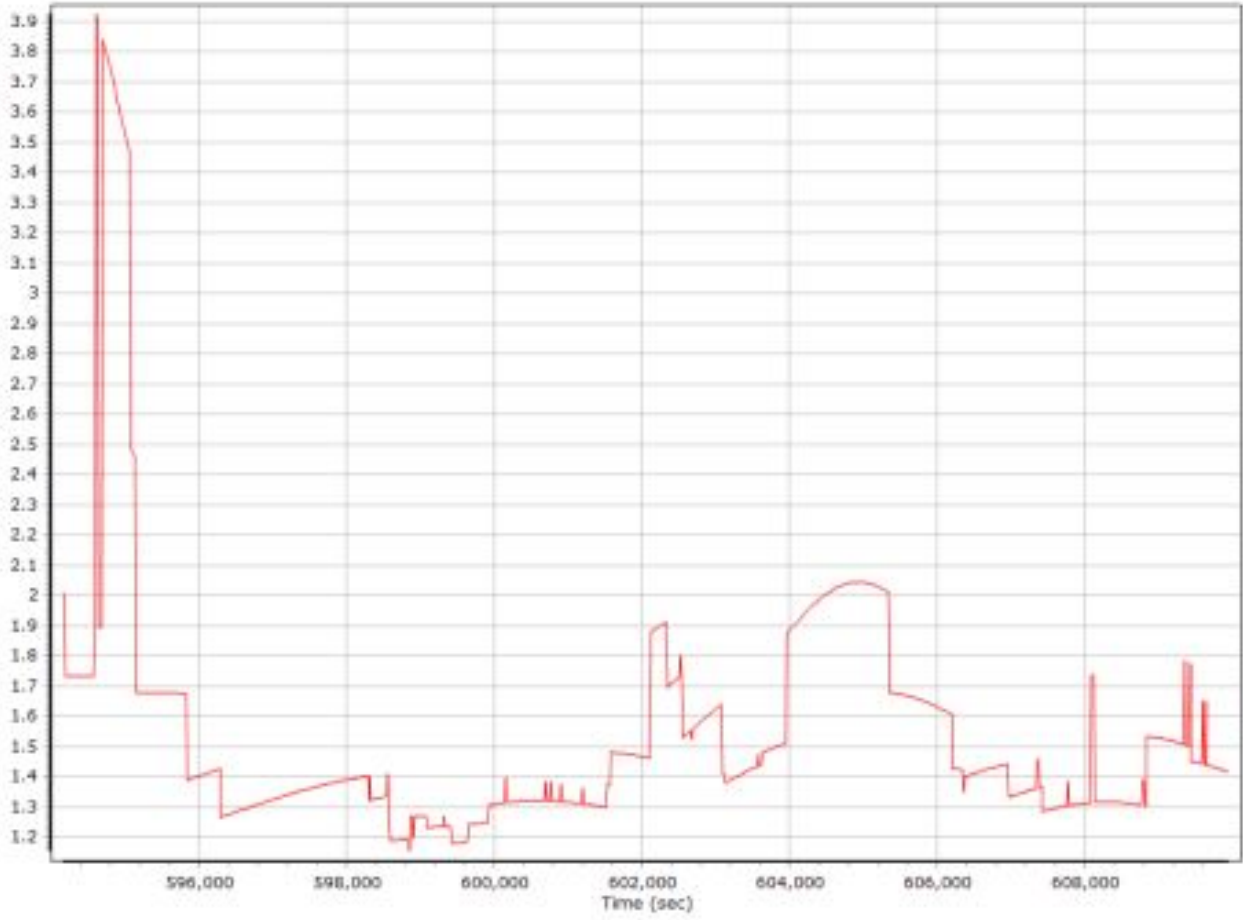
### Number of Satellites



### Forward/Reverse Separation



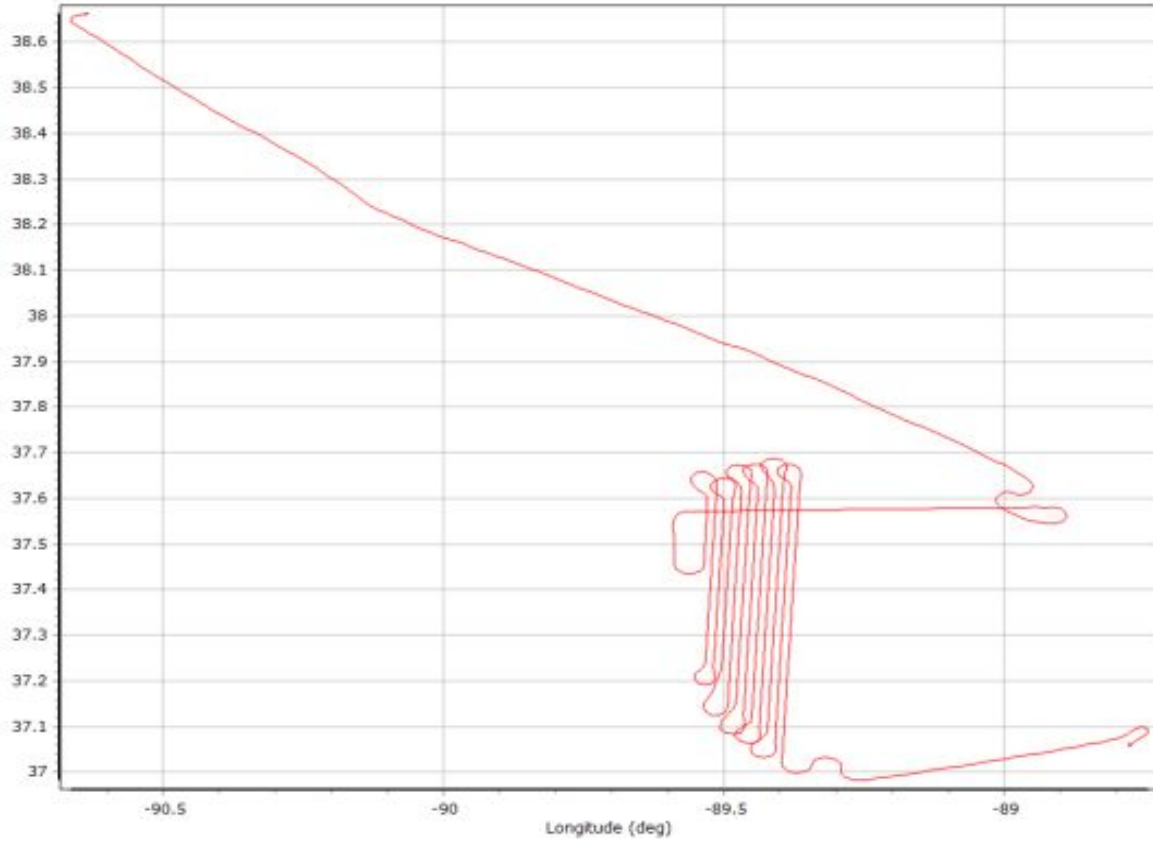
PDOP





120520a448.docx QC Report - 6/28/2021 10:48:15  
 Smoothed Trajectory Information

Top View



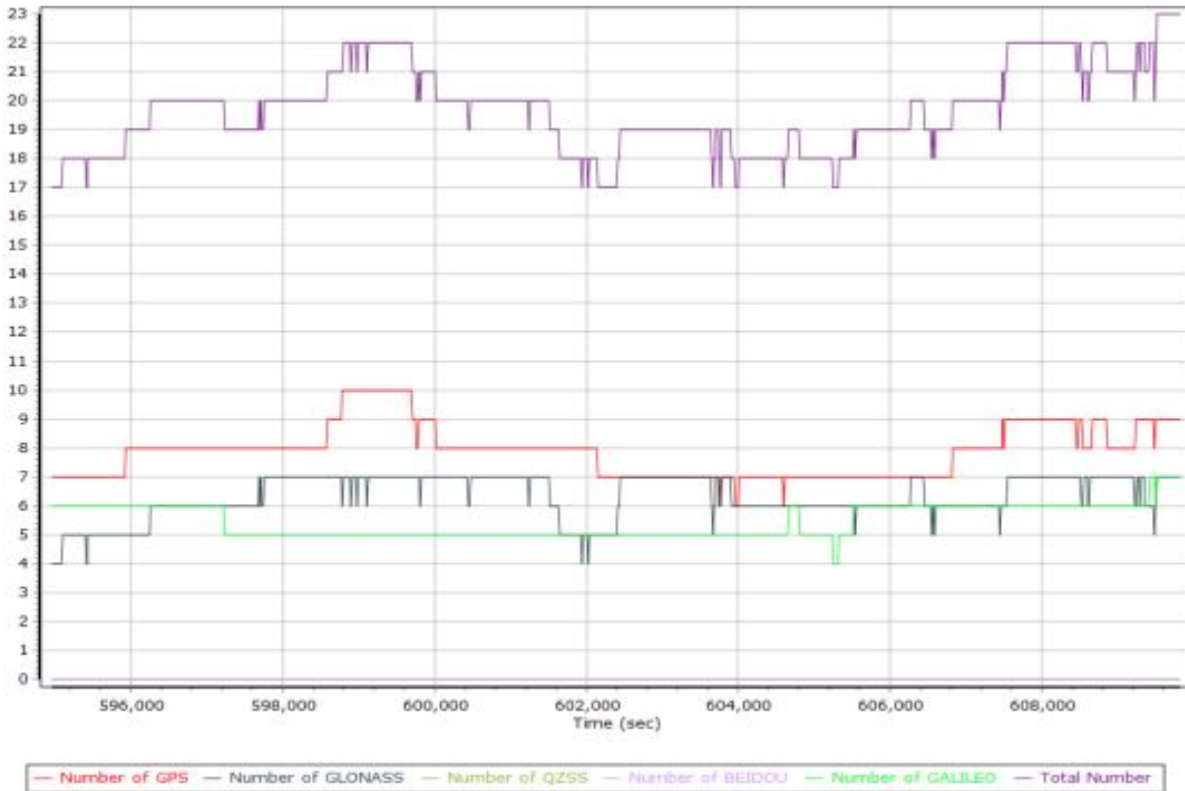
**GNSS QC**

**GNSS QC Statistics**

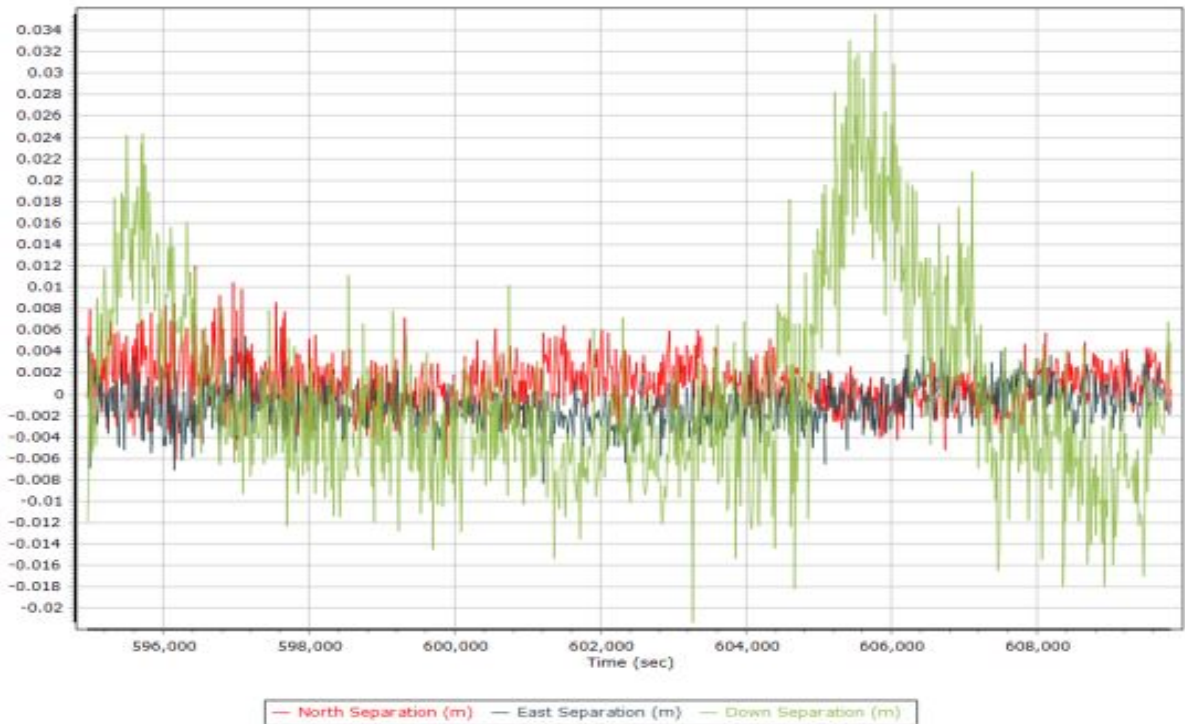
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	10	8
Number of GLONASS SV	4	7	6
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	2	7	6
Total number of SV	14	23	20
PDOP	1.06	2.54	1.23
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	15468.00	0.00	0.00
Percentage	100.00	0.00	0.00



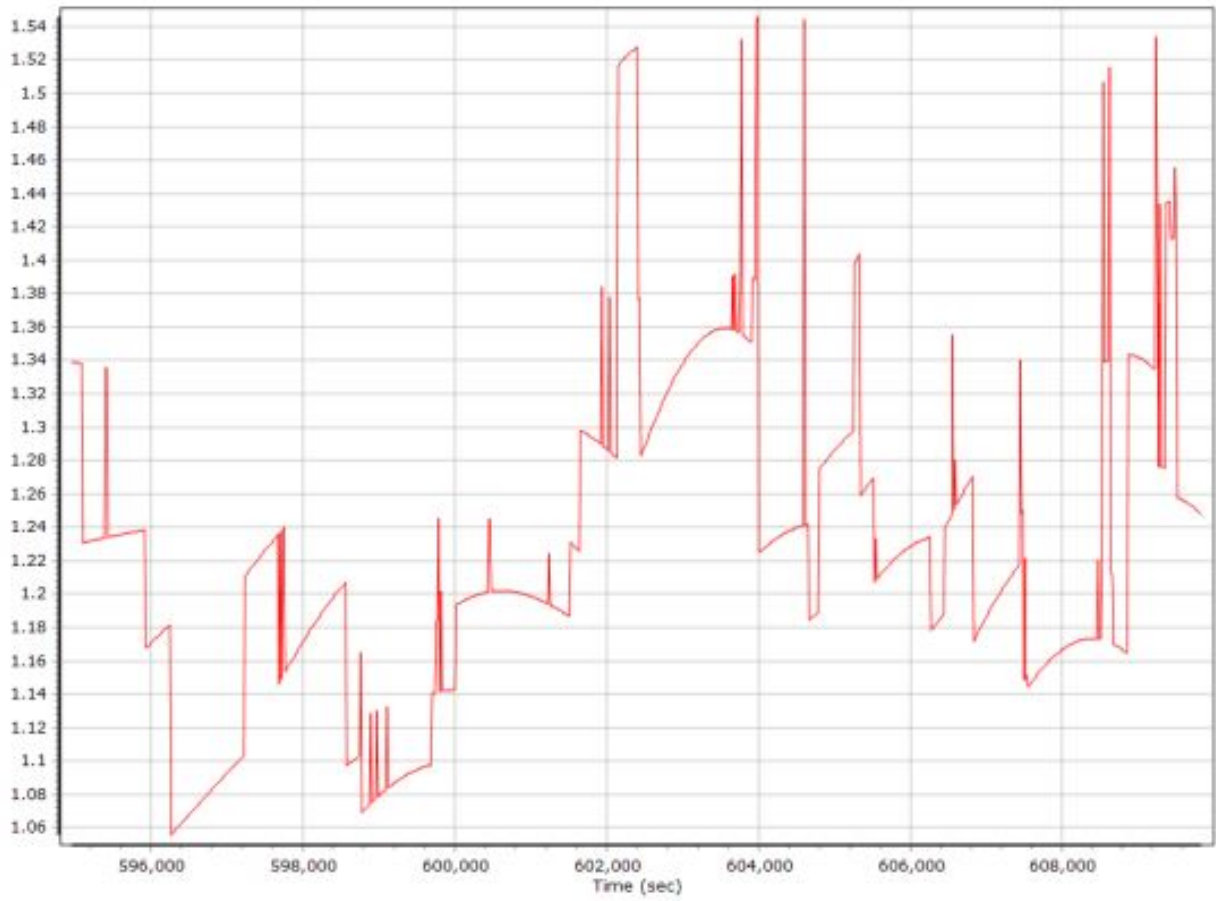
### Number of Satellites



### Forward/Reverse Separation

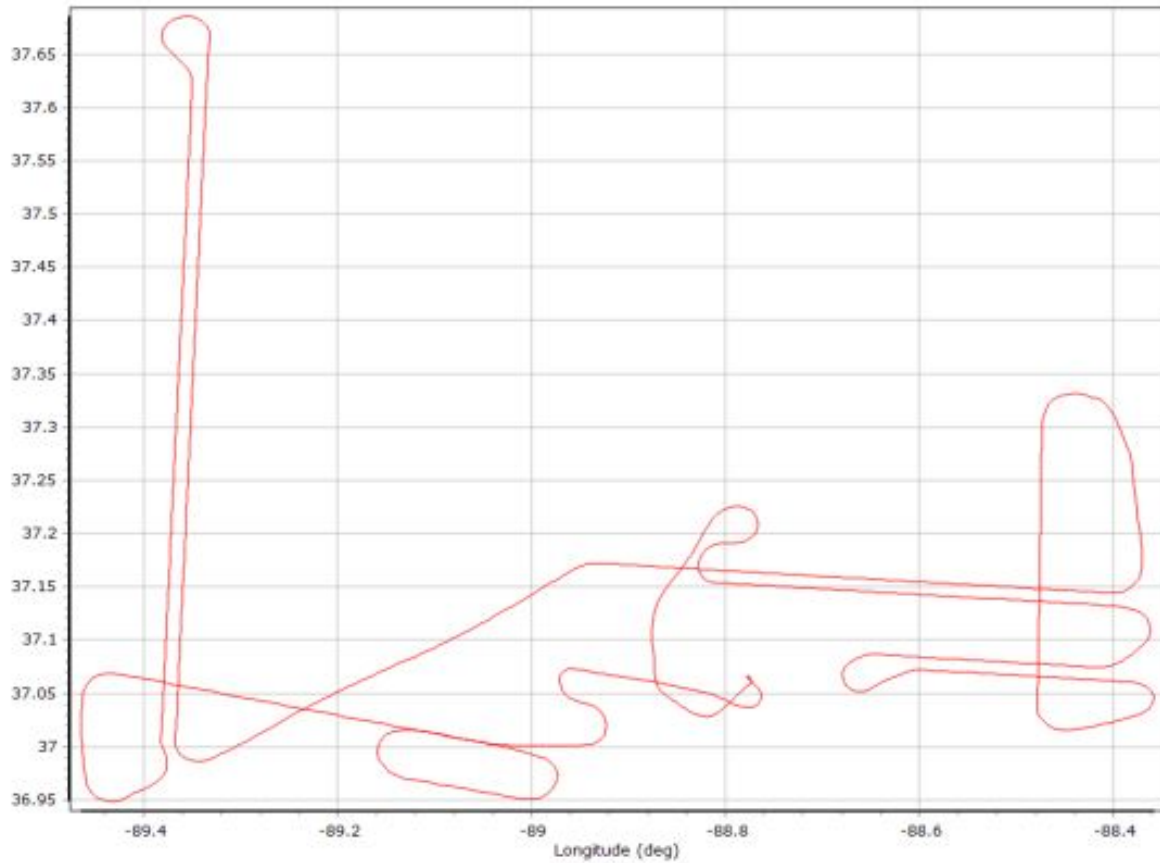


PDOP



120620a448.docx QC Report - 6/28/2021 10:56:35  
 Smoothed Trajectory Information

Top View

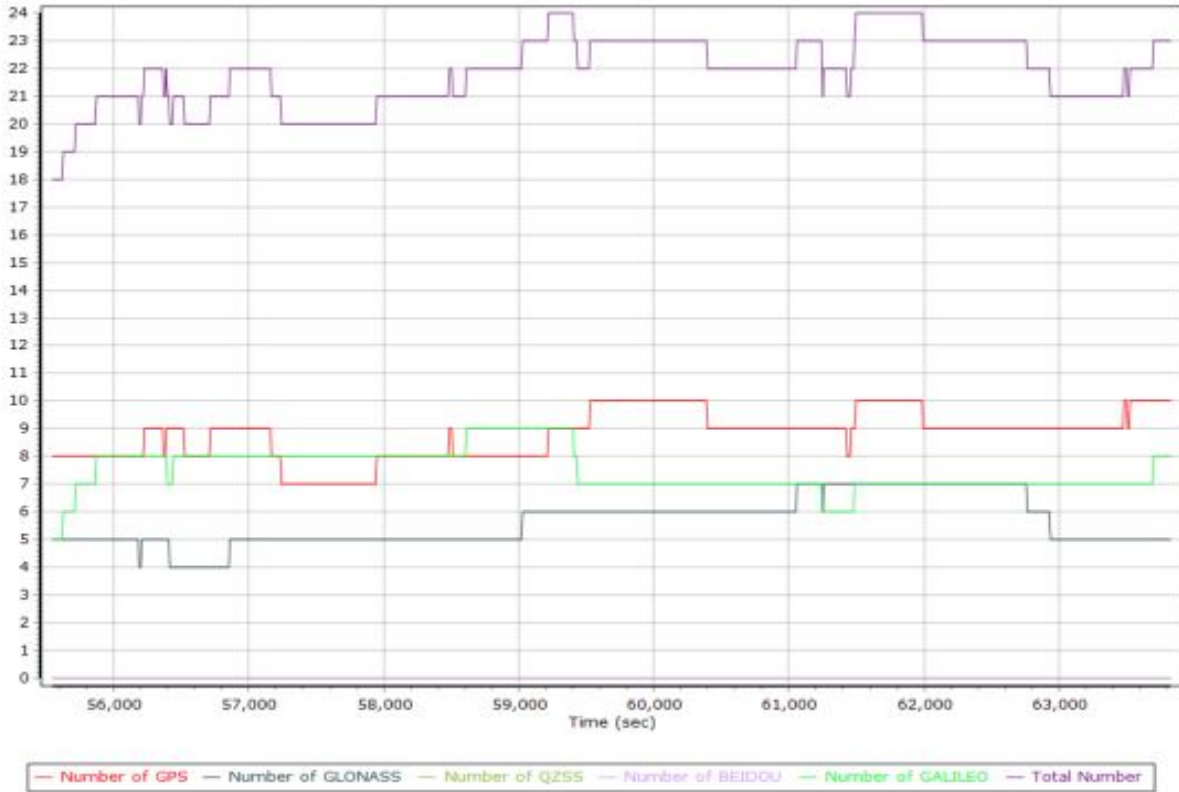


**GNSS QC**

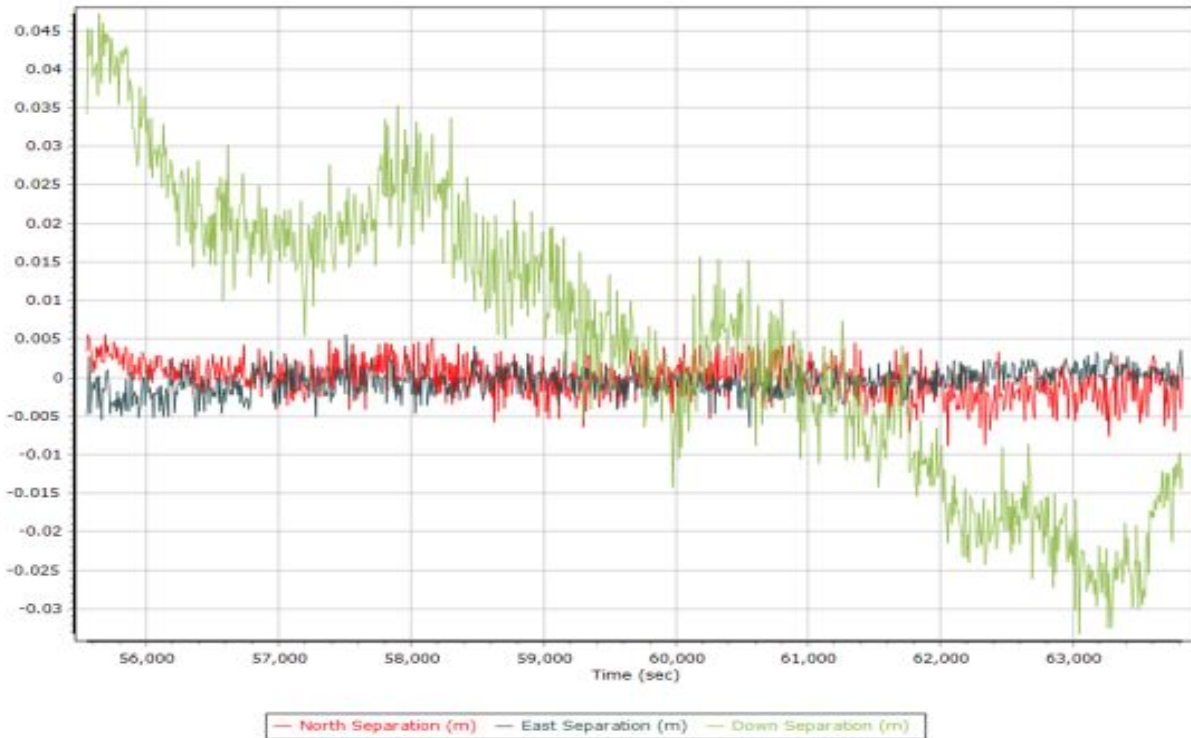
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	10	9
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	9	7
Total number of SV	16	24	22
PDOP	1.03	1.56	1.17
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	8983.00	0.00	0.00
Percentage	100.00	0.00	0.00

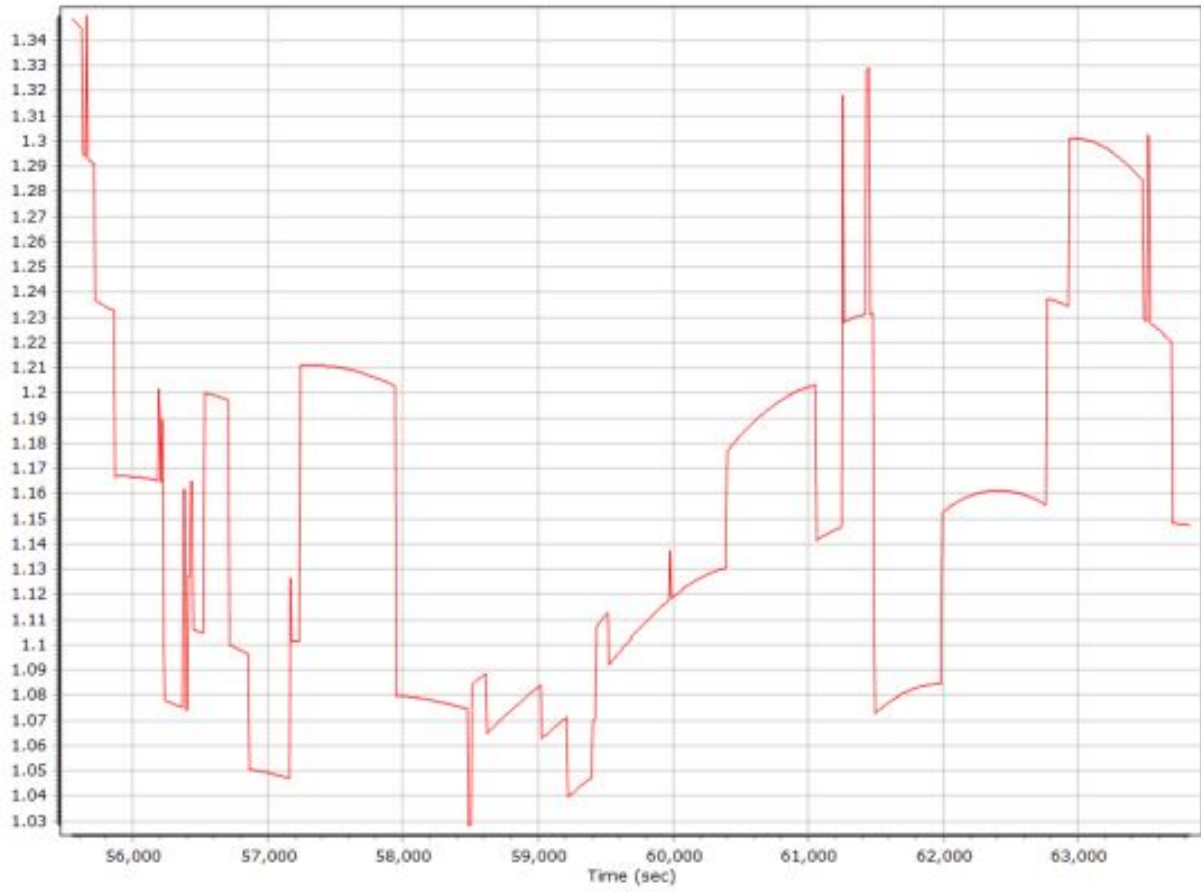
### Number of Satellites



### Forward/Reverse Separation



PDOP



120820a386.docx QC Report - 6/28/2021 11:00:27  
 Smoothed Trajectory Information

Top View



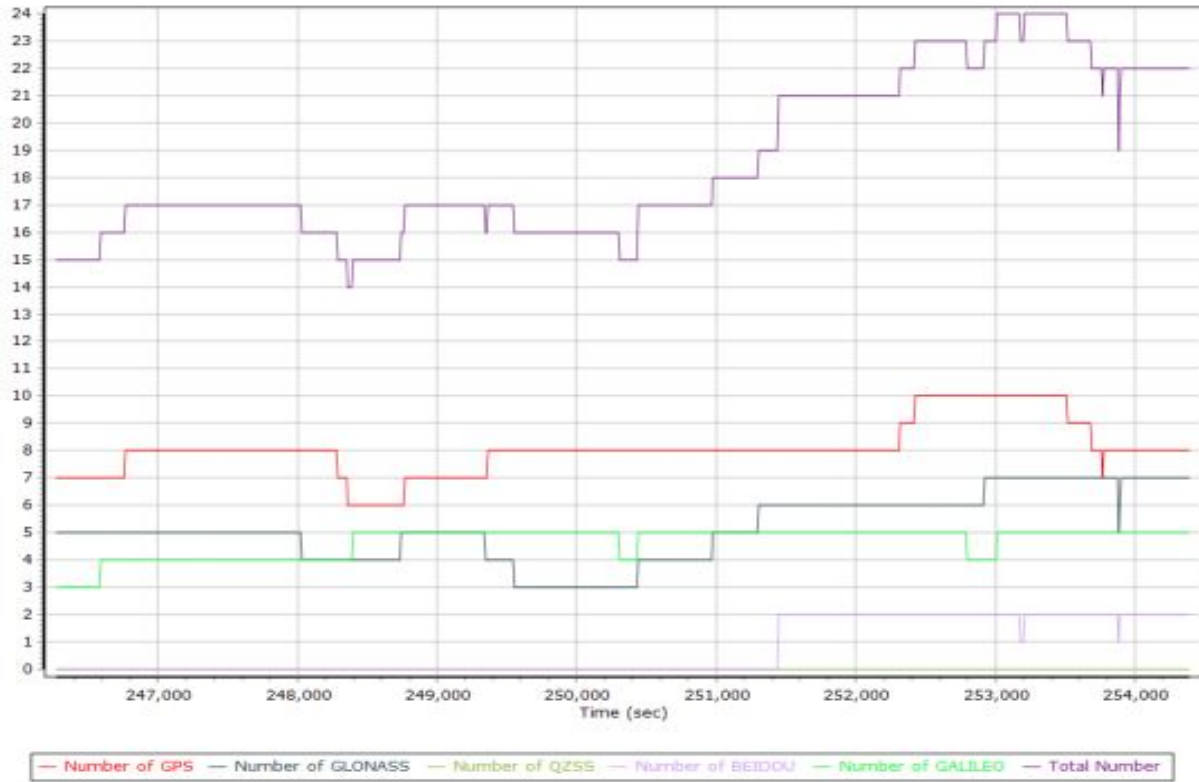
**GNSS QC**

**GNSS QC Statistics**

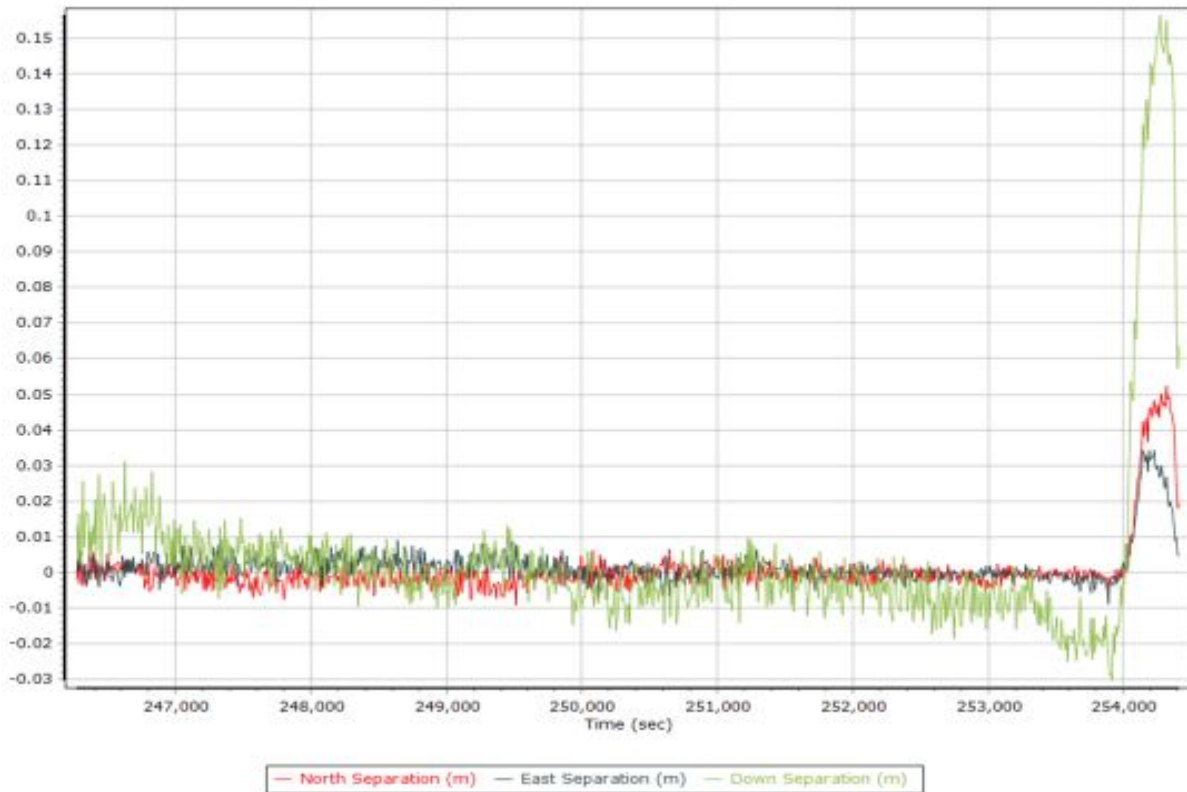
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	7	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	1
Number of GALILEO SV	2	5	5
Total number of SV	12	24	18
PDOP	1.02	1.95	1.30
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	8699.00	0.00	0.00
Percentage	100.00	0.00	0.00



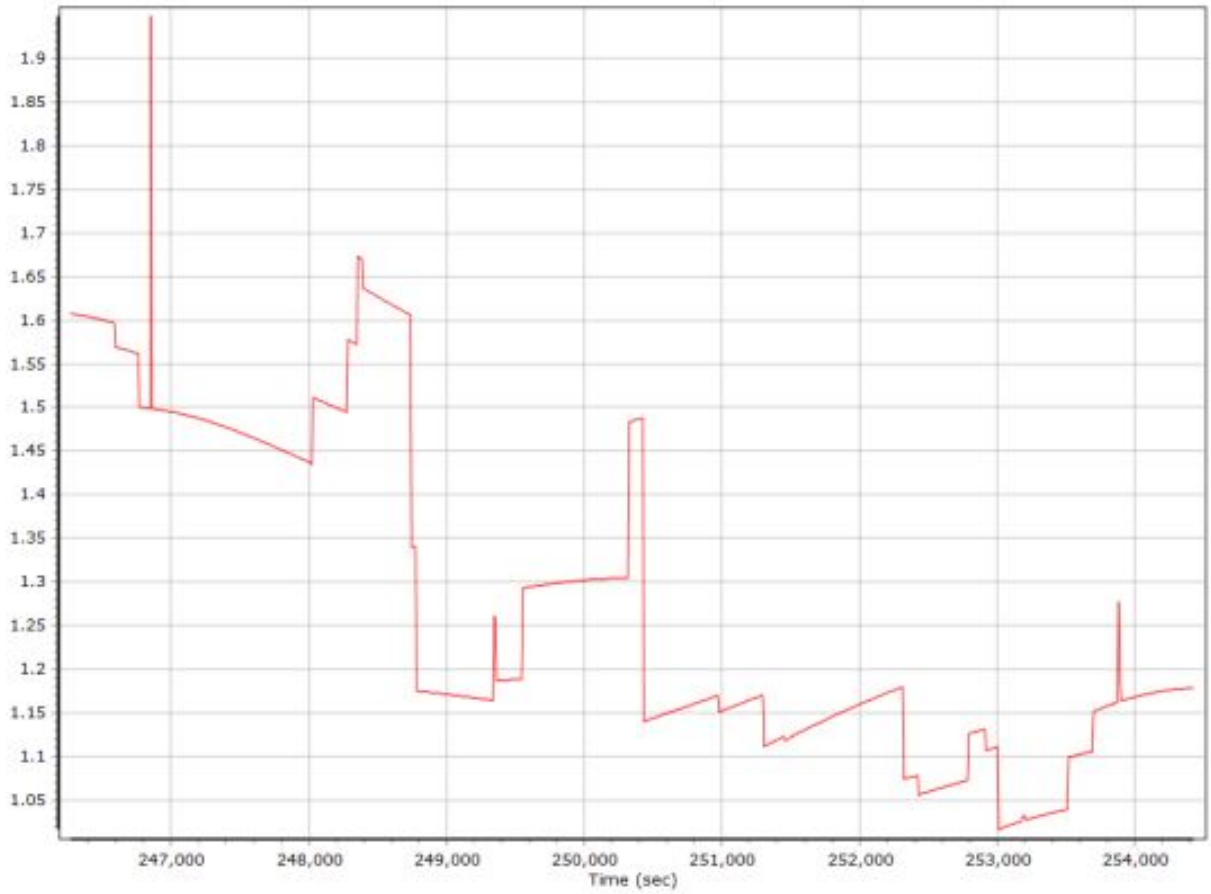
### Number of Satellites



### Forward/Reverse Separation



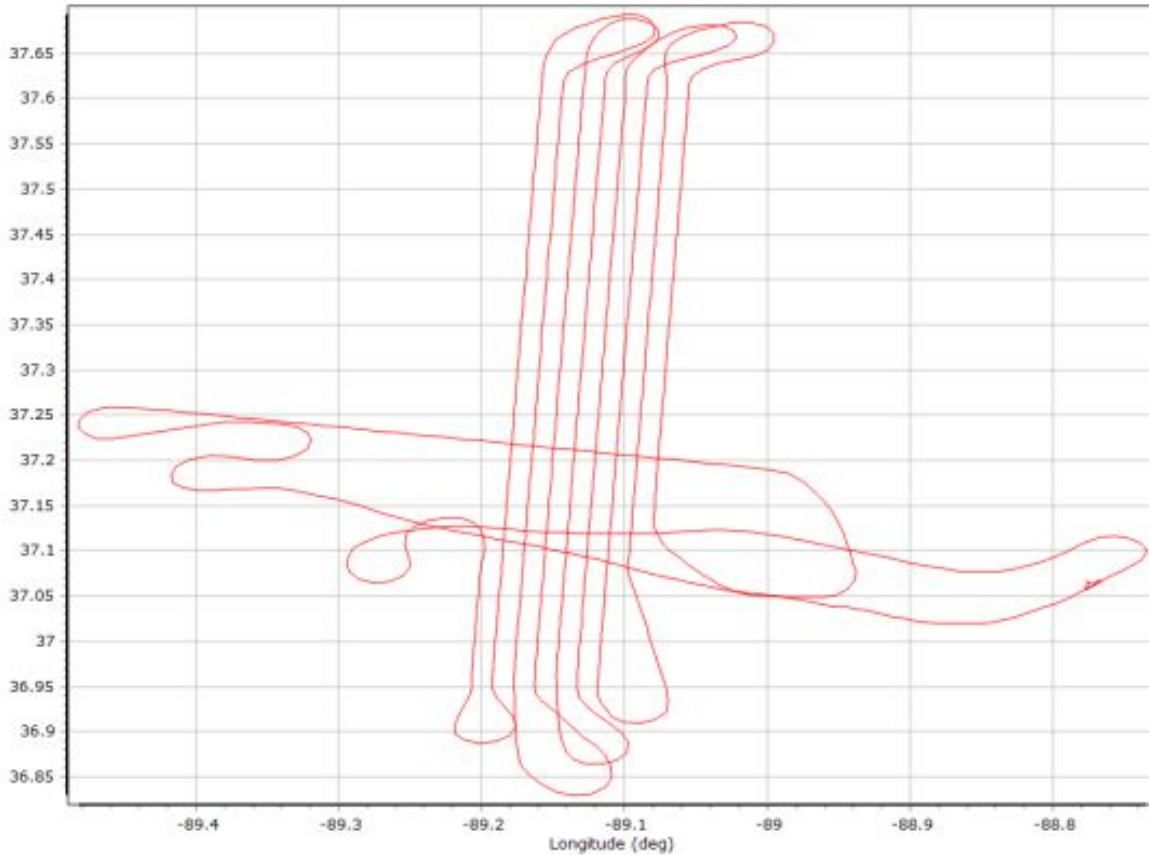
### PDOP





120920a386.docx QC Report - 6/28/2021 11:13:43  
 Smoothed Trajectory Information

Top View

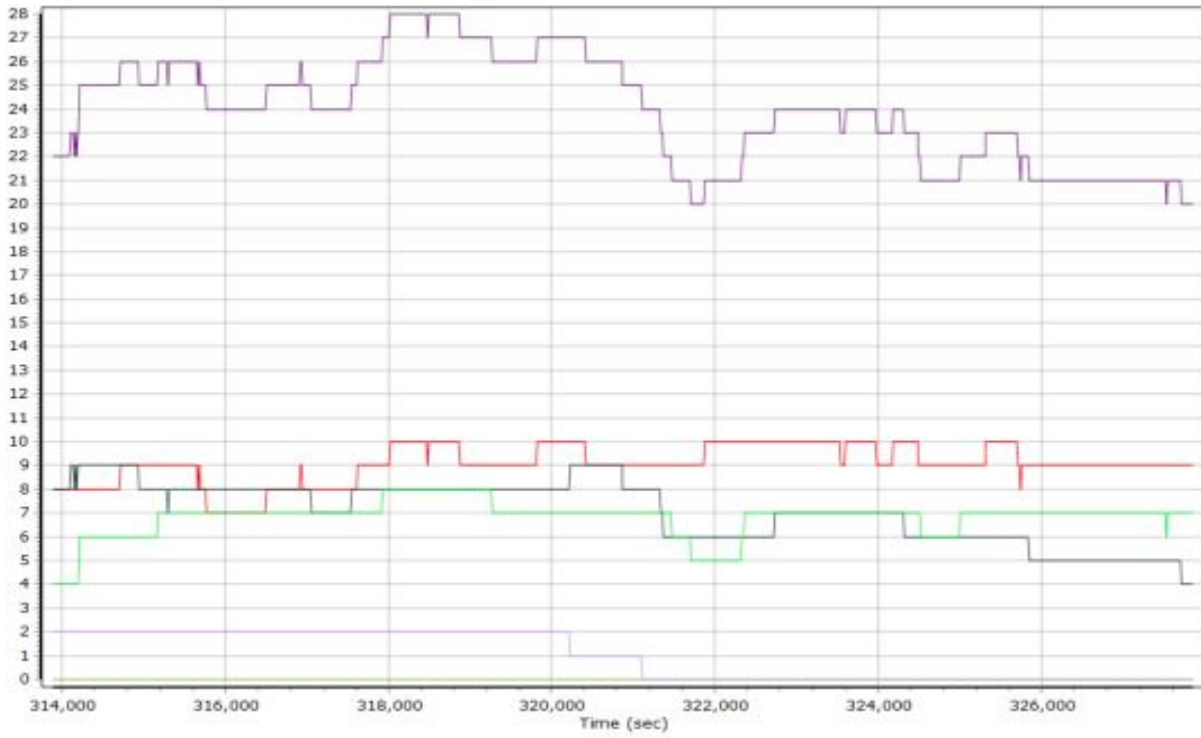


**GNSS QC**

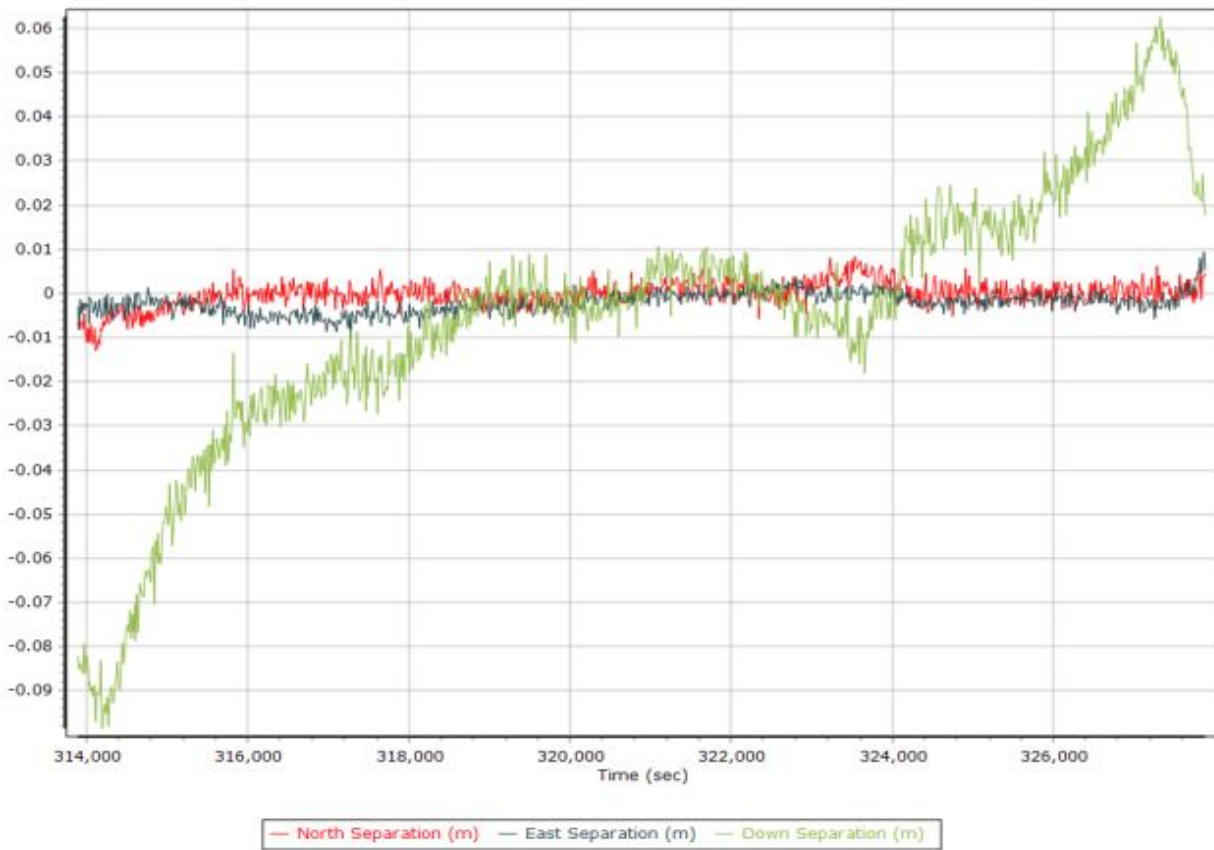
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	7	10	9
Number of GLONASS SV	0	9	7
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	1
Number of GALILEO SV	0	8	7
Total number of SV	12	28	24
PDOP	0.99	1.56	1.11
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	14558.00	0.00	0.00
Percentage	100.00	0.00	0.00

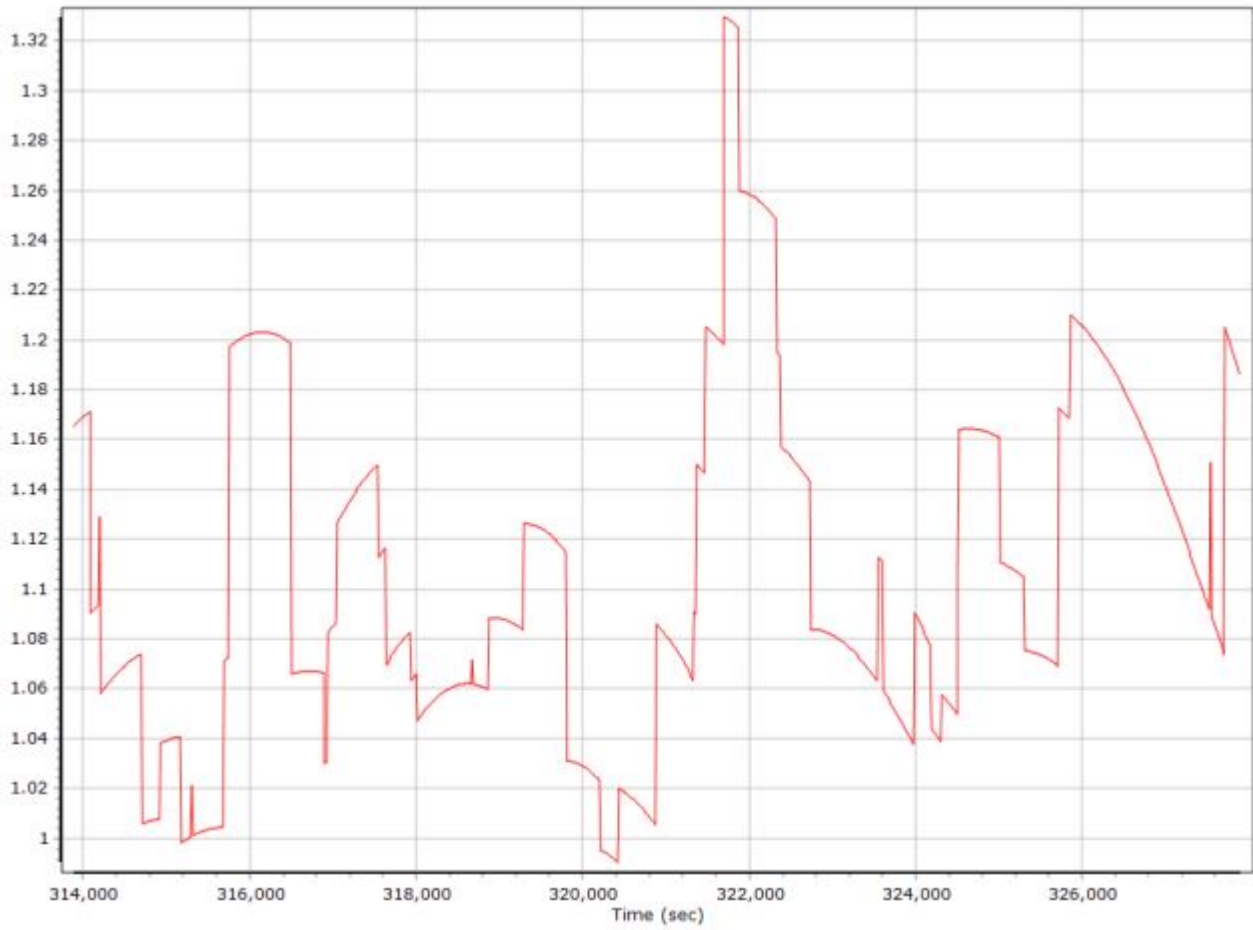
### Number of Satellites



### Forward/Reverse Separation

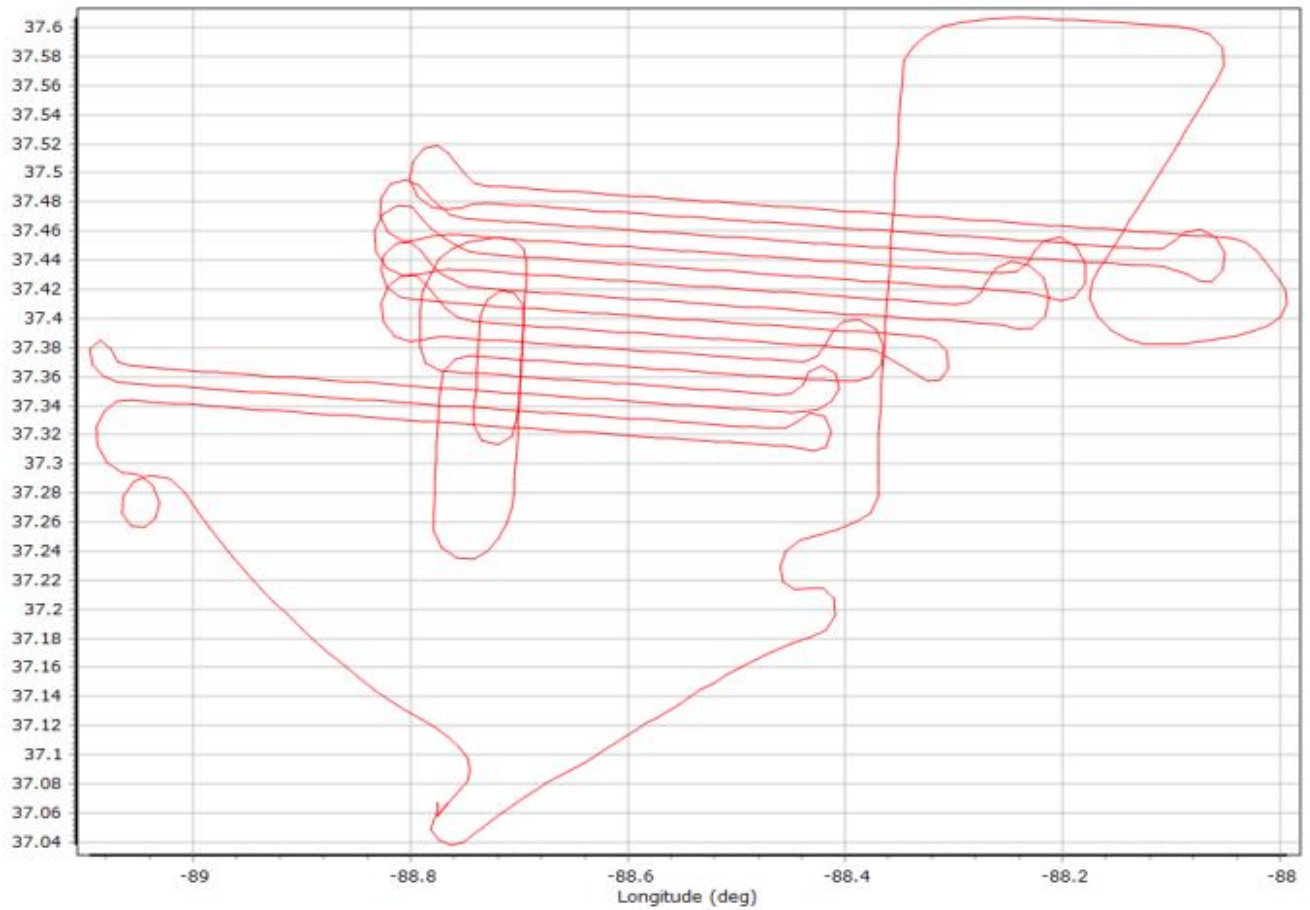


PDOP



120920a448.docx QC Report - 6/28/2021 11:22:53  
 Smoothed Trajectory Information

Top View



**GNSS QC**

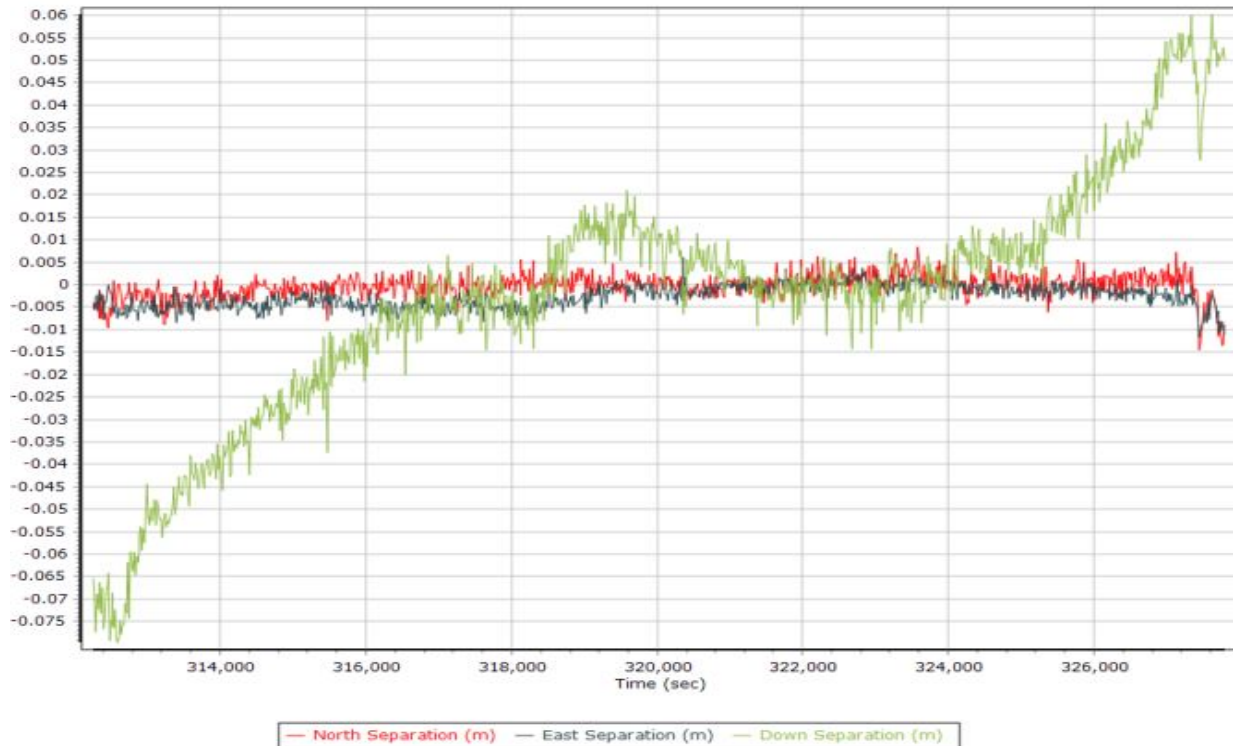
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	3	10	9
Number of GLONASS SV	4	9	7
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	1
Number of GALILEO SV	3	8	7
Total number of SV	12	28	24
PDOP	0.99	1.75	1.12
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	16720.00	0.00	0.00
Percentage	100.00	0.00	0.00

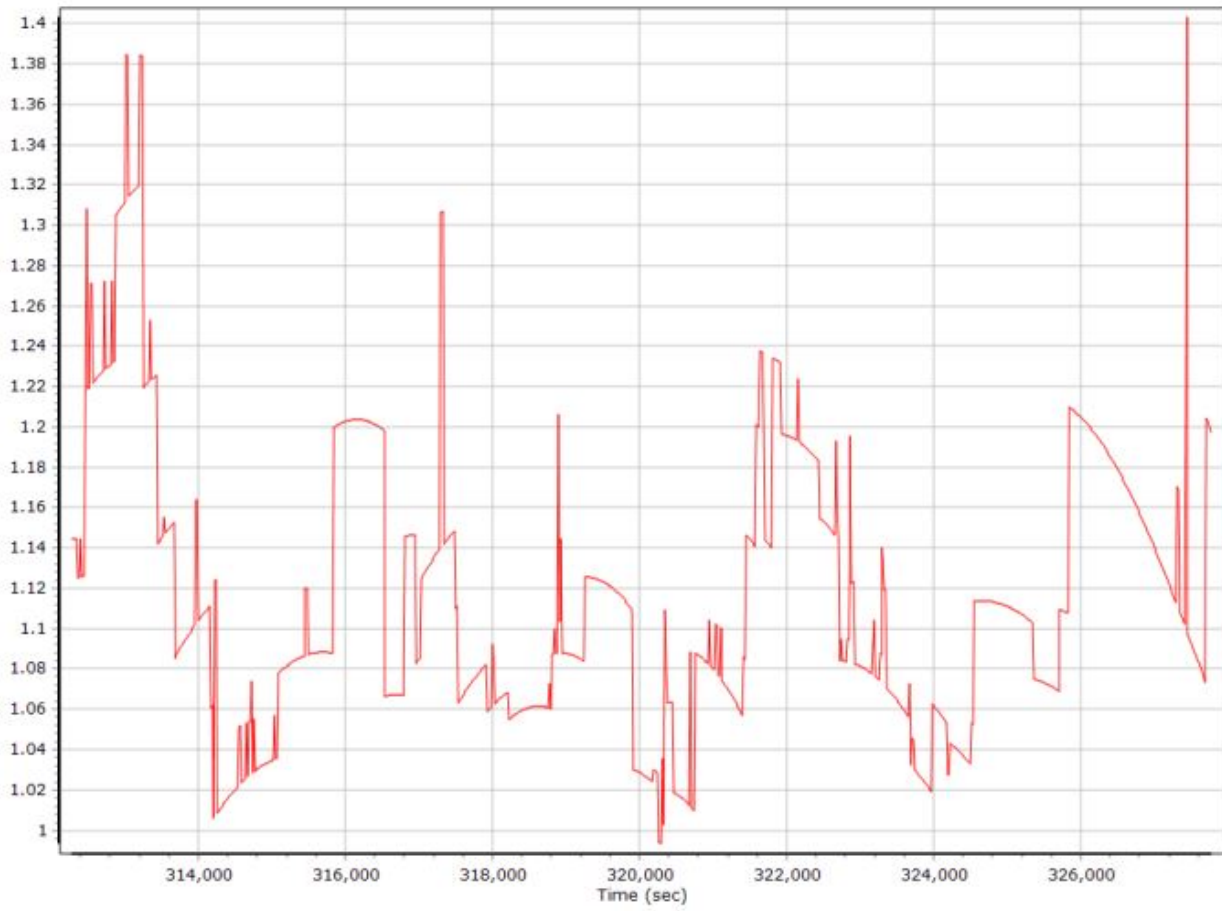
### Number of Satellites



### Forward/Reverse Separation



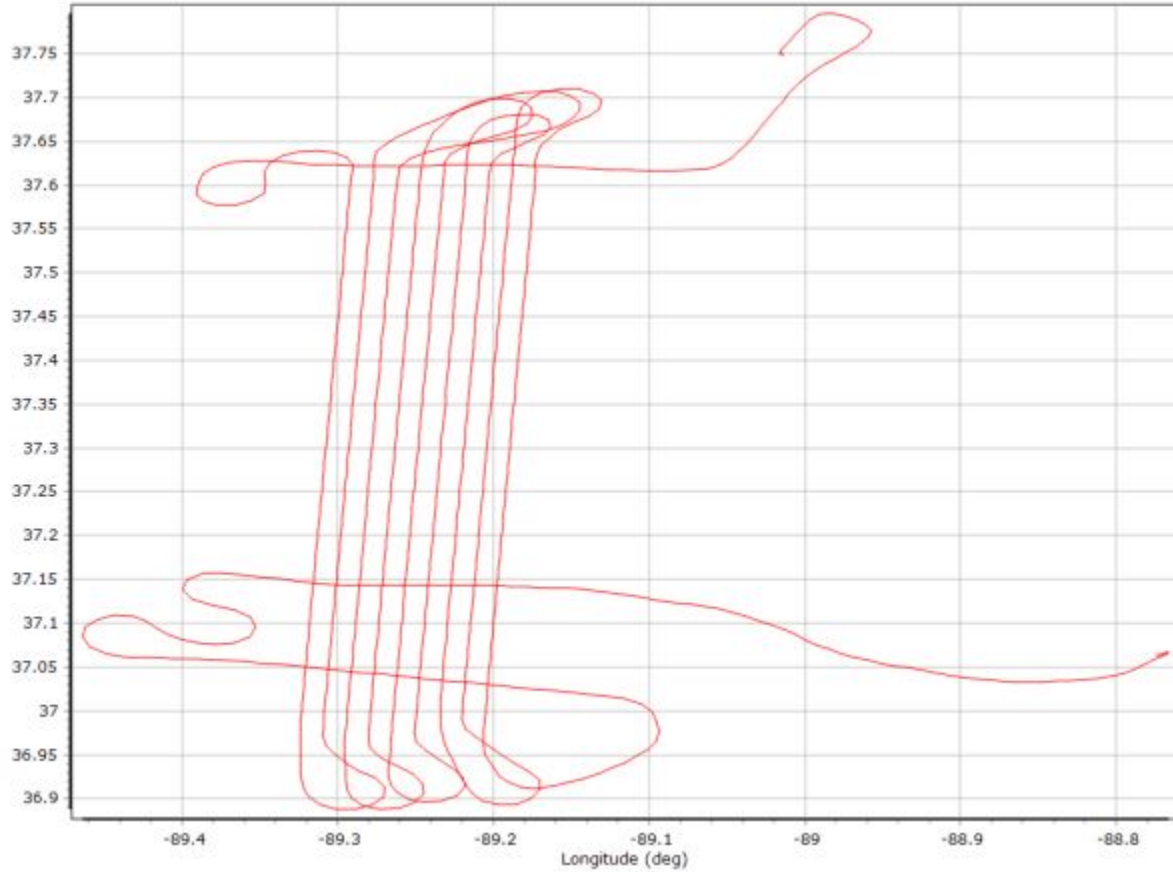
PDOP





120920b386.docx QC Report - 6/28/2021 11:28:16  
**Smoothed Trajectory Information**

**Top View**



**GNSS QC**

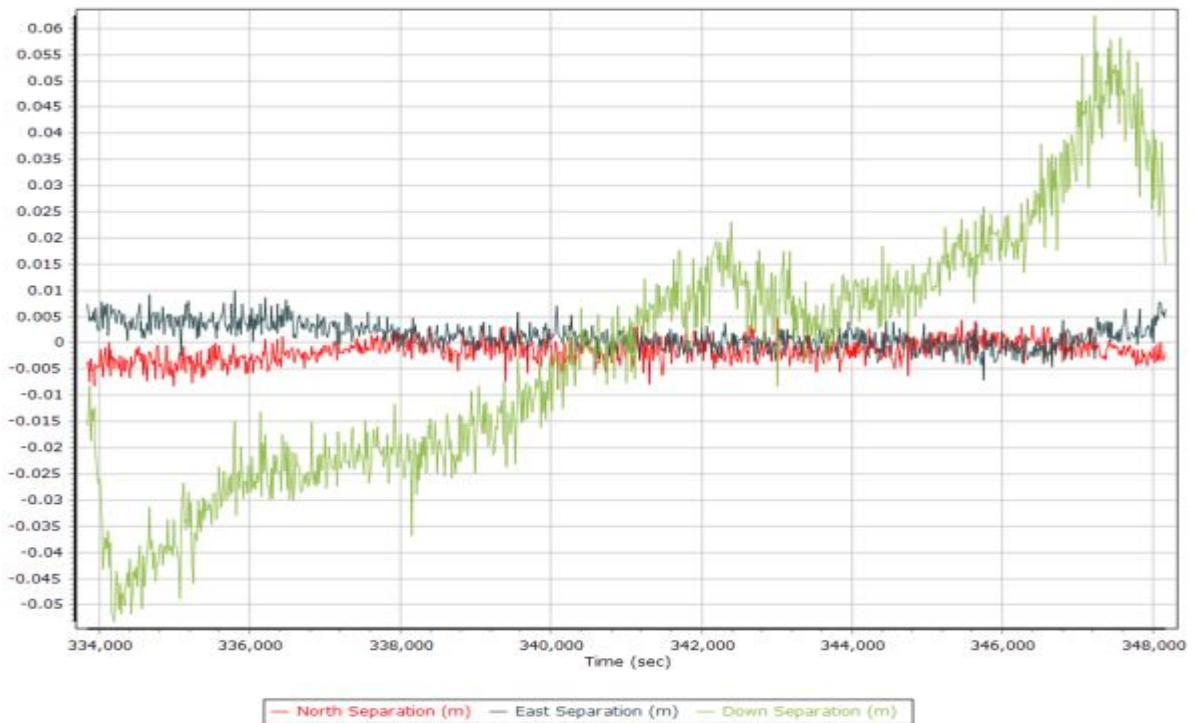
**GNSS QC Statistics**

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	1
Number of GALILEO SV	5	8	6
Total number of SV	14	25	20
PDOP	1.04	1.52	1.24
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	14558.00	0.00	0.00
Percentage	100.00	0.00	0.00

### Number of Satellites

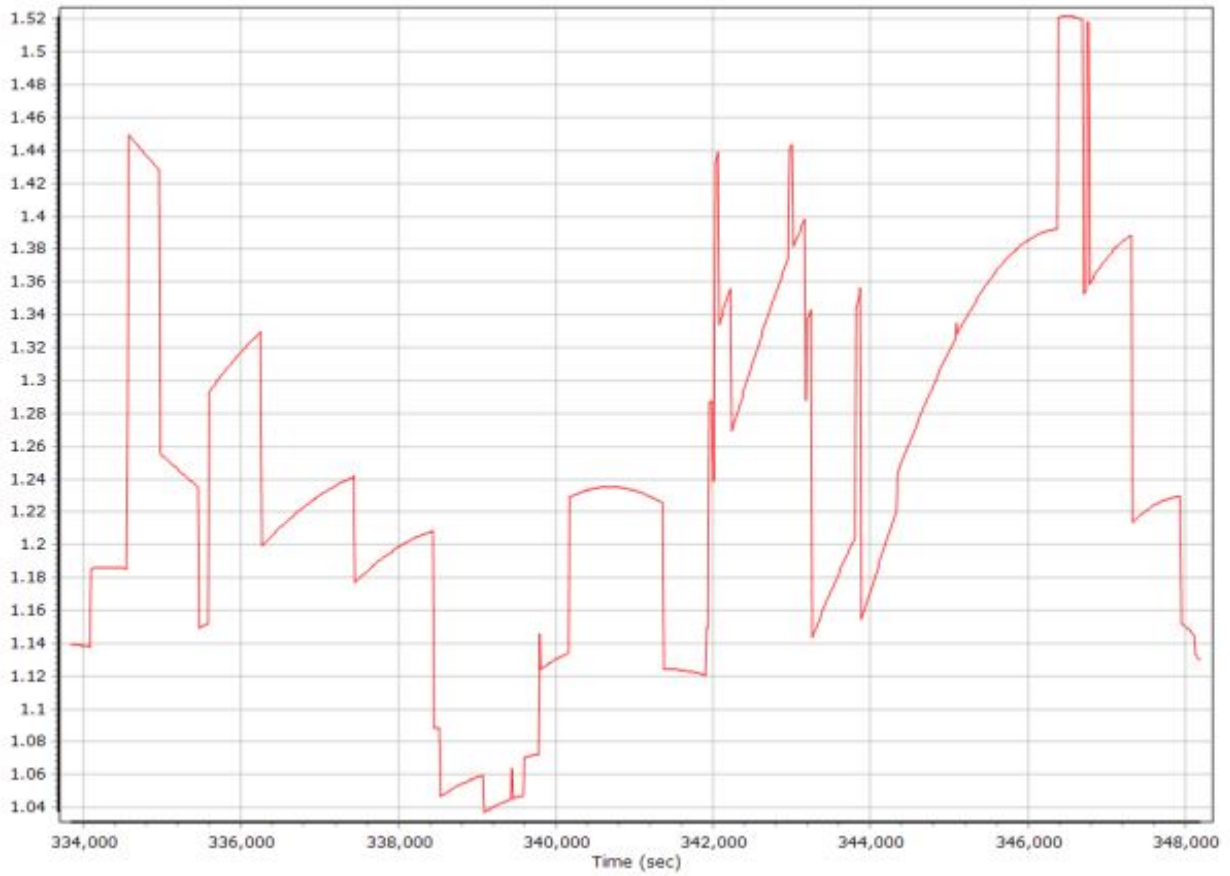


### Forward/Reverse Separation



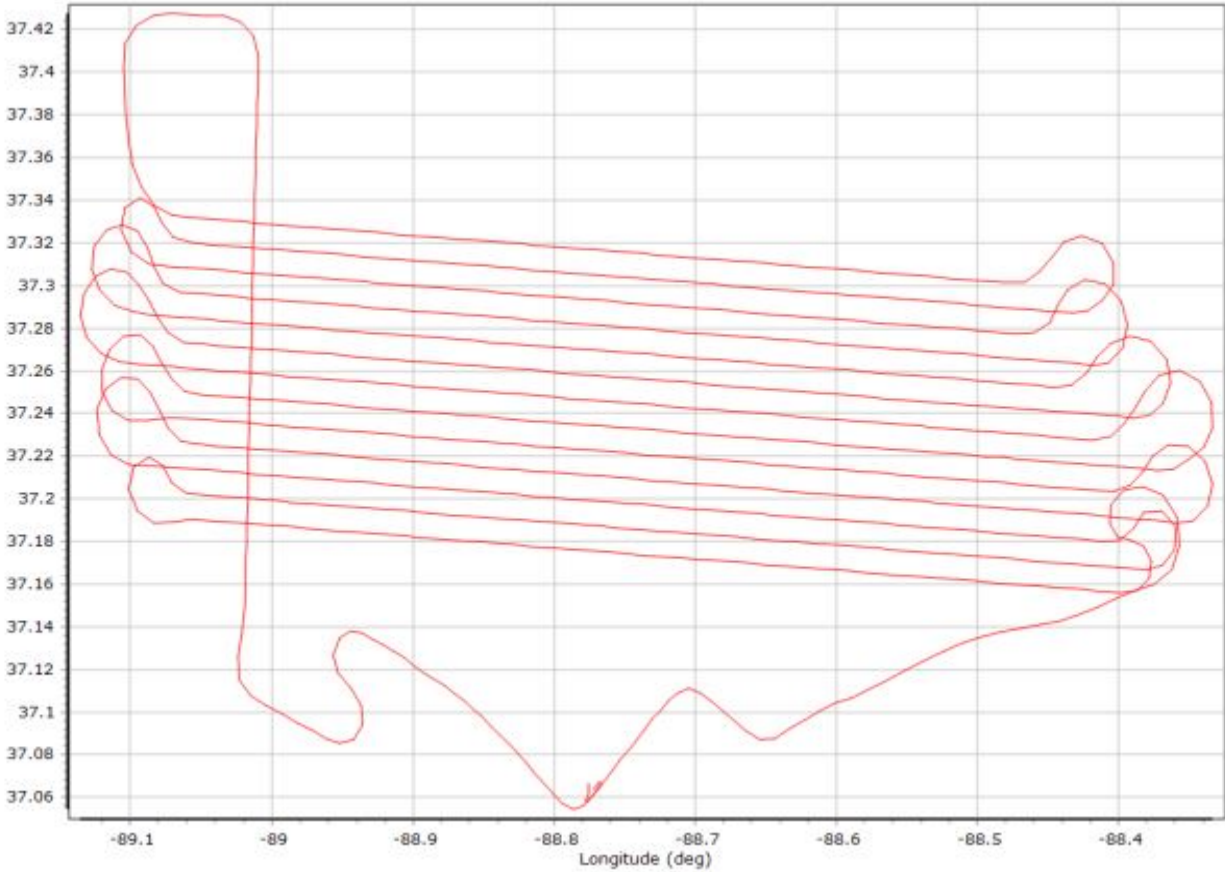


PDOP



120920b448.docx QC Report - 6/28/2021 11:38:44  
 Smoothed Trajectory Information

Top View



**GNSS QC**

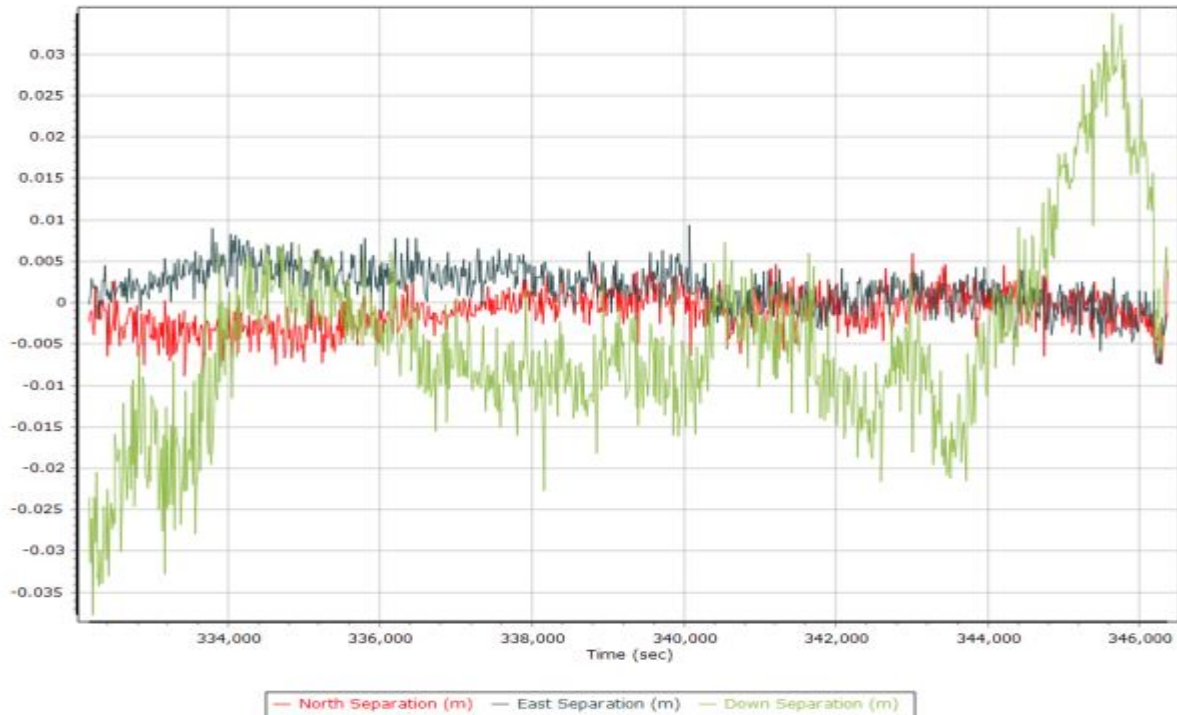
**GNSS QC Statistics**

Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	6	10	8
Number of GLONASS SV	3	7	5
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	2	1
Number of GALILEO SV	5	8	6
Total number of SV	16	24	20
PDOP	1.04	1.68	1.21
QC Solution Gaps	0.00	0.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	14615.00	0.00	0.00
Percentage	100.00	0.00	0.00

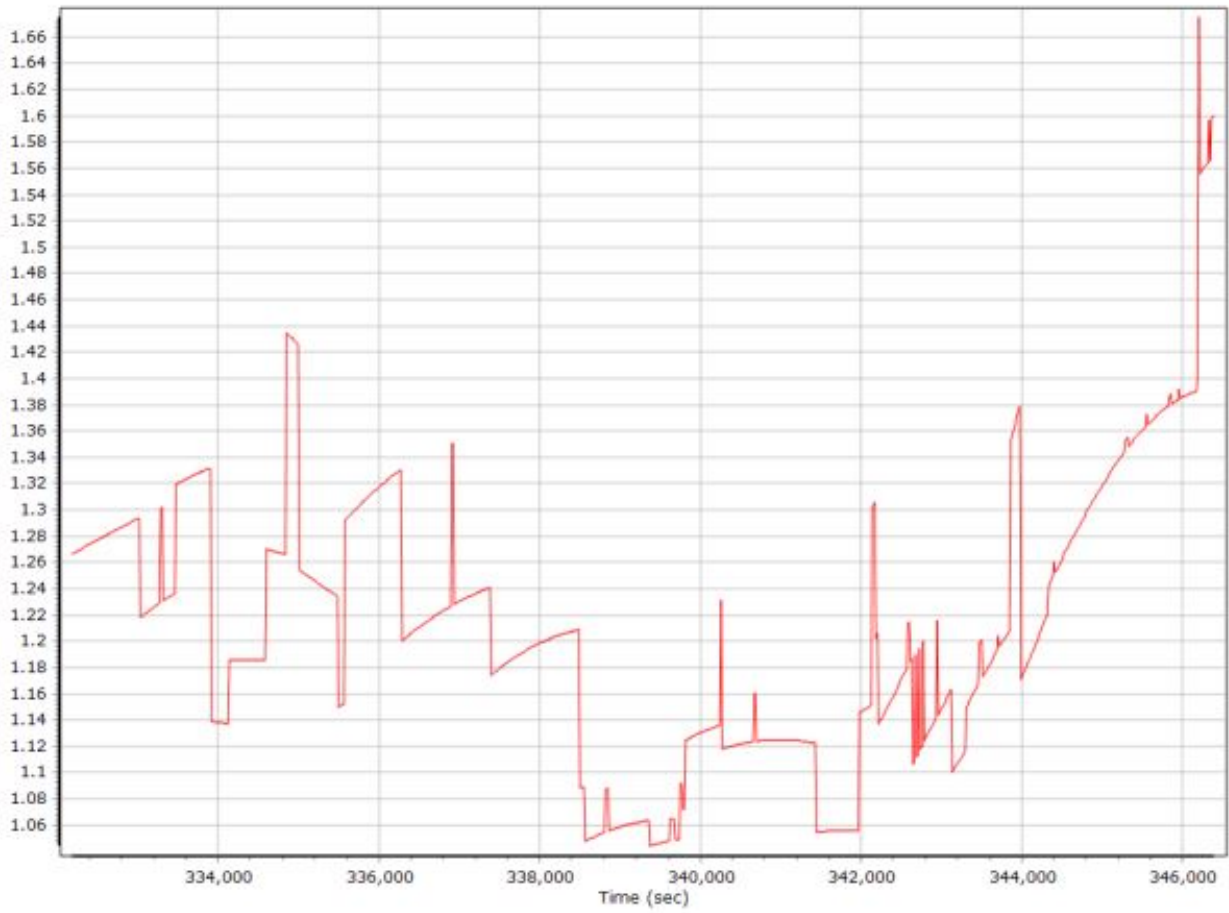
### Number of Satellites



### Forward/Reverse Separation

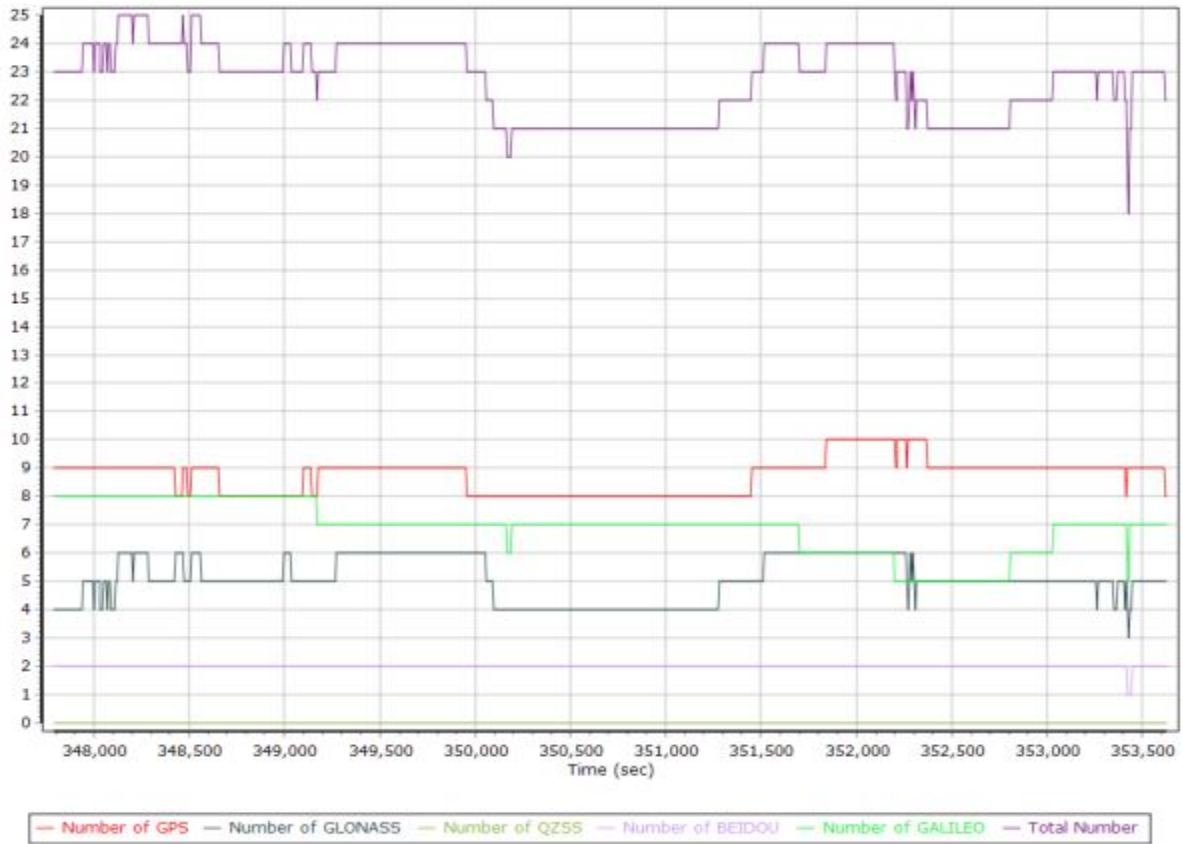


PDOP

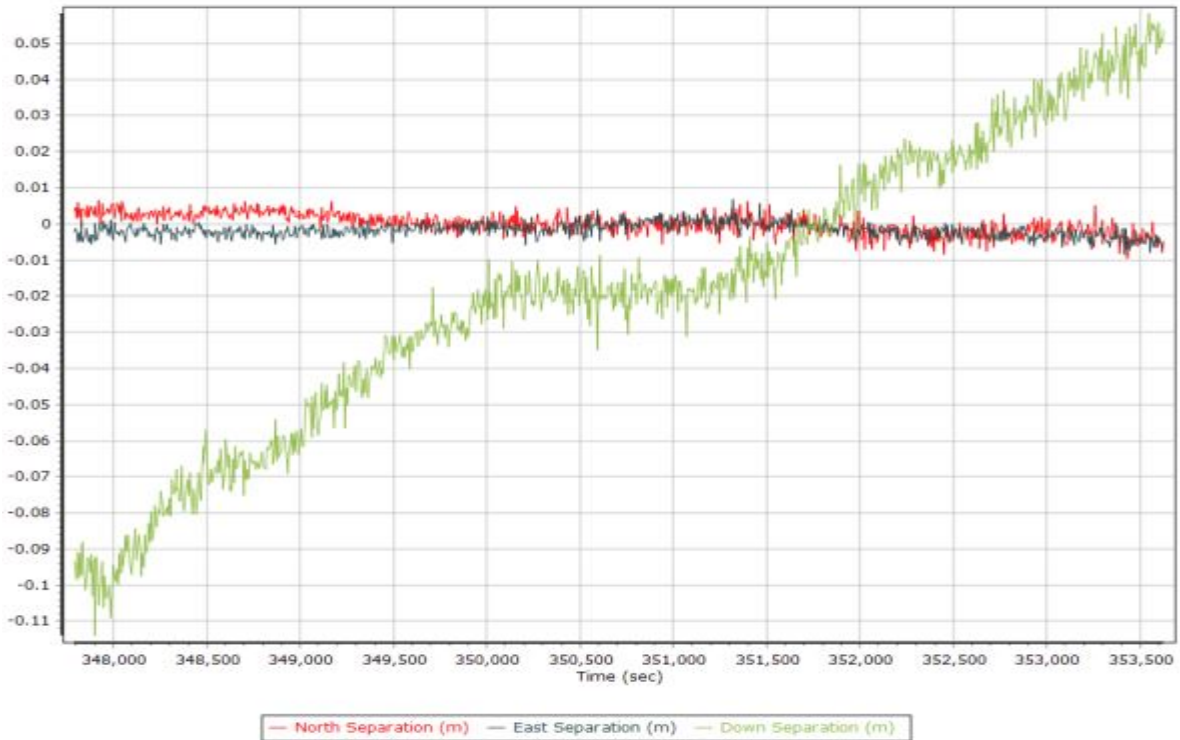




### Number of Satellites



### Forward/Reverse Separation





PDOP

